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Design of a distributed RFID system model for asset tracking and development of the required software abstraction layer.

By

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Abstract

The spread of Radio Frequency Identification [RFID] technology throughout the asset management industry has led to a number of companies deploying RFID enabled asset management solutions. These companies have a foot hold in the market place and an in-depth knowledge of current RFID technologies. With this foot hold and RFID expertise, it is hard for start up companies to gain the knowledge to confidently utilise RFID technologies and help their business grow.

The research within this thesis aims to give a start up company a greater understanding of the current RFID technologies and a view of the direction that future RFID technologies will take. Along with the understanding of the technology, the research also gives a good understanding of the requirements that should be met when selecting RFID equipment, testing RFID equipment and the deployment of the equipment for an effective RFID enabled asset tracking system.

Chapter 1

Introduction

Fixed asset management is the management and tracking of all of a company's assets. While there has been large focus on the research, development and deployment of new technology to other areas of a business such as supply chain management, the area of fixed asset management has seen less interest, largely relying on the tried and trusted bar code for all it's tracking needs. The lack of deployment of new technologies to this sector has left a large gap that this project aims to fill utilising RFID. Just as supply chain management has used RFID to optimise the management of the supply chain, this project aims to utilise RFID to streamline, help cut costs and improve efficiency of the fixed asset management process. With a more efficient fixed asset management process a company will be better able to utilise the current assets it has through tracking the movement of the assets. This will have a twofold benefit to a company:

1. Improve the use of vital equipment and hence reduce the requirement for the purchase of extra equipment.
2. It will help with the tracking and reduce the possibility of assets being misplaced.

1.2 What is RFID and how can it improve fixed asset tracking?

RFID consists of a group of technologies that utilises Radio Frequency [RF] signals to transmit information from a RFID tag back to a RFID reader. The RFID reader then sends the RFID tag information back to a middleware application. Processing the information stored in the middleware application can give a number of key pieces of information about a RFID tagged item:

1. The asset's previous and current location.
2. Whether or not the asset is currently in use.
3. It's frequency of use.

The above information is only a snapshot of some of the data that can be collected from a RFID based fixed asset management system. Using this information, key decisions can be made for more effective and efficient asset management and utilisation.

1.3 Research done prior to the start of the project

This main research project was proceeded by a feasibility study. The aim of the feasibility study was to assess the state of RFID technology and determine if it could be utilised as part of an asset tracking system.

If the research indicates that the technology was mature enough and could be used in an asset tracking system, the second part of the feasibility study was to deliver a project plan for the design, development and test of an operational RFID system for asset tracking, including the required user interfaces, middleware, interface drivers for the RFID technology and the RFID system itself.

1.4 Overview of the research

The research conducted is part of a larger project involving two researchers. The main project was divided into two distinct areas; with one area being hardware and interfacing (including some high level and embedded software) reported on in this thesis and the other being the middleware and brokerage systems software development, which is reported on in a separate thesis by Fidel Nunez.

The whole research program set out to investigate if RFID can be utilised as part of an asset tracking solution and then to design, develop and test a new system utilising open-source software where possible.

This project being reported on here, researches design methods for a system that can be deployed to customer sites and operate reliably in the majority of the area without redesigning the system. The other part of the overall project, carried out by the other team member will not be discussed within this thesis, except where there has been an overlap.

Although as explained earlier, the major part of the software in the new system was developed by another researcher and reported on separately, it has to be remembered that the whole system is an integration of hardware, interface software, middleware and web interface so although this project focused mainly on the hardware and interfacing, the final system was a result of close co-operation between the team members at the design stage to avoid possible errors and problems later on.

The result of this research was to create an asset tracking system that would prove reliable and accurate without a complete redesign of the overall system for each individual customer's site. To achieve this a review of the current RFID asset tracking system used by the partner company was completed. This review highlighted the problems with the original system and provided a starting point for the project.

The system design and hardware deficiencies identified in the original system were:

1. Improper deployment techniques.
2. False readings due to the poor design of the system.
3. Poor understanding of the importance of tag positioning and placement.

These deficiencies were addressed by the new system in the following ways; a complete redesign of the system, design and development of the necessary low level interface and abstraction layer to interface to the RFID readers, development of the correct protocols for the testing and deployment of the system and the importance of the correct selection, positioning and placement of RFID tags.

1.5 Importance of the Study

The importance of this research is twofold:

First the initial research of RFID technology for both the college and partner company. The research performed at this stage will allow for the college to develop a core knowledge in the field of RFID and allow for the development of further RFID projects. The research is important to the partner company as it will allow for the development of new products and the addition of extra functionality to existing products allowing them to expand and grow.

Second as the project progresses, it may allow for the development of a complete asset tracking system that may meet all existing requirements of the partner company. This research may provide the partner company with all the required information, designs, testing procedures and deployment procedures for a moderately skilled and trained person to be able to deploy the RFID system with little hassle and great speed. It may also help the partner company avoid the use of expensive third party software or having an expensive system developed by a third party.

1.6 Guideline

1. Introduction
   An introduction to thesis is presented along with objectives, methodology and justification for the research.

2. Technology review
   An in-depth review of the current and future state of RFID technology is performed along with other technologies used within this part of the project.

3. RFID test bed analysis and test plan creation
   Analysis of the current RFID system, development of the necessary RFID testing environment and test plans.

4. System analysis and design
   Analysis of the current RFID system used in conjunction with the partner company's solution and development of a set of requirements of the RFID system.

5. Implementation
   Execution of the test bed development plan, detailed analysis of the test bed operation and data gathering from it.

6. Conclusion and future work
   What was learned from the test bed and future work leading from this project.

1.7 Limitations

Limitations imposed by RFID, system deployment locations and assets to be tagged. The limitations within this project came from a number of sources:

1. The use of RF as the transmission method for the data from the RFID tag to the RFID reader. This imposes a limitation on the testing of a RFID system as no two tests will ever give the same results.
2. While the partner company will be deploying RFID asset tracking systems to a diverse range of customers hence no two deployments will ever be the same, this project focuses mainly on the deployment of two main industries:
    1. Media; mainly television stations.
    2. Medical device manufacturing companies.

The deployment of a system to either of these two types of industries would be similar as the main assets tagged would be metal bodied equipment.

1.8 Summary

This chapter has laid the foundations for the thesis and gives a brief overview of RFID and how it will improve the asset tracking process. It has also introduced the motivation behind the research along with a number of other critical topics such as the limitations imposed with the use of RF based technologies.

