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Wireless Sensor Networks: A Survey

[1]Rasneet Kaur, [2]Madan Lal
[1,2]Dept. of Computer Engineering, University College of Engineering, Punjabi University, Patiala, Punjab, India

Abstract

This Paper reviews about the wireless sensor networks-architectures, protocols, applications and simulators.The demand of wireless sensor networks has robustly increased in current years. Wsns are increasingly deployed in a variety of applications, primarily for military application and currently used in monitoring of medical conditions inside human body, monitoring the climate change and also used in reporting the mechanical stresses in building and bridges. Research on several aspects of Wsns like energy efficiency, power management, topology control, data management and security are progressing extensively. In this paper a survey on recent trends in wireless sensor network research, different topologies, routing protocols, simulators and applications is carried out.

Keywords

Sensor Networks, Topology, Routing Protocols, CLH,WSN

I. Introduction

A wireless Sensor Network (WSN) is a focused wireless network that composes of a number of sensor nodes deployed in a specified area for monitoring environment conditions such as temperature, air pressure, humidity, light, motion or vibration, and so on. The sensor nodes are usually involuntary to monitor or collect data from surrounding environment and pass the information to the base station for remote user access through various communication technologies. Fig. 1 shows general wireless sensor network architecture. Typically, a sensor node is a small device that consists of four basic components as shown in fig. 2, (1) sensing subsystem for data gathering from its environment, (2) processing subsystem for data processing and data storing, (3) wireless communication subsystem for data transmission and (4) energy supply subsystem which is a power source for the sensor node. However, sensor nodes have small memory, slow processing speed, and scarce energy supply. These limitations are typical characteristics of sensor nodes in wireless sensor networks [1].

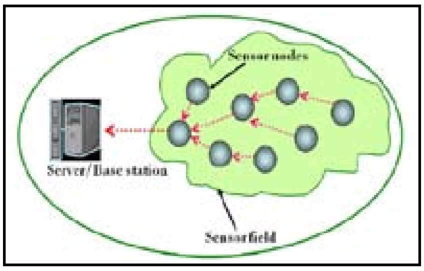


Fig. 1: Wireless Sensor Network [1]

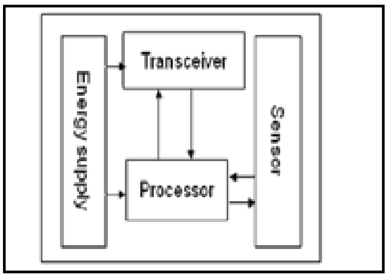


Fig. 2: Overview of Sensor Node Components [1]

II. Architecture of Wireless Sensor Network

A communication network is composed of several nodes, each of which has some computing power and can transmit and receive messages over wired or wireless communication links. There are several network topologies for communication networks and include fully connected, mesh, star, ring, tree, bus. A single network may consist of several interconnected subnets of different topologies.

A. Star Topology

In star topology, shown in fig. 3, all nodes are connected to a single unique node which operates as a PAN coordinator. The coordinator requires greater message handling, routing, and decision-making capabilities than the other nodes. Each device willing to join the network and communicate with other devices must send its data to the PAN coordinator, which is then sent to the destination devices. If any communication link is broken, it only affects one node but if the coordinator is broken the entire network is destroyed. Any node selected as a PAN coordinator will get its battery resources rapidly ruined. Taking these issues into consideration, the IEEE 802.15.4 standard recommends the star topology for applications such as home automation, personal computer peripherals, toys and games [2].

