DEVELOPMENT OF CDMA WIRELESS SENSOR NETWORK

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DEVELOPMENT OF CDMA WIRELESS SENSOR NETWORK

by

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LIST ABBREVIATION

ADC	Analog-to-Digital Converter
CDMA	Code Division Multiple Access
CMU	Central Monitoring Unit
CO	Carbon Monoxide
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
FDMA	Time Division Multiple Access
RF	Radio Frequency
MAC	Media Access Control
RFID	Radio Frequency Identification
SoC	System-on-a-Chip
TCP/IP	Transmission Control Protocol/Internet Protocol
TDMA	Time Division Multiple Access
UHF	Ultra-High Frequency
WCU	Wireless Central Unit
WiFi	Wireless-Fidelity
WSN	Wireless Sensor Network
SSSM	Smart System for Shiitake Mushroom
SHS	Smart Hospital System

PEMBANGUNAN RANGKAIAN SENSOR TANPA WAYAR CDMA

ABSTRAK

Rangkaian sensor tanpa wayar (WSN) merupakan satu teknologi yang telah dicadangkan sebagai satu pendekatan untuk memantau keadaan persekitaran, keadaan kesihatan, keselamatan awam dan aplikasi-aplikasi lain. Dalam projek ini, WSN digunakan untuk mengesan kebakaran di kawasan berlainan. Permasalahan projek ini adalah isu jalur lebar saluran WSN yang terhad untuk mengesan kebakaran di Kawasan lebih luas. Objektif projek adalah membangunkan sebuah WSN yang cekap bagi sistem pengesanan kebakaran dengan penggunaan penghantaran tanpa wayar pembahagian kod pelbagai akses (CDMA) dan mereka-bentuk sebuah WSN yang mampu mengukur dan memantau data yang diperlukan bagi pengesanan kebakaran. Kod CDMA Walsh digunakan untuk menyebar isyarat data terkumpul keatas saluran jalur lebar yang terhad bagi membezakan isyarat daripada pelbagai nod. Dalam projek ini, nod-nod sensor dipasangkan dengan sensor suhu dan sensor gas karbon monosikda untuk mengumpul data daripada persekitaran. Protokol CSMA/CA MAC telah dilaksanakan untuk menangani penghantaran isyarat daripada pelbagai nod sensor. Satu applikasi telefon pintar telah dicipta untuk membolehkan pengguna memantau pembacaan sensor yang telah dimuatnaikkan ke platform IoT di kawasan terletaknya nod sensor. Jarak maksima penghantaran ialah 115 m. Pembacaan suhu sensor dan pembacaan thermometer digital menunjukkan 1.08% kesilapan sederhana. Sensor gas CO menunjukkan pembacaan melebihi 10 apabila asap pembakaran dikesan. Satu applikasi telefon pintar telah dicipta untuk membolehkan pengguna memantau parameter kebakaran untuk mengelakkan kebakaran. WSN telah dibangunkan dengan penggunaan penghantaran CDMA dan mampu mengukur dan memantau data bagi pengesanan kebakaran. Dalam kerja masa depan, satu antena dengan keuntungan yang tinggi boleh diggunakan bagi menambahbaikkan jarak penghantaran data. Sensor boleh ditambah untuk meningkatkan ketepatan pengesanan kebakaran. Antena CDMA yang mampu menerima pelbagai isyarat serentak boleh mengatasi akses daripada pelbagai nod sensor.

DEVELOPMENT OF CDMA WIRELESS SENSOR NETWORK

ABSTRACT

Wireless sensor network (WSN) is a technology which had been proposed as an approach to monitor environment condition, health condition, public safety and many other applications. In this project WSN will be used to detect fire at different areas. The problem statement of this project is the issue of limited channel bandwidth of WSN for wider detection area. The objectives of this project are to develop an efficient WSN for fire detection system using the code division multiple access (CDMA) wireless transmission, and to design a WSN which able to collect and to monitor the required data for fire detection. CDMA Walsh code was used to spread the collected data signal over the limited channel bandwidth to differentiate the signal among the nodes. In this project, sensor nodes equipped with temperature sensors and CO gas sensors to collect data from the environment. CSMA/CA MAC protocol was implemented to handle the multiple transmissions from the sensor nodes. A mobile phone app was devised to allow the user to monitor the sensors readings uploaded to IoT platform of the area located with the sensor node. The maximum distance of data transmission is 115 m. The temperature sensor readings and the digital thermometer readings shows average percentage error of 1.08%. The CO gas sensor shows the reading above 10 when burning smoke is detected. A smartphone application had been devised to allow user to monitor the fire parameter for fire prevention. The WSN had been developed successfully with CDMA transmission method and it able to collect and to monitor data for fire detection. In future work, an antenna with higher gain can be used to improve the distance of data transmission. More sensors can increase the accuracy of the fire detection. A special CDMA antenna which able to receive multiple signals simultaneously can be designed to handle the multiple access from more sensor nodes.

CHAPTER 1

INTRODUCTION

1.1 Background

Recently, wireless sensor network (WSN) is widely employed in commercial and industrial applications, to monitor surrounding conditions such as health, environmental, military and many other areas. Environmental application of WSN include fire detection, flood detection and agriculture control [1]. This is because of WSN is equipped with low-power usage of embedded computing devices with inexpensive sensor nodes which able to detect event in the surrounding environment [2]. A sensor node usually is divided into four subsystems, namely computing, communication, sensing, and power supply. Computing subsystem usually is a microcontroller which would be used to control the sensing devices and the communication module, and a place to buffer the data collected by the sensing devices. Communication subsystem has a wireless communication transceiver such as RF transceiver that allow the communication between the nodes or between the node and the main controller system. Sensing subsystem is a group of devices that connect the nodes with the surrounding environment [2]. The sensor nodes acquire the data from the environment and transmit the data to a central server which is known as base station. The base station processes the incoming data into a presentable form, decision making based on the acquired data [3].

