Routing Protocols in Wireless Sensor Network: A Survey

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ABSTRACT
Wireless Sensor Networks (WSNs) consist of thousands of tiny nodes having the capability of sensing, computation, and wireless communications. Many routing, power management, and data dissemination protocols have been specifically designed for WSNs where energy consumption is an essential design issues. Since wireless sensor network protocols are application specific, so the focus has been given to the routing protocols that might differ depending on the application and network architecture. The study of various routing protocols for sensor networks presents a classification for the various approaches pursued. The three main categories explored are data-centric, hierarchical and location-based. Each of the routing schemes and algorithms has the common objective of trying to get better throughput and to extend the lifetime of the sensor network.

1. INTRODUCTION
A wireless sensor network is a collection of nodes organized into a cooperative network. Each node consists of processing capability (one or more microcontrollers, CPUs or DSP chips), may contain multiple types of memory (program, data and ash memories), have a RF transceiver (usually with a single Omni- directional antenna), have a power source (e.g., batteries and solar cells), and accommodate various sensors and actuators. The nodes communicate wirelessly and often self-organize after being deployed in an ad hoc fashion. Such systems can revolutionize the way we live and work. Currently, wireless sensor networks are beginning to be deployed at an accelerated pace. It is not unreasonable to expect that in 10-15 years that the world will be covered with wireless sensor networks with access to them via the Internet. This can be considered as the Internet becoming a physical network. This new technology is exciting with unlimited potential for numerous application areas including environmental, medical, military, transportation, entertainment, crisis management, homeland defense, and smart spaces. Since a wireless sensor network is a distributed real-time system a natural question is how many solutions from distributed and real time systems can be used in these new systems? Unfortunately, very little prior work can be applied and new solutions are necessary in all areas of the system. The main reason is that the set of assumptions underlying previous work has changed dramatically. Most past distributed systems research has assumed that the systems are wired, have unlimited power, are not real-time, have user interfaces such as screens and mice, have a fixed set of resources, treat each node in the system as very important and are location independent. In contrast, for wireless sensor networks, the systems are wireless, have scarce power, are real-time, utilize sensors and actuators as interfaces, have dynamically changing sets of resources, aggregate behavior is important and location is critical. Many wireless sensor networks also utilize minimal capacity devices which places a further strain on the ability to use past solutions.

2. ROUTING IN WIRELESS SENSOR NETWORK
Routing is a process of determining a path between source and destination upon request of data transmission. In WSNs the network layer is mostly used to implement the routing of the incoming data. It is known that generally in multi-hop networks the source node cannot reach the sink directly. So, intermediate sensor nodes have to relay their packets. The implementation of routing tables gives the solution. These contain the lists of node option for any given packet destination. Routing table is the task of the routing algorithm along with the help of the routing protocol for their construction and maintenance.

2.1 Routing Objective
Some sensor network applications only require the successful delivery of messages between a source and a destination. However, there are applications that need even more assurance. These are the real-time requirements of the message delivery, and in parallel, the maximization of network lifetime.

Non-real time delivery: The assurance of message delivery is indispensable for all routing protocols. It means that the protocol should always find the route between the communicating nodes, if it really exists. This correctness property can be proven in a formal way, while the average-case performance can be evaluated by measuring the message delivery ratio.

Real-time delivery: Some applications require that a message must be delivered within a specified time, otherwise the message becomes useless or its information content is decreasing after the time bound. Therefore, the main objective of these protocols is to completely control the network delay. The average-case performance of these protocols can be evaluated by measuring the message delivery ratio with time constraints.

Network lifetime: This protocol objective is crucial for those networks, where the application must run on sensor nodes as long as possible. The protocols aiming this concern try to balance the energy consumption equally among nodes considering their residual energy levels. However, the metric used to determine the network lifetime is also application dependent. Most protocols assume that every node is equally important and they use the time until the first node dies as a metric, or the average energy consumption of the nodes as another metric. If nodes are not equally important, then the time until the last or high-priority nodes die can be a reasonable metric.

3. CLASSIFICATION OF ROUTING PROTOCOLS

Routing protocols can also be classified based on whether they are reactive or proactive. A proactive protocol sets up routing paths and states before there is a demand for routing traffic. Paths are maintained even there is no traffic flow at that time. In reactive routing protocol, routing actions are triggered when there is data to be sent and disseminated to other nodes. Here paths are setup on demand when queries are initiated.

