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A Review of Energy Efficient Routing Algorithms in Wireless Sensor Networks

Mandeep Kaur Gulati*

*(Department of Computer Science, Khalsa College for Women, Amritsar, Punjab, India
Email: mandeepkaur606@gmail.com)

Abstract:

A Wireless Sensor Network (WSN) is a collection of tiny nodes that have low energy levels and have become an essential component of the modern communication infrastructure and very important in industry and academia. Energy is crucial in WSN, and thus the design of WSN in the research community is based on energy efficiency, and node energy consumption is a great challenge to enhance WSN's lifetime. It may be costly or even impossible to charge or replace consumed batteries because of the difficult environment. Many energy efficient algorithms have been discussed in this paper with their strengths and weeknesses so so as to explore the future directions of research.

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Keywords — **Wireless Sensor Networks (WSN), Energy Efficiency, Routing Algorithms, LEACH**

I. INTRODUCTION

Advances in embedded microprocessors, low-power analog and digital electronics, and radio communicationsmhave enabled the development of small and low-priced sensor nodes (SNs) that made Wireless Sensor Networks (WSNs) one of the promising technologies during the past decade. In most cases, a WSN is comprised of a large number of irreplaceable, battery-powered SNs, scattered densely and randomly in a geographical area of interest. In general, the SNs in a WSN sense and gather data from surrounding environment and transmit it to logically more potent nodes, called sinks, to perform more intricate processing. Sensor based applications span a wide range of areas, including scientific research, military, disaster relief and rescue, health care, industrial, environmental and household monitoring.

Sensor nodes are usually powered by battery. These sensor nodes have limited processing, storage capacities and limited energy capacity. In most situations, they are deployed in a harsh or hostile environment, where it is very difficult or even impossible to change or recharge the batteries. If any node runs out of power, the entire network connectivity collapses and intend of the deployment might become futile. Because of this reason, most of the research in the area of WSNs has concentrated on energy efficiency where the design of energy efficient routing protocols plays a major role. Extensive research work on energy efficiency in routing algorithms, protocols and techniques in WSNs has been done in the last few years. A few of the energy efficient routing algorithms have been discussed in this paper with their advantages and disadvantages.

II. SURVEY OF ENERGY EFFICIENT ROUTING ALGORITHMS IN WSNs

In this section, survey of some of the energy efficient routing algorithms in WSNs has been done along with their strengths and weeknesses.

Low-Energy Adaptive Clustering Hierarchy (LEACH): Low Energy Adaptive Clustering Hierarchy (LEACH) [1] is one of the first hierarchical clustering protocols. It creates clusters of nodes based on signal strength and use cluster heads to aggregate, compress, and transmit packets to the Base Station. The optimal cluster head number is estimated around 5% of total nodes, while all of the processes as data fusion and data aggregation are performed locally in the clusters. During LEACH operation, cluster heads change randomly to balance remaining energy and network lifetime. In the cluster formation process, nodes compare signal strength of their neighbor cluster heads and join the one with the strongest signal. In LEACH, transmissions are reduced, resulting in reduced energy loss. In addition, global network knowledge is not required. However, as it uses single hop routing, it is not suggested for sensor networks deployed in large areas. In addition, dynamic clustering creates overhead that may shrink gain in energy consumption.

Low-Energy adaptive Clustering Hierarchy-Centralized (LEACH-C): This algorithm [2] is a variation of LEACH that forms clusters using the Base Station (BS). During clustering, nodes transmit to the BS energy level and location information. The BS divides the network into a fixed number of clusters and their cluster heads, based on the energy needed during data transmission from cluster nodes to their cluster heads. In LEACH-C, more energy efficient clusters for data transmission are produced. In addition, the optimal number of cluster heads is predetermined. On the other hand, overhead is produced to the BS.

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 Sensor Nodes (SNs) reporting data to Cluster Heads (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 it is not known if a node is dead.

Hybrid, Energy-Efficient Distributed Clustering (HEED): HEED [4] 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.