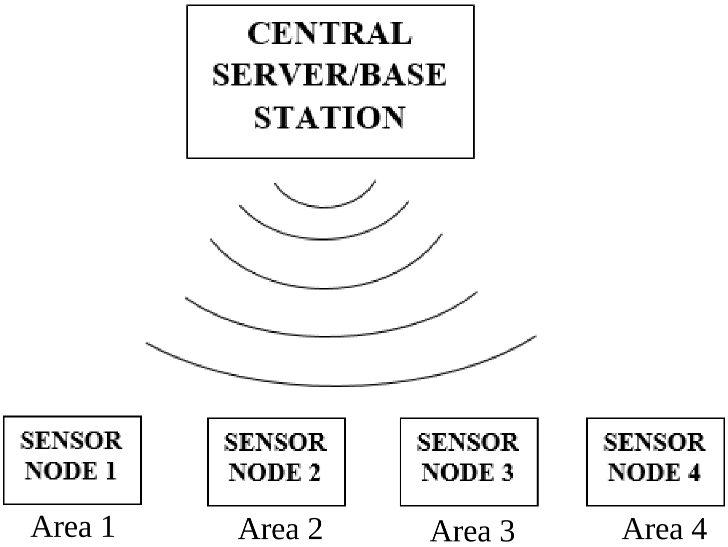

Figure 1.1: Block diagram of WSN [2]

However, bandwidth or number of frequency channel limitation exists in the WSN. As the number of the sensor nodes increases, this will become an issue when the transmission of signal from multiple nodes to the base station which may cause the signal collision. In order to overcome this issue, access multiplexing on a limited bandwidth channel must be employed. Access multiplexing is a process used by a communication system to coordinate and allow more than 1 user to access the communication channels within the system. The common access multiplexing method are time division multiple access (TDMA), frequency division multiple access (FDMA), and code division multiple access (CDMA), where the multiple access to the channel bandwidth is shared in time, frequency, and code divisions, respectively, among the multiple nodes. In this project, the idea of CDMA as the access multiplexing method on a WSN with limited bandwidth is proposed.

According the statistic made by the Fire and Rescue Department Malaysia, on average, about 6,000 premises are destroyed by fire every year nationwide [4]. Fire can cause the loss of property, money and the pollution to the environment such as the forest fire. Furthermore, the weather in Malaysia which is hot throughout the year allow the fire occurs easily. Therefore, the early fire detection is important to avoid major loss caused by the fire. To employ the WSN technology in environmental application, fire detection integrated with CDMA based WSN is proposed.

1.2 Problem Statement

Fire incident can damage humans and their property. Early information about the potential fire will help in fire prevention. Therefore, a fire detection device and early warning of fire which provide early information to act more quickly and precisely is required. Wireless Sensor Network, or commonly known as WSN, is one of the solution for detection and early warning of fire. To utilize the application of WSN with limited channel bandwidth of the wireless communication device for wider fire detection area, access multiplexing technique, code division multiple access (CDMA) is employed.

In the previous work done by Goh [5], a CDMA-based WSN was applied into Arowana fish pond monitoring system. CDMA code was used at the base station of the WSN to differentiate the incoming data from various sensor nodes. However, each sensor node had been assigned with small frequency division to prevent multiple collision at the antenna of the base station. The limited bandwidth of the RF antenna used caused the limitation to the number of sensor node communicating with the base station. Saputra et. al. [6] proposed a home early fire detection system based on WSN using temperature and gas sensors. Fuzzy logic was implemented to determine the occurrence of fire. The idea was only applicable to a single sensor node because the media access control (MAC) method was not applied to handle the multiple transmission from sensor nodes to base station. Kassim et. al. [7] implemented mobile phone application in WSN to monitor shiitake mushroom cultivation in the project. The users able to use the mobile phone application to access the agriculture parameters of the shiitake mushroom cultivation environment. The idea of implementation of mobile phone application in WSN is useful in the development of CDMA WSN for fire detection.

In this project, the low cost and user-friendly RF transceiver modules consist of single antenna is used to establish the wireless communication between sensor nodes and base station. Since the antenna at the base station receives the data from multi-user, the data collision probably will occur. A suitable MAC protocol is implemented to detect the data transmitted by each sensor node and to avoid collision. CDMA method is applied in the project to differentiate the data from each sensor nodes. Sensor nodes are equipped with sensors to collect parameters for fire detection. A mobile smart phone application is implemented to allow the users to monitor the parameter for fire detection.

1.3 Objectives

The objectives of this project are as follows:

i. To develop an efficient wireless sensor network for fire detection system using the Code Division Multiple Access (CDMA) wireless transmission.

ii. To design a wireless sensor network which able to collect and to monitor the required data for fire detection.

1.4 Scope of Project

In this project, CDMA-based WSN is developed by using Arduino Mega board as the microcontroller of base station, and Arduino Nano as the microcontroller of sensor nodes. Each sensor node is equipped with some sensors to sense the condition of environment for fire detection. The wireless communication between the base station and sensor nodes must be established. CDMA code is programmed at both base station and sensor nodes for multiple access. A monitoring system for fire detection is developed with smartphone application.

1.5 Thesis Outline

This thesis consists of five chapters, which are Introduction, Literature Review, Methodology, Results and Discussions and Conclusions. Chapter 2 explains about the concept of data communication system. Then, the multiple access methods is further explained. The concept on CDMA in data communication is briefly explained in this chapter. Some works related to this project are briefly described.

Chapter 3 discusses methodology of the project. This chapter shows the method to create Walsh code in both base station and sensor nodes. This chapter explains the data encoding and decoding in the WSN. Details about the data transmission between the devices are explained in this chapter too. The technique to detect the data from multi-node and to avoid collision at base station is described. The method to test the functionality of the sensors is proposed, and the method to make real-time monitoring purpose possible are shown in this chapter.

Chapter 4 explains the details of the results obtained by using the method proposed in Chapter Three. This chapter discusses the results obtained on the verification of the developed CDMA wireless sensor network system, the functionality test of the sensors, and the explanation about the created mobile phone app. All the experiments and the test results are recorded and presented in this chapter.

Chapter 5 concludes the development of the CDMA wireless sensor network. The output of the results is summarized in this chapter. The future work of development is suggested to improve this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The theories and information related to this project are discussed in this chapter after reviewing book, journal and internet. Section 2.2 discusses about the theory of data communication which consists of five elements namely, message, sender, transmission medium, receiver, and protocol. The theory about the channelization multiple access methods such as FDMA, TDMA and CDMA are briefly discussed. This section also includes the explanation about RF transceiver. Section 2.3 shows the hardware will be used to implement CDMA WSN for fire detection. Section 2.4 discusses about the related work done by other researchers especially for implementation of WSN.

2.2 Background Theory

2.2.1 Theory of Data Communication

Data communication is the exchange of information between two parties via some form of transmission medium. The data communicating devices consists of hardware and software for data communication to occur. The basic data communication system is made up of 5 elements which are message, sender, receiver, transmission medium and protocol. The message is the data to be communicated between two devices. The sender is the device send the message to be received by the receiver device. The transmission of the message from the sender to the receiver is completed through the transmission medium. The data communication between the sender and the receiver is governed by protocol which defines the rule to be followed by the communicating devices. The block diagram of five components of data communication is shown in Figure 2.1.

