ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 5, Issue 3, September 2015

Routing Protocols of Wireless Sensor Networks - A Survey

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Abstract- Recent developments in the area of micro-sensor devices have accelerated advances in the sensor networks field leading to many new protocols specifically designed for wireless sensor networks (WSNs). Wireless sensor networks with hundreds to thousands of sensor nodes can gather information from an unattended location and transmit the gathered data to a particular user, depending on the application. These sensor nodes have some constraints due to their limited energy, storage capacity and computing power. Data are routed from one node to other using different routing protocols. There are a number of routing protocols for wireless sensor networks. In this paper, we discuss the architecture of wireless sensor networks. Further, we categorize the routing protocols according to some key factors and summarize their mode of operation.. In order to gain a comprehensive understanding of each protocol, we highlight their innovative ideas, describe the underlying principles in detail and analyze their advantages and disadvantages. The three main categories explored in this paper are data-centric, hierarchical and location-based. Each routing protocol is described and discussed under the appropriate category. Finally some open issues in routing protocol design in wireless sensor networks and conclusions are proposed.

Index Terms- **Wireless sensor networks, routing protocols, sensor nodes, architecture, micro-sensor devices.**

I. INTRODUCTION

Recent advances in wireless communication technologies and digital electronics have enabled the development of low-cost, low-power, multifunctional sensor nodes that are small in size and communicate untethered in short distances. These tiny sensor nodes, which consist of sensing, data processing, and communicating components, leverage the idea of sensor networks based on collaborative effort of a large number of nodes operating in an unattended environment [1] The decrease in the size and cost of sensors, resulting from today's technological advances, has fueled interest and motivated intensive research in the past few years addressing the potential of collaboration among sensors in data gathering and processing and the coordination and management of the sensing activity and data flow to the sink. The basic components [2] of a node are a sensor unit, an ADC (Analog to Digital Converter), a CPU (Central processing unit), a power unit and a communication unit. Due to their ease of deployment and the multi-functionality of the sensor nodes, wireless sensor networks have been utilized for a variety of applications such as healthcare, target tracking, and environment monitoring [3].

Sensor nodes are micro-electro-mechanical systems [4] (MEMS) that have sensing circuitry which measures ambient conditions related to the environment surrounding the sensor and transforms them into an electric signal. Processing such a signal reveals some properties about objects located and/or events happening in the vicinity of the sensor. The sensor sends such collected data, usually via radio transmitter, to a command center (sink) either directly or through a data concentration center (a gateway).. Sensor nodes are operated in high volumetric densities, and can be autonomous and adaptive to the environment. Wireless sensor nodes are equipped with a limited power source [5]. Each sensor node has a certain area of coverage for which it can reliably and accurately report the particular quantity that it is observing.

Several sources of power consumption in sensors are: (a) signal sampling and conversion of physical signals to electrical ones; (b) signal conditioning, and (c) analog-to-digital conversion. Resource limitations of the sensor nodes and unreliability of low-power wireless links [6], in combination with various performance demands of different applications impose many challenges in designing efficient communication protocols for wireless sensor networks [7]. Since a sensor node has limited sensing and computation capacities, communication performance and power, a large number of sensor devices are distributed over an area of interest for collecting information (temperature, humidity, motion detection, etc.). These nodes can communicate with each other for sending or getting information either directly or through other intermediate nodes and thus form a communication routing protocols. Research on addressing schemes and routing concentrates: (a) on how to assign addresses to mobile hosts so that IP based protocols may be used for routing messages, and (b) on how to optimize the search cost for locating a mobile host. -The location of a mobile host refers to the address of the base station to which it is currently connected. In an internet working protocol is proposed where base stations act both as gateways and routers. Mobile hosts are confined to addresses that form a single "virtual network". Each base station maintains a database describing the machines that are in its cell