Chapter 2

Technology review

In this chapter an in-depth technology review will be conducted. This review focuses on RFID technologies and covers both the current RFID hardware, standards, operation and emerging technologies. The technology review will provide a good foundation for the research and will highlight the main features and weaknesses of the technologies. It will also provided the research team with the ability to make informed recommendations on RFID hardware to the partner company and on the design and development of the RFID design for the Juno system.

2.1 How a RFID system works

RFID comes in a number of forms with the most common being passive or active tag based. All RFID systems are based on three main components; tags, readers [mobile or fixed] and the antenna. The uses for RFID technology is constantly expanding with new applications for the technology being discovered everyday. The main categories that they fall under are asset management, production process, warehousing, supply chain, IT/infrastructure, retail, security and access control.

The basic processes of any RFID system are:

1. The RFID tag contains an Electronic Product Code [EPC] and any extra data programmed onto it by the user [serial number, description, etc.].
2. When the tag enters a read zone, the information on the tag is read by the RF signal from the reader.
3. Once the read of the tag has been completed, the EPC number and any other information read from the tag is passed back to the RFID middleware, which stores it in a database.

4. From the database, a separate piece of software is used to interpret the data into a human readable form [graph, exception reports, etc.] (Patrick J. Sweeney. RFID for Dummies. 2005).

2.1.1 Differences between passive and active systems

While the two types of systems operate in similar ways, there are numerous differences between the two systems: (Daniel Dobkin. The RF in RFID. Passive UHF RFID in Practice. Sep.2007):

1. The operating frequencies for passive UHF systems are between 865MHz and 868MHz in Europe while active RFID systems operate at 433.92MHz and has a 500KHz bandwidth.
2. Standards for passive tags and readers have been well established with a number of standards covering most parts of the systems. Active systems have been neglected in this area and have few standards in governing the development of both readers and tags.
3. Ability of tags and readers.
    1. Passive tags act more as reflectors that modulate its' data onto the reflected signal. The returned signal is very weak so it requires a very sensitive reader to pick it out of all the noise.
    2. Active tags can perform many different functions depending on what functionality has been built into the tag. Many tags come with temperature probes or movement sensors. This is possible because they have a power supply and can offer more functionality.

2.2 Current state of RFID technology

2.2.1 Passive RFID

Passive RFID has been an area of constant growth since the early 20th century. It has seen many uses within a number of fields and this had led to the development of a number of different standards and technologies. A review of the current state of passive RFID is done in this chapter.

2.2.2 Passive RFID frequency bands

2.2.2.1 Low frequency [LF] RFID

LF RFID normally operates at either 125 or 134.2 KHz. It is used in the tagging of animals, identification and security systems, for work in progress systems and it's greatest use within the automotive industry is for car immobilisers where the RFID chip is embedded in the key and the reader is placed close to the ignition barrel of the car. The greatest property of LF RFID is it's ability to penetrate many different types of materials such as metals, liquids and tissue of humans or animals (Daniel Dobkin. The RF in RFID. Passive UHF RFID in Practice. Sep.2007).

The biggest drawbacks of LF RFID are:

1. Easily effected by electrical noise caused by electrical motors or other electrical equipment.
2. Readers can only read a single tag at a time.
3. Expensive tags due to the antenna designs.
4. Lower communications speed.

2.2.2.2 High frequency [HF] RFID

HF RFID operates at a frequency of 13.56 MHz. It is a globally accepted frequency for RFID systems allowing for the deployment of HF RFID system anywhere in the world with the only limits being bandwidth and antenna output power. HF RFID deals well with many types of materials such as metals and liquids, but to a lesser extent when compared to LF RFID. The increase in frequency over LF RFID also provides a number of benefits such as higher communication rates, smaller antenna, relatively immune to electrical noise, cheaper tags and large memory capacity. The biggest disadvantage found for HF RFID is the cost of the tags, while still slightly cheaper than LF RFID the cost is high enough for it to be to expensive for customers (Daniel Dobkin. The RF in RFID. Passive UHF RFID in Practice. Sep.2007).

2.2.2.3 Ultra high frequency [UHF] RFID

UHF RFID operates in a number of different frequency ranges with Europe utilising between 860 and 868 MHz, while it operates around 956 MHz in the United States and other countries around the world. UHF RFID has improvements over both HF and LF RFID in tag communications, read range, tag price and tag functionality. The tag cost for UHF RFID is also the lowest of the all the RFID standards. These advantages have led to the widespread adoption of UHF RFID for many different uses and this adoption has led to high levels of research and development [Wal-Mart and DoD have been using it with their logistics operations] within the area. While UHF RFID has many improvements over both HF and LF RFID, it is very susceptible to interference caused by placing a RFID tag on a metal surface or in contact with a liquid. Clever tag design can negate some of the effects caused (Daniel Dobkin. The RF in RFID. Passive UHF RFID in Practice. Sep.2007).

2.2.3 Communications between passive RFID readers and tags

The tiny electrical current induced in the antenna of a passive RFID tag by the incoming radio frequency signal from the RFID reader provides just enough power for the integrated circuit [IC] in the tag to power and transmit a response back to the reader.

The communication can be preformed using may different types of technology depending on the frequency band and coupling of the tag and reader. The follow section gives an in-depth look into the techniques and technologies used in passive RFID systems.

2.2.3.1 Methods used for full and half duplex communications to passive RFID tags

Due to the nature of passive RFID, the return signal from the tag can be extremely weak compared to the RF signal being transmitted from the reader. Due to this, the return signal from the tag must be sent in a way that will make it easy to pick it out from the RF field being transmitted by the RFID reader and this can be achieved using different methods.

2.2.3.2 Full duplex

Full duplex communications involve the reader and tag communications being performed close to or at the same time. So when the reader sends a command to the tag, the tag will reply to the reader's command without having to wait for the reader to stop transmitting commands to the tag. The energy transfer between the reader and tag is constant during the entire process (Klaus Finkenzeller. RFID handbook, second addition. 2003).

