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Study of Wireless Communication Technologies on Internet of Things for Precision Agriculture

Xiang Feng[1] · Fang Yan[1] · Xiaoyu Liu[1]

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Abstract
Precision agriculture is a suitable solution to these challenges such as shortage of food, deterioration of soil properties and water scarcity. The developments of modern information technologies and wireless communication technologies are the foundations for the realization of precision agriculture. This paper attempts to find suitable, feasible and practical wireless communication technologies for precision agriculture by analyzing the agricultural application scenarios and experimental tests. Three kinds of Wireless Sensor Networks (WSN) architecture, which is based on narrowband internet of things (NB-IoT), Long Range (LoRa) and ZigBee wireless communication technologies respectively, are presented for precision agriculture applications. The feasibility of three WSN architectures is verified by corresponding tests. By measuring the normal communication time, the power consumption of three wireless communication technologies is compared. Field tests and comprehensive analysis show that ZigBee is a better choice for monitoring facility agriculture, while LoRa and NB-IoT were identified as two suitable wireless communication technologies for field agriculture scenarios.

Keywords Precision agriculture · Wireless communication technology · WSN · Internet of things

1 Introduction

According to Food and Agriculture Organization of the United Nations (FAO), the world's population is estimated to reach 9.2 billion by 2050. Moreover, the alarming scarcity of water resources, decrease of arable lands and declining agricultural labor force. Under the serious conditions, it is not an easy task to feed the ever-growing population. Various technologies such as sensor technology, information and communications technology (ICT), information processing technology, geographic information systems (GIS), environment-friendly farming through flexible fertilization technology, and information management are integrated and thus productivity is guaranteed, even with a small labor force [1–3].

✉ Fang Yan
707622060@qq.com

[1] School of Information Engineering, Jiangsu Polytechnic College of Agriculture and Forestry, Zhenjiang 212400, China

In the recent past, these technologies mentioned above have been playing an important role in promoting innovation in the agriculture sector, and the concept of precision agriculture (PA) is formed [3, 4]. In order to optimize production and maximize profitability by accounting for variability and uncertainties while potentially reducing usage of fertilizer and environmental impacts, a set of techniques, such as perception, transmission, storage, process and control, are applied in PA. These techniques are combined and formed intelligent perception system, wireless communication system, intelligent process and control system. The systems work together to decide which, where, when and how to use sensors and actuators, and thus the precise control for a greenhouse or a field is realized [5]. Sensors placed in greenhouses or fields allow farmers to obtain detailed data on real-time as variables such as soil and ambient temperature, atmospheric humidity, soil electric conductivity (EC) and PH level, luminance, etc. These data can be transmitted through Wireless Sensor Networks and analyzed by Artificial Intelligence (AI) system; AI system gives the corresponding methodologies to actuators to satisfy the specific conditions for crop growths. Farmers could use their smartphones to remotely monitor their crops and equipment and to make reasonable decisions. These are the meaning of PA and its technical realization [6].

There is no doubt that PA offers a solution to these challenges such as population growth, shortage of food, deterioration of soil properties and water scarcity. Furthermore, PA can also minimize the wastage of pesticides to effectively control pests, diseases, and weeds and ensure that crops receive sufficient nutrients, thereby leading to an efficient, green and sustainable agriculture. As we described above, the implementation of PA involves many modern information technologies. In order to combine modern communication technology effectively with PA, we must first understand the characteristics of agriculture and understand the application scene of modern communication technology in agriculture. This article focuses on the wireless communication technologies used in PA, highlighting the communication distance, power consumption and other issues. In the actual application of wireless communication technologies to precision agriculture in the process of information transmission, these are the main considerations and other issues. Through the analysis of several kinds of wireless communication technologies and agricultural application scenes, this paper tries to find feasible and practical wireless communication technologies for PA applications.

Typical application scenes of agriculture generally include two situations: field agriculture and facility agriculture. Field agriculture is characterized by its wide geographical scope and complex terrain. Therefore, in order to obtain accurate large-scale field data in the field environment, problems such as the deployment mode of sensors, power consumption of sensor nodes, transmission distance, and data transmission mode of nodes must be fully considered [7]. In addition, maintainability and feasibility must also be considered. Compared with field agriculture, the facility agriculture has the characteristics of small area and flat terrain, and the key issues considered under this condition are power consumption and transmission distance. Data collected by field sensors are generally small, whether in field agriculture or facility agriculture (greenhouses), and the requirements for real-time transmission are low. Therefore, the wireless communication technologies suitable for precision agriculture have the characteristics of long distance (for field agriculture), low data volume, insensitive delay, low power consumption, and large number of connections.

