A Real-Time Tracking System using RFID in Mecca

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By

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ABSTRACT

Muslims from all over the world visit the holy city of Mecca in Saudi Arabia every year to perform the Hajj, which is the largest annual pilgrimage in the world. Ministry of Hajj statistics have shown that the number of pilgrims is increasing annually. The continuous increase has made the Hajj more difficult for the pilgrims and the authorities. Many pilgrims die and get injured every year due the congestion. Therefore, new technologies have become critical to control the crowds. Recently a few projects have been conducted in Mecca. However, the need for more practical and economical solutions is still required.

The aim of this project is to track missing people and determine their current location on a map during the season of the Hajj. This project is mainly aimed at children and elderly. However, the system can also be implemented in many different places including airports, shopping malls, parks, offices and industrial fields, and it also can monitor assets as well as people.

“ This thesis is dedicated to all of those

who have died in the Hajj and their families ”

ACKOWLEDGEMENTS

First and foremost, I am greatly expressing all praise to ‘Allah’ the most merciful, for helping me in putting this work together. I could never have done this without the faith I have in you.

I would like to extend deep thanks to my supervisor Professor Subhas Mukhopadhyay for his support, patience and encouragement during this project. I am lucky to have had such an active and hardworking supervisor.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Determining the location of an object is called a positioning system. Positioning systems can be used globally or locally. Local positioning systems do not use technology that has global coverage like the global navigation satellite systems (GPS); they use local technologies that use local coverage. Any wireless technology can be used as a local positioning system, and it can do the task with high accuracy, low cost and in real-time. The wireless technologies include WiFi, and Bluetooth and Radio frequency identification technology (RFID) is usually used in the implementation of any local positioning system [1, 2]

1.2 Radio frequency identification

Radio-frequency identification (RFID) uses radio waves to transfer data between readers and tags that can be attached to objects or people for the purpose of identification and tracking. RFID is a technology that has been in usesince 1984 [3, 4]. In recent years, RFID has drawn more attention and it has been applied and used in many industries. The United States Department of Defense (DoD) and very well-known market stores around the world, including Wal-Mart, Pfizer, Tesco, and Gillette's, have used RFID technology [5, 6].Furthermore, the European Central Bank is trying to prevent counterfeiting of banknotes by using RFID tags [7, 8]. RFID can also be used in crowded public places where people often lose their family members and children [9, 10].Therefore, RFID technology will make the Hajj season in Mecca much easier for many people.

1.3 Hajj season

The Hajj is considered as one of the largest annual gathering in the world. Muslims from all over the world visit the holy city of Mecca in Saudi Arabia every year to perform the Hajj. The latest statistics on the number of pilgrims provided from the Ministry of Hajj have shown that the number is increasing annually [11].

1.4 Problem definition

The continuous increase in the number of pilgrims has made the Hajj more difficult for the pilgrims and the authorities. One of the most difficult tasks during the Hajj season is when someone gets lost in the crowd. Young children and the elderly are the most affected in this situation. Many pilgrims die, get injured and kidnapped every year due the congestion [12, 13]. Therefore, the new technologies have become critical to help the pilgrims. Recently, a few projects have been conducted in Mecca in order to curb the Hajj problems. However, the need for more practical and economical solutions is still required.

1.5 The aim of the project

The aim of this project is to build a real-time positioning system using an RF-based wireless sensor network to track and identify the location of the pilgrims during the Hajj season. This system will help the security division of Hajj to find the current location of a missing person. This system is mainly aimed at children aged less than 15 years because they are more likely to get lost and it is difficult for them to find their way back.

1.6 Organization of the thesis

The rest of the thesis is organized as follows. Chapter II will provide information about the place where the system will be applied on and an overview of positioning technologies. The specification and system design will be explained in Chapter III. Chapter IV will be about the network simulation. Chapter V is an implementation of the trilateration method in the system. In Chapter VI the hardware and software implementation is considered. Chapter VII provides conclusion, discussion and future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Mecca and Hajj

The holy city of Mecca is located in the western part of Saudi Arabia. Mecca has the largest mosque in the world (The Grand Mosque) accommodating 1.5 million worshippers at a time. The city of Mecca is considered to be the most sacred place in Islam. Therefore, people from all over the world visit Mecca every year to pray and perform Umrah and Hajj. Umrah is a small Hajj that can be performed at any time of the year. However, Hajj comes just in the twelfth month of the Islamic calendar and it lasts for five continuous days. Hajj is the fifth pillar of Islam and it is obligatory for every muslim, sane, free, and physically and financially able to do so, according to the teachings of Islam. The total number of pilgrims reached around 2 million every year making the Hajj season one of the largest gatherings in the world. The latest statistics on the number of pilgrims provided from the Ministry of Hajj have shown that the number is increasing annually as shown in Figure 2.1. In 1996, the number of pilgrims was 1,865,234, this number had increased to 2,012,074 pilgrims in 2004 [11].

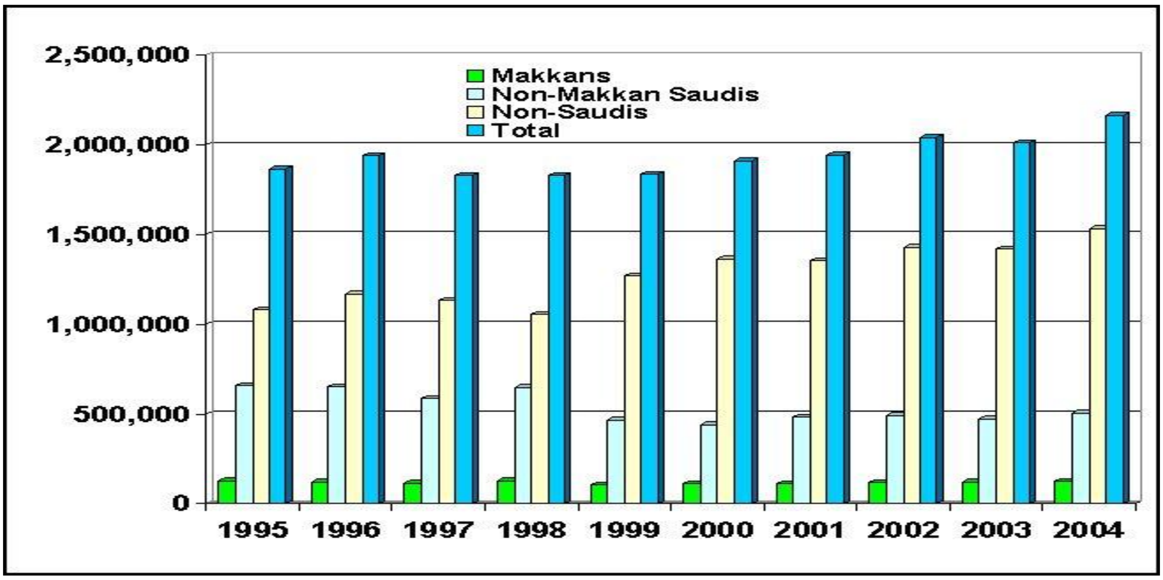


Figure 2.1: Hajj statistics [11]

The government of Saudi Arabia has made great efforts in the expansion of the ritual sites and the provision of medical and security services. Moreover, the government established a Ministry for Hajj in 1961 to take care of everything related to the Hajj season.

Despite all the efforts concerning the Hajj season there are still problems among the crowds leading to injuries, missing pilgrims and death. According to news reports, in 1998 more than 118 pilgrims died during the Hajj and 180 were wounded [14]. Around 35 pilgrims lost their lives in 2001, and another 14 people in 2003 [15, 16]. The number of deaths in 2004 had increased to 251 pilgrims and 244 people suffered injuries [17].

2.1.1 Pilgrimage sites

Hajj is a series of ritual acts done in five days. During these days, pilgrims visit four different places, namely, the Grand Mosque, Mina, Mozdalifah, and Arafat as shown in Figure 2.2. At each of these places, the pilgrims perform religious acts at specific times. Mostly, Pilgrims travel between these places walking along a 22 km pedestrian path.

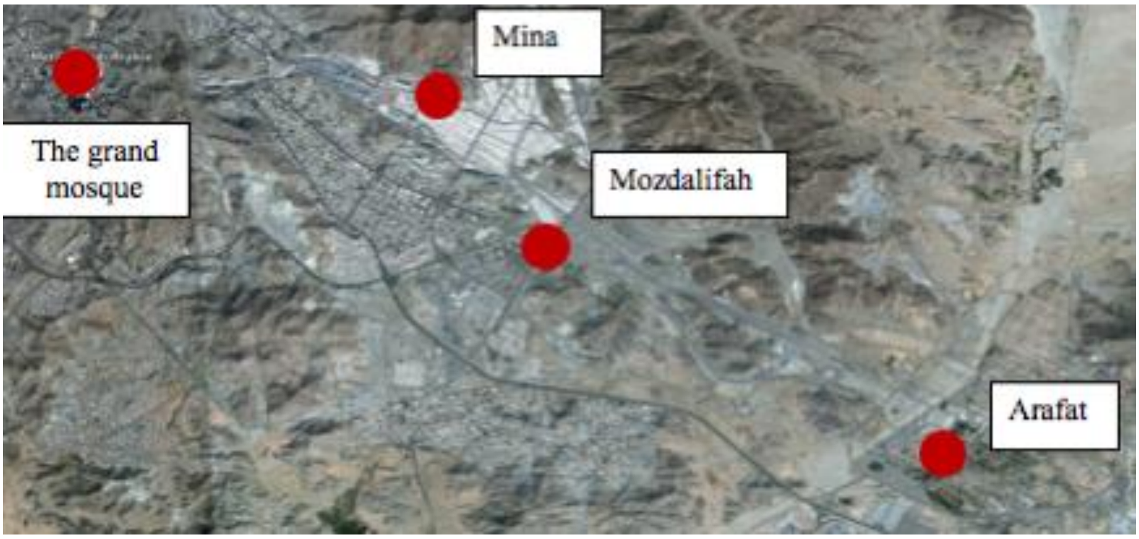


Figure 2.2: Pilgrimage sites [37]

2.1.2 Sequence of the hajj journey

Day1:

Ihram: Before entering the Holy city of Mecca, the pilgrim must wear special clothes, which are two white sheets draped across the body.

Umrah: Once in Mecca, the pilgrims enter the grand Mosque and perform their first Tawaf. In the Tawaf, the pilgrims circle the Kaaba seven times Figure 2.3.

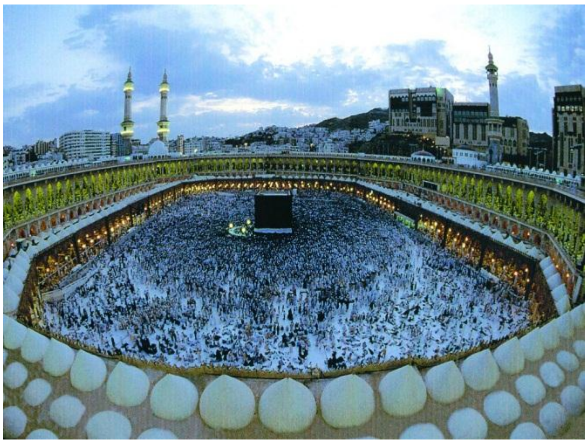


Figure 2.3: The Tawaf ritual [18]

After Tawaf, the pilgrims perform sai; running and walking seven times between the hills of Safa and Marwah, which are 450 meters apart as show in Figure 2.4. At the end of the first day, pilgrims travel to Mina, which is three miles to the east of Mecca.

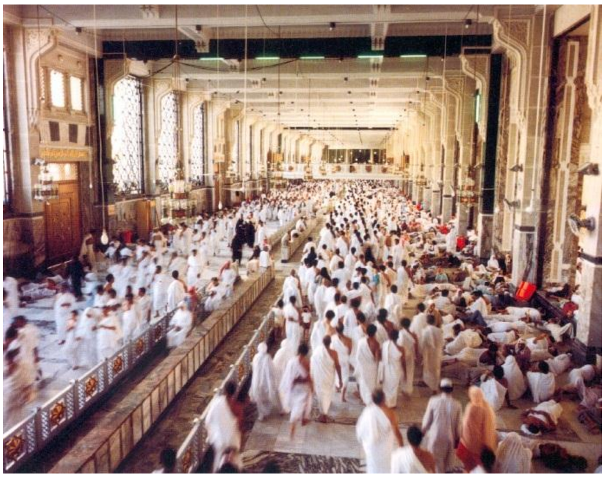


Figure 2.4: Safa and Marwah [19]

Day2:

Arafat: On the second day of Hajj, the pilgrims travel 14.4 km (9 miles) east from Mina to Mount Arafat. Pilgrims stay there from afternoon to sunset. They stand facing Mecca, in prayer and reflection. In the evening after Arafat, pilgrims leave for Mozdalifah, traveling 9 km (5.6 miles).

Mozdalifah: At Mozdalifah, which is located between Arafat and Mina they spend the night in prayer and gathering stones for the next day's ritual; the "stoning of the devil." Before the sun has risen, the pilgrims return to Mina.

Day3:

Ramy al-jamarat: On the third day, in Mina, pilgrims perform the 'stoning of the devil' where they throw their stone pebbles at three Jamarat pillars as shown in Figure 2.5. After the stoning, an animal is sacrificed, either by the pilgrim or through the appointment of someone else.

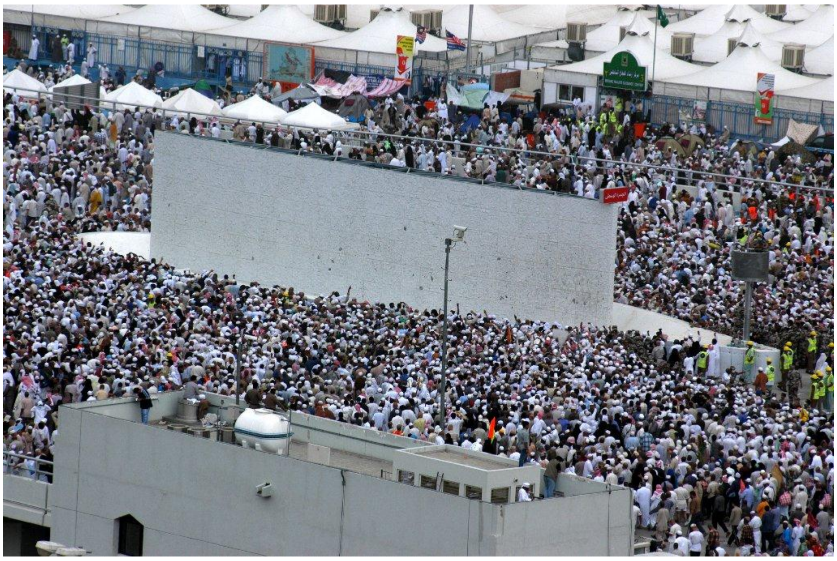


Figure 2.5 Ramy al-jamarat ritual (stoning of the devil) [20]

Tawaf al-Ifadah: on the same day the pilgrims return to the grand mosque for one more Tawaf, called Tawaf al-Ifadah. As a final sacrifice, the pilgrim then shaves his/her head or cuts off a portion of hair.

Day4/5:

The Days of Tashriq: The pilgrims then return to Mina for two days. On each of the two days, pilgrims, again, stone the Jamarat pillars, each with seven stones. The throwing of the stones is not mandatory for the physically weak or women. These two days are spent in contemplative prayer. On the fifth day, pilgrims return to Mecca where a Farewell Tawaf is performed and the Hajj is complete.

2.2 Existing technologies

In recent years, some researchers have proposed a number of solutions for the problems faced by the pilgrims and the authorities during the Hajj season. Mohamed Mohandes has developed a portable device using RFID technology to help the authority in the identification of pilgrims [21] as shown in Figure 2.6.

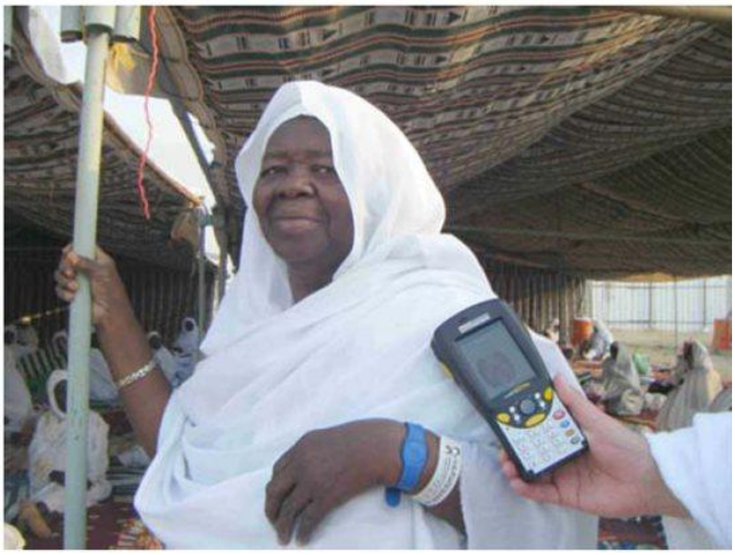


Figure 2.6: RFID Pilgrim Identification System [21]

One of the problems that leads to congestion during the Hajj is the lack of information about the correct rituals. Therefore, Shahida Sulaiman and Hasimah Mohamed have developed an expert system called Hajj-QAES. The system is to assist the pilgrims in the learning process and during the hajj to know what to do quickly without asking others or making serious mistakes such as walking against the crowd [22]. Figure 2.7 shows the main window of their system.

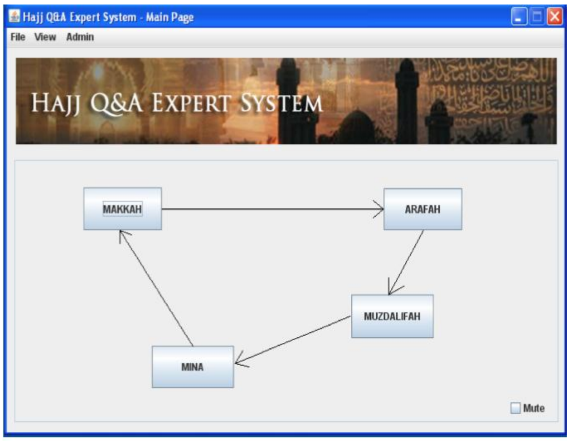


Figure 2.7: The main window of Hajj-QAES [22]

Willy Wahyn Mulyana presents a simulation of the crowd’s behaviour during the Hajj to train the pilgrims before the actual Hajj and to highlight the most crowded places to take action [23] Figure 2.8 shows simulation results.

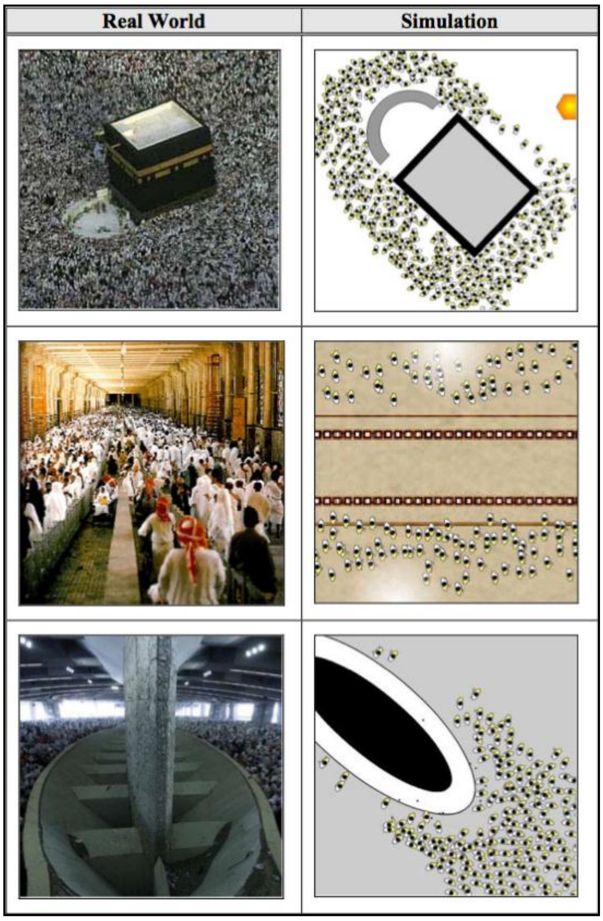


Figure 2.8: The crowd simulation results [23]

However, knowing the exact location of any person among thousands of pilgrims during the Hajj is a very difficult task. It may take several days to find a missing person, especially children or the elderly, and they would be subjected to many problems. The best way to locate a person location is by using a tracking system.

2.3 RFID technology

One of the well-known tracking systems is RFID technology, as it can provide outstanding performance with reasonable costs. RFID technology has been used by many industries and it has proven its worth, especially in tracking people or assets using RFID tags. The RFID tracking system contains 3 main components: RFID Tags, RFID reader and RFID PC reader [24].

2.3.1 RFID tags

There are two different kinds of RFID tag: passive and active tags [24, 25].

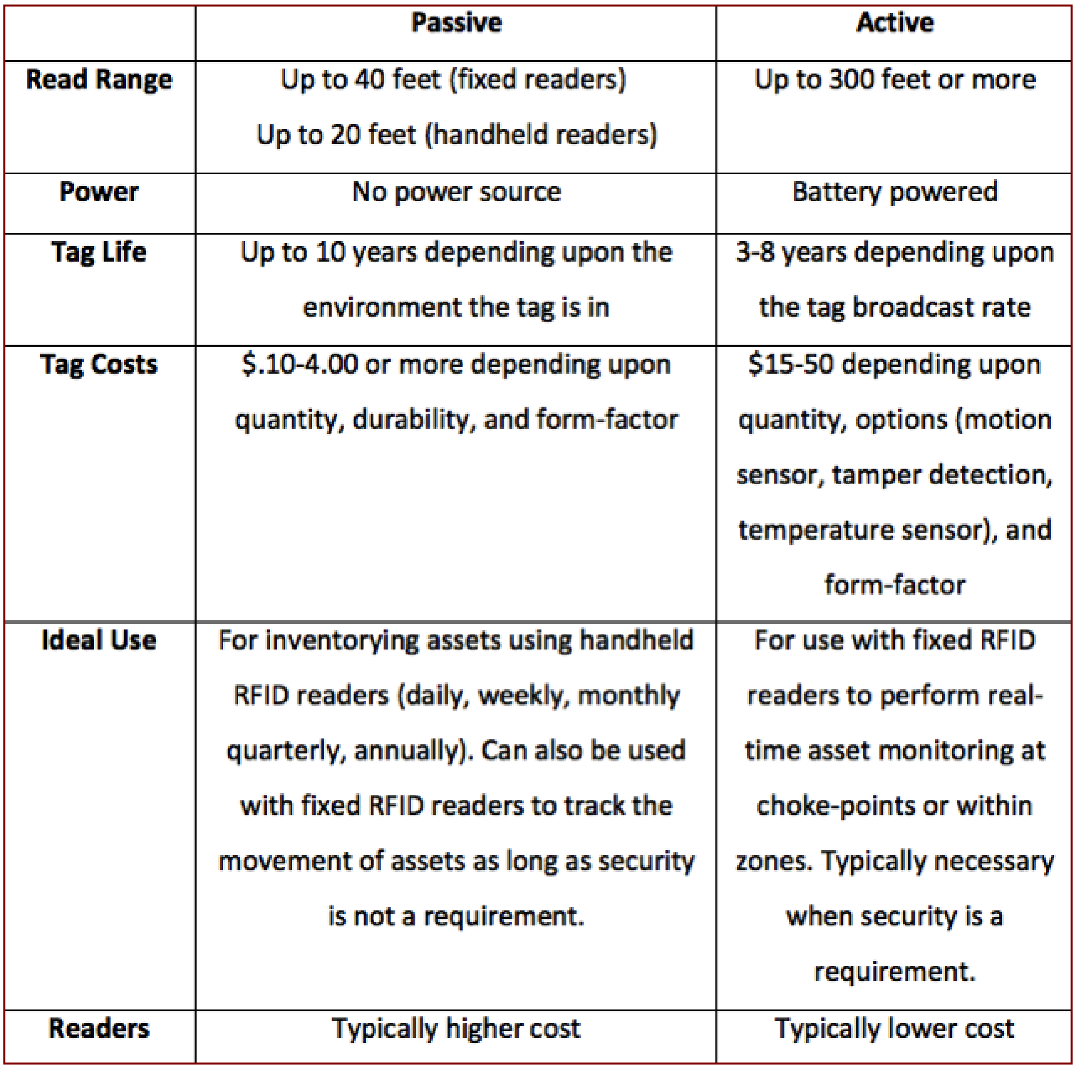
2.3.1.1 Passive RFID tags

Passive tags do not require batteries. They, basically, convert the RF signal that comes from the RFID reader into energy to return the signal back again to the RFID reader. Passive tags are usually chosen because they are low cost and small size. However, they have shorter reading range and less memory size.

2.3.1.2 Active RFID tags

Active tags require batteries, unlike the passive tags. The main advantages of the active tag are the long communication range and the high data transmission rates. Table 2.1 summaries the difference between passive and active RFID tags.

Table 2.1: Passive and active RFID tags



	Passive	Active
Read Range	Up to 40 feet (fixed readers) Up to 20 feet (handheld readers)	Up to 300 feet or more
Power	No power source	Battery powered
Tag Life	Up to 10 years depending upon the environment the tag is in	3-8 years depending upon the tag broadcast rate
Tag Costs	$.10-4.00 or more depending upon quantity, durability, and form-factor	$15-50 depending upon quantity, options (motion sensor, tamper detection, temperature sensor), and form-factor
Ideal Use	For inventorying assets using handheld RFID readers (daily, weekly, monthly quarterly, annually). Can also be used with fixed RFID readers to track the movement of assets as long as security is not a requirement.	For use with fixed RFID readers to perform real-time asset monitoring at choke-points or within zones. Typically necessary when security is a requirement.
Readers	Typically higher cost	Typically lower cost

2.3.2 RFID reader

The RFID reader basically receives signals from the RFID tags and forwards them to the RFID PC reader. The RFID reader can be used in three different ways [26]:

2.3.2.1 Hand-held, reader

A handheld reader is a small device carried by the user to find the location of any tag. The location can be determined by measuring the Received Strength Signal Indicator (RSSI).

2.3.2.2 Fixed reader installed in area

A fixed reader technique has a number of readers installed at fixed known places creating a wireless network. Unlike the hand-held reader the fixed reader technique is more accurate and covers a larger area. The fixed reader technique is usually used with active RFID tags.

2.3.2.3 Fixed reader installed at chokepoint

A fixed reader at a chokepoint is a technique that is used mainly with passive RFID tags and is the most common technique. The readers read the signals whenever the tags come within the range of the reader.

