Wireless Sensor Networks and Its Application for Agriculture

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Abstract The wireless sensor network (WSN) is the most proven technology in today's world. WSN has gained its applications that are different from other networks and even the usage of WSN has also inferred with other networks like VANETS that uses different types of sensors in its network. Arduino or raspberry pi uses different sensors to monitor and data can be obtained from any remote location at a very lower cost. Thus, miniaturization is possible using WSN. In this paper, WSN is being discussed in terms of evolution, scenario, hardware design, application, research issues, design constraints, research problem to provide an insight into WSN in different disciplines. Finally, the applications of WSN in agriculture with routing protocols are also being discussed. Thus, remote monitoring of agriculture using a sensor is demonstrated through this paper.

Keywords Wireless sensor network (WSN) · Agriculture · Sensor node

1 Introduction

The adoption of wireless sensor network (WSN) has been heard over a decade, and its applications are now witnessed a global presence. Characterized by low computational capability and minimal resources, a sensor node is programmed to extract environmental data and forward to the sink. This data forwarding mechanism is affected by many factors, e.g., routing technique applied, deployment strategy

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adopted, security protocols implemented, etc. Out of all these factors, energy is one of the prominent factors that affect the data forwarding operation of a node. This proposed work shows that the real-time sensors can also be used using routing protocols as most of the authors consider single-hop communication between sensor node and gateway. Routing protocols used in sensors makes it possible to have 2 or more sensors with a single gateway so that communication of larger distance can be done, thus using minimal sensors large coverage of agriculture area is possible. This paper introduces the fundamental concept utilized in the proposed study followed by the research problem adopted, research goals, and methodologies with one of the applications of WSN.

1.1 Wireless Sensor Network Background

WSN is a network that is built up of multiple sensors (popularly called 'Motes'), which consists of sensors, computing also and communication subunits. Ad hoc technologies and computation are initiating the network collaboration among these nodes in distributed manner. The first ever known WSN [1] application was implemented in 1950s by United States Military to detect and track the opponent USSR submarines, by the name sound surveillance system (SOSUS). This application is still serving US Military for peaceful functions of monitoring underwater wildlife and volcanic activities. Research activities on WSN started in academia at the late 1970s. Carnegie Mellon University and Massachusetts Institute of Technology joined their hands with US Military and started the distributed sensor network (DSN) program under the banner of United States Defense Research Project Agency (DARPA) [2]. They began exploring the challenges in implementing distributed/wireless sensor networks. The scope of WSN is for many defense and civil society applications where the various environmental parameters act as core data or information to make application workable. The collected data routes in a hop wise manner towards the primary data sink. The data from the sink traverse through the gateway to the monitoring stations [3].

1.2 Wireless Sensor Network Scenario

Fig. 1 below depicts a typical WSN (IEEE 802.15.4.) supervising the area of interest will initiate by deploying the application-specific sensor. Clusters are created to minimize the overload on the entire network; wherein cluster-head governs each cluster, also takes the responsibility of collecting, aggregating, and forwarding the data to the base station [4].

Although in the beginning, WSN were employed for a subtle deployment and that limited to the defense-related applications, today the invent of internet of things (IoT) has made WSN as a core component of it [4]. Applications which are built from