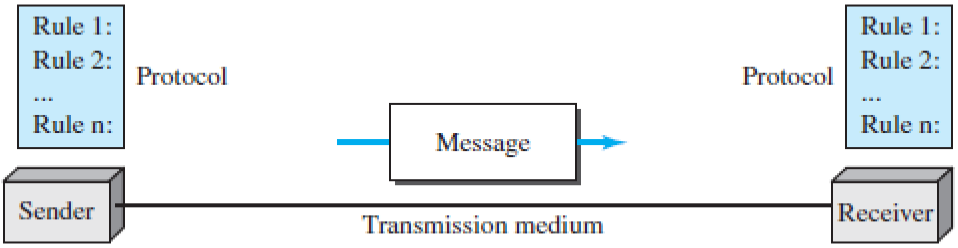

Figure 2.1: Components of data communication [8]

2.2.2 Channelization

Channelization is a multiple access method in which the available bandwidth for data communication is being shared by multiple nodes. There are 3 main types of channelization multiple access, namely frequency division multiple access (FDMA), time division multiple access (TDMA) and code division multiple access (CDMA).

In frequency division multiple access (FDMA), the sharing of bandwidth for data communication is done by frequency division. Each node is allocated with a specific frequency band to communicate with receiving device. All nodes can communicate with the receiving device at the same time. The sharing of bandwidth in FDMA system is shown in Figure 2.2.

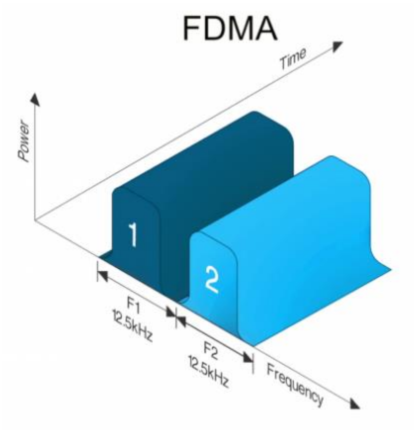

Figure 2.2: FDMA [9]

In time division multiple access (TDMA), the sharing of bandwidth for data communication is done by time division. Each node is allowed to access the available bandwidth for data communication at different time slot. Figure 2.3 shows the sharing of bandwidth by TDMA system.

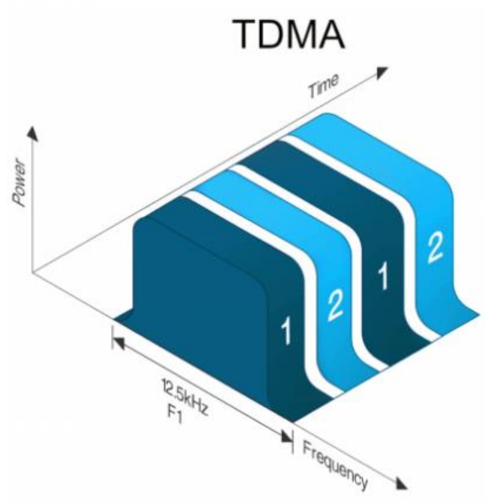

Figure 2.3: TDMA [9]

2.2.3 Code Division Multiple Access

Code division multiplexing access (CDMA) is a multiple access scheme based on spread-spectrum communication technique. The data signal is spread to a wide bandwidth by using a unique code that can differentiate users [10]. Frequency and time division is not needed for CDMA multiple access, thus, improve the communication system capacity.

In CDMA transmission system, the limited channel bandwidth is shared by multiple stations. The data, d sent from each station will be assigned with a unique code, c which is a sequence of number made of N numbers, where N is the number of stations. Let, 4 stations access a channel. Each assigned code will have these two properties: If a code multiply by another code, the output is 0; if a code multiply by itself, the output is N. Based on these two code properties, the data from a station can be decoded as follow:

$$\text{Data} = [(d_1 \cdot c_1 + d_2 \cdot c_2 + d_3 \cdot c_3 + d_4 \cdot c_4) \cdot c_1]/4 \quad (2.1)$$

$$= (4 \times d_1)/4$$

$$= d_1$$

The spreading code is a key component in CDMA as a spread-spectrum communication. The commonly used spreading cod in CDMA is Walsh code. Walsh code is an orthogonal code which have following properties [8]:

1. If N is the number of the station, the number of each sequence is N.
2. In multiplication with a number, each element in a sequence will be multiplied by the number.
3. The number of N will be obtained with multiplication of two equal sequence.
4. The result of 0 will be obtained with multiplication of two different sequences.
5. The addition of two sequences will generate another sequence.

Walsh codes have length $N=2^k$ and can be generated using the following equation:

$$W_1 = [1] \qquad W_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \qquad W_N = \begin{bmatrix} W_k & W_k \\ W_k & -W_k \end{bmatrix} \quad (2.2)$$

Walsh codes with length of $N=2^k$ will generate N × N Walsh-Hadamard Matrix. Both row and column of the matrix gives a set of N elements orthogonal codewords [11]. Let say, the number of the sensor nodes (station) in a wireless sensor network (WSN) is 4, the number of the elements in a sequence is N=4. Based on the above equation, the Walsh Matrix is generated as follow:

$$W_4 = \begin{bmatrix} W_2 & W_2 \\ W_2 & -W_2 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix} \quad (2.3)$$

Thus, the sequences corresponding to each station are [1 1 1 1], [1 -1 1 -1], [1 1 -1 -1], and [1 -1 -1 1].

2.2.4 CDMA Transmitter and Receiver

In CDMA transmission, the stations will share a limited bandwidth of a channel. The source signal from the stations will be spreading over the bandwidth. Each source signal is encoded with a specific orthogonal code to differentiate the signals for multiuser detection purpose. All the users share the frequency spectrum (carrier) at the same time. The encoded source signal will form a composite signal and will be modulated by a carrier frequency for transmission [12]. The block diagram of the CDMA transmitter design is shown in Figure 2.4.

Based on the multiplication properties of the orthogonal code, the source signals transmitted can be decoded at the CDMA receiver with specifics orthogonal code. The block diagram of the CDMA transmitter and receiver is shown in Figure 2.4.