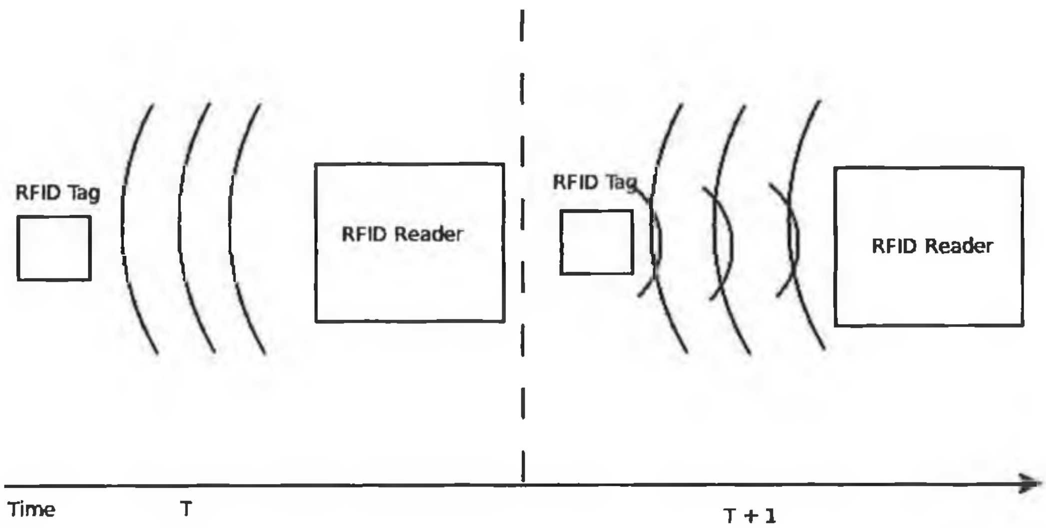

Figure 1 – Full duplex communication between tag and reader

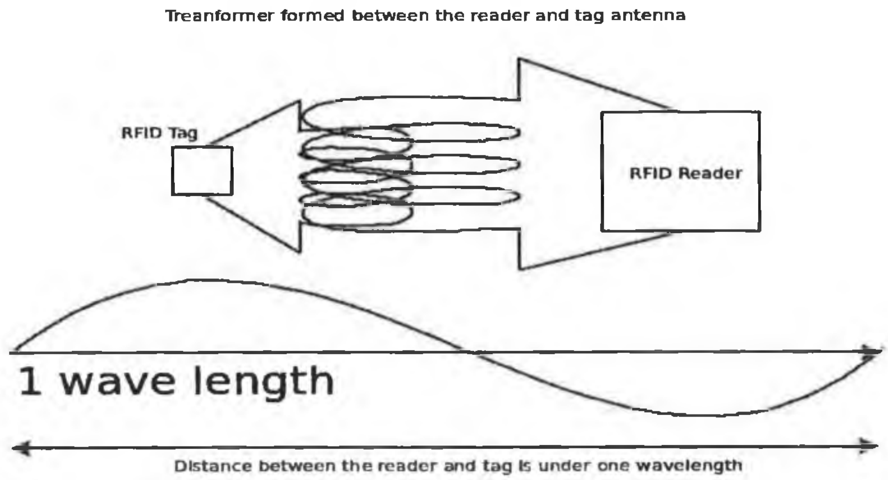

Figure 3 – Inductive coupling energy transfer

Data transfer

Data transfer between the reader and tag are normally performed using one of the following methods.

Load modulation

The switching of a load resistance on and off at the tags antenna causes a voltage change at the reader's antenna. This voltage change can be compared to amplitude modulation of the voltage at the readers. If the amplitude is controlled by the data contained on the tag, the data can be easily transferred from the tag to the reader using this method. Once the voltage is rectified on the reader side of the communications, load modulation is used in inductively coupled systems where a transform type coupling is used between the primary coils in the reader's antenna and the secondary coils in the tag. This type of data transfer works for distances below 0.15 of the wavelength of the transmission frequency of the reader (Klaus Finkenzeller. RFID handbook, second addition. 2003).

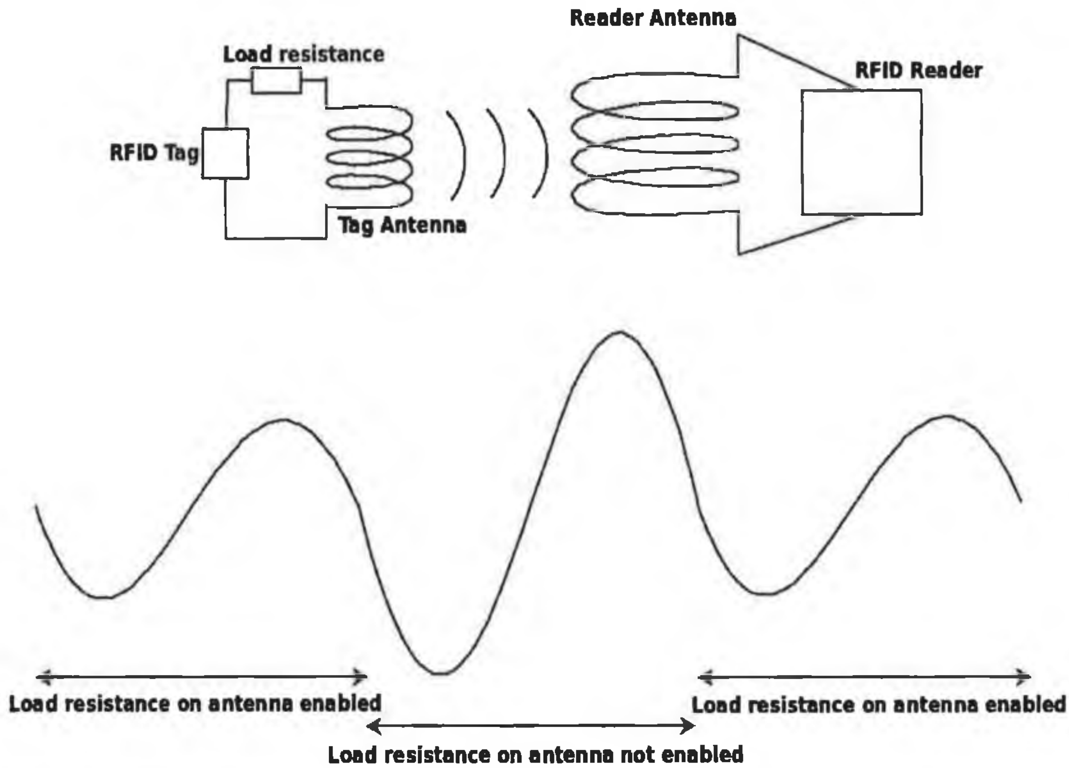

Figure 4 – Load modulation

Load modulation with sub-carrier

Load modulation with sub-carriers works on the principle that switching the load at the tag antenna on and off at a high frequency of fs [fs is lower then the transmission frequency of the reader] causes two sub carriers to be created at both -fs and +fs around the carrier frequency of the reader and these sub-carriers can be easily detected. Data can be transferred on these sub carriers by a number of means i.e. Amplitude-shift keying, Frequency-shift keying, Phase-shift keying [ASK, FSK or PSK] or by a number of other different encoding modulation methods. The modulated side bands at +fs and -fs can be separated from the readers with the stronger signal coming from the reader by using two bandpass filters tuned to the frequencies +fs and -fs and the signal coming from the bandpass can be simply demodulated. The transmission of the extra sub carriers means this technique is only usable in systems with a high bandwidth [HF (13.56MHz) or above] (Klaus Finkenzeller. RFID handbook, second addition. 2003).