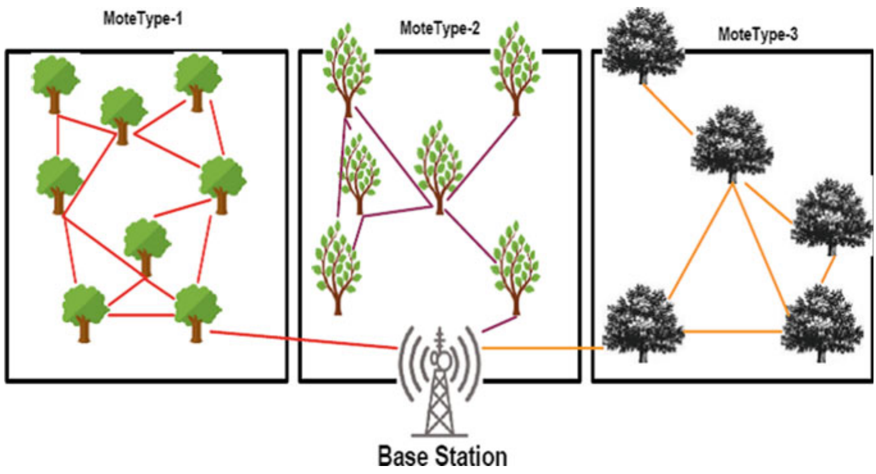

Fig. 1 A scenario of typical WSN

WSN and to name the few includes, smart cities, smart homes, healthcare, predictive maintenance, energy-saving smart grids, high confidence transport and asset tracking and intelligent buildings, etc. [5, 6]. A WSN will comprise several groups of 'nodes,' ranging from a few hundred nodes to several thousands of nodes, where each node will connect to another node or multiple neighboring nodes. A wireless sensor node is a typical equipment consisting a radio transceiver with inbuilt or external antenna, an application-specific sensor (transducer), a microcontroller, an interfacing electronic circuit housing Digital-Analog converter, a memory unit and an energy source in the form of battery. Occasionally, sensor nodes may also be facilitated with a solar cell and a charging circuit to extend the energy supply. A sensor node can have a size of a brick to a magnitude of a visible dust particle depending on the application. A sensor node, the familiar name is 'mote,' any functioning mote with a microscopic size is still under research. The cost of a mote may vary from a few dollars to several hundred dollars; it is application-specific, i.e., depending on the sensor used and the complexity of the mote. Earlier WSN technology [7] was narrow due to factors like insufficient bandwidth, limitations in the integrated circuit design, the size of the network nodes, the cost of the node, inefficient power management techniques [8].

The improvements in WSN technology allows robust monitoring, better power management techniques, control over remote monitoring, and even successful implementation in human inaccessible areas. Features like bidirectional communication, data transfer with acknowledgment, and also output conditions are configurable. The research in WSN and RF technology has extended the applications of WSN to agribusiness, water management, and underwater acoustic and deep-space networks. But, mostly WSN is preferred in human inaccessible and nodes are prone to damages due to natural calamities, battery life, stepping of human or animals, etc. A lot of research challenges are open for developing a rugged node, better node connectivity as WSN is an infrastructure-less and self-configurable network, lifetime optimization as the battery is not substitutable in the unreachable areas [9].

It is imperative that if any sensor node is not completely operational, necessary action should be taken to overcome any possible situation that may lead to degraded performance of the WSN upon identification of malfunction. Such defective nodes also result in an adverse influence on the WSN connectivity. The affected node not only stops the communication from itself, but also acts as an impediment of progressive routing from the other nodes as well. Hence, various existing topologies in WSN must be studied carefully and evolves up with better topological-based research to understand the coverage issues. Studies towards such direction can affirm a series of nodes to form a network which has less chance of getting broken. At the same time, equal stress should be given to the energy efficiencies, without which the sensor nodes are nonfunctional.

1.3 Hardware Design of Mote

A WSN requires all its constituent nodes to be productive and readily accessible, as it is most important during the construction. As per the demand of the application, the nodes participating in the construction of WSN should satisfy the prerequisites of the target application. They must be miniature in size, energy-efficient, modest, they must be equipped with an appropriate sensor, appropriate transceiver, sufficient memory hardware, and computing facilities. Extensive research work is in progress focusing miniaturization of the node size, optimization of energy consumption, economical design, based on the generalized node to application-specific requirements in the node.

Figure 2 exhibits the building blocks of a typical wireless sensor node are the microcontroller, transceiver, memory, sensor, an electronic integrated circuit, and a power source [10]. The controller schedules tasks like executing algorithms efficient energy utilization, controlling and processing the data collected from the sensor, memory management and controls the functionalities of all other components. Usually, a controller may be microcontroller/microprocessor. The transceiver is a combination of transmitter and receiver; transceiver operates in four different states like transmit, receive, idle, and sleep. Wireless sensor nodes are usually equipped

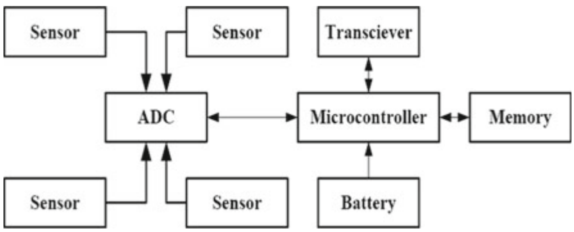

Fig. 2 Architecture of typical sensor node

with RF antennas, as radio frequency is the best suitable communication medium for WSN. Also, sensor nodes can use optical communication or an infrared medium. Infrared does not require an antenna, but they are limited to broadcasting only. Wireless sensor nodes equip with two different types of memories, one is program memory for programming the microcontroller, and the other is user memory for storing the data.

