

An Active Low Cost Mesh Networking Indoor Tracking System

Sean Carlin, Faculty of Computing and Engineering, University of Ulster, Derry, Ireland

Kevin Curran, Faculty of Computing and Engineering, University of Ulster, Derry, Ireland

ABSTRACT

Indoor radio frequency tracking systems are generally quite expensive and can vary in accuracy due to interference, equipment quality or other environmental factors. Due to these limiting factors of the technology, many businesses today find it hard to justify investing in RFID tracking technologies to improve the safety, efficiency and security of their working environments. The aim of this project was to provide a budget RFID tracking system that was capable of tracking a person or object through an indoor environment. To minimize the cost of the RFID tracking system, the components of the system were built from existing electronic equipment and hardware. The software was also written to minimize licensing and support fees allowing a cost effective budget RFID tracking system to be developed. The tracking system consists of a tag, reader nodes and a PC reader which utilize synapse RF 100 engines with python scripts embedded on to the chips. The tracking system software operates through a web portal utilizing web technologies such as HTML, JavaScript and PHP to allow the tags location to be represented on a two dimensional map using scalable vector graphics. During development of the system a new trilateration algorithm was developed and used convert the signals received from the tag to a virtual position on the map correlating to the actual physical position of the tag. A unique contribution of this system is the low cost of building which we estimate as less than £200 UK sterling for a five node system.

Keywords: HTML, JavaScript, PHP, Radio, Radio Frequency, RFID

1. INTRODUCTION

Real Time Location Systems (RTLS) are becoming increasingly integrated within everyday society and large corporations. Many large businesses are benefiting from the range of functionality and cost savings that real time location systems are providing. RTLS can use a variety of technologies that are currently available such as GPS, GSM, Wi-Fi and RFID. Most of these technologies are considered inadequate

for tracking people and assets within an indoor environment. The most common technology used for internal tracking systems is based on wireless technologies such as Radio frequency identification (RFID), Zigbee, Bluetooth and Wireless 802.11. Wireless offers many large and complex businesses a method of streamlining and automating many internal processes that can cut costs, increase efficiency and revenue. Although RFID has many potential benefits and is considered quite accurate in tracking people

DOI: 10.4018/ijaci.2014010104

and assets within an indoor environment, the technology itself is considered to be expensive requiring many tags, readers and software to be purchased. Hence the technology has not been widely adopted by smaller end businesses and public sector service providers managed by the government. Many of these businesses are constrained by a budget, which is affecting their need to improve processes via investing in wireless tracking technology.

There has been many wireless indoor tracking systems developed to date, often deployed in prisons, super markets, supply chains and within the farming industry. These existing approaches all have common features and have all encountered a similar drawback that is an inherent problem with the use of wireless for tracking. There is a neglect to cater for the lower end and smaller business to improve their efficiencies and processes through the utilization of wireless tracking technologies. For wireless tracking technology to be truly widely adopted this issue must be addressed and a lower budgeted solution must be investigated and made available. The drawback is the price of the hardware components of the system, this research hopes to address and demonstrate that inexpensive and effective solution is viable.

We present here a mesh based indoor wireless tracking system that is capable of tracking a person or asset within an indoor environment. We can demonstrate here that not only the tracking software can be developed but also the wireless hardware such as the tags and readers needed to track a person or object can be built from existing hardware components. The software can be written to integrate with each of these homemade tracking components to produce an accurate and reliable wireless tracking system. Mesh networks is a LAN (usually wireless) where each node is connected to many others, configured to allow connections to be rerouted around broken or blocked paths, with the signal hopping from node to node until it reaches its destination (Kay, 2009). A wireless mesh network has advantages over other network topologies. Once set up, a wireless mesh network can manage its load to avoid clogging a certain network node. If one node becomes

busy, the network traffic is redirected through other nodes, maintaining a good balance of the network load. Mesh networks can be described as self-healing, as the network will re-route data itself if a node become damaged, disconnected or blocked meaning that the network is reliable and dynamic in its approach to data routing. They rely on the same WiFi standards (802.11a, b and g) already in place for most wireless networks allowing them to be easily fitted into already existing systems using the same protocols. Wireless mesh networks are easily expanded due their node structure once a new node is added the whole network can immediately use it within its data routes.

The system outlined here is mesh based with a web-based portal that will allow the user to monitor the tags location, status and information. The purpose of building the location determination equipment is to demonstrate that an indoor tracking system does not have to be expensive and developers do not have to purchase costly premade readers or tags but that an effective wireless tracking system can be developed with a budgeted approach. This budget approach would essentially offer small to medium sized businesses an effective tracking system with an attractive price point.

2. LOCATION DETERMINATION TECHNOLOGIES

Location determination technologies are the technologies used and are capable of producing real time location systems. Real time location systems capture, process and store location specific data (Popat, 2007). This section outlines many technologies that can and are being used to today to produce people and asset tracking systems.

2.1. Mobile Cellular Systems

Mobile cellular systems can locate mobile systems (MS) by using the various methods of measuring the radio signals traveling between the mobile system and a set of fixed base stations (BS) or cellular towers. The signal measurements are first used to determine the

length or direction of the radio path, and then the MS position is derived from known geometric relationships (Caffery & Gordon, 1998). A location can be determined through mobile cellular systems by two key methods known as signal attenuation and time of arrival (TOA). Signal attenuation can locate a mobile system by measuring the signal strength of the system against three or more base stations also known as multilateration and determining the location by calculating the distance the mobile device is from the base stations/cellular towers by the strengths recorded. Jami et al. (1999) identified that “the main problem of this approach is the accurate estimation of the signal strength in a multipath fading environment and particularly how this relates to distance, given that the fading characteristics may be different in the directions of the three BSs”. Although the accuracy of using mobile cellular systems can be deemed at times inaccurate due to signal interference caused by adverse weather conditions and the fact that it is an estimation of location and not exact location the technology can still be used to benefit some industries such as the transport industries. Hellebrandt and Mathar (1999) stated that “knowing the position of vehicles in a transport system, e.g., allows for an efficient planning and use of resources. Also, in case of a car breakdown or an emergency call, automatic monitoring of the position would be of great help for immediate assistance”. The time of arrival (TOA) method uses various estimation algorithms where a signal is produced by the mobile system or base station and a round trip time is calculated. The distance of the MS from a BS is related to half the round-trip time and the location of the MS is found by the intersection of three circles of appropriate radius (trilateration) (Jami et al., 1999).

2.2. GPS (Global Positioning System)

GPS is made up of 24 satellites (seen in the figure below) and is one of the most popular methods of tracking offering a wide range of location-based services today. The 24 satellites that make up the GPS space segment are

orbiting the earth about 12,000 miles above us. They are constantly moving, making two complete orbits in less than 24 hours. These satellites are traveling at speeds of roughly 7,000 miles an hour². GPS receivers are required to communicate with the satellites to allow a user's location to be processed and calculated. A GPS receiver is an electronic device that uses the Global Positioning System to determine its exact location on earth with pin-point accuracy³. Oman (1995) re-enforces this by stating that GPS systems can have an “accuracy to one centimeter”. Requiring specific hardware components can be seen as a limitation as the receivers as they can be expensive. For the receivers to operate properly they require a clear view of the sky, in the line-of-sight of at least four satellites, which precludes their use in indoor or RF-shadowed environments (Mark et al., 2002). This is the main limitation for the technology as it is deemed inappropriate to use for tracking within indoor environments due to the fact that the satellites need line of sight and there can also be interference by materials such as metals and concrete etc. GPS usually use triangulation or trilateration to determine the location of a device. To triangulate means to calculate the position from the distance measurement or range, between the GPS receiver and the actual satellite (Wright, 2003).

2.3. ZigBee

ZigBee is the set of specs built around the IEEE 802.15.4 wireless protocol. The technology can be described as smart, low cost, low maintenance, low powered and efficient. ZigBee is compatible with most topologies including peer-to-peer, star network and mesh networks, and can handle up to 255 devices in a single WPAN. ZigBee allows the seamless communication of devices running the protocol, which is perfect for developing small-scale monitor and control systems. ZigBee Applications include home and building automation, industrial control, building management systems, environmental monitoring, vehicle fleet management systems etc (Dissanayake, 2008). A tracking system can be developed using the ZigBee protocol due to

the interoperability of each device in the ZigBee network. There are three categories of ZigBee devices within a ZigBee enabled network:

1. **ZigBee Network Coordinator:** Smart node that automatically initiates the formation of the network.
2. **ZigBee Router:** Another smart node that links groups together and provides multi-hopping for messages. It associates with other routers and end-devices.
3. **ZigBee End Devices:** Where the rubber hits the road-sensors, actuators, monitors, switches, dimmers and other controllers.

2.4. Wi-Fi

Many products already support the wireless protocol 802.11 a/b/g/n and many support connecting to each other through Wi-Fi networks. Recently, a growing interest of the scientific community in techniques that rely on IEEE 802.11 local area networks has been appreciated, since this type of communications infrastructure is being deployed in most of buildings and hence allows the design of flexible and low-cost positioning systems (Ciurana et al., 2007). Wireless networks are fully capable of tracking the movements of an object through its network and access points (AP's). A popular approach to tracking through wireless network is by attaching a Wi-Fi tag to an object. Wi-Fi-Tags are targets for locating and tracking they collect signal strength information of APs and send it to Data Server (Chen & Luo, 2007). There are many factors that can be used to calculate an objects location within a Wi-Fi network, these factors can measure and used by many propagation-based techniques. Propagation-based techniques measure the received signal strength (RSS), angle of arrival (AOA), or time difference of arrival (TDOA) of received signals and apply mathematical models to determine the location of the device (Chan, 2009). These techniques are similar to those used by GPS and mobile cellular systems discussed earlier in this chapter to intelligently estimate the location of an object.

2.5. Bluetooth

Bluetooth is a short-range wireless technology, which was developed for low-cost, low-bandwidth communication scenarios (Figueiras et al., 2005). Bluetooth like many other location tracking technologies was primarily developed for communication but it is slowly being adapted in a number of ways to be utilized for location-based tracking. Bluetooth has had a number of experimental tracking systems developed many of which use nodes which are much like wireless access points (AP's). The signal strengths received from the Bluetooth node servers, during the location determination phase, are gathered as vectors samples. They are compared to the location-map and the "best" match is returned as the estimated user location (Barahim et al., 2007). MIT have tried and tested many methods of tracking using Bluetooth technology and have even boosted signals and performance using many unconventional products such as tin foil (Kenneth et al., 2008). The technology is considered relatively cheap and requires little infrastructure to implement, as a single Bluetooth Access Point (AP) is the only hardware infrastructure necessary for this system to function (Kelly, 2008). This may be true but would offer a very limited service and could not be robust or extensible enough to support a large-scale project. With the release of Bluetooth 3.0 having faster speeds, more bandwidth and a larger range, Bluetooth may see more interest around the technology itself and how it can be used to track the locations of devices.