In recent years, there have been some literatures on the application of ZigBee and LoRa communication technologies to agriculture [8, 9], and narrowband internet of things (NB-IoT), the latest technology emerging in low power wide area (LPWA), has so far rarely been used in agriculture domain. In this paper, the basic framework of NB-IoT technology applied to agriculture is proposed, and a NB-IoT based precision agricultural system is developed. In order to compare the applicability of these three kinds of communication technologies in agriculture from the aspects of system structure, technical characteristics and realization, this paper also presents ZigBee and LoRa based precision agricultural application systems.

The other contributions of this paper are summarized as follows.

- There's a lot of literature on the application of wireless communication technologies to PA domain. This paper summarizes the literatures according to the communication distance of the wireless communication technologies used in these literatures.
- The communication technologies suitable for agricultural application are analyzed from the aspects of communication distance, power consumption. In addition, through comparison, the prospects and challenges of existing communication technologies applied in PA field are analyzed.
- In this paper, the normal communication time is used as an index to measure the power consumption of different communication technologies. This method is different from the traditional one. Compared with the traditional method, this method has the advantages of intuition and easy measurement.

The rest of this paper is organized as follows. Section 2, we introduce a collection of wireless communication technologies and make a comprehensive comparison of these communication technologies. The purpose of the comparison is to find out the wireless communication technologies suitable for precision agriculture. Section 3 reviews related works in PA domain. Information Technologies applied in PA are reviewed, including Internet of Things (IoT) technologies, the capabilities and potential of cloud, edge and fog computing paradigms in these scenarios. Section 4, three WSNs, which is based on NB-IoT, LoRa, and ZigBee wireless communication technologies, are presented respectively and explained in detail. Section 5, the feasibility of three types of WSN is verified and the power consumption of NB-IoT, LoRa, and ZigBee is compared. Finally, conclusions are provided in Sect. 6.

2 An Overview of Wireless Communication Technologies

With the development of information technology, many wireless communication technologies have been proposed for a variety of applications [10, 11]. Generally, these technologies are divided into three categories according to the transmission distance, as shown in Fig. 1, namely short-distance wireless communication technologies (distance $\leq$ 10 m), medium-distance wireless communication technologies (distance ranges from 10 m to 100 m) and long-distance wireless communication technologies (distance $\geq$ 100 m). Typical short-range wireless communication technologies include radio-frequency identification (RFID), Bluetooth [12], ultra-wideband (UWB), etc. Wi-Fi [13] and ZigBee [14] are two major medium-distance wireless communication technologies. For long-range wireless communication technologies, in addition to the well-known cellular networks (2G/3G/4G), LPWA is a new type of technology with a wide scenarios of application. In the past few years, several LPWA technologies like LoRa [15], NB-IoT [16] and Sigfox [17] have emerged. In

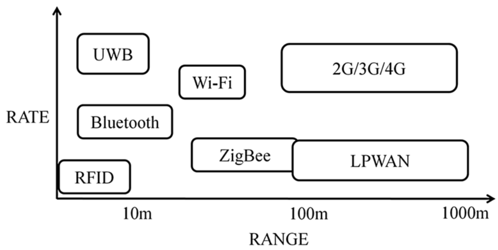


Fig. 1 Range and rate comparisons among wireless communication technologies

contrast to classical long-range wireless communication technologies (2G/3G/4G), LPWA technologies feature low power consumption, low data rate, deep/wide coverage and massive connections. Therefore, LPWA technologies cannot be used for audio or video data streaming, but is perfectly suited for connecting devices that only need to transmit tiny amounts of data over a long range, while maintaining long battery life. The better performance of LPWA technologies, such as long transmission distance and low power consumption, are at the expense of low data rate and high latency. So, the typical application scenarios for LPWA technologies are delay tolerant, do not need high data rates, low power consumption and low cost.

Among the wireless communication technologies mentioned above, Bluetooth, Wi-Fi, ZigBee, LoRa, and NB-IoT are among the most popular ones. We briefly describe them below and provide a comprehensive comparison in Table 1.

From the above introduction and the comparison presented in Fig. 1 and Table 1, if power consumption is a critical factor, then Bluetooth is the best technology. Its main drawback is the limited communication range. The other eligible choice is the ZigBee technology, which offers a communication range of 100 m with 250 kbps data rate and transmission power consumption of about 39.6 mw. If data rate is not as important as both long range and low power consumption, the most attractive technology is the two kinds of LPWA technologies (LoRa and NB-IoT). They offer more than a 15 km communication range at acceptable rate with about 100 mw power consumption at transmission.