WSN are usually implemented in human unreachable regions, replacing the battery is ruled out. So, while developing an energy source for a wireless sensor node requires provisioning of adequate power available to energize the system for a long duration. A sensor node may get equipped with either rechargeable batteries through solar cells or a non-rechargeable battery [11]. Sensors are nothing but transducers having the capability of converting one form of energy to another form, for example, a thermal sensor senses atmospheric temperature and converts heat to electrical energy. Similarly, humidity, vibration, chemical, radioactive, sound, sonar, light, etc. Sensors are used based on the application requirements. Integrated electronic circuitry is also included to interface sensor, transceiver, the power source to the microcontroller, to provide an interface between microcontroller and analog to digital converter, an essential component to process the sensed data for processing and the output data from the microcontroller to antenna.

2 Literature Review

In [1] the author discusses various aspects of WSN like programming, security, localization, time synchronization, power management, network layer, physical layer, operating systems, node architecture. WSN is again well briefed in [2] on different issues like the anatomy of a sensor node, radio communication, link management, multi-hop, clustering. WSN is discussed in [3] with its application, MAC protocol, energy-centric simulation, privacy, and security [7]. Here, author concludes that clustering is a method to increase WSN lifetime and introduces the working of WSN. Here, author [4] discusses the advancement of sensor technology, smart instrumentation, WSN miniaturization [5]. Discusses design and modeling, network management, data management, security, and WSN applications. Here, [6] data collection, routing and transport protocols, energy-saving approaches, data storage and monitoring, physical layer and interfacing, and WSN application are discussed. This paper [8] discusses an overview of design fabrication and test-based MEMS inertial sensors and also shows how an application can be transformed into a practical design. This paper [9] discusses single-path routing protocols like LEACH, PEGASIS. Discussion is also extended for multipath routing protocols. Here [10] WSN applications have been discussed.

3 Wireless Sensor Network Application

At present, the sensor network has multiple commercial applications that demand both time-bound and mission-bound response. Some of the widely-known application:

- *Security Applications:* Sensor nodes are applicable in capturing data in stealth mode in various adverse conditions. Such applications are useful in monitoring line-of-control to check intrusive movements. Consequently, observation of unmanned regions, assets, perimeter, borders, and plateaus can be productive with the help of sensor networks.
- *Environmental Monitoring:* A sensor node contribute to a significant role in environmental monitoring, some key research areas under environmental monitoring are watershed, scientific investigation, pollution monitoring, weather, natural calamities, chemical disaster, mining safety, etc.
- *Industrial Development:* Industrial process automation, process control, production optimization, to manage the impact of environmental influences on production, remote monitoring of production process, etc.
- *Agriculture:* The modern approach of farming enables to improve the yield of the crop and minimize the cost incurred using sensors. It helps to measure various atmospheric and soil parameters. It also supports for intruder prevention, pest detection, disease prevention, protection against fire accidents, irrigation automation, etc.
- *Natural Disasters:* Collaborative decision techniques have enhanced wireless sensor networks to warn against natural disasters like earthquake, volcanic eruption, landslide, forest fire, twisters, tsunami, etc.
- *Automotive:* Wireless sensor motive industry has a broad range of application in the automotive sector, e.g., resisting vehicle collision, smart parking, identification, monitoring natural calamities, etc.
- *Health:* Body area networks have enabled WSN to monitor various parameters of the human body. Wireless autonomous sensors implanted in different parts of the body or wearable sensors used to measure the critical parameters of the patient and forward the clinically-important data to the physician based on which the doctor remotely monitors patient with the help of data received.
- *Monitoring of Structures:* Continuous monitoring of structures like bridges, buildings, etc., for their health status. Continuous monitoring is critical for structural integrity, environmental factors, wear and tear due to load, temperature humidity, corrosion, etc.
- *Under Water Sensor Networks:* Sensor nodes are useful in monitoring event under the water using acoustics. It is also important to note that wireless sensor networks can be utilized only at thermally solid depth; else acoustic communication is not much favorable due to reflection and refraction.
- *Future Markets:* Today WSN is becoming popular in retail outlets and public places for automatic door opening, motion detection, fire alarm, CCD devices, etc.

