DESIGN AND IMPLEMENTATION OF AN INVENTORY MANAGEMENT SYSTEM IN LIBRARIES USING RADIO FREQUENCY IDENTIFICATION TECHNOLOGY

Meryle K. Mvoulabolo
211027790

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Department of Process Control & Computer Systems

Faculty of Engineering and Technology

Vaal University of Technology

Vanderbijlpark

South Africa

Supervisor: Prof MO. Ohanga

Co-supervisor: Dr TND. Mathaba

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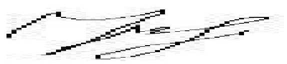
DECLARATION

I, Meryle Karrel Mvoulabolo, student number 211027790, hereby declare that the dissertation entitled Design and Implementation of an Inventory Management System based on Radio Frequency Identification Technology is the result of my own research and presents my own work and that all the resources that I have used or quoted have been indicated and acknowledged by means of complete references. I further declare that I have not previously submitted this work, or part of it, for examination at Vaal University of Technology for another qualification or at any other higher education institution.



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Meryle Karrel Mvoulabolo   Date

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ABSTRACT

Radio Frequency Identification Technology (RFID) technology is increasingly being used in multiple applications due to its low cost and ability to provide a high quality of identification. The cost benefit of RFID system is seen in the reduction in labor required to perform routine tasks such as inventory. With RFID, inventory-related tasks can be done in substantially less time compared to other commonly used auto-identification systems. Recent research has illustrated the application of RFID in multiple application scenarios. RFID can be used for real-time patient identification and monitoring in hospitals, but also for product expiration-date management in retail industries. Some enterprises in South Africa uses a combination of RFID technology and Internet of Things (IoT) to detect misplaced products and to detect low stock levels. Furthermore, RFID is also used for inventory management in libraries as discussed in this dissertation. In this dissertation, a combination of RFID and ZigBee technologies was used to reduce the time spent to perform inventory in libraries. An inventory management system was designed, simulated and built in order to count and locate books inside a library hence improving inventory process time in libraries. The overall results were satisfactory which lead to the achieving of the objectives set in this study.

PUBLICATION

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GLOSSARY OF TERMS

ANA	Adaptive N-tree algorithm
Auto-ID	Automatic identification
BBS	Backward binary search
BS	Binary search
BSA	Binary search algorithm
CDMA	Code division multiple access
COMPIM	Com port physical interface module
dB	decibel
DSA	Dynamic search algorithm
EHR	Electronic health record
EM	electromagnetic
EMI	Electromagnetic interference
EPC	Electronic product code
FDMA	Frequency division multiple access
HC	Host computer
IC	Integrated circuit
ICASA	Independent communication authority of South Africa
ID	Identification card
IMS	Inventory management system
IoT	Internet of things
LibBot	RFID-equipped robot
M6E-Nano	Simultaneous RFID reader
MSB	Most significant bit
NI	Node identifier
OBS	Optimized binary search
PAN	Personal area network
PCB	Printed circuit board
PVSM	Proteus virtual system modelling
QT	Query tree
RFID	Radio Frequency Identification
RSSI	Received signal strength indicator
SDMA	Space division multiple access

SN	Sink node
SRTR	SparkFun simultaneous RFID reader
TDMA	Time division multiple access
TTH	Time and temperature history
UHF	Ultra-high frequency
UNISA	University of South Africa
VITALIS	Internet of things-based health information system
VSPE	Virtual serial port emulator
WSN	Wireless sensor network
WSNode	Wireless sensor node

CHAPTER ONE: INTRODUCTION

1.1 Introduction and background of the study

Nowadays, automatic identification (Auto-ID) systems are deployed in many service industries to help identify articles, goods or people. For a very long-time barcodes had been used in libraries for book management such as sorting, check-in or check-out. This system has few limitations such as:

(i) Inability to track and locate books on shelves.
(ii) Long queuing time when checking books in or out as the books need to be scanned one by one.
(iii) The impossibility to read, write, modify or update information printed on the book.
(iv) Low level of security.

Thus, barcodes make circulation, inventory and shelving of the reading material in a library a quite difficult work which takes most of the time of the library staff (Singh & Mahajan 2014).

The limits of barcodes lead to the development of other forms of identifications, with the ability to store information and transactions. The integrated circuit (IC) memory cards or smart cards are an example of Auto-ID with data storage capability. Smart cards can store electronic data. The data is read using smart card readers by supplying the smart card with energy and a clock pulse via the contact surfaces. However, one of the biggest disadvantages of smart cards is that the card must be in contact with the reader in order to transmit data (Yu 2008). The development of a contactless Auto-ID system with data storage capability is then essential. Contactless Auto-IDs are referred to as Radio Frequency Identification (RFID).

RFID is defined as a wireless communication technology that uses electromagnetic field to uniquely detect and identify objects, animals, or people (Patil *et al.* 2017). RFID technology was developed during World War II for military purposes. Currently, RFID technology has moved from military application into diverse application areas for private, scientific and industrial purposes (Ting *et al.* 2017). RFIDs are now used to replace barcodes for access control, logistic, tracking and inventory (Moreno 2014). Applications of RFID technology can be found in areas such as food safety management systems, health and medical treatment, home and public security, livestock management and supply chain management (Mathaba *et al.* 2017; Ting *et al.* 2017). Wal-Mart, the world's largest retailer, has applied RFID technology to its top 100 suppliers since 2005 (Heller 2017). The differences between Auto-ID systems are presented in Table 1.1.

Table 1.1: Comparison of different Auto-ID systems (Finkenzeller 2010)

System parameters	Barcode	Smart card	RFID
Data density	Low	Very high	Very high
Distance of communication	Short (0-50 cm)	Very short (direct contact)	Long (0-5 m)
Reading speed	Low (≈4 s)	Low (≈4 s)	Very fast (≈0.5 s)
Cost	Very low	Low	Medium
Effect by environment	High	Low	Low

In libraries, RFID technology provides a solution for materials management, circulation services, real-time services, staff costs, security and theft (Alwadi *et al.* 2017). RFID is also considered as an effective solution to the problem of misplacement of reading materials (Tao *et al.* 2016). With RFID, the amount of time taken to perform inventory-related tasks can be reduced compared to when using barcode readers or other auto-identification systems (Ayre 2013). RFID technology can read or detect a material ten-thousand times faster compared with using barcodes technology (Cheng *et al.* 2017). RFID technology therefore improves the transaction flow for the library and provides immediate and long-term benefits to library in traceability and security.

However, some major challenges in implementing RFID systems includes the system cost, low reading efficiency and long inventory time. Only around 2000 RFID equipped libraries are found worldwide (Zhang 2013). Singapore National Library is referred to as the first library to fully apply the RFID technology in 1998. Books can be borrowed by every Singapore citizen using identification card (ID) or driver's licence (Singh 2014). In China, RFID systems are found in the Hong Kong Library, Cheng Yi College Library of Jimei University, Shenzhen Library and Wuhan Library (Zhang 2013). In South Africa, only the University of South Africa (UNISA) is equipped with a RFID system.

A basic RFID system is made of the following components:

(i) RFID tag (or transponder).

(ii) RFID reader (which includes staff workstations, self-check-in/out stations, exit sensors and portable scanner)

(iii) Data processing unit (Zhang 2013; Patil *et al.* 2017).

According to Zainud-Deen *et al.* (2014), the reading antenna is one of the key factors that influences the reading efficiency of the RFID inventory management system (IMS). The design of the reading antenna is therefore an important part of the RFID system (Cheng *et al.* 2017). Another key factor affecting the reading efficiency of the system is referred to as collision. Collision occurs when two or several tags communicate at the same time with a reader (tag collision) or when signals from different readers overlap each other (reader collision) (Bai *et al.* 2017; Bonuccelli & Martelli 2017). Most of available RFID systems for libraries make use of handheld RFID readers to scan the reading materials. The handheld devices need to be moved next to each book on the shelves to identify and record the RFID tags. This process is still considered as manual and time-consuming as the handheld reader need to scan each book individually (Ehrenberg *et al.* 2007).

This research seeks to design an efficient automatic shelf reading system in order to minimize the time spent on inventory management and improve the reading efficiency when using the commercial RFID solutions.

1.2 Dissertation layout

This report is on the development of an inventory management system using RFID technology which will improve the time spent to perform inventory process in libraries. Chapter one gives an introduction and background to the study. Chapter two discusses previous work done on the topic. Motivation on the research are also given in this section. Chapter three provides an analysis of the units of the proposed solution. Chapter four presents a performance analysis of selected RFID anti-collision algorithms and their area of application. Chapter five discusses the designed inventory management system. Chapter six provides the simulated model of the proposed inventory management system. Chapter seven presents the developed system with measurements and tests conducted. Chapter eight concludes the dissertation with research outcomes and recommendations.

CHAPTER TWO: REVIEW OF RFID-BASED MANAGEMENT SYSTEMS

2.1 Introduction

Inventory management process in libraries includes identifying misplaced books, locating books and counting the books on shelves. The introduction of human errors during the process of inventory had led to the development of new technologies to reduce human errors and make inventory management process easier. A review of the use of RFID technology for locating and monitoring in inventory management systems is presented in this chapter.

2.2 Problem statement

Inventory process in libraries nowadays is still performed using manual traditional inventory management techniques, by scanning or reading books individually. This result in inconsistency in the inventory process, increase in inventory management time and mis-shelving of the collections. In their research Alwadi *et al.* (2017) stated that manual inventory techniques demand high level of resources with regard to the number of people and time required to perform the task, which are likely to introduce human errors, hence affecting the efficiency of a library management system. The authors proposed a RFID simulation framework as a solution to the challenges outlined above. However, issues of antenna design and collisions, which influence the efficiency RFID systems, were not addressed. Also, the proposed simulation framework was not implemented into a prototype to prove the simulation results.

2.3 Aim and objectives of the study

2.3.1 Aim of the study

The main aim of this study was to design and implement a tracking and counting system for libraries using RFID technology that is able to read tagged materials directly on the shelf. The designed system should have a high reading time and efficiency.

2.3.2 Objectives of the study

The purpose of this research is to improve the inventory processes in libraries using RFID technology, in order to reduce dependence on traditional inventory management techniques. The research will also analyse the reading time and efficiency of the proposed RFID inventory system; that is respectively the speed with which the tags are read and whether all the tags are read and localised correctly. Thus, the main objective of the research is to design a system that minimizes the time spent for inventory and improves the reading efficiency when using RFID solutions.

The specific objectives of the research are as follows:

(i) Evaluating the performance of different anti-collision algorithms in order to select the appropriate algorithm for library application.

(ii) Analyzing the parameters and functionalities of existing reader antennas in order to select the appropriate antenna for the system.

(iii) Designing, building and testing of a prototype RFID-based IMS for libraries.

(iv) Analyzing and evaluating the performance results of the prototype system and comparing with simulations to determine if the prototype meets the objective set.

(v) Analyzing the effect of the surrounding environment and mobile devices on the prototype performance.

2.4 Review of RFID-systems

The common inventory management system (IMS) based RFID applied in libraries are made of three components: the tagged object, the portable reader and central unit (Kumar *et al*. 2007; Kaur *et al.* 2011). In this system a portable RFID reader is used by librarians to scan every shelf and read the tags. Numerous RFID systems are being developed to replace the traditional systems used in libraries. Tests are also made to determine the effect of environment and surrounding devices on RFID systems. Golding & Tenant (2008) found that cell phone and computers have little or no effect on the RFID data exchange. Dhanalakshmi & Mamatha (2009) discussed the effect of the position of the tagged book on the reading efficiency. The study results show that the tag position has an effect on the reading efficiency; as for different positions, the reading percentage is different. Commercial RFID systems are considered as time consuming as the librarian need to scan row of books to perform the inventory. However, other RFID-based systems developed by researchers are presented in the following sections.

2.4.1 RFID and the Internet-of-Things

One of the main objectives of the Internet-of-Things (IoT) is to integrates intelligence within objects to allow them to collect and transmit data but also to communicate among themselves without human intervention. RFID low-cost, simple implementation and automatic identification capabilities make it an important component of the IoT (Eteng *et al.* 2018). RFID can be used in the IoT for sensing, identification and localization of objects and people. RFID connected with other technologies in the IoT allows the access and share of the collected data over long distances. Several developed systems combine RFID with technologies able to connect to the internet. Such technologies include Wi-Fi, Arduino and Raspberry Pi. This allows users to locate, identify or collect information anywhere and anytime.

Mathaba (2014) proposed an IMS for South African enterprises based on the combination of RFID and Web 2.0 technologies. This solution uses Arduino board and Beachcomber controller to manage and monitor products. A fixed RFID reader is used and the products are placed on a rotating wood made structure. The designed system detects misplaced products and low stock levels. Update notifications are sent to inventory managers using Twitter, to keep them informed about the status of inventory. The limitations of this system are that it only provides accurate readings for limited number of tags and it is influenced by ferrous materials resulting in wrong readings.

Turcu (2017) proposed the application of RFID and Internet of Things (IoT) technology in health care industry for the management of information in hospitals. The proposed solution, an Internet-of-Things based health information system (VITALIS), provides real-time patient identification and monitoring. VITALIS is an individual's medical card (made of a RFID tag) where key medical information about the patient are stored. This information includes drug allergies, blood type, medical history and current treatment. The patient's electronic health records are stored in an electronic health record (EHR) system that can be accessed in specified locations by authorized medical staff. The proposed solution also includes the measuring and monitoring of the temperature of tagged people or objects. The benefits of this system, according to the author, include the improvement of patients' safety by the reduction of medical errors, an efficient management of medical information and an enhancement of inventory management in hospitals. However, health care requires hospital environment to be maintained clean and sterile to avoid potential contamination (Ngai *et al*. 2009). The solution did not present the effects of the possible electromagnetic interference (EMI) produced by the system on the normal operations of the many type of electronic equipment within hospitals.

Gaukler *et al.* (2017) simulated a system for the management of expiration date of products using RFID and sensor technologies. In this solution, the authors believe that retailers can set expiration dates correctly using environmental conditions, mostly time and temperature history (TTH). RFID technology and temperature sensors are used to provide detailed information about the products. The authors then use the recorded time and temperature information to estimate the lifetime of each products using a simulation process. This solution shows that RFID technology can be used to determine more effectively products expiring date compared to traditional practices. The limitations of this system are that it has not been tested in real life. The simulation results presented by the authors might considerably change when implemented in real life due effect of real environment.

2.4.2 RFID in libraries

The introduction of RFID technology in libraries has started in the early 90's. Since then a great number of systems have been developed to assist librarians with library related tasks. Ozer *et al.* (2020) discuss ways to turn traditional libraries into smart libraries by using management systems based on Internet-of-Things technologies. The authors proposed a combination of technologies such as RFID, Arduino, Raspberry Pi and enterprise resource planning (ERP) system in order to perform library tasks such as inventory control, location of material and self-check-in/out.

Ehrenberg *et al.* (2007), on the other hand, designed an RFID-equipped robot (LibBot) as a solution for library inventory management. LibBot uses an embedded RFID tag to scan the shelves and localize books as shown in Figure 2.1. The effect of metallic bookshelf on the reading accuracy was analysed in this study and was found to be minimal to be considered. The authors also claim this solution to be significantly less expensive than systems that use handheld readers or those that have RFID reader antennas on every library shelf. The disadvantage of this solution is that the robot can only detect books that are placed on the lowest level of a bookshelf due to its height. In addition, this solution is time consuming as the robot takes time to scan the shelf to read the tags. Finally, the system cannot pinpoint the exact location of a tag, which is another strong limitation.

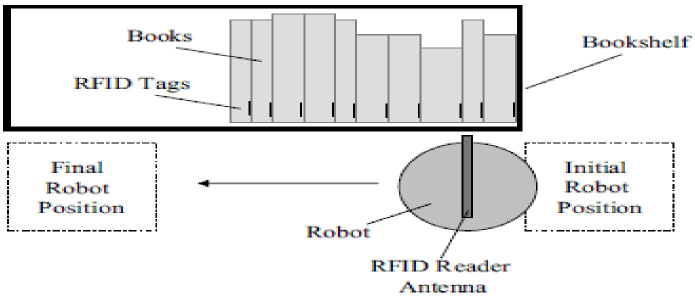

Figure 2.1: Top view of the LibBot and trajectory (Ehrenberg *et al.* 2007)

The introduction of RFID technology in libraries has several advantages. Using RFID, the time needed to perform library related duties is considerably reduced. Staff can assist patron in other areas such as face-to-face services. Moreover, with RFID librarians can better control the flow of material in and out of the library hence reducing human errors. Finally, RFID allows several items to be read at the same time. This improves the time to perform tasks such as inventory, books location and items check-in and check-out (Wang *et al.*2019; Bergeron *et al.* 2018). However, the application of RFID technology in libraries has few limitations including cost, security, reduction of staff number, reader collision, tag collision. Table 2.1 presents the advantages and disadvantages of RFID technology in libraries.

Table 2.1: Advantages and disadvantages of RFID in libraries

Advantages	Disadvantages
Reduction of staff duties	Reduction of staff number
Multiple identification capability	High cost
Reliability	Security
Easy stock verification	Collision
Automated check-in/ check-out	Frequency block

2.4.3 RFID anti-collision algorithms

In multiple tag systems, transponders respond to a reader's query command simultaneously. This creates a tag recognition collision problem at the reader. RFID collision problem includes tags collision and reader collision (Bai *et al.* 2017; Zhang *et al.* 2013). Anti-collision algorithms are used to overcome these issues (Zhang *et al.* 2013; Narayanan *et al.* 2005). Different types of anti-collision algorithms are available to solve the tags collision issue: time division multiple access (TDMA), code division multiple access (CDMA), frequency division multiple access (FDMA) and space division multiple access (SDMA). In passive tags systems, anti-collision algorithms based on time division multiple access are usually used due to their power limitations and function (Zhang 2013). TDMA is divided into two categories: ALOHA-based and query tree-based algorithms which includes binary search (BS) and query tree (QT) algorithms (Bai *et al.* 2017; Zhang *et al.* 2013).

Zhang *et al.* (2013) proposed a new reader-tag algorithm using QT method. In his solution, the conflict bit is used for the identification of tags. The conflict bit is generated by the reader using the tags IDs. The conflict bit recorded by the reader is used by the tags to generate temporary

IDs which are saved in their respective internal registers RC. To detect tags individually, a query prefix is sent by the reader and compared to the tags temporary IDs. A tag communicates with the reader only when its ID corresponds to the prefix. This anti-collision algorithm is claimed by the authors to be more efficient, requiring fewer reading cycles for tag's IDs compared to the traditional QT-based algorithm. However, the proposed algorithm has a longer search time and a large amount of transmitted data.

Another anti-collision algorithm solution based on BS is discussed by Bai *et al.* (2010) in their research. In the BS algorithm, the reader generates an ID request that is transmitted over the RFID network. If tags respond to the request, the reader then checks for collision bits. When collision bits are detected, the highest collision bit is set to "0" and the other collision bits to "1s". The reader then generates a new request to all the tags. A tag is identified when no collision bit is detected. The process is then repeated until all tags are identified. However, the identification efficiency of the basic binary search algorithm is low thus increasing the number of requests and the length of the binary code (Mingliang & Shun 2010). The workflow of the binary search algorithm is presented in Figure 2.2.

