ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

International Journal of Advanced Research in Computer and Communication Engineering
Vol. 2, Issue 5, May 2013

Statistical Analysis of Energy Efficient Hierarchical Routing Protocols in WSN

Tintu Devasia[1], Gopika S[2]

Department of Computer Science Rajagiri School of Engineering & Technology Rajagiri Valley,
Kochi-39, Kerala, India[1,2]

Abstract: Wireless sensor nodes with limited battery power are deployed to collect data from the environment. Initially WSN was developed for military purpose, now it is extended to wide range of applications. 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.
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Keywords: Wireless Sensor Networks, Routing Protocols, energy efficiency, cluster head**.**

I. INTRODUCTION

Wireless sensor network is a collection of nodes organized into a cooperative network. The nodes communicate wirelessly and often self-organize after being deployed in an ad hoc fashion. The position of sensor nodes need not be engineered or predetermined. This allows random deployment in inaccessible terrains or disaster relief operations. This also means that sensor network protocols and algorithms must possess self-organizing capabilities. The unique feature of sensor networks is the cooperative effort of sensor nodes. Sensor nodes are embeded 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, entertainment, crisis management, homeland defense, and smart spaces.

Realization of these applications requires efficient routing protocols [7]. Although several algorithms and protocols have been proposed for traditional wireless networks they are not suitable for the requirements of sensor networks because of the limitations in energy, computation and communication capabilities. In order to deploy nodes in inaccessible areas, energy efficient routing protocols [10] need to be developed since power supply is usually a battery and replacement of batteries is impossible.

In general, based on the network structure routing in wireless sensor network can be flat-based, location-based and hierarchical [9] .In this paper, we will explore the energy efficient hierarchical routing mechanisms for sensor networks developed in recent years. Each routing protocol is discussed briefly. Our aim is to help better understanding of the current energy efficient hierarchical routing protocols for wireless sensor networks and comparing their performance.

The paper is organized as follows. In Section 2, sensor networks are classified and briefly summarize routing challenges. Section 3 describes energy efficient hierarchical routing protocols under two types. Performance comparison of all protocols is studied in Section 4. Finally, Section 5 concludes the paper with a summary of the surveyed approaches.

II. CLASSIFICATION OF SENSOR NETWORKS AND ROUTING CHALLENGES

Based on the mode of functioning and the type of target application sensor networks can be classified [11] into two major types. They are:

A. *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.

B. *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

ISSN (Print) : 2319-5940
ISSN (Online) : 2278-1021

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time critical applications like military surveillance or temperature sensing.

Routing in sensor networks is very challenging [9] due to several characteristics that distinguish them from contemporary communication and wireless ad hoc networks.

1. **Global Addressing Scheme**: It is not possible to build a global addressing scheme for the deployment of sheer number of sensor nodes. Therefore, classical IP-based protocols cannot be applied to sensor networks.
2. **Flow of Data**: In contrary to typical communication networks almost all applications of sensor networks require the flow of sensed data from multiple regions (sources) to a particular sink.
3. **Redundancy in Data**: Generated data traffic has significant redundancy in it since multiple sensors may generate same data within the vicinity of a phenomenon. Such redundancy needs to be exploited by the routing protocols to improve energy and bandwidth utilization.
4. **Physical Constraints**: Sensor nodes are tightly constrained in terms of transmission power, on-board energy, processing capacity and storage and thus require careful resource management.

III. ENERGY EFFICIENT 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 sensors 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.

A. 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 [8][9] is one of the first hierarchical routing approaches for sensors networks. The idea proposed in LEACH has been a base for many hierarchical routing protocols. We explore hierarchical routing protocols in this section.

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 clusterheads, 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

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

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 being 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 Fig 1.

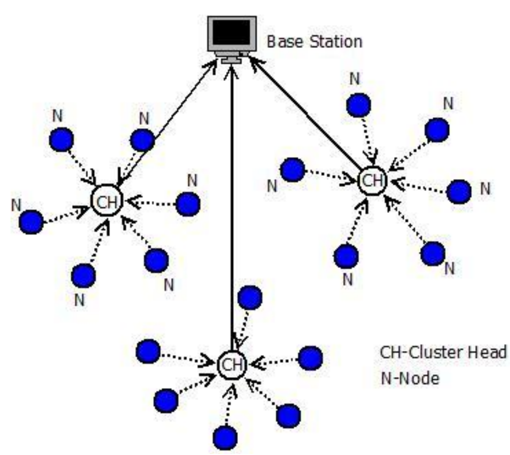

Fig 1: LEACH topology

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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2) *Centralized LEACH(LEACH-C):*

