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A Characteristics Study of Wireless Sensor Networks Along with Open Issues in Routing Protocols

Sunny Arya,
Research Scholar, Deptt. of Computer Science,
North East Frontier Technical University, Arunachal Pradesh

Dr. Umesh Prasad,
Research Supervisor, Deptt. of Computer Science,
North East Frontier Technical University, Arunachal Pradesh

ABSTRACT

Wireless sensor network (WSN) is deployed in number of applications for real-time data collection. Sensors that are smaller, cheaper, and more sophisticated have made this possible in recent years. These sensors are outfitted with wireless interfaces through which they can connect with one another to build a network. 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 review article, 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. Finally, we provide a comparative study on these various protocols. After that, we have studied and analysed the various research papers are published in these routing protocols. Finally, open research challenges are defined based on the study.

Keywords: wireless sensor networks, routing; energy efficiency; clustering

INTRODUCTION

Ad hoc sensor networks are ad hoc networks that are characterized by decentralized structure and ad hoc deployment. Sensor networks have all the basic features of ad hoc networks but to different degrees – for example, much lower mobility and much more stringent energy requirements. We analyze the current state of research and evaluate open issues in development of routing techniques in wireless sensor networks.

A **wireless sensor network (WSN)** consists of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location. The more modern networks are bi-directional, also enabling control of sensor activity. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance; today such networks are used in many industrial and consumer applications, such as industrial process monitoring and control, machine health monitoring, and so on.

Due to recent technological advances, the manufacturing of small and low cost sensors became technically and economically feasible. The sensing electronics measure ambient conditions related to the environment surrounding the sensor and transform 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. A large number of these disposable sensors can be networked in many applications that require unattended operations. A Wireless Sensor Network (WSN) contains hundreds or thousands of these sensor nodes. These sensors have the ability to communicate either among each other or directly to an external base-station (BS). A greater number of sensors allows for sensing over larger geographical regions with greater accuracy. Basically, each sensor node

comprises sensing, processing, transmission, mobilize, position finding system, and power units (some of these components are optional like the mobilizer). The same figure shows the communication architecture of a WSN. Sensor nodes are usually scattered in a sensor field, which is an area where the sensor nodes are deployed. Sensor nodes coordinate among themselves to produce high-quality information about the physical environment. Each sensor node bases its decisions on its mission, the information it currently has, and its knowledge of its computing, communication, and energy resources. Each of these scattered sensor nodes has the capability to collect and route data either to other sensors or back to an external base station(s) 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 a user can have access to the reported data.
The WSN is built of "nodes" – from a few to several hundreds or even thousands, where each node is connected to one (or sometimes several) sensors. Each such sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source, usually a battery or an embedded form of energy harvesting. A sensor node might vary in size from that of a shoebox down to the size of a grain of dust, although functioning "motes" of genuine microscopic dimensions have yet to be created. The cost of sensor nodes is similarly variable, ranging from a few to hundreds of dollars, depending on the complexity of the individual sensor nodes. Size and cost constraints on sensor nodes result in corresponding constraints on resources such as energy, memory, computational speed and communications bandwidth. The topology of the WSNs can vary from a simple star network to an advanced multi-hop wireless mesh network. The propagation technique between the hops of the network can be routing or flooding.

APPLICATIONS OF WIRELESS SENSOR NETWORKS:

Some of the recent applications of WSN are given as follows:

- Area Monitoring
- Environmental/Earth monitoring
- Air Quality Monitoring
- Interior Monitoring
- Exterior Monitoring
- Air Pollution Monitoring
- Forest Fire Detection
- Landslide Detection
- Water Quality Monitoring
- Natural disaster prevention
- Machine Health Monitoring
- Data Logging
- Industrial Sense and Control Applications
- Water/Waste Water Monitoring including
- Agriculture
- Passive Localization and Tracking
- Smart Home Monitoring

CHARACTERISTICS OF WIRELESS SENSOR NETWORKS:

The main characteristics of a WSN include:

- Power consumption constrains for nodes using batteries or energy harvesting
- Ability to cope with node failures
- Mobility of nodes
- Communication failures
- Heterogeneity of nodes
- Scalability to large scale of deployment
- Ability to withstand harsh environmental conditions
- Ease of use

Sensor nodes can be imagined as small computers, extremely basic in terms of their interfaces and their components. They usually consist of a processing unit with limited computational power and limited memory, sensors or MEMS (including specific conditioning circuitry), a communication device (usually radio transceivers or alternatively optical), and a power source usually in the form of a battery. Other possible inclusions are energy harvesting modules, secondary ASICs, and possibly secondary communication devices (e.g. RS-232 or USB).