2.6. Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID) is any system of identification wherein an electronic device that uses radio frequency or magnetic field variations to communicate and is attached to an item (Bhatt and Glover, 2006). RFID is a widespread technology and is currently being used worldwide to solve a variety of problems and issues. The RFID tag also known as a transponder is the piece of integrated circuit

that is placed onto an individual object, the transponder has a digital memory and has a unique product identification code which allows the tag to be uniquely identified. The transponder is responsible for storing data/information on the object, power management, broadcasting and intercepting radio frequency signals. RFID tags can be labelled into two distinct groups known as Active and Passive tags.

Passive tags have no onboard power supply, Charlebois (2004) states that passive tags consume power provided by the reader through inductive coupling and they only operate in the presence of a nearby reader. Lieshout et al. (2007) enforces this stating passive tags are most often used for short read-range applications (<1.5 m) and require a high-powered reader with antenna capable of reading the information. This is the main drawback for passive tags as they need to be close or pass a reader to function, which limits their range of use. The fact that passive tags do not have their own power supply is in ways beneficial as the tags are cheaper to produce and they have a very generous life expectancy as they can last for decades which means this will lower maintenance costs. Passive tags are known to communicate with the reader using one of two methods that modulate the tags ID signal. In low frequency tags they release varying levels of energy from a capacitor, which affects the radio frequency emission of the tag. The reader then detects the varying frequencies and demodulates the signal. In high frequency tags they use backscatter, this involves the tags changing resistance levels in the antennas, which causes the radio frequencies emitted to vary allowing the reader to pick up and demodulate the waves.

Active RFID tags do have their own power source and Weinstein (2005) believes that because they have their own power source, active tags transmit a stronger signal, and readers can access them from further away. The on-board power source makes them larger and more expensive, so active RFID systems typically work best on large items tracked over long distances. One of the main advantages of active RFID tags is that they can transmit independently from

the reader, meaning that backscatter between the reader and tag is not needed. The tags also benefit with a larger internal storage giving the tag the ability to retain more information about the object it is attached to. Active tags do however have some drawbacks as they do not have as generous a life span as passive tags due to the fact they have battery life and they are considered more expensive and bulky.

Semi-passive tags is the intermediate category between passive and active tags, the semi-passive tags do use battery power like the active tags. They use the back scattering method used by passive tags to communicate radio frequency signals as they do not contain any radio transmitter circuit, but simply reflect back a small fraction of the power, which is emitted by the RFID reader. The main advantage of using semi-passive tags over active tags is since both passive RFID and semi-passive RFID use a backscatter mechanism to communicate with the reader, a passive RFID reader does not need to distinguish between these two types of tags. Seetharam and Fletcher (2007) meaning that they can be used with existing passive infrastructure. Also since the semi passive tags do not require a radio transmitter this also cuts the cost of producing the chips.

The antenna is one of the most important features for a RFID tag, it is this component, which affects how effective the transmission of the radio frequency signals are and is also responsible for producing the tags power for passive tags. Since the energizing and communication between the reader and tag is accomplished through antenna coils, it is important that the device must be equipped with a proper antenna circuit for successful RFID applications (Lee, 1999). A number of different types of antennas can be used with RFID tags, dipole antenna and its variants are among the most common. Most antennas utilize one of two main types of polarization known as linear and circular. The polarization of an antenna is the direction/plane of which the emitted waves travel along. As with many technologies, RFID does have some drawbacks and limitations, which are mostly inherent problems with using radio

frequencies as a communication medium. There are limitations such as passive tags not being read near metal or liquids and The American firm Intermec wants a license fee for each EPC implementation (Farragher, 2004). Radio Frequency technology is also considered a security risk, as often data read and written to the tags are not encrypted leaving them open to snooping or interception through the radio frequency medium (Kaur, 2011).

3. A LOW COST INDOOR LOCATION TRACKING SYSTEM - DESIGN

This section provides a detailed outline of the design of a low cost Zigbee wireless tracking system. There are many technologies capable of tracking people and assets. The problem that we are addressing is the costs of most of these systems. We aim to outline a tracking system capable of tracking people and assets in an indoor and potentially cramped environment which is accurate, relatively low cost to build and develop and ultimately reliable. Wireless tracking systems can be expensive, to limit the expense of the developing the system for this project each component of the tracking system will be built, which includes the RFID tags, RFID readers and PC reader. This will allow a low cost solution to be developed and will also allow the systems hardware components to be

easily upgraded to enhance the system in the future. The tracking system is built from scratch. This required the sourcing and acquiring of the individual hardware components necessary to build a wireless tag, pc-reader and multiple reader nodes. These components can be bought from many electronic stores and wholesale suppliers such as synapse radio frequency engines, which will be used to transmit and receive the radio frequencies between the devices. Buying the components separately and building the tracking devices can keep costs to an absolute minimum. Below is a list of the components that must be sourced and acquired to build an RFID tag, three reader nodes and PC reader.

- 1. **RFID Tag Components:** Presented in Table 1.
- 2. **Reader Node Components:** Presented in Table 2.
- 3. **PC Reader Components:** Presented in Table 3.
- 4. **General Components:** Presented in Table 4.
- 5. **Total Cost of Hardware for Tracking System:** Presented in Table 5.

Once the components are acquired and are assembled a desktop or laptop computer will be required to create and run the tracking software.

Table 1. Details hardware components needed to build a working RFID tag with prices

Name Of Component	Manufacturer	Quantity	Price
Pocket Card Enclosure (PC.4)	Teko	1	£3.56
RF100PC6 Synapse RF Engine	Future	1	£14.43
3mm LED	Maplin	1	£0.34
LED Cover/Clip	Maplin	1	£0.34
AAA Battery Holder Enclosed type	Radioshack	1	£2.79
2x AAA Batteries	Panasonic	1	£1.50
FE32K Sml Stick On Feet (4 pack)	Maplin	1	£1.19
FW38R Lg Stick On Feet (4 pack)	Maplin	1	£1.19
		Total	£25.34

Table 2. Details the hardware components needed to build a working three reader nodes with prices

Name Of Component	Manufacturer	Quantity	Price
Miniature ABS Box 1551 Series (N49FK)	Maplin	1	£1.99
RF100PC6 Synapse RF Engine	Future	1	£14.43
5mm LED	Maplin	1	£0.59
LED Cover/Clip	Maplin	1	£0.34
2.1mm DC Socket	Maplin	1	£1.99
Regulated 3V DC 400mA Power Adapter	Maplin	1	£9.99
		Total	£29.33

Table 3. Details the hardware components needed to build a working PC reader node and the prices

Name Of Component	Manufacturer	Quantity	Price
Miniature ABS Box 1551 Series (N78BQ)	Maplin	1	£1.99
RF100PC6 Synapse RF Engine	Future	1	£14.43
5mm LED	Maplin	1	£0.59
LED Cover/Clip	Maplin	1	£0.34
SNAPstick USB Module Interface	Future	1	£23.87
		Total	£41.22

Table 4. Details general components needed to build the tracking system, the most important being the Synapse Starter Kit, that will allow the programming of the synapse RF engines

Name Of Component	Manufacturer	Quantity	Price
AAA Batteries	Panasonic	1	£2.00
Synapse Network Starter Kit (EK2100)	Future	1	£59.74
1502 Series Boardmount Socket	Digital Key	1	£2.99
SAM1242-12-ND Cable	Digital Key	1	£3.09
		Total	£68.71

Table 5. The costs of the entire systems components and expenditures together showing the components necessary for building a basic RFID tracking system

System Components	Quantity	Price
RFID Tag	1	£25.34
Reader Node	3	£29.33
PC Reader	1	£41.22
General Components	1	£68.71
	Total	£223.26

3.1. Software

Software required in order to develop the RFID tracking system included **Synapse Portal (version 2.4.17)** for creating and transferring python scripts onto each of the RF100PC6 Synapse RF Engine's. These python scripts run on the RF engines and allow the position of the tag to be transmitted. **Microsoft Visual Studio 2010/Visual C# Express edition** as a C# script required to forward the location data received from the PC reader to the web portal. **Notepad ++** - or similar for writing the web portal using HTML, PHP and JavaScript and **PhpMyAdmin** to create and manage the MySQL database to hold the RFID tags tracking information recorded by the reader nodes and will also record Meta information associated with the tag.

Figure 1 illustrates the entire system and its main components. The transponder will awaken on a set regular interval and broadcast its location to the reader nodes. The RFID will be asleep and will only awaken to broadcast its signal as the RFID tag will be battery powered and this will conserve energy. The reader nodes unlike the RFID tags will be powered by the mains power supply and will have a steady income of electricity. The reader nodes will be constantly listening in the mesh network for the RFID tag to broadcast a signal so the reader nodes can capture the signal strength and pass this information through the mesh network and to the PC reader node. The PC Reader Node is the node that communicates directly with the PC. It is responsible for collecting the information received from all the reader nodes within the mesh network and forwarding this information to the PC. The Mesh Network is made up of reader nodes, the PC reader and the RFID tag. The synapse RF engines support this mesh networking right out of the box. The mesh network allows each of the signal strengths recorded by the reader nodes to be forwarded to the PC reader and ultimately to the PC. A desktop or laptop is needed to be set up with the PC reader and running the synapse portal software to allow the PC to accept the information from the mesh network. Once the PC receives the

signal strengths, it forwards the posts the data to a database using HTTP protocol.

The MySQL database is responsible for storing all the tracking information collected from the mesh network. The user using the Web Portal can then access this information. Finally, the Web Portal is a HTML5 application using various web-based technologies such as JavaScript, JQuery and PHP. This is responsible for reading and interpreting the location coordinates from the database and showing the user where the RFID tag is in relation to the defined perimeters.

3.2. Software and Physical Design for Hardware Components

The tag, reader nodes and PC reader all use synapse RF100 engines that can be programmed with python scripts. The scripts are sent over the air and onto the chips using the synapse portal software. The RF100 datasheet has all the technical information such as the maximum voltage and the maximum signal strength. It also has this table detailing the function of each pin which needs to be taken into account when designing the python scripts.

