A Review on Routing Protocols in Wireless Sensor Network

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Abstract In wireless sensor network, Routing is the process by which the data gathered by sensors is relayed towards the end user (usually termed as sink).A lot of routing protocols have been developed since now and these protocols differ according to network structure and field of application. In this paper, a survey of the routing protocols developed so far in field of WSN is presented. Broadly, routing protocols are classified depending on network structure and protocol operation. The advantages and performance issues of hierarchical protocols will also be highlighted.

Keywords Wireless sensor networks. Routing protocols. Routing challenges. Network structure. Protocol operation

I. INTRODUCTION

Wireless Sensor Network has been a subject for extensive research for recent years due to its wide range of applications in various fields such as military surveillance, battlefield surveillance, atmosphere monitoring and medical etc. A wireless sensor network consists of very tiny devices deployed in field of interest .These devices have capabilities of monitoring their surroundings, processing the information gathered, storing the information for future reference and communicating this information to their neighbours or directly to the sink. The information sent to the sink is used by the end user to make decisions. The sensing devices may be deployed deterministically or randomly depending on the difficulty level of field of interest (FoI).

The WSN is a kind of personal area networks (PAN's) which are used to interconnect devices wirelessly over short distances. The physical and MAC layers of WSN's are compatible with IEEE 801.15.4 standard that is designed for low rate (LR-PAN's [14, 15]), low cost and low complexity wireless PAN's. These features make WSN's suitable for applications which require long operational duration and random deployment with large number of nodes. The topologies supported by this standard are peer-to-peer and star topologies. For increasing energy efficiency, sleep/active modes are employed. IEEE 802.15.4 provides low hop delay [15] allowing data transmission to be done in multi-hop approach and preventing high energy consumption in long range transmissions.

The basic architecture of a WSN is shown in figure 1.

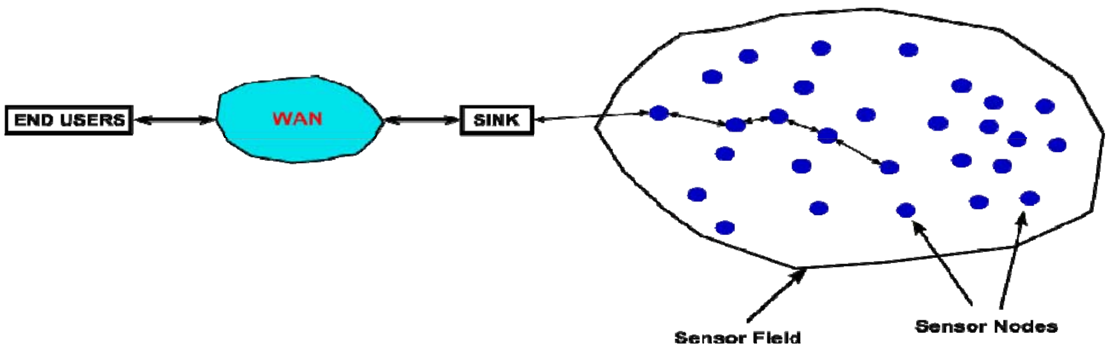

Figure 1 The basic network architecture of a WSN with multi-hop communication

The components inside a sensor node as shown by Jamal N. Al. Karaki et. al. in [1] are shown in figure 2