2.3.3 RFID PC reader

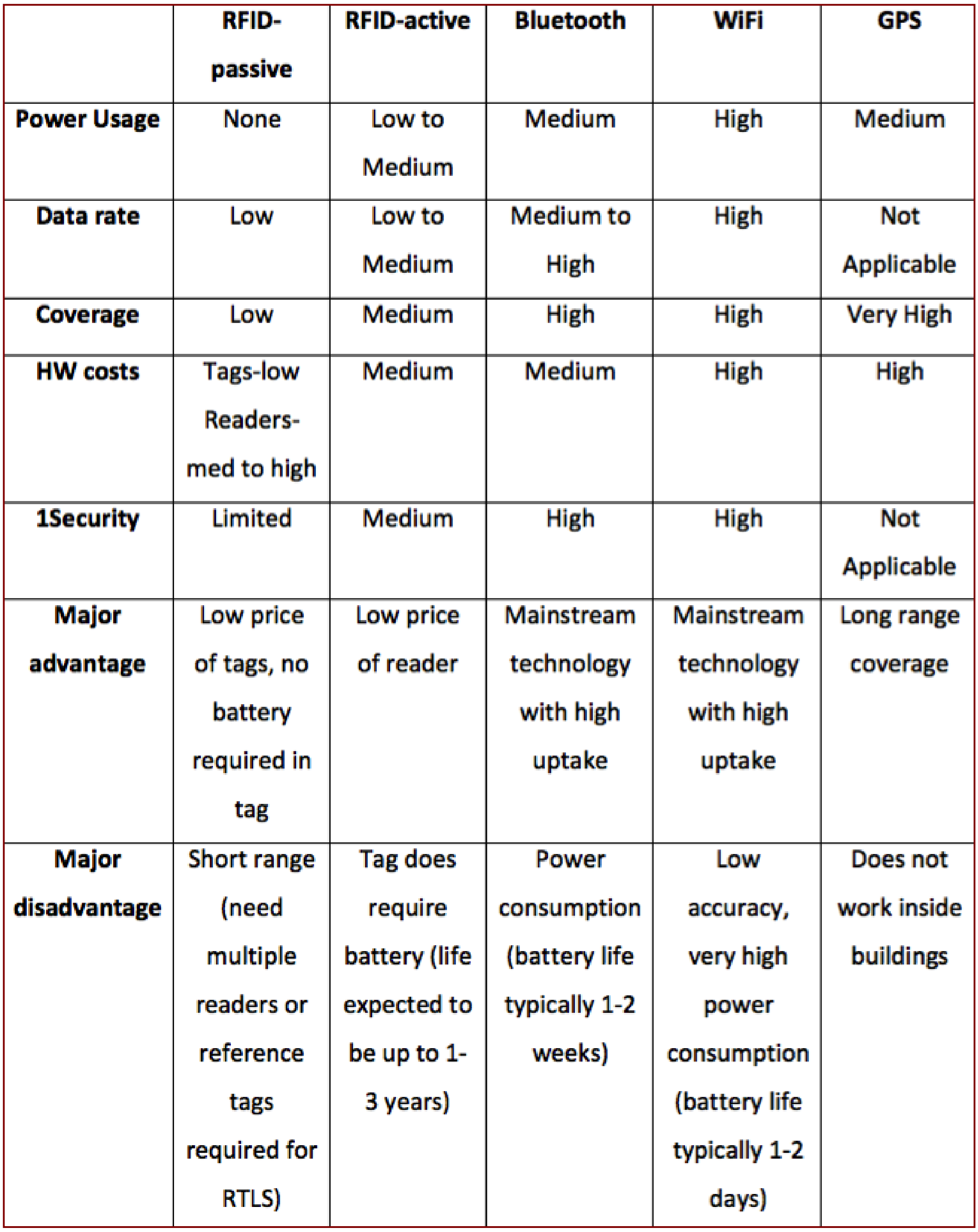
A PC reader or middleware connects between a network of several readers and a host computer. Through a PC reader data received from the tags can be collected from the readers to display them on the host computer. The PC reader works as a receiver and transmitter also.

2.4 Comparison of positioning systems

RFID technology is not the only tracking system available. There are other positioning technologies, such as GPS (Global Positioning System), WiFi, Infrared, and Bluetooth.

GPS is a satellite-based navigation system and it is one of the most popular technologies used for positioning. It is also commonly used in vehicles. However, GPS appears to be unsuccessful within buildings [27]. Table 2.2 shows the differences between these technologies.

Table 2.2: Comparison of positioning technologies



	RFID-passive	RFID-active	Bluetooth	WiFi	GPS
Power Usage	None	Low to Medium	Medium	High	Medium
Data rate	Low	Low to Medium	Medium to High	High	Not Applicable
Coverage	Low	Medium	High	High	Very High
HW costs	Tags-low Readers-med to high	Medium	Medium	High	High
1Security	Limited	Medium	High	High	Not Applicable
Major advantage	Low price of tags, no battery required in tag	Low price of reader	Mainstream technology with high uptake	Mainstream technology with high uptake	Long range coverage
Major disadvantage	Short range (need multiple readers or reference tags required for RTLS)	Tag does require battery (life expected to be up to 1-3 years)	Power consumption (battery life typically 1-2 weeks)	Low accuracy, very high power consumption (battery life typically 1-2 days)	Does not work inside buildings

CHAPTER 3

SPECIFICATION AND DESIGN OF THE SYSTEM

3.1 Introduction

The system is based on 3 main hardware components like any location tracking system:

- Tags
- Reader nodes
- PC reader node.

The sensor module that will be used is Synapse RF Engine. The language programming to program these sensors is python programming language. The system will be designed around the concept of trilateration method. All of these hardware and software components will be described in this chapter.

3.2 Synapse RF engine

The main hardware component used in the system is the Synapse RF Engine, IEEE 802.15.4-based, as shown in Figures 3.1 and 3.2. These small, low-power, transceiver modules, running from sub-GHz to 2.4 GHz, have a wide range coverage and a low power consumption with a 2.5 µA low power mode. See Appendix C.1 for more details about the Synapse RF Engine. Table 3.1 shows a detailed description of this model.

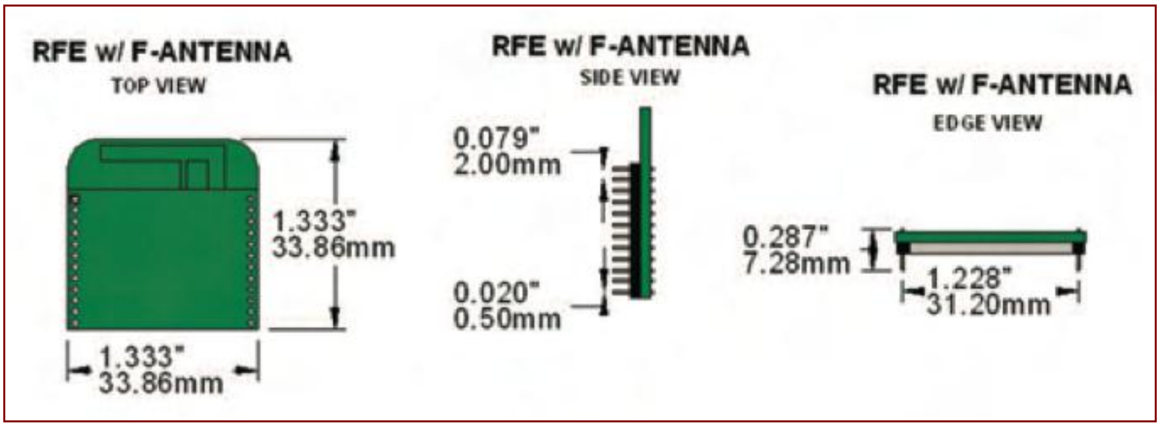


Figure 3.1: Synapse RF Engine dimensions [Appendix C.1]

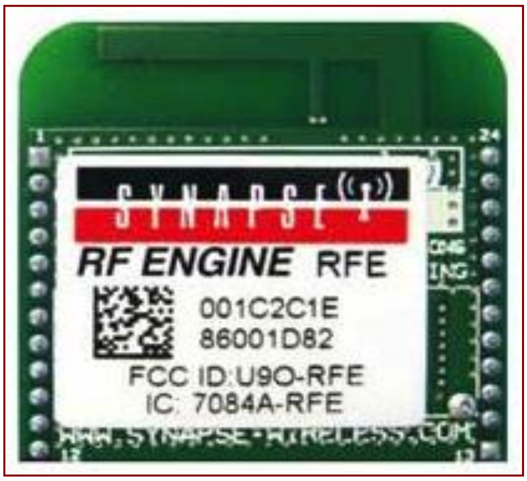
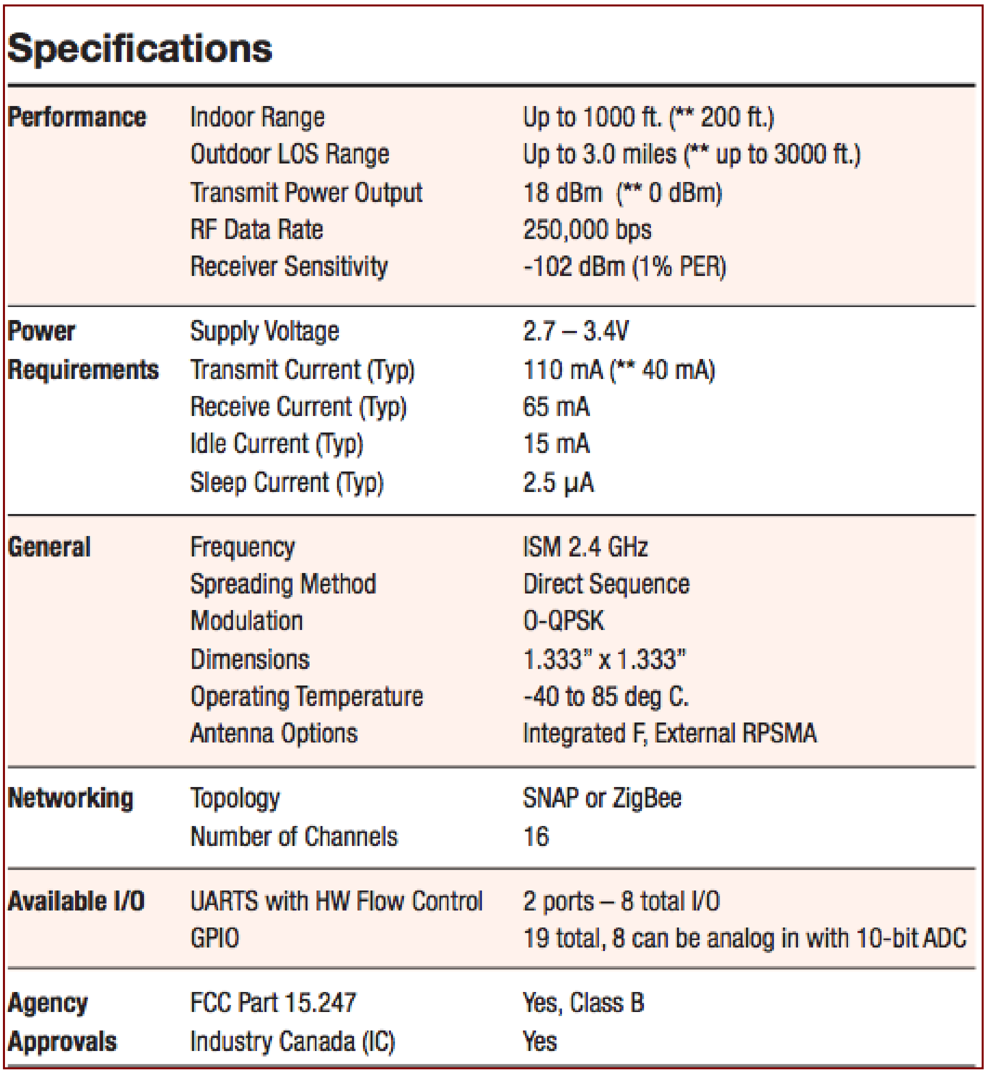


Figure 3.2: Synapse RF Engine [Appendix C.1]

Table 3.1: Synapse RF Engine specifications [Appendix C.1]



Specifications

Performance	Indoor Range	Up to 1000 ft. (** 200 ft.)
	Outdoor LOS Range	Up to 3.0 miles (** up to 3000 ft.)
	Transmit Power Output	18 dBm (** 0 dBm)
	RF Data Rate	250,000 bps
	Receiver Sensitivity	-102 dBm (1% PER)
Power Requirements	Supply Voltage	2.7 – 3.4V
	Transmit Current (Typ)	110 mA (** 40 mA)
	Receive Current (Typ)	65 mA
	Idle Current (Typ)	15 mA
	Sleep Current (Typ)	2.5 µA
General	Frequency	ISM 2.4 GHz
	Spreading Method	Direct Sequence
	Modulation	O-QPSK
	Dimensions	1.333" x 1.333"
	Operating Temperature	-40 to 85 deg C.
	Antenna Options	Integrated F, External RPSMA
Networking	Topology	SNAP or ZigBee
	Number of Channels	16
Available I/O	UARTS with HW Flow Control	2 ports – 8 total I/O
	GPIO	19 total, 8 can be analog in with 10-bit ADC
Agency Approvals	FCC Part 15.247	Yes, Class B
	Industry Canada (IC)	Yes

3.3 Evaluation Kit

A Synapse evaluation kit (EK2100) will be required to upload python scripts into the tags, reader nodes and PC reader node. The Synapse evaluation kit contains: SNAPstick, ProtoBoard and Portal software. See Appendix C.3 for more details about the Synapse evaluation kit (EK2100).

3.3.1 SNAPstick

SNAPstick is a USB stick designed to work as a bridge to connect a PC to Synapse RF engine network (Figure 3.3).

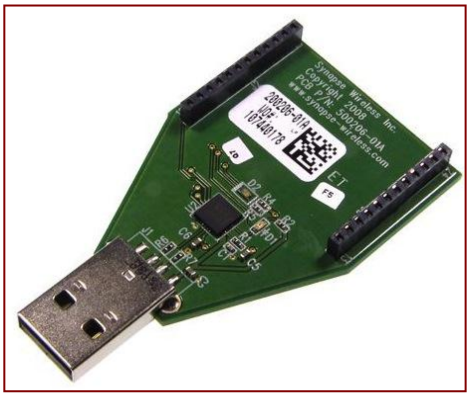


Figure 3.3: SNAPstick [Appendix C.3]

3.3.2 ProtoBoard

ProtoBoard is a board that provide a full access to the RF engine (Figure 3.4).

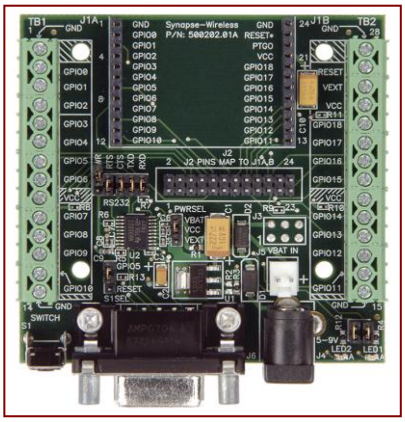
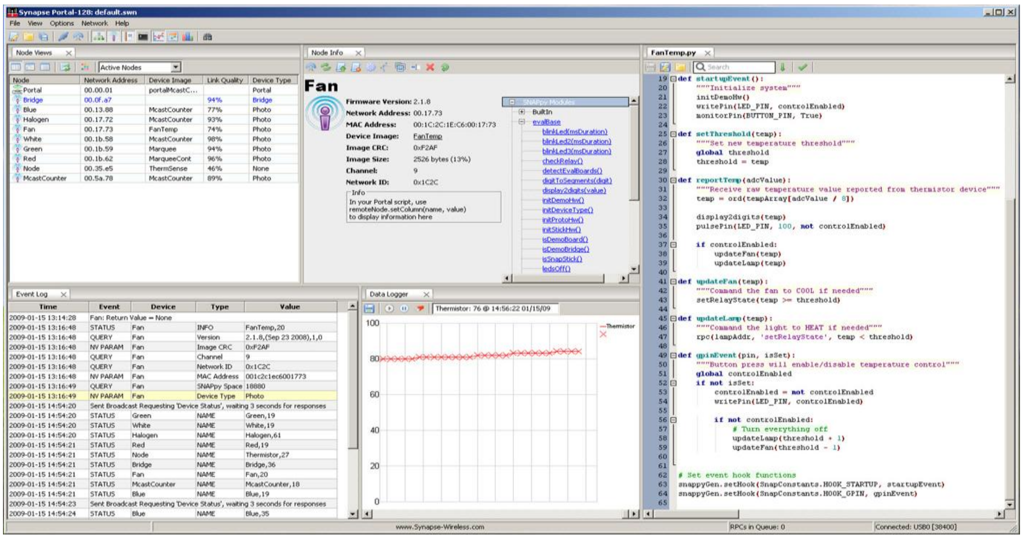


Figure 3.4: SNAP Node ProtoBoard [Appendix C.3]

3.3.3 Portal software

Portal is software that can be used to upload script to the RF engines, delete scripts, monitor activities and more. See Appendix C.2 for more details about the Synapse Portal software. It gives total control to the RF engines with an easy graphical user interface as shown in Figure 3.5.



Node	Network Address	Device Image	Link Quality	Device Type
Portal	00.00.01	portalMcastC...		Portal
Bridge	00.0f.a7		94%	Bridge
Blue	00.13.88	McastCounter	77%	Photo
Halogen	00.17.72	McastCounter	93%	Photo
Fan	00.17.73	FanTemp	74%	Photo
White	00.1b.58	McastCounter	98%	Photo
Green	00.1b.59	Marquee	94%	Photo
Red	00.1b.62	MarqueeCont	96%	Photo
Node	00.35.e5	ThermSense	46%	None
McastCounter	00.5a.78	McastCounter	89%	Photo

Fan

Firmware Version:	2.1.8
Network Address:	00.17.73
MAC Address:	00:1C:2C:1E:C6:00:17:73
Device Image:	FanTemp
Image CRC:	0xF2AF
Image Size:	2526 bytes (13%)
Channel:	9
Network ID:	0x1C2C

Info
In your Portal script, use
remoteNode.setColumn(name, value)
to display information here

```
def startupEvent():
    """Initialize system"""
    initDemoHw()
    writePin(LED_PIN, controlEnabled)
    monitorPin(BUTTON_PIN, True)

def setThreshold(temp):
    """Set new temperature threshold"""
    global threshold
    threshold = temp

def reportTemp(adcValue):
    """Receive raw temperature value reported from thermistor device"""
    temp = ord(tempArray[adcValue / 8])

    display2digits(temp)
    pulsePin(LED_PIN, 100, not controlEnabled)

    if controlEnabled:
        updateFan(temp)
        updateLamp(temp)

def updateFan(temp):
    """Command the fan to COOL if needed"""
    setRelayState(temp >= threshold)

def updateLamp(temp):
    """Command the light to HEAT if needed"""
    rpc(lampAddr, 'setRelayState', temp < threshold)

def gpinEvent(pin, isSet):
    """Button press will enable/disable temperature control"""
    global controlEnabled
    if not isSet:
        controlEnabled = not controlEnabled
        writePin(LED_PIN, controlEnabled)

        if not controlEnabled:
            # Turn everything off
            updateLamp(threshold + 1)
            updateFan(threshold - 1)


# Set event hook functions
snappyGen.setHook(SnapConstants.HOOK_STARTUP, startupEvent)
snappyGen.setHook(SnapConstants.HOOK_GPIN, gpinEvent)
```

Time	Event	Device	Type	Value
2009-01-15 13:14:28	Fan: Return Value = None			
2009-01-15 13:16:48	STATUS	Fan	INFO	FanTemp,20
2009-01-15 13:16:48	QUERY	Fan	Version	2.1.8,(Sep 23 2008),1,0
2009-01-15 13:16:48	NV PARAM	Fan	Image CRC	0xF2AF
2009-01-15 13:16:48	QUERY	Fan	Channel	9
2009-01-15 13:16:48	QUERY	Fan	Network ID	0x1C2C
2009-01-15 13:16:48	NV PARAM	Fan	MAC Address	001c2c1ec6001773
2009-01-15 13:16:49	QUERY	Fan	SNAPpy Space	18880
2009-01-15 13:16:49	NV PARAM	Fan	Device Type	Photo
2009-01-15 14:54:20	Sent Broadcast Requesting 'Device Status', waiting 3 seconds for responses			
2009-01-15 14:54:20	STATUS	Green	NAME	Green,19
2009-01-15 14:54:20	STATUS	White	NAME	White,19
2009-01-15 14:54:20	STATUS	Halogen	NAME	Halogen,61
2009-01-15 14:54:21	STATUS	Red	NAME	Red,19
2009-01-15 14:54:21	STATUS	Node	NAME	Thermistor,27
2009-01-15 14:54:21	STATUS	Bridge	NAME	Bridge,36
2009-01-15 14:54:21	STATUS	Fan	NAME	Fan,20
2009-01-15 14:54:21	STATUS	McastCounter	NAME	McastCounter,18
2009-01-15 14:54:21	STATUS	Blue	NAME	Blue,19
2009-01-15 14:54:23	Sent Broadcast Requesting 'Device Status', waiting 3 seconds for responses			
2009-01-15 14:54:24	STATUS	Blue	NAME	Blue,35

Figure 3.5: Portal software [C.2]

3.4 System structure

This system works as follows:

1. The Tag sends a signal to the nearest reader node showing its location.
2. The Reader node sends a signal of the tag location and its ID to the PC reader node.
3. The PC reader forwards the signal received from the reader node to PC software called the PC Serial to HTTP converter.
4. The PC Serial to HTTP converter processes the data and then sends it to a server.
5. Graphical user interface software uses the data from the server to locate the tags on a map. Figure 3.6 shows a diagram of the system structure.

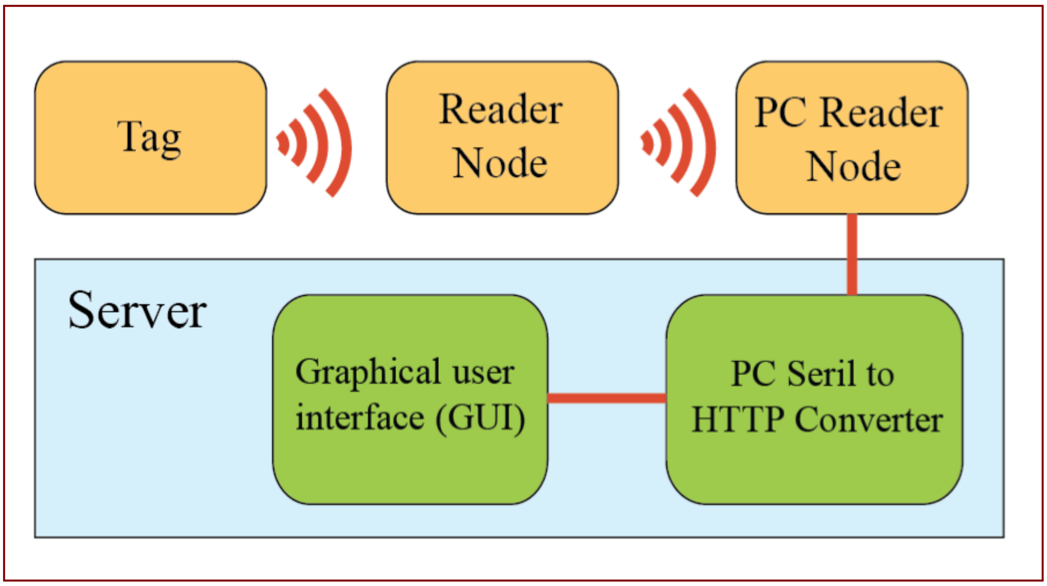


Figure 3.6: System structure

3.4.1 Tag

There are two kinds of tags, passive and active tags as mentioned before. The active tags have been used in this project. Passive tags have some advantages over the active tags in terms of cost and size, but the reason for excluding the passive tags is their short reading range which is crucial in this project. The Synapse RF engine requires minimum power of 2.5V. So the tag will be powered by a Li-Ion Rechargeable Coin Cell batteries (PD3555) to keep the tag small. The battery holder will be soldered directly to the module; (-) on the battery goes to the pin 24 on the module and (+) goes to pin 21 on the module. Figure 3.7 shows the wiring for the tag and Figure 3.8 shows a prototype of the tag.

