AROWANA FISH PONDS MONITORING SYSTEM USING CDMA-BASED WIRELESS COMMUNICATION

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AROWANA FISH PONDS MONITORING SYSTEM USING CDMA-BASED WIRELESS COMMUNICATION

BY

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ACK	Acknowledgments
CDMA	Code-Division Multiple Access
FDMA	Frequency-Division Multiple Access
GSM	Global system for mobile
IDE	Integrated development environment
IOT	Internet of Thing
LTE	Long-Term Evolution
RF	Radio frequency
RFID	Radio frequency identification
TDMA	Time-Division Multiple Access
WSN	Wireless Sensor Network

SISTEM PEMANTAUN UNTUK KOLAM IKAN KELISA DENGAN MENGGUNAKAN KOMUNIKASI CDMA WAYARLES

ABSTRAK

Ikan kelisa adalah sejenis ikan yang amat sensitif terhadap kualiti air dan menuntut kualiti air yang baik untuk pertumbuhan yang sihat. Sistem pengurusan kualiti air yang boleh dipercayai amat diperlukan untuk mengekalkan kualiti air kolam ikan pada tahap optimum. Memeriksa kualiti air setiap kolam satu demi satu secara manual adalah amat memakan masa dan tidak cekap. Projek ini bertujuan untuk membinakan sistem pemantauan tanpa wayar untuk memeriksa kualiti air kolam ikan kelisa. Suhu air dan pH nilai setiap kolam diukur menggunakan sensor. Setiap sensor pada kolam disambungkan kepada Arduino Nano dengan modul RF bertindak sebagai stesen pangkalan, manakala stesen pemantauan utama menggunakan BeagleBone Black dengan modul Sierra dan modul RF. Selepas pengekodan data, data sensor dari semua stesen pangkalan dihantar ke saluran frekuensi yang telah ditetapkan. Stesen pemantauan utama mendapatkan semula data dari saluran frekuensi. Selepas penyahkodan, data akan dihantar ke Cloud melalui rangkaian LTE. Analisis data dilakukan dalam Cloud untuk menentukan kesan kualiti air setiap kolam terhadap ikan kelisa. Keputusan ujikaji menunjukkan bahawa sistem ini fungsi dengan betul apabila jarak penghantaran data adalah lebih pendek daripada 100m dan kesilapan peratusan data daripada sensor adalah boleh diterima.

AROWANA FISH PONDS MONITORING SYSTEM USING CDMA BASED WIRELESS COMMUNICATION

ABSTRACT

Arowana fishes demand good water quality for their healthy growth. A reliable water quality management system is very much required in order to maintain the water quality of the fish pond at optimum level. Manually checking the water quality of each pond one by one is very time consuming and inefficient. This project is aimed to develop a wireless monitoring system for Arowana fish ponds water quality. The water temperature and pH values of each pond are measured using sensors. Each pond sensor is connected to the Arduino Nano with RF module acting as base station, while the main monitoring station of the system uses a BeagleBone Black with Sierra wireless module and RF module. After data encoding, the sensors data from all base stations are sent to main monitoring system via pre-assigned frequency channel in each station. The main monitoring station retrieves data from the frequency channel. After decoding, the data will be sent to the cloud via the LTE network. Data analysis will be done in cloud to determine how the water quality of each pond affects the Arowana fish. Result shows that the system functions properly when the distance of data transmission is shorter than 100m and the maximum percentage error of data from water parameter sensor is acceptable

CHAPTER 1

INTRODUCTION

1.1 Research Background

Arowana fish, also known by the Chinese as the “Dragon Fish”, is one of the most expensive aquarium fish in the world [1]. The most expensive species of Arowana is the Platinum or White Arowana , a single Platinum Arowana has a value of approximately $US 400,000.000 (RM 1682400.00) [2]. The Arowana fishes are so expensive also because breeding them in the artificial environment is very difficult as compared with other aquarium fishes. In order to grow healthy, they require good water quality. A good healthy Arowana Fish should grow up to at least 24 to 30 inches (60-75cm) [3].

Arowana fishes respond to their living environment in a very obvious manner. When they are placed in an artificial environment from their natural habitat, the chances of getting diseases is high [4]. Therefore, their living conditions need to be taken care of very well especially in regard with the water quality. Bad water quality management will expose the fishes to diseases. Table 1.1 shows the water quality guidelines for good healthy Arowana fishes [5].

Table 1. 1: Water quality guidelines for Arowana [5]

Water quality parameter	Water quality guidelines
Temperature	29 °C – 31 °C
pH	6.5 – 8.5
Dissolved oxygen	5ppm
Ammonia	1ppm
Secchi disc	30cm

Arowana fishes have a great resistance against diseases so long as they are not weakened by bad water quality, such as contaminated water, lack of oxygen or sudden change in water temperature. Water quality is very important to the fish. The negligence and ignorance in water quality management will cause stress and injury to the fish [6].

With the advancement of wireless communication systems technology, many works has been implementing the wireless sensor network (WSN) in the field of agriculture and fisheries to improve the productivity and efficiency by monitoring the relevant data from the field. WSN consists of massive sensors deployed in monitoring region with the characteristics of micro and low power consumption [7] .

An important problem in WSN is that the bandwidth or the number of frequency channels available is limited but the number of users is much larger [7]. In addition, transmission of multiple signals from sources to destination via wireless communication involves a lot of threats such as signal collision. Hence, a method to transmit data for a number of users over frequency channel is required.

Channelization is a multiple-access method in which the available bandwidth of a link is shared in time, frequency, or through code, among different stations. Multiple access to channels can be divided by time (TDMA), frequency (FDMA) or coding and modulation, as is done in CDMA.

1.2 Problem Statement

The ponds need to be checked frequently in order to maintain their water quality. However, manually checking one by one of the water quality from each pond is very time consuming and inefficient. Human resource is also wasted in doing this job. Thus, a

more efficient monitoring system is very much required that can automatically record data and which make the owner able to perform data analysis easily.