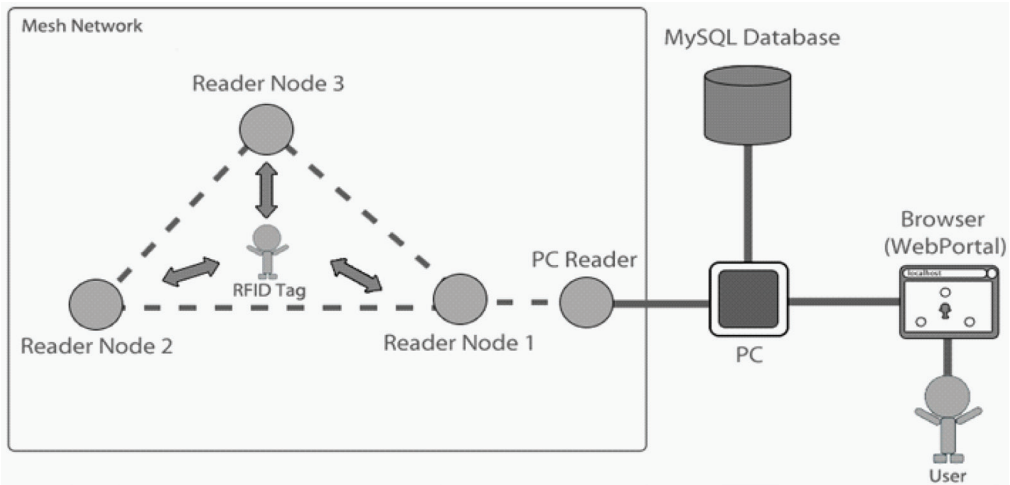
3.2.1. The Tag

The Tag is mobile and the power pins of the RF100 engine are soldered to a 3 Volt power supply which is a battery pack enclosure that houses 2 AAA batteries (1.5V each). The tag has a 3mm LED that is connected to pin 14 (positive) and pin 16 (negative) which is initially off and will blink when the tag sends the signal. Figure 2 illustrates how the tags python script operate and the design of the tag can be seen in Figure 3.

3.2.2. The Reader Node

The reader nodes are stationary in a fixed position and powered by the mains. They use a 3V DC adapter. The DC adapter plugs into a 2.1mm Jack which is soldered onto the reader nodes RF100 power pins (21 and 24). The reader nodes also have a 5mm LED that is connected

Figure 1. Showing how each component of the RFID tracking system will integrate together



to pin 14 (positive) and pin 16 (negative). The LED is always on which indicates if the Nodes are receiving power and when they receive a signal they will blink. Once the nodes receive a ping from the tag, they must forward the signal and the node address to the PC reader. The flow diagram show how the reader nodes python script operate and the design of the tag can be seen in Figure.

3.2.3. The PC Reader

The PC Reader plugs into the PC's USB port by combining the RF 100 engine with a Synapse SnapStick. This allows the RF 100 to be powered by the PC and also allows it to pass data to the USB/COM ports. The PC reader listens for data being forwarded by the reader nodes, the data contains the tags address and signal strength and the readers address. The PC reader then sends this data to the USB port that it is plugged into. The PC reader python script will operate as shown in Figure 4.

3.3. Web Portal Interface and Map Design

We outline here the design for the maps/floor plan to be used. It also illustrates the various functionality and form interfaces to be available to the user.

3.3.1. Floor Plan/Map Design

The tracking portal supports the ability to upload new maps and floor plans. For tracking people or assets the map (See Figure 5) can be designed to reflect where the individual nodes are physically positioned. Each of the four physical nodes here has a different color of LED to allow the node to be identified easily. The map has a colored square for each node that corresponds to the physical nodes LED color and the middle of each square has the node address printed in the center. The reader nodes are represented by brown colored squares on the map and the tag is a colored circle. Ideally the tag (white circle) in the portal map will move towards the node as the physical tag moves towards the physical reader node.

3.3.2. Portal Controls

The portal has a number of controls. It allows the user to select between maps if more than one is available. This caters for situations where multiple maps would be necessary e.g. tracking in a multi-story building. The portal also has a tag key that shows the color and identity of any tags within the tag database. Finally it contains buttons that opens forms that allow readers, maps and tags to details to be add/edited or

Figure 2. Flow diagram of tag & tag design

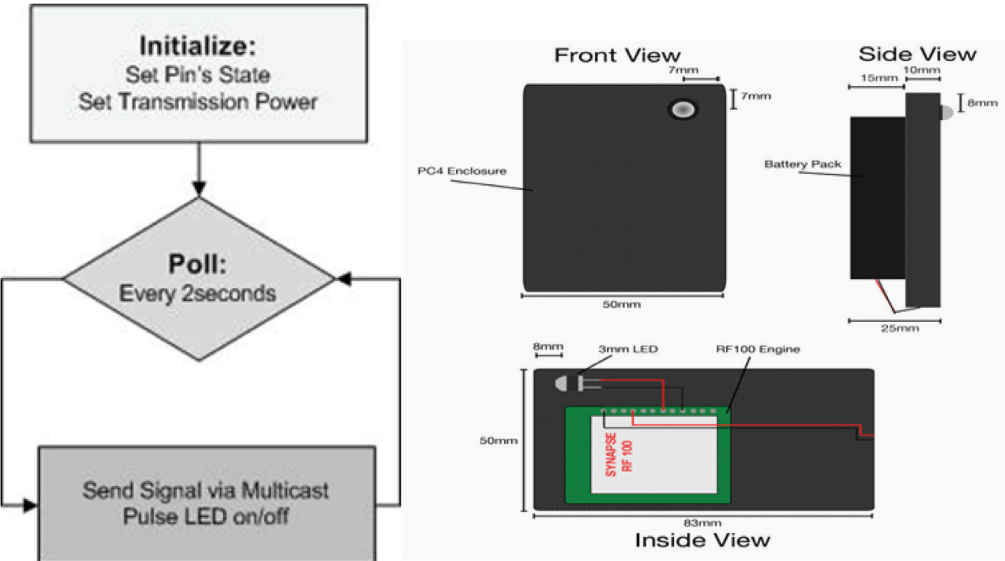
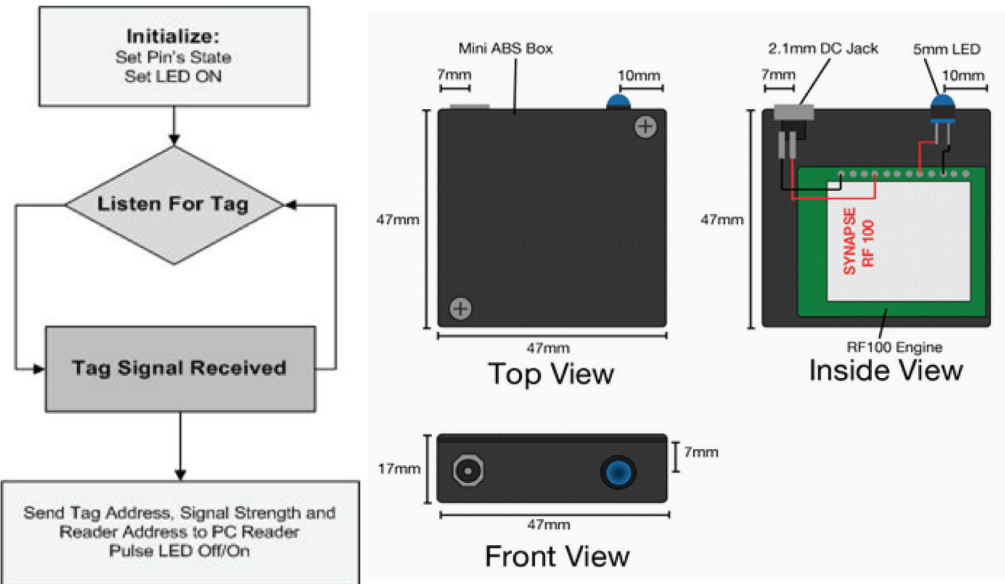


Figure 3. Reader and flow diagram



deleted. The last button is the button that clears all tracking data; this will delete all tracking records from the database (See Figure 6).

3.3.3. Portal Form Design

The portals 3 button controls (Tags, Readers, Maps) link to 3 management pages that allow details to be add/edit/delete. Figure 7 shows

Figure 4. PC reader sequence

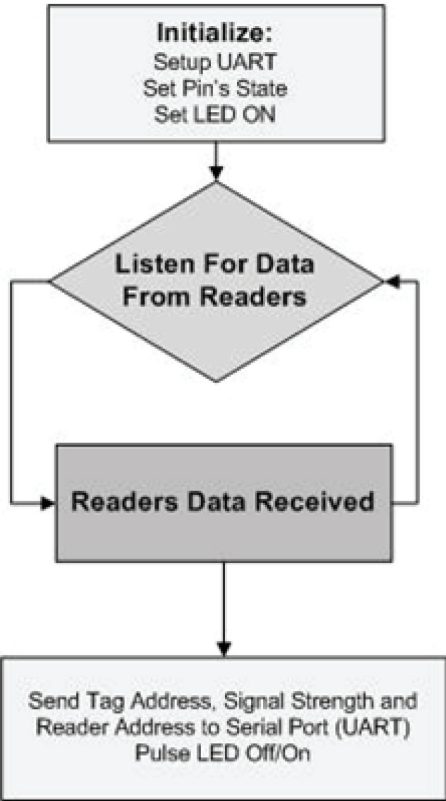


Figure 5. Portal map proportional to the physical area bound by the reader nodes

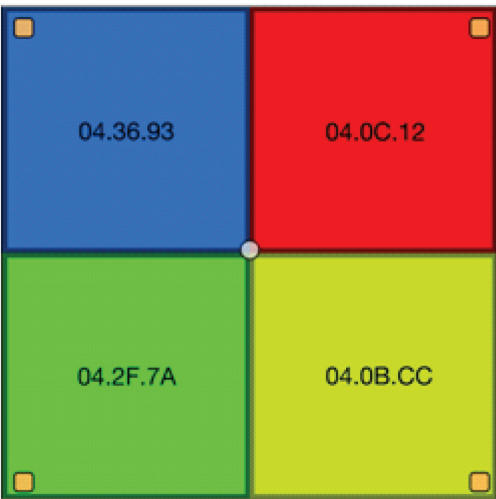


Figure 6. The design for the portals controls

Map

Color_Zones

Tag Key

☐ Tag

Controls

Tags

Readers

Maps

Clear Tracking Data

what the reader node management page will look like and the map and tag forms will look similar to this and will have the exact same functionality.