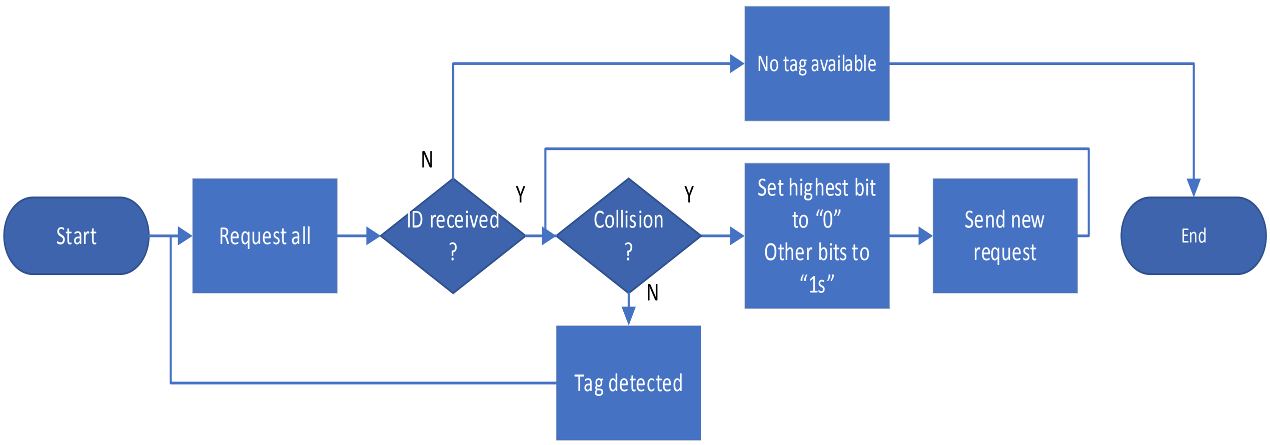

Figure 2.2: BS algorithm workflow

In this section several RFID-based systems and anti-collision algorithms have been reviewed. Limitations of these systems were also highlighted. It becomes important to compare the performance and efficiency of each system to determine which one result in better application of RFID technology to perform inventory in libraries. Issues related to inventory time and reading efficiency will be addressed.

2.5 Proposed solution

The proposed solution is the design of a static RFID system, meaning neither the tagged objects nor the user will need to move during the inventory process. It is intended to better assist librarians in performing inventory tasks by improving the time spent and efficiency. This problem has been attempted before but with no real solutions on the improvement of the reading efficiency.

The block diagram of the proposed solution is presented in Figure 2.3. In this proposed solution, the tag is used as an identifier. The information about the object to be identified are saved in the tag. The reader is used to detect the tags individually and read the information it contains. The information is then sent to a host computer through a wireless sensor network. The host computer's function is to process and save the received information. The information is then accessed by the librarian using a mobile device. The proposed system is divided in 4 units: RFID unit, wireless sensor network unit, inventory management system (IMS) unit and the user unit. These units are discussed in the following sections. The proposed solution will improve the reading efficiency of existing fixed RFID systems by using the convenient reader antenna specifications and the appropriate anti-collision algorithm.

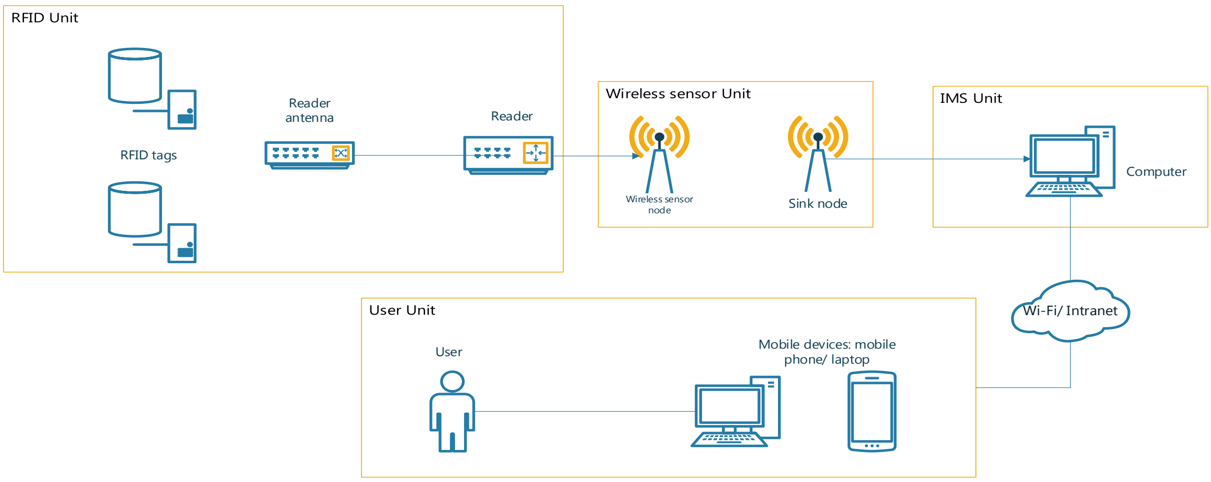

Figure 2.3: Proposed solution block diagram

2.6 Chapter conclusion

In this chapter motivations for the research were presented. The chapter continues with a review of RFID-based management systems. RFID technology can be applied for different purposes such as management tracking and medical monitoring. The chapter also presents how RFID can be applied with IoT technologies for remote data access and control. For each solution given in this section, the limitations were also presented. Later the issue of reader-tags collision was discussed with the possible solutions to that issue given. The chapter concludes with a brief description of the proposed solution. The next chapter is an analysis of the modules of the proposed solution.

CHAPTER THREE: ANALYSIS OF THE PROPOSED SOLUTION

3.1 Introduction

The different modules of the proposed solution are discussed in this chapter. Functions and analysis of each module is given. The chapter discusses the unit of the proposed solution: the RFID unit, the wireless sensor network unit and the inventory management system (IMS) unit.

3.2 RFID unit

RFID communications can be referred to as near field and far field communications. Near field communication, uses magnetic coupling for data exchange. This limit the communication distance of the system to few centimetres. On the other hand, far field communication, operates in the ultrahigh frequency (UHF) or microwave frequency range therefore allowing longer communication distances for up to 25 meters (Duroc & Tedjini 2018).

3.2.1 Operating frequency

RFID frequencies vary between 100 KHz and 5 GHz. The commonly used frequencies bands and their communication range is presented in Table 3.1. There are no global standards frequencies allocated to RFID world-wide. Standards and regulations differ according to countries and regions (Singh 2014). Table 3.2 presents RFID frequency regulations in some countries/regions. In South Africa, RFID frequency allocation is done by the Independent Communication Authority of South Africa (ICASA). The frequency band 915.2 – 915.4 MHz was allocated for UHF passive tags (South Africa 2008).

Table 3.1: RFID frequency bands (Bibi *et al.* 2017)

	Frequency range	Reading range	Coupling type	Area of application
LF	125 KHz – 134 KHz	~0.1 m	Near field	Animal tracking
HF	13.56 MHz	~1 m	Near field	Cold chain monitoring
UHF	860 MHz – 960 MHz	~2-20 m	Far field	Identification, inventory
Microwaves	2.4 GHz – 5.8 GHz	~100 m	Far field	Toll, access control

Table 3.2: International RFID frequencies (Takur 2008)

Country/Region	LF (KHz)	HF (MHz)	UHF (MHz)
United States	125-134	13.56	902-928
Europe			865-865.5
Japan			Not allowed
Singapore			923-925
China			Not allowed

3.2.2 RFID tag

RFID tags are used for the identification of the items they are attached on. RFID tags are made of two parts: the antenna and the microchip. The microchip stores information about the items while the antenna is used for their transmission to the reader (Khan 2009). RFID tags are classified in two main categories: active and passive.

3.2.3 Passive tags

Passive tags do not have their own energy source, they obtain their operating power from the reader. Passive tags are low-cost and consumes less power compare to other tags and have a lifespan of up to 10 years, depending on the environment the tags are in (Jalal 2015; Ferdous *et al.* 2016). Passive RFID systems communication is based on the backscatter principle: the reader transmits electromagnetic (EM) waves with a given frequency and constant amplitude. The transmitted RF (radio frequency) signal produces a current in the tag's antenna. The RF signal is then reflected back to the reader with added information where it is demodulated and saved in a database (Duroc & Tedjini 2018). The working principle of passive RFID tags is shown in Figure 3.1.

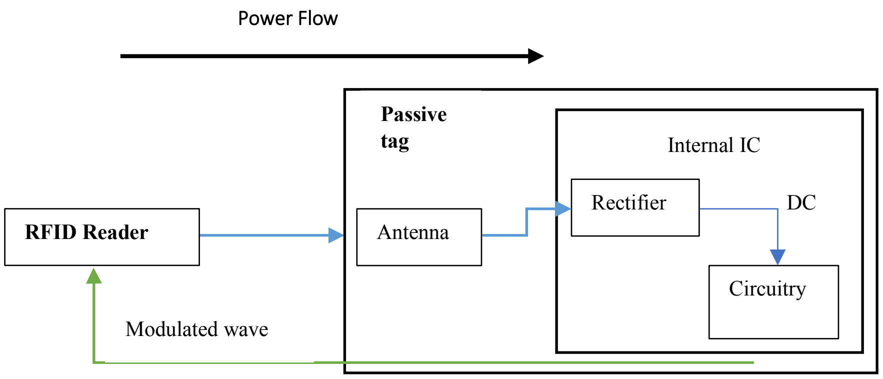

Figure 3.1: Passive RFID tags working principle (Ferdous *et al.* 2016)

3.2.4 Active tags

Active tags are made of an internal power source used to power the chip and to transmit data to the reader (Zhu *et al.* 2012). The internal power source makes active tags to constantly transmit their ID signal. In active RFID systems, tags can be accessed by the reader from far away as they transmit stronger signals (Kolhe *et al.* 2016). The communication range in active RFID systems is from several metres to up to 1000 m. Active RFID tags operate at high frequencies (433-455 MHz) and microwave frequencies (2.4 GHz or 5.8 GHz) (Zhang *et al.* 2016). Nevertheless, active tags are high cost tags with lower lifespan compare to passive tags because and the built-in battery must be replaced periodically (Ilie-Zudor *et al.* 2006; Kaur *et al.* 2011).

In this research passive tags will be used. Passive tags are durable and low cost compared to the other tags. This is an important parameter when it comes to the overall cost of the system. Also, passive tags are battery-free tags making their life span longer compared with active tags. They are considered to be suitable for tracking and tracing of items (Yang *el at.* 2011; Karuppuswami *et al.* 2017).

3.2.5 RFID reader

The reader is used to read the information saved in the tag. In passive systems, the tag is powered up by the reader emitted signal (Thakur 2008). In this research the M6E-nano simultaneous UHF RFID reader will be used as tag reader. The operating frequency range of this reader is 902.75 – 927.25 MHz.

However, two major problems occur in systems using multiple readers or tags: reader collision and tag collision. Reader collision happens when signals from two or more readers interfere with each other (Golsorkhtabaramiri *et al.* 2014). On the other hand, tag collision occurs when two or more tags respond to a reader inquiry simultaneously. A RFID reader can only communicate with one tag at a time. IF several tags respond simultaneously to a reader's request they will not be read by the reader (Tan *et al.* 2016).

Readers make use of anti-collision algorithms (singulation algorithms) to solve the reader-tag collision issue. Anti-collision algorithms are designed according to different channel access methods. FDMA is a channel access method where each tag is allocated a certain frequency band for the communication with the reader. In TDMA method, tags transmit using the same frequency channel but each tag communicate with the reader at a given time. Finally, in the CDMA method, each tag is encoded with a private key that can only be accessed by the reader. Tags cannot therefore access the reader at the same time as they do not have the same private key (Zhang *et al.* 2014; Kuriakose & Aghdasi 2007).

TDMA algorithms are simple in implementation and operation making them the most used type of algorithms for passive tags applications (Saadi *et al.* 2017). TDMA algorithms are divided into two categories: ALOHA-based algorithms and binary search (BS) based algorithms (Bai *et al.* 2017; Zhang *et al.* 2013). ALOHA-based algorithms are simple and easy to implement but are considered not stable, leading to misidentification and lack of identification of tags. Furthermore, ALOHA-based algorithms only work well for small number of tags (Zhang *et al.* 2014; Yong *et al.* 2017). Therefore, this study mainly focuses on binary search-based types algorithms. It is intended to reduce the system's read cycles and decrease the amount of data exchange. This will improve the identification efficiency compared to existing algorithms.

3.2.6 Reader antenna

The reader antenna plays a crucial part in the identification of the tags. Antennas for fixed reader installations are relatively large compared to handheld reader antennas. In this solution the antenna is placed directly on the shelf. A good antenna selection is therefore important to achieve a good identification rate. The antenna selection is made based on parameters such as: the operating frequency, the size, the gain and polarization. Antennas are either linearly or circularly polarized. Several RFID systems are made of circular polarized reader antennas in order to detect tags placed in any direction. Linear gain and circular gain relationship of an antenna is established using equation 3.1. In this equation, A represents the antenna axial ratio. (Nikitin & Rao 2008).

$$G[dBic] = G[dBil] + 3 + 20\log\left(\frac{1 + 10^{-\frac{A}{20}}}{2}\right) \tag{3.1}$$

There is signal path loss between the reader and tag antennas. The path loss (PL) level is affected by the propagation environment. It can be calculated in free space using equation 3.2. In that equation *d* represents the direct distance between the antennas and λ represents the wavelength.

$$PL\ (dB) = 20log\left(\frac{4\pi d}{\lambda}\right) \quad (3.2)$$

In a multipath environment, there are several models of path loss. The path loss depends mainly on the distance separating the transmitter and the receiver antennas but also on the number of reflection ray paths. Leong & Cole (2005) proposed equations 3.3 as a model for path loss:

$$PL\ (dB) = PL\ (d_0) + 10nlog\left(\frac{d}{d_0}\right) \quad (3.3)$$

where, d_0 is a reference distance and n the number of ray reflections.

In Figure 3.2 Nikitin & Rao (2008) proposed an example of path loss calculation. In this model a 2-ray ground reflection is used. The path loss for the case in Figure 3.2 is presented in equation 3.4. The path loss affects the reading distance of a tag.

$$PL = \left(\frac{4\pi d}{\lambda}\right)^2 \left(1 + \frac{d}{d_1} e^{-jk(d_1 - d)}\right)^2 \quad (3.4)$$

where, the reflected ray path length is $d_1 = \sqrt{d^2 + (2h)^2}$.

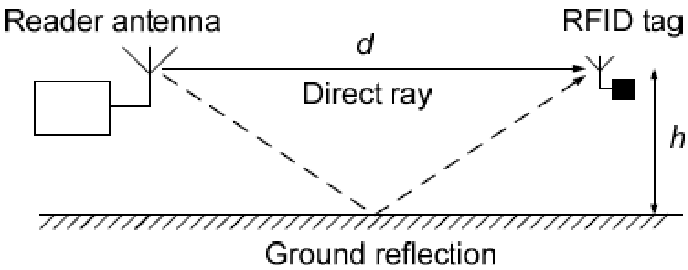

Figure 3.2: Path loss with 2-ray reflection (Nikitin 2008)

The signal strength between the reader and tag antennas can be determine. The reader-tag communication is referred to as the forward channel and is the power received by the tag from the reader (P_{FC}). On the other hand, the tag-reader communication represents the reverse channel (backscatter) and is the power received by the reader from the tag (P_{BS}). The forward channel power is obtained using Friis formula in equation 3.5 and the backscatter power is obtained using equation 3.6 (Farhat *et al.* 2017; Nikitin & Rao 2008).

$$P_{FC} = P_{reader} \cdot G_{reader} \cdot G_{tag} \cdot PL \cdot \tau \cdot \chi \quad (3.5)$$

where, P_{reader} is the reader's power, G_{reader} the reader antenna's gain, G_{tag} the tag antenna's gain, τ the impedance matching factor between the antenna and the tag chip and χ is the polarization factor between the tag and the reader antennas.

$$P_{BS} = P_{reader} \cdot G_{reader}^2 \cdot G_{tag}^2 \cdot PL \cdot\ K \qquad (3.6)$$

Where, *K* is the backscatter modulation loss.

The tag range can be determined from equation 3.5 (Jankowski-Mihulowicz & Weglarski 2014). The maximum tag's detection distance depends on different factors such as the tag sensitivity, the power and gain of the reader and the path loss. This distance is found using equation 3.7.

$$d_{upmax} = \frac{\lambda}{4\pi}\sqrt{\frac{P_{reader} \cdot G_{reader} \cdot G_{tag} \cdot \tau \cdot \chi}{P_{tagmin}}} \qquad (3.7)$$

where P_{tagmin} is the chip power threshold sensitivity.

Table 3.3 presents candidate models of antennas, their technical specifications and was created using information provided in the datasheets. The WRL-14131 antenna model was considered as the reader antenna for this research as the specifications provided in the datasheet meet the desired reader antenna specifications (Alien Technology 2016; Taggit n.d.; Tectus n.d.).

Table 3.3: Antennas technical specifications

Antenna model		Manufacturer	Operating frequency (MHz)	Gain	Polarization	Reading range
TPA-WIRA-70		TECTUS	860 – 960	8.5dBi @866MHz	Circular	Up to 10m
RFID patch antenna		Taggit	860 – 960	8dBi	Linear	Not specify
WRL-14131		Sparkfun	860 – 960	6dBi	Vertical	Not specify
ALR-A1001	ALR-A1001-F-X	Alien Technology	902 – 926	8.5dBi	Circular	Up to 9m
	ALR-A1001-E-X		865 - 867			
MTI-242043		MTI wireless	865 – 956	8.5dBi	Circular	Not specify

3.3 Wireless sensor network unit

Wireless data communication is selected over wire data communication for the transmission of the collected between the readers and the host computer. Wireless communication enables the transmission of data over a longer distance compared to wire communication. Wireless sensor networks (WSNs) have been used for many applications including vehicle movements monitoring or medical assistance. There are many available wireless technologies like Wi-Fi, Bluetooth and ZigBee. Wi-Fi, also known as IEEE-802.11 standard, is one of the most used wireless technology for communication. The communication range is between 20 to 250 metres (Wcislik *et al*. 2015). Wi-Fi works on both 2.4 GHz and 5 GHz radio band. It is susceptible to interference from microwave ovens or some Bluetooth devices. Bluetooth is a type of wireless technology that uses UHF radio waves to transfer information. This technology, based on the IEEE-502.15.1 standard, is used for short distance communication and it is mostly installed in small devices such as phones, tablets or smart watches. ZigBee is a short range (typically 10-100 m) wireless communication technology. ZigBee is registered under the IEEE-802.15.4 standard. This technology is mostly found in wireless control and monitoring systems such as WSNs, hospitals, smart metering and home automation (Singh 2012). ZigBee will be used for wireless data transmission in this research because it is a low-cost and low-power dissipation technology compared to the other wireless technologies (Ali *et al.* 2016; Yang *et al.* 2011).