The time interval for checking the ponds' water quality manually is hardly feasible at a constant time. However, a wireless water quality monitoring system can record the data of water parameters such as water temperature and pH value for all fish ponds at constant time interval for 24 hours. This will ease the process of data analysis. In addition, water contamination can occur at any time and can occur at any pond. Manually checking the fish ponds is impossible to detect the changing of water quality as early as possible. Therefore, a wireless monitoring system is necessary to monitor the water quality of Arowana fish pond for 24 hours.

1.3 Objectives of Research

The objectives of this project are as follows:

i. To develop an efficient wireless water quality Arowana fish's pond monitoring system using the Code Division Multiple Access (CDMA) wireless transmission.
ii. To collect the data required and analyze the water qualities of Arowana fish's ponds maintain to be at optimum level.
iii. To design and implement Internet of Things (IOT) in wireless water quality Arowana fish's pond monitoring system.

1.4 Scope of Research

This project can roughly divided into 2 parts: base station and main monitoring system. Each base station has an Arduino Nano, pH sensors, water temperature sensor and HC-12 RF module for wireless communication. Arduino Nano is programmed by Arduino IDE. While main monitoring system has BeagleBone Black, HC-12 RF module and Sierra Wireless module for IOT application**.** BeagleBone Black is a mini computer to process data in main monitoring system and it is programmed by Eclipse IDE.

Temperature sensor and pH sensor are used to measure water pH value and temperature of fish pond for data analysis. The wirelessly data transmission and reception between base station and main monitoring system is not more than 100m due to the limitation of HC-12 RF module's transmitting power. In addition, HC-12 RF module is only provided 100 frequency channel for wireless communication, the frequency ganchannel provided is between 433.4MHz to 473.0MHz. The line of sight between base station and main monitoring system is assumed unobstructed.

1.5 Organization of Thesis

Chapter one introduces the background of the project, problem statement, research objectives and research topics. In background of the project, difficulty of manually checking water quality of fish pond is being briefly introduced.

Chapter two summarizes the literature reviews about information that is related to this project. Different typed of approach for wireless water quality monitoring system will be discussed in this chapter. Channel access methods such as FDMA, TDMA and CDMA are also explained in this chapter.

Chapter three discusses the data communication between base station and main monitoring system. Data encoding, data decoding and data communication between base station and main monitoring system are explained in this chapter. Graphical illustrations such as block diagram and flow chart are included in this chapter.

Chapter four shows the result obtained for this project. The data communication between base station and main monitoring system is tested in few different cases to find out the reliability of the system. Results obtained from water parameter sensors will be tabulated and compared with real values to calculate the percentage error.

Chapter five concludes the project. Limitations of the project are discussed and suggestions on performance improvement of the water quality monitoring system are included for future works.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A wireless sensor network (WSN) is a set of nodes organized into a cooperative network. Each node has low power consumption and contains a microcontroller, a RF transceiver, power supply and accommodates various sensors. The nodes can communicate wirelessly and self-organize after being deployed in monitoring region [8]. This technology can be implemented in numerous application areas such as agriculture and fisheries to monitor the relevant data from the field. With the application, it can improves the way we live and work.

Code Division Multiple Access (CDMA) is a modulation and multiple access scheme based on the spread-spectrum communication technology. It is well-established technology and applied to digital cellular radio and wireless communication systems in the early 1995 and provided approximately 10 times more capacity than analog networks, far more than TDMA or GSM [9].

CDMA is an alternative to frequency division and time division multiple access schemes which allows multiple users to transmit data over a same frequency channel simultaneously. This can be done by assigning a unique code or signature to each user. In this work, concept of CDMA will be apply on the wireless sensor network of water monitoring system.

2.2 Background Theory

This section will discuss about the background theory of this project, includes Walsh codes, channels access methods, hardware and software used.

2.2.1 Walsh Codes

Walsh Codes are a set of perfectly orthogonal codes and are widely used in multi-user CDMA communications [10]. The Walsh code is used to separate the user in the forward CDMA link. In any given station, each station is assigned a distinct Walsh code. Walsh code is selected in this project because it is easy to generate and apply in CDMA system.

The process to generate orthogonal code starting with a seed of 0, the codes are generated by repeating the 0 horizontally and vertically, and then complementing the 1 diagonally. This process is repeated with the newly generated block until the desired codes with the proper length are generated. Sequences created in this way are referred as "Walsh" code. Walsh Code is a linear code that maps n length messages to codes of length 2n. These codes are mutually orthogonal. Hence, a set of n mutually orthogonal codes of length 2n can be generated [10].

2.2.2 Channel Access Methods

There are 3 multiple-access method: frequency-division multiple access (FDMA), time-division multiple access (TDMA) and code-division multiple access (CDMA).

2.2.2.1 Frequency-Division Multiple Access (FDMA)

Figure 2.1 shows the sharing of FDMA channel.