3.3.4. Portal Database Design

The portal will be linked to a MySQL database. There are a number of tables including one called reader which will hold all the information for the positioning (x and y coords) and identification

Figure 7. The readers details management form

<< First < Prev Page 1 of 2 Next > Last >> Add Reader					
Name	Node Address	Map ▼	X Pos	Y Pos	
Red Node	040C12	Color_Zones	750	30	
Blue Node	043693	Color_Zones	30	30	
Green Node	042F7A	Color_Zones	30	750	
Yellow Node	040BCC	Color_Zones	750	750	
Stock Room	000001	Sample Map 1	130	100	
Office 2	000002	Sample Map 1	310	140	
Office	000003	Sample Map 1	480	150	
Staff Lounge	000004	Sample Map 1	640	160	
Shop Area 2	000005	Sample Map 1	130	340	
Shop Area 1	000006	Sample Map 1	420	300	
<< First < Prev Page 1 of 2 Next > Last >> Add Reader					

(address) of the nodes on the map/floor plan (map_id). There will also be a table to hold the information of the tag which will store the address and name of the tag. The preferred colour is also stored this will change the colour of the tag on the map. The position of the tag (x and y coords) will be stored in the position table and this table will be associated with the tag table and map table. The portal enables multi maps and floor plans to be uploaded therefore it is necessary to have a table for maps which will store each of the maps/floor plans and basically link all of the tables relationally.

4. TWO DIMENSIONAL TRILATERATION ALGORITHM

To allow the tag to be tracked and displayed in the correct position, we designed an algorithm to calculate the position of the tag within a set area using 3 reader nodes and display the location correctly on a 2D map. This method assumes the nodes are arranged in square-like fashion and are equally spaced.

4.1. 2D Trilateration Algorithm

The Carlin 2D Trilateration algorithm has 8 steps; each step is outlined here:

Step 1: Calculate Signal to Distance and Pixel to Distance Ratio

Step 2: Calculate the Nearest and Adjacent Nodes

Step 3: Convert Signal Values to Distances

Step 4: Calculate Area of Width Triangle and Height Triangle

Step 5: Calculate Area of Width Rectangle and Height Rectangle

Step 6: Calculate Unknown sides of Rectangles from Areas

Step 7: Convert Width and Height to Pixel Points

Step 8: Calculate True direction and Coordinates on Map

4.1.1. Calculate Signal to Distance and Pixel to Distance Ratio

To calculate the signal to distance ratio a maximum and minimum signal must first be identified. The difference must then be calculated by taking the maximum away from the minimum:

$$\frac{\text{max_min_signal_difference}(\text{dBm})}{\text{max_signal}(\text{dBm}) - \text{min_signal}(\text{dBm})} =$$

The distance in meters between the nodes is then divided by the max_min_signal_difference to achieve the signal to distance ratio:

$$\frac{\text{signal_to_distance_ratio}(\text{m per dBm})}{\text{node_distance_metres}(\text{m})} =$$

To calculate the pixel to distance ratio the physical distance(m) between the node must be divided by the virtual distance(px):

$$\frac{\text{pixel_to_distance_ratio}(\text{px per m})}{\text{node_distance_pixels}(\text{px})} =$$

4.1.2. Calculate the Nearest and Adjacent Nodes

The nearest node will always be the one with the lowest signal and the adjacent nodes can be identified by analyzing the x and y coordinates of the nearest node. The adjacent node that will affect the tags x-coordinate will have the same x-coordinate as the nearest node and will have a different y-coordinate as the nearest node. The opposite conditions identify the adjacent node that will affect the tags y-coordinate as this node

will have the same y-coordinate as the nearest node and will have a different x-coordinate as the nearest node.

4.1.3. Convert Signal Values to Distances

Take the signal values from the nearest and adjacent nodes and convert them into distances using the `signal_to_distance_ratio`.

4.1.4. Calculate Area of Width Triangle and Height Triangle

The area of the triangle can be found using Heron's Formula, where a, b, c are the length of the sides of the triangle:

$$\text{Area Of Triangle} = \sqrt{P(P-a)(P-b)(P-c)}$$

in this formula is the perimeter of the triangle, which is found by:

$$\text{Perimeter} = \frac{a + b + c}{2}$$

The area of the width triangle uses the distances obtained between the closest node, the tag and the adjacent node(that will affect the x-coordinates of the tag). The area of the height triangle uses the distances obtained between the closest node, the tag and the adjacent node(that will affect the y-coordinates of the tag).

4.1.5. Calculate Area of Width Rectangle and Height rectangle

The area of the width rectangle and height rectangle can be found by multiplying the area of the width triangle and area of the height triangle by 2 respectively.

$$\text{Area of Rectangle} = \text{Area of Triangle} \times 2$$

4.1.6. Calculate Unknown sides of Rectangles from Areas

The unknown sides can then be discovered by dividing the area of the rectangle by the known side to get the value of the unknown side. The unknown side of the width rectangle will be the distance in meters the tag is from the left or right side of the tracking area (square) depending on which nodes are used. The unknown side of the height rectangle will be the distance in meters the tag is from the top or bottom side of the tracking area (square) depending on which nodes are used.

$$\text{Unknown side of Rectangle} = \frac{\text{Area of Rectangle}}{\text{Known side}}$$

4.1.7. Convert Width and Height to Pixel Points

Convert the unknown side of the width rectangle (tag x-coordinate) and the unknown side of the height rectangle (tag y-coordinate) to pixels by multiplying them by the `pixel_to_distance_ratio`. The tag can now be represented on a 2D Map using the boundaries of the nodes and the X and Y coordinates obtained.

4.1.8 Calculate True direction and Coordinates on Map

Depending on which node was the closest to the tag the co-ordinates obtained need to be modified according to where the nodes are placed on the map to position the tag in the correct location and direction.

If the top left node was the closest to the tag then:

$$\text{true_x-coordinate} = \text{x-coordinate} + \text{readers_x-coordinate}$$

$$\text{true_y-coordinate} = \text{y-coordinate} + \text{readers_y-coordinate}$$

If the top right node was the closest to the tag then:

$\text{true_x-coordinate} = \text{x-coordinate} - \text{readers_x-coordinate}$

$\text{true_y-coordinate} = \text{y-coordinate} + \text{readers_y-coordinate}$

If the bottom left node was the closest to the tag then:

$\text{true_x-coordinate} = \text{x-coordinate} + \text{readers_x-coordinate}$

$\text{true_y-coordinate} = \text{y-coordinate} - \text{readers_y-coordinate}$

If the bottom right node was the closest to the tag then:

$\text{true_x-coordinate} = \text{x-coordinate} - \text{readers_x-coordinate}$

$\text{true_y-coordinate} = \text{y-coordinate} - \text{readers_y-coordinate}$

5. A LOW COST INDOOR LOCATION TRACKING SYSTEM - IMPLEMENTATION

5.1. Building the hardware components

This section outlines how each component of the RFID tracking system was physically built with a step-by-step guide of the building process and details any improvements or design considerations that could have been made during the building process.

5.1.1 The Reader Node

The reader node needs a Regulated 3V DC 400mA Power Adapter to power the RF Engine and requires the following components to build:

1. Miniature ABS Box 1551 Series (N53FK)
2. RF100PC6 Synapse RF Engine

3. 2.1mm DC Socket
4. 5mm LED and LED Holder/Socket
5. Double sided/wall mounting tape

Use measuring tape and a marking pin or scribe to mark where the DC Socket and LED socket will be drilled on the N53FK ABS box (See Figure 8). The DC Socket marker should be 7mm from the narrowest side with the curve and 7.5mm from the left side where the lid is located. The LED socket should be 10mm from the opposite from the DC Socket narrowest side with the curve and 7.5mm from the left side where the lid is located. To drill the hole for the DC socket, hold the ABS Box firmly and position a power drill with a 3mm drill bit attached perpendicularly to where the mark was left with the scribe for the DC Socket (See Figure 9).

Start to drill slowly and steadily pick up speed once the drill bit begins to take root in the box (See Figure 10). A firm grip must be kept on the ABS box while drilling. Once the drill bit goes fully through the ABS Box, the easiest way to remove the drill bit from the hole is to put the power drill into reverse mode and remove slowly while drilling in reverse.

Once the initial guide hole has been drilled, change the drill bit to a 5.5mm drill bit and widen the guide hole by drilling perpendicularly into it with the drill bit centered on the guide hole (See Figure 10). Once the drill bit goes fully through the ABS Box put the power drill into reverse mode and remove slowly while drilling in reverse. This step of widening the hole is repeated one more time using a 8mm drill bit so the DC socket can be secured into the hole (See Figure 11).

To drill the hole for the LED socket (See Figure 12), hold the ABS Box firmly and position a power drill with a 3.5mm drill bit attached perpendicularly to where the mark was left with the scribe for the LED Socket. Once the drill bit goes fully through the ABS Box put the power drill into reverse mode and remove slowly while drilling in reverse until the bit has left the hole in the ABS box (See Figure 13).

Figure 8. Marking holes for DC and LED socket

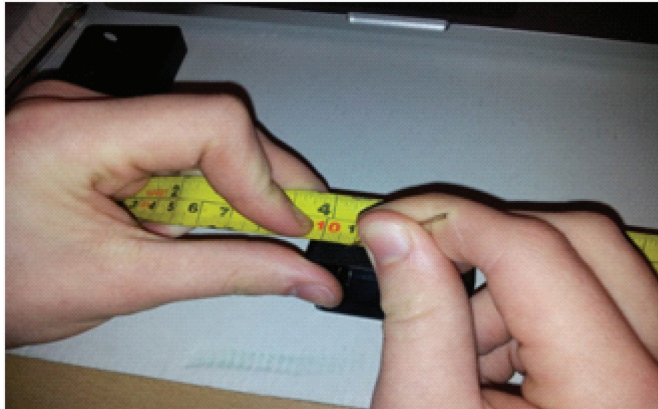


Figure 9. Position drill to drill hole for DC socket



Figure 10. Start drilling hole

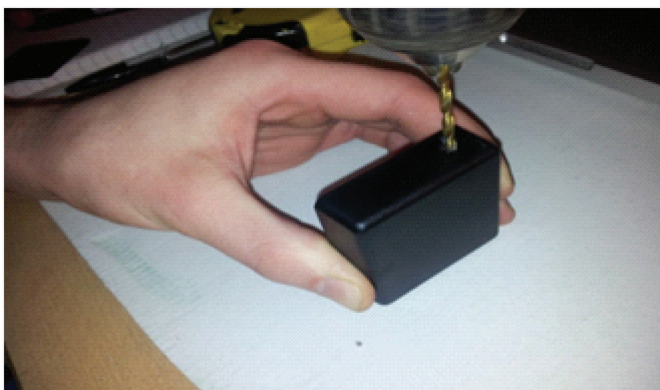


Figure 11. Remove drill from hole once drilled



Figure 12. Widen hole with bigger drill bit

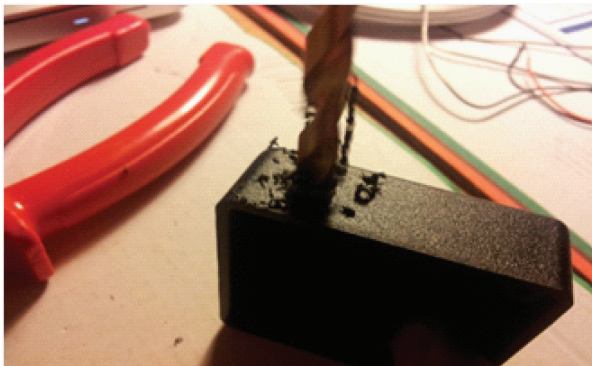


Figure 13. Remove larger drill bit from hole



Once the initial guide hole for the LED Socket has been drilled, change the drill bit to a 6mm drill bit and widen the guide hole by drilling perpendicularly into it with the drill bit centered on the guide hole for the LED Socket (See Figure 14). The ABS box should now have two holes present one the DC Socket 8mm thick and one for the LED Socket which is 6mm thick (See Figure 15).