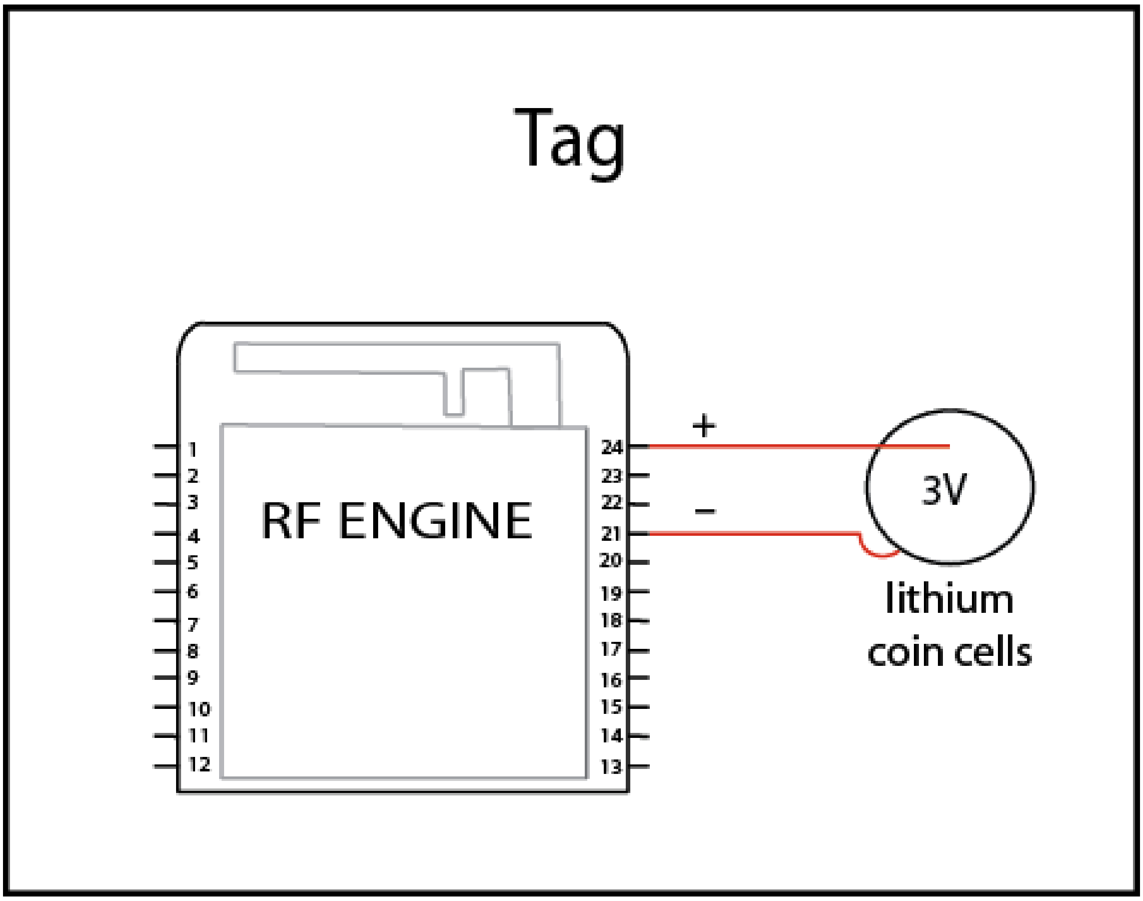


Figure 3.7: Tag’s structure

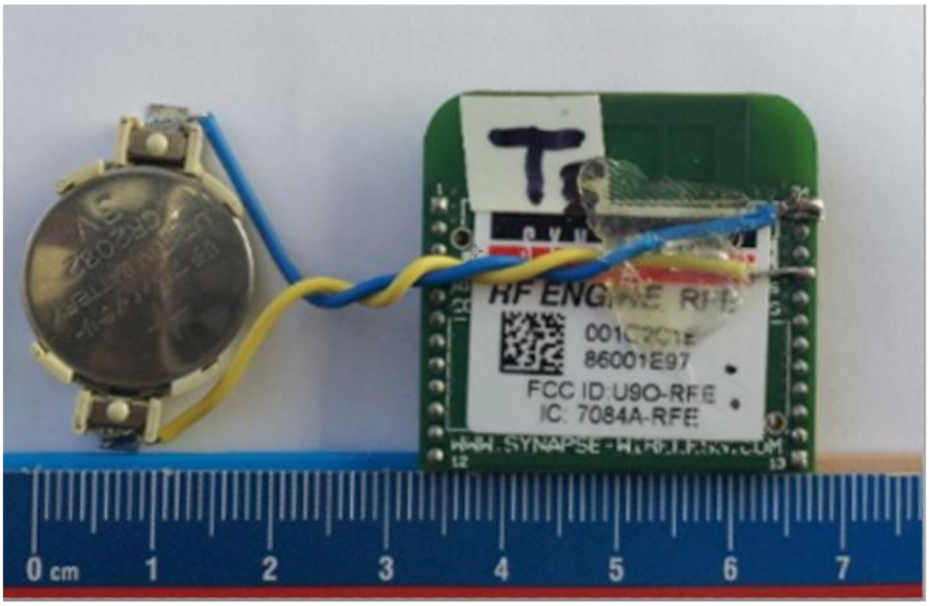


Figure 3.8: Prototype of the tag

A Pocket card enclosure will be used to house the tag . The enclosure dimensions are 85mm length, 54 mm width and 10mm height. These will make the tag portable and easy to be carried around as shown in Figure 3.9.

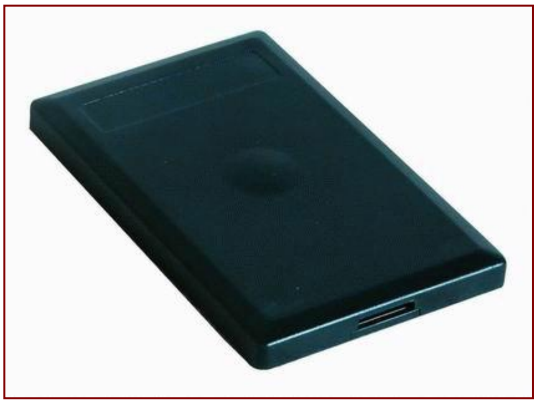


Figure 3.9: Tag enclosure

The script uploaded in the tag makes the tag send a ping and then it goes to sleep mode before the next ping and that will increase the battery life .The Python script for the tag can be seen in Appendix A.1. Figure 3.10 illustrates the process of the tag.

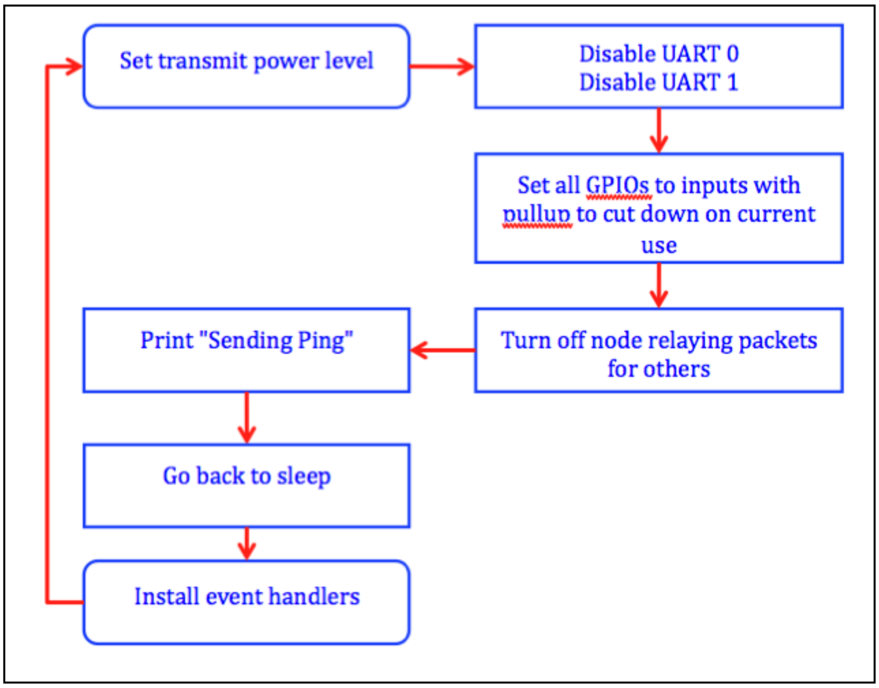


Figure 3.10: Tag’s code

3.4.2 Reader node

The RFID tracking system has three techniques: Hand-held reader, fixed reader installed in area, and fixed reader installed at chokepoint. For this project “fixed reader installed in area” will be used to cover wide areas and to get higher accuracy. The reader nodes will be installed at fixed places and will be powered by a 3 V DC 400 mA Power Adapter. Similar to the tag wiring setup, (-) on the DC plug goes to the pin 24 on the module and (+) goes to pin 21 on the module, as shown in Figure 3.11.

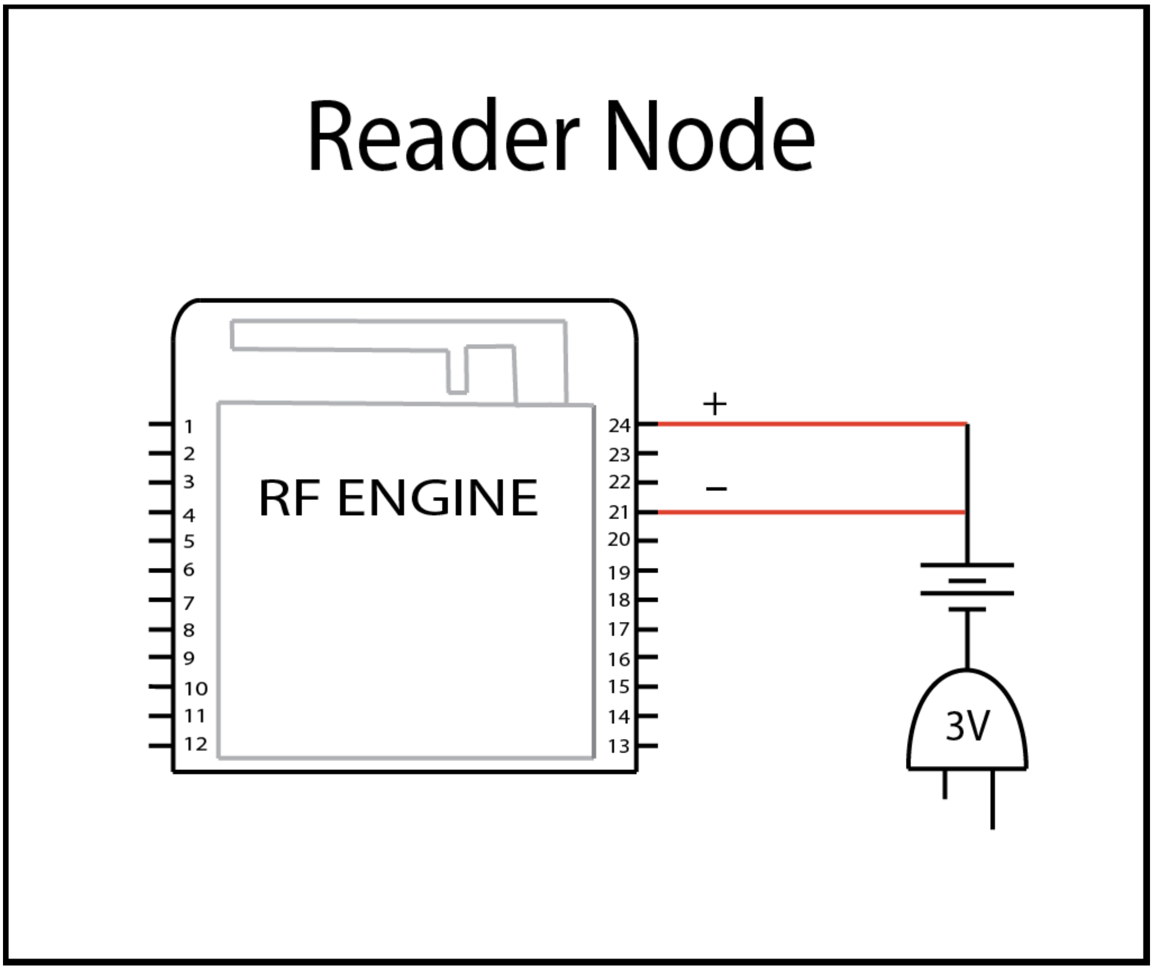


Figure 3.11: Reader node’s structure

The reader node will be put in an enclosure to protect the module. The dimensions of the enclosure are 50 mm length 50 mm width 20 mm height as shown in Figure 3.12.

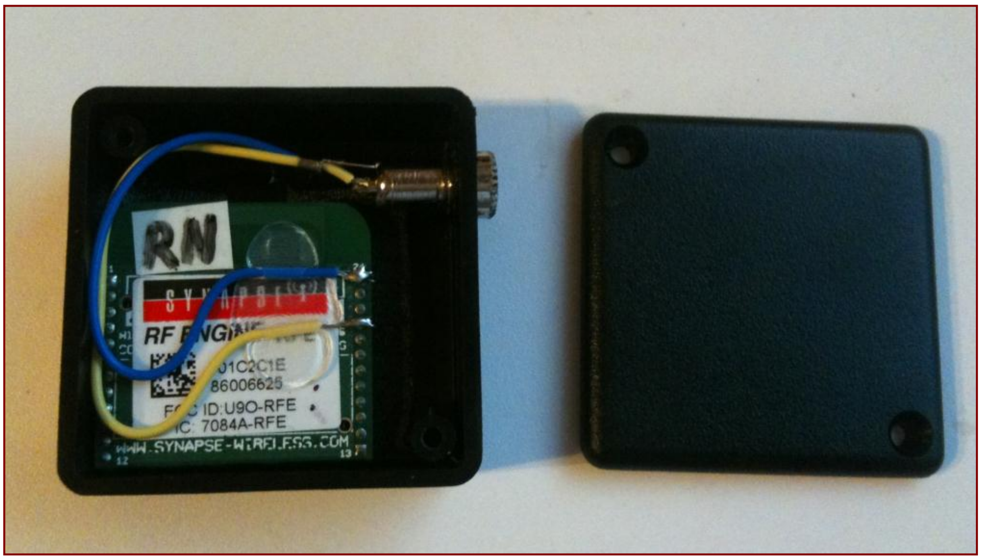


Figure 3.12: Prototypes of the reader node

Python script will be uploaded to reader node by the Synapse Evaluation Kit. The python script of the reader node can be seen in Appendix A.2. This script will make the reader node receive signals of the tag and send them back to the PC reader node along with the id of the reader itself. Figure 3.13 shows how the reader node works.

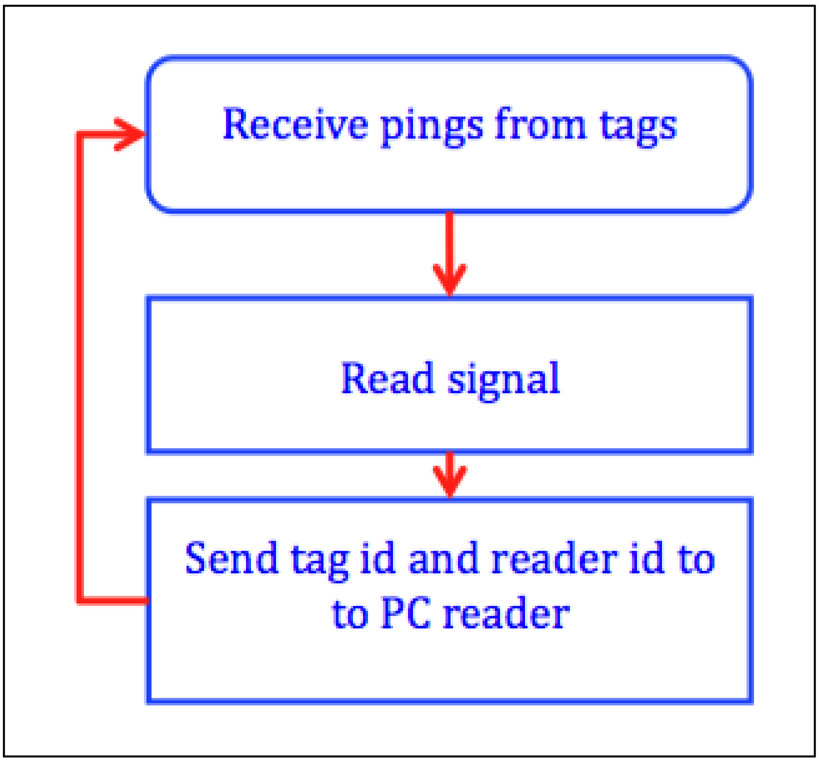


Figure 3.13: Reader node’s code

3.4.3 PC reader node

To connect the PC reader to the host computer, a FTDI USB to serial cable will be used. The USB end plugs into the host computer and the other end connects to the UART pins on the module. The USB port provides 5V but the module needs 3V so a LP2950ACZ-3.0 Voltage Regulator will be used to convert the power. Figure 3.14 shows the wiring for the PC reader.

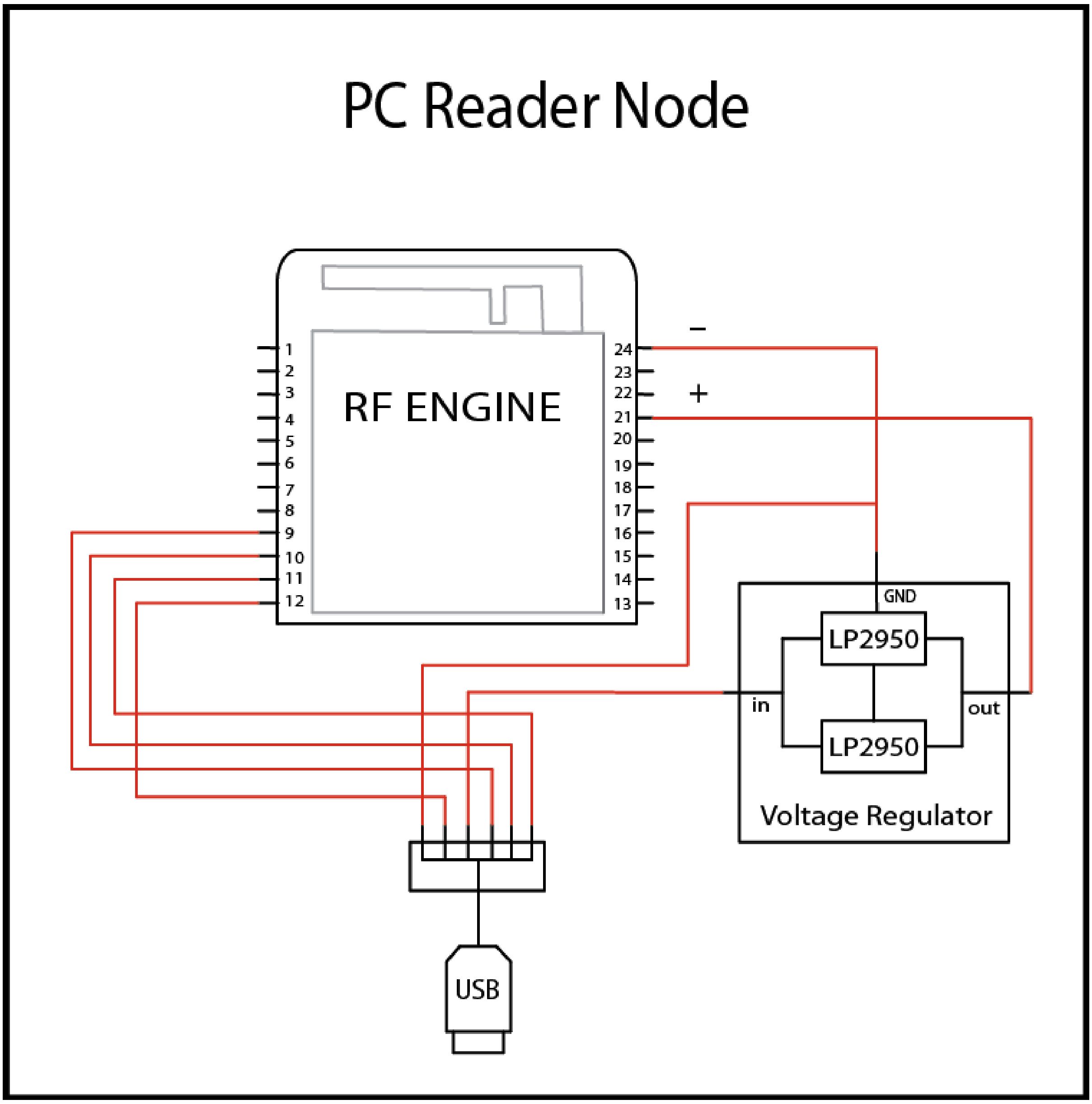


Figure 3.14: PC reader node's structure

The Python Software will allow the PC reader node to receive data wirelessly from the network of the reader nodes and will forward it to the host computer. The python script of the PC reader node can be seen in Appendix A.3. Figure 3.15 shows how the PC reader node works.

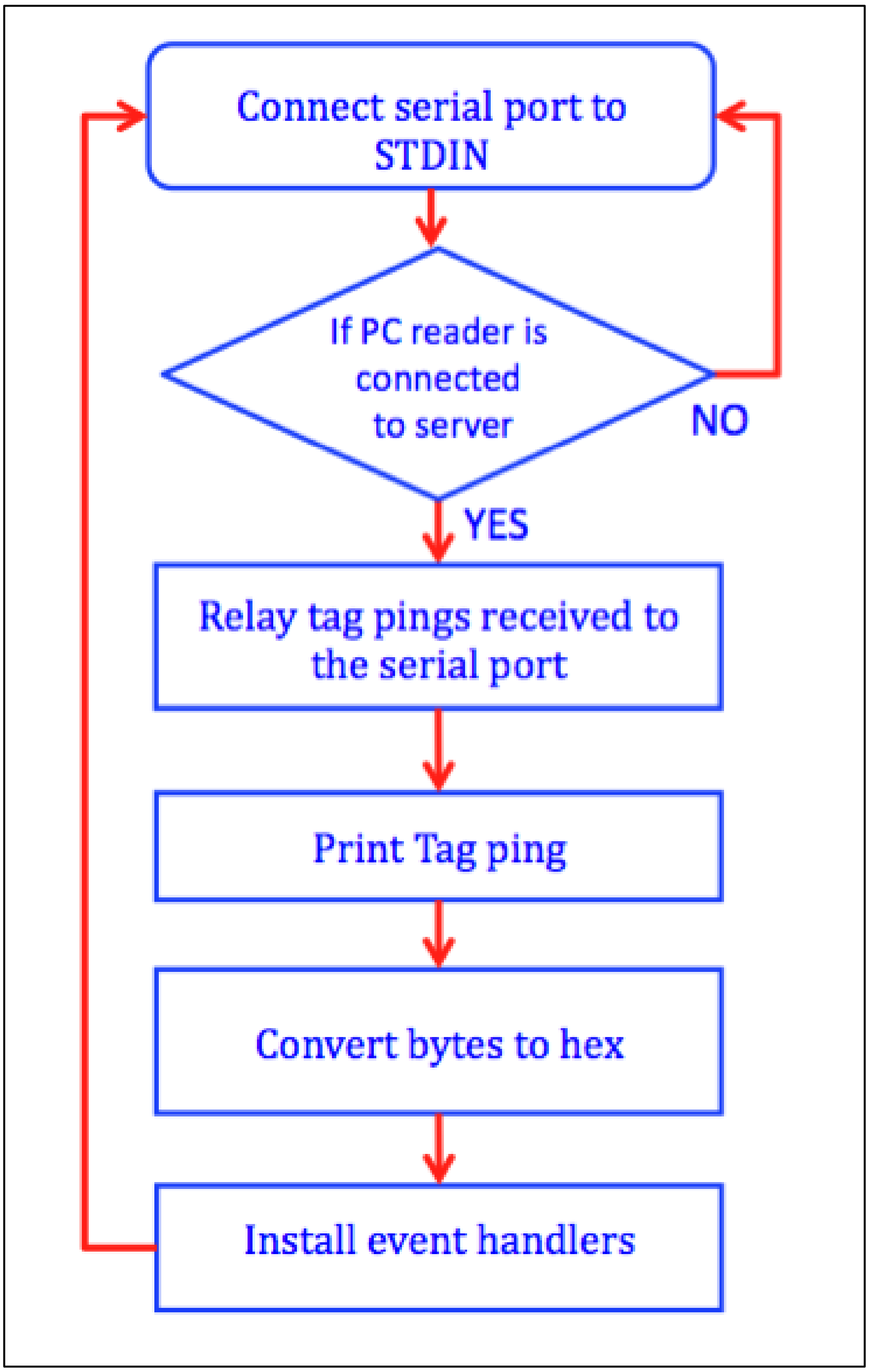
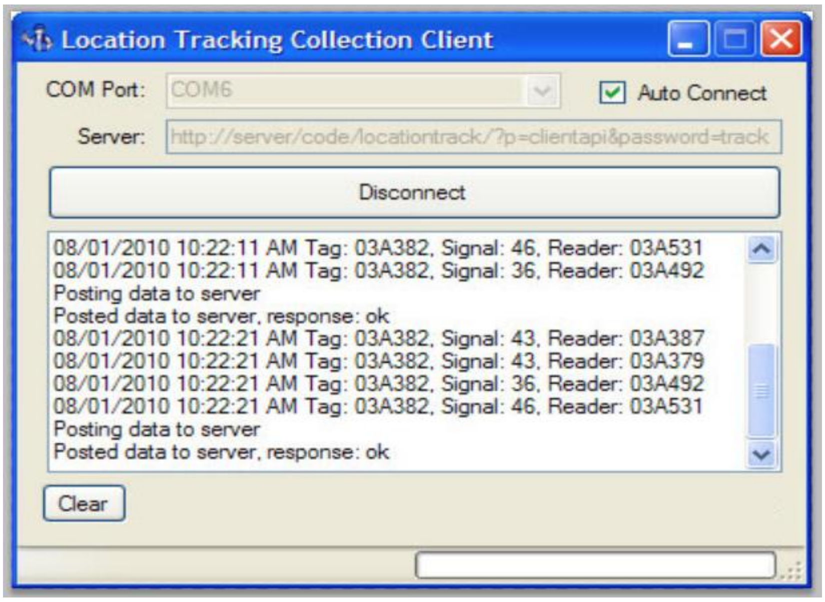

Connect serial port to STDIN
If PC reader is connected to server
NO
YES
Relay tag pings received to the serial port
Print Tag ping
Convert bytes to hex
Install event handlers

Figure 3.15: The PC reader node's code

3.4.4 PC serial to http converter

Software written in c# language and running on the host computer receives the data from the PC Reader via the FTDI adapter and then forwards the data to an HTTP server via HTTP Port Figure 3.16.



COM Port: COM6

☑ Auto Connect

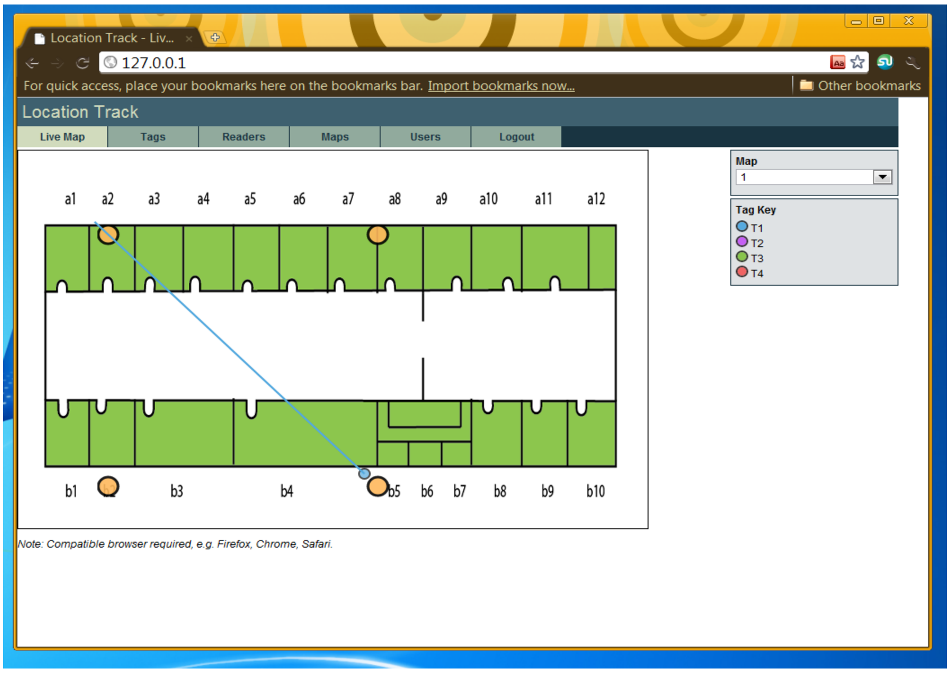
Server: http://server/code/locationtrack/?p=clientapi&password=track

```
08/01/2010 10:22:11 AM Tag: 03A382, Signal: 46, Reader: 03A531
08/01/2010 10:22:11 AM Tag: 03A382, Signal: 36, Reader: 03A492
Posting data to server
Posted data to server, response: ok
08/01/2010 10:22:21 AM Tag: 03A382, Signal: 43, Reader: 03A387
08/01/2010 10:22:21 AM Tag: 03A382, Signal: 43, Reader: 03A379
08/01/2010 10:22:21 AM Tag: 03A382, Signal: 36, Reader: 03A492
08/01/2010 10:22:21 AM Tag: 03A382, Signal: 46, Reader: 03A531
Posting data to server
Posted data to server, response: ok
```

Figure 3.16: PC Serial to HTTP converter

3.4.5 Display GUI

The Graphical User Interface (GUI) for this project is coded in PHP programming. So the GUI is web based and it can be accessed via any Internet browser. The GUI receives the data from the PC Serial to HTTP converter and displays the location of the tags on a map, which has been drawn for the actual location. The GUI is designed to allow the user to add, delete or modify any information including tags, reader nodes, maps and system users. Figure 3.17 shows a snapshot of the GUI.

