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Analysis on Different Routing Protocols for Wireless Sensor Network

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Abstract **Review Article**

Recent advances in wireless sensor networks have led to many new protocols specifically designed for sensor networks where energy awareness is an essential consideration. Most of the attention, however, has been given to the routing protocols since they might differ depending on the application and network architecture. This paper surveys recent routing protocols for sensor networks and presents a classification for the various approaches pursued. The three main categories explored in this paper are data-centric, hierarchical and location-based. Some Routing protocol is described and discussed under the appropriate category. Moreover, protocols using contemporary methodologies such as network flow and QoS modeling are also discussed.

Keywords: Wireless Sensor Network, Routing Protocols, Classification of Protocols.

1. INTRODUCTION

Wireless sensor networks can provide low cost solution to a variety of real-world problems. Sensors are low cost tiny devices with limited storage, computational capability and power. The large scale deployment of wireless sensor networks is expected to guarantee real time communication. Devices in sensor networks have a much smaller memory, constrained energy supply, less process and communication bandwidth. Topologies of the sensor networks are constantly changing due to a high node failure rate, occasional shutdown and abrupt communication interferences. Due to the nature of the applications supported, sensor networks need to be densely deployed and have anywhere from thousands to millions of sensing devices, which are the orders of magnitude larger than traditional ad hoc mobile networks. In addition, energy conservation becomes the center of focus due to the limited battery capacity and the impossibility of recharge in the hostile environment. Wireless sensor networks (WSN) allow flexible, powerful, automated data collection and monitoring systems to be created. Many routing protocols have been proposed to facilitate data transport from sensor nodes to a base station. Surveys of Al-Karaki and Kamal [2] and Jiang and Manivannan [3] identify a wide range of approaches to routing in wireless sensor network. Few of these protocols have been formally verified or operationally deployed however. The Minimum Cost Forwarding (MCF) routing protocol [1], has been proposed. The application of MCF is restricted to networks possessing a single sink node and multiple source nodes. However, it offers several potential advantages for sensor nodes with limited resources.

2. RELATED WORK

The growing interest in WSNs and the continual emergence of new techniques inspired some efforts to design communication protocols for this area. Communication protocols take the task of data transmission in the large scale network and are important to achieve possible better performance. Normally, current routing can be typically classified into four main categories, namely data-centric protocols, hierarchical protocols, location-based protocols and flow-based and QoS-aware protocols [4]. Of course, there are also some hybrid protocols that fit under more than one category. The typical data-centric routing protocols proposed for WSNs include SPIN [5] and Directed Diffusion [6], which are obviously different from traditional address-based routing; location-based protocols such as MECN, GAF and GEAR require location information for sensor nodes, which are energy-aware. Hierarchical protocols are scalable for a larger number of sensors covering a wider region of interest, which overcome the defects of single-gateway architecture. LEACH is one of the first hierarchical routing approaches for WSNs [7]. Although the above three categories are promising in term of energy efficiency, more attentions should be paid to address the issues of network flow and QoS posed by realtime applications. One of the protocols for WSNs that includes some notions for QoS in its routing decisions is the Sequential Assignment Routing (SAR) [9]. The SAR protocol creates trees routed from one-hop neighbor of the sink by taking into account the QoS metric, the energy resource on each path and the priority level of each data packet. By using created trees, multiple paths from sink to sensors are formed. One of these paths is selected according to the energy resources and achievable QoS on each path. Akkaya *et al.,* extend SAR by selecting a path from a list of candidate paths that meet the end-to-end delay requirement and maximizing the throughput for best effort traffic. Their protocol does not require sensors involved in route setup so that the overhead problems in SAR approach can be avoided. Minimum cost forwarding protocol is a kind of flow-based routing protocol. It aims at finding the minimum cost path in large scale sensor networks, which will be simple and scalable. The data flows over the minimum cost path and resources on the nodes are updated after each flow. Ye *et al.,* also propose a cost field based protocol to Minimize Cost forwarding Routing (MCR) [1]. In the design, they present a novel back off-based cost field setup algorithm that finds the optimal cost of all nodes to the sink with one single message overheadS at each node. Once the field is established, the message, carrying dynamic cost information, flows along the minimum cost path in the cost field. Each intermediate node forwards the message only if it finds itself to be on the optimal path, based on dynamic cost states.

3. DATA CENTRIC PROTOCOLS

Data-centric protocols are query-based. In many applications of sensor networks, it is not feasible to assign global identifiers to each node. Sink sends queries to certain regions and waits data from sensors located in that region. Attribute based naming is necessary to specify properties of data.

