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Energy Efficient Routing Protocols and Algorithms for Wireless Sensor Networks - A Survey

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Abstract - Wireless Sensor Networks (WSNs) are an emerging technology for monitoring physical world. The sensor nodes are capable of sensing various types of environmental conditions, have some processing capabilities and ability to communicate the sensed data through wireless communication. Routing algorithms for WSNs are responsible for selecting and maintaining the routes in the network and ensure reliable and effective communication in limited periods. The energy constraint of WSNs make energy saving become the most important objective of various routing algorithms. In this paper, a survey of routing protocols and algorithms used in WSNs is presented with energy efficiency as the main goal.

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I. Introduction

Wireless Sensor Networks (WSN) are found in many applications including environmental monitoring, health applications, military surveillance, habitat monitoring and smart homes. A Wireless Sensor Network consists of many sensor nodes deployed in environment and connected to a base station that processes the sensed data from the sensors. One of the key characteristics of sensor nodes is that they are energy constrained[9]. Typically sensor nodes rely on finite energy sources like battery for power in unmanned positions.

Due to massive number of deployment and remote, unattended positions, replacements of batteries are quite impossible. Harvesting energy from the environment is currently a promising but under developed research area and therefore, energy has to be used judiciously. The expectancy of longer lifetime of sensor nodes has put researchers to work on every possible aspect of sensor nodes in gaining energy efficiency.

II. Classification of Sensor Networks and Design Objectives

Sensor Networks can be classified on the basis of their mode of functioning and the type of target application into two major types. They are

a) Proactive Networks

The nodes in this network switch on their sensors and transmitters periodically, sense the data and transmit the sensed data. They provide a snapshot of the environment and its sensed data at regular intervals. They are suitable for applications that require periodic data monitoring like moisture content of a land in agriculture.

b) Reactive Networks

The nodes in this network react immediately to sudden and drastic changes in the value of the sensed attribute. They are therefore suited for time critical applications like military surveillance or temperature sensing.

Most sensor networks are application specific and have different application requirements. Thus, all or part of the following main design objectives is considered in the design of sensor networks[11,13]:

(i) ***Small node size:*** Since sensor nodes are usually deployed in a harsh or hostile environment in large numbers, reducing node size can facilitate node deployment. It will also reduce the power consumption and cost of sensor nodes.

(ii) ***Low node cost:*** Since sensor nodes are usually deployed in a harsh or hostile environment in large numbers and cannot be reused, reducing cost of sensor nodes is important and will result into the cost reduction of whole network.

(iii) ***Low power consumption:*** Since sensor nodes are powered by battery and it is often very difficult or even impossible to charge or recharge their batteries, it is crucial to reduce the power consumption of sensor nodes so that the lifetime of the sensor nodes, as well as the whole network is prolonged.

(iv) ***Reliability:*** Network protocols designed for sensor networks must provide error control and correction mechanisms to ensure reliable data delivery over noisy, error-prone, and time-varying wireless channels.

(v) ***Scalability:*** Since the number sensor nodes in sensor networks are in the order of tens, hundreds, or thousands, network protocols designed for sensor networks should be scalable to different network sizes.

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(vi) *Self-configurability:* In sensor networks, once deployed, sensor nodes should be able to autonomously organize themselves into a communication network and reconfigure their in the event of topology changes and node failures.

(vii) *Channel utilization:* Since sensor networks have limited bandwidth resources, communication protocols designed for sensor networks should efficiently make use of the bandwidth to improve channel utilization.

(viii) *Fault tolerance:* Sensor nodes are prone to failures due to harsh deployment environments and unattended operations. Thus, sensor nodes should be fault tolerant and have the abilities of self-testing, self-calibrating, self-repairing, and self-recovering.

(ix) *Adaptability:* In sensor networks, a node may fail, join, or move, which would result in changes in node density and network topology. Thus, network protocols designed for sensor networks should be adaptive to such density and topology changes.

(x) *Security:* A sensor network should introduce effective security mechanisms to prevent the data information in the network or a sensor node from unauthorized access or malicious attacks.