3 Related Work

The development of sensor technologies, wireless communication technologies and remote sensing technologies provide the possibility for the implementation of PA. In order to improve crop yields and quality, the transmission of some of the necessary field information in the crop growing environment to information processing centers through wireless communication technology is the basis for the efficient use of limited agricultural resources and the development of precision agriculture. In this paper, the literatures on wireless communication technologies for precision agriculture are divided into three categories. That is, the literatures on short distance, medium distance and long distance wireless communication technologies for precision agriculture.

Table 1 Comparison of different wireless communication technologies

Parameters/technologies	Bluetooth	ZigBee	Wi-Fi	LoRa	NB-IoT
Standard	IEEE802.15.1	IEEE802.15.4	IEEE802.11	IEEE802.15.4g	3GPP release 13
Frequency	2.4 GHz (unlicensed)	868/915 MHz and 2.4 GHz(unlicensed)	2.4 GHz (unlicensed)	869/915 MHz (unlicensed)	LTE frequency (licensed)
Modulation	GMSK	BPSK/OQPSK	BPSK/OQPSK	GFSK	SC-FDMA(UL) OFDMA(DL)
Data rate	1 Mbps	20, 40, and 250 kbps	11–54 and 150 Mbps	50kbps	160–200kbps(UL) 160–250 kbps(DL)
Power consumption (Tx)	10 mw	36.9mw	835mw	100 mw	106 mw
Range	indoor: 20 m outdoor:100 m	100m	100m	Urban: 2–5 km suburban: 15 km	Urban: 1–8 km suburban: 25 km

3.1 Applications of Short-Distance Wireless Communication Technologies in Agriculture

There are two kinds of short-distance wireless communication technologies used in precision agriculture: Bluetooth wireless protocol and RFID. The Bluetooth wireless protocol is used to establish a communication link between movable and portable devices over a short range of up to 10 m. A Bluetooth based greenhouse information acquisition system was designed in [18] to monitor relative humidity and temperature in greenhouse. Compared with the traditional data acquisition system, the developed information acquisition system has the advantages of convenient installation and simple maintenance. Based on soil and weather information, a Bluetooth module based integrated irrigation control system for greenhouse was developed in [19], which improved the leaf number, height of red and romaine lettuce in greenhouses, and also had the advantages of saving water and electricity. Using Global Positioning System (GPS) and low-cost Bluetooth wireless communication technologies, the smart system in [20] was developed for irrigation application to save water and increase farmland productivity through remote monitoring of weather information, soil information and sprinkler position. In order to make better use of the increasingly scarce water resources, several intelligent APPs [21, 22] based on smart-phone Bluetooth protocol were developed, these APPs have the advantages of low power consumption and ease of use for farmers. WSNs based on the Bluetooth wireless protocol have been widely used in different fields to monitor different equipment status, parameters and encoding equipment communication [23–25].

The applications of RFID in agriculture are many and varied. The most common applications include livestock identification or traceability control. Combining with RFID technology and mobile networking, a platform for livestock management based on RFID-enabled mobile devices is introduced in [26]. The platform uses RFID tags to store animal information that can be used to identify the animal in case it gets lost, or even recognize some basic information about it. [27] summarizes the literature of application of RFID in agriculture and discusses its limitations and challenges. In order to build virtual organizations of agents that can communicate between each other while monitoring crops, The authors [28] designed a system for collecting heterogeneous information by means of several short-distance wireless communication methods (RFID, Bluetooth), using sensors such as temperature, solar radiation, humidity, pH, humidity and wind.

3.2 Applications of Medium Distance Wireless Communication Technology in Agriculture

The applications of medium distance wireless communication technologies in agriculture mainly include Wi-Fi standards (IEEE 802.11 a/b/g/n) and ZigBee (IEEE 802.15.4 standard). In agricultural applications, Wi-Fi extends the use of heterogeneous architectures that connect multiple-type devices through an ad-hoc network. An example of a WSN-based monitoring system using IEEE 802.11 a/b/g/n transceivers was presented in [29]. The system monitors parameters such as temperature and soil moisture and performs irrigation calculations based on field data and rules-based knowledge to make the best decision. A Wi-Fi based remote monitoring system, which attempts to minimize wiring connections, lower cost, and enhance the mobility and flexibility of the sensing nodes in WSN, is proposed for agricultural application in [30]. The climate conditions of the agricultural field or greenhouse, such as temperature, humidity, light, water level, and soil moisture, are monitored. In [31], the WSN nodes collect field data through soil and environmental sensors (such as soil moisture sensors, soil temperature sensor, environmental temperature sensor, environmental humidity sensor, CO_2 sensor, and sunlight intensity sensor, etc). The field data were stored in a gateway then transmitted to the server computer via the Wi-Fi network for the prediction of soil moisture content.

