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Multi-Channel WSNs for Environmental Monitoring in Plant Factory

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ABSTRACT

Some factors, such as temperature and humidity, may have a large impact on crop growth. Recently, plant factory has become a new cultivation technique in agriculture, and all environmental parameters in plant factory are controlled thereby the crops can be stably supplied. However, uneven temperature distribution can be still found in plant factories, so additional sensor techniques, including wireless sensor networks should be employed to monitor the environment in plant factories. A large number of sensors densely deployed in a closed space may increase the chance of packet collision, causing data loss. With incomplete data, the variation in temperature may not be detected. In order to solve the problem of data loss, this study proposes a multi-channel mechanism to avoid the packet collision in a plant factory.

Keywords: Plant factory, Wireless sensor network, Packet collision, Multi-Channel, Taiwan

1. INTRODUCTION

Global warming is worsening, causing the difficulty of growing crops in outdoor environments, so the quality and quantity of crops are not stable. The concept of plant factory (PF) was proposed to promote a well-controlled growth environment for plants (Kozai *et al*., 2001). PF is a type of agricultural automation technologies through which plant cultivation proceeded in a highly intensive and stably indoor environment. A PF generally includes shelves, air-conditioning systems, artificial media or hydroponic systems and LED lights. All of the devices are under control; for examples, illumination can be controlled by LEDs, and an air-conditioning system can control temperature and relative humidity. On the other hand, because PF utilizes hydroponic systems, heavy metal pollution and soil-transmitted diseases can be reduced. The crops are isolated from the outdoor environment, so pesticide residues can also be avoided. However, variations in monitored parameters can be found in a PF, and these variations may influence plant growth. Chang et al., for example, suggested that uneven temperature and relative humidity distribution affected the dry and fresh weight of the crops (Chang *et al*., 2011). Thus, a number of additional micro sensors should be added to measure

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and monitor the environmental parameters in a PF, and wireless sensor networks (WSNs) were able to complete these measuring tasks.

The WSN techniques was firstly developed by a research team from U. C. Berkeley, and applied to military affairs (Kahn *et al*., 1999). In general, the wireless communication protocol is based on ZigBee (IEEE 802.15.4), and operates in the industrial, scientific and medical (ISM) radio bands; 868 MHz in Europe; 915 MHz in the US and Australia; and 2.4 GHz worldwide. A total of 16 channels are allocated in the 2.4 GHz band. (USA: ZigBee Alliance, 2008) The wireless sensor nodes have the features of small size and low power consumption, and they can communicate with each other via radio frequency, rather than through wiring. So, a large number of sensor nodes can be deployed in a monitoring field. Recently, the achievement of WSNs has been well-known in electrical engineering (Lu *et al*., 2006), ecological monitoring (Martinez *et al*., 2004), and environmental monitoring (Liao *et al*., 2012), even in PF (Juo *et al*., 2012). Furthermore, wireless sensor nodes communicate with each other or gateways through packet transmission. If nodes are densely deployed in a confined area, such as in a PF, and if a gateway requests sensing data from all nodes at the same time, packets might collides with each other. Gateways cannot access to the packets once they packets are collided, and the data delivery rate will thus decline (Cai *et al*., 2012). Without complete sensing data, any variation in temperature or relative humidity in a PF may not be found. In fact, gateways can request sensing data from nodes again, if they do not receive packets due to collision. Such a strategy, however, may lead to additional energy consumption for nodes that are required to retransmit packets. The energy of these nodes is depleted ahead of time, and in turn the network lifetime also decreases. In addition, the incomplete temperature or humidity data may affect the accuracy of further data analysis. Thus, this study proposed a multichannel mechanism applied to gateways, so they could assign packets to different channel to avoid packet collision.

2. MATERIAL AND METHODS

As shown in figure 1, the proposed environmental monitoring system in a PF mainly included two parts: a front-end sensing system and a back-end database. The front-end sensing system consisted of several wireless sensor nodes and one gateway. The gateway was equipped with one base node to transmit command packets to nodes and receive data packets from the nodes. The gateway then organized and transmitted the received sensing data to a back-end database through another communication protocol, such as Wi-Fi, GSM, 3G, or Wi-Max. Users could access to the back-end database to browse or download sensing data through an internet service.