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 5, Issue 3, September 2015

and those that have recently moved out of its cell. To identify the LAN in which a mobile host is currently located, a base station builds up a second database of other LANs that hold mobile hosts by using a combination of broadcast-based search and caching. [8] A routing protocol [9] is a protocol that specifies how routers (sensor nodes) communicate with each other, disseminating information that enables them to select routes between any two nodes on the network, the choice of the route being done by routing algorithms. There are three categories of sensor nodes:

- Passive Omni Directional Sensors: passive sensor nodes sense the environment without manipulating it by active probing. In this case, the energy is needed only to amplify their analog signals. There is no notion of "direction" in measuring the environment.
- Passive Narrow-Beam Sensors: these sensors are passive and they are concerned about the direction when sensing the environment.
- Active Sensors: these sensors actively probe the environment

Advantages

- Network setups can be done without fixed infrastructure.
- Ideal for the non-reachable places such as across the sea, mountains, rural areas or deep forests.
- Flexible if there is ad hoc situation when additional workstation is required.
- Implementation cost is cheap.

Disadvantages

- Less secure because hackers can enter the access point and get all the information.
- Lower speed compared to a wired network.
- More complex to configure than a wired network.
- Easily affected by surroundings (walls, microwave, large distances due to signal attenuation, etc.).

Taking into account the reduced capabilities of sensors, the communication with the sink could be initially conceived without a routing protocol. With this premise, the flooding algorithm stands out as the simplest solution. In this algorithm, the transmitter broadcasts the data which are consecutively retransmitted in order to make them arrive at the intended destination. However, its simplicity brings about significant drawbacks. Firstly, an implosion is detected because nodes redundantly receive multiple copies of the same data message. Then, as the event may be detected by several nodes in the affected area, multiple data messages containing similar information are introduced into the network. Moreover, the nodes do not take into account their resources to limit their functionalities. One optimization relies on the gossiping algorithm [11]. Gossiping avoids implosion as the sensor transmits the message to a selected neighbor instead of informing all its neighbors as in the classical flooding algorithm. However, overlap and resource blindness are still present. Furthermore, these inconveniences are highlighted when the number of nodes in the network increases. Due to the deficiencies of the previous strategies, routing protocols become necessary in wireless sensor networks. Nevertheless, the inclusion of a routing protocol in a wireless sensor network is not a trivial task. One of the main limitations is the identification of nodes. Since wireless sensor networks are formed by a significant number of nodes, the manual assignation of unique identifiers becomes infeasible [12].. Each router has a prior knowledge only of the networks attached to it directly. A routing protocol shares this information first among immediate neighbors, and then throughout the network. This way, routers gain knowledge of the topology of the network.

There are mainly two types of routing process: one is static routing and the other is dynamic routing.. Static routing allows routing tables in specific routers to be set up in a static manner so network routes for packets are set. Dynamic routing [6] performs the same function as static routing except it is more robust. If a router on the route goes down, the destination may become unreachable. Designing suitable routing protocols to fulfill different performance demands of various applications is considered as an important issue in wireless sensor networking. In this context, researchers have proposed numerous routing protocols to improve performance demands of different applications through the network layer of wireless sensor networks protocol stack [13].

II. ROUTING IN WIRELESS SENSOR NETWORKS

Data transmission from the target area towards the sink node is the main task of wireless sensor. Due to the intrinsic features of low-power wireless sensor networks, routing in these networks is much more challenging compared to the traditional wireless networks such as ad hoc networks [14]. First of all, according to the high density of sensor nodes, routing protocols should be able to support data transmission over long distances, regardless of the network size. In addition, some of the active nodes may fail during network operation due to energy depletion of the sensor nodes, hardware breakdowns or environmental factors, but this issue should not interrupt the normal network operation. Moreover, as sensor nodes are tightly limited in terms of power supply, processing capability, memory capacity and available bandwidth, routing and data dissemination should be performed with efficient network resource utilization. Furthermore, since the performance demands of the wireless sensor networks are application specific, routing protocols should be able to satisfy the QoS demands of the application for which the network is being deployed. Normally, according to the underlying network structure, the traditional WSNs routing protocols can be roughly classified according to the following criteria. According to their mode of functioning and type of target applications, protocols can be classified as:

- Proactive,
- Reactive and
- Hybrid,

Proactive Protocol

In this protocol the nodes switch on their sensors and transmitters, sense the environment and transmit the data to a Base Station (BS) through the predefined route. The Low Energy Adaptive Clustering hierarchy protocol (LEACH) utilizes this type of protocol [15].

