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A review on Hierarchical Protocols in Wireless Sensor Networks

Anshu Arora (Research Scholar)
Department of CSE, SBMNU,
Rohtak, India

Abstract: As we know that wireless sensor networks are used in various applications but there are strict constraints due to the storage capacity, energy consumption and computation power that effect the network life time. WSN contains a large number of sensor nodes that are interconnected by a communication network. Each sensor nodes majorly depend on batteries for energy, which get consumed very quickly. So it is essential to design effective and energy aware protocol in order to enhance the network lifetime. This paper presents an overview of hierarchical based routing protocols and also provides an overview of the protocol's performance. In last this article concludes with possible future research areas.

Keywords: Clustering, LEACH, M-LEACH, TEEN, APTEEN, Cluster-Head.

I. Introduction

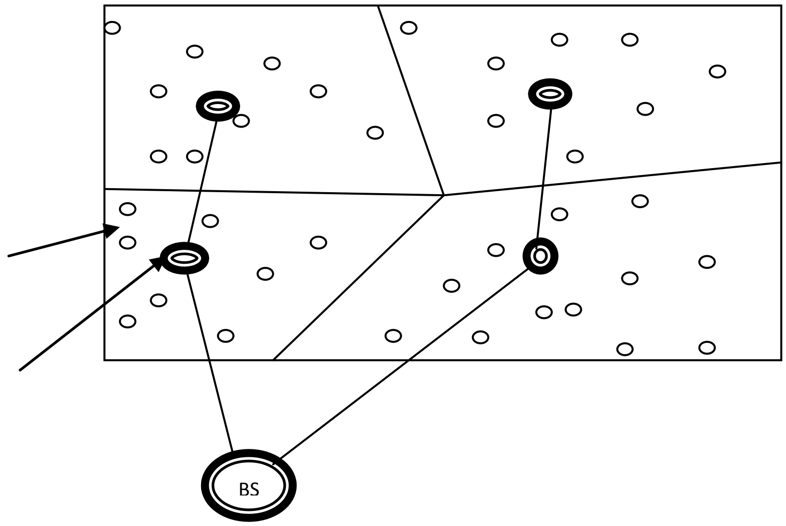
Wireless Sensor Networks (WSNs) is renowned as one of the emerging technologies of the 21st century. They are expected to develop interaction between humans and environment to a new level. However the technology is still in its infancy and undergoing rapid evolution with a tremendous amount of research effort in the networking community. The main purpose of a WSN is to assist in monitoring a physical phenomenon by gathering and delivering information to the interested party. Sensor nodes deploy a particular field and helps in tracking and conveying information to a base station[1][2]. The main success of the operation can be attributed to the recent development of micro-electronic-mechanical systems (MEMS) and this technology have enabled the production of powerful micro sensor nodes. WSN can be applied to any field in which monitoring is necessary e.g. military applications, security surveillance, traffic monitoring, health applications environmental applications, home applications[4][5].

The design of WSN is influenced by many factors, including fault tolerance, scalability, production costs, operating environment, sensor network topology, hardware constraints, transmission media, and power consumption [1][8]. The components of a sensor node such as location finding system, mobilize, and power generator may also be present. The sensor node senses the physical quantity being measured and coverts it into an electrical signal.

Then, the signal is fed to an A/D converter and is ready to be used by the processor. The processor will convert the signal into data depending on how it is programmed and it sends the information to the network by using a transceiver. The sensing data are shared between the sensor nodes and are used as input for a distributed estimation system [2][4][5]. The fundamental objectives for WSN are reliability, accuracy, flexibility, cost effectiveness, and ease of deployment. WSN is made up of individual multifunctional sensor nodes. The power unit may be supported by solar cells or battery. These sensor nodes operate in an ad-hoc manner and they have specific features. The design for all protocols focuses on the extension of network lifetime, since sensor nodes have a limited amount of energy [6][8].

