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# Classification of Hierarchical Routing Protocols in Wireless Sensor Network

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***ABSTRACT:*** *Wireless Sensor Network (WSN) stands forefront in the scientific research community recently. WSNs are highly scattered self-organizing system and are deployed in various fields. Routing schemes have the common objective of trying to get better throughput with minimum delay and to prolong the lifespan of the sensor network. This paper mainly focused on brief technical introduction to WSN stack architecture, classification for hierarchical routing protocols and its comparisons based on their characteristics. With respect to the recent advances in the development of hierarchical routing protocols for WSN, there is need to investigate the significance, performance issue of each routing technique as well as the detailed operation of LEACH, PEGASIS, H-PEGASIS, TEEN, APTEEN and HEED. To solve these issue, to close the gap between technology and application.*

***Keywords:*** Wireless Sensor Networks, Hierarchal Routing Protocol, LEACH, PEGASIS, H-PEGASIS, TEEN, APTEEN, HEED

## I INTRODUCTION

Wireless networking technology has seen a thriving development in recent years. Wireless sensor networks integrated into the environment, machinery and human, coupled with the efficient delivery of sensed information, could deliver tremendous benefits to society. Some of the potential benefits are reinforced emergency response, preservation of natural resources, improved homeland security and enhanced manufacturing productivity. The significance of sensor networks have low energy consumption, sufficient intelligence for signal processing, low cost, self-organizing capability, data gathering and querying ability[1].

A. The Architecture of the Protocol Stack for Wireless Sensor Networks

The sensors are usually scattered in a sensor field. Each of these sensors has the capabilities to collect data related to application specific parameters (like temperature, vibration) and route data back to the sink by a multihop infrastructureless architecture. The sink may communicate with the task manager via Internet or Satellite. A three-dimensional sensor network generalized protocol stack for WSNs is presented by Akyildiz et al. [1], which comprises five layers with three planes as shown in Fig. 1.



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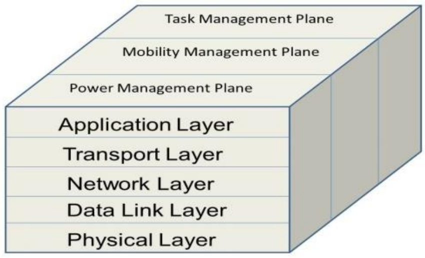


Fig. 1. Protocol Stack Architecture of WSN

The upper layer is the *application layer*, which is quite specific to the usage and distribution environment of the WSN. It provides various specific value-added services as well as the functions of time synchronization, positioning of sensor/sink, traffic management and send queries to obtain certain information. The *transport layer* is needed to establish an end-to-end connection and to provide reliable transmission service with reasonable overhead and congestion avoidance. The *network layer* takes care of routing the reliable data across the network from the source to the destination. To discover reliable, efficient path according to predetermined metric (minimum delay, maximum throughput, etc.,) and is quite unique from protocol to protocol. The main purpose of the *data link layer* is to guarantee the exactness of data transferred by the physical layer, for efficiently utilize the frequency. It is responsible for multiplexing data streams, data frame detection and error control. The MAC protocol in the Data Link Layer deals with issues such as channel access policies, time scheduling, synchronization among the sensors and able to minimize collision with neighbors' broadcast. The *physical layer* is the lowest layer in a communication system and is responsible for the conversion of a stream of bits into signals vice-versa over physical medium, which deals with radio-related tasks such as carrier frequency generation, frequency selection, signal detection, robust modulation and data encryption for transmission purposes. In addition, the power, mobility and task management planes monitor the power, movement and task distribution among the sensors respectively. These management planes are needed, so that sensors can work together in a power efficient way, route data in a sensor network and share resources between sensors [2, 3].

**II RELATED WORKS**

*B*. Routing Protocols in Wireless Sensor Networks

Advances in WSNs have led to many new protocols which are particularly designed for specific application. Routing protocol has to monitor the change of network's topological structure, know the routing information, find the destination, select the route and transfer the information through route. Initially, Ad Hoc routing protocols had been used in WSNs, but due to the characteristics of WSN, these protocols often perform with unsatisfactory because of their structure complexity. So, a careful approach is needed while designing a routing protocol for WSNs based on their metrics such as lowest delay, maximum throughput, least energy consumption, or the best link quality whose primary aim is to establish a best path between sources and sink [4].

C. Classification of Hierarchical Routing Protocols for WSN

Last few years many researchers have explored hierarchical cluster-based routing protocols in WSN from different perspective depends on their application [5, 6]. The main goal of hierarchical routing is to efficiently maintain the energy consumption of sensors by involving them in multi-hop communication as well as minimize the number of transmission to the sink and to cover a large geographical area without degrading the service. The cluster head with a high energy sensor, can be used to data aggregate, fusion and send the information, the rest of sensors in their cluster can perform tasks of sensing. To provide a comprehensive analysis of the most recently proposed some of the hierarchical routing protocols for WSNs are discussed below in this section.

