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Recent Advances in Energy-Efficient Routing Protocols for Wireless Sensor Networks

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Abstract: In recent development, the use of Wireless Sensor Network (WSN) to handle more complex functions is increasing drastically which in turns requires their powered battery sensors to efficiently utilise their energy in order to prolong the network lifetime for the heterogeneous nodes. Clustering is one of the techniques used to optimise this energy consumption and increasing the network lifetime as well. In wireless sensor networks energy alertness is an essential consideration & it explored to many new protocols specifically designed for sensor networks. A wireless sensor network (WSN) consists of low cost, low power, small in size and multi functional sensor nodes. Routing protocols in WSNs emphasize on data dissemination, limited battery power and bandwidth constraints in order to facilitate efficient working of the network, thereby increasing the lifetime of the network. Routing protocols in WSNs are also application specific which has led to the development of a variety of protocols. Based on the underlying network structure, routing techniques can be classified into three categories: data-centric, hierarchical and location based routing. WSN has a design trade-off between energy and communication overhead which forms the nerve center of the routing techniques.

Key words: Wireless Sensor Networks · Routing Protocols · Energy Efficient Protocols · Data-Centric protocols · Hierarchical Protocols and Location Based Protocols

INTRODUCTION

A wireless sensor network (WSN) is growing in diverse areas so as to provide new opportunities to the network as well as to the services. A wireless sensor network (WSN) consists of tiny, battery powered sensor nodes having limited storage, on-board processing and radio capabilities.

A sensor node consists of following units:

- A Sensing Unit: Used to collect data from the surroundings.
- A Processing Unit: Used for data processing.
- A Communication Unit: Used to store data i.e. memory.
- A Power Unit: Used to perform the required tasks.

The report is sensed by the nodes and then sends that data to the processing centre named as “Sink”. The main challenge in the WSN is to extend the network lifetime by efficiently utilise their small battery power.

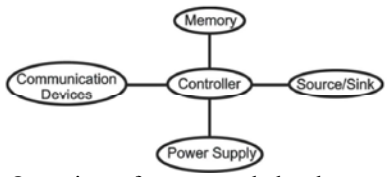

Fig. 1: Overview of sensor node hardware components

The following ways have been defined to efficiently utilise the energy [1]:

- Deployment of sensor nodes.
- Energy Efficient Clustering.
- Energy Efficient Scheduling.
- Data Aggregation.
- Energy Efficient Routing Protocols.

The Routing Protocols for Protocol Operation

Negotiation Based Routing: These protocols use high-level data descriptors called ¯meta-data? in order to eliminate redundant data transmission through negotiations. The necessary decisions are based on available resources and local interactions.

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Sensor Protocols for Information via Negotiation (SPIN) [2]: Is one of well known Negotiation based routing protocol for WSN. The SPIN protocols are designed to disseminate the data of one sensor to all other sensors assuming these sensors are potential base-stations. Hence, the main idea of negotiation based routing in WSN is to suppress duplicate information and prevent redundant data from being sent to the next sensor or the base-station by conducting a series of negotiation messages before the real data transmission begins.

Multipath Based Routing: These protocols offer fault tolerance by having at least one alternate path (from source to sink) and thus, increasing energy consumption and traffic generation. These paths are kept alive by sending periodic messages.

Maximum Lifetime Routing in Wireless Sensor Networks [3]: is a protocol that routes data through a path whose nodes have the largest residual energy. The path is switched whenever a better path is discovered. The primary path will be used until its energy is below the energy of the backup path. By means of this approach, the nodes in the primary path will not deplete their energy resources through continual use of the same route, thus achieving longer lifetime. A disadvantage for applications that require mobility on the nodes, is that the protocol is oriented to solve routing problem in static wireless networks.

Hierarchical Power-Aware Routing in Sensor Networks [4]: Protocol enhances the reliability of WSN by using multipath routing. It is useful for delivering data in unreliable environments. The idea is to define many paths from source to sink and send through them the same subpackets. This implies that the traffic will increase significantly (not energy aware), but increasing the reliability of the network. The idea is to split the original data packet into subpackets through each path. This can offer at the end, even with the loss of subpackets, the reconstruction of the original message.

Query Based Routing: In these protocols, the destination nodes propagate a query for data (sensing task or interest) from the node through the network. The nodes containing this data send it back to the node that has initiated the query.

Rumor Routing Protocol [5]: Is one of the routing protocol used in the context of event notification. The approach does not flood the network with information about an event occurrence but only installs few paths in the network by sending out one or several agents. The agents propagate through the network installing routing information about the event in each node that is visited. When the agents come across shorter paths or more efficient paths, they optimize the paths in the routing tables accordingly. Each node can also generate an agent in a probabilistic fashion.