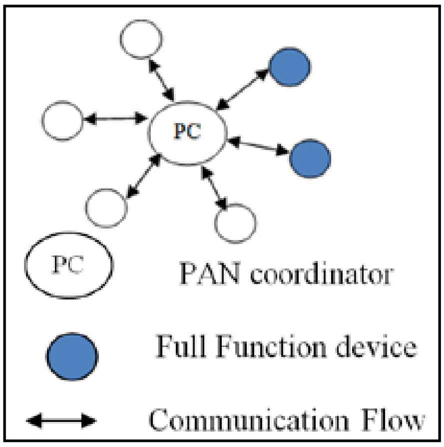
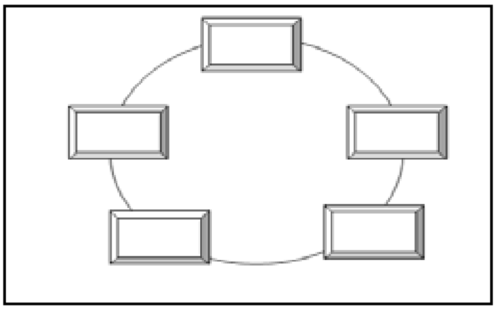


Fig. 3: Star Topology Model

B. Ring Topology

In the ring topology shown in fig. 4, all sensor nodes perform the same function and there is no coordinator node. Messages generally travel around the ring in a single direction. But if any link of the ring is cut, the entire communication is broken [2].

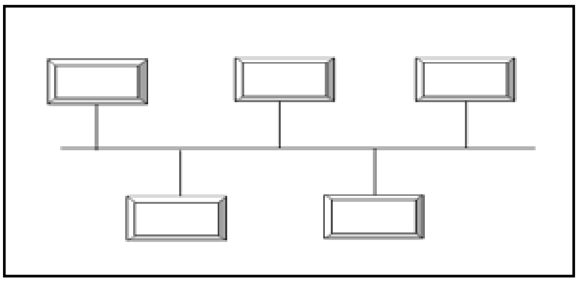


RING

Fig. 4: Ring Topology Model

C. Bus Topology

In the bus topology shown in fig. 5, the data messages will be broadcasted on the bus to all the nodes. When the node receives it checks the destination address in the message header and then decides whether the message is for itself or some other node. In this topology each node simple listens for the data messages and is not responsible for retransmitting any messages if any message is lost, thus the being a passive topology [2].



BUS

Fig. 5: Bus Topology Model

D. The Cluster-Tree Topology

The Cluster Tree topology shown in fig. 6 is a special case of a peer-to-peer topology in which most of the nodes are Full Functional Devices (FFD). Only one of them will be nominated as the PAN coordinator for identifying the network. This coordinator synchronizes with all other nodes and coordinators in the network. The Reduced Function Devices (RFD) will then connect to this cluster tree at the end of a branch and links with only one FFD.

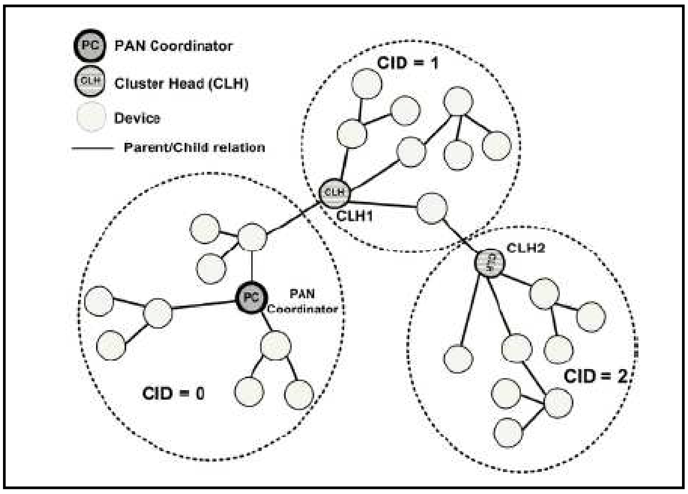


Fig. 6: Cluster-Tree Topology [2]

The first cluster is formed by the PAN coordinator by designating itself as CLuster Head (CLH) with a cluster identifier (CID) value of zero. The coordinator then chooses an unused PAN identifier and broadcasts beacons to all neighboring devices. Any device who receives the beacon can join the network by requesting the CLH. If the coordinator accepts this request, it adds the requesting device as the child in its neighbor list. In turn the newly joined device adds the CLH as its parent in its neighboring list and starts sending beacons. Any other devices who receive these beacons may join the network at this device. If in case the requesting device cannot join the network at the cluster head, it will search for another parent device. For a large-scale wireless network a mesh of multiple neighboring clusters can be formed [2].