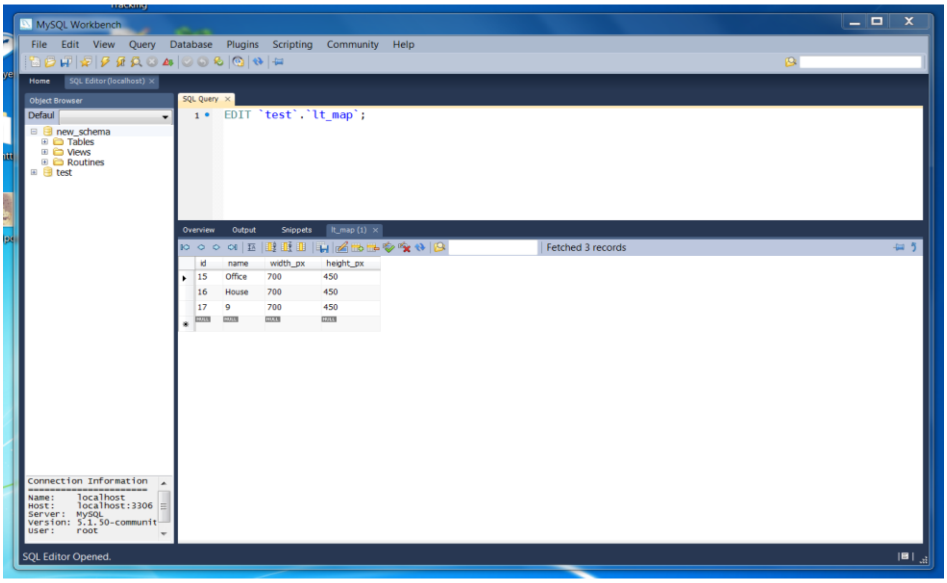


Note: Compatible browser required, e.g. Firefox, Chrome, Safari.

Figure 3.17: The Graphical User Interface (GUI)

3.4.6 My SQL database

Database 'My SQL' will be used to restore and recall any information including tags, reader nodes, maps and the authorized users of the system Figure 3.18.



```
EDIT `test`.`lt_map`;
```

Fetched 3 records

id	name	width_px	height_px
15	Office	700	450
16	House	700	450
17	9	700	450
NULL	NULL	NULL	NULL

```
Connection Information
=======================
Name:     localhost
Host:     localhost:3306
Server:   MySQL
Version:  5.1.50-communit
User:     root
```

SQL Editor Opened.

Figure 3.18: My SQL database

3.5 Key considerations for developing the system

While developing the system, some points have been taken into consideration including the ease of use by the provider and the beneficiary, low cost and practical and work under any conditions. The main advantages of the system are summarized below:

1. The system does not require software to be installed to view the map because the GUI is web based.
2. Works on any platform where users have Internet browser including Windows, UNIX or Mac.
3. Can be accessed from anywhere worldwide.
4. The map can be viewed by multiple users at the same time.

CHAPTER 4

TRILATERATION METHOD

4.1 Positioning In Wireless Sensor Networks

In Wireless Sensor Networks the location of the tags can be determined in different ways including: Triangulation, Trilateration, Fingerprinting and Multilateration [30, 31]. These methods use the radio signal properties provided by the RF module infrastructure in order to calculate the location of the tag. The radio signal properties are: Time of Arrival (ToA), Time Difference of Arrival (TDoA), Angle of Arrival (AoA) and Received Signal Strength Indicator (RSSI).

4.1.1 Multilateration

The multilateration method is based on TDoA (Time Difference of Arrival) [32]. This method requires at least three nodes to estimate the unknown location of the tag. However, multilateration method needs a high accuracy in the time synchronization of the received signals to do the calculation.

4.1.2 Triangulation

The triangulation method uses triangle geometry to calculate the unknown location of the tag [33]. AOA (Angle of Arrival) is used in this method and it requires a minimum of two reference nodes. The only disadvantage in this method is the use of the antenna direction in the calculation of the tag location.

4.1.3 Fingerprinting

The fingerprinting method uses RSSI to build a database of several tag locations. For a new calculation, new RSSI measurements will be obtained and it will try to find similar conditions using the database. This method is time consuming especially in large and dynamic networks. [34, 35].

4.1.4 Trilateration

This system is designed around the principle of the trilateration method. The trilateration code used in this system can be seen in Appendix B. The trilateration method has been widely used for wireless sensor network localizations. This method requires at least three fixed nodes. Receiver Signal Strength Indication (RSSI) is used to calculate the location of the tag [36].

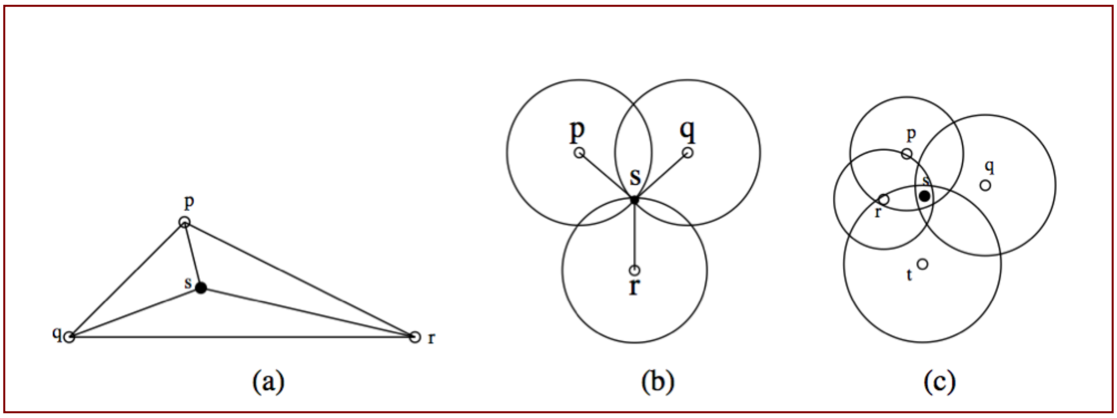


Figure 4.1: (a) Triangulation (b) Trilateration (c) Multilateration

4.2 Received Signal Strength Indicator (RSSI)

RSSI is mostly affected by variable factors including obstacles, multipath and node distribution and has most frequent errors in indoor environments. Mecca is an open environment with a high probability of Line of Sight (LoS) and low multipath effect. In the fixed nodes distribution, also, it is very important to have accurate results. Therefore, we take into consideration that the nodes are distributed equally so the tags are in the range of at least 3 nodes. The highlighted area in Figure 4.2 shows the coverage of 3 or more reader nodes. The relationship between the Received Signal Strength (RSSI) and the distance test is shown in Figure 4.3.

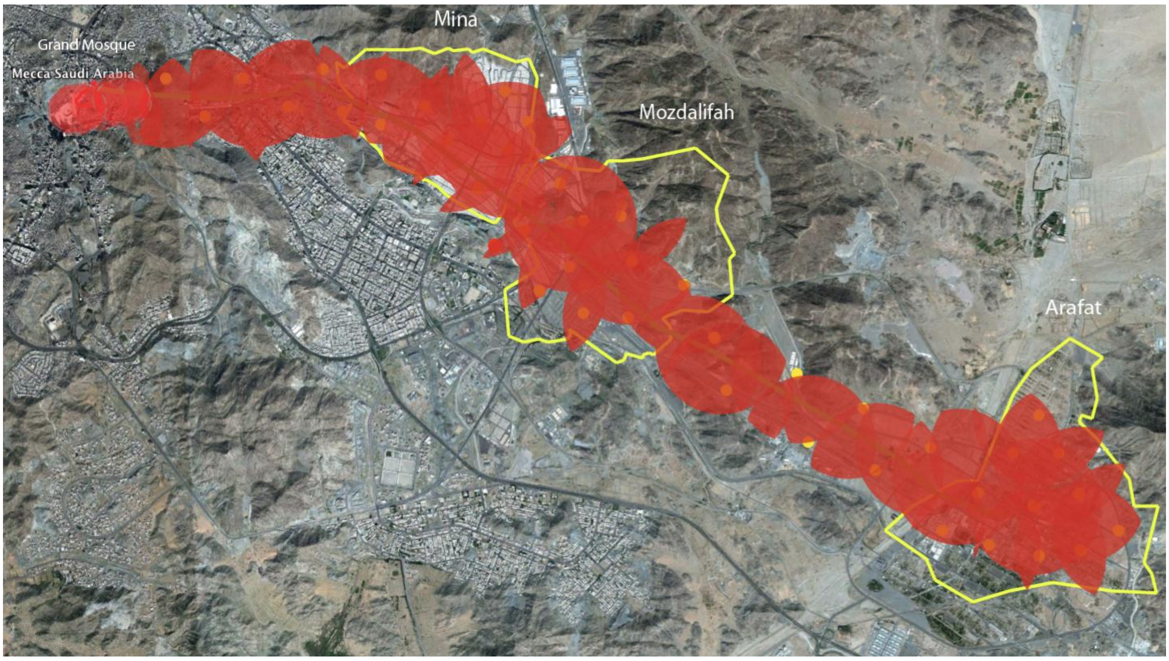


Figure 4.2: Three or more reader nodes coverage [37]

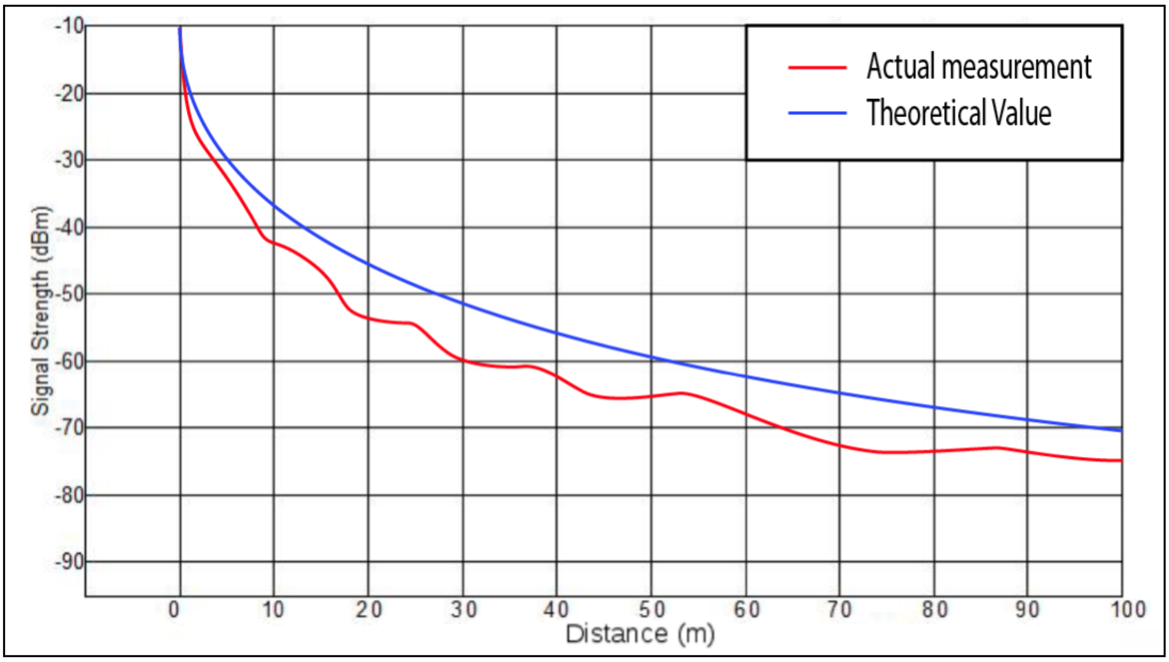


Figure 4.3: Relationship between RSSI and distance

4.3 The mathematics of the trilateration method

The basic formula for a circle is shown (1)

$$d^2 = x^2 + y^2 \tag{1}$$

If we assume there are three reference nodes at points (x_a, y_a), (x_b, y_b) and (x_c, y_c). The distances between these nodes and the target node are *$(d_a d_b d_c)$* as shown in Figure 4.4.

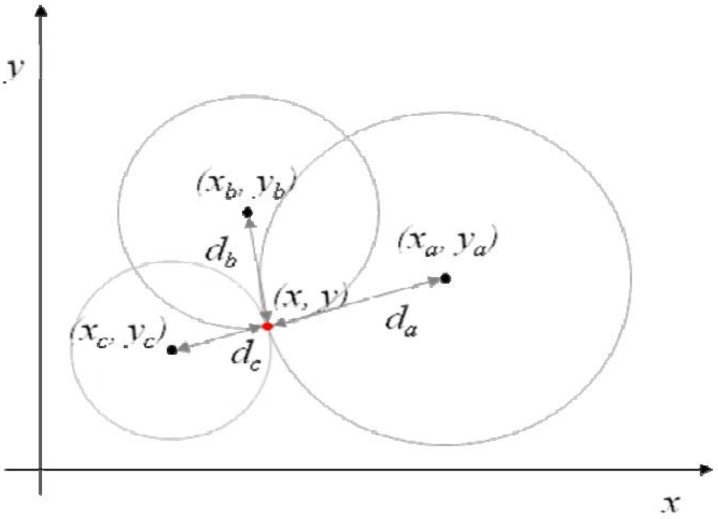


Figure 4.4: Intersection of 3 circles

The formulas for the three circles are as shown in equations (2), (3) and (4).

$$d_a{}^2 = (x - x_a)^2 + (\mathrm{y} - y_a)^2 \tag{2}$$

$$d_b{}^2 = (x - x_b)^2 + (\mathrm{y} - y_b)^2 \tag{3}$$

$$d_c{}^2 = (x - x_c)^2 + (\mathrm{y} - y_c)^2 \tag{4}$$

Equations (2), (3) and (4) are expanded to become equations (5), (6) and (7)

$$d_a{}^2 = x^2 - 2x.x_a + x_a{}^2 + y^2 - 2y.y_a + y_a{}^2 \tag{5}$$

$$d_b{}^2 = x^2 - 2x.x_b + x_b{}^2 + y^2 - 2y.y_b + y_b{}^2 \tag{6}$$

$$d_c{}^2 = x^2 - 2x.x_c + x_c{}^2 + y^2 - 2y.y_c + y_c{}^2 \tag{7}$$

The next step is using a method proposed by Dixon [8] to get radical plane for circle intersection by subtracting 2 circles. In this case, equation (7) will be subtracted from equation (6) to get equation (8) and equation (5) will be subtracted from equation (6) to get equation (9).

$$d_b{}^2 - d_c{}^2 = 2x(x_c - x_b) + x_b{}^2 - x_c{}^2 + 2y(y_c - y_b) + y_b{}^2 - y_c{}^2 \qquad (8)$$

$$d_b{}^2 - d_c{}^2 = 2x(x_a - x_b) + x_b{}^2 - x_a{}^2 + 2y(y_a - y_b) + y_b{}^2 - y_a{}^2 \qquad (9)$$

Rearranging the equation (8) and (9) will generate new variables called *Va* in equation (10) and *Vb* in equation (11)

$$\frac{x(x_b - x_c) - \mathrm{y}(y_b - y_c) = (x_c{}^2 - x_b{}^2) + (y_c{}^2 - y_b{}^2) + (d_b{}^2 - d_c{}^2)}{2} = v_a \qquad (10)$$

$$\frac{x(x_b - x_a) - \mathrm{y}(y_b - y_a) = (x_a{}^2 - x_b{}^2) + (y_a{}^2 - y_b{}^2) + (d_b{}^2 - d_a{}^2)}{2} = v_b \qquad (11)$$

The intersection points ‘x’ and ‘y’ of equation (10) and (11) are shown in (12) and (13)

$$y = \frac{v_b(x_b - x_c) - v_a(x_b - x_a)}{(y_a - y_b)(x_b - x_c) - (y_c - y_b)(x_b - x_c)} \qquad (12)$$

$$x = \frac{y(y_a - y_b) - v_b}{(x_b - x_c)} \qquad (13)$$

4.4 Trilateration field experiment

In this section the distance error was measured by observing the distance between the actual tag location and the tag location calculated in the GUI. A network of 6 reader nodes and the PC reader node were set up. 8 tags were placed in several different places within the range of at least three reader nodes.

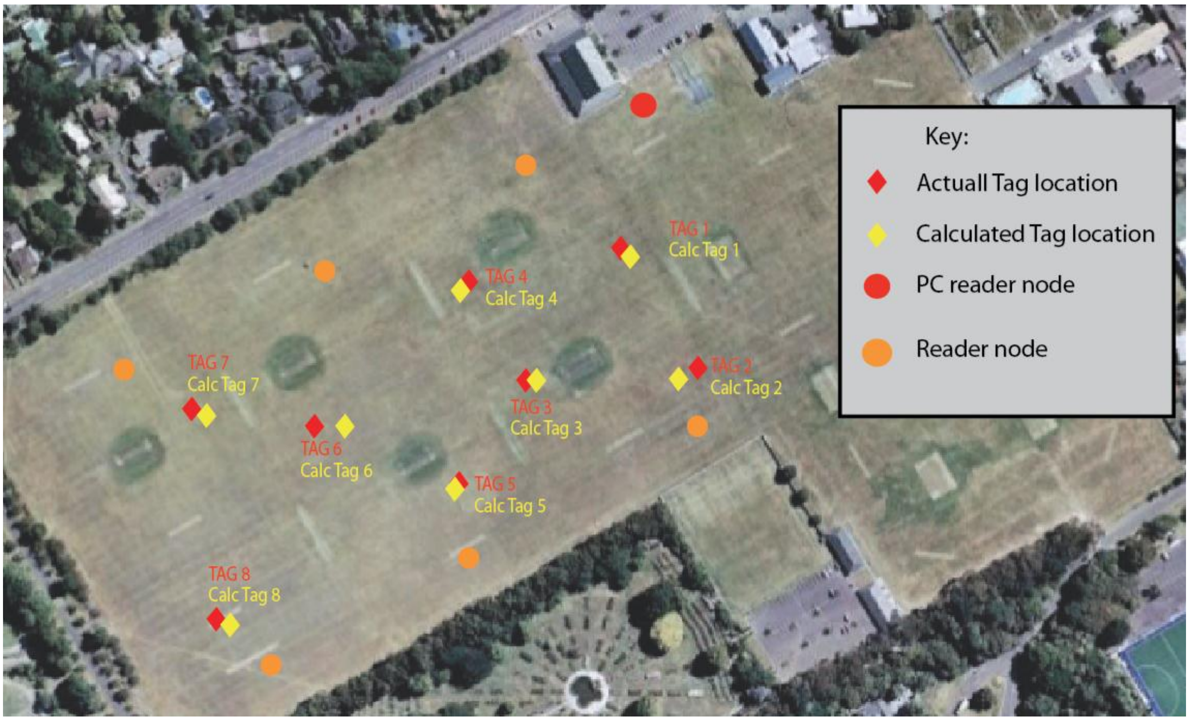


Figure 4.5: Trilateration field results [38]

As shown in Figure 4.5 the distance error is relatively low. Table 4.1 shows the distance in meters between the actual tag location and the calculated location.

Table 4.1: Distances between the actual and the calculated tag location

Tag	Tag1	Tag2	Tag3	Tag4	Tag5	Tag6	Tag7	Tag8	Average
Distance (m)	2.5	4.0	3.5	2.5	1.5	5.0	4.5	3.0	3.5

CHAPTER 5

HARDWARE AND SOFTWARE IMPLEMENTATION

5.1 Readers positioning

This section outlines how the actual coverage of the readers was measured, how many readers are required and where they should be located in Mecca.

5.1.1 Introduction

Before measuring the coverage of the readers, the outer borders of the pilgrimage sites need to be identified. As mentioned earlier, the pilgrims must visit four different sites in order to complete their Hajj; the Grand Mosque, Mina, Mozdalifah and Arafat as shown in Figure 5.1. The Grand Mosque is 100.000 m2, Mina is 8 km2, Mozdalifah is 12 km2 and Arafat is 13 km2.

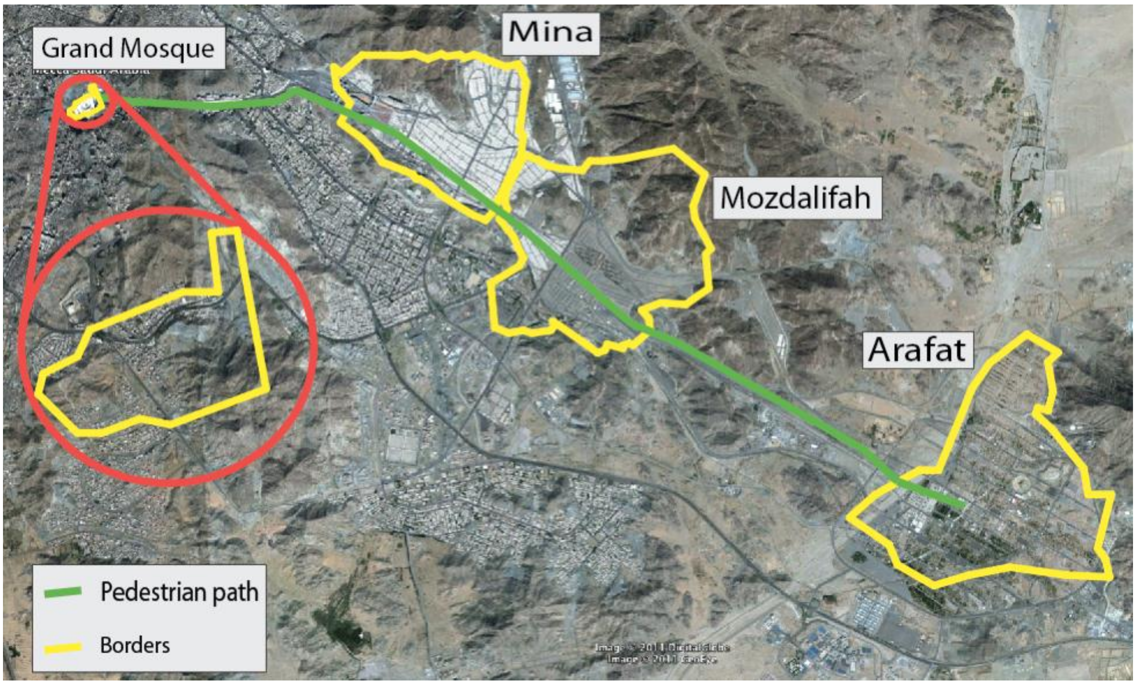


Figure 5.1: Pilgrimage sites borders [37]

5.1.2 Reader node coverage experiment

Five reader nodes and the PC reader node (main) were used in this experiment. The Synapse Portal program was used to measure the link quality. The experiment was done outdoors at a local park of 577.43m length and 257.13m width as shown in Figure 5.2. The signal strength between the reader node and the PC reader was measured every 20 meters.

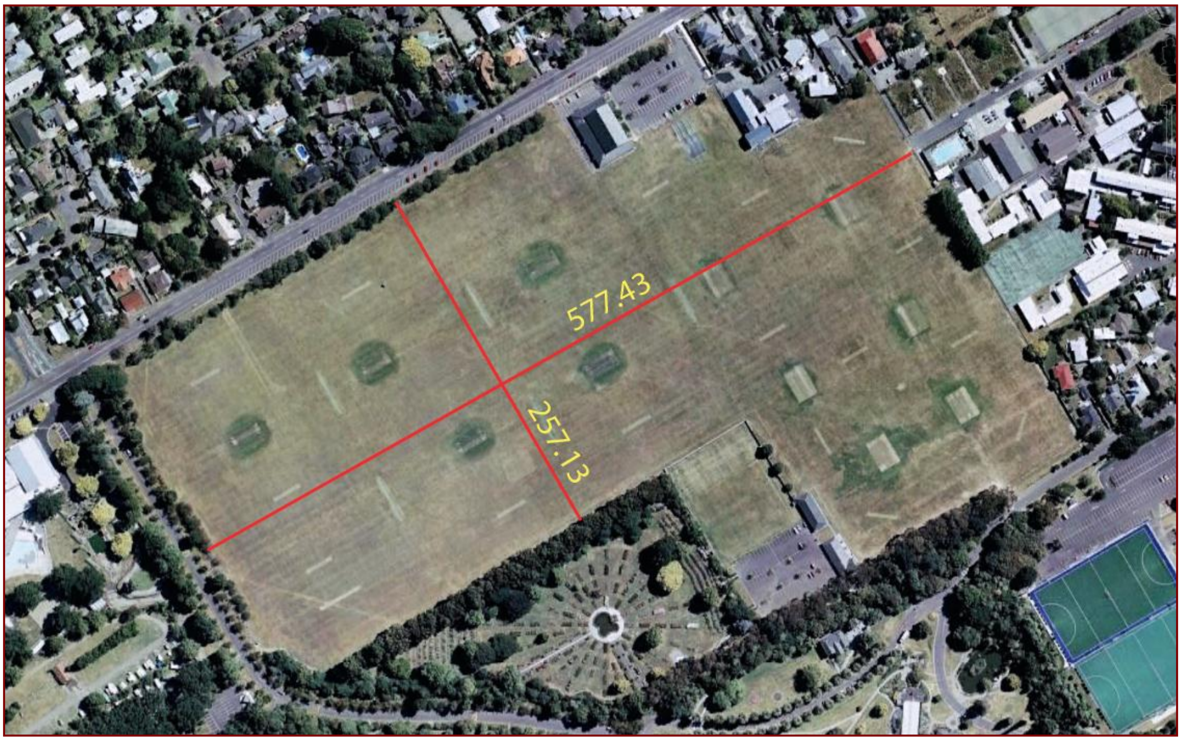


Figure 5.2: Experiment field [38]

As shown in Table 5.1 and Figure 5.3 the coverage area for a signal reader node is about 200 meter radius.

