Design Issues, Characteristics and Challenges in Routing Protocols for Wireless Sensor Networks

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ABSTRACT
The modern research has found a variety of applications and systems with vastly varying requirements and characteristics in Wireless Sensor Networks (WSNs). The research has led to materialization of many application specific routing protocols which must be energy-efficient. As a consequence, it is becoming increasingly difficult to discuss the design issues requirements regarding hardware and software support. Implementation of efficient system in a multidisciplinary research such as WSNs is becoming very difficult.
In this paper we discuss the design issues in routing protocols for WSNs by considering its various dimensions and metrics such as QoS requirement, path redundancy etc. The paper concludes by presenting the suitable applications and QoS of routing protocols for WSNs.

General Terms
Applications, Design issues, Routing protocols

Keywords
WSN, MANET, Metrics, QoS, routing protocol

1. INTRODUCTION
Now-a-days, Wireless Communication technology is one of the key technologies for enabling the normal operation of a Wireless Sensor Network (WSN). It has been extensively studied for conventional wireless networks in the last couple of decades and significant advances have been obtained in various aspects of wireless communication. At the physical layer, a variety of modulation, synchronization, and antenna techniques have been designed for different network scenarios and applications. Where as, at higher layers, efficient communication protocols have been developed to address various networking issues, for example medium access control, routing QoS, and network security. These communication techniques and protocols provide a rich technological background for the design of wireless communication in WSNs.
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WSN can be distinguished from traditional wireless communication networks, for example, cellular systems and mobile ad hoc networks (MANET) and have unique characteristics such as densely deployment of node, higher unreliability of sensor nodes, and severe energy, computation, and storage constraints [3][7], which present many new challenges in the development and applications of WSNs.
WSN is an emerging technology that promises a wide range of potential applications in both civilian and military areas. The development of WSNs largely depends on the availability of low-cost and low-power hardware and software platforms for sensor networks. With the micro-electro-mechanical system (MEMS) technology, the size and cost of a sensor node have been significantly reduced. On the other hand, energy efficiency can significantly be enhanced if energy awareness is incorporated in the design of system software, including the operating system, and application and network protocols. System lifetime can considerably be prolonged by incorporation energy awareness into task scheduling process [6].
Today, research has been carried out by the researchers and the research institutions to investigate and overcome the limitations of WSNs and solve the challenges in the design and application issues. In this paper various routing protocols for WSN have been discussed and compared by considering the performance metrics. The paper is organized as follows. In section 2 and section 3, we discuss design objectives and design issues in WSNs. A comprehensive survey of routing protocols for sensor networks is presented in Section 4. Applications & selections of protocols are described in section 5 and section 6. In section 7, a summary of future research directions on routing in sensor networks is discussed. Finally, we presented conclusions in section 8.

2. WSN Design Objectives:
Most sensor networks are application specific and have different application requirements. Thus, all or part of the following main design objectives is considered in the design of sensor networks [11]:

2.1 Small node size:
Since sensor nodes are usually deployed in a harsh or hostile environment in large numbers, reducing node size can facilitate node deployment. It will also reduce the power consumption and cost of sensor nodes.

2.2 Low node cost:
Since sensor nodes are usually deployed in a harsh or hostile environment in large numbers and cannot be reused, reducing cost of sensor nodes is important and will result into the cost reduction of whole network.

2.3 Low power consumption:
Since sensor nodes are powered by battery and it is often very difficult or even impossible to charge or recharge their batteries, it is crucial to reduce the power consumption of sensor nodes so that the lifetime of the sensor nodes, as well as the whole network is prolonged.

2.4 Scalability:
Since the number sensor nodes in sensor networks are in the order of tens, hundreds, or thousands, network protocols designed for sensor networks should be scalable to different network sizes.

2.5 Reliability:
Network protocols designed for sensor networks must provide error control and correction mechanisms to ensure reliable data delivery over noisy, error-prone, and time-varying wireless channels.

2.6 Self-configurability:
In sensor networks, once deployed, sensor nodes should be able to autonomously organize themselves into a communication network and reconfigure their connectivity in the event of topology changes and node failures.

2.7 Adaptability:
In sensor networks, a node may fail, join, or move, which would result in changes in node density and network topology. Thus, network protocols designed for sensor networks should be adaptive to such density and topology changes.

