Comparison of Network Topological Routings in Wireless Sensor Networks

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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.

A comparison has been made between two routing protocols, Flooding and Directed Diffusion, on the basis of throughput and lifetime of the network. Simulation of AODV (WPAN) is also carried over two topologies with same source and destination node.

Keywords
Wireless Sensor Networks, Flooding, Directed Diffusion, AODV.

1. INTRODUCTION
The popularity of laptops, cell phones, PDAs, GPS devices, RFID, and intelligent computing devices is increasing day-by-day. This made the things cheaper, more mobile, more distributed, and more pervasive in daily life. Now, it is possible to construct a wallet size embedded system with the equivalent capability of a PC. Such embedded systems can be supported with scaled down Windows or Linux operating systems. In this scenario, the emergence of wireless sensor networks (WSNs) is essentially toward the miniaturization and ubiquity of computing devices. Sensor networks are composed of thousands of resource constrained sensor nodes and also some resourced base stations are there. All nodes in a network communicate with each other via wireless communication. Moreover, the energy required to transmit a message is about twice as great as the energy needed to receive the same message. On the other hand, using a long route composed of many sensor nodes can significantly increase the network delay. At the same time, always choosing the shortest path might result in lowest energy consumption and lowest network delay. Finally, the routing objectives are tailored by the application; e.g., real-time applications require minimal network delay, while applications performing statistical computations may require maximized network lifetime. Hence, different routing mechanisms have been proposed for different applications. These routing mechanisms primarily differ in terms of routing objectives and routing techniques, where the techniques are mainly influenced by the network characteristics

1.1 Back Ground Work
Routing is a process of determining a path between source and destination upon request of data transmission. In WSNs, the layer that is mainly used to implement the routing of the incoming data is called as network layer. When the sink is far away from the source or not in the range of source node, multi-hop technique is followed. So, intermediate sensor nodes have to relay their packets. The implementation of routing tables gives the solution.In flooding [6], the source node floods all events to every node in the network. Whenever a sensor receives a data message, it keeps a copy of the message and forwards the message to every one of its neighboring sensors and the cycle repeats. Direct Diffusion [8, 21] is the data centric protocol. It is the first proposed protocol for the wireless sensor network scenarios. If directed diffusion does not perform better than flooding, it cannot be considered viable for sensor networks. It consists of several elements: interests, data messages, gradients, and reinforcements.

When a node receives an interest, it checks if the interest exists in the cache. If no matching interest exists *i.e.,* the interest is distinct; the node creates an interest entry and determines each field of the interest entry from the received interest. This entry contains a single gradient toward the neighbour from which the interest was received, with the specified event data rate. Thus, it is necessary to distinguish individual neighbours. Any locally unique neighbour identifier like an IEEE 802.11 MAC address [10], a Bluetooth cluster address [11], a random, ephemeral transaction identifier may be applicable. If there is the matching interest entry, but no gradient for the sender of the interest, the node adds a gradient toward that neighbor and updates the timestamp and duration fields appropriately. It is mainly used for ad-hoc networks. In March 1999, the IEEE established the 802.15 [14, 15] working group as part of the IEEE Computer Society's 802 Local and Metropolitan Area Standards Committee. The 802.15 working group was established with the specific purpose of developing standards for short distance wireless networks, otherwise known as wireless personal area networks (WPANs). When two nodes want to send data at the same time, CSMA-CA [16, 17] comes into play. It gives the solution of hidden node problem in CSMA-CD, in which a node cannot detect another node that also wants to transmit packet resulting a collision. CSMA-CA protocol uses four-way handshake.

