FEATURES OF WSN AND VARIOUS ROUTING TECHNIQUES FOR WSN: A SURVEY

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Abstract

A Wireless Sensor Network is the collection of large number of sensor nodes, which are technically or economically feasible and measure the ambient condition in the environment surrounding them. The difference between usual wireless networks and WSNs is that sensors are sensitive to energy consumption. Most of the attention is given to routing protocols, for energy awareness, since they might differ depending on the application and network architecture. Routing techniques for WSN are classified into three categories based on network structure: Flat, hierarchical and location-based routing. Furthermore, these protocols can be classified into multi-path based, query based, negotiation-based, QoS-based, and coherent–based, depending on the protocol operation. In this paper the survey of routing techniques in WSNs is shown. It is also outlined the design challenges and performance metrics for routing protocols in WSNs. Finally We also highlight the advantages and performance issues of different routing techniques by it's comparative analysis. Future-directions for routing in sensor network is also described.

Index Terms: *Wireless sensor network, Routing techniques, Routing challenges and future directions.*

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1. INTRODUCTION

A sensor network is defined as being composed of a large number of nodes with sensing, processing and communication facilities which are deployed either inside the phenomenon or very close to it. Each of these nodes collects data and route this information back to a sink. The network must possess self-organizing capabilities since the positions of individual nodes are not predetermined. Cooperation among nodes is the dominant feature of this type of network, where groups of nodes cooperate to disseminate the information gathered in their vicinity to the user [1] as shown in fig 1. As it is shown here there are several sensor nodes scattered randomly and the data content of individual sensor nodes gets collected in the sink. Then through internet the user can view the data collected by the network. A sensor node is made up of four basic components as shown in the figure a sensing unit, including one or more sensors for data acquisition[12], a processing unit, a transceiver unit and a power unit. They may also have application dependent additional components such as a location finding system, a power generator and a mobilizer. Sensing units are usually composed of two subunits: sensors and analog to digital converters (ADCs). The analog signals produced by the sensors based on the observed phenomenon are converted to digital signals by the ADC, and then fed into the processing unit. The processing unit, which is generally associated with a small storage unit, manages the procedures. A transceiver unit connects the node to the network. One of the most important components of a sensor node is the power unit. Power units may be supported by a power scavenging unit such as solar cells.

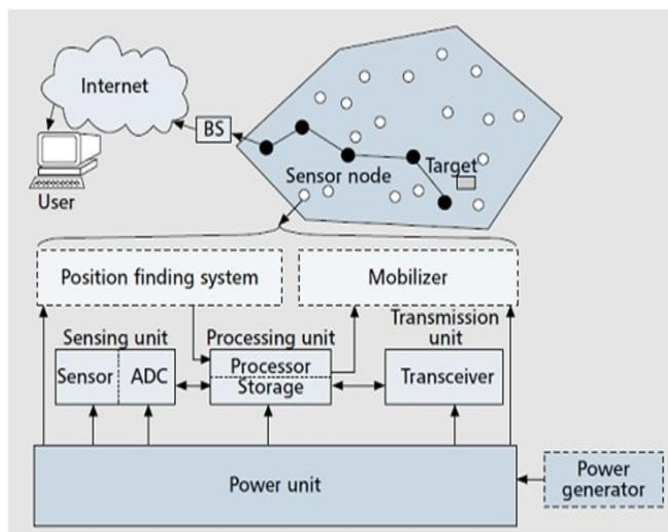

Fig-1: The components of a sensor node [1]

Sensor networks may consist of many different types of sensors such as seismic, low sampling rate magnetic, thermal, visual, infrared, acoustic and radar. Applications of the WSNs include to monitor a wide variety of ambient conditions like temperature, humidity, vehicular movement, lightning condition, pressure, soil makeup, noise levels, In Military for target field imaging, Earth Monitoring, Disaster management. Fire alarm sensors, Sensors planted underground for precision agriculture, intrusion detection and criminal hunting [1][5].

