Wireless Sensor Network in Agriculture: Needs, Challenges and Solutions

Neha Gupta, Preeti Singh, and Pardeep Kaur

Abstract Wireless communication technologies are increasingly growing in today's era, which are providing great research opportunities in the networking area. Wireless sensor network (WSN) is one such example of wireless communication technology. WSNs are widely used in agricultural field in order to help farmers cut down their expenses and increase the profit margin. Precision agriculture (PA) is a management strategy that helps to improve the quality as well as the quantity of the production. In this paper, sensor networks are classified on the basis of different parameters, the various issues and the challenges that are faced while deploying WSNs are also reviewed for improved farming. In this review paper, the comparison of different wireless communication protocols and energy-efficient protocols is analyzed comprehensively.

Keywords Base station · Routing protocol · Sensor nodes · Wireless sensor networks

1 Introduction

With the increasing population, the demand for agricultural crops is also increasing at a rapid pace. As per the reports of UN world population prospects 2019, the population of the world is estimated to rise by 2 billion in the next 30 years, i.e. from 77 billion cur recently to 9.7 billion in 2050 [1]. Also the agricultural land has reduced to 37% according to the food and agriculture organizations. The reasons for this decrease comprise of urbanization, global warming, natural disasters and the shortage of water availability. Wireless sensor network (WSN) technology can alleviate the problem of less agricultural output by implementing the precision agriculture. WSN is a system that comprises of sensors, processing unit, radio frequency transceiver unit and power unit as shown in Fig. 1.

N. Gupta (✉) · P. Singh · P. Kaur
UIET, Panjab University, Chandigarh, India
e-mail: nehagupta101005@gmail.com

P. Singh
e-mail: preeti_singh@pu.ac.in

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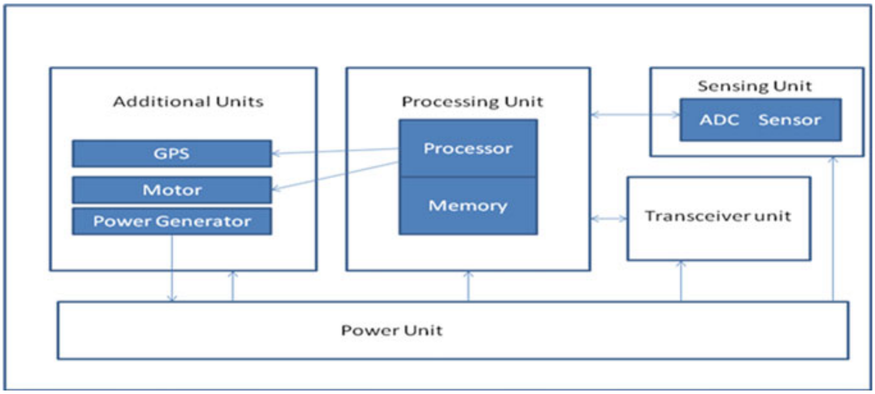

Fig. 1 Wireless sensor node architecture

Wireless sensor networks can be used for various applications in agriculture like precision agriculture, irrigation scheduling and optimization of plant growth, farmland monitoring, agricultural production, process management and security in crops [2]. Precision agriculture is based on the phenomena of collecting the information from the soil using the sensors and sending the information to the sink node either by single-hop or multi-hop communication. The sink node then transmits the collected information to the base station and then the base station (BS) forwards it to the system where the actual decision is taken and the information is finally sent to the farmer regarding the crop as depicted in Fig. 2. There are different concerns that need to be taken into mind while working in the field of wireless sensor networks like quality of service, energy consumption, data processing and compressing techniques [3]. Among all energy consumption in WSNs is a major concern in agricultural field. When the base station and the source nodes are located far away from each other and if there is direct communication between them then a lot of energy gets wasted in