1.2 Problem Statement And Objective Routing Protocols in WSNs

In this section, we survey the state-of-the-art routing protocols for WSNs. In general, routing in WSNs can be divided into °at-based routing, hierarchical-based routing, and location-based routing depending on the network structure. In °at-based routing, all nodes are typically assigned equal roles or functionality. In hierarchical-based routing, however, nodes will play different roles in the network. In location-based routing, sensor nodes' positions are exploited to route data in the network. A routing protocol is considered adaptive if certain system parameters can be controlled in order to adapt to the current network conditions and available energy levels. Furthermore, these protocols can be classified into multipath-based, query-based, negotiation-based, QoS-based, or coherent-based routing techniques depending on the protocol operation. In addition to the above, routing protocols can be classified into three categories, namely, proactive, reactive, and hybrid protocols depending on how the source finds a route to the destination. In proactive protocols, all routes are computed before they are really needed, while in reactive protocols, routes are computed on demand. Hybrid protocols use a combination of these two ideas. When sensor nodes are static, it is preferable to have table driven routing protocols rather than using reactive protocols. A significant amount of energy is used in route discovery and setup of reactive protocols. Another class of routing protocols is called the cooperative routing protocols. In cooperative routing, nodes send data to a central node where data can be aggregated and may be subject to further processing, hence reducing route cost in terms of energy use. Many other protocols rely on timing and position information. We also shed some light on these types of protocols in this paper. In order to streamline this survey, we use a classification according to the network structure and protocol operation (routing criteria). The classification is shown in Figure 1 where numbers in the figure indicate the references.

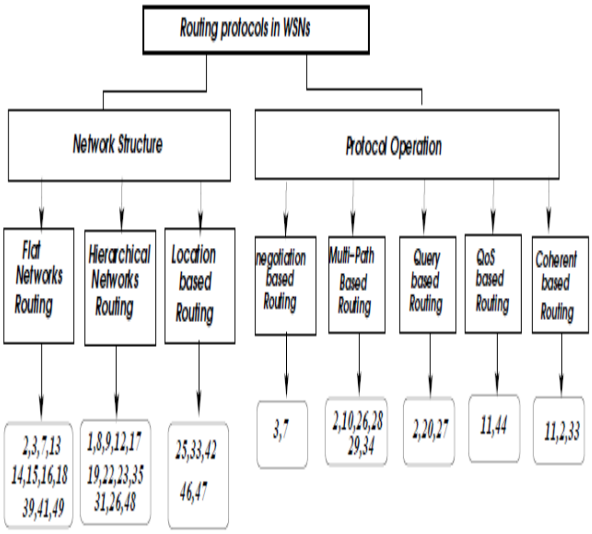

Figure 1. Routing protocols in WSNs: A taxonomy

1.3 Network Structure Based Protocols

The underlying network structure can play significant role in the operation of the routing protocol in WSNs. In this section, we survey in details most of the protocols that fall below this category.

1.4 Flat Routing

The first category of routing protocols are the multihop flat routing protocols. In °at networks, each node typically plays the same role and sensor nodes collaborate together to perform the sensing task. Due to the large number of such nodes, it is not feasible to assign a global identifier to each node. This consideration has led to data centric routing, where the BS sends queries to certain regions and waits for data from the sensors located in the selected regions. Since data is being requested through queries, attribute-based naming is necessary to specify the properties of data. Early works on data centric routing, e.g., SPIN and directed diffusion [18] were shown to save energy through data negotiation and elimination of redundant data. These two protocols motivated the design of many other protocols which follow a similar concept. In the rest of this subsection, we summarize these protocols and highlight their advantages and their performance issues.

1.5 Energy Aware Routing

The objective of energy-aware routing protocol [39], a destination ini-tiated reactive protocol, is to increase the network lifetime. Although this protocol is similar to directed diffusion, it differs in the sense that it maintains a set of paths instead of maintaining or enforcing one optimal path at higher rates. These paths are maintained and chosen by means of a certain probability. The value of this probability depends on how low the energy consumption of each path can be achieved. By having paths chosen at different times, the energy of any single path will not deplete quickly. This can achieve longer network lifetime as energy is dissipated more equally among all nodes. Network survivability is the main metric of this protocol. The protocol assumes that each node is addressable through a class-based addressing which includes the location and types of the nodes. The protocol initiates a connection through localized flooding, which is used to discover all routes between source/destination pair and their costs; thus building up the routing tables. The high-cost paths are discarded and a forwarding table is built by choosing neighboring nodes in a manner that is proportional to their cost. Then, forwarding tables are used to send data to the destination with a probability that is inversely proportional to the node cost. Localized flooding is performed by the destination node to keep the paths alive. When compared to directed diffusion, this protocol provides an overall improvement of 21.5% energy saving and a 44% increase in network lifetime. However, the approach requires gathering the location information and setting up the addressing mechanism for the nodes, which complicate route setup compared to the directed diffusion.

