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Modern Energy Efficient Routing Algorithms in Wireless Sensor Network: A Survey

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Abstract: Wireless sensor networks (WSNs) are becoming popular research area from last few decades due to their various modern applications. With the recent technological growth in Internet of Things (IoT) and embedded electronics, the wireless sensors attracted these smart devices for rapid research and development. The increasing applications of wireless sensors in industries, smart cities and agricultures are presenting the challenging ideas for future research. In this paper, we are surveying the modern energy efficient routing algorithms in wireless sensor networks. The energy efficiency is major concern for research because the sensors nodes are equipped with some limited low power battery backup. The battery recharge and replacements are not possible once the sensor networks are deployed and they work until the batteries of the nodes die out. This survey concludes along with future enhancement and improvement in the energy efficiency of wireless sensor networks.

Keywords: Wireless Sensor Network, Energy Efficient Routing, Clustering, Cluster Head, Base Station, Low Energy.

1 Introduction

A regular wireless sensor network (WSN) is considered as an particular variety of wireless ad hoc networks with reduced or no mobility. In WSN, sensor gather information about environmental phenomenon or the occurrence of events such as rise or drop in temperature [1][2]. Sensor networks are usually composed of "nodes", it has a specific name that is "Sensor" because these nodes are furnished with automatic sensors [3]. A sensor node is a type of electro-mechanical device which converts a sensed attribute like temperature, humidity, pressure, vibrations into a data pattern readout by the users [4]. In WSN, nodes are not mobile however, it is a category of adhoc networks. So in case of ad-hoc network, the mobility characteristic is more. Data are inquired depending on bounded physical quantity in wireless sensor network. A sensor node have transducer, an embedded processor with small memory unit and a wireless transceiver, all these devices run on the power supplied by an attached battery [5][6]. The modern wireless sensors nodes are electromechanical and they have been used today they are widely used in industry process control, healthcare applications, traffic control, home automation, environmental monitoring and battle field surveillance [7].

The microelectronic mechanical systems (MEMS) is a modern technology which improved and developed low-cost, small, power efficient and multi-functional sensor devices for WSN [8][9]. For military, industrial and scientific applications sensor nodes are positioned and linked through the Internet. The nodes basically sense physical or environmental conditions like sound, humidity, light, temperature, radiation, motion, vibration, pressure etc [10]. The table 1 shows various sensor classifications with examples. The modern networks are bi-directional, user can send control signal for sensor activity [11]. WSNs have specific properties such as node heterogeneity, denser level of node deployment, capability to withstand polluted or harsh environmental conditions, severe energy, computation and storage constraints, which represent much new technological advancement in the development and application of WSNs [12][13].

The hundreds or thousands of "nodes" built a WSN, node is connected to one or more sensors. Each sensor node has main components: a microcontroller, a basic radio transceiver integrated with antenna or connection to an external antenna, an electronic circuit for interfacing with the sensors and an battery as one time power source [14][15]. The cost and size of the sensor depends on memory, power back up, bandwidth and processing speed [13]. Also cost of sensor nodes varies, depending on the applications, accuracy, functionality, range and complexity of the individual sensor nodes. The geographical topology of the WSNs vary from a simple star network topology to a complex multi-hop wireless mesh network. The data transmission technique between the hops of the

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Table 1: Sensors Classifications with Examples

Type	Examples
Humidity	MEMS-based Humidity Sensors, Hygrometers, Capacitive and Resistive Sensors.
Temperature	Thermocouples, Thermistors.
Motion, Vibration	Photo Sensors, Gyroscopes, Accelerometers.
Radiation	Geiger–Mueller Counters, Ionization Detectors.
Position	GPS, Inclinometers, Ultrasound-based Sensors, Infrared-based Sensors.
Mechanical	Piezo Resistive Cells, Strain Gauges, Capacitive Diaphragms, Tactile Sensors.
Flow	Anemometers, Mass Air Flow Sensors.
Pressure	Barometers, Pressure Gauges, Ionization Gauges.
Chemical	Infrared Gas Sensors, pH Sensors, Electrochemical Sensors.
Optical	CCD Sensors, Photodiodes, Infrared Sensors, Phototransistors.
Acoustic	Piezoelectric Resonators, Microphones.
Electromagnetic	Magnetometers, Hall-effect Sensors.

sensor network can be routing or flooding [16].

This paper provides a comprehensive survey and issues regarding energy efficiency and network lifetime of wireless sensor network. An exploratory analysis is presented on energy efficient protocols and methods used in wireless sensor networks.

