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A Survey on Routing Techniques in Wireless Sensor Network

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Abstract: ***Wireless Sensor Networks (WSNs) comprised of small nodes embedded with sensing, computation and wireless communications capabilities. Power management, routing and data aggregation techniques have been specifically designed for WSNs where energy consumption is a critical design issue. The emphasis, however, has been laid on the routing protocols which can be different from each other depending on the application, operation and network architecture. In this paper first the design issues for routing protocols in WSNs are discussed after that a comprehensive survey of different routing techniques are given.***

Keywords: Wireless sensor network, network lifetime, Energy Efficiency

1. Introduction

The mobile computing approach deals with anytime and anywhere services in the area of wireless sensor network. The advancements in the field of wireless technology are also one of the major stimuli for the growth of mobile computing. But the mobile computing architecture is different from the normal fixed architecture. The advancement in these wireless transmission techniques lead to the development of the wireless sensor networks. Energy [2] efficient protocols are required due to the ad-hoc nature of sensor network and severe battery energy limitations at all the layers of the protocol stack. Since a sensor network is designed with an objective of gathering data, for a given initial battery energy so it is desired that the network performs continuously and provide data updates for longer time. This is referred to maximum lifetime in sensor networks. A Wireless

Sensor Network (WSN) contains large number of these sensor nodes and each node has the capability to communicate either among each other or directly to an external base-station (BS). A large number of sensor nodes perform sensing function over larger geographical regions with greater accuracy. Figure 1 shows the schematic diagram of wireless sensor network. Basically, each sensor node consists of sensing units, power, processing, transmission and position finding system. Sensor nodes are usually scattered in a sensor field and coordinate among themselves to produce high-quality information about the physical environment in which they have been deployed. A base station may be a fixed node or a mobile node capable of connecting the sensor network to an existing communications infrastructure or to the internet where reported data can be sent to user . Wireless sensor nodes may have major effect on the efficiency of many military and civil applications such as target field imaging, weather monitoring, intrusion detection, security and tactical surveillance, distributed computing, detecting ambient

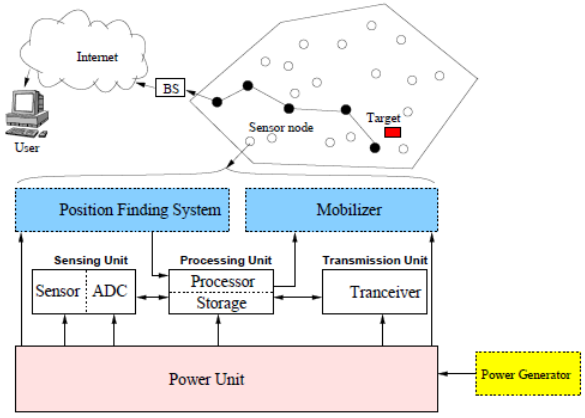


Figure 1: The components of a sensor node

conditions such as temperature, pressure, movement, sound, light, or inventory control, and disaster management. A sensor network in these applications can be in random fashion (e.g., dropped from an airplane) or can be planted manually (e.g., fire alarm sensors). In Section 2, routing challenges and design issues in WSNs are discussed .A classification and a comprehensive survey of routing techniques in WSNs are presented in Section 3. In last Conclusion with final remarks are given in Section 4.

2. Routing Challenges and Design Issues in WSNs

WSNs employed for large number of applications, but these networks have several limitations, e.g., limited bandwidth, limited computing power, limited sensing and limited energy sources of the sensor nodes linked to each other. One of the major design goals of WSNs is to carry out efficient data communication among nodes while trying to prolong the network lifetime and prevent connectivity failure of nodes.

a) **Node deployment:** The node deployment in wireless sensor network is application oriented. The deployment of nodes can be either deterministic or randomized. In deterministic deployment, the sensors are manually placed and data communication is takes place in pre-determined manner. However, in random node deployment, the sensor nodes are scattered randomly creating ad-hoc network.