A simple wireless network is made of two transceivers; one connected to the reader and the other one connected to the host computer (sink). A single transceiver is composed of a ZigBee module and an Arduino module. The Arduino module collects and process the data from the reader and then communicate them to the ZigBee, in order to be transmitted to the transceiver, connected to the host computer. In the case of multiple readers, the ZigBee modules associated to these readers will communicate in a ZigBee wireless network topology. A ZigBee network can be connected in three types of topologies: star, tree and mesh topology as shown in Figure 3.3.

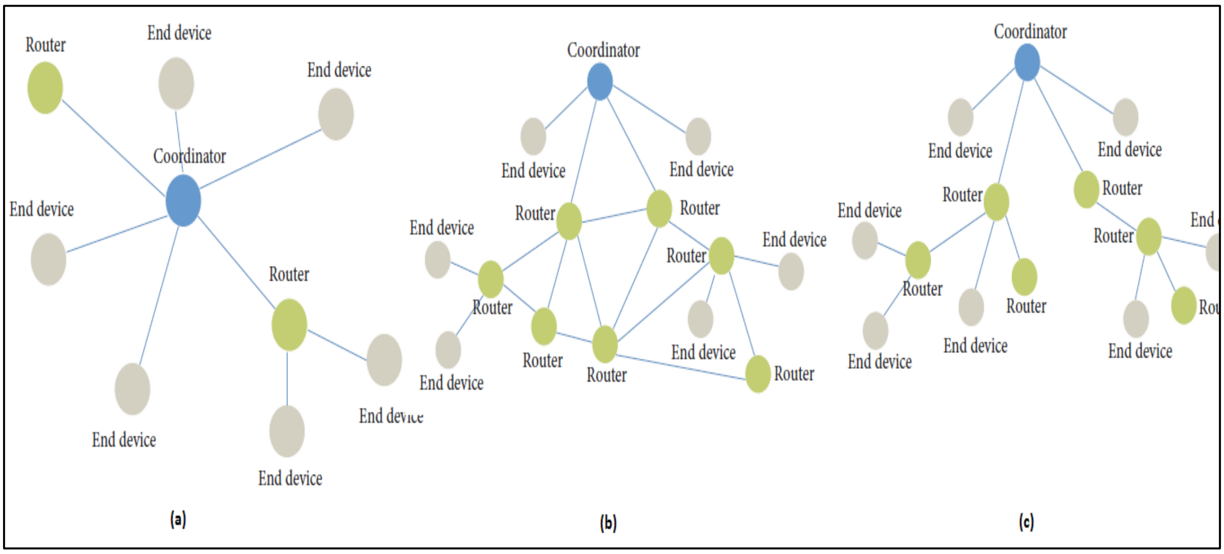

Figure 3.3: ZigBee network topologies: (a) star topology (b) mess topology (c) tree topology (Wu *et al.* 2018)

In the star topology, several end devices are connected to a central Personal Area Network (PAN) coordinator. In the tree topology, the central PAN coordinator is located at the node with devices connected in a branch structure below. The mesh topology is made of one central PAN coordinator and several routers and end devices. It is a multi-hop network where the message passes through multi-hop distance to reach their destination (Jaslin deva gifty & Sumathi 2016). ZigBee networks are a solution to the issues of high-power consumption, high rate of interference and data congestion encountered in other wireless networks (Ghosh & Chakraborty 2016).

3.4 Inventory management system unit

Inventory in library involves checking the library collection on the shelves against the catalogue records. It can also include equipment and supplies inventory. The host computer is an essential part of the inventory system. It is used to store and process the collected data (Jing & Tang 2013). In this system, the host computer represents the link between the RFID unit and the user. It contains a database table which have the list of available books in the library. Therefore, when performing the inventory, data from readers is compared with the database present in the host computer (Cheng 2017). The database table was created using MySQL software. The database table contains few information about the book, such as the title, the author's name and date of publication of the books as well as the shelf and row number on which the book is located.

3.5 Chapter conclusion

An analysis of the units contained in the proposed solution was carried out in this chapter. A comparison of available technologies was done and reason for the selection the components used in this study was given. The chapter firstly highlighted the difference between the type of RFID tags and later provided equations for the calculation the tags detection distance. A discussion was conducted on the available ZigBee topologies and reasons for choosing ZigBee technology over other method of wireless communication were given. The next chapter presents a performance analysis of recent anti-collision algorithms.

CHAPTER FOUR: PERFORMANCE ANALYSIS OF BINARY-BASED RFID ANTI-COLLISION ALGORITHMS

4.1 Introduction

This chapter presents a performance analysis of a list of recently proposed binary search (BS)-based anti-collision algorithms. The performance analysis is based on three criteria that include the search time, the data traffic and the system efficiency. The candidate algorithms considered in this analysis are; the basic binary search algorithm (BSA), the dynamic search algorithm (DSA), the backward binary search (BBS) algorithm, the adaptive N-tree algorithm (ANA), and the optimized binary search (OBS) algorithm. The analysis provided in this chapter will assist RFID system designers in selecting the most suitable anti-collision algorithms.

4.2 Binary-search algorithms analysis

4.2.1 Manchester coding

Implementation of the binary search algorithm requires three fundamental factors for implementation. Firstly, all tags within the reader's identification area must have a global unique ID serial number. The tags must be accurate, fast and synchronized when communicating with the reader. Finally, the binary data exchange in the RFID system uses the Manchester coding method, and so the detection of collision bits (Bai *et at*. 2017).

Manchester coding is a simple block code where the high-to-low transition of a signal represents logic 0 and the low-to-high transition of a signal represents logic 1 (Tao *et al*. 2018; Tripathi & Sujediya 2018). When multiple tags send different bit values on the corresponding bits the resulting signal level will not change. In this way, it is possible to determine the position of the collided bits by considering the bit period in which the resulting signal level does not vary. The Manchester coding principle applied in detecting collision is shown in Figure 4.1.

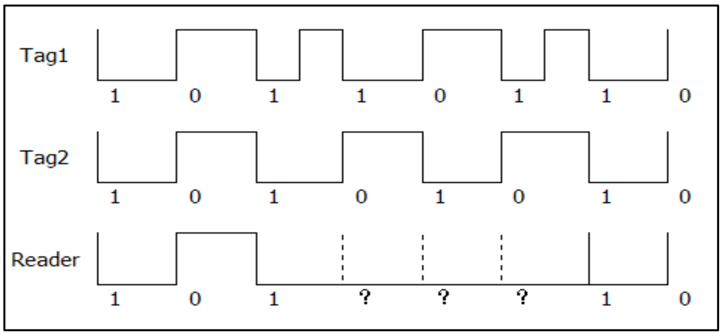

Figure 4.1: Manchester coding principle (Bai *et al.* 2017)

4.2.2 Binary search algorithm (BSA)

The simplest of the binary search-based algorithms is the basic binary search algorithm. The BSA is mainly based on four steps including requesting the tag number, choosing the serial number, reading the data and identifying the tag. The basic principle of the BSA is shown in Table 4.1. The reader's first requests all tags present in its reading area to return their IDs (Ouakasse & Rakrak 2014; Zhiwen & Min 2016; Bai *et al*. 2017). In the case of the collision, the reader will change the highest collision bit to 0 and the remaining collided bits to 1 and issues a new request. In this case only tags with IDs equal or less than the request will respond. This process is repeated until a tag is identified. The identified tag is then put to sleep and the reader send a new request from the beginning requesting all IDs. This whole process is repeated until all tags are identified.

Table 4.1: Binary search algorithm

Initialize
Loop
Get all
If no response: break
While there is collision
Update request ID
New request
End while
Get ID
Sleep
End loop

4.2.3 Dynamic search algorithm (DSA)

The dynamic search algorithm, presented in Table 4.2, is an improved version of the BSA. In the DSA, when a collision is detected, the reader will change the highest collision bit to 0 and all the bits after to 1. The reader only requests the highest collision bit and the most significant bits (MSB) before. The amount of data transmission is therefore reduced, thus improving the efficiency of the system (Bai *et al*. 2017; Lui & Feng 2017).

Table 4.2: Dynamic search algorithm

Initialize
Loop
Get all
If no response: break
While there is collision
Update request ID
New request: collision bit and MSB before
End while
Get ID
Sleep
End loop

4.2.4 Backward binary search (BBS) algorithm

The major factor affecting the efficiency of the BSA is the repetition of the generated data (Lui and Feng 2017). The backward binary search algorithm, described in Table 4.3, intends to overcome this issue. The BBS working principle is set as follow: after the collision detection, the highest collided bit is set to 0 or 1, making two request groups. A new request is then generated. In case of collision, the new highest collided bit is set to 0 or 1 and added to the previous highest collided bit, making it now "00" or "11". The reader starts the search from the beginning after a tag is detected (Mingliang & Shun 2010; Annul *et al*. 2017).

Table 4.3: Backward binary search (BBS) algorithm

1.	Initialize
2.	Loop
3.	Get all
4.	If no response: break
5.	If collision: load stack
6.	Get ID and sleep
7.	End loop
8.	Loop (while stack not empty)
9.	New request: top of stack
10.	If no response
11.	If collision: load stack
12.	Else: get ID and sleep
13.	Else: remove ID from stack
14.	End loop

4.2.5 Adaptive N-tree algorithm (ANA)

In the adaptive N-tree algorithm proposed by Zhiwen & Min (2016), the reader considers the first three highest collided bits to generate a new request, giving eight possible cases (000, 001, 010, 011, 100, 101, 110, and 111). The remaining collided bits after the third highest collided bit are set to 1 and the other bits are kept unchanged. If the number of collided bits is less or equal to two, the dynamic algorithm is applied. This process is repeated until all tags are identified. The adaptive N-tree algorithm process is shown in Table 4.4.

Table 4.4: Adaptive N-tree algorithm

1.	Initialize
2.	Loop
3.	Get all
4.	If no response: break
5.	If no collision: get ID and sleep
6.	End loop
7.	Save collision ID
8.	Start sequence
9.	Loop
10.	If at 111: break
11.	Update first 3 highest collided bits
12.	New request
13.	If no response: update sequence
14.	If collision: back to 13

4.2.6 Optimized binary search (OBS) algorithm

In the algorithm proposed by Zhi & Yigang (2017) in Table 4.5, the initial request is the highest bits used (111…111) asking for all tags to return their IDs. The number of collided bits leads to different scenarios: if the number of collided bits is equal to 0, a tag is directly identified. If it is equal to 1, the two fork York data is applied for the detection of tags. In case the number of collided bits is greater than 1, the first two highest collided bits are considered and set to the four possible values. The other collided bits are set to 1 and the remaining bits are kept unchanged. This process is repeated until all tags are identified.

Table 4.5: Optimized binary search algorithm

1.	Initialize
2.	Loop
3.	Get all
4.	If no response: break
5.	End loop
6.	While collision
7.	Save collision ID
8.	If collision bits <1: use BSA algorithm
9.	Start new sequence
10.	End while
11.	Loop
12.	While sequence <11
13.	Update request ID
14.	New request
15.	If no response: update sequence
16.	If no collision: get ID and sleep
17.	If collision bits >1: back to 13
18.	End while
19.	End loop

4.3 Experimental results: testing and performance analysis

All the five algorithms were implemented in MATLAB and then simulated to collect performance statistics. The MATLAB simulations was on RFID systems with a set of randomly generated tags ranging from 100 to 1000 tags of 12 bits each. The performance analysis is based on the search time, the average number of bits required for tag identification and the system efficiency. Figure 4.2 shows the compared results of the system's search time. The search time is the number of requests needed to identify all tags available in the reader's identification range. The results show that the read cycle is proportional to the number of tags to be identified. However, some algorithms need fewer read cycles to detect tags compare to others. The backward binary search (BBS), the adaptive N-tree (ANA) and the optimized binary search (OBS) algorithms have better search times than the rest of the other algorithms.

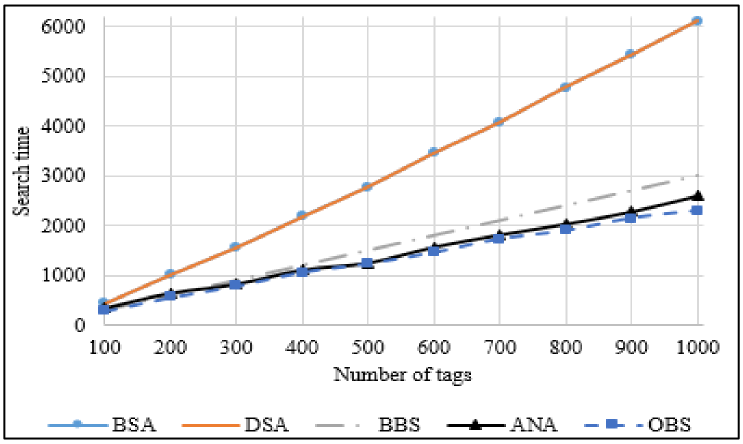

Figure 4.2: Comparison of search times

Figure 4.2 shows that the BBS, OBS and ANA require search times of less than 2250 even for 1000 tags. This is because these algorithms deal directly with a certain number of collided bits and do not request all available tags after detection. Also, these algorithms use a stack to remember the previous requests hence reducing the number of requests. On the other hand, the binary search (BSA) and dynamic search (DSA) algorithms present the worst performance from the results. Both algorithms require very high read cycles to detect all tags, around 6000 for 1000 tags. The search time is similar in these algorithms because the identification process repeat itself from the highest request every time a tag is identified.

Figure 4.3 compares results of the average number of bits transmitted to identify all the tags. It is found by dividing the total number of bits received for all requests by the total number of tags to be identified. The data traffic is far greater in the traditional BSA compared with the improved algorithms. That is because all available tags send their full IDs every time a tag is detected. In the DSA, only few bits are requested every time hence a lower data traffic compared to the BSA. In the BBS, ANA and OBS algorithms the number of transmission bit is greatly reduced.

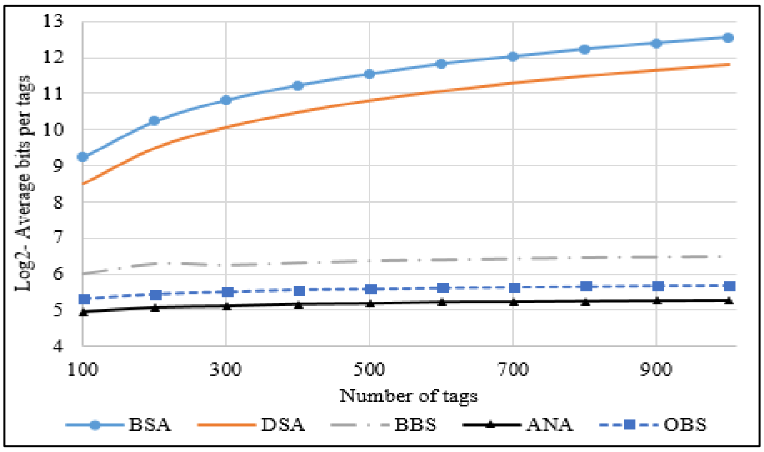

Figure 4.3: Comparison of average bits transmitted per tags

It tends to be constant as the number of tags increases. The ANA algorithm has better data traffic, 38 bits for 1000 tags, compared to the other algorithms. The OBS and BBS algorithms follow respectively with 52 and 90 bits for 1000 tags. In these algorithms, only a specific group of tags is requested to respond with their IDs during every request. This limits the number of data traffic during the search process.

In Figure 4.4 the system efficiency of the discussed algorithms is shown. The system efficiency is the total number of tags over the number of read cycles needed to identify all tags. Here again the BSA and the DSA algorithms have the worst performances. Their efficiencies decrease when the number of tags increases. For example, they have an efficiency of 0.24 for 100 tags and 0.16 for 100 tags. This shows that in these two algorithms the larger the number of tags, the more time they take to identify them. On contrary compared to the BSA and DSA algorithms, the efficiencies of the ANA and OBS algorithms increase with the number of tags, meaning that these two algorithms will take less time to identify large number of tags. However, the BBS algorithm is the only algorithm with a relatively constant efficiency of around 0.33, regardless of the number of tags detected. This means that the tags detection time in this algorithm is barely affected by the number of tags to be detected.

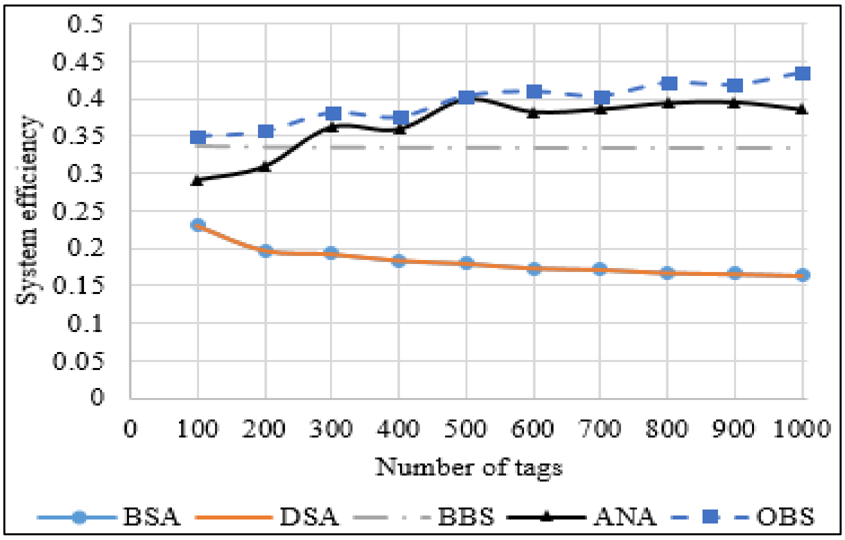

Figure 4.4: System efficiency

4.4 Chapter conclusion

In this chapter, a performance comparison of different binary search based anti-collision algorithms is done. The performance analysis is done based on the read cycles, the amount of data transmission and the identification efficiency. On the search time, the results show that the OBS, ANA and OBS algorithms have lower total number of read cycles compared to other algorithms. The data transmission results show that reader-tags bits exchange in ANA, OBS and BBS algorithms is lower during the identification process. The traffic data in the BSA and DSA algorithms in very high. The efficiency results show that the system efficiency varies the number of tags.

The performance of the BSA and DSA algorithms quickly deteriorates with the increasing number of tags. However, these algorithms can still be used for their simplicity in implementation and for systems with moderate number of tags. Because of their high efficiencies, OBS and ANA algorithms are more suitable for high density application. Finally, the OBS algorithm is more suitable for predictable systems because of its constant efficiency. For this study BBS, OBS and ANA algorithms are recommended because of their good performance in situations of high number of tags as shown by the results obtained. The next section discusses the design of the proposed inventory management system.