ZigBee technology offers a long battery life, smaller size, higher reliability, and thus, is very suitable for agricultural applications such as the intelligent control of irrigation, fertilizer and pesticide. Given the low duty cycle, ZigBee technology is considered one of the best candidates in agriculture. There are three main applications of ZigBee technology in agriculture: intelligent irrigation control, greenhouse monitoring, and livestock monitoring. According to the different demands of soil moisture and pH value of crops, a ZigBee and GPRS based multi-functional intelligent water management system was developed [32], and the whole system was powered by solar panels. Several types of sensor, such as air temperature sensor, soil humidity sensor, soil nutrient sensor etc., were used to collect real-time data in [33]; these sensors connect with the Internet of things intelligent gateway by CC2530 ZigBee modules based wireless network. A combination of artificial intelligence with ZigBee based WSN for greenhouse climate control was presented in [8]. This combination was proved effective methods in term of cost, energy, productivity and flexibility. In order to accurately collect real-time agricultural data in large-field environment, a ZigBee based farmland environment monitoring system was designed in [34]. The system solved the problems of complex wiring, high cost and short communication range in large-field environment monitoring.

By comparing ZigBee technology with Wi-Fi and Bluetooth, [35] made an explorative application of ZigBee technology in greenhouse, and proposed a greenhouse monitoring and control system. In order to achieve scientific cultivation and reduce management costs, a low-cost and practical greenhouse monitoring system was developed in [36]. Several key environmental parameters (temperature, humidity and illumination) were collected by sensors and transmitted through ZigBee-based WSNs.

A low power and low cost cattle location system was presented in [37]. The cattle location in grazing fields was determined by the link quality indication of the ZigBee links. A high performance ZigBee-based ad hoc WSN has been used to monitor the behavior of a flock in [38], five types of animal behavior can be classified by this method.

3.3 Applications of Long-Distance Wireless Communication Technologies in Agriculture

According to different power consumption and transmission rate, we divide the long-distance wireless communication technologies applied in agriculture into two categories, the one is high data rate and high power consumption (2G/3G/4G), and the other is low data rate and low power consumption.

The authors [39] use Code Division Multiple Access (CDMA) wireless communication to realize long-distance and real-time information transmission. Multiple parameters for farmland, such as chlorophyll content of crop leaves, air temperature, air humidity, and light intensity, are collected. Plant growth information and environmental information are transmitted to the information processing center to realize remote monitoring of crop state and environmental conditions. Using General Packet Radio Service (GPRS) module and WSN, an automatic crop irrigation system, which based on information collected by distributed soil moisture and temperature sensors installed at the root zone of plants, was developed [40]. Up to 90% water savings achieved compared with traditional irrigation practices in agricultural. Similar GPRS application can be found in [41].

Focusing on solving the problem of high energy consumption in 3G open watering system, the authors presented a low-energy and long-range system over LoRa [42]. To meet the need for monitoring greenhouse environmental parameters with high power efficiency, a LoRa wireless protocol based star topology network was constructed [9]. The network may communicate with a cloud server over a long range and with 90% power efficiency. A remote three-level hierarchical monitoring system was designed to collect all possible information on the environmental conditions surrounding the beehives [43]. The monitoring system was formed by LoRa wireless nodes, a local data server, and a cloud data server.

From the literatures mentioned above, we can see that wireless communication technologies suitable for PA needs to have characteristics such as long range, low power consumption, large number of connections, and low cost. Combining the comparison in Table 1, the ZigBee and LPWA (LoRa, and NB-IoT) have been identified as the most suitable wireless communication technologies for PA applications because of their low power consumption, long communication range (acceptable for ZigBee and long for LPWA), easy network implementation.