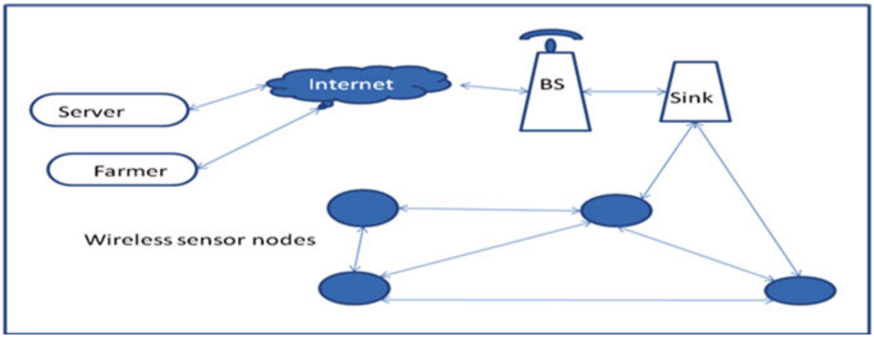

Fig. 2 Deployment of WSN in field

this process. Thus an efficient routing algorithm is needed that minimizes the energy consumption.

1.1 Motivation

In today's era, agriculture sector is a very important factor for economic growth of a country so it should be modernized with technologies and should replace the traditional way of farming. With the availability of micro and cheap sensors in the market, it has enabled advancement in traditional agricultural practices [4]. But there are also few challenges associated with WSN, i.e. energy consumption, less memory of sensors, fault tolerance and computational complexity, which need to be addressed [5]. WSN technology can be applied in different areas like irrigation scheduling by monitoring the moisture of the soil, early warning system of plant health by predicting any invasive species or disease likely to happen. The solutions need to be cost-effective so that the farmers can use these technologies. There is a lot of potential of WSN in agriculture since very limited work is done till date. In today's era of artificial intelligence, wireless sensor networks are widely used in agricultural fields like animal census is being carried out on a large scale. Drone monitoring of the agricultural fields, spraying of pesticides, fertilizers is nowadays a very common trend.

1.2 Organization of the Paper

In this paper, the different techniques that are associated with the WSNs are discussed along with their potential scope for the advancement in agricultural field. The sensor networks are classified on the basis of different parameters, which are used in the agricultural field. Section 2 presents the basics of WSNs and sensors network classification is also discussed. Issues and challenges faced while deploying the sensor nodes are presented in Sect. 3. The standards, technologies that are used in agricultural applications are discussed in Sect. 4. Section 5 discussed the implementation of WSNs in the agricultural field. The existing routing algorithms are discussed and analyzed in Sect. 6. In Sect. 7, the paper is concluded with the scope of future work.

2 Types of Sensor Networks

The sensor networks are classified on the basis of different parameters, which are discussed below. The type of sensor network is selected based upon the requirement of the application. Figure 3 shows the classification of sensor networks with respect to different parameters.

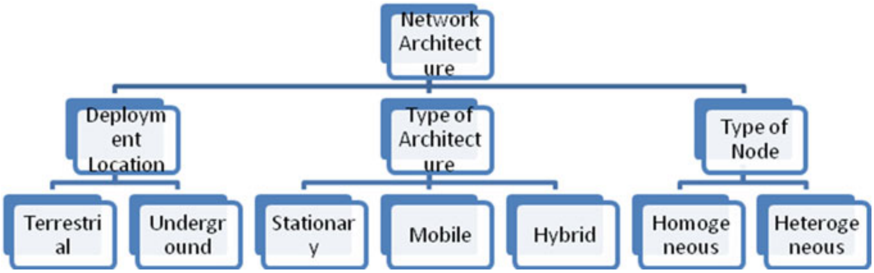

Fig. 3 Classification of sensor networks

2.1 Based on the Deployment Location

The location of the deployment of the sensor nodes is a very important parameter in wireless sensor networks as it determines the viability of the network. The sensor nodes can be deployed below the ground or above the agricultural ground depending upon the requirements of the application.

