Eloping Prevention, Occupancy Detection and Localizing System for Smart Healthcare Applications

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Abstract

The purpose of this thesis is to devise a system based on RFID (Radio Frequency IDentification) that can be used for smart healthcare applications. Location estimation, eloping prevention and occupancy detection are monitoring applications of smart healthcare which can provide very useful information for the nursing and administration staff of the nursing-home/hospital. The introduction of ubiquitous networking along with the concepts such as Internet of Things (IoT) can certainly help achieve the goals of smart healthcare. RFID technology has features, such as low power and small size, which makes this technology suitable for researching solutions for smart healthcare.

Today several nursing-home/hospital monitoring solutions exist in the market and academia alike. The solutions marketed commercially are very expensive whereas the solutions from academia provides solutions to isolated problems but a comprehensive all in one solution that can meet the need of smart healthcare monitoring applications is missing.

In this thesis we present a system that is low cost and suitable for accommodating a number of the smart healthcare applications including occupancy detection, location estimation, eloping prevention and access control. The solution is implemented on a customized Openbeacon Active RFID System (OARS). Active RFID based proximity detection is the core of our system. Practical experiments based on novel Proximity Detection based Weighted Centroid Localization (PD-WCL) method were done to analyze the performance of the system with different applications to highlight the applicability of the system.

Acknowledgment

This thesis would never had been completed without the support of many. I would like to extend my gratitude to my father, Rauf Ahmed Roshan, my mother, Samina Rauf and my sisters for always being supportive and helpful. I would also like to thank my lab mates Jing Wang, Majed Rostamian and Ovidiu Draghici for their assistance and creative ideas.

I would like to thank NSERC and Zodiac Inc. for funding this research. Above all I would like to express gratitude to my supervisor and mentor, Dr Miodrag Bolic, for always being patient, and helpful. I would also like to thank all the Professors and Teachers who have taught me and helped me in my Master's and Bachelor's Degree and to all those who I might have missed mentioning. Surely this landmark have contributions from all of the above.

In the end, I dedicate this work to the people I love the most my parents and Ibrahim and Inaya.

Muhammad Hassan Ahmad Roshan.

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Chapter 1. Introduction

1.1. Overview of the Field

1.1.1 Smart Healthcare

Healthcare Systems have evolved in phases with time. In the past, healthcare systems were dominated by "medical" model. In medical model healthcare providers determined what was required by the patients, and where and how their treatment will take place. However this model has changed overtime and is replaced by a more recent "social healthcare" model. In social healthcare model demands of the patients weigh the most, the services required have changed to services demanded [1]. This situation, along with increasing percentage of elderly population in the developed countries of 20% to 36% by 2050 [1], leaves us with no option other than to explore smart healthcare.

Smart healthcare, in simple words, is nothing other than the infusion of technology in the existing healthcare system in order to improve its efficiency. Mark Weiser, a renowned name in computing said: *"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it"* [2] and today emergence of pervasive and ubiquitous computing have made such technologies possible [1].

A complete healthcare solution consists of several parts, interaction between patients and practitioners, insurers and hospitals, nurses and doctors, patients and pharmacy. Today's healthcare system is highly inefficient therefore need of computing to supervise, observe, crosscheck and to point out mistakes is required. When the computing condition is fulfilled, along with sensors and networks, it gives birth to the concept of smart healthcare.

During the course of this thesis, it is impossible to work on all of these parts therefore we will be directing our efforts towards development and exploration of RFID based smart healthcare applications.

1.1.2 RFID

RFID stands for “Radio Frequency Identification”. As the name suggests, RFID is a technology that can identify tag carrying objects using radio frequency waves. Therefore RFID systems are designed to identify objects remotely without any need of manual scanning [3]. A typical RFID system consists of following three core components [3].

- A tag (also called a transponder), typically consists of a semi-conductor chip, antenna and sometimes battery.
- A reader (also called an interrogator), consists of an antenna or multiple antennas, an RF electronics module, and a control electronics module.
- A Host (also known as middleware), it is usually an application implemented on a workstation or a server.

As shown in *Figure 1-1*: A Typical RFID System, tags and readers communicate with each other via a RF LINK. The tags are responsible for carrying some sort of data such as ID, Electronic Product Code (EPC), time stamps or serial numbers. Whenever a tag or a tag carrying object enters an area within the range of a reader, the reader asks the tag to transmit the stored data. Upon receiving this signal from the reader, the tag transmits the stored data. Once the data is received by the reader, it is relayed to server or workstation to which the reader is connected [4].

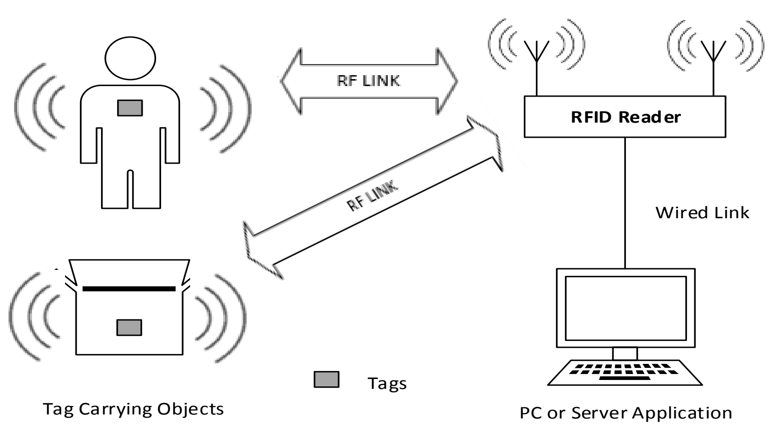


Figure 1-1: A Typical RFID System

Based on the frequency at which the radio link between the reader and tag exists RFID systems can be divided into four types: Low Frequency (LF), High Frequency (HF), Ultra-High Frequency (UHF) and Microwave Frequency [4]. Similarly based on the type of tags used, RFID systems can be divided into further three types: Active Systems, Passive Systems and Semi-Passive Systems [3]. Detailed discussion about the features and differences in all these types mentioned here will further be elaborated in Chapter 2 of this thesis. Some common applications of RFID technology in industry today are [3]:

- Supply chain tracking used by Wal-Mart and United States of America's Department of Defense (DoD).
- Access Control Systems, which will be mentioned in the later part of this document.
- Animal tracking, Vehicle tracking, and automated toll collection.

1.1.3 OpenBeacon Active RFID System (OARS)

OARS is the platform we are using for the development of the system presented in this thesis. OARS is developed by a German company, Bitmanufaltur GmBH [5]. It is an open platform system which works in a license free 2.4 GHz spectrum. Openbeacon active RFID tags have the capability of detecting proximity of other Openbeacon tags in the vicinity. The tags operate in a beacon mode and transmit periodically. The readers in OARS are pure listeners and wait for the transmissions from the tags. *Figure 1-2* shows an overview of OARS. Tags that are close, can see each other whereas the reader can see all the tags. No transmission is made by the reader therefore it is always listening. Once a tag detects another tag in its vicinity, it stores the ID of the tag and appends it in the next packet that is due to be transmitted. As long as two tags remain within the range of each other they both will report its own ID and ID of the tag close by. As soon as the tags move away from each other, they will not be able to see each other and will start reporting its own ID only.

Proximity detection is principle we have based our system on and this is the why we have chosen OARS as the platform to develop on.

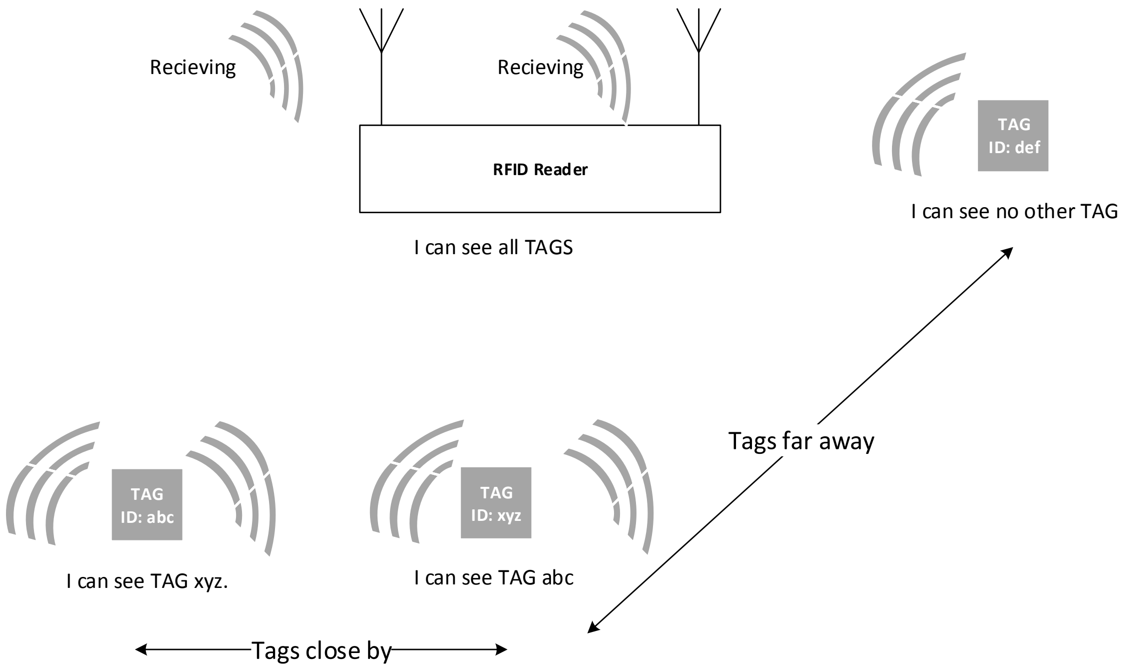


Figure 1-2: Openbeacon Active RFID System – Overview

1.1.4 Performance of a RFID based Smart Healthcare Monitoring System

The performance of monitoring system is defined by parameters such as: Precision to which it can locate an object; Accuracy to which it can prevent eloping from occurring and ability to which it can detect correct occupant in a particular room. On the other hand efficiency of a RFID system can be described by: range – the distance at which the reader can see the tags; read rate – number of times reader could read tags; scalability – ability to expand the system; and robustness – Multiple tags reading capability which includes protocols and multiple access techniques.

1.2. Thesis Statement

Existing RFID based smart healthcare monitoring systems either have poor performance or are very expensive and time consuming to deploy. Therefore the objective of this thesis is to propose a solution which can overcome the shortcomings of current monitoring systems, a system which is low cost, accurate and which can provide us with a mechanism to implement multiple applications of smart healthcare monitoring. Smart healthcare monitoring applications, related to hospitals and nursing homes, which will be under consideration are: location estimation (localization), occupancy detection and eloping prevention. Central to the solution proposed are the modified Openbeacon Active Tags, referred in this document as: Landmark Tags (LT) which have been modified to operate in conditional beacon mode and transmits only if the proximity of an MT is detected; and Mobile Tags (MT) which work in beacon mode.

1.3. Motivation

Health, safety and better life quality, for elderly and patients, is the motivation for this research. Alzheimer and dementia patients suffer from memory loss which resultantly can put them in dangerous situations. Problems, such as eloping, pose great threat to the health and safety of the patients. On the other hand, human error from the nursing staff can be life taking; in one of the recent event, a dementia patient went missing and died of hypothermia on the grounds of a *care home* as the nursing staff failed to realize that one of the patients was missing [6]. In order to avoid such situations we need technology so that human error can be minimized, lives can be saved, efficiency can be increased and cost can be reduced. Thus ability to keep track of patients locations, cross check medication schedules and control access to prohibited areas and exits of the nursing homes is the only way to ensure health and safety. The work load on the part of the nurses is itself tiring and unforgiving. According to [7], 25% of the clinical staff's time is wasted in finding things. Due to their workload and redundancy of actions, nurses themselves, sometimes forget if they provided medication to every patient. In such case infusion of technology can certainly help.

RoamAlert [8] is one solution from industry which targets the same monitoring applications addressed in this thesis but is composed of several different devices (using different technologies) which are integrated to make a complete system. The use of multiple devices adds to cost due to which the system is expensive and only large organizations can afford it. On the other hand Sens-a-Tag (ST) [9] is a RFID based localizing solution but is larger in size and requires a special hardware (ST) to detect passive tags nearby to localize itself. Although in academia, Openbeacon system has been explored for location estimation in [10] but at best it can be described as coarse indoor localization. In [11] an Openbeacon based system and targets room level localization using proximity data but again is limited to one implemented application. In such a scenario, if the gap can be filled by a system which require no additional hardware, can cater multiple applications and is also inexpensive to own, can indeed be resourceful.

1.4. Thesis Contributions

Our thesis work revolves around a very basic concept and that is proximity detection based on RFID. Today several solutions exists such as Gen 2 Listener, Augmented RFID Reader (ARR), Sense-a-Tag (ST) [12], and Openbeacon Active RFID systems (OARS) [5]. But none of them provide an absolute solution: some of the tags are bigger in size while others are not power efficient. OARS has been used previously for location estimation [10] and proximity based room level localization [11] but both of the solutions have low accuracy (~2m for [10] and room level for [11]). For the applications mentioned in section 1.2, Sense-a-Tag and Openbeacon Active RFID platforms are most suitable, therefore in this thesis comparison with these two systems will be done. Although in this thesis we use the OARS as our selected hardware we implemented new firmware on tag side that changes the functionality of tags. Based on the functionality tags are presented as Landmark Tags (LT) and Mobile Tags (MT). Introduction of LT and MT improves the performance of existing OARS dramatically providing it a significant advantage in accuracy as compared conventional OARS. The presented solution in the thesis also provides better accuracy the aforementioned Openbeacon based systems.

In this thesis we also present a C# based application which can process information received from the reader and translate it in the context of location estimation, occupancy detection, access control and scheduling. We also present a Proximity Detection Weighted Centroid Localization (PD-WCL) algorithm for indoor localization up to sub-regions using LT as compared to readers being used in Dynamic Degree Weighted Centroid Localization (DWCL) presented in [13].

1.5. Thesis Outline

This Section provides an outline about the content of this thesis and provides a brief description of what each chapter presents.

Chapter 2: Background, Research and Related Work provides the introduction and background for all the contents of the thesis. The chapter also contains some important related work that have been done and accomplished prior to this thesis. The sole purpose of this chapter is to provide readers with basic understanding of technologies that are being used and to understand their objectives.

Chapter 3: The Active RFID System provides a detailed description to the Openbeacon RFID System. The Chapter describes different components of this Openbeacon system from Bitmanufaktur. The chapter also describes the system modifications that have been done in order to serve the objectives of the thesis. Lastly this chapters compares the Openbeacon system with the modified version system and several other open platform system in the market.

Chapter 4: Implemented Applications is used to describe the applications that we have implemented using the discussed system. We establish the fact that a single system can be used to integrate all important applications needed for smart healthcare.

Chapter 5: Conclusion is the last chapter of our thesis and explains how the thesis has contributed to the research community and what can be done in the future.

Chapter 2. Background and Related Work

2.1. History

The origin of radio frequency for identifying dates back to early decades of 20^{th} century and the first applications of radio frequency identification (RFID) emerged in the era of post WW-II [14], known as radar system. These systems were able to detect metal objects in air and sea. The principle was simple; a radio wave was sent and a reflection wave from the object was received at the transmitter to detect the presence of objects. But still radar technology was missing the ability to identify between a friend and a foe. During WW-II, Germans invented a simple and ingenious method for distinguishing between friend and foe. The German squadron were doing simple front roll maneuver with their planes to change the frequency of the reflected wave. The blip at Radar Operation Center was generated and was recognized as a symbol of friendly aircrafts. This was the world's first RF based passive identification method. The US and Britain in response innovated a solution known as IFF (Identify Friend or Foe) in 1937/38 [14]. A simple beacon on the aircraft was used to identify between friend and foe. This is the first known Active method using RF to identify.

The radar technology, at present time, is a refined and developed technology which involves sophisticated algorithms for identification; but discussion on Radar is beyond the scope of this thesis. However, unlike Radar technology, RFID technology is neither that old nor that refined. In addition, although RFID and Radar systems both identifies objects using electromagnetic waves there are still many of differences; where a Radar system depends on receiving reflection signal, passive RFID depends on the receiving the backscattered signal by harvesting the power from the interrogating signal.

During the recent years the need of auto ID systems have increased enormously [4]. Manual scanning (Bar codes) or counting methods, for keeping track of large consignments of big corporations such as Walmart, or government departments such as US defense, have failed in such scenarios. Thus in view of the need of the hour a technology that can identify objects automatically was needed and RFID was the answer.

2.2. Introduction to RFID Systems

Every RFID System is composed of three basic components:

- A Reader responsible for interrogating or reading tags.
- A Tag that can reply with information/data (such as EPC, timestamps etc.) stored in its memory to the reader.
- A software application that can display and record results obtained from the reader. This software application can be integrated with reader or can be made to run on a server depending upon the need.

The communication between the passive tags and reader is usually done in five steps: *Step 1:* The antenna of the reader sends a strong EM signal, known as Query, in the air; *Step 2:* Query is received at the tag. EM waves of Query are used to generate power to drive the tag circuitry using inductive or radiative coupling; *Step 3:* The Query signal is now demodulated and decoded at the tag; *Step 4:* Tags backscatters a modulated response towards the reader with encoded information; *Step 5:* This modulated signal is decoded by the reader and sent to the application where it can be displayed. *Figure* 2-1 shows an over-view of how an RFID System works.

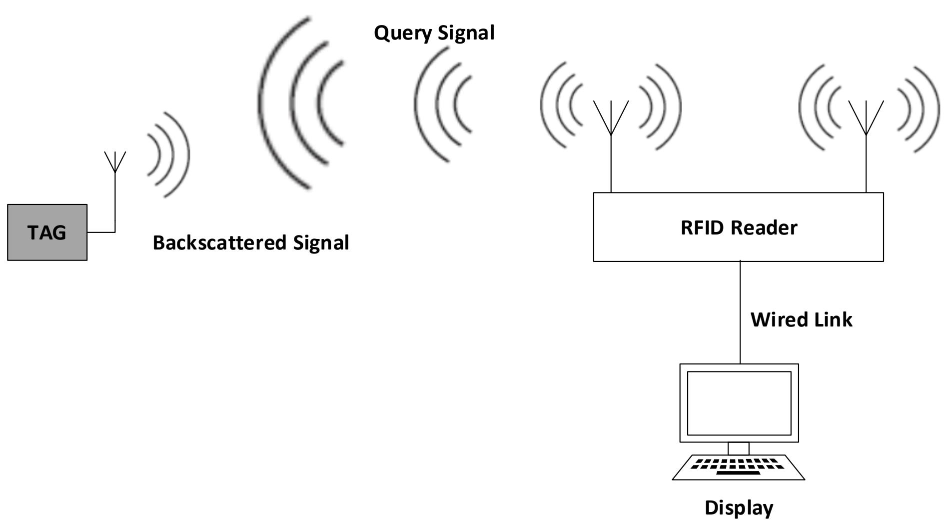


Figure 2-1: RFID System: Working Principle

Figure 2-2 shows the basic blocks of RFID chip in a passive tag. Rectifier converts the AC current from the Electromagnetic (EM) waves of Query signal into DC which is then managed and transferred to different components of the tag by the regulator. Modulator/Demodulator modulates the data that is to be transmitted from the tag and demodulates query signal from the reader. Encoder/Decoder unit decodes the query signal from reader to insure authenticity and encodes the reply so that only a reader can decode the backscattered response (not all tags consist this unit). The memory unit serves as the memory and state machine for the tag and contains data and instruction sets for its operation.

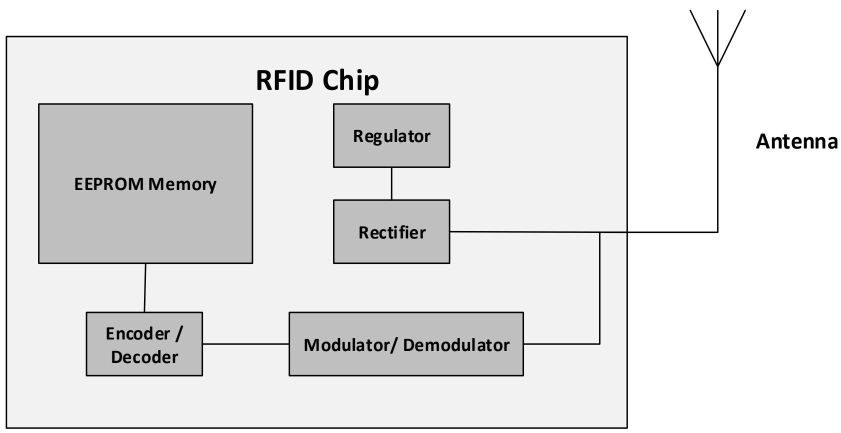


Figure 2-2: Block Diagram: Typical Components of RFID Tag [15]

RFID Systems can be further categorised depending upon their frequency and type of operations.

2.2.1 Operation Based Categorisation

Passive RFID Systems

The RFID systems in which tags require no battery or any other source to communicate with the reader are known as passive RFID systems. The tags of such system uses the power of the EM waves of the reader as a source of energy and backscatters a load modulated signal. The main advantages of passive systems is the fact that tags can be produced at a low price. But the low price of these tags (UHF and LF) comes at a price of lower range and lower processing power which means these tags are not suitable for applications that require high security in form of complex encryption. HF passive tags offer more security then LF and UHF passive tags and are used in applications such as smart cards.