2.8 Channel utilization:
Since sensor networks have limited bandwidth resources, communication protocols designed for sensor networks should efficiently make use of the bandwidth to improve channel utilization. *Fault tolerance:* Sensor nodes are prone to failures due to harsh deployment environments and unattended operations. Thus, sensor nodes should be fault tolerant and have the abilities of self testing, self-calibrating, self-repairing, and self-recovering.

2.9 Security:
A sensor network should introduce effective security mechanisms to prevent the data information in the network or a sensor node from unauthorized access or malicious attacks.

2.10 QoS support:
In sensor networks, different applications may have different quality-of-service (QoS) requirements in terms of delivery latency and packet loss. Thus, network protocol design should consider the QoS requirements of specific applications.

3. WSN DESIGN & ROUTING ISSUES
Due to various wireless network constraints, the design of routing protocols is very challenging for WSNs. There are several network design issues for WSNs, such as, energy, bandwidth, central processing unit, and storage [5][8].
The design challenges in sensor networks involve the following main aspects [5][7][8]:

3.1 Limited energy capacity:
Since sensor nodes are battery powered, they have limited energy capacity. Energy poses a big challenge for network designers in hostile environments. Furthermore, when the energy of a sensor reaches a certain threshold, the sensor will become faulty and will not be able to function properly, which will have a major impact on the network performance.

3.2 Sensor locations:
Another challenge that faces the design of routing protocols is to manage the locations of the sensors. Most of the proposed protocols assume that the sensors either are equipped with global positioning system (GPS) receivers or use some localization technique [3] to learn about their locations.

3.3 Limited hardware resources:
Sensor nodes have also limited processing and storage capacities, and thus can only perform limited computational functionalities. These hardware constraints present many challenges in software development and network protocol design for sensor networks.

3.4 Massive and random node deployment:
Sensor node deployment in WSNs is application dependent and can be either manual or random which finally affects the performance of the routing protocol. In most applications, sensor nodes can be scattered randomly in an intended area or dropped massively over an inaccessible or hostile region.

3.5 Network characteristics and unreliable environment:
A sensor network usually operates in a dynamic and unreliable environment. The topology of a network, which is defined by the sensors and the communication links between the sensors, changes frequently due to sensor addition, deletion, node failures, damages, or energy depletion. Also, the sensor nodes are linked by a wireless medium, which is noisy, error prone, and time varying. Therefore, routing paths should consider network topology dynamics due to limited energy and sensor mobility as well as increasing the size of the network to maintain specific application requirements in terms of coverage and connectivity.

3.6 Data Aggregation:
Since sensor nodes may generate significant redundant data, similar packets from multiple nodes can be aggregated so that the number of transmissions is reduced. Data aggregation technique has been used to achieve energy efficiency and data transfer optimization in a number of routing protocols.

3.7 Diverse sensing application requirements:
Sensor networks have a wide range of diverse applications. No network protocol can meet the requirements of all applications. Therefore, the r outing protocols should guarantee data delivery and its accuracy so that the sink can gather the required knowledge about the physical phenomenon on time.

3.8 Scalability:
Routing protocols should be able to scale with the network size. Also, sensors may not necessarily have the same capabilities in terms of energy, processing, sensing, and particularly communication. Hence, communication links between sensors may not be symmetric, that is, a pair of sensors may not be able to have communication in both directions. This should be taken care of in the routing protocols.

4. ROUTING PROTOCOLS FOR WSN

In many ways the routing in WSNs differs from the routing in fixed sensor networks. There is no infrastructure, wireless links are unreliable, sensor nodes may fail, and routing protocols have to meet strict energy saving requirements [7]. For WSNs, different routing algorithms were developed. The major routing protocols proposed for WSNs may be divided into four categories as shown in Fig 1.

4.1 Data Centric Protocols

In *address-centric* protocols, each source sensor that has the appropriate data responds by sending its data to the sink independently of all other sensors. When the source sensors send their data to the sink, intermediate sensors can perform some form of aggregation on the data originating from multiple source sensors and send the aggregated data toward the sink. This process can result in energy savings because of less transmission required to send the data from the sources to the sink.

4.1.1 Sensor Protocols for Information via Negotiation (SPIN):

The SPIN [17] protocols are resource aware and resource adaptive. The sensors running the SPIN protocols are able to compute the energy consumption required to compute, send, and receive data over the network. Thus, they can make informed decisions for efficient use of their own resources. The SPIN protocols are based on two key mechanisms namely *negotiation* and *resource adaptation.* SPIN enables the sensors to negotiate with each other before any data dissemination can occur in order to avoid injecting non-useful and redundant information in the network.