2. ROUTING CHALLENGES AND DESIGN ISSUES IN WSNs

Here is a list of the most common factors affecting the routing protocols design [1][3][7]:

• *Node Deployment:* It is an application-dependent operation affecting the routing protocol performance, and can be either deterministic or randomized.
• *Node/Link Heterogeneity:* The existence of heterogeneous set of sensors gives rise to many technical problems related to data routing and they have to be overcome.
• *Data Reporting Model:* Data sensing, measurement and reporting in WSNs depend on the application and the time criticality of the data reporting. Data reporting can be categorized as either time-driven (continuous), event driven, query-driven, and hybrid.
• *Energy Consumption Without Losing Accuracy:* Sensor nodes can use up their limited supply of energy to perform computations and to transmit information. Sensor node lifetime shows a strong dependence on battery lifetime [1].

The malfunctioning of some sensor nodes due to power failure can cause significant topological changes.
• *Scalability:*. WSNs routing protocols should be scalable enough to respond to events like huge increase of sensor nodes, in the environment
• *Network Dynamics:* Mobility of sensor nodes is necessary in many applications, like moving target monitoring.
• *Transmission Media:* In a multi-hop WSN, communicating nodes are linked by a wireless medium. One approach of MAC design for sensor networks is to use TDMA based protocols that conserve more energy compared to contention-based protocols like CSMA.
• *Coverage:* In WSNs, a given sensor's view of the environment is limited both in range and in accuracy; it can only cover a limited physical area of the environment.
• *Quality of Service:* Data should be delivered within a certain period of time. However, in a good number of applications, conservation of energy, which is directly related to network lifetime, is considered relatively more important than the quality of data sent. Hence, energy aware routing protocols are required to capture this requirement.
• *Data Aggregation:* Data aggregation is the combination of data from different sources according to a certain aggregation function, e.g. duplicate suppression.

2.1 Performance Metrics Of Routing In WSNs

The performance of the network is then measured based on quantifiable parameters called performance metrics [2][3][13]
•*Network Lifetime:* Network lifetime is defined as the number of data aggregation rounds till x % of sensors die where x is specified by the system designer. For instance, in applications where the time that all nodes operate together is vital, lifetime is defined as the number of rounds until the first sensor is drained of its energy.
•*Data accuracy:* The definition of data accuracy depends on the specific application for which the sensor network is designed. For instance, in a target localization problem, the estimate of target location at the sink determines the data accuracy.
• *Latency:* Latency is defined as the delay involved in data transmission, routing and data aggregation. It can be measured as the time delay between the data packets received at the sink and the data generated at the source nodes.
•*Average Energy Dissipated:* This metric shows the average dissipation of energy per node over time in the network.
•*Total Number of Nodes Alive:* This metric is also related to the network lifetime. It gives an idea of the area coverage of the network over time.
•*Bandwidth, Capacity and Throughput:* These indicate the capacity of data which can be sent over a link within a given time, however since the data size is very small bandwidth rarely matters.
•*Hop Count:* No of hop in communication determine the cost of path, and eventually the energy consumed in the process.

3. ROUTING PROTOCOLS BASED ON NETWORK STRUCTURE

In this section we survey the routing protocols for WSNs. In general, routing in WSNs can be divided into *flat-based* routing (*data-centric* routing), *hierarchical-based* routing, and *location-based* routing depending on the network structure.(fig. 2) In flat-based routing, all nodes are typically assigned equal roles or functionality. In hierarchical-based routing, nodes will play different roles in the network. In location-based routing, sensor nodes' positions are exploited to route data in the network. Furthermore, these protocols can be classified into *multipath-based*, *query-based*, and *negotiation-based*, *QoS-based*, or *coherent-based* routing techniques depending on the protocol operation[2][14]. Routing protocols can be classified into three categories, proactive, reactive, and hybrid, 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 reactive protocols. A significant amount of energy is used in route discovery and setup of reactive protocols[1]. Another class of routing protocols is called *cooperative*. 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.

