Comprehensive Study of Routing Management in Wireless Sensor Networks- Part-1

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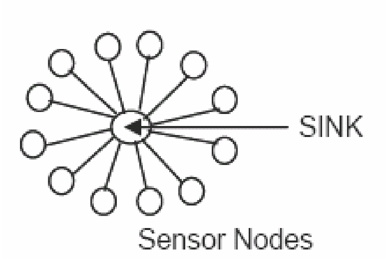
Abstract

Increasing computing and wireless communication capabilities will expand the role of the sensors from mere information dissemination to more demanding tasks as sensor fusion, classification, collaborative target tracking. Wireless sensor nodes can be mobile within a chosen area and communicate with neighboring nodes in the bounds of protocol limits. Typically they are densely deployed in large numbers and are prone to failures, and frequent topology changes. Among many concerns about design of sensor networks are growing bandwidth demands, speed of information retrieval and transporting bytes over the wireless networks to provide a quality service for the diverse requirements of the users, such as signal processing or multimedia applications. This Paper has been split in two parts to discuss past and ongoing research in routing schemes in WSNs. Current work a comprehensive investigation of different routing schemes used in wireless sensor networks. Depending on the sensor applications, the design challenge, advantage and performance concern for each routing protocols is also revealed.

1. Introduction

We review the state-of-the-art routing techniques for wireless sensor networks. The routing scheme for wireless sensor networks has to be straightforward and simple which does not expend much computation power and memory, and eventually minimize communication among nodes to save its power. Routing protocols may be classified into one of the ensuing three models [1] (a) single hop model, (b) multi-hop model and (c) Cluster-based hierarchical model. We will discuss each model briefly and further classify the protocol based on network structure and protocol operation in the subsequent sections. Single hop model is the simplest model and act as a direct communication model. In this model, fig 1 (a), all the nodes travel one hop to reach to a base station or the sink node. This kind of single hop transmission is highly unrealistic in the real world. The transmission range of each node and the energy consumed plays a crucial role in defining the sensor network. The multi-hop model supports the collaborative effort of several nodes within the sensor cloud, fig 1 (b). Each sensor node has a radio range, which is referred to as the distance at which the signal strength remains above the minimum usable level for that particular node to transmit and receive. If two nodes cannot communicate directly, the nodes positioned between those two nodes, transmit an information packet from the source node to the destination node. Information is received only by nodes within the radio range of the forwarding node in a wireless medium. In view of efficient energy consumption, this model follows more practically feasible approach and is employed by [2], [3], [4], [5], [6]. The multi hop model uses the data aggregation techniques.



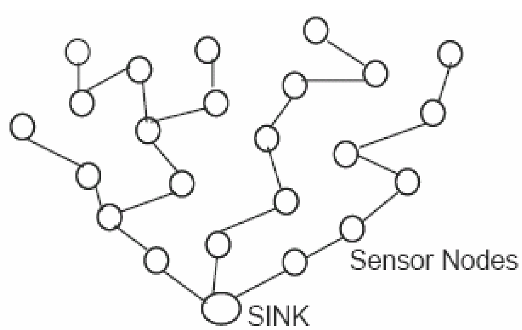


Figure 1 (a) Single hop routing model (b) Multi-hop routing model

Within a sensor cloud, variation in the rate of consuming power by each node depends on factors such as event sensing rate, distance from sink node, and location of each node relative to other nodes. This disparity in energy consumption in wireless sensor network causes an imbalance of node power status., Figure 1(c) resulting in diminishing overall network lifetime. If the sink node is at one fixed location, information packets gather from the entire network to one fixed sink. This result in denser information traffic around the nodes in vicinity of the sink, as compared with the nodes placed farther from the sink. Hence, the nodes close to the sink will exhaust energy at the faster pace. If the nodes around the sink drain their energy, the sink is isolated from the entire sensor network, thereby making the data collection impossible. The segregation of the sink node from entire network is called self induced black hole effect [1]. To avoid isolation of sink node from the network, it is necessary to adopt an energy conservation heuristic on nodes located around the sink.

