# Application of Zigbee Technology for Monitoring Enviromental Variables in Greenhouses

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**Abstract.** This paper describes the application of the Zigbee standard for the development of a Wireless Sensor Networks (WSN) based system, which is used for monitoring environmental variables in greenhouses. This development allows to connect multiple wireless devices for the sake of transmitting variables such as temperature and relative humidity. The Zigbee platform was made in three stages: 1) hardware development, which includes the analysis and hardware selection; 2) construction of a network and the integration of sensors; and, 3) evaluation, in order to define the specifications of each node and scope of communication.

**Keywords:** Environment variables, Greenhouses, WSN, Zigbee.

## 1 Introduction

Greenhouses are used to reduce the influence of adverse factors that limit production and quality of crops. They include the control of environmental variables and make an efficient use of water. On the other hand, modern greenhouses covers several hundreds of square meters, where the location to measure temperature, humidity and lighting is carefully chosen in order to improve production efficiency; thus, a Wireless Sensor Network (WSN) is required.

A WSN system includes several spatially distributed devices that use sensors to monitor various conditions in several points, including temperature, sound, vibration, pressure, motion and pollutants [1]. WSN systems have been used for various applications, e.g. habitat monitoring, agriculture, industrial monitoring and control, electronics, home automation and medical health care [2]. There are different technologies for WSN; however, the technology known as Zigbee is one of most widespread. Zigbee was developed for applications where energy consumption and complexity are the main concern. Zigbee is suitable for communicating sensors, actuators and other small devices among them. It makes use of a narrow bandwidth, low energy consumption and low latency [3]. Zigbee is based on the IEEE 802.15.4 standard and defines the hardware and software described in terms of network connection, such as physical layer (PHY) layer and medium access control (MAC). Basically, the system developed in present work consists of a sensor node and a coordinator device. The sensor node is basically a data acquisition unit, and it is responsible for collecting climate variables such as temperature, relative humidity, and light, and transmits the collected data to the coordinator station through Zigbee modules.

### 2 Background

Wireless sensor networks represent a significant advance over traditional invasive methods for the monitoring species, which can achieve lower costs and errors in the measurement process [4]. For instance, WSN are used for monitoring the reproductive behavior of birds in the Great Duck Island (Maine, USA), as described in [5]. This system enables biologists the analyzing of changes in the environmental conditions inside and outside the burrows during the breeding season. On the other hand, environmental conditions are also a concern. It is developed in [6] a monitoring system of the pollution caused by the emission of gases from car exhausts.
The data generated by the gas sensors are transmitted to remote stations via Zigbee modules. Similar Zigbee based systems have been used to monitor water quality in rivers and lakes, as explained in [7], [8]. In agriculture, wireless sensor networks are used to increase efficiency in the production and growth of the crop. Usually, sensed data correspond to environmental conditions such as temperature, wind speed, wind direction, soil moisture and physical and chemical properties of soil such as pH [9].
Another way to increase efficiency in crops is by water resource management; and in this respect, several systems based on sensor networks have been implemented. In [10] it is described the development of a crop irrigation control system in Pakistan. This system makes use of wireless sensor-actuator networks (WSAN) to monitor environmental parameters, which are sent through Zigbee modules to a computer. These variables serve as inputs to the control system. Additionally, the authors in [11] propose the design and implementation of an irrigation system based on low-cost Zigbee technology. Monitored variables are temperature and humidity. The other hand, in [12] it is introduced the use of a wireless sensor network based on Zigbee technology (ZWSN). The climatic variables monitored are temperature, speed and direction of air, relative humidity and rainfall. The data and images related to the amount of leaves and fruits are sent to a personal digital assistant (PDA), which processes and displays the information in order to monitor, in a detailed way, the evolution of diseases. In particular, the impact caused by fruit fly is tracked.
Finally, the authors in [13] develop a wireless sensor network based on Zigbee technology, which uses MPWiNodeZ devices, intended for precision viticulture applications. A mesh topology network is utilized to monitor the moisture content of soil, air temperature, relative humidity and solar radiation.

## 3 Materials and Methods

### 3.1 System description and hardware development

The system consists on a sensor node and a coordinator device that are communicated between them. The sensor node is basically a data acquisition unit, and it is responsible for collecting climate variables such as temperature, relative humidity and light. In addition, the system transmits the collected data to the coordinator station through Zigbee modules. In this work, SHT71 was selected as the integrated temperature and humidity sensor chip. Regarding humidity, the operating range is from 0 to100%, and the operating range of temperature is from -40 to 125 °C. SHT71 sensors have low power consumption and fast response time.

Temperature accuracy is ± 0.4°C and the accuracy of the relative humidity is less than ±3.0 %. Therefore, SHT71 is a good solution for monitoring these variables in the agriculture field [14].