Passive tags are designed so that maximum power from the radio waves of the reader can be translated to drive the tag. Some power from query signal is used to drive the RFID chip and some is used to backscatter the signal, as shown in *Figure* 2-3 [4]. The reader in a passive system is always an active reader because of an obvious reason that is; absence of the interrogator signal will lead to no operation at all.

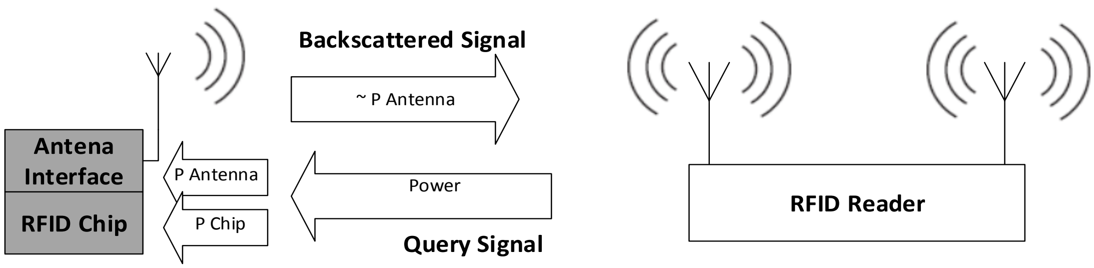


Figure 2-3: Passive RFID System [4]

Active RFID Systems

In active RFID systems the tags have a battery that ensures complete independent power source for the tags. Tags neither use the energy from the reader to backscatter nor to drive its circuitry. The advantages of active tags is longer range and higher processing power but of course these features come at a price of larger size and expensive tags with a shorter life time leading to a high maintenance cost.

The active RFID systems can be divided into two further categories based on their mode of operation.

- Beacon mode.
- Interrogated mode.

In beacon mode the tags transmit periodically after a certain condition is satisfied such as time out, motion sensor etc. Tags operating in this mode does not require an active reader thus a simple passive reader is used with these tags. These readers only act as pure listeners. However in interrogated mode of operation the use of passive readers is not suitable. Although the tags are self-sufficient when it comes to the power of the tag is concerned but still these tags require a properly formatted query signal from the reader to begin their operation. *Figure* 2-4 shows a typical Active RFID system.

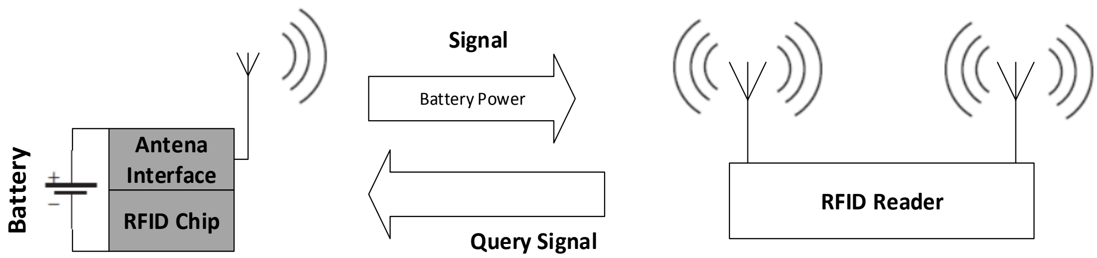


Figure 2-4: Active RFID System

Semi-Passive RFID Systems

As the name suggests these systems are kind of a hybrid of active and passive systems. Just like passive tags these tags uses the incoming reader signal for backscattering whereas just like active tags these tags uses the on-board power source to drive the processing parts of the chip. The main advantage of these tags is power conservation. Unlike active tags these tags require much smaller battery and tags require less frequent maintenance and lasts longer. Thus a semi-passive tag provides us with a range greater then a passive tag along with the ability to do more complex calculations on the chip. Today in market there are several semi-passive tags that can operate even when their batteries run out, however once the battery is dead these tags just act as passive tags.

The readers in such systems again need to be Active Readers with high output power which can be utilised by the tags for backscattering purposes. *Figure 2-5* shows a typical Semi-Passive RFID System.

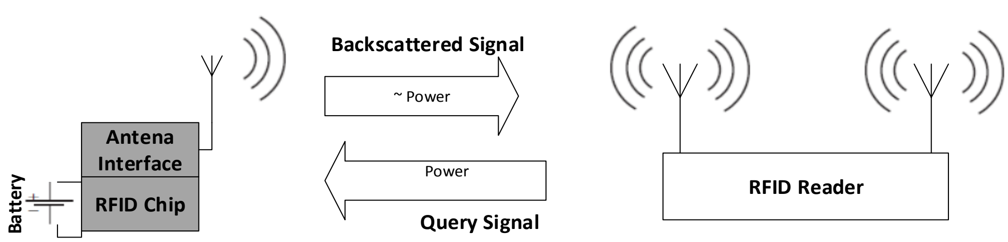


Figure 2-5: Semi-Passive RFID Tag

2.2.2 Frequency based Categorisation

The range of operation of RFID systems varies vastly, it starts from around 100 KHz and goes up to about 5 GHz [1]. Although the range is vast but majority of the RFID systems work in narrow frequency bands. Based on the where the frequency band of a RFID System lies these systems can be divided into following three types[1]:

- Low Frequency Systems (LF Systems): Most of the LF RFID systems operate within the band of 125/134 KHz. These systems are usually used near water, living tissues and metal objects due to ability of the signals at that frequency range to penetrate them most efficiently. Among all these types, read speed is the slowest due to low data transfer speed and the range typically does not exceed 3 ft.
- High Frequency Systems (HF Systems): All the systems that uses 13.56 MHz fall into this category. Usage usually includes smart cards, vicinity cards and smart shelves. A typical read range is about 3 ft.
- Ultra High Frequency Systems (UHF Systems) and Microwave Frequency Systems: Systems that uses the bands of 860 MHz to 960 MHz are UHF, and systems that use 2.4 GHz or 5 GHz to 5.8 GHz belong to Microwave Frequency systems. Systems working on 433 MHz can also be found and they are categorised as UHF systems. The application of these systems are found in super markets inventory control, and warehouses. These systems are the fastest of all and have the highest read range around 10ft – 30ft for passive tags and much longer for active.

2.2.3 Summary

After all the discussion from above sections it can be inferred that in all RFID systems tags are the defining factors. However the selection of the tags and their frequency of operation depend largely on the application they are used in. *Table 2-1* shows typical uses of RFID systems based on their application.

Table 2-1: RFID Frequency band Characteristics

Frequency Class	**LF**	**HF**	**UHF and Microwave**

Power Class	Generally Passive RFID	Generally Passive RFID	Generally Passive, Semi-Passive and Active RFID
Penetration	High	Less than LF	Low
Affected by Water	Low	Low	Highly
Data Rate	Low	Medium	High
Reading Multiple Tags	Poor	Good	Excellent
Applications	Access control and security, Employee ID's, Harsh Environ-ments like mine fields or near met-als / water etc.	Access Control, Li-braries, smart cards, smart shelves, pay pass etc.	Asset Tracking, Real-Time Localiza-tion Systems, High-way tolls, Fleets etc.

2.3. Smart HealthCare

2.3.1 The Concept of Smart Cities

For the first time in the human history more than 50% of the human population lives in urban areas [16], so this scenario has led us into a situation where we need to be very precise in how to use our resources. We also need to be very efficient in our ways how to manage these resources in order to provide people with an efficient and sustainable living environment. Thus in order to meet this need, researchers are coming up with ideas to tackle this problem and one idea that has interested people in the recent years is called "Smart City".

Smart city mainly focuses on applying next generation information technology in all fields of life, embedding sensors and equipment to hospitals, power grids, railways, bridges, buildings, roads, dams, water systems, oil and gas pipelines, homes and several other objects on each and every corner of the world, in order to transform all these things into the Internet of things. The idea is then to connect all these things via Internet and, once this is accomplished, to sense, analyze and integrate information from all these key sensor nodes and come up with intelligent responses for a better management of all the systems in the city. So to summarize we can say “internet+ internet of things+ artificial intelligence = smart city” [17].

2.3.2 Smart Healthcare

Smart City is a complete solution for the next generation living, and smart healthcare is a very important part of this solution. From an engineering point of view, a smart healthcare solution can be generalized having four basic layers [17], as shown in *Figure 2-6*.

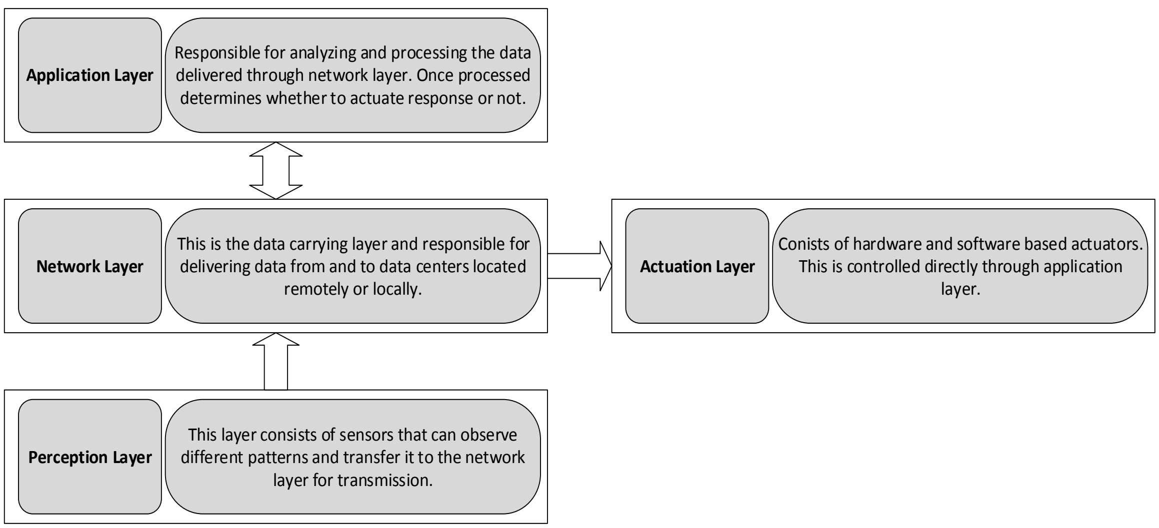


Figure 2-6: Smart Healthcare basic structure [17].

Perception layer consists of different sensors and intelligent electronic devices that are specifically designed for a particular purpose such as GPS, RFID Tags, cameras etc. *Perception layer* collects the data from the everyday environment and sends it to the *Network Layer*. *Network layer* consist of nodes and access points located at different areas of the environment. These nodes and access points receive data from perception layer and is responsible for carrying data to the servers where *Application Layer* takes over. Application layer processes the data, analyses it and saves the important information and discards the irrelevant information. Once the processing stage is completed, *Application Layer* decides whether to actuate a response or not. Information regarding control of actuators are released to *Network Layer* where it is carried to *Actuation Layer* and actuation is done. *Actuation Layer* can consist of software based alerts such as displaying messages on work-stations or hardware based alerts such as triggering door locks, sounding alarms etc.

Some basic applications that are considered under smart healthcare includes tracking equipment, tracking patients, tracking nurses, remote health monitoring, automated medication reminders, automated medication checkers etc. Whichever application is considered the requirements for the feasibility of applications, in terms of technology are the same: At the *perception layer* the sensors and devices should be pervasive and power efficient and at the *network layer* the network should be ubiquitous [18].

In this document, *Perception Layer* consists of Openbeacon RFID tags; *Network Layer* consists Openbeacon Ethernet Reader and *Application Layer* will be C# based application that has been developed.

2.3.3 Role of RFID in Smart Healthcare

A ubiquitous network and pervasiveness is a requirement of smart healthcare. Ubiquitous means something that can be everywhere at all times while pervasive means something that has permeated in the environment [18], therefore wireless technology suits this description best. Today several wireless solutions exist such as Wi-Fi, Bluetooth, Zigbee, RFID etc. The question is which of these is the most suited for smart healthcare? Keeping in view requirement of smart healthcare applications, it should also be kept in mind that sensors and devices have to be small, easy to wear, power efficient and designed such that they do not become a source of distraction for the nurses, doctor and patients.

Typical Zigbee, Wi-Fi, Bluetooth and Openbeacon RFID are compared and a comparison between size, data rate, range and power efficiency is done in order to support which of these technology is better for the required application.

Table 2-2: Characteristics of different wireless devices

	Wi-Fi	**Bluetooth**	**Zigbee**	**Openbeacon RFID**
Size	Large	Medium	Medium	Small
Data rate	up to 144 mbps	up to 1 mbps	≤ 250 kbps	up to 2mbps

Range	up to 100 m	up to 10 m	up to 100 m	up to 30 m
Power Consumption	High	Medium	Low	Lowest

According to *Table 2-2,* Wi-Fi is the fastest of all and have the highest range but have high power consumption and large size. Zigbee is small and has comparable range to Wi-Fi but has poor throughput. Bluetooth is neither power efficient nor have the best range. However Openbeacon Active tags are power efficient, good data rate, smallest size and decent range making it the most balanced and suitable technology for smart healthcare applications.

2.4. Introduction to Location Estimation

2.4.1 Overview

The process of finding the location of an object in an environment/space is called *location estimation* or *localization.* Satellite based positioning method known as GPS (Global Positioning System) is an example of a localization technique that is extensively used in today's world. GPS is a network of 24 satellites orbiting earth. The orbits of the satellites are positioned such that at least four satellites are visible at all times [19]. GPS receiver needs at least three satellites to determine its position using a technique called Trilateration. Other than GPS several other localization methods exist today such as GSM based localization methods, Wi-Fi based localization methods, RFID based localization methods etc. Based on the environment where localization is needed, localization methods can be divided into two types: *Indoor* and *Outdoor Localization methods.* Methods such as GPS, GSM based localization are examples of outdoor localization methods whereas Wi-Fi based and RFID based localization methods are examples of indoor localization methods. However based on the technology these methods use, they can again be divided into two types: *RF based* and *Non RF based methods.* Methods such as GPS, Wi-Fi based, RFID based and GSM based are all examples of RF based methods whereas methods which use ultrasonic, infrared, laser etc. are examples of non RF based methods.

Depending upon the environment the localization methods are used in and application, each method can have their advantages and disadvantages. GPS is suited for tracking objects outdoor but works poorly in the indoor environment. Similarly while RF based methods can still function without Line of Sight (LoS), non RF based methods need LoS to be effective. But discussing all these methods in detail are beyond the objective of this document. In this document we are concerned with RFID based Indoor localization algorithm.

2.4.2 RFID based Indoor Localisation

This section summarizes some of the basic techniques that are used for RFID based localization and related work in this domain. Just like all other RF based localization technologies RFID based localization is also dependent on information obtained from the propagation characteristics of RF waves [15]. The propagating wave can provide us with several important metrics which can be used for location estimation.

RFID localisation system can be divided into two blocks: Location Sensing and Location Processing, as shown in *Figure 2-7*: Block Diagram of RFID Positioning .

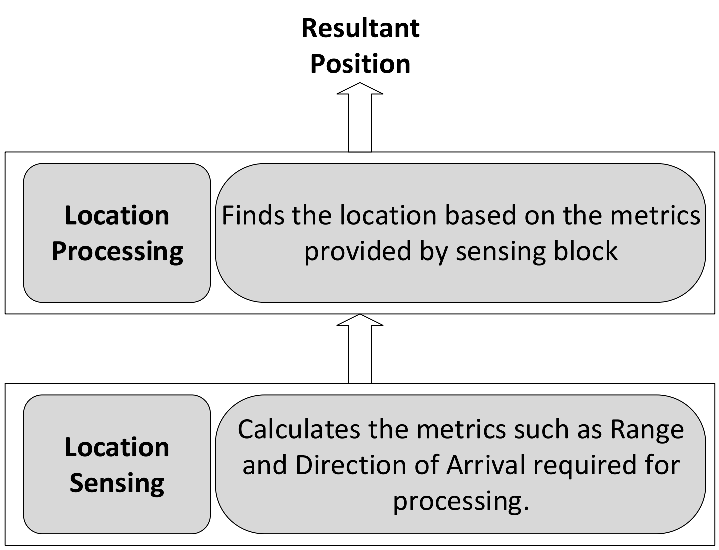


Figure 2-7: Block Diagram of RFID Positioning [20]

Location Sensing

The sensing part include following metrics [20]

Range

Received Signal Strength (RSS) can provide information regarding range easily because signal strength attenuates with increasing distance between the reader and the tag. RSS can be calculated using *Free Space Propagation Model* shown in (2.1) [21].

$$P_{RX} = P_{TX}\eta G_{tag}^2 G_{reader}^2 (\frac{\lambda}{4\Pi d})^{2n} \tag{2.1}$$

Where P_{RX} is the power of the backscattered signal or signal from the tag, P_{TX} is power transmitted by the reader, η is the power transfer efficiency whose typical value for passive tags is $\frac{1}{3}$ or -5 dB [14] and 1 for active tags, G_{tag} and G_{reader} reader and tag antenna gains respectively, d is distance, λ is wavelength and *n* is path loss exponent whose typical value ranges for 1.6 to 1.8 for indoor environment and 2 to 6 for outdoor environment [21].

RSS for ranging is one of the simplest approaches, however this approach can be combined with tag read count or other data to improve accuracy. In-spite of combining RSS with other data, the accuracy received on ranging is not robust for complex propagation environments because of factors such as obstacles in LoS (referred as shadowing), human body presence etc. that can cause severe estimation errors.

Time of Flight (ToF) is commonly used in estimating the range. The distance *d* can easily be calculated using *(2.2)* [20].

$$d = c \times \frac{\Delta T}{2} \tag{2.2}$$

$$where\ \Delta T = t_{stop} - t_{start} - T_{processing}$$

t_{start} is the time instant when the signal is transmitted from the reader, t_{stop} is the time instant when the backscattered signal is received at the reader and $T_{processing}$ is the processing time required by the tag to respond. Since passive and semi-passive tags have no on-chip clock source therefore no synchronization is required between the tag and reader and this method is suitable for passive and semi-passive RFID tags. For active tags (which have an on-chip independent clock source) determining one directional time of flight is impractical because of synchronization issues between the reader and the tag clock [20]; therefore Time Difference of Arrival (TDoA) is used with multiple antennas.

For systems having higher bandwidth, such as mentioned in [22], time based range estimation techniques can be promising but for conventional narrowband RFID system time based poses difficulty due to limited availability of the bandwidth [20].

Phase Difference of Arrival (PDoA) at the reader is also used for obtaining range information. The reader transmits two or more continuous-wave (CW) signals at different frequencies towards the tag. Tag receives these CW and backscatters the signals. Since the distance each CW needs to travel is same thus phase delays are directly proportional to the respective frequencies of CW. Therefore the phase difference observed at two different frequencies can be used to estimate the range. Although this method provides a very robust ranging mechanism but still error can be there due to multipath propagation. However this multipath propagation problem can be resolved using more than one pair of CW frequencies and averaging over these values. Larger the separation of frequency pair lower the error is [20].

Direction of Arrival (DoA): If the direction of the backscattered signal can be determined the approximate location of the tag from this information can be retrieved. Therefore DoA is another technique that is used in location sensing. In order to sense the direction of the backscattered signal, we need to use directional antennas or phased arrays or smart antennas [23] [24]. The use of afore mentioned antennas also enhances read range and reduces interference and multipath effects [20].

Location Processing

Once the information regarding the range or DoA is received from the sensing block, different techniques can be implied to find the position of the tag. Therefore this block, shown in *Figure 2-7,* is defined as position processing block. Several popular algorithms can be used to accomplish this task, however these techniques can be divided into two basic types: *Range Based* and *Range Free Algorithms* [25]. *Range based Algorithms* require point to point range or angle to estimate location while *Range Free Algorithms* require no such information; in-fact location is estimated based on the known position of the nodes in the vicinity.

Range based Algorithms that will be mentioned in following section include:

- Trilateration/Multilateration.
- Triangulation.
- Radio Map Matching.

Some Range Free algorithms explained are:

- Proximity.
- Centroid and Weighted Centroid Localization (CL & WCL).
- Approximate Point-in-Triangulation (APIT).
- Dead Reckoning (DR)

Trilateration/ Multilateration

Range information from the reader alone is not sufficient for locating a tag in an environment. However if range information of a tag from multiple readers/antennas is known then the location of the tag can be derived easily. And this techniques of using range information from multiple readers/antennas, whose positions are known, is called multilateration. Usually position is to be determined in a 2-dimensional environment, therefore three readers are used. When range from three reader is used to calculate the location of the tag then this process is called trilateration. However for any other $n>3$ number of readers, the process is called multilateration. It should also be kept in mind that in order to find location of an object in an n-dimensional space, $n+1$ number of reference points (readers/antennas) will be required [20].

Figure 2-8 shows how trilateration works. Let's suppose d1, d2, and d3 are the range information obtained from reader 1, reader 2 and reader 3 respectively. It means that at d1 distance the tag can lay anywhere around reader 1 and same goes for reader 2 and 3. Therefore the point where three circles (each with radius d1, d2 and d3 respectively) intersect is the position P(x,y) of the object.

