Design of automatic irrigation system for greenhouse based on LoRa technology

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***Abstract*—The application of wireless communication technology to precision agriculture systems helps meet the requirements for real time, reliability and sustainability in the monitoring and control of environmental factors for crop-growth environment. This paper presents the design of automatic irrigation system for the greenhouse agriculture based on LoRa (abbreviation of Long Range) technology with outstanding advantages in terms of transmission range and power consumption. The system consists of Sensor Nodes that collect the data of soil moisture, temperature and humidity. These data will be transmitted to a central station named Concentrator, the Concentrator will use it to control the irrigation process through the Control Nodes located at the field level. The data is also sent to the Supervisor Computer and the Web Server for storage for future analysis. Users can monitor, set up irrigation mode, configure system, access data and manage crops through both Computer Interface and Web Interface. In order to increase the reliability, we also propose to apply the medium access control method Master/Slave for the LoRa network in this system. Finally, we presented some results to evaluate the performance of the system.**

***Index Terms*—Wireless Sensor Network, Greenhouse agriculture, Smart Agriculture, Sensor, LoRa Network, LoRa technology**

I. Introduction

The automatic irrigation system for the agricultural greenhouse is a system that performs the functions of collecting environmental data in the greenhouse and uses them to irrigate the crops automatically ensuring maximum water and energy savings. The system is usually organized into three levels including field level, control level and supervisor level. In recent years, there were many studies in this field. For instant, the Intelligent Greenhouse Environment Monitoring System introduced in [1], in which research has developed wireless sensor nodes to measure the environmental parameters used in control of irrigation, ventilation and lighting in the greenhouse. The system is based on ZigBee and embedded technology. It has the limitation that the use of medium access control (MAC) method called Pure Aloha reduces the reliability of the system especially in the case of large number of nodes in the network. A study on applications of wireless sensor network (WSN) for irrigation systems [2] has also been conducted. In this study, the authors created a system consisting of a central device connected to environmental data collection stations via ZigBee standard and developed an automatic irrigation algorithm. However, more irrigation algorithms should be developed instead of only one based on soil moisture. Moreover, the remote monitoring and control mode is only referred to as a development direction that has not yet been implemented in this study. Systems designed to fit the IoT trend are also a new research direction. The integrated system between Web Server, Ethernet and ZigBee technology specified in [3] is one of them. Although this is an advanced system however it is only designed to perform monitoring functions without control functions. One common finding in all of these studies is the use of ZigBee communication. The advantages of ZigBee such as low power consumption, high stability have explained for this. However, the limitation on transmission range is the main disadvantage of ZigBee technology (about 100 m), which becomes a major barrier when we need to expand the area of greenhouses. From the analysis above, we have researched and designed an automatic irrigation system for greenhouse crops to overcome the shortcomings of the above studies with a new approach. In this study, we have used the LoRa technology with outstanding advantages in transmission range and energy saving. In addition, in order to increase the stability of the system, we also propose to apply Master/Slave medium access control method for LoRa network. The irrigation modes are also more diversified and can be easily installed via Local User Interface or Web Interface.

II. LORA TECHNOLOGY

LoRa is a wireless communication standard that utilizes the Chirp Spread Spectrum (CSS) modulation technology. This technique has been used for a variety of military ap-

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plications such as radar systems. LoRa is the world's first commercially available wireless technology with low cost, long transmission range and optimal power consumption. The Table I below compares some parameters including transfer rate, transmission range, power consumption and cost between some popular wireless technologies. Accordingly, LoRa has shown its superiority in many aspects. Its only weakness is the data rate. However, in wireless sensor network applications, this is not an issue.