Reactive Protocol

In this protocol if there are sudden changes in the sensed attribute beyond some pre-determined threshold value, the nodes immediately react. This type of protocol is used in time critical applications. The Threshold sensitive Energy Efficient sensor Network (TEEN) [16] is an example of a reactive protocol.

Hybrid protocols

This protocols incorporate both proactive and reactive concepts [17]. They first compute all routes and then improve the routes at the time of routing According to the participation style of the nodes, protocols can be classified as:

- Direct Communication Protocol
- Flat Protocol
- Clustering Protocol

Direct Communication Protocol

In direct communication protocols, any node can send information to the BS directly. When this is applied in a very large network, the energy of sensor nodes may be drained quickly. Its scalability is very small.

Flat Protocol

If any node needs to transmit data, it first searches for a valid route to the BS and then transmits the data. Nodes around the base station may drain their energy quickly. Its scalability is average

Clustering Protocol

In this protocol, the total area is divided into numbers of clusters. Each and every cluster has a cluster head (CH) and this cluster head directly communicates with the BS. All nodes in a cluster send their data to their corresponding CH

According to the network structure, protocols can be classified as

- Hierarchical Protocol
- Data Centric Protocol
- Location Based Protocol

Hierarchical Routing Protocol

This protocol is used to perform energy efficient routing, i.e., higher energy nodes can be used to process and send the information; low energy nodes are used to perform the sensing in the area of interest.

Data Centric Routing Protocol

These protocols are query based and they depend on the naming of the desired data, thus it eliminates much redundant transmissions. The BS sends queries to a certain area for information and waits for reply from the nodes of that particular region. Since data is requested through queries, attribute based naming is required to specify the properties of the data. Depending on the query, sensors collect a particular data from the area of interest and this particular information is only required to transmit to the BS and thus reducing the number of transmissions

Location Based Routing Protocol

These protocols [18] need some location information of the sensor nodes. Location information can be obtained from GPS (Global Positioning System) signals, received radio signal strength, etc. Using location information, an optimal path can be formed without using flooding techniques. GEAR is an example of a location based routing protocol.

III.DESIGN CONSTRAINTS FOR ROUTING IN WIRELESS SENSOR NETWORKS

Due to the reduced computing, radio and battery resources of sensors, routing protocols in wireless sensor networks are expected to fulfill the following requirements [5]:

- Autonomy: The assumption of a dedicated unit that controls the radio and routing resources does not stand in wireless sensor networks as it could be an easy point of attack. Since there will not be any centralized entity to make the routing decision, the routing procedures are transferred to the network nodes.
- Energy Efficiency: Routing protocols should prolong network lifetime while maintaining a good grade of connectivity to allow the communication between nodes. It is important to note that the battery replacement in the sensors is infeasible since most of the sensors are randomly placed. Under some circumstances, the sensors are not even reachable. For instance, in wireless underground sensor

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 5, Issue 3, September 2015

networks, some devices are buried to make them able to sense the soil [6].

- Scalability: Wireless sensor networks are composed of hundred of nodes so routing protocols should work with this amount of nodes.
- Resilience: Sensors may unpredictably stop operating due to environmental reasons or to the battery consumption. Routing protocols should cope with this eventuality so when a current-in-use node fails, an alternative route could be discovered.
- Device Heterogeneity: Although most of the civil applications of wireless sensor network rely on homogenous nodes, the introduction of different kinds of sensors could report significant benefits. The use of nodes with different processors, transceivers, power units or sensing components may improve the characteristics of the network. Among other, the scalability of the network, the energy drainage or the bandwidth are potential candidates to benefit from the heterogeneity of nodes [7].
- Mobility Adaptability: The different applications of wireless sensor networks could demand nodes to cope with their own mobility, the mobility of the sink or the mobility of the event to sense. Routing protocols should render appropriate support for these movements.