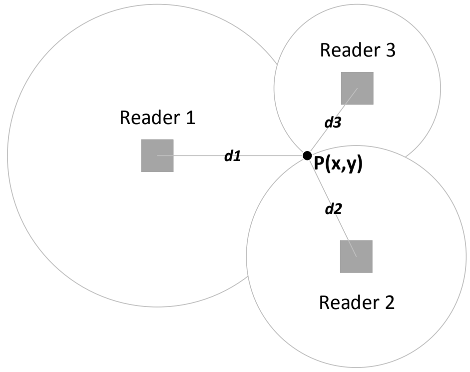


Figure 2-8: Trilateration Location Estimation

Triangulation

DoA information tells us about the direction of the tag but this information is not enough to locate the tag. However if DoA information is available from two or more reference points (reader/antennas) this can be used to find missing information such as range to locate the tag accurately. This method of location estimation is called triangulation. Contrary to trilateration, which uses range information from multiple reference points, triangulation uses angle information from multiple reference points to compute location.

Figure 2-9 shows how triangulation works. If the lines are drawn from the reference point in the DoA then the point at which these lines intersect gives us the location P(x,y) of the object. Mathematics can further be read from [20].

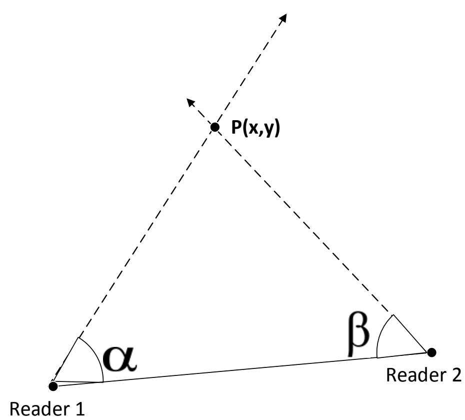


Figure 2-9: Triangulation Process

It must be noted that today hybrid techniques also exist which use DoA along with range to locate objects without needing multiple reference points. *Figure 2-10* shows hybrid method by using range d and DoA α.

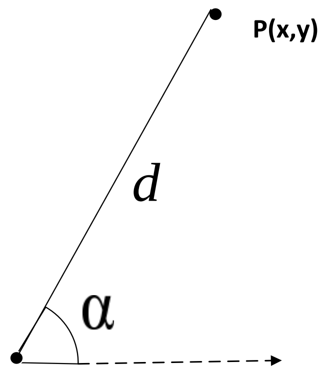


Figure 2-10: Hybrid Technique (Range and DoA)

Radio Map Matching

Radio map matching is also referred as "Scene Analysis" [20] or "fingerprinting". This method is accomplished in two steps: First step is fingerprinting, which involves gathering RF signatures from different positions in the environment with reference to fixed points where reader or antennas are to be installed. These signatures are stored in databases and a radio map is created from these signatures. Using this map the location of the target is calculated by matching the RF signature from the target with the closest matching signature stored on the map. Usually RSS is the property which is used as the RF signature for creating a map - however properties such as number of times a tag is read can also be incorporated to make it accurate.

Unfortunately above mentioned radio map matching method is not robust and is subject to unignorable errors occurring due to changes in the environment. As already discussed indoor environment can be affected severely by changes in temperature, moving bodies etc. Therefore in order to counter these changes modified methods have been introduced which change radio map with changing environment using some reference tags/beacons or using some probabilistic model.

k-Nearest-Neighbour (kNN) is a popular technique that uses reference tags/beacons. A RSS based radio map is created as mentioned before and positions of reference tags/beacons along with their RSS is also stored in the radio map. The position of these reference tags or beacons is known and changes in their RF signatures compared to the RSS stored in radio map can provide us information that can be used to calculate error at the instance of calculation. This calculated error is then taken into account for calculating location of the target [26].

Probabilistic Approach can also be used to find the location of target from *n* possible locations by applying probabilistic models such as Posteriori probability and Bayes formula [26]. Generally Probabilistic methods involve different stages such as calibration, active learning, error estimation and tracking with history [26]. As compared to *kNN*, probabilistic approach is more complicated and computationally exhaustive but on the upside the need of reference tag can be avoided with this approach. Some of the famous solutions are LANDMARC [27] using k-Nearest-Neighbour and LEMT using probabilistic model [28].

Proximity

Proximity means "*nearness in time, space or relationship".* Therefore any sensor that can detect proximity of an object, person or any other thing is called proximity sensor. One of the most common application of proximity that we use every day is in our smart phones which turns on or off the screen when we bring the smartphone near our ear.

Proximity based localization involves some fixed landmark sensors whose positions are known and whenever these sensor detect proximity of an Object of Interest (OI), OI location can be estimated. RFID based proximity solution relies on a dense deployment of multiple reader antennas or tags. When the presence of a tag is detected by a fixed reader antenna or tags, tag is assumed to be located in the proximity of that antenna or tag [29]. Some RFID based proximity solutions uses a dense deployment of tags instead of antennas and a small mobile reader is attached to the tracking commodity. Since the location of tags is known the reader location can be approximated by using the tags read by the reader. Today some more sophisticated RFID tags exist which can detect proximity of each other opening doors to new techniques such as tag to tag and tag to reader communication to locate objects. The accuracy of this method depends on the density of the reader antennas or tags and thus application of this method is easy yet expensive.

Figure 2-11 shows a simple Proximity based RFID localization set up where tags are placed at reference points and reader is attached to the object to be tracked. As the tags are read location of the object can be calculated in real-time.

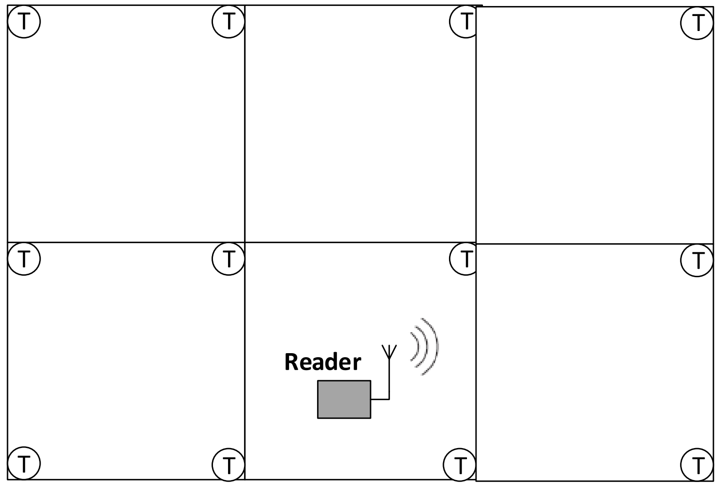


Figure 2-11: Proximity based RFID Location Estimation Setup

Centroid and Weighted Centroid Localization (CL and WCL)

This type of technique is usually used in distributed networks such as shown in *Figure 2-11*. The target calculates its position as the center of the positions of the nodes/tags that are in the vicinity or are read [30], as shown in *Figure 2-12 (a)*. However this method can easily be improved to provide better localization accuracy by introducing weights in the system. Weights are directly used to calculate the distance of the target from each respective node/tag, as shown in *Figure 2-12 (b)*. Weights can be a function of the power level of the signal received by the reader or the number of tags read. In the first phase each neighbor node sends its location (x_i, y_i) to the node/tag who does not know its position and in the second phase node/tag determines its position (x_i', y_i') based on the information of the position from the neighboring tag/node given by (2.4) for CL and (2.5) for WCL.

$$(x_i', y_i') = \frac{1}{n}\sum_{j=1}^{n}(x_j, y_j) \quad (2.4)$$

$$(x_i', y_i') = \frac{\sum_{j=1}^{n} w_{ij} \times (x_j, y_j)}{\sum_{i=1}^{n} w_{ij}} \quad (2.5)$$

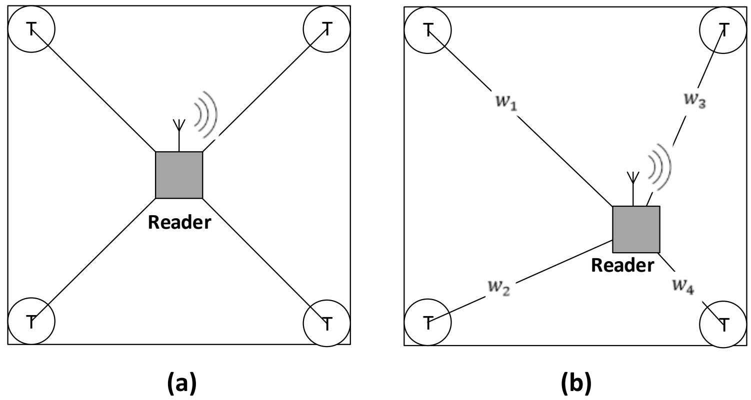


Figure 2-12:(a) Centroid Localization; (b) Weighted Centroid Localization

Approximate Point in Localization (APIT)

APIT [31] is used to localize an object/tag in a distributed network type setting. Several tags/nodes are distributed in an area and each node tries to estimate its position by listening to neighboring tags/nodes who have already discovered its position (referred as anchor nodes). Beacons from three anchor nodes are chosen by the tag/node to test if it lays inside the triangle formed by connecting the anchor nodes. This procedure is repeated and the triangle is narrowed down, until all possible groupings of anchor nodes are exhausted or the desired accuracy is achieved. Once this narrowing down operation is complete the node/tag determines its position to be the center point of the smallest triangle. This process is known as APIT, shown in *Figure 2-13*. *Figure 2-13* shows the possible triangles in which tag/node can lay, out of which the central point of smallest possible triangle (marked by solid lines) is chosen as the tag/node's position.

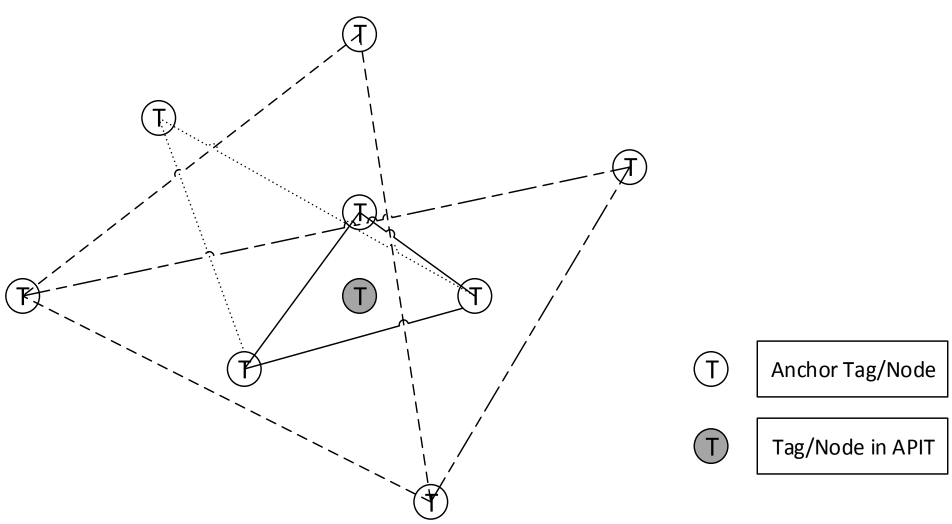


Figure 2-13: APIT triangular narrowing

Dead Reckoning (DR)

Unlike other localization method, this method does not rely on information from different reference or anchor tags/nodes. In-fact once the position of the tag/node is established, consequent positions of the tag/node can be determined using direction (AoA) and speed of travelling [32]. Due to the characteristic of this algorithm, it is not suitable for stationery nodes. However this algorithm is often applied as a filter on several localization techniques mentioned above to aid in localization of moving tags/nodes.

2.4.3 Related Work – Indoor Location Estimation

Today industry and academia both are doing extensive research on Indoor Location Estimation. The following text will highlight some of the existing solutions in this domain. Several technologies such as infrared, ultrasonic, RF, RFID are used in different setup to accomplish indoor localization.

One method that utilizes Active RFID for indoor tracking is known as LANDMARC (LocAtioN iDentification based dynaMic Active Rfid Calibration) [27]. The method uses reference tags to locate objects (Tracking Tags). Several reference tags are distributed in the environment and the readers can send query at different power levels ranging from 1-8. In the first stage, depending on which power level the tag responds an approximate location of the tracking tag is determined. However due to complex indoor environment the RSS values can fluctuate rapidly and an estimate solely based on RSS is not reliable. This is where reference tags are helpful because along with tracking tag, reference tags neighboring tracking tag, also respond. Based on the received RSSI of the reference and tracking tag, a Euclidean distance is determined between reference and tracking tag. Once Euclidean distance for all tags are known the location of the tracking tag can be detected by the nearest k algorithm. The system can be configured to use multiple reference tags as nearest tags. Higher the number of reference tags used the higher will be the accuracy of estimation. Therefore the tracking tag coordinates can be found by using (3.1).

$$(x, y) = \sum_{i=0}^{k} w_i (x_i, y_i) \tag{3.1}$$

Where w_i is the weight of the i^{th} reference tag. Giving equal weight to all reference tags will induce error therefore the authors propose to assign highest weight to the reference tag with lowest Euclidean distance given (3.2).

$$w_i = \frac{1/E_i^2}{1/\sum_{i=0}^{k} E_i^2} \quad (3.2)$$

In the best case scenario for *k=4* the average error for the LANDMARC was found to be 1.09 meter or ~42.9 inches. However these results varies also with the number of readers used and strategy of placing reference tags. Similar method is implemented in [33] where the authors use two readers with known location of landmarks. The location of the tags is calculated to obtain a set of data for locations. This data is further compared with pre-known positions and simple MMSE algorithm is applied.

In [34] the author presents a solution for indoor location estimation using Angle of Arrival method. Two readers are placed on two corners of the room. Passive UHF tags are scattered in the room. The directional reader antennas are mounted on stepper motors which are moving at a constant angular velocity. Since passive tags are used so whenever the tag comes in the angular beam of the antenna they respond and as soon as the beam moves away the tags stop responding. Therefore the angular velocity of the stepper motor and the time at which the reader was able to read the tag can be used to estimate the angle of arrival for both the readers. Once the AoA is known triangulation technique can be used to estimate the location of the tag. The accuracy of the location estimation is the function of angular velocity of the stepper motor: At 10 degree per second the error for stationary tags is reported to be 20%; whereas at 90 degree per second the error rises rapidly to as high as 78%. From the error information it can be concluded that the minimum error at 10 degree per second is equal to 1.4 meter or 55.1 inches (20% of the length of the room used for experimentation).

A similar stepper motor concept is also applied in a system known as Sherlock [35] but with addition of cameras. The fine grain sweeping of the area to detect passive RFID tags using directional antennas is the key to Sherlock, this end is referred as RFID endpoint. But contrary to [34], Sherlock antennas also have the ability to change power levels continuously thus giving it ability to approximate tags' range. Antenna sweeping along with switchable power levels and read rate all encompass in Sherlock to locate objects/tags. The most recent detection of the object/tag along with the antenna from which it was detected is updated at the software side. The next is camera end point, which is responsible to get the visual description of a new object that enters the area. Once the RFID endpoint discovers and identifies a new tag/object the camera synchronizes with the reader direction and captures the image of the object. This image is then stored in a database along with existing objects/tags. Once the entry in the database is made the user can simply search for the object from the database and Sherlock can point to its last known or current position. According to the author Sherlock has the ability to locate most of the objects (90%) with the accuracy of 0.55 cubic meter or 21.65 cubic inches.

In [13] an improved Weighted Centroid Algorithm (WCL) which the author refers to as DWCL. In this method the WLAN access points are used and RSSi is used as the matric to assign weights. The author explains that in conventional WCL algorithm weight w_{ij} is given by received power P_{rx} raised to a static measured coefficient g_s given as $w_{ij} = {P_{rx}}^{g_s}$. However author claims if this g_s is dynamic instead of static then the error can be reduced as much as 30%. In order to prove the claim the author used for WLAN access points and ran WLAN algorithm with different g_s values to find $g_{opt}$for each position. $g_{opt}$was now characterized by region, and based on comparative RSSI values from AP's, a table was built to divide the region into sub regions. Based on this table once the sub region is determined g_{opt} and other balancing equations are used to calculate the position. The initial scanning to find g_{opt} however is not the most efficient method.

Distributed RFID tag network is another interesting approach that has been used by researchers for localization [36]. [37] and [38] both use the same distributed RFID tag network in a grid formation to localize robots. Robots carry the reader which detects the tags in its range, based on which the location of the robot is determined. This method is known as proximity detection based localization. But since this method requires the mobile objects to carry readers, this makes this solution expensive and impractical to implement at a larger scale. In our localization technique, we use a similar grid formation based RFID tag networks but instead of a reader, our method uses a tag that can sense proximity of other tags making it a more practical solution.

Use of passive tags for location estimation is also a very interesting approach. The low cost of the tags, in a passive system, provides inexpensive scalability options. In [39] author presents such an approach where passive tags are used as reference tags, along with a new tag referred as Sense-a-Tag (ST). ST has the ability to sense the communication between the reader and the tags and to backscatter the sensed information to the reader. ST implements a novel locator protocol which allows it to convey binary associations with the tags in the vicinity. Locator protocol has two states: *Listen*, for collecting information on tags in the vicinity; *Respond state* which allows the ST to act as a tag and relay the information collected to the reader so that localization algorithm can be performed. Since ST can sense only those tags which are close to it, this information can be used to track ST. [9] presents a similar approach based on the same hardware mentioned in [39]. In [9] author deals with localization of stationary objects, while [39] in contrast deals with tracking moving objects.

In [40] author describes a system for localization based on ultrasonic and zig-bee technology. The ultrasonic sensors work on the principle of TOA whereas the zig-bee devices are tuned to work and localize based on RSSI values. The information from both the sources is calculated on a central server and (x,y) coordinates of the node is determined.

Indoor location estimation not only interests academia but in fact a lot of work has been performed in the industrial sector as well. Patient safety in hospitals and nursing home offers opens a huge opportunity for the industries to enter the market with solutions. Stanley Healthcare is one of the biggest names today providing solutions to the market. Some of their famous solutions include RoamAlert [8], WanderGuard [41] and Fall Management [42]. While RoamAlert keeps track of the patients in the nursing home or a hospital, WanderGuard is designed for wander prevention whereas Fall Management system has been designed to monitor if the patient has taken a fall. A typical RoamAlert system contains: RoamAlert tag for the patients designed to be worn on wrists or ankle; Asset tag designed to attach to the valuable equipment so that they can be found in a timely manner; Door Controller which basically is the tag reader and control who accesses the door; Elevator Controller, similar function to the door controller but has been designed to control elevator access; Display for the client PC from which a client can monitor all the progress and network to connect and integrate all these parts. In addition to these different parts RoamAlert has some optional alarm modules that can work as event driven triggers such as if the patient has been trying to exit through a particular door for more than 55 seconds. WanderGuard on the other hand can be said a smaller version of RoamAlert. It just works as an access control to the doors and prevents patients from eloping the hospital or the nursing home. Like all other solutions presented by industry, Stanley Healthcare solution is also very expensive which is a drawback considering that it will not be adopted by smaller and low budget hospitals and nursing homes.

Summary

Table 2-3 provides a summary of the popular location estimation systems from the industry and the academia. Location estimation system presented in *Table 2-3* comprise of various technologies ranging from infrared to Wi-Fi to RFID. All these systems calculate positions based on different techniques.

Table 2-3: Different Indoor Localization Solutions

SYSTEM	TECHNOLOGY	METHOD	ACCURACY	PROS/CONS
COMPASS [43]	WLAN	Radio-map	~2m	P: Takes into account orientation of the user. C: Multi user scenario not considered
EKAHAU-PATIENT SAFETY [44]	RFID over Wi-Fi	RSSI	Sub Room	P: Low power & small wearable devices comparable to Active RFID. C: Low Accuracy
SONITOR SENSE [45]	Ultrasound, Wi-Fi, LF RFID	Combination.	Sub Room	P: Easier Deployment, Multiple Sensors on tags. C: Low accuracy
UBISENSE [46]	UWB	TDOA, AOA	~<10cm	P: High Accuracy, Large Coverage Area, No LOS restriction C: Expensive, Same hardware resources required for smaller areas.
ACTIVE BAT [47]	Ultrasonic	Multilateration	~<5cm	P: Large area coverage, high accuracy C: Prone to reflections, Large number of transmitters on ceiling
ROAMALERT [8]	RFID, Wi-Fi	unknown	<3.3m	P Small wearable tags C: Expensive and Low Accuracy
AEROSCOUT RTLS [48]	Active RFID & Wi-Fi	TDOA & RSS	~5m	P: Sensors and Technology provides crosschecks within system components. C: Low Accuracy, Expensive

ACTIVE BADGE [49]	Infrared	RSS	Room	P: Solves privacy related issues C: Low Accuracy, Slow, LOS problems
IRIS-LPS [50]	Infrared	Triangula-tion	˜ ±16%	P: Covers a large area C: Possible interference from other light sources
THIS DOCUMENT	Active RFID	Proximity	25 cm	P: Low cost power, Cheap, Large area C: Lengthy deployment time
SENS-A-TAG [39]	Semi-Passive RFID	Proximity	30 cm	P: Low power, cheap C: Accuracy dependent on tag density.
LOST [51]	2.4 GHz (zigbee, wi-fi compatible)	TOA	Sub meter	P: designed to co-exist with exist-ing 2.4 GHz infrastructure. C: Tag size, difficult wearable.
SHERLOCK [35]	Passive RFID, Camera	AOA, RSS	0.55 m^3	P: Visual support to user using cameras. C: Complexity and Cost

2.5. Introduction to Occupancy Detection

By definition any sensor that can detect human presence in a particular space can be regarded as an occupancy detection sensor. Today ranging from smart spaces, smart buildings to healthcare to transportation all can benefit from occupancy detection in order to utilize resources in an efficient manner. On one hand where occupancy detection can be used to conserve energy [52], similarly at the same time occupancy detection can be used to detect human presence in the restricted areas, catering human safety [53].