II. Clustering process

The major objectives of clustering are even distribution of the sensors, tolerating the failure of CHs , increased connectivity, reduced delay and maximal network longevity. The clustering process divides the network into clusters (sections), and every cluster is often lead by a node called Cluster Head (CH). A CH can be elected by the sensor nodes based on some criterion or may be pre-assigned by the network designer**.** The CH's head task is to manage communication among member nodes of the cluster, data processing, and relay processed sensed data to the Base Station (BS) directly[12][13]. The division of network into clusters, selection of cluster-head and assignment of tasks to cluster-head, all these decisions varies from one protocol to another. Clustering based routing algorithms are techniques with special advantages related to scalability and efficient communication. The main aim of this type of routing is to optimize energy consumption of sensor nodes by arranging the nodes into clusters. Data aggregation and fusion is performed within the cluster in order to decrease the number of transmitted messages[14].



III. Cluster based routing protocols in WSN

A. Low Energy Adaptive Clustering Hierarchy – (LEACH) [6][7][46]

Leach [2] is the first dynamic and is the most popular clustering algorithm for WSNs. Most of the hierarchical routing protocols e.g., LEACH-C, LEACH-V, LEACH-F, M-LEACH etc are derived from LEACH. The LEACH operation is based upon rounds. Each round includes two stages: 1. Cluster-formation (Set-up phase) 2. Data transmission (Steady-state phase)

***A (1).* 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 set-up phase is further divided into

- Advertisement Phase
- Cluster set-up phase

In the advertisement phase, the randomly generated CHs advertise their status as clusters to its neighborhood sensor nodes. This is followed by the Cluster set-up phase where the sensor nodes which received the advertisement of a cluster-head can join the CH with higher signal strength. Thus full network is divided into clusters at the end of this round and steady state phase starts..

***A(2)* 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 [20] can be further classified into

- 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 [20]. When all the data are received, the CH aggregates them and sends the aggregated data to the Sink Node.

LEACH is able to perform local aggregation of data in each cluster to reduce the amount of data transmitted to the base station. LEACH reduces this energy dissipation by :

- Reducing the number of transmission to sink using cluster-head
- Reducing the date to be transmit through compression technique
- LEACH Increase the life time of all nodes through randomizes rotation being as CH.
- LEACH allows non-cluster-head nodes to keep sleeping except specific time duration.
- In LEACH routing protocol nodes die randomly and dynamic clustering enhance network lifetime
- LEACH routing protocol makes wireless sensor network scalable and robust.

Although LEACH improved energy consumption over traditional non-clustering protocols, still there exist many failure points:

- CH selection is randomly, that does not take into account energy consumption.
- It can't cover a large area.
- CHs are not uniformly distributed; where CHs can be located at the edges of the cluster.

B . Enhanced Low-Energy Adaptive Clustering Hierarchy (E-LEACH)

E-LEACH [33] is an improvement on LEACH. E-LEACH algorithm assumes that sensors have global information about other sensors' remaining energy. It uses a cluster head selection algorithm for non-uniform starting energy level among the sensors. E-LEACH also determines that, under certain assumptions, the required number of cluster heads has to scale as the square root of the total number of sensor nodes to minimize the total energy consumption. Other aspects of E-LEACH are the same as LEACH.

C . LEACH-C: Base Station Cluster Formation

In LEACH, the clusters are adaptive; obtaining a poor clustering set-up during a given round will not greatly affect overall performance of LEACH. However, using a central control algorithm to form the clusters may produce better clusters by dispersing the cluster-head nodes throughout the network. This is the basis for LEACH-C (LEACH-Centralized), a protocol that uses a centralized clustering algorithm and the same steady-state protocol as LEACH. During the set-up phase of LEACH-C, each node sends information about its current location and energy level to the base station. The base station runs an optimization algorithm to determine the clusters for that round. The clusters formed by the base station will in general be better than those formed using the distributed algorithm. However, LEACH-C requires that each node transmit information about its location to the base station at the beginning of each round [20]. This information may be obtained by using a global positioning system (GPS) receiver that is activated at the beginning of each round to get the node's current location[25][26].
LEACH-C is able to deliver more effective data than LEACH even though cluster formation is more expensive because the centralized algorithm can use network topology information to form good clusters that require less energy for operation than the ad-hoc clusters formed in LEACH. However, this protocol comes at the price of having to know node location.