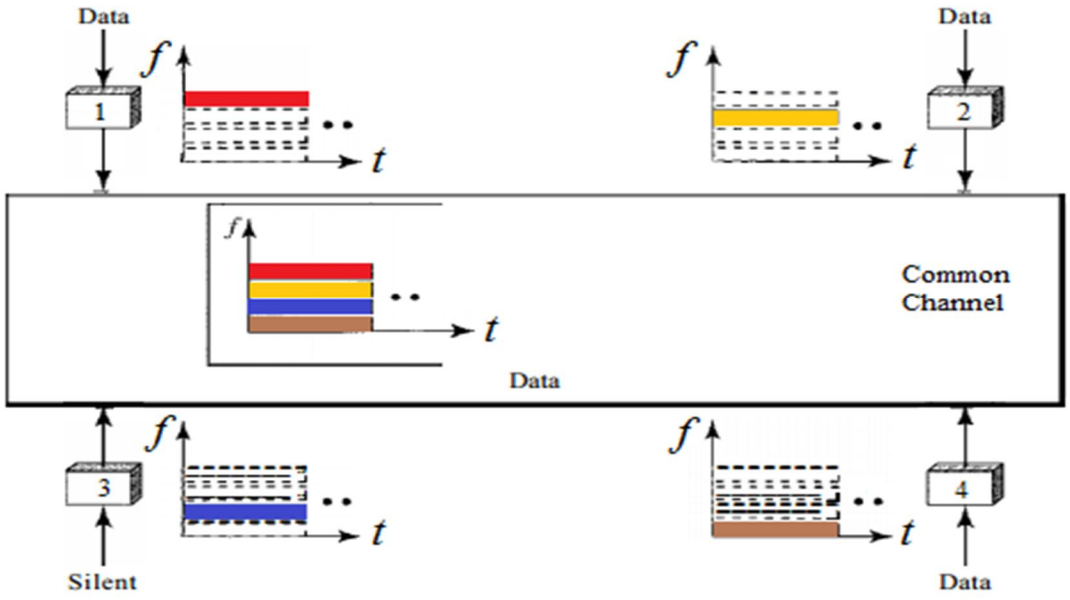

Figure 2. 1: Sharing of FDMA channel

For frequency-division multiple access, the available bandwidth is shared via frequency. The available bandwidth in FDMA system is divided into small frequency slots. Each user in FDMA system uses only a portion of a whole available frequency bandwidth and the users are separated in frequency domain. To prevent interface, the allocated band to each users is separated from one another by a small guard bands.

2.2.2.2 Time-Division Multiple Access (TDMA)

For time-division multiple access (TDMA), the available bandwidth of the channel is shared in time. Each user in TDMA is allocated a time slot which it can send data. Each user transmits data in its assigned time slot and the transmission occupy the whole frequency domain. Figure 2.2 shows the sharing of TDMA channel.

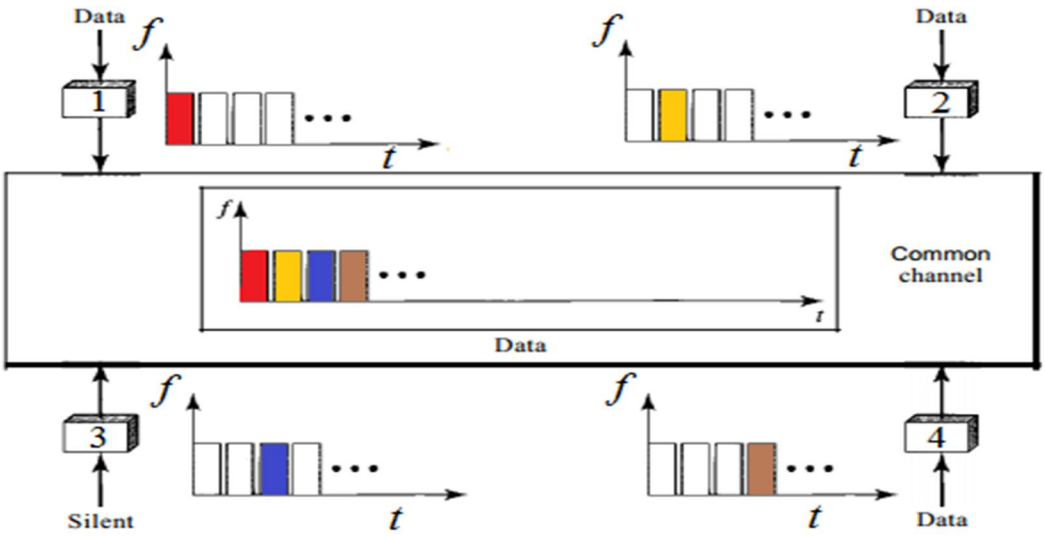

Figure 2. 2: Sharing of TDMA channel

2.2.2.3 Code-Division Multiple Access (CDMA)

Code-division multiple access simply means communication with different codes. In CDMA, there is no time sharing and one channel occupies the entire bandwidth. Each user in a CDMA system is assigned a unique code sequence and data from the user is encoded with the assigned code. The destination knows the code sequence of each user and decodes the received signal to recover original data.

With the assigned code, the receiver is able to distinguish between users, provided that each user has a unique code that has a sufficiently low cross correlation with the other codes. Figure 2.3 shows the sharing of CDMA channel.

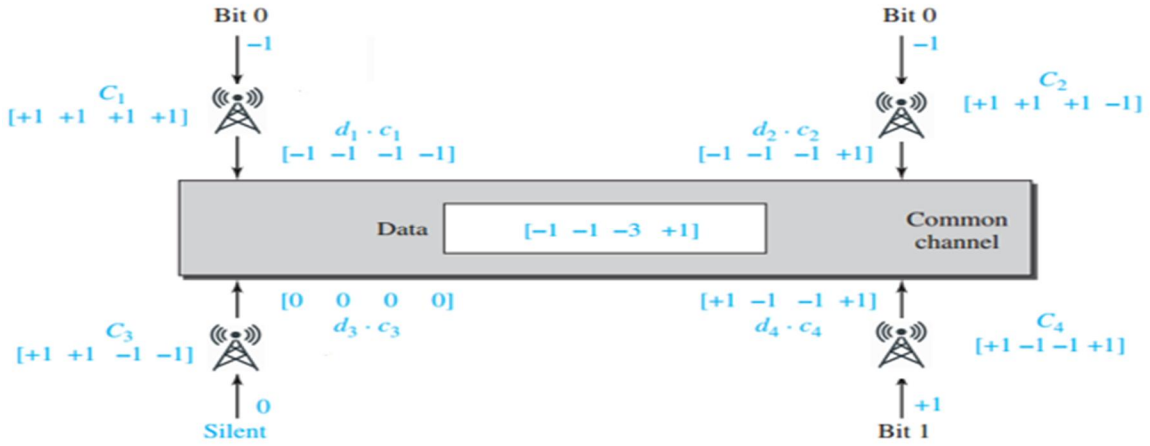

Figure 2. 3: Sharing of CDMA channel

2.2.3 Arduino Nano

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. Figure 2.4 shows the Arduino Nano pin layout. Table 2.1 shows the pin assignment of Arduino Nano in this project.