TABLE I
THE COMPARISON OF SOME WIRELESS TECNOLOGY [4]

	Tx Range	Tx Rate	Tx Power	Sleep Power	cost
Bluetooth (FBT06)	15 m	3 Mbps	20 mA	16 uA	low
Wifi (CC3200)	150 m	3 Mbps	75 mA	3.5 mA	high
3G/4G (U8300)		14 Mbps	800 mA	50 uA	high
ZigBee (REX3DP)	100-200 m	250 Kbps	200 mA	0.4 uA	low
LoRa (SX1278)	3000 m	2.4 Kpbs	110 mA	2.0 uA	low

A. Characteristic Parameters of LoRa

In LoRa technology, there are three main types of parameters to consider:

- Spreading Factor (SF): A tradeoff between data rate and range is provided by SF. Choice of higher spreading factor can increase the range but decreases the data rate and vice versa. Each symbol is spread by a spreading code of length 2^{SF} chips
- Coding Rate (CR): Define the number of bits added in the payload of the LoRa Packet that the receiver can use to detect and often to correct errors in the message, but it also decreases the effective data rate.
- Bandwidth (BW): LoRa provides three scaleable BW settings of 125 kHz, 250 kHz and 500 kHz. Transmitter sends the spread data at a chip rate equal to the system bandwidth in chips per-second-per-Hertz. So a LoRa bandwidth of 125 kHz corresponds to a chip rate of 125 kcps.

SF, BW and CR are the basic and important parameters of the LoRa chipset. In that, SF and BW will affect the data rate and range while CR only affect the data rate. Depending on the specific application requirements for range, data rate we can choose the reasonable values to optimize the transmission.

B. LoRa Packet Structure

Preamble	Header	CRC	Payload	Payload
	Explicit mode only			CRC

Fig. 1. LoRa Packet Structure

LoRa offers maximum packet size of 256 bytes. The LoRa Packet (Fig. 1) is composed as follows:

- Preamble field: is transmitted first for the synchronization purposes of receiver with the incoming data flow.
- Header field: Depends on the selection of one of the two supported modes. In default Explicit Mode, the number of bytes in the header field specifies Forward Error Correction (FEC) code rate, payload length and presence of CRC in the frame. The second Implicit Mode specifies that coding rate and payload in a frame are fixed. In this mode, frame does not contains this field, which gives reduction in transmission time. Header field also contains 2 bytes CRC field which allows the receiver to discard packets with invalid header. Header field along with its CRC field are 4 bytes long.
- Payload field: Contains application data transmitted through LoRa. Length of payload field varies from 2 to 255 bytes.
- CRC: Comprises 2 bytes of cyclic redundancy check (CRC) for error detection of payload field. This field is optional.

C. Time on the Air of data packet

For LoRa, the actual time on the air for a packet can be defined as [5]:

$$T_{packet} = T_{preamble} + T_{payload} \tag{1}$$

In this formula, $T_{preamble}$ is transmission time of preamble field and $T_{payload}$ is transmission time of payload field. $T_{preamble}$ can be defined as:

$$T_{preamble} = (n_{preamble} + 4.25) \times T_{sym} \tag{2}$$

Where $n_{preamble}$ is preamble length and T_{sym} defines the time required to transmit a symbol:

$$T_{sym} = 2^{SF}/BW \tag{3}$$

with SF as Spreading Factor, BW as Bandwidth
The payload transmission time is:

$$T_{payload} = n_{payload} \times T_{sym} \tag{4}$$

$n_{payload}$ is calculated as:

$$\begin{cases} X = ceil[\dfrac{(8PL - 4SF + 28 + 16CRC - 20IH)}{4(SF - 2DE)}] \\ n_{payload} = 8 + max(X \times (CR + 4), 0) \end{cases}$$

In the formula above:

- PL: number of bytes in payload field.
- IH: 0 when the implicit header mode is used and 1 for vice versa.
- DE: 1 for enabled low data rate optimization and 0 for opposite case.
- CR: code rate (1 corresponds to CR = 4/5, 4 corresponds to CR = 4/8).

So total time on the air T_{packet} can be defined by using Equations 1, 2 and 4

$$T_{packet} = (n_{preamble} + n_{payload} + 4.25) \times T_{sym} \quad (5)$$

III. LORA NETWORK CONSTRUCTION

Application Layer				
MAC Layer				
Physical Layer (LoRa Modulation)				
Regional ISM band				
EU 168	EU 433	US 915	AS 430	-

Fig. 2. Model of LoRa network referenced with OSI model

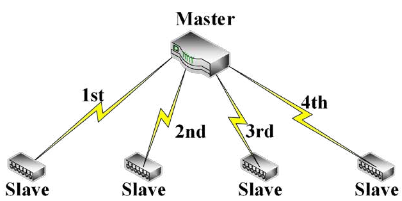

Fig. 3. Master/Slave network model

The LoRa network in this system was designed with star topology. Each of the devices in the network is structured in three layers according to the OSI model. Where the highest layer is the application layer. Under it, is the MAC layer (using master/slave medium access control method). The lowest layer is the physical layer (using LoRa modulation) Fig. 2.