CHAPTER FIVE: DESIGN OF THE INVENTORY MANAGEMENT SYSTEM

5.1. Introduction

This chapter summaries the design of the proposed solution. It is divided into three sections; Section 5.1 presents the system applications; Section 5.2 provides a discussion of the components and modules used in the system and Section 5.3 finally gives the system's working principles.

5.2. System applications

Inventory management is time consuming for the librarians and is prone to human error. Automated inventory management systems are therefore important for faster counting and identification of the materials. In this research, inventory means the counting and location of books in the library. In the proposed system shown in Figure 5.1, the user interacts with the system to count and identify location of books in the entire library. In libraries, books are easily checked in or out and moved from one shelf to another. It is sometimes difficult for the librarians to keep track of the books all the time. Therefore, this system proposes a real-time tracking and counting of books inside the library.

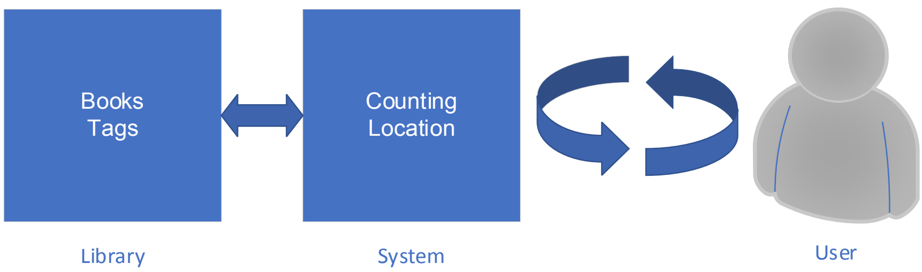

Figure 5.1: User-system interaction

The system setup is shown in Figure 5.2 where the books are placed on the shelves and the RFID readers paced on the sides. A wireless sensor node (WSNode) sends the information wirelessly to the host computer through the sink node (SN). Both WSNode and sink node are composed of a ZigBee module and an Arduino module. The Arduino module collects and process the data while the ZigBee exchanges data wirelessly. Each of the readers attached to its ZigBee module communicates in a ZigBee wireless network topology.

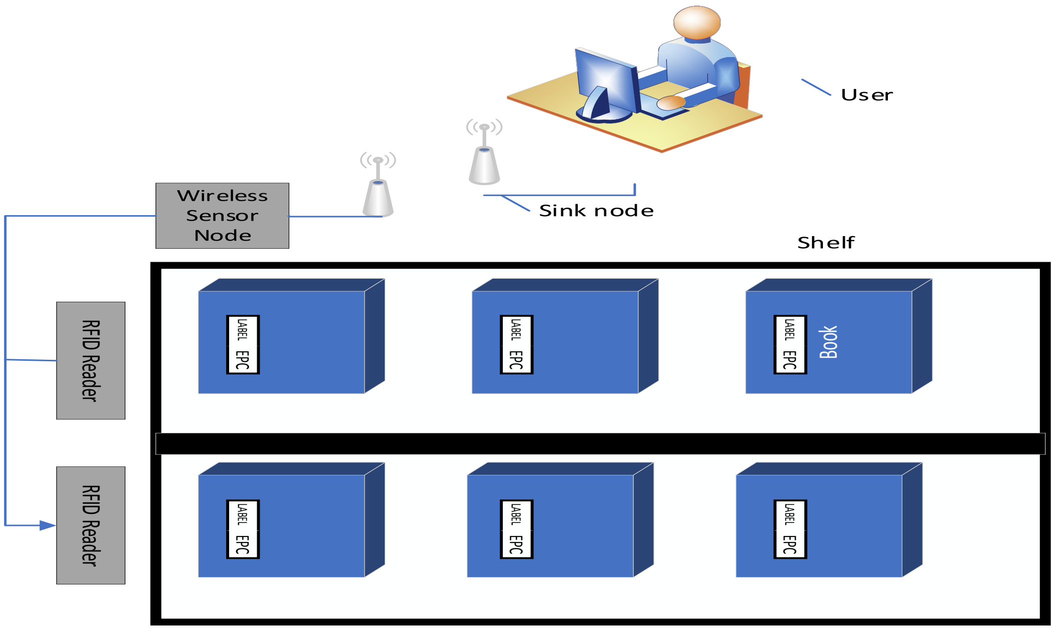

Figure 5.2: System setup

The counting and localization of books is done through the interaction between the user, the system and the library. The system contains all the collecting and processing devices whereas the library represents the books with the tags attached. On the computer interface, the user requests the inventory through the inventory page. An inventory command is generated and sent to the sink node connected to the computer to be broadcasted to all wireless sensor nodes (WSNodes) in the library. Upon receiving the request, the WSNode will then send it to the reader for data collection. The readers request all available tags in the library to send their electronic product code (EPC) which is a unique code for a tag. Readers then send the tags EPC to the WSN which sends the information to the host computer. The proposed system is shown in Figure 5.3.

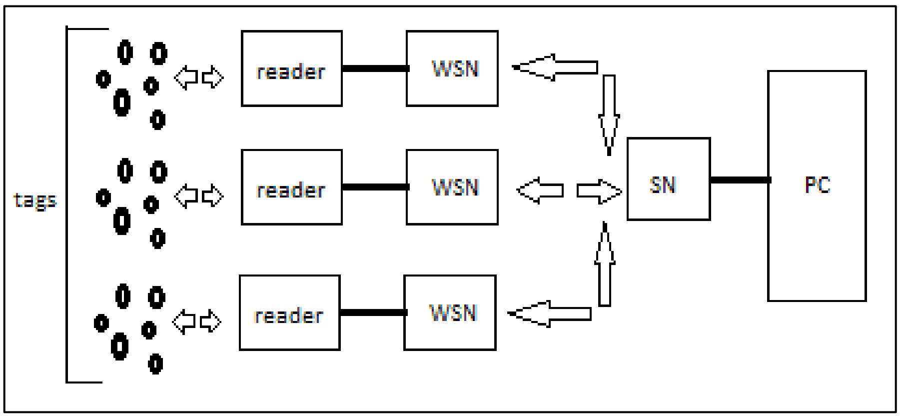

Figure 5.3: Invenotry management system

The EPC of a tag can be changed to the book's title and even author in order to improve the search process. Writing a tag can be simple. Using the appropriate software like Arduino IDE, a name can be assigned to a tag. Firstly, scan the tag by the reader. Once the tag has been read, select the tag EPC and then select “change EPC”. The EPC can now be set to any value or name. Nevertheless, data can only be written on passive UHF RFID tags supporting writing to the user memory in this research.

Information about the book include the book’s title, author and year of publication. All encoded tag’s information is then linked to the library IMS database. When scanning tags, the reader collects all available EPCs. The EPCs are sent to the host computer where they are checked against the previous recorded data. If the user is looking for a specific book, only the EPC of that book will be searched in the system. When found, the EPC will be returned to the IMS with the number of the reader which identified it. If a book needs to be removed from the system, the tag attached to it can be put to sleep or just be killed. Killing a tag means it will not be used anymore. A tag is killed using a killing code which when sent to the tag will make it unusable.

5.3. System characteristics and connections

In the proposed system, the reader reads the tags EPCs located on the shelves and sends them to the transceiver which attach the shelves’ numbers to every IDs before transmission. The transceiver then sends the information to the host computer which processes them and checks a database. The host computer hosts a MySQL database and a web page which can later be accessed through a separate computer or mobile device within the library. This section discusses the main parts of the system and their connections.

5.3.1 EPC Gen2 tags

The UHF EPC Gen2 tags are used in this research. EPC Gen2 is short for EPC global UHF Class 1 Generation 2 RFID tags. It is an air interface that defines the communication between RFID readers and passive tags, operating in the 860-960 MHz frequency range. The category of tags used has a memory of 800 bits (Sparkfun n.d.). They are long read distance (up to 12m), can be written and can work well close to metal, liquids and other RF unfriendly materials.

5.3.2 RFID reader

In this research the SparkFun simultaneous RFID reader (SRTR) shown in Figure 5.4 is used for the tag’s detection. It is a multiple tags reader with a maximum detection range of more than 4.5m. The SRTR is mainly based on the M6E-Nano module. It is a multi-tag reading module which works with common, low cost, passive Gen2 UHF tags. It is a transmitter capable of outputting up to 27 dBm. The module runs on 5 V and is controlled via the serial connections available on the board.

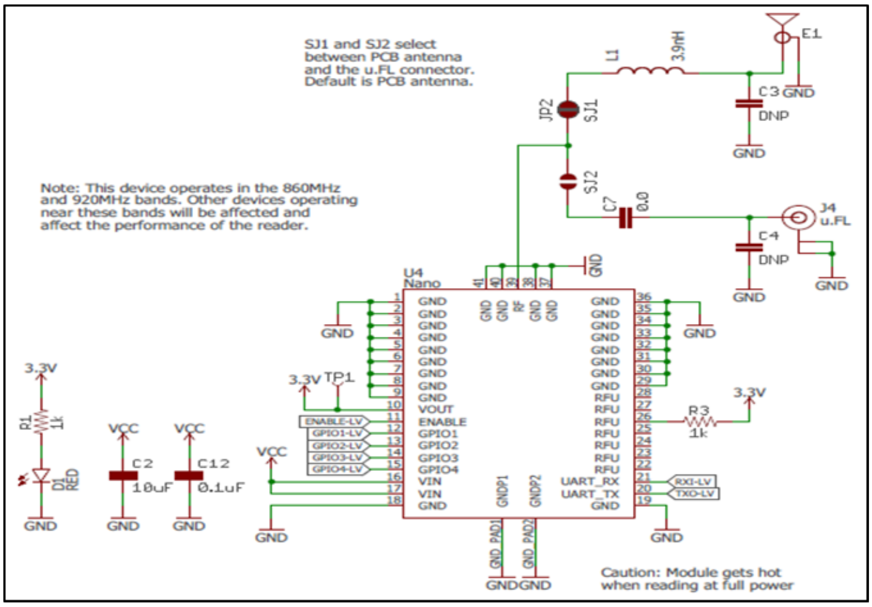

Figure 5.4: RFID reader schematic (SparkFun 2017)

The SRTR board can be used with the on-board PCB trace antenna or an external antenna. When using the internal antenna, which has a low gain, the reader can only detect up to 67 cm. This is a small reading range for this project. However, with an external antenna the reading is above 4m. The board has a u.FL connector where the external antenna can be connected. The external antenna must be of a higher gain bidirectional antenna with a gain of 8.15 dBi or less. The selected antenna for this research meets the above requirements. It is a linear vertical polarized antenna with a gain of 6 dBi and an operating frequency of 860-960 MHz (Sparkfun n.d.).

5.3.3 Wireless sensor module

The transceiver module made of the Arduino-XBee connection is used for the communication between the host computer and the RFID system. The pin connection of the transceiver module, shown in Figure 5.5, is such as pins 8 and 9 of the Arduino are respectively connected to pins Rx and Tx of the XBee. The Arduino Uno model is used in this research. It is a development board built using the ATmega328 microcontroller. The board is mostly made of 20 digital input/output (I/O) pins, a 16 MHz resonator, a USB connection and a power jack. The Arduino board can be powered through the USB port or using an AC-to-DC adapter. The recommended supply is 7-12 V from the DC power jack and 5 V from USB connector. The ATmega328 provides UART (5V) serial communication, which is available on digital pins 0 (Rx) and 1 (Tx), but also support I2C and SPI communication. Arduino uses a simplified version of C++ as programming language.

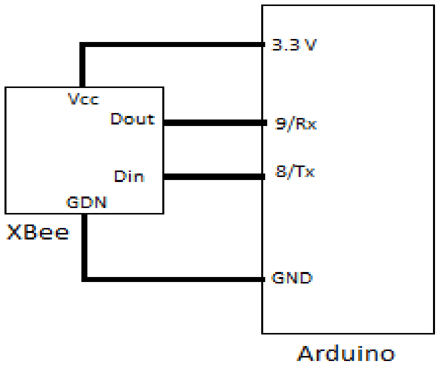

Figure 5.5: Transceiver connection

The XBee radio family is made of several models, operating at various frequencies ranging between 868 MHz and 2.4 GHz. The XBee ZigBee model is the most suitable for this project because it is a low-current consumption module compare to the other modules discussed in the Analysis chapter. The operating frequency is 4 GHz for a maximum communication range of up to 60 m (indoors). This module can be connected as a mesh network and support both the UART and SPI serial connections.

The transceiver module has a different purpose depending on which part of the system it is connected to. It is seen as a sensor node (SN) when connected to the computer and as a wireless sensor node (WSNode) when connected to the reader. The SN acts as a coordinator, receiving data from the WSNode and sending them to the host computer for processing. The connection between the SN and the HC is made using a USB cable as shown in Figure 5.6.

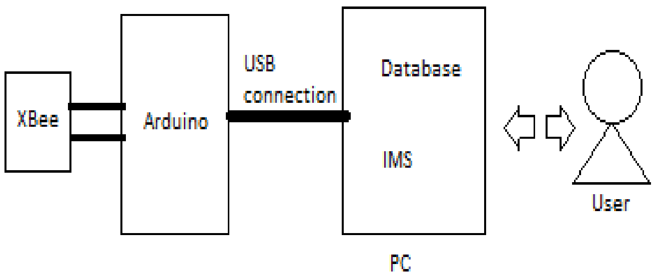

Figure 5.6: SN to computer connection

The SN's operating algorithm is shown in Table 5.1. Its main functionalities include receiving and transmission of data, analyzing of the data and managing the communication between the different WSNodes.

Table 5.1: Sink node pseudo code

1.	Initialize
2.	Listen to incoming message from the host computer
3.	Transmit the message to the wireless sensor nodes
4.	Listen to the responses from the wireless sensor nodes
5.	Read responses and make decisions
6.	Load responses into database

On the other hand, the WSNode is connected to the M6E-Nano reader through the Arduino board. The connection between the WSNode and the reader is shown in Figure 5.7. Pins 0 and 1 of the Arduino are respectively connected to pins 2 ad 3 of the reader. The WSNode is a controller to the reader. It commands the reader on when to collect the tag's EPCs. The WSNode pseudo code is shown in Table 5.2. It is mainly responsible for collecting and transmitting data to the sink node.

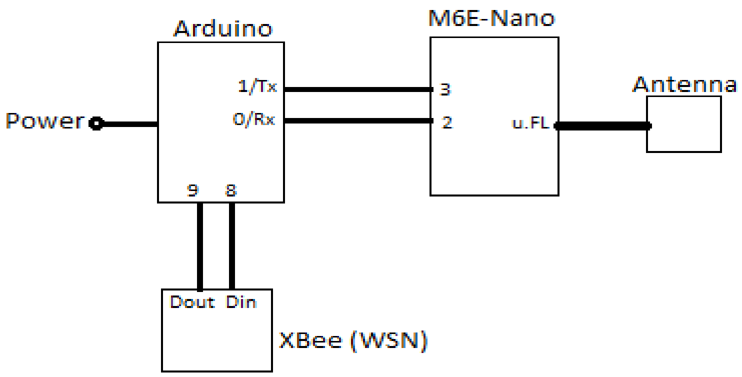

Figure 5.7: WSNode to reader connection

Table 5.2: Wireless sensor node pseudo code

1.	Initialize
2.	Listen to incoming message from the sink node
3.	Interpret the message and make decisions
4.	Activate reader port
5.	Listen to the reader
6.	Generate a response message according the sink node message
7.	Send response to the sink node

The WSNode also analyzes and interprets the messages received from the sink node. It generates an appropriate response depending on the received message. Each WSNode is allocated an identification number which is attached to the response sent to the SN. Attaching the WSNode identification before sending the response to the SN is important in identifying from which WSNode the response is originating.

5.4. System working principle

The sequence diagram in Figure 5.8 demonstrates the interaction process of components within the IMS. In this sequence, various components (host computer, SN, WSNode and reader) interact in order to access the information loaded into the tag. When requesting for inventory or location of a single tag, a read request is generated at the host computer and sent to the sink node which will broadcast it to all WSNodes. The read request is only transmitted once then the SN switch into receiving mode. When a WSNode receive the message, it activates the reader to read all tags in its coverage. The reader sends a request to all tags to respond with their information. A waiting time is set in the reader where it waits for any response from the tags. The reader will start scanning for tags if no response is received when the waiting time elapse.

Upon receiving the requested information, the reader applies the anti-collision algorithm to avoid tag collision. The identified tags information is then sent to the WSNode. The reader's response to the WSNode is in the following format: responseType = nano.readTagEPC(myEPC, myEPClength, 500). The response contains the waiting time (500ms), the read information (myEPC) which includes the location, EPC, received signal strength indicator (RSSI), timestamp and frequency, and the array size (myEPClength). The WSNode then generate a response packet based on the request received and sent it to the SN and the host computer. A detailed description of this process is discussed in the next sections.

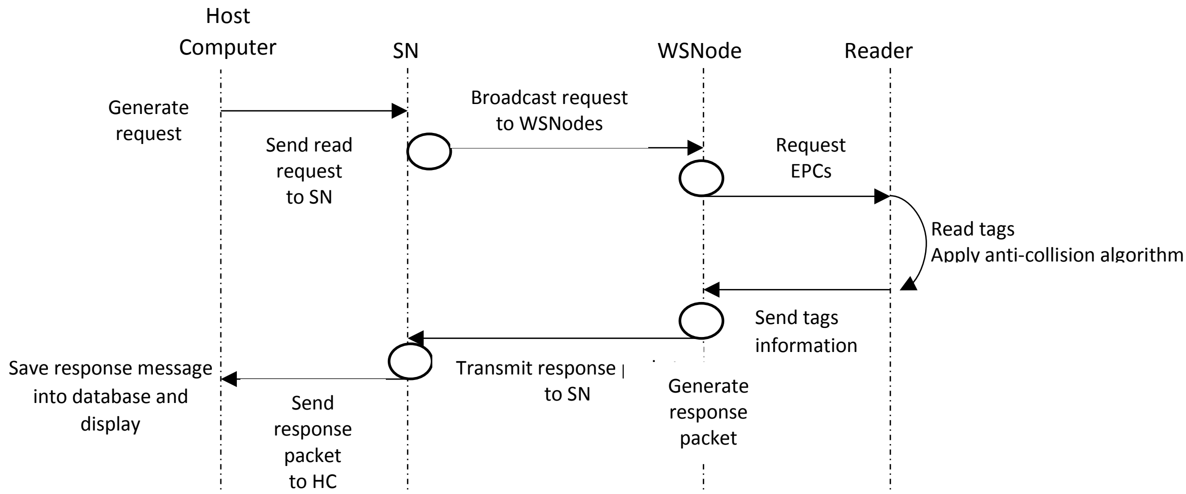

Figure 5.8: IMS sequence diagram

5.4.1 Host computer

The host computer is where all data from the system is centralized and processed. The configuration of the HC is presented in Figure 5.9. It is composed of a web page to display the results obtained from the system, a database that saves and analyse the collected data and a serial port driver. The serial port driver software is used for the communication between the web page and the SN. The communication protocol is given in Appendix A. The serial port driver used in this research is called Processing IDE.