D. Low-Energy Adaptive Clustering Hierarchy (LEACH)

W. Heinzelman, A. Chandrakasan and H. Balakrishnan have proposed a hierarchical cluster-based routing protocol for sensor networks, called LEACH [7]. It is the first and most popular self-organizing, energy-efficient protocol that was focused on extend the lifespan of sensor networks and also perform data fusion. LEACH splits a network into several clusters of sensors, which are constructed by using localized coordination and control based on the received signal strength. In each cluster, a dedicated sensor with extra privileges called Cluster Head (CH) acts as the *local base station* is responsible for routing data to the sink which is represent in Fig. 2. To give a chance to all sensors to act as CHs by using randomized rotation of a high-energy sensor as CH in order to evenly distribute the energy load among the sensors in the network and avoid draining the battery of any one sensor in the network.

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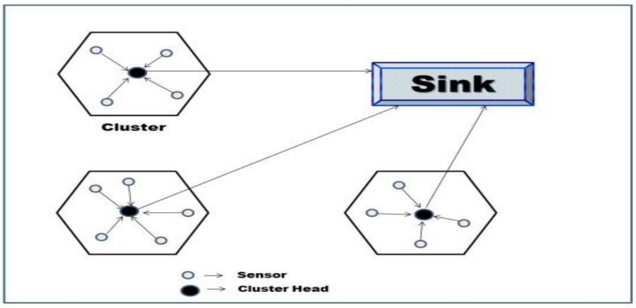


Fig. 2. Cluster-based LEACH Protocol

The operation of LEACH is divided into rounds having two phases are

i) Setup Phase: To organize the sensor network into clusters, a sensor generates a random number between 0 and 1. If this number is less than the threshold T(n), it becomes a CH for the current round and it is determined as follows

$$T(n) = \begin{cases} p/1-p*(r \bmod p^{-1}) & \text{if } n \in G \\ 0 & \text{Otherwise} \end{cases}$$

where r is the current round, p is the desired percentage for becoming CH and G is the set of sensors that have not been elected as a CH in the last 1/ p rounds. After the sensors has elected themselves to be CHs. In advertisement phase, the CHs inform their neighborhood with an advertisement packet that they become CHs. In the cluster setup phase, the member sensors inform the CH that they become a member to that cluster with *join packet* contains their IDs using CSMA. After this phase, the CH knows the number of member sensors and their IDs. Then, the CH creates and broadcast a TDMA schedule to cluster members for data transfer prevents intra-cluster collisions.

ii) Steady-state Phase: Data transmission begins, sensors send their data during their allocated TDMA slot to the CH and the radio of each sensor can be turned off until its allocated TDMA slot, thus minimizing energy dissipation by the individual. When all the data has been received, the CH performs data aggregation, compression and transmission to the sink.

Compared to direct communication, LEACH achieves over a factor of 7 decreases in energy consumption. Optimal number of CHs is estimated to be 5% of the total number of sensors. But it is not applicable to deployed in large regions and the idea of dynamic clustering brings extra overhead for changing CHs, advertisements and etc., which may reduce energy consumption.

E. Power-Efficient GAthering in Sensor Information Systems (PEGASIS)

S. Lindsey and C.S. Raghavendra introduced a chain-based hierarchal routing protocol is PEGASIS [8], which is also proposed for prolong the lifespan of network by communicate with closest neighbor which is near optimal for data gathering applications in sensor networks. It is an enhancement over LEACH. PEGASIS assumes that sensors are homogeneous, stationary and have a global knowledge of the network. The operation is performed in two steps i) Chain Construction: Rather than forming clusters, chain of sensors can be constructed using greedy algorithms and each sensor can take turn of being a leader of the chain. ii) Data Gathering: Leader of sensor is responsible for routing the aggregated data to the sink. Each sensor aggregates the collected data with its own data and then passes the aggregated data to the next sensor in the chain. This process is continued until all the sensors are included in the chain as shown in Fig. 3.

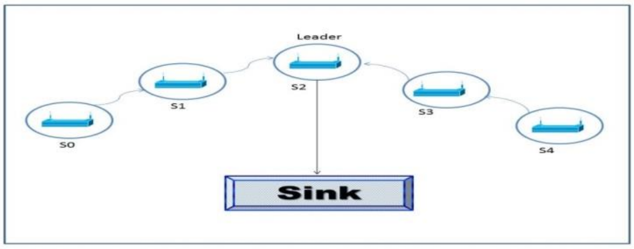


Fig. 3. Chain-based PEGASIS Protocol

Simulation results showed that PEGASIS is able to increase the lifetime of the sensor networks twice when compared to LEACH. The difference from LEACH is to employ multi-hop routing by forming chains and selecting only one sensor to transmit to the sink instead of using multiple sensors and required low bandwidth to transmit data. PEGASIS outperforms LEACH by about 100 to 300% for

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different topologies and network sizes. Such performance gain is achieved through the elimination of the overhead of dynamic cluster formation in LEACH and through minimizing the number of transmissions and receives by using data aggregation. However, for large networks introduces excessive delay and a single leader can become a bottleneck.