3.1 Research Issues in Wireless Sensor Networks

Some of the key research areas are:

- Transducer design: Development of bio-degradable, environmental friendly sensors, also adhering to the constraints compact in size, low power consumption, and economical designs.
- Electronic system design: Miniaturization of the integrated circuit with modern techniques is the real challenge today. Digital data extraction from integrated sensors through appropriate electronic circuitry, data aggregation, and transmission through electronics and removal of noise using sensor arrays are possible in today's technology.
- Node design: Design and development of robust and rugged nodes, yet consumes very less power, high processing capability, and excellent network communication.
- System Design: This problem pertains in using the existing nodes while applying a scheduling scheme.

3.2 Design Constraints for Wireless Sensor Networks

The design constraints of the sensor network are as follows, [12].

- *Fault Tolerance:* WSN deployed in unmanned areas, may fail due to blockages, power failure, physical damage, environmental issues or intruder, etc. However, such issues should not be affecting the usual networking performance of the sensor node.
- *Scalability:* Scalability is another critical design constraint over sensor network which states that some sensors used over the area affect the performance. Environmental monitoring may need several thousand nodes; a megastructure may require millions of nodes. But, a simple application like surveillance may require several hundred to less than a hundred nodes. The new scheme developed should be able to work with several nodes to millions of nodes.
- *Production Cost:* The deployed sensor nodes are not easily replaceable, and also, they are prone to damages due to various reasons. The number of nodes deployed may vary from several hundred to several million nodes application specifics; the production cost is paramount and should be very low.
- *Hardware:* A sensor node is always application-specific, apart from the essential components. The design of the sensor node should accommodate the entire required element, yet the size should be minuscule sometimes to the size of the dust.
- *Network Topology:* Wireless sensor networks are deployed based on the purpose. In the deployment stage, it can be placed uniformly, thrown randomly, dropped by plane, etc. In the post-deployment phase, the topology of the network may change due to node placement and its position, the distance between two consecutive

nodes for connectivity, obstacles, damages, etc. In some cases, additional nodes may be redeployed to re-establish the coverage and connectivity.

- *Environment:* Sensor nodes are also deployed in chemically contaminated areas, war field, deep ocean, valleys, mountains, megastructures, etc.
- *Transmission Media:* Sensor nodes today adopt different transmission media like infrared, bluetooth, optical, radio waves, etc. Enabling the network for universal operation requires, proper transmission media should be made available. The traditional transmission medium is radio frequency 2.4 GHz. But, smart dust adopts optical medium for communication.
- *Power Utilization:* The sensor being a microelectronic device can be equipped with the limited battery source, typically <0.5Ah, 1.2 V. The node has to perform three essential operations like sensing, communication, and data processing. Therefore, a sensor node lifetime depends on the battery life of the sensor.
- *Heterogeneity:* Modern application demands programming to support communication between different hardware technologies, as the applications areas are becoming more and more challenging. Sensor development is also very fast, so the program should support the broad range of sensor node technologies.
- *Coverage:* A connected sensor defines how effective the coverage range is and how stable the route establishment has been for a given area. When nodes distributed sparsely, only a particular area of interest may get covered. Redundant nodes may occur in some physical locations where accuracy and redundancy are required.
- *Connectivity:* The physical location of the individual sensor and the distance between two consecutive sensors, whether they are in communication range or not, defines the connectivity of the network. Connectivity is irregular due to the partitioning of the network, even if some part of the network gets partitioned, transmission can be done by using mobile nodes.
- *Lifetime:* The battery of a sensor node has a definite lifetime which consistently drains during the communication. Development of extended life battery with proper power scheduling algorithm is very essential.

3.3 Research Problem for Wireless Sensor Network

Multiple dependable factors contribute to ensuring connectivity among the nodes in WSN, where the primary factor is energy and secondary factor is node deployment strategy. However, the presented study inclines towards investigations in the direction of energy efficiency mainly along with the fault-tolerant operation of the nodes. Such identification will help in setting up a proper wireless sensor network for various applications.

The occurrences of node failures are usually caused owing to security breaches in the wireless sensor network. Due to the various types of attacks, there is a possibility that a compromised node can act maliciously and can tend to either drop a packet or corrupt the routes. There is also a possibility of uncertain hardware circuitry problems owing to certain external reason causing node failures. Imperfect usage of routing protocol may also lead to dissemination of error-prone data.

