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A Study on Energy Efficient Routing Protocols in Wireless Sensor Networks

Davender Krishan Malhotra
Research Scholar, MMICT&BM, M.M.U.
Email: davendermalhotra@yahoo.co.in
Aarti Singh
Associate Professor, MMICT&BM, M.M.U.
Email: singh2208@gmail.com

Abstract
A wireless sensor network (WSN) consists of small, multifunctional, low cost and low power sensor nodes. In WSNs, the routing protocol has limited battery power and bandwidth constraints and yet they have to facilitate efficient working as well as prolonged lifetime of these networks. On the basis of network structure routing techniques can be classified as data-centric, hierarchical and location based. Routing protocol being the backbone of communication in WSNs suffer from design trade-off between energy efficiency and communication overhead. This paper explores the various routing protocols existing for WSNs and focuses on protocols enabling optimal utilization of energy.

Keywords: Sensor Networks, Communication Protocols, Routing Protocols, Energy Efficient Protocols, Hierarchical Protocols.

1. Introduction

Wireless sensor network (WSN) is a collection of small, self-powered and inexpensive sensor nodes that can sense a physical area for collecting specific information, process it and communicate with other devices to send information from one location to another. The sensor nodes can intermingle with their environment by sensing or controlling some physical parameter such as temperature, pressure, humidity etc. However, a single node can sense only small amount of data, thus to accomplish a complex task many sensor nodes need to collaborate with each other. Collaboration among sensors is achieved through wireless communication mediums such as infrared technology, radio waves, optical media or Bluetooth, which help achieve communications. Depending on the method of communication chosen and the transmission range requirements, suitable communication protocol is used. In a WSN, sensor nodes gather information from a specific source and pass this gathered information to the base station. Many intermediate sensor nodes help in passing sensed information from source to the target node. A sensor network is made up of thousands or millions of sensor nodes. Each node have processing capabilities (microcontroller, CPUs), memory (flash or data memory), a single Omni directional antenna and a power source (batteries or solar cells) in it [16]. Normally, the battery is the source of energy for sensor nodes and it cannot be recharged after the deployment of the sensor [5]. When a sensor acts as inter- mediator for passing some information, its energy is consumed. Thus energy efficient routing protocols are highly desired for WSNs so as to retain their battery life. To reduce the energy consumption in nodes, many protocols have been proposed [10].

This work explores various routing protocols existing for WSNs with focus on energy consumption. Next section presents various routing protocols for WSNs.

2. Routing Protocols for WSNs

There are various routing protocols developed for WSNs which can be classified into the following categories as shown below in table 2.1:

Table 2.1: Routing Protocols for Wireless Sensor Networks

Sr. No.	Types	Routing Protocols
1.	Data-centric Routing	SPIN, Directed Diffusion, Rumor Routing, Gradient-Based Routing,

		Energy-aware Routing
2.	Hierarchical Routing	LEACH, PEGASIS, TEEN, APTEEN
3.	Location based Routing	MECN, SMECN, GAF, GEAR, TBF
4.	Multipath based Routing	Sensor-Disjoint Multipath, Braided Multipath, N-to-1 Multipath Discovery
5.	Heterogeneity based Routing	IDSQ, CADR, CHR
6.	QoS based Routing	SAR, SPEED

2.1 Data-Centric Routing Protocols:
In these routing protocols base station sends its request to a particular network location in which the network is operating and then the base station waits for the data which will be sent by the sensor nodes of that particular location. In data-centric routing protocols the attributes of a sensor is important than its address [23]. Some important data-centric routing protocols are given below:

Sensor Protocol for Information via Negotiation (SPIN): It is a part of adaptive protocol which includes SPIN-1 and SPIN-2. SPIN is the very first routing protocol of data-centric routing protocol for wireless sensor networks. In SPIN routing protocol the data messages are minimize the size and transmitted. When a sensor receives data it sends an advertisement message to its nearby sensors, any sensor can requires that data will send a query message to that sensor. When the sensor received the query message from its nearby sensors it transmits its data to that particular sensor which requested for the data.

Directed-Diffusion: It is the important protocol in data-centric routing protocols for wireless sensor networks. This protocol is designed in such a way when a new request is made the routing will start based on it. This protocol works with attribute value of the data and queries the sensor on demand bases, however it cannot be applied on all network [23]. The request receives by any sensor will store all parameters in its memory for further use [23]. Sensors can store data locally on an onboard storage device or on removable media and reduce the amount of information to be sending. Sensor receive request from other sensors of network will send data to its nearby sensors and a gradient is formed, Gradient is a return path by which all nearby sensors have received that request. Number of paths will be created between receiver and transmitter by making gradient, between these entire paths only one path will be selected. The choice of path depends on size of receiving data.