Table 5.1: Distance vs. link quality

Distance (m)	10	20	40	60	80	100	120	140	160	180	200
R1	100%	96%	94%	93%	85%	82%	77%	69%	54%	34%	14%
R2	100%	98%	97%	91%	88%	83%	75%	66%	52%	30%	10%
R3	100%	97%	96%	94%	89%	82%	74%	67%	55%	33%	13%
R4	100%	95%	95%	93%	86%	81%	75%	68%	53%	34%	12%
R5	100%	97%	96%	92%	87%	84%	76%	67%	54%	33%	11%
Average	100%	97%	96%	93%	87%	82%	75%	67%	54%	33%	12%

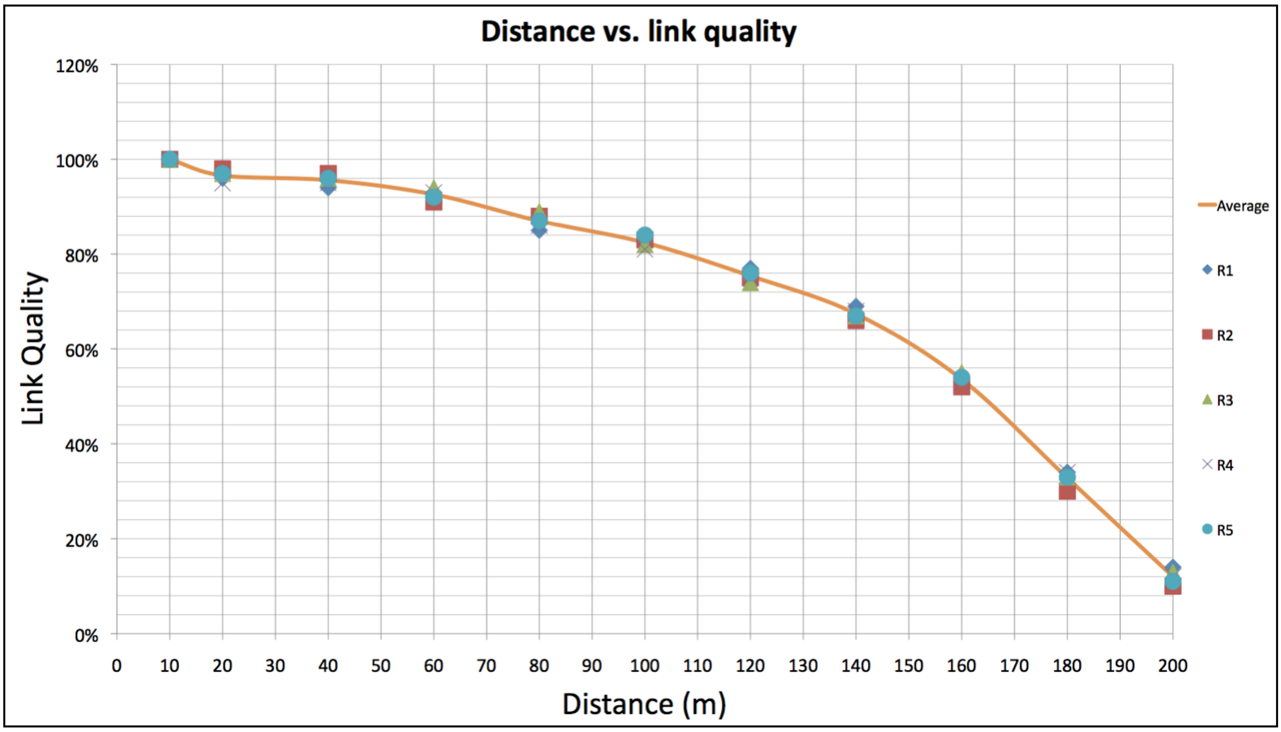


Figure 5.3: Distance vs. link quality

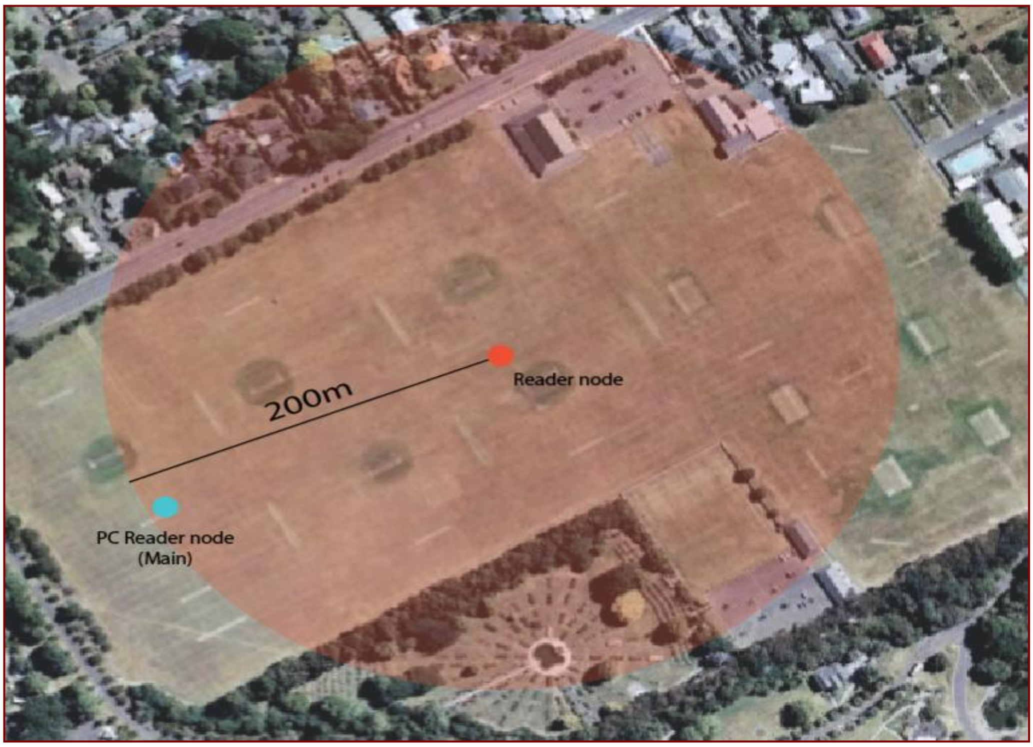


Figure 5.4: The coverage of a single reader node [38]

5.1.3 Positioning results

Using the reader nodes coverage test the appropriate places for the reader nodes at the pilgrimage sites were about to be determined. 50 is the minimum number of reader nodes required to achieve the best coverage and to enable the system to precisely locate the tags using the trilateration method. While one PC reader node would be enough, we decided to use four PC reader nodes, one in each region. The reasons for that were: firstly, to reduce the load imposed on the PC reader node and, secondly, to make it easier for the viewer to track the tags in each region individually. That means we had four networks connected together and the viewer could access all of them from one place. Based on the results of the local test, the suitable places for the reader nodes in Mecca were identified so that the distance between each node did not exceed 200 meters. The node distribution can be seen in Figure 5.5.

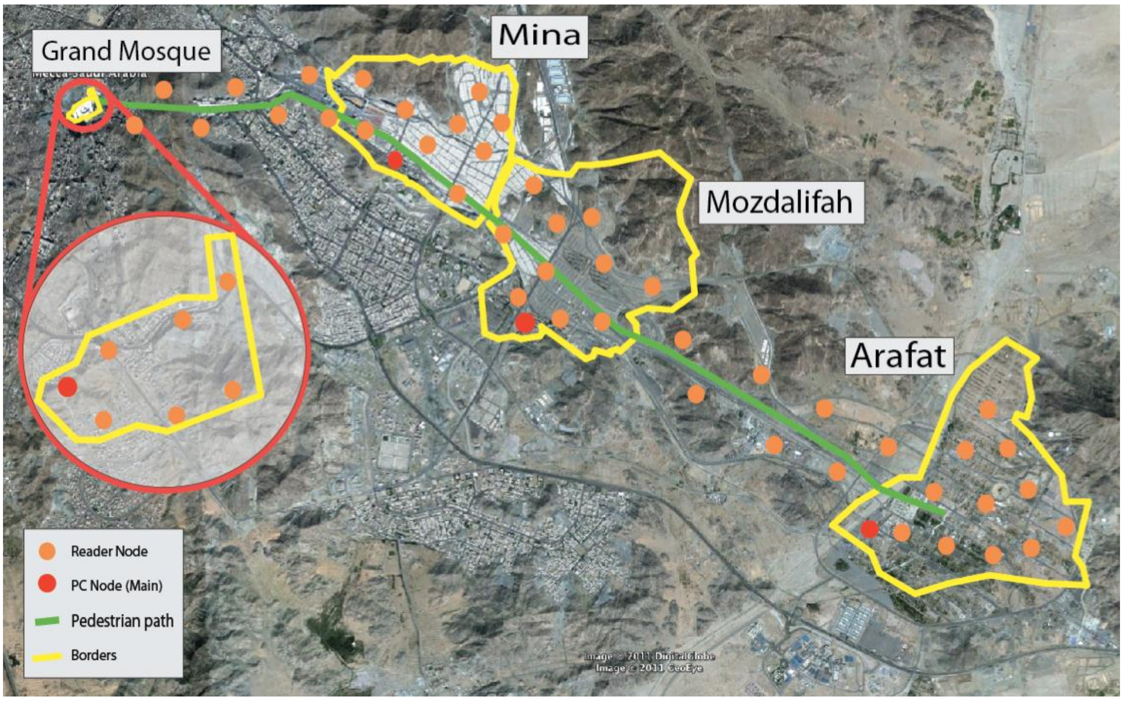


Figure 5.5: Reader nodes distribution [37]

5.2 Mesh network test

The Synapse RF Engine provides instant-on, multi-hop, mesh network. In this case just one reader node has to be close to the PC reader node. In order to test the mesh networking capability in this system a network of 3 reader nodes (R1, R2, R3) and the PC reader node were trialled. R1 was placed within the range of the PC reader whereas R2 and R3 were not as shown in Figure 5.6.

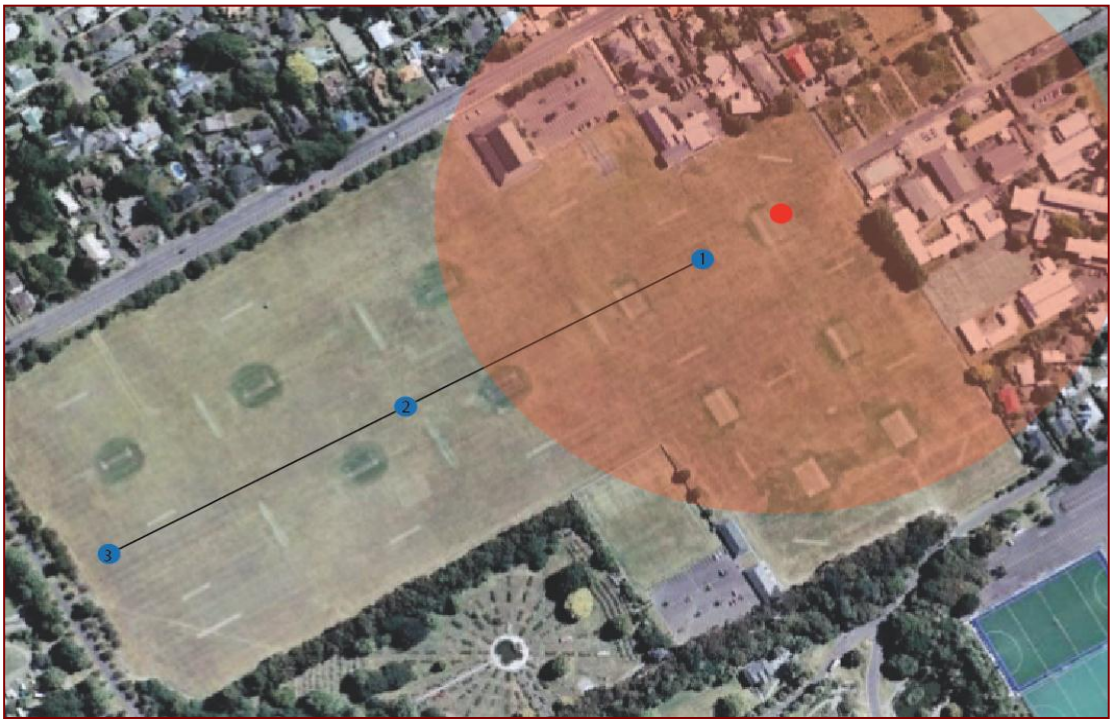
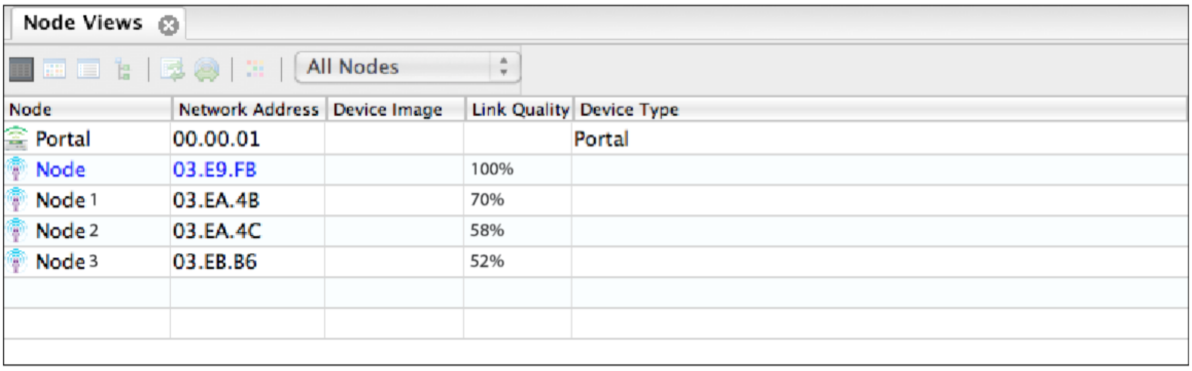


Figure 5.6: Mesh network test (stage one) [38]

The result, as shown in Synapse Portal program, proved that R1, R2 and R3 were connected the PC reader node (Figure5.7).



Node	Network Address	Device Image	Link Quality	Device Type
Portal	00.00.01			Portal
Node	03.E9.FB		100%	
Node 1	03.EA.4B		70%	
Node 2	03.EA.4C		58%	
Node 3	03.EB.B6		52%	

Figure 5.7: Portal results of the mesh network test (stage one)

That means R2 and R3 were connected to the PC reader via mesh network capability. Next, we disabled R2 as shown Figure 5.8.

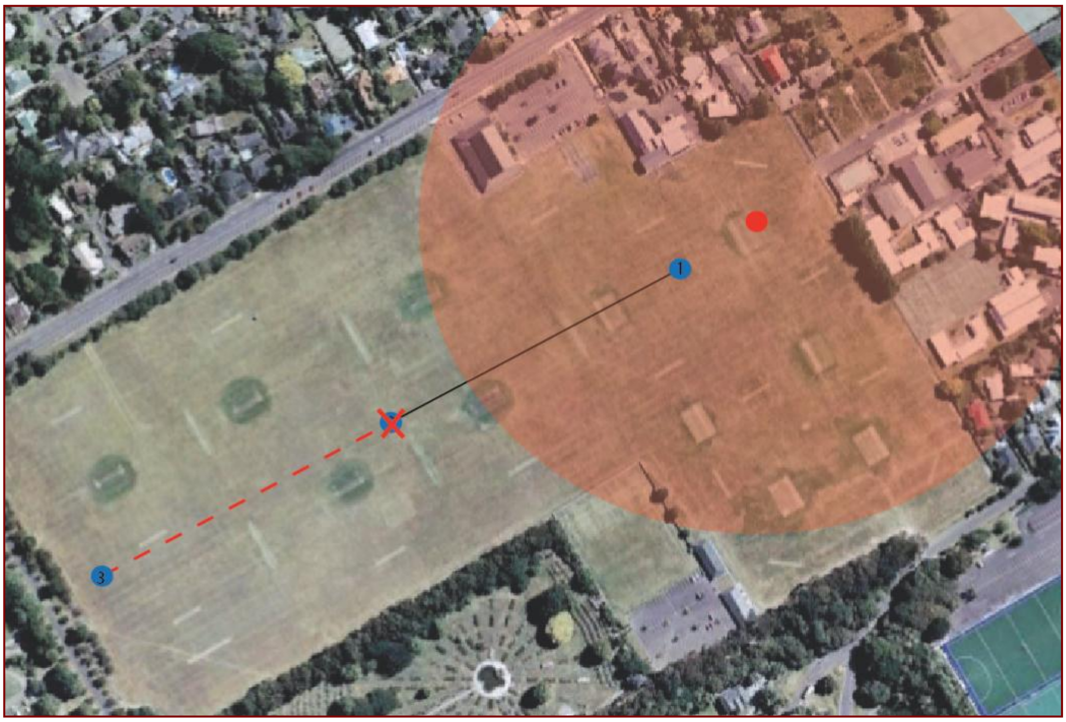
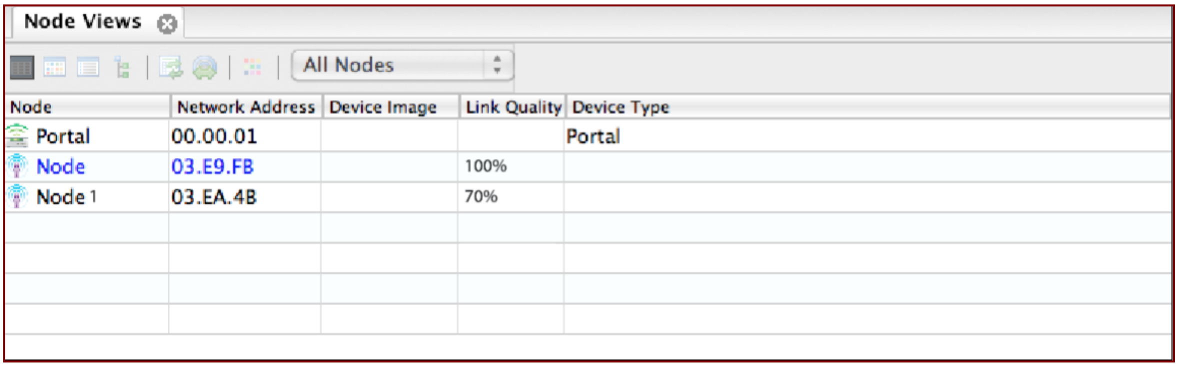


Figure 5.8: Mesh network test (stage two) [38]

The results show that R3 was not connected to the PC reader node as can be seen in Figure 5.9. This test proves that the mesh network is working as expected.



Node	Network Address	Device Image	Link Quality	Device Type
Portal	00.00.01			Portal
Node	03.E9.FB		100%	
Node 1	03.EA.4B		70%	

Figure 5.9: Portal results of the mesh network test (stage two)

5.3 Tag battery life test

A single tag requires 2.7-3.4 Voltage. The batteries that were used to power the tags are Li-Ion Rechargeable Coin Cell batteries (PD3555). These batteries can produce 3.7 voltages with a capacity of 500 mAh. The advantages of this battery are: rechargeable, small size, lightweight, portability, availability, easy to replace and long-time duration. The tag has been programmed to consume the lowest amount of energy possible as it sends a signal and then puts itself in sleep mode for ten minutes. The power consumption will be measured by a digital Voltmeter. The batteries will be measured before putting them into the tags. Then, when the tags are powered and start transmitting, the battery life will be measured once every day for a week (7 days) without switching the tags off.

Table 5.2: Tag battery life test results

Time	Before using	Day1	Day2	Day3	Day4	Day5	Day6	Day7
Battery life	3.74V	3.61V	3.53V	3.38V	3.29V	3.13V	3.03V	2.91V

The minimum voltage to operate the tag is 2.5V. The results show that the battery for the tag drops from 3.74V to 2.91V in the duration of 7 days as shown in Table 5.2 and Figure 5.10. According to these results, the tags will be expected to stop operating in 11 days. The Hajj season will not take longer than 5 days, so the tags will cover the Hajj season without having to recharge the batteries.

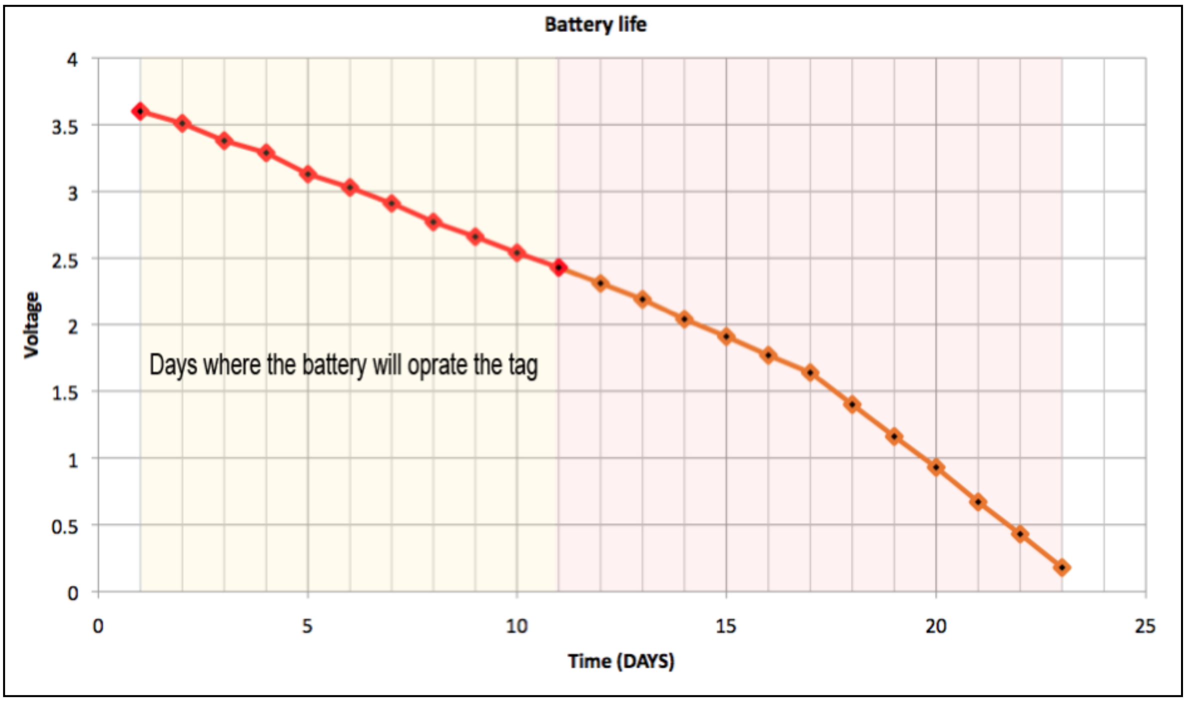


Figure 5.10: Tag battery life test graph

5.4 Battery charge time calculation

The formula below helps to know the time it takes to fully charge a battery.

$$\mathbf{BC / CRC = MTFC}$$

MTFC - Maximum time to full charge (hr)

BC - Battery capacity (mAh)

CRC - Charge rate current (mA)

$$\mathbf{500 / 150 = 3.33}$$

About 3 hours is the time to charge one battery of the Li-Ion rechargeable coin cell (PD3555) type. However, efficiency loss during the charging process has to be taking into consideration. Therefore, the following formulas show the battery charging time with some efficiency loss.

((BC / CRC) * 11) / 10 = MTFC (10% Efficiency Loss)

(500 / 150) * 11/10 = 3.6 hr

((BC / CRC) * 12) / 10 = MTFC (20% Efficiency Loss)

(500 / 150) * 12/10 = 4 hr

((BC / CRC) * 13) / 10= MTFC (30% Efficiency Loss)

(500 / 150) * 13/10 = 4.3 hr

((BC / CRC) * 14) / 10= MTFC (40% Efficiency Loss)

(500 / 150) * 14/10 = 4.6 hr

Table 5.3: battery charging time with some efficiency loss

Efficiency Loss percentage	Time to full charge (hour)
0% Efficiency Loss	3.33 hr
10% Efficiency Loss	3.6 hr
20% Efficiency Loss	4 hr
30% Efficiency Loss	4.3 hr
40% Efficiency Loss	4.3 hr

5.5 System implementation

This section describes how the system can be operated. In order to do so, four steps have to be done.

5.5.1 Step one: placing the readers

First, the reader nodes have to be placed at fixed known places taking into consideration the distance. Figure 5.11 shows the positions of the readers. The highlighted area in the figure is the area that is covered by three or more reader nodes.

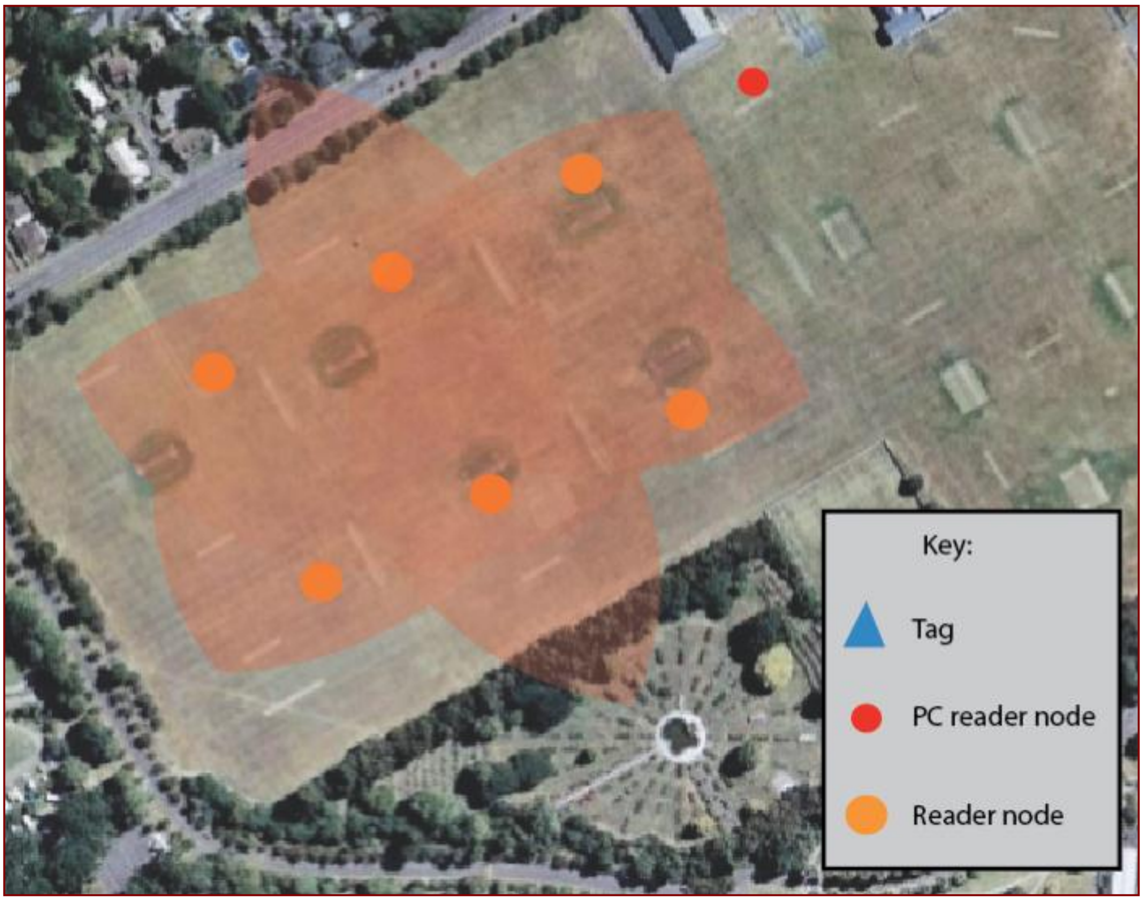
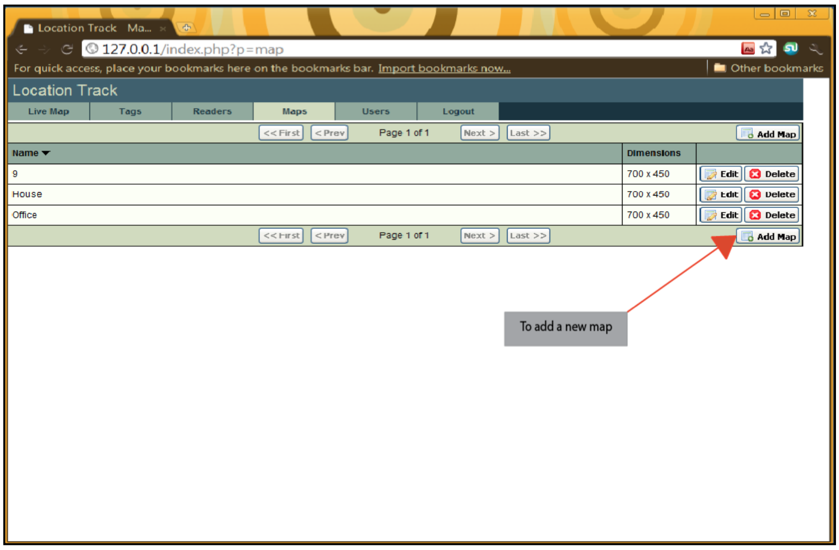


Figure 5.11: System implementation (Readers positions) [38]

5.5.2 Step two: uploading the maps

Uploading the map into the GUI can be done by pressing the “Add Map” button in the “Map” section. The map can be a satellite picture of the location. Moreover, more than one map can be added into the GUI as shown in Figure 5.12.