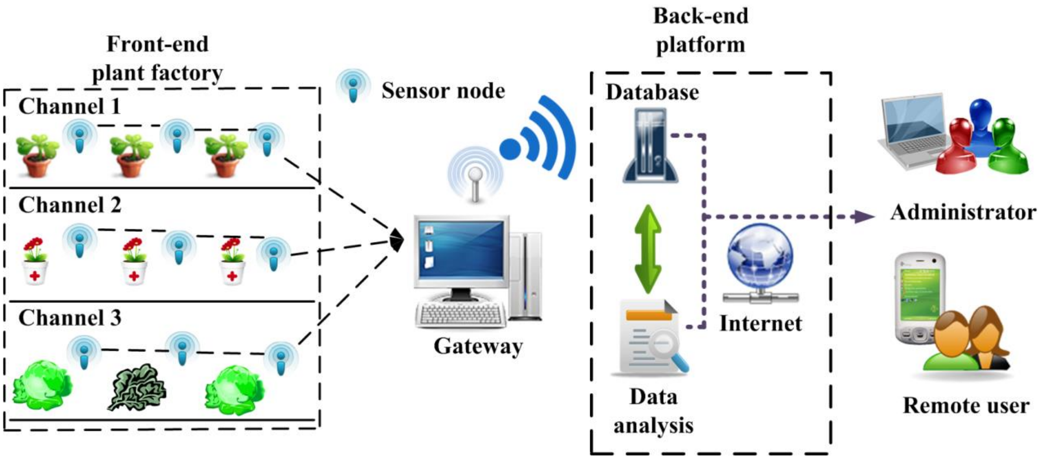

Figure 1. System architecture of the proposed monitoring system

In order to avoid packet collision caused by nodes densely deployed in a confined area, all of the nodes were assigned to different communication channels provided by the ZigBee protocol. The base node in the gateway was also able to receive sensing data from different channels. The components and operation procedure used in this study are presented in the following sections.

2.1 Wireless Sensor Node

The Octopus II was used in this study as the wireless sensor node (Sheu *et al*., 2008). The Octopus II consisted of an MSP430 microcontroller, a wireless communication module based on the TI CC2420 communication chip, and a sensor board. It followed the IEEE 802.15.4 specification, and its communication frequency band was at 2.4 GHz with a transmission rate up to 250 kbps. The front and back side of the Octopus II are shown in figure 2. The sensor board was equipped with a temperature, relative humidity, and light intensity sensor, which inserted in a stackable connector.

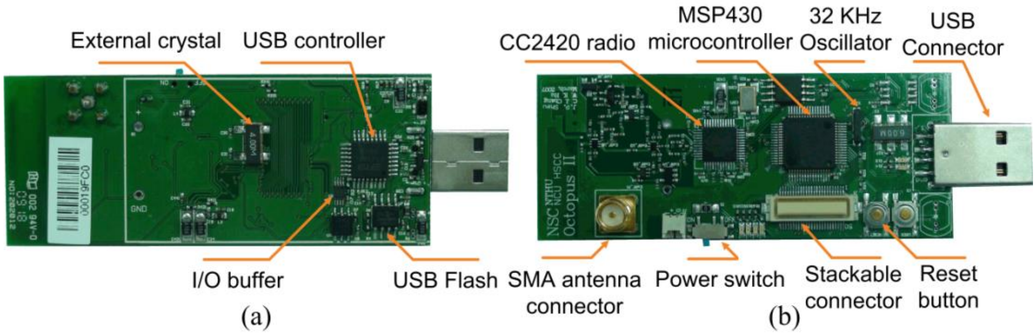

Figure 2. The Octopus II used in this study (a) The front of the Octopus II; (b) The back of the Octopus II.

2.2 Gateway

PF is a humid environment because it often utilizes hydroponic systems, thus the electrical components easily rusted in such an environment. In order to overcome this problem, this study utilized an industrial PC (IPC) as the gateway in the PF. The case of the IPC was able to resist high humidity. In this study, the gateway was equipped with four base nodes, and each base node had its own corresponding channel. After the gateway received all sensing data, the sensing data would be transmitted the back-end database through the Ethernet communication protocol.