The present study focuses on the critical cause of node placement as well as fault-tolerant issues on the energy factor. In the long run, when the sensor nodes start depleting the energy, the declined performance of that node affects the entire network performance negatively. Such a situation very often gives rise to network partitioning problems.

The availability of sufficient residual energy significantly supports the potential radio transmission in wireless sensor network [13, 14]. When a node depletes energy, other nodes connected to it have to dissipate extra energy to make the communication operational, thereby causing faster degradation of available power. Another significant cause of energy dissipation is external environmental factors, e.g., rain, the surface condition of the earth, interference, noise, etc. Such environmental factors strongly influence the performance of the sensor nodes for capturing the real-time event of the surroundings and uses extra battery life to process the raw information. The presence of various types of natural objects like trees, hills, etc., also affects the transmission quality resulting in degradation of communication performance. The prime research problems of the proposed study are as follows:

- **Node Placement**: Node placement is one of the significant problems that initiate from the beginning of the cluster setup stage. Majority of the existing trends of research towards WSN uses random deployment of the sensor for the large scale area and uniform (or grid) deployment for the smaller-scale area. This is mainly done for the convenience of deployment viewpoint. However, random deployment does not ensure that all the nodes are in sensing range of each other while grid deployment does not ensure effective optimization of energy and resource.
- **Energy Efficiency**: From more than a decade, energy has always been the primary problem. Even the existences of hierarchical protocols are in constant phases of enhancement, which means lack of any protocol to ensure maximized energy conservation. Moreover, with lower computational capability, the sensor node will need to deplete more energy to perform transmission. In the concept of data aggregation, a cluster-head consumes maximum energy which is still not found to be lowered. Hence, energy is one of the ongoing issues which need a smart alternative solution without degrading communication.
- **Fault Tolerance**: Sensor network is always characterized by a large number of interconnected nodes, where the presence of a direct link is extremely less. Majority of the nodes performs communication with the help of the relay node. Therefore, any form of fault in a sender can generate a faulty sensory reading.
- **Agricultural Application**: Sensors used over the crop field normally extracts multiple forms of environmental data for ensuring better information gain for crop cultivation. These sensors are normally affected by harsh climatic condition, and hence, they will not operate as anticipated over an as large scale. At the same time, physical damage in any sensor will not draw any attention due to large scale operation. Hence, at any cost, the node connectivity management gets adversely affected which indirectly affects the crop cultivation.

From the survey of WSN, it is found that WSN has narrow work in a few areas which can be taken up for research

1. Node placement and higher fault tolerance that ensures energy efficiency, reliability, and
2. Cost-effectiveness with better applicability over agricultural-based application.

4 Proposed Work

In proposed work, our discussion will be towards the usage of WSN for agriculture. Real-time sensor nodes along with humidity, temperature, moisture sensor (HTP) are considered. Routing protocol level-based (LBR) and MAC-based (MBR) are considered. Figure 3 shows communication between four sensor nodes and a radio module with a gateway with neighbors involved in communication. Such instance would cause a higher range of communication, as with four sensors will be able to communicate for about a km long. Thus, a unique approach is being found to replace the typical way of agriculture by introducing technology and calling it as e-agriculture.

Figure 4 shows the working with sensors and radio modules, which considers the parameter Humidity, temperature, pressure (HTP) that is related to the crop. As shown in Fig. 4, all the three parameters at times can be measured from a crop of the greenhouse. The algorithm is such that any change with temperature, pressure, or humidity is automatically detected onto the screen. The readings are brought down to the computer interface and displayed on screen which is a desktop or laptop, which in future can be extended for remote users with the farmer from anywhere using mobile. The HTP sensor is again been used with both LBR and MBR routing protocols, where LBR is performing well with HTP. Reason for better performance is as the data is through neighbors, part of data is lost with MBR protocol.