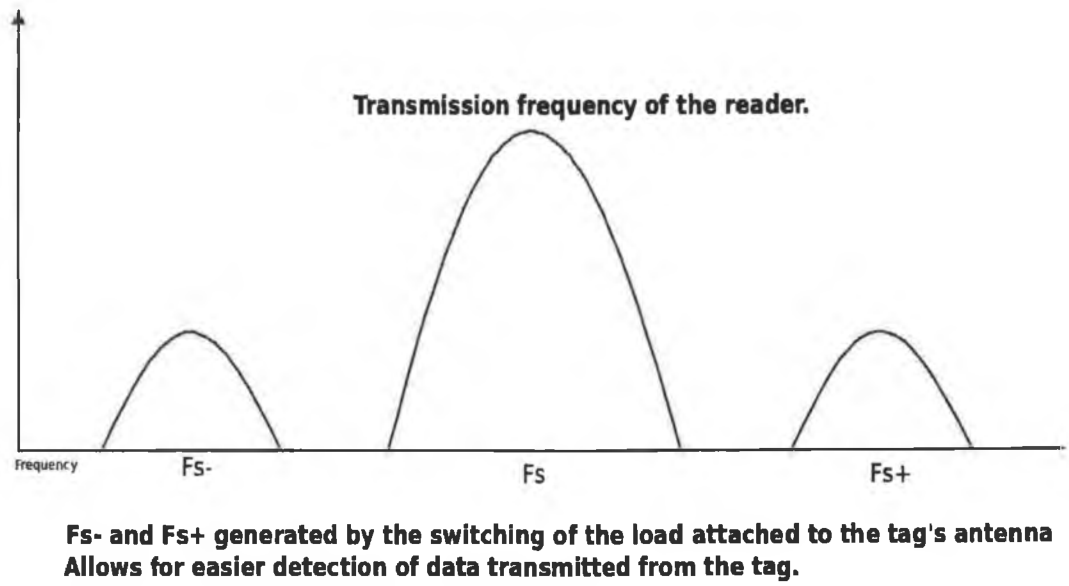

Figure 5 – Load modulation with a sub carrier

2.2.3.5 Electromagnetic backscatter coupling

These types of systems operate above 30Mhz (433Mhz, 868Mhz, 915Mhz, 2.5Ghz and 5.8Ghz) and give a range between 0.1M to close to 3M depending on the frequency used [2.5 and 5.8GHz will give read ranges on the lower end of the scale]. The higher frequencies allow for the use of antennas with smaller dimensions and greater efficiency (Klaus Finkenzeller. RFID handbook, second addition. 2003).

Energy transfer to tag

The transfer of energy to the tag is performed by the generation of a high frequency electromagnetic field from the reader's antenna. The electromagnetic field penetrates the coil of the tag and is used to power the tag.

Data transfer

Data transfer between the reader and tag is performed using modulated reflection cross section and this works on the same principle as radar detection of a plane. The returned

signal is caused by the microwaves from the radar bouncing off the plane. This signal can then be used to determine a number of things about the plane.
With a RFID tag, the control of the returning signal can be used to return the data stored on the tag. The reflection cross section of the tag's antenna can be changed by the switching of a load resistor connected in parallel to the antenna. The switching of this load causes the reflection cross section of the antenna to change and in doing so causes less power to be reflected back to the reader's antenna. The switching of the load resistor is controlled by the data being reflected to the reader, the reader detects the changes in reflected power and can be decoupled from the outgoing signal allowing for the data to be recovered from the signal (Klaus Finkenzeller. RFID handbook, second addition. 2003).

2.2.3.6 Close coupling

As the name suggests the systems are designed to work in close proximity below the 1cm range. This means that the tag needs to be placed into or onto the reader for the tag to be read.

Energy transfer

Due to the short read range of this type of reader, it allows the tag to be placed in a predetermined position from where the tag can be easily powered by the induction of an electrical current in the tag's antenna. The positioning of the tag's antenna coil close to the antenna coil of the reader allows for the reader's coil to induce an electrical current in the tag's antenna coil. The transfer of energy from the reader to the tag is very high and this allows the tags to use chips with higher power requirements (Klaus Finkenzeller. RFID handbook, second addition. 2003).

Data transfer

Data between the reader and tag can be communicated in two ways:

1. Magnetic coupling

Magnetic coupling also uses load modulation with a sub carrier for the transmission of data between the reader and tag. The operation of load modulation with a sub carrier has been covered earlier in this chapter.

2. Capacitive coupling

When the tag is placed against the reader it forms a capacitor with a low capacitance and this allows for a capacitance to build up between the tag and reader. The capacitance can then be used to transfer the data between the tag and reader (Klaus Finkenzeller. RFID handbook, second addition. 2003).

2.2.3.7 Electrical coupling

Energy transfer

The reader generates a high frequency electrical field between the reader's antenna [electrode] and the reader's ground. This is done by applying a high frequency voltage to an electrode usually a metal plate. The high frequency voltage is generated by a resonance circuit and the frequency of the resonance circuit is equal to the required frequency for the reader. The antenna in the tag consists of two conductive plates in a plane formation. When the tag enters the electrical field of the reader, a voltage is generated between the two metal plates in the tag and this is then used to power the chip (Klaus Finkenzeller. RFID handbook, second addition. 2003).

Data transfer tag to reader

The coupling capacitance between the tag and the reader varies by the switching of the load resistance on the tag's antenna. The change in the capacitive coupling between the reader and tag has an effect on the resonance circuit of the reader. The switching of the load resistance in the tag allows for two different levels of change in the resonance circuit of the reader. The switching of the tags load resistance allows for the transmission of the tag data back to the reader (Klaus Finkenzeller. RFID handbook, second addition. 2003).

Data transfer reader to tag

The reader commands to the tag can be transmitted using a number of different methods of modulation with ASK, PSK, and FSK being the most widely used. Out of the three modulation methods, ASK is the most popular due to its ease of implementation.

2.2.4 Methods used for sequential communications to passive RFID tags

Another method for the transmission of data from the tag to the reader is when the reader's RF field is turned on and off. During the period when the RF signal is off, the tag can transmit it's data back to the reader. A weakness in this system is that the tag is powered by the RF field from the reader and once the RF field is turned off the tag has a very limited amount of energy to make it's transmission. Once the RF field has been switched off, the loss in power must be covered by the provision of capacitors within the tag's circuit. The discharging of the capacitors allows the tag to operate long enough to send it's data back to the reader (Klaus Finkenzeller. RFID handbook, second addition. 2003).