III. Routing Protocols

Routing is a process of determining a path between source and destination upon request of data transmission. In WSNs the network layer is mostly used to implement the routing of the incoming data. It is known that generally in multi-hop networks the source node cannot reach the sink directly. So, intermediate sensor nodes have to relay their packets. The implementation of routing tables gives the solution. These contain the lists of node option for any given packet destination. Routing table is the task of the routing algorithm along with the help of the routing protocol for their construction and maintenance.

WSN Routing Protocols can be classified in various ways like according to the network structure, according to the protocol operation etc. Fig. 7 shows the classification of WSN routing protocols.

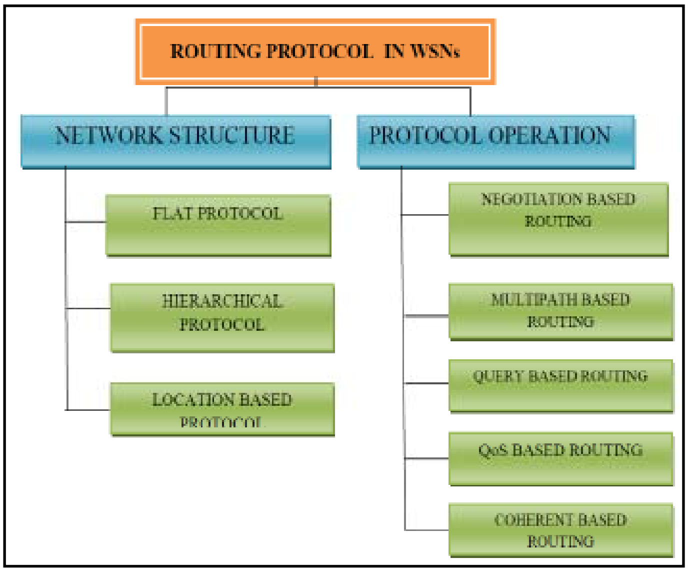


Fig. 7: Classification of WSN Routing Protocols

A. Network Structure Based Protocol

The underlying network structure may play an important role in the operation of routing protocols in WSNs.

1. Flat Protocol

This type of protocol is multihop flat routing protocols. In flat networks, each node usually plays the same role and sensor nodes cooperate together to carry out sensing task. Due to large number of nodes, it is not entitled to set global identifier for each node. This consideration has led to focused data path, where the BS sends queries to certain areas and wait for data from sensor located in the selected area. Since data is being requested through queries, attribute-based name is necessary to specify the data attributes. In flat routing group, we can find a huge variety of protocols:

- Sensor Protocols For Information Via Negotiation(SPIN)
- Direct Diffusion
- Rumor Routing
- Energy Aware Routing
- Gradient-Based Routing

2. Hierarchical Protocol

Hierarchical or cluster-based routing, originally proposed in wireline networks, are well-known techniques with special advantages related to scalability and efficient communication. As such, the concept of hierarchical routing is also utilized to perform energy-efficient routing in WSNs. In a hierarchical architecture, higher energy nodes can be used to process and

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send the information while low energy nodes can be used to perform the sensing in the proximity of the target. This means that creation of clusters and assigning special tasks to cluster heads can greatly contribute to overall system scalability, lifetime, and energy efficiency. Hierarchical routing is an efficient way to lower energy consumption within a cluster and by performing data aggregation and fusion in order to decrease the number of transmitted messages to the BS. Hierarchical routing is mainly two-layer routing where one layer is used to select cluster heads and the other layer is used for routing. However, most techniques in this category are not about routing, rather on "who and when to send or process/aggregate" the information, channel allocation etc., which can be orthogonal to the multihop routing function [3]. In this protocol group, we can find a huge variety of protocols:

- Low Energy Adaptive Cluster Hierarchy Protocol (LEACH)
- Power-Efficient Gathering in Sensor Information Systems (PEGASIS)
- Threshold-sensitive Energy Efficient Protocol (TEEN)
- Adaptive Periodic Threshold-Sensitive Energy Efficient Protocol(APTEEN)
- Hierarchical Power-aware Routing (HPAR)

3. Location Based Protocol

In this kind of routing, sensor nodes are addressed by means of their locations. The distance between neighbouring nodes can be estimated on the basis of incoming signal strengths. Relative coordinates of neighbouring nodes 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 (Global Positioning System), if nodes are equipped with a small low power GPS receiver. To save energy, some location based schemes demand that nodes should go to sleep if there is no activity. More energy savings can be obtained by having as many sleeping nodes in the network as possible. The problem of designing sleep period schedules for each node in a localized manner was addressed in. In the rest of this section, we review most of the location or geographic based routing protocols. In location based protocol, we can find a huge variety of protocols [3].

- Geographic Adaptive Fidelity (GAF)
- Geographic and Energy Aware Routing (GEAR)
- Most Forward within Radius(MFR)
- Geographic Distance Routing(GEDIR)

B. Routing Protocols based on Protocol Operation

In this section, we review routing protocols that different routing functionality.

1. Negotiation Based Routing Protocols [3]

In order to eliminate redundant data transmissions, these use high level data descriptors through negotiation. Based on the resources that are available to them, communication decisions are taken. The motivation is that the use of flooding to disseminate data will produce implosion and overlap between the sent data; hence nodes will receive duplicate copies of the same data. This consumes more energy and more processing by sending the same data to different sensor nodes. So, 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 node or the base-station by conducting a series of negotiation messages before the real data transmission begins.

2. Multipath Routing Protocols [3]

Multiple paths are used to enhance the network performance. When the crucial path fails between the source and the destination an alternate path exists that measured the fault tolerance (resilience) of a protocol. This can be increased, by maintaining multiple paths between the source and the destination. This increases the cost of energy consumption and traffic generation. The alternate paths are kept alive by sending periodic messages. Due to this, network reliability can be increased. Also the overhead of maintaining the alternate paths increases.

3. Query Based Routing Protocols [3]

The destination nodes propagate a query for data (sensing task) from a node through the network and a node having this data sends back the data to the node that matches the query to the query that initiates. Usually these queries are described in natural language, or in high-level query languages.

4. QoS-Based Routing Protocols [3]

In order to satisfy certain QoS (Quality of Service) metrics, e.g., delay, energy, bandwidth, etc. when delivering data to the Base Station, the network has to balance between energy consumption and data quality.

5. Coherent and Non-Coherent Processing [3]

Data processing is a major component in the operation of wireless sensor networks. Hence, routing techniques employ different data processing techniques. There are two ways of data processing based routing before being sent to other nodes for further processing. The nodes that perform further processing are called the aggregators.

(i). Coherent Data Processing

In coherent routing, the data is forwarded to aggregators after minimum processing. The minimum processing typically includes tasks like time stamping, duplicate suppression, etc. When all nodes are sources and send their data to the central aggregator node, a large amount of energy will be consumed and hence this process has a high cost. One way to lower the energy cost is to limit the number of sources that can send data to the central aggregator node.

(ii). Non-Coherent Data Processing

In this, nodes will locally process the raw data before being sent to other nodes for further processing. The nodes that perform further processing are called the aggregators.

IV. Applications

A. Area Monitoring

Area monitoring is a common application of WSNs. In area monitoring, the WSN is deployed over a region where some phenomenon is to be monitored. A military example is the use of sensors to detect enemy intrusion; a civilian example is the geo-fencing of gas or oil pipelines [5].