. All occupancy detection methods, consists of the basic structure mentioned in *Figure 2-6.* Perception Layer block usually consist of on-site sensors that collect data real-time from the environment. Network Layer connect the sensors with the *Application Layer* where all the processing is done and decisions for *Actuation Layer* are released.

Some of the popular sensors or methods that are used for occupancy detection are [54]:

- Infrared Motion Detectors: Passive infrared detectors can sense minute heat changes over a small duration of time, detecting human presence in the area of deployment [54]. These sensors are perfect for light control type standalone applications which do not require much of processing. Integration of infrared sensors with network devices such as Wi- Fi and Zigbee can solve networking challenges and can be used for large deployments.

- Ultrasonic sensors: Ultrasonic sensor also has the ability to detect human presence environment. Just like infrared sensors these sensor also need to be combined with network modules for large scale deployment.

- Photoelectric and laser based sensors: These sensor incorporate laser ranging methods for detecting occupancy status. Although laser sensors are very accurate but still they are the least popular of all because of high cost.

- RF based devices such as RFID, Zigbee, Wi-Fi etc.: RF based methods are the most interesting methods for occupancy detection because these devices have their unique identification metrics which can be associated to the object carrying the device. Thus not only can occupancy detection can be performed but questions like who occupies can also be answered.

- Vision based: Uses cameras and vision processing techniques to identify human presence in a particular space. This method is expensive and requires very sophisticated image processing techniques to be effective.

2.5.1 Related Work – Occupancy detection

Occupancy detection have been an area of interest for researchers not only in healthcare but also in smart offices and smart places. Today Occupancy detection is not only being used as means to conserve energy but also to monitor spaces. One important application that relates to the one of the application presented in this thesis is to detect room that has been occupied, and visited by the patients. This type of application can also do a coarse indoor location estimation of the patients and it can also be used to analyze coarse daily movement patterns of the patients. Although the application have been accomplished in this thesis using RFID proximity detection however today this application has been implemented with several different technologies. One such method is Doorjamb [55]. In door jamb ultrasonic range finders are mounted above the doors in the doorway of the building. The idea presented in the paper is to detect the person as they walk through the doors of the building and keep a track of each person as they go from rooms to rooms. However the metric that is used to identify the person is height, which can work if deployed in the environment where only a few people are present and each one of them have different heights. Therefore identifying people using height will always be ambiguous. Even if the complete path of a person can be monitored all the time introduction of another person with the same height can affect the accuracy of the system severely. The unobtrusive nature of the system is its advantage. Whereas identity detection based on height of the person is not a robust metric for identification. Another system that utilizes ultrasound is WALRUS [56]. In [56] author proposes to use microphone of a PDA device as the receiver for acoustic signals generated through simple speakers of a computer. The PDA runs the software that can log the 802.11 datagrams along with listening to the acoustic signal. The ID of the room is not embedded in the acoustic signal in fact is a correlation function of 802.11 data packets and acoustic signals. The author claims that this type of arrangement reduces the computation complexity and provides enough accuracy to localize up to a room level.

Use of camera have also been a solution explored for occupancy detection, [57] presents an image processing based occupancy detection. The author claims that although passive infrared can detect the occupancy status however its inability to detect the number of people in a particular room is a disadvantage. Therefore the method proposed by author is more robust in that regard as it has the ability to detect occupancy of the room along with number of occupants in the room. However the fact that author uses only the head type blob shape to count the number of occupants can result in false alarms as indicated by the results by the author. However the author presents two suitable image processing techniques; direct gradient map matching, detects number of occupants with an accuracy of 84% and canny edge detection with an accuracy of 76%. However all the results reported have been tested on just 10 pictures and no real situation experiments have been conducted which is a big disadvantage. Therefore practicality of this system is a big question mark.

Infrared is another technology that have been used widely to detect room level localization for the application of occupancy detection. Although most of the infrared based solutions and patents are implemented for energy conservation including [58], [59], and [60] but still some solutions such as [49] have been designed to serve to detect occupancy detection. Active badge [49] uses RSSI do detect room level presence. Unlike most of the infrared based solutions where occupants information is unavailable, [49] can provide identity details of the occupant.

Another solution for occupancy detection is using WSN (Wireless Sensor Network) [61]. On the sensor side PIR (Passive Infrared Sensors) are used. In case of no movement PIR can fail to detect presence therefore microphone are attached so that human created noise can be detected to provide redundancy for the PIR sensors. A hierarchal Zig-bee based network topology was implemented where sensor node communicates to cluster head node, cluster head communicates to the router, router communicates to the gateway and the gateway communicates to the sink. Author provides with a deployment strategy and claims the accuracy of 100%.

Summary

In summary all the above mentioned techniques are robust enough for occupancy detection. But multiple application support, such as fine grain localization within a room etc., of these systems is a question mark. *Table 2-4* provides an overview of the solutions discussed.

Table 2-4: Occupancy Detection Solutions

SYSTEM	OCCUPANCY DETECTION (OD) TECHNIQUE	MULTIPLE APPLICATION SUPPORT	PROS (P) AND CONS (C)
DOORJAMB [55]	Ultrasonic	Possible	P: Accurate OD C: Frail occupant Identification
VIDEO BASED [57]	Camera	Not Possible	P: Sophisticated Image Processing technique C: No Practical Implementation, frail occupant identification
ACTIVE BADGE [49]	PIR	Possible	P: Robust Occupant Identification C: Heavy infrastructure cost
WSN [61]	PIR and Microphone	Not Possible	P: Accurate OD C: No Occupant Identification

Chapter 3. The Active RFID System

The description of how an Active RFID System works is given in Section 2.1.3. This section is dedicated to describe in detail the RFID system which we have used in order to complete the goals of this thesis.

For the thesis, we have used an active system from a German company known as Bitmanufaktur. Bitmanufaktur have been working on open-platform RFID systems which can be used in industry and academia for research. The open-platform known as "Openbeacon" is what we have chosen to work on.

3.1. Description of OpenBeacon Active RFID System

Just like any other RFID System, OpenBeacon also comes with three basic components.

- Reader (OpenBeacon Ethernet EasyReader PoE II, see appendix A for description)
- Tag (OpenBeacon Proximity Tag)
- Middleware Application (OpenBeacon Tracker Application)

The reader and tag can be characterized as the hardware portion of the system whereas Middleware Application can be characterized as the software portion of the System.

3.1.1 OpenBeacon Hardware

OpenBeacon Proximity Tags

Overview

The OpenBeacon proximity tags are Active tags and they operate in beacon mode. The frequency of operation is 2.45GHz and the tags have the ability to detect the presence of other tags in their proximity. Each tag is also equipped with resistive touch sensor. Each tag has its own ID which they transmit periodically. Typically transmission from the tags is encrypted using "XXTEA" cypher. *Figure 3-1* displays the block diagram of the tag. At the hardware layer, each tag consist of a Micro-processing unit, RF Chip and Antenna.

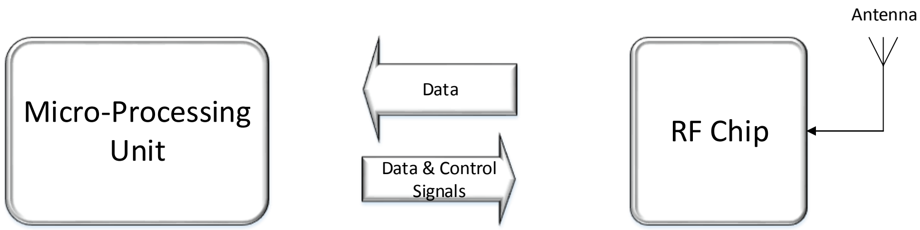


Figure 3-1: Block Diagram - OpenBeacon Proximity Tag

Each tag consists of following major components, shown in *Figure 3-2*: OpenBeacon Proximity Tag. (a) Back (b) Front

- Micro-Controller (MCU): Microchip PIC16F688/PIC16LF1825 [65] [66].
- RF Chip: Nordic Semiconductor nRF24L01 [67]
- Antenna: Rainsun AN1003 [68]

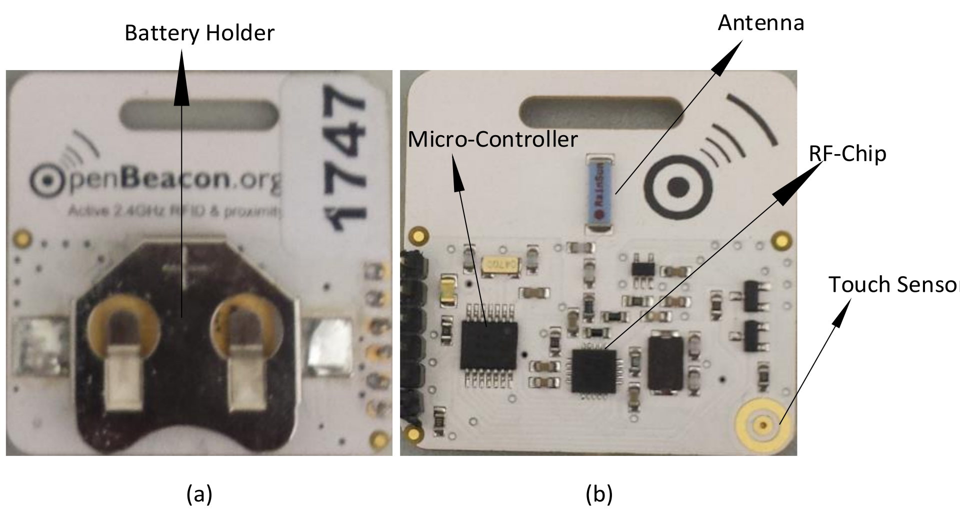


Figure 3-2: OpenBeacon Proximity Tag. (a) Back (b) Front

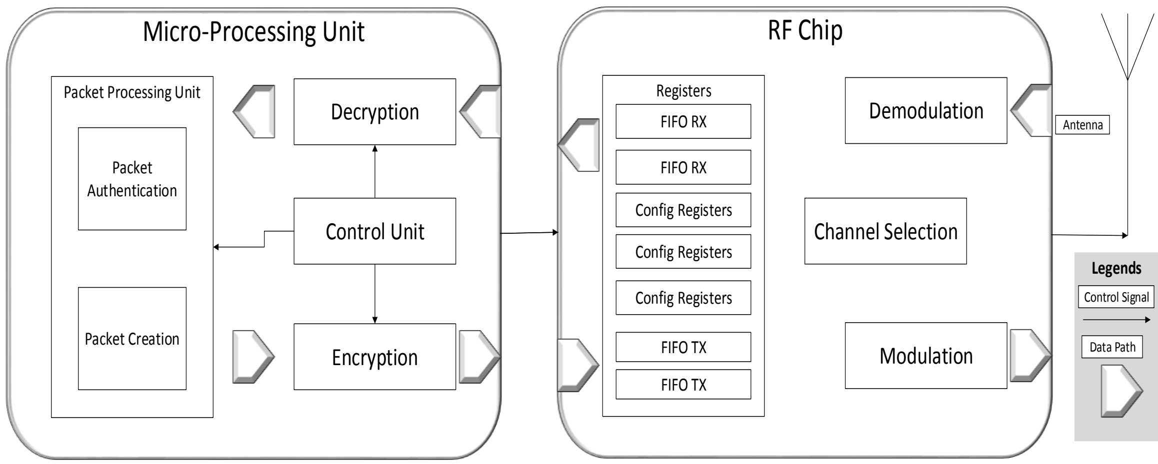


Figure 3-3: Detailed Block Diagram - OpenBeacon Proximity Tag

The control unit, which in case of OpenBeacon proximity tags is PIC16F688/PIC16LF1825, controls the blocks of micro-processor unit, as shown in *Figure 3-3*, and it also controls other chips, such as RF unit on the tag and is responsible for transporting packet to and from the RF-Chip. Decryption and packet authentication along with encryption and packet creation is done in the Micro-processing Unit. In the RF chip there are several registers. The registers that set up the configuration of operation are mentioned in the block diagram as the “Config Registers” whereas the RF chip also contains two types of data registers dedicated to incoming and outgoing data packets mentioned as “FIFO TX and FIFO RX” in the block diagram. There are five registers dedicated to incoming and outgoing packets each. Each data register is capable of storing up to 32 bytes of data. The RF chip operates at 2.4 GHz range and consist of 126 channels. The bandwidth of each channel is 1 MHz or 2 MHz depending on the data rate chosen for operation (1 Mbps or 2 Mbps). The modulation scheme used by this particular chip is GFSK (Gaussian Frequency Shift Keying). “Config Registers” are used to select options, such as data rate, channel selection, transmitting power etc., whereas “FIFO RX” and “FIFO TX” registers are used as buffer registers to transport packets in between the RF Chip and micro-processing unit.

Packet Structure

Each packet received at the middleware software consists of 32 bytes, shown in *Figure 3-4*.

Since the protocol used is UDP, first eight bytes are occupied by the UDP Header. Next three fields, sequence, timestamp and reader ID are filled by the reader whereas rest of the 16 bytes of information comes from the tags. Order of the fields depends how the packet is handled by the middleware application (big endian or little endian), therefore the field order shown in *Figure 3-4* does not portray exact order. Details of the fields are as follows:

- **Sequence (4 bytes):** tells about the packet sequence number processed by the reader, field is populated by the reader.
- **Timestamp (4 bytes):** Marks the packet with the time at the reader, field populated by the reader.
- **Reader ID (2 bytes):** Embeds the reader ID in the packet, field populated by the reader.
- **Strength (1 byte):** Contains information regarding the strength at which the tag transmitted the power, field populated by the tag.
- **Packet Type (1 byte):** In case of different types of packets sent by the tag, this field is used to indicate what kind of packet is being transmitted so that the middleware application can adapt accordingly.
- **Tag ID (2 bytes):** indicates the ID of the transmitting tag.
- **Flag (1 byte):** indicates the use of the touch sensor at the tag.
- **Proximity Tag ID (2 bytes):** Indicates the ID of the tag detected by the transmitting tag.
- **Sequence:** Packet sequence number of the tag used for tag to tag communication.
- **Tag CRC:** Checksum for tag to tag, tag to reader, tag to middleware communication.

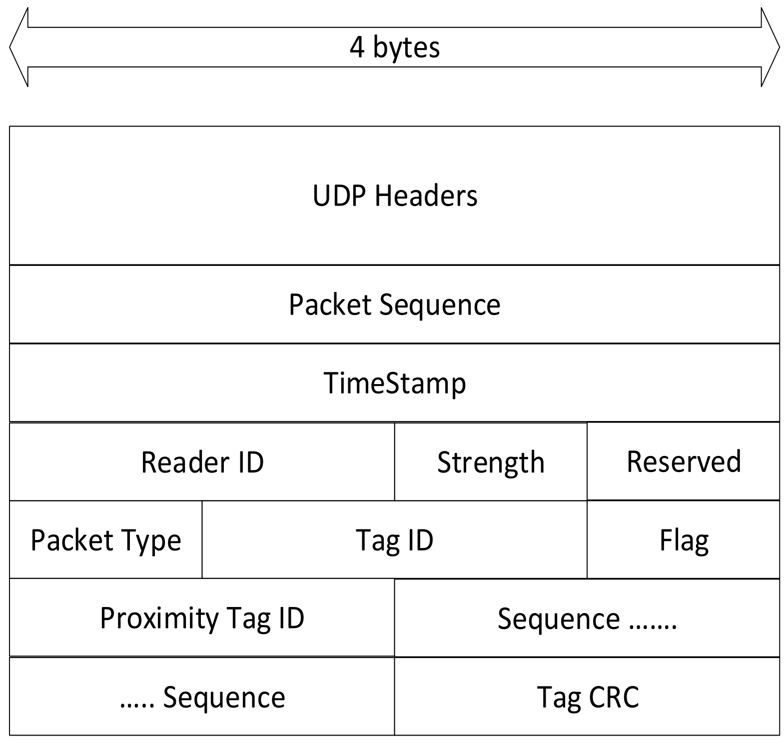


Figure 3-4: Structure of the Packet received at the middleware (not in the exact order)

Firmware

The firmware of the Openbeacon Proximity tags can be divided into four stages based on their function:

- Initialization.
- Reception.
- Packet Creation.
- Transmission.

Consider *Figure 3-5* to understand the working of the tag. Micro-processor used has a property of Power-on Reset (PoR), which means whenever the micro-processor turns on, it resets all its registers and ports. But the same resetting property is not true for the RF chip. Therefore it is important to check the configuration of the RF chip before proceeding. So an initialization sequence has to run in order to set the tag to the required condition of operation. So configuring it to transmitting channel is the first task. Once the initialization is accomplished LED on the tag blinks to show that the tag is ready to use. This stage is referred as *Initialization Stage.*

In the *Reception Stage,* the tag switches to the Rx channel and checks if any other tag is transmitting nearby. If the transmission is detected the chip buffers the packet in "FIFO RX" registers of the RF Chip and relays it to the micro-processor where it is decrypted.

Once the packet is received by the micro-controller, *Packet Creation Stage* starts. Authenticity of the packet is determined, information such as ID of the tag whose transmission has been detected is stored. The next step is to accumulate all the data about the tag and place in the packet. All the fields, tag is responsible to populate of the packet are populated in this step. The stored tag ID from the received packet is also added in the packet to be transmitted. If there was no packet received the field for the proximity ID is left blank. Once all the fields are populated the packet is encrypted using "XXTEA" cypher.
Once the packet is ready, micro-controller transfers the packet to the RF chip. RF Chip stores the packet in the "FIFO TX" buffers and waits for further instructions from the micro-controller. Now micro-controller sets the RF chip's transmission channel and transmission power and packets are transmitted.

Once the packet is transmitted the tag goes into sleep for a random interval. And the tag repeats the instructions from *Reception Stage. Initialization Stage* is not executed until the tag powers off.

3.2. Description of Customizations

The system described above has been customized and modified in order to accomplish the purpose of the thesis. The modification includes one hardware module addition, PC based middleware and firmware development for the tags, listed below:

- Relay Triggering Module (RTM).
- Mobile Tags (MT)
- Landmark Tags (LT)
- PC based middleware.