4.1.2 Constrained Anisotropic Diffusion Routing (CADR): This routing techniques, is proposed in [9]. CADR aims to be a general form of directed diffusion. The key idea is to query sensors and route data in the network such thattheinformationgainismaximizedwhilelatencyandbandwidth areminimized.CADRdiffusesqueriesbyusingasetofinformation criteriatoselectwhichsensorscangetthedata. In CADR, each node evaluates an information/cost objective and routes data based on the local information/cost gradient and end-user requirements. Estimation theory was used to model information utility measure.

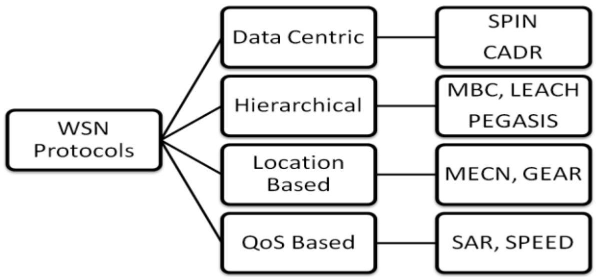

Fig 1: Categories of WSN routing protocols

4.2 Hierarchical Protocols

Last few years many researchers have explored hierarchical clustering in WSN from different perspectives [11]. Clustering is an energy-efficient communication protocol that can be used by the sensors to report their sensed data to the sink.

4.2.1 Mobility-Based Clustering (MBC):

The protocol takes an estimated connection time to build a more reliable path depending on the stability or availability of each link between a non-cluster-head sensor node and a cluster head node. In the MBC protocol, a node elects itself as a cluster head based not only on its residual energy but also on its mobility in order to achieve balanced energy consumption among all nodes and thus longer lifetime of the network. During clustering, a non-cluster-head node takes into account its connection time with and the distance from a cluster head, and the residual energy and node degree of the cluster head, which can guarantee a stable link with a cluster head and thus increase the successful packet delivery rate, and reduce the control overhead and energy consumption because of the less frequent membership changes [2].

*4.2.2 Low-*Energy *A*daptive *C*lustering *H*ierarchy *(LEACH):* The first and most popular energy-efficient hierarchical clustering algorithm for WSNs that was proposed for reducing power consumption. In LEACH [15][16], the clustering task is rotated among the nodes, based on duration. Direct communication is used by each cluster head (CH) to forward the data to the base station (BS). It uses clusters to prolong the life of the wireless sensor network. LEACH is based on an aggregation (or fusion) technique that combines or aggregates the original data into a smaller size of data that carry only meaningful information to all individual sensors. The operation of LEACH is divided into rounds having two phases each namely (i) a setup phase to organize the network into clusters, CH advertisement, and transmission schedule creation and (ii) a steady-state phase for data aggregation, compression, and transmission to the sink.

4.2.3 Power-Efficient Gathering in Sensor Information Systems (PEGASIS): PEGASIS [12] is an extension of the LEACH protocol, which forms chains from sensor nodes so that each node transmits and receives from a neighbor and only one node is selected from that chain to transmit to the base station (sink). The data is gathered and moves from node to node, aggregated and eventually sent to the base station. The chain construction is performed in a greedy way. Unlike LEACH, PEGASIS avoids cluster formation and uses only one node in a chain to transmit to the BS (sink) instead of using multiple nodes. A sensor transmits to its local neighbors in the data fusion phase instead of sending directly to its CH as in the case of LEACH. PEGASIS routing protocol, the construction phase assumes that all the sensors have global knowledge about the network, particularly, the positions of the sensors, and use a greedy approach. When a sensor fails or dies due to low battery power, the chain is constructed using the same greedy approach by bypassing the failed sensor. In each round, a randomly chosen sensor node from the chain will transmit the aggregated data to the BS, thus reducing the per round energy expenditure compared to LEACH.

4.3 Location-based Protocols

Sensor nodes are addressed by means of their locations. Location information for sensor nodes is required for sensor networks by most of the routing protocols to calculate the distance between two particular nodes so that energy consumption can be estimated.