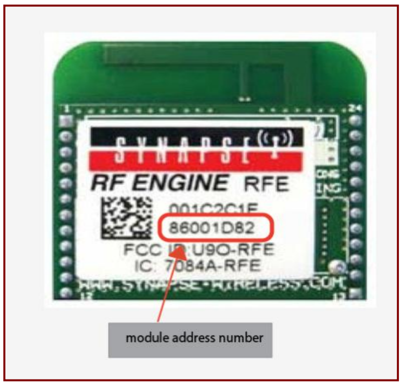
Name	Dimensions	
9	700 x 450	Edit Delete
House	700 x 450	Edit Delete
Office	700 x 450	Edit Delete

To add a new map

Figure 5.12: GUI “Map” section

5.5.3 Step three: locating the reader node on the map

The reader nodes can be added from the “Reader” section. The module address is required to add the reader nodes. Reader addresses can be found in the Synapse portal software or on the RF module itself as shown in Figure 5.13. After that, the map has to be chosen to put the reader nodes on.



module address number

Figure 5.13: RF module address [Appendix C.1]

To locate the reader nodes in the GUI to match the real readers in the experiment field, an (X, Y) axis has to be identified for each reader node. The system will ask to put a number from 100 to 400 in each axis. Figure 5.14 illustrates the process of adding an (X, Y) axis.

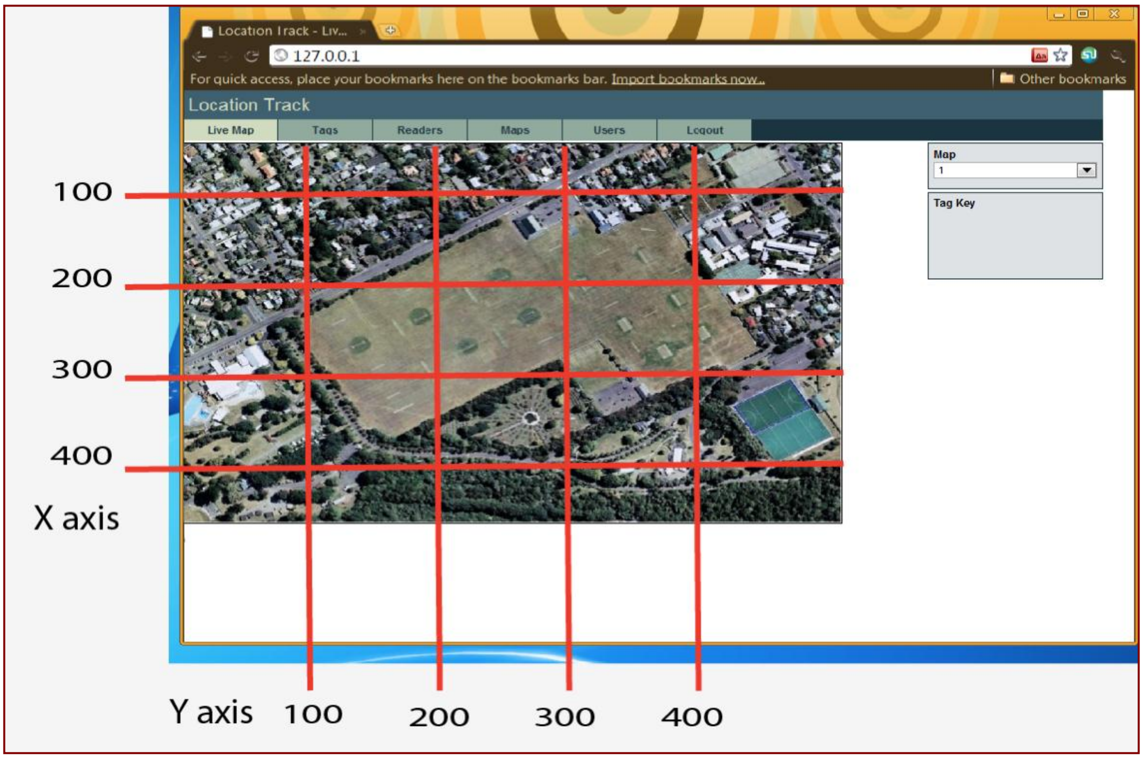
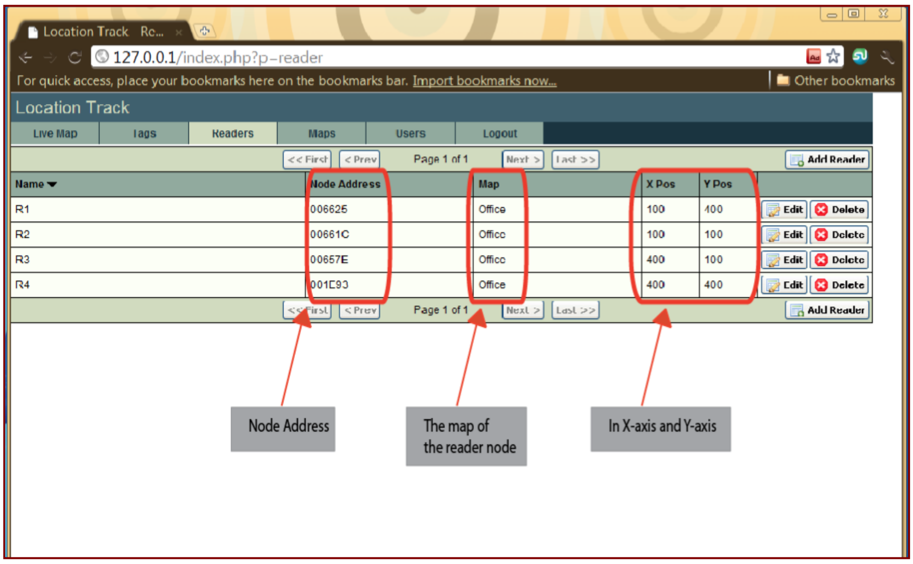


Figure 5.14: Reader node (X, Y) axis

The GUI also allows the user to edit and delete at any time. Figure 5.15 shows the reader node section in the GUI.



Name	Node Address	Map	X Pos	Y Pos	
R1	006625	Office	100	400	Edit Delete
R2	00661C	Office	100	100	Edit Delete
R3	00657E	Office	400	100	Edit Delete
R4	001E93	Office	400	400	Edit Delete

Node Address

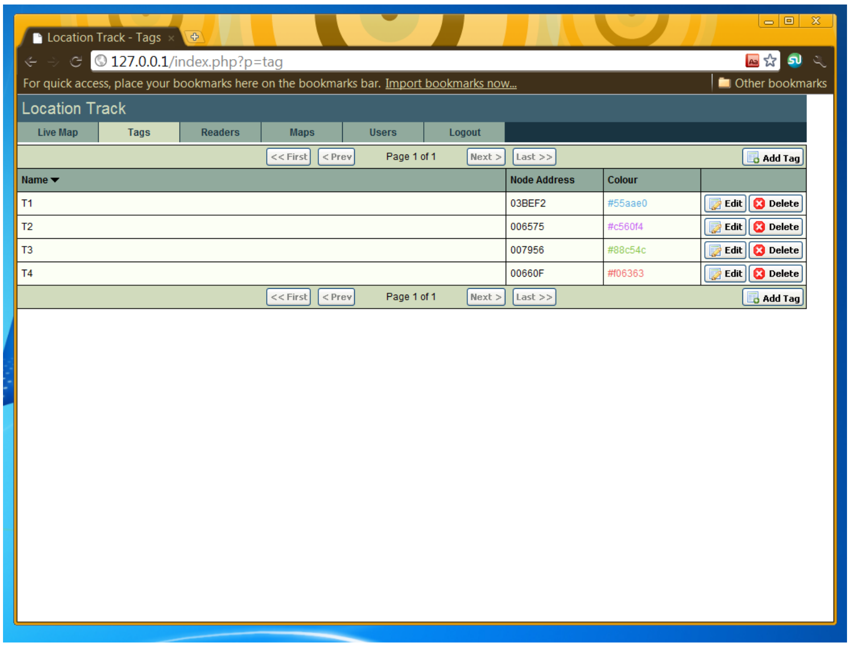
The map of the reader node

In X-axis and Y-axis

Figure 5.15: GUI “Reader node” section

5.5.4 Step four: adding the tags

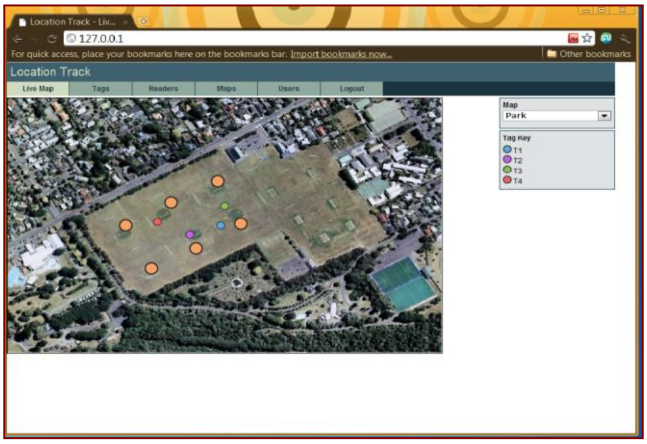
Finally, as with the reader node, the module address has to be provided. However, there is no need to choose a map, because the tag will appear with the reader nodes in its region. The name and the colour of each tag can be chosen. Figure 5.16 shows the “Tag” section.



Name	Node Address	Colour	
T1	03BEF2	#55aae0	Edit Delete
T2	006575	#c560f4	Edit Delete
T3	007956	#88c54c	Edit Delete
T4	00660F	#f06363	Edit Delete

Figure 5.16: GUI “Tag” section

When the four steps are done, the movements of the tags can be viewed in the main section in the GUI "Live Map" as shown in Figure 5.17.



Map
Park

Figure 5.17: GUI "Live Map" section

5.6 Efficiency of the system in a dynamic environment experiment

The system has proven highly efficient in finding the location of the tags. However, it is very important to test the system in a dynamic environment with a large number of people. Therefore, the system was deployed in a large local shopping mall. A person was advised to walk in the shopping mall carrying the tag. Then two people (A and B) were asked to find the person with the tag. "A" has used the system while "B" has used the traditional way to find a person. This process was repeated 10 times for both "A" and "B". The time it takes to find the person with the tag will be obtained for both "A" and "B". While conducting this experiment the following elements have been taken into account:

- Both "A" and "B" have started from the same point.
- The experiment for both "A" and "B" is done in the same day.
- The time stops when "A" or "B" touches the person with tag.
- The person with the tag was moving randomly in the experiment field.
- Both "A" and "B" are not allowed to use any communication devices to find the target.

Table 5.4: Dynamic environment experiment results

Attempts	Group A Time(mm:ss)	Group B Time(mm:ss)
1st attempt	06:26	06:45
2nd attempt	03:07	09:54
3ed attempt	04:21	06:34
4th attempt	02:15	07:42
5th attempt	04:03	08:22
6th attempt	05:22	06:13
7th attempt	03:17	09:32
8th attempt	04:23	08:18
9th attempt	03:35	06:04
10th attempt	05:27	06:45
Average	04:14	07:37

The final results as shown in Table 5.4 prove that "A", who uses the system, is 43.82% more likely to find the target. Figure 5.18 is a line graph that shows, clearly, the difference in time of finding the target between "A" and "B".

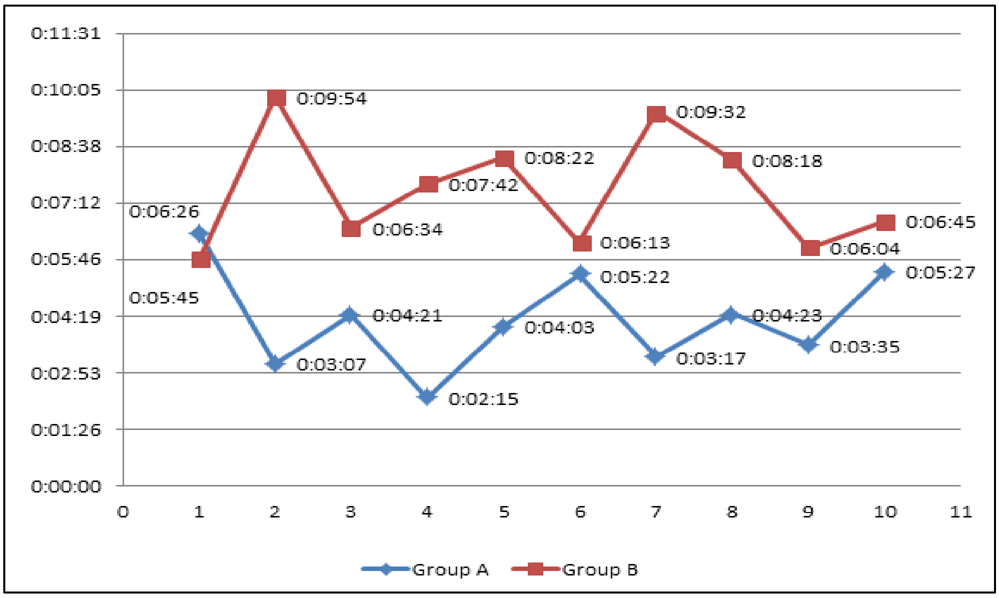


Figure 5.18: Dynamic environment experiment results

CHAPTER 6

SIMULATION RESULTS

6.1 Introduction

The system contains a large number of nodes. This makes it difficult to simulate with physical tests. Therefore, OPNET Modeller simulator has been used to accurately model and predict the behaviour of the real system in order to develop and evaluate the systems. OPNET supports star, tree and mesh topologies. This chapter will describe the use of the OPNET simulation tools in this system and shows the final results of the simulation.

6.2 Node types

The Synapse RF engine is IEEE 802.15.4 based as can be seen in Appendix C . Therefore the nodes can be categorized into three types as shown in Figure 6.1.

6.2.1 Coordinator

The coordinator is considered as the top root node in the network as it allows other nodes in the network to connect to it. In this system the PC reader node is the coordinator node.

6.2.2 Router

The Router node relays messages from one node to another and allows End Device nodes to connect to it. The reader nodes in this system work as the Router nodes.

6.2.3 End Device

The Tags in this system are End Device nodes where they sending and receiving messages without the ability to relay messages.

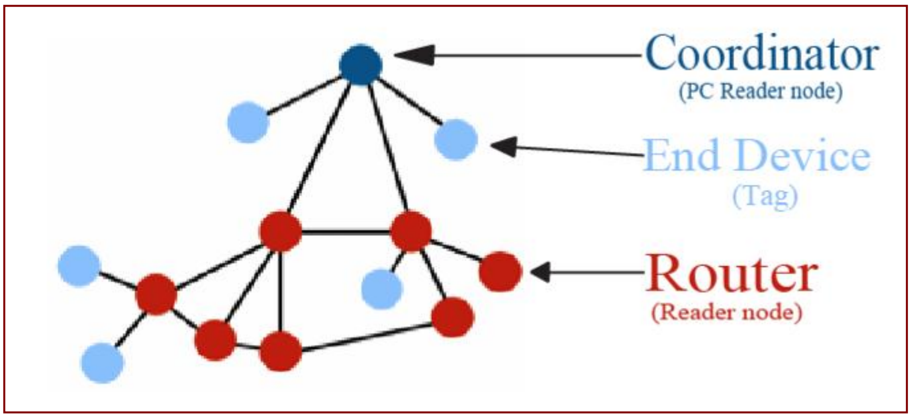


Figure 6.1: Node types

6.3 Network Topologies

There are three common types of network topologies: Star, Tree and Mesh topology as shown in Figure 6.2.

6.3.1 Star Topology

In the Star topology the coordinator node is connected to all other nodes in the network and the messages travel via the coordinator node.

6.3.2 Tree Topology

The Tree topology has a branch structure in which the coordinator is connected to one or more other nodes that are one level lower in the hierarchy. The message travel up and down the tree to reach its destination.

6.3.3 Mesh Topology

The Mesh topology also has a tree structure. However, the nodes in some leaves are directly connected allowing the messages to travel on the shortest paths available.

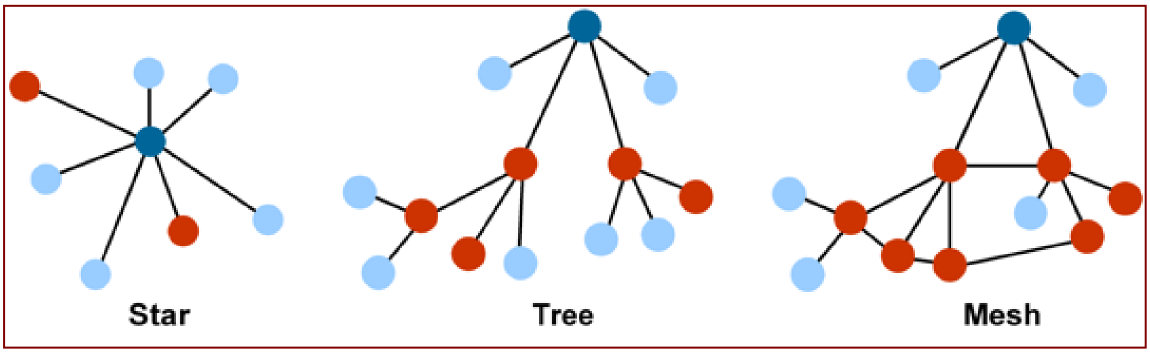


Figure 6.2: Types of network topologies

Synapse RF Engine provides an instant-on, multi-hop, mesh network [Appendix C.1]. The Readers (reader nodes) can communicate with each other as long as they are in range of one another. Moreover, if one of the reader nodes stops working the rest of the radar nodes will be still connected. The Mesh Network will greatly expand the coverage area of the tracking.

6.4 The IEEE 802.15.4 Simulation Model

The IEEE 802.15.4/ Zigbee model provided in the OPNET Modeller simulator consists of four layers: physical, MAC, network and an application layer in addition to a battery model [28]. Figure 6.3 shows the structure of the IEEE 802.15.4 simulation model.

6.4.1 Physical layer

The physical layer has a wireless radio transmitter (tx) and receiver (rx) at 2.4 GHz frequency band and 250 Kbps of bit rate.

6.4.2 MAC layer

The MAC layer implements the slotted CSMA/CA and GTS mechanisms. The MAC layer also generates beacon frames and synchronizes the network.

6.4.3 Network layer

This layer basically controls the MAC layer and provides a suitable interface to the next layer which is the application layer.

6.4.4 Application layer

This layer is responsible for generating the traffic source including Traffic Source, GTS Traffic Source and Traffic Sink.

6.4.5 Battery model

The battery model is used to calculate the energy consumption and the remaining energy.

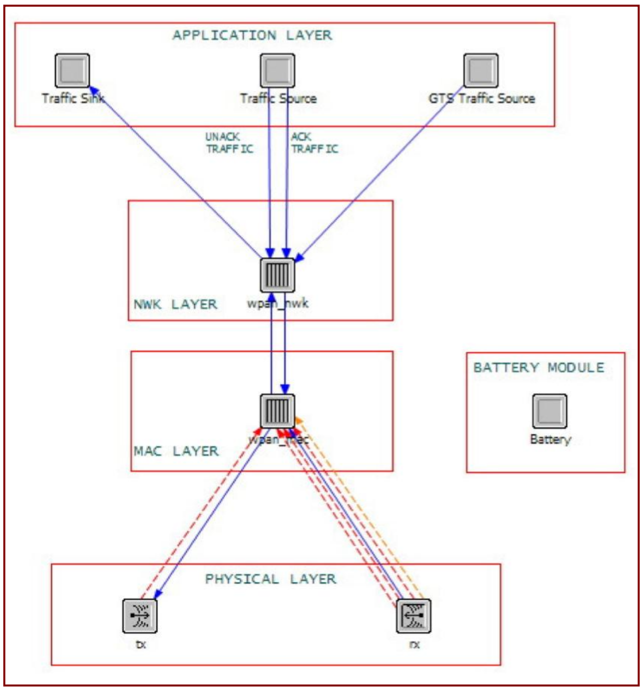


Figure 6.3: Structure of the IEEE 802.15.4 simulation model

6.5 Random Mobility

The coordinators and the router in this system are stationary but the end devices are mobile. The mobility of the end devices is taken into consideration during the simulation. OPNET provides three kind of mobility; random, predictable and controllable. The random direction mobility model is chosen due its independence from the network topology, traffic flows and residual energy of nodes [29]. Figure 6.4 shows an example of the random direction mobility density.

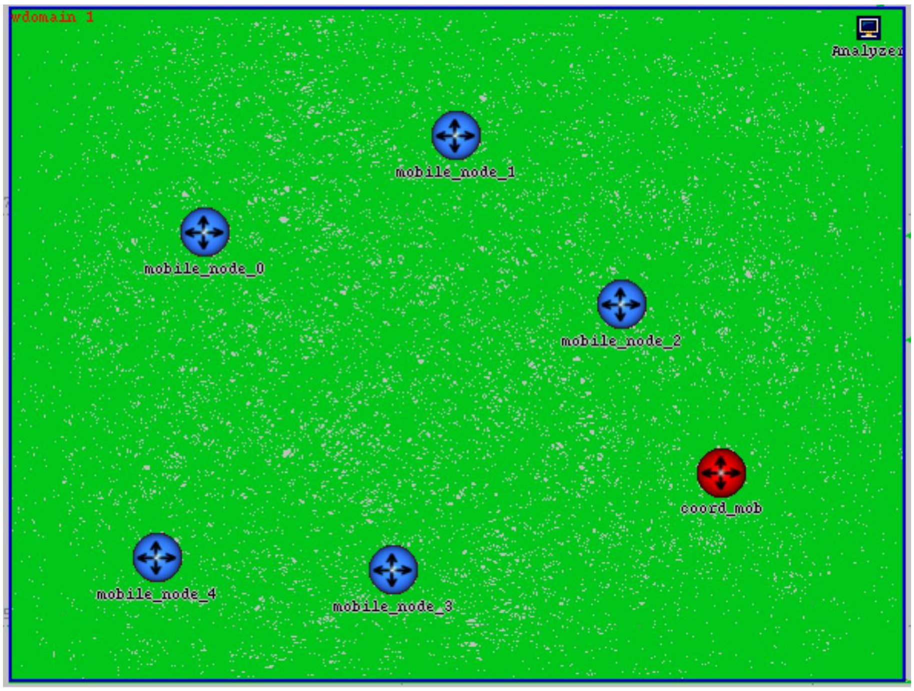


Figure 6.4: Example of the random direction mobility density

6.6 The Simulation Setup

The scenario contains the following devices:

- 4 Coordinators (PC Reader nodes) as the root of the network.
- 50 Routers (Reader nodes) are used to connect the coordinator and the end devices.
- 200 End devices (Tags) have been modified to move randomly in the simulation area.

The devices are distributed in a 20km x 7km area, to match the real place (Mecca). Figure 6.5 shows the simulation scenario layout. The radio range of the devices is set to approximately 180m, according to the reader node coverage test. Destination of the traffic is set to the end devices (Tags), through the router (Reader nodes). These devices have been modelled with suitable parameters as seen in Tables 6.1-6.4. Finally, the simulation runtime is set to 5000 second.

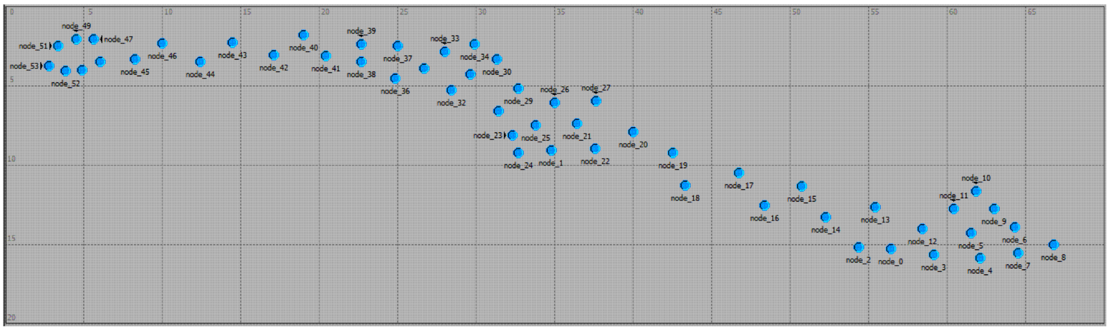


Figure 6.5: Simulation scenario layout

Table 6.1: Physical Layer Parameters

Physical layer	
Data rate	250 kbps
Receiver sensitivity	-102 dBm
Transmission band	2.4 GHz
Transmission Power	18 dBm

Table 6.2: MAC Parameters

MAC parameters	
ZCK Wait Duration	0.05
Number of Retransmission	5
CSMA Parameters	
Minimum Back off Exponent	3
Maximum Back off Exponent	4
Channel Sense Duration	0.1
Topology type	Mesh
Synchronization mode	Beacon-enabled

Table 6.3: Traffic Module Parameters

Traffic Module Parameters	
Traffic type	Exponential
Packet Size	1 Byte

Table 6.4: Battery Module Parameters

Battery Module Parameters	
Radio power in receiving	66 mA
Radio power in sending	110 mA
Radio power in idle	15 mA
Radio power in sleeping	2.5 µA

6.7 Simulations and results

The simulation results for the described scenario are:

- Throughput.
- Dropped packets.
- End-to-end delay.
- Radio receiver business and collision status.
- Total traffic received.