2 WSN System Model

The hundreds or thousands of sensor nodes construct the sensor network to monitor and gain information about their environment. The functionalities such as sensing, processing, storing, location finding, data packet transmission, power consumption etc. are available in each of the nodes [17][18].
The major components of WSN are:

Sensor Node

Sensor Node is the main component of a WSN. It take multiple works in a network, like as simple sensing, processing, data storing, routing, path searching and data transmission.

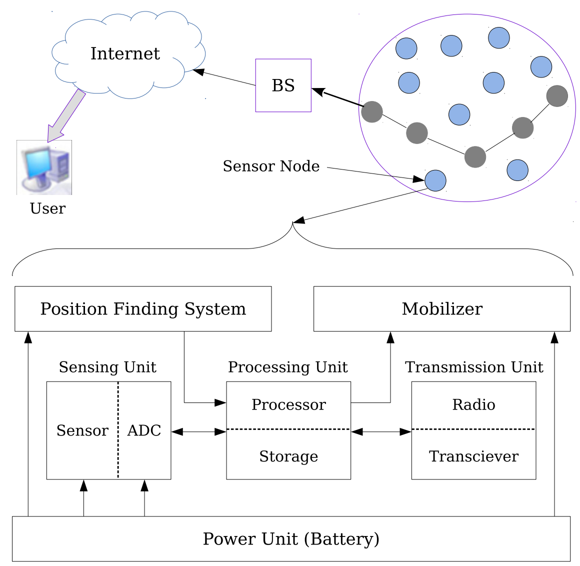

Figure 1: Architecture of Wireless Sensor Network

Clusters

It is a group of sensor nodes. Normally sensor nodes are collected into clusters. Clusters are the organizational unit for WSNs. The cluster simplify the task of communication by dividing the dense network into groups.

Cluster Head

Cluster heads (CHs) are the group leader of a cluster. All sensor node send their data to the cluster head within a cluster. CHs are required to organize activities in the cluster. These tasks include data-aggregation and organizing the communication schedule of a cluster. Cluster head directly communicates with the base station.

Base Station

Base station (BS) provides the communication link between the sensor network and its end-user. It is at the higher level of the hierarchical in WSN. Base station receives data from the cluster heads.

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End User

It is the user or observer of the WSN. The sensed data in a wireless sensor network can be used for various applications. Therefore, a general application may make use of the network data over the internet, using a Laptop, PDA, a desktop computer. In a basic queried sensor network where the required data is collected from a query sent through the network which is produced by the end user.

The structural model of sensor network is shown in figure 1. Transmission unit, sensing unit, processing unit, and power unit (battery) are the four major ingredients of sensor nodes assigned with dissimilar jobs. To detect the physical environment, sensing unit is used and reports the CPU to compute or process and store the sensed data. Transmission unit is tasked to accept the information from CPU and convey it to the cluster head or base station. Power unit regulate battery power to sensor node [14].

Due to various characteristics that distinguish WSNs from other kind of wireless networks like mobile ad hoc networks (MANET) or cellular networks, routing in WSN is major challenging task [19]. These include very dense deployment of sensor nodes, significant redundancy of data, limited bandwidth and limited power of transmission.

3 Survey of Clustering Based Routing Algorithms

A comprehensive survey on energy optimizing protocols [20] based on their classifications is presented in this section. The main objective of this survey is how to design an effective and energy optimizing protocol in order to improve the networks lifetime for many application specific environments because the sensor nodes are constrained to one time battery power resources itself which is very limited, so [21].
The main classifications of routing protocols are:

- Data Centric Protocols.
- Hierarchical Based Routing Protocol (Clustering).
- Location-Based Routing Protocol (Geographic).
- Network Flow and QoS Aware Protocol.

These are the network structure dependent protocols in WSNs. In this survey, only some prominent hierarchical routing protocols such as LEACH [22], PEGASIS [23], H-PEGASIS [24], SEP [25], ESEP [26], TEEN [27] and APTEEN [28] are discussed as shown in Table 2.

Table 2: Categories of Routing Protocols

Category	Representative Protocols
Hierarchical Protocols	LEACH, PEGASIS, H-PEGASIS, SEP, ESEP, TEEN & APTEEN.

Hierarchical-Based (Clustering) Protocols:
Hierarchical-Based routing [29] is used for point-to-point routing with minimum routing state. It has certain advantage of scalability and efficient data packet transmission. Hierarchical routing [30] maintains the power consumption of sensor nodes and performs data aggregation for helping in minimizing the number of transmitted data packets to the base station. The whole wireless sensor network is divided into a number of clusters in term with the specific rules [31][32]. Some hierarchical protocols are discussed here.