Data Centric Protocols are

- Flooding,
- Gossiping,
- Sensor Protocols for Information via Negotiation (SPIN),
- Directed Diffusion,
- Energy-aware Routing,
- Rumor Routing,
- Gradient-Based Routing (GBR),
- Constrained Anisotropic Diffusion Routing (CADR),
- COUGAR,
- Active Query Forwarding In Sensor Networks (ACQUIRE).

3.1 Sensor Protocols for Information via Negotiation (SPIN)

Hein Zelman *et al.,* [5] in proposed a family of adaptive protocols called Sensor Protocols for Information via Negotiation (SPIN) that disseminate all the information at each node to every node in the network assuming that all nodes in the network are potential base stations. This enables a user to query any node and get the required information immediately. These protocols make use of the property that nodes in close proximity have similar data, and hence there is a need to only distribute the data that other nodes do not possess. One of the advantages of SPIN is that topological changes are localized since each node needs to know only its single-hop neighbors. SPIN provides much energy savings than flooding, and meta-data negotiation almost halves the redundant data.

SPIN Messages

SPIN nodes use three types of messages to communicate:

- ADV – new data advertisement. When a SPIN node has data to share, it can advertise this fact by transmitting an ADV message containing meta-data. REQ - request for data. A SPIN node sends a REQ message when it wishes to receive some actual data.
- DATA - data message. DATA messages contain actual sensor data with a metadata header.

Because ADV and REQ messages contain only metadata, they are smaller, and cheaper to send and receive, than their corresponding DATA messages. Using SPIN routing algorithm, sensor nodes can conserve energy by sending the metadata that describes the sensor data instead of sending all the data. SPIN can reduce the power consumption of individual node, but it may decrease the lifetime of the whole network due to extra messages.

3.2 Directed Diffusion (DDiff)

Intanag onwiwat, C. *et al.,* [6] proposed a popular data aggregation paradigm for WSNs, called directed diffusion. Directed diffusion is a data-centric (DC) and application- aware paradigm in the sense that all the data generated by sensor nodes is named by attribute-value pairs. The main idea of the DC paradigm is to combine the data coming from different sources and combines them by eliminating redundancy, minimizing the number of transmissions; thus saving network energy and prolonging its lifetime. But still power consumption is high.

Therefore, we propose an algorithm that tries to prolong the network lifetime by compromising between minimum energy consumption and fair energy consumption without additional control packets. It also improves its data packet delivery ratio, minimizes delay and maximizes throughput of the network.

4. HIERARCHICAL PROTOCOLS

Aim at clustering the nodes so that cluster heads can do some aggregation and reduction of data in order to save energy. Scalability is one of the major design attributes of sensor networks. A single-tier network can cause the gateway to overload with the increase in sensors density. Such overload might cause latency in communication and inadequate tracking of events. The single-gateway architecture is not scalable for a larger set of sensors covering a wider area of interest.

Maintain energy consumption of sensor nodes:

- By multi-hop communication within a particular cluster.
- By data aggregation and fusion decrease the number of the total transmitted packets.

Hierarchical Protocols are

- LEACH : Low-Energy Adaptive Clustering Hierarchy.
- PEGASIS: Power-Efficient Gathering in Sensor Information Systems.
- Hierarchical PEGASIS.
- TEEN: Threshold sensitive Energy Efficient sensor Network protocol.
- Adaptive Threshold TEEN (APTEEN).
- Energy-aware routing for cluster-based sensor networks.
- Self-organizing protocol.

4.1 Low-Energy Adaptive Clustering Hierarchy (LEACH)

LEACH is a clustering-based protocol that minimizes energy dissipation in sensor networks [7]. LEACH randomly selects sensor nodes as cluster heads, so the high energy dissipation in communicating with the base station is spread to all the sensor nodes in the sensor network. However, data collection is centralized and is performed periodically. LEACH collects data from distributed micro sensors and transmits it to a base station. LEACH uses the following clustering-model: Some of the nodes elect themselves as cluster-heads. These cluster heads collect sensor data from other nodes in the vicinity and transfer the aggregated data to the base station. Since data transfers to the base station dissipate much energy, the nodes take turns with the transmission– the cluster-heads “rotate”. This rotation of cluster-heads leads to a balanced energy consumption of all the nodes and hence to a longer lifetime of the network. Therefore, this protocol is most appropriate when there is a need for constant monitoring by the sensor network. LEACH can suffer from the clustering overhead, which may result in extra power depletion.

