Energy Efficient MAC Protocol for Ubiquitous Agriculture

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Abstract

Various technologies are used in the agricultural sites now. Especially, the recent application of sensor network related technology is quite notable. Considering the efficiency of MAC protocol of WSN is being researched in various aspects, it is believed that a research on how to apply the MAC protocol to agriculture would be also required. This research is based on the sensor node developed by Sunchon University ITRC. Once the sensor nodes are effectively located in the farm, they operate for a long time and they are rarely relocated once installed. The concentration of multiple sensor nodes in a narrow area is another characteristic the sensor node. The purpose of this research is to select a sensor network MAC protocol, which would be most proper to agricultural site with good energy efficiency and excellent transmission delay performance. The applicable protocols such as S-MAC and X-MAC were set up for the installation environment. They were compared and a methodology to select the most optimum protocol to agricultural site is suggested.

Keywords: *WSN, Ubiquitous, u-IT, cultivation facility, Paprika*

1. Introduction

The recent innovation in IT technology is accelerating the fusion between industries. The fusion between IT and traditional industries continuously goes on. The application of ubiquitous technology to agriculture, which is a primary industry, is getting expectation that the convergence technology would enhance the added-value and productivity of agriculture [1]. In order to establish such u-agriculture environment successfully, the core ubiquitous technology development optimized to agriculture, such as sensor hardware, middleware platform, routing protocol and agriculture environment application service, would be essentially required [2].

For the development of such ubiquitous technology, various energy-efficient MAC protocols were studied in the wireless sensor network. S-MAC[3], applying “sleeping, stand-by”, was suggested to improve the energy efficiency of MAC protocol. T-MAC[4] was suggested to reduce the unnecessary waking hours even a little bit more. Adaptive S-MAC [5] was developed to avoid the transmission delay phenomenon occurring when applying the duty cycle and hybrid type Z-MAC [6] was developed combining CSMA and TDMA. There is also the X-MAC [7], which preoccupies the channel using preamble during the sleeping period in asynchronous method.

This research chooses the MAC protocol, which demonstrates the most efficient energy performance when WSN would be applied to paprika cultivation in a cultivation facility. Further, a methodology to choose MAC protocol proper to certain cultivation method or stock

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raising method will be suggested. Actual cultivation facility was taken as the model for the research and sensors were located proper to the cultivated crop. The network topology of the sensors was conFigureured and sensors performance will be measured by a simulator.

Paprika cultivation facility was chosen because paprika takes an important role among Korean major exporting horticultural products. Paprika is being exported to Japan and United States, Russia and Taiwan are potential export markets [8]. Paprika is a tropical garden fruit. The harvest quantity of paprika shows big variation, dependent on sunlight, temperature and humidity environments in the cultivation facility, in addition to cultivation and management technology [9]. Especially, the harvest-cycle variation range of paprika is very big, dependent on the number of fruit-setting caused by interaction between luminosity and temperature [10]; therefore, very precise control of luminosity and temperature is required. When the productivities of paprika in the plastic film house and glass greenhouse were compared, the glass greenhouse showed twice productivity of plastic film house [11]. The productivity of paprika in Korea were 6.8 kg/m^2 in year 2000 and 9.4 kg/m^2 in year 2007. Even there was 38% productivity increase during seven years; it is still 30% of average productivity in Netherlands. [12].

This research paper comprised of followings. The MAC protocols to be compared and analyzed in this research will be introduced in Chapter 2. In Chapter 3, the methodology of selecting MAC protocol to be used at cultivation site is suggested and candidate MAC protocols are compared. Then there will be a conclusion section.

2 Background of Research

The research that aims to connect ubiquitous systems such as WSN, etc. to the agricultural facility environment such as greenhouses and stalls, etc. was variously attempted. The work for applying a computer as well as sensor networks to agriculture was attempted in world countries since 1970 and has developed various automation systems, and plant factories were activated in close Japan. Glass greenhouses are being operated in Netherlands and its output per unit area is a world-best level. Korea is doing various attempts to several fields to reduce this gap, and one among them is making effort to make an automated, quantified and optimized agricultural environment by combining ubiquitous computing with agriculture. The next research examines cases that connect ubiquitous computing to agriculture and the efforts for optimizing efficiency in WSN being mainly used in ubiquitous computing is being examined.

