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Study on hierarchical cluster-based energy-efficient routing in Wireless Sensor Networks

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Abstract - *The current technical developments in communication and computation has overall led to a development of low-cost, low-power, small in size, multifunctional nodes in wireless sensor networks. As radio broadcast and reception consumes lot of energy so one of the important problems of wireless sensor network comprises inadequate battery power and short life span. In order to maximize the complete network performance, it is preferable to dispense energy all over the network. Much research has been done in the recent years, examining different features like low power protocols, routing protocols, network coverage problems and network formations. There are various routing protocols like location-aided, multi-path, data-centric, QoS based, hierarchical routing, hybrid routing etc. which are aimed to achieve ideal routing in the context of energy. In this paper, the prime focus is mainly over the study on the energy-efficient hierarchical cluster-based routing for WSN*.

***Key Words*: Wireless Sensor Networks, Cluster Head, Hierarchical clustering, Base Station, PEGASIS, TEEN**

1. INTRODUCTION

With fast development in electronics industry, small cheap battery-powered wireless sensors have now started to make an influence on the communication with the physical world. With the starting of micro-electronic mechanical systems (MEMS)[8] and wireless communication technologies have allowed the development of tiny, low-cost, low-power, and multifunctional smart sensor nodes in a wireless sensor network (WSN). These sensor nodes are positioned over a wide area using a drone which are networked with wireless connections. The wireless nodes were initially used first by the military organisations for frontline surveillance [2].

A WSN generally comprises of vast number of nodes (tens to thousands) which are either mobile or static. These are small devices which are implanted with microprocessors, radio receivers and different components for computing, communication and actuation. Any sensor node of that property can be power-driven by a AA battery and can continue for three years without failure with a 1% low duty cycle mode.

However, these sensor nodes are very disposed to failures, for that reason they are densely installed in large numbers over a fixed area.

Figure 1 shows a diagram of a wireless sensor network. After they are deployed, these nodes are accountable for self-organizing in a suitable network architecture using several network algorithms. Position can be precisely obtained using global positioning systems (GPS) or positioning algorithms. The information can be collected from all nodes across the network and they are transported to the base station.

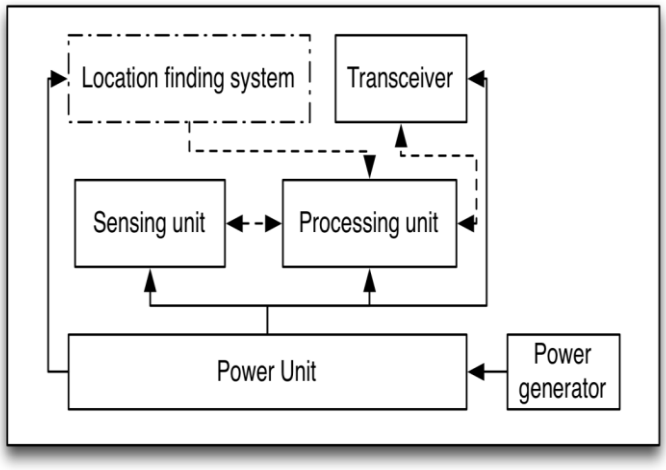


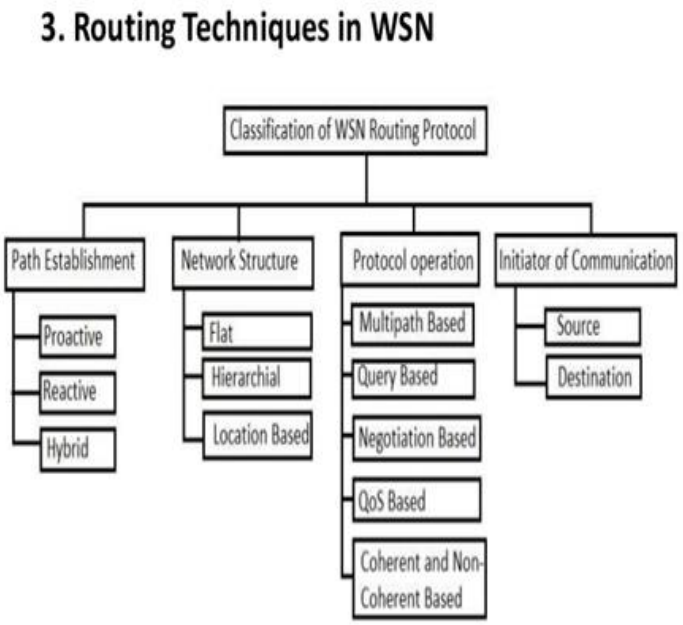
Fig -1: Schematic of a Wireless Sensor Network Architecture

In an ideal case we can originate information from WSN by giving queries and gathering results from base stations (also called sink nodes) which acts as an interface between users and network. Hence, WSN is a distributed database.