LEACH-C [2] is an enhancement over the LEACH protocol. It uses a centralized clustering algorithm that is, it utilizes base station for cluster formation. LEACH-C protocol can produce better performance by dispersing the cluster heads throughout the network. During the set-up phase of LEACH-C, each node sends information about its current location and residual energy level to the sink. In addition to determining good clusters, the sink ensures that the energy load is evenly distributed among all the nodes. For this, sink computes the average node energy, and determines which nodes have energy below this average. The sink finds *k* optimal clusters. Once the cluster heads and associated clusters are found, the sink broadcasts a message that obtains the cluster head ID for each node. If a cluster head ID matches its own ID, the node is a cluster head; otherwise the node determines its TDMA slot for data transmission and goes sleep until its time to transmit data. The steady-state phase of LEACH-C is identical to that of the LEACH protocol. LEACH-C has better performance over LEACH because the base station utilizes its global knowledge of the network to produce better clusters that require less energy for data transmission and the number of cluster heads in each round of LEACH-C equals a predetermined optimal value, whereas for LEACH the number of cluster heads varies from round to round due to the lack of global coordination among nodes.

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 neighbour or receives data from a neighbour 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 neighbour 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.

Fig 2: Chaining in PEGASIS

4) Base-Station Controlled Dynamic Clustering Protocol (BCDCP):

BCDCP [4] is a centralized routing protocol which distributes the energy dissipation evenly among all the sensor nodes to improve the network lifetime. BCDCP operates in two phases, setup and data communication. The main activities in setup phase are cluster setup, cluster head selection, CH-to-CH routing path formation, and schedule creation for each cluster. The clusters are formed by an iterative cluster splitting algorithm which ensures that the selected cluster heads are uniformly placed throughout the whole sensor field by maximizing the distance between cluster heads in each splitting step. Also to evenly distribute the load on all cluster heads, the balanced clustering technique is utilized where each cluster is split so that the resulting sub clusters have approximately the same number of sensor nodes. It uses a CH to-CH multihop routing scheme to transfer the sensed data to the base station. The routing paths are selected by first connecting all the cluster head nodes using the minimum spanning tree approach and then randomly choosing one cluster head node to forward the data to the base station. The BCDCP protocol utilizes a time-division multiple access (TDMA) scheduling scheme to minimize collisions between sensor nodes trying to transmit data to the cluster head For Schedule creation BCDCP assigns an interim schedule creation ID for all nodes in the cluster. Once data from all sensor nodes have been received, the cluster head performs data fusion on the collected data, and reduces the amount of raw data that needs to be sent to the base station. The compressed data, along with the information required by the base station to properly identify and decode the cluster data, are then routed back to the base station via the CH-to-CH routing path created by the base station. Also the fused data from a given cluster head undergoes further processing as it hops along the CH-to-CH routing path. Simulation results show that BCDCP outperforms LEACH, LEACH-C and PEGASIS.

B. Reactive Network Protocols

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

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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.

2) *Adaptive Threshold Sensitive Energy Efficient Sensor Network Protocol (APTEEN):*
APTEEN [6] is an improvement to TEEN to overcome its short comings 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 HT, it transmits data only when the value of that attribute changes by an amount equal to or greater than the ST. 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
(i) Historical query: To analyze past data values,
(ii) One-time query: To take a snapshot view of the network;
(iii) 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. Fig 3 shows hierarchical clustering of TEEN and APTEEN.

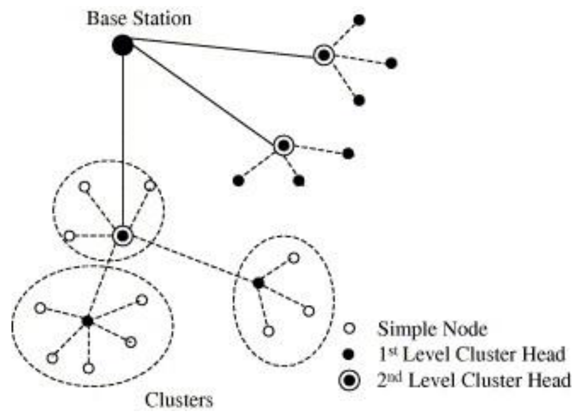

Fig 3: Hierarchical clustering in TEEN and APTEEN

IV. PERFORMANCE COMPARISON

Performance comparison is done by examining the simulation results of the routing protocols. By comparing various results the performance [4] can be measured using system lifetime graph.