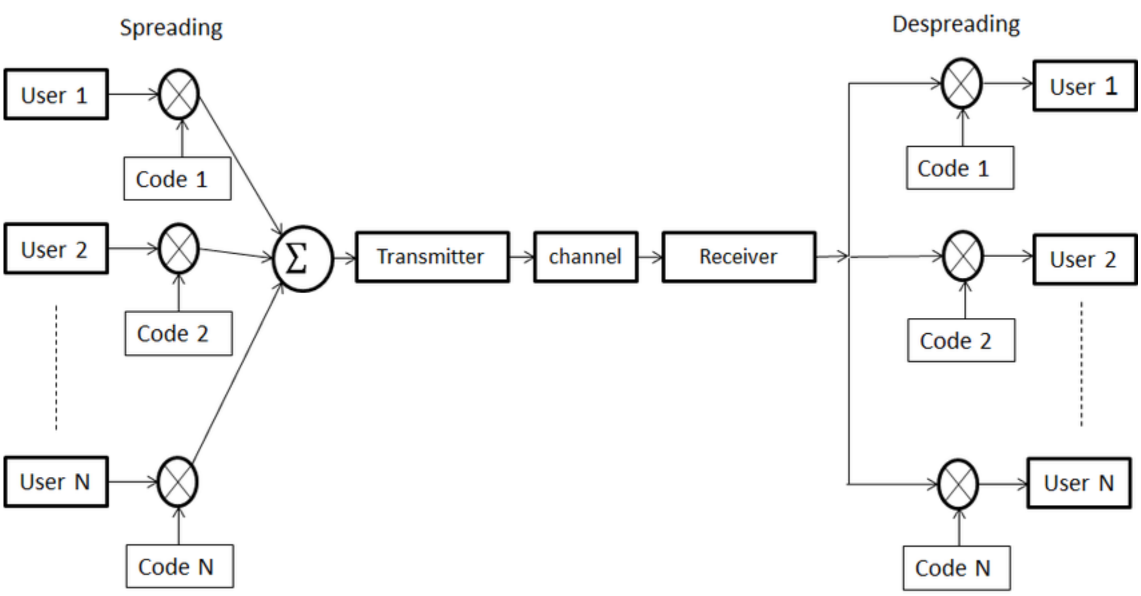

Figure 2.4: CDMA transmitter and receiver [13]

2.2.5 RF Transceiver

RF module is a small size electronic device used to transmit or receive radio signals between two devices. RF module is usually used as an embedded system to communicate with another device wirelessly. RF transceiver is a combination of transmitter and receiver in a single package. Mostly, the RF transceiver is working in half duplex, where the device will stop receiving signal when it is transmitting signal, or vice versus. An electronic switch permits the transmitter and receiver sharing an antenna separately. This kind of transceiver may cause the signal collision at the antenna, thus an efficient transmission algorithm is needed to utilize the transceiver. The block diagram of a typical RF transceiver is shown in Figure 2.3.

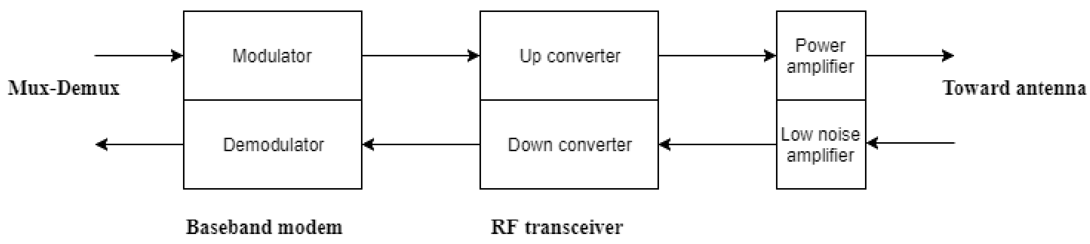

Figure 2.5: General block diagram of RF transceiver [14]

2.3 Hardware Requirement

Arduino MEGA is a microcontroller board developed based on the ATmega2560. It can be programmed with Arduino IDE software. Arduino MEGA is used as the microcontroller for the base station of the fire detection system. It is interfaced with HC-12 RF transceiver module to communicate with the sensor nodes for data transmission purpose, and with ESP 8266 WiFi module to upload the data to the cloud server for data analysis.

The **Arduino Nano** is a small, complete, and breadboard-friendly microcontroller based on the processor of ATmega328 or ATmega168. Arduino Nano does not have DC power jack bit it works with a Mini-B USB cable instead of a standard one. The Arduino

Nano can be programmed with the Arduino IDE software. In this project, four Arduino Nano are used as the microcontroller of the sensor nodes. Each Arduino Nano is interfaced with DHT11 temperature sensor and MQ-7 CO gas sensor for environment parameter collection, and with RF module for data transmission to the base station.

HC-12 RF Transceiver module is a multi-channel embedded wireless data transmission module with working frequency band of 433.4-473.0 MHz. The multiple channel can be set with stepping of 400kHz, and there are 100 channels in total. The maximum transmission distance is 1km in open space. Five HC-12 RF module is used to implement the fire detection system, which four for sensor nodes, and one for the base station. It allows the communication between the base station and the sensor nodes.

The **ESP8266 WiFi Module** is a self-contained SoC with integrated TCP/IP protocol stack that can give any microcontroller access to WiFi network. In this project, the WiFi module is used to interface with the Arduino Uno working as the base station to upload the data collected from the sensor nodes to the cloud server.

DHT11 is a digital temperature sensor which give output voltage proportional to the temperature in Celsius (centigrade). In this project, DHT11 is implemented on the sensor node microcontroller to sense the environmental temperature changes due to the combustion.

The product of combustion will release carbon monoxide (CO) gas. **MQ-7** is a carbon monoxide (CO) gas sensor, used for sensing CO concentrations in the air. The MQ-7 can detect CO gas concentrations from 20 to 2000 ppm. This sensor has a high sensitivity and fast response time. The sensor’s output is an analog resistance. The output pin of the sensor is connected to the sensor node microcontroller analog-to-digital converter pins.

2.4 Related Works

Development of wireless sensor networks (WSN) has been becoming a hot research area in this recent years. WSN is widely applied in the fields of medical monitoring, environmental monitoring, military surveillance, agriculture application etc. WSN able to get the data from physical world to virtual world for computing or data analysis to improve human life quality.