The elementary goal of a WSN is to provide information from raw sensed data by individual sensor node. The resource-controlled nature of sensor nodes poses a great challenge to the design of WSN. On the other hand, inadequate power dictates, the design of energy-efficient communication protocol.

Routing is also a very challenging job as the nodes can either be mobile or stationary which distinguishes it from mobile ad-hoc networks 0. The sensor nodes have limits over processing ability, transmission power, storage and on-board energy and thus require careful resource management. Researchers have found several protocols [4] for communication, security and routing correct data to the base station in WSN. All these protocols can be divided into 4 categories as shown in Table 1.

Table -1: Different Routing Protocols



In this paper several hierarchical cluster-based routing protocols for wireless sensor network are discussed and compared. This paper is ordered into 3 sections. In section 2, energy-efficient structures are discussed and in section 3, various hierarchical cluster-based routing protocols are discussed and compared.

2. ENERGY EFFICIENT CLUSTERING STRUCTURES IN WSN

The main reason of clustering is to minimize the entire transmission power over the nodes in a specified path, and to sustain a balance of load among the nodes for extending the network lifetime. Clustering is a sample of layered protocols in which a network is made of several clusters of sensors. As in Figure 2, each cluster is managed by a special node called cluster head (CH), which acts a leader node and is accountable for organizing the data transmission activities of all sensors in its region. All sensors in a cluster communicate with a cluster head for performing intra-transmission arrangement and data aggregation. Cluster heads in turn transmits the sensed data to the global sink. The distance between the sensor to their cluster head is much lesser than their respective distances to global sink. Since a network is characterized by its inadequate wireless channel bandwidth, it would be useful if the amount of data transmitted to the sink can be reduced. To achieve this objective, a local collaboration between the sensors in a cluster is required to reduce bandwidth.

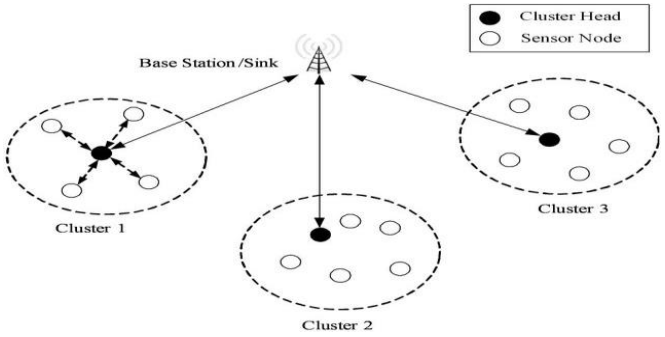


Fig -2: Clustering in WSN

2.1 Cluster-based Hierarchical Model

As shown in Figure 3, the hierarchical splits the entire network into layers of clusters or hierarchies [5]. Nodes are categorised into clusters which again forms bigger clusters leading to tree-like structures. Data travels from the lowest clustered layer to highest layer. Clustering thus offers integral optimization abilities at the CHs. In the cluster-based hierarchical model, data is first combined and analysed in the cluster then sent to the higher-level cluster-head. As it moves upwards from lower to higher level, it covers greater distances, which in turn decreases the travel time and latency. This model is better than any single-hop or multi-hop models.

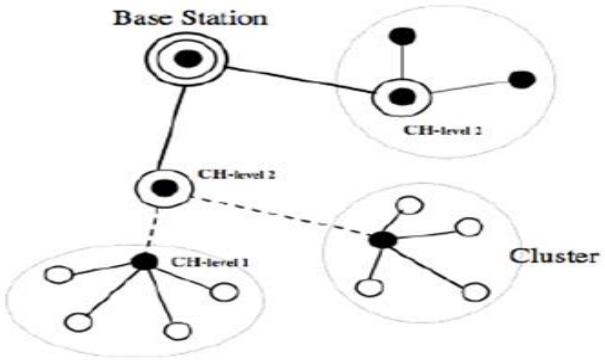


Fig -3: Cluster Based Hierarchical Model

A cluster-based hierarchy is very efficient as data moves faster to base station from the cluster heads thus decreasing latency than in a multi-hop model. Also, in cluster-based model only cluster-heads are responsible for data aggregation but in the multi-hop model every intermediate node performs data aggregation. As a result, the cluster-based model is more suitable for real-time applications than the multi-hop model. However, it has a major problem, i.e., as the distance between clustering level increases, the energy spent is proportionate to the square of the distance. This increases energy expenditure. Regardless of this pitfall, this technique overshadows its disadvantage. A cluster-based hierarchical model provides a better method to routing for WSNs.