Inside the ABS box two cylinder pieces of plastic must be removed using a pair of pliers. Hold the base of the plastic cylinders with the pliers and rock the ABS box back and forth until the cylinder becomes removed (See Figure 16). Take the plastic LED Socket (See Figure 17) and fold the legs of it inward while pushing it into the hole until it clicks in.

Take the LED and push it in from the inside of the box into the socket. The positive leg (longer leg) should be the furthest away from the side adjacent to the LED socket (See Figure 18). Next cut two pieces of double sided/mounting tape and place one piece on the bottom and one piece on the left side of the box. Take the RF engine and place it under the LED legs and push it onto the mounting tape to fixate inside the box securely (See Figure 19).

Use a wire cutter and strimmer to prepare approximately 5.5cm of black wire and 6.0cm of red wire to solder onto the RF Engine and DC Socket. Red is used for positive connections and black is used for ground. The red wire should be soldered to the inner leg of the 2.1mm DC Socket and to PIN 20 of the RF Engine. The black wire should be soldered to any of the outer legs of the 2.1mm DC Socket and to PIN 24 of the RF Engine, which is the ground pin (See Figure 20). When soldering the wires to the RF Engine and DC socket it is easier to solder while the chip and DC Socket is out of the box. Once the soldering is complete the chip and DC Socket can be fitted into the box and the DC Socket can be secured by screwing the locking nut from the outside (See Figure 21).

Take the wire clippers and trim the legs of the LED to approximately 2mm after the solder points for the pins. This extra space makes sure there is enough room to allow the

legs to be maneuvered above the correct pins and soldered (See Figure 22). Maneuver the legs of the LED above PIN 18 (Negative) and PIN 16 (Positive). Use a soldering Iron and carefully solder the pins onto the surface connection points of the RF Engine making sure the LED legs and surface points are making contact (See Figure 23).

To power the reader node a Regulated 3V DC 400mA Power Adapter is used (See Figure 24). The RF Engines maximum voltage is 3.6V and these restrictions can be found in the RF Engines datasheet. Plug the Regulated 3V DC 400mA Power Adapter with a 2.1mm head attached into the DC Socket and the reader node will now have power and python scripts can now be uploaded onto the node using the synapse portal software (See Figure 25).

This project required more than one reader node and by following the steps that have been outlined it is possible to build as many as the project necessitates (See Figure 26). Once the reader nodes have power they can be seen by the synapse portal software and the reader_node.py script can be uploaded on to each node (See Figure 27). Once the script has been uploaded onto the nodes the LED's should turn on to show that the nodes are active, receiving power and listening for the Tags signal (See Figure 28).

5.1.2 The Tag

The RFID tag had to be mobile so it receives its power from a battery pack which is mounted on the back of the tag and requires the following components to build:

1. Pocket Card Enclosure (PC.4)
2. RF100PC6 Synapse RF Engine
3. Double sided/wall mounting tape
4. 3mm LED and LED Holder/Socket
5. Battery holder, 3x micro "AAA" housing with switch (65 x 38 x 15 mm)

Spit the Pocket Card Enclosure (PC.4) with hands and take the thicker half and lye it flat on a piece of cardboard. Then take a power drill and use a 2mm bit to drill a guide hole, 9mm