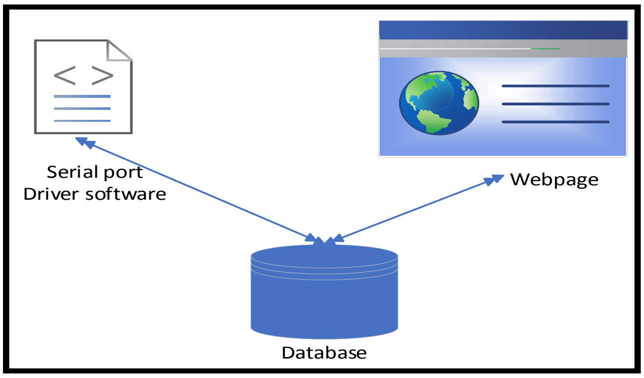

Figure 5.9: Host computer configuration

The serial port driver acts as a link that connects the Arduino of the SN to the web page. It communicates with the Arduino IDE through serial communication. Any information send by the web page is read by driver and written onto the serial port. This driver also connects directly to the database. The data sent to the serial port by the Arduino is therefore directly loaded into the system database. The working process of the serial port driver is shown in Table 5.3.

Table 5.3: Serial port driver pseudo code

1.	Initialize
2.	Initialize serial port
3.	Connect to database
4.	Read incoming message from web page
5.	Write message onto serial port
6.	Read incoming data from serial port
7.	Load read serial port data into database

In order for the user to use the system, he has to login his detail first. After logging in successfully, the user can now select between performing inventory and the location of a book. The main web page contains a button for the inventory and a search box to enter the wanted ID. When the inventory or location button is pressed, a message is generated requesting the tags EPCs. The generated requested is loaded in the serial port driver and transmitted by the sink node. The driver then waits for any incoming data from the SN. The returning packet from the system is received by driver and loaded into the database.

The web page is linked to a database designed in MySQL. The database contains four tables: bookepc, authorlist, rfid_results and users. The bookepc table contains the books titles and tags EPCs. In this table each book is matched to a unique EPC number. The authorlist table contains the names of the book's authors. The bookepc and authorlist tables are linked such that one book can have multiple authors and an author multiple book. That connection is shown in Figure 5.10. The rfid_results table contains the time at which the inventory was performed, the read tags EPCs and the WSNode identification number. This table is linked to the main table in such a way that when the inventory is performed the read EPCs are directly matched to the corresponding books and display on the web page. However, when trying to locate a book, the user will enter the title of the book which is linked to a certain EPC in the reference table. So only the requested EPC is search in the system instead of the book's title. The users table contains all the users created and their passwords.

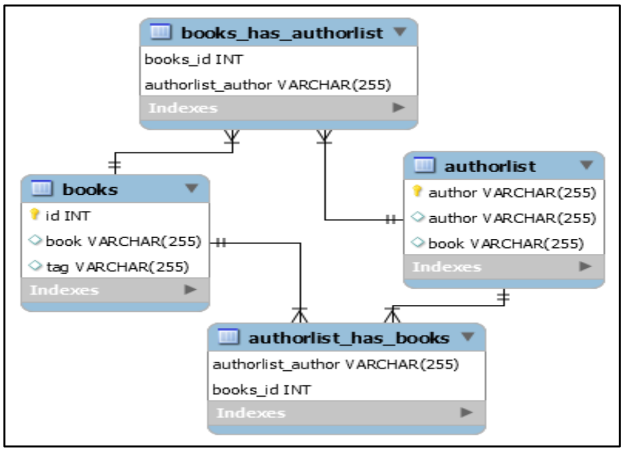

Figure 5.10: Database tables relation

5.4.2 Requesting inventory

The inventory sequence diagram is shown in Figure 5.11. When requesting for the full inventory of the library, a single character "I" is generated at the host computer. This character is read by the serial port driver and written onto the serial port. The SN needs to read any data available on the serial port in order to proceed with its functions. If the received character is not equal to "I", the SN checks if the character "L" is received or returns an "Invalid request" message. On the other hand, if the character matches the SN proceeds to transmitting it to the WSNodes. The SN then gets into an idle state, waiting for any incoming message from the WSNodes. Whenever there is any data coming from one of the WSNodes the SN writes it to the serial port. The driver reads the serial port to get the data and upload them into the RFID inventory database. This working process of the SN is described by the flowchart in Figure 5.12.

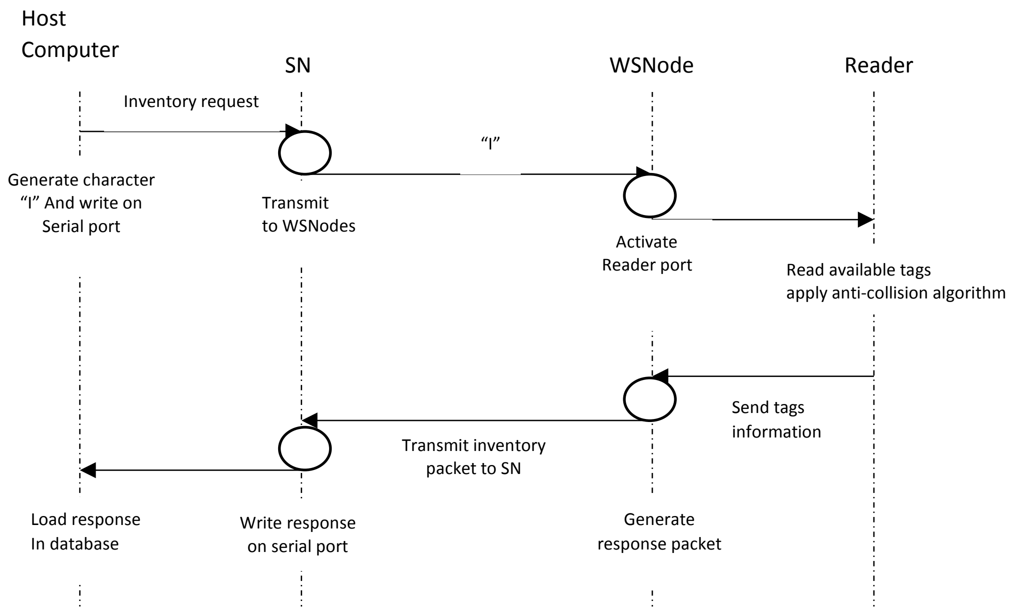

Figure 5.11: Inventory sequence diagram

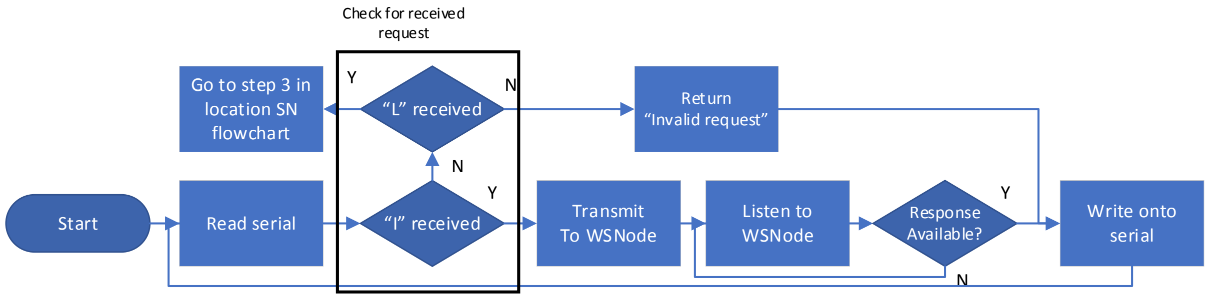

Figure 5.12: Inventory SN flowchart

The WSNode, on the other side, is constantly listening to any information coming from the SN. When the character "I" is received, the port connected to the reader is activated. The WSNode then start receiving the tags information. After the reader has read all the tags available in its vicinity, the WSNode generates a response packet which then transmit to the SN and get back to the listen state. The inventory packet response contains each tag's EPC, timestamp, frequency and RSSI. The working process of the WSNode in the inventory state is shown in Figure 5.13.

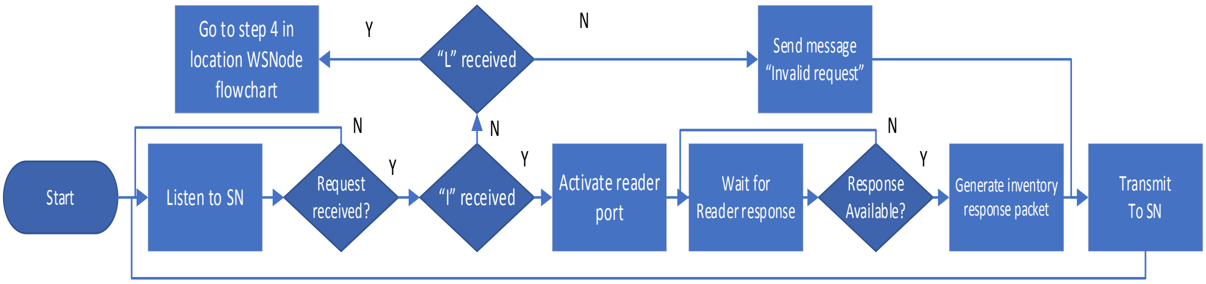

Figure 5.13: Inventory WSNode flowchart

5.4.3 Requesting location of a tag

The process of requesting for the location of a single tag is similar to doing the inventory process with the difference that the character "L" is sent over the network instead of "I". The location process is shown in Figure 5.14. The character transmitted by the SN is generated at the web page and read by the serial port driver. After it is transmitted to the available WSNodes, the SN gets into an idle state, listening to responses from the network. The SN then compares the total number of received responses with the number of available WSNodes. All received responses are then saved into the location database. The working steps of the SN is presented in Figure 5.15.

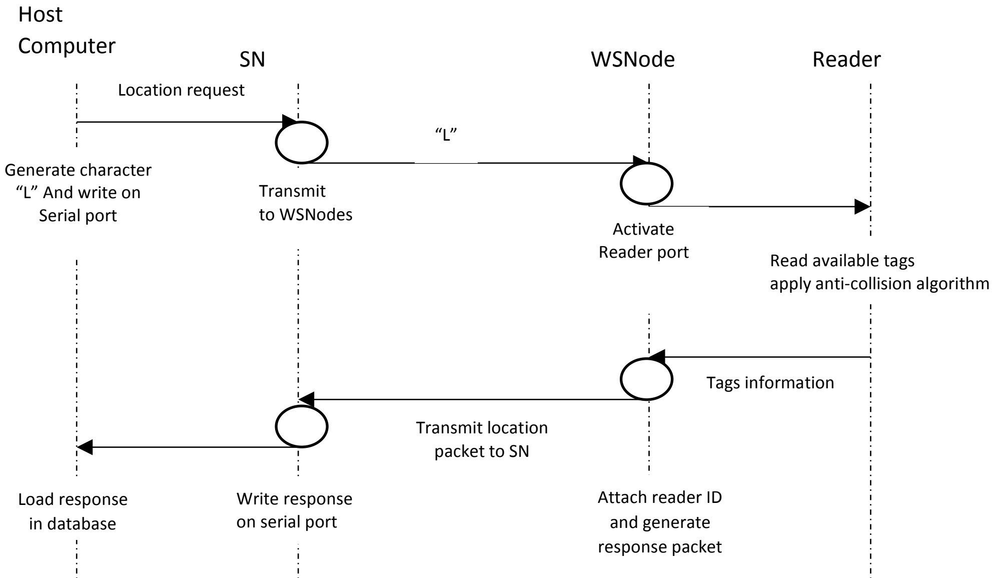

Figure 5.14: Location sequence diagram

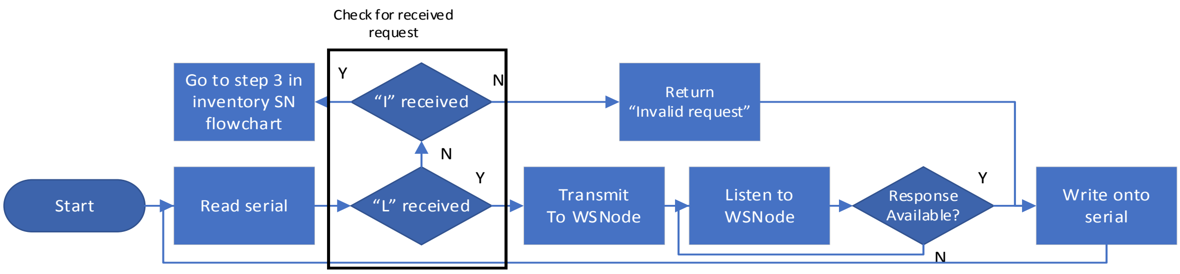

Figure 5.15: Location SN flowchart

The working process of the WSNode during the location of a book is presented in Figure 5.16. When the character "L" is received by the WSNode, the port connected to the reader attached to it is activated. This tells the reader to read all tags in its vicinity. The WSNode then gets all read tags information. Next the ID of the WSNode making the readings is attached to each received information. The WSNode generates a response packet which then transmit to the SN and get back to the listen state. The location packet response contains the transmitting WSNode ID along with each tag's EPC, timestamp, frequency and RSSI.

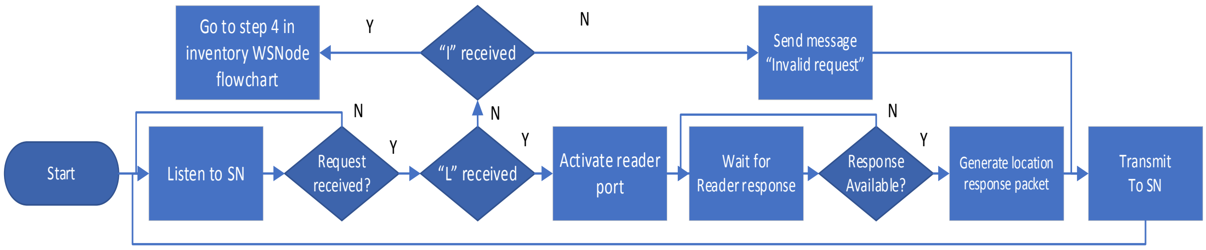

Figure 5.16: Location WSNode flowchart

5.5. Chapter conclusion

In this chapter the design of the proposed solution was discussed. Discussions about the connections of the main parts of the system and their working principle were made. The proposed solution has two objectives: to perform the inventory of all available books and to locate the position of a book in the library. All the major components used in the designed system are presented in Figure 5.17. Tags are read using a RFID reader. The reader uses an anti-collision algorithm to avoid tag reading collision. The collected data are then shared between the wireless sensor node and the sink node. Upon receiving the data, the sink node sends them to the host computer where they are saved and displayed on a webpage.

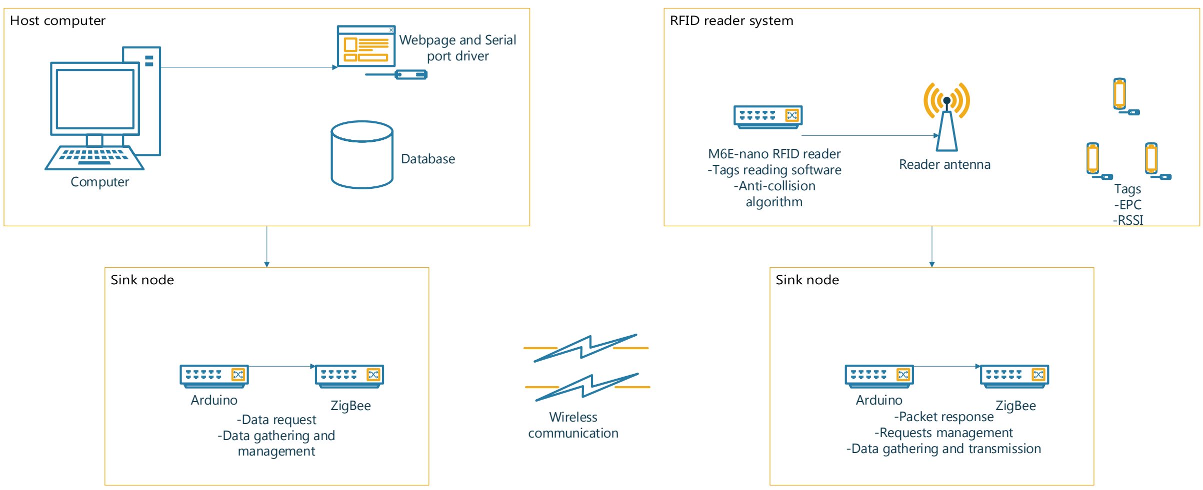

Figure 5.17: System overall connections

Figure 5.18 presents the full system communication flowchart. On the host computer side, the user generates a data request which is sent to the SN via a serial port driver. The data exchanged between the sink node and the wireless sensor nodes depends on the action performed. While performing inventory, the SN will send a request containing the character “I” to the WSNode. In return, the WSNode will send an inventory response packet back to the SN. On the other hand, during the location of a single tag, the SN will send the “L” request to the WSNode and in return will receive a location response packet. In both cases, the sink node goes into waiting mode after transmitting the request for tag information.

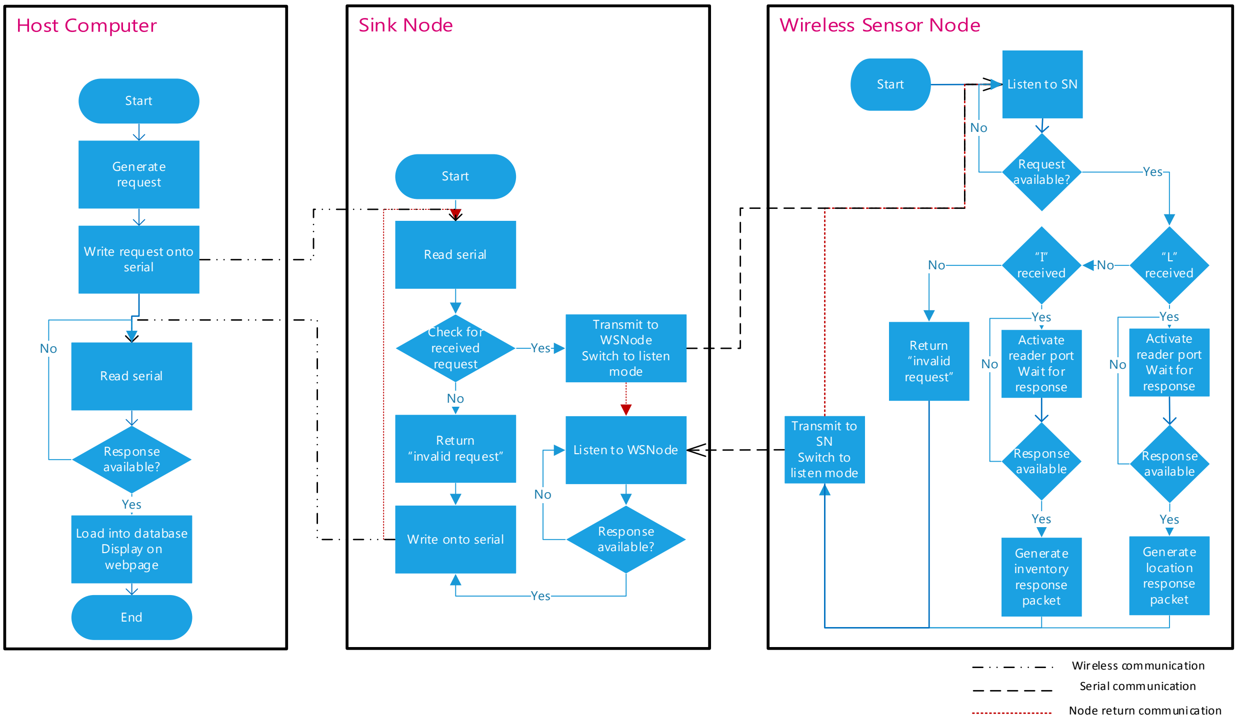

Figure 5.18: Full system communication flowchart

It is worth noting that the anti-collision algorithm determines how quick the reader detects the tags. This also affects the speed at which the WSNode responds to the SN request. Therefore, it is important to use an anti-collision algorithm that resolve the tag collision issue quickly in order to have fast responding WSNode.