IV.ALGORITHM PARADIGMS FOR WIRELESS SENSOR NETWORKS

The algorithm paradigm is an important factor to take into account when deciding about the routing protocol to employ in the network.. In fact, three kinds of algorithms can be executed on wireless sensor networks [4]:

- Centralized Algorithms: They are executed in a node that posses the knowledge of the whole network. These algorithms are quite rare because of the cost of transmitting the data to make the node know the status of the complete network.
- Distributed Algorithms: The communication is supported by message-passing. and efficiently support the communication between any two pairs of nodes
- Local based Algorithms: The nodes use restricted data acquired from a close area. With this local information, the algorithm is executed in one node. . The nodes depend on some solution that provides geographic coordinates, like GPS, making the solution more expensive.

V. OPTIMIZATION TECHNIQUES FOR ROUTING IN WIRELESS SENSOR NETWORKS

The particular characteristics of wireless sensor networks and their constraints have prompted the need for specific requirements to routing protocols. When compared to mobile ad hoc networks routing protocols, the algorithms in wireless sensor networks usually realize the following specifications:

- Attribute-based
  In these algorithms, the sink sends queries to certain regions and waits for the response from the sensors located in this area. Following an attribute-value scheme, the queries inform about the required data. The selection of the attributes depends on the application. An important characteristic of these schemes is that the content of the data messages is analyzed in each hop to make decisions about routing.
- Energy Efficiency
  Multiple routes can communicate a node and the sink. The aim of energy-aware algorithms is to select those routes that are expected to maximize the network lifetime. To do so, the routes composed of nodes with higher energy resources are preferred.
- Data Aggregation
  Data collected in sensors are derived from common phenomena so nodes in a close area usually share similar information. A way to reduce energy consumption is data aggregation. Aggregation consists of suppressing redundancy in different data messages. When the suppression is achieved by some signal processing techniques, this operation is called data fusion.
- Addressing Scheme
  Wireless sensor networks are formed by a significant number of nodes so the manual assignation of unique identifiers is infeasible. The use of the MAC address or the GPS coordinates is not recommended as it introduces a significant payload [3]. However, network-wide unique addresses are not needed to identify the destination node of a specific packet in wireless sensor networks. In fact, attribute-based addressing fits better with the specificities of wireless sensor networks. In this case, an attribute such as node location and sensor type is used to identify the final destination. Concerning these identifiers, two different approaches have been proposed [3]. Firstly, the ID reuse scheme allows identifiers to be repeated in the network but keeping their uniqueness in close areas. In this way, a node knows that its identifier is unique in a

k-hop neighborhood, being k a parameter to configure. On the other hand, the field-wide unique ID schemes guarantee that the identifiers are unique in the whole application. With this assumption, other protocols such as routing, MAC or network configurations can be simultaneously used.

- Location-based
  When this technique is used, a node decides the transmission route according to the localization of the final destination and the positions of some other nodes in the network.
- Multipath Communication
  With this technique, nodes use multiple paths from an origin to a destination in the network. As multipath communications are intended to increase the reliability and the performance of the network, these paths should not share any link. Multipath communications can be accomplished in two ways.
- Quality of Service
  The network application business and its functionalities prompt the need for ensuring a QoS (Quality of Service) in the data exchange. In particular, effective sample rate, delay bounded and temporary precision are often required. Satisfying them is not possible for all the routing protocols as the demands may be opposite to the protocol principles. For instance, a routing protocol could be designed to extend the network lifetime while an application may demand an effective sample rate which forces periodic transmissions and, in turn, periodic energy consumptions.

VI. SENSOR NETWORK ARCHITECTURE AND DESIGN ISSUES

Depending on the applications used, different architectures and designs have been applied in sensor networks. Again, the performance of a routing protocol depends on the architecture and design of the network, so the architecture and design of the network is very important features in WSNs. The design of the wireless sensor network is affected by many challenging factors which must be overcome before an efficient network can be achieved in WSNs. In the following section we try to describe the architectural issues and challenges for WSNs.