Routing protocols are also classified based on whether they are destination-initiated (Dst-initiated) or source-initiated (Src-initiated). A source-initiated protocol sets up the routing paths upon the demand of the source node, and starting from the source node. Here source advertises the data when available and initiates the data delivery. A destination initiated protocol, on the other hand, initiates path setup from a destination node.

Routing protocols are also classified based sensor network architecture. Some WSNs consist of homogenous nodes, whereas some consist of heterogeneous nodes. Based on this concept we can classify the protocols whether they are operating on a flat topology or on a hierarchical topology. In Flat routing protocols all nodes in the network are treated equally. When node needs to send data, it may find a route consisting of several hops to the sink. A hierarchical routing protocol is a natural approach to take for heterogeneous networks where some of the nodes are more powerful than the other ones. The hierarchy does not always depend on the power of nodes. In Hierarchical (Clustering) protocols different nodes are grouped to form clusters and data from nodes belonging to a single cluster can be combined (aggregated).The clustering protocols have several advantages like scalable, energy efficient in finding routes and easy to manage.

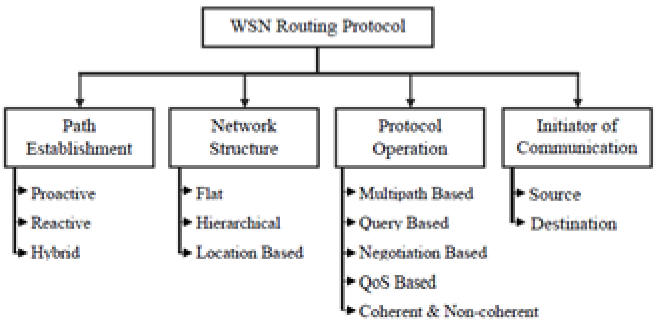

Fig 1. Classification of routing protocols

4. ROUTING PROTOCOLS IN WIRELESS SENSOR NETWORK

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4.1 Attribute-based or flat or Data-centric Routing Protocols

In this category, the following protocols stand out:

1. SPIN (SENSOR PROTOCOLS FOR INFORMATION VIA NEGOTIATION)

A family of adaptive protocols, called SPIN (sensor protocols for information via negotiation), that efficiently disseminate information among sensors in an energy-constrained wireless sensor network. Nodes running a spin communication protocol name their data using high-level data descriptors, called meta-data. They use meta-data negotiations to eliminate the transmission of redundant data throughout the network. In addition, spin nodes can base their communication decisions both upon application-specific knowledge of the data and upon knowledge of the resources that are available to them. This allows the sensors to efficiently distribute data given a limited energy supply. Four specific spin protocols were simulated and analyzed: SPIN-PP and SPIN-EC, which are optimized for a point-to-point network, and SPIN-BC and SPIN-RL, which are optimized for a broadcast network.

Limitation of this protocol is that data advertisement cannot guarantee the delivery of data i.e. If the node interested in the data are far from the source, data will not be delivered. This is not good for applications requiring reliable data delivery, e.g., intrusion detection

2. Directed Diffusion

As a data-centric protocol [1], applications in sensors label the data using attribute-value pairs. A node that demands the data generates a request where an interest is specified according to the attribute-value based scheme defined by the application. The sink usually injects an interest in the network for each application task. The nodes update an internal interest cache with the interest messages received. The nodes also keep a data cache where the recent data messages are stored. This structure helps on determining the data rate. On receiving this message, the nodes establish a reply link to the originator of the interest. This link is called gradient and it is characterized by the data rate, duration and expiration time. Additionally, the node activates its sensors to collect the intended data. The reception of an interest message makes the node establish multiple gradients (or first hop in a route) to the sink. In order to identify the optimum gradient, positive and negative reinforcements are used.

