Sub-1GHz wireless sensing and control instruments for greenhouse farming system

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Abstract. Radio frequency enabled devices was developed to make the data gathering and instruments control process become wirelessly possible for greenhouse. This research used 915 MHz radio frequency band, which is also known as ISM (industrial, scientific, and medical) band. To accomplish the experiments, three main devices was developed. They are node sensors (NoSe), node actuators (NoAc), and gateway. According to communication range test, the devices can transmit flawlessly up to 43 meters in harsh environment (Non-Line of Sight or Non-LoS). The result was increased dramatically in an open field (Line of Sight or LoS) with maximum range that can be achieved is up to 280 meters. The RSSI (Received Signal Strength Indication) for LoS and Non-LoS measurements were recorded. The number of transmitted data was approximately 500 samples and transferred approximately every 200 ms. In Non-LoS scenario, RSSI ranged from -74 dB to -96 dB with average -82 dB. The better performance was shown in LoS measurement that is RSSI varied from -67 dB to -89 dB with average -76 dB. Based on that results, this technology have a great prospect as an option to greenhouse wireless sensing and controlling technology.

1. Introduction

Global climate change and global warming are a serious challenge faced by the society. These phenomena effect many areas including farming system [1-4]. A conventional farming systems that rely on the open area of planting are very susceptible with many plant diseases and environmental disturbances. One alternative to overcome this problem is by applying greenhouse farming systems [1].

Various studies have been done in developing the greenhouse farming systems. The environmental data recording and control for electrical instruments are main activities in technology-based greenhouse [5]. Nowadays, the automatic data recording for environmental parameters is very important to increase the productivity [6]. Environmental parameter such as temperature and humidity are often controlled for many plantation systems [7-8].

In technology-based greenhouse, many sensors and actuators can be involved. Therefore, the concept of Internet-of-Things (IoT) is very applicable. Internet of Things (IoT) is a networking system that allows various devices to communicate with each other [9]. Connectivity is probably the most basic building block of the IoT paradigm. A low-power WANs using ISM band application can be a solution for overcome this problem [10]. The ISM band was originally allocated for the non-commercial and unlicensed use of radio frequency (RF) for non-communication applications. ISM does not produce too much noise in the spectrum [11].
Beside ISM application, another communication protocols are commonly used. IEEE 802.11 (Wi-Fi) protocol contains the provision for a deauthentication frame. Sending the frame from the access point to a station is called a "sanctioned technique to inform a rogue station that they have been disconnected from the network" [12]. An attacker can send a deauthentication frame at any time to a wireless access point, with a spoofed address for the victim. The protocol does not require any encryption for this frame, even when the session was established with Wired Equivalent Privacy (WEP) for data privacy, and the attacker only needs to know the victim's MAC address, which is available in the clear through wireless network sniffing [13,14]. The IEEE 802.11 was first created in 1997 and improved over the years. IEEE 802.11w-2009 is currently the most powerful security standard available for WLAN users [15,16]. The MAC layer of the 802.11 protocol is based on the exchange of request/response messages i.e. each request message sent by a station (STA) must be responded with a response message sent by the AP. Probe Request Flood (PRF) attacks are designed to take advantage of this request and respond design flaw [17]. Flooding attacks cause serious performance degradation or prevent legitimate users from accessing network resources such as the bandwidth, access points, gateways, servers and target user systems. This vulnerability is increased due to the unprotected beacon or probe request and probe response frames which can be read by anyone to learn about the network.

In our research, the wireless communication nodes for greenhouse was developed by applying ISM frequency band (sub-1GHz). The activity was mainly focus on watering system that involved various sensors and actuators. The communications among the nodes were developed, and the maximum communication range was evaluated.

2. Methodology

2.1. Communication System of Nodes

In this research, three main components prepared for further greenhouse infrastructure were developed. Those components are sensing modules (Node sensors/NoSe), actuator modules (Node actuators/NoAc), and gateway module. NoSe has a capability for sensing the environment condition (ambient temperature, humidity, light intensity, etc.), whereas NoAc has a capability for controlling particular devices such as pumps, control valves, fertilizer mixer, watering instruments, air conditioners, etc.