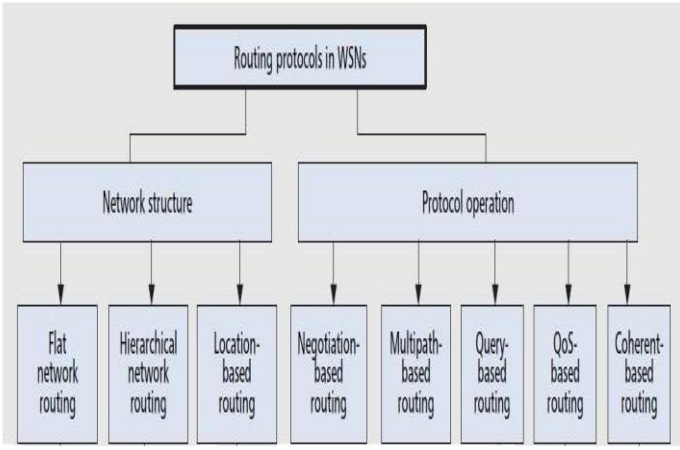

Fig- 2: Routing protocols in WSN [1]

3.1 Data-Centric Protocols

In data-centric routing, the sink 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. SPIN is the first data-centric protocol, which considers data negotiation between nodes in order to eliminate redundant data and save energy [5]. Later, Directed Diffusion has been developed . Then, many other protocols have been proposed either based on Directed Diffusion or following a similar concept [7]. This section describes these protocols in details.

1)Sensor Protocols for Information via Negotiation (SPIN) : The idea behind SPIN is to name the data using high level descriptors or meta-data. Before transmission, meta-data are exchanged among sensors via a data advertisement mechanism, which is the key feature of SPIN. Each node upon receiving new data, advertises it to its neighbors and interested neighbors, means those who do not have the data, retrieve the data by sending a request message. SPIN's meta-data negotiation solves the classic problems of flooding such as redundant information passing, overlapping of sensing areas and resource blindness thus, achieving a lot of energy efficiency. There is no standard meta-data format and it is assumed to be application specific. There are three messages defined in SPIN to exchange data between nodes. These are: ADV message to allow a sensor to advertise a particular meta-data, REQ message to request the specific data and DATA message that carry the actual data. Details of it can be studied from [5] .In SPIN, topological changes are localized since each node needs to know only its single-hop neighbors. SPIN is not used for applications such as intrusion detection, which require reliable delivery of data packets over regular intervals.

2) Directed Diffusion(DD): DD is an important milestone in the data-centric routing research of sensor networks. The idea aims at diffusing data through sensor nodes by using a naming scheme for the data. DD suggests the use of attribute-value pairs for the data and queries the sensors in an on demand basis by using those pairs. In order to create a query, an interest is defined using a list of attribute-value pairs such as name of objects, interval, duration, geographical area, etc. The interest is broadcast by a sink through its neighbors. Each node receiving the interest can do caching for later use. The nodes also have the ability to do in-network data aggregation. The interests in the caches are then used to compare the received data with the values in the interests. The interest entry also contains several gradient fields. A gradient is a reply link to a neighbor from which the interest was received. Hence, by utilizing interest and gradients, paths are established between sink and sources. Several paths can be established so that one of them is selected by reinforcement. DD is highly energy efficient since it is on demand and there is no need for maintaining global network topology. However, DD can not be applied to all sensor network applications since it is based on a query-driven data delivery model[1].Details of DD can be studied from [5].

3) Rumor Routing (RR): RR is a compromise between flooding queries and flooding event notifications. The main idea of this protocol is to create paths that lead to each event , unlike event flooding which creates a network-wide gradient field. Thus, in case that a query is generated it can be then sent on a random walk until it finds the event path, instead of flooding it throughout the network. As soon as the event path is discovered it can be further routed directly to the event. On the other hand, if the path cannot be found, the application can try re-submitting the query or flooding it. The RR can be a good method for delivering queries to events in large networks [3].