In the application of WSN in medical monitoring, a research was done by Gogate et. al. [15] on implementation of WSN in smart healthcare monitoring system. In the research, temperature sensor and pulse rate sensor were used to collect the body temperature and pulse rate of the patients. The collected data would be transmitted through the Zigbee module attached on an Arduino board to the laptop at the receiving end consists with a Zigbee module. The collected data were stored in MySQL database. An alert e-mail was sent to the medical stuff when the data were not in the pre-defined acceptable range. Another research was done by L. Catarinucci et. al. [16] on integration of UHF RFID and WSN technologies in healthcare systems. The smart hospital system (SHS) with the research work able to provide patient localization, tracking, and monitoring services within hospitals.

For the environmental monitoring application, Fitriawan et. al [17] shows the implementation of Zigbee based WSN in environmental monitoring. The developed system consists of sensor node and coordinator node. The sensor node plays the role to sense the temperature and humidity of the environment. An Arduino UNO was used as the processing unit of the sensor node equipped with LM35DZ temperature sensor, DHT11 humidity sensor and Xbee S2 which working based on ZigBee protocol within 2.4 GHz frequency band with 250 Kbps RF data rate for data communication purpose. Another project done by Siregar et. al [18] shows the implementation of WSN in monitoring the quality standard of waste water for smart environment. In the research work, waspmote main board was used as the micro-controller and smart water sensor equipped with pH sensor, conductivity sensor, dissolved oxygen sensor, and water temperature sensor was used as the sensing device to collect the data from the environment. The Waspmote main board used 3G module to communicate with the server. The data collected from the sensors were stored in a databased system and were represented in web-based form.

To apply WSN in agriculture activity, a research conducted by Cabaccan et. al. [19] shows the development of WSN in monitoring agriculture environment. The light sensor, temperature and humidity sensors were used to sense the light intensity, and the temperature and humidity of the surrounding. A Raspberry Pi 3 Model B board equipped with those sensors operating as the processing unit of the sensor node. The data collected by the Raspberry Pi was sent to PC by using wireless communication. Another research done by Kassim et. al. [7] shows the application of WSN in shiitake mushroom cultivation. The basic principles of WSN and mobile computing technology were used to implement a Smart System for Shiitake Mushroom (SSSM) cultivation in a greenhouse environment. The temperature, humidity and carbon dioxide sensors were used to collect data in the system. The control devices are activated based on predefined threshold values to monitors sensor data. The collected data by using the sensor would be uploaded to the cloud. The user would be able to access the data by using a designed Android smartphone. The proposed system was shown in Figure 2.6.

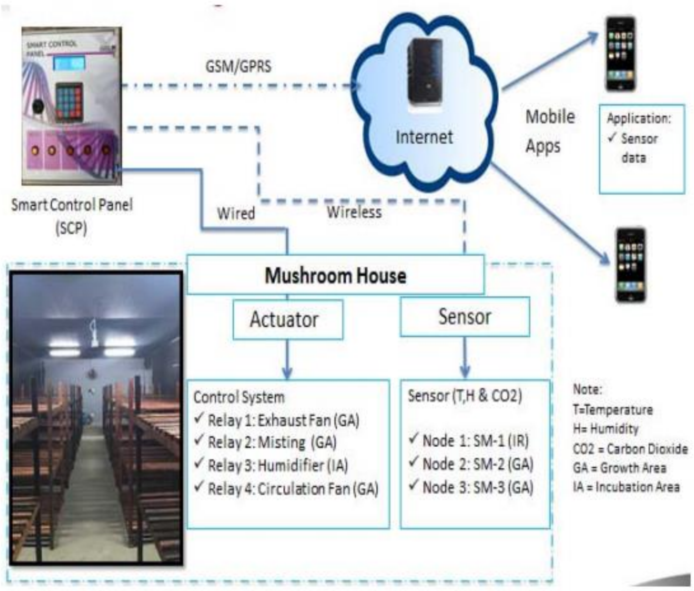

Figure 2.6: Architecture for Smart System for Shiitake Mushroom [7]

In military application, a research done by Chaitanya [20] shows the implementation of WSN in military surveillance system. PIR motion sensor was used to detect the motion of surveillance area. The sensor was attached to the Arduino board which working as the processing unit of the node. Zigbee module was used as the communication unit for the system. The idea of alert message activation through GSM module when there is detection of motion was also proposed in the research work. In the research done by BayÕlmÕú et. al. [21], WSN was applied to implement remote personnel monitoring system in military zones. The system consists of three components which are WSN, wireless central unit (WCU), and central monitoring unit (CMU). The WSN measures the military personnel data and transmit the data to CMU trough WCU. Wireless communication module, nRF24L01+ operating as the WCU with SPI serial interface. The data could be monitored at CMU.

The gateway node based on CDMA for wireless sensor network (WSN) was researched and designed by lin et. al. [12] . The WSN gateway node was designed by using the combination of two wireless communication methods of ZigBee and CDMA.

The data includes sensor node network ID, node ID, network status, voltage, temperature, data length can be transmitted from ZigBee wireless network to the remote data centre by connecting to the Internet using CDMA networks. The idea in this paper meets the requirements of wireless communication with low cost, small size, and high reliability. A research done by S. [22], a smart helmet with intelligent sensing and warning system for underground mines safety was created by using RF and WSN technologies. The RF technology was used for communication in the mines, and the WSN technology was used for sensing environment condition. The WSN equipped with various sensor to sense mine environment parameters such as temperature, pressure, humidity, gases like methane, carbon monoxide, etc. The collected parameters are processed and are used for an early warning system with the help of programmed alarm sounds, if the data exceed normal parameter value range. The RF technology also working as a locating system to locate mines workers.

Chae et. al. [23] developed a wireless sensor network system for suspension bridge health monitoring based on CDMA technology. The Zigbee technology was used for short distance wireless communication between the sensors, and the CDMA technology was used for the long distance wireless communication with remote location. The WSN structural health monitoring (SHM) was proposed to overcome the issues caused by the wired SHM such as implementation cost, installation difficulties, and dependency component of wired based SHM. In the project development, five sensors were selected to monitor structural health of a bridge. The sensors consist of an accelerometer to measure hanger tension and stiffening truss vibration, strain gauge to measure stiffening truss stress, a thermometer to measure the temperature of main cable and a wind gauge to measure wind load. The sensor nodes were integrated with Zigbee module, sensor, and ADC. A network gateway/base station was integrated with Zigbee and CDMA communication. A software program was developed to analyse the sensors data and monitor the bridge health condition.

