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Energy Efficient Hierarchical Routing Protocols For Wireless Sensor Networks: A Survey

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Abstract:
Wireless Sensor Networks have limited resources with traditional data gathering techniques. One of the limitations of wireless sensor nodes is its inherent limited energy resource. Gathering sensed data in an energy efficient manner is critical to operate the network for a long period of time. For different applications many protocols have been developed. This paper surveys various energy efficient hierarchical routing protocols for sensor networks and presents a classification and comparative study of the various approaches pursued.

Key words: *Wireless sensor networks, routing protocols, Energy Efficiency*

1. Introduction

Wireless Sensor Networks communicate over a short distance through wireless channels for information sharing and cooperative processing to accomplish a common task. The unique feature of sensor networks is the cooperative effort of sensor nodes. Sensor nodes are embedded with an onboard processor. Instead of sending the raw data to the nodes responsible for the fusion, they use their processing abilities to locally carry out simple computations and transmit only the required and partially processed data. Currently, wireless sensor networks are beginning to be deployed at an accelerated pace, with unlimited potential for numerous application areas including environmental, medical, military, transportation, and homeland defense.

In general, based on the network structure routing in wireless sensor network can be flat-based, location-based and hierarchical. Each protocol is adapted to a specific situation and must take into account the type of the application. We will explore the energy efficient hierarchical routing mechanisms for sensor networks developed in recent years. Each routing protocol is discussed briefly.

The expectancy of longer lifetime of sensor nodes has put researchers to work on every possible aspect of sensor nodes in gaining energy efficiency.

2. Elements of a Wireless Sensor Network

Let us look at the elements of a generic Wireless Sensor Network, and examine how the clustering phenomenon is an essential part of the organizational structure [8].

- Sensor Node: A sensor node is the core component of a WSN. Sensor nodes can take on multiple roles in a network, such as simple sensing, data storage, routing and data processing.
- Clusters: Clusters are the organizational unit for WSNs. The dense nature of these networks requires the need for them to be broken down into clusters to simplify tasks such a communication.
- Cluster heads: Cluster heads are the organizational leader of a cluster. They often are required to organize activities in the cluster. These tasks include, but are not limited to data-aggregation and organizing the communication schedule of a cluster.
- Base Station: The base station is at the upper level of the hierarchical WSN. It provides the communication link between the sensor network and the end-user.
- End User: The data in a sensor network can be used for a wide-range of applications. Therefore, a particular application may make use of the network data over the internet, using a PDA, or even a desktop computer by the end user.

3. Sensor Network Classification

Based on the mode of functioning and the type of target application sensor networks can be classified into two major types [8].

3.1. Proactive Networks

The nodes in this network switch on their sensors and transmitters periodically, sense the environment and transmit the sensed data to a BS through the predefined route. They provide a snapshot of the environment and its sensed data at regular intervals. They are suitable for applications that require periodic data monitoring network.

3.2. Reactive Networks

The nodes in this network react immediately to sudden changes in the value of the sensed attribute beyond some pre-determined threshold value. They are therefore suited for time critical applications like military surveillance or temperature sensing.

4. Hierarchical Routing Protocols

The major design attributes of sensor networks is scalability. A single-tier network can cause the gateway to overload with the increase in sensor density. Such overload might cause latency in communication and inadequate tracking of events. In addition, the single-gateway architecture is not scalable for a larger set of sensors covering a wider area of interest since the sensors are typically not capable of long-distance communication. To allow the system to cope with additional load and to be able to cover a large area of interest without degrading the service, networking clustering has been pursued in some routing approaches [9].

4.1. Proactive Network Protocols

The main aim of hierarchical routing is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a particular cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the sink. Cluster formation is typically based on the energy reserve of sensors and sensor's proximity to the cluster head. LEACH is one of the first hierarchical routing approaches for sensor networks. The idea proposed in LEACH has been a base for many hierarchical routing protocols. We explore hierarchical routing protocols in this section.

4.1.1. Low-Energy Adaptive Clustering Hierarchy (LEACH)

LEACH [1] is a clustering-based protocol that minimizes energy dissipation in sensor networks. The purpose of LEACH is to randomly select sensor nodes as cluster heads, so the high energy dissipation in communicating with the base station is spread to all sensor nodes in the sensor network. The operation of LEACH is separated into two phases, the setup phase and the steady phase. The duration of the steady phase is longer than the duration of the setup phase in order to minimize overhead.