Limitation of this protocol is that it is inappropriate for applications requiring continuous data delivery, e.g., environmental monitoring

3. Rumor

In this algorithm [2], the queries generated by the sink are propagated among the nodes that have observed an event related to the queries. To do so, a node that observes an event inject a long-lived packet called agent. The agents are propagated in the network so distant nodes have knowledge about which nodes have perceived certain events. To optimize the behavior of agents, when an agent reaches a node which has detected another event, the agent is still forwarded but aggregating the new discovered event. Additionally, the agents maintain a list of the recent visited nodes so loops are partially avoided. On reception of agents, nodes can acquire updated information about the events in the network. This knowledge is reflected in the node's event caches. By using the event cache, a node can conveniently send a query message. However, some nodes may not be aware of the event's originator. Under these circumstances, the query is sequentially propagated to one of the neighbors selected randomly. Once the query arrives at a node with an entry related to the demanded event in its event cache, the query is then forwarded through the learnt path. Following this procedure, the cost of flooding the network with the query is clearly suppressed.

The drawback of this is that it works well only when the number of events is small. Also the cost of maintaining a large number of agents and large event tables will be prohibitive.

4. COUGER

Under this approach [4], the network is foreseen as a distributed database where some nodes containing the information are temporary unreachable. Since node stores historic values, the network behaves as a data warehouse. Additionally, it is worth noting that poor propagation conditions may lead to the storage of erroneous information in the nodes. Taking into account this circumstance, COUGAR provides a SQL-like interface extended to incorporate some clauses to model the probability distribution. The sink is responsible for generating a query plan which provides the hints to select a special node called the leader. The network leaders perform aggregation and transmit the results to the sink. One of the limitations of this is extra overhead & energy consumption required due to the extra query layer also the synchronization is required for data aggregations.

Drawback of this is it required extra overhead & energy consumption due to the extra query layer. Synchronization is required for data aggregations. Also leader nodes should be dynamically maintained to prevent them from being hotspots

5. ACQUIRE (Active Query Forwarding in Sensor Networks)

This algorithm [6] also considers the wireless sensor network as a distributed database. In this scheme, a node injects an active query packet into the network. Neighboring nodes that detects that the packet contains obsolete information, emits an update message to the node. Then, the node randomly selects a neighbor to propagate the query which needs to resolve it. As the active query progress through network, it is progressively resolved into smaller and smaller components until it is completely solved. Then, the query is returned back to the querying node as a completed response

4.2 Hierarchical Routing Protocols

The main objective of hierarchical routing is to reduce energy consumption by classifying nodes into clusters. In each

Table 1. Comparisons of flat routing protocols

Paper	Author	Advantages	Disadvantages
SPAN: An energy-efficient coordination algorithm for topology maintenance in ad hoc wireless networks	B. Chen, K. Jamieson, H. Balakrishnan, R. Morris	1. Each node only needs to know its one-hop neighbours 2.Significantly reduce energy consumption compared to flooding	1.Data advertisement cannot guarantee the delivery of data 2.If the node interested in the data are far from the source, data will not be delivered 3.Not good for applications requiring reliable data delivery, e.g., intrusion detection
Directed diffusion: a scalable and robust communication paradigm for sensor networks	C. Intanagonwiwat, R. Govindan, and D. Estrin,	1.Data centric: All communications are neighbour to neighbour with no need for a node addressing mechanism 2. Each node can do aggregation & caching	1.On-demand, query-driven: Inappropriate for applications requiring continuous data delivery, e.g., environmental monitoring 2. Attribute based naming scheme is application dependent
Rumor Routing Algorithm for Sensor Networks,"	D. Braginsky and D. Estrin,	1.No need for query flooding 2.Only one path between the source and sink	1.Rumor routing works well only when the number of events is small 2.Cost of maintaining a large number of agents and large event tables will be prohibitive
The cougar approach to in-network query processing in sensor networks	Y. Yao and J. Gehrke,	1. View a WSN as a distributed database 2. Use declarative queries to abstract query processing from the network layer—network layer independent	1. Extra overhead & energy consumption due to the extra query layer 2. Synchronization is required for data aggregations 3.Leader nodes should be dynamically maintained to prevent them from being hotspots

cluster, a node is selected as the leader or the cluster head. The different schemes for hierarchical routings mainly differ in how the cluster head is selected and how the nodes behave in the inter and intra-cluster domain.