3.2 Hierarchical Protocols

The main aim of hierarchical routing is to efficiently maintain the energy consumption of sensor nodes by involving them in multi-hop communication within a particular cluster. Here data aggregation and fusion is performed in order to decrease the number of transmitted messages to the sink. Here all nodes get a chance to become cluster head for the cluster period[15]. Cluster formation is typically based on the residual energy of sensors and sensor's proximity to the cluster head . LEACH is one of the widely used hierarchical routing protocol for sensors networks. We explore hierarchical routing protocols in this section.

1) Low-Energy Adaptive Clustering Hierarchy (LEACH) : It is one of the most popular hierarchical routing algorithm. The idea is to form clusters of the sensor nodes based on the received signal strength and use local cluster heads(CHs) as routers to the sink. This will save energy since the transmissions will only be done by CHs rather than all sensor nodes. Optimal number of CHs is estimated to be 5% of the total number of nodes[1]. All the data processing such as data

fusion and aggregation are local to the cluster. CHs change randomly over time in order to balance the energy dissipation of nodes. This decision is made by the node by choosing a random number between 0 and 1. The node becomes a CH for the current round if the number is less than the following threshold:

$$T(n) = \frac{p}{(1-p)(r \bmod \frac{1}{p})} \quad n \in G$$

$$T(n) = 0 \quad \text{otherwise}$$

Where p is the desired percentage of CHs , r is = the current round, and G is the set of nodes that have not been selected as cluster heads in the last 1/p rounds[1]. LEACH achieves over a factor of 7 reduction in energy dissipation compared to direct communication and a factor of 4-8 compared to the minimum transmission energy routing protocol[8]. The nodes die randomly and dynamic clustering increases lifetime of the system.

2) Power-Efficient GAthering in Sensor Information Systems (PEGASIS):It is an improvement of the LEACH protocol. Rather than forming multiple clusters, PEGASIS 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). Gathered data moves from node to node, aggregated and eventually sent to the base station. The chain construction is performed in a greedy way, as shown in Fig. 3.

n0→n1→n2←n3←n4
↓
BS

Fig. 3: chaining in PEGASIS

PEGASIS has been shown to outperform LEACH by about 100 to 300% for different network sizes and topologies[5]. However, PEGASIS introduces excessive delay for distant node on the chain. Hierarchical-PEGASIS solves this problem

3)Threshold sensitive Energy Efficient sensor Network protocol (TEEN): It is a hierarchical protocol designed to be responsive to sudden changes in the sensed attributes such as temperature. The sensor network architecture is based on a hierarchical grouping where closer nodes form clusters and this process goes on the second level until base station is reached. The model is depicted in Fig. 4

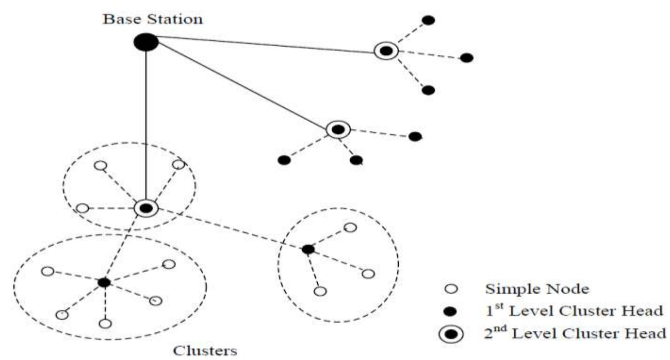

Fig- 4: Hierarchical clustering in TEEN and APTEEN [5]

After the clusters are formed, the cluster head broadcasts two thresholds to the nodes. These are hard and soft thresholds for sensed attributes. Based on these threshold values , It gives accurate data[15].However, TEEN is not good for applications where periodic reports are needed since the user may not get any data at all if the thresholds are not reached[5]. The Adaptive Threshold sensitive Energy Efficient sensor Network protocol (APTEEN) is an extension to TEEN and aims at both capturing periodic data collections and reacting to time-critical events [9] [15].

3.3 Location-Based Protocols

In this section, location-based protocols for WSNs, is presented. They are based on two principal assumptions [3]:

• It is assumed that every node knows its own network neighbors positions.
• The source of a message is assumed to be informed about the position of the destination.