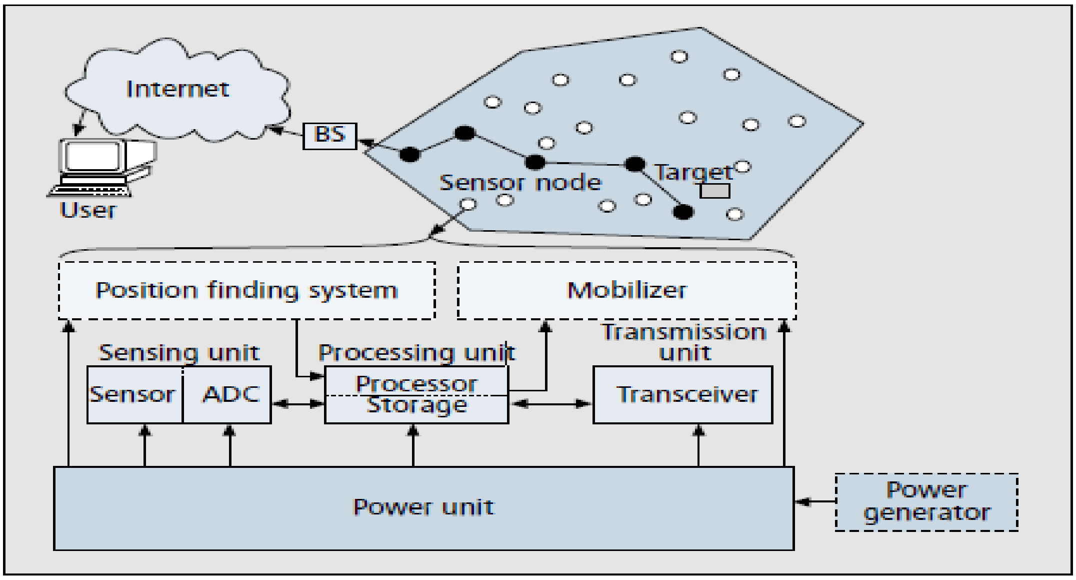

Figure 2 The components inside a sensor node

Every node in a wireless sensor network is equipped with the following units:

1. Sensing unit: Used for monitoring the area within its sensing range.
2. Power supply: To drive the whole circuitry.
3. Microprocessor: To process the attributes sensed and converting them into information.
4. Communication unit: Communicating the data to other sensor or sink by using radio links.
5. Memory: For storing the information gathered. The capacity of storage is usually small. This information may be referenced later.

The applications of WSN's are numerous and may be summarised as follows:

1. Environmental and habitat monitoring.
2. Agriculture
3. Asset tracking
4. Healthcare
5. Military and battlefield surveillance
6. Industrial applications

The rest of the paper is organised as follows: In section II, the most challenging design and routing issues are summarised. Section III includes the study of existing surveys for routing mechanisms in WSN's. In section IV, the classification of routing protocols for WSN's is presented. Section V concludes the paper along with some future directions.

II. DESIGN AND ROUTING ISSUES

WSN's have several issues such as limited computing power, limited processing capabilities, limited storage capacity and energy supply. Due to these limitations, a lot of design issues are there which may be stated as follows:

1. **Energy constraints**: As sensor are deployed in difficult to reach places, it is impossible to recharge their batteries. So, it is very necessary to design coverage methods and routing protocols which are energy efficient. This is usually done by efficiently scheduling the sensor.
2. **Coverage**: The sensors deployed in field of interest must provide the coverage required by its intended usage. The coverage desired depends on the criticality of the application. For example, some of the applications may require complete coverage while some others may require only partial coverage or only target coverage. Thus an appropriate deployment strategy must be adopted.
3. **Connectivity**: The sink should be reachable from every sensor so that the data sensed by the sensor may be sent to the sink. This connectivity may be either single hop (data may be sent from the sensor to sink directly) or multi-hop (other sensors are used to forward the data to sink). In the practical applications, multi-hop routing is used due to limitation of communication range of sensor.
4. **Lifetime**: Lifetime is extremely critical for most applications of wireless sensor networks, and its primary limiting factor is the energy consumption of the nodes. Often, lifetime is referred to the time when the first node dies off. The protocols should be designed in such a way that lifetime is optimized.

5. **Security**: A sensor network should be able to protect itself and its data from external attacks, but the limitations of lower-end sensor node hardware make security a true challenge.
6. **Scalability:** The number of sensor nodes deployed may be of the order of hundreds or thousands, or more. Any routing scheme must be capable of working with this huge number of sensor nodes. In addition to this, wireless sensor network routing protocols should be scalable enough to respond to events in the environment and intelligent node scheduling schemes should also be used for better energy efficiency.
7. **Network Dynamics:** In many researches, sensor nodes and sink are considered to be static but now-a-days sensor nodes are capable of moving according to various models. Thus the routing technique should be capable of handling the mobility of nodes as allowing mobility adds extra overhead of rerouting packets to current location of moveable sensors.
8. **Data Aggregation:** Since sensor nodes may generate redundant data; identical packets from multiple nodes can be aggregated to reduce the amount of data transmitted. Data aggregation merges the data from different nodes according to a certain aggregation function (e.g., duplicate suppression, maxima, minima and average). This technique has been used to provide energy efficiency as it results in reduced number of transmissions.
9. **Quality of Service:** QoS implies that certain quality should be maintained in data transmissions; otherwise the data will be of none use. The QoS may be examined by various parameters such as throughput, delay, latency, packet delivery ratio etc, but as efficient energy consumption is a challenge for WSN's , energy awareness should also be assured in order to prolong network lifetime.