1.6 Routing Protocols with Random Walks

The objective of random walks based routing technique [50] is to achieve load balancing in a statistical sense and by making use of multi-path routing in WSNs. This technique considers only large scale networks where nodes have very limited mobility. In this protocol, it is assumed that sensor nodes can be turned on or o® at random times. Further, each node has a unique identifier but no location information is needed. Nodes were arranged such that each node falls exactly on one crossing point of a regular grid on a plane, but the topology can be irregular. To find a route from a source to its destination, the location information or lattice coordination is obtained by computing distances between nodes using the distributed asynchronous version of the well-known Bellman-Ford algorithm. An intermediate node would select as the next hop the neighboring node that is closer to the destination according to a computed probability. By carefully manipulating this probability, some kind of load balancing can be obtained in the network. The routing algorithm is simple as nodes are required to maintain little state information. Moreover, different routes are chosen at different times even for the same pair of source and destination nodes. However, the main concern about this protocol is that the topology of the network may not be practical.

1.7 Hierarchical Routing

Hierarchical or cluster-based routing, originally proposed in wireline networks, are well-known techniques with special advantages related to scalability and efficient communication. As such, the concept of hierarchical routing is also utilized to perform energy efficient routing in WSNs. In a hierarchical architecture, higher energy nodes can be used to process and send the information while low energy nodes can be used to perform the sensing in the proximity of the target. This means that creation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an efficient way to lower energy consumption within a cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the BS. Hierarchical routing is mainly two-layer routing where one layer is used to select cluster heads and the other layer is used for routing. However, most techniques in this category are not about routing, rather on "who and when to send or process/aggregate" the information, channel allocation etc., which can be orthogonal to the multihop routing function.

1.8 LEACH Protocol

Heinzelman, et. al. [1] introduced a hierarchical clustering algorithm for sensor networks, called Low Energy Adaptive Clustering Hierarchy (LEACH). LEACH is a cluster-based protocol, which includes distributed cluster formation. LEACH randomly selects a few sensor nodes as clusterheads (CHs) and rotate this role to evenly distribute the energy load among the sensors in the network. In LEACH, the clusterhead (CH) nodes compress data arriving from nodes that belong to the respective cluster, and send an aggregated packet to the base station in order to reduce the amount of information that must be transmitted to the base station. LEACH uses a TDMA/CDMA MAC to reduce inter-cluster and intra-cluster collisions. However, data collection is centralized and is performed periodically. Therefore, this protocol is most appropriate when there is a need for constant monitoring by the sensor network. A user may not need all the data immediately. Hence, periodic data transmissions are unnecessary which may drain the limited energy of the sensor nodes. After a given interval of time, a randomized rotation of the role of the CH is conducted so that uniform energy dissipation in the sensor network is obtained. The authors found, based on their simulation model, that only 5% of the nodes need to act as cluster heads.

2. SENSOR PROTOCOLS FOR INFORMATION VIA NEGOTIATION (SPIN)

Heinzelman et.al. in [3] and 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 posses. The SPIN family of protocols uses data negotiation and resource-adaptive algorithms. Nodes running SPIN assign a high-level name to completely describe their collected data (called meta-data) and perform meta-data negotiations before any data is transmitted. This assures that there is no redundant data sent throughout the network. The semantics of the meta-data format is application-specific and is not specified in SPIN. For example, sensors might use their unique IDs to report meta-data if they cover a certain known region. In addition, SPIN has access to the current energy level of the node and adapts the protocol it is running based on how much energy is remaining. These protocols work in a time-driven fashion and distribute the information all over the network, even when a user does not request any data.