1)Distance Routing Effect Algorithm for Mobility (DREAM): It is a proactive protocol and each Mobile Node (MN) maintains a location table for all other nodes in the network[3]. To maintain the table, each MN transmits location packets to nearby MNs in the sensor network at a given frequency and to far away MNs in the sensor network at another lower frequency. Since far away MNs appear to move more slowly than nearby MNs, it is not necessary for a MN to maintain up-to-date location information for far away MNs. Thus, by differentiating between nearby and far away MNs, DREAM attempts to limit the overhead of location packets.

2) Geographic and Energy Aware Routing (GEAR): Unlike previous geographic routing protocols, GEAR does not use greedy algorithms to forward the packet to the destination [10]. Thus, it differs in how they handle communication holes. The GEAR uses energy aware and geographically informed neighbor selection heuristics to route a packet towards the target region. Two main characteristics of this protocol are :

• When a closer neighbor to the destination exists GEAR picks a next-hop node among all neighbors that are closer to the destination.
• When all neighbors are further away, there is a hole. GEAR picks a next-hop node that minimizes some cost value. The main advantage of the GEAR is that each node knows its own location and remaining energy level, and its neighbors locations and remaining energy levels through a simple neighbor hello protocol. Also it attempts to balance energy consumption and thereby increase network lifetime.

3) Minimum Energy Relay Routing (MERR) - Location: It is based on the idea that the distance between two nodes that transmit data is very important [11]. This distance is closely related to the energy consumed on the entire path, from the source to the base station, Thus, in MERR each sensor seeks locally for the downstream node within its maximum transmission range whose distance is closest to the characteristic distance. As soon as a sensor has decided to use the next hop, it adjusts its transmission power to the lowest possible level such that the radio signal can just be received by the respective node. This can minimize the energy consumption. If the distances between each pair of sensors are all greater than the characteristic distance, each sensor will select its direct downstream neighbor as the next hop node. The MERR works well when the sensors are deployed over a linear topology and sends data to a single control center. Whereas, minimizing transmit energy means that it chooses the nearest neighbor as router. So, a large amount of energy is wasted in case that the nodes happen to be very close to each other.

ROUTING PROTOCOLS BASED ON PROTOCOL OPERATION

In this section we review routing protocols with different routing functionality. It should be noted that some of these protocols may fall under one or more of the above routing categories [1].
1)Multipath Routing Protocols--- It includes the algorithms that routes the data through a path whose nodes have the largest residual energy. The path is changed whenever a better path is discovered. DD is this kind of protocol [5].
2) Query-Based Routing — Here, the destination nodes propagate a query for data from a node through the network, and a node with this data sends the data that matches the query back to the node that initiated the query. Usually queries are described in natural language or high-level query languages. DD and RR protocol are examples of this type of routing.
3) Negotiation-Based Routing Protocols — These protocols use high-level data descriptors to eliminate redundant data transmissions through negotiation. The SPIN protocols are examples of negotiation-based routing protocols.
4) QoS-based Routing — Here, the network has to balance between energy consumption and data quality. The network has to satisfy certain QoS metrics (delay, energy, bandwidth, etc.) when delivering data to the BS. Sequential Assignment Routing (SAR) and SPEED are this type of protocols.
5) Coherent and Noncoherent Processing —These are data-processing based routing. In noncoherent data processing routing, nodes will locally process the raw data before it is sent to other nodes for further processing. In coherent routing, the data is forwarded to aggregators after minimum processing like time stamping and duplicate suppression. To perform energy-efficient routing, coherent processing is normally selected. Single Winner Algorithm (SWE) and Multiple Winner Algorithm are the examples of non-coherent and coherent data processing, respectively.