Energy Aware Routing (EAR): The selection of path in this protocol is same as directed-diffusion protocol. In EAR path is selected by possibility option which depends upon the energy consumption of the path. Before sending the data to the sink node will must start the discovery process of the route and create a list of all nearby nodes in the sensor network. In this process request and reply messages are interchanged between the nodes in a sensor network. The request message contains the address of source, sequence number to determine the message origin from the same source, hop count, required link quality threshold for forwarding the packets, destination address and required energy threshold. Several checks performed by the sensor node before sending message. Before sending message firstly check the node energy availability. If the level of energy is less than the required energy for the operation then the node is not able to perform any kind of tasks and the received request is rejected by the node. If the level of energy is sufficient to perform the task, then the node measured the link quality of the received signal. The link quality depends upon the distance between the transmitter and receiver. The link quality of received signal should be weak, if the receiver is far away from the transmitter. When the request messages are transmitted again from these sensor nodes then the message collision will takes place to avoid the request messages are not to be retransmitted. The node has to broadcast the message with back off timer. Every node computes its back off delay considering its distance away from the destination.

Rumor Routing: It is a routing algorithm of a wireless sensor network. The main objective of this routing algorithm is to consume less energy. When the event happens the rumor routing create paths to each event, and later to route queries along these paths [2]. The queries are routed on these paths which are generated by rumor routing agents. To link the paths queries are sent on the network. Each node will maintain the list of neighboring sensor nodes and forwarding information of all events performed by the node. Expiration time stamp added to the table entries if the events are required for a definite time or if the volume of the event table is

small [14]. Rumor routing is an energy efficient algorithm compared to Directed Diffusion routing and Gossip based routing. The randomized rumor routing algorithm increases the robustness of rumor routing algorithm [15].

Gradient Based Routing (GBR): Gradient based routing protocol employ a shortest path principle [22]. This routing protocol is an effective and important method for WSNs. To increase the efficiency of a WSN by using all routing protocols employs a shortest path to route data packets. A sink builds a gradient field in the sensor network on which it has the lowest gradient index [7]. When a data packet travels from source to destination using shortest path and it should consume less resources to reach destination. Initialization of every sensor node during the network to learns its gradient through gradient information [25], message transmitted by sensor nodes in the network which will have the information regarding location, distance between nodes and it's all nearby nodes. Each sensor node defines the gradient as minimum cumulative node cost along the path in gradient based routing protocols, will be used to broadcast data to the receiver [17].

2.2 Hierarchical Routing Protocols: Clustering based methods are more energy efficient routing protocols for WSNs. Clustering is grouping of similar objects or data. In each cluster, elect a node as the cluster head (CH) while the remaining are member nodes. For large population of wireless sensor networks or to cover a large area of network always proposed multipoint clustering. The objective of hierarchical routing is to manage the energy consumption efficiently in any WSN by establishing multi-hop communication within a cluster, and fusion to decrease the transmitted packets by performing data aggregation [6].

Low Energy Adaptive Clustering Hierarchy (LEACH): It is a hierarchical protocol which is used in the network when a node fails or stops working due to its battery problem. LEACH is self-organizing adaptive protocol [16] in which nodes will arrange themselves into clusters and cluster head is selected by cluster members to avoid energy excessive usage. Each and every cluster guided by the cluster head. Data aggregation reduces the amount of message sent to the base station. The basic operation of LEACH is organized in two phases: setup phase and steady state phase [5].

Setup Phase: For organizing the network into clusters, Advertisement of cluster heads and Transmission schedule creation.
Steady State Phase: The data aggregation, Compression and Transmission to the sink.
It reduce energy consumption by switching close node heads in LEACH all sensor nodes transmits directly to cluster heads using single hop routing. LEACH is not applicable for the large region networks. It provides scalability in the network by various clusters by limiting most of the communication [6].

Power-Efficient Gathering in Sensor Information System (PEGASIS): It is a classical chain-based routing protocol which saves energy by improving the cluster configuration and the delivery method of sensing data [18]. PEGASIS is an improved version of LEACH [8]. In PEGASIS, all sensor nodes communicate with their neighbor nodes and all nodes have a spin to become cluster head. It selects a cluster head to communicate with the base station in each round. [8]. PEGASIS operations are divided into two phases:

Construction of Chain: By the use of greedy algorithm a chain can be constructed starting from the remotest node from the base station.