I must also be indicated that if no response is provided by the WSNode, the SN will enter a loop and wait indefinitely. The design proposed in this Chapter only considered the case where the wireless sensor node responds to every SN request. The design did not cater for the case where no response is obtained from the WSNode.

CHAPTER SIX: SIMULATION OF THE INVENTORY MANAGEMENT SYSTEM

6.1 Introduction

This chapter provides simulation of different sections of the proposed solution. Communication between different sections of the circuit in presented here. The chapter starts with the simulation of data transfer between the sink node (SN) and the wireless sensor node (WSNode) then moves to the Excel data saving and finishes with the updating into the database.

6.2 Wireless sensor network simulation model

A simplified model of the wireless sensor network (WSN) data communication was redrawn and simulated in proteus virtual system modelling (PVSM) 8 software. PVSM is a circuit simulation software with functionalities such as schematic capture and PCB layout. This simulation software also contains several virtual measuring instruments such as oscilloscope, voltmeter, ammeter and virtual terminal. It also helps with simulation of sensor modules (ultrasonic, PIR, gas and flame sensor), wireless communication modules (XBee and GPS) and Arduino boards.

The model simulated in PVSM tests the data transfer between the SN and the WSNode. In this model, buttons are used to replace the commands generated by the host computer (HC). Button 1 (BTN1) sends the inventory request while button 2 (BTN2) sends a specific tag EPC. The simulation model of the WSN communication is shown in Figure 6.1.

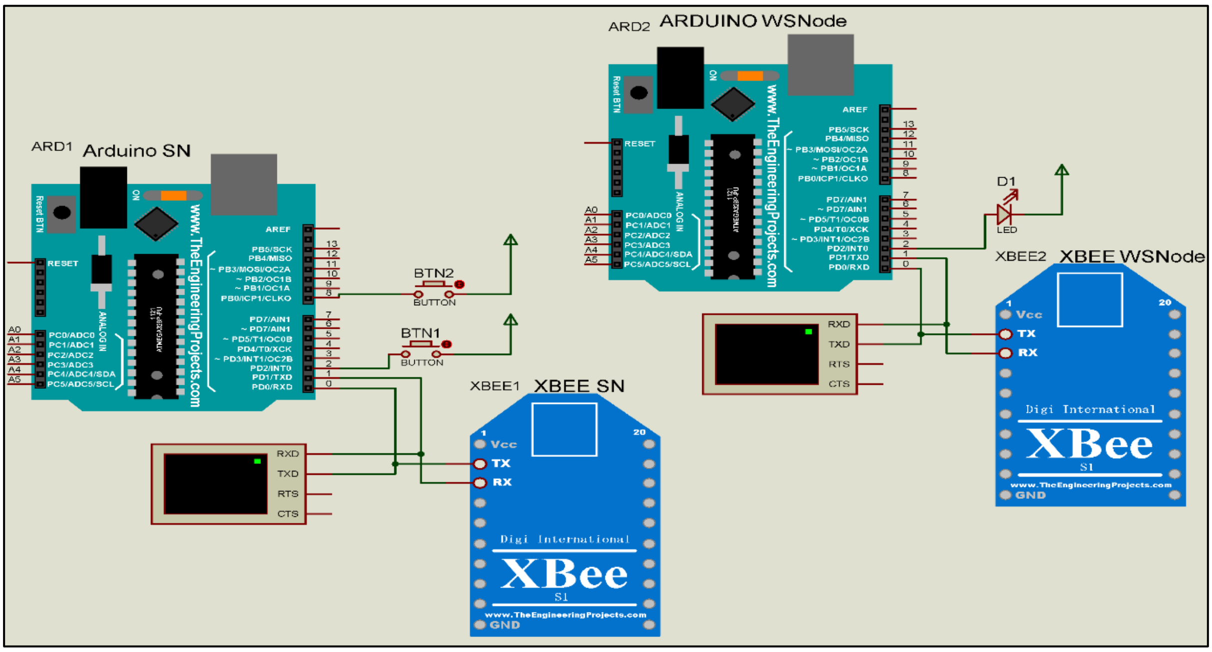

Figure 6.1: Wireless communication simulation model

The communication between the XBee modules is carried out through a virtual serial port emulator (VSPE). The VSPE is used because it is free and easily accessible. In the VSPE both SN and WSNode XBees are connected respectively to ports 3 and 4.

Figure 6.2 presents the inventory flowchart simulation model. When BTN1 is pressed, the Arduino at the SN generate a character “I” which is then sent over to the WSNodes. When receiving the transmitted character, the Arduino on the WSNode activate port 2 at which is connected a led. When the LED is on the port is active and when it is off the port is off. This port represents the actual port at which the reader will be connected in the final prototype. When port 2 is active the Arduino generates random numbers representing the RFID tags EPCs. These numbers are then transmitted to the SN and display on the serial monitor. The matching of the numbers by the SN and WSNode confirms the wireless transfer of data between the two sections of the system.

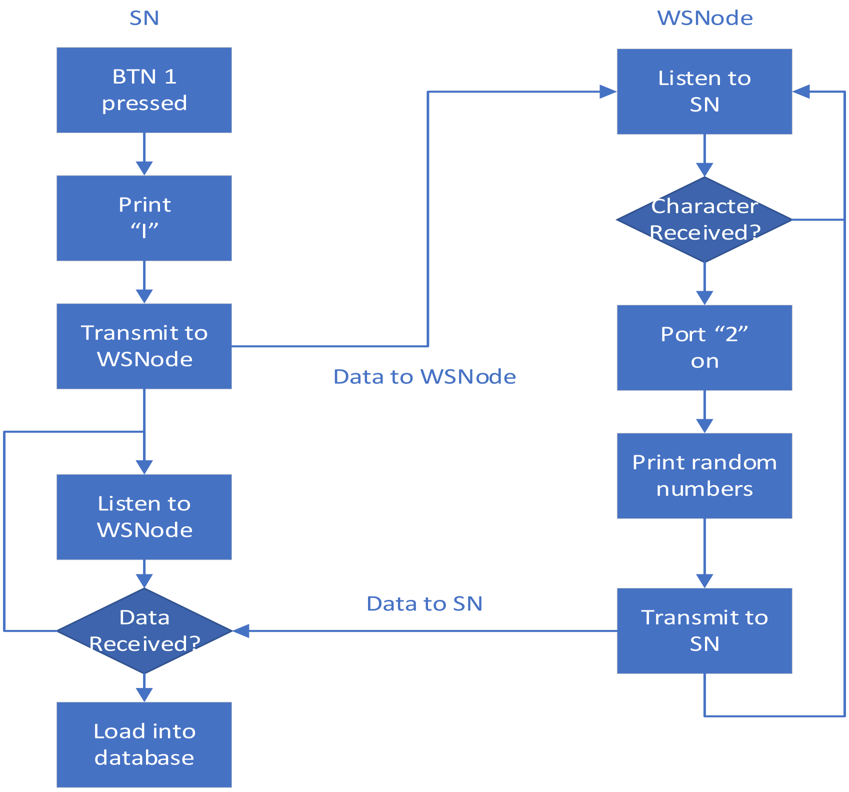

Figure 6.2: Inventory flowchart simulation model

Figure 6.3 on the other hand presents the flowchart simulation model for the location of a single tag. When BTN2 is pressed the character “L” is assigned to the button. It is then sent to the WSNode. On the other side when receiving the character “L”, random numbers are generated by the Arduino. An ID number is then attached to the generated numbers. The response message is then sent to the SN, displayed on the serial monitor and saved in the database. The user can look for a specific number by using the search option in Excel.

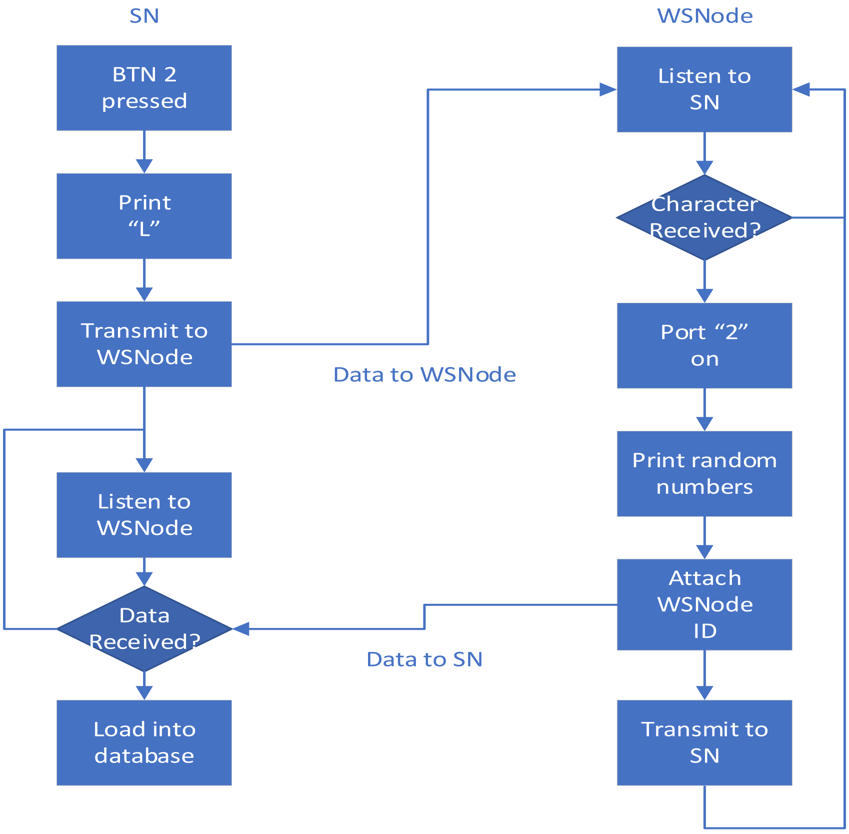

Figure 6.3: Tag location flowchart simulation model

6.3 Sink node to database

At the SN, the Arduino saves the received EPCs (numbers) into a database which code is presented in Table 6.1. For simulation purposes, Excel was chosen as the database. It replaces the actual MySQL database used in the implementation report. The Excel sheet is used to show how the received data can be saved into a database and be used later for processing. The number of columns printed depends on the set of data recorded. In this example, two set of data are printed on columns A and B. A com port physical interface module (COMPIM) is used to simulate the communication between the Arduino in PVSM and Excel. In this case, not the normal Excel found in Microsoft Office package is used. A data acquisition for Excel software named PLX-DAQ is used. PLX-DAQ is a data acquisition software that allows real-time data capturing into Excel. Before starting recording the data, the port and baud rate of the PLX-DAQ and the COMPIM must match. In this case they were set to port 1 and a baud rate of 9600. The communication between PVSM and the PLX-DAQ software is done through the VSPE. Port 1 must be enabled as shown in Figure 6.4.

Table 6.1: Arduino to Excel

```
void setup(){
    Serial.begin(9600);
    Serial.println("CLEARDATA");
    Serial.println("LABEL, Acolumn, Bcolumn, …);
    Serial.println("RESETTIMER");
}
void loop() {
    Serial.print("DATA, TIME");
    Serial.print(Adata); //add formula for Adata
    Serial.println(Bdata);    //add formula for Bdata. println indicates it goes to the next row on the second run
    delay(100);
}
```

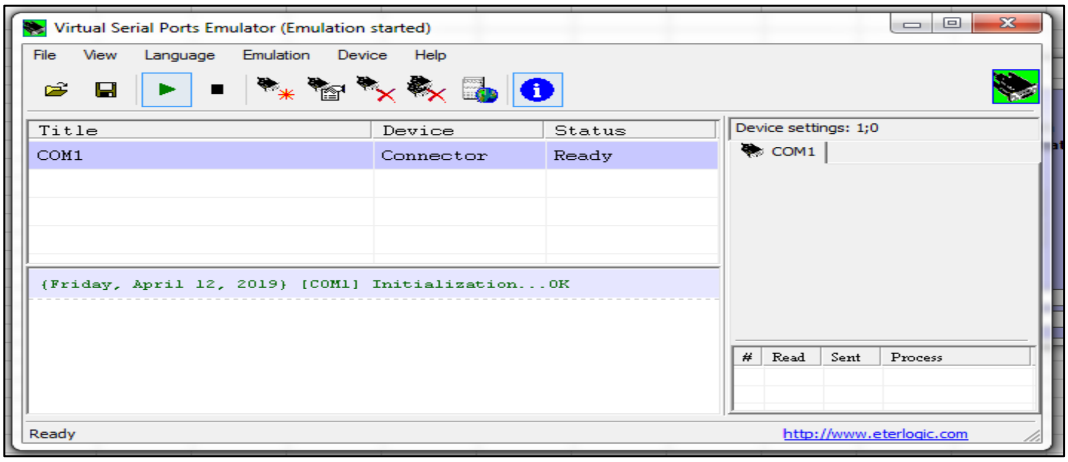

Figure 6.4: VSPE port setting

The received data in Excel is compared with the data in PVSM in Figures 6.5 and 6.6. It can be seen that both recordings match. For 14 recordings in both cases the binary numbers printed are the same. The data are recorded with the date and time. Time and date help to track the moment the inventory is performed.

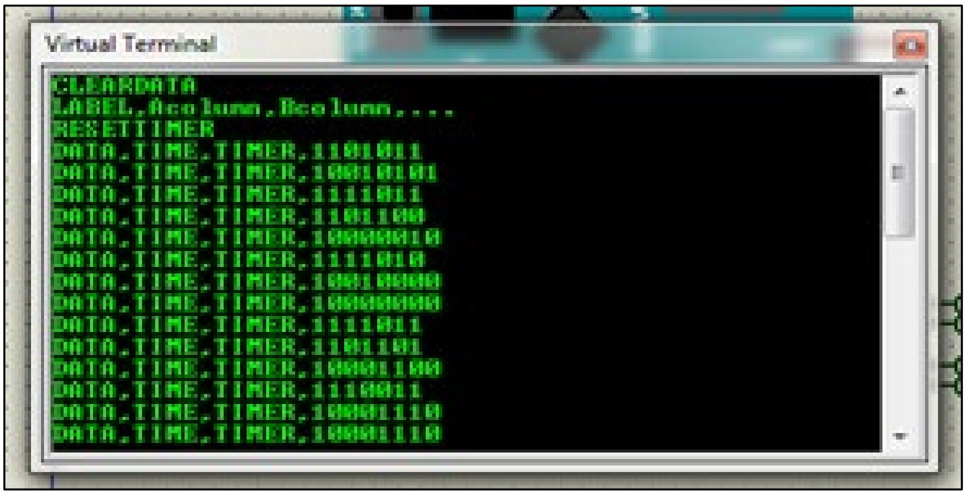

Figure 6.5: PVSM results

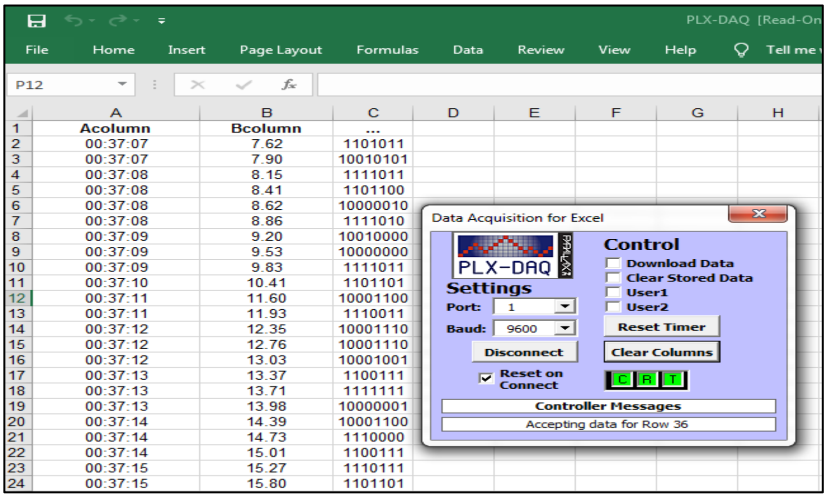

Figure 6.6: Excel results

6.4 Chapter conclusion

In this chapter the simulation of the wireless communication module was performed using PVSM software. Randoms numbers which represents tags EPCs were generated at the WSNode. These numbers were then sent wirelessly to the SN. They are later saved into an Excel datasheet which represents the database. The objective of this simulation is to show that data can be transmitted wirelessly from the sink node to the wireless sensor node and then later be loaded into a database. The next chapter presents the implementation of the designed solution and the tests performed.

CHAPTER SEVEN: IMPLEMENTATION AND TEST PROCEDURES

7.1 Introduction

In the previous chapters the proposed solution was designed and explained in detail. In this chapter a hardware prototype of the proposed solution is presented. The practical setup was done using Arduino Uno board, the M6E-nano RFID reader, the XBee module and software as mentioned in the design chapter.

7.2 Prototype connection setup

The full practical setup is made of a host computer running the inventory management system and the appropriate driver software needed for the communication with other parts of the design, the sink node, the wireless sensor node connected to the RFID reader and the shelf where books containing tags are placed. The next sections discuss the connections and setup of each parts of the system.

7.2.1 Host computer (HC)

The HC contains the database, the web application interface and all the driver software needed to operate the system. The database of the system is designed in MySQL database software. Figure 7.1 shows the database with the different tables. It contains 4 tables as described in the design chapter:

(i) Authorlist table lists the different authors and their books. One author can have many books.

(ii) Bookepc2 table lists the books and the EPC number of the tag attached to it. In this case the EPC number is specific to a book.

(iii) Rfid-results table is where the EPCs read by the system are saved during the inventory process. This table only contains the EPC number column.