4.3.1 Minimum Energy Communication Network (MECN): MECN [14] is a location-based protocol for achieving minimum energy for randomly deployed ad hoc networks, which attempts to set up and maintain a minimum energy network with mobile sensors. It is self-reconfiguring protocol that maintains network connectivity in spite of sensor mobility. It computes an optimal spanning tree rooted at the sink, called minimum power topology, which contains only the minimum power paths from ach sensor to the sink. It is based on the positions of sensors on the plane and consists of two main phases, namely, enclosure graph construction and cost distribution. For a stationary network, in the first phase (enclosure graph construction), MECN constructs a sparse graph, called an enclosure graph, based on the immediate locality of the sensors. An enclosure graph is a directed graph that includes all the sensors as its vertex set and whose edge set is the union of all edges between the sensors and the neighbors located in their enclosure regions. In other words, a sensor will not consider the sensors located in its relay regions as potential candidate forwarders of its sensed data to the sink. In the second phase (cost distribution), non-optimal links of the enclosure graph are simply eliminated and the resulting graph is a minimum power topology.

4.3.2 Geographic and Energy-Aware Routing (GEAR): GEAR is an energy-efficient routing protocol proposed for routing queries to target regions in a sensor field, In GEAR, the sensors are supposed to have localization hardware equipped, for example, a GPS unit or a localization system [10] so that they know their current positions. Furthermore, the sensors are aware of their residual energy as well as the locations and residual energy of each of their neighbors. GEAR uses energy aware heuristics that are based on geographical information to select sensors to route a packet toward its destination region. Then, GEAR uses a recursive geographic forwarding algorithm to disseminate the packet inside the target region.

4.4 QoS-based Protocols

In addition to minimizing energy consumption, it is also important to consider quality of service (QoS) requirements in terms of delay, reliability, and fault tolerance in routing in WSNs. In this section, we review a sample QoS based routing protocols that help find a balance between energy consumption and QoS requirements.

4.4.1 Sequential Assignment Routing (SAR): SAR [4] is one of the first routing protocols for WSNs that introduces the notion of QoS in the routing decisions. It is a table-driven multi-path approach striving to achieve energy efficiency and fault tolerance. Routing decision in SAR is dependent on three factors: energy resources, QoS on each path, and the priority level of each packet [5][8][13]. The SAR protocol creates trees rooted at one-hop neighbors of the sink by taking QoS metric, energy resource on each path and priority level of each packet into consideration. By using created trees, multiple paths from sink to sensors are formed. One of these paths is selected according to the energy resources and QoS on the path. Failure recovery is done by enforcing routing table consistency between upstream and downstream nodes on each path. Any local failure causes an automatic path restoration procedure locally. The objective of SAR algorithm is to minimize the average weighted QoS metric throughout the lifetime of the network. If topology changes due to node failures, a path re-computation is needed. A handshake procedure based on a local path restoration scheme between neighboring nodes is used to recover from a failure. Failure recovery is done by enforcing routing table consistency between upstream and downstream nodes on each path.

4.4.2 SPEED: SPEED [13] 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 neighbors 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 Non-deterministic Forwarding Geographic (SNFG) and works with four other modules at the network layer. 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.

There are different ways in which the routing protocols of WSNs can be classified and compared. Table 1 gives classification and comparison respectively of major routing protocols for WSNs.

5. APPLICATIONS OF WSN

WSNs [4][7] have fascinated the research community in recent years and a vast amount of research work has been conducted to solve the practical and theoretical issues. This has resulted in a surge of civil and military applications over the last few years. Today, most deployed WSNs measure scalar physical phenomenon line temperature, pressure, humidity, or location of objects. Most sensor networks are designed for delay-tolerant and low-bandwidth applications. For this reason research on sensor networks has focused on the low-power and delay-tolerant network paradigm, which is referred as terrestrial sensor networks.

WSNs were originally motivated by military applications, which range from large-scale acoustic surveillance systems for ocean surveillance to small networks of unattended ground sensors for ground target detection [1]. However, the availability of low -cost sensors and wireless communication has promised the development of a wide range of applications in both civilian and military fields. In this section, we introduce a few examples of sensor network applications. Applications of WSN [7] are summarized in Table 2.

In addition to the above applications, self configurable WSNs can be used in many other application areas, for example, disaster relief, traffic control, warehouse management, and civil engineering.

