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Energy Efficient Wireless Sensor and Actuator Networks for Agricultural Monitoring and Irrigation Control Systems: A Review

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ABSTRACT

Wireless sensor and actuator networks (WSAN) have been tremendously developed and therefore it can be employed in smart agriculture to establish optimal scheduled irrigation systems. It helps to interconnect physical objects that are equipped with sensors, actuators, control and computing units and is capable to collaborate them on any task in a network. Wherein each smart objects collects data from the environment, process them and starts appropriate actions. So, the wireless sensor and actuator networks can bring incredible benefits and assists people in building smart and luxuries life. Since it is achievable to build high potential applications using WSAN, it has been being considered as a very important subject of scientific research. Therefore, in this paper, applications of wireless sensor and actuator networks on smart irrigation systems has been studied and analyzed. Furthermore, this paper comprehensively introduced the WSAN technologies, different applications domains in which WSAN is applied for the modern irrigation systems, its benefits and includes a review of literature.

Key words: WSAN, smart irrigation, automation, energy efficiency

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INTRODUCTION

There are abundant research works and literature on energy saving of wireless sensor and actuator networks, as many research methods have been proposed in recent years. Furthermore, there is still a lot of ongoing researches on how to optimize energy consumption in wireless networks' battery-limited sensors and actuators. However, none of the proposed solutions is comprehensively applicable for Uzbekistan rural and desert areas. For example, while security applications require rapid and timely response capability, this is not the case for other applications, such as agriculture, where the delay property is not as important. We believe that WSN's power-saving issues should be dealt with in consideration of application requirements more systematically.

Wireless Technologies for Agriculture

Various type of wireless protocols and standards which are employed in agriculture are presented in this section. Besides, those wireless communication technologies are compared in order to determine the most appropriate technology in terms of communication distance and energy consumption. Because those two metrics are the most challenging in WSAN based agricultural applications [1, 2]. WSAN can be a great uprising for any sphere in which any connectible things will be connected.

Long Range (LoRa) technology

LoRa (Long Range Radio) is firstly introduced as a protocol stack by the LoRa Alliance for low power and long range wireless communications technologies [3]. The network architecture of a LoRaWAN consists of LoRa end devices, LoRa gateways or base-stations and a LoRa network server (Figure 1). The LoRa end-devices communicate with the gateways and LoRa gateways send the packets collected from the end devices to a LoRa network server. The LoRa gateways operate with the LoRa network server as bidirectional communication. LoRa network server decodes the data packets sent by LoRa devices and makes the frames which will be transmitted back to the devices. LoRa can provide a low-cost technique to connect mobile devices to the network or to end-devices. In order to ensure a communication in remote location, LoRa technology was employed in [4] for monitoring bee colonies in rural areas. In [5], LoRa wireless technology is used along with microcontrollers and various sensors for monitoring temperature and moisture of soil, temperature and humidity of air and light intensity in greenhouses. LoRa gateway gathers information from LoRa nodes in order to build star network topology. It can exchange data with cloud server over a long range of communication.

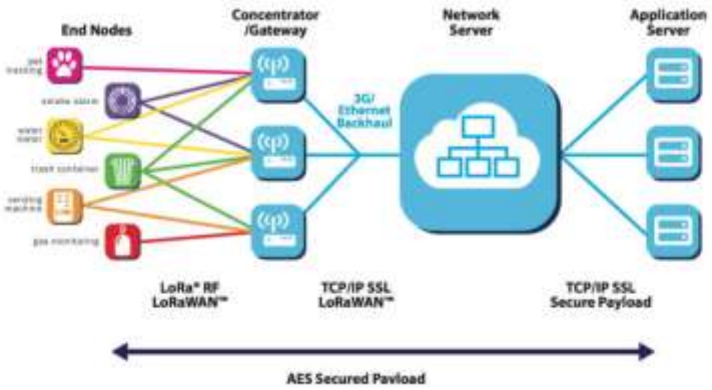

Fig. 1 LoRaWAN Network architecture [6]

In fact, so far LoRa has been used in various agricultural research projects which were developed by the Libelium Company [7] of Spain, which are smart irrigation system for kiwi production in Italy, smart garden system to monitor green areas in Spain, improving fertilization technique for corn yields in Italy and banana yields in Colombia, climate condition control for tobacco crops in Italy, smart irrigation system to decrease water usage in Barcelona, Spain and monitoring system for vineyard crops in Switzerland and Spain.