The coordinator system, who acts as a central station, is responsible for receiving the data acquired by the sensor nodes forming a star topology network. This system process, stores and provides to the user a convenient and easy way of displaying real time information by means of a GUI (Graphic user interface) on an LCD device. The functional diagram of the system is showed in Fig 1.

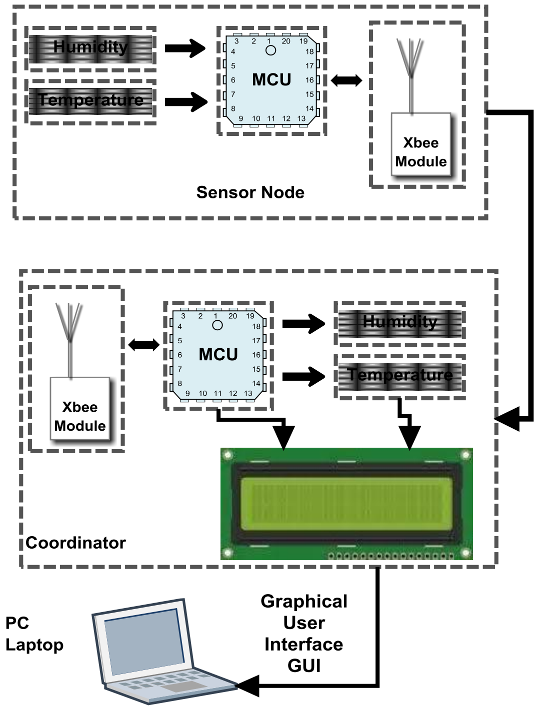


**Fig. 1.** Structure of wireless monitoring system. (System Overview)

### 3.2 Prototype network node and the integration of sensors.

The sensor node is composed by four (4) elements:
The module of sensors
The processing module
The wireless communication module

The power supply module

### 3.2.1 Sensor Node Design

The sensor module is responsible for collecting information about temperature and relative humidity. The processing module stores and processes data collected by the sensors, and controls the operation of the sensors node; which are achieved by using a microcontroller (MCU). An HCS08 based MCU, the MC9S08JM16, was selected as the main control chip of the sensor node. HCS08 MCUs are suitable due to their processing and memory capacities, being sufficient to support Zigbee. The wireless communication module communicates with other nodes, allowing the exchanging (receiving/transmitting) of data. The power supply device provides energy to the sensor, processing and the wireless communication modules. The power supply of the sensor node corresponds to a 9V alkaline (Zn/MnO2) battery. Using a battery is a low cost, portable and low maintenance solution. On the other hand, the Xbee module, SHT71 sensor and MC9S08JM60 microcontroller require 3.3 V, which are provided by an LM1117 regulator. The block diagram of the sensor node or end device shown in Fig 2.

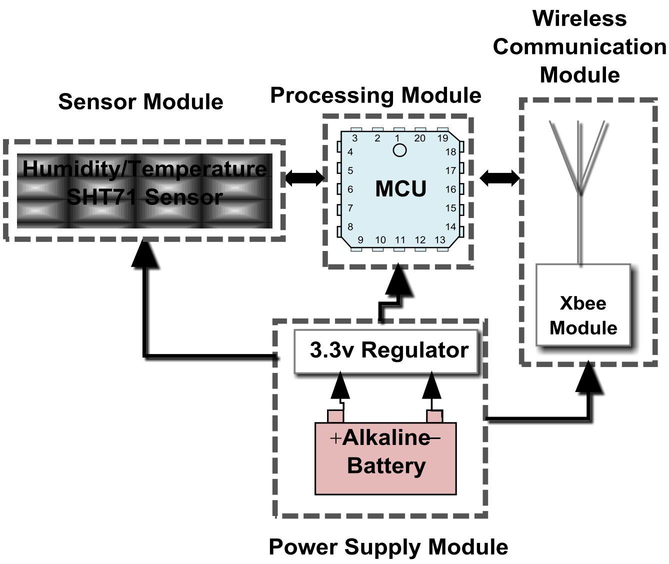


**Fig. 2.** Block diagram of sensor node.

The final design consists of two PCB layers. The top layer is used to place the XBee module, LEDs (power, Rx and Tx indicators), microcontroller, SHT71 sensor, battery plug, and on/off switch. Bottom layer is used to place3.3V voltage regulator and as a ground plane under XBee module to minimize any interference cause by the RF signals. An important aspect of the design was miniaturization. Therefore most circuitry components used for the sensor station are either surface-mounted (SMD) or are very small in size. The final design of the sensor node is shown on Fig 3.