Figure 14. Drill guide hole for LED

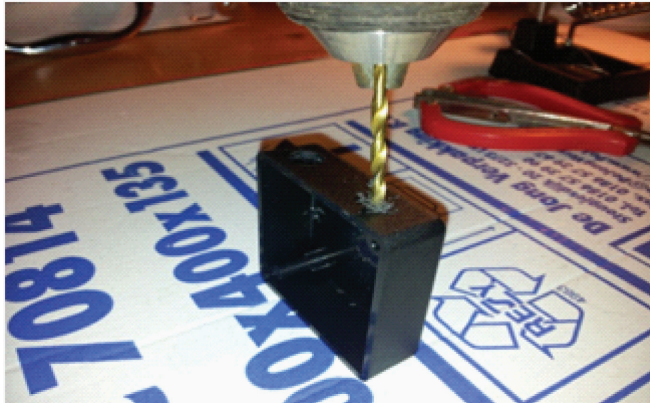


Figure 15. Remove drill from guide hole



Figure 16. Widen LED guide hole

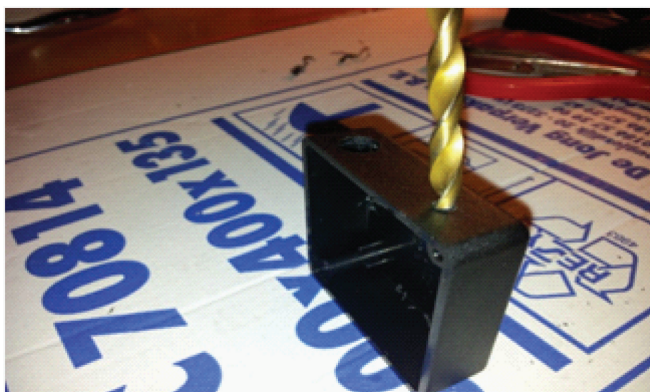


Figure 17. Box should have 2 holes



Figure 18. Remove pieces of plastic from inside



Figure 19. Install LED socket into ABS box

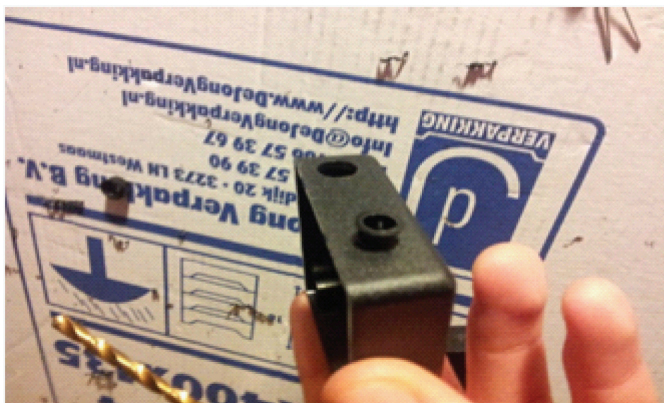


Figure 20. Put LED into socket



Figure 21. Install RF engine into ABS box



Figure 22. Solder DC socket to RF engine

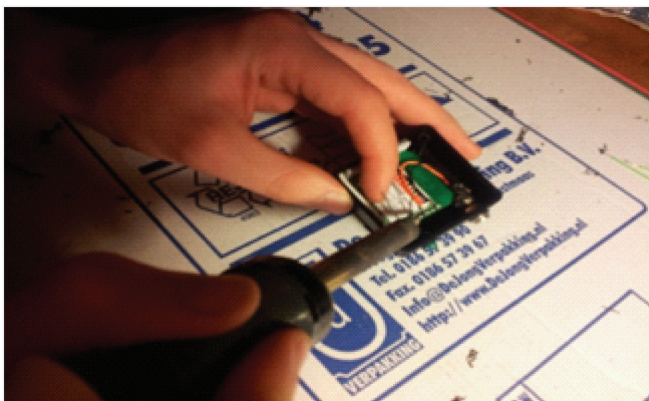


Figure 23. DC Socket soldered to correct pins

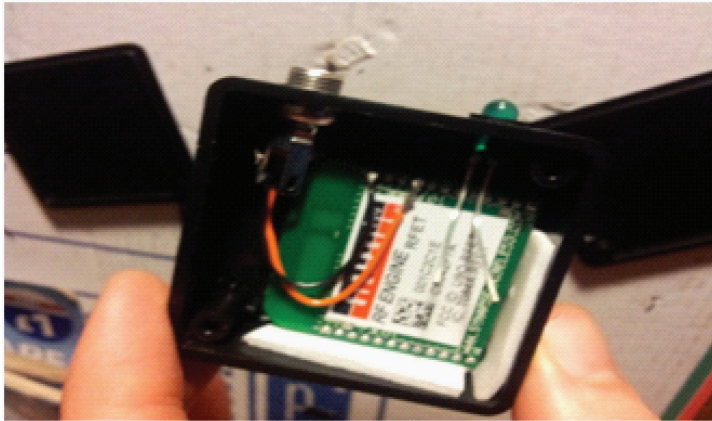


Figure 24. Trim LED legs

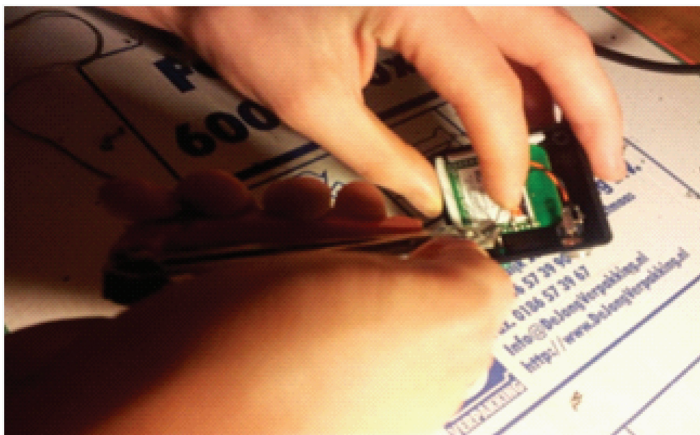


Figure 25. Solder LED legs to correct pins

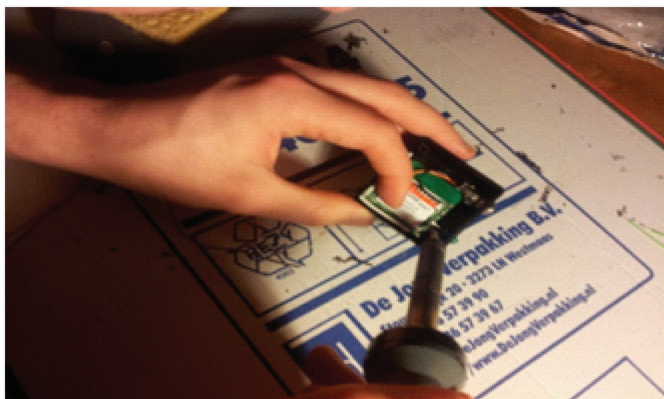


Figure 26. 3V power adapter



Figure 27. Plug power adapter into reader node



Figure 28. Four reader nodes powered up



from the bottom and left of the enclosure for the 3mm LED Socket. Increase the size of the drill bit by 0.5mm and continue to widen until the 3mm LED Socket fits securely into the PC enclosure lid (See Figure 29). Take the AAA Battery holder pack and place double sided/wall mounting tape onto the back of the pack (See Figure 30) (The opposite side to where the on/off switch is located). Place the battery pack onto the back of the PC enclosure (the side that does not have the LED). Make sure the on/off switch is facing the opposite direction to the LED on the front of the enclosure.

Take the Front of the PC enclosure (The side with the LED hole) and on the bottom drill using a small bit (approx 2.5mm) and create a small channel for the power pack's power cables to enter the inside of the PC enclosure (See Figure 31). Take the back of the PC enclosure and before the RF Engine can be placed inside the pins on the bottom must be carefully bent outwards using a pair of pliers. Once the RF Engine is flat and fits inside the enclosure take the battery packs positive (red) and negative (black) wires, trim them and solder them onto PIN 20 and 24 respectively. Next solder wires onto the 3mm LED and solder the negative wire onto PIN 18 and solder positive onto PIN 16 (See Figure 32).

Carefully take the back of the enclosure with the battery pack attached and RF Engine on top. Next take the top of the PC enclosure and place it on top of the RF Engine and back of the enclosure making sure the wires for the battery pack are traveling out through the cavity on the top (See Figure 33). Before closing the PC enclosure take a pin and press the LED into the LED Socket until it clicks and is securely in place. Close the PC Enclosure and make sure to screw the center of the enclosure with the screw that came with the enclosure. The power pack can contain 3xAAA batteries, but should only ever have two in at one time as each AAA battery supplies 1.5V so if all three batteries were present that would equate to 4.5V as each of the batteries are wired in series. The maximum voltage that the chips are allowed is 3.6V so if all three batteries were used it would damage

the RF Engine. In order to only need to use two batteries to power the RF Engine a piece of wire must be soldered and used to complete the circuit from the positive to the negative terminal as seen in Figure 34 and Figure 32.

By following the steps outlined, the RFID Tag should look like something in Figure 35. Once the tags battery pack is toggled to ON, it should be discoverable by the synapse portal software and the `rfid_tag.py` script can be uploaded on to the tag. Once the script has been uploaded onto the tag the LED should turn begin to flash at 3 second intervals which shows the tag is active, receiving power and Broadcasting its signal.

5.1.3 The PC Reader

The PC Reader accepts the signals received from the reader nodes and forwards this information into the USB slot that it is plugged into. The Pc Reader requires the following components to build:

1. Synapse SnapStick
2. RF100PC6 Synapse RF Engine

Take the RF100PC6 Synapse RF Engine and Synapse Snapstick (See Figure 36). Take the RF engine and place the pins into the Synapse SnapStick making sure the orientation of the chip matches the Figure 37. Plug the SnapStick into the computers USB Drive so the device is discoverable by the portal software and upload the `pc_reader.py` script. The next step is to make the SnapStick operate as a Virtual Com Port (VCP) instead of a USB device. This will allow the signal strength data to be received by the PC Reader and forwarded to a com port that can then be gathered by a port listening program and posted online to the server.

5.2 Software for the Hardware Components (Python Scripts)

The RF100 engines are programmed using python scripts programmed in the Synapse portal software (v2.4.17). The scripts can be

Figure 29. Drill LED hole in PC4 enclosure

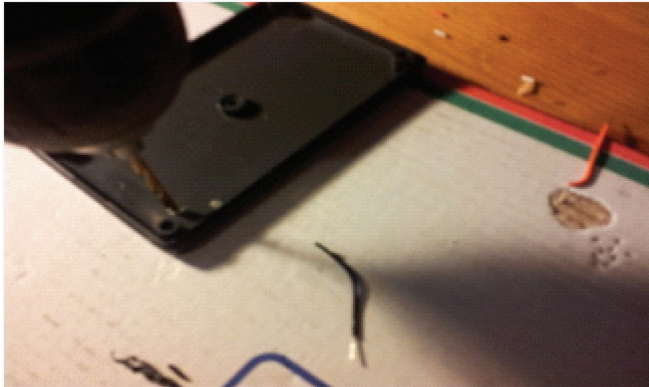


Figure 30. Stick wall mounting tape on battery

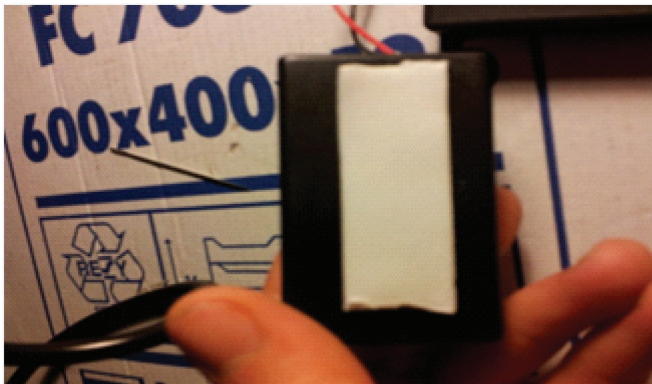


Figure 31. Hole for batter pack wires

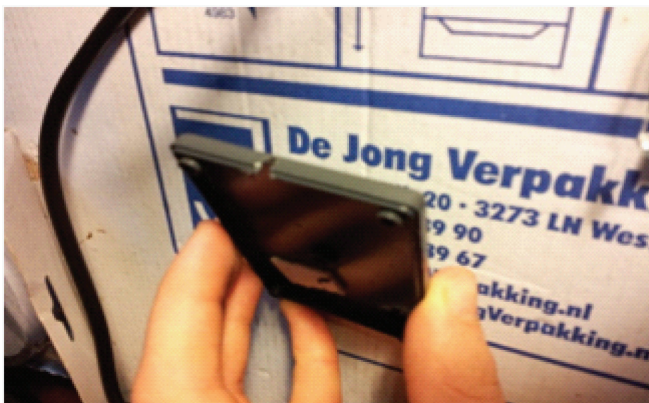


Figure 32. Solder LED & power pack to pins

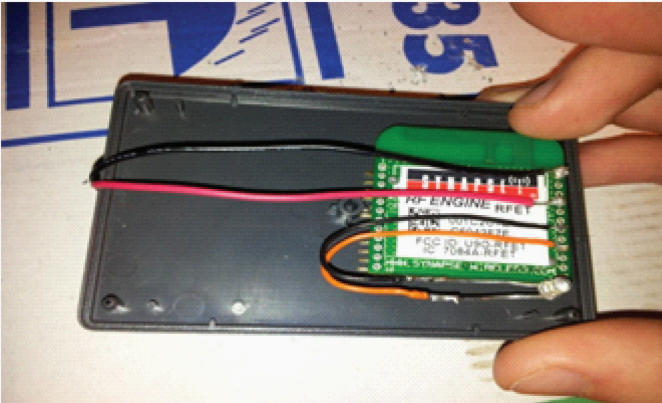


Figure 33. Close PC4 enclosure with RF engine and battery pack



Figure 34. Solder a wire to last battery terminal



Figure 35. The finished tag

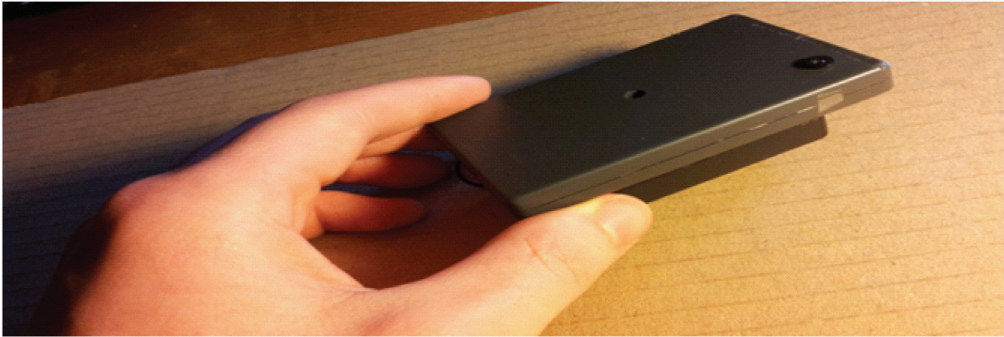


Figure 36. Synapse snapstick and RF engine

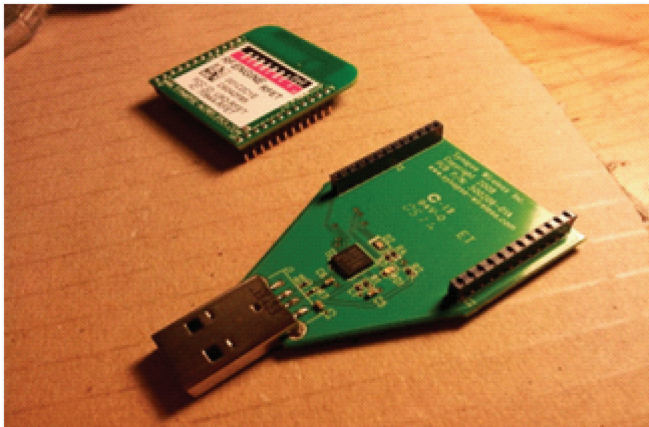


Figure 37. Synapse snapstick and RF engine combined



transferred to the chips by placing them on the evaluation board (See Figure 38). The evaluation needs a power supply to operate and to make the RF100 engine live therefore a battery pack must be attached. A RS323 (Serial cable) can then be attached to the PC with the synapse portal software running and the tag should then be programmable through the Synapse portal software (See Figure 39).