With this Master/Slave medium access control method, the Master station is responsible for allocating access to slaves (Fig. 3). Slaves are passive, so they only access the line and exchange the data when requested by Master. The Master Station either chose directly a slave to communicate with or uses polling method according to the purpose of access. The sequence diagram in Fig. 4 illustrates how polling method is implemented by Master.

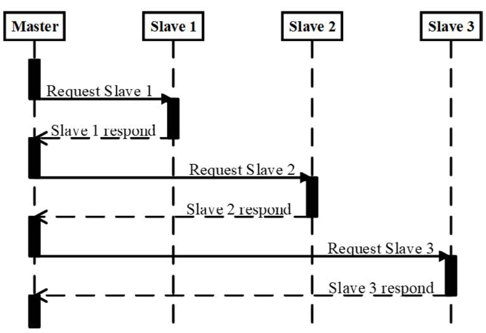

Fig. 4. Sequence diagram of master polling

The Master/Slave has the advantage of being simple and cost-effective because the Master Station is the only one that managing all network connections. With a well-designed Master Station, the reliability of the network will be guaranteed. The major disadvantage of this method is that the exchange of information between the Slave Stations (if any) is limited because the data must pass through the intermediate station also known as Master. However, in this design, field-level devices (Slaves) do not need to exchange information with each other, so the defect does not appear.

IV. SYSTEM ARCHITECTURE

The system architecture is designed as shown in Fig. 5. It includes a Concentrator, End Nodes, Local Database & User Interface and Web Server.

- Concentrator: Coordinates the operation of the network, receives data of environmental parameters from the Sensor Nodes and forwards this data to the Supervisor Computer and Web Server via Wi-Fi or GPRS/3G service. In addition, this device also functions to control the irrigation process according to the mode that the user has installed from the Computer Interface or Web Interface. In automatic irrigation mode, the data sent from Sensor Nodes is used as feedback to control the irrigation process. The Concentrator does not directly control the state of the valves, which is done through the Control Nodes located at field level.
- End Nodes: Includes Sensor Nodes and Control Nodes. In particular, the Sensor Nodes performs the measurement of air temperature, humidity and soil moisture, while the Control Nodes directly controls the actuators such as pumps and valves ordered by the Concentrator.
- Local Database & User Interface : This is where all data of the system is stored. User are also provided the option of monitoring, installing and managing system.
- Web Server & Web Interface: Is an online Server for storing data from measurement points. It not only provides tools for remote monitoring and control but also data analysis based on user requirements.