The base stations are one or more components of the WSN with much more computational, energy and communication resources. They act as a gateway between sensor nodes and the end user as they typically forward data from the WSN on to a server. Other special components in routing based networks are routers, designed to compute, calculate and distribute the routing tables.

UNIQUE FEATURES OF WIRELESS SENSOR NETWORKS:

It should be noted that sensor networks do share some commonalities with general ad hoc networks. Thus, protocol design for sensor networks must account for the properties of ad hoc networks, including the following:

- Lifetime constraints imposed by the limited energy supplies of the nodes in the network.
- Unreliable communication due to the wireless medium
- Need for self-configuration, requiring little or no human intervention.

However, several unique features exist in wireless sensor networks that do not exist in general ad hoc networks. These features present new challenges and require modification of designs for traditional ad hoc networks. These are the following:

- While traditional ad hoc networks consist of network sizes on the order of 10s, sensor networks are expected to scale to sizes of 1000s.
- Sensor nodes are typically immobile, meaning that the mechanisms used in traditional ad hoc network protocols to deal with mobility may be unnecessary and overweight.
- Since nodes may be deployed in harsh environmental conditions, unexpected node failure may be common.
- Sensor nodes may be much smaller than nodes in traditional ad hoc networks (e.g., PDAs, laptop computers), with smaller batteries leading to shorter lifetimes, less computational power, and less memory.
- Additional services, such as location information, may be required in wireless sensor networks.
- While nodes in traditional ad hoc networks compete for resources such as bandwidth, nodes in a sensor network can be expected to behave more cooperatively, since they are trying to accomplish a similar universal goal, typically related to maintaining an application-level quality of service (QoS), or fidelity.
- Communication is typically data-centric rather than address-centric, meaning that routed data may be aggregated/compressed/prioritized/dropped depending on the description of the data.
- Communication in sensor networks typically takes place in the form of very short packets, meaning that the relative overhead imposed at the different network layers becomes much more important.
- Sensor networks often have a many-to-one traffic pattern, which leads to a “hot spot” problem.

Incorporating these unique features of sensor networks into protocol design is important in order to efficiently utilize the limited resources of the network. At the same time, to keep the protocols as light-weight as possible, many designs focus on particular subsets of these criteria for different types of applications. This has led to quite a number of different protocols from the data-link layer up to the transport layer, each with the goal of allowing the network to operate autonomously for as long as possible while maintaining data channels and network processing to provide the application’s required quality of service.

ROUTING CHALLENGES AND DESIGN ISSUES IN WSNS:

Despite the innumerable applications of WSNs, these networks have several restrictions, e.g., limited energy supply, limited computing power, and limited bandwidth of the wireless links connecting sensor nodes. One of the main design goals of WSNs is to carry out data communication while trying to prolong the lifetime of the network and prevent connectivity degradation by employing aggressive energy management techniques. The design of routing protocols in WSNs is influenced by many challenging factors. These factors must be overcome before efficient communication can be achieved in WSNs. In the following, we summarize some of the routing challenges and design issues that affects routing process in WSNs.

Node Deployment: Node deployment in WSNs is application dependent and the performance of the routing protocol. The deployment can be either deterministic or randomized. In deterministic deployment, the sensors are manually placed and data is routed through pre-determined paths. However, in random node deployment, the sensor nodes are scattered randomly creating an infrastructure in an ad hoc manner. If the resultant distribution of nodes is not uniform, optimal clustering becomes necessary to allow connectivity and enable energy efficient network operation. Inter sensor communication is normally within short transmission ranges due to energy and bandwidth limitations. Therefore, it is most likely that a route will consist of multiple wireless hops.

Energy Consumption without Losing Accuracy: sensor nodes can use up their limited supply of energy performing computations and transmitting information in a wireless environment. As such, energy- conserving forms of communication and computation are essential. Sensor node lifetime shows a strong dependence on the battery lifetime. In a multihop WSN, each node plays a dual role as data sender and data router. The malfunctioning of some sensor nodes due to power failure can cause significant topological changes and might require rerouting of packets and reorganization of the network.

Data Reporting Model: Data sensing and reporting in WSNs is dependent on the application and the time criticality of the data reporting. Data reporting can be categorized as either time-driven (continuous), event-driven, query-driven, and hybrid. The time-driven delivery model is suitable for applications that require periodic data monitoring. As such, sensor nodes will periodically switch on their sensors and transmitters, sense the environment and transmit the data of interest at constant periodic time intervals. In event-driven and query-driven models, sensor nodes react immediately to sudden and drastic changes in the value of a sensed attribute due to the occurrence of a certain event or a query is generated by the BS. As such, these are well suited for time critical applications. A combination of the previous models is also possible. The routing protocol is highly influenced by the data reporting model with regard to energy consumption and route stability.