*F.* Hierarchical-PEGASIS (H-PEGASIS)

It is an upgrading to PEGASIS, which aims to minimize the delay by using simultaneous transmissions of data and proposes a solution to the data gathering problem by considering metric such as energy and delay [9]. In order to avoid collision of simultaneous transmission and possible signal interference among the sensors, two approaches are proposed. The first is incorporates signal coding namely CDMA. In the second approach only spatially separated sensors are allowed to transmit at the same time. The chain-based protocol with CDMA capable sensors, constructs a chain of sensors, that forms a tree like hierarchy and each selected sensor in a particular level transmits data to the sensor in the upper level of the hierarchy. Since the tree is balanced, the delay will be in O(log N) where N is the number of sensors. Here, to ensures data transmitting in parallel and minimize the delay significantly.

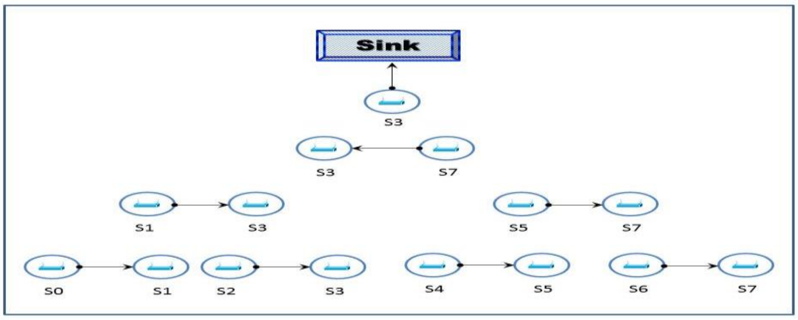


Fig. 4. Hierarchical- PEGASIS Protocol

In Fig. 4, sensor s3 is the designated leader for round 3. Since, s3 is in odd position 3 on the chain, all sensors in an even position will send to their right neighbor. Sensors that are receiving at each level rise to next level in the hierarchy. Now at the next level, s3 is still in an odd position. Again all sensors in an even position will aggregate its data with its received data and send to their right. At the third level, s3 is not in an odd position, so s7 will aggregate its data and transmit to s3. Finally, s3 will combine its current data with that received from s7 and transmit the message to the sink. Such chain-based protocol has been shown to perform better than the regular PEGASIS scheme by a factor of about 60. Although the H-PEGASIS approaches avoid the clustering overhead of LEACH, it still requires dynamic topology adjustment since every sensor needs to know about energy status of its neighbors in order to know where to route its data. Such topology adjustment can introduce significant overhead especially for maintaining sensor networks lifetime.

*G. Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN)*

A.Manjeshwar and D.P Agrawal have proposed a hierarchical cluster-based routing protocol along with data centric approach with responsive to sudden changes in the sensed attributes (eg. temperature) and network operated in reactive mode [10]. Using TEEN in sensor network, the closer sensors form clusters, with each led by a CH as routers to the sink. The sensors sense environment continuously and send sensed data to their first level CH. It transmits aggregated data to next level CH until the data reaches the sink as shown in Fig. 5. After the clusters are formed, the cluster-head broadcasts two threshold values to its members as followings: Hard Threshold: This is the minimum possible threshold value of the sensed attribute to trigger a sensor to turn on its transmitter when the attribute is in the range of interest and report to its cluster head, thus reduce the number of transmissions significantly. Soft Threshold: Once a sensor senses a value at or beyond the hard threshold, it sends data only when the value of that attributes changes by an amount equal to or greater than the soft threshold. As a consequence, soft threshold will further minimize the number of transmissions if there is little or no change in the sensed attribute value.