5. FUTURE DIRECTIONS OF ROUTING IN WSN

Future trends in routing techniques in WSNs focus on different directions, all share the common objective of prolonging the network lifetime. We summarize some of these directions as follows [4]:

A. Tiered architectures (mix of form/energy factors):
Hierarchical routing is an old technique to enhance scalability and efficiency of the routing protocol. However, novel techniques to network clustering which maximize the network lifetime are also a hot area of research in WSNs [1].
B. Time and location synchronization
Energy-efficient techniques for associating time and spatial coordinates with data to support collaborative processing are also required.
C. Self-configuration and reconfiguration are essential to the lifetime of unattended systems in a dynamic and energy constrained environment. This is important for keeping the network up and running.
D. Localization: Sensor nodes are randomly deployed into an unplanned infrastructure. The problem of estimating spatial coordinates of the node is referred to as localization. GPS cannot be used in WSNs as GPS receivers are expensive. Hence, there is a need to develop other means of establishing a coordinate system.
E. Exploit spatial diversity and density of sensor/actuator nodes: Nodes will span a network area that might be large enough to provide spatial communication between sensor nodes. Achieving energy-efficient communication in this densely populated environment deserves further investigation.
F. Secure routing: protocols have not been designed with security as a goal, it is important to analyze their security properties. One aspect of sensor networks that complicates the design of a secure routing protocol is in-network aggregation[1][4].

6. COMPARATIVE ANALYSIS

Comparative analysis of certain techniques has been shown in the following Table-I, II and III.

Table-1: Comparison of Data-Centric Routing Schemes

Name of the Protocol	Route Metric	Mobility	Advantages	Disadvantage/Issues
SPIN	Each node sends data to its single hop neighbors	Yes	simplicity, implosion avoidance and the minimal start up cost	It does not guaranty the delivery of the data and consumes unnecessary power
DD	The Best Path	Limited	It extends the network lifetime	It can't be used for Continuous Data delivery or event driven applications
RR	Shortest Path	Low	It is able to handle node failure gracefully, degrading its delivery rate linearly with the number of failed nodes	It may deliver duplicated messages to the same node

Table-2: Comparison of Hierarchical Routing Schemes

Name of the Protocol	Route Metric	Mobility	Advantages	Disadvantage/Issues
LEACH	Shortest Path	Fixed BS	(1) Low energy, distributed dynamic clustering protocol so increases network lifetime (2) it achieves over a factor of 7and 4-8 reduction in energy dissipation compared to direct communication and MTE routing protocol	(1) It is not applicable to networks deployed in large regions and the dynamic clustering brings extra overhead (2) The CHs are randomly selected and CHs in the network are not uniformly distributed (3)All nodes have same initial energy Including CH.
PEGASIS	Greed route selection	Fixed BS	The transmitting distance for most of the node is reduced	Base station's location and the energy of nodes are not considered when one of the nodes is selected as the head node
TEEN	The best route	Fixed BS	(1)It works well in the conditions like sudden changes in the sensed attributes such as temperature (2) TEEN is better than LEACH and APTEEN because it reduces number of transmissions.	(1) A lot of energy consumption and overhead in case of large network (2) overhead with forming clusters at multiple levels
APTEEN	The best route	Fixed BS	Low energy consumption	(1)Long delay (2) overhead with forming clusters at multiple levels

Table-3: Comparison of Location-based Routing Schemes

Name of the Protocol	Route Metric	Mobility	Advantages	Disadvantage/Issues
DREAM	The Path that minimize total power consumption	Good	Efficient data packet transmission	The waste of network bandwidth due to differentiating between nearby and far away MNs
GEAR	The best route	Limited	It attempts to balance energy consumption and thereby increases the network lifetime	The periodic table exchange
MERR	The Path that minimize total power consumption	Low	It distributes the energy consumption of the sensors uniformly to the network sensors	It chooses the nearest neighbor as router. Thus, a large amount of energy is wasted in case that the nodes happen to be very close to each other.

CONCLUSIONS

Routing in sensor networks is an emerging area of research. In this paper we present a comprehensive survey of routing techniques in wireless sensor networks .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, and QoS-based routing techniques depending on protocol operation. Comparative analysis of different protocols is also shown here and the design challenges and future directions for routing in sensor network is also described.

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