1. LEACH (Low Energy Adaptive Clustering Hierarchy)

In LEACH the role of the cluster head is periodically transferred among the nodes in the network in order to distribute the energy consumption. The performance of LEACH is based on rounds. Then, a cluster head is elected in each round. For this election, the number of nodes that have not been cluster heads and the percentage of cluster heads are used. Once the cluster head is defined in the setup phase, it establishes a TDMA schedule for the transmissions in its cluster. This scheduling allows nodes to switch off their interfaces when they are not going to be employed. The cluster head is the router to the sink and it is also responsible for the data aggregation. As the cluster head controls the sensors located in a close area, the data aggregation performed by this leader permits to remove redundancy. A centralized version of this protocol is LEACH-C. This scheme is also based on time rounds which are divided into the set-up phase and the steady-phase. In the set-up phase, sensors inform the base station about their positions and about their energy level. With this information, the base station decides the structure of clusters and their corresponding cluster heads..

One of the limitation of this is it assumes all nodes can transmit with enough power to reach BS if necessary (e.g., elected as CHs).

2. PEGASIS (Power-Efficient Gathering in Sensor Information Systems)

It is considered an optimization of the LEACH algorithm. Rather than classifying nodes in clusters, the algorithm forms chains of the sensor nodes. Based on this structure, each node transmits to and receives from only one closest node of its neighbors. With this purpose, the nodes adjust the power of their transmissions. The node performs data aggregation and forwards it the node in the chain that communicates with the sink. In each round, one node in the chain is elected to communicate with the sink. The chain is constructed with a greedy algorithm.

3. TEEN (Threshold Sensitive Energy Efficient Sensor Network Protocol)

TEEN is other hierarchical protocol for reactive networks that responds immediately to changes in the relevant parameters. In this protocol a clusters head (CH) sends a hard threshold value and a soft one. The nodes sense their environment continuously. The first time a parameter from the attribute set reaches its hard threshold value, the node switches on its transmitter and sends its data. The nodes then transmits data in the current cluster period if the following conditions are true: the current value of the sensed attribute is greater than the hard threshold, and the current value of the sensed attribute differs from sensed value by an amount equal to or greater than the soft threshold. Both strategy looks to reduce energy spend transmitting messages. The main drawback of this scheme is that, if the thresholds are not reached, the nodes will never communicate; the user will not get any data from the network at all and will not come to know even if all the nodes die. Thus, this scheme is not well suited for applications where the user needs to get data on a regular basis.

The drawback of this is inappropriate for periodic monitoring, e.g., habitat monitoring. Also ambiguity in between packet loss and unimportant data.

Table 2. Comparisons of hierarchical routing protocols

Paper	Author	Advantages	Disadvantages
LEACH: "Energy-Efficient Communication Protocol for Wireless Microsensor Networks	W. Heinzelman, A. Chandrakasan and H. Balakrishnan,	1. Distributed, no global knowledge required 2. Energy saving due to aggregation by CHs	1. LEACH assumes all nodes can transmit with enough power to reach BS if necessary (e.g., elected as CHs) 2. Each node should support both TDMA & CDMA
TEEN: a routing protocol for enhanced efficiency in wireless sensor network	A. Manjeshwar and D. P. Agarwal	1. Good for time-critical applications 2. Energy saving 3.Less energy than proactive approaches	1. Inappropriate for periodic monitoring, e.g., habitat monitoring 2.Ambiguity between packet loss and unimportant data

4.3 Location Based Protocol

1. SPEED

SPEED [3] is another QoS routing protocol for sensor networks that provides soft real-time end-to-end guarantees. The protocol requires each node to maintain information about its neighbours and uses geographic forwarding to find the paths. In addition, SPEED strive to ensure a certain speed for each packet in the network so that each application can estimate the end-to-end delay for the packets by dividing the distance to the sink by the speed of the packet before making the admission decision. Moreover, SPEED can provide congestion avoidance when the network is congested. The routing module in SPEED is called Stateless Geographic Non-Deterministic forwarding (SNFG) and works with four other modules at the network layer. The beacon exchange mechanism collects information about the nodes and their location. Delay estimation at each node is basically made by calculating the elapsed time when an ACK is received from a neighbour as a response to a transmitted data packet. By looking at the delay values, SNGF selects the node, which meets the speed requirement. If it fails, the relay ratio of the node is checked, which is calculated by looking at the miss ratios of the neighbours of a node (the nodes which could not provide the desired speed) and is fed to the SNGF module. When compared to Dynamic Source Routing (DSR) and Ad-hoc on-demand vector routing (AODV), SPEED performs better in terms of end-to-end delay and miss ratio. Moreover, the total transmission energy is less due to the simplicity of the routing algorithm, i.e. control packet overhead is less, and to the even traffic distribution. Such load balancing is achieved through the SNGF mechanism of dispersing packets into a large relay area. SPEED does not consider any further energy metric in its routing protocol. Therefore, for more realistic understanding of SPEED's energy consumption, there is a need for comparing it to a routing protocol, which is energy-aware.