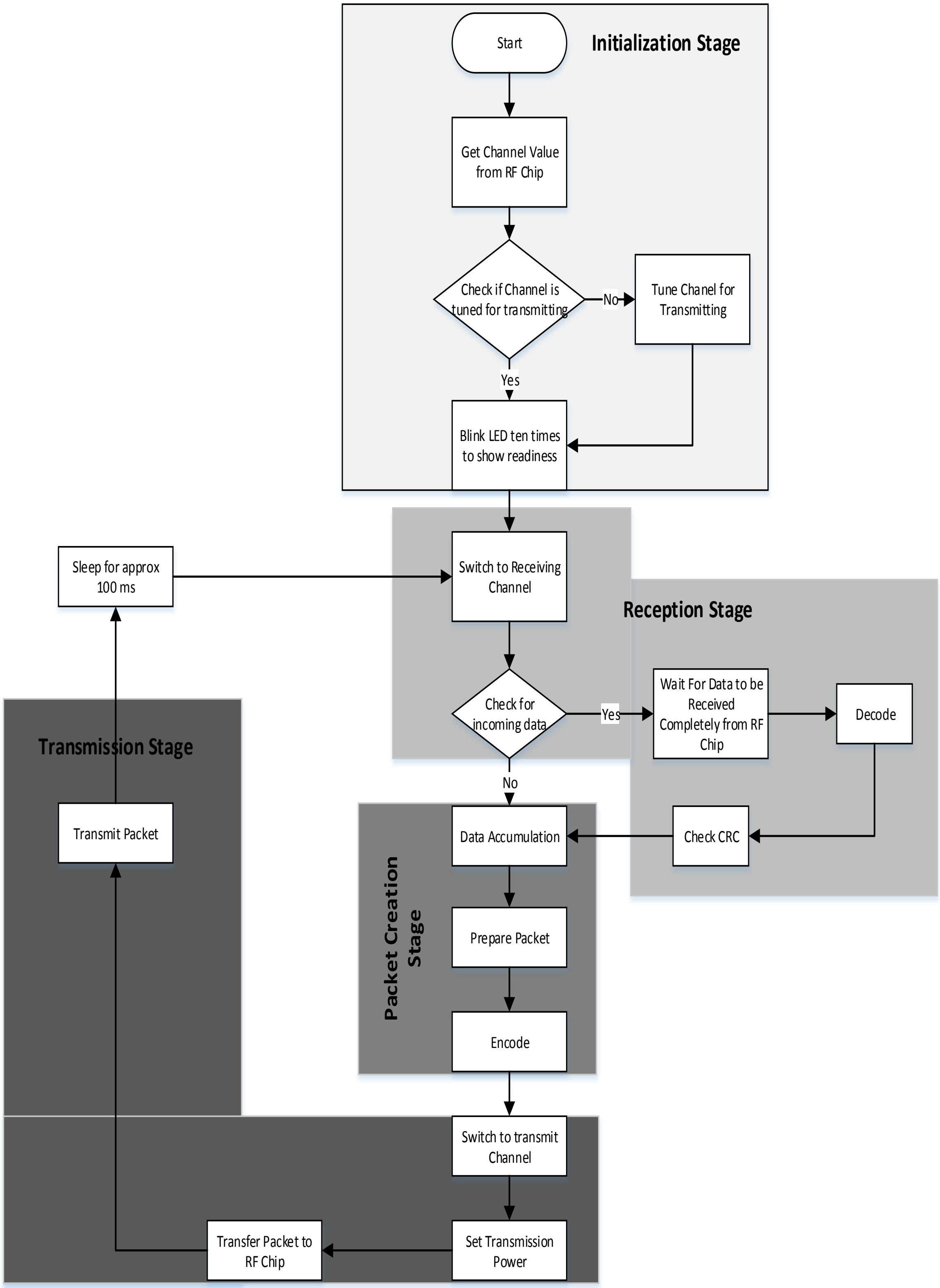
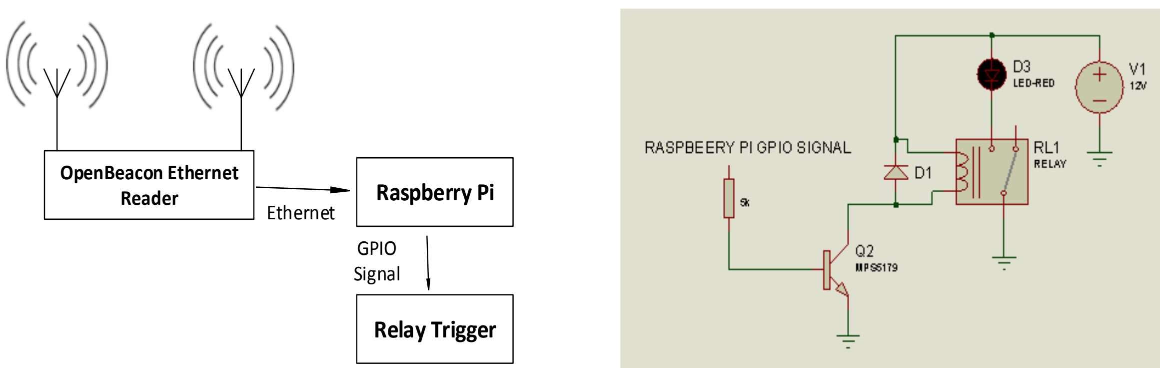


Figure 3-5: Openbeacon Proximity Tag Firmware

3.2.1 Relay Triggering Module (RTM)

In order to accomplish the task of access control we needed a hardware that can control the locking/unlocking of the doors. For this we decided to create a stand-alone hardware that can receive the data from the Openbeacon Ethernet Reader, process data and actuate responses. A proto-type RTM was made using Raspberry Pi [69] which runs a C based code to control the relay using the GPIO (General Purpose Input Output) pins of the Raspberry Pi, as shown in *Figure 3-6 (a)*. *Figure 3-6 (b)* shows the schematic of the *Relay Trigger* block shown in *Figure 3-6 (a).*



(a) (b)

Figure 3-6: (a) RTM block diagram; (b) Relay Trigger Schematic

RTM Firmware

Raspberry Pi is the main processing unit of the RTM. Raspberry is connected to the reader through an Ethernet interface. Once the packet is received by the Raspberry Pi it is decrypted and authenticity of the packet is checked. If the packet is authentic then the next step is to fetch the tag's ID in the decrypted packet. In Raspberry Pi, the list of restricted users is already stored in an array. The program looks through the array and checks if the matching ID to the tag ID exist in the array. If the ID is found the next step is to detect the direction of the tagged object. If the direction is towards the door, door is locked and a latch is placed. However if the direction is away from the door the door latch is released. Absence of the restricted tag for more than 30 seconds also releases the latch and the door is unlocked. The direction detection algorithm will be explained in the next chapter.

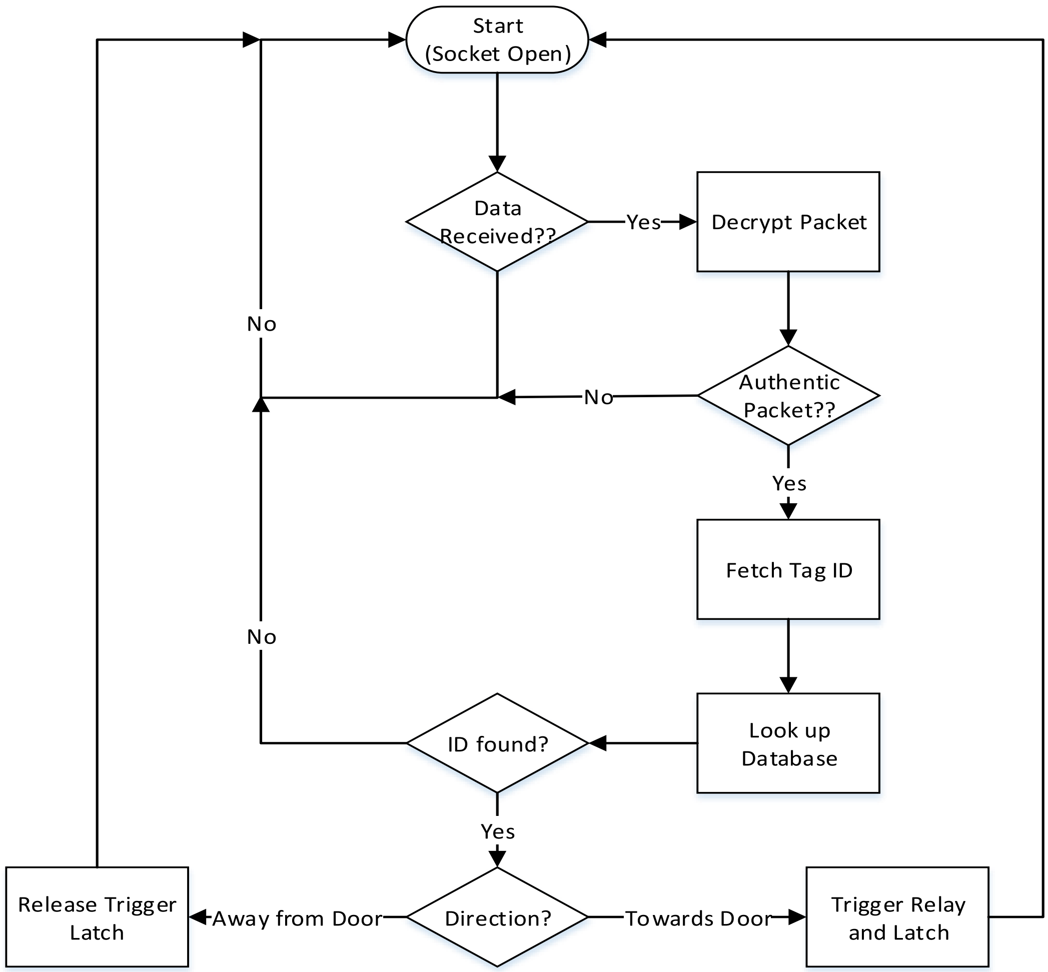


Figure 3-7: RTM Program Flow

3.2.2 The Concept of Mobile Tags (MT) and Landmark Tags (LT)

The solutions presented in this thesis are based on proximity detection and that is the reason why OARS is chosen as the development system. Although the proximity tags from open-beacon can detect proximities but still the performance of proximity detection needed to be improved in order to be used effectively. The goal to improve proximity detection rate and review of state of the art lead us to the concept of MT's and LT's.

MT are those tags that will be attached to person or object. MT's are programmed to work in beacon mode and they transmit periodically after a set delay. RF chip on the tags is capable of transmitting at four different power levels: -18 dBm, -12 dBm, -6 dBm and 0 dBm. A counter index “N” is used as a counter to transmit three packets at present power level before switching to the next power level. Once packets on all four power levels are transmitted three times, the counter index “N” returns to zero and re-initiates the cycle. MT takes one second to complete one cycle of power iterations. Before transmission MT encrypts the packet that is to be transmitted. The packet structure is the same, as shown in *Figure 3-4*, except that the proximity ID field is always empty.

LT are those tags which are fixed to a known position. LT’s are tuned to work in a conditional beacon mode: they act as pure listeners until a MT comes in their vicinity. As soon as MT is detected LTs are triggered. Then the LT records the ID and transmitting power of the MT, embeds this information in the packet and transmits it to the reader. This packet at the software level is used not only to detect the proximity of the MT but also to determine the distance between the MT and LT.

MT and LT operate in complement with each other. The firmware enhancement increases the proximity report ratio which makes them ideal for proximity based applications. The performance will be discussed in detail later in this chapter. *Figure 3-8(a) and Figure 3-8 (b)* explains the working of the two tags.

3.2.3 PC based Middleware Software - Introduction

A C# based application was developed for Windows Operating System. The application is responsible for receiving the data from the reader and displaying on the GUI. The application also filters the data received and logs all the proximity reports in MS access database. Information such as Tag ID, Proximity Tag ID, Transmit Power, Date and Time is stored in the database, this table will referred as “logger”. MS Access database contains another table which is also linked with the software that contains coordinates of LT’s, this table will be referred as “LT coordinates”. Two more identical database tables exist which contains tag ID’s against nurses and patients, these tables will be referred as “Nurse ID table” and “Patient ID table” respectively. All these tables store essential information which is required to accomplish the desired applications. The introduction page of the software is shown in *Figure 3-9.* This page displays the basic information received from the reader to the user, such as which ID’s of the tags that can be read by the reader, proximity reports and further basic activity going on at that particular moment.

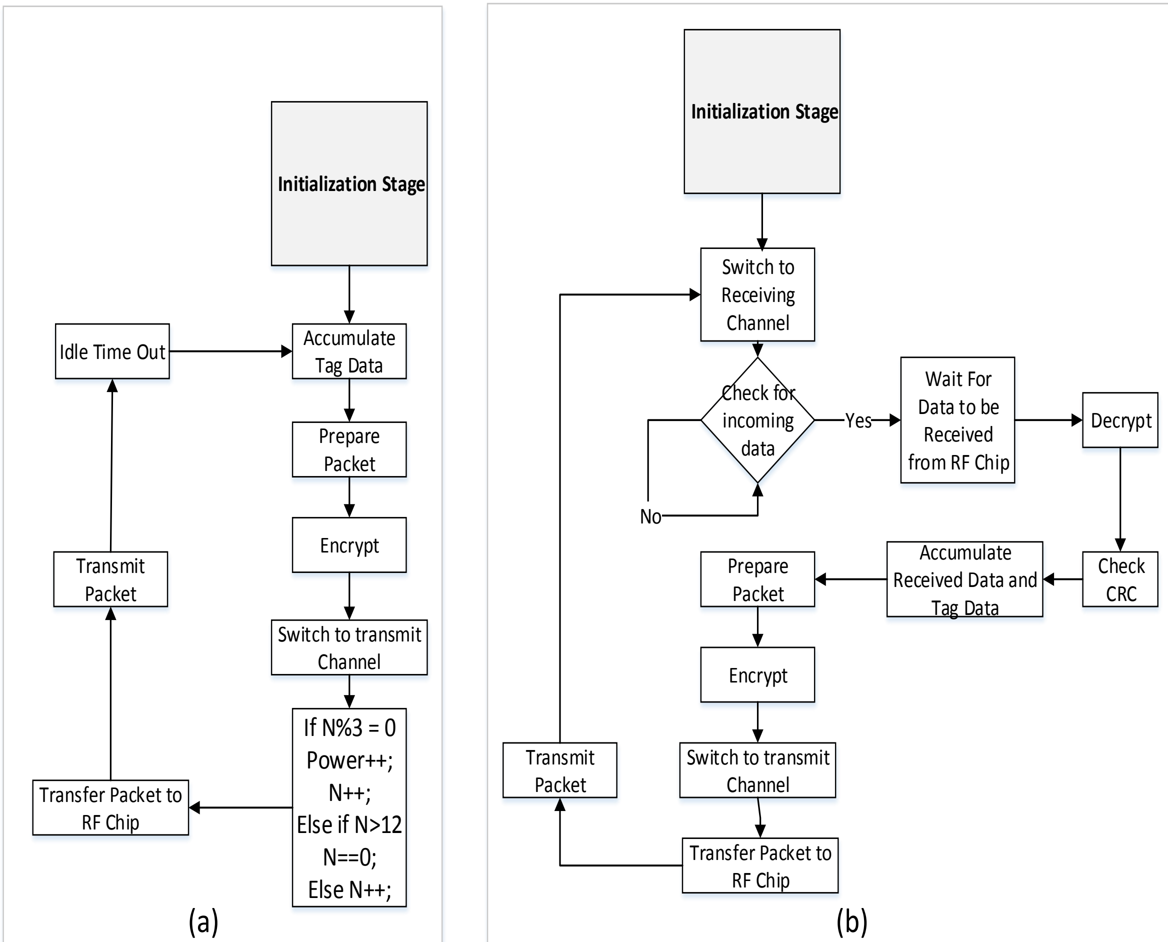


Figure 3-8: (a) MT Firmware; (b) LT Firmware

Figure 3-9: PC Application - Main Page

3.3. Performance

3.3.1 Power Consumption – Effects on Battery Life

Since active RFID tags require a power source to operate therefore analyzing power consumption to estimate battery life is necessary. Openbeacon Proximity tags operate in beacon mode and transmit after regular intervals - therefore estimating battery life is easier.

During our development we used two methods to estimate battery life: *Theoretical* and *Practical*. From the firmware we know that on average the time required by the RF Chip to transmit a packet is 2ms and on each cycle the time for listening proximity packet is defined to be 5ms, after which the tag goes to sleep for a random interval between 50ms to 92ms. From the datasheet of the chips we know the power consumption characteristic in each state. Therefore this data can be used to calculate a rough estimate.

Let T be the time taken for each cycle, Tx_t is the time spent in transmission mode in each cycle, Rx_t is the time spent for receiving in each cycle and S_t be the time spent in standby mode. Let the current drawn in each state be I_T, I_R and I_S respectively, where I_S is the regular operational current drawn by the MC and RF chip. Let the capacity of the battery be $B\ mAh$. The calculation of battery life as follows:

$$T = Tx_t + Rx_t + S_t \tag{4.1}$$

$$I_{ave} = \frac{(Tx_t \times I_T) + (Rx_t \times I_R) + (S_t \times I_S)}{T} \tag{4.2}$$

$$Battery\ Life_{days} = \frac{B}{I_{ave} \times 24} \tag{4.3}$$

Where I_{ave} is the average current drawn per cycle.

Practically, a C# based code was written that recorded the tag report time in a database. Five tags were placed 1 meter away from the reader, at a height of 3 feet from the ground. Each tag was installed with a new Panasonic 3V coin cell battery (Manganese Di Oxide Lithium [70]) with the capacity of 220 mAh. All five of these tags were tuned to transmit 10, 13, 15, 18 and 20 packets per second. Tx_t and Rx_t values for all the tags were kept constant.The first transmission received by the tags were recorded as the start time and date of that tag in the database. All consequent transmissions from the tags were recorded as the end time and date. Every time a tag reported its new transmission the end time and data was updated. This result was used to compare our theoretical results with original values. *Figure 3-10(a)* shows the results of the conducted tests, red line shows the theoretical life prediction whereas blue line shows the practical results. It can be seen that increase in number of transmissions per second decreases the life of the tags. It can be seen that the values calculated theoretically are mere estimates because some other components on tag, such as resistors and capacitors, are not accounted in the theoretical results. However still the theoretical calculation provides us a good estimate how the tags will perform in the real environment.

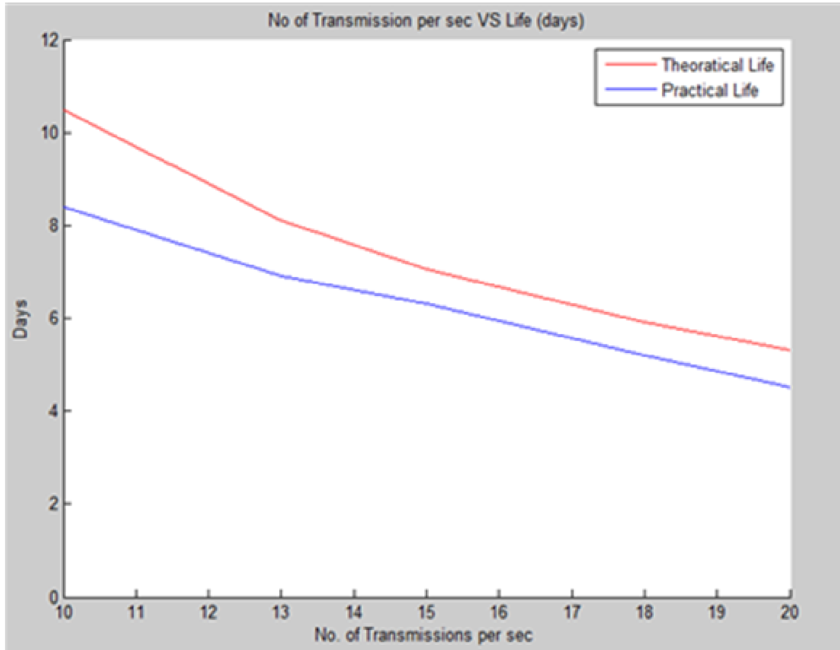
The next experiment was designed to estimate the effect of Rx_t value on the battery life. This information is crucial in order to estimate the life periods of the LT's. *Figure 3-10(b)* shows the results of the test. It can be seen that increasing the value of Rx_t decreases the life of the tags significantly because the RF Chip draws the highest amount of current while receiving. *Table 3-1* shows the

Table 3-1: Summary of Tags life on different firmwares

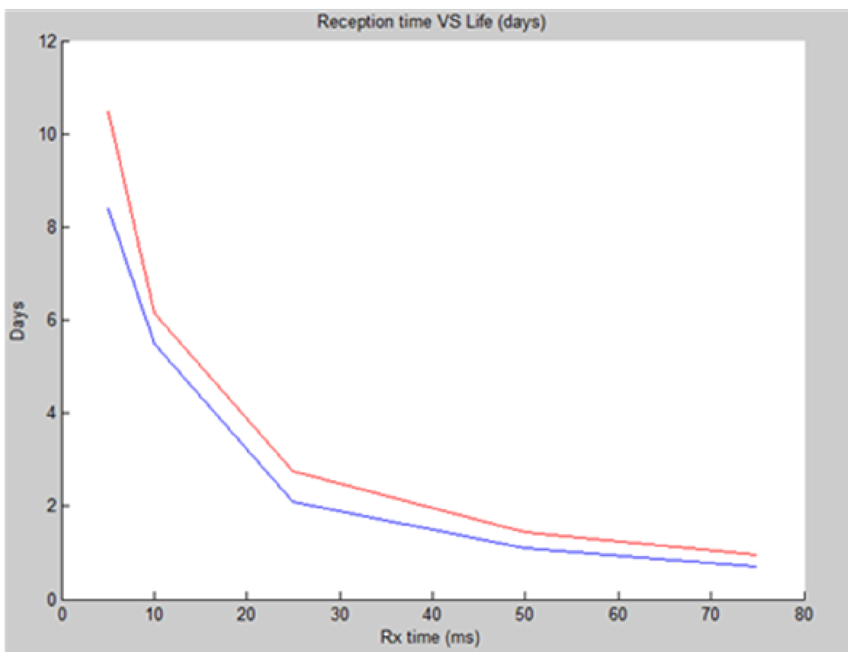
Tag Firmware	OpenBeacon (Stock)	Landmark Tags	Mobile Tags
Life	8 days	0.8 days	8 days

3.3.2 Read Rate vs. Range

The number of times a tag is read by the reader is referred as the read rate. Usually in RFID systems the read rate of the tag is dependent on the distance of the reader from the tag. Openbeacon system is also no exception. However since Openbeacon tags operate in beacon mode therefore in close proximity of the reader the read rate becomes constant and cannot exceed the number of transmissions from the tag. A series of experiments were conducted in order to determine this relation. Openbeacon tag was tuned to transmit at a maximum power level -18 dBm and number of transmissions was set to 20 packets per second. Distance was increased periodically by 10 feet and read rate was observed using the C# application. The experiment not only categorizes the read rate but also tells us the maximum range the reader can read up to in an open area.



(a)



(b)

Figure 3-10: Battery Life: (a) Effect of No. of Transmissions per second; (b) Effect of Reception time

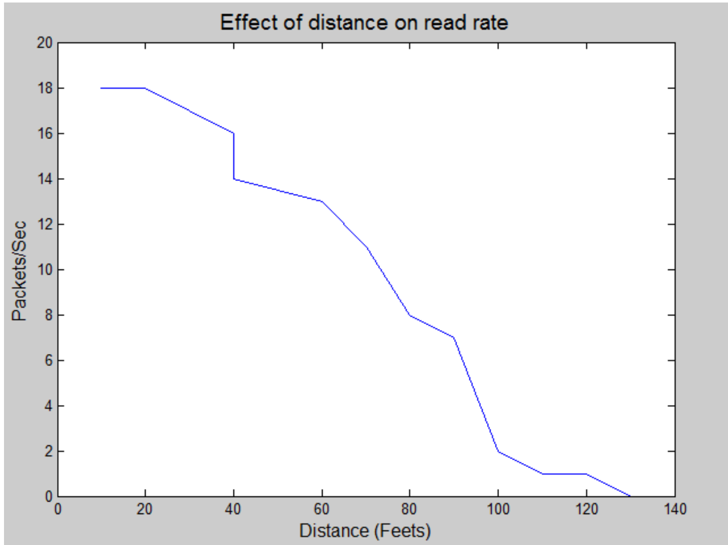


Figure 3-11: Effect of distance on the packet reception from MT

3.3.3 Proximity Detection

Openbeacon Proximity Tags have the ability to detect each other presence using tag to tag communication. However the antenna on the tags is less sensitive as compared to the antenna of the reader. Therefore the range of the tag to tag communication is shorter as well. In order to characterise the range of the tag to tag communication a series of experiments are performed.