D. Static clustering

In a static clustering protocol nodes are organized into clusters initially, and these clusters and the cluster-heads remain fixed throughout the lifetime of the network. Nodes transmit their data to the cluster-head node during each frame of data transfer, and the cluster-head forwards the data to the base station. Since data from nodes located close to each other are highly correlated, the cluster-head node aggregates the signals to reduce the actual amount of data that must be transmitted to the base station. Since the cluster-head must transmit the data to the end-user via the shared wireless channel, if the cluster-head could not aggregate the data, there would be no advantage to using this approach over an approach where each node sent its data directly to the base station[9][18].
The static clustering protocol is identical to LEACH except the clusters are chosen a-priori and fixed. The clusters are formed using the simulated annealing algorithm as in LEACH-C. Static clustering includes scheduled data transmissions from the cluster members to the cluster-head and data aggregation at the cluster-head.

E . Efficient-Routing Leach (ER-LEACH) [51]

ER-LEACH proposes vital solutions to some shortcomings of the basic LEACH; there are three contributions in this protocol which are, enhancing the selection of the cluster head during setup phase by taking into account the residual energy of any sensor node which intends to become a CH to prolong the network lifetime. The second contribution is trying to reduce the overhead of dynamic clusters generation by using alternative CH which is expected to take the role of the CH in case that the underlying CH died which will prolong the lifetime of each cluster, and finally for the sake of load balancing the zone routing protocol is used which attempts to balance the load over CHs evenly by permitting the CH to discover the optimal route to the BS with less cost messages update and then sends the fused data to the BS through many other CHs instead of direct sending to the BS. ER-LEACH is expected to perform well especially when the mobility is very high and will prolong the overall network lifetime through load balancing.

F . Multi-hop LEACH (M-LEACH)

M-LEACH [53] modifies LEACH allowing sensor nodes to use multi-hop communication within the cluster in order to increase the energy efficiency of the protocol. Other works define special nodes (called gateways) that are able to send the information generated inside the cluster directly to the sink [50]. This extends the existing solutions by allowing multi-hop inter-cluster communication in sparse WSNs in which the direct communication between CHs or the sink is not possible due to the distance between them. Thus, the main innovation of the solution proposed here is that the multi-hop approach is followed inside the cluster (messages from sensor nodes to the CH) and outside the cluster (from CHs to the sink using intermediate sensor nodes). CHs can also perform data fusion to the data receive, allowing a reduction in the total transmitted and forwarded data in the network.

G . Vice-CH LEACH (V-LEACH)

In the V LEACH [49] CH is responsible only for sending data that is received from the cluster members to the BS and there is another node called vice-CH that will become a CH of the cluster in case of CH dies. In the original leach, the CH is always on receiving data from cluster members, aggregate these data and then send it to the BS that might be located far away from it. The CH will die earlier than the other nodes in the cluster because of its operation of receiving, sending and overhearing. Vice-CH takes the role of CH when it dies and there is no need of electing a new CH every time increasing the network lifetime [52].

H . LEACH with Fixed Cluster (LEACH-F)

LEACH-F [19] is the further development of LEACH, which is based on clusters that are formed once and then fixed. Then, the cluster head position rotates among the nodes within the cluster. The advantage with this is that, once the clusters are formed, there is no set-up overhead at the beginning of each round. To decide clusters, LEACH-F uses the same centralized cluster formation algorithm as LEACH-C. The fixed clusters in LEACH-F do not allow new nodes to be added to the system and do not adjust their behavior based on nodes dying[41].

I . Leach – Spare Management (LEACH-SM)

LEACH-SM protocol [50] modifies LEACH by enhancing it with an efficient management of spares. It is also designed for static sensor nodes and static targets. LEACH-SM deals with both energy-consumption inefficiencies of LEACH. Identification of spares alone increases the overall WSN lifetime. LEACH-SM adds a phase, called the spare selection phase, to the original LEACH protocol. It follows the setup phase, and is followed by the regular operation of the WSN (Regular WSN operation is divided into frames, during which nodes follow cycles of awake and nap intervals.) The Decentralized Energy-efficient Spare Selection Technique (DESST) [5] is run during this spare selection phase. DESST, run in parallel on all WSN nodes in all clusters, allows each node to decide whether it should become a spare. It is done in such a way that the above-threshold target coverage is maintained by the WSN. All spares go asleep to conserve energy. As the result, WSN's lifetime is extended.