3.1 LEACH

LEACH (Low-Energy Adaptive Clustering Hierarchy) [22] is the first hierarchical-based routing protocol. Whenever, the sensor node in the WSN breaks down or its battery power becomes low then LEACH [22] protocol is used in the network. In LEACH, [22] wireless sensor nodes are grouped into local clusters and its cluster members elect their cluster head (CH) to keep off extra energy consumption by sensor nodes and incorporate data aggregation which minimizes the amount of data packet sent to the base station, to enhance the life time of the network. Therefore this protocol has an effect in the context of energy saving.

Two-Level Hierarchy LEACH (TL-LEACH) [33] is an improved form of the LEACH protocol which has of two levels of cluster heads called primary and secondary, in place of a single cluster head. The advantage of two-level structure of TL-LEACH is that it minimizes the amount of sensor nodes that transmit data packets to the base station, effectively reducing the total energy consumption [33].

Cross-Layer protocol based on LEACH (CL-LEACH) [34] is based on LEACH for energy conservation of clustered WSNs. CL-LEACH especially in he application with a large and aparse monitoring region and remote sink node. The cross-layer design is a mostly-used technique for improving energy conservation and network performance.

3.2 PEGASIS and H–PEGASIS

PEGASIS [23] (Power-Efficient Gathering in Sensor Information Systems) is chain-based routing protocol which is an improved modification over LEACH. PEAGSIS [13] designs a node chain whenever sensor nodes are deployed randomly in the environment then each sensor node communicates only with its nearer neighbor, take its turns and transmit data packet to the base station, so it decreases the amount of energy consumption per round.

PEGASIS [23] performs better than LEACH [22] by elimination of taking dynamic cluster formation scheme, since data packet transmission is asynchronous, the transmission time will be very long. Hierarchical-PEGASIS [24] makes a further improvement, it allows simultaneous data packet transmission when the nodes are not adjacent.

As compared to LEACH [22], the two protocols eliminate the overhead of cluster formation, but both of them do not analyze the energy condition of next hop into consideration while choosing a routing path, for heavy-loaded network, they are not applicable. For large quantity of sensor nodes in WSNs, the delay of data packet communication is larger, so they are not appropriate and unsuitable for sensor networks where global identification is difficult to obtain.

3.3 TEEN

TEEN [27] (Threshold Sensitive Energy Efficient Sensor Network) protocol and it was first developed for reactive routing networks. It is mostly applied in temperature sensing application. TEEN [27] is based on hierarchical clustering which separates the sensor nodes twice for clustering for detecting the sudden variations in the sensed data such as temperature. After the clusters formation, TEEN [27] divides the cluster head (CH) into the second-level cluster head and uses "Hard" and "Soft" threshold values to detect the sudden variations.

Hard threshold minimizes the number of packet transmissions by providing the sensor nodes to transmit packet only when the sensed data value is in the high range of consideration. The soft threshold minimizes the number of packet transmissions by forbidding all the packet transmissions which occurs when there is minimum variation in the sensed value.

The disadvantage of TEEN [27] is that it is not applicable for applications where data is needed on regular basis. The practical implementation is not reliable that there are no collisions in the cluster. TDMA scheduling of the sensor nodes can be applied for this type of problem but it creates some delay in the reporting of the time-critical data. For this problem, CDMA may be a possible solution. TEEN [27] is best applicable for time critical applications such as explosion detection, intrusion detection, radiation detection etc.

3.4 APTEEN

The Adaptive Threshold Sensitive Energy Efficient Sensor Network protocol (APTEEN) [28] is a modified enhancement of TEEN and targeted at both capturing periodic sensed data collections and reacting to time critical events. The architecture of APTEEN is similar as in TEEN. In APTEEN, once the cluster heads are selected, in each cluster period, the cluster head broadcasts the parameter such as sensed values, threshold and count time to all its cluster nodes.

The performance of APTEEN [28] lies between TEEN [27] and LEACH [22] in terms of battery power consumption and lifetime of the sensor network. While sensing the environment, TEEN [27] protocol only transmits the time critical sensing data, whereas APTEEN [28] supports periodic report for time-critical events. The disadvantages of the two protocols are the overhead and complexity of forming clusters.