Location Based Routing: In the protocols, the nodes are addressed by their location. Distances to next neighbouring nodes can be estimated by signal strengths or by GPS receivers. Location based routing protocols are:

Small Minimum Energy Communication Network (Smecn) [6]: Protocol sets up and maintains a minimum energy network for wireless networks by utilizing low power GPS. Although, the protocol assumes a mobile network, it is best applicable to sensor networks, which are not mobile.

Geographic Adaptive Fidelity (GAF) [7]: protocol is energy-aware location-based routing designed primarily for mobile ad hoc networks and can be applicable to sensor networks as well. GAF keeps energy by turning off unnecessary nodes in the network without affecting the level of routing fidelity.

Geographic and Energy Aware Routing (GEAR) [8]: Is the protocol which uses geographic information while disseminating the queries to the areas of interest since data queries often includes geographic attributes. The protocol uses energy aware and geographically informed neighbour selection to route a packet towards the target area. GEAR can complement directed diffusion by restricting the number of interests sent and only considering a certain area rather than sending the interests to the whole network. In GEAR, each node keeps an estimated cost and a learning cost of reaching the destination through its neighbours.

Virtual Cord Protocol (Vcp) [9]: A virtual relative position based routing protocol for sensor networks that provides methods for data management is Virtual Cord Protocol (VCP) [9]. VCP is a Distributed Hash Table like protocol that offers an efficient routing mechanism, besides standard DHT functions. The key characteristics of VCP are the geographical vicinity of virtual neighbors, which reduces the communication load, VCP only needs information about direct neighbors for routing and it cannot be stuck with dead ends. The protocol is easy

to be implemented on the top of a typical MAC layer. All data items are associated with numbers in a pre-defined range is captured by the available nodes.

The Routing Protocols for Network Structure

Flat Based Routing: In these protocols, all nodes have assigned equal roles in the network. The well known protocols considered in flat based routing are: Sequential Assignment Routing (SAR), .Directed Diffusion, Energy Aware Routing (EAR) etc.

Sequential Assignment Routing [10]: Proposed was one of the first protocols for WSN that considered QoS issues for routing decisions. The objective of SAR algorithm is to minimize the average weighted QoS metric throughout the lifetime of the network .SAR makes a routing decision based on three factors: energy resources, QoS planned for each path and the packet‘s traffic type, which is implemented by a priority mechanism. To resolve reliability problems, SAR uses two systems consisting of a multipath approach and localized path restoration done by communicating with neighboring nodes. The multipath tree is defined by avoiding nodes with low-energy or QoS guarantees while taking into account that the root tree is located in the source node and its ends in the sink nodes set. In other words, SAR creates a multipath table whose main objective is to obtain energy efficiency and fault tolerance. Although this ensures fault tolerance and easy recovery, the protocol suffers certain overhead when tables and node states must be maintained or refreshed. This problem increases especially when there are a large number of nodes.

Directed Diffusion (DD) [11]: Is a data-centric and application aware paradigm since all data generated by sensor nodes are named by attribute value pairs. The objective of the directed diffusion paradigm is to aggregate the data coming from different sources by deleting redundancy, which drastically reduces the number of transmissions.

A new energy-aware WSN routing protocol, reliable and energy efficient protocol (REEP) is proposed in [12]. REEP is also a fault tolerant. REEP has been motivated by the existing network layer data-centric routing protocol directed diffusion. REEP makes sensor nodes establish more reliable and energy-efficient paths for data transmission. In addition, the energy conservation heuristic of SPIN-2 has been used to maintain an energy threshold value in each REEP node in order to make the sensor nodes energy-aware.

REEP: consists of five important elements. These are: sense event, information event, request event, energy threshold value and request priority queue (RPQ). A = sense event‘ is a kind of query, which is generated at the sink node and is supported by the sensor network for acquiring information. The response of this query is the = information event‘, which is generated at the source node. It specifies the detected object type and the location information of the source node. After receiving this information, =request events‘ are generated at the sink node and are used for path setup to retrieve the real data. The real data in any sensor network are the collected or processed information regarding any physical phenomenon. Each node in REEP uses an = energy threshold value‘ by checking which node agrees or denies for participating in path setup with adequate energy for data transmission. It gives more reliable transmission of any event information or real data. RPQ is a kind of first-in-first-out (FIFO) queue, which is used in each node to track over the sequence of = information event‘ reception from different neighbours. It is used to select a neighbour with highest priority in order to request for path setup in case of failed path, without invoking periodic flooding.

The authors used four performance metrics like average packet transmission, average data loss ratio, average delay and average energy consumption to analyse and compare the performance of both protocols DD and REEP. The performance of REEP has been found to be superior to directed-diffusion routing protocol.