2.1 Green House Integrated Management System

In order to create a ubiquitous agricultural environment as well as measure temperature, humidity, flux of solar radiation, carbon dioxide, ammonia, wind velocity and rainfall, etc. influencing cultivation environments, the present research composed sensor networks in greenhouses and developed a greenhouse environment's monitoring system that controls a device having influence on change of environmental factors such as ventilation fans, windows, heating, humidification and illumination, etc. This system can grasp a greenhouse state in real time through the Internet, and can perform remote monitoring of a state inside a greenhouse through CCTV with the naked eye, and is a system that can manage a greenhouse at any place where its remote control is possible by delivering a warning signal through a personal terminal, even if a manager doesn't watch the system in case of generation of hindrance or an abnormal condition[2].

Figure 1. Green House Integrated Management System GUI

2.2 Ubiquitous Stall Monitoring System using IP-USN

This research was carried out as a part of joint technology development's support business supported by the Small and Medium Business Administration. This was researched from June 2009 to May 2010 and is a stall monitoring and control management system using IP-USN technology. And this is a system that monitors a stall environment such as temperature, humidity and ammonia, etc. by installing sensors for environmental measurement at a stall, and that when abnormalities such as an abnormal environment and fire, invasion and theft, etc. occurred, it informs the abnormalities to a producer so that he can cope with it quickly. In addition, the scalability capable of monitoring large-scale stalls is provided by using sensor nodes applied with IP technology, and application models suitable for various rural environments were constructed by guaranteeing mobility of sensor nodes. WSN is also used as USN in Korea[13].

Figure 2. u-Stall Monitoring System GUI (Smart phone and WEB)

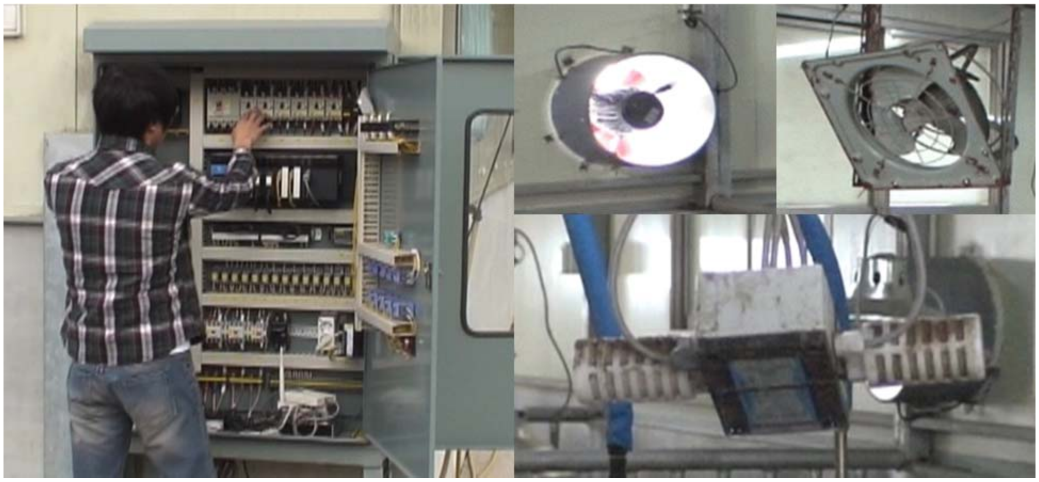

Figure 3. Environment Control Device and Sensor

2.3 S-MAC

SMAC is a representative synchronous MAC protocol. It periodically repeats inactivated "sleep mode" and activated "listen mode" with fixed lengths [3]. In the "listen mode", the data transmission between two nodes is possible. In the "sleep mode", power waste at each sensor node is reduced by providing with minimum power to maintain the sensor node, while main power is shut-off. However, there will be "listen-sections" without communication caused by fixed lengths and power is wasted because of these unused "listen-sections". Also, there is a disadvantage in the "sleep-section", which is data transmission delay caused by inability to receive signal in the "sleep-section".