Bluetooth wireless technology

Bluetooth wireless technology is generally employed to build a communication between mobile and portable devices over a range up to 10 meters. Bluetooth has been used to meet the requirements of agriculture [8]. Global positioning system (GPS) and Bluetooth technologies are utilized to monitor temperature, soil moisture, sprinkler position and weather information. The proposed system in [9] was developed to increase the field productivity and reduce fertilization consumption. The Bluetooth module was utilized in the control technique [10] to control the irrigation system of greenhouses. The control was based on the soil and weather data and the proposed system increased the number of leafs, height and improved the weight of lettuce in greenhouses. The integrated control technique improved the estimated water usage and electricity by ninety percent compared to the traditional method. Due to the low energy consumption, wide availability and being easy to use of Bluetooth technology has been utilized in various agricultural applications [11-16], such as automated irrigation systems, agricultural and weather monitoring systems and control systems of fertilizers and pesticides.

SigFox wireless technology

SigFox is ultra narrowband wireless communication technology [17] and this technology suits well for the applications which uses infrequently and requires small data exchanges, because SigFox transmits data at low transmission rate (100-600 bits per second) [18]. However, it is claimed by the SigFox that it can cover the area up to 50km in rural areas and up to 10 km in urban areas by handling up millions of connected devices to gateways [19]. SigFox was used in [20, 21] in order to construct geolocations system which localizes animals in mountain. In [20], the proposed system is able to assist farmers to locate their cattle, while its power consumption analyses was studied in [21].

ZigBee wireless technology

ZigBee wireless technology is one of the most suitable candidate for agricultural and farming applications, like LoRa technology. Owing to its low energy consumption rate, ZigBee is considered very appropriate for agricultural applications which require cyclic data update, such as irrigation control [18], water quality management, fertilizer and pesticide control applications. In those applications, wireless nodes can exchange data with coordinator or router in a range of several hundred of meters. Furthermore, this technology is employed to study the influence of signal strength on node spacing, antenna height of base station and even leaf density in [22]. In [23], ZigBee and GSM/GPRA wireless communication technologies were employed for monitoring and control of key parameters, such as temperature, humidity and others in greenhouses. In order to overcome the issues of high power consumption and unreliability, ZigBee is being employed in many applications, such as in smart beehives [24], orange orchards [25], monitoring systems for daily healthcare of animals [26], automated irrigation systems [27], monitoring systems of greenhouses [28] and livestock monitoring [29]. Due to its low power consumption, low cost, wide range of availability and appropriate communication range, ZigBee has been used in several agricultural applications as reliable wireless communication technology.

WiFi wireless technology

Currently the most extensively used wireless technology in our lives is the WiFi technology. It is available in the devices, such as laptops, tablets, smartphones and other different portables devices. The communication range of WiFi is 20meters and 100 meters in indoor and outdoor environments, respectively. Agricultural information including soil temperature and moisture, weather temperature and humidity, sunlight intensity and CO_2 were stored in a gateway and WiFi transmission to server computer is performed in [30]. Generally, WiFi consumes high-energy amount in contrast with other discussed wireless technologies above. Although WiFi requires much power and long communication time, it transmits huge data payload [29]. Because of being not compatible with multi-hope scheme applications and effected by high number of users and signal intensity, WiFi is not preferable for agricultural wireless sensor networks.

Power Consumption Reducing Techniques

The sensor nodes of wireless sensor networks are usually employed to collect environmental parameters in real time and send data to coordinator devices wirelessly. Modern agricultural applications are one of the significant types relying on WSNs [31]. Since the majority of the agricultural applications are placed under the open sky, they are designed to be rechargeable by renewable energy sources. Each sensor node in them is integrated with rechargeable batteries, which have limited charging capacity, and it is one of the most challenging issue to overcome in long-term applications [32]. In order to operate each electronic components of the sensor nodes properly these back-up batteries supply with necessary current at the required voltages. The total power consumption of a single sensor node is sum of each component integrated with the node, such as microcontroller, radio module, sensors etc.

Many researchers have tried to develop different power reduction methods in order to extend the lifetime of wireless sensor nodes as longer as possible. This section reviews various power reduction strategies of WSNs that can be utilized in agricultural applications.

Sleep-Wake technique

The wireless radio modules consume considerably more energy compared to microcontrollers. During the reception and transmission process, the most of the energy is spent. The radio transceivers can be entered into sleep mode when not operating any job in order to save energy and wake up when it comes to collect and transmit or receive data wirelessly. In agricultural applications, the sleep-wake method can be performed through duty cycle, medium access control protocols and technology protocol scheme.