B. Environmental/Earth Monitoring

The term Environmental Sensor Networks, has evolved to cover many applications of WSNs to earth science research. This includes sensing volcanoes, oceans, glaciers forests etc. Some of the major areas are listed below.

1. Air Quality Monitoring
The degree of pollution in the air has to be measured frequently in order to safeguard people and the environment from any kind of damages due to air pollution. In dangerous surroundings, real time monitoring of harmful gases is a pertaining to process because the weather can change with severe consequences in an immediate manner. Fortunately, wireless sensor networks have been launched to produce specific solutions for people [5].

2. Air Pollution Monitoring
Wireless sensor networks have been deployed in several cities (Stockholm, London or Brisbane) to monitor the concentration of dangerous gases for citizens. These can take advantage of the ad-hoc wireless links rather than wired installations, which also make them more mobile for testing readings in different areas. There are various architectures that can be used for such applications as well as different kinds of data analysis and data mining that can be conducted [5].

3. Forest Fire Detection
A network of Sensor Nodes can be installed in a forest to detect when a fire has started. The nodes can be equipped with sensors to measure temperature, humidity and gases which are produced by fire in the trees or vegetation. The early detection is crucial for a successful action of the firefighters; thanks to Wireless Sensor Networks, the fire brigade will be able to know when a fire is started and how it is spreading [5].

4. Landslide Detection
A landslide detection system makes use of a wireless sensor network to detect the slight movements of soil and changes in various parameters that may occur before or during a landslide. Through the data gathered it may be possible to know the occurrence of landslides long before it actually happens [5].

5. Natural Disaster Prevention
Wireless sensor networks can effectively act to prevent the consequences of natural disasters, like floods. Wireless nodes have successfully been deployed in rivers where changes of the water levels have to be monitored in real time [5].

C. Industrial Monitoring

1. Machine Health Monitoring
Wireless sensor networks have been developed for machinery Condition-Based Maintenance (CBM) as they offer major cost savings and enable new functionalities. In wired systems, the installation of enough sensors is often limited by the cost of wiring. Previously inaccessible locations, rotating machinery, hazardous or restricted areas, and mobile assets can now be reached with wireless sensors [5].

2. Data Logging
Wireless sensor networks are also used for the collection of data for monitoring of environmental information; this can be as simple as the monitoring of the temperature in a fridge to the level of water in overflow tanks in nuclear power plants. The statistical information can then be used to show how systems have been working. The advantage of WSNs over conventional loggers is the "live" data feed that is possible [5].

3. Water/Waste Water Monitoring
Monitoring the quality and level of water includes many activities such as checking the quality of underground or surface water and ensuring a country's water infrastructure for the benefit of both human and animal. The area of water quality monitoring utilizes wireless sensor networks and many manufacturers have launched fresh and advanced applications for the purpose [5].

4. Preventing Natural Disaster
The consequences of natural perils like floods can be effectively prevented with wireless sensor networks. Wireless nodes are distributed in rivers so that changes of the water level can be effectively monitored [5].

D. Agriculture
Using wireless sensor networks within the agricultural industry are increasingly common; using a wireless network frees the farmer from the maintenance of wiring in a difficult environment. Gravity feed water systems can be monitored using pressure transmitters to monitor water tank levels, pumps can be controlled using wireless I/O devices and water use can be measured and wirelessly transmitted back to a central control center for billing. Irrigation automation enables more efficient water use and reduces waste [5].

1. Accurate Agriculture
Wireless sensor networks let users to make precise monitoring of the crop at the time of its growth. Hence, farmers can immediately know the state of the item at all its stages which will ease the decision process regarding the time of harvest [5].