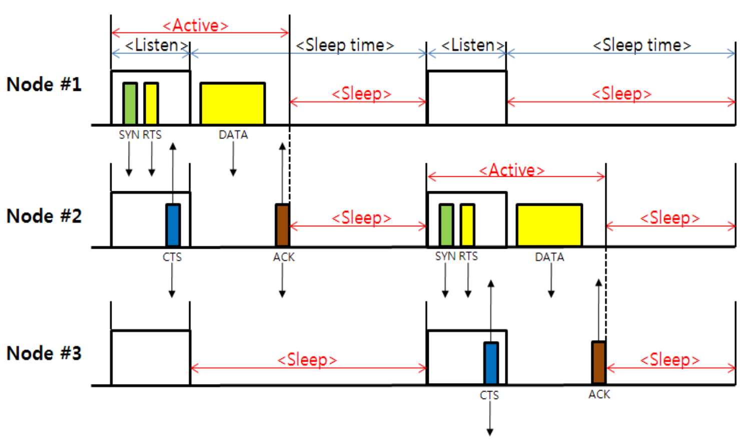

Figure 4. S-MAC

2.4 X-MAC

The X-MAC protocol is suggested to resolve the problem of overhearing caused by the long preamble used in the B-MAC[15] protocol. It reduces the preamble overhearing of B-MAC protocol by repeated transmission of minimum preamble for synchronization and the "strobed preamble" containing the destination address. When there is data to transmit, the node operating with X-MAC transmits the minimum preamble and the "short preamble", containing the destination address, in order to tell nearby nodes that it has data to transmit. Then the node maintains "stand-by" mode of data reception for a sufficient period to receive early ACK [7].

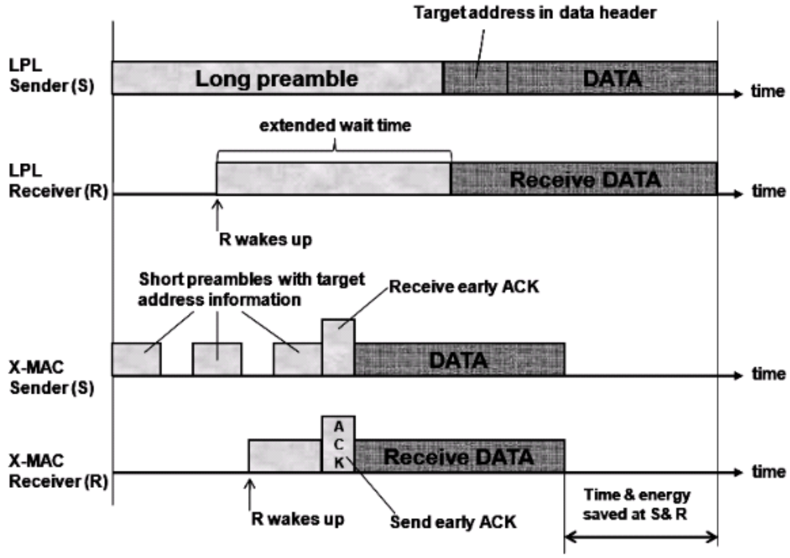

Figure 5. X-MAC's short preamble approach[7].

2.5 LPMAC

LPMAC(Link quality based on Power control MAC) protocol transmits isochronous packet using maximum power in the synchronization process before it sends the data to the neighborhood node. The nodes which received this packet measures the RSSI and LQI, determines the most optimum power and exchanges the maximum power value during synchronization process.