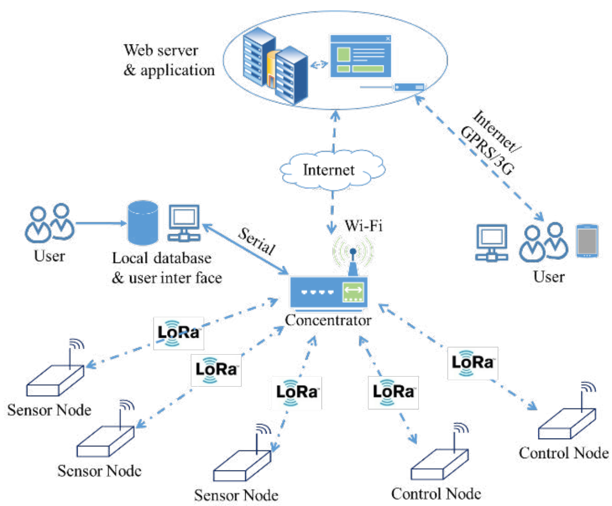

Fig. 5. System Architecture

V. DESIGN

A. Design of Concentrator

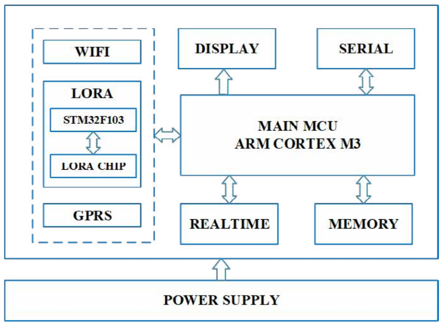

Fig. 6. Concentrator block diagram

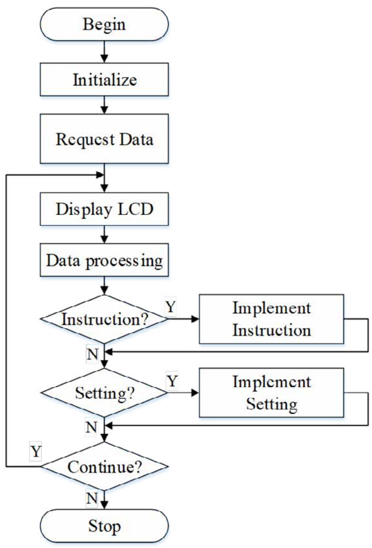

Fig. 7. Main program flowchart for Concentrator

As represented in Fig. 6. The main processing unit in the Concentrator is a 32-bit microcontroller (STM32F103RCT6) for powerful processing with clock speeds up to 72 MHz. The Concentrator is equipped with three types of wireless communication. While LoRa communication enables the Concentrator to connect to field-level devices, WiFi (ESP8266) and GPRS (SIM 800L) provide internet service for connecting the system to the Web Server. These blocks are handled by the central processing unit through UART standard. In order to increase the processing capacity and reduce the load on the central processing unit, the LoRa communication block is equipped with a particular microprocessor connected to the LoRa SX1278 modem via the SPI standard. Nearly every communication task in the LoRa network is processed by this microcontroller. Communication between the Concentrator and the Supervisor computer in case of configuration is performed by serial communication block (CH34G).

The flowchart Fig. 7 describes the design of software for Concentrator.

B. Design of Sensor Node

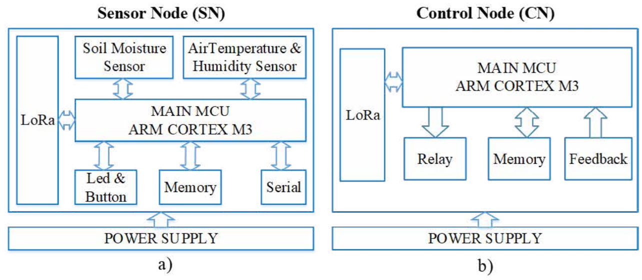

Fig. 8. Sensor Node and Control Node block diagram

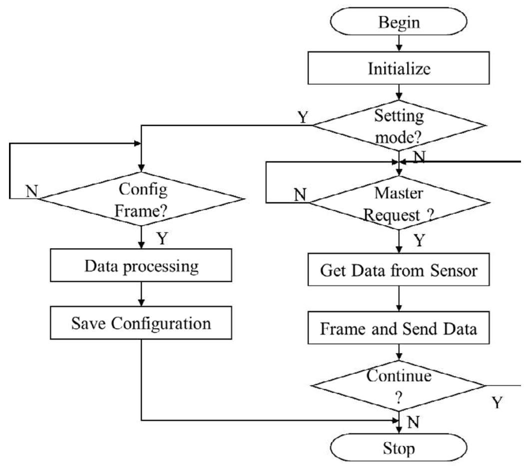

Fig. 9. Main program flowchart for Sensor Node

There are eight main blocks in the design of Sensor Node (Fig. 8a). The central processing unit in Sensor Node handles LoRa communications task and communicates with sensors as well as processes the data given by sensor, so the STM32F103 microcontroller is selected to meet the requirement of processing capacity. The LoRa modem (SX1278) is connected to the central processing unit via SPI. The temperature-humidity sensor (DHT11) is operated by the central processing unit via one-wire standard measuring from 0 to 50 °C (±2 °C) for temperature and 20-90 %RH (±5 %RH) for air humidity. The parameter of soil moisture is also given by a smart sensor that is linked to the central processing unit through 2-wire synchronization standard. Besides, the connection between Sensor Node and Computer for address configuration is provided by the serial communication block (CH340G). The configuration parameters for the device will be stored in the EPROM. Finally, the LEDs show the operating status of the device while the button is used to select either setting mode or running mode for the Sensor Node.