4 Application Architecture

The IoT-based precise agriculture is to establish a system that uses sensors (temperature, humidity, light, soil moisture, etc.), modern information transmission and processing technologies to monitor the crop field and intellectualize farmland management. WSN play the role of connecting data collection and processing throughout the system [2]. The system architecture of IoT-based precise agriculture, as illustrated in Fig. 2, consists of three parts, which are of "things" (sensors/actuators or end-devices), local gateways (or base stations), and the network server (or cloud server). Usually, "Things" have the function of field data collection and control. The IoT-based solutions have "things" controlled and managed using data locally and/or connected to local gateways (or base stations) that provide extended functionality. However, most existing "things" were not specifically designed to connect to the Internet and cannot directly exchange data with the network server (or cloud server). To solve the problem between "things" and server, gateway acts as intermediaries for them, providing the required connectivity, interactivity, and security. The network server provides data storage, management, analysis and processing services, as well as information support for intelligent decision making.

To identify the performance of the NB-IoT, LoRa and ZigBee standards for monitoring farmlands, three kinds of WSNs were implemented. In the next parts, based on the wireless

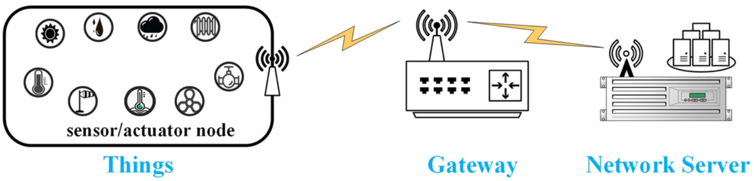


Fig. 2 The system architecture of IoT-based precise agriculture

communication technologies of NB-IoT, LoRa and ZigBee, we will present communication networks for precision agriculture respectively, so that the characteristics of the three networks can be clearly compared.

4.1 NB-IoT Based WSN for Precision Agriculture

An application framework of NB-IoT for PA is shown in Fig. 3. The framework consists of three components, that is, NB-IoT terminals, transmission networks and application server. They perform functions such as data collection, data transmission, data analysis and decision-making respectively. Various environmental sensors and NB-IoT modules form the NB-IoT terminals to complete the function of field data collection. Sensors are used to collect environmental data, and then the collected environment data is transmitted to the NB-IoT modules through the RS485 bus; Data transmission network consists of NB-IoT network and Internet network. Sensing data from the NB-IoT terminals are transmitted to the Internet network via the NB-IoT network; the tasks of the application server include receiving, saving, and visualizing data, and then make reasonable decision based on data analysis. This process can also be summarized as follows. NB-IoT terminals (including various environmental sensors and NB-IoT communication modules) transmit sensing data to transmission network. The data then are relayed forward and stored to application servers.

In contrast, the commands issued by users to end actuators are transmitted through application servers, transmission network, and NB-IoT terminals. After receiving the control commands, the end actuators will execute them and return the execution results to the application servers.

4.2 LoRa Based WSN for Precision Agriculture

A LoRa based WSN, as shown in Fig. 4, is presented. Three different types of components are included in the star-topology network: end-devices, gateways and network server. The end-devices consist of sensors/actuators, LoRa transceiver and LoRa receiver. Their main function is to upload the sensing data to the gateway through LoRa transmitter, or to receive command message from the gateway through LoRa receiver. Gateways are the intermediate between the end-devices and network server; in other words, gateways are only bidirectional relays, or protocol converters. Gateways forward raw data frames from

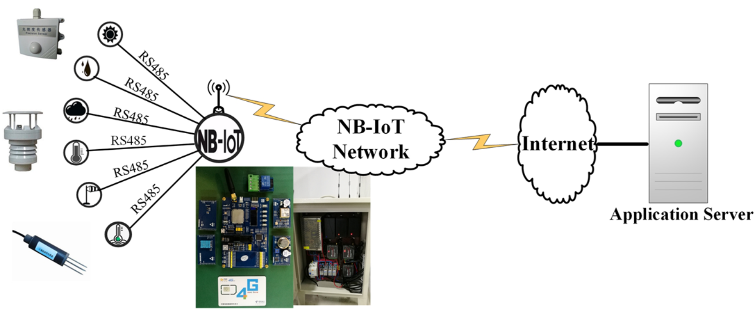


Fig. 3 The application architecture of NB-IoT for precise agriculture

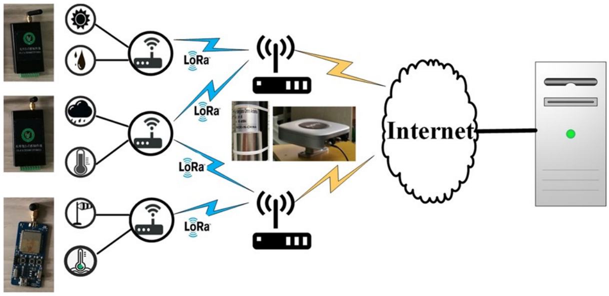


Fig. 4 The application architecture of LoRa for precise agriculture

the end-devices to the network server over an Ethernet backhaul interface with higher throughput. The network server is responsible for copying and decoding sensing packets sent by the end-devices or generating decision-making packets that should be sent back to the end-devices. Unlike cellular based NB-IoT networks, the end-devices in a LoRa network are not associated with a specific gateway in order to have access to the network, that is, the same packet can be received (or forwarded) by more than one LoRa gateway.