2.1 Directed Diffusion

In [2], C. Intanagonwiwat et. al. 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 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 reroute (in-network aggregation) by eliminating redundancy, minimizing the number of transmissions; thus saving network energy and prolonging its lifetime. Unlike traditional end-to-end routing, DC routing finds routes from multiple sources to a single destination that allows in-network consolidation of redundant data.

Table 1: Comparison between SPIN, LEACH and Directed Diffusion

	SPIN	LEACH	Directed Diffusion
Optimal Route	No	No	Yes
Network Lifetime	Good	Very Good	Good
Resource Awareness	Yes	Yes	Yes
Use of Meta-Data	Yes	No	Yes

The above mentioned °at and hierarchical protocols are different in many aspects. At this point, we compare the different routing approaches for °at and hierarchical sensor networks, which is shown in Table 2.

Table 2. Structure of Routing Algorithms Features

Hierarchical routing	Flat routing
Reservation-based scheduling	Contention-based scheduling
Collisions avoided	Collision overhead present
Reduced duty cycle due to periodic sleeping	Variable duty cycle by controlling sleep time of nodes
Data aggregation by clusterhead	node on multihop path aggregates incoming data from neighbors
Simple but non-optimal routing	Routing can be made optimal but with an added com-plexity.
Requires global and local synchronization	Links formed on the fly without synchronization
Overhead of cluster formation throughout the network	Routes formed only in regions that have data for trans-mission
Lower latency as multiple hops network formed by clusterheads always available	Latency in waking up intermediate nodes and setting up the multipath
Energy dissipation is uniform	Energy dissipation depends on traffic patterns
Energy dissipation cannot be controlled	Energy dissipation adapts to traffic pattern
Fair channel allocation	Fairness not guaranteed

Table 2: Hierarchical vs. °at topologies routing

Data processing is a major component in the operation of wireless sensor networks. Hence, routing tech-niques employ different data processing techniques. In general, sensor nodes will cooperate with each other in processing different data flooded in the network area. Two examples of data processing techniques pro-posed in WSNs are coherent and non-coherent data processing-based routing [11]. In non-coherent data processing routing, nodes will locally process the raw data before being sent to other nodes for further processing. The nodes that perform further processing are called the aggregators. In coherent routing, the data is forwarded to aggregators after minimum processing. The minimum processing typically includes tasks like time stamping, duplicate suppression, etc. To perform energy-efficient routing, coherent processing is normally selected.

Non-coherent functions have fairly low data traffic loading. On the other hand, since coherent processing generates long data streams, energy efficiency must be achieved by path optimality. In non-coherent processing, data processing incurs three phases: (1) Target detection, data collection, and preprocessing (2) Membership declaration, and (3) Central node election. During phase 1, a target is detected, its data collected and preprocessed. When a node decides to participate in a cooperative function, it will enter phase 2 and declare this intention to all neighbors. This should be done as soon as possible so that each sensor has a local understanding of the network topology. Phase 3 is the election of the central node. Since the central node is selected to perform more sophisticated information processing, it must have sufficient energy reserves and computational capability.

In [11], a single and multiple winner algorithms were proposed for non-coherent and coherent processing, respectively. In the single winner algorithm (SWE), a single aggregator node is elected for complex processing. The election of a node is based on the energy reserves and computational capability of that node. By the end of the SWE process, a minimum-hop spanning tree will completely cover the network. In the multiple winner algorithm (MWE), a simple extension to the single winner algorithm (SWE) is proposed. When all nodes are sources and send their data to the central aggregator node, a large amount of energy will be consumed and hence this process has a high cost. One way to lower the energy cost is to limit the number of sources that

Figure Comparison of Various Routing Protocols can send data to the central aggregator node. Instead of keeping record of only the best candidate node (master aggregator node), each node will keep a record of up to n nodes of those candidates. At the end of the MWE process, each sensor in the network has a set of minimum-energy paths to each source node (SN). After that, the single winner algorithm is used to find the node that yields the minimum energy consumption. This node can then serves as the central node for the coherent processing. In general, the MWE process has longer delay, higher overhead, and lower scalability than that for non-coherent processing networks.