III. RELATED SURVEYS

Routing protocols in WSN's have gained much attention due to emergence of advanced technologies and to provide high energy efficiency for these technologies. Lots of surveys have been done in field of routing protocols for WSN's. Akkaya and Younis in [2] gave broad perspective of three main categories of routing protocols for WSN's. The survey gives a sufficient introduction of routing protocols in WSN's. In [1], AL. Karaki and Kamal described routing issues and design challenges in WSN's. The authors also describe classification of routing protocol according to network structure and protocol operation but no simulation results were provided. Villalba et. al. [3] and Singh et. al. [4] described almost the same classification as done in [2] and [1]. In [3], the authors propose an optimization technique in routing protocols called as SHRP (Simple Hierarchical Routing Protocol). Singh et. al. [5] review the mechanisms and specifications of a few published cluster-based routing protocols such as LEACH, Leach-centralized, Multi-hop LEACH, Energy-Efficient Hierarchical Clustering, LEACH with fixed cluster, TEEN, PEGASIS and APTEEN. However, the author did not discuss strengths and weaknesses of each protocol. Abbasi and Younis in [6] gave a broad classification taxonomy of several published clustering schemes. The clustering algorithms were compared based on certain features such as cluster stability, cluster overlapping, convergence rate, location awareness and mobility etc. In [7], the network lifetime metrics FND (First Node Dies) and HNA (Half of the NODES Alive) were introduced in addition to Last Node Dies. In [8], Samar Awwad, Noordin, A. Rashid introduced Cluster-Based Routing protocol for Mobile nodes in WSN's(CBR-Mobile) which supports mobility of sensor nodes that collaborates with hybrid MAC protocol. The performance evaluation of CBR-Mobile was performed using MATLAB and the observations showed that packet delivery ratio, energy consumption and delay were better as compared to LEACH-Mobile and AODV protocols. Noordin, Manap, Chee Kyun et. al. in [9] reviewed HRP's and gave performance analysis of LEACH, TEEN, APTEEN, PEGSIS and PEDAP-PA.

IV. CLASSIFICATION OF ROUTING PROTOCOLS FOR WSNs

Routing is the process of relaying the data gathered by the sensors to the sink. A lot of coverage and connectivity preserving routing protocols have been developed. These protocols have their own advantages and disadvantages. The routing may be direct (one hop) or multi-hop. In the practical applications of WSN, multi-hop routing is used due to limited communication range of sensor nodes. Two types of approaches are used for routing data to the sink. Routing protocols are classified depending on network structure and protocol operation.

4.1 Routing Protocols Classification Based on Network Structure: The underlying network structure can play a significant role in the operation of the routing protocol in WSNs. According to network structure, routing protocols are classified as flat , hierarchical and location-based routing protocols.

4.1.1 Flat Routing: All nodes in a flat routing protocol are assigned equal roles or functionality and the nodes collaborate to perform the sensing tasks [1]. The BS sends queries to certain regions within the WSN and awaits data from the sensors located in that region. SPIN (W. Heinzelman, J. Kulik, & H. Balakrishnan,1999) and Directed Diffusion (C. Intanagonwiwat, R. Govindan, & D. Estrin,2000) are good examples of flat routing protocols.

4.1.2 Hierarchical Routing: Hierarchical routing protocols are more energy efficient as compared to flat routing. The special feature of this approach is that it provides self-organization capabilities to allow large scale network deployment. In a hierarchical architecture, some nodes take responsibility to perform high energy transmission while the rest perform normal task. Power –aware algorithm is used to select eligible high energy nodes to relay the data from normal nodes to BS [9]. HRPs can be categorized into two types based on the topology management. These are as follows:

Clustering Based HRPs: Clustering routing protocols are used to minimize the energy consumption due to long distance transmissions. In clustering protocols, the sensors are grouped into distinct clusters where each cluster has a cluster head and multiple cluster members. The role of cluster head is switched among nodes according to cluster head replacement strategies. The network lifetime is divided in rounds. In each round, two phases are there, setup-phase and steady-state phase. The setup phase includes the formation of the clusters by selecting cluster heads and member nodes. The cluster head forms a TDMA schedule based on number of member nodes and broadcasts it to all member nodes. The member nodes may send their data at their respective turns only. The nodes awake only at their respective turns and they sleep during all other schedules. Thus the energy is conserved by timely sleep/awake schedule. The cluster head aggregates the data gathered from all member nodes along with its own data and sends the aggregated data to sink directly or by using multi-hop. The advantages of cluster based protocols are energy conservation, collision avoidance, supporting node mobility etc. However the overhead of cluster head selection during each round is also there. The cluster based protocols may be used with both homogeneous and heterogeneous nodes, static and mobile nodes. The most popular cluster based protocol is Low Energy Adaptive Clustering Hierarchy(LEACH) and its variations (LEACH-C, T-LEACH, enhanced LEACH(E-LEACH), multi-hop LEACH(M-LEACH), LEACH with fixed cluster(LEACH-F) etc),Threshold Sensitive Energy Efficient Sensor Network (TEEN), Adaptive Periodic TEEN(APTEEN) etc.

Chain Based HRPs: In chain-based HRPs, all nodes deployed in the field are connected in a chain structure. Then, the most energy healthy node is chosen as the chain leader to mediate the data transfer from normal nodes and the BS. The role of chain leader is rotated periodically to balance the load distribution among the nodes. Examples of chain based protocols are PEGASIS (Power Efficient Gathering in Sensor Information Systems) and Power Efficient Data gathering and Aggregation Protocol-Power Aware (PEDAP-PA). In simulation results the chain based protocol are proved to be more efficient.

4.1.3 Location-Based Routing Protocols: In this kind of routing mechanism, sensors are addressed by means of their locations. The distance between neighbours can be estimated on the basis of incoming signal strengths. Relative coordinates of neighbours can be obtained by exchanging such information between neighbours. Alternatively, the location of nodes may be available directly by communicating with a satellite using GPS if nodes are equipped with a small low-power GPS receiver. To save energy, location-based schemes demand that nodes should go to sleep if there is no activity. More energy can be saved by having as many sleeping nodes in the network as possible. Examples of such protocols are GAF (Geographic Adaptive Fidelity), GEAR(Geographic and Energy Aware Routing) , GOAFR(Greedy Other Adaptive Face Routing) , MFR(Most Forward within Radius), GEDIR(Geographic Distance Routing), SPAN etc[1].

4.2 Routing Protocols Based on Protocol Operation:

4.2.1 Multipath-Based: Multipath based routing protocols that use multiple paths rather than a single path so that network performance may be enhanced. The fault tolerance of a protocol is assessed by the possibility that an alternate path exists between a source and a destination when the primary path gets failed. This can be increased by maintaining multiple paths between the source and destination but energy consumption and traffic generation are increased at the same time. These multiple paths are kept alive by sending messages at regular time intervals [1]. It is known that network reliability can be increased by providing several paths from source to destination and sending the same packet on each path. However, using this technique, traffic will get increased significantly. Hence, there should be a trade-off between the amount of traffic and the reliability of the network. Directed diffusion is a good candidate for robust multipath routing and delivery. It has been found that the use of multipath routing provides a viable alternative for energy-efficient recovery from failures in WSNs. The motivation for using these braided paths is to keep the cost of maintaining the multipath low. The costs of alternate paths are comparable to the primary path because they tend to be much closer to the primary path.

4.2.2 Query-Based Routing: In this type of routing, the destination nodes transmit a query for data through the network, and a node with the data that matches the query transmits the data back to the node that initiated the query. Usually these queries are described in natural language or high-level query languages. The Rumor routing protocol [10] uses a set of nodes to create paths that are directed toward the events they require. When shorter paths or more efficient paths are discovered, the optimized paths are stored in routing tables accordingly. Each node maintains a list of its neighbours and an events table that is updated whenever new events are encountered. A node will not generate a query unless it learns a route to the required event. If there is no route available, the node transmits a query in a random direction. Then the node waits for a certain amount of time to know if the destination received the query, after which the node floods the network if no response is received from the destination.