Many scholars proposed the duty cycle strategy in order to decrease the energy consumption in several agricultural applications employing wireless sensor and actuator network. Usmonov and Gregoretti [1] proposed a wireless sensor and actuator network based control system for drip irrigation using LoRa technology. In order to reduce the power consumption of the wireless nodes, the devices were always in sleep mode and wake up to operate when data had to be collected or transmitted/received. This study proposed ZigBee based and energy efficient WSAN for urban garden irrigation system [2]. Each wireless node powered up by single rechargeable battery and charged by solar power. The wireless sensor nodes went to sleep when idle and woke up to collect data and transmit it. In order to establish energy management, the parameters were divided into two groups: more frequently and less frequently checked up parameters. For example, the charge status of battery and moisture level are in the first group since they may cause battery explosion or over irrigation and dying of plant by thirst. The achieved result was more than two years of lifespan of each sensor nodes. In [33], a monitoring system of environmental conditions, such as temperature, humidity, rain level, pH, wind speed and direction and water level in crop fields was presented. The sensor nodes were powered up a solar cell. The wireless sensor nodes employed C1120 transceiver and GPRS/3G to transmit environmental parameters to base station. They scheduled sleep-wake in which 30sec of actuated time and 14 min 30 sec sleep time. As a result, the system reached high energy saving. Besides, overall system consumed 207 mW power and 2-Watt-solar cell was employed to supply power.

The topology protocol scheme is a network energy consumption reducing method which is based on decreasing the number of active wireless nodes of wireless sensor network. Choosing the most appropriate topology considering the application requirements is very necessary in this strategy. In order to save energy and prolong the network lifespan, the particular sensor nodes which do not have task to operate can enter sleep mode. In [34], Ad hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR) protocols over a several topology of ZigBee based WSN were implemented in simulation environments. OPNET software employed for the system simulation. Sensor nodes equipped with soil moisture sensors were deployed in 100 to 100 meters square field. Besides that, 1 gateway node located in it. Sensor nodes measure soil moisture level and transmit it to the gateway via ZigBee wireless protocol, and the gateway forwards the date to controlling system of irrigation valve. The study proved that WSN consumes less power in DSR protocol over the star topology compared to AODV protocol.

Data compression

Data compression is very useful technique to build sensor nodes with limited energy sources. The data is encoded in sensor nodes, while it can be decoded in the sink nodes, as well. Employing the data compression method for achieving reduction of data size which is sent through wireless channels can also decrease the power consumption and increase the battery life of wireless devices. In [35] this article, researchers applied data compression method to decrease the power consumption for auto-irrigation system which based on CC1100 radio frequency module. Through this approach, the battery life of sensor node has extended up to 359 days. However, the one limitation of this work is being necessary to encode all nodes when a new wireless device is added to network.

Radio Optimization technique

Many researches have proved that the radio modules of WSNs consume largest portion of the power compared to the date processing units [36]. The mostly employed radio optimization techniques are based on transmission power control (TPC), Modulation Scheme and Cognitive Radio in order to decrease the power consumption of radio modules in agricultural WSNs. In agricultural fields, RF transmitted power of the wireless devices can be modified in order to reduce the power consumption based on the transmission distance between coordinator and sensor nodes, so transmission power control can be used properly there. The application of TPC in reducing the power consumption of the wireless devices in used precision agriculture has been investigated by the authors in [37]. The different experimental processes deployed at several power levels and different receiver sensitivity levels. Results proved that the power reduction can be improved up to 10% relative to the traditional mode. In contrast, another work showed that the battery lifetime of the sensor nodes prolonged by more than 8.5 % and this is achieved by modifying the transmitted power of CC2420 transceiver.

Benefits of Wsans in Smart Monitoring and Irrigation Systems

There are different kind of benefits and advantages of utilizing WSAN in smart agricultural monitoring and irrigations systems. Some of the major benefits are presented below.

Energy efficiency: the use of WSAN in optimal methods can achieve high impact on the energy efficiency.

Water efficiency: it can decrease the water usage

Cost reduction: it can decrease the production cost

Profitability: it can increase the profitability of the gardeners.

Sustainability: it can improve the sustainability.

Safety: it can perform crucial role in the food safety and environment protection

CONCLUSION

A review of Wireless sensor networks – based agricultural applications for smart monitoring and irrigation systems was presented in this paper. A comparison between different wireless technologies such as WiFi, ZigBee, Bluetooth, GPRS/3G/4G, LoRa and SigFox has been studied and analyzed. The results proved that ZigBee and LoRa technologies are the most suitable wireless standards for agricultural monitoring and irrigation systems due to their low power consumption, low data rate and wide range availability in market. Among those two technologies, ZigBee dominates in energy efficiency domain but can be used for the ranges up to 1200 meters in fields. For the longer communication ranges, the LoRa technology cannot be replaceable. Furthermore, different energy saving techniques are also analyzed and discussed above.

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