During the setup phase, a sensor node chooses a random number between 0 and 1. If this random number is less than the threshold T (n), the sensor node is a cluster head. T(n) is calculated as

$$T(n) = \frac{P}{1-P*\left(r \bmod \frac{1}{P}\right)} \quad if\, n \in G$$

T (n) = 0 otherwise (1)

Where P is the desired percentage to become a cluster head, r is the current round, and G is the set of nodes that have not been selected as a cluster head in the last 1/P rounds. After the cluster heads are selected, the cluster heads advertise to all sensor nodes in the network, which decide which cluster they want to belong based on the signal strength of the advertisement from the cluster heads to the sensor nodes. Then the sensor nodes inform the appropriate cluster heads that they will be a member of the cluster. A TDMA approach created by the cluster head is used to gather data from nodes. During the steady phase, cluster heads aggregates and compresses the data and transmits the data to the sink. The topology is shown in Figure 1.

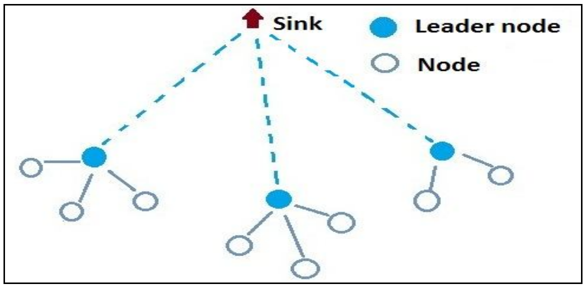

Figure 1: LEACH topology

LEACH uses single-hop routing where each node can transmit directly to the cluster-head and the sink. Therefore, it is not applicable to networks deployed in large regions. Furthermore, the idea of dynamic clustering brings extra overhead, e.g. head changes, advertisements, etc., which may diminish the gain in energy consumption.

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4.1.2. Multi-hop LEACH (M-LEACH)

M-LEACH [10] 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.

This work 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.

4.1.3. Power-Efficient Gathering in Sensor Information Systems (PEGASIS)

PEGASIS [3] is an extension of the LEACH protocol. It forms chains from sensor nodes, each node transmits the data to neighbor or receives data from a neighbor and only one node is selected from that chain to transmit data to the BS. The data is finally aggregated and sent to the BS. PEGASIS avoids cluster formation, and assumes that all the nodes have knowledge about the network, particularly their positions using a greedy algorithm. Figure 2 shows the chaining in PEGASIS.

Although clustering overhead is avoided, PEGASIS requires dynamic topology adjustment since the energy status of its neighbor is necessary to know where to route its data. This involves significant overhead particularly in highly utilized networks. Results show that PEGASIS is able to increase the lifetime of the network twice as much the LEACH protocol.

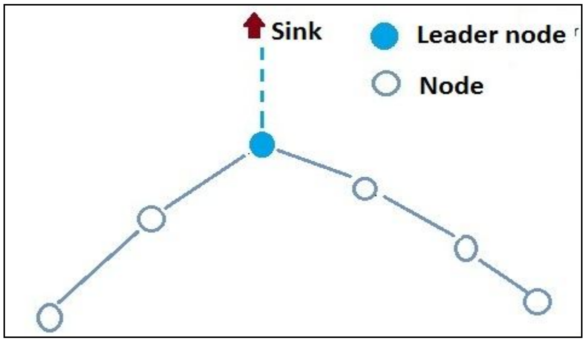

Figure 2: PEGASIS Topology

4.1.4. Hierarchical PEGASIS protocol

Hierarchical PEGASIS [13] protocol is an extension of the well known PEGASIS which aims to reduce the delays transmission of packets to the base station. In the new protocol PEGASIS, hierarchical organization of the nodes, belonging to the same cluster, in the form of a chain allows improving and regulating the dissipation of energy, which allows reducing the load on the cluster-head. In fact, the nodes communicate only with their neighbors and not directly with cluster-head, which saves more energy. Data aggregation at each node in the chain reduces the amount of data exchanged between the nodes and their Cluster-head, which has the effect of preserving the energy budget of nodes. Figure.3 shows how the nodes will be organized inside of the clusters.

In this protocol, each node sends its data to its near neighbor, the latter one aggregate the received data with its own and then transmit the whole to its neighbor and so on until reaching the Cluster-Head which passes it directly to the BS. In hierarchical PEGASIS, the nodes are arranged as a chain which forms a hierarchical tree. Each node, chosen at any level in the tree, transmits data to the nodes in the top level of the hierarchy until reaching the BS.

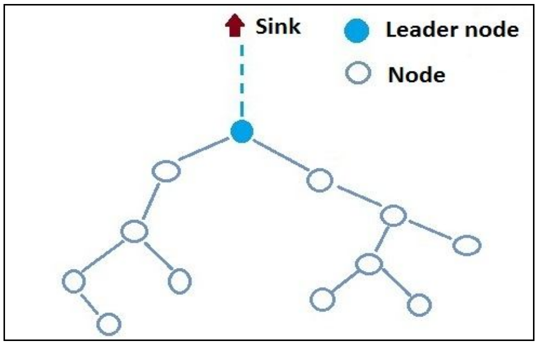

Figure 3: Hierarchical PEGASIS Topology

4.1.5. PEGASIS-MH protocol

PEGASIS-MH [13] protocol follows an approach based on the clusters and chains. This protocol is a more efficient combination of the well known protocols hierarchical LEACH and PEGASIS.