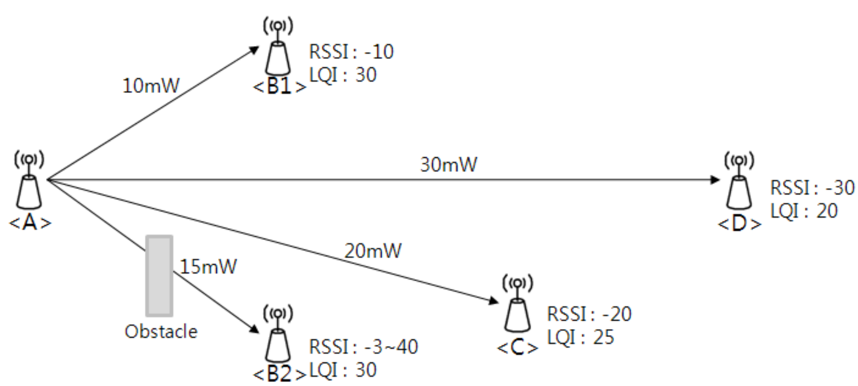

Figure 6. LPMAC

The smaller the RSSI of received signal, the bigger power should be suggested; however, it examines the communication quality at the time, and, if the communication quality is good, it suggests the transmission power one level lower. The transmitted power selects the power with good communication quality by considering the communication quality with relevant node every time transmitting/receiving of the data would be made with neighborhood node and SYNC packet. This process is done in the synchronization process regardless of transmitting/receiving nodes. The energy consumption can be reduced more by such control of transmitting power[14].

3 Method of protocol adaptation

3.1 Cultivation Environment of Paprika

This research takes the actual paprika greenhouse in Gwangyang, Chollanam-do. Sensor nodes are located in the greenhouse and the network performance was examined in advance so that the sensor network can be installed for efficient operation by choosing the efficient MAC at site.

In the facility cultivation, paprika seeds are sown to the rock wool trays and they are planted temporarily on the rock wool cubes. When there would be the first branch stem, they will be permanently planted to the culture medium for cultivation. Then culture solution made for the best paprika growth will be supplied. At the lower part of the culture medium, boiler pipe way will be installed and warm water will be supplied to maintain the temperature at the paprika rooting zone constant. LED lightings will be installed in the upper part to enhance the growth of paprika and ventilation equipment will be also installed to mix the upper air and lower air for constant temperature. Mobile screens will be installed inside of greenhouse roof to shut off the strong sunlight.

Figure 7. LED Lamp, Sun Shield and Warm water supply

The paprika rock wool cubes will be located at 30cm distance with each other. There will be four rock wool cubes for each culture medium. Each culture medium will make 50m length in parallel with the rail installed at greenhouse floor. Each group of culture media will be located at 50cm distance having the rail between them. Other than moving and working space in the greenhouse, the whole greenhouse will be filled with culture media planted with paprika. For growth environment, daytime 22~25℃, nighttime 18~20℃ and humidity 70~75% will be maintained.

3.2 Hardware Description

Figure 8. Sensor Node

The sensor node developed by Sunchon National University ITRC Research Center will be applied to this research. This sensor node can collect the information of leaf wetness, leaf temperature, greenhouse temperature/humidity and control the relay by one sensor. MSP430 MCU is applied to the CPU and CC2420 RF module of Chipcon Co. is used as the data transmission/reception device. The MSP430 microprocessor has 16 bit RISC structure and it works in very fast speed with its 48 Kbyte program memory and 10Kb RAM. 3.6V battery is used for power supply [16].