4.2.3 Negotiation-Based Routing Protocols*:* These protocols use high-level data descriptors in order to eliminate redundant data transmissions through negotiation. Communication decisions are made based on the resources available to them. The SPIN family protocols [11] and the protocols in [12] are examples of negotiation-based routing protocols. The SPIN protocols are designed to transmit the data of one sensor to all other sensors, assuming these sensors are potential BSs. Hence, the main idea of negotiation-based routing in WSNs is to suppress duplicate information and prevent redundant data from being sent to the next sensor or the BS by conducting a series of negotiation messages before the actual data transmission begins.

4.2.4 QoS-based Routing*:* In QoS-based routing protocols, the network has to balance between energy consumption and data quality. In particular, the network has to satisfy certain QoS metrics (delay, energy, bandwidth, etc.) when delivering data to the BS. Sequential Assignment Routing (SAR) proposed in [13] is one of the first routing protocols for WSNs to introduce the notion of QoS into routing decisions. A routing decision in SAR is dependent on three factors namely energy resources, QoS on each path, and the priority of each packet. To avoid the disadvantage of single route failure, a multipath approach is used. In order to create multiple paths from a source node, a tree from the source node to destination nodes (i.e., the set of BSs) is built. The paths of the tree are constructed excluding nodes with low energy or QoS values. At the end of this process, each sensor node will be part of a multipath tree. If topology changes due to node failures, paths are computed again. To prevent undesirable situations, a periodic re-computation of paths is initiated by the BS to handle any changes in topology. SAR maintains multiple paths from sensors to BS. SPEED is also an example of this type of protocol.

4.3 Routing Protocols Classification Based on Route Discovery:

4.3.1 Proactive: In proactive protocols, all routes are constructed before they are really needed. When sensor nodes are static, it is preferable to have table-driven routing protocols rather than reactive protocols. Sensors advertise their routing state to the entire network to maintain a common partial or complete topology of the network. OSPF is an example of proactive routing protocol.

4.3.2 Reactive: In reactive protocols, routes are computed on demand. Reactive protocols establish paths only upon request, e.g. in response to a query; meanwhile, sensors remain idle in terms of routing behaviour. Sensors forward each routing request to nodes until it arrives at a destination; the latter will respond over the reverse communication path. AODV and DSR are examples of reactive routing protocols used in ad-hoc networks. AODV is loop-free, self-starting, and scalable to large numbers of mobile nodes. It is an on demand algorithm, meaning that it constructs routes between nodes only as desired by source nodes. It maintains these routes as long as these are needed by the sources. AODV builds routes using a route request / route reply query cycle. When a source requires a route to a destination for which it does not already have a route, it broadcasts a route request (RREQ) packet across the network. Sensors receiving this packet update their information for the source node and set up backwards pointers to the source node in the routing tables. In addition to the source’s IP address, current sequence number, and broadcast ID, the route request message RREQ also contains the most recent sequence number for the destination of which the source node is aware. A sensor receiving the RREQ may transmit a route reply (RREP) if it is either the destination or if it has a route to the destination with corresponding sequence number greater than or equal to that contained in the RREQ. If this is the case, it unicasts a route repair message RREP back to the source. Otherwise, it rebroadcasts the route request message RREQ. Nodes keep track of the RREQ's source IP address and broadcast ID. If they receive a RREQ which they have processed already, they discard the RREQ and do not forward it. As the route reply message RREP propagates back to the source node, nodes set up forward pointers to the destination. Once the source node gets the RREP, it may begin to forward data packets to the destination. If the source later receives a route reply message RREP containing a greater sequence number or contains the same sequence number with a smaller hop count, it may update its routing table information for that destination and begin using the better route. As long as the route keeps alive, it will continue to be maintained.

V. CONCLUSION AND FUTURE DIRECTIONS

The paper reviews the routing protocols developed for WSN’s. The routing protocols for WSN’s are classified based on network structure and protocol operation. The applicability of a protocol for a particular network may be decided by analysing adaptability between network type and protocol specifications. Reactive and proactive networks require different protocols. Various energy efficient methods such as clustering and chain formation are used for increasing lifetime of network. Various parameters such as remaining energy, number of neighbours, cost of transmission to BS, etc may be used for selecting coordinator. Thus, further improvement in the energy efficiency and fair load distribution may be assured.

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