- Node Distribution: Node distribution [13] in WSNs is either deterministic or self-organizing and application dependant. The uniformity of the node distribution directly affects the performance of the routing protocol used for this network. In the case of deterministic node distribution, the sensor nodes are mutually placed and gathered data is transmitted through pre-determined paths. In the other case, the sensor nodes are spread over the area of interest randomly thus creating an infrastructure in an ad hoc manner.
- Network Dynamicity: Since the nodes in WSNs may be static or dynamic, dynamicity of the network is a challenging issue. Most of the routing protocols assume that the sensor nodes and the base stations are fixed i.e., they are static, but in the case of dynamic BS or nodes routes from one node to another must be reported periodically within the network so that all nodes can transmit data via the reported route. Again depending on the application, the sensed event can be dynamic or static. For example, in target detection/tracking applications, the event is dynamic, whereas forest monitoring for early fire prevention is an example of a static event. Monitoring static events works in reactive mode. On the other hand, dynamic events work in proactive mode.
- Energy efficiency: The sensor nodes in WSNs have limited energy and they use their energy for computation, communication and sensing, so energy consumption is an important issue in WSNs. According to some routing protocols nodes take part in data fusion and expend more energy. Since the transmission power is proportional to distance squared, multi-hop routing consumes less energy than direct communication, but it has some route management overhead. In this regard, direct communication is efficient. Since most of the times sensor nodes are distributed randomly, multi-hop routing is preferable. In some applications nodes sense environment periodically and lose more energy than the nodes used in some applications where they sense environment when some event occurs.
- Data Transmission: Data transmission in WSNs is application specific. It may be continuous or event driven or query-based or hybrid. In case of continuous data transmission, sensor nodes send data to the base station periodically. In event driven and query-based transmission they send data to the base station when some event occurs or a specific query is generated by the base station. Hybrid transmission uses a combination of continuous, event driven and query-based transmission, so for

architecture and design of WSNs data transmission is a very significant issue.

- Scalability: A WSN consists of hundreds to thousands of sensor nodes. Routing protocols must be workable with this huge number of nodes i.e., these protocols can be able to handle all of the functionalities of the sensor nodes so that the lifetime of the network can be stable.
- Data Fusion: Data fusion [14] is a process of combining of data from different sources according to some function. This is achieved by signal processing methods. This technique is used by some routing protocols for energy efficiency and data transfer optimization. Since sensor nodes get data from multiple nodes, similar packets may be fused generating redundant data. In data fusion or data aggregation process awareness is needed to avoid this redundant data.

VII. CONCLUSION

Concerning the routing protocols, the reduced energy resources, the scalability and the resilience arise as the main limitations in wireless sensor networks. The routing techniques are classified as proactive, reactive and hybrid based on their mode of functioning and type of target applications. Further, these are classified as direct communication, flat and clustering protocols, according to the participating style of nodes. Again depending on the network structure, these are categorized as hierarchical, data centric and location based. Since the sensor networks are application specific, we can't say any particular protocol is better than other. Although the performances of these protocols are encouraging for improving scalability of WSNs, some issues remain to be considered. First of all, as the number of nodes in WSNs increases, the density of the network is increased. Therefore, more redundant information is created and this makes the network congestion more serious. In addition, data transmission delays are an unavoidable problem when time-sensitive tasks such as fire alarms are assigned to an entire network. In this case, routing must be prepared in advance and maintained constantly. Embedding this consideration in the routing design is desirable. Nonetheless, with the increasing functionalities available to a wireless sensor node, more complicated tasks which involve more energy consumption and network overhead may be assigned to the sensor nodes, so how to increase energy efficiency and scalability of the network remains a challenging research area.

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ISSN: 2277-3754
ISO 9001:2008 Certified
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Volume 5, Issue 3, September 2015

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