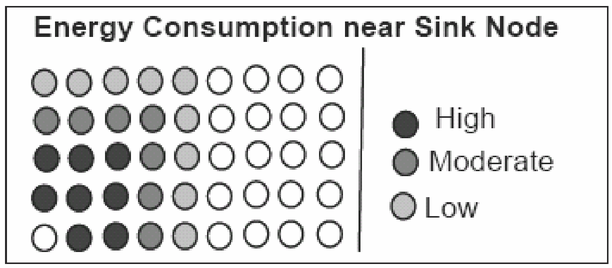


Figure 1(c) Disparities in power spending

In the cluster based model, fig 2, the network is divided into clusters comprising of “X” amount of nodes. Cluster head, which is master node, within each respective cluster is responsible for routing the information to the other cluster head. Data is first aggregated within the cluster and then from cluster to cluster. As the data packets moves from one cluster to another, it covers larger distances. This results in very low data latency as compared to multi hop model and single hop model respectively. However this model has a drawback. As the distance between clustering levels increases, the energy spent grows proportional by the square of distance. This definitely increases the energy consumption of the sensor network.

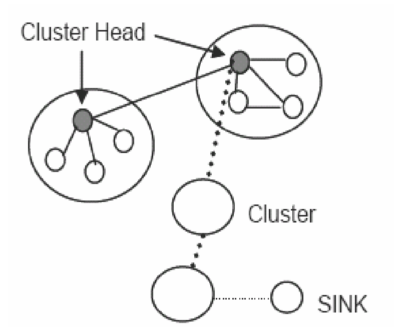


Figure 2 Cluster based hierarchical routing model

2. Protocol Assessment

In traditional networks, the focus is on Quality of Service (QoS). In wireless sensor networks QoS requirements can be relaxed to preserve energy and the network lifetime. At each layer of protocol stack, steps must be taken to (a) save energy, (b) allow sensor nodes to reconfigure, and (c) update their respective tasks according to the resources available. The simulation test bed should be as simple as possible. Diverse environmental conditions need to be implemented in analyses and simulations [1]. Some of the parameters used to evaluate the routing performance are (a) Energy consumption, both with respect to an individual node and the whole network (b) Simulation time and latency, (c) success rate of the data packets reaching the sink, (d) network size, and finally (e) fault tolerance capability of the entire network. In addition, the routing protocol should incorporate some kind of security to evade vulnerability from adversaries.

3. Routing Methodology in Wireless Sensor Networks

In WSNs, discovering the routes and then sustaining them is practically insignificant because of the energy constraints and sudden node failures. First of all, there is no control on topology of the nodes within a sensor network cloud. Secondly the unpredictable topological change makes it impossible to stick to a fixed routing strategy. Some well known routing plans such as data-centric methods, in-network processing, clustering, data diffusion, data aggregation and energy aware methods are proposed in the literature to cater the requirements for wireless sensor networks. Figure 3 illustrates the lineage of the routing protocols in wireless sensor networks. Broad classification is on the basis of

- Network structure and
- Protocol operation

Based on the network structure, the protocols are further classified as flat-network routing, hierarchical-based routing, and location-based routing. Flat routing protocols distribute information as needed to any reachable sensor node within the sensor cloud. No effort is made to organize the network or its traffic, only to discover the best route hop by hop to a destination by any path. All nodes are assigned uniform functionality. In hierarchical-network routing, nodes play different roles in the network. These protocols often group sensor nodes together by functionality and merge them into a hierarchy. Location-based routing uses the physical position of a sensor node in the network to route packets to that node. If a node changes location, the connection to that node will be broken and another route is required to establish its new location. Based on their operation, the protocols are further classified into Query based, negotiation based, multipath based, QoS based and coherent routing. The protocols categorized here often overlap on top of each other. We will explain each relevant protocol on the basis of network structure and protocol operation respectively.