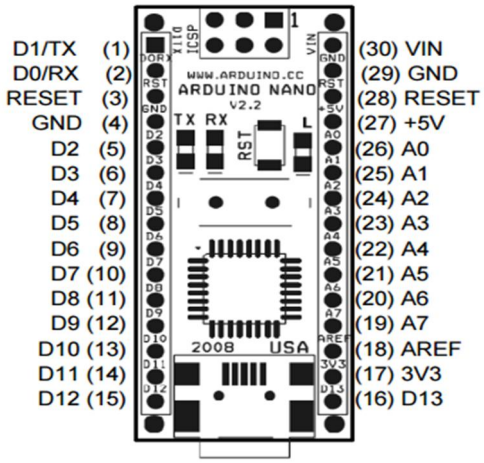

Figure 2. 4: Arduino Nano pin layout

Table 2. 1: Pin assignment of Arduino Nano

Pin Number	Name	Type	Assignment
3, 28	RESET	Input	Reset (active low)
4, 29	GND	PWR	Supply ground
5	D2	Tx pin	Connected to Rx of HC-12 RF module
7	D4	Output	Used to set mode of HC-12 RF module
9	D6	Input	Collect digital data from temperature sensor
12	D9	Rx pin	Connected to Tx of HC-12 RF module
26	A0	Input	Collect analog data from pH sensor
27	+5v	PWR	+5v output
30	VIN	PWR	Supply voltage to Arduino Nano

2.2.4 MOTOROLA WI-COM Board

MOTOROLA WI-COM board consists of a BeagleBone Black and a Sierra wireless MC7304 PCI express mini card. The hardware BeagleBone Black is using a low cost processor, Sierra XAM3359AZCZ100 Cortex A8 ARM from Texas Instruments. BeagleBone Black is interfaced with RF module to receive encoded data and Sierra Wireless module to upload data to cloud. The detail of pin definition of BeagleBone can refer on Appendix C. Table 2.2 shows the pin assignment of BeagleBone Black.

Table 2. 2: Pin assignment of BeagleBone Black

Pin Number	Name	Type	Assignment
1	DGND	PWR	Supply ground
3	+3.3v	PWR	Supply 3.3v
5	+5v	PWR	Supply 5v
12	GPIO_60	Output	Used to set mode of HC-12 RF module
24	UART1_TX	Tx pin	Connected to Rx of HC-12 RF module
26	UART1_RX	Rx Pin	Connected to Tx of HC-12 RF module

There is a precaution that need to be taken when working with the boards to prevent damage. The max voltage level for all GPIO pins of BeagleBone Black is 3.3v. Any direct application of 5v to GPIO pin of BeagleBone Black will cause damage.

For Sierra Wireless MC7304 PCI Express Mini Card, it is a compact, light, wireless UMTS-and LTE-based modem. The modem, based on Qualcomm's MDM9215 baseband processor, supports data operation on LTE, DC-HSPA+, HSPA+, EDGE, GPRS, and GSM networks. In this project, Sierra Wireless module is connected to BeagleBone Black by USB in order to provide LTE network. Decoded data are uploaded to cloud via the LTE network. Figure 2.5 shows the hardware structure of Sierra Wireless MC7304 PCI Express Mini Card.

Figure 2. 5: Hardware structure of Sierra Wireless MC7304 PCI Express Mini Card

2.2.5 HC-12 RF Module

HC-12 RF module is a multichannel embedded wireless data transmission module that work in half-duplex. Its wireless working frequency channel is 433.4-473.0MHz, there are totally 100 channels can be used, with the stepping frequency of 400 KHz. The maximum communication distance is 1km in open space [11]. The receiving sensitivity of RF module

will be changed if setup is difference. Figure 2.6 shows the hardware structure of HC-12 RF module.

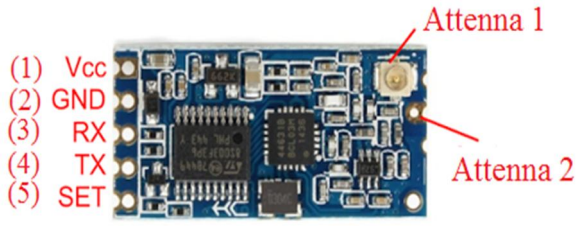

Figure 2. 6: Hardware structure of HC-12 RF module

The RF module has 2 transmission mode, transparent and AT mode. The transparent transmission mode is only used for receiving and sending serial data, so it is simple to use. While in AT mode, it is only for AT-command programming.

2.2.6 Water Parameter Sensor

There are 2 types of sensor used in this project: BNC connector probe pH sensor with module and water proof DS18B20 temperature sensor.

2.2.6.1 BNC Connector Probe pH Sensor with Module

To measure the pH value of fish pond, BNC connector probe PH sensor is used in this project. The working pH range for the sensor is 0-14 pH. Its operating temperature is 0-60Celsius. The response time of the sensor is less than 1min. In a pH 7 solution, the pH Sensor will produce a voltage of around 1.75 volts. The voltage will increase by about 0.25 volts for every pH number decrease. The voltage will decrease by about 0.25 volts/pH number as the pH increases. Arduino Nano cannot directly interfaces with BNC connector, so a module is required in order to accept data from BNC connector of PH sensor and transfer

the data to Arduino Nano by pins. Figure 2.7 shows the hardware structure of the pH sensor and its module.

Figure 2. 7: Hardware structure of the pH sensor and its module

2.2.6.2 Water Proof DS18B20 Temperature Sensor

The sensor used to measure the water temperature of fish pond is DS18B20 waterproof temperature sensor. The power supply range of the sensor is 3.0v to 5.0v. Its operating temperature is -55°C to +125°C. The estimate accuracy of the sensor over the range of - 10°C to +85°C is ±0.5°C. It is easy to use and communicate with devices because its unique 1-wire interface. It can converts temperature data to a 12-bit digital word in a period of 750ms. Figure 2.8 shows the hardware structure of the temperature sensor.