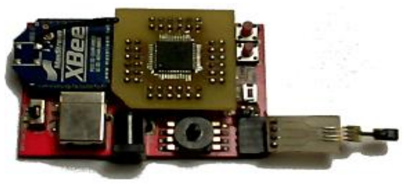

**Fig. 3.** Final design of the sensor node.

### 3.2.2 Coordinator Design

The coordinator receives the signals from the sensor node, and then it integrates and stores the data automatically. The coordinator is composed by five parts: processing module, wireless communication module, power module, display module, and USB communication module. The processing module controls the operation of the sensor nodes; and, stores and processes the collected data. The wireless communication module is responsible of receiving/transmitting data from/to the sensor node. The power supply module provides power to the other modules. The data logger is responsible for storing the sensor data, which are displayed on a liquid crystal display LCD. The union of these allows the coordinator to periodically receive data from the sensor node. The block diagram of coordinator system is shown in Fig 4.

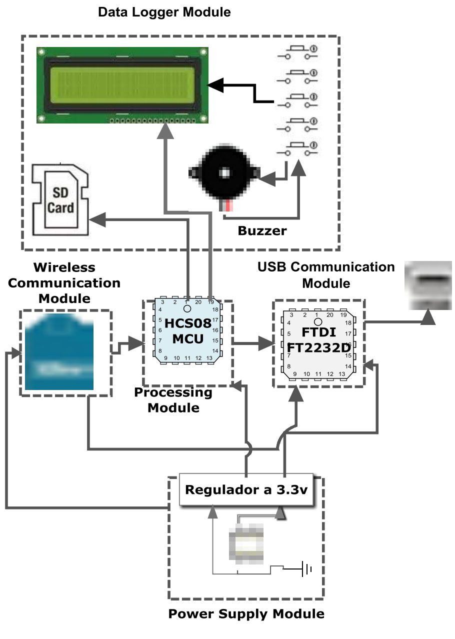


**Fig. 4.** Block diagram of coordinator device.

For the coordinator, as well as in the sensor node, the XBee modules based on the IEEE 802.15.4/Zigbee Wireless Personal Area Network (WPAN) standards to build a low-power, low-maintenance, and self-organizing WSN [15] was used. Small size, low power, low cost and long battery life are the reasons of using ZigBee.

In case of the hub, the power supply is derived from the PC's USB port via a connector type B. The data logger module includes an LCD and five buttons that are utilized select the physical variables to be displayed and stored in an SD memory card. In order communicate the PC to the coordinator, it was used an FT2232D FTDI chip. The final design of the sensor coordinate is shown on Fig 5.

**Fig. 5.** Final design of the coordinator.

### 3.3 Sensor Configuration

The temperature sensor output was set to 12 bit format, and RH was configured to 8 bit format; thus, it is achieved an accuracy of 0.04 C and 0.5 for temperature and RH variables, respectively. The sensor and the microcontroller interact by using I²C protocol, hence only two pins on the microcontroller are required. One of the pins will be used for synchronization while the other is utilized for bidirectional data transfer between the two devices. The pin on the microcontroller that is used for Rx/Tx was pulled up in order to prevent signal contention. In order to interact adequately with the sensor, a specific sequence of events must be followed. The flow chart in Figure 8 illustrates the events to be followed in order to request the sensor to take measurements such that the information can be read.

### 3.4 Communication between devices

The communication of the SHT71 sensor with the microcontroller MC9S08JM16 was through I²C module. This is possible because there is not any device connected to the I²C output of the microcontroller, thus it does not generate interferences [16]. Communication with this sensor requires the implementation of a protocol, which is very similar but not compatible with the I2C standard. Therefore, the context integration is strictly controlled. The protocol includes a start condition, and data block both reading and writing with ACK bit. The communication is based into two pins; a clock (SCK), that is used to synchronize the microcontroller and the sensor; and, the bidirectional data pin.

## 4. Results and Discussion

After verifying proper communication between the various elements of the system built, we proceeded to test the proper connectivity to all the prototype and the proper functioning of the tasks. In order to emulate a greenhouse environment, it was set a space containing two ornamental plants. Near each plant, it was located a sensor node that measures relative humidity and temperature around the plants. The sensor node outcomes are visualized on the LCD. Fig 6 shows the plants and the corresponding measures shown on the LCD.


**Fig. 6.** Plants 1y 2 of the test displayed in the LCD.

The results of test are depicted in Fig 7 and Fig 8. The results obtained from the experiments show small variations between the readings of the SHT71 sensor for the two tests.
Future experiments will entail comparing data collected from these sensors with calibrated standard devices for the sake of obtaining more accurate results.