Distributed Regional Energy Efficient Multi-hop-Maximum Energy (DREEM-ME): DREEM-ME [5] is a routing protocol for homogeneous WSNs that uses a fixed number of cluster heads in each round and ensures that these cluster heads have the maximum energy. DREEM-ME separates the network into concentric circles, forming four equal sectors that divide the area in regions, excluding the first, which is in the center of the area containing the base station. Each region elects cluster heads and utilizes multi-hop communication between the other regions with the exception of region one, which uses direct communication to communicate with the base station. Furthermore, DREEM-ME reduces packet loss, during bad wireless link status, with the implementation of the Random Uniformed Distribution Model mechanism.Thus, by using DREEM-ME, not only is energy saving achieved, but also a lower number of packets are dropped. Additionally, extended stability period is attained. On the other hand, energy depletion is not balanced. In addition, scalability is limited.

Power-Efficient Gathering in Sensor Information Systems (PEGASIS): PEGASIS [6] 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 utilized networks.

Energy-Balanced Chain Cluster Routing (EBCRP): In this routing technique, the nodes are divided into rectangular clusters, the nodes in each rectangle or clusters form chain with Cluster Head (CH) [7]. This CH collects data from all nodes and send it to BS. The energy is balanced in such a way that each CH will remain CH until all of its energy is depleted. This technique has three phase, (i) Cluster formation (through ladder algorithm) (ii) CH selection and (iii) The steady state phase. Once a CH is selected and remains CH until it dies, this state is called steady state phase. After steady state phase, a new round is started and another node become CH. This technique suffers from transmission delay because of two reasons, if there are nodes (successive) far from each other. The other reason is the direct communication between CH and BS.

Zone-Stable Election Protocol (Z-SEP): Z-SEP [8] is a clustering routing protocol for heterogeneous WSNs that combines nodes with two energy levels and a double communication scheme, as some nodes can communicate directly to the base station while others form clusters and transmit their data to the base station using the SEP algorithm.

Z-SEP divides the network into three zones:
(i) Head Zone 0, which includes the base station and normal energy nodes.
(ii) Head Zone 1, which includes randomly deployed advanced nodes.
(iii) Head Zone 2 that includes randomly deployed advanced nodes as Head Zone 1.

During data transmission, nodes in Head zone 0 transmit packets directly to the base station while nodes in Head Zones 1 and 2, which are more dense than Head zone 0, transmit their data through an elected cluster head using an SEP algorithm. With ZSEP, energy consumption is decreased, high throughput is achieved, and stability period is increased. Yet, the suggested network infrastructure may not be realistic. Also, overhead is added.

Fuzzy Logic-Based Energy Efficient Packet Loss Preventive Routing Protocol (FEEPRP): FEEPRP [9] is an energy aware packet loss preventive routing protocol, which aims to save energy and, at the same time, contro congestion, avoid malicious nodes, and prevent data losses. FEEPRP uses a fuzzy control mechanism that monitors the past records of residual energy, packets dropped at each node, and hop count to decide which route to select for sending messages. Each time, a di_erent route is selected according to the output given by the fuzzy logic mechanism. The residual energy of each route is considered as one of the inputs in the fuzzy control to assure energy conservation as well. Energy conservation is enhanced more by letting nodes sleep when idle. The throughput achieved is high. However, processing overhead is notable. In addition, mobility of nodes is not supported.

Geographic and Energy Aware Routing (GEAR): GEAR [10] uses two heuristics for packet routing, energy aware, and geographically informed neighbor selection. GEAR localizes interests of the Directed Diffusion protocol in a target region instead of sending them in the entire network. GEAR operation consists of two phases:

(i) Packet forwarding towards a target region: When a node receives a packet, it forwards it to the neighbor closer to target region. In case there is no close neighbor to the target region, there is a hole in the network and sending node forwards the packet to a node with the minimum cost.

(ii) Packet forwarding within target region: If the packet reaches the targeted region, it can be diffused in it with the use of either restrictive flooding or recursive geographic flooding.