Fig. 3 Scenario of two sensors setup for measuring various parameters of crop

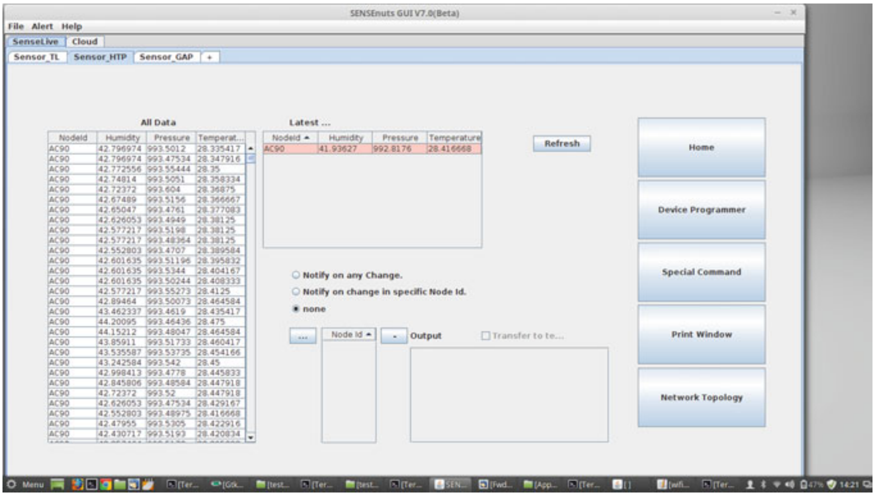

Fig. 4 LBR-based routing protocol to measure temperature, humidity, pressure

5 Simulation

The sensor used for sugarcane monitoring, monitor data for HTP and able to successfully receive data at the gateway which is away from the sensor nodes. Figure 5 shows a measurement of light intensity with the crop using both LBR and MBR routing protocols; the methodology is similar to that done with the temperature measurement. Better readings can achieve with LBR routing that has been again compared with a simple hop to hop communication using a radio module sensor with the radio module gateway, of which readings are same as that of LBR routing which is used with fewer nodes for a shorter range of communication.

Figure 6 shows a graph of humidity measurement of the crop in the greenhouse, using LBR and MBR routing protocols and Fig. 7 shows a measurement of pressure using same routing protocols, and dynamo is measuring pressure and humidity related with the crop. As these are the parameters related to water content with crop and the water presence may be due to many reasons like rainwater or natural water from the stored tank or vapor content during the morning hours, because of these reasons variation in the readings may be obtained. Hence, the measurement with the greenhouse effect is preferred. However, the LBR protocol can achieve better with both the measurements.

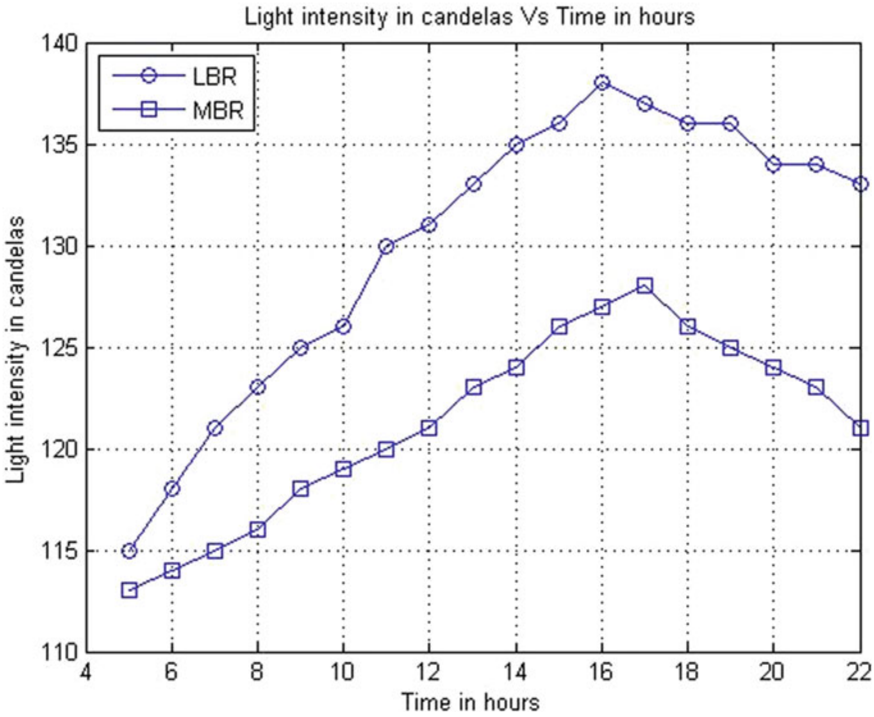

Fig. 5 Showing light intensity measurement for LBR and MBR routing protocols

6 Conclusion

In this paper, the architecture, application, design constraints, research problem, etc., of WSN are discussed so that researcher can get to know all the basic information of WSN. Further, one application of WSN in agriculture is considered. Most of the time sensors used as single-hop communication to the gateway are replaced by routing technique to increase the communication range of WSN and to save energy of nodes, demonstrated through the proposed experiment.