Data Gathering and Transmission to Base Station: Any node can be selected as the cluster head randomly which communicates with the base station. When a node is out of battery a new chain is formed bypassing the dead node. The cluster head receives all the data messages from other nodes and send to the base station.

Threshold sensitive Energy Efficient sensor Network protocol (TEEN): It is the first protocol developed for reactive networks. It is used in temperature sensing applications. TEEN splits the cluster heads into the second level and uses hard-threshold and soft-threshold to detect sudden change in the network. In hard-threshold, the sensor nodes to transmit only when the sensed quality is in its range to minimized the number of transmissions. The soft-threshold also minimizes the number of transmissions by removing all the transmission. In TEEN, when we are implementing the network we have to ensure that there are no crash in the sensor node. It cannot be used if we want the data regularly.

Adaptive Threshold Sensitive Energy Efficient Sensor Network Protocol (APTEEN): The

architecture of APTEEN is same as of TEEN. In APTEEN the cluster heads are decided in every network, and then cluster heads transmits the data to other nodes. In APTEEN routing protocol, only periodic data gathered and reacting to time critical events.

2.3 Location based Routing Protocols: In this routing all protocols requires location information to calculate the gap or distance between the sensor nodes in wireless sensor networks. Energy efficiency of a network is increase when the addressing scheme for network is unknown.

Minimum Energy Communication Network (MECN): It is a location based protocol to attain minimum energy in any ad-hoc network. MECN attempts to structure a minimum energy network with mobile sensors. Minimum energy communication network is self-reconfiguring protocol which keeps the network connectivity. MECN distinguish a relay region for every sensor node. The relay region contains sensor node in its neighborhood, through which transmission is energy efficient then the direct transmission. The main objective of the MECN to find a network within the network so that the energy consumption of a network is reduced by using lesser number of sensor nodes without considering all nodes of the network, so that global minimum power paths are found. The small minimum energy communication network (SMECN) is an extension to MECN [24]. It is assumed that in MECN every sensor can transmit to every other sensor in the network which is not possible sometimes, but in SMECN every possible difficulty between any two pairs of nodes are considered but sensor network is still assumed to be connected in MECN. Minimum energy usage in SMECN may be smaller than as constructed in MECN if the transmissions are able to reach to all possible nodes in a specific region around the transmitter. As a result number of hops for transmission will be decreased. There is less energy consumption in SMECN as compared to MECN and the low maintenance cost of links.

Geographic Adaptive Fidelity (GAF): This protocol is designed for ad-hoc mobile network which is energy aware location based routing protocol. However it may be applicable to WSNs also. In GAF [26] energy consumption is reduced by switching off or turning off unwanted sensor nodes without affecting the routing fidelity of the network. It forms an essential grid for the observed area of network in which each node uses its location indicated with the help of GPS, sensor nodes related with the same point on the grid are taken as equal in terms of cost of routing packet. Some nodes in specific grid area in sleeping state to save energy of the network. When the number of nodes is increased in GAF then the lifetime of a network is also increased. In GAF there are three states discovery, sleep and active. The discovery node determines the neighbors in the grid, the active node take parts in routing process and when the radio is off the node in sleep mode. Before leaving the grid the active node dies and sleeping nodes wave up and one of them become active node.

Geographic and Energy Aware Routing (GEAR): In GEAR [3] the nodes are assumed to have localization hardware equipped for example GPS unit [12]. It is helpful for sensor nodes to know their current locations as well as sensor nodes are aware of their residual energy of every nearby sensor nodes. GEAR uses energy aware heuristics that is based on geographical information for the selection of route of data packets towards the receiver side. The GEAR uses recursive geographic forwarding algorithm to disseminate the packet inside the target region.

Trajectory Based Forwarding (TBF): It is a routing protocol which requires a sufficient dense network and the presence of localization system so that sensor can know their current location and judge the distance or gap between them and their nearby sensor nodes. The sensor node specifies the trajectory in the packet, but does not indicate the path on hop by hop basis. In TBF maintains the location information of its nearby sensor nodes route is not affected by sensor node mobility. To increase the reliability and capacity of the network implementation of multipath routing in TBF is possible. TBF can also be used to discovery, flooding and network management.

2.4 Multipath based Routing Protocols: Data transmission from source to destination can be done in two ways that are single path routing and multipath routing. In single path routing each sensor node send its data towards sink using shortest path whereas multipath routing each sensor node having any data firstly finds the shortest path towards sink and then divides its load among these paths.