3. ENERGY-EFFICIENT HIERARCHICAL CLUSTER ROUTING TECHNIQUES

As discussed in [8], these techniques maximise the time period of a network with a huge number of sensor nodes. The EEHC technique splits the entire WSN into clumps where each clump has a cluster head and the clusters are in the form of a hierarchy. The CH gather the data from the adjacent nodes and transfers it to the CHs of upper hierarchical levels which eventually reaches the global sink or base station.

Numerous research projects in the past few years have explored hierarchical clustering in WSN from different perceptions. Various protocols have been proposed for extending the life of WSN and for routing the exact data to the base station. Some of them are LEACH, PEGASIS and TEEN.

3.1 Low-Energy Adaptive Clustering Hierarchy (LEACH)

[3] LEACH is the initial and the most powerful EEHC technique for WSNs which was proposed for dropping power consumption. In LEACH, based on time-interval the nodes alternately perform the clustering. Each cluster head (CH) directly communicate to relay the data to the base station. It is an application-specific data distribution protocol that uses clusters to extend the life of the wireless sensor network LEACH is based on an *aggregation* technique that combines the original data into a smaller size meaningful data to all individual sensors. LEACH splits the whole network into several clusters of sensors, which are built by using localized coordination and control not only to decrease the amount of data that are transmitted to the sink, but also to make routing and data distribution more available. Energy dissipation of the sensor depends on the distance and the data size to be transmitted. Hence, LEACH tries to transmit data over short distances and reduce the number of transmission and reception activities. LEACH uses single-hop routing where each node transmits directly to the cluster-head and the sink. Therefore, it is not valid for networks which are deployed in large areas. Also, LEACH clustering terminates in a finite number of loops, but does not guarantee good Cluster Head distribution.

3.2 Power-Efficient Gathering in Sensor Information Systems (PEGASIS)

[7] PEGASIS can be called as a superset of LEACH protocol. It forms multiple clusters and creates chains from sensor nodes so that each node transmits and receives from a neighbouring node and only one node is selected from that chain to transmit to the base station. After the data is collected and aggregated it moves from node to node and is finally delivered to the base station. The chain creation is performed using greedy approach. Unlike LEACH, PEGASIS does use form cluster. However, it uses only one node in a chain to transmit data to the base station instead of using various nodes. A sensor transmits data to its adjacent nodes in the data fusion phase without sending straight to its CH as in the case of LEACH. In PEGASIS routing technique, the construction stage assumes that all the sensors have information about all other nodes, mainly, the positions of the sensors, and uses a greedy approach to calculate nodal positions. Precisely, it begins with the farthest sensor from sink to make sure that sensors which are very far apart from the sink have adjacent nodes. If any sensor dies due to low battery, the chain is formed using the greedy approach by sidestepping the eliminated sensor. In each round, an arbitrarily sensor node from the chain is chosen which transmits the aggregated data to the BS, hence reducing the per round energy expenditure as compared to LEACH. Thus, PEGASIS is an ideal chain-based protocol.

3.3 THRESHOLD SENSITIVE ENERGY EFFICIENT SENSOR NETWORK PROTOCOL (TEEN)

[6] TEEN is a hierarchical clustering protocol, which groups sensors into clumps each having a CH. All the sensors forming a transfer their sensed data to the CH. The CH then sends the collective form data to higher level CH till the data reaches to the BS. Thus, the sensor network architecture in TEEN is based on a series of hierarchies where closer nodes make a cluster and this procedure goes on till the BS is reached. TEEN is fit for applications where the users can control a trade-off among energy efficiency, data accuracy, and response time.

Salient features of TEEN comprise of its correctness for time critical sensing applications. Also, since message transmission uses additional energy than data sensing, so the energy consumption in this system is less than the proactive networks. The soft threshold can be varied. At every cluster change time, new parameters are broadcasted and so, the user can change them as needed. However, TEEN is not apt for sensing applications where periodic reports are needed since the user may not get any data at all if the thresholds are untouched.

4. CONCLUSIONS

Due to the scarce energy resources of sensors, energy efficiency is one of the key challenges in the design of protocols for WSNs. The ultimate objective behind the protocol design is to keep the sensors operating prolonged time, therefore extending the network lifetime. In this paper we have studied and summarized current research works focused primarily on the energy efficient hierarchical cluster-based routing protocols for WSNs. As this is a comprehensive area, this paper has only covered few routing protocols. The protocols discussed in this paper have individual advantages and drawbacks. Based on the topology, the protocol and routing strategies can be applied. The factors affecting cluster formation and CH communication are open topics for future research.

Moreover, the process of data aggregation and fusion among clusters is also an fascinating problem to explore.

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