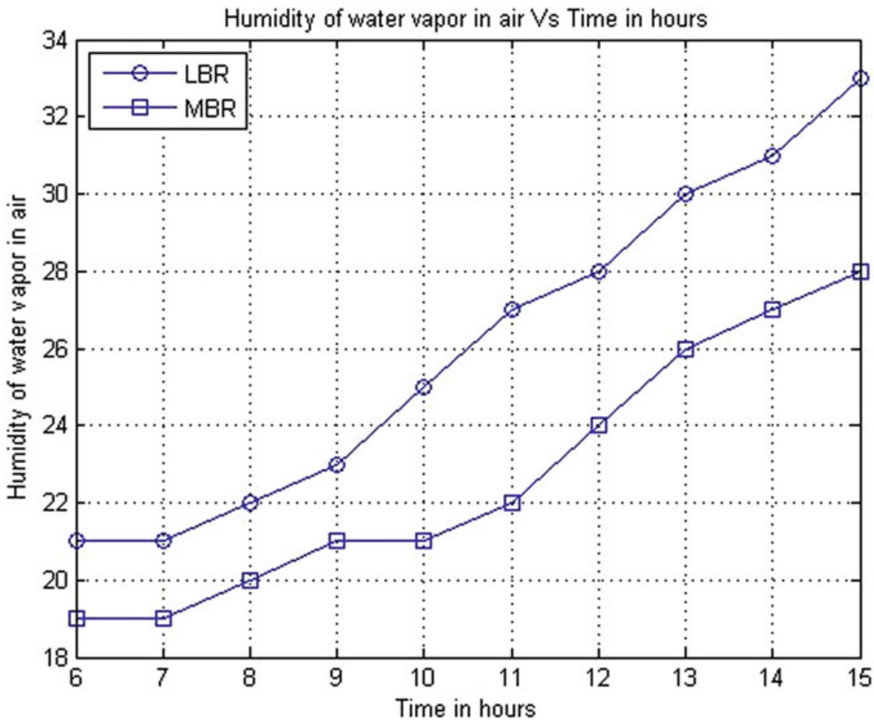

Fig. 6 Showing humidity measurement for LBR and MBR routing protocols

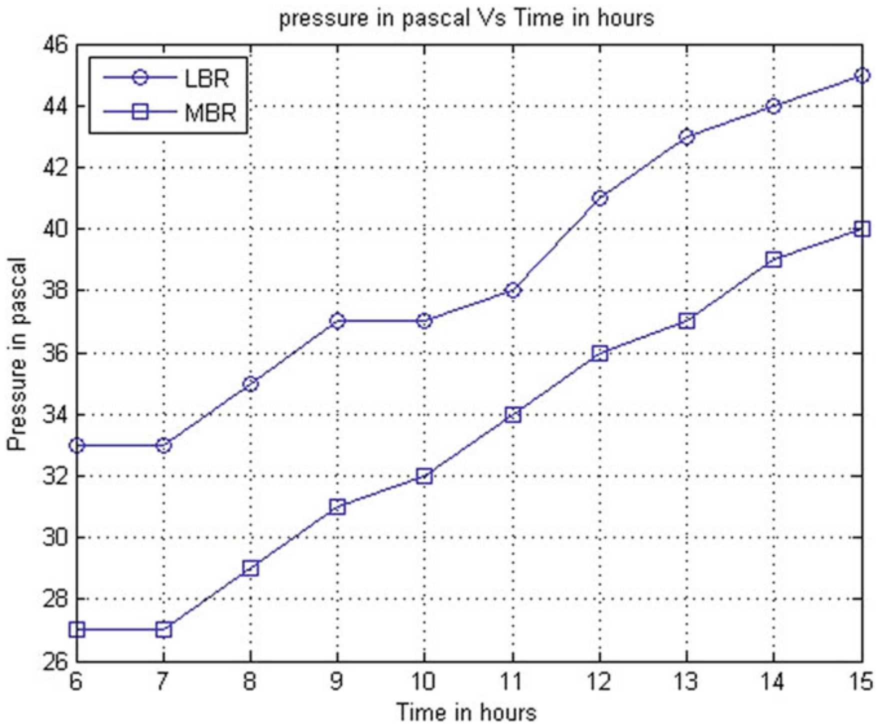

Fig. 7 Showing a pressure measurement for LBR and MBR routing protocols

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