4.3 ZigBee Based WSN for Precision Agriculture

The ZigBee network has three topological structures, namely, star, tree, and mesh. Compared with the other two, the tree topology has the advantages of high connectivity and low routing overhead, and is more suitable for farmland periodic monitoring and other applications. The ZigBee-based tree networking topology, presented in Fig. 5, represents a high reliability, energy-efficient and low-cost solution that has extensively been used in agriculture for monitoring different environmental and soil parameters. In this tree topology network, there are three types of node that can be configured: end-device, router and coordinator. Their configuration is done by ZigBee Module Configure shown in Fig. 6. The collected data (such as air temperature, air humidity, and soil moisture) from the sensors and end-devices are firstly transmitted wirelessly to coordinator via the routers; and then relay to network server by GPRS way.

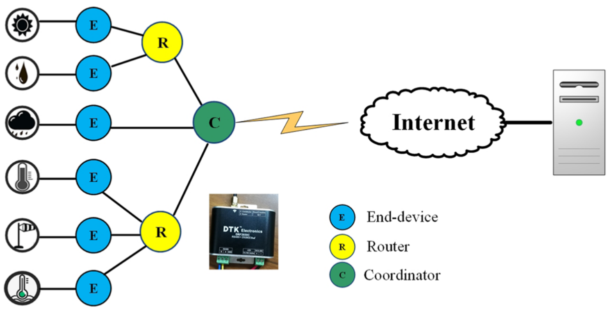


Fig. 5 The application architecture of ZigBee for precise agriculture

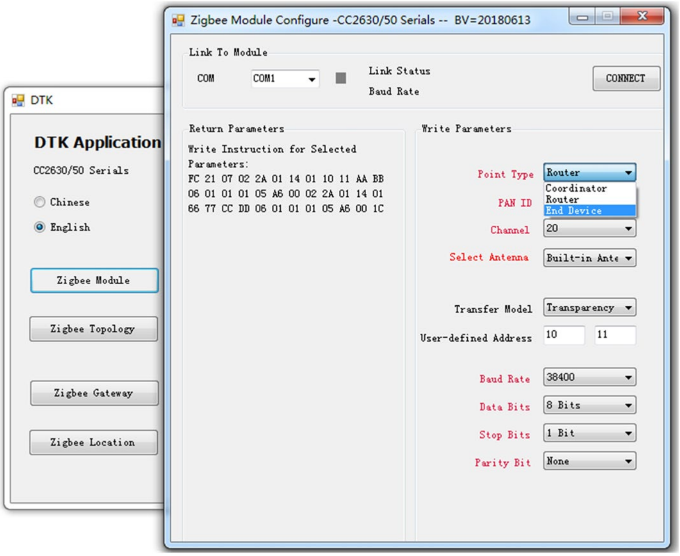


Fig. 6 The configuration for ZigBee Module

5 Field Tests

All the following tests were completed in a field of area nearly 12 square meters. The purpose of the field tests is two. The first one is to test the feasibility of the above three application frameworks, especially for the feasibility of the latest LPAW technology NB-IoT application architecture. Secondly, the power consumption of three kinds of wireless communication technologies is compared.

5.1 The Feasibility Tests

The feasibility of NB-IoT based application architecture, as shown in Fig. 3, is first tested. The NB-IoT module we select is BC95-B5 of Quectel, with 850 MHz frequency band. Low-cost STM32 is selected as a controller. The sensors collect environmental and soil data, which include ambient temperature, atmospheric humidity, luminance, and soil moisture and temperature, every half an hour and transmit them to the application server via the NB-IoT network. Figure 7 shows the values obtained on the field testing for 24 h.

In the following tests, the WSNs shown in Figs. 3, 4 and 5 are simultaneously used to collect environmental and soil data. The ZigBee modules we select are CC2630 of TI Company. The development board with Semtech SX1278 is used as the end-devices. Figure 8 shows the average daily data that are provided by the field sensors for 13 days. All the five sub-figures in Fig. 8 show that there is little variation between the data within the same time period. The testing results demonstrate the feasibility of the three kinds of WSNs.