J. Hybrid, Energy-Efficient Distributed Clustering (HEED)

HEED 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[30][31]. 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, and (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 [29]. 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 pmin. A CH is either a tentative 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 electsitself 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.

In HEED, the distribution of energy consumption extends the lifetime of all the nodes in the network, thus sustaining stability of the neighbor set[32]. Nodes also automatically update their neighbor sets in multi-hop networks by periodically sending and receiving messages. The HEED clustering improves network lifetime over LEACH clustering because LEACH randomly selects CHs (and hence cluster size)., which may result in faster death of some nodes. The final CHs selected in HEED are well distributed across the network and the communication cost is minimized. However, the cluster selection deals with only a subset of parameters, which can possibly impose constraints on the system. These methods are suitable for prolonging the network lifetime rather than for the entire needs of WSN.

K. Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN)

TEEN is a hierarchical clustering protocol, which groups sensors into clusters with each led by a CH[34][35]. The sensors within a cluster report their sensed data to their CH. The CH sends aggregated data to higher level CH until the data reaches the sink. 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 (sink) is reached. 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.

TEEN is a clustering communication protocol that targets a reactive network and enables CHs to impose a constraint on when the sensor should report their sensed data. After the clusters are formed, the CH broadcasts two thresholds to the nodes namely (i) shard threshold (HT), and (ii) 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. Thus, the hard threshold allows the nodes to transmit only when the sensed attribute is in the range of interest, thus reducing the number of transmissions significantly. Once a node senses a value 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. As a consequence, 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 sensors will send only sensed data that are of interest 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. One can adjust both hard and soft threshold values in order to control the number of packet transmissions. However, both values of hard and soft thresholds have an impact on TEEN. These values should be set very carefully to keep the sensors responsive by reporting sensed data to the sink.

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. The soft threshold can be varied. At every cluster change time, fresh parameters are broadcast and so, the user can change them as required. However, 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.

L. Adaptive Threshold Sensitive Energy Efficient Sensor Network Protocol (APTEEN)

APTEEN is an improvement to TEEN to overcome its shortcomings and aims at both capturing periodic data collections (LEACH) and reacting to time-critical events (TEEN). Thus, APTEEN is a hybrid clustering-based routing protocol that allows the sensor 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 [36]. The architecture of APTEEN is same as in TEEN, which uses the concept hierarchical clustering for energy efficient communication between source sensors and the sink. When the base station forms the clusters, the CHs broadcast the attributes, the hard and soft threshold values, and TDMA transmission schedule to all nodes, and a maximum time interval between two successive reports sent to a sensor, called count time (TC). CHs also perform data aggregation in order to save energy. APTEEN supports three different query types namely (i) historical query, to analyze past data values, (ii) one-time query, to take a snapshot view of the network; and (iii) persistent queries, to monitor an event for a period of time.

APTEEN guarantees lower energy dissipation and a larger number of sensor alive [47]. Simulation of TEEN and APTEEN has shown them to outperform LEACH [3]. Experiments have demonstrated that APTEEN ís performance is between LEACH and TEEN in terms of energy dissipation and network lifetime. While in LEACH sensors transmit their sensed data continuously to the sink, in APTEEN sensors transmit their sensed data based on the threshold values. TEEN gives the best performance since it decreases the number of transmissions. The main drawbacks of the two approaches are the overhead and complexity of forming clusters in multiple levels, implementing threshold-based functions and dealing with attribute-based naming of queries.

IV. Conclusion and Future Research

The protocols discussed in this paper have individual advantages and pitfalls. Based on the topology, the protocol and routing strategies can be applied. The factors affecting cluster formation and CH communication are open issues for future research. Moreover, the process of data aggregation and fusion among clusters is also an interesting problem to explore. For realization of sensor networks, it is needed to satisfy the constraints introduced by factors such as fault tolerance, scalability, cost, topology change, environment, and power consumption. Since these constraints are highly stringent and specific for sensor networks, new wireless ad hoc networking techniques are required to be explored further. Though the performance of the protocols discussed in this paper is promising in terms of energy efficiency, further research would be needed to address issues related to Quality of Service (QoS) posed by video and imaging sensors and real-time applications.

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