Figure 1. Research schematic.
Each node is connected to \textit{Master Node} or \textit{Gateway}. Gateway is composed by a single-board computer which is connected to TCP/IP network (WLAN/WAN/Internet) and it is mainly as a translator among the IoT modules. In the gateway, a dynamic web-based interface is installed and it can be accessed by any device that supports modern web technology such as smartphone, desktop, laptop, or other devices. By using that interface, all nodes can be monitored and controlled. For recording purposes, all environment parameters can be stored using local database system which is stated on the gateway. The research schematic is shown in Figure 1.

2.2. Hardware Schematic of Nodes
Each node is assigned by a unique network address and their network is accessible based on code and encrypted password. Practically, a group of node in the greenhouse will have the same network code but assigned with different network addresses. All nodes are configured based on star topology with a master node acts as the main controller.

Both \textit{NoSe} and \textit{NoAc} are modules composed by a low-power microcontroller equipped by a radio wave transceiver (RF Transceiver). A low-power microcontroller ATmega328 is chosen as a node’s core as it meet the controller’s requirements. It is a low-cost microcontroller featured by sufficient resources for research purposes. The RF Transceiver works at 915 MHz which is belongs to ISM Band. This frequency is chosen as it occupies a clean-band for radio wave propagations compared to a 2.4GHz band which is dedicated to general communications. The ISM band also offers wider range and better wave penetration compared to 2.4 GHz so that it has an opportunity for more robust IoT communication systems. The hardware schematic for \textit{NoSe}, \textit{NoAc} and \textit{Gateway} are shown in Figure 2.

2.3. Nodes Installation
The nodes installation schematic is shown in Figure 3. Our research goal is mainly focus on how to control the watering system. In this research step, we are neglecting other parameters that impact the greenhouse environments such as light intensity, air and soil temperatures, humidity, etc. However, we putted some sensor to monitor those parameters just for collecting the environment’s information. The main used sensor is soil humidity sensor as it useful to detect the soil condition for watering purposes. In this research, the greenhouse watering and fertilizing systems are done at the same time by using \textit{drip irrigation} method. It is mean that the fertilizers (type A and B) are in liquid form. Liquid fertilizers and water are mixed in a dedicated tank before pumped to the greenhouse, as shown in Figure 3.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Hardware schematic of Nodes: (a) Node Sensor, (b) Node Actuator, and (c) Master Node}
\end{figure}
As explained in previous section, all nodes are operated wirelessly. It is mean that the use of wire can be reduced significantly. In Figure 3, several NoAc and NoSe placement are shown. The installed NoAcs are mainly to energize actuators such as pumps and control valves. For achieve this goal, the NoAc is mainly composed by driver circuits and relays. The NoSes are sensing devices. Therefore, the NoSes are equipped with sensors for various purposes. In the tanks for collecting the water, fertilizer (type A and B), and mixed water and fertilizer, the installed NoSes are equipped with level sensors, whereas in the greenhouse environment, the NoSes are equipped with many other sensors such as soil humidity, light intensity, air humidity, and air temperature sensors. Both NoAc and NoSe are controlled by Master Node. All NoSes send environment data to the Master Node with a specific time period. The received data from the NoSes will then be processed by the Master Node, and it will deliver an appropriate task to the NoAc. Both receiving and transferring data are done wirelessly.

3. Results and Discussions

3.1. Node Devices
In this research, the produced hardware are still a prototype. Both NoAc and NoSe are composed by the same circuit board. They are distinguished by the attached devices. NoAc is equipped with actuator driver whereas NoSe is attached with a specific sensor. An Atmel ATmega328 microcontroller attached on Moteino board [18] is applied as a central processor. The microcontroller and its components are embedded on a single PCB board which has size approximately 33mm × 20mm. The device example is shown in Figure 4.