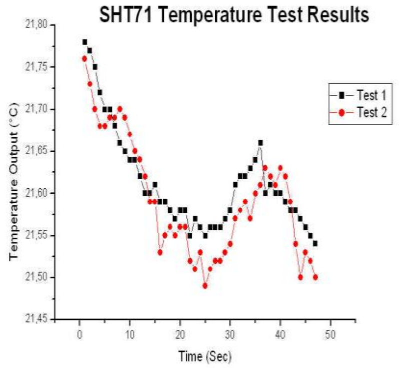


**Fig. 7.** SHT71 experimental results (Ambient Temperature)

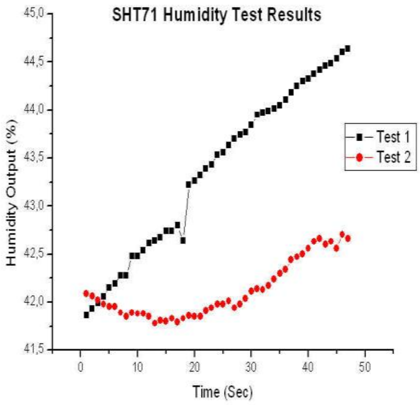


**Fig. 8.** SHT71 experimental results (Relative Humidity)

Other experiment consisted on verifying the communication between the two Xbee modules. Figure 9 describes the distances that separate the sender (red icon) of the receptor (blue icon). Measures were taken of packet reception and level RSSI (Received Signal Strengh Indicator) of the received packet to 30 m, 60 m and 100 m away. For the test used two Xbee devices, two laptops and two USB boards for development of digi connected. In the X-CTU software was used Range-test option with its default settings. This configuration is sending 32 bytes of data from one device to another, which returns the data frame to the origin. Others experimental results were based on the Lost Packets with values between 0 to 1000 and LQI within typical values between -95dBm to -18dBm according to IEEE 802.15.4 [16]. Below are the results of the experimental measures of three sequences, with 5, 10 and 20 bytes of payload size per packet, and a Zigbee Network implementation with Monitoring Environmental Variables network. In Fig 10, measures of LQI and Lost packages are shown respectively for 5 bytes in payload per packet.

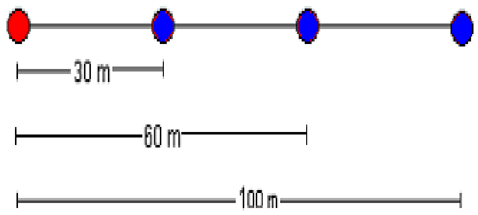


**Fig. 9.** Diagram for test of outdoor.

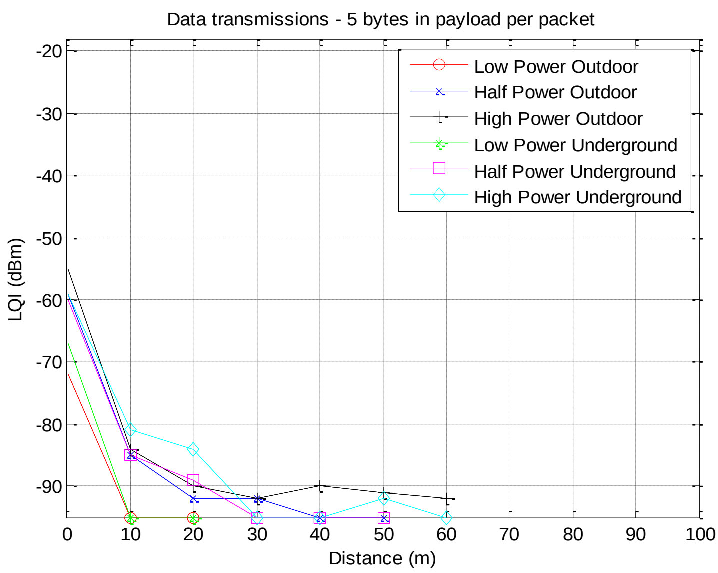


**Fig. 10.** Graphics of LQI vs. distance between devices

## 5. Conclusions and Future Work

In this work, it is presented a wireless solution for greenhouse monitoring. The system is based on HCS08 Freescale MCU´s, which monitors environmental variables through SHT71 humidity/temperaure sensor and uses and Xbee modules. Also, it is shown the design of the wireless nodes, network establishment and the software system. Monitoring system is based on ZigBee standard and provides nearly unlimited installation of transducers, which increases network robustness and reduces considerably

installation costs. The designed wireless monitoring system uses different sensors and has capability to measure different types of environmental parameters.

Developed system helps farmers to increase the harvest production with a better quality. Additionally, it has capability to detect changes in the environment. Finally, the system was tested in a greenhouse located in Boyacá-Colombia. It is concluded that the ZigBee-based monitoring system is a good solution for greenhouse monitoring. As future work, I aim to develop a neural network system in order to carry out intelligent control; this element will be constructed together with a model for data mining and system decision support.

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