2.1.1 Terrestrial Wireless Sensor Networks (TWSN)

In such type of sensor networks, sensor nodes are deployed above the ground to create an intelligent network by the means of small and cheap sensors. In precision agriculture field, this type of sensor network is used in soil moisture, temperature and humidity measurement [6]. It is widely used in WSN applications because of less cost, less energy consumption and higher communication range and frequency.

2.1.2 Wireless Underground Sensor Networks (WUSN)

In this type of sensor networks, the sensor nodes are deployed inside the soil in the agricultural field. It is used to check the quality index of the soil [7]. One of the major limitations of these networks is the attenuation of signals at higher frequencies and comparatively lower frequency signals are able to penetrate inside the soil. As a result of which the communication area gets limited and thus more number of nodes are required when compared with TWSN thus it is not widely used in wireless sensor applications.

2.2 Based on the Characteristics of Sensors

Wireless sensor networks have different architectures depending upon the nature of sensor nodes, i.e. whether the autonomous nodes are stationary or moving. Sensing the data input from the nodes plays an important part in an effective communication so sensor nodes should be chosen carefully.

2.2.1 Stationary Architecture

In this type of architecture, the sensor nodes are always stationary and the routing is fixed. Applications like irrigation management, optimizing the use of pesticides, groundwater monitoring require stationary architectures [8].

2.2.2 Mobile Architecture

In this type of architecture, the sensor nodes are continuously moving in order to collect the data from different nodes and give it to the base station or sink. In mobile wireless sensor networks, the routing is dynamic [9]. The major limitations are self-organization of nodes, navigation and control, maintenance, localization.

2.2.3 Hybrid Architecture

In this type of architecture, the sensor nodes are both stationary as well as mobile in nature. It is one of the best architectures when compared with other two architectures in terms of energy and self-organization capability. This type of architecture can be used for tracking the movement of animals, which enters the field and sending the message to the farmer.

2.3 Based on the Sensing and Transmission Power

2.3.1 Homogeneous Network

In this type of network, all the sensor nodes in the network collect the same level of the transmission power with the same parameters of the data, and the collected data are sent to the base station. This type of network is best suited for in situ monitoring of the agricultural field. One of the major drawbacks of this network is the lack of variety in communication hardware.

2.3.2 Heterogeneous Network

In this type of network, all the sensor nodes sense the different parameters of the data having different transmission ranges. These networks use multiple hoping techniques to reach the cluster head of the network [10]. One of the limitations is non-uniform energy drainage because every node requires different amount of energy to send the data to the cluster head based on its location. But the major advantage is the increase in the lifetime of the network.

Thus, it is concluded that uniform energy drainage and lower hardware cost are the two parameters that need to be kept in mind while deploying sensor nodes. On one hand, homogeneous networks have uniform energy drainage and on the other hand, heterogeneous networks have lower hardware cost. The solution can be proposed to include both features in a single network.

2.4 Layout of the Sensor Nodes

Layout means the physical arrangement of the sensor nodes in the agricultural field. Placing the sensor nodes in the field is a very important part of precision agriculture, which should be given proper attention. The agricultural output will eventually grow with time and thus can affect the output of the system. So care should be taken while placing the nodes in the field. The nodes can be placed both horizontally and vertically.

2.4.1 Horizontal Layout

In this type of layout, the nodes are placed in the grid pattern, i.e. nodes are placed in rows and columns forming a grid pattern. Although this layout looks like easy implantation but overlapping of the sensor nodes is a serious problem. Jing et al. have proposed to implement this layout in orchid farms to measure soil moisture, humidity, temperature parameters [11].

2.4.2 Vertical Layout

In this type of layout, the nodes are not placed on the ground, i.e. they are placed on the plants. This is because of the fact that all the plants grow either in upward or downward direction. Hence, this type of layout is better than the horizontal layout. Harris et al. (2016) have placed the nodes at seven different heights of the tomato plant to measure the temperature–humidity parameters [12]. Also, Akkas et al. (2017) have fixed the height of the sensor nodes at one point and monitored the humidity, temperature and pressure parameters [13].