Some techniques on fire detection system based on WSN had been proposed previously. Nugroho et. al. [2] implemented WSN for fire detection based on RF wireless communication technology developed Zigbee. Five Zigbee RF transceiver module with mesh topology were used to design the fire detection system, four modules for sensor nodes, and one for base station. The system used LM35 temperature sensor and MQ-7 gas sensor to detect the environment parameter. Micorcontroller ATMega8535 was used to process the environment condition such as temperature and carbon monoxide (CO) concentration. For the LM35 temperature sensor, the output of the sensor is red by the ADC pin of the microcontroller. The input of ADC is converted to Celsius unit by using Equation 2.4. For the MQ-7 CO gas sensor, the value of ADC is converted to unit ppm by using Equation 2.5. From the experimental result, the average error of measuring is 1.3 of 11 testing.

$$°C = \frac{ADC \times 5000mV}{1024 \times 10} \tag{2.4}$$

$$ppm = \frac{ADC \times 1980}{1024} + 20 \tag{2.5}$$

In journal prepared by Vijayalakshmi and Muruganand [24], the WSN for fire detection real time monitoring was implemented. Each sensor node consists of an XBeePro transceiver operating in the 2.4 GHz Industrial-Scientific-Medical (ISM) free RF band for transmitting information to computer system, a single sensor, DHT-11 used to sense environment temperature and humidity, and MSP 430 microcontroller to process the incoming data from the sensor. Two algorithms were used to detect fire. First algorithm is comparison algorithm based on equation 2.6. This algorithm compares the value difference of the collected temperature value at 1 s interval with the predefined threshold value. If the difference value exceeds the threshold for 5 times consecutively, the system will report fire.

$$Fire\_Risk(s) = (temp(s) - temp(s-1)) > temp_{threshold} \quad (2.6)$$

where *Fire_Risk(s)* represents the alarm of fire state at the time s, *temp(s)* represents the temperature value at 1 second time s, *temp(s-1)* represents the temperature value of 1 second ago at time s and $temp_{threshold}$ represents the threshold value.

The second algorithm using the theory of belief function, Dempster-Shaffer Theory (DST) to predict the occurrence of fire. Figure 2.7 shows the algorithm to predict fire. If the average value for taken temperature and average humidity value for five consecutive values are equal to the predefined threshold values, the mass value for temperature and humidity value will be calculated using Lagrange interpolation method in equation 2.7.

$$\frac{(x-x_0)\times\cdots\times(x-x_{i-1})\times(x-x_{1+1})\times\cdots\times(x-x_n)}{(x_i-x_0)\times\cdots\times(x_i-x_{i-1})\times(x_i-x_{1+1})\times\cdots\times(x_i-x_n)} \quad (2.7)$$

where x is the temperature values at the time of *i* for temperature or humidity threshold.

When the mass value for the temperature is higher than or equal to the threshold value for the temperature, and the mass value for the humidity is lower than or equal to the threshold value for humidity, the system will report fire. The combination mass value for temperature and humidity would be calculated by using Dempster's rule of combination in equation 2.8 when the mass value for temperature is higher than or equal to its threshold value and the mass value for humidity is higher than its threshold, or the mass value of temperature is lower than or equal to its threshold, and the mass value for the humidity is lower than or equal to its threshold value. The system will report fire when the combination mass value is higher than a predefined threshold. Both algorithm give a good performance to detect fire.

$$\text{mass } 1{,}2(\text{f}) = \frac{mass1(f)mass2(f)+mass1(f)mass2(k)+mass1(k)mass2(f)}{1-mass1(f)mass2(u)-mass1(u)mass2(f)} \quad (2.8)$$

Algorithm 2.1

---

1. Define read temperature, humidity function
2. Define report_fire function
3. Define variable:
   3.1 temp_average=0;
   3.2 humid_average=0;
   3.3 Define temp_threshold value;
   3.4 Define humid_threshold value;
   3.5 Define threshold value;
   3.6 mass1=0;
   3.7 mass2=0;
   3.8 mass12=0;
4. while(1)
5. call read temperature, humidity function
6. temp_average=temp of 5 values/5
7. if (temp_average==temp_threshold) do
   7.1 mass1=mass from Lagrange interpolation method for temperature
   7.2 temp_average=humidity of 5 values/5
   7.3 if (humid_average==humid_threshold) do
      7.3.1 mass2=mass from Lagrange interpolation method for humidity
      7.3.2 if (mass1>=temp_threshold) and (mass2<=humid_threshold) do
         7.3.2.1 call report_fire function
      7.3.3 else if ((mass1>=temp_threshold) and (mass2>humid_threshold)) or ((mass1<=temp_threshold) and (mass2<=humid_threshold)) do
         7.3.3.1 mass12=mass from Dempster's rule of combination using equation 2.8
         7.3.3.2 if (mass12>=threshold)
         7.3.3.3 call report_fire function
      7.3.4 end else if
   7.4 end if

8 end while

Figure 2.7: Algorithm 2.1 that defines DST algorithm [22]

Saputra et. al. [6] in their research describe an home early fire detection system based on WSN using temperature, air humidity, Carbon Monoxide, and smoke sensors. Each sensor node was equipped with those sensors. Fuzzy logic was implemented to determine the occurrence of fire. If the fire is detected, system will perform an action of unlocking home door lock, turning an alarm, and notifying the user. In the fire detection algorithm, the input of each sensors was used as the input of fuzzy variable, and the fire probability as the output variable. The input variables were set with fuzzy membership of LOW, MEDIUM and HIGH, whereas the output variable is set with NORMAL, ALERT and FIRE. The fuzzy membership functions are shown in Figure 2.8(a) to Figure 2.8(e).

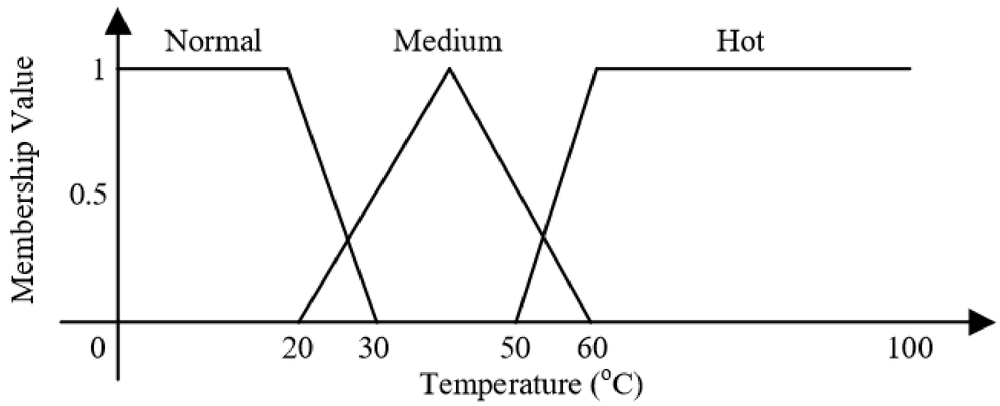

Figure 2.8(a): Membership function for temperature [23]