To pass the data collected by the PC reader plugged into the USB port to the server online, a Serial to Http data forwarder must be used. The Serial to Http data forwarder used in this project was developed by Nicholas Skinner who was also the initial designer/architect of this tracking system¹⁶. The program requires you to select a serial port to listen to and it requires you to give the URL of the page you wish the data received from the serial port to be posted to. The data coming in can be seen in the text box underneath the connection button which is useful when debugging and collecting test data.

6. TESTING

The testing includes the benchmark and distance testing of the RF 100 engines to find the optimum range that the nodes can be apart.

6.1 Determining Optimum Range Between Nodes

This was to benchmark the best distance for the nodes to be placed apart for the most accurate signal results. This test data was achieved using the synapse portal on a laptop with a synapse SnapStick acting as a bridge to receive the link quality (signal strength) from the reader node plugged in at the end of the hall way. The reader node was stationary and the laptop was moved from the reader node further up the hall at a distance of 1 meter at a time. The raw data (See

Table 6 is presented in Figure 40 for a higher level comparison of the signal strength to distance results of each of the reader nodes.

6.2 Rough data collected to improve calibration for calculating position

We present data collected the first time the tracking system and physical tracking area was set up. The tag was placed in 5 different set locations multiple times to allow the signal data to be recorded, an average to be calculated and signal fluctuations to be analysed. This data was used when designing the tracking algorithm and developing our grouping solution to improve data consistency and minimize fluctuations.

Figure 38. RF100 plugged into evaluation board powered up

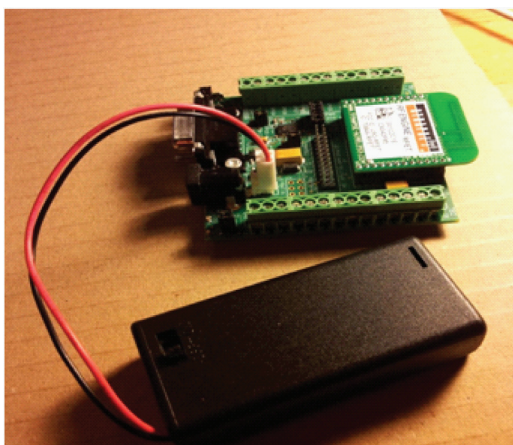
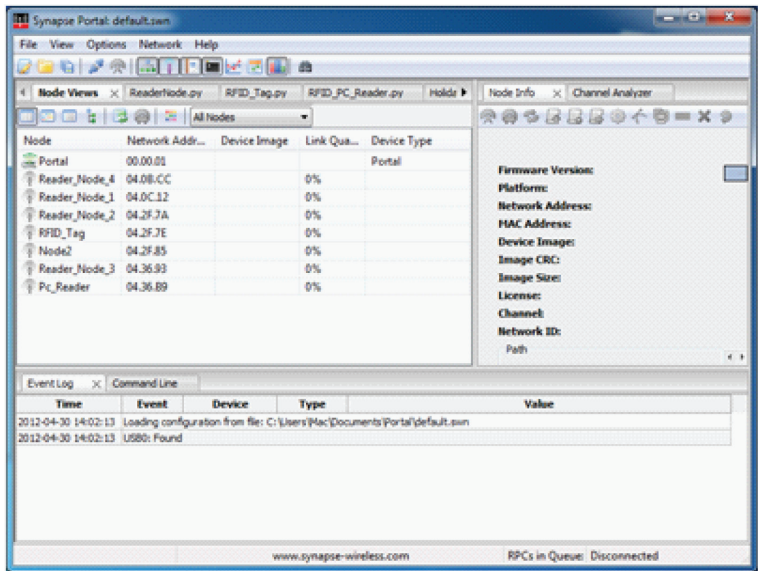


Figure 39. Synapse portal software (v2.4.17) for programming the RF engines



The tag was positioned in the middle of the 2m x 2m tracking area and 5 sample signals (Tests 1 - 5) were taken and recorded in a table (See Table 7). The average of each of the nodes was taken and the maximum and minimum boundaries were also recorded.

The tag was positioned beside the blue node within the 2m x 2m tracking area and 5 sample signals (Tests 1 - 5) were taken and recorded

in a table (See Table 8). The average of each of the nodes was taken and the maximum and minimum boundaries were also recorded.

The tag was positioned right beside the green node within the physical 2m x 2m tracking area and 5 sample signals (Tests 1 - 5) were taken and recorded in a table (See Table 9). The average of each of the nodes was taken

Figure 40. Signal strengths received from different distances from the node for each reader node

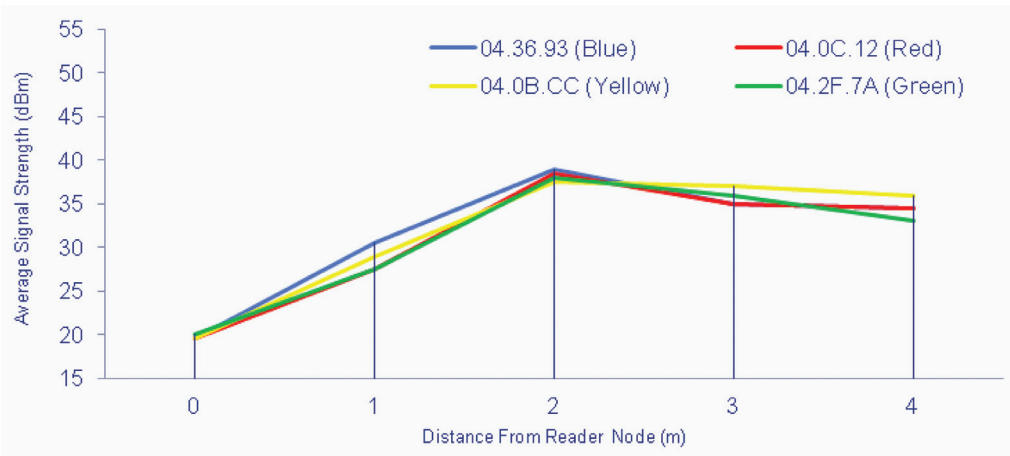


Table 6. No tag – Signal strength of each node to the distance of the computer running the portal software

Reader Node	Distance (m)	Link Quality (dBm)	Average Link Quality (dBm)
04.36.93 (Blue)	0	19 – 20	19.5
	1	28 - 33	30.5
	2	37 - 41	39
	3	33 - 37	35
	4	33 - 36	34.5
04.0C.12 (Red)	0	19 - 20	19.5
	1	26 - 29	27.5
	2	37 – 40	38.5
	3	34 – 36	35
	4	33 - 36	34.5
04.2F.7A (Green)	0	19 - 21	20
	1	26 - 29	27.5
	2	37 - 39	38
	3	35 - 37	36
	4	32 - 35	33
04.0B.CC (Yellow)	0	19 - 20	19.5
	1	28 - 30	29
	2	36 - 39	37.5
	3	36 - 38	37
	4	35 - 37	36

Table 7. Testing from the middle position of the 2m x 2m square

Reader Nodes with signal strengths received (dBm)					Position of Tag
	Blue	Red	Yellow	Green	
Test 1	53	52	43	52	
Test 2	45	49	46	40	
Test 3	43	52	46	44	
Test 4	40	43	40	46	
Test 5	41	46	44	41	
Min - Max	40 - 53	43 - 52	40 - 46	40 - 52	
Average	44.4	48.4	43.8	44.6	

Key

Tag Location

Position of Reading

Table 8. Testing from the position of the blue node in the 2m x 2m square

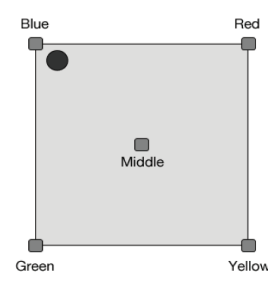
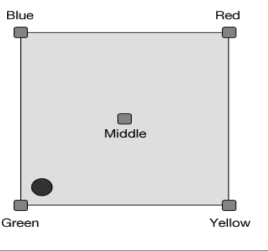
Reader Nodes with signal strengths received (dBm)					Position of Tag
	Blue	Red	Yellow	Green	
Test 1	37	53	56	51	
Test 2	33	46	56	41	
Test 3	39	49	50	48	
Test 4	28	47	43	35	
Test 5	32	57	49	47	
Min - Max	28 - 39	46 - 57	43 - 56	35 - 51	
Average	33.8	50.4	50.8	44.4	

Table 9. Testing from the position of the Green node in the 2m x 2m square

Reader Nodes with signal strengths received (dBm)					Position of Tag
	Blue	Red	Yellow	Green	
Test 1	38	53	39	32	
Test 2	51	55	61	36	
Test 3	42	49	45	32	
Test 4	57	45	46	27	
Test 5	61	55	46	23	
Min-Max	38 - 61	45 - 55	39 - 61	23 - 36	
Average	49.8	51.4	47.4	30	

and the maximum and minimum boundaries were also recorded.

The tag was positioned beside the yellow node within the 2m x 2m tracking area and 5 sample signals (Tests 1 - 5) were taken and recorded in a table (See Table 10). The average of

each of the nodes was taken and the maximum and minimum boundaries were also recorded.

The tag was positioned beside the red node within the 2m x 2m tracking area and 5 sample signals (Tests 1 - 5) were taken and recorded in a table (See Table 11). The average of each

Table 10. Testing from the position of the Yellow node in 2m x 2m square

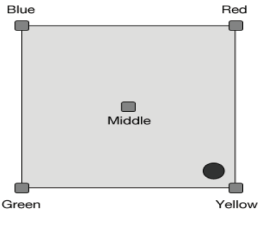
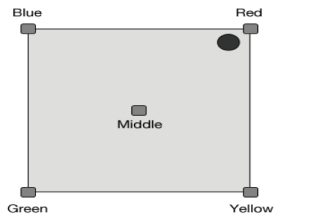
Reader Nodes with signal strengths received (dBm)					Position of Tag
	Blue	Red	Yellow	Green	
Test 1	66	51	35	39	
Test 2	52	55	42	45	
Test 3	55	48	39	46	
Test 4	46	45	36	43	
Test 5	54	51	36	46	
Min-Max	46 - 66	45 - 55	35 - 42	39 - 46	
Average	54.6	50	37.6	43.8	

Table 11. Testing from the position of the Red node in 2m x 2m square

Reader Nodes with signal strengths received (dBm)					Position of Tag
	Blue	Red	Yellow	Green	
Test 1	38	35	43	43	
Test 2	40	34	43	44	
Test 3	47	36	44	51	
Test 4	64	40	47	49	
Test 5	53	37	55	46	
Min-Max	38 - 64	34 - 40	43 - 55	43 - 51	
Average	48.4	37.4	46.4	46.6	

of the nodes was taken and the maximum and minimum boundaries were also recorded.