3 Challenges Associated While Deploying Sensor Nodes

Deploying sensor nodes in an organized manner ensures better monitoring of the agricultural field. Although there are various challenges that are faced while placing sensor nodes in an agricultural field. These challenges are discussed as follows:

3.1 Node Size

The size of a sensor is a very crucial factor that needs to be addressed properly. With the advancement of MEMS technology, it has been made possible that small size sensors are available for different parameters like temperature sensors, humidity sensors, wind sensors etc., so appropriate sensors should be chosen as per the requirements of the application [14].

3.2 Energy Consumption

Energy is consumed while performing different tasks like sensing the data, processing it and transmitting the data to the base station. So a lot of energy is required for day-to-day monitoring of the agricultural field. The proposed solution can be the solar energy. It is one of the potential alternatives to battery-powered wireless sensor networks. Greenhouse monitoring using solar panels is one such application.

3.3 Fault Tolerant

The system needs to be fault-tolerant as the nodes are deployed in an open field so there are lots of physical barriers experienced like with the increase in height of crops interference in signals occur, lack of communication between different sensor nodes, blockage by animals, etc. [15]. So in order to address these problems, fault-tolerant techniques need to be designed and addressed. To the best of author's knowledge not much work has been done in this field so there is a lot of potentials to work in this field.

The proposed solution can be the consideration of the coverage area. It is one of the most important aspects to consider while deploying sensor nodes in a network that shows how a particular area or barrier is being monitored. There are three coverage problems, which need to be addressed:

I. Target coverage: To cover only particular points in the monitored area is termed as targets.
II. Area coverage: To cover a particular area of the sensor field.

III. Barrier coverage: It is a round area in which any person, animal can be detected by the sensors, which are deployed inside the circle.

3.4 Transmission Range

Transmission range is also a very important factor since the sensors need to be placed very close to one other for effective communication. But in an open field due to ecological imbalances like rainfall, wind etc. the communication between the sensor nodes gets affected [16]. So one alternative is indoor agriculture, i.e. greenhouse cultivation in which the crops are cultivated in a closed environment and monitored continuously [17]. Another way is to increase the communication range by using different architecture topologies like mesh architecture, multi-tier architecture [18].

4 Communication Technologies Used in Wireless Sensor Network

The data that have been sensed by the sensors need to be communicated to the system where the decision can be taken and conveyed same to the farmer. In this, sensors need to communicate the data to the base station. For efficient way of data communication, the technology should be chosen based on the requirements of the application [19]. A survey of various communication technologies is discussed in this section.

4.1 Zigbee

The origin of Zigbee technology originated in 1991 but it was standardized in 2000 by the Zigbee alliance and came into use [20]. It operates in 2.4 GHz ISM band and is used in communication from layer 3 onwards [21]. This standard operates as IEEE 802.15.4; its function is to provide the network with routing and networking functionalities [22]. It supports various network topologies like master to master or master to slave. In this technology, the system comprises of three different devices: router, Zigbee coordinator and Zigbee end device [23]. The network has one coordinator, which functions as a bridge by handling and storing the data while doing the receiving and transmission tasks [24]. It has the communication range of 10–20 m. Due to its low power consumption and low-cost capabilities, it is a widely used communication technology.

4.2 Bluetooth

The Bluetooth technology was invented in 1994. This standard operates as IEEE 802.15.1 with frequency band 2.45 GHz [25]. It can connect eight different devices within a range of 10 m. This network comprises of a single master and up to seven slaves. This type of arrangement is termed as piconet and when these piconets combine together this arrangement is called scatternet [26]. Hseih et al. (2016) have used this configuration to design an irrigation network. Master initiates the communication and the slaves respond to it [27]. The Bluetooth module is active in the first three layers whereas the host is active in the last two layers. This type of interfacing between these two groups is termed as host controller interface [28].