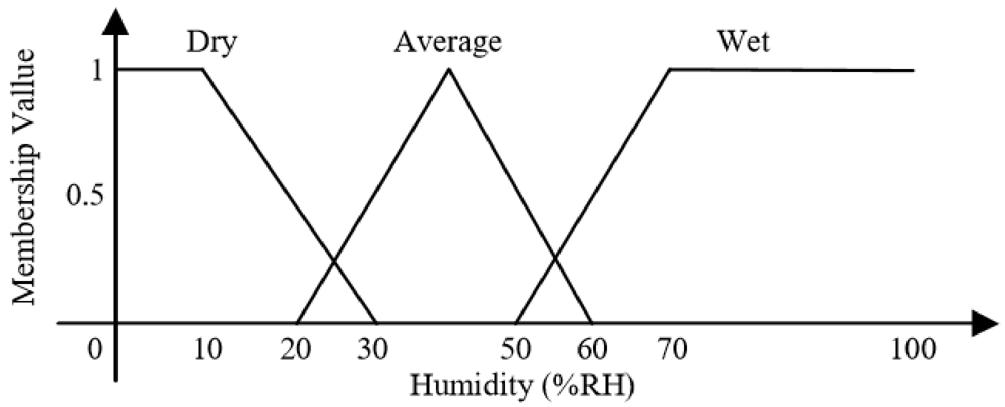

Figure 2.8(b): Membership function for humidity [22]

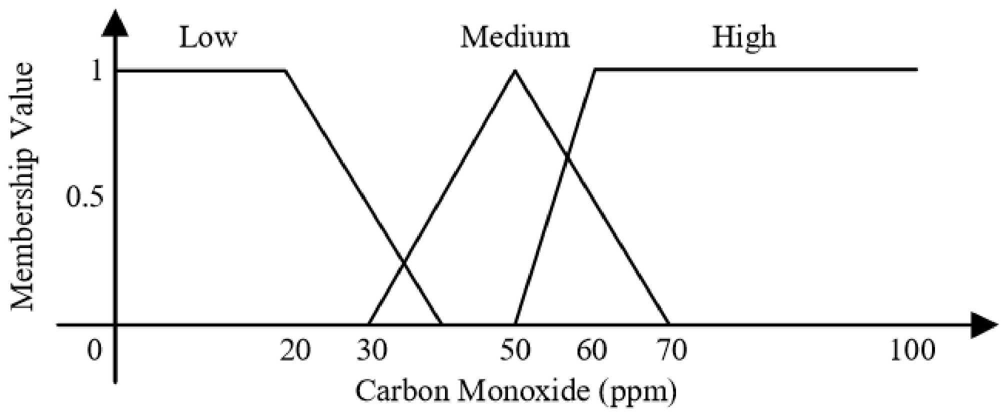

Figure 2.8(c): Membership function for CO [22]

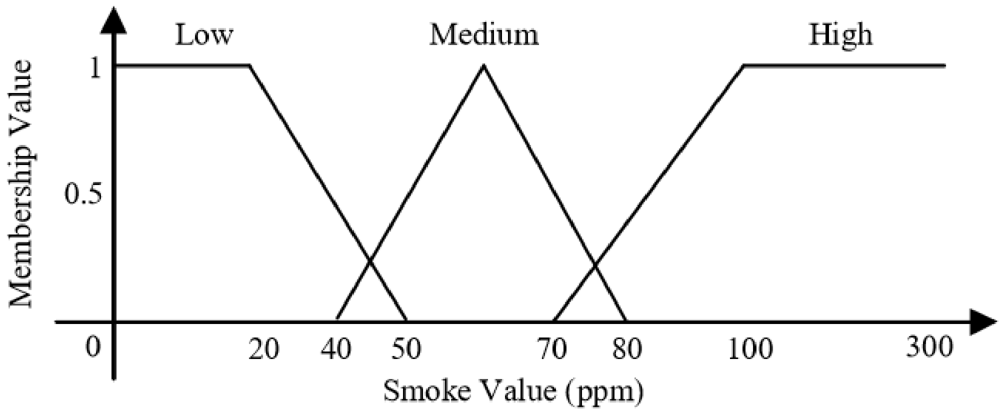

Figure 2.8(d): Membership function for smoke [22]

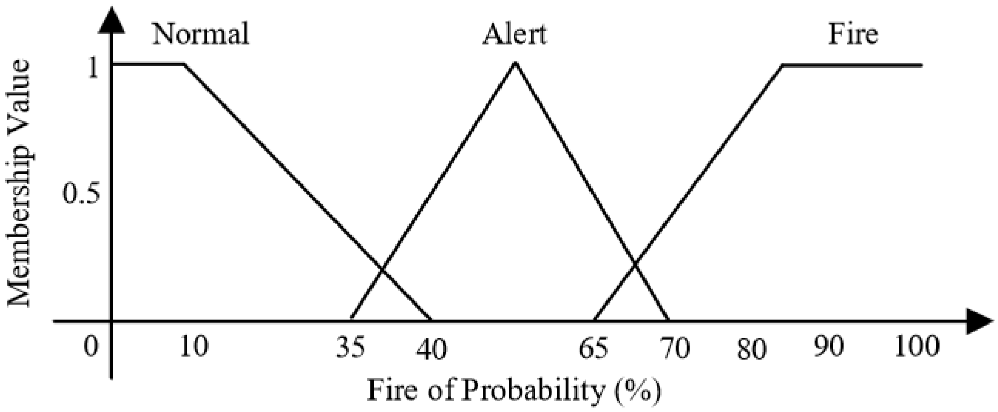

Figure 2.8(e): Membership function for fire probability [22]

In the research, four input variables with three memberships respectively, gives 81 used rules in total. The rule can be observed from Table 2.1. The proposed system in the research was able to alert user precisely to prevent fire occurrence early with a 6.67 % error ratio.