III. Energy Efficient Wireless Sensor Network Protocols

Protocols for Sensor networks must be designed in such a way that the limited power available at the sensor nodes is efficiently used. Routing in WSN is quite challenging due to its inherent constraints and basic characteristics that distinguish WSN from other wireless networks. They are

- There is no global addressing scheme in WSN. Therefore, routing protocols of IP based networks cannot be used in WSN.
- Characteristic of data flow in WSN is a bit different. Data from multiple nodes actually go to a single point that is a sink or base station.
- Data from multiple sources can create significant redundancy in the data traffic.
- Nodes are tightly constrained about resources.

There are a handful number of routing protocols have been proposed for WSN. These protocols can be broadly categorized into six different types, namely, data - centric, hierarchical, location-aware, mobility based, heterogeneity – based and Quality of Service (QoS) based.

a) Data Centric Protocols

Data-centric protocols aim at aggregating the data by the intermediate sensors on the data originating from the source sensors and send the aggregated data toward the sink. This results in energy savings due to lesser transmission required to send the data from the sources to the sink. In this section, some the data-centric, energy efficient routing protocols for WSNs are discussed.

i. *Directed Diffusion*

Directed diffusion [7, 8] is a data-centric routing protocol for sensor query dissemination and processing. It is energy-efficient, scalable and robust.

A sensing task is described by a list of attribute-value pairs. The sink specifies a low data rate for incoming events at the beginning of the directed diffusion process. The sink can thereafter reinforce one particular sensor to send events with a higher data rate by resending the original interest message with a smaller interval.

ii. *Sensor Protocols for Information via Negotiation (SPIN)*

SPIN [10, 23] protocol was developed to overcome the problems like implosion and overlap caused by flooding protocols. The SPIN protocols are able to compute the energy consumption required to compute, send, and receive data over the network.

SPIN uses meta-data as the descriptors of the data that the sensors want to disseminate. The notion of meta-data avoids the occurrence of overlap given the sensors can name the interesting portion of the data they want to get. The size of the meta data should be less than that of the corresponding sensor data.

SPIN-1(SPIN_PP) uses negotiation mechanism to reduce the consumption of the sensors. SPIN-2(or SPIN-EC) uses a resource –aware mechanism for energy savings.

iii. *Energy-Aware Data-Centric Routing(EAD)*

EAD[1] is energy aware and helps extend network lifetime.EAD is a distributed routing protocol, which builds a virtual backbone composed of active sensors that are responsible for in-network data processing and traffic relaying.

The network is represented by a broadcast tree spanning all sensors in the network and routed at the gateway, in which all leaf nodes' radios are turned off while all other nodes correspond to active sensors forming the backbone and thus their radios are turned on.

b) Hierarchical Protocols

Hierarchical clustering in WSN is an energy efficient protocol with three main elements: sensor nodes (SN), Base station (BS) and Cluster Heads (CH). The SNs are sensors deployed in the environment to collect data. The main task of a SN in a sensor field is to detect events, perform quick local data processing, and transmit the data. The BS is the data processing point for the data received from the sensor nodes, and from where the data is accessed by the end-user. The CH acts as a gateway between the SNs and BS. The CH is the sink for the cluster nodes, and the BS is the sink for the cluster heads. This structure formed between the sensor nodes, the sink and the base station can be replicated many times, creating the different layers of the hierarchical WSN.

i. *Low Energy Adaptive Clustering Hierarchy(LEACH):*

LEACH [24, 25] was the first dynamic energy efficient cluster head protocol proposed for WSN using homogeneous stationary nodes .

In LEACH all nodes have a chance CH and therefore energy spent is balanced for every node. The CH for the Clusters are selected based on their energy load. After its election, the CH broadcasts a message to other nodes, which decide which cluster they want to belong to, based on the signal strength of the CH. The clusters are formed dynamically in each round and the data collection is centralised. A TDMA schedule created by the CH is used to gather data from the sensors. The operation of LEACH is divided into rounds having two phases each namely

c) a setup phase to organize the network into clusters, CH advertisement, and transmission schedule creation and
d) a steady phase to for data aggregation, compression and transmission to the sink.