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b) **Energy consumption:** Sensor nodes use their limited supply of energy for sensing, performing computations and transmitting information in a wireless environment. As such, energy-conservation in process of communication and computation is essential. Sensor node lifetime shows a strong dependency on the battery lifetime.
c) **Node Heterogeneity:** In most of the scenario sensor nodes were assumed to be homogeneous, i.e., having equal capacity in terms of computation, sensing communication, and power. However, based on the application a sensor node can have different role or capability and deployment.
d) **Fault Tolerance:** In most of the situations some sensor nodes may get damaged or be blocked due to lack of power, energy or environmental interference. The failure of such sensor nodes should not affect the overall performance of the sensor network. If many nodes fail, routing protocols must able to form new links and route the data efficiently to base stations.
e) **Scalability**: The number of sensor nodes deployed in the sensing area may be large in number so any routing scheme must be able to cope up with this huge number of sensor nodes. In addition, sensor network routing protocols should be scalable enough to respond to events in the environment timely.
f) **Transmission Media:** In a multi-hop sensor network, communicating nodes are connected by a wireless medium. The traditional problems associated with a wireless channel (e.g., fading, high error bit rate may also affect the operation of the wireless sensor network). So transmission medium plays an important role in routing.
g) **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 is the collection of certain aggregation function, e.g., duplicates suppression, minima, maxima and average. This technique has been used for achieving energy efficiency and data transfer optimization in routing protocols.
h) **Quality of Service:** In some applications, data should be delivered within a certain time constraint from the moment it is sensed otherwise the data collected will be useless. Therefore bounded latency for data delivery is another criterion for time-constrained applications (e.g. military application and disaster management).

3. Routing Protocols in WSNs

In general, routing in WSNs can be broadly classified into Network Structure, Communication model, Topology based and Reliable Routing

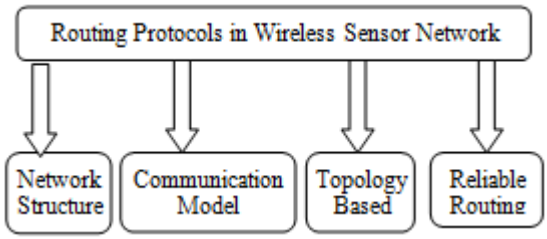


Figure 2: Different Routing protocols in WSN

3.1 Network Structure Based Protocols

3.1.1 Flat Routing

In flat network architecture, for sensing task coordination among nodes is important. Due to deployment of large number of such nodes in sensing region it is not always possible to assign a global identifier to each node. This consideration has led to data centric routing approach, where the BS sends queries to selected regions and waits for information coming 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.

Flooding and Gossiping:

Flooding and gossiping [12] are the most traditional network routing. In flooding mechanism, each sensor node receives a data packet from selected node and then broadcasts it to all neighboring nodes. When the packet reaches at the destination or the maximum number of hops is reached, the broadcasting process is stopped. On the other hand, gossiping is slightly upgraded version of flooding where the receiving node sends the packet to randomly selected neighbors, which pick another random neighbor to forward the packet to and so on. Although flooding is very easy, it has several drawbacks like overlap, implosion and resource blindness problem.

Rumor Routing:

Rumor routing is proposed in [14], which queries are allowed to be sent to events in the desired region of the network. It is mainly applied for context where geographic routing criteria is not applicable. Rumor routing is tradeoff between setup overhead and delivery reliability. Generally, directed diffusion floods the queries to the entire network and data can be sent through multiple paths at lower rates but in case of rumor routing maintains only one path between source and destination .In this protocol, paths are created for queries to be delivered and when a query is created it is sent for a time until it finds the path, instead of flooding it to the whole network. When the event path is detected by the query, it can be routed directly to the event. When events are flooded through the network, node detects an event, maintains its event table and creates an agent. The table entries contain the information about source node, events and last hop node. The main job of the agent is to transfer the information about local events to all distant nodes.

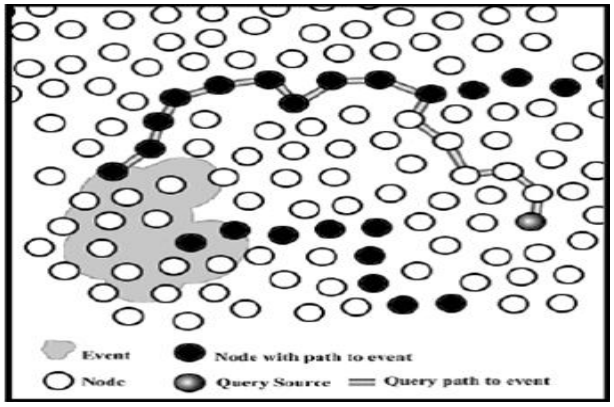


Figure 3: Query is originated from the query source and search for a path to the event.