In PEGASIS-MH protocol, an improvement to PEGASIS hierarchical protocol allowing the use of multi-hops routing between the cluster-heads (say inter-clusters multi-hops routing) in order to attain the BS with minimum energy cost. In PEGASIS hierarchical protocol, because the CHs located far from the base station are prone to rapidly deplete their energy budget since they must use strong signals to reach BS. Figure.5 shows PEGASIS-MH Topology.

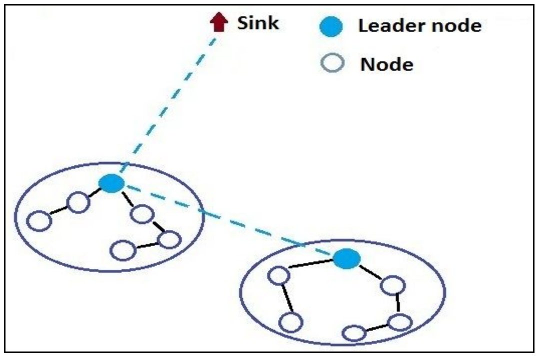

Figure 4: PEGASIS-MH Topology

4.2. Reactive Network Protocols

4.2.1. Threshold sensitive Energy Efficient sensor Network protocol (TEEN)

TEEN [5] is a hierarchical clustering protocol, which groups sensors into clusters with each led by a CH. 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. 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. 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.

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

APTEEN [6] 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. APTEEN 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. 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. CHs also perform data aggregation in order to save energy. When the base station forms the clusters, the CHs broadcast the parameters. The node senses the environment continuously, and only those nodes which sense a data value at or beyond the hard threshold transmit. Once a node senses a value beyond hard threshold, it transmits data only when the values of that attribute changes by an amount equal to or greater than the soft threshold. If a node does not send data for a time period equal to the count time, it is forced to sense and retransmit the data. A TDMA schedule is used and each node in the cluster is assigned a transmission slot. APTEEN supports three different query types namely

- Historical query: To analyze past data values,
- One-time query: To take a snapshot view of the network;
- Persistent queries: To monitor an event for a period of time.

APTEEN is best suited for both periodic sensing & reacting to time critical events such as habitat monitoring. So APTEEN is a hybrid protocol that is both proactive and reactive. Figure 5 shows hierarchical clustering of TEEN and APTEEN.

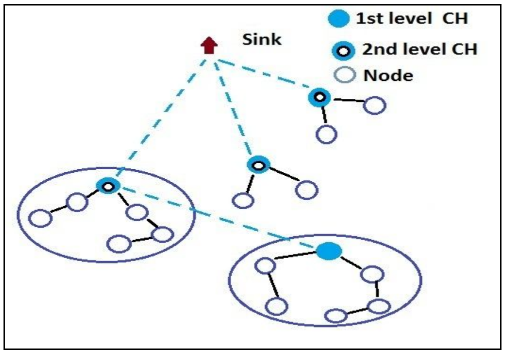

Figure 5: Hierarchical TEEN and APTEEN

Protocol	Advantages	Drawbacks	Route	Scalability
LEACH	Low energy, ad-hoc, distributed	Not applicable to large region & dynamic clustering brings extra overhead	Shortest path route	Limited
M-LEACH	Data transmission energy is less then LEACH	Overhead	Best route	Limited
PEGASIS	Transmission distance for most of the node is reduced	No CH node selection policy and transmission delay for far node	Greedy route	Good
PEGASIS-MH	Transmission distance reduced	No inter-cluster CH selection policy	Multi-hop route	Better
TEEN	Works well in conditions like sudden changes in attributes	lot of energy consumption and overhead	Best route	Good
APTEEN	Low energy consumption then TEEN	Long delay	Best Route	Better

Table 1: Hierarchical Routing Protocol Comparison

5. Conclusion and Future Research

WSN routing protocol is a new area of research, this paper have surveyed and summarized recent research works focused mainly on the energy efficient hierarchical cluster-based routing protocols for WSNs. As this is a broad area, this paper has covered only few sample of routing protocols. The protocols discussed in this paper have individual advantages and pitfalls. Based on the topology, the protocol and routing strategies can be applied. Here we try to show some new protocols developed over the years based on legacy based algorithms like LEACH, PEGASIS, TEEN, APTEEN these new algorithms depict some new concepts and techniques.

The ultimate objective behind the protocol design is to keep the sensors operating for as long as possible, thus extending the network lifetime.

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