2.3 Operation Procedure of the Network Using the Multi-Channel Mechanism

The main goals of this study were 1) to decrease the number of packet collisions when each sensor node transmitted the packets to the gateway; 2) to ensure that sensing data can be transmitted to the gateway in a faster round; 3) to reduce the rounds of re-requesting caused by packet collision to minimize the additional energy consumed by a node retransmitting data. This study allowed the packets to be simultaneously transmitted to a gateway through different channels in a highly dense deployment area. This study also actually implemented the mechanism and adjusted the number of channels to measure the delay time and the rate of data collision from different channels. Figure 3 shows the flow chart of the operation procedure of the network. First, the gateway broadcasted a data collection command to each node through the base nodes with different channels. After the base nodes received the packets, the gateway checked to find if data collection was complete. If data collection was not complete, the gateway would request to retransmit the data again, and all data would be stored in the gateway.

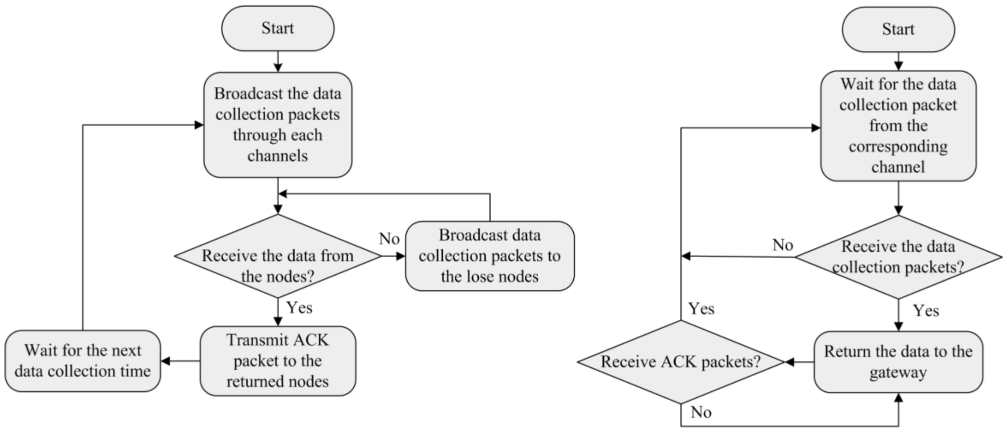

Figure 3. The flow chart of the network operation procedure using the multi-channel mechanism, (a) for the gateway and (b) the sensor nodes

3. EXPERIMENTAL RESULTS

This study actually deployed 48 nodes and one gateway with four base nodes using different channel designs in a small room (6m × 6m) to simulate a closed space like PF. A star topology was used as the network topology in this study. Each round of data collection time was set at 180 seconds. Four experimental scenarios, each employing single, double, triple, and quadruple channels, was used to assign the packets. Hence, 48 nodes were evenly assigned to one to four channels. After that, the gateway received the packets from nodes that employed different channels at the same time to examine the impact of the multi-channel mechanism on packet collision, as showing in figure 4. Figure 4 also shows the number of rounds that the gateway needed to receive all packets after each packet collision.