Figure 2. 8: Hardware structure of DS18B20 Temperature Sensor

2.3 Existing Wireless Communication Technology for Water Quality Monitoring System

The existing technology for wireless data communication in water quality monitoring system including Radio-frequency identification, Global system for mobile and wireless communication with ZigBee protocols.

2.3.1 Radio-Frequency Identification (RFID)

Radio-frequency identification (RFID) is a wireless communication technology using radio frequency signals for identification and information collection. A typical RFID system is composed of a controller, a reader and numerous tag-attached objects [12]. The tag, a microchip being attached to the antenna, has a distinct serial number acting as the identity of a person or object [13]. It communicates with the reader through a wireless channel. Once activated, when the tag receives commands from the reading unit, it generates a radio waves signal back to the reader. The reader can transform the radio waves reflected back from the tag into digital information, which is sent to the central controller who can make use of this information to support various applications [14].

The RFID aquarium sensing system consist of a RFID tag with built in temperature sensor, a RFID reader and a personal computer with an application program installed. The RFID reader receives sensor data from RFID tag via wireless communication and delivers the data to computer for analysis and decision making [15]. Figure 2.9 shows the structure of RFID reader and RFID tag.

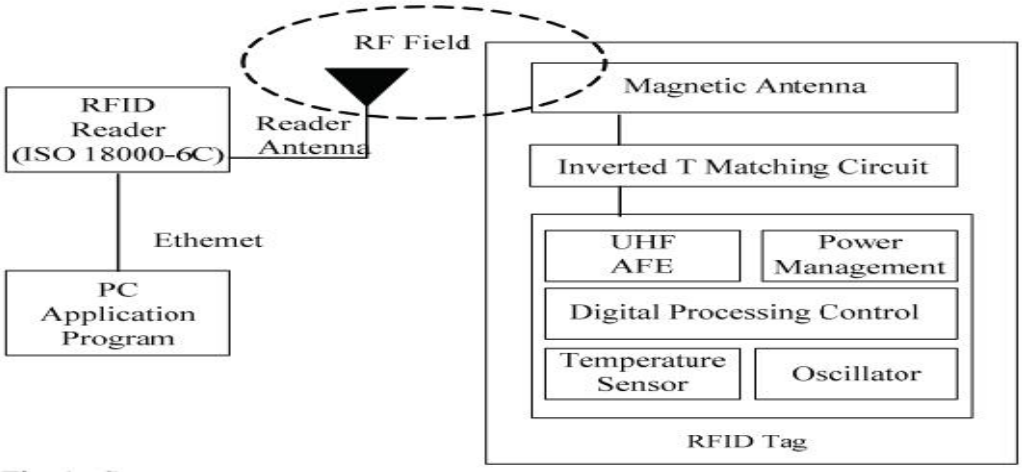

Figure 2. 9: Structure of RFID reader and RFID tag.

RFID can be read wirelessly and without line of sight and are more robust. This approach has a great advantage in production cost because RFID tag is a low-cost item. RFID technology offers the benefits of relatively low cost compared to other wireless technology but it has limitation. It is not easy to read multiple RFID tags simultaneously and may cause signal collision and data loss [16].

2.3.2 Global System for Mobile (GSM)

The typical approach is to measure water parameter such as water temperature and pH value by sensors and the sensor data are collected by a microcontroller board. The data collected can the either be stored on board via a SD card or sent to a cloud server via a GSM (Global System for mobile) module.

GSM is a standard developed by Conference Europeenne des Postes et Telecommunication (CEPT) in 1982. The task of GSM is to describe the protocols for second-generation (2G) .A GSM network consists of several elements: the mobile station

(MS), the subscriber identity module, the base transceiver station (BTS), the base station controller, the transcoding rate and adaption unit (TRAU), the mobile services switching (MSC), the home location register (HLR), the visitor location register (VLR), and the equipment identity register (EIR) [17].

A local machine in conjunction with the cloud server is utilised for data analysis [18]. The advantage of this approach is that it applies IoT (Internet of Things) application in design and allows the communication between devices. However, this method is expensive in production cost because each station of the water monitoring system requires a GSM module, which is high in cost. Figure 2.10 shows the overall block diagram of system operation.

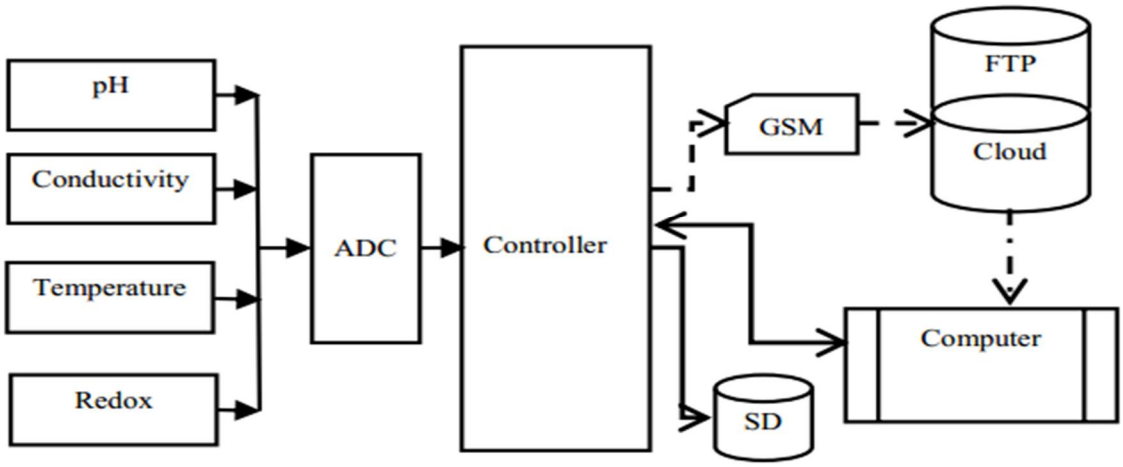

Figure 2. 10: Overall block diagram of system operation

2.3.3 Wireless Communication with Zigbee Protocol

Zigbee is a low cost wireless radio frequency communication standard that has low data rate and low power consumption. It is cheap and easy to use [19]. Xbee is one of the devices that apply Zigbee protocol. The system consists of 3 parts, sensing block, data logger and sampling block. The sensing block consists of sensors to measure water parameter and a

microcontroller to collect measured data from the sensor probes and transmitting the values to the data logger [20].