3.3 Network Topology

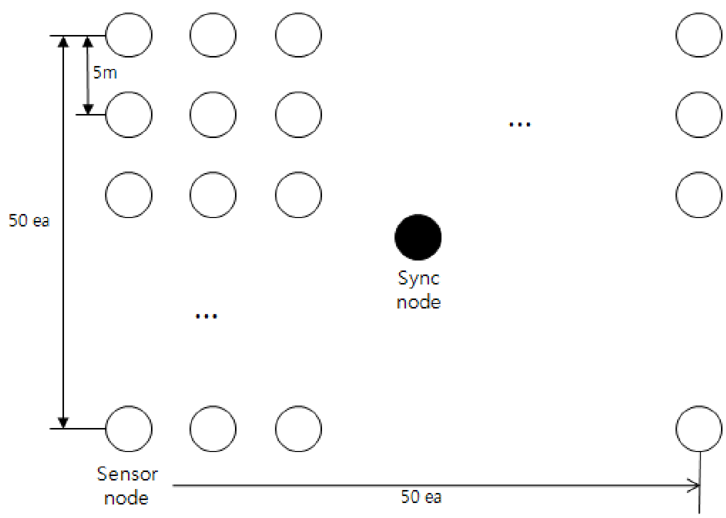

Figure 9. Network Topology

The sensor nodes will be installed at every 5m along the culture media lined up in reference to the paprika at the most outer side. They will be installed alternately for the root zone parts and upper parts. Installation will continue to the culture media with 5m distance in reference to the culture media with sensors installed. The overall location shape of sensor nodes is grid-type with 5m distance. The sink node to transmit collected data to the server will be located in the center of 50 * 50 grids. The shape of sensor nodes location is grid shape; however, the network topology is a star topology in reference to the sink node in the center of the grid.

3.4 Duty Cycle

The sensor of sensor node measures leaf temperature, leaf wetness and greenhouse temperature/humidity. They are measured in 3 minutes cycle and transmitted to the server. The relay control port of the sensor node will not be used. The measurement cycle can be different dependent on the characteristic of the crops.

Then, the duty cycle to be applied to sensor node will be determined. The generated data and the number of nodes to transmit data to sink node, during the measurement cycle of crop environment data, will be estimated. Total number of data which can be generated during the measurement cycle will be estimated and the data quantity which can be processed for each duty cycle will be deduced. The duty cycle will be chosen so that it can process more data than the data generated during the measurement cycle. 10% allowance will be given so that waste data would not be generated. If the measured data would be missed, the on-time responding to the change of crops growth environment change will be difficult and the quality, quantity of the harvested crop will get negative impact.

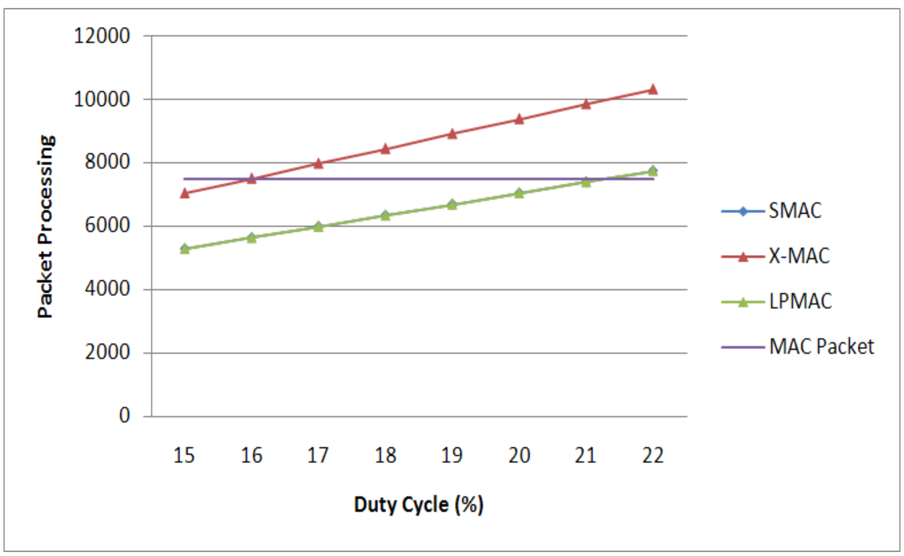

Figure 10. Available Duty cycle by MAC Protocols

Figureure 10 shows the packets which can be processed by S-MAC, X-MAC, LPMAC dependent on duty cycles. In the established situation, the effective duty cycle of S-MAC and LPMAC are 22%, including 10% allowance. For X-MAC, the proper duty cycle is shown as 16.3%.

3.5 Simulation

A simulation will be done to measure the energy performance of the MAC considered for the application. The performances of S-MAC, X-MAC and LPMAC will be examined. For this, a simulation environment was made using NS-2 [17]. Table 1 is the system parameters for the simulation.