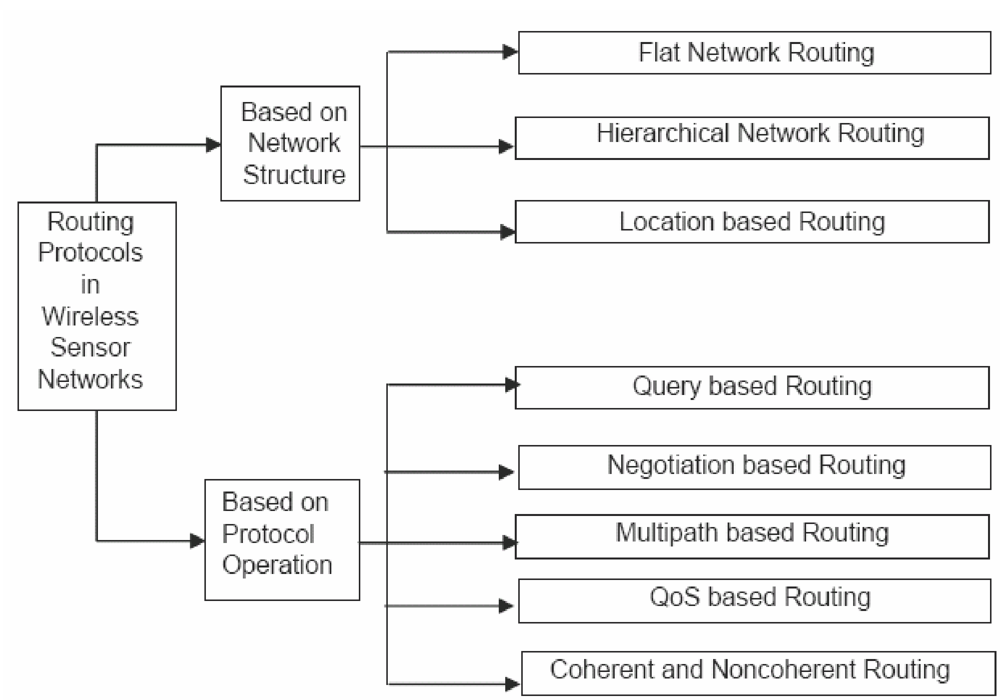


Figure 3 Classification of Routing Protocols [7]

4. Flat Routing

In flat network architecture all the sensor nodes are equal and connections between nodes are set up in short distance to establish the radio communication. Route discovery can be carried out in sensor networks using flooding or broadcasting which do not involve topology maintenance. In this section, we will provide an in-depth knowledge of the flat routing based protocols.

4.1 Flooding

Flooding is an example of simple flat routing scheme. When a sensor node receives a data packet, it stores the data and broadcasts it to its neighboring nodes. This process repeats until the information reaches all the sensor nodes in an entire network. To perform flooding, figure 4 (a), sensor nodes do not need any knowledge of the network configuration. Sensor nodes distinguish each data packet, while receiving or transmitting a data packet. This will save the limited memory space of each node. Since flooding does not require any complicated routing algorithms, it can be easily implemented for sensor networks. However, there are some shortcomings in this scheme which dissipate the limited resources of the sensor nodes [2].

One such problem in classic flooding is implosion. Implosion occurs, when a data receiving node broadcast the data packet to its all neighboring nodes, irrespective of whether the neighboring node already has the same data or not. Figure 4 (b) illustrates implosion; here node D floods the information to its neighboring nodes E and F respectively. Node H being the neighbor to both E and F, gets the same copy of the information from both E and F. Due to indiscriminate transmission of data, sensor nodes in this scheme expend limited transmission energy and bandwidth. Another problem associated with flooding is overlap. This situation occurs when multiple nodes observe the same sensor region, they generate the overlapping data. The sensor nodes within its neighborhood receive the multiple copies of the same packet containing the same information. Overlap, like implosion expends transmission power and bandwidth. Figure 4 (c) shows that J and K collect overlapped information and flood to their respective common neighbor/s, here node L. In flooding, the overlap problem is more difficult to solve than the implosion problem, because implosion is a function of network topology, whereas overlap is a function of both topology and observed data. Additionally, in classic flooding, the sensor nodes are not resource aware, i.e. sensor nodes do not update their activity status according to the energy constraints at any given time. These shortcomings reduce the battery life of sensor node and therefore shorten the entire network life span.