Table 2.1: Fuzzy logic rule base [22]

No	Temperature	Humidity	CO	Smoke	Probability
1	normal	wet	low	low	normal
2	normal	wet	low	med	normal
3	normal	wet	low	high	alert
…	…	…	…	…	…
80	high	dry	high	med	fire
81	high	dry	high	high	fire

In the research done by Goh [5], a CDMA-based WSN was developed for arowana fish pond monitoring system. Four arowana fish ponds were used for demonstration purpose. The temperature reading and pH value of the arowana fish pond water were taken by using water proof DS18B20 temperature sensor and BNC connector probe pH sensor. The sensors were connected to Arduino Nano to operate as a sensor node. MOTOROLA WI-COM Board consists of a BeagleBone Black and a Sierra wireless MC7304 PCI express mini card was used as the base station for the WSN. Both sensor node and base station equipped with HC-12 RF transceiver modules for wireless communication between the devices. Walsh code was used as the CDMA code for the WSN. Sensor node encodes the sensors data with Walsh code and sends them to base station. The data were encoded at the base station to retrieve the original data. Figure 2.9 shows the general overview of the CDMA-based arowana fish pond monitoring system.

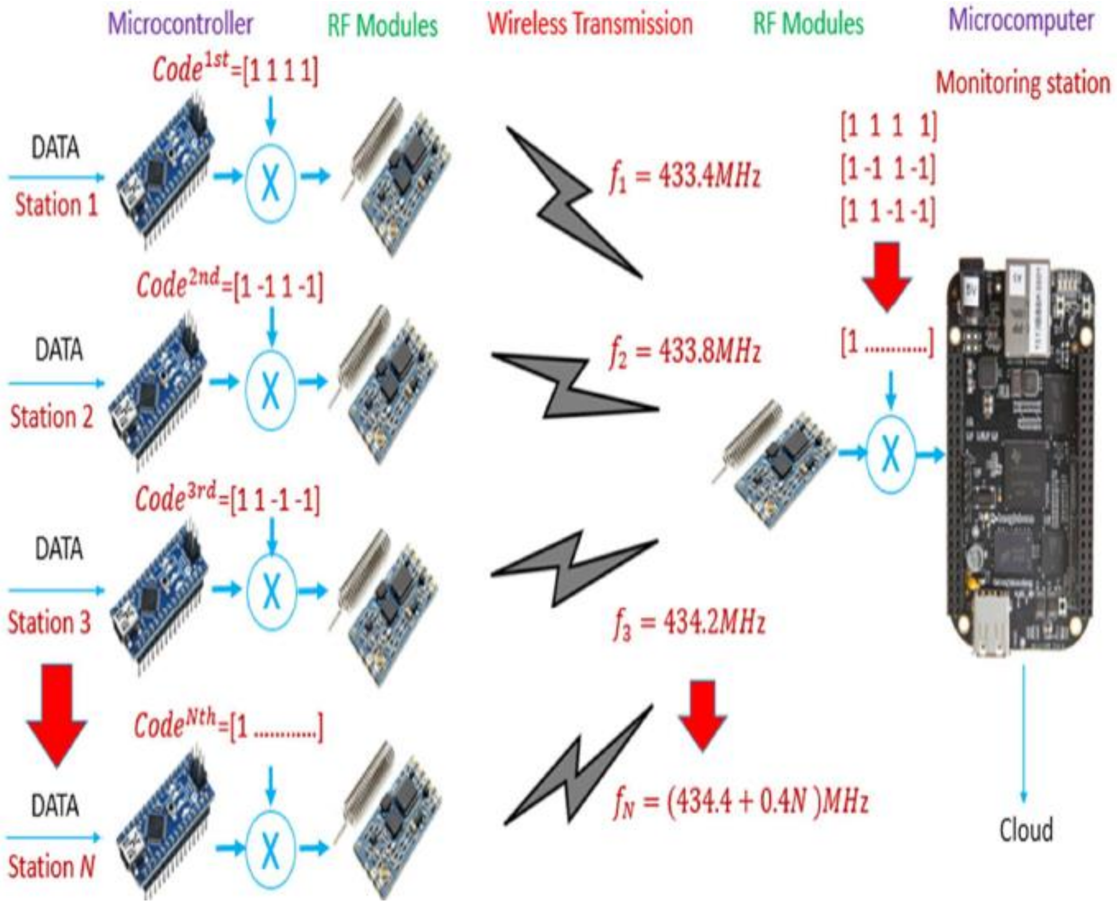

Figure 2.9: CDMA-based arowana fish pond monitoring system [5]

In this project, each sensor node was assigned with different frequency channel to communicate with the base station. The base station would hop a frequency channel to access a sensor node at a time. Stop-and-wait protocol was implemented to avoid the data collision at base station for multiple nodes access. Although, the multiple access method for WSN was developed in this project, the CDMA method was not being fully utilized as the frequency division method was applied, which small deviation in frequency channels were assigned to each sensor node, and there is limitation of frequency channel in HC-12 RF transceiver hardware.

2.5 Summary

The theory of data communication was explained in this chapter. Each type of channelization multiple access methods is mentioned in the subsection of this chapter. Besides, the concept of Walsh code as CDMA code for WSN is discussed. The introduction of the hardware used for base station and sensor nodes implementations in this project is given in this chapter. Lastly, the discussion of the related work is shown in this chapter. In the previous work done by Goh [5], there is a limitation in the proposed CDMA-based WSN with small deviation in frequency channels assigned to each sensor node, which shows the scenario of FDMA. In this project, the work on improving the multiple access method and the communication protocol among the base station and the sensor nodes are explained in the next chapter.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This section discusses about the methods used in realizing the development of CDMA wireless sensor network. Section 3.2 presents the flow of the entire project. Section 3.3 explains overview of the project with block diagram. The development of the CDMA wireless sensor network is discussed in Section 3.4 which includes the Walsh generator, Walsh code encoding, Walsh code decoding, CSMA/CA MAC protocol, the maximum distance for data communication measurement, and the latency measurement. Section 3.5 explain the solution of the system for real time monitoring. The social design criteria which are included in the development of this project is explained in Section 3.6. Last, Section 3.7 describes the experiment procedure of this project.

3.2 Project Implementation Flow

The project implementation flow is shown in Figure 3.1. The project was started with programming the Walsh CDMA code generator algorithm on base station and senor nodes of the system. The algorithm must be working on the system to generate N×N metric Walsh code, where N is the number of sensor nodes. Next, the sensor nodes and base station were programmed to be able to encode the collected data from surrounding with the code, and able to decode the encoded data with the code to retrieve the sensor data respectively. This step was done to ensure the data communication multiple access can be completed in CDMA scenario.

After that, the sensor nodes and base station were programmed with MAC protocol for multiple access data transmission from sensor nodes at the base station.