4.3 Wi-Fi

Wi-Fi nowadays is the trending most used wireless network technology. It stands for "Wireless Fidelity". The origin of Wi-Fi dates back to 1991 and was invented by AT&T in the Netherlands. This standard operates as IEEE 802.11 and uses radio frequency band [29]. It has the range of 20–100 m with a high speed 2–55 Mbps. Thakur et al. (2018), Guo et al. (2018) have used the Wi-Fi module to communicate the data to the farmers. This technology is widely used to connect many devices over a long range [30].

4.4 GPRS

General Packet Radio Service (GPRS) was introduced in the market in 2000 by the European Telecommunications Standards Institute (ETSI) but is now maintained by the third generation partnership project (3GPP) [31]. It is one of the best technologies in terms of latency and throughput. It has a data speed ranging from 56 to 114 Kb/s [32]. When 2G technology combines with GPRS, it is termed as 2.5G, i.e. a technology that is between 2 and 3G Technology. Humberto et al. analyzed this technology as a gateway between Zigbee wireless sensor networks and internet for precision agriculture. Joaquin et al. used the GPRS module [33] to communicate the soil moisture and temperature parameters to the system, which resulted in water savings of up to 90% when compared with traditional irrigation practices.

4.5 WiMAX

Worldwide Interoperability for Microwave Access was introduced in 2001 by the WIMAX forum. This standard is based on the IEEE 802.16 and was introduced as an alternative to cables and DSL [34]. It has data speed up to 1Gb/s. Musha et al. (2014) have used this technology [35] to monitor and control the agricultural field for irrigation system using sensors. However, it is an expensive technology in terms of installation and operational cost. Also, it has poor quality service. This is because in situations when more number of people are accessing the same tower at the same time, it becomes very tough to maintain high quality [36].

4.6 Comparison of Different Communication Technologies

As per Table 1, the comparison of different communication technologies on the basis of different parameters is shown. If the application requires data transmission of longer distance with medium power consumption then WiMAX is the best option. Based upon the requirements and applications, suitable technology can be selected to decrease the cost.

Table 1 Comparison of technologies [38]

Parameters	Zigbee	Bluetooth	WIFI	GPRS	WiMAX
Frequency band	2.5 GHz	2.4 GHz	2.4 GHz	900–1800 MHz	2.5–3 GHz
Range	10–100 m	1–100 m	20–100 m	Gprs coverage area	1–30 m
Data rate	20–250 Kbps	1–24 Mbps	2–54 Mbps	32–48 Kbps	1 Gbps
Cost	Low	Low	High	High	High
Power consumption	Low	Medium	High	High	Medium
Network size	64,000 nodes	8 nodes in piconet	30 nodes	1000 nodes	Varies
Mode of communication	Peer to peer	Master and slave, Peer to Peer	From one point to all devices	From Base station to all devices	From one point to multipoint
Security (bits)	128	128	128	128	128

5 Wireless Sensor Network Applications in Agriculture

Wireless sensor network technology can be applied in the agricultural field to increase the production of the crops and thus increase the profit margin of the farmers. The various applications include.

(1) Monitoring the environmental conditions.
(2) Precision agriculture.

5.1 Monitoring the Environmental Conditions

The environment can be monitored through stationary sensors, which are deployed in the fields. These sensors can sense the water quality, soil quality and send the information to the system where the data can be analyzed and the corresponding action can be taken [37].

Crossbow Technology Inc. (2004) developed a wireless sensor network [39] based on solar power that collected the atmospheric weather condition like moisture in the air through the use of sensors and the collected data were conveyed to the end-users. **Soil** Tsvetelina et al. (2016) developed a wireless sensor network [40] to monitor the soil quality parameters. But, however, there were few limitations in this research work while dealing with an appropriate management technology. There are very few research papers in the monitoring of soli parameters so work can be done in the future in this area. S.N. Shylaja et al. (2017) developed a mobile application [41] for the farmers to help them gather real-time information about the fertility of soil and suggested the right time to put fertilizers in the field.