The sensing block consists of sensors to measure water parameter and a microcontroller with Xbee 2.4 GHz shield for wireless data transmission. The microcontroller collects data from sensor and transmits data to the data logger via 2.4 GHz frequency channel. The microcontroller with Xbee wireless receiver accepts the transmitted data and carries out data processing to compare the measure sensor data against the predefined threshold. Then, the processed data is passed to computer for graphical display and sampling block for sample collection. Figure 2.11 shows water quality monitoring system with Zigbee protocol.

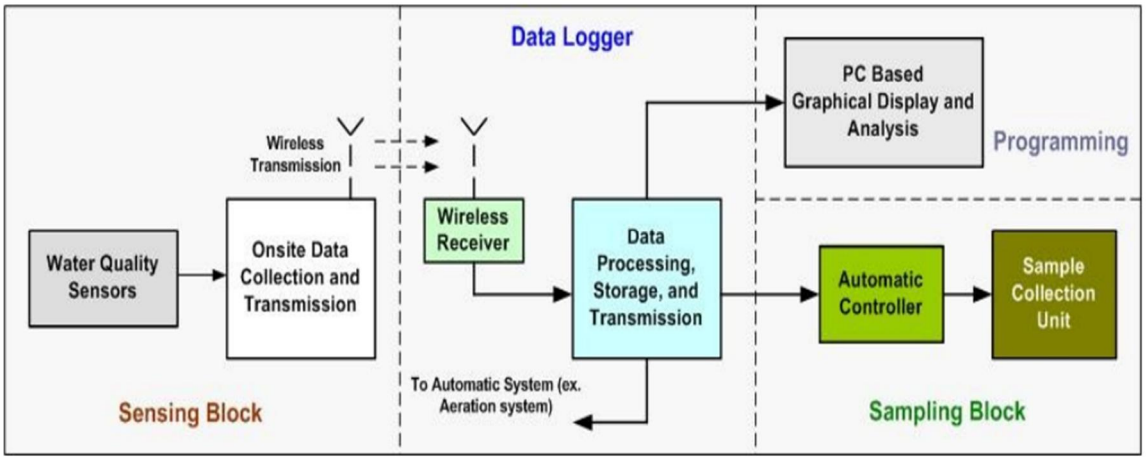

Figure 2. 11: Water quality monitoring system with Zigbee protocol

This system with Zigbee protocol is easy to set-up and ZigBee protocol stack provides low cost, low data rate, and low energy consumption characteristics for Wireless Sensor Networks (WSN).

2.4 Summary

Several technology used in wireless communication for water quality monitoring system have been discussed, such as RFID, GSM and wireless communication with Zigbee protocol. However, RFID is not suitable for simultaneously transmission and GSM is too expensive. The wireless transmission with Zigbee is the most suitable one for WSN because it is less expensive and consume less energy since WSN required only low data rate. However, Zigbee works in 2.4 GHz radio frequency, 2.4 GHz is a high frequency. With high frequency, Zigbee has low penetration through solid objects and can only travel shorter distances as compared to low frequency. Therefore, HC-12 RF module is chosen instead of Zigbee because HC-12 RF module work in frequency range of 433.4MHz to 473.0 which is in lower frequency range to provide better penetration power and transmission distance.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This work focuses on improving efficiency of wireless water quality Arowana fish's pond monitoring system by using the Code Division Multiple Access (CDMA) wireless transmission. In CDMA, the source of the data can be justified when decode the data at destination. This is achieved by using Walsh coding technique. Each pond acts as a base station and has a unique CDMA host code. Communication between base station and main monitoring system is in half duplex mode. Stop and wait protocol is implemented for data transmission and receive. Data will be sent from main station to cloud via LTE network.

3.2 Project Implementation Flow

The general flow of the proposed system is as shown in Figure 3.1. Each pond acts as a base station and has a water proof DS18B20 temperature sensor and pH sensor with module, sensor data from each pond are transmitted to Arduino Nano with an HC-12 RF module. Each base station is associated with its Walsh host code. Walsh codes are a set of orthogonal codes and are widely used in multi-user CDMA communications.

During the start-up of the system, the delay for message from each base station to reach main monitoring system is checked. The delay is recorded and set as timeout to wait reply from the base station. After that, once the base station receives request form main monitoring system, the base station encodes the sensor data with the corresponding Walsh code and sends the data via frequency channel by using the RF module.