2. Geographic and Energy Aware Routing (GEAR)

Yu et al. [5] discussed the use of geographic information while disseminating queries to appropriate regions since data queries often include geographic attributes. The protocol, called Geographic and Energy Aware Routing (GEAR), uses energy aware and geographically-informed neighbour selection heuristics to route a packet towards the destination region. The key idea is to restrict the number of interests in directed diffusion by only considering a certain region rather than sending the interests to the whole network. By doing this, GEAR can conserve more energy than directed diffusion. Each node in GEAR keeps an estimated cost and a learning cost of reaching the destination through its neighbours. The estimated cost is a combination of residual energy and distance to destination. The learned cost is a refinement of the estimated cost that accounts for routing around holes in the network. A hole occurs when a node does not have any closer neighbour to the target region than itself. If there are no holes, the estimated cost is equal to the learned cost. The learned cost is propagated one hop back every time a packet reaches the destination so that route setup for next packet will be adjusted.

3. Geographic Adaptive Fidelity (GAF)

GAF [8] is an energy-aware location-based routing algorithm designed primarily for mobile ad hoc networks, but may be applicable to sensor networks as well. The network area is first divided into fixed zones and forms a virtual grid. Inside each zone, nodes collaborate with each other to play different roles. For example, nodes will elect one sensor node to stay awake for a certain period of time and then they go to sleep. This node is responsible for monitoring and reporting data to the BS on behalf of the nodes in the zone. Hence, GAF conserves energy by turning off unnecessary nodes in the network without affecting the level of routing fidelity. Each node uses its GPS-indicated location to associate itself with a point in the virtual grid. Nodes associated with the same point on the grid are considered equivalent in terms of the cost of packet routing. Such equivalence is exploited in keeping some nodes

Located in a particular grid area in sleeping state in order to save energy. Thus, GAF can substantially increase the network lifetime as the number of nodes increases. There are three states defined in GAF. These states are discovery, for determining the neighbours in the grid, active reflecting participation in routing and sleep when the radio is turned off. In order to handle the mobility, each node in the grid estimates its leaving time of grid and sends this to its neighbours. The sleeping neighbours adjust their sleeping time accordingly in order to keep the routing fidelity.

4. SPAN

Another position based algorithm called SPAN [7] selects some nodes as coordinators based on their positions. The coordinators form a network backbone that is used to forward messages. A node should become a coordinator if two neighbours of a non-coordinator node cannot reach each other directly or via one or two coordinators (3 hop reachability). New and existing coordinators are not necessarily neighbours in, which, in effect, make the design less energy efficient because of the need to maintain the positions of two or three hop neighbours in the complicated SPAN algorithm.

Table 3. Comparisons of location based routing protocols

Paper	Author	Advantages	Disadvantages
GAF: Geography-informed Energy Conservation for Ad-hoc Routing	Y. Xu, J. Heideman n, D. Estrin	1.Energy-aware location-based protocol mainly designed for MANET 2.Each node knows its location via GPS	1. It works only relatively small number of traffic load 2. It causes large range of location error
GEAR: Geographical and Energy-Aware Routing	Y. Yu, D. Estrin, and R. Govindan	1.GEAR successfully delivers significantly more packets than GPSR	1.Sensitive to location error
SPEED: A stateless protocol for real-time communicati on in sensor networks	T. He et al.	1.Each node maintains info about its neighbors and uses greedy geographic forwarding to find the paths 2.Higher energy consumption	1.It require more computation

5 ACKNOWLEDGMENTS

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