Range - Openbeacon vs. Our System (LT and MT)

Openbeacon stock firmware vs. a combination of LT and MT was used as comparison for the proximity detection range. Tags were placed on the paper cups in an upright position, as shown in *Figure 3-12(a).* The distance between the tags was increased by five inches, step by step. Similar experiment was repeated for other two orientations shown in *Figure 3-12. Table 3-2* shows the results of the experiments and the respective range in achieved in each orientation.

(a) (b) (c)

Figure 3-12: Tag Orientations; (a) 0 degrees (b) 180 degrees (c) 90 degrees

Table 3-2: Proximity Detection Range

Firmware	Orientation (degrees)	Distance (Inches)
Openbeacon	0	72
	90	38
	180	10
LT and MT	0	100
	90	44
	180	19

It can be seen from the results that the proximity range has been increased significantly using LT and MT. The reason for this increase in range is due to the fact that the LT`s spend most of the time in listening for other tags whereas MT`s are pure transmitters. However contrary to this Openbeacon Tags are switching to listening mode for only 5% of the total time, therefore the probability of missing a transmission from another tag in the vicinity is higher and this corresponds to a lower range.

Rate - Openbeacon vs. Our System (LT and MT)

The listening time of Openbeacon firmware does not only have adverse effects on the proximity range but it also affects the rate of proximity detection. In order to determine the effect of MT and LT firmware, one LT and one MT was placed at a distance of 8 inches from each other and 3 feet from the reader. MT and Openbeacon tags were tuned to transmit at a rate of 10 packets per second. Similar setup for two Openbeacon tags was created and Performance of Openbeacon Proximity Tags vs. MT and LT was evaluated over a period of two minutes each. The experiment was repeated five times. It can be seen from *Figure 3-13*: Number of packets generated: Our System vs. Openbeacon that over a period of two seconds the proximity reports recorded by the PC software is 120 for our system vs. 60 for Openbeacon. The firmware not only improves the proximity reports but in fact reduces the congestion on the medium which consequents into lesser collisions.

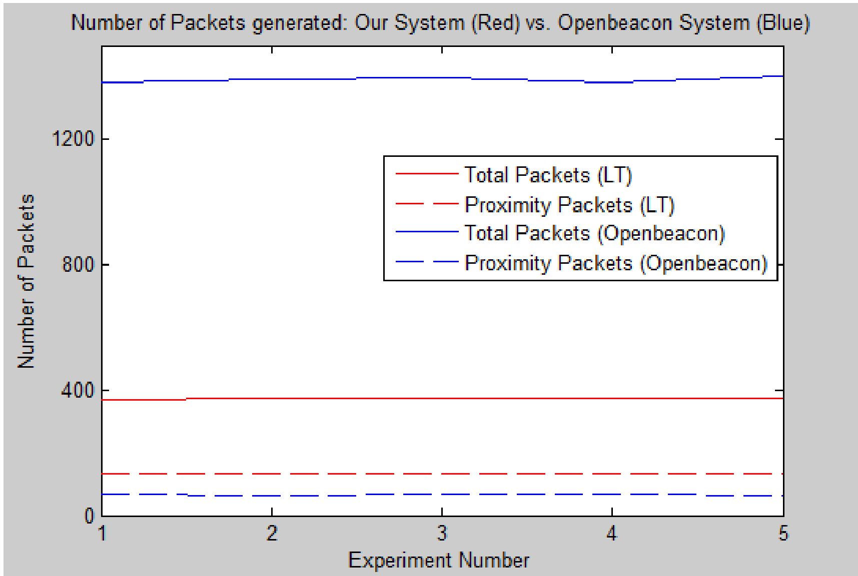


Figure 3-13: Number of packets generated: Our System vs. Openbeacon

Proximity Range Characterisation

The range at which the proximity can be detected can be used to locate tag carrying objects. Openbeacon tags have four power transmission levels and at each transmission level the proximity range is different. Similarly proximity range is also a function of the orientation of the tags and their relative position with respect to each other. In order to study the range of proximity detection all these factors are to be considered.

Thus in order to study all these relations a series of experiments were performed. All three mentioned orientations in *Figure 3-12* were explored with an LT in the middle. MT was placed at a distance from LT at 0 degree mark, shown in *Figure 3-14.* The arrow in the *Figure 3-14* indicates the front side of the tag. Distance between LT and MT was increased periodically until no proximity can be detected. This is the maximum range for the proximity detection. Tag was then moved to the 15 degree mark and same procedure to find range at this angle was repeated. A similar procedure was repeated at 15 degree intervals and range values were collected for all 360 degrees. *Figure 3-14(a)* shows the range plot in inches for 0 degree orientation, *Figure 3-14(b)* shows the plot for 180 degrees orientation and *Figure 3-14(c)* shows the plot for 90 degrees orientation.

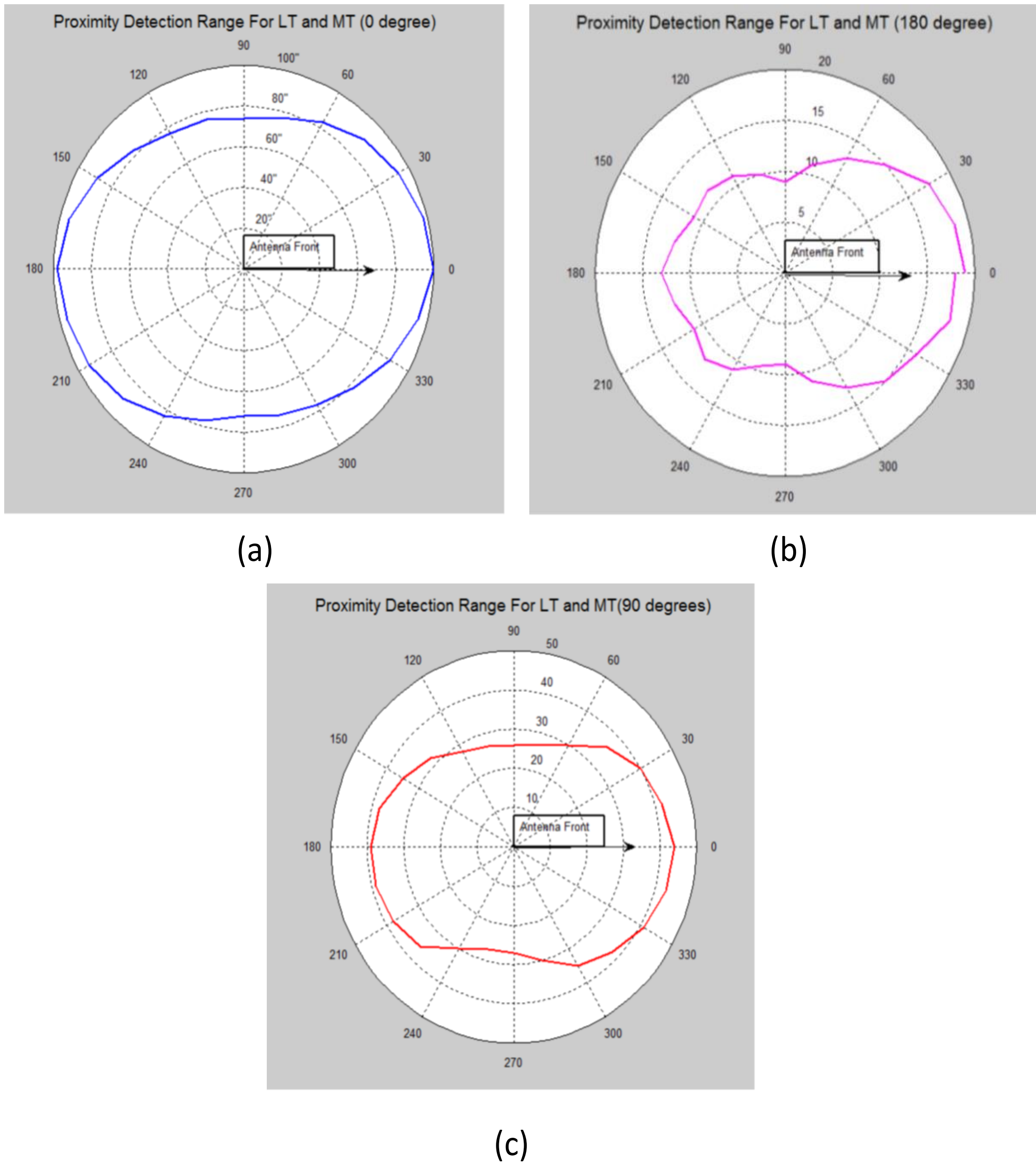


Figure 3-14: Proximity Range achieved at different LT and MT Orientations

3.4. Summary

In this chapter Openbeacon system has been explained. All the hardware specifications along with firmware specification that were offered by the Openbeacon system have been explained and discussed in detail This was important in order to describe the modifications that were made to this system. The second section of this system explained the modifications and additions, hardware in terms of RTM addition, software in terms of C# application and modification to the firmware of the Openbeacon proximity tags, categorized as LT and MT. The third and last section is dedicated to analyzing the performance parameters of the Openbeacon system and modified Openbeacon system. The performance analysis is vital for the application implementation and algorithm development.

Chapter 4. Implemented Applications

Based on the modifications that were made to the Openbeacon system we implemented location estimation and occupancy detection to measure the suitability of the modifications on the applications of smart healthcare.

4.1. System Overview

The implemented system comprise of three basic layers: *Perception Layer,* LT and MT are the two components of our perception layer; *Network Layer,* Openbeacon PoE Ethernet Reader, RTM and a work station are the network layer components of our system; and *Application Layer,* which is the PC-based application. The reason why multiple applications can be supported by this system is the fact that no changes are required at the network and perception layer. Since all algorithms for different applications uses data analysis approach therefore a multi support agent at the application layer can handle everything.

4.1.1 PC based Application Architecture

Figure 4-1 provides an overview of the PC based application architecture. Two basic units can be seen, one is *data collection unit* and the other one is *data analyzing unit*. In the collection unit, data is logged in the respected databases which are identified by looking at the ID of the LT in the proximity report. LTs that are deployed for Moving object location estimation are stored in a separate database and same is true for LTs used for Stationary Location Estimation and Occupancy detection.

However analyzing unit only runs when it is required to run. Analyzing unit keeps on looking at the database and runs when the new dataset appears in the database. Analyzing unit contains all the logic and algorithm for all the applications. All algorithms will be explained in the upcoming sections when we look in detail into application. RTM firmware contains all the logic and data it requires to run independently. Thus once the data collection unit receives data all of this data is also relayed to the RTM which then processes it accordingly. The nurse scheduling application is a branch that could be implemented using this system however in this thesis we do not implement this application.

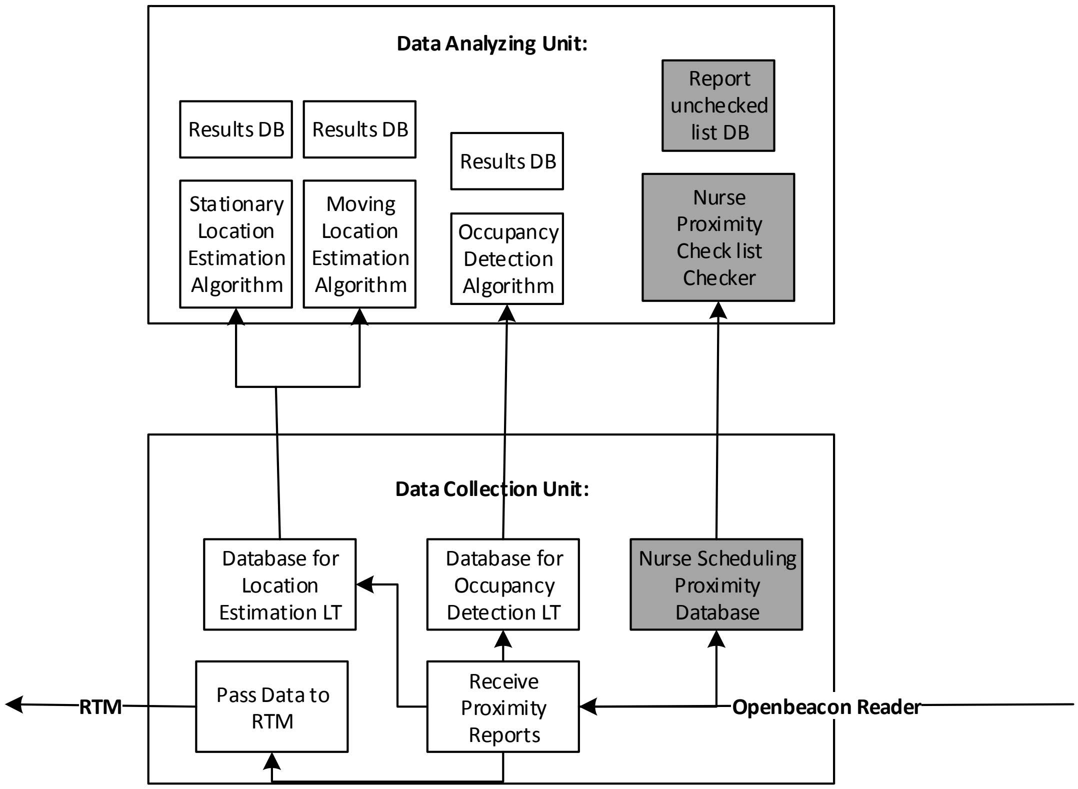


Figure 4-1: PC based Middleware Application - Architecture

4.2. Moving Object Location Estimation

In this section we show experiments conducted to detect the moving MT. The purpose of these experiment is to demonstrate the ability of the system to track and locate moving objects. This approach can be used to track patients, nurses, visitors, workers and objects. We also present PD-WCL algorithm, implemented on the modified Openbeacon system. The modifications aid PD-WCL algorithm implementation for accurate location estimation.

4.2.1 Experimental Setup

Application of tracking and locating moving objects is accomplished using proximity detection principle. Based on the requirements for this application and the method used several landmark tags (LT) were arranged in a grid formation and the principle of proximity detection is used for location estimation. Proximity detection, with different LT's, along with the transmission power information from the MT is used to pinpoint MT in the in a 2-D environment. *Figure 4-2(a)* provides an overview of how the area is covered by the landmark tags whereas *Figure* 4-2*(a)* provides a view of the internal sectors of the each block.

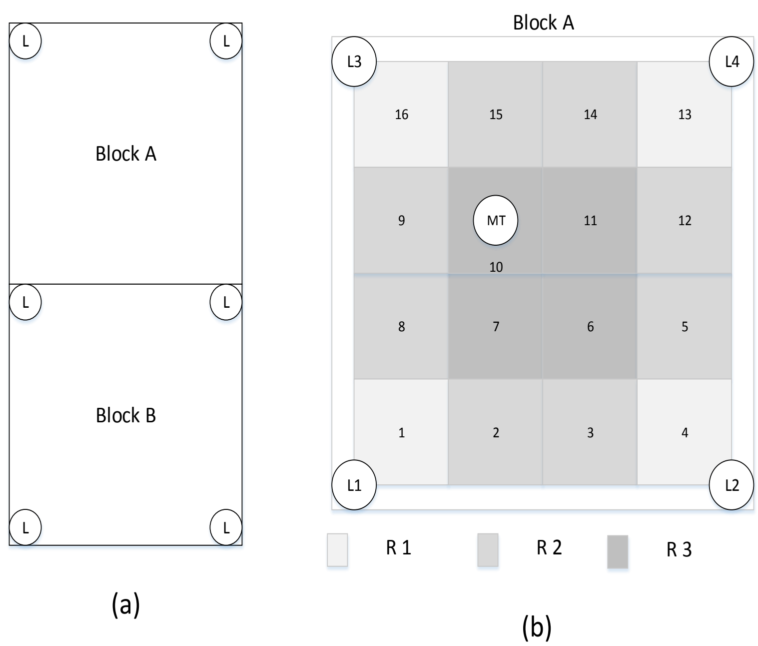


Figure 4-2: (a) Square Block layout to cover the area with tags; (b) Internal structure of each block

Each block in *Figure 4-2(a)*, is measured as 72-inches on each side, with a Landmark tag on each of its corner. Each block is further divided into 16 sub-blocks (numbered 1 to 16 in *Figure 4-2(b)*) measuring$\left(\frac{72"}{4} \times \frac{72"}{4}\right)$. The subdivision of each block is done keeping in view the proximity range data shown in *Figure 3-14*. A small area measured 144"×72" was covered by 6 LT's as shown in *Figure 4-4*. A predetermined path was marked through the blocks covered by LT's (Shown as blue dotted line in *Figure 4-4*). LT's were placed on paper cups at a height of 3.5". Considering *Figure 3-12*, 0 degree orientation between MT and LT is used. LT & MT are oriented perpendicular to the surface of the floor. 0 degree orientation covers the maximum possible area for location estimation therefore less LT's are required to cover a large area. MT was attached to a line tracking robot which was moving at a speed of approximately 2.25 inch/sec. The height of robot is 2 inches from the ground therefore a paper cup was cut so that MT and LT both can be at the same height of 3.5”. The position of the reader was such that it was able to read all the LT’s.

In a real world scenario, the idea is to attach the tags to the wrist of the person to be tracked and to deploy LT in the tiles of the floor such that the antenna of LT is perpendicular to the surface of the tile. In this set up the worst possible orientation of MT with respect to LT will be 90 degree (Right most in *Figure 3-12*).

On the software side PD-WCL algorithm is used for calculating the coordinates of the MT. Since the points are abrupt therefore a smoothing dead-reckoning filter is applied to smoothen the calculated path. Once MT coordinates are known, results are entered in the database.

4.2.2 PD-WCL Algorithm

Figure 4-3, provides an overview of the decision making components of our algorithm. Blocks, in Figure 4-2(a), are divided in smaller blocks shown in Figure 4-2(b). Each section below is dedicated to describe each stage of the algorithm.

Stage 1 - Accumulate Data

This section describes the data accumulation stage of the algorithm. Experimental setup and system characteristics ensures following:

- MT transmits first transmits at Power Level 0 (-18dBm) then Power Level 1 (-12dBm), Power Level 2 (-6dBm), and Power Level 3 (0dBm) respectively and then again rolls back to Power Level 0 and repeats the sequence.

- With every proximity report, sent by the LT, the power at which the MT transmitted is also stored by LT. Therefore the packet received at the middleware application from LT contains MT ID, LT ID and MT transmission power level.

- LT spacing ensures that during one cycle of power iteration MT is detected at least by 3 LT’s of the block MT lays in.

- During one cycle the maximum LTs reported cannot exceed the length of 4, maximum in a block.

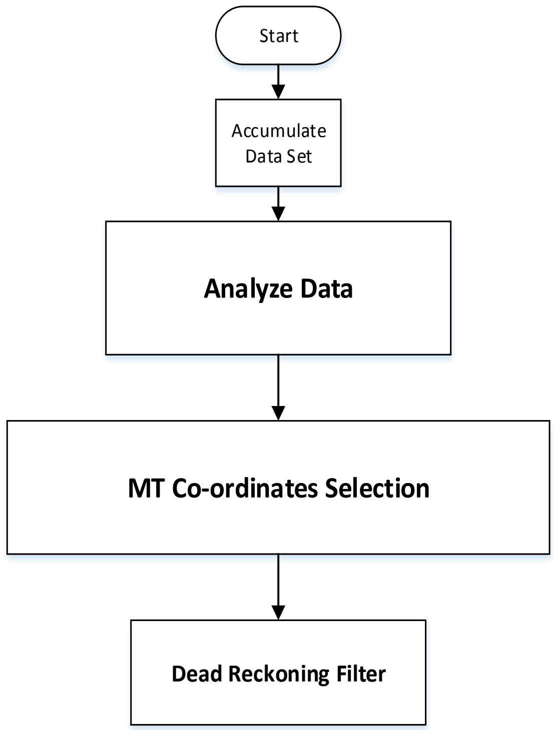


Figure 4-3: Components of Decision making process.

Stage 2 - Analyze Data

Following information can be concluded after data accumulation:

- After one cycle of power iteration (4.1) is obtained and is used to identify the block MT lays in.