The software's algorithm for Sensor Nodes is pointed out in flowchart Fig. 9.

C. Design of Control Node

In the block diagram of Control Node Fig. 8b, the Control Node also includes a central processing unit (STM32F103), Lora communication block (SX1278), EPROM memory with the same function as the Sensor Node. Control the actuators such as valves and pumps is the main function of the Control Node performed directly by the Relay block. As an important part of Control Node, Feedback block provide information about the actual operating state of the actuators so that it allows for quick detection of unexpected problems. The software of Control Node device is designed as flowchart shown in Fig. 10.

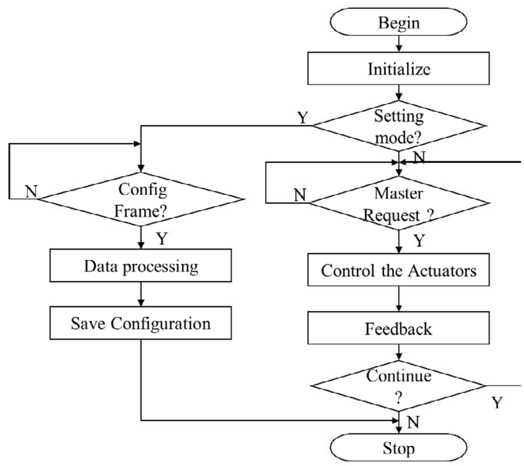

Fig. 10. Main program flowchart for Control Node Node

D. Design of Local DataBase & User Interface

The Local User Interface (Fig. 11) is designed with main functions corresponding to 5 interfaces:

- Data monitoring interface: Display data and status of pumps and valves in the system.
- Control Interface: Allows setting of irrigation mode for each area. There are three modes of irrigation: Schedule mode, Automatic mode and Handle mode.
- Setting interface: Allows to add, remove farming area, set up the connection, enable the monitoring mode via Internet and chose the data sampling cycle. In addition, the interface provides advanced settings related to LoRa's parameters such as address, frequency, spreading factor, coding rate, bandwidth to devices in the network.
- Reporting interface: Allows us to access the data and displays in the form of line chart and table. Data can also be extracted as Excel file.
- Crop management interface: Provide crop management functions, inquire crop information and propose appropriate crop.

E. Web Server Intergration

Currently, we have built-in Web Server (Fig. 12) based on Ubiodot's platform providing remote monitoring, control and data storage. Depending on the Internet connection technology selected is GPRS or WiFi we respectively use the HTTP method Get/Post or use the TCP/IP protocol to send and request data interactively to the Web Server.