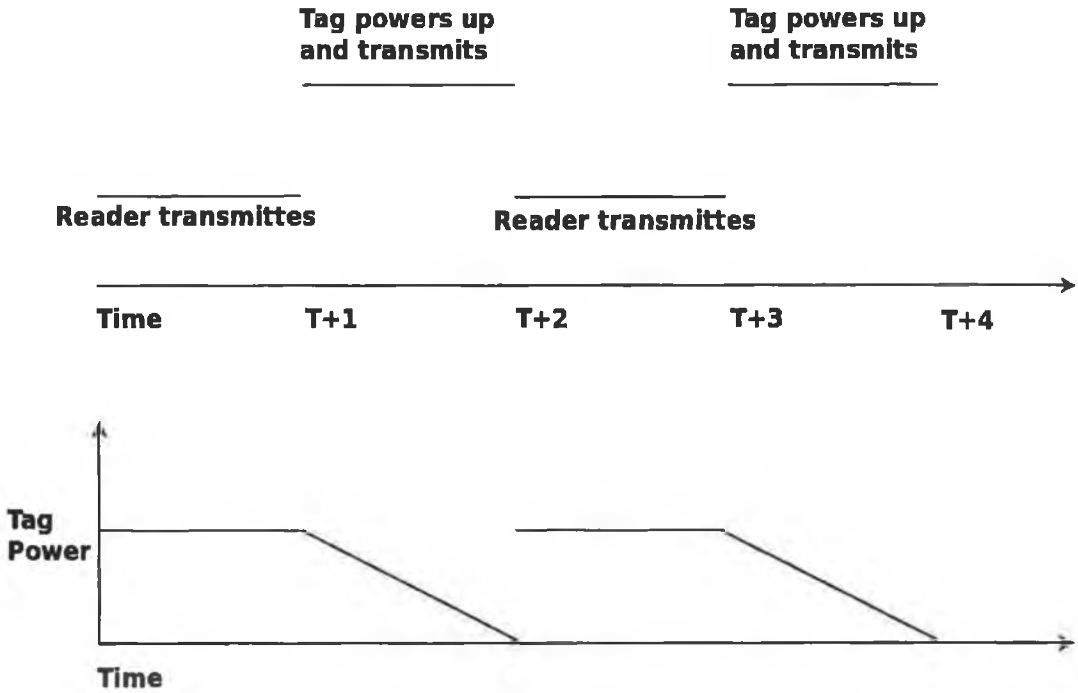

Figure 6 – Sequential communication

2.2.4.1 Inductive coupling

Inductive coupling operates in the same way as full/half duplex inductive coupling, but the tag must store some of the induced voltage to allow for the tag to transmit it's response once the reader has stopped transmitting. This gives the tag a small window in which it will have enough energy stored to transmit its reply back to the reader. The small transmission window requires the tag to transmit the data in an effective manner. This is achieved by the tag having a built in trimming capacitor to allow for further adjustment due to manufacture tolerances (Klaus Finkenzeller. RFID handbook, second addition. 2003).

Energy transfer

Energy transfer between the reader and tag operates like a transformer, with the reader acting as the primary winding and the tag acting as the secondary winding. This is the same method as described in the electrical coupling section in half and full duplex communications section.

Data transfer

The data transfer from the tag to the reader occurs in two stages; the charging stage and the reading stage. The charging stage is used to charge the capacitor in the tag so once the reader has turned off it's read field, the charge stored in the capacitor can be used to power the tag and transmit the required data back to the reader. A weak magnetic alternating field is generated by the tag at the frequency of the reader's transmission field. This weak magnetic alternating field is then detected by the reader. The tag's alternating field is controlled by the data to be transmitted by the microchip in the tag. Due to the sequential nature of the transmission [the reader field turning off before the tag transmits] this method can have a better read range when compared to similar read methods used in full or half duplex communication methods. This can be attributed to the reduced noise in the read zone when the reader switches off it's transmission field.

2.3 Active RFID

2.3.1 Frequencies and standards

Active RFID has been neglected when it comes to both standards and the frequency band for it to operate in. While passive UHF RFID has attracted much attention with the research and development of both new standards and new technologies, active RFID has not had the same type of interest. This has resulted in active systems that are available using proprietary standards and operate in the 433MHz band.

Standards for active systems have recently been created (ISO 18000-7 Wireless standard for active RFID at 433.92MHz). These standards could led to more active RFID systems coming to market, providing competition to the current providers and in time dropping the price of both readers and tags. This would allow for greater use of active tags within asset tracking systems. The development of the ISO standard for active systems has lead to the clearing of the 433.92MHz band for use for active systems in a number of countries leading to greater research and development push behind active systems.

2.3.2 Communications between tag and reader

Many different communications can be used for the interaction between the reader and tags. Backscatter radiation identical to the way passive tag communicate with a reader can be employed [see above for a detailed description].

The active readers used in the project utilise Amplitude Shift Key modulation [ASK]. ASK works by changing the amplitude of the RF wave to represent the data being transmitted.

2.4 State of the art in RFID

2.4.1 Tag design and manufacture

2.4.1.1 Printed RFID tags

A RFID tag consists of an integrated circuit connected to a copper antenna. While the integrated circuits can be as small as 0.05x0.05mm (*RFID Journal March 14, 2003),* once the antenna is attached the size and cost of the tags increase dramatically. Printing of electronic circuits is not a new development as the printing of conductor paths and devices made from polymers has been used for a number of years. Due to the materials used in the printing process, the electrical properties of these printed circuits are of poor quality and cause the signal propagation to be slower than inorganic materials. The use of this printing method in the development of RFID tags would led to RFID tags with a shorter read range than standard tags.

A breakthrough in the printing of electronic circuits using inorganic material opens new doors to the development of printed RFID tags that can equal their standard RFID tags read range. The new development was made by Fraunhofer Institute of Integrated Systems and Device Technology IISB in Erlangen, Germany. It utilises a printer similar to an ink jet printer found in any office and the biggest development is the uses of a special ink made of nano particles and a stabilizer to stop the partials clumping. This development could reduce the price of tags considerably to the point where they can be applied to everyday items such as yoghurt pots.