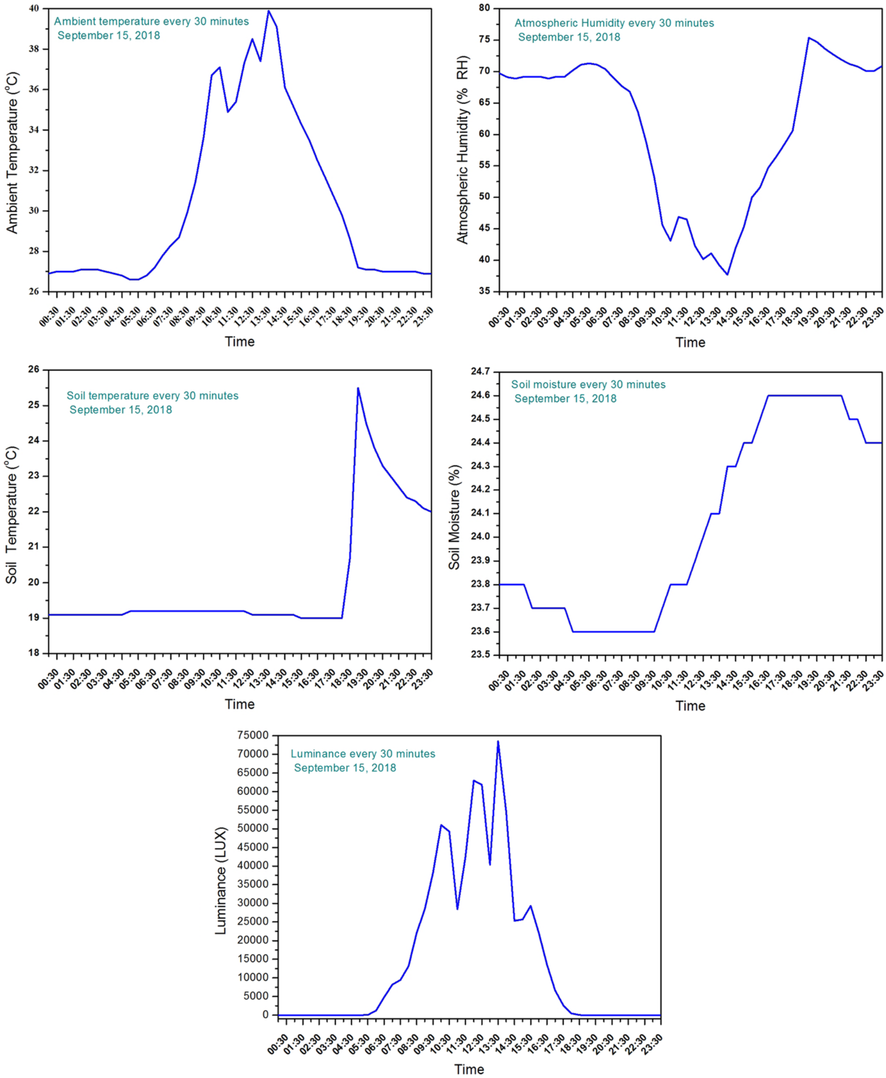


Fig. 7 The daily testing curve obtained by NB-IoT based WSN

5.2 Comparison of Power Consumption

Power consumption is the power consumed by communication equipment per unit time. Under the condition that the total power supply is determined, the normal communication time of communication equipment can be used as an indicator to measure the power consumption of communication equipment. The longer the normal communication time is, the lower the power consumption is. The purpose of the test is to compare the power consumption of three wireless communication technologies (ZigBee, LoRa and NB-IoT). In an open environment, the power consumption of three communication technologies at different communication distances is tested. The testing topology is shown in Fig. 9. For ZigBee communication technology, longer communication distances are provided by routing relay,

Fig. 8 Average daily data collected on the field

as shown in Fig. 9a. For NB-IoT and LoRa, communication distance is changed by adjusting the distance between the terminal and the gateway, as shown in Fig. 9b, and no relay is required. The adjustable distance depends on testing requirements.