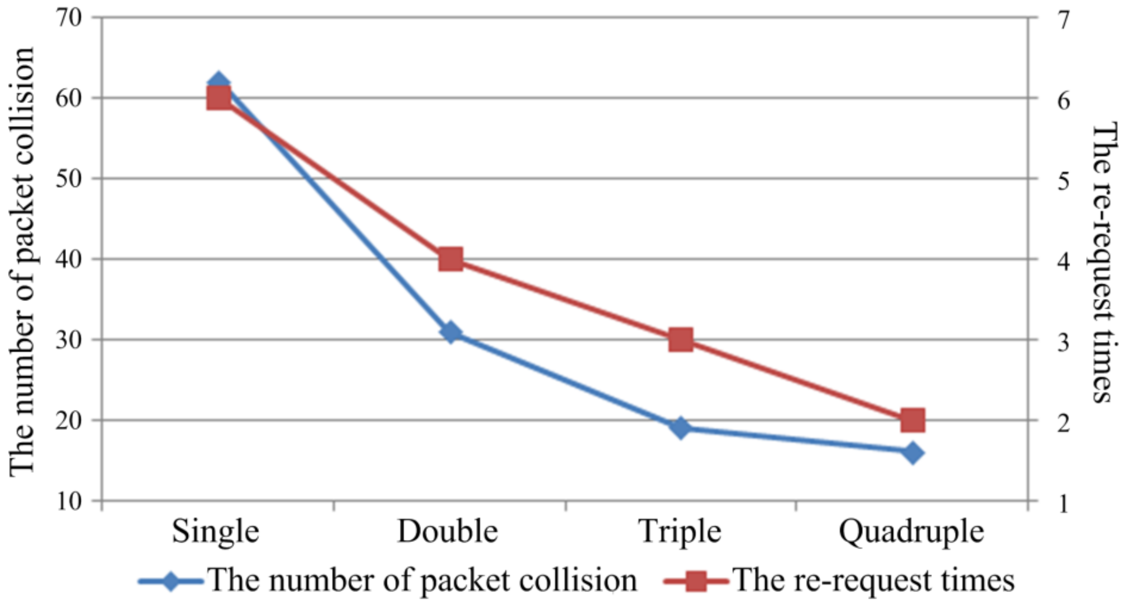

Figure 4. The effects of using single, double, triple, and quadruple channels on packet collision and the frequency of re-requesting until the gateway obtained all the packets.

The experimental results show that the number of packet collision decreased when the number of the employed channels increased. Therefore, with multiple communication channels, the gateway not only can more quickly obtain sensing data in a real-time manner, but also can establish an un-distorted model for temperature and relative humidity variations in a PF. As the frequency of re-request increased, nodes would consume more energy, and the network lifetime eventually decreased. Table 1 shows the power consumption for each task done by the Octopus II (Sheu *et al*., 2008). The power source for the Octopus II was two AA batteries, and their capacity was about 2700 mAh.

Table 1. The power consumption for each task done by the Octopus II

	Receiving task	Transmitting task	In the sleep mode

Voltage	3.3 V	3.3 V	3.3 V
Current	18.8 mA	8.5 mA	20 μA
Power Consumption	566,550 nJ/Byte	11,560 nJ/Byte	66 μW
dBm	-95	-25	N/A

*N/A: Because the nodes switched off the radio frequency when they were in the sleep mode.

The end of the network lifetime in this study was defined by a sensor node depleting its energy at first time. Figure 5 shows that the network lifetime for each channel design.

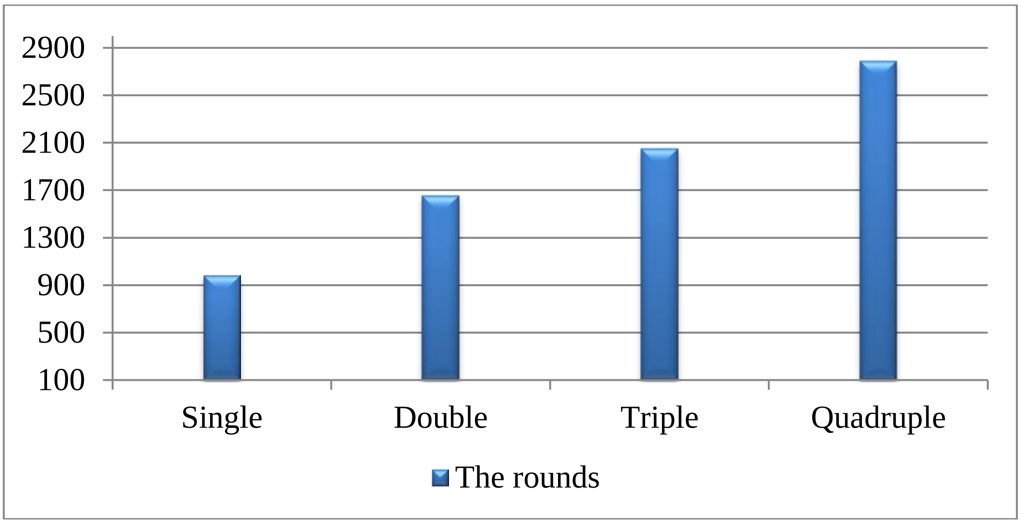

Figure. 5 The network lifetime for each channel design in this study.

4. CONCLUSIONS

The research results show that multi-channel mechanism is capable of lowering transmission delay and packet collisions. The system allows users to monitor and control the environmental factors more effectively. Using this system, plants can grow up much better in a well-controlled environment. The total plant output of the plant factory significantly increases, so the proposed system could make a contribution to the improvement of agricultural production.

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