2.4.1.2 Semi active or battery assisted passive tags

Semi active tags have certain characteristics in common with both active and passive tags. Like active tags they have an internal power supply which is used for the transmission of the data from the RFID tag back to the RFID reader. Unlike active tags they are not transmitting this information back to the RFID reader all the time. In fact the tags lay in a dormant state until they are switched on by a RFID reader. It is this

characteristic they share with passive tags. They require a signal from a RFID reader to turn them on. Once on they act like normal active tags for a set period of time before going back into their reduced power state once again. The advantages of semi active over fully active RFID is that it saves battery power, extending the life time or time before the power supply has to be changed/recharged. The advantages they have over passive RFID tags is the extended read range that the semi tags offer.
Audi is incorporating semi-passive tags able to withstand high temperatures and painting into the assembly process for its Audi TT sports cars (RFID Journal Jan. 29, 2007).

2.4.1.3 Active tags

Active tags are becoming more and more complex as extra functionality is added to the devices. The newest breed of active RFID tags incorporate sensors [pressure, temperature and stress meters] for the measurement of levels that the tagged item is exposed to. This can be used simply for the measurement of how a package is handled; if it is dropped an accelerometer would measure the package's acceleration from when it leaves the factory until it reaches it's destination.
Use of active RFID on oil tanks and cooling fans with sensor-enabled active RFID tags can create a wireless mesh network to communicate data and initiate appropriate actions when necessary.

2.4.2 Near field RFID

All of the present standards of RFID [LF, HF and UHF] all use far field communications techniques. Near field RFID uses the magnetic field and this field does not suffer from interference from items containing or made of metal/water. The near field RFID tags can be placed in/on the item containing metal or water and still be read perfectly. The drawback of this type of system is the read range. The read range of the system is physically limited by the wavelength of the frequency being used and is normally so the maximum read distance that you can get from this type of system is only part of one wavelength of the frequency being used. So for example at a frequency of 13.56 MHz the maximum read range of a near field RFID tag would be λ/2 pie = 3.5 meters.

2.4.3 Real time location system [RTLS]

An RTLS based on RFID can be implemented using a number of solutions depending on the requirements of the overall system.

2.4.3.1 A requirement for tracking items over a vast area or long journey

In this situation, a real-time global location system would consist of the following technologies: RFID, Global positioning system [GPS] and General package radio system [GPRS].

The use of RFID, GPS and GPRS locate and track RFID tagged items in real time across the world. The RFID tags provide information about the items they are attached to, the GPS provides the coordinates of where the item is, while the GPRS provides a communication system for the transmission of the data back to the base station. This allows for the real-time tracking of an item or group of items from anywhere in the world with the use of mobile networks. These types of systems can also be deployed on vehicles so that not only can the vehicle be tracked, but in the case of a van or truck it's cargo can be tracked as well.

This sort of system could also be extended to use satellite communications to provide a way of tracking items in containers on ships crossing oceans.

2.4.3.2 A requirement to track assets within a building

Many new systems on the market based on 433 MHz or 2.45 GHz frequency can provide the necessary functionality for a RTLS system. The systems on the market are in two separate categories; WI-FI ID based and 433 MHz or 2.45 GHz RFID systems.

WI-FI ID based

WI-FI based systems utilise the currently deployed wireless network within a customer's site to act as readers for specially designed tags. These tags operate like any device connected to a TCP/IP based network and they get an IP address allowing them to operate on the network. Using the currently deployed wireless access points allows for massive savings to be made during the deployment phase of the system. Due to the more complex tags used for these types of systems, they can be very expensive [Ekahau T301-A - €380 for 10 tags]. Another hidden cost for these types of systems are the proprietary middleware software required to determine the location of the tags. These positioning engines are the brains behind the system. They make sense of the incoming data and using a number of different methods, provides the location of the tags. The price of the positioning engine can vary depending on supplier but the project was quoted €6000 for the Ekahau positioning engine to track 25 items.

433 MHz or 2.45 GHz RFID based

Unlike the WI-FI ID based system, a RFID based system requires the deployment of a separate set of RFID readers to perform the interrogation of the RFID tags. The systems in the lower frequency range come into their own in damp environments or where slightly longer read ranges are required, with a trade of the accuracy of the location of the tags. The 2.45 GHz RFID based systems provide increased accuracy, but would not outperform the 433 MHz systems in read range or performance in adverse environments.

Methods used to determine the location

The location of the tags in either a 433 MHz, 2.45 GHz RFID or WI-FI based system are performed using a number of methods. The most common being used are Radio Signal Strength Information [RSSI], Time Difference Of Arrival [TDOA] and for more complex and accurate systems Statistical Probability Modelling of the environment. This type of system is deployed in conjunction with either RSSI or TDOA.

Time Difference Of Arrival [TDOA]

TDOA is used to calculate the location of a tag using one of the following methods:

1. Calculating the time difference of arrival of a signal emitted from the tag to three or more readers.
2. Calculating the time difference of arrival of a signal emitted from three or more readers to be detected by the tag.

With at least three time differences calculated, the triangulation of the tag can take place. TDOA is really only suited to large open areas due to the system being based on time differences between signals from different readers covering a distance at the same speed. The ability of the signal to cover a distance is hampered by obstacles in it's path. The other disadvantage of using TDOA is that it requires a vendor specific receiver and WI-FI ID tags that communicate specific timing information back to the reader. This would increase the overall cost of deployment (STEPHEN B. MILES, SANJAY E. SARMA, JOHN R. WILLIAMS. RFID Technology and Applications. June.2008).

Radio Signal Strength Information [RSSI]

RSSI can be used to triangulate the location of a tag using two main methods:

1. Signal strength from the tag perspective
2. Signal strength from the access point perspective

Both of these methods rely on the fact that the further a signal travels the more it degrades, so the weaker the signal the further away the reader or tag must be. The first option should allow for a more reliable reading as the signal coming from the reader will be stronger and more reliable than a signal coming from the tag. As with TDOA, this system also requires at least three readers to provide location information about a tag. RSSI based systems tend to be more reliable in cluttered environments where the signal must negotiate a number of obstacles before reaching it's destination and it will also operate equally well in open environments. Since RSSI is a part of all the protocols in the IEEE 802.11 protocol family, a RTLS based on the use of RSSI can be implemented using the shelf hardware with the only extra requirement being the addition of extra software to triangulate the position of the tag. The fact that RSSI is found in all IEEE 802.11 protocols allows for the deployment of RTLS using RSSI to be cheaper and easier to deploy than TDOA based systems (STEPHEN B. MILES, SANJAY E. SARMA, JOHN R. WILLIAMS. RFID Technology and Applications. June. 2008).

Things to be aware of when using WI-FI ID based RTLS

Network Null Spots

Due to the nature of RF, null spots are unavoidable. A thorough site survey is still required even with the advances that come with WI-FI ID based systems.