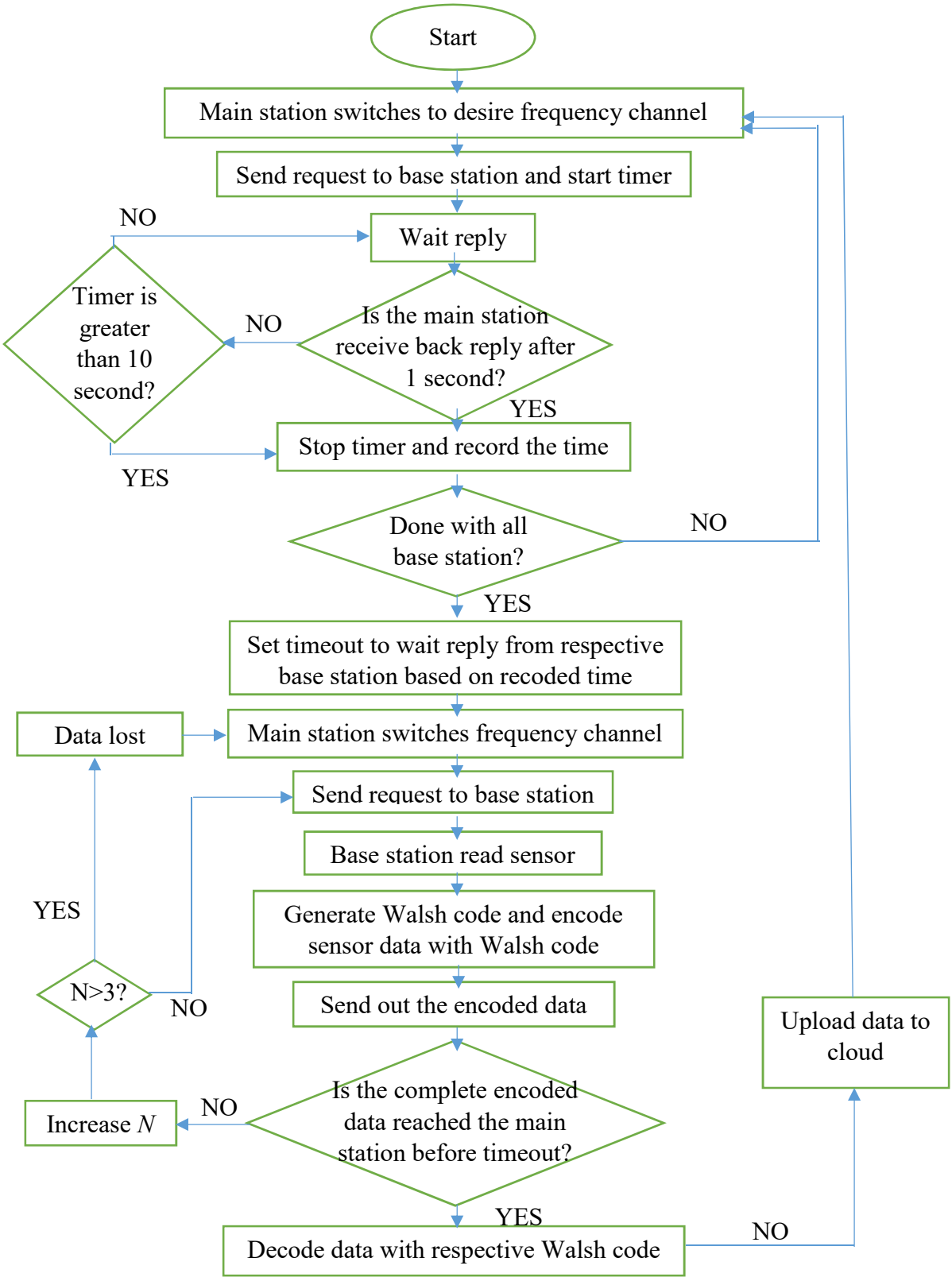

Figure 3. 1: Project implementation flow

The main monitoring station uses the BeagleBone Black with Sierra wireless module and HC-12 RF module. If the encoded data do not reaches the main monitoring system within timeout or the received encoded data is not complete, main monitoring system will send again the request to base station. If a complete encoded data is received within timeout, the data is decoded with Walsh code. From Walsh code decoding, the source of the data can be justified. Since the main monitoring station has the Sierra wireless module, the decoded data can be uploaded to the cloud via the LTE network for data analysis.

3.3 System Overview

In this project, only four water ponds are implemented for demonstration purpose. This system is not just limited to only four water ponds but it can be expanded by using Walsh code expansion [21]. Each water pond has an Arduino Nano as microcontroller to collect data from Ph sensor and temperature sensor. The Beaglebone Black with a RF module will act as a main monitoring system.

Each base station is assigned a unique Walsh code and frequency channel. The frequency of base station is stepped up by 400 KHz. The communication between the main monitoring system and base station in fish pond is half-duplex with stop and wait protocol. Each base station is assigned a unique Walsh code and communication frequency channel. The main monitoring system will hop to the particular frequency channel and send its request to a particular fish pond. After the Arduino Nano receives the request to send data, it will start collecting data and encoding it with Walsh code. The encoded data is sent to a particular frequency channel via RF module. The main monitoring system receives the encoded data and decode it to retrieve the original data. After that, the data will be uploaded to cloud for

data analysis. The detail block diagram of the Arowana fishes monitoring system using CDMA system is as illustrated in Figure 3.2.