LEACH reduces energy consumption by

a. minimizing the communication cost between sensors and their CH.
b. Turning off non-head nodes when not required.

ii. *Power-Efficient Gathering in Sensor Information Systems (PEGASIS):*

PEGASIS [20] is an extension of the LEACH protocol, and simulation results show that PEGASIS is able to increase the lifetime of the network twice as much as the LEACH protocol.

PEGASIS 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. 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 utilised networks.

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

TEEN [3] is a energy efficient hierarchical clustering protocol which is suitable for time critical applications TEEN has SNs reporting data to CHs. The CH sends aggregated data to the next higher level CH until data reaches the sink. TEEN is designed for reactive networks, where the sensor nodes react immediately to sudden changes in the value of the sensed attribute. Sensor nodes sense the environment continuously, but data transmission is done occasionally and this helps in energy efficiency. This protocol sends data if the attribute of the sensor reaches a Hard Threshold and a small change -the Soft Threshold. The drawback of this protocol is that if the threshold is not reached, the nodes may not communicate and. we do not know if a node is dead.

iv. *Adaptive Periodic Threshold Sensitive Energy Efficient Sensor Network Protocol (APTEEN):*

APTEEN [2] is an improvement to TEEN and aims at periodic data collection and reacting to time critical events. It is a hybrid clustering based protocol and supports different types of queries like (i) historical query, to get results on past data (ii) one-time query that gives a snapshot of the environment and (iii) persistent queries, to monitor an event for a time period. The cluster head selection in APTEEN is based on the mechanism used in LEACH-C. The cluster exists for an interval called the cluster period, and then the BS re-groups clusters, at the cluster change time.

APTEEN used modified TDMS, where each node in the cluster is assigned a transmission slot, to avoid collisions. For query responses it uses node pairs. If adjacent nodes sense similar data, only one of them responds to a query, the other one goes to sleep mode and thereby saves energy.

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

HEED [16, 17] is an extension of LEACH and uses residual energy and node degree or density asymmetric for cluster selection to achieve power balancing. HEED has the following features.

(i) prolongs network lifetime by distributing energy consumption,
(ii) terminates clustering process within a constant number of iterations,
(iii) minimizes control overhead and
(iv) produces well distributed CHs and compact clusters.

HEED selects CHs based on the residual energy of the SNs and intra-cluster communication cost as a function of cluster density or node degree. HEED clustering improves network lifetime over LEACH clustering randomly selects CHs and cluster size and therefore nodes die faster.

vi. *Clustered Aggregation Technique (CAG)*

CAG[29] is a protocol for reactive networks and the first in-network aggregation algorithm exploiting spatial correlation, which trades a negligible quality of result (precision) for a significant energy saving. CAG forms clusters of nodes sensing similar values .The CAG algorithm operates in two phases: query and response. During the response phase, CAG transmits the value of aggregated data within the cluster to the BS. CAG achieves efficient in-network storage and processing by allowing a unified mechanism between query routing (networking)and query processing (application). CAG generates synopsis by filtering out insignificant elements in data streams to minimize response time, storage, computation, and communication cost. CAG uses only sensor values from the cluster heads to compute the aggregates and so it is a lossy clustering algorithm.

vii. *Updated CAG Algorithm*

Updated CAG Algorithm[30] is an improvement of CAG algorithm, where the clusters are still formed from nodes sensing similar values within a given threshold, but in this case, the clusters remain as long as the sensor values stay within a given threshold over time(temporal correlation). This ensures that the performance of CAG become independent of the magnitude of sensor readings and network topology. When used in the interactive mode, the protocol alternates query and response phases. This algorithm builds a new forwarding tree each time a query is sent out. This rebuilding of trees frequently is a waste if the sensed data is almost the same over time.

viii. *Energy Efficient Homogeneous Clustering Algorithm for Wireless Sensor Networks*