Node/Link Heterogeneity: In many studies, all sensor nodes were assumed to be homogeneous, i.e., having equal capacity in terms of computation, communication, and power. However, depending on the application a sensor node can have different role or capability. The existence of heterogeneous set of sensors raises many technical issues related to data routing. For example, some applications might require a diverse mixture of sensors for monitoring temperature, pressure and humidity of the surrounding environment, detecting motion via acoustic signatures, and capturing the image or video tracking of moving objects. These special sensors can be either deployed independently or the functionalities can be included in the same sensor nodes. Even data reading and reporting can be generated from these sensors at different rates, subject to diverse quality of service constraints, and can follow multiple data reporting models. For example, hierarchical protocols designate a cluster- head node different from the normal sensors. These cluster heads can be chosen from the deployed sensors or can be more powerful than other sensor nodes in terms of energy, bandwidth, and memory. Hence, the burden of transmission to the BS is handled by the set of cluster-heads.

Fault Tolerance: Some sensor nodes may fail or be blocked due to lack of power, physical damage, or environmental interference. The failure of sensor nodes should not affects the overall task of the sensor network. If many nodes fail, MAC and routing protocols must accommodate formation of new links and routes to the data collection base stations. This may require actively adjusting transmit powers and signaling rates on the existing links to reduce energy consumption, or rerouting packets through regions of the network where more energy is available. Therefore, multiple levels of redundancy may be needed in a fault-tolerant sensor network.

Scalability: The number of sensor nodes deployed in the sensing area may be in the order of hundreds or thousands, or more. Any routing scheme must be able to work with this huge number of sensor nodes. In addition, sensor network routing protocols should be scalable enough to respond to events in the environment. Until an event occurs, most of the sensors can remain in the sleep state, with data from the few remaining sensors providing a coarse quality.

Network Dynamics: Most of the network architectures assume that sensor nodes are stationary. However, mobility of both BS's and sensor nodes is sometimes necessary in many applications. Routing messages from or to moving nodes is more challenging since route stability becomes an important issue, in addition to energy, bandwidth etc. Moreover, the sensed phenomenon can be either dynamic or static depending on the application, e.g., it is dynamic in a target detection/tracking application, while it is static in forest monitoring for early ¯re prevention. Monitoring static events allows the network to work in a reactive mode, simply generating traffic when reporting. Dynamic events in most applications require periodic reporting and consequently generate significant traffic to be routed to the BS.

Transmission Media: In a multi-hop sensor network, communicating nodes are linked by a wireless medium. The traditional problems associated with a wireless channel (e.g., fading, high error rate) may also the operation of the sensor network. In general, the required bandwidth of sensor data will be low, on the order of 1-100 kb/s. Related to the transmission media is the design of medium access control (MAC). One approach of MAC design for sensor networks is to use TDMA based protocols that conserve more energy compared to contention based protocols like CSMA (e.g., IEEE 802.11). Bluetooth technology can also be used.

Connectivity: High node density in sensor networks precludes them from being completely isolated from each other. Therefore, sensor nodes are expected to be highly connected. This, however, may not prevent the network topology from being variable and the network size from being shrinking due to sensor node failures. In addition, connectivity depends on the, possibly random, distribution of nodes.

Coverage: In WSNs, each sensor node obtains a certain view of the environment. A given sensor's view of the environment is limited both in range and in accuracy; it can only cover a limited physical area of the environment. Hence, area coverage is also an important design parameter in WSNs.

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 combination of data from different sources according to a certain aggregation function, e.g., duplicate suppression, minima, maxima and average. This technique has been used to achieve energy efficiency and data transfer optimization in a number of routing protocols. Signal processing methods can also be used for data aggregation. In this case, it is referred to as data fusion where a node is capable of producing a more accurate output signal by using some techniques such as be to combine the incoming signals and reducing the noise in these signals.

Quality of Service: In some applications, data should be delivered within a certain period of time from the moment it is sensed; otherwise the data will be useless. Therefore bounded latency for data delivery is another condition for time-constrained applications. However, in many applications, conservation of energy, which is directly related to network lifetime, is considered relatively more important than the quality of data sent. As the energy gets depleted, the network may be required to reduce the quality of the results in order to reduce the energy dissipation in the nodes and hence lengthen the total network lifetime. Hence, energy-aware routing protocols are required to capture this requirement.

CONCLUSION

The past few years have witnessed a lot of attention on routing for wireless sensor networks and introduced unique challenges compared to traditional data routing in wired networks. Routing in sensor networks is a new area of research. Since sensor networks are designed for specific applications, designing efficient routing protocols for sensor networks is very important. In our work, first we have gone through a comprehensive survey of routing techniques 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. We can compare these protocols with respect to some parameters only. Future perspectives of this work are focused towards modifying one of the above routing protocols such that the modified protocol could minimize more energy for the entire system.

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