6.7.1 Throughput

Throughput is the average number of bits or packets successfully received or sent by the receiver or transmitter per second. Figure 6.6 shows the throughput results for this simulation.

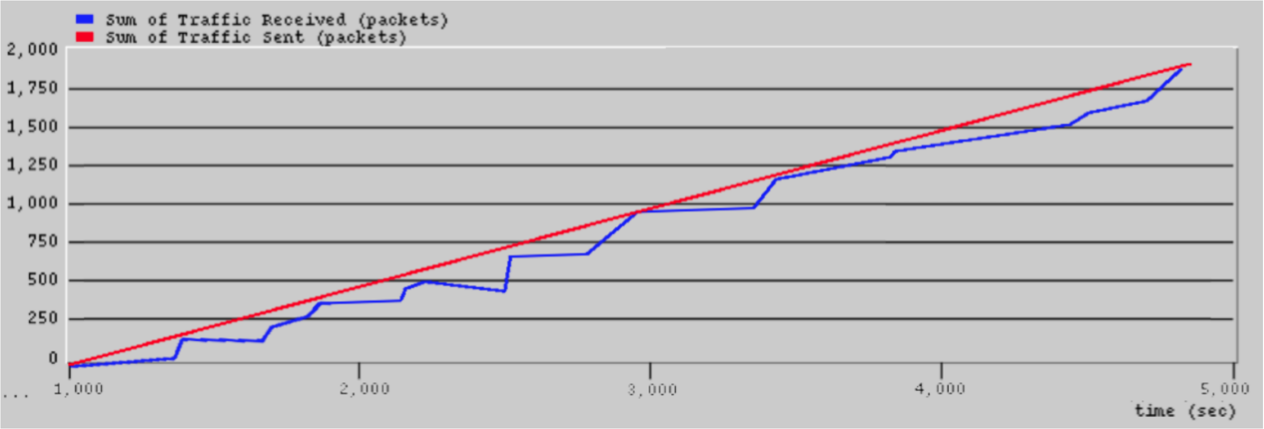


Figure 6.6: Total number of received and sent packets

This Figure shows that the traffic generation is constant. However, not all of the generated packets have reached their destination successfully.

6.7.2 Dropped packets

As shown in Figure 6.7 most of the packets have been received successfully and 5.13% of the packets have dropped.

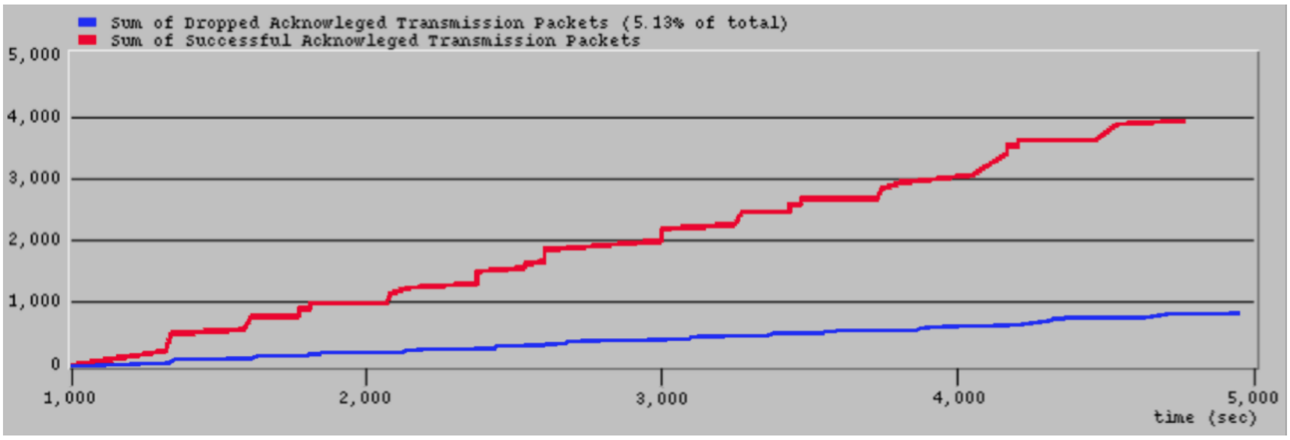


Figure 6.7: Dropped packets

6.7.3 End-to-end delay.

End-to-end delay is one of the main factors that affects throughput. The end-to-end delay is the time taken to send a packet from the transmitter to the destination node and includes all possible delays. The end-to-end delay result is shown in Figure 6.8.

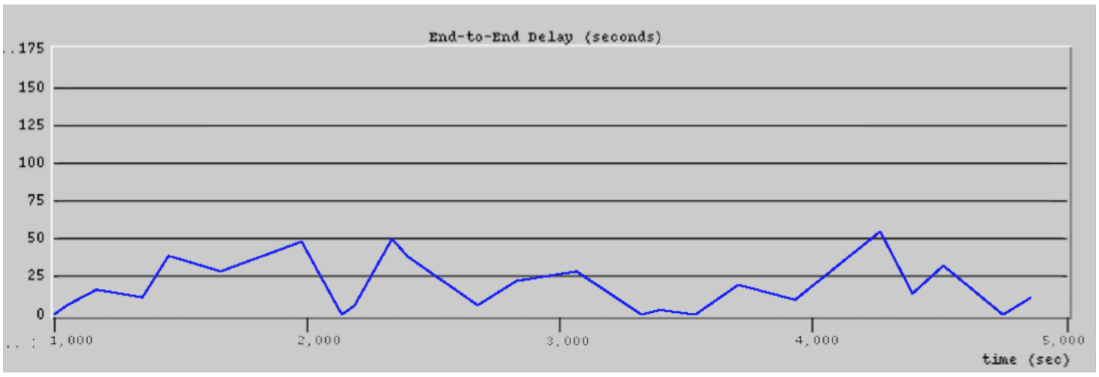


Figure 6.8: End-to-end delay

6.7.4 Radio receiver business and collision status

Higher end-to-end delay means low performance caused by network congestion. Radio receiver business and collision status indicators can be used to measure network congestion as shown in Figure 6.9. The collision ratio in this simulation as seen in this figure is 0.087%.

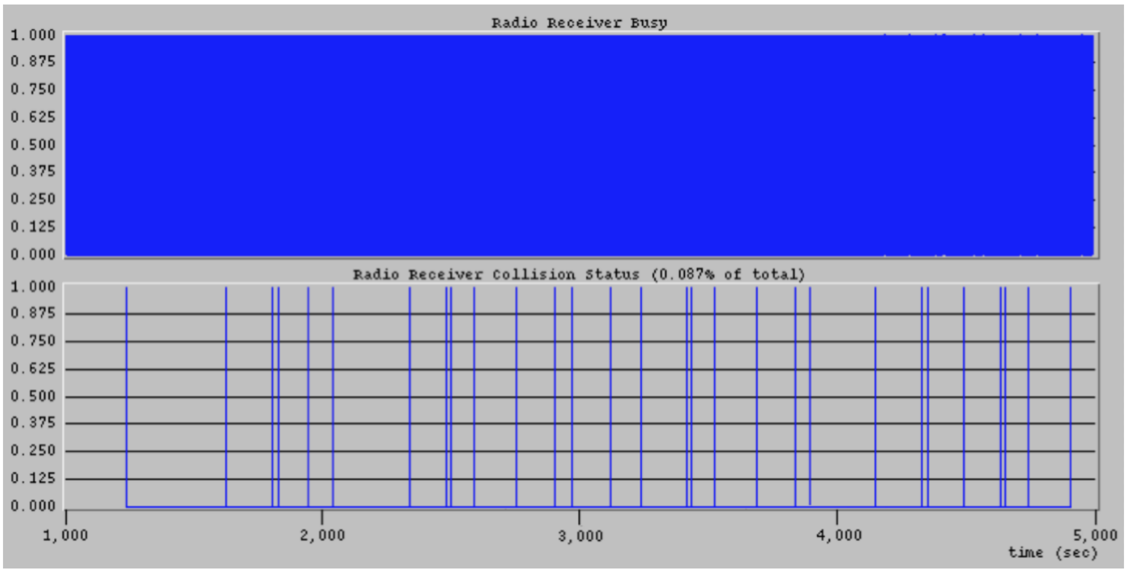


Figure 6.9: Radio receiver business and collision status

6.7.5 Total traffic received.

The total traffic received by the four coordinator nodes is shown in Figure 6.10

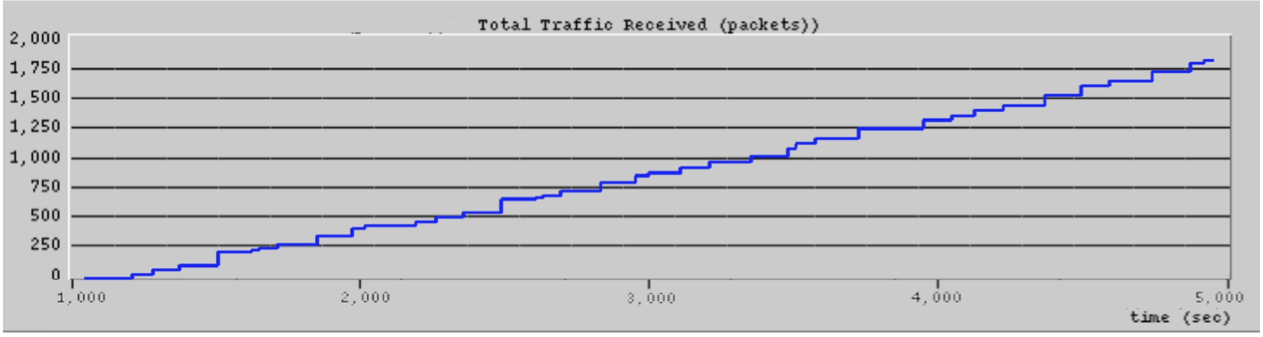


Figure 6.10: Total received traffic by coordinator nodes

6.8 Conclusion

This chapter provides a briefly description about the network topology for this system and the IEEE 802.15.4 standards. The focus has been on the performance evaluation of the system. The results have shown some delays and dropped packets due to network congestion. However, these errors are relatively low and will not lead to system failure.

CHAPTER 7

DISCUSSION, CONCLUSION AND FUTURE WORK

7.1 Conclusion and Future Work

In recent years, Mecca has seen tremendous expansions in size and infrastructure to accommodate the increasing number of pilgrims. These expansions have made the Hajj journey much easier than ever in terms of accommodation, transportation, health services and security. However, the chance of getting lost in Mecca has also increased. The security division in Mecca is using the traditional way to find a missing person and that process is long and arduous. The proposed system will operate by tracking RFID tags worn by the pilgrims during the Hajj. If a person were to go missing, the security division will be able to locate his exact location. This system is mainly aimed at children aged less than 15 years because they are more likely to get lost and it is difficult for them to find their way back.

This thesis has presented a detailed study of this system and how it should operate. Several experiments have been conducted on the system to ensure its effectiveness and to avoid any technical errors that may occur in the future. The obtained results have been very encouraging. A number of important aspects have been taken into consideration while designing the system, such as the cost of building and using the system and the ease of use by the service provider and the beneficiary.

Future work will be to develop the system to be a handheld device instated of the PC. The tag also will be improved to be more interactive so the tag holder will be able to receive messages and alert from service providers.

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[37] "Mecca." 21°23'44.19" N and 39°54'43.47" E. Google Earth.

[38] "Palmerston North" 40°22'06.72" S and 175°36'51.07" E. Google Earth.

FULL FORM OF ABBREVIATED TERMS IN THE THESIS

AoA	Angle of Arrival
CSMA/CA	Carrier sense multiple access with collision avoidance
dBm	Unit for signal level, dB relative to 1mW power
GHz	Gigahertz
GPS	Global Positioning System
GTS	Guaranteed Time Slot
GUI	Graphical User Interface
HTTP	Hyper Text Transfer Protocol
Kbps	kilobits per second
LoS	Line of Sight
mA	milliamps
MAC	Media Access Control
PHP	Hypertext Preprocessor
RFID	Radio-frequency identification
RSSI	Received Signal Strength Indicator
Rx	Receiver
TDoA	Time Difference of Arrival
ToA	Time of Arrival
Tx	Transmitter
UART	Universal Asynchronous Receiver/Transmitter
µA	Symbol for the microampere

Appendix A – Python scripts

A.1 Tag python script

```
def startup():
    global seccounter

    #Set transmit power level
    txPwr(17)

    #Disable UART 0
    initUart(0, 0)
    flowControl(0, False)

    #Disable UART 1
    initUart(1, 0)
    flowControl(1, False)

    #Set all GPIOs to inputs with pullup to cut
down on current use
    setPinDir(0, 0)
    setPinPullup(0, 1)

    setPinDir(1, 0)
    setPinPullup(1, 1)

    setPinDir(2, 0)
    setPinPullup(2, 1)

    setPinDir(3, 0)
    setPinPullup(3, 1)

    setPinDir(4, 0)
    setPinPullup(4, 1)

    setPinDir(5, 0)
    setPinPullup(5, 1)

    setPinDir(6, 0)
    setPinPullup(6, 1)

    setPinDir(7, 0)
    setPinPullup(7, 1)

    crossConnect(DS_NULL, DS_PACKET_SERIAL)

    setPinDir(8, 0)
    setPinPullup(8, 1)

    setPinDir(9, 0)
    setPinPullup(9, 1)

    setPinDir(10, 0)
    setPinPullup(10, 1)

    setPinDir(11, 0)
    setPinPullup(11, 1)

    setPinDir(12, 0)
    setPinPullup(12, 1)

    setPinDir(13, 0)
    setPinPullup(13, 1)

    setPinDir(14, 0)
    setPinPullup(14, 1)

    setPinDir(15, 0)
    setPinPullup(15, 1)

    setPinDir(16, 0)
    setPinPullup(16, 1)

    setPinDir(17, 0)
    setPinPullup(17, 1)

    setPinDir(18, 0)
    setPinPullup(18, 1)

    #Turn off node relaying packets for others
    saveNvParam(NV_MESH_OVERRIDE_ID, 1)

def poll100ms():
    #print "Sending Ping"
    mcastRpc(1, 1, "tagping", localAddr())

    #Go back to sleep
    sleep(0, 3)


#Install event handlers
snappyGen.setHook(SnapConstants.HOOK_STARTUP,
startup)
snappyGen.setHook(SnapConstants.HOOK_100MS,
poll100ms)
```

A.2 Reader node python script

```
#Replace with the address of the reader plugged
into a PC
PC_LINKED_READER = '\x03\xa2\x83'

#Receive pings from tags
def tagping(address):

    #Read signal
    lq = getLq()

    #Send tag id, signal, reader id to reader
connected to server (via mesh network)
    rpc(PC_LINKED_READER, 'tagping_collect',
address, lq, localAddr())
```

A.3 PC reader node python script

```
#Init
def startup():

    initUart(1, 9600) #Set UART1 to 9600 baud
    #flowControl(1, False) #Turn off flow
control

    #Connect serial port to STDIN
    crossConnect(DS_UART1, DS_STDIO)
    print "Reader Powered Up"

#If this is the reader connected to server,
erlay any tag pings received to the seral port
def tagping_collect(tag_addr, lq, reader_addr):

    #print "A Tag Ping From: ",
bin2hex(tag_addr), " Link: ", lq, " Received at:
", bin2hex(reader_addr)
    print bin2hex(tag_addr), ",",
bin2hex(reader_addr), ",", lq

#Convert bytes to hex
def bin2hex(str):

    hex = ""
    count = len(str)
    index = 0
    while index < count:
        byte = ord(str[index])
        hex += bin2hex_nibble(byte >> 4)
        hex += bin2hex_nibble(byte)
        index += 1
    return hex

def bin2hex_nibble(nibble):
    hexStr = "0123456789ABCDEF"
    return hexStr[nibble & 0xF]

# Install event handlers
snappyGen.setHook(SnapConstants.HOOK_STARTUP,
startup)
#snappyGen.setHook(SnapConstants.HOOK_STDIN,
stdinHandle)
```

Appendix B – trilateration code

```
static public function trilateration($a, $b, $c)
{
        // BOOST SIGNALS (distances) TO ENSURE
OVERLAPPING CIRCLES
        // Do these circles overlap?
        // 1. determine distance between points
        // 2. determine whether combined radii
is >= distance
        $ab = sqrt(pow($b['x'] - $a['x'], 2) +
pow($b['y'] - $a['y'],2));
        $abr = $a['dist'] + $b['dist'];

        $bc = sqrt(pow($c['x'] - $b['x'], 2) +
pow($c['y'] - $b['y'],2));
        $bcr = $b['dist'] + $c['dist'];

        $ca = sqrt(pow($a['x'] - $c['x'], 2) +
pow($a['y'] - $c['y'],2));
        $car = $c['dist'] + $a['dist'];

        // If the distance between the
centerpoints of any 2 circles is
        // greater than the combined signals,
find amount needed to increase
        // signals to cause overlap of circles
        $abd = $bcd = $cad = 0;
        if ($abr < $ab) {
            $abd = ceil($ab - $abr);
        }

        if ($bcr < $bc) {
            $bcd = ceil($bc - $bcr);
        }

        if ($car < $ca) {
            $cad = ceil($ca - $car);
        }

        if ($abd > 0 || $bcd > 0 || $cad > 0) {
             // Determine greatest ratio between
max required and actual
             $aratio = $ab / $abr;
             $bratio = $bc / $bcr;
             $cratio = $ca / $car;

             $modifier =
max($aratio,$bratio,$cratio);

             $a['dist'] = $a['dist'] *
$modifier;
             $b['dist'] = $b['dist'] *
$modifier;
             $c['dist'] = $c['dist'] *
$modifier;
         }

         // ROTATION
/////////////////////////////////////
         //  The process of trilateration finds
the location of a point that is described in
terms of fixed
         //  distances to three known points. In
order for this process to be executed with
minimal computation,
         //  the three known points must be
oriented such that one point represents the
origin (0, 0)
         //  and one point represents a point on
the x-axis (p, 0). The third point (q, r) will
be realigned
         //  according to its relative position
to the first two.
         // Given a, b, c, return new coordinates
with a at 0,0, b at x,0 and resultant c
         $ax0 = $ax = $a['x'];
         $ay0 = $ay = $a['y'];

         $bx = $b['x'];
         $by = $b['y'];
```

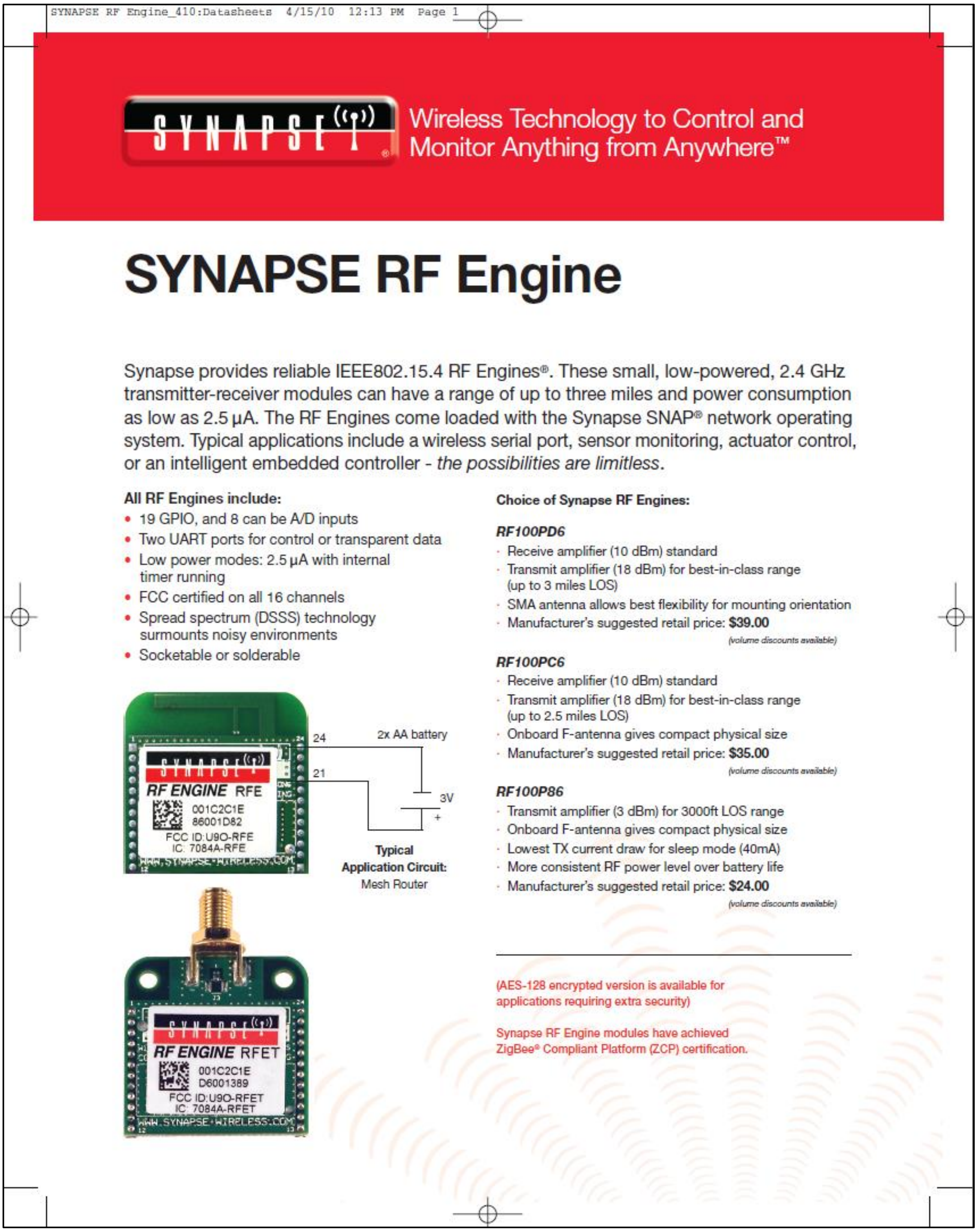
```
        $cx0 = $cx = $c['x'];
        $cy0 = $cy = $c['y'];

        // Move a to 0,0 by simple x/y
translation
        $xmove = $ax;
        $ymove = $ay;

        $ax = 0;
        $ay = 0;

        $bx = $bx - $xmove;
        $by = $by - $ymove;

        $cx = $cx - $xmove;
        $cy = $cy - $ymove;

        // Now, move b to x, 0 by rotation

        // Theta: 1.030376827 =ATAN2(B9, C9)
        // Phi: 0 =ATAN2(B10, C10)
        // R1: 17.49285568 =SQRT((B4-B3)^2+(C4-
C3)^2)
        // R2: 21 =SQRT((B5-B3)^2+(C5-C3)^2)
        $theta = atan2($by,$bx);
        $phi = atan2($cy,$cx);
        $r1 = sqrt( pow($bx - $ax,2) + pow($by -
$ay,2) );
        $r2 = sqrt( pow($cx - $ax,2) + pow($cy -
$ay,2) );

        // Leaving polar coordinates for rotated
system:
        $ar = 0;
        $at = 0;

        $br = $r1;
        $bt = 0;

        $cr = $r2;
        $ct = $phi - $theta;
```

```
         // Convert to rectangular coords
         // ax/ay already determined.
         // by already determined. bx is already
calculated
         $bx = $r1;

         // Must calculate both for c
         $cx = $cr * cos($ct);
         $cy = $cr * sin($ct);
         // END ROTATION
//////////////////////////////////////

         // Now that we have translated coords,
calculate rotated solution.
         $ra = $a['dist'];
         $rb = $b['dist'];
         $rc = $c['dist'];

         $dx = ( pow($ra,2) - pow($rb,2) +
pow($bx, 2) )/($bx * 2);

         $dy1 = sqrt( pow($ra,2) - pow($dx,2) );
// value is +/-
         $dy2 = 0 - $dy1;

         // Convert solution to polar coordinates
         $dr = sqrt( pow($dx,2) + pow($dy1, 2) );
// SQRT(B31^2+B32^2)
         $dt1 = atan2($dy1,$dx); //
ATAN2(B31,B32) value is +/-
         $dt2 = 0 - $dt1;

         // Unrotate solution based on 2 possible
solutions.
         $dt1 = $dt1 + $theta;
         $dt2 = $dt2 + $theta;

         // Convert solution to rectangular
coords
         $dx1 = $dr * cos($dt1);
```

```
        $dy1 = $dr * sin($dt1);

        $dx2 = $dr * cos($dt2);
        $dy2 = $dr * sin($dt2);

        // Untranslate from translation of point
1 to 0,0
        $dx1 += $ax0;
        $dy1 += $ay0;

        $dx2 += $ax0;
        $dy2 += $ay0;

        // Test solutions...
        // Calculated distance to C, solution 1
        $cd1 = sqrt( pow($dx1 - $cx0,2) +
pow($dy1 - $cy0,2) );
        $cdiff1 = abs($rc - $cd1);

        // Calculated distance to C, solution 2
        $cd2 = sqrt( pow($dx2 - $cx0,2) +
pow($dy2 - $cy0,2) );
        $cdiff2 = abs($rc - $cd2);

        // Use the smallest difference
        if ($cdiff1 < $cdiff2) {
            $dx = round($dx1);
            $dy = round($dy1);
        } else {
            $dx = round($dx2);
            $dy = round($dy2);
        }

        return array('x' => $dx, 'y' => $dy);
    }
}
```

Appendix C – SYNAPSE Data Sheets

C1. SYNAPSE RF Engine



SYNAPSE RF Engine_410:Datasheets 4/15/10 12:13 PM Page 1

Wireless Technology to Control and Monitor Anything from Anywhere™

SYNAPSE RF Engine

Synapse provides reliable IEEE802.15.4 RF Engines®. These small, low-powered, 2.4 GHz transmitter-receiver modules can have a range of up to three miles and power consumption as low as 2.5 µA. The RF Engines come loaded with the Synapse SNAP® network operating system. Typical applications include a wireless serial port, sensor monitoring, actuator control, or an intelligent embedded controller - *the possibilities are limitless*.