Energy Efficient Homogeneous Clustering Algorithm for Wireless Sensor Networks [21] is a algorithm that proposes homogeneous clustering for WSNs that save power and prolongs network life. The life span of the network is increased by homogeneous distribution of nodes in the clusters. A new CH is selected based on the residual energy of existing cluster heads, holdback value and nearest hop distance of the node. The cluster members are uniformly distributed , and thus , the life of the network is extended.

c) Location-Based Protocols

Sensor nodes are addressed by means of their locations in location based protocols. Energy consumption is estimated by the distance between two sensor nodes and so location information is essential. Some queries from sensor nodes are also location specific and so location-based sensors find a wide number of applications. We present some location-based protocols in this section.

i. *Geographic and Energy-Aware Routing (GEAR)*

GEAR[27] is an energy-efficient routing protocol for routing queries to target regions in a sensor field. Sensors have localization hardware like GPS so that they know their current positions. The sensors are aware of their locations and their residual energy and also the locations and residual energy of their neighbours. GEAR uses a recursive geographic forwarding algorithm to disseminate the packet inside the target regions for data communication. GEAR also uses energy aware heuristics that are based on geographical information to select sensors to route a packet towards its destination.

ii. *Geographic Adaptive Fidelity (GAF)*

GAF [28] is an energy aware routing protocol proposed for MANETs but can also be used for WSNs because it aims at energy conservation. GAF turns off unnecessary sensors while keeping a constant level of routing fidelity (or uninterrupted connectivity between communicating sensors). A sensor field is divided into grid squares and every sensor uses its location information, which can be provided by GPS or other location systems. The sensor associates itself with a particular grid and this helps GAF to identify the sensors.

The state transition diagram in GAF has three states:

(i) *Sleeping state:* A sensor turns off its radio in the sleeping state.
(ii) *Discovery state:* A sensor exchanges discovery messages to learn about other sensors in the same grid.
(iii) *Active state:* A sensor periodically broadcasts its discovery message to inform equivalent sensors about its state. GAF aims to maximize the network lifetime by reaching a state where each grid has only one active sensor based on sensor ranking rules. The residual energy levels helps to rank the sensors. A sensor with a higher rank handles routing within their corresponding grids.

iii. *Minimum Energy Communication Network(MECN):*

MECN [22] is a location-based protocol for achieving minimum energy for randomly deployed networks, which uses mobile sensors to maintain a minimum energy network. It computes an optimal spanning tree with sink as root that contains only the minimum power paths from each sensor to the sink. This tree is called minimum power topology. It has two phases:

(i) Enclosure Graph Construction: MECN constructs sparse graph, called a enclosure graph, based on the immediate locality of the sensors. An enclosure graph is a directed graph that includes all the sensors as its vertex set and edge set is the union of all edges between the sensors and its neighbours located in their enclosure regions.
(ii) Cost distribution: In this phase non-optimal links of the enclosure graphs are simply eliminated and the resulting graph is a minimum power topology. This graph has a directed path from each sensor to the sink and consumes the least total power among all graphs having directed paths from each sensor to the sink. Every sensor broadcasts its cost to its neighbours, where the cost of a node is the minimum power required for this sensor to establish a directed path to the sink.

iv. *Small Minimum-Energy Communication Network (SMECN)*

SMECN[14] is a routing protocol that improves MECN by constructing a minimal graph characterised with regard to the minimum energy property. This property ensures that there s minimum energy-efficient path between any pair of sensors in a graph that has the smallest cost in terms of energy consumption over all possible paths. In SMENC protocol every sensor broadcasts a neighbour discovery message using some initial power to discover its neighbours. It then checks whether the theoretical set of neighbours that are computed analytically is a subset of the set of the set of sensors that replied to that neighbour discovery message. The sensor uses a corresponding power p to communicate with its immediate neighbours for this case and else it increments p and rebroadcasts its neighbour discovery message.

v. *Coordination of Power Saving with Routing(SPAN)*

SPAN[4,5] is a routing protocol is applied to WSNs though it was proposed for MANETs since it is energy efficient. This protocol turns off the radio when not in use since the wireless network interface of a device is often the single largest consumer of power. Span helps sensors to join a forwarding backbone topology as coordinators that will forward packets on behalf of other sensors between any source and destination.