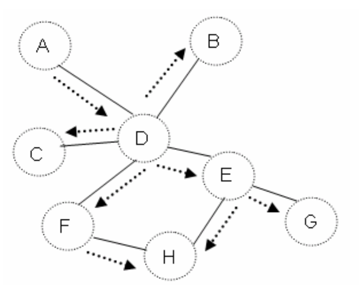


Figure 4(a) Flooding Techniques

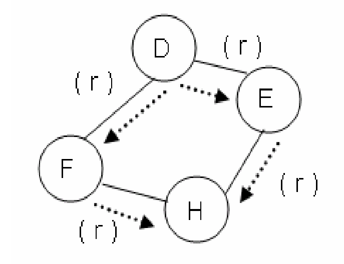


Figure 4 (b) Implosion Problem

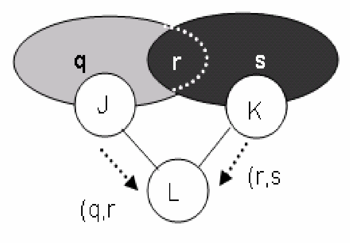


Figure 4 (c) The Overlap Problem associated with Flooding

Nonetheless, Flooding, due to its easier implementation and simple design has been investigated intensively to overcome the abovementioned shortcomings. In [9] and [10], each sensor node only needs to know a small portion of entire network configuration, which is the location information of its neighboring nodes, instead of the information of entire network topology. Gossiping is another by-product of flooding [8].When a node receives the data packet it selects a subset of its all neighboring nodes and transmits the data packet to the subset, instead of all neighboring nodes. This reduces the consumption of transmission energy.

4.2 SPIN- Sensor Protocols for Information via Negotiation

Another example of flat routing is negotiation based protocols. Sensor Protocols for Information via Negotiation- SPIN [2] intend to disseminate data towards the sink using negotiations. It is assumed that the source has an observed data meant to be transported to sink node. The source node advertises its data over the sensor network. Those nodes desiring the sensor data, request it from the source. For the negotiations, the information descriptors called “meta-data” are used. Upon sensing the information packet, figure 5, the observer or source node transmits a small advertisement packet (ADV) to its all neighboring nodes except the one from which the node receives the data packet. The ADV contains the information of actual data. Upon receiving the ADV, a neighboring node checks its local cache whether the node already has the same data or not. If the neighboring node already has the data, the ADV is rejected. If the node does not have the desired data, it sends a request message (REQ) to the receiving node. Then, the receiving node transmits the data packet (DATA) to the neighboring nodes, which request the data by sending the REQ message. The corresponding neighboring node then replicates this procedure with its neighbors. As a result, the entire sensor network will acquire a copy of the data. This guarantees that there is no redundant information sent throughout the network. The SPIN family of protocols includes several schemes with minor modifications on the actual proposal [2].

SPIN-1 includes negotiation before transmitting information to guarantee that only useful information will be transferred. It is a three-way handshake protocol, as mentioned above. SPIN-2 is a modification to SPIN-1 which in addition to a three- way handshake includes a resource awareness mechanism [7]. SPIN-2 works under resource constraint environment. Each sensor node has its own resource manager, which keeps account of the expended and remaining power. Before each transmission, the nodes examine their resource manager and curb on other energy expending activities to increase the lifetime of the node.

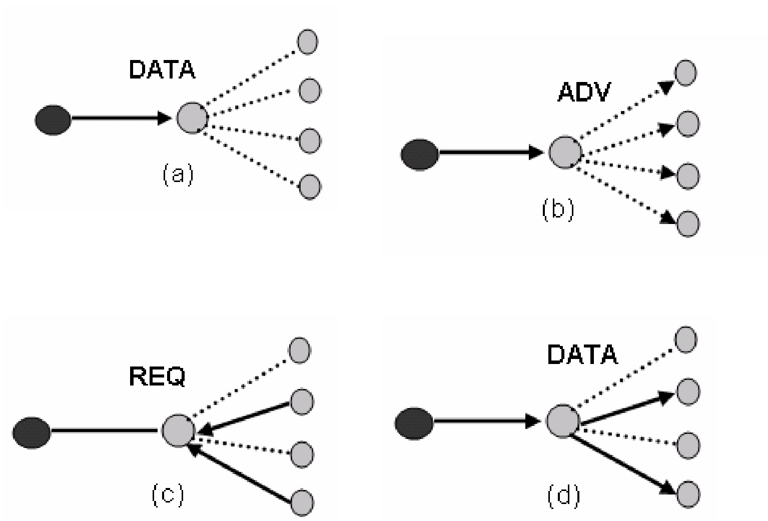


Figure 5 (a) Observer / Source node acquiring Data, (b) Receiver sending ADV message, (c) Desired nodes sending REQ message and (d) Source sending the Data to selective neighbors