GEAR reduces and balances energy consumption. However, periodic table exchanges cause increased overhead.

EADAT (Energy-Aware data Aggregation Tree): The technique focuses on the issue of energy consumption considering energy aware data centric routing. The tree is created keeping the residual energy of every node in consideration. The tree construction is performed in the following manner, initially the sink node, which is also considered as root node, sends control message to every other node. Each node has a timer associated with it, lower the value of the timer, higher its residual energy is. A leaf node selects a node with higher residual energy and its shortest path to the sink and make that node its parent. This process continues up to sink until a full tree is constructed. When a node's energy becomes less than some pre-determined threshold, it broadcasts help message to all other nodes and the shutdown, now the nodes attaches to it either as parents or child will create a new topology according to above mechanism [11]. The protocol is data centric in a way that the nodes with higher residual energy and shortest paths become more responsible and more data flows through them as compared to others, this increases network life as well as energy consumption is even around the system. But the mechanism described above for creating tree sometimes create a longer path than the real minimum path which causes transmission delay as well as more energy is consumed.

Energy-Aware Data-Centric Routing (EAD): EAD [12] 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.

Sensor Protocols for Information via Negotiation (SPIN): SPIN [13] 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.

Position-based Aggregator Node Election (PANEL): As its name suggests, it selects some data aggregators on the basis of some position information criteria [7]. The nodes are divided into geographical clusters. An aggregator is selected for each cell, with respect to the lower left corner of the cluster. The communication formats re of two type, inter-cluster in which data is sent to a single cluster closer to BS and intra-cluster in which data is sent or aggregated to an aggregator and then the data is sent from aggregator to sink or Base Station. PANEL provides load balancing as aggregators are changed after sometime or after each round. However the selection of aggregators based on geographical locations needs extra complex technology on both hardware and software side, thus may be considered cost-effective.

Line-based Data Dissemination (LBDD): In this method, the nodes are divided into two parts creating a fence called vertical strip or line of nodes. This line acts as a storage area and all the data is sent to this line or inline nodes before sending it to the sink the nodes within the area of line are called inline nodes. The operation is performed in two phases, in first phase, a node generates new data and send it to the nearest inline node. In the second phase, the sinks sends query to the vertical strip and the query is flooded to all the nodes of the strip, upon receiving the query, the nodes having some data received from other nodes send data to the sink node. This technique experiences the problem of load balancing because the strip nodes are responsible for data transmission, if there are less number of nodes on the strip line, they will deplete energy very quickly, resulting in reduced network life [14].

Opportunistic energy-efficient routing protocol (OEERP): This algorithm is used for reducing network energy consumption [15]. It provides accurate target location detection, energy efficiency, and network lifespan extension. It is intended to schedule idle nodes into a sleep state, thereby optimising network energy consumption. Sleep is dynamically adjusted based on the network's residual energy (RE) and flow rate (FR). It saves energy for a longer period. The sleep nodes are triggered to wake up after a certain time interval. The simulation results show that the proposed OEERP algorithm outperforms existing state-of-the-art algorithms in terms of accuracy, energy efficiency, and network lifetime extension.

Division Algorithm Based Energy-Efficient Routing Scheme: Kumar et al. [16] proposed a new routing concept using divide-and-rule sectorization (DRS) scheme to curtail the energy efficiency issues in WSNs. In this scheme, each forwarder node is dynamically selected for WSNs which balances the energy consumption among the sensor nodes significantly. The network area is divided into subareas to reduce the unbalance loading condition, and each subarea known as the segment, efficiently decrease the energy hole creation problem of the network. Moreover, the analytical analysis of the energy consumption for the proposed scheme has also been presented. The simulation results confirm that the proposed DRS scheme has better enduring stability, prolonging network lifetime, and minimized energy consumption as compared to available state-of-the-arts.

III. CONCLUSIONS

The ultimate aim of a routing algorithm 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 algorithms have been discussed. This survey helps in understanding the working of these algorithms and the strengths and weeknesses of the protocols may provide a good research direction for the future applications.

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