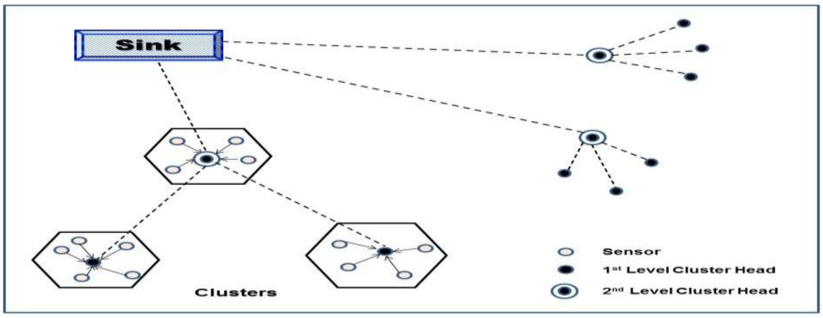


Fig. 5 Hierarchal Clustering in TEEN

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Important features of TEEN include its suitability for time critical sensing applications where the users can control a trade-off between energy efficiency, data accuracy and response time dynamically. To control the number of transmission by adjust both hard and soft threshold values and ensure that there are no collisions in the cluster. The main drawback of this scheme is that, if the thresholds are not reached, the sensors will never communicate the user and not get any data from the network. Thus, this protocol is not suitable for applications where the user needs to get data on a regular basis.

*H. Adaptive Periodic Threshold-sensitive Energy Efficient Sensor Network (APTEEN)*

A. Manjeshwar and D. P. Agrawal introduced an enhanced version of TEEN and the architecture of APTEEN is same as in TEEN. It aims at both capturing periodic collection of data (LEACH) and reacting to time-critical events (TEEN). Thus, APTEEN is a hybrid cluster based hierarchical protocol that allows the sensor to send their sensed data periodically (Proactive) and react to any sudden change (Reactive) in the value of the sensed attribute by reporting the corresponding values to their CHs [11]. In APTEEN, the sink is to form clusters, each CH broadcast the following parameters: i) Attributes: This is a set of physical parameters which the user is interested in obtaining data about. ii) Thresholds: It consists of a hard threshold and a soft threshold. iii) Schedule: This is a TDMA schedule assigning a time slot to each sensor. iv) Count Time: It is the maximum time period between two successive reports sent by a sensor.

APTEEN supports three different types of query namely: Historical query (to analyze past data values), One-time query (to take a snapshot view of the network) and Persistent queries (to monitor an event for a period of time). The simulation result shows that APTEEN's performance is between LEACH and TEEN in terms of energy dissipation and network lifetime. The main limitation of APTEEN is that additional overhead and complexity required to forming multilevel clusters, implementing the threshold functions and dealing with attribute based naming of queries. However, this is a reasonable trade-off and provides additional flexibility and versatility.

*I. Hybrid, Energy-Efficient Distributed Clustering protocol (HEED)*

HEED extends the basic scheme of LEACH by using residual energy and node degree (number of neighbors) 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 used to probabilistically select an initial set of CHs based on their residual energy of each sensor and the secondary parameter is the intra-cluster communication cost as a function of cluster density or node degree. The HEED clustering improves network lifetime over LEACH. 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 [12].

## III COMPARATIVE ANALYSIS OF HIERARCHICAL ROUTING PROTOCOLS OF WSN

The routing protocols mentioned in the above sections are developed for different applications. Table – I demonstrate detailed operational characteristic of the hierarchical routing protocols related to different categories [13,14].

TABLE – I Comparison among different hierarchical routing protocols

| Routing Protocols | LEACH | PEGASSIS | H-PEGASIS | TEEN | APTEEN | HEED |
|---|---|---|---|---|---|---|
| Category | Hierarchical | Hierarchical | Hierarchical | Hierarchical | Hierarchical | Hierarchical |
| N/w Life Time | Very Good | Very Good | Very Good | Very Good | Very Good | Very Good |
| Resource Awareness | Yes | Yes | Yes | Yes | Yes | Yes |
| Data Delivery Model | Cluster based | Chain based | Chain based | Active Threshold | Active Threshold | Cluster based |
| Data Aggregation | Yes | Yes | Yes | Yes | Yes | Yes |
| Over head | High | Low | Low | High | High | High |
| Power Usage | High | Max | Max | High | High | High |
| Query Based | No | No | No | Yes | Yes | No |
| QOS | Low | Low | Low | Low | Low | Low |
| Mobility | Sink Fixed | Sink Fixed | Sink Fixed | Sink Fixed | Sink Fixed | Sink Fixed |
| Scalability | Good | Good | Good | Good | Good | Good |

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## IV CONCLUSIONS AND FUTURE DIRECTION

The routing protocols designed for WSN should consider the goal, technology associated with architecture and application area of the network. The design of routing protocols is influenced by many challenging factors caused by the nature of the WSNs. These factors must be overcome before efficient communication can be achieved in WSNs. In this paper, we presented the stack architecture for WSN, hierarchical routing protocols for WSNs. Finally, all the presented hierarchical routing protocols are summarized in Table 1 to provide a fast overview of the main motivations behind their design and the methods used to achieve the desired goals. In this paper, to introduce some recommendation and directions as guidelines and hints that would assist and give enhancements to the future design of protocols for WSN are suggested and put forward. To this aim, different hierarchical routing approaches should be integrated efficiently.

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