Fig. 9 Topology for power consumption tests. **a** Test for ZigBee communication technology. **b** Test for LoRa and NB-IoT communication technologies

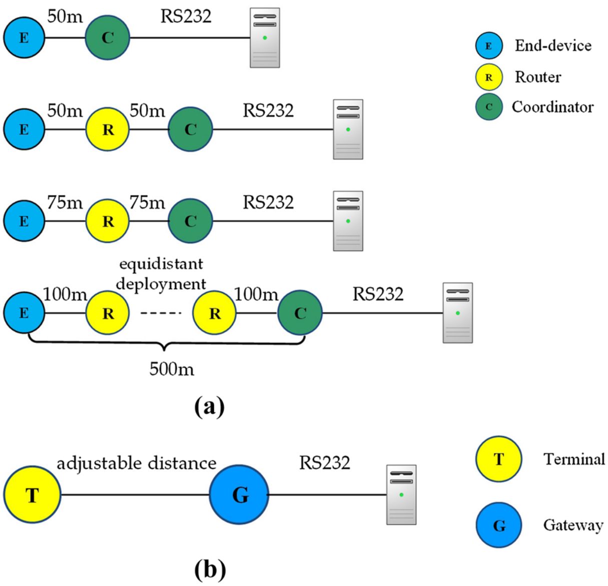
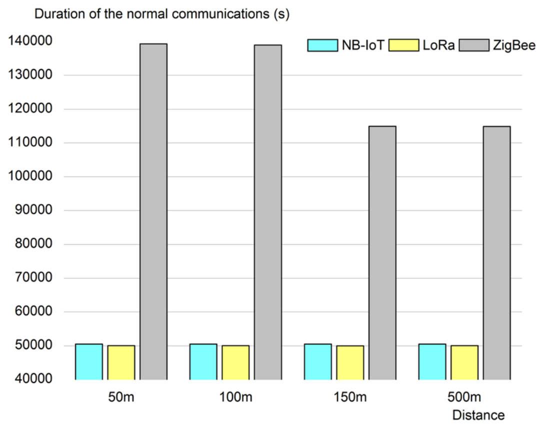


Fig. 10 Comparison of normal communication time of three topological structures



Unlike traditional methods, the following tests use normal communication time as a measure of power consumption. In the case of a certain communication distance and a certain battery capacity, the end-devices/terminals continuously send data until the server cannot get data normally due to the exhaustion of the end-devices/terminals battery. The normal communication time can be regard as a token of the corresponding power consumption. The longer normal communication time, the lower power consumption, and vice versa. Figure 10 illustrates the duration of the normal communications for the three wireless communication technologies when the testing distance is 50 m, 100 m, 150 m, and 500 m, respectively. ZigBee wireless communication technology has the smallest power consumption among the three wireless communication technologies, while the other two wireless communication technologies (LoRa and NB-IoT) have approximately the same power consumption, about three times as much as ZigBee wireless communication technologies.

6 Conclusions

The development of communication technologies has provided the possibilities for their application in the field of PA. By analyzing and summarizing the characteristics of agricultural application scenes and experimental tests, this paper tries to find the wireless communication technologies suitable for PA application. Wireless communication technologies suitable for PA have the characteristics of low power consumption, long distance, large connection volume, and low cost. From the above discussion and the experimental results presented in Figs. 7, 8 and 9, the NB-IoT, ZigBee and LoRa wireless communication technologies have been identified as the most suitable communication technologies for PA applications.

If power consumption is the critical consideration, ZigBee is the best technology. The main drawback of ZigBee is its limited coverage. Therefore, ZigBee is a better choice for monitoring and control of facility agriculture (greenhouse) than two other communication technologies. If coverage distances are more than 5 km, the available choice is LPWA (NB-IoT and LoRa) technology. They offer more than a 15 km cover range at acceptable throughput with smaller power consumption at transmission. The main drawback of NB-IoT technology is the monthly subscription costs, which need to be paid to the provider, meanwhile the main drawback of LoRa technology is maintenance costs.

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Xiang Feng received his Ph.D. degree in information and communications engineering from Xidian University in the year 2008. Now, he is working as Professor in Jiangsu Polytechnic College of Agriculture and Forestry. He had published more than 40 papers in the research areas of communication signal processing, wireless sensor network, intelligent agriculture and internet of things.

Fang Yan is a professor at Jiangsu Polytechnic College of Agriculture and Forestry. His research areas include wireless sensor network, smart power grid and intelligent agriculture.

Xiaoyu Liu is a lecturer who works in Jiangsu Polytechnic College of Agriculture and Forestry, China. She obtained her Ph.D. in University of the Chinese Academy of Sciences. And her research mainly focuses on assessing the uncertainty of soil organic carbon at regional scale with modelling approaches. In recent years she has presided and attended several National Natural Science Foundation of China, and has published several academic research papers in international journals already.