Network Traffic

As wireless networks become faster, network traffic has become less of a problem. The amount of data that needs to be sent to or from a tag is minimal, but constant high network traffic could degrade the operation of the RTLS system.

Tag Costs

Due to the more complex tags used in WI-FI ID and active systems, tag costs can be quite high. This factor needs to be taken into account before the initial design of the system.

2.4.4 Ultra wide band RFID

UWB RFID is the latest development in RFID technology. It operates in the microwave range of the frequency spectrum utilising the 6Ghz frequency and provides a very accurate platform for RTLS offering accuracy up to one meter. It is also seen as a better solution for RTLS in hospitals were the UHF and HF standards can interfere with the operation of some types of medical equipment.

2.5 Review of current RFID standards

2.5.1 International Standards Organisation [ISO] 18000 standards

ISO has developed RFID standards for automatic identification and item management. This standard known as the ISO 18000 series covers the air interface protocol for RFID systems. They cover the major frequencies used in RFID systems around the world. The seven parts are:

1. 18000–1: Generic parameters for air interfaces for globally accepted frequencies
2. 18000–2: Air interface for 135 KHz [RFID LF]
3. 18000–3: Air interface for 13.56 MHz [RFID HF]
4. 18000–4: Air interface for 2.2.4.4 Ultra wide band RFID45 GHz
5. 18000–5: Air interface for 5.8 GHz [RFID UWB]
6. 18000–6: Air interface for 860 MHz to 930 MHz [RFID UHF]
7. 18000–7: Air interface at 433.92 MHz [Active RFID]

EPC Global Gen 2 standard could be submitted to ISO under 18000-6, but it's not clear when that will happen or how quickly it will be approved. ISO slowed approval of 18000-6 to see if it could be aligned with Gen 2 (Daniel Dobkin. The RF in RFID. Passive UHF RFID in Practice. Sep.2007), (Patrick J. Sweeney. RFID for Dummies. 2005), (Klaus Finkenzeller. RFID handbook, second addition. 2003), (George Roussos. Networked RFID. Systems, Software and Services. 2008), (Himanshu Bhatt, Bill, Glover. RFID Essentials. January 2006), (Harvey Lehpamer. RFID Design Principles) and (Roy Want. RFID Explained: A Primer on Radio Frequency Identification Technologies).

2.5.2 EPC standards

The EPC developed it's own RFID air interface protocols. Originally the centre planned to have one protocol that could be used to communicate with different classes of tags. Each successive class of tag would be more sophisticated than the one below it. The classes changed over time but here is what was originally proposed:

1. Class 1: a simple, passive, read-only backscatter tag with one-time, field-programmable non-volatile memory.
2. Class 2: a passive backscatter tag with up to 65 KB of read-write memory.
3. Class 3: a semi-passive backscatter tag with up to 65 KB read-write memory; essentially a Class 2 tag with a built-in battery to support increased read range.
4. Class 4: an active tag that uses a built-in battery to run the microchip circuitry and to power a transmitter that broadcasts a signal to a reader.
5. Class 5: an active RFID tag that can communicate with other Class 5 tags and/or other devices.

In 2004, EPC Global began developing a second-generation protocol (Gen 2), which would not be backward compatible with either Class 1 or Class 0. The aim was to create a single, global standard that would be more closely aligned with ISO standards. Gen 2 was approved in December 2004. RFID vendors that had worked on the ISO UHF standard also worked on Gen 2.

2.6 Technology that would have been useful in this project

During the course of the project, there was a number of developments within RFID technology that could have proven to be interesting and useful technologies to explore within the system of asset tracking. Some of these technologies are listed below:

2.6.1 Mojix STAR System

The Mojix STAR System takes a new approach to the RFID reader. A standard RFID reader performs two tasks; first it transmits information to the RFID tags and the second task is to receive information coming from the RFID tags. The transmitting part of this operation is relatively easier to perform as it requires the reader to transmit at the specified power levels to power the RFID tags and also send the correct command to the tags. The receiver part of the reader is required to listen for a tiny signal returning from the RFID tags.

The Mojix STAR System separates these two parts of the standard RFID reader, the Mojix START Receiver and the Mojix eNode. The system then operates with the START Receiver listening for responses coming from RFID tags that are powered by an eNode. Depending on the price of the Mojix hardware, it could be an ideal solution for the use of passive RFID tags for asset tracking.

2.6.2 Zigbee based systems

Zigbee based ID systems have been around for a number of years, but due to their cost they have been excluded from the project. Near the end of the project, an open source project was discovered called SquidBee. The aim of the project is to develop an open mote [a mote is a node of a SquidBee or Zigbee network]. The motes based on the SquidBee open source project were within a price range that they could have proven a viable option for asset tracking. While the development of a production standard asset tracking system based on SquidBee technology would have taken too much time and have been outside the scope of this project, it was felt with the right resources and personnel available, a low cost asset tracking system could have been developed. The SquidBee mote would also have been able to offer a level of functionality far higher than most other systems that the project team have encountered but at a lower cost.

2.7 Summary

In this chapter a detailed technology review was performed. This technology review encompassed the current state of RFID technologies, how it operates and what standards are used. The technology review also took into account other types of RFID technology that were emerging and could have proven to be useful within the scope of this project if time and budget constraints had permitted.

Chapter 3

RFID test bed analysis and test plan creation

This chapter will deal with two different RFID systems; the RFID system that will be created in the Engineering department as the test bed environment and the RFID system that was used with the partner company's asset tracking solution.
The first two parts of the chapter will deal with the necessary work required to deploy a RFID test bed within the Engineering department. This work includes:

1. The development of the requirements for the RFID system.
2. The testing required for deploying a RFID system.
3. The testing of the parts of the RFID system or of future components for an asset tracking system to replace the partner company's system.

The final part of this chapter deals with the RFID system used by the partner company's asset tracking solution. A brief review of the operation of this system is required so as to avoid making the same mistakes with the design and deployment of the test bed system within the Engineering department.

3.1 Analysis and development of lab requirements

From the test cases [partner company's pilot], it was made very obvious that the development of the partner company's system could not take place within an active environment alone. This led to the development of a set of requirements for the creation of a test lab within the Engineering department.

3.1.1 Aims for the development of a lab

1. To provide a controlled test environment for the testing of current and new readers, tags and antenna.
2. To provide a test environment for the testing of the positioning of tags, positioning of readers and antenna.
3. To provide a test environment for the testing and validation of current and future versions of the partner company's middleware.
4. To develop the necessary knowledge for the accurate design, development and deployment of RFID systems.