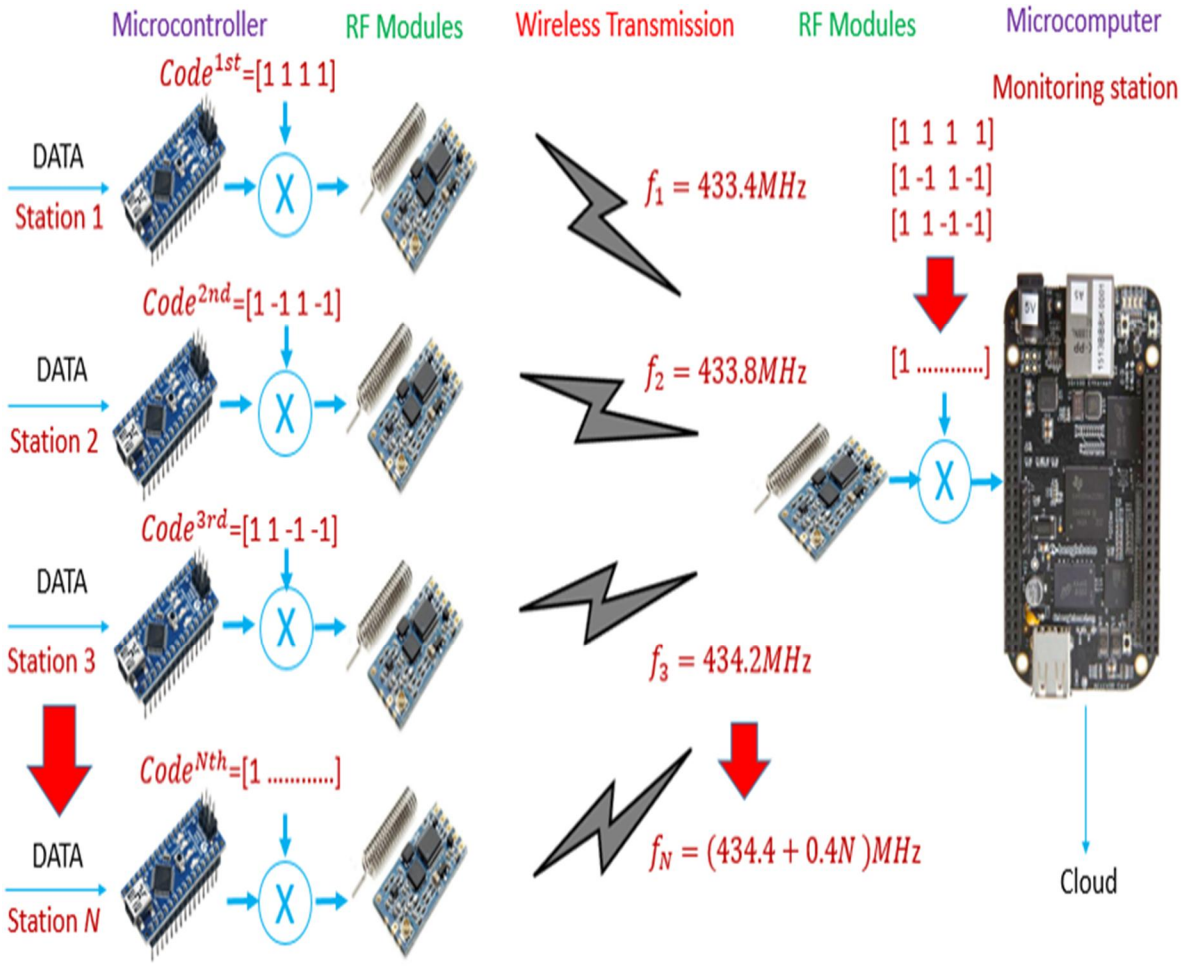

Figure 3. 2: General overview of the Arowana fishes monitoring system using CDMA communication

3.4 Walsh Code Encoding and Decoding

Communication in CDMA involves more than one users, when data are sent from multiple users to a destination, the source of the data need to be determined at destination [22]. Walsh codes are a set of orthogonal codes and are widely used in multi-user CDMA

communications [10]. With Walsh code encoding and decoding, the source of the data can be discovered.

3.4.1 Walsh Codes Generator

Walsh codes are generated in base station and main monitoring system by using Hadamard Matrix method. The Walsh codes generator is developed by using C++ programing language based on the Hadamard Matrix method. Figure 3.3 shows the flow of Walsh code generator.

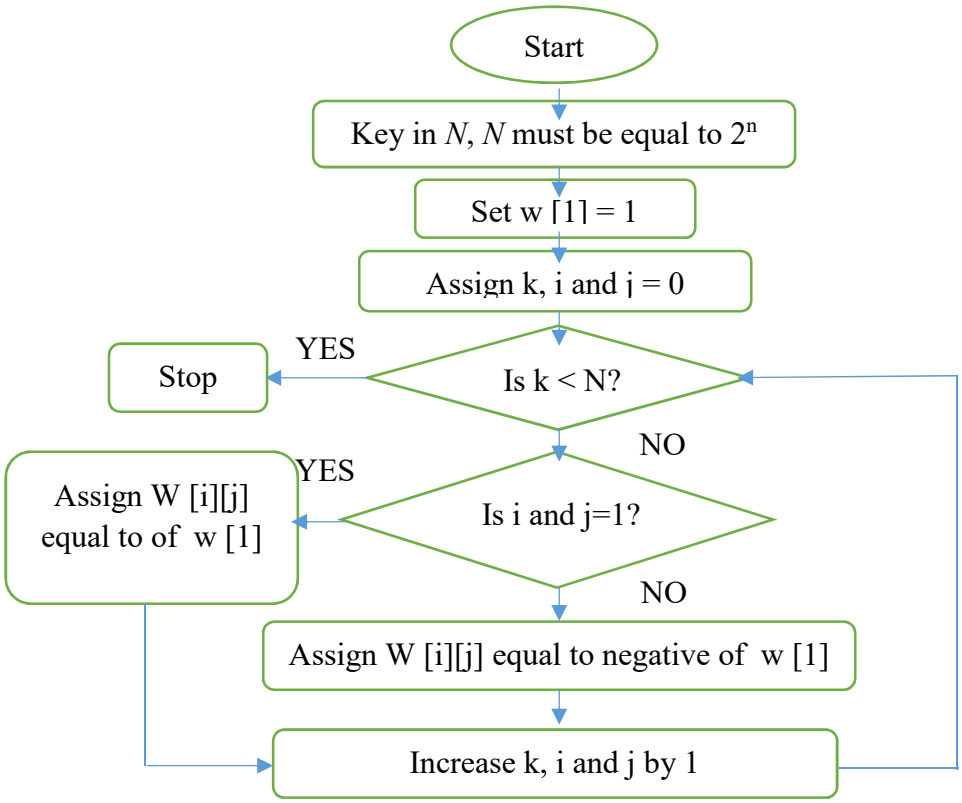

Figure 3. 3: Flow of Walsh code generator

A Hadamard Matrix H having order n is an nxn matrix of 1s and 0s in which $HH^T = nI_n$, where I_n is the n × n identity matrix. H_n denotes the nth matrix. The matrix can be found