d) Heterogeneous-Based Protocols

Heterogeneous-based protocols ate used for heterogeneous networks where there are two types of sensors namely line-powered sensors that have no energy constraint, and battery-powered sensors having limited lifetime. The battery powered sensors have limited energy and so protocols should minimize their data communication and computation. We present some heterogeneous-based protocols in this section.

i. *Cluster-Head Relay Routing (CHR)*

CHR Routing protocol[26] uses two types of sensors to form a heterogeneous network with a single sink:

(i) A large number of low-end sensors denoted by L-sensors and
(ii) A small number of powerful high-end sensors denoted by H-sensors

Both types of sensors are static and location-aware. These sensors are randomly deployed over the environment and CHR partitions the heterogeneous network into clusters or groups of sensors with L-sensors and headed by a H-sensor.

Within the cluster, the L-sensors sense the environment and send the data to H-sensor in multihop routing. The H-sensors are responsible for data fusion within their own clusters and forwards them to the sink. Therefore H-sensors are used for long-range data communication to the sink and other H-sensors and L-sensors are used for short-range data communication between L-sensors and its cluster head.

ii. *Information-Driven Sensor Query (IDSQ)*

IDSQ[15,19] maximises information gain and minimises detection latency and energy consumption for target localization and tracking by dynamic sensor querying and data routing. In order to conserve energy only a subset of sensors are active at times when there are critical events to report in some parts of the sensed network. The choice of this active subset of sensors is balanced by the communication costs needed for communication of all sensors. A leaded is selected in this protocol that decides the optimal subset of sensors necessary for information sensing from the network.

e) Mobility-Based Protocols

Mobility based protocols have mobile sinks that are responsible for data collection from the network. In this section, we discuss mobility-based protocols that aim at energy efficiency.

i. *Data MULES Based Protocols*

Data MULEs(Mobile Ubiquitous LAN extensions) are used collect data from a sparse network while reducing energy consumption of the sensors[18].The MULE architecture has three main layers:

(i) The bottom layer consists of wireless static sensors that are responsible for sensing the environment.
(ii) The middle layer has mobile entities(MULEs) that collect the data from the sensors by moving in proximity to them and deliver them to access points.
(iii) The top layer contains WAN connected devices and access points/central repositories for analysing the sensed data. These access points communicate with a central data warehouse and synchronise the data collected, reduces redundant data and acknowledges the receipt of the of the data sent by the MULEs.

ii. *Scalable Energy - Efficient Asynchronous Dissemination(SEAD):*

SEAD [6] is proposed to trade-off between minimizing the forwarding delay to a mobile sink and energy savings. The source sensor reports sensed data to multiple mobile sinks and the protocol consists of three main components namely:

(i) Dissemination tree(d-tree) construction,
(ii) Data dissemination and
(iii) Maintaining links to mobile sinks.

SEAD assumes that sensors are aware of their own geographic locations. Data dissemination tree is built for every sensor routed at itself and all the dissemination trees for other sensor nodes are constructed separately. SEAD sits on top of a location aware routing protocol and can be viewed as an overlay network.

f) Quality of Service-Based Protocols

Quality of Service (QoS) requirements like delay, reliability and fault tolerance are as important in routing in WSNs as energy efficiency. A routing protocols that support QoS with energy efficiency is discussed in this section.

i. *Energy-Aware QoS Routing Protocol*:

Real-time traffic is generated by imaging sensors in this QoS energy aware routing protocol [12].This protocol finds the least cost and energy efficient path and the link cost is a function that captures the nodes' energy reserve , transmission energy, error rate and some communication parameters. The queuing model allows service sharing for real time and non-real-time traffic. This algorithm performs well with respect to QoS and energy metrics.

IV. Conclusion

The ultimate aim of a routing protocol design is 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 routing algorithm should be designed to reduce energy consumption while transmitting data.

In this paper, different routing protocols and algorithms based on data-centric routing, grouping or clustering of sensors, location information, network heterogeneity and QoS have been discussed. This survey helps in understanding the working of these protocols and the advantages of these algorithms combined together may be a good research direction for future applications.

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