- In each power iteration cycle in range LT will report, therefore the MT transmission level and positions of the LT reported can be used to assign weights. After each power iteration cycle following LT datasets can be obtained.

$$LT = \{id_1, id_2, \dots . id_4\} \tag{4.1}$$

LT dataset can be further divided into following power level (PL) conditional subsets, given by (4.1.a), (4.1.b), (4.1.c), and (4.1.d). Union of (4.1.a), (4.1.b), (4.1.c), and (4.1.d) gives us (4.1).

$$(LT|PL_0) = \{\ldots.\} \qquad (4.1.a)$$

$$(LT|PL_1) = \{(LT|PL_0) + \cdots\} \qquad (4.1.b)$$

$$(LT|PL_2) = \{(LT|PL_1) + \cdots\} \qquad (4.1.c)$$

$$LT = (LT|PL_3) = \{(LT|PL_2) + \cdots\} \qquad (4.1.d)$$

From this data we need to find which sub-block does the MT lies in. Pseudo code presented below is used to do this analysis:

$\boldsymbol{If(\ count\ LT|PL_0 == 1)}$

$\{$

$belongs\ to\ region\ R1$

$use\ (x, y) coordinates\ of\ LT\ Reported\ in\ LT|PL_3\ to\ find\ subblock$

$\}$

$\boldsymbol{else\ if\ \left(count\ LT \middle| PL_1 \geq 1\ \&count\ LT|PL_2 == 2\right)}$

$\{$

$belongs\ to\ region\ R2$

$use\ LT|PL_2\ to\ find\ possible\ side\ of\ block\ out\ of\ 4\ sides$

$use\ LT|PL_3\ to\ select\ subblock$

$\}$

$\boldsymbol{else\ if(count\ LT|PL_2\ > 2)}$

$\{$

$belongs\ to\ region\ R3$

$use\ LT|PL_2\ to\ select\ subblock\ amongst\ region\ R3$

$\}$

$\boldsymbol{else}$

$\{$

$data\ inconclusive\ MT\ lays\ in\ the\ center\ of\ the\ block$

$use\ LT\ dataset\ to\ find\ the\ block$

$\}$

Stage 3 - MT Co-ordinates Selection

The third stage is MT Co-ordinate Selection. Once the sub-block is known, MT coordinates can easily be calculated using *Table 4-1*. These fixed weighted offset values are determined based on the block size “$k \times k$”. For sub-block 1, as shown in *Figure 4-2: (*a) Square Block layout to cover the area with tags; (b) Internal structure of each block, a fixed offset value is added to the coordinates of L1 to find the position of the MT, same logic is true for rest of the sub-blocks.

Table 4-1: Fixed weighted offset used for localization.

Sub-block	Weighted Offset Output	Sub-block	Weighted Offset Output
1	L1(x,y)+($\frac{1}{8}$k, $\frac{1}{8}$k)	**9**	L3(x,y)+($\frac{1}{8}$k,- $\frac{3}{8}$k)
2	L1(x,y)+($\frac{3}{8}$k, $\frac{1}{8}$k)	**10**	L3(x,y)+($\frac{3}{8}$k,- $\frac{3}{8}$k)
3	L2(x,y)+($-\frac{3}{8}$k, $\frac{1}{8}$k)	**11**	L4(x,y)+(-$\frac{3}{8}$*k*,- $\frac{3}{8}$*k)*
4	L2(x,y)+($-\frac{1}{8}$k, $\frac{1}{8}$k)	**12**	L4(x,y)+($-\frac{1}{8}$k,- $\frac{3}{8}$k)
5	L2(x,y)+($-\frac{1}{8}$k, $\frac{3}{8}$k)	**13**	L4(x,y)+($-\frac{1}{8}$k, $-\frac{1}{8}$k)
6	L2(x,y)+($-\frac{3}{8}$k, $\frac{3}{8}$k)	**14**	L4(x,y)+($-\frac{3}{8}$k, $-\frac{1}{8}$k)
7	L1(x,y)+($\frac{3}{8}$k, $\frac{3}{8}$k)	**15**	L3(x,y)+($\frac{3}{8}$k, $-\frac{1}{8}$k)
8	L1(x,y)+($\frac{1}{8}$k, $\frac{3}{8}$k)	**16**	L3(x,y)+($-\frac{1}{8}$k, $-\frac{1}{8}$k)

Stage 4 - Dead Reckoning Filter

Dead Reckoning is an approach used in navigational systems. Speed, direction and last known location is used to approximate the current position. The output of the *MT co-ordinate selection* are scattered raw points, as shown in *Figure 4-4*. Therefore in order to smooth this path we use Dead-Reckoning filter. Let the last calculated output from third stage be (x_0, y_0) at time t_0 and the current output from third stage be (x_1, y_1) at time t_1. Since the robot travels with a constant speed “s” the maximum distance d_{max} is given by (4.2). And (4.3) can be used to calculate the distance between the previous and current calculated position. If $d_{max} < d$ then the current calculated position needs to be adjusted to such that $d_{max} = d$. The angle Θ between the two points is used as direction, given by (4.4). Based on this coordinates (x_1, y_1) are adjusted to smoothen the path through (4.5.a) and (4.5.b).

$$d_{max} = s \times (t_1 - t_0) \tag{4.2}$$

$$d = \sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2} \quad (4.3)$$

$$\theta = \tan^{-1}\{\frac{(y_1 - y_0)^2}{(x_1 - x_0)^2}\} \quad (4.4)$$

$$x_1 = x_0 + (d_{max} \times \cos\theta) \quad (4.5.a)$$

$$y_1 = y_0 + (d_{max} \times \sin\theta) \quad (4.5.b)$$

4.2.3 Results and Analysis

Figure 4-4 presents the results obtained using PD-WCL algorithm for localization. Three experimental repetitions are presented in *Figure* 4-4, so that average error estimation can be done, shown in *Figure 4-5.* The actual position of the tag is compared against the calculated position. (4.6.a) is used to calculate the Estimation Error (EE) at a particular instant in time *t.* (4.6.b) is used to calculate Mean Estimation Error (MEE).

$$EE = \sqrt{(x_n - x_{n-1})^2 + (y_n - y_{n-1})^2} \quad (4.6.a)$$

$$MEE = \frac{\sum_{n=0}^{N}\sqrt{(x_n - x_{n-1})^2 + (y_n - y_{n-1})^2}}{N} \quad (4.6.b)$$

In *Figure 4-4*, scattered green dots are the raw points calculated at the third stage. The calculation of position is dependent on the data received by the middleware. But due to collisions the probability of gathering 100% of data is less. So most of the times the algorithm calculates the position based on incomplete dataset. Due to which these raw points cannot be used to track the path. Thus a dead reckoning filter, in stage 4, can help smoothen the path and reduce the fluctuations in the raw points. The solid green line is the output of dead reckoning filter. Solid red line is the result of the second repetition of the experiment and solid black line is the result for the third repetition of experiment. Although experiment has been repeated several times but only three are presented for easier analysis. Since the robot moves at a constant speed therefore the position of the robot is known at all time during experimentation. The calculated point at a certain position after dead-reckoning filter is used to calculate estimation error using (4.6.a). *Figure 4-5* shows the EE at each point for all the experimental repetitions. Two blocks have been used for experimentation and it can be seen from *Figure 4-4* that a fine grain localization can be achieved using PD-WCL. In the current setup when PD-WCL can provide fine grain positions within a block, a conventional CL algorithm will only be able to point to the center of the each block. Since we have two blocks in the setup CL will only be able to switch between to possible points resulting in huge error. Similarly in [71] where the author uses ST [9] using a WCL method for localization states the error to be ~8” using 20”×20” block. However in [71] the author is working with passive tags as Landmark tags compared to our Active tags. The method and system proposed in this paper provides a clear advantage over estimation error with an average EE of ~10”. The block size is also big which ultimately means lesser tags will be required to cover a larger area. Compared to ~75 inches in [10] using OARS the presented location estimation algorithm presents a far better accuracy.

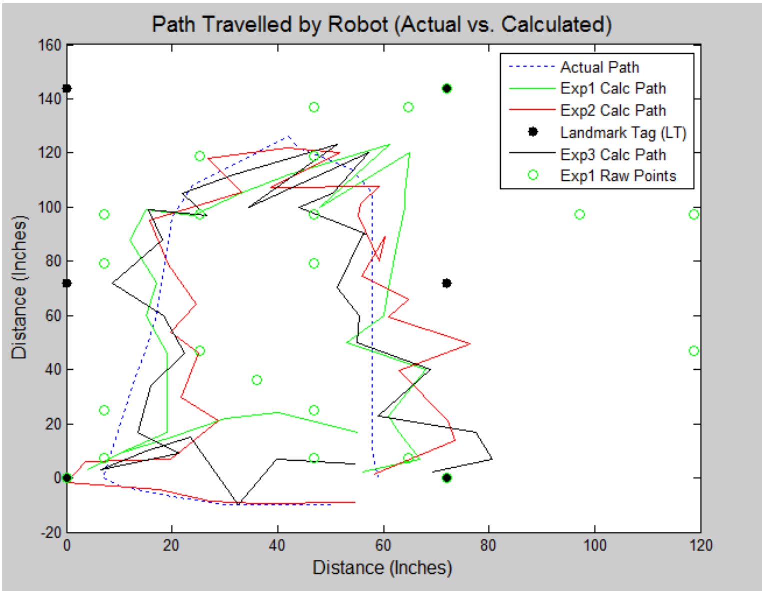


Figure 4-4: Localization results – PD-WCL algorithm

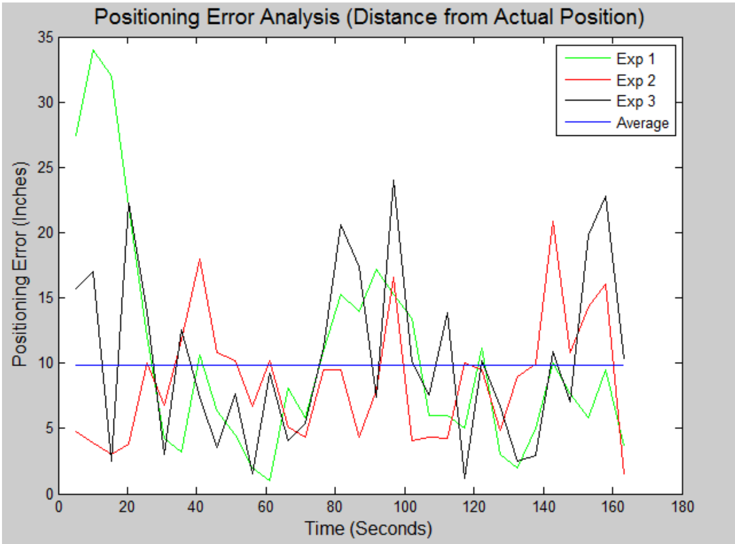


Figure 4-5: Estimation Error at different Time instants during PD-WCL algorithm experimentation.

4.3. Stationary Object Location Estimation

In this section we explain stationary object location estimation. This type of location estimation can be very helpful in finding lost objects or objects that do not move very often such as brief cases, cups etc. The block size used in this experiment is much smaller and the setup can be used for the applications such as smart desks, smart cupboards etc. A similar grid type layout is used as shown in *Figure 4-2(b).* 180 degree orientation is used, as shown in *Figure 3-12*, for this experiment so that fine grain location estimation can be achieved to locate small objects such as cups, accessories etc. The block size based on the selected orientation is 20”×20”. *Figure 4-6* shows how LT’s and Stationary MT’s (S-MT) have been laid out. S-MT were switched between pre-determined locations and the results were compared vs the calculated position by the software.

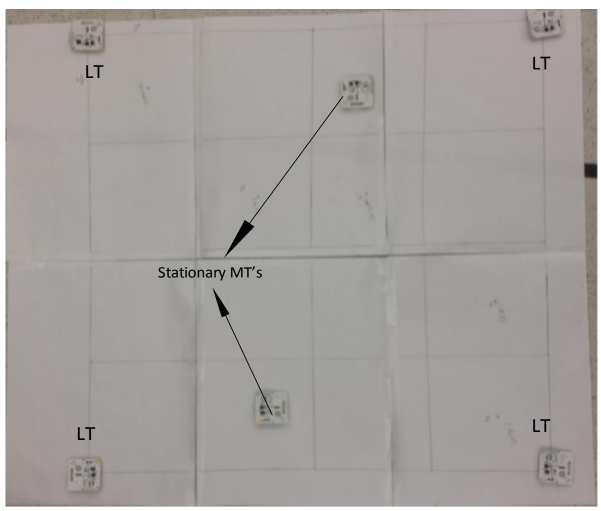


Figure 4-6: Experimental Setup - Stationary MT's

4.3.1 Algorithm

A similar algorithm is used for this application as well. However based on the requirement of this application some fine changes were made to the algorithm since in stationary object location estimation application, a real-time location update is not required. Therefore only after a certain time window *‘t’* location will be updated. The value of the time window can be adjusted based on the user requirement. For this application, the path object travelled is not of interest, so only current location of the object needs to be known and thus dead-reckoning filter is no longer needed for this application. However a new filter is introduced at stage 2 – Analyze data. During the timed window several LT datasets, described by (4.1) will be obtained and we can select the most complete dataset from the available datasets. This approach helps in increasing the accuracy of the system and helps in selecting the correct sub-block. The rest of the algorithm works exactly as mentioned in section 4.1.2

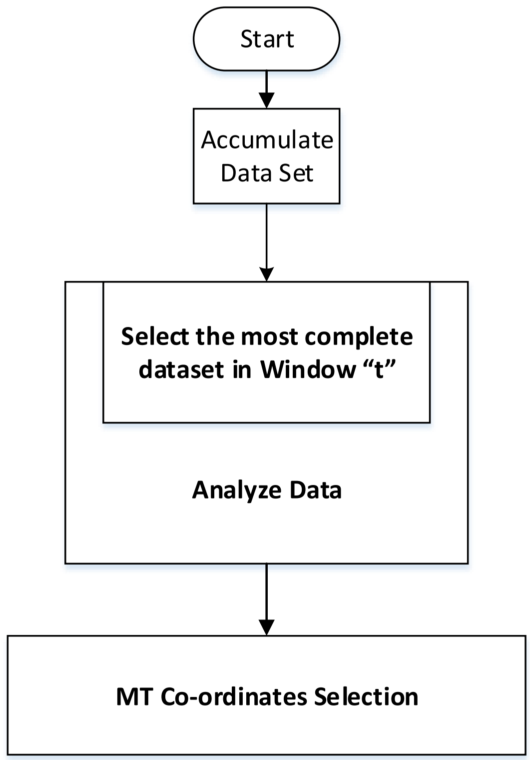


Figure 4-7: Stationary object location estimation flow diagram

4.3.2 Results and Analysis

Different time windows were selected and the percentage of correct sub-block detection was selected as the measure. For each time window, experiment was repeated 10 times. S-MT was switched between 10 pre-determined sub-blocks in the same order. Every time window the location of S-MT was changed. Following timed windows were used for analysis, as shown in *Figure 4-8:*

- 15 sec time window (red).
- 30 sec time window (blue).
- 45 sec time window (green).

- 60 sec time window (black).

It can be seen from the graph in *Figure 4-8* that higher the time window the better the accuracy of sub-block detection is. However once the time window increases beyond 45 seconds the increment in the percentage of accuracy does not increase dramatically. Same trend was observed time windows above 60 seconds.

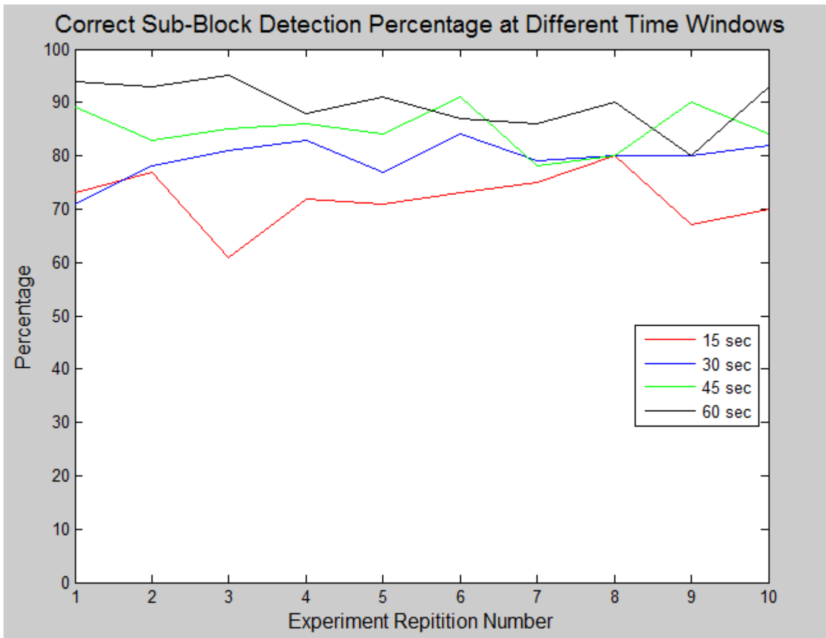


Figure 4-8: Percentage of correct sub-block detection.

4.4. Occupancy Detection

Occupancy detection refers to determining the area occupied by a person wearing an MT in the simulated environment. The deployed LTs are placed at strategic locations that are application dependent. In nursing homes, LTs would be placed at the doors, corridors, beds, chairs etc. This approach is selected when we want to deploy minimum number of the tags in the nursing home in order to approximate the room level location of patients.

The movements of patients are of interest because sometimes their movements, in certain areas of the building, can cause serious injuries to them. Therefore if we can record their movements we can learn certain patterns of their daily routine and based on this knowledge we can detect anomalies.

4.4.1 Experimental Setup

Figure 4-9 shows the experimental setup for this application. In our lab, a nursing home setup is simulated. The setup consists of a bedroom, washroom, and corridor. LT's are deployed 12 inches inside the bedroom door and washroom doors. So as soon as someone enters the room proximity can be detected. All the Landmark tags are denoted by black dots in the *Figure 4-9*. In a large area, like bedroom, an extra Landmark Tag is attached to bed, so that detection of mobile tag can be further aided by this tag. The simulated environment in our lab is small therefore in a real world environment, it should be ensured that at least one LT is in range of MT once it enters the LT deployed room. If such an arrangement is not present, the results presented in the following section will no longer be achievable. Once all the tags were deployed, a mobile tag was worn by the volunteer (1 person only) who was asked to move in the simulated area. The purpose of the experiment is to find an optimized placement of the LTs for the setup. During this initial stage, MT was programmed to transmit at a specific power level and then the results were compared to find the optimum power setting.

A Windows based application was recording all the proximity reports, along with the time these proximities were detected. During the experiment, volunteer was asked to sign a log sheet and record time whenever they entered or exited a specific place. Each experiment, *Exp OD (Experiment Occupancy Detection)*, was designed to last around 15 minutes. At the end of the experiment the results of our system are compared with the log sheet and the accuracy of the system was determined. *Exp OD*, shown in Figure 4-10, consist of 3 scenarios; *1 is for presence detection in the bedroom, 2 is for presence detection in the bathroom, 3 is for checking if the false alarm (Presence in bathroom is detected while someone moved close to the bathroom door without entering).* All these scenarios are again repeated in a different order for each experiment.

4.4.2 Algorithm

LT ID's and their locations were stored in one datatable of the database. Whenever the proximity of MT was reported, another datatable of database was used to record these entries.

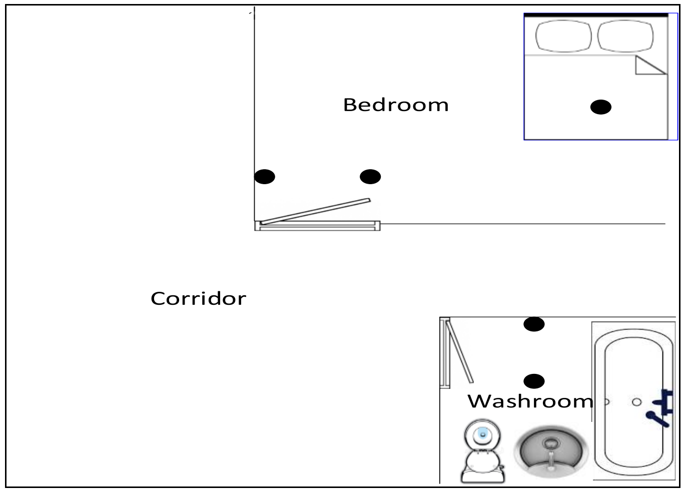


Figure 4-9: Pictorial view of the simulated environment

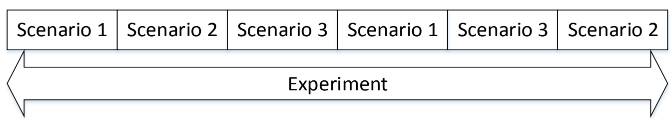


*Figure 4-10: Components of **Exp OD** (**Exp**eriment **O**ccupancy **D**etection)*

Figure 4-11 shows the decision making process for occupancy detection. Let's suppose ***N*** number of proximities are logged in database with time P_0, P_1 ***…..*** P_N. The time interval (Δ***t)*** between two consecutive proximity reports is given by (4.7). The running average of last ten reported proximities in a particular room (Δ***T)*** of Δ***t*** is given by (4.8). Time out ***(To)*** is given by (4.9). The maximum value of ***To*** is limited to 30 seconds at the software level. Theoretically MT and LT if in range should report proximity every second however in practice proximity rate is a function of orientation, distance and LOS between MT and LT. ***To*** is the calculated value and if Δ***t*** exceeds ***To*** then this is translated as MT is no longer present at a location "xyz" room and last proximity report recorded at location "xyz" serves as an end time. The time at which the first proximity report is received at a location "xyz" is recorded as the start time at this location.

$$\Delta t_{x-1} = P_x - P_{x-1} \tag{4.7}$$

$$\Delta T = \frac{\sum_{x=0}^{x=N} \Delta t_x}{N} \tag{4.8}$$

$$To = 2 \times \Delta T \tag{4.9}$$

In our setup LT`s are arranged in such order that once a tagged person enters in LT deployed region, it will be in proximity range of at least one LT all the time. All three mentioned parameters in (4.7), (4.8) and (4.9) help in decision making process at the software level. Incoming proximity reports are filtered based on the MT ID. LT reported in the proximity report tells about the room MT is in. If this proximity report is the first report for the given LT then this time is recorded as the entry time and ***To*** value calculation is started. At least 10 proximity reports will be required at the present room before the value of ***To*** is determined by the software. Meanwhile a hardcoded 30 second is used as a value for ***To***. The next proximity report's $\Delta t_{x-1}$is compared with value of ***To.*** If no further proximity reports are available for $> To$ the software agent marks an exit time for the MT ID at this room.