We found that the maximum distance the nodes could be placed apart from each other was 2 meters this assumption can be made because after 2 meters the signal starts to drop meaning the signal received would erroneous and inaccurate. This would have a strange effect on the tracking system as after 2 meters because of the signal dropping it would cause the system to think the tag/object was closer rather than further away from a node. For this reason the maximum physical tracking area was 2m by 2m. I have assumed that the distance constraint was down to hardware limitations; specifically the RF 100 engines power output and the fact that the RF engine that was used (RF100PC6) only had an F antenna. Many of synapses models allow antennas to be screwed on and also allow many different antennas to be used which could give a better and further reading. We believe that incorporating some of synapses other models of RF Engines will improve the range and precision of the hardware and system.

The best performance and most accurate tracking data was recorded when the maximum signal was capped around 7dBm lower than the actual maximum signal recorded and the minimum signal was capped 5dBm higher than the actual minimum signal recorded. The data was grouped into groups of four which meant that there was enough plot points to allow the data to be displayed accurately and catered for

the fluctuating signals which minimized the tag jumping around the screen when standing still.

Finally, we found our trilateration method to be quite accurate at calculating the position of the tag and representing it accurately on the portal map. There was in tests some fluctuation in the signal strengths even when standing still. The work around for this was to create grouping bands which would minimize the tags movement when the signals fluctuated slightly. There are other methods of trilateration such as the Nonlinear Least Squares method, Circle Intersections with Clustering method and Intersection of Two Circles method but we found our trilateration algorithm to be most suitable. We did make some assumptions such as assuming that the nodes were equally spaced and were distributed in a square-like fashion. One of the benefits however of distributing the nodes equally apart and in a square-like fashion is that this model can be up-scaled quite easily to form a grid network of nodes which will allow large areas to be covered and would still allow the tags to be tracked accurately using my trilateration method.

7. CONCLUSION

(Curran et al., 2011) conducted an evaluation of the leading indoor determination systems and ranking them according to various features (See Table 12). These systems included the Ekahau and Trapeze LA-200 systems (Wi-Fi), Ubisense (Ultrawideband) and the TolleyScan (RFID)

radar. The Ekahau system including software & support was approximately £5,000 UK sterling and the LA200 (Trapeze) was double that at approximately £10,000 UK sterling. The homemade tracking system that was built during this project cost roughly around £200 UK Sterling. By building all of the software and hardware components it meant that a substantial amount of savings were made. However, the time spent developing and building each component must be taken into account. The characteristics of each tracking solution can be seen in Table 12. The homemade tracking system built within this project has even better accuracy results and lower latency times than many of the commercial applications. Most of the other solutions use Wi-Fi or a combination of Wi-Fi and RFID to track whereas the solution developed within this project has been purely RFID based. This means that the other systems do have a wider tracking range and the home made tracking system can only track within the areas where reader nodes are deployed. Because the homemade tracking system has been developed from scratch it does not have any software support. However there are no licensing fees

and a completely bespoke tracking solution can be developed. It seems the home made tracking solution stand ups well against the other commercial applications (See Table 12) with only some limitations but the cost effectiveness of the tracking solution is clear to see.

We believe we have shown here that it is possible to build an asset/people/robot tracking system within a reasonable budget. However there are some constraints. The distance constraint of using 2 metres between the nodes can possibly be increased by using a different synapse RF Engine model and antenna. If the hardware was not upgraded you can still achieve a longer distance of tracking. Using the method we are using to calculate the position of the tag within the four node square it is quite possible to increase the amount of nodes to form a grid of nodes so they can track the tag within a larger distance. This of course would add to the cost but the tracking results and accuracy would be equal to and maybe even better than that of commercial and off the shelf software for a fraction of the price. The system could also allow the user to add Meta Data to the tag and nodes, which would be recorded into

Table 12. Summary of characteristics of leading location tracking systems in comparison

	Trapeze	Ubisense	Ekahau	RFID Radar	Our Homemade Tracking System
Avg. Accuracy claims	10ft	3.1 ft	3.5ft	10ft	6.56ft
Tracking Range	WLAN covered site	WLAN covered site	WLAN covered site	WLAN covered site	Within boundary of reader nodes
Latency claims	<3 sec	<3 sec	< 5 sec	<5 sec	< 2 sec
Software API	Vendors need to integrate	Open API for 3 rd party apps	Open API: SDK (Java) or TCP	Proprietary	none
Client software	yes	none	yes	yes	Custom built
Proprietary Hardware	yes	yes	Tags but also Wi-Fi clients	yes	yes
Summary	Hardware & software based Wi-Fi solution.	HW/SW using Wi-Fi and Active RFID	Wi-Fi devices & tags.	RFID solution for fast moving & static tracking	By building the system and components the system will have no licensing costs and is the cheapest solution.

the database and would dynamically be pulled out and made available and presented well to the user when they hover over the tag or node within the portal.

REFERENCES

- Barahim, M., Doomun, M., & Joomun, N. (2007). *Low-cost bluetooth mobile positioning for location-based application*.
- Bhatt, H., & Glover, B. (2006). *RFID essentials*. O'Reilly.
- Caffery, J., & Gordon, L. (1998). Senior member, subscriber location in CDMA cellular networks. *IEEE Transactions On Vehicular Technology*, 47(2).
- Chan, E., Baci, G., & Mak, S. (2009). Using Wi-Fi signal strength to localize in wireless sensor networks. In *Proceedings of the International Conference on Communications and Mobile Computing*.
- Charlebois, O. (2004). *Radio frequency identification (RFID): Principles and applications, electromagnetic fields and waves ECSE*. McGill University.
- Chen, Y., & Luo, R. (2007). *Design and implementation of a WiFi-based local locating system*.
- Ciurana, M., Barcelo-Arroyo, F., & Izquierdo, F. (2007). *A ranging method with IEEE 802.11 data frames for indoor localization*. IEEE. doi:10.1109/WCNC.2007.392
- Curran, K., Furey, E., Lunney, T., Santos, J., Woods, D., & McCaughey, A. (2011). An evaluation of indoor location determination technologies. *Journal of Location Based Services*, 5(2), 61-78. ISSN: 1748-9725, DOI:10.1080/17489725.2011.562927
- Dissanayake, S., Karunasekara, P., Lakmanarachchi, D., Rathnayaka, A., & Samarasinghe, A. (2008). *Zigbee wireless vehicular identification and authentication system*.
- Farragher, M. (2004). *Practical use of RFID*. FirstFocus.
- Figueiras, J., Schwefel, H., & Kovacs, I. (2005). *Accuracy and timing aspects of location information based on signal-strength measurements in Bluetooth*.
- Garg, K. V. (2007). *Wireless communications and networking*. Elsevier.
- Hellebrandt, M., & Mathar, R. (1999). *Location tracking of mobiles in cellular radio networks*. The Institution of Electrical Engineers.
- Ilie-Zudori, E., Kemeny, Z., Egri, P., & Monostori, L. (2006). The RFID technology and its current applications. In *Proceedings of the Modern Information Technology in the Innovation Processes of the Industrial Enterprises (MITIP 2006)* (pp. 29-36). ISBN 963 86586 5 7.
- Intermec. (2003). *The write stuff: Understanding the value of read/write RFID functionality*. Intermec White paper.
- Jami, I., Ali, M., & Ormondroyd, R. F. (1999). *Comparison of methods of locating and tracking cellular mobiles*. The Institution of Electrical Engineers.
- Kaur, M., Sandhu, M., Mohan, N., & Sandhu, P. (2011). RFID technology principles, advantages, limitations & its applications. *International Journal of Computer and Electrical Engineering*, 3(1), 1793-8163.
- Kay, R. (2009). *QuickStudy: Mesh networks*. Retrieved from http://www.computerworld.com/s/article/341095/Mesh_Networks
- Kelly, D., Me Loone, S., & Dishongh, T. (2008). *Experimental evaluation of a single access point bluetooth localisation system*.
- Kenneth, C., Cheung, S., Intille, S., & Larson, K. (2008). *An inexpensive bluetooth-based indoor positioning hack*.
- Lee, Y. (1999). *Antenna circuit design for RFID applications*. Microchip Technology Inc.
- Lieshout, M., et al. (2007). RFID technologies: Emerging issues, challenges and policy options (pp. 32-33). European Commission Joint Research Centre (EUROPA).
- Mark, B., & Zaidi, Z. (2002). *Robust mobility tracking for cellular networks*. OECD - Organisation for economic co-operation and development. (2008). Seoul, Korea: Ministerial Meeting on the Future of the Internet Economy.
- Oman, H. (1995). *Global positioning system, opportunities and problems*. Institute of Navigation, National Technical Meeting.
- Popat, A. (2007). *Real time location systems*. Informatics Wiki.
- Shi, S., Peng, J., Lin, J., & Ma, D. (2009). *WORM, write-once read-many-times memory based on a single layer of Pentacene*.

- Srivastava, N. (2006). *RFID introduction, present and future applications and security implications*. George Mason University, Scholarly Paper.
- Tektronix. (2004). *Radio frequency identification (RFID overview)*. Tektronix Technical Brief.
- Weinstein, R. (2005). RFID: A technical overview and its application to the enterprise (pp. 27–28).
- Weis, A. S. (2008). *RFID (radio frequency identification): Principles and applications*. MIT CSAIL.
- Wright, M., Stallings, D., & Pu, D. (2003). The effectiveness of global positioning system electronic navigation. In *Proceedings IEEE South East Con*.
- Xiao, Q., Gibbons, T., & Lebrun, H. (2009). *RFID technology, security vulnerabilities, and countermeasures, defence research and development Canada*. Ottawa 2Canadian Operational Support Command Canada, Intech.

Kevin Curran is a Reader in Computer Science at the University of Ulster. Dr Curran has made significant contributions to advancing the knowledge and understanding of computer networking and systems, evidenced by over 700 published works. He is a regular contributor to BBC radio & TV news in the UK and is an IEEE Technical Expert for Internet/Security matters. Sean Carlin is a Computer Science student at the University of Ulster. He has worked for a number of years in the software industry and his research interests include web design, network protocols and security.