3.5 FLEACH

Factor-based LEACH (FLEACH) [35] investigated the impact of secondary cluster aggregation on the network lifetime of WSN. We systematically consider various cluster head energy-levels and distances to the base station as thresholds to control when secondary cluster head aggregation occurs. The idea behind this is to increase the secondary cluster heads chances for data aggregation to understand how it affects the network life-time. This approach achieves a considerable increase in the network lifetime of the network terrain. this research has led to the optimal-case i.e. FLEACH which is to ensure that the highest residual energy node within each cluster performs data fusion all through the network operation, while the CH transfers to the base station. Afterwards, a deterministic component is included called FLEACH-E to give more chances to higher energy nodes to be CHs. FLEACH presents a considerable performance with respect to the network lifetime and energy consumed.

4 Problem Formulation

Generally, the sensor node in WSNs are equipped with one time limited power source. Due to battery limitations, researchers are currently focusing on the designs and methods of power aware protocols and algorithms for wireless sensor network. Basically, the problem statement is not problems in the energy efficient routing protocols rather these are limitations of the routing protocols. In this section, we are pointing out some notable limitations of modern energy efficient routing protocols which was analyzed in the section of literature survey.

Equal Sized Clustering

Clusters are formed of equal size, in LEACH[22], SEP [25], ESEP [26], TEEN [27] protocols, the cluster heads (CHs) nearer to the base station (BS) have high work load as compared to other cluster heads which are farther away from their base station (BS), because cluster heads nearer to base station receive data packets from sensor node of his cluster as well as from other cluster head (CH) through multi-hopping and so they have to work with heavily data traffic.

As a result, the battery power of the cluster head (CH) nearer to the base station will die soon as compared to other cluster heads. This equal sized clustering concept creates some unbalancing condition in wireless sensor network for network lifetime enhancement point of view. Also according to requirements, attribute values can be changed at the time of cluster head selection in equal sized clustering.

Probability Based Cluster Head Selection

In LEACH, SEP, ESEP and TEEN protocols, the cluster head (CH) selection is on the bases of the probability. There are no calculations of energy level of the sensor nodes from cluster during the cluster head selection. Because the ratio of current energy to initial energy among the sensor nodes are different so cluster head selection on probability based create unbalancing in selection of cluster head.

Proactive Routing Protocol

In LEACH[22], SEP [25] and ESEP [26], protocols, all sensor nodes continuously sense their environment and continuously send the data packets to their base station so they work as a proactive routing protocol. Because transmission of data packets consumes more energy as compared to sensing so proactive routing protocol has this limitation.

The continuously received sensed data packets have same repeated attributed or values in the data which may be useless for the observer of the sensor network.

Limitation of Heterogeneity

SEP [25] and ESEP [26] protocols are heterogeneity aware protocols which improve stability period and network lifetime but here a limitation of heterogeneity is this that throughput is also increased which decrease network lifetime. To improve energy efficiency, accuracy and to enhance network lifetime, our proposed protocol is observed to be better than other protocols.

5 Proposed Approach

To improve and enhance the lifetime of a wireless sensor network, clustering provides an efficient and effective way [36]. The clustering protocols discussed in previous section usually apply two techniques, selection of cluster heads with more residual energy and rotation of cluster heads (CHs) on the probability basis periodically, for fairly even distribution of energy consumption among sensor nodes in each cluster and enhance the network lifetime. When cluster heads cooperate with other cluster heads for forwarding their data packets to the base station, then the cluster heads nearer to the base station are loaded with high data packet transmission traffic and it tend to die early, leaving areas of the network uncovered and produce network partition.

To minimize this problem, the concept of unequal clustering mechanism can be proposed for periodical gathering of data packets in wireless sensor networks. It groups the sensor nodes into the clusters of unequal size, and clusters closer to the base station (sink) have smaller in size than those farther away from the base station. Thus cluster heads nearer to the base station can preserve some energy for the inter-cluster data packet forwarding.

6 Conclusion

The general and comprehensive analysis of various energy efficient methods in WSN has been presented in this survey, by which network lifetime can be improved. We mainly focused on hierarchical routing protocols which provide power optimization and enhance the network lifetime. Popular hierarchical routing protocols such as LEACH and LEACH based protocols like TL-LEACH, CL-LEACH, PEGASIS, H-PEGASIS, SEP, ESEP, TEEN, APTEEN and FLEACH have been discussed with their features. The concept of unequal clustering mechanism is presented as an improvement over modern hierarchical protocols. Effectiveness, scalability, adaptability are major challenging issues still exist which is to be solved. Hierarchical routing protocols are effective, but still major future challenging issues are needed to be developed in the sensor networks.

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