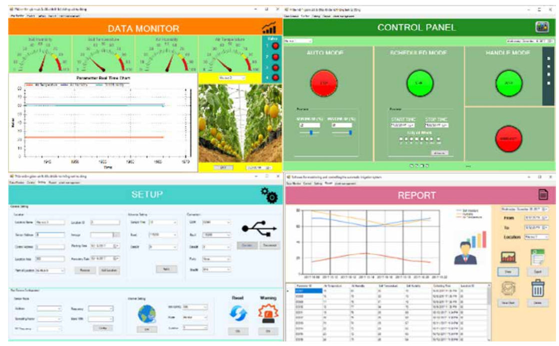

Fig. 11. Computer Interfaces

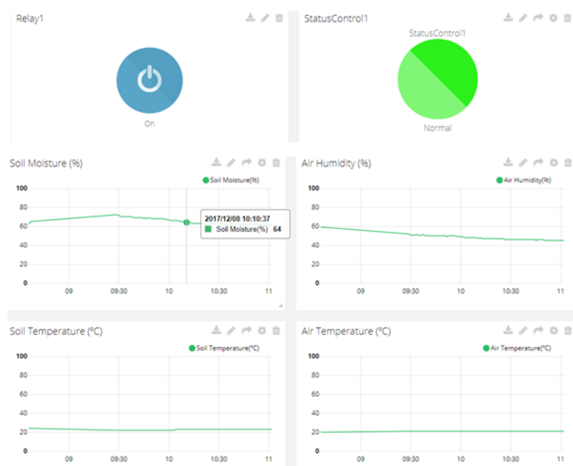

Fig. 12. Web interface based on Ubidots Platform

VI. TEST AND RESULT

Fig. 13. The whole system

We have successfully designed a test system (Fig. 13) including 1 Concentrator, 2 Sensor Nodes, 2 Control Nodes, 1 Local Database & User Interface and 1 Web Server (Ubidots). The tests were conducted on the campus of Hanoi University of Science and Technology. Accordingly, the End Devices are located about 350 meters from the Cordinator. The Control Nodes were connected to the pump (12VDC) and the valves to control the irrigation process for the areas where the soil moisture sensors of the Sensor Nodes are located. The experiments indicate that the system operate stably and meet the functions as designed. The irrigation modes also works correctly. The Fig. 14 and Fig. 15 demonstrates the experimental process of automatic and scheduled irrigation during 24 hours.

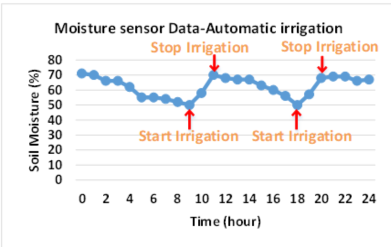

Fig. 14. Automatic Irrigation

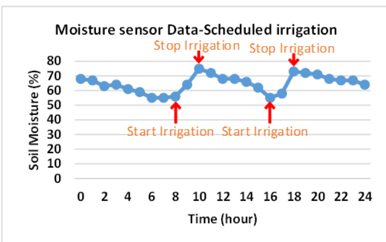

Fig. 15. Scheduled Irrigation

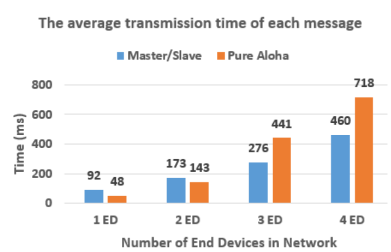

Fig. 16. The average transmission time of each message

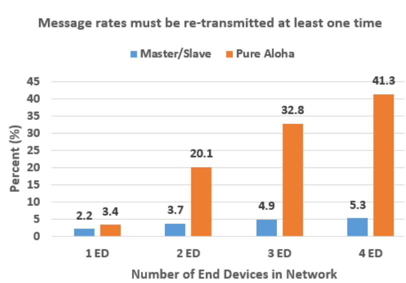

Fig. 17. Message rates must be re-transmitted at least one time

In order to evaluate the stability of the system using the Master/Slave medium access control method compared to the Pure Aloha method, we created the continuous transmission of 100 messages (16 bytes per messages) from End Devices to the Concentrator then assessed the rate of re-transmitted message and the average transmission time of each message. This test was individually conducted in 4 cases with 1, 2, 3 and 4 End Devices connected in the network. Fig. 16 and Fig. 17 indicate that the higher of End Device, the higher average time needed to transmit a message, but the rate of re-transmitted message is always low and almost unchanged in case of Master/Slave method is used. For the Pure Aloha method, when the number of End Devices increases, the rate of re-transmitted messages rises dramatically causing the increase in average transmission time of each message. According to that trend, if the number of End Devices continues to increase the system may fail. In summary, it is clear that Master/Slave medium access control is more stable and reliable than Pure Aloha.

VII. CONCLUSION

The paper have presented the design of an automatic monitoring and control system for greenhouse agriculture including the overall structure of the system and the design in detail of each component including hardware and software design. In this study we used LoRa technology combined with the Master/Slave medium access control method to resolve the remaining issues of some previous studies such as range and reliability of wireless network, system functionality and irrigation modes are also made more diversified. Furthermore, the ability to control and monitor the system remotely via a Web Interface has also been integrated. Lastly, we have also provided some experimental results to support our study. With the results achieved, the system will be further studied to improve the stability and reliability of the system so that it can be put into practice in the near future.

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