SPIN-BC is developed for broadcast networks in which the sensor nodes use a single shared channel to communicate with each other. In SPIN-BC, the sensor node on receiving the ADV message does not send a REQ message instantaneously. Instead, it waits for a certain time before sending the REQ message. This is to avoid the redundant request for the same message. In SPIN-RL, each node keeps track of all the nodes from where it hears the advertisement. If it does not receive any requested data within a certain period of time, it sends out the request again. Similarly after transmitting the data message, sensor node waits for a certain period of time before responding to other requests for the same data message. Mainly SPIN-RL is used for the lossy channels. SPIN-PP has been developed to work with point-to-point communication. In SPIN-PP, two nodes can have a direct communication, without the need for intermediate nodes. It is a simple 3-way handshake scheme in which energy is not considered to be a constraint. [11]. In SPIN-EC the sensor nodes follow the 3-way handshake like SPIN-PP but there is an energy-conservation heuristic added to it. Sensor node contributes actively in the protocol only if it is above a certain energy threshold and believes it can complete all the other stages of the protocol. Performance evaluation of SPIN [2] demonstrates that SPIN is more energy-efficient than flooding or gossiping while distributing data at the same rate or faster than these protocols. However the SPIN suffers from the weakness [12] of transmitting all the data packets at the same Energy level and not using the distance to a neighbor to adjust the energy level. Besides a large overhead in broadcasting the data, energy consumption is a concern in SPIN.

4.3 Directed Diffusion

Directed Diffusion, [13], [14] is a data-centric and application-aware routing scheme where all the information generated by sensor nodes is named by attribute-value pairs. This is a Sink-initiated reactive routing paradigm in which routes are established as they are requested. In data centric routing the data originating from different sources are combined with in-network aggregation by eliminating redundancy, minimizing the number of transmissions; thus saving network energy and prolonging its lifetime. Unlike conventional networks, maintaining a node addressing table, results in a large overhead. Instead the data queries are exchanged. For example in the task of monitoring a building's entrance, the request to gather the "The total number of people going out" is more appropriate than the request to "gather the readings from the nodes W,X,Y,Z". The sink node requests data by broadcasting "interests" or sensing task. Interest specifies the sensing task; include type of sensing event, sensing area, duration of sensing task, and event transmission frequency. Figure 6 illustrates the operation of directed diffusion. The interest is disseminated throughout the network in a hop-by-hop manner. The query is initiated by the sink node and it broadcasts its interest message periodically to all of its neighbors. An interest cache is maintained by each node. When a node receives an interest, it stores the interest and also sets up a gradient toward the node, from which it received the interest. This process continues until gradients are established from the sources back to the sink. If a respective node has the requested data, which matches the received interest, the node sends back the data packet to the sink in multiple paths according to the gradients. On receiving the data packet at the sink, the reinforcement of the optimal path is initiated by the sink. The criterion for the selecting the optimal path highly depends on the application. It may be the shortest path or minimum energy consuming path, whichever suits the application. The best path is reinforced by the sink sending a new interest to the path.

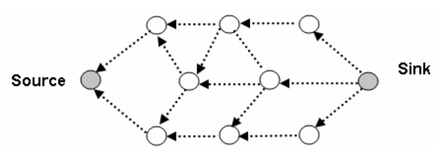


Figure 6 (a) Directed diffusion operation - Diffusing interests

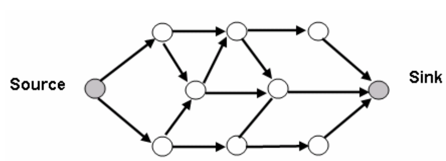


Figure 6 (b) Directed diffusion operation- Setting up gradients

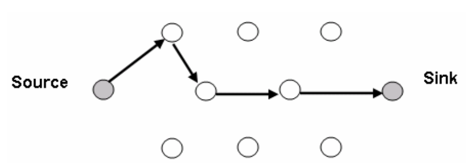


Figure 6 (c) Directed diffusion operation - Path reinforcement

In flooding and SPIN, data collection is initiated by source nodes. In other words, source nodes start transmitting data whenever an event is observed. On the contrary, in directed diffusion data collection is initiated by sink nodes. Because of sink initiated data collection, directed diffusion can limit data flow. By doing so, it will reduce unnecessary data transmissions and thus energy consumption of sensor nodes will be reduced. Such type of information retrieval is appropriate for continual queries where requesting nodes do not anticipate data that fulfill a query for duration of time. Possibility of transmission overhead created by interests creates another disadvantage of using this scheme. When a sink broadcasts an interest, the sink does not know whether the data, which will match the interest, is obtainable or not. If the data is not available at that time, sink node can not collect any data at all. Furthermore, this makes it unsuitable for one-time queries, as it is not worth setting up gradients, which use the path only once. For instance, directed diffusion is not applicable data dissemination scheme for surveillance purpose because sensor nodes have to transmit data as soon as they detect abnormality.