2. Irrigation Management
When real time data is delivered, farmers are able to achieve intelligent irrigation. Data regarding the fields such as temperature level and soil moisture are delivered to farmers through wireless sensor networks. When each plant is joined with a personal irrigation system, farmers can pour the precise amount of water each plant needs and hence, reduce the cost and improve the quality of the end product. The networks can be employed to manage various actuators in the systems using no wired infrastructure [5].

V. Simulators
The Wireless Sensor Network applications require an end-to-end data transmission to achieve the required performance. It requires much effort and is expensive to study and analyze the behaviors of such WSNs by means of a test bed or deploying the WSN nodes. Various network simulators have been developed and they mainly focus on protocols used in WSNs. Some of them are general simulators, while others are to a specific to a hardware platform or operating system. This section describes some of the simulators used for Wireless Sensor Network.

A. NS-2
NS-2 is a predominant discrete event, object-oriented, network simulator in scientific environment written in C++. It is a widely used general purpose network simulator and has a rich library of protocols but focuses mainly on IP networks. It simulates the network at the packet level and allows a wide range of heterogeneous network configurations. It provides substantial support for simulation of TCP, routing, and multicast protocols over wired and wireless networks. OTcl is used as scripting language

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to control and configure simulations. It provides a GUI support with the network animator (Nam) and only reproduces NS-2 trace. Though NS-2 is a popular and widely used simulator there are some drawbacks. NS-2 does not provide detailed support for measuring the energy utilization of different hardware, software, and firmware components of a WSN node. The interdependence between modules due to object oriented design of Ns2 makes addition of new protocol more difficult [2].

B. GloMoSim

GloMoSim (Global Mobile Information System Simulator) is a scalable simulation environment for large scale wired and wireless communication networks. It uses a sequential set of library modules and parallel discrete-event simulation for wired and wireless networks. Glomosim uses the node aggregation technique to improve the performance. The Node aggregation implies that while maintaining the same number of entities in the simulation, the number of nodes can be increased. In GloMoSim, each entity represents a geographical area of the simulation [2].

C. OPNET

OPNET Modeler is a commercial platform for simulating communication networks. Conceptually, OPNET model comprises processes that are based on finite state machines and these processes communicate as specified in the top-level model. The wireless model is based on a pipelined architecture to determine connectivity and propagation among nodes. Users can specify frequency, bandwidth, and power among other characteristics including antenna gain patterns and terrain models [4].

D. OMNETT++

Objective Modular Network Test-bed in C++ (OMNeT++) is a public-source, component-based, modular simulation framework. It is has been used to simulate communication networks and other distributed systems.[4] The depth of module nesting is not limited, which allows the user to reflect the logical structure of the actual system in the model structure. Modules communicate through message passing. It can feature varying user interfaces for different purposes: debugging, demonstration and batch execution.

VI. Conclusion

Wireless sensor networks have become part of our networked world and their significance has grown extremely. Wireless Sensor Network an thrilling and open field of research. Still several technical issues have to be fully addressed and solved. Such successful approaches require highly developed paradigms, interdisciplinary expertise and cross-layer solutions. Some potential areas where research can be taken up in the wireless sensor networks are self-configuration, fault-tolerance, adaptation, flexibility, energy efficiency, efficient protocol design and operation, scalability and heterogeneity, security, privacy and trust, architectural issues etc. Wireless sensor networks [2] have great long-term economic potential, ability to transform our lives, and pose many new system-building challenges.

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Rasneet Kaur is pursuing M.TECH. Final year in department of computer engineering at University College of Engineering, Punjabi University, Patiala. She has done her B.TECH. in trade CSE from Punjab technical university,Jalandhar.. She has presented papers in national conferences. Her topic of research is wireless sensor newtork.

Madan Lal is Assistant Professor at University College of Engineering, Punjabi University, Patiala. He is pursuing P.hd from Punjabi university, Patiala. He has received his M.TECH. degree from Punjabi University, Patiala. His area of specialization is image processing.. He has to his credit many papers in international journals and national and international conferences.