Total 2,500 nodes comprised the network topology as in Figureure 9. The physical shape of nodes is grid; however, the shape of network topology is a star-shape with sink node in the center. Each node generates 40 bytes per minute of sensing data when the number of the nodes is fixed and the energy consumption at this time is measured. Each node measures leaf temperature, leaf wetness and greenhouse temperature/humidity. They are measured in 3 minutes cycle and transmitted to the server; however, it will be assumed in the simulation that the measurement items will be data with same size and the data is generated in one minute cycle.

Table 1. Simulation Parameter

	S-MAC	X-MAC	LPMAC
NS2 Version	NS-2.34		
Simulation Time	5000 Second		
Packet Size	40 byte		
Packet Interval	1 minute / node		
Node Count	2500		
Routing Protocol	DSDV		
Duty Cycle	22%	16.3%	22%
Bandwidth	250Kbps		
Initial Energy	30,000 J		

The simulation measurement result in Figureure 11 suggested that the energy performance of LPMAC is slightly better than X-MAC and S-MAC. It is believed that this phenomenon occurs when there are many nodes and the number of packets being transmitted is very small. As we can learn from the simulation result, when we apply sensor network to agricultural environment, the protocol proper to the operation environment can be chosen through the comparison and analysis of MAC protocol to be applied, together with the design of network topology in advance.

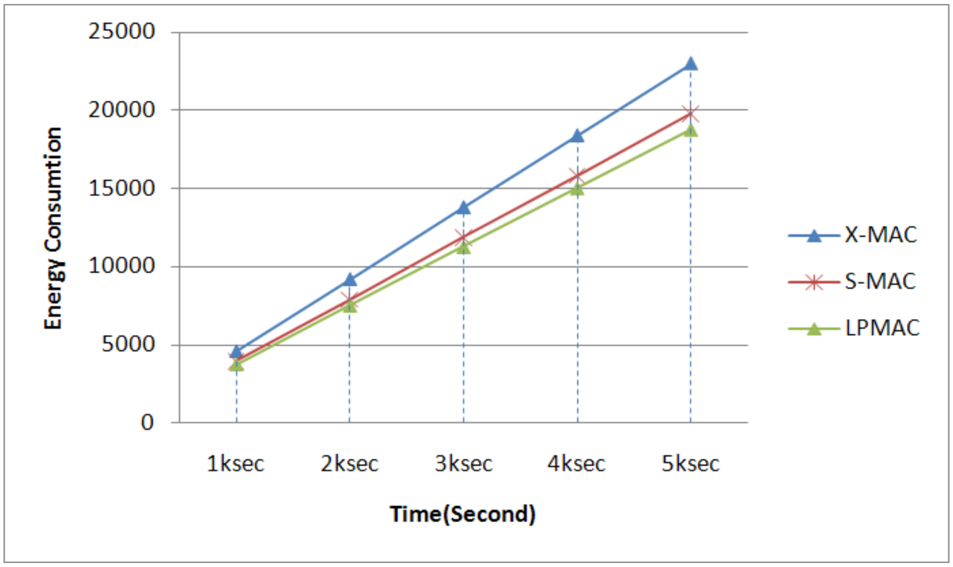

Figure 11. Energy Consumption

4 Conclusion

When applying a wireless sensor network to agriculture, the first thing to determine is whether agricultural site is dynamic or static. Next will be the sensors proper to the environment information of the crops to be measured, number of sensors for each sensor node and the data measurement cycle. If one sensor node will have multiple sensors, there will be more power consumption to operate sensor, in addition to the data transmission/reception. The capacity of the sensor to be used would be chosen considering all these.

Then the sensors will be located at the position of the crop to be measured. The location of sink node will be determined by the methodology of data collection. Then the data generation cycle of sensor and the shape of network topology will be determined. After that, the MAC protocol will be determined, applying the MAC protocol determining methodology suggested by this research. It was found that the LPMAC protocol is proper as the MAC to be applied to the facility cultivation of paprika.

This research result suggested the methodology to deduce the most efficient protocol which can be applied to the facility cultivation of paprika. However, it is believed that this result can be also applied to the outdoor cultivation, outdoor stock-raising and cultivation of other crops than paprika in the determination of proper MAC protocol for the situation and subsequent efficient operation.

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