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3.1.2 Hierarchical Routing

Hierarchical or cluster-based routing, originally suggested for wireless sensor networks, are well-known techniques with special advantages related to scalability, energy efficiency and efficient routing. In a hierarchical routing, higher energy nodes can be used to process and send the information to BS while low energy nodes can be used to perform the sensing task in the desired region. This means that formation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an effective way to lower energy consumption within a cluster and by performing data aggregation in order to decrease the number of transmitted messages to the BS. Hierarchical routing is mainly two-layer architecture where one layer is used to select cluster heads and the other layer is used for routing. In this two approaches are used

a) Clustering approach
b) Tree approach

3.1.3 Clustering approach

LEACH protocol:

Heinzelman, et. al. [1] proposed a hierarchical clustering algorithm for sensor networks, called Low Energy Adaptive Clustering Hierarchy (LEACH). LEACH is a cluster formation based protocol. LEACH randomly selects a few sensor nodes as cluster heads (CHs) and rotate this role to evenly distribute the energy load among the sensors in the network. In LEACH, the cluster head (CH) nodes gather the data from nodes that belongs to the respective cluster called cluster members, 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. In LEACH TDMA/CDMA MAC technique is used to reduce inter-cluster and intra-cluster collisions. In LEACH data collection is centralized and is performed periodically. Therefore, this protocol is most appropriate for an application where there is a need for constant monitoring is required. The operation of LEACH is separated into two phases, the setup phase and the steady state phase. In the setup phase, the clusters are organized and CHs are selected. In the steady state phase, the actual data transfer from cluster members to the base station takes place. The duration of the steady state phase is more than the duration of the setup phase in order to minimize overhead. During the setup phase, a predetermined fraction of nodes p, elect themselves as CHs . A sensor node chooses a random number r, between 0 and 1. If this random number is less than a threshold value, T(n), the node becomes a cluster-head for the current round. The threshold value is calculated based on an equation that incorporates the desired percentage to become a cluster-head, the current round, and the set of nodes that have not been selected as a cluster-head in the last (1/P) rounds, denoted by G. It is given by:

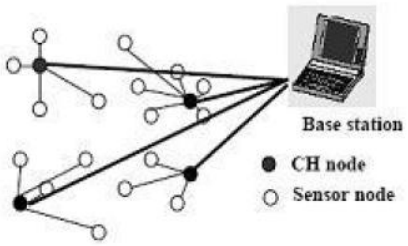


Figure 4: LEACH

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

Where G is the set of nodes that are involved in the CH election.

3.1.4 Tree approach

Power-Efficient Gathering in Sensor Information Systems (PEGASIS)

In [17], an enhancement over LEACH protocol was suggested. The protocol, called Power Efficient Gathering in Sensor Information Systems (PEGASIS), is a chain-based algorithm. The main idea of the protocol is that in order to prolong network lifetime, nodes need only communicate with their closest neighbors and they take turns in communicating with the base-station. This helps in reducing the power required to transmit data per round as the power consumption is distributed evenly over all nodes. Thus, PEGASIS has two main objectives. First is to increase the lifetime of each node by using collaborative techniques. Second is to reduce the bandwidth requirement by allowing only local coordination between nodes that are close to each other .Unlike LEACH, PEGASIS there is no cluster formation. Instead of using multiple nodes only one node in a chain is selected to transmit data to the BS.

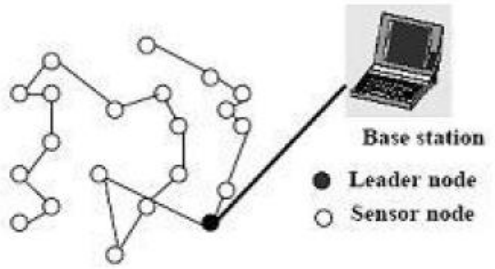


Figure 5: Chain construction using greedy algorithm

Threshold-sensitive Energy Efficient Protocols (TEEN and APTEEN):

Two hierarchical routing protocols called TEEN (Threshold-sensitive Energy Efficient sensor Network protocol), and APTEEN (Adaptive Periodic Threshold-sensitive Energy efficient sensor Network protocol) are suggested in [8] and [9], respectively. These protocols were proposed for time-constrained applications. In TEEN, sensor nodes sense the medium continuously, but the data transmission takes place periodically. A cluster head sensor sends its members a hard threshold limit, which is the threshold value of the sensed attribute and a soft threshold limit, which is a small change in the value of the sensed attribute that triggers the node to switch on its transmitter. Thus the hard threshold tries to

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reduce the number of transmissions by allowing the nodes to transmit only when the sensed attribute is in the region of interest. The soft threshold further reduces the number of transmissions that might have otherwise occurred when there is small or no change in the sensed attribute. The major disadvantage of this scheme is that, communication will not occur if the thresholds are not received, and the user will not get any data from the network at all.