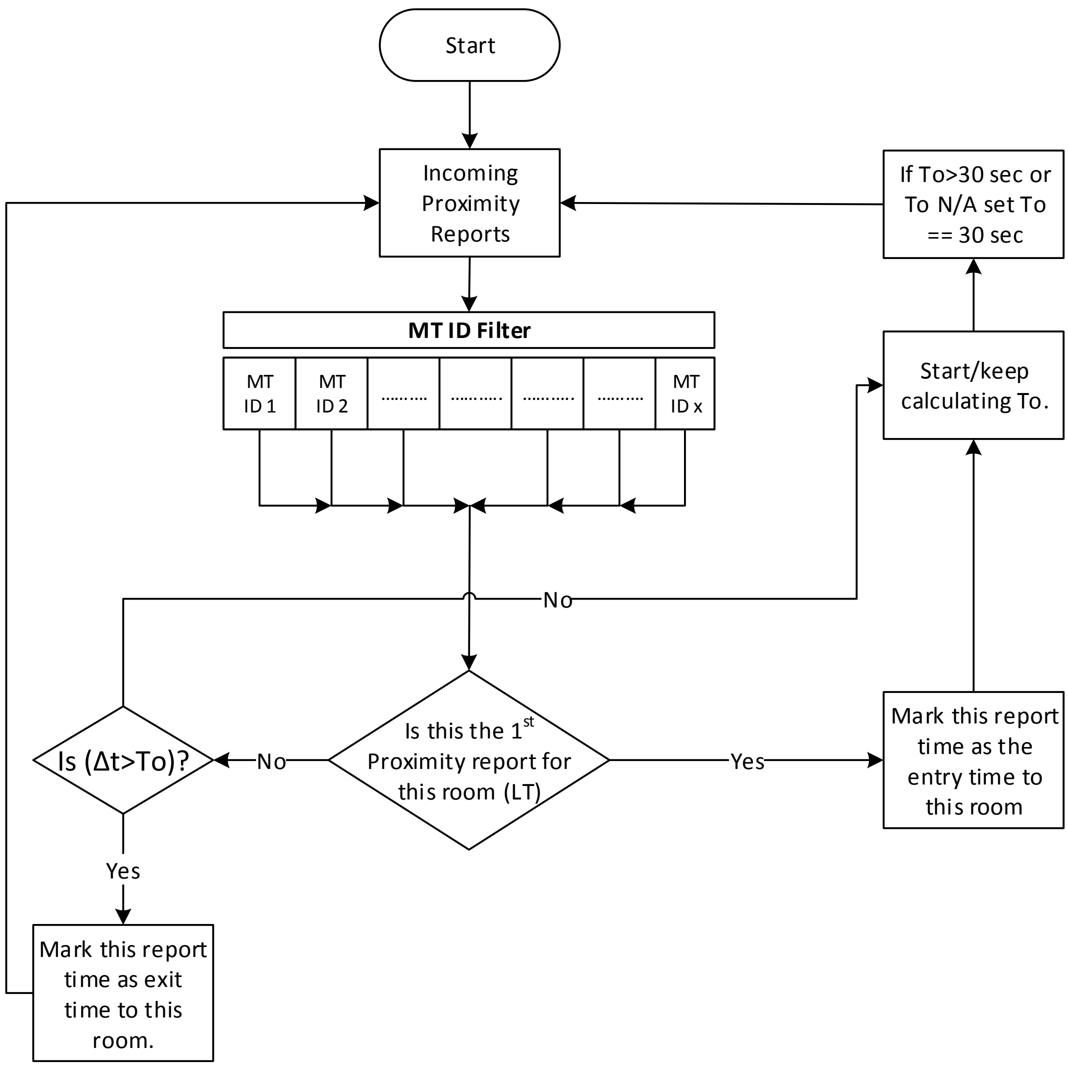


Figure 4-11: Software agent decision making process

4.4.3 Results and Analysis

During experimentation, two types of errors can occur. Type 1 error will occur when there is no MT around the LT but still LT is reporting its presence. Type-II error occurs when LT has missed reporting the presence of the MT. Based on the above mentioned deployment strategy the experiment, *Exp OD*, was repeated 15 times for each power level. Scenario 3 in our *Exp OD* was the scenario in which volunteer was asked to roam outside the door of the washroom to check how many times was the false alarm reported. Since Δt between reports in scenario 3 is much higher therefore these false reports are filtered out by the ***To*** criterion. However the number of false reports which could not be filtered out by ***To*** were reported as an error. The percentage of errors/false-reports compared to overall reports from the system is the metric we used to analyze performance. *Figure 4-12* presents the accuracy achieved by the system at different power levels of MT during experimentation. In our setup in the lab the area was relatively small so the best results were achieved at -6dBm as shown in *Figure 4-12.* At 0dBm the number of type-I errors increased resulting in a higher percentage of error/false reports. Similarly for -12 dBm Type II errors reduced the accuracy of the system. For a larger area 0dBm should work better however the performance of the system in a larger area cannot be categorized by certainty based on results obtained in a simulated environment which is a limitation of this application.

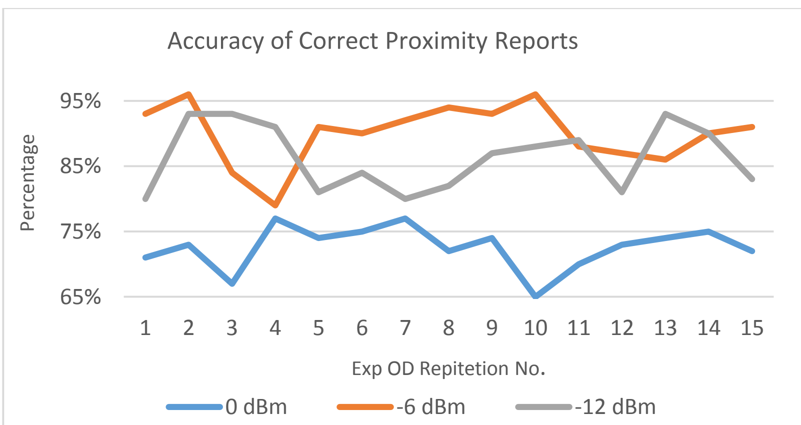


Figure 4-12: Percentage Accuracy Achieved for each repetition of Exp OD

Compared to our system, [11] uses a much complex software algorithm for approximating the location. [11] also requires along length of training data to initialize the software agent in an environment where the system is to be deployed, whereas comparatively our system is much simpler, versatile and easy to implement. Less collisions and improved rate of proximity report makes our system more accurate in small rooms building even with a very simple algorithm. Therefore if a similar intelligent agent like [11] is implemented with the modified tags the accuracy can be much higher.

4.5. Eloping Prevention and Access Control

The last application implemented in this thesis is eloping prevention. With this application the system described in the thesis can be used as a complete solution for important smart healthcare applications. Today in market several eloping prevention system exist such as [41] and eloping prevention is arguably the simplest application to implement. But with RF systems eloping prevention poses challenges as the direction detection of walking is not easy using Omni-directional antennas.

However the LT and MT can be used to sort this problem. The firmware and logic of RTM has been explained *Figure 3-7.* As soon as the MT holder comes with in the Level 1 “L1” LT’s, it waits for the detection at Level 2 “L2” LT to conclude that the MT holder is moving towards the door. This conclusion then triggers the door lock. Direction detection block is the component of the flow chart shown in *Figure 3-7.* Flow diagram, *Figure 4-14* explains the direction detection logic.

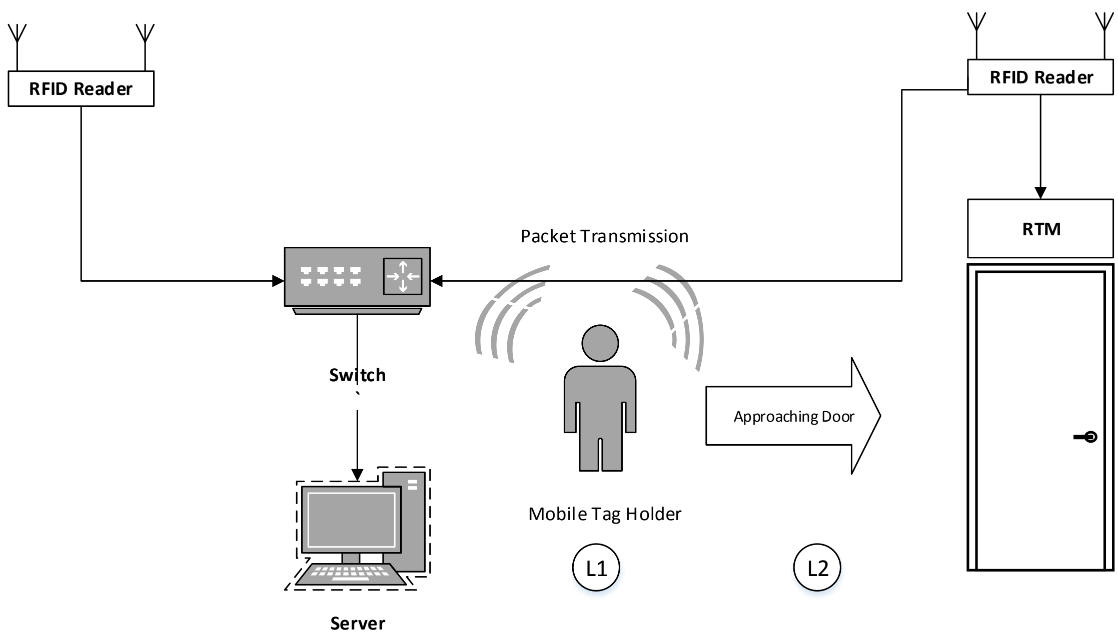


Figure 4-13: Eloping Prevention System – Overview

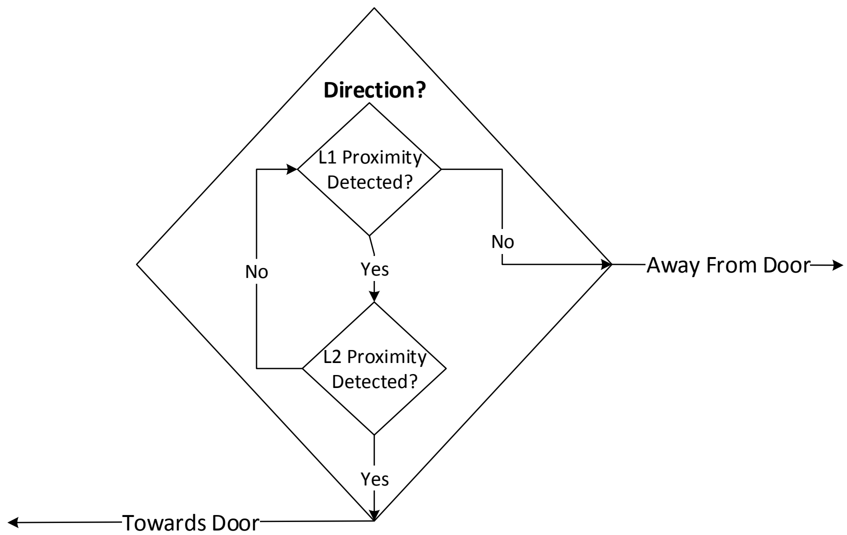


Figure 4-14: Walking Direction detection.

4.5.1 Analysis

The L1 LT's are deployed so that all possible angle of approaches towards door can be covered. The number of LT's that exist in this category can vary from 2 to 8 depending upon the corridor layout. L1 LT's are placed at 12 feet from the door. So in case of a narrow corridor only 2 LT's can do the job, as shown in *Figure 4-15 (a)*, whereas in case of a wider corridor will be required as shown in *Figure 4-15 (b)*. During the experimentation stage narrow corridor was used with Level 1 LT's at 12 feet from door and Level 2 LT's at 5 feet from door. A simple red LED was used with RTM instead of a door lock and a green LED was used to signal the Level 1 detection.

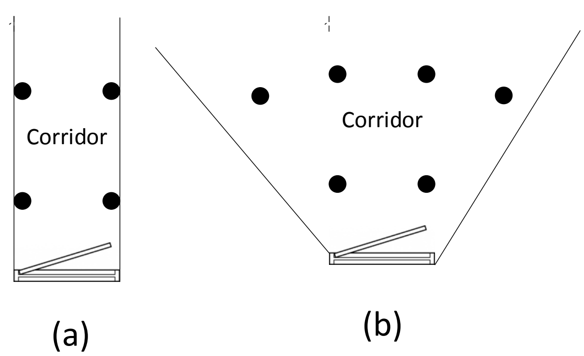


Figure 4-15: LT deployment (a) Narrow Corridor; (b) Wide Corridor

A volunteer was asked to move towards the door with an MT on the shirt. According to

[72] the typical walking speed of a human is 4 feet per second. Therefore experiments were conducted to see the accuracy of direction detection at 2, 4 and 6 feet per second respectively. At each speed 20 experiments were conducted to find the percentage of correct direction detection. In each experiment volunteer was asked to move towards and away from door 15 times each. *Table 4-2* show the results of the experiments.

Table 4-2: Walking direction detection results

WALKING SPEED (FPS)	ACCURATE DIRECTION DETECTION (%AGE)
2	99.71
4	87.28
6	78.93

4.6. Summary

In this chapter we have discussed the prototyped applications of healthcare that have been implemented. We establish the fact that Openbeacon system have the ability to fill in the gaps of the existing solutions and proximity detection is a powerful approach to implement monitoring and tracking applications of smart healthcare. A method for location estimation is described which is superior in accuracy to the present state of the art [10] [11] implemented using OARS. Location estimation system uses proximity detection and performance is comparable to state of the art such as mentioned in [71], [39] and [9] without any need of a special tag or sniffer. PD-WCL algorithm is introduced which provides sophisticated data analysis for estimating its output using tags compared to Wi-Fi access points used in [13]. We were also able to integrate applications such as eloping prevention using RTM and occupancy detection using OARS within one system.

Chapter 5. Conclusion

At the beginning of our research we aimed the goal of building and developing a healthcare monitoring system that can be used for the smart healthcare applications. As explained earlier, smart healthcare is composed of several components. We identified nursing home/hospital monitoring as the area to work at. The idea is to prototype the system and algorithms so that multiple applications of smart healthcare could be supported. Currently the systems available are either very expensive or some inexpensive systems cater to isolated applications. Some systems are good for monitoring and some can track objects but fail to locate patients or nurses. In this scenario, a vacuum had been created where a need for all in one solution was required. In this thesis we tried to work and fill this empty space by providing a prototype system in which all this could be integrated into one fabric. We started by choosing active RFID as the choice of technology and later Openbeacon active RFID system was chosen as a platform to work on. The system revolved around the idea of proximity detection and that is the very reason why Openbeacon system was chosen.

5.1. Thesis Contribution

The thesis contribution are as follows:

- We present a novel way the Openbeacon system can be used for proximity detection by developing and modifying the firmware of the Openbeacon proximity tags. Landmark Tags (LT) and Mobile Tags (MT) concept is introduced using the same stock Openbeacon proximity tag hardware. This approach improves the proximity detection rate between tags by 100% and also reduces the number of overall packets in air resulting in lesser collisions.
- Based on LT, MT and Openbeacon Ethernet reader we have developed a system which can localize objects, provide room level occupancy status and

door control. These systems can be further expended into our target applications including Locating patients, nurses and objects; detecting room level occupancy status; providing eloping prevention measures.

- We also present a C# based PC application which act as an intelligent middleware agent. We present a data analyses approach based location estimation algorithm which can potentially localize moving objects/people up to an accuracy of 10 inches, however for experimentation purposes we used a robot as the moving object. Stationary objects that can be localized with an accuracy of ~2.3 inches. The algorithm used is called Proximity Detection based Weighted Centroid Localization.

5.2. Future Work

The Openbeacon system has a lot of potential but the absence of multiple access technique in the system makes it viable to a lot of collisions. Therefore as a result in a scenario where many tags are transmitting simultaneously the efficiency of the system will be degraded exponentially. Openbeacon system also does not follow any international standard due to which commercial development of the solutions based on this system is difficult. A possible implementation could be making it ISO 18000 compatible.

On the tag side some simple sensors such as accelerometer can be added which can be used to calculate orientation and speed of the moving objects. This information can be used by PD-WCL algorithm for an improved path estimation. Another enhancement at the tag level (MT) could be the introduction a new RF-Chip which could use more power levels or provide information regarding RSSI which can contribute towards further fine grain localization. Sensitive antennas can be used on the tags which can result in increased proximity detection range between tags.

On the LT side a RF-Chip which can support four antennas can be used. Since LT blocks are needed to be on the ground therefore LT can be installed in the tiles of the floor with four ceramic antennas on the corners of 72”×72” tile with a distributed DC power lines powering the tags in the tile. The use of four antennas can reduce the required number of LT’s by four times as one LT will be required per tile instead of currently used four per block. This technique will reduce the cost of the system four times. This approach will make LT’s hidden and help the technology become pervasive and ubiquitous.

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Appendix A:

OpenBeacon Ethernet EasyReader PoE II

EasyReaders [62] are designed as pure listeners which means they just listen to the incoming packets from the Openbeacon tags, processes the packet (embeds reader ID in packet) and then relays the packet to the middleware. Since the OpenBeacon proximity tags operate in beacon mode, therefore there is no need for the reader to send the query signal. The reader just need to know the decoding algorithm for the packet, populate the fields required, encode and transmit it along the network using UDP protocol through the Ethernet link. On the physical side, as seen in *Figure A-1*, EasyReader consist of two antenna interfaces and an aluminium box containing the PCB. Although the Firmware of EasyReader is made public but on the downside, PCB layout, design and hardware schematics are kept private. Still the system provides enough flexibility for modifications required to achieve the goals of the thesis.

Figure A-1: Openbeacon Ethernet EasyReader PoE II – Active 2.4 GHz RFID Reader [62].

On the PCB layer, EasyReader consist of a 32 bit Atmel Sam7 ARM processor, two antenna connectors, an Ethernet connector, mini USB pin for power and flashing, and LED’s for showing status.

User Datagram Protocol (UDP)

UDP is a transport layer protocol used in IP networks for providing datagram service to the end system (IP host) [63] [64]. This protocol provides a datagram mode for the packet switched computer communication in the environment of several interconnected computer networks. UDP is designed to support applications that require minimum protocol mechanism, therefore unlike other protocols, such as TCP/IP, UDP requires no handshaking which results in less reliable packet delivery.

Since UDP does not create an end to end connection between the client and server therefore addressing information regarding the sender and receiver has to be added in the header of the UDP packet. A typical UDP packet structure is shown in ***Error! Reference source not found.***. **Source Port** is optional and indicates the port of the sending process. **Destination Port** serves as the destination port address in the context of the network. **Length** indicates the total length of the packet in bytes (including the header and payload). **Checksum** provides a mechanism to cross check the integrity of the data as it makes way through the routers and bridges within the network. The total length of a header in a UDP packet is 8 bytes and maximum size of a UDP packet is 65,535 bytes (including UDP and IP headers).

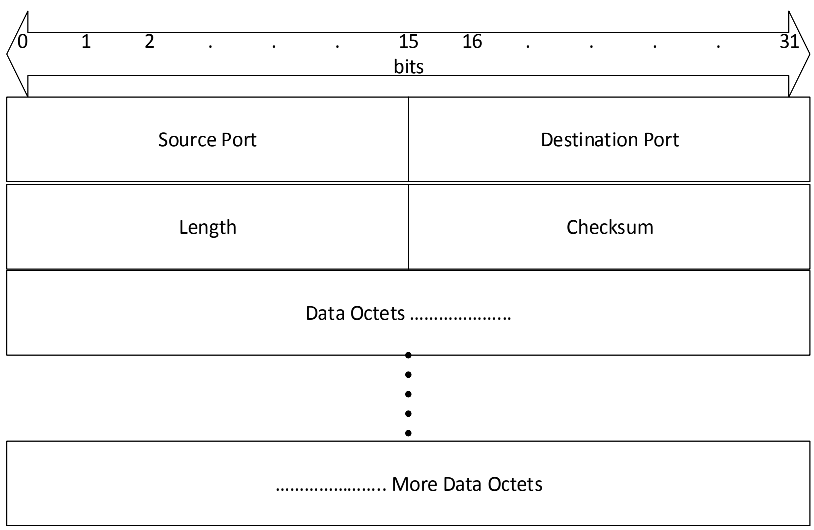

Figure A-2: UDP Packet Format