Energy Aware Routing [13] is a reactive protocol to increase the lifetime of the network. This protocol maintains a set of paths instead of maintaining or reinforcing one optimal path. The maintenance and selection depends on a certain probability, which relays on how low the energy consumption of each path can be achieved. The protocol creates routing tables about the paths according to the costs. Localized flooding is performed by the destination node to maintain the paths alive.

Hierarchical Based Routing: It is also known as cluster-based routing. In these protocols, the nodes can play different roles in the network and normally the protocol includes the creation of clusters. Additionally, designations of tasks for the sensor nodes with different characteristics are also performed.

Low Energy Adaptive Clustering Hierarchy (LEACH): Is one of the most popular clustering algorithms with distributed cluster formation for WSNs

[14, 15]. The algorithm randomly selects cluster heads and rotates the role to distribute the consumption of energy. LEACH uses TDMA/CDMA MAC to reduce inter-cluster and intra-cluster collisions and data collection is centralized with defined periods. It forms clusters based on the received signal strength and uses the CH nodes as routers to the base-station. All the data processing such as data fusion and aggregation are local to the cluster. LEACH forms clusters by using a distributed algorithm, where nodes make autonomous decisions without any centralized control. Initially a node decides to be a CH with a probability P and broadcasts its decision. Each non-CH node determines its cluster by choosing the CH that can be reached using the least communication energy. The role of being a CH is rotated periodically among the nodes of the cluster in order to balance the load.

Power-Efficient Gathering in Sensor Information Systems (PEGASIS) [16]: Protocol is a LEACH-inspired protocol. PEGASIS is not exactly a cluster-based protocol, as nodes are not explicitly grouped into clusters. PEGASIS is instead a chain based approach, in which each node only communicates with a close neighbour and takes turns to transmit to the BS, thus reducing the amount of energy spent per round. This approach distributes the energy load evenly among the sensor nodes in the network.

The PEGASIS protocol is designed for a WSN containing homogeneous and energy-constrained nodes, with no mobility. The BS (sink) is fixed and far away from nodes. The radio model adopted is the first-order radio model, same as the LEACH protocol. Using this model, energy efficiency can be improved by minimizing the amount of direct transmissions to the sink node. This idea is common to the LEACH protocol, [17] in which clustering is used to reduce both the duty cycle of the nodes and direct transmissions to the BS. A way in which energy efficiency can be further improved is to decrease the number of nodes that perform long-range direct transmissions. So the basic idea of PEGASIS [18] is to have only one designated node that directly transmits to the BS in each round. This can be achieved with a linear chain based approach, where sensor nodes form a chain, in which gathered data moves from node to node, gets fused and eventually a designated node will transmit it to the BS. As nodes take turns to transmit to the BS and transmissions are between close neighbours, the average energy spent by each per round is reduced.

Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN) [19]: Is a hierarchical protocol. It is useful for time-critical applications in which the network operates in a reactive way. Closer nodes form clusters and elect a cluster head. Each cluster head is responsible for directly sending the data to the sink. Adaptive Periodic Threshold-sensitive Energy Efficient sensor Network protocol (APTEEN) is an extension to TEEN presented in [20]. The main features of these protocols are that it combines proactive and reactive policies and modification of parameters that allow better control in the cluster heads.

Virtual Grid Architecture (VGA) [21]: Is based on the concept of data aggregation and in-network processing. This routing paradigm considers an extremely low mobility of sensor nodes. Therefore, this protocol arranges the nodes in a fixed topology forming clusters that are fixed, equal, adjacent and non-overlapping with symmetric shapes. One node per zone is considered as cluster head which is in charge of aggregating and transmitting data. It is possible to implement specific strategies for aggregation of data.

Adaptive Based Routing: In these protocols, the system parameters are controlled to be adapted to the actual network conditions by means of acquired information of the network and negotiation between nodes (e.g. the available energy on the node or QoS of the path).

Sensor Protocols for Information via Negotiation (SPIN): Adaptive based routing is based on the family of protocols called which is described in Negotiation based routing. The SPIN protocols are designed based on two basic ideas:

- Sensor nodes operate more efficiently and conserve energy by sending metadata instead of sending all the data.
- Flooding technique wastes energy and bandwidth when sending extra and unnecessary copies of data by sensors covering overlapping areas.

Bio-Inspired Routing: In recent years insect sensory systems have been inspirational to new communications and computing paradigms, which have lead to significant advances like bio inspired routing [22]. The most popular ACO (Ant Colony Optimization) is a colony of artificial ants is used to construct solutions guided by the pheromone trails and heuristic information they are not

strong or very intelligent; but they successfully make the colony a highly organized society. Swarms are useful in many optimization problems. A swarm of agents is used in a stochastic algorithm to obtain near optimum solutions to complex, non-linear optimization problems [23].