Sensor Disjoint Multipath Routing: It helps in finding number of alternate paths that have no sensor

nodes in common with primary path. The primary path is best available path for the sensor disjoint multipath routing. If it fails, then it stays local and does not affect any of these alternate paths. The finest quality data by the shortest delay and lowest loss can be provided by the nearby sensor node of the sink. Although disjoint paths are more resilient to sensor nodes failure, they can be potentially longer than the primary path and thus less energy efficient [13].

Braided Multipath: It is a partially disjoint path from primary one after relaxing and disjointedness constraint [13]. A braided multipath can be made by calculating the primary path firstly and then it is calculated for every sensor node. Thus best path is calculated from source to sink by calculating the braided multipath can be created in a localized manner in which the sink sends out primary path reinforcement to its first preferred neighbor and alternate path reinforcement to its second preferred nearby sensor node.

N-to-1 Multipath Discovery: The main aim of multipath routing protocols is to find partially or multiple disjoint paths between a single source destinations [6]. It is based on the simple flooding starting from sink. It consists of two phases, in phase-1 branch aware flooding and phase-2 is multipath extension of flooding. Both phases use same routing message type.

2.5 Heterogeneity based Routing Protocol: In heterogeneity based routing protocol sensor networks are two types of sensors - with limited lifetime battery powered sensor nodes and line powered sensor nodes which have no energy limitation. It is energy efficient by minimizing the communication and data computation.

IDSQ: In IDSQ, addresses the problem that is how to query sensors dynamically and route data in a sensor network so that maximized information is gain while bandwidth consumption is minimized [1] for target tracking and localization. To increase the tracking accuracy and the detection latency communication between sensor nodes consumes significant energy. To save energy of the sensor nodes in the network needs to be active when there is something to transmit in the sensor network. In IDSQ routing protocol, the first step is selection of any node as cluster head from the sensors group. This cluster head is responsible for selecting best sensor node on the basis of some information utility measure.

Cluster Head Relay Routing (CHR): It uses two types of sensors from heterogeneous network with single sink a large number of sensors L-sensor (low-end sensors) and a small number of powerful sensors called H-sensors (high-end sensors). Both of these sensors are aware of their location information by the use of some location service like GPS. Both of these sensors are static, uniformly and randomly spread in the field of sensors. This protocol divides the network into group of clusters. These sensors create L-sensor and guided by H-sensors with a group of sensors. L-sensor manages sensing and forwarding of data packets towards cluster heads in multi-hop form. Whereas H-sensor is in charge for data fusion within their own group of sensors in network and forwarding data packets towards sink originated by other cluster heads in a multi-hop form using cluster heads. The L-sensor uses short range data transmission to their nearby H-sensor with in the same group of sensors on the other hand H-sensor doe's long range data communication to all nearby H-sensor and the sink.

2.6 Qos based Routing Protocol: In addition to energy consumption quality of service (QoS) is also very important in terms of delay, fault tolerance and reliability of routing in wireless sensor networks.

Sequential Assignment Routing (SAR): This routing depends on three factors quality of service on each path, energy resources and priority level of each packet [19]. SAR is the first protocol that providing QoS supports for WSN. This protocol is a table driven multipath routing protocol and it tries to get both fault tolerance and energy efficiency [4]. SAR creates a tree nodes rooted at one hop of neighbors of the sink node. By using QoS metrics, energy resources in every path and the priority of each data packet with the use of created tree multiple paths is selected on the basis on energy resources and QoS on each path failure, recovery is done by using routing table consistency on every path between upstream and downstream node. The purpose of SAR algorithm is to decrease the average weighted QoS metrics throughout the network lifetime due to node failure topology changes a path re-computation is needed.

SPEED: It is a QoS and real time routing protocol for WSN [20]. The requirement of this protocol is to keep the information of each sensor node about its

neighbor sensors. It also uses geographic information for its routing decisions. In SPEED protocol the minimum usage of memory so it is called stateless and does not use routing tables [9]. The module used for routing in SPEED is called stateless non-deterministic geographic forwarding (SNGF). Delay at each node is calculated by elapsed time when an acknowledgment is received from neighbors who help SNGF to select a node meets speed requirement. Due to its simplicity the total transmission energy is less.

3. Conclusion

The major challenge is energy efficiency in the field of wireless sensor network. The common objective behind all routing protocols is to increase life time of sensor nodes so that they can operate as long as possible. Sensors utilized maximum energy by data reception and transmission of data, so that the routing protocols should be energy efficient. In this paper, we have study number of routing protocols which are classified as location based, hierarchical, multipath, data centric, heterogeneity and QoS based protocols depending on the network structure.

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