5.2 Precision Agriculture

Wireless sensors are used in precision agriculture to help in data collection, precision irrigation and technology for communication. In data collection, J.John (2018) developed the shortest path tree-based wireless sensor network [42] to collect the different parameters like relative humidity, atmospheric pressure. The system was composed of different sensors deployed in the field that include atmospheric temperature sensor, relative humidity sensor, soil moisture sensor, soil temperature sensor. In precision irrigation, Y.Hamouda et al. (2018) developed an optimal heterogeneous irrigation system for measuring the content of water in the soil. Kalman filter was used to differentiate the sensed soil moisture and the temperature from the surrounding environment.

6 Different Routing Protocols

Routing protocol reduces the power consumption by minimizing the path between the sensor nodes and the base station. This section analyzes the different routing algorithms used for WSN. Haider et al. (2013) have proposed REECH-ME [43] routing protocol in which a node having maximum energy became the cluster head that resulted in a fixed number of cluster head in each round. In this protocol, network lifetime and throughput improved significantly. It has better results when compared with LEACH routing protocol. Amjad et al. (2013) have proposed DREEM–ME [44] routing protocol in which the network area was divided into three concentric circles with center as origin that resulted in a reduction in distance between cluster heads and base station. This protocol has improved network stability and lifetime of the network significantly when compared with LEACH protocol. Nadeem et al. (2013) have proposed gateway-based M-GEAR [45] protocol for WSN in which the area was divided into four logical regions. The base station was placed outside the sensing region and the gateway node was placed at the center. Arati et al. (2001) have proposed TEEN [46] routing protocol for reactive networks. This protocol reduced the transmissions by using hard and soft threshold values. It is best for time-critical applications where lifetime of the network is a crucial issue but if the threshold values are not reached in time then it becomes the drawback of this protocol. Then to overcome this problem, the author proposed a new protocol called APTEEN in which the problem of periodic data collection was resolved. The major limitations of both these protocols are overhead and time constraints. Parul et al. (2010) have proposed TDEEC [47] routing algorithm for a heterogeneous WSN to increase the energy efficiency of the system.

6.1 Comparison of Different Routing Protocols

As per Table 2, the comparison of different routing protocols on the basis of different parameters is shown. Among all the routing protocols, Regional Energy-Efficient

Table 2 Routing protocol comparison

Routing protocol in comparison With LEACH protocol	Network stability	Network lifetime in terms of alive nodes
REECH-ME [42]	79% more	66% more
DREEM-ME [43]	40% more	36% more
MGEAR [44]	50% more	64% more
TEEN [45]	50% more	40% more
APTEEN [46]	70% more	60% more

Cluster Heads based on Maximum Energy (REECH-ME)-based protocol is the best in terms of network stability and network lifetime.

7 Conclusion and Future Work

The agricultural field has a lot of potential for a country's economic growth so proper attention should be given to this area and this can be achieved with the help of wireless sensor networks. In this paper, a variety of communication technologies and power reduction techniques are reviewed. The major issues involved while deploying wireless sensor networks are power consumption, cost and complexity. Power consumption is a very crucial factor in today's era in every field so an efficient routing protocol should be used in order to minimize the energy consumption. While deploying sensors in the field, the cost factor should be kept in mind. The deployment of sensors, communication protocols are very complex, so the generalized structure needs to be designed. In this paper, different communication technologies like Zigbee, GPRS, Wi-Fi and more technologies are reviewed. Among all these technologies, Zigbee is the best technology in terms of transmission data rate. Various routing protocols like MGEAR, TDEEC are also reviewed. Among those, REECH-ME is the best routing protocol in terms of network lifetime and stability. Also, sensor deployment challenges are discussed in this paper. Deployment of wireless sensor nodes in agriculture can increase the profit margin, agricultural output for a farmer and thus boosts the economy of a country.Wireless sensor technologies have a lot of potential in agriculture, which is not yet explored. There are many challenges of wireless sensor networks that are not much explored yet. These include throughput, network lifetime and delay. Balancing the tradeoff between power consumption and network lifetime is an area of concern. Digital signal processing field can be collaborated with this field to solve this issue.

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