Minimum Ant-Based Data Fusion Tree (MADFT) [24]: Is a sink selection heuristic routing algorithm. It is based on ACO for gathering correlated data in WSN. It first assigns ants to source nodes. Then, the route is constructed by one of the ants in which other ants search the nearest point of previous discovered route. The chosen formula is Probability function composed of pheromones and costs in order to find the minimum total cost path. MADFT not only optimizes over both the transmission and fusion costs, but also adopts ant colony system to achieve the optimal solution.

The Many-to-One-Improved Adaptive Routing Protocol [25]: Is an ant colony-based routing protocol. It is specifically designed to route many-to-one sensory data in a multi-hop WSNs. Actually, in a many-to-one routing paradigm generates lots of traffic in a multihop WSN that results in greater energy wastage, higher end-to-end delay and packet loss. So, to mitigate the collision, it comes with a lightweight congestion control algorithm. It has the capability of handling both event- based and periodic upstream sensory data flow to the base station.

Swarm Intelligence Optimization Based Routing Algorithm [26]: Works with the objective to balance global energy consumption and avoiding some node‘s premature energy exhausting. The algorithm chooses the nodes with less pheromone as next hop, taking less hop numbers into consideration. The algorithm is different from traditional ant colony algorithms. It is better than the directed diffusion routing protocol both in end-to-end delay and global energy balance. It can effectively balance the global energy consumption and prolong the network lifetime.

Recent Advances and Open Research Issues: In the recent years routing in wireless sensor networks has attracted a lot of attention to the researchers. This section summarized some of the research results on data routing in WSNs. There are mainly three routing categories, namely data-centric, hierarchical and location-based. Important considerations for these routing protocols are energy efficiency and traffic flows. Achieving a good trade-off between energy efficiency and QoS is one of the main issue in WSNs [27]. The most effective way to reduce energy consumption is to have a low duty-cycle which in turn causes increase in delay. In order to improve network lifetime, suitable cluster-based approaches have been proposed in the literature. The main research issue regarding such protocols is how to form the clusters so that the energy consumption and contemporary communication metrics such as latency is optimized.

The factors affecting cluster formation and cluster-head communication are open issues for future research. Moreover, the process of data aggregation and fusion among clusters is also an interesting problem to explore. The problem of intelligent utilization of the location information in order to help energy efficient routing is the main research issue. Spatial queries and databases using distributed sensor nodes and interacting with the location-based routing protocol are open issues for further research.

Future research issues should focus on security, QoS and node mobility. Routing techniques for WSNs should address application-dependent security issues such as reliability, authentication, confidentiality etc. should be examined. Currently, there is very little research that looks at handling QoS requirements in a very energy constrained environment like sensor networks. QoS routing in sensor networks have been applied to several applications including multimedia applications like video and imaging sensors. It also applied in real-time applications like target tracking in battle environments, emergent event triggering in monitoring applications etc.

In applications where sensor nodes are mobile, new routing protocols are needed to handle frequent topology changes and reliable delivery. In the literature, most of the protocols assume that the sensor nodes and the sink are stationary. However, there might be situations such as battle environments where the sink and possibly the sensors need to be mobile. In such cases, the frequent update of the position of the command node and the sensor nodes and the propagation of that information through the network may excessively drain the energy of nodes. New routing algorithms are needed in order to handle the overhead of mobility and topology changes in such energy constrained environment.

In the past, many researchers in the WSN field denounced the use of IP as inadequate and in contradiction to the needs of WSNs. Since then the WSN field has matured, standard links have emerged and IP has evolved. The introduction of LoWPANs [28], the concept has changed about WSN. Design of complete IPv6-based network architecture for WSNs in [29, 30].

CONCLUSION

From the above study, it is concluded that efficient energy utilisation plays an important role in the wireless sensor network (WSN). Wastage of energy also takes place in making the clusters of the nodes that do not have any data to send and results in reduction of efficiency of the network. WSNs have discovered a wide range of applications in the recent era. Growing demand for WSN has accelerated the research and development of routing protocols used in WSNs. In this paper we classify the routing protocols in WSNs into data-centric, hierarchical and location based depending on the network structure. Data-centric protocols use the metadata structure to transmit the sensed information to the BS. Naming the data helps to construct a query which requests for only certain attributes of the data, thus known as data-centric routing techniques. Regardless, the sensor nodes can also be grouped for efficient data dissemination to the sink. Hierarchical routing protocols adopt the clustering approach by grouping sensor nodes. This approach is highly scalable and thus used in a number of applications. Location based protocols use the information of position of sensor nodes intelligently to route data. We epitomize the logic behind these protocols followed by the advantages and constraints. We also mention the possible application domain of these protocols and scope for improvement in the future.

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