4.4 Rumor Routing

Rumor routing [15] is a data centric scheme proposed for applications where geographic routing is not practically possible. Rumor routing directs the queries to the sensor nodes that have observed a specific event rather than flooding the entire sensor network to extract information about the occurring events. The rumor routing utilizes a set of long-lived agents which create paths that are directed towards the events they encounter. On detecting an event, sensor node adds it to its events table, and generates an agent. Agents travel within the sensor network to disseminate information about local events to distant nodes. When a node generates a query for an event, the nodes that know the route, may reply to the query by inspecting its respective event table. The agent has a lifetime of a specific amount of hops after which it dies. Any node creating a query will transmit the query if it has a route to the event, otherwise it will transmit it in a random direction. If the node discovers that the query did not reach the destination, then it will flood the network. The fewer the number of queries which flood, the less is the energy consumed. Unlike directed diffusion where data can be routed through multiple paths at low rates, rumor routing keeps only one path between source and destination. Simulation results [15] show that rumor routing can handle the node failure and achieve major energy savings when compared to flooding. Rumor routing performs well as long as the number of events is small. For the large number of events, the cost of generating and maintaining the event tables and agents results in a large overhead [7].

4.5 COUGAR

COUGAR [16] is a data- centric protocol and follows the directed diffusion model along the database approach. COUGAR utilizes in-network data aggregation for power saving. There exists an additional query layer between network and application layer. It abstracts the information generated by network in an update-only relational table. The attribute in this relational table is (a) details about the sensor node, for example its location, ID and (b) information collected from respective node (e.g., temperature, light). Sensor applications are often interested in summarized and consolidated data that are produced by aggregated queries rather than detailed data. In addition, sensor nodes choose a leader node to initiate the aggregation and transmit the information to the sink. Sink is liable for generating a query, which specifies the details about the data flow and in-network computation for the incoming query and sends it to the appropriate nodes. In COUGAR, sensor readings are treated like "virtual" relational database tables and a query language like SQL may be used to issue tasks to the WSN. COUGAR has some drawbacks [7]. First, inclusion of query layer on each sensor node puts an extra overhead on the nodes and the entire network in terms of power and memory storage. Second, a high level of synchronization among the sensor nodes is required to achieve the in-network data computation.

4.6 ACQUIRE

ACQUIRE [17] stands for active query forwarding in sensor networks. It is a data-centric, application specific scheme for querying wireless sensor networks. In ACQUIRE an active query is passed through the sensor network. The intermediate sensor nodes use cached local information (within the look ahead of "d" hops) to partially resolve the query. When the query is resolved an entire response is sent directly back to the querying node. For the complex queries, directed diffusion may not be the right choice, because it uses flooding based query mechanism, which would expend energy. ACQUIRE can adjust the look ahead parameter "d" to offer an efficient querying [7]. When d is equal to the network diameter, ACQUIRE performs similar to flooding. If "d" is too small, the query has to travel more hops. ACQUIRE performs better than directed diffusion and the optimal ACQUIRE can lessen the energy consumption by more than 60% as compared to expanding the ring search.

5.0 Conclusions

The sensor networks, jointly with sensing devices, embedded processors, and communication components, uses an appropriate energy-efficient and fast routing strategy to deliver the data to the desired node.To make sensor networks truly advantageous for common applications, they must be reliable, robust, energy efficient and resistive to topology changes. Although the commercially available sensor nodes are very cheap, but designing the infrastructure and application usage cost should be minimal. Collecting data and routing appropriate and needed data to the end user is a challenging issue in such a wireless battery operated small sensor networks. Sensor information is data centric and using traditional network protocols are not always appropriate or sufficient. This paper provides a comprehensive investigation of different routing schemes used in wireless sensor networks. Depending on the sensor applications, the design challenge, advantage and performance concern for each routing protocols is also revealed.

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