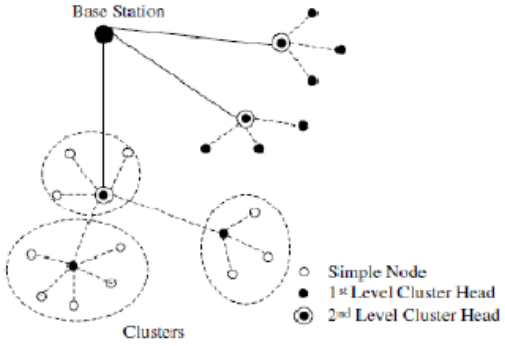


Figure 6: Clustering in TEEN and APTEEN

3.2 Communication based Model

3.2.1 Negotiation Based

Sensor Protocols for Information via Negotiation (SPIN): Heinzelman et.al. in [3] and [7] suggested 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 about any node and get the required data immediately. The SPIN family of protocols uses resource-adaptive and data negotiation algorithms.

3.2.2 Query Based

Directed Diffusion

In [2], C. Intanagonwiwat et. al. suggested a popular data aggregation for WSNs, called directed diffusion. Directed diffusion is a data-centric (DC) and application- aware approach. In this all data generated by sensor nodes is named by attribute-value pairs. The main idea of the DC approach is to combine the data coming from different sources that is performing in-network aggregation for eliminating redundancy, minimizing the number of transmissions, thus leads to saving network energy and prolonging the network lifetime. Unlike traditional end-to-end routing, DC routing finds routes from multiple sources to a single destination that enables in-network consolidation of redundant data.

3.2.3 Coherent and non coherent routing

Coherent Data Processing-Based Routing: This category is an energy efficient approach where each sensor node performs the minimum processing. By employing time stamping, duplicate suppression minimum processing can be done. After the minimum processing, the data is forwarded to the aggregators.

Non Coherent Data processing-based routing: In this data is processed locally and then send it to the other nodes for further processing. The nodes that perform further processing are called the aggregators. The phases of data processing in non-coherent routing are (a) Target detection, data collection, and preprocessing (b) Membership declaration and (c) Central-node election. In target detection stage, an event is detected; its information is collected and pre-processed. In the membership declaration phase, the sensor node chooses to participate in a coordinate fashion and declare this intention to all neighbors. In the central node election stage, a central node is chosen to perform more refined information processing.

3.3 Topology based

3.3.1Location based routing protocol

Geographic and Energy Aware Routing (GEAR):

Yu et al. [42] discussed the use of geographic information while disseminating queries to selected regions since data queries often include geographic attributes. The protocol, called Geographic and Energy Aware Routing (GEAR), uses energy aware and geographically-informed neighbor selection methods to route a packet towards the desired destination region. The basic idea is to limit the number of transmission overheads in directed diffusion by only considering a certain region rather than sending the queries to the whole network. By using this technique, more energy can be saved than directed diffusion. Each node in GEAR keeps an estimated cost and a learning cost of reaching the destination through its neighbors.

3.4 Reliable Routing

3.4.1 Multipath routing protocols

The multipath routing protocols multiple paths are taken rather than a single path to increase the network performance. The fault tolerance of a protocol is estimated with presence of an alternate path exists between a source and a destination when the primary path fails. This can be increased by maintaining multiple paths between the source and the destination at the expense of an increased energy consumption and traffic generation. In this alternate paths are kept alive by using periodic messages.

3.4.2 QoS-based routing

In QoS-based routing protocols, the network has tendency to balance between energy consumption and data quality. In particular, the network has to satisfy certain QoS metrics, e.g., energy, delay, bandwidth, etc. when sending data to the BS. Sequential Assignment Routing (SAR) proposed in [11] is one of the first routing protocols for WSNs that introduces the QoS in the routing procedure decision. Routing decision in SAR is based on three factors: QoS on each path, energy resources and the priority of each packet. To avoid single route failure, a multi-path approach is utilized and localized path restoration methods are used. In order to create multiple paths from a source node, a tree rooted at the source node to the destination nodes (i.e., the set of base-stations (BSs)) is built. The paths of the tree are built while avoiding nodes with low energy or QoS guarantees.

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4. Conclusions

The routing techniques can be classified based on the network structure, communication model, topology and reliability. In this paper the design tradeoffs between energy, power, communication overhead savings as well as the merits and demerits of each routing technique are presented. Although many of these routing techniques look promising, there are still many challenges in design and communication need to be solved in the future.

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