(iv) Users table records all the user’s information. It contains the usernames and passwords of all users registered on the system.

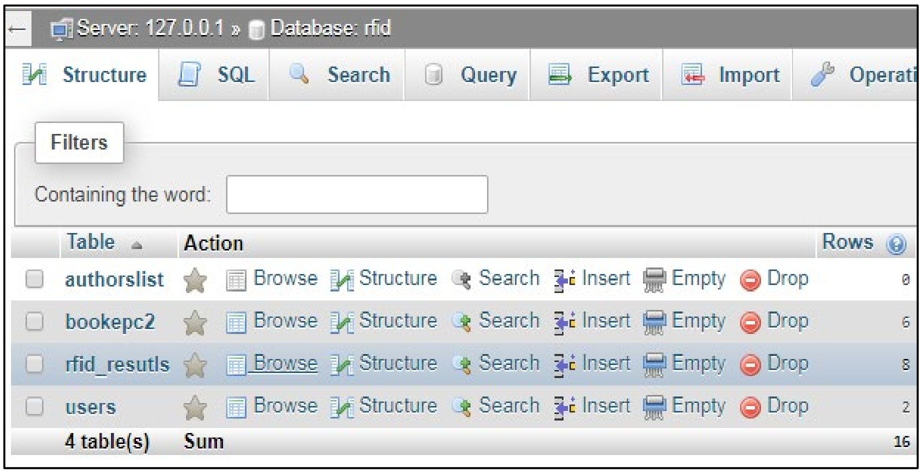

Figure 7.1: Database tables

Figure 7.2 presents the login page designed for this system. On this page the user register with the username and a password. These details are saved into a database table and user later if the same user want to login.

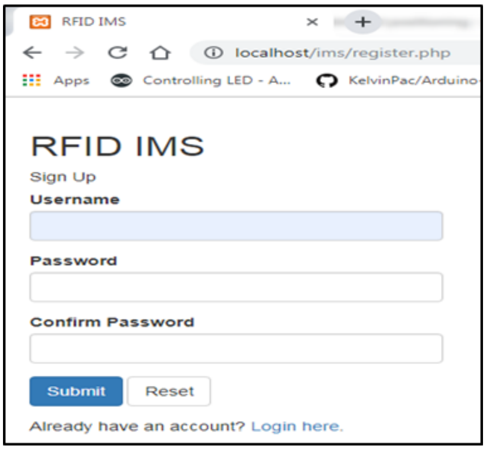

Figure 7.2: System signing up interface

The system interface is shown in Figure 7.3. This page contains buttons for inventory, book location, password reset and account logout. The use of the inventory and inventory buttons is described in section 3 of this chapter. The webpage is designed in PHP. The PHP-database connection code is given in Appendix B.

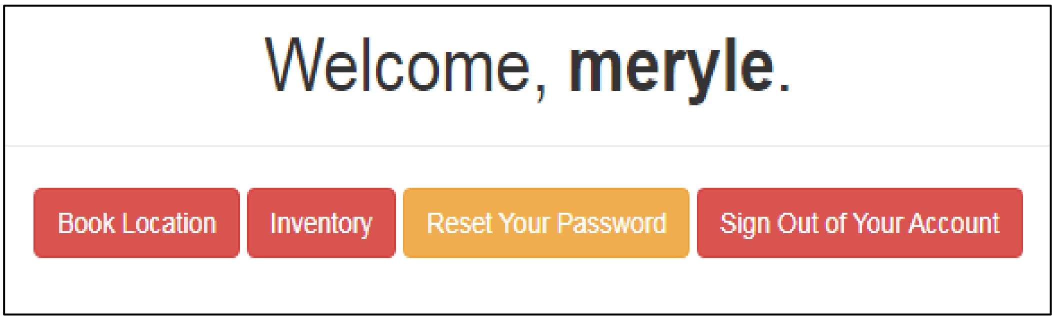

Figure 7.3: System welcome interface

In order to transmit data through the XBee modules they must be configured in the same network. The configuration of the XBees is done using the XCTU software. Few settings needed to be changed such as the personal area network (PAN ID), the destination addresses (DH and DL) and the node identifier (NI). Some values are unchanged and remain as default values. Table 7.1 presents the XBee configuration settings for the coordinator and the router.

Table 7.1: XBee modules configuration settings

Parameters	Coordinator	Router	Description
ID	1234	1234	Defines the network the radio needs to join. This must be the same for the coordinator and router.
JV	Unchanged	Enabled [1]	Check if coordinator exists on the same channel to join the network.
CE	Enabled [1]	Unchanged	Set the device as coordinator.
DH	Unchanged	0	Defines the destination address (High part) to transmit data to.
DL	Unchanged	0	Defines the destination address (Low part) to transmit data to.
NI	Coordinator	Router	Defines the node identifier.
SP	1F4	1F4	Defines the duration of time spent sleeping in hexadecimal. 1F4 = 500 (decimal) * 10ms = 5 seconds.

7.2.2 Sink node connection setup

The XBee on the sink node is connected to the Arduino board using an Arduino shield board. Pins connections are such as pins Tx and Rx of the XBee were connected respectively to pins 2 and 3 of the Arduino. The SN is then connected to the host computer through a USB to serial cable. The sink node connections are shown in Figure 7.4. The SN broadcasts the HC request to the WSNode and at the same time writes the received response on the HC. The Arduino reads all data (request) sent by the HC through the serial port. That command is then sent to the WSNode using the XBee module. The SN then goes into listening mode then it waits for incoming data from the WSNode. Any response received is written onto the serial port.

Figure 7.4: Sink node connections

7.2.3 Wireless sensor node and RFID unit connection setup

In the prototype model of the system, the reader is placed on top of the Arduino board. Stackable headers need to be soldered in the reader board to help connecting on the Arduino and at the same time to allow the connection of the XBee module. The Arduino-reader connection is shown in Figure 7.5. An external antenna was used for the implementation. To use the external antenna, the solder jumper to the trace antenna is cleared while the solder jumper to the u.FL connector is closed by adding a blob of solder. The antenna was connected to the reader board using a RP-SMA connector cable and the XBee module trough an Arduino shield bord. Pins Tx and Rx of the XBee were connected respectively to pins 8 and 9 of the reader. The connection setup of the reader, antenna and XBee is shown in Figure 7.6.

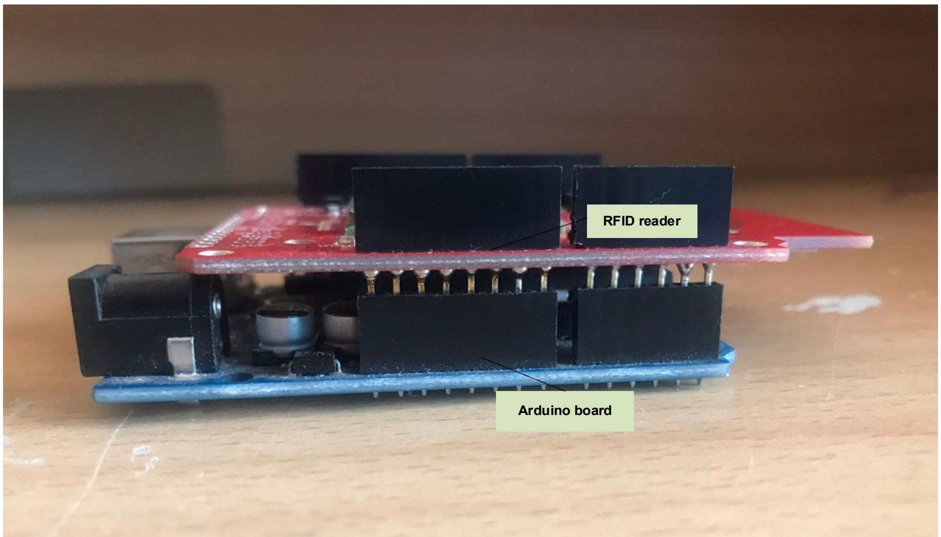

Figure 7.5: Arduino-reader connection

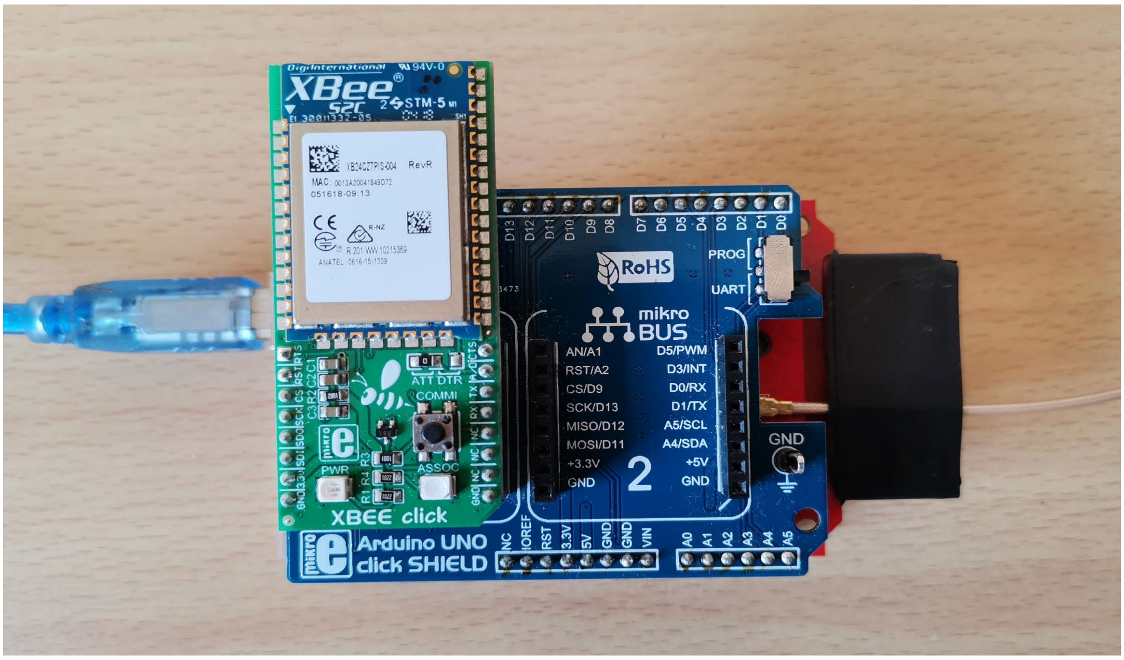

Figure 7.6: Wireless sensor node and RFID unit connection setup

7.3 System implementation

Books are placed on the shelf with tags placed in them. All tags are place on the front cover page of the books. The two application of this system are discussed in this section. The first part describes the performing of inventory by the system and the second shows the location of a single book.

7.3.1 Books inventory

When the inventory button is pressed on the main webpage, the inventory page is displayed as shown in Figure 7.7. The page contains two links. The first link is used to request the inventory of the books. By clicking on "proceed with inventory" the character "I" is sent to the system and all available tags are read. The returned EPCs are saved into the database. To access the results of the inventory the user needs to click on "view inventory". This link connects to the table where read EPCs are saved. All available books in the library are then displayed.

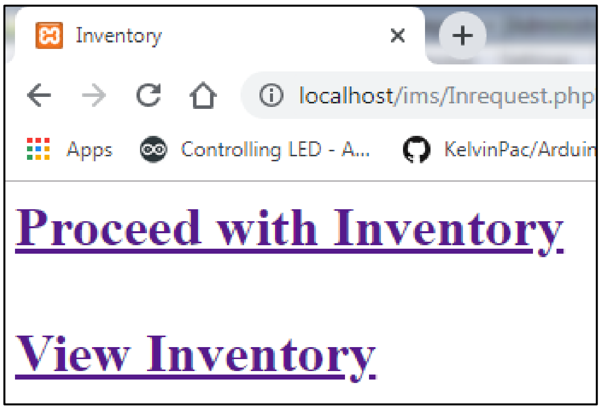

Figure 7.7: Inventory interface

Books Inventory

Inventory Results

Book Title	Author	Available
Electronic communication	Floyd TL.	1
Microwave Engineering	Gillispie J.	1
Physics	Joubert PJ.	2
Radio Engineering	Shufeldt H.	1
Visual C#	Vernon L.	3
Writing English	Mazidi A. McKinlay RD.	2

Figure 7.8: Inventory results

The results of the inventory are shown in Figure 7.8. The number of each book available in the library are displayed. The inventory results show display the title and author's name of the books available in the library. The amount of each available book is also given in the third column. Using these results, the librarian can determine the number of each book available in the library and also compute the total number of books.

7.3.2 Books location

Identifying a book can be done by either searching for its tittle, the author’s name or the shelf details. The information about the book to be located is entered into the search box and sent to the system by pressing the search button. The MySQL query used to perform the search is “{$search_term = mysqli_real_escape_string($conn, $_POST['search_box']); $sql = "SELECT * FROM rfid_resutls WHERE Books LIKE '%$search_term%' OR Author LIKE '%$search_term%' OR Location LIKE '%$search_term%'";}”. This query makes the search not case sensitive and will retrieve all results related to the search. The user can have more than one result depending on the word or name searched.

Figure 7.9: Search results using author’s name

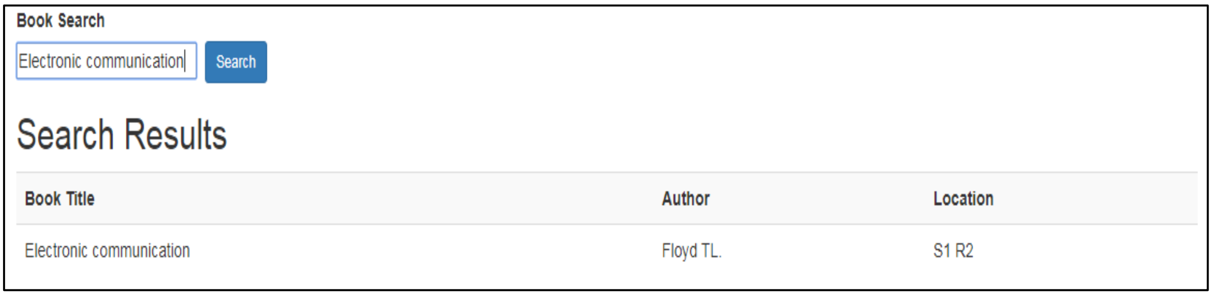

Figure 7.10: Search results using book’s tittle

The search results using the book’s title or the author’s name are shown respectively in Figure 7.9 and 7.10. The results displayed give the tittle and the author of the book as well as its location in the library. The user can also check for books available on a specific shelf by using the shelf location reference as shown in Figure 7.11. The place at which a book is located is given as “S1 R2” where “S1” stands for shelf 1 and “R2” for row 2.

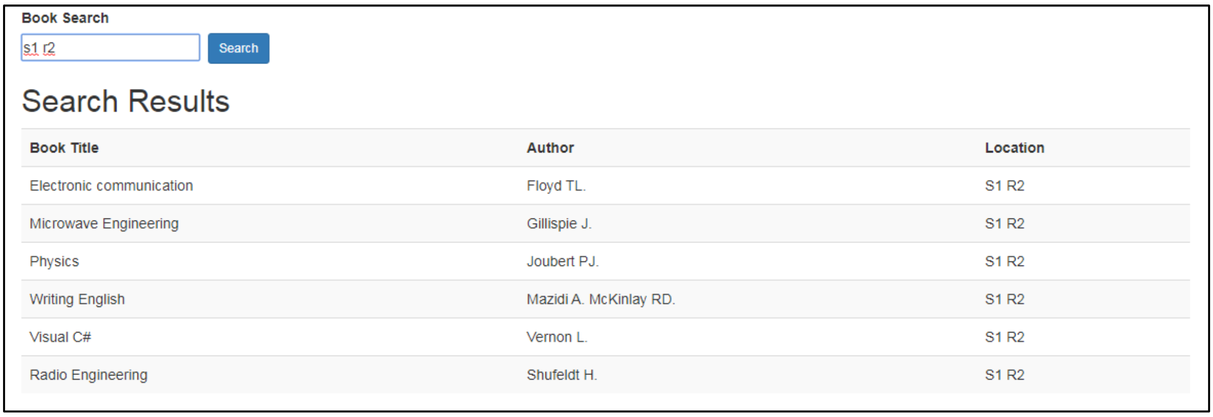

Figure 7.11: Search results using shelf details

7.4 System tests and discussions

A set of measurements were done in order to determine if the reader could read tags to up to 2m as described in the analysis section. For this a book with a tag attached vertically at the cover is placed at distances away from the reader's antenna. Ten measurements are taken at 20cm distance intervals with the maximum distance being 200cm (2m). Measurements are taken for the reader output power set at 5, 10, 15, 20 and 27dBm. The measurement did not start at 0cm from the antenna due to recommendations of the manufacturer that specifies that the tag should be placed at a certain distance from the antenna. The maximum output power this reader can provide is 27dBm. For every reading, the reader gives the tag's EPC, the received signal strength indicator (RSSI) and the frequency at which the tag is responding. In a RFID system, the RSSI value indicates how well a tag is responding to the reader's initial transmission power. The Arduino code for the EPC readings is given in Appendix C. Figure 7.12 shows results obtained at 20cm with a power of 27dBm. At that distance the RSSI is -38dBm.

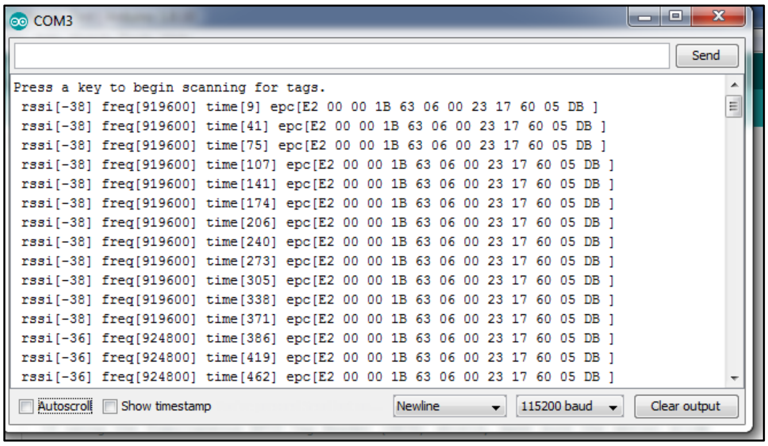

Figure 7.12: Readings at 20cm with 27dBm output power

Figure 7.13 shows results for readings between 20 cm and 2 m. The results shown were taken for the reader's output at 5, 10, 20 and 27 dBm. The RSSI value drops as the distance between the tag and the antenna increases. If the RSSI value goes to 0 dBm it means that the tag is out of the readers' reading range. This is the case for an output power of 5dBm where the maximum reading range is found at around 60 cm. For 10 dBm output power, the maximum reading point is reached at around 1 m. On the other hand, the reader can still read tags at 2 m for output power values of 20 and 27 dBm where the RSSI value is respectively -62 dBm and -59 dBm. The tag can still be read at 27 dBm than at 20 dBm because of the high power it received from the reader. RSSI value might vary slightly for one reading. This is due to the multipath the signal takes during the identification.