Three AA batteries are sufficient for powering the board. The required logic voltage for radio chip is 3.3 Volts. The three AA batteries produce 4.5 Volts which is then reduced to 3.3 Volts by on-chip regulator for supplying the radio chip. For NoSe, most analog sensors work on 5 Volt voltage supply but still tolerant with 4.5 Volts supply from the three batteries. It is also the same work with actuator drivers. The drivers use solid state relays (SSR) rather than electro-mechanical relays. It consumes much lower current than electro-mechanical does. Therefore, in this research, the three AA batteries is considered sufficient.
3.2. Web-based interface

A web-based interface for the users is developed as shown in Figure 5. However, it is still in development step. By using a web-based technology and broadband connection, it is possible to display various sophisticated contents to desktops, laptops, or mobile devices anywhere in the world. This in an advantages for the operators or authorized persons as all greenhouse parameters can be received and monitored wherever and whenever it is convenient for them. To support wide range of web-enabled devices, a responsive web interface design is implemented. Therefore, the web will automatically adjust the wide-size of the user’s display.

![Web-based interface](image)

**Figure 5.** Web-based interface

The created interface will accommodate the use of both NoAk and NoSe with plug-and-play system. The Nodes (either Noak or NoSe) will soon be detected by the system and it will be displayed on the interface automatically, without manual setting. In Figure 5, two Nodes are detected and shown on the interface named Node 2 and Node 3. Node 1 was not displayed because it acts as a Master Node. Node 2 in the figure is connected with DS18B20 temperature sensor whereas Node 3 is attached with YL69 soil humidity sensor.

For information purpose, an RSSI (Received Signal Strength Indicator) from each Node is equipped. The RSSI is very useful parameter for showing the signal strength transmitted by each Node to the Master Node. It also can be used to predict the failure communication between Nodes and Master Node.

3.3. Node-Gateway Communication Evaluation

NoAk, NoSe and Master Node communicate among them within an ISM frequency band. The ISM frequency is provided internationally for industrial, scientific and medical purposes. It will not mixed
with the general telecommunication frequency range. The ISM band is applied for the non-telecommunication area, like oven/microwave frequency, medical devices, etc. ISM is generally used for low-power communication.

The Nodes work within 868-915 MHz frequency range with RFM69HW applied as a radio chip. Nodes is configured as a network. Each network composed by maximum 255 nodes. If the number of Nodes exceed 255, we should create another network. According to the manufacturer, the communication distance between the two nodes can reach up to 560 meters at 38.4 kbps. Moreover, with a dipole antenna, it can reach up to 2.5 kilometers at 1,2 bps. Therefore, the use of ISM communication band will be technically possible for wide-range internet-of-things (IoT) communication systems.

![Figure 6. Communication range test with different test conditions with respective map locations and RSSI levels for LoS and Non-LoS](image)

In this research, a very simple 8 cm single wire antenna is used. Then, the maximum communication distance between Node (either NoAk or NoSe) and Master Node was evaluated by using two conditions, as shown in Figure 6. Firstly, a direct communication without any obstacle was noted (Line of Sight or LoS). In this test, the acceptable range test was up to 280 meters without any data losses. Secondly, the test was done with many obstacles (Non-Line of Sight or Non-Los). The master Node was placed inside a concrete room. Many other buildings are also surrounding the test place. According to our evaluation, the distance can achieve about 43 meters. It is still acceptable for a very simple antenna. To extend the commutation range, more specific antenna e.g., dipole antenna should be used.

The RSSI (Received Signal Strength Indication) for LoS and Non-Los measurements were recorded. The number of transmitted data was approximately 500 samples. The data transferred approximately every 200 ms. In Non-Los scenario, RSSI ranged from -74 dB to -96 dB with average -76 dB. The better performance was shown in LoS measurement that is RSSI varied from -67 dB to -89 dB with average -76 dB.

4. Conclusions
Sub-1GHz ISM frequency band has a wide opportunity to be applied for IoT communication system. According to communication range test, the devices can transmit flawlessly up to 43 meters in Non-LoS. The result was dramatically increased in LoS measurement that can be achieved is up to 280 meters. The RSSI for both LoS and Non-LoS measurements were recorded. The number of transmitted data was approximately 500 samples and the data transferred approximately every 200 ms. In Non-LoS scenario, RSSI ranged from -74 dB to -96 dB with average -82 dB. The better performance was shown in LoS measurement that is RSSI varied from -67 dB to -89 dB with average -76 dB.

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