4.2 Power-Efficient Gathering in Sensor Information Systems (PEGASIS)

PEGASIS [8] is an extension of the LEACH protocol, which forms chains from sensor nodes so that each node transmits and receives from a neighbor and only one node is selected from that chain to transmit to the base station (sink). The data is gathered and moves from node to node, aggregated and eventually sent to the base station. The chain construction is performed in a greedy way. Unlike LEACH, PEGASIS avoids cluster formation and uses only one node in a chain to transmit to the BS (sink) instead of using multiple nodes. A sensor transmits to its local neighbors in the data fusion phase instead of sending directly to its CH as in the case of LEACH. In PEGASIS routing protocol, the construction phase assumes that all the sensors have global knowledge about the network, particularly, the positions of the sensors, and use a greedy approach. When a sensor fails or dies due to low battery power, the chain is constructed using the same greedy approach by bypassing the failed sensor. In each round, a randomly chosen sensor node from the chain will transmit the aggregated data to the BS, thus reducing the per round energy expenditure compared to LEACH.

PEGASIS has been shown to outperform LEACH by about 100–300% for different network sizes and topologies.

5. LOCATION-BASED PROTOCOLS

IT utilizes the position information to relay the data to the desired regions rather than the whole network. Most of the routing protocols for sensor networks require location information for sensor nodes. There is no addressing scheme for sensor networks like IP-addresses. Location information can be utilized in routing data in an energy efficient way. Protocols designed for Ad hoc networks with mobility in mind:

- Applicable to Sensor Networks as well.
- Only energy-aware protocols are considered.

Location-based protocols are

- MECN & SMECN (Minimum Energy Communication Network).
- GAF (Geographic Adaptive Fidelity).
- GEAR (Geographic and Energy Aware Routing).

6. NETWORK FLOW & QOS AWARE

These are based on general network-flow modeling and protocols that strive for meeting some QOS requirements along with the routing function. In addition to minimizing energy consumption, it is also important to consider quality of service (QoS) requirements in terms of delay, reliability, and fault tolerance in routing in WSNs. In this section, we review a sample QoS based routing protocols that help find a balance between energy consumption and QoS requirements.

Network Flow

Maximize traffic flow between two nodes, respecting the capacities of the links**.**

QOS-aware protocols

Consider end-to-end delay requirements while setting up paths.

Network Flow & QOS-aware Protocols are
- Maximum Lifetime Energy Routing.
- Maximum Lifetime Data Gathering.
- Minimum Cost Forwarding.
- Sequential Assignment Routing.
- Energy Aware QOS Routing Protocol.
- SPEED.

6.1 Sequential Assignment Routing (SAR)
SAR [9] is one of the first routing protocols for WSNs that introduces the notion of QoS in the routing decisions. It is a table-driven multi-path approach striving to achieve energy efficiency and fault tolerance. Routing decision in SAR is dependent on three factors: energy resources, QoS on each path, and the priority level of each packet. The SAR protocol creates trees rooted at one-hop neighbors of the sink by taking QoS metric, energy resource on each path and priority level of each packet into consideration. By using created trees, multiple paths from sink to sensors are formed. One of these paths is selected according to the energy resources and QoS on the path. Failure recovery is done by enforcing routing table consistency between upstream and downstream nodes on each path. Any local failure causes an automatic path restoration procedure locally. The objective of SAR algorithm is to minimize the average weighted QoS metric throughout the lifetime of the network. Simulation results showed that SAR offers less power consumption than the minimumenergy metric algorithm, which focuses only the energy consumption of each packet without considering its priority. SAR maintains multiple paths from nodes to sink. Although, this ensures fault-tolerance and easy recovery, the protocol suffers from the overhead of maintaining the tables and states at each sensor node especially when the number of nodes is huge.

7. COMPARISON OF ROUTING PROTOCOLS
In this paper we compared the following routing protocols according to their design characteristics.
- SPIN [5]: Sensor Protocols for Information via Negotiation.
- DD [6]: Directed Diffusion.
- RR: Rumor Routing.
- GBR: Gradient Based Routing.
- CADR: Constrained Anisotropic Diffusion Routing.
- COUGAR.
- ACQUIRE: ACtive QUery forwarding in sensoR nEtworks.
- LEACH [7]: Low Energy Adaptive Clustering Hierarchy.
- TEEN & APTEEN: [Adaptive] Threshold sensitive Energy Efficient sensor Network.
- PEGASIS [8]: The Power-Efficient GAthering in Sensor Information Systems.
- VGA: Virtual Grid Architecture Routing.
- SOP: Self-Organizing Protocol.
- GAF: Geographic Adaptive Fidelity.
- SPAN.
- GEAR: Geographical and Energy Aware Routing SAR [9]: Sequential Assignment Routing. SPEED: A real time routing protocol.