The system lifetime of the proactive routing protocols such as LEACH,LEACH-C,PEGASIS and BCDCP is shown in Fig.4.Here FND(First Node Dies),HNA(Half of the node alive)and LND(Last Node Dies) is the metric used to represent the lifetime of sensor networks. With BCDCP, all the nodes remain alive for more than 75 percent of rounds, while the corresponding percentile for LEACH, LEACH-C, and PEGASIS are about 30, 48, and 58, respectively. Fig 4 depicts the performance graph. Furthermore, if system lifetime is defined as the number of rounds for which 75 percent of the nodes remain alive; BCDCP exceeds the system lifetime of LEACH by 100 percent and outperforms that of LEACH-C by 30 percent. A 5 percent improvement in system lifetime is observed for BCDCP over PEGASIS.
Fig 5 shows the average energy dissipation of the protocols under the number of rounds of operation .This plot clearly shows that BCDCP exhibits a reduction in energy consumption of 30 and 40 percent over LEACH and LEACH-C because all cluster heads in LEACH and LEACH-C transmit data directly to base station causing large energy losses in cluster head nodes. And cluster head to cluster head routing approach in BCDCP outperforms greedy algorithm approach in PEGASIS because increasing neighbour distance increases communication cost, so a 5 percent increase is obtained over PEGASIS.

The system lifetime of the reactive protocols such as TEEN and APTEEN is shown in Fig.6.Since APTEEN is both proactive and reactive both are compared with LEACH protocol. FND, HNA and LND is the metric used to represent the lifetime of sensor networks. Here Y-axis represents time over BS.
From the graph it is clear that APTEEN is much better than LEACH and almost at par with TEEN.

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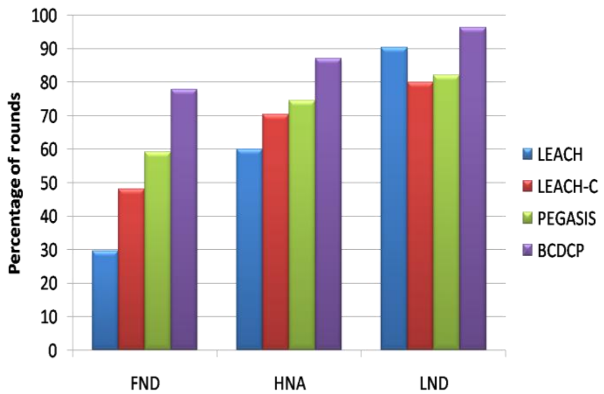

Fig 4: A comparison of the system lifetime of proactive protocols

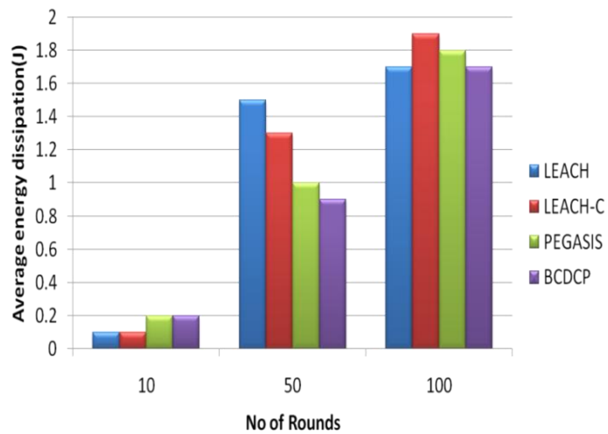

Figure 5: A comparison of the average energy dissipation of proactive routing protocols.

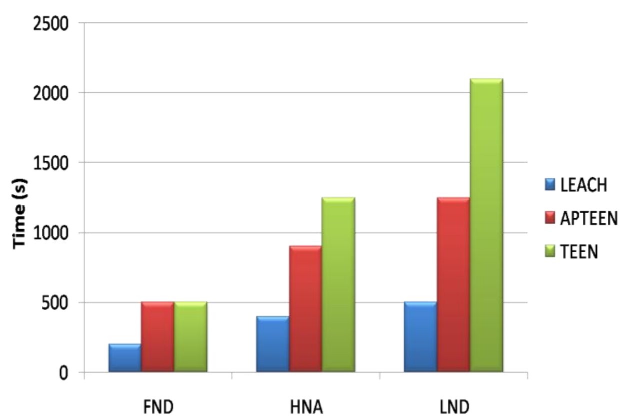

Figure 6: A comparison of the system lifetime of reactive and LEACH protocol

V. CONCLUSION

The routing protocols are designed to extend the lifetime of the network by keeping the sensors alive for a maximum time. Since energy spent on transmission is very high compared to that of sensing, the aim of the routing algorithm is to reduce energy consumption while transmitting data.

In this paper, we have summarized recent research results on energy efficient hierarchical routing in sensor networks and classified the approaches into two main categories, namely proactive and reactive networks.

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