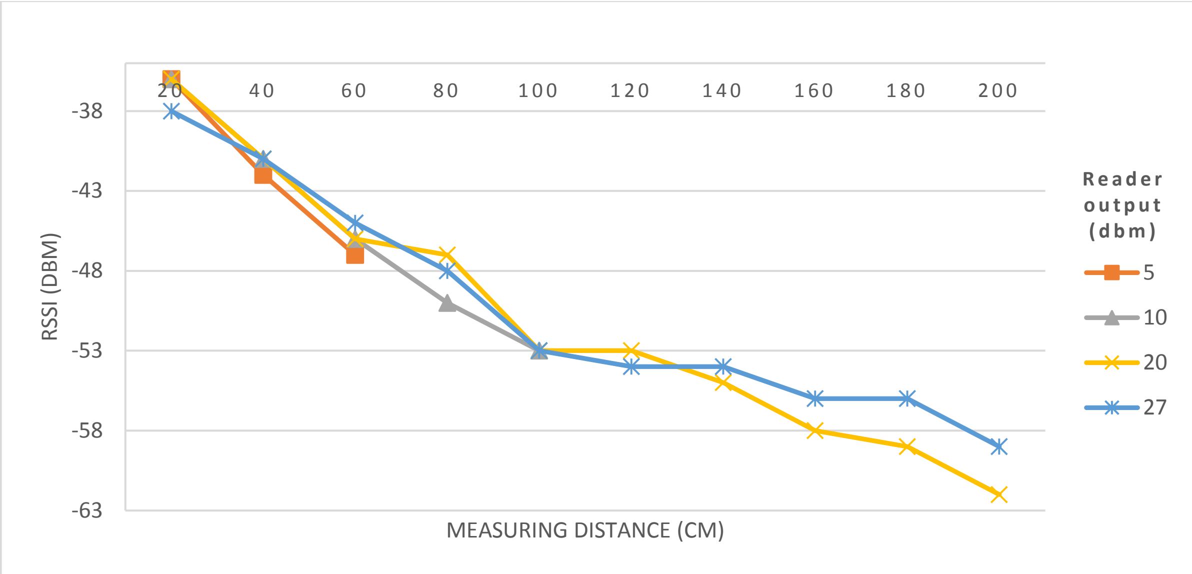

Figure 7.13: Measured RSSI over 2 meters

The system reading efficiency is determined by placing 10 tags at different distance intervals from the antenna and recording the number of tags responding. Intervals considered are 40-80cm, 100-140 cm and 160-200 cm. The number of responding tags will help to calculate the identification efficiency of the system. The identification efficiency is determined at each reading distance. The efficiency is found using the equation 7.1.

$$\eta = \frac{\textit{Number of tag detected}}{\textit{Total number of tags}} \tag{7.1}$$

Table 7.2 shows the number of tags identified and the efficiency at each distance. For measuring distances of 40-80 cm and 100-140 cm all 10 tags can be identified resulting in a 100% system reading efficiency. For reading range of 160-200 cm only 9 tags are detected out of the 10. This gives an efficiency of 90%. The system has a relatively good reading efficiency over 2 m with detection efficiency between 90% and 100%. As the reading distance increases the reading efficiency goes to 90%. This is due to the multipath propagation that the signal takes to reach the reader's antenna.

Table 7.2: System detection efficiency

Measuring distance (cm)	Number of read EPCs	Efficiency
40-80	10	100%
100-140	10	100%
160-200	9	90%

During the experiment it was noticed that the position of the tag influences the results of the readings. The number of identified tags placed vertically differs from the number of the number of identified tags placed horizontally. Figure 7.14 shows the tags read when placed horizontally. Only 4 tags are detected out of the 10 tags present in front of the antenna.

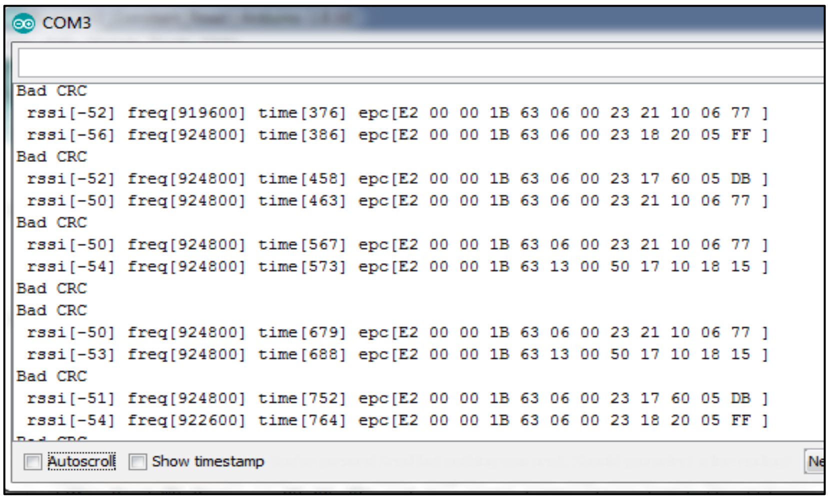

Figure 7.14: Readings for horizontally placed tags at 20-60cm

The reader also transmitted the reading timestamp each time a tag responded to the request to transmit as shown in Figures 7.13 and 7.14. The timestamp is the time at which a tag is read, relative to the time the request to read was issued by the reader. It is measured in milliseconds. In Figure 7.14, the reader recorded a timestamp of 764ms at the 10^{th} response. This represents a relatively fast time response. However, it was noticed that some tags were read more than once. The protocol used by the reader to identify the tags allows tags to respond to a request to transmit more than once. This issue causes the timestamp to be high when identifying all the tags. The reader's protocol should prevent tags to respond with their information after they were identified as in BBS, ANA and OBS algorithms discussed in chapter 4. Nevertheless, with an identification time of less than 1s for 10 tags, the system identifies the books faster than when using a handheld RFID reader or barcode technology.

Finally, Table 7.3 presents the results obtained from readings in both horizontal and vertical positions. The detection efficiency is calculated in both cases. Figure 7.15 shows a graph of the detection efficiency with respect to the reading distance. When the tags are placed in the horizontal position the detection efficiency drops considerably as the distance from the antenna is increased. Only 40% of tags are detected when placed close to the reading antenna and no tags are detected over 120 cm. However, when the tags are placed vertically the system has a perfect detection efficiency of 100% between 2 and 120 cm. The detection efficiency slightly drops to 90% for a range of 160-200 cm. These results show that for this system tags should be placed in a vertical position in order to identify all books present in the reading area of the reader.

Table 7.3: Tag's position effect

	Horizontal readings		Vertical readings	
Measuring intervals (cm)	Number of tags read	Efficiency	Number of tags read	Efficiency
20-60	4	40%	10	100%
80-120	3	30%	10	100%
160-200	0	0%	9	90%

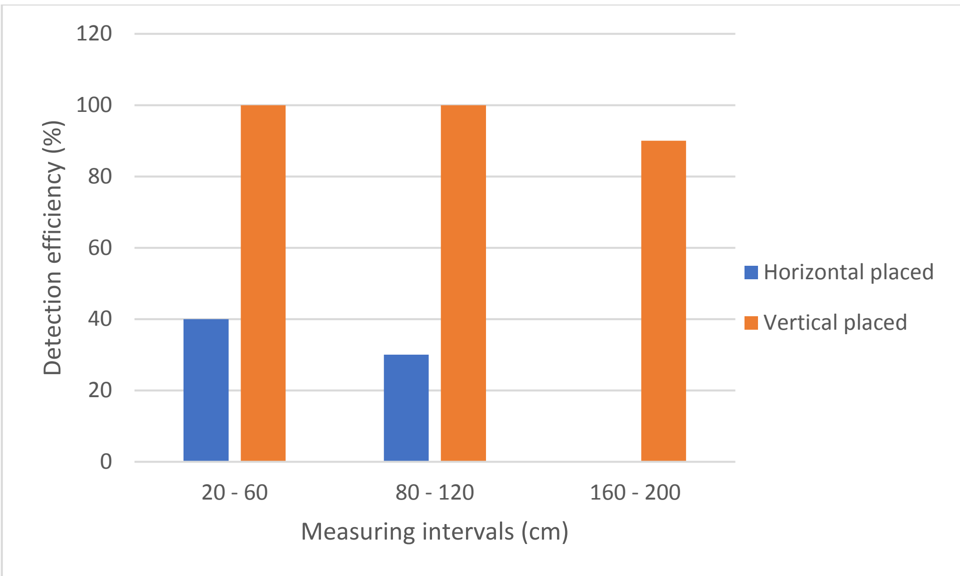

Figure 7.15: System detection efficiency measurement

7.5 Chapter conclusion

In this chapter the implementation of the proposed solution was performed. The implementation was done by using a RFID reader with a wireless system made of XBee and Arduino technologies. The chapter starts by presenting the system's connection setup.

Connections of the sink node and wireless sensor node are shown. The chapter later gives the results of the implementation of the inventory management system. A webpage was designed using PHP programming language in order to display the inventory and location results. The webpage is linked to a database where all collected EPCs are saved. The results obtained show that the system is able to perform static reading of the RFID tags from a computer. This chapter concludes with a discussion on the system's reading efficiency. This includes the measurement of the tags RSSI and calculations of the system's detection efficiency. The effect of the tag's position on the system efficiency is also discussed in this section. The summary of the results obtained are presented in the next chapter.

CHAPTER EIGHT: CONCLUSION AND FUTURE WORK

8.1. Introduction

In this chapter, a summary of the dissertation as well as the conclusion obtained with regards to the design and the development of an inventory management system using RFID technology are presented. A comparison between the obtained results and the objectives of the project is later discussed.

8.2. Research outcomes

In this study, a book identification system based on RFID technology was developed. The system was made of a RFID reader, ZigBee technology used for wireless communication and a computer used for data management. The M6E-NANO RFID reader module was used because it is capable of simultaneous tags reading but also because it is low-cost reader compared to available types of simultaneous tags reading devices. The host computer holds a database and a webpage used to control the system and analyse the collected data.

The main objective of this study was to design and implement a system that minimizes the time used to perform inventory in libraries and improves the reading efficiency when using RFID solutions. This was achieved in this report through the following:

(i) By designing a system that is able to detect tags placed on books. Discussions about connections of the main parts of the system and their working principle were made. A thoroughly analysis of the components used in the designed solution was made. This helped in identifying the appropriate technologies to be used in this research.

(ii) By proposing a suitable anti-collision algorithm to be used in scenario of high density of tags. The performance analysis of the algorithms was determined based on the read cycles, the amount of data transmission and the identification efficiency. Results showed that the optimized binary search (OBS), the adaptive N-tree algorithm (ANA) and the backward binary search (BBS) algorithms performed better in situation of high number of tags, making these algorithms more appropriate for this research.

(iii) The simulation of the wireless communication between the sink node and the wireless sensor node. This was done in PVSM simulation software. The simulation model was to determine whether data could be sent over a wireless network made of XBee technology and saved into a database. The data exchange between the SN and the WSNode was simulated in PVSM software. The exchanged data was then saved in a

Microsoft Excel spreadsheet used as a database. The simulation results showed that data can in fact be sent over the wireless sensor network and then saved into a database.

(iv) The implementation of a static counting system that identifies the books available on a shelf. This static method of identifying books leads to the reducing of the time spent to perform inventory as the librarian can count the books available directly from the computer. The system was able to count the number of books available on a shelf and also to locate the position of books by giving the shelf and row number on which the book is placed.

(v) The communication between the sink node and the wireless sensor node was implemented. Tags placed at the WSNode were read and their EPCs sent wirelessly to the SN. The received data at the SN were then sent to the host computer. An inventory management system webpage interface was designed using PHP programming language at the HC for the management of the collected data. These results showed the number of books available in the library as well as their location.

(vi) The reading efficiency of the system at various distances was calculated and was found to be between 90% and 100%. This shows that the system is able to identify all the books placed on the shelf. However, as the detection distance increases the reading efficiency decreases. Also, using the tag's RSSI, the reading distance was determined. The measuring distance was recorded at different reader output powers. It was noticed that the detection distance greatly depends on the reader power. This means that the reading efficiency is affected by the distance separating the reader antenna and the tags but also by the power supplied to the tags by the reader.

(vii) The reading of the timestamp by the reader which helps to determine the time taken by the RFID reader to identify all in the tags in its vicinity. The identification time for the system was less than 1s. However, limitations were found in the identification mode of the reader which allow tags to respond more than once to a request to transmit. With search times of less than 2250 for 1000 tags, the ANA, OBS and BBS algorithms discussed in chapter 4 could be used to solve this issue. The algorithms only allow a tag to respond with its ID once and is later put to sleep. This will reduce the number of search requests hence improving the identification time of the system.

(viii) By analyzing the position of the tags on the books which leads to improving the reading efficiency as it was shown that the position of the tag affects the efficiency of the system. This is important to notice as the position at which a book is placed when returned on a shelf can affect the inventory and location results. For the system to perform well, the books should be in the same position as the reader's antenna.

8.3. Application of the research

The proposed inventory management system can later be used in different areas for the identification, tracking and counting of products or people. The sector where the RFID IMS can be used are:

(i) Libraries.
(ii) Retail businesses.
(iii) Hospitals, medical centers and pharmacies.
(iv) Universities and schools (for attendance purposes)

8.4. Research limitations

Few issues where encountered during this study which are considered as limitations of the system.

(i) The performance of the recommended anti-collision algorithm could only be simulated and not tested with an actual reader. This is due to the fact that the reader used in this study does not offer the possibility of loading an anti-collision algorithm. This could lead into further work.
(ii) The reader used cannot be used at maximum reading output power because of thermal limitation. If used for a long period when on maxim output power, the reader can get damaged.
(iii) The reading efficiency of the system can be affected by the position of the book. The reader's antenna and the book should be placed in the same direction in order to achieved maximum reading efficiency.

8.5. Future work

Future work to this research could include using a more advance RFID reader that allows the user to load and test different anti-collision algorithms. This is to this is to further improve the response time of the WSNode. Furthermore, the tests performed in this research were done using one antenna. This limits the identification capacity of the system. Another recommendation would be to include an antenna multiplexer to allow the connection of multiple antennas hence increasing the identification capacity of the system.

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APPENDIX: A SERIAL PORT DRIVER CODE

```
import de.bezier.data.sql.*;
import processing.serial.*;
Serial port;
int tag = 0;
String buffer = "";
MySQL dbconnection;

void setup()  {
     String arduinoPort = Serial.list()[0];
     port = new Serial(this, arduinoPort, 115200);
     String user = "root";
     String pass = "";
      String database = "rfid";
      dbconnection = new MySQL(this, "localhost", database , user , pass);
}

void draw() {
      String onoroff[] = loadStrings("http://localhost/test/LEDstate.txt"); // Insert the
     location of  .txt file
      print(onoroff[0]);
      println();
      port.write(onoroff[0]);
      delay(100);
      while (port.available() > 0) {
           char inByte = (char)port.read();
           buffer = buffer + char (inByte);
            print(buffer);
      }
  if ( dbconnection.connect() ) {
       dbconnection.execute("INSERT INTO `rfid`.`rfid_resutls` (`tag`) VALUES ('" +
       buffer + "');");

   } else {
         println("Error in the connection :-( ");
   }
    delay(100);
}
```

APPENDIX B: PHP INVENTORY SCRIPT

```
<?php


$host = "localhost";
$username = "root";
$password = "";
$database = "rfid";

//Create connection
$conn = mysqli_connect($host, $username, $password, $database);

//Check connection
if ($conn->connect_error) {
        die ("connection failed: " . $conn->connect_error);
}

$sql = "SELECT bookepc2.book, bookepc2.tag, bookepc2.Author, bookepc2.Available, rfid_resutls.tag FROM bookepc2, rfid_resutls WHERE bookepc2.tag = rfid_resutls.tag ORDER BY bookepc2.book";
$result = $conn->query($sql);

if ($result->num_rows > 0) {


// output data of each row
        while($row = $result->fetch_assoc()) {
                echo "<tr>
                  <td>".$row["book"]."</td>
                  <td>".$row["Author"]."</td>
                  <td>".$row["Available"]."</td>
                  </tr>";
        }
        echo "</table>";
} else {
        echo "0 results";
}
$conn->close();
?>
```

APPENDIX C: PHP LOCATION SCRIPT

```
<?php
$host = "localhost";
$username = "root";
$password = "";
$database = "rfid";

//Create connection
$conn = new mysqli($host, $username, $password, $database);

//Check connection
if ($conn->connect_error) {
	die ("connection failed: " . $conn->connect_error);
}
$sql = "SELECT * FROM location";

if(isset($_POST['search_box'])) {
	$search_term = mysqli_real_escape_string($conn, $_POST['search_box']);
		$sql = "SELECT * FROM rfid_resutls WHERE Books LIKE '%$search_term%' OR Author LIKE '%$search_term%' OR Location LIKE '%$search_term%'";
}

$result = mysqli_query($conn, $sql);
?>
```

APPENDIX D: ARDUINO EPC READING CODE

```
#include <SoftwareSerial.h>
#include "SparkFun_UHF_RFID_Reader.h"
SoftwareSerial softSerial(2, 3);
SoftwareSerial XBee(8,9);
RFID nano;
String reading;

void setup() {
  XBee.begin(115200);
  Serial.begin(115200);
  while (!Serial);
  Serial.println();

  if (setupNano(38400) == false)
  {

    while (1);
  }

  nano.setRegion(REGION_NORTHAMERICA);
  nano.setReadPower(2700);
}

void loop() {
  while (Serial.available()) {
   reading = Serial.readString();

   if(reading == "I") {

  byte myEPC[12];
  byte myEPClength;
  byte responseType = 0;

  while (responseType != RESPONSE_SUCCESS)
  {
    myEPClength = sizeof(myEPC);
    responseType = nano.readTagEPC(myEPC, myEPClength, 500);
     }

   Serial.print(F(" R1["));
  for (byte x = 0 ; x < myEPClength ; x++)
  {
    if (myEPC[x] < 0x10) Serial.print(F("0"));
    Serial.print(myEPC[x], HEX);
    Serial.print(F(" "));
  }
  Serial.println(F("]"));
}
```

```
boolean setupNano(long baudRate)
{
  nano.begin(softSerial);
  softSerial.begin(baudRate);
  while(!softSerial);
  while(softSerial.available()) softSerial.read();
  nano.getVersion();

  if (nano.msg[0] == ERROR_WRONG_OPCODE_RESPONSE)
   {
  Serial.println(F("Module continuously reading. Asking it to stop..."));

    delay(1500);
   }
  else
   {

    softSerial.begin(115200);
    nano.setBaud(baudRate);
    softSerial.begin(baudRate);
   }

  nano.getVersion();
  if (nano.msg[0] != ALL_GOOD) return (false);
  nano.setTagProtocol();
  nano.setAntennaPort();
  return (true);
        }
   }
}
```