Table 1: Comparison of WSN routing protocols

Protocol	Category	Mobility	Power Usage	Scalability	Over-heads	Traffic	QoS
SPIN	Data Centric	Possible	Limited	Limited	Low	Low	Low
CADR		No	Limited	Limited	Low	Moderate	Low
MBC	Hierarchical	Possible	Limited	Good	Low	Low	Low
LEACH		Fixed	Maximum	Good	High	High	Low
PEGASIS		Fixed	Maximum	Good	Low	Low	Low
MECN	Location Based	No	Maximum	Low	Moderate	Low	Low
GEAR		Limited	Limited	Limited	Moderate	Moderate	Low
SAR	QoS Based	No	High	Limited	High	High	High
SPEED		No	Low	Limited	Low	High	High

Table 2: Applications of WSN

Area	Purpose	Applications
Environmental Monitoring	Monitoring environmental parameters or conditions	1) Habitat monitoring 2) Air or water quality monitoring 3) Hazard monitoring 4) Disaster monitoring
Military Applications	Military command, control communication and intelligence (C3I) system [4]	1) Battlefield monitoring 2) Object protection 3) Intelligent guiding 4) Remote sensing
Health Care Applications	To monitor and track elders and patients for health care purposes.	1) Behavior monitoring 2) Medical monitoring
Industrial Process Control	Monitoring manufacturing processes and conditions for	1) Monitoring and control of production processes

	reducing maintenance cost, and increasing machine lifetime.	2) Condition monitoring
Security and Surveillance	For surveillance of buildings.	Identifying and tracking intruders
Home Networks	To provide more convenient and intelligent living environments.	1) Smart home 2) Remote monitoring

6. ROUTING PROTOCOL SELECTION FOR WSNs BASED ON APPLICATION

There are various routing protocols proposed for WSNs. Different applications require different types of routing protocols having different grades of reliability. However, routing protocols in WSNs should be energy-efficient, functionally distributed to use resources effectively, and should provide reliability differentiation to support different reliability grades in order to suit the requirements of applications regarding throughput, latency and energy consumption. Table 3 present selection of routing protocols in WSNs based on the applications [12][14][15].

Table 3: Selection of protocol based on applications & QoS

Applications	Routing Protocol	QoS
Environmental Monitoring	PEGASIS	Low
Military Applications	SPEED, LEACH	High, Low
Health Care Applications	SAR	High
Industrial Process Control	SAR	High
Security and Surveillance	SPIN	Low
Home Networks	GEAR	Low

7. FUTURE DIRECTIONS

Even though efforts have been put in so far on the routing problem in WSNs, there are still some challenges that need to be addressed for the effective solutions of the routing problem.

First, majority of the wireless applications uses sensor nodes in the real world. For remote applications sensors are embedded. This is different from traditional Internet, PDA, and mobility applications that interface primarily and directly with human users.

Second, sensors are characterized by a small footprint, and as such nodes present stringent energy constraints since they are equipped with small, finite, energy source. This is also different from traditional fixed but reusable resources. Third, communications is primary consumer of energy in this environment where sending a bit over 10 or 100 meters consumes as much energy as thousands-to-millions of operations

Although the performance of these protocols is promising in terms of energy efficiency, further research would be needed to address issues such as Quality of Service (QoS) posed by real-time applications. Energy aware QoS routing in sensor networks will ensure guaranteed bandwidth through the duration of connection as well as providing the use of most energy efficient path. New routing algorithms are needed in order to handle the overhead of mobility and topology changes in energy constrained environments. Future trends in routing techniques in WSNs focus on different directions, all share the common objective of prolonging the network life time, QoS, and network overhead.

8. CONCLUSION

Routing in wireless sensor networks is an area of research, with a limited, but rapidly growing set of research results. In this paper, we presented a survey of some of the important routing techniques for sensor networks. They have the common objective of trying to extend the life time of the sensor network, while not compromising data delivery & QoS.

Overall, the routing techniques are broadly classified into four categories: data centric, hierarchical, location and QoS based routing protocols. In addition, these protocols are classified into low, moderate and high overheads, low and high QoS based routing techniques depending on the protocol operation. We also highlight the design tradeoffs between power usage, mobility and communication overhead savings in some of the routing paradigm, as well as the selection of each routing technique for specific applications. Although many of these routing techniques look promising, there are still many design issues and challenges that need to be solved in the sensor networks. We highlighted those issues, challenges and pinpointed future research directions in this regard.

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