Table 1: Classification and Comparison of routing protocols in WSNs

Routing Protocols	Classification	Power Usage	Data Aggregation	Scalability	Query Based	Over head	Data delivery model	QoS
SPIN	Flat / Src-initiated / Data-centric	Ltd.	Yes	Ltd	Yes	Low	Event driven	No
DD	Flat/ Data-centric/ Dst-initiated	Ltd	Yes	Ltd	Yes	Low	Demand driven	No
RR	Flat	Low	Yes	Good	Yes	Low	Demand driven	No
GBR	Flat	Low	Yes	Ltd	Yes	Low	Hybrid	No
CADR	Flat	Ltd		Ltd	Yes	Low	Continuously	No
COUGAR	Flat	Ltd	Yes	Ltd	Yes	High	Query driven	No
ACQUIRE	Flat/ Data-centric	Low	Yes	Ltd	Yes	Low	Complex query	No
LEACH	Hierarchical / Dst-initiated /Node-centric	High	Yes	Good	No	High	Cluster-head	No
TEEN & APTEEN	Hierarchical	High	Yes	Good	No	High	Active threshold	No
PEGASIS	Hierarchical	Max	No	Good	No	Low	Chains based	No
VGA	Hierarchical	Low	Yes	Good	No	High	Good	No
SOP	Hierarchical	Low	No	Good	No	High	Continuously	No
GAF	Hierarchical / Location	Ltd	No	Good	No	Mod	Virtual grid	No
SPAN	Hierarchical / Location	Ltd	Yes	Ltd	No	High	Continuously	No
GEAR	Location	Ltd	No	Ltd	No	Mod	Demand driven	No
SAR	Data centric	High	Yes	Ltd	Yes	High	Continuously	Yes
SPEED	Location/Data centric	Low	No	Ltd	Yes	Less	Geographic	Yes

Table 1 represents Classification and Comparison of routing protocols in WSNs. Table 2 represents routing protocols selection for particular applications in WSNs. These tables are based on the survey of Ref. [10].

Table 2: Routing protocols selection for particular applications in WSNs

Application type	Project	Node deployment	Topology	Size	Routing protocol
Habitat monitoring	Great Duck[32]	Manual one time	Cluster Head	10-100	SPAN , GAF
Environment monitoring	PODS Hawaii[33]	Manual one time	Multi-hop Multi-path	30-50	DD
	Food Detection[34]	Manual	Multi-hop	200	COUGAR, ACQUIRE
Health	Artificial Retina[35]	Manual one time	Cluster Head	100	LEACH
	Vital Sign[36]	Manual	Star	10-20	GBR,SAR,SPEED
Military	Object Tracking[37]	Random	Multi-hop	200	GAF
Home/Office	Aware Home[38]	Manual Iterative	Three Tiered	20-100	APTEEN, GEAR
Production/ Commercial	Cold Chain[39]	Manual, Iterative	Three Tiered	55	SAR

8. CONCLUSION

One of the main challenges in the design of routing protocols for WSNs is energy efficiency due to the scarce energy resources of sensors. The ultimate objective behind the routing protocol design is to keep the sensors operating for as long as possible, thus extending the network lifetime. The energy consumption of the sensors is dominated by data transmission and reception. Therefore, routing protocols designed for WSNs should be as energy efficient as possible to prolong the lifetime of individual sensors, and hence the network lifetime.

It is an evolving field, which offers scope for a lot of research. Moreover, unlike MANETS, sensor networks are designed, in general, for specific applications. Hence, designing efficient routing protocols for sensor networks that suits sensor networks serving various applications is important. In this paper, we have surveyed a sample of routing protocols by taking into account several classification criteria, including location information, network layering and in-network processing, data centricity, path redundancy, network dynamics, QoS requirements, and network heterogeneity. For each of these categories, we have discussed a few example protocols and also compared and contrasted the existing routing protocols. As our study reveals, it is not possible to design a routing algorithm which will have good performance under all scenarios and for all applications. Although many routing protocols have been proposed for sensor networks, many issues still remain to be addressed.

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