We observed that there are some hybrid protocols that under more than one category. We summarize recent research results on data routing in WSNs in the Table shown in Figure 2.

Table shows how different routing protocols under different category and also compare different routing techniques according to many metrics.

	Classification	Mobility	Position Awareness	Power Usage	Negotiation based	Data Aggregation	Localization	QoS	State Complexity	Scalability	Multipath	Query based
SPIN	Flat	Possible	No	Limited	Yes	Yes	No	No	Low	Limited	Yes	Yes
Directed Diffusion	Flat	Limited	No	Limited	Yes	Yes	Yes	No	Low	Limited	Yes	Yes
Rumor Routing	Flat	Very Limited	No	N/A	No	Yes	No	No	Low	Good	No	Yes
GBR	Flat	Limited	No	N/A	No	Yes	No	No	Low	Limited	No	Yes
MCFA	Flat	No	No	N/A	No	No	No	No	Low	Good	No	No
CADR	Flat	No	No	Limited	No	Yes	No	No	Low	Limited	No	No
COUGAR	Flat	No	No	Limited	No	Yes	No	No	Low	Limited	No	Yes
ACQUIRE	Flat	Limited	No	N/A	No	Yes	No	No	Low	Limited	No	Yes
EAR	Flat	Limited	No	N/A	No	No		No	Low	Limited	No	Yes
LEACH	Hierarchical	Fixed BS	No	Maximum	No	Yes	Yes	No	CHs	Good	No	No
TEEN & APTEEN	Hierarchical	Fixed BS	No	Maximum	No	Yes	Yes	No	CHs	Good	No	No
PEGASIS	Hierarchical	Fixed BS	No	Maximum	No	No	Yes	No	Low	Good	No	No
MECN & SMECN	Hierarchical	No	No	Maximum	No	No	No	No	Low	Low	No	No
SOP	Hierarchical	No	No	N/A	No	No	No	No	Low	Low	No	No
HPAR	Hierarchical	No	No	N/A	No	No	No	No	Low	Good	No	No
VGA	Hierarchical	No	No	N/A	Yes	Yes	Yes	No	CHs	Good	Yes	No
Sens or aggregate	Hierarchical	Limited	No	N/A	No	Yes	No	No	Low	Good	No	Possible
TTDD	Hierarchical	Yes	Yes	Limited	No	No	No	No	Moderate	Low	Possible	Possible
GAF	Location	Limited	No	Limited	No	No	No	No	Low	Good	No	No
GEAR	Location	Limited	No	Limited	No	No	No	No	Low	Limited	No	No
SPAN	Location	Limited	No	N/A	Yes	No	No	No	Low	Limited	No	No
MFR, GEDIR	Location	No	No	N/A	No	No	No	No	Low	Limited	No	No
GOAFR	Location	No	No	N/A	No	No	No		Low	Good	No	No
SAR	QoS	No	No	N/A	Yes	Yes	No	Yes	Moderate	Limited	No	Yes
SPEED	QoS	No	No	N/A	No	No	No	Yes	moderate	Limited	No	Yes

Figure: 2 Classification and comparison of routing protocols in wireless sensor networks

3. CONCLUSIONS

Routing in sensor networks is a new area of research, with a limited, but rapidly growing set of research results. In this paper, we presented a comprehensive survey of routing techniques in wireless sensor networks which have been presented in the literature. They have the common objective of trying to extend the lifetime of the sensor network, while not compromising data delivery.

Overall, the routing techniques are classified based on the network structure into three categories: flat, hierarchical, and location based routing protocols. Furthermore, these protocols are classified into multipath-based, query-based, negotiation-based, or QoS-based routing techniques depending on the protocol operation. We also highlight the design tradeoffs between energy and communication overhead savings in some of the routing paradigm, as well as the advantages and disadvantages of each routing technique. Although many of these routing techniques look promising, there are still many challenges that need to be compared.

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