All RF Engines include:

- 19 GPIO, and 8 can be A/D inputs
- Two UART ports for control or transparent data
- Low power modes: 2.5 µA with internal timer running
- FCC certified on all 16 channels
- Spread spectrum (DSSS) technology surmounts noisy environments
- Socketable or solderable

Typical Application Circuit: Mesh Router

Choice of Synapse RF Engines:

RF100PD6

- Receive amplifier (10 dBm) standard
- Transmit amplifier (18 dBm) for best-in-class range (up to 3 miles LOS)
- SMA antenna allows best flexibility for mounting orientation
- Manufacturer's suggested retail price: **$39.00**

(volume discounts available)

RF100PC6

- Receive amplifier (10 dBm) standard
- Transmit amplifier (18 dBm) for best-in-class range (up to 2.5 miles LOS)
- Onboard F-antenna gives compact physical size
- Manufacturer's suggested retail price: **$35.00**

(volume discounts available)

RF100P86

- Transmit amplifier (3 dBm) for 3000ft LOS range
- Onboard F-antenna gives compact physical size
- Lowest TX current draw for sleep mode (40mA)
- More consistent RF power level over battery life
- Manufacturer's suggested retail price: **$24.00**

(volume discounts available)

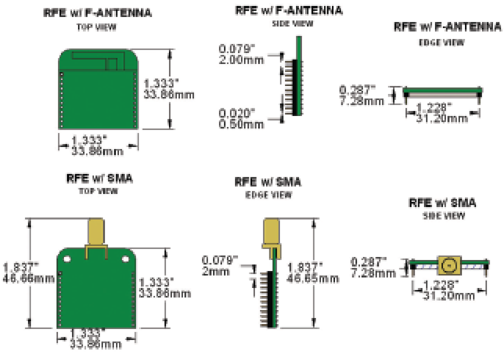
(AES-128 encrypted version is available for applications requiring extra security)

Synapse RF Engine modules have achieved ZigBee® Compliant Platform (ZCP) certification.

Wireless Technology to Control and
Monitor Anything from Anywhere™

SYNAPSE RF Engine

Physical Dimensions



Specifications

Performance	Indoor Range	Up to 1000 ft. (** 200 ft.)
	Outdoor LOS Range	Up to 3.0 miles (** up to 3000 ft.)
	Transmit Power Output	18 dBm (** 0 dBm.)
	RF Data Rate	250,000 bps
	Receiver Sensitivity	-102 dBm (1% PER)
Power Requirements	Supply Voltage	2.7 – 3.4V
	Transmit Current (Typ)	110 mA (** 40 mA)
	Receive Current (Typ)	65 mA
	Idle Current (Typ)	15 mA
	Sleep Current (Typ)	2.5 µA
General	Frequency	ISM 2.4 GHz
	Spreading Method	Direct Sequence
	Modulation	0-QPSK
	Dimensions	1.333" x 1.333"
	Operating Temperature	-40 to 85 deg C.
	Antenna Options	Integrated F, External RPSMA
Networking	Topology	SNAP or ZigBee
	Number of Channels	16
Available I/O	UARTS with HW Flow Control	2 ports – 8 total I/O
	GPIO	19 total, 8 can be analog in with 10-bit ADC
Agency Approvals	FCC Part 15.247	Yes, Class B
	Industry Canada (IC)	Yes

*** RFE with receive only amp specs, all other specs apply to all RF Engines*

For more technical details, see SNAP Hardware Technical Manual on the SYNAPSE Customer Forum: forums.synapse-wireless.com

Part Selection

Part No.	Antenna	Receive Amp	Power Amp
RF100PD6	External *	Yes	Yes
RF100PC6	F type	Yes	Yes
RF100P86	F type	Yes	No

** External antenna sold separately - ask your sales representative*

Pinout

Pin No.	Name	Direction	Description
1	GND	-	Power Supply/Return
2	GPIO0_TPM1CH2	Bidirectional	GPI/O, or Timer1 Channel 2 (PWM)
3	GPIO1_KBI0	Bidirectional	GPI/O, Keyboard In
4	GPIO2_KBI1	Bidirectional	GPI/O, Keyboard In
5	GPIO3_RX_UART0	Input	UART0 Data In
6	GPIO4_TX_UART0	Output	UART0 Data Out
7	GPIO5_KBI4_CTS0	Bidirectional	GPI/O, Keyboard In, or UART0 CTS
8	GPIO6_KBI5_RTS0	Bidirectional	GPI/O, Keyboard In, or UART0 RTS
9	GPIO7_RX_UART1	Input	UART1 Data In
10	GPIO8_TX_UART1	Output	UART1 Data Out
11	GPIO9_KBI6_CTS1	Bidirectional	GPI/O, Keyboard In, or UART1_CTS
12	GPIO10_KBI7_RTS1	Bidirectional	GPI/O, Keyboard In, or UART1_RTS
13	GPIO11_AD7	Bidirectional	GPI/O, or Analog In
14	GPIO12_AD6	Bidirectional	GPI/O, or Analog In
15	GPIO13_AD5	Bidirectional	GPI/O, or Analog In
16	GPIO14_AD4	Bidirectional	GPI/O, or Analog In
17	GPIO15_AD3	Bidirectional	GPI/O, or Analog In
18	GPIO16_AD2	Bidirectional	GPI/O, or Analog In
19	GPIO17_AD1	Bidirectional	GPI/O, or Analog In
20	GPIO18_AD0	Bidirectional	GPI/O, or Analog In
21	VCC	-	Power Supply
22	Reserved	-	-
23	RESET_L	Bidirectional	Module Reset, Active Low
24	GND	-	Power Supply/Return

SYNAPSE Wireless, Inc. 500 Discovery Drive, Huntsville, Alabama 35806
877 982-7888 · synapse-wireless.com

C2. **SYNAPSE Portal**

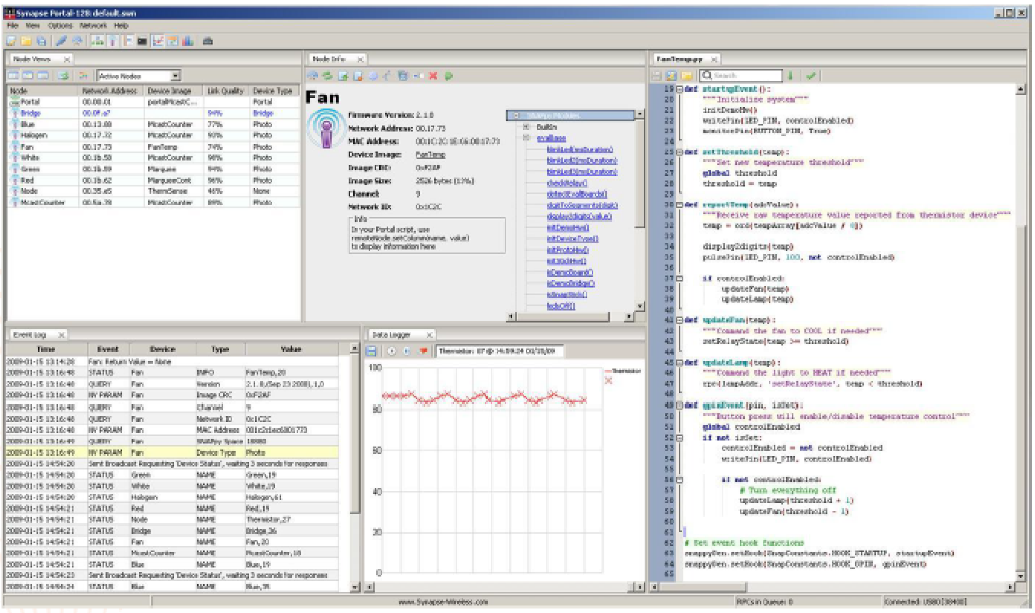
SYNAPSE

Wireless Technology to Control and Monitor Anything from Anywhere™

SYNAPSE Portal

Wireless Application Development Environment

Fast, real time view of your SNAP network
Runs on Windows (2000, XP, Vista) or Linux
Configuration and monitoring of your devices
Customized data logging with native Python scripts
Interactive, rapid application development – wirelessly!



Synapse Portal-128: default.swn

Node	Network Address	Device Image	Link Quality	Device Type
Portal	00.00.01	portalMcastC...		Portal
Bridge	00.0f.a7		94%	Bridge
Blue	00.13.88	McastCounter	77%	Photo
Halogen	00.17.72	McastCounter	90%	Photo
Fan	00.17.73	FanTemp	74%	Photo
White	00.1b.58	McastCounter	98%	Photo
Green	00.1b.59	Marquee	94%	Photo
Red	00.1b.62	MarqueeCont	96%	Photo
Node	00.35.a5	ThermSense	46%	None
McastCounter	00.5a.78	McastCounter	89%	Photo

Fan

Firmware Version: 2.1.0
Network Address: 00.17.73
MAC Address: 00:1C:2C:1E:06:00:17:73
Device Image: FanTemp
Image CRC: 0xF2AF
Image Size: 2526 bytes (13%)
Channel: 9
Network ID: 0x1C2C

Info
In your Portal script, use
remoteNode.setColumn(name, value)
to display information here

SNAPpy Modules
- Builtin
- evalBase
  - blinkLed(msDuration)
  - blinkLed2(msDuration)
  - blinkLed3(msDuration)
  - checkRelay()
  - detectEvalBoards()
  - digitToSegments(digit)
  - display2digits(value)
  - initDemoHw()
  - initDeviceType()
  - initProtoHw()
  - initJ3Hw()
  - isDemoBoard()
  - isDemoBridge()
  - isSnapStick()
  - ledsOff()

```
def startupEvent():
    """Initialize system"""
    initDemoHw()
    writePin(LED_PIN, controlEnabled)
    monitorPin(BUTTON_PIN, True)

def setThreshold(temp):
    """Set new temperature threshold"""
    global threshold
    threshold = temp

def reportTemp(adcValue):
    """Receive raw temperature value reported from thermistor device"""
    temp = ord(tempArray[adcValue / 4])

    display2digits(temp)
    pulsePin(LED_PIN, 100, not controlEnabled)

    if controlEnabled:
        updateFan(temp)
        updateLamp(temp)

def updateFan(temp):
    """Command the fan to COOL if needed"""
    setRelayState(temp >= threshold)

def updateLamp(temp):
    """Command the light to HEAT if needed"""
    rpc(lampAddr, 'setRelayState', temp < threshold)

def gpinEvent(pin, isSet):
    """Button press will enable/disable temperature control"""
    global controlEnabled
    if not isSet:
        controlEnabled = not controlEnabled
        writePin(LED_PIN, controlEnabled)

        if not controlEnabled:
            # Turn everything off
            updateLamp(threshold + 1)
            updateFan(threshold - 1)


# Set event hook functions
snappyGen.setHook(SnapConstants.HOOK_STARTUP, startupEvent)
snappyGen.setHook(SnapConstants.HOOK_GPIN, gpinEvent)
```

```
Time                 Event     Device        Type          Value
2009-01-15 13:14:28  Fan: Return Value = None
2009-01-15 13:16:48  STATUS    Fan           INFO          FanTemp,20
2009-01-15 13:16:48  QUERY     Fan           Version       2.1.0,(Sep 23 2008),1,0
2009-01-15 13:16:48  NV PARAM  Fan           Image CRC     0xF2AF
2009-01-15 13:16:48  QUERY     Fan           Channel       9
2009-01-15 13:16:48  QUERY     Fan           Network ID    0x1C2C
2009-01-15 13:16:48  NV PARAM  Fan           MAC Address   001c2c1e06001773
2009-01-15 13:16:49  QUERY     Fan           SNAPpy Space  16000
2009-01-15 13:16:49  NV PARAM  Fan           Device Type   Photo
2009-01-15 14:54:20  Sent Broadcast Requesting 'Device Status', waiting 3 seconds for responses
2009-01-15 14:54:20  STATUS    Green         NAME          Green,19
2009-01-15 14:54:20  STATUS    White         NAME          White,19
2009-01-15 14:54:20  STATUS    Halogen       NAME          Halogen,61
2009-01-15 14:54:21  STATUS    Red           NAME          Red,19
2009-01-15 14:54:21  STATUS    Node          NAME          Thermistor,27
2009-01-15 14:54:21  STATUS    Bridge        NAME          Bridge,36
2009-01-15 14:54:21  STATUS    Fan           NAME          Fan,20
2009-01-15 14:54:21  STATUS    McastCounter  NAME          McastCounter,18
2009-01-15 14:54:21  STATUS    Blue          NAME          Blue,19
2009-01-15 14:54:23  Sent Broadcast Requesting 'Device Status', waiting 3 seconds for responses
2009-01-15 14:54:24  STATUS    Blue          NAME          Blue,35
```

Thermistor : 87 @ 14:59:24 01/15/09

www.Synapse-Wireless.com RPCs in Queue: 0 Connected: USB0 [38400]

Portal takes you beyond traditional network commissioning tools by giving you an end-to-end view into your wireless application. Implement the functionality you need one step at a time – dynamically, interactively, wirelessly. Portal is with you every step of the way, providing complete access to all functions in every node on your SNAP® network. Want to send an email when a remotely monitored threshold is exceeded? Portal® provides email logging of user-defined events. But that's just the tip of the iceberg. Through Portal, remote devices can access the full power of the PC – opening up the potential to virtually unlimited application functionality. As a bridge between the SNAP network and the PC, Portal provides a simple and flexible Python-based interface. Remote nodes can invoke Python functions in Portal using built-in SNAPpy™ RPC calls.

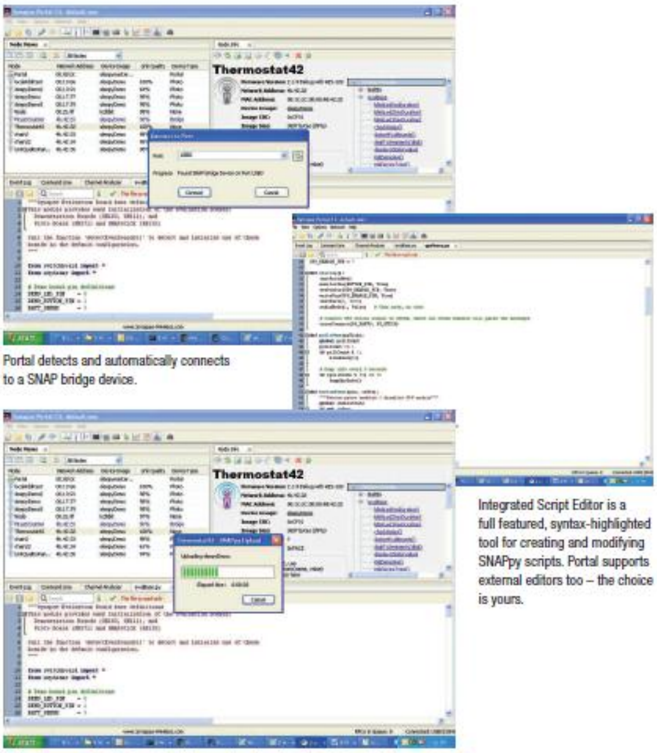
430-0110.01B

SYNAPSE

Wireless Technology to Control and Monitor Anything from Anywhere™

SYNAPSE Portal

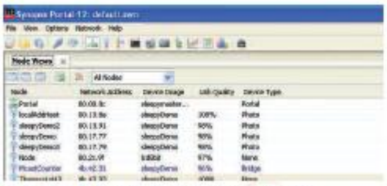
Wireless Application Development Environment



Portal detects and automatically connects to a SNAP bridge device.

Integrated Script Editor is a full featured, syntax-highlighted tool for creating and modifying SNAPpy scripts. Portal supports external editors too – the choice is yours.

Upload new application functionality over the air – the ultimate fast development cycle.


Synapse Portal 12: default.snm
File View Options Network Help
Node Views
All Nodes

Configurable Node Views allow easy management, even with thousands of devices.

Portal's Script Scheduler allows recurring calendar-time events to be controlled from a central management location.

Portal Features

- Comprehensive administration tool for SNAP networks
- Participates as a full-fledged peer on the network
- Runs on Windows (2000, XP, Vista) or Linux
- Invoke (RPC) script functions on any device in the network
- Remote nodes can invoke (RPC) user-defined scripts within Portal® itself
- Quick and easy interface for modifying and uploading scripts
- Syntax-highlighted Python™ editor for developing SNAPpy™ scripts
- Connect to a SNAP Gateway™ over the Internet or TCP/IP LAN
- SNAPpy application scripts running within Portal have full access to the PC's resources
- Event Log with timestamps and filtering
- Automatically scans for Synapse USB and RS-232 devices
- Intercepts STDOUT of selected remote devices for easy development / debug
- Runtime error detection highlights the line of script code where the error occurs
- Graphical firmware upgrade manager
- Powerful command-line provides full access to local and remote services
- Node configuration editor
- Script scheduler allows actions to be triggered from calendar-time events
- Graphical "Data Logger" view can be configured to display multiple user-defined process values
- Channel analyzer to find ideal channel for network
- Channel scanner to detect new or un-configured nodes

Part Selection

Part No.	Software	Nodes Supported
SW24006	In EK2100 kit	6
SW24012	In EK2500 kit	12
SW24000	Portal	Unlimited

For OEM License, Call Synapse Sales

SYNAPSE Wireless, Inc. 132 Export Circle, Huntsville, Alabama 35806
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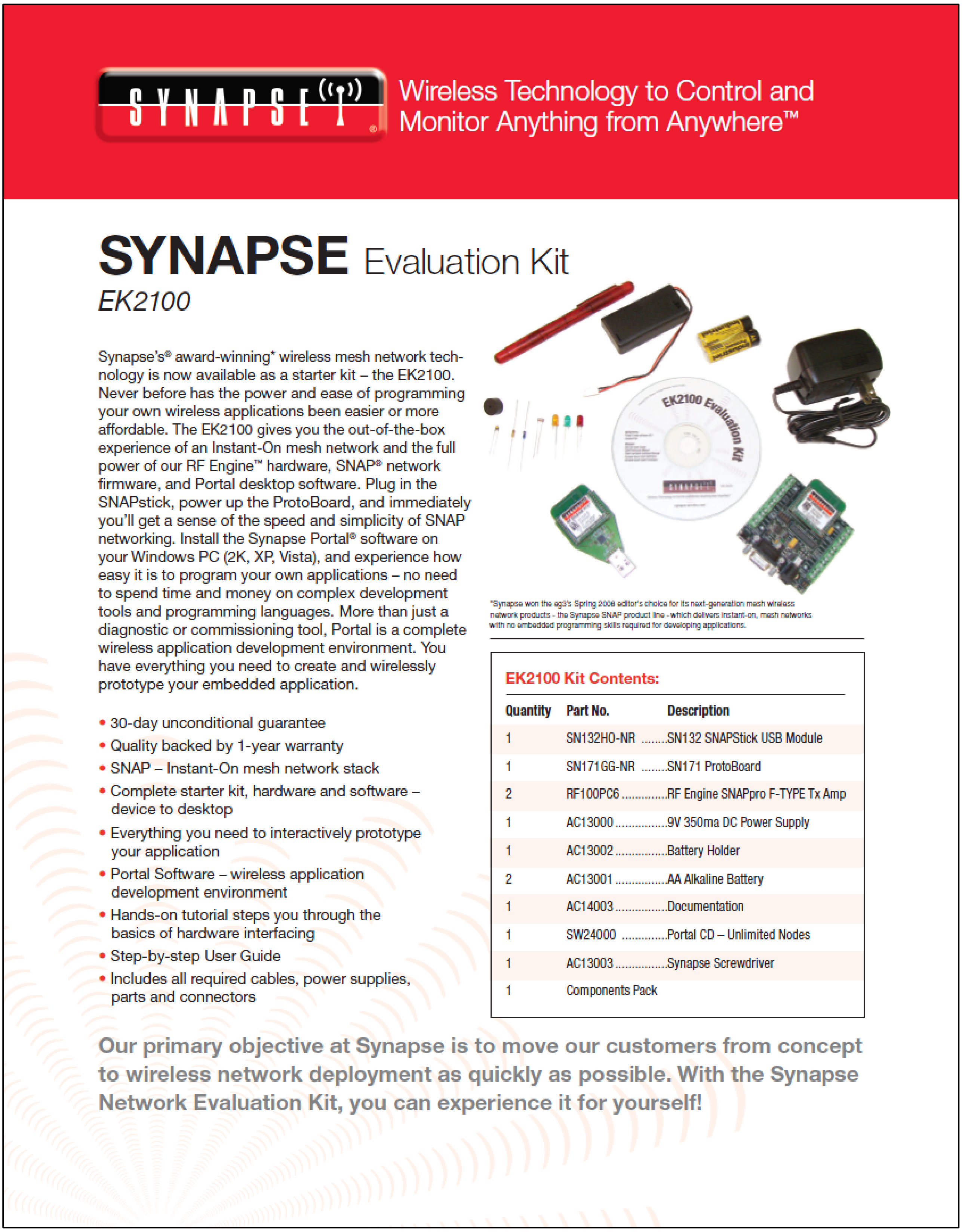
All specifications are subject to change without notice. © 2008 SYNAPSE® All Rights reserved. Patents pending.

C3. **SYNAPSE Evaluation Kit**



Wireless Technology to Control and Monitor Anything from Anywhere™

SYNAPSE Evaluation Kit

EK2100

Synapse's® award-winning* wireless mesh network technology is now available as a starter kit – the EK2100. Never before has the power and ease of programming your own wireless applications been easier or more affordable. The EK2100 gives you the out-of-the-box experience of an Instant-On mesh network and the full power of our RF Engine™ hardware, SNAP® network firmware, and Portal desktop software. Plug in the SNAPstick, power up the ProtoBoard, and immediately you'll get a sense of the speed and simplicity of SNAP networking. Install the Synapse Portal® software on your Windows PC (2K, XP, Vista), and experience how easy it is to program your own applications – no need to spend time and money on complex development tools and programming languages. More than just a diagnostic or commissioning tool, Portal is a complete wireless application development environment. You have everything you need to create and wirelessly prototype your embedded application.

- 30-day unconditional guarantee
- Quality backed by 1-year warranty
- SNAP – Instant-On mesh network stack
- Complete starter kit, hardware and software – device to desktop
- Everything you need to interactively prototype your application
- Portal Software – wireless application development environment
- Hands-on tutorial steps you through the basics of hardware interfacing
- Step-by-step User Guide
- Includes all required cables, power supplies, parts and connectors

*Synapse won the eg3's Spring 2008 editor's choice for its next-generation mesh wireless network products - the Synapse SNAP product line - which delivers Instant-on, mesh networks with no embedded programming skills required for developing applications.

EK2100 Kit Contents:

Quantity	Part No.	Description
1	SN132H0-NR	SN132 SNAPStick USB Module
1	SN171GG-NR	SN171 ProtoBoard
2	RF100PC6	RF Engine SNAPpro F-TYPE Tx Amp
1	AC13000	9V 350ma DC Power Supply
1	AC13002	Battery Holder
2	AC13001	AA Alkaline Battery
1	AC14003	Documentation
1	SW24000	Portal CD – Unlimited Nodes
1	AC13003	Synapse Screwdriver
1	Components Pack	

Our primary objective at Synapse is to move our customers from concept to wireless network deployment as quickly as possible. With the Synapse Network Evaluation Kit, you can experience it for yourself!

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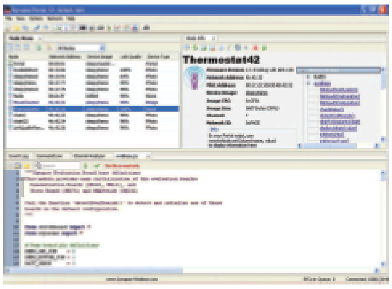
SYNAPSE

Wireless Technology to Control and Monitor Anything from Anywhere™

SYNAPSE Evaluation Kit

EK2100

The **EK2100 Evaluation Kit** is designed to guide the user through a basic SNAP network setup and a series of application demonstrations. It includes all the hardware and software needed to gain a fundamental understanding of SNAP® mesh networking and the capabilities of SNAP nodes. Included are the SNAPstick and ProtoBoard, each with an RF Engine, which will provide a network performance and evaluation platform right out-of-the box.



Portal desktop software

Hardware

SN132 SNAPstick
The compact design of the Synapse SNAPstick provides an easy way to connect a PC to a SNAP wireless network. The SNAPstick can be powered using any form of standard USB connection. The module supports all choices of the Synapse RF engines and is fully compatible with Synapse's Portal® management software.

SN171 SNAP Node ProtoBoard
With terminal blocks exposing all 19 GPIO RF Engine pins, a jumper-selectable RS232 port, LEDs, and pushbutton, the ProtoBoard is a playground for your wireless imagination. A low-power device with so much digital and analog capability that's programmable in a modern high-level scripting language makes the ProtoBoard pretty unique. Doing all this with full-mesh wireless networking is truly amazing!

RF Engines
The SNAPstick and the SNAP ProtoBoard come equipped with the amplified, internal "F" antenna, RF Engine. Synapse's amplified RF Engines are designed to transmit over greater distances and through more obstacles. Two additional RF Engine models are available from Synapse: an unamplified internal F antenna for low-cost applications, and an amplified external antenna for up to 3 miles LOS distance (all types have input amplification as standard).

Component Pack
A hands-on tutorial is included that takes you step-by-step through the basics of interfacing to the hardware. Clear pictures and instructions guide you in connecting the different resistors, LEDs, and thermistor, photo-cell and buzzer. Several, complete application examples show how the software can control and monitor the output devices, or receive input and take action on it. You can immediately begin to modify the behavior of any wireless node, and update that behavior over-the-air.

Software

Portal
The starter kit comes standard with a 6-node license for Portal, Synapse's complete wireless application development environment. This easy-to-use graphical user interface gives you access to control and monitoring functions that deliver complete network visibility and management. With Portal, you will see wireless devices graphically and control them individually or collectively, monitor activities, keep event logs, run scripts, and much more.

- Interactively control and monitor the nodes on the network
- Modify device behavior (embedded scripts) wirelessly
- Design, test, verify and deploy your application in record time

Portal includes a variety of sample applications demonstrating the power of Synapse's embedded Python engine, SNAPpy™.

SNAP – *Synapse's revolutionary wireless mesh networking firmware.*
Representing a leap-forward in embedded intelligence, SNAP is built on a foundation of peer-to-peer networking and free-form RPC calls. The result is the first system in its class supporting the capability to interactively develop custom applications using a modern, dynamic programming language.

Expand your Network

Synapse makes it easy for you to expand you network. Additional SNAP nodes can be purchased on-line from any of our distributors: Future Electronics, Digi-Key, Sager Electronics, or Carlton-Bates. Choose a SNAP node which provides a sensor input port and relay actuator to interface with the outside world. Or select additional SNAP ProtoBoards, which give you complete access to all pins of the RF Engine by your application. As soon as you power-up any SNAP Node,it immediately integrates itself into your network. The rest is up to your imagination.

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