3.1.2 Lab environment test plan

The setup of the test bed within the engineering department started with a site survey to identify a number of key points:

1. The sources of Ambient Electromagnetic Noise [AEN]
2. The best location for and design of the interrogation zones

The site survey consisted of two different tests; a full Faraday cycle analysis to identify all possible sources of RF noise that could interfere with the RFID system and the second test was the mapping of the interrogation zones using RF contour mapping and star charting the results of the previous test.

3.1.2.1 Identification of possible sources of AEN

Once the location for the test bed had been selected, a full Faraday cycle analysis was done on a number of points around the location area. The Faraday cycle analysis was conducted in the following manner (Patrick J. Sweeney. RFID for Dummies. 2005):

Equipment setup:

1. Connect ½ wave antenna to spectrum analyser and mount on tripod.
2. Setup the spectrum analyser as follows:
    1. Span 60 MHz

2. Bandwidth 100KHz
3. Video bandwidth 30KHz
4. Amplitude attenuation of 0dB
5. Set maximum hold on

Aims:

1. To locate all sources of AEN within the test bed facility.
2. To record the results over the period of a full working day to get the best idea of what sources of AEN there are [Don't run the test on the weekend as it will be quiet and the results will not represent the actual working conditions of the system].
3. To take readings at each interrogation zone.
4. To move around the test bed environment to get an idea of the levels of AEN throughout the entire test bed site.
5. To create maps for all interrogation zones.

Method

1. Move the testing equipment to the interrogation zone.
2. Setup equipment as specified above.
3. Start testing and if possible record all test data from the spectrum analyser for the duration of the test. If this is not possible take screen captures from the spectrum analyser during the test.
4. Analyse the recorded data for AEN tests.
5. Use the recorded data to try and locate all sources of AEN identified.

3.1.2.2 Mapping of the interrogation zone

The next step in the design of the lab is the RF path loss contour mapping of the interrogation zones. RF path loss contour mapping allows you to see how objects around the read field will affect the shape and strength of this field. This is particularly helpful in identifying blind spots caused by the read field surroundings.

3.1.2.3 RF path loss contour map

An RF path loss contour map can be created for each interrogation zone using a frequency generator, ½-wave dipole antenna, spectrum analyser and a circular polarised UHF antenna. Before the necessary equipment was gathered, a test plan was developed for the lab. This test plan could be used in future deployments of RFID equipment.

Method:

1. Setup equipment.
    1. Connect ¼ wave dipole antenna to signal generator and place in the middle of the desired read zone. Set the signal generator to 866MHz and power output to a reasonable level; -14dBm has been recommended from research and has been proven to work reasonably well.
    2. Connect the UHF antenna for the RFID reader to the spectrum analyser [Sirit Infinity 510 can also double as a spectrum analyser for the range of frequencies that it operates in].
2. Perform testing in the following manner:
    1. Place the dipole antenna connected to the signal generator in the middle of the selected read zone.
    2. Around the antenna mark out the read zone as a circle wide enough to take up the space between the two edges of the door. Then divide the circle into sections at 0, 45, 90, 135, 180, 225, 270 and 315 degrees.
    3. Use these points marked on the circle's circumference as test points for the positioning points of the spectrum analyser antenna, keeping the distance between the two antennas the same for all 8 points.
    4. For each of the test points around the signal generator, three readings should be taken for the following frequencies 865.6MHz, 866.8MHz and 868Mhz. These three points will provide information on how the signal from the reader will be affected throughout the frequency range that it will be operating in.
    5. From the readings taken a chart can be constructed. These can be useful tools in the identification of areas where the interrogation of tags could be problematic.

The above testing was used to setup the lab for the project. It should also be used for the deployment of RFID within a business.

3.2 Readers, antenna and tag testing within the lab

3.2.1 Antenna patterning test

The aim of this test is to develop an accurate map of the signal coming from the antenna at different distances and signal strengths. Once performed it will help with the selection of the correct antenna for different environmental conditions.

Equipment required:

1. RFID reader
2. Antenna mounted on appropriate stand
3. RFID tag attached to RF transparent material [plastic, wood or cardboard]

The method used in this test is simple with the aim of getting a radiation pattern for the antenna that is being tested. The antenna is placed in the centre of a measured grid. The RFID tag is mounted onto a piece of RF transparent material. This is then moved around the antenna until the tag is not read by the RFID reader. Once this happens the same test is run again but one square of the grid farther away from the antenna. This is repeated until the tag can no longer be read by the RFID reader.

Method used:

1. Create a grid on the floor of about 5 meters by 5 meters, mark the internal squares in the grid 0.5 of a meter by 0.5 of a meter giving a grid of 10 boxes by 10 boxes. At the centre of this, place the antenna you wish to test onto a suitable stand or tripod.
2. Mount a RFID tag on a piece of RF transparent material and suspend it in front of the antenna at a distance of one box.
3. Move the tag to the right until the RFID reader stops reading the tag. Mark this position off on a piece of graph paper with a grid drawn to scale.
4. Move the tag from the farthest position on the right where the reader will read to the farthest position on the left one box at a time. Keep moving the tag a box at a time until the RFID reader stops reading the tag. For each box where the tag was read mark it off on your graph paper.
5. Move the antenna back to the centre point of the antenna, then move it one box

on the grid further away from the antenna.

6. Repeat steps three and four followed by step five until the tag is no longer read by the RFID reader.
7. Once this has been concluded, the graph paper where you plotted the squares where the tag was read will provided a pattern of the RF field of the antenna.

3.2.2 Reader performance test (for distance and speed)

While most RFID reader benchmarks deal with identifying readers for placement on dock door, conveyor belts or other types of assembly lines, this project deals solely with asset tracking. So what works or is important for the dock door, assembly line or conveyor belt do not ring true for asset tracking. While originally the system called for the deployment of RFID readers at doors and other choke points throughout a building, it became clear very quickly that this was proving to be a very inaccurate method of detecting tagged items leaving the building. A better solution to this is the deployment of RFID readers to cover the entire building floor area. With this in mind, the criteria for benchmarking a RFID reader can be chosen, with distance coming in first followed closely by accuracy and speed.

3.2.2.1 Distance testing

Testing for the maximum distance a RFID reader will read a tag from is an easy enough test to perform, but due to the nature of the Juno system, the tags are not applied to boxes passing along a conveyor belt where every item is identical. Instead the tags are placed on many different kinds of materials. This means all testing should be performed on a number of different samples of materials allowing for the greatest diversity to the testing. This will give you a real world idea of what sort of distance you will get from tags placed on different materials.

Equipment:

1. RFID reader and attached antenna.
2. A number of RFID tags of identical design applied to different types of materials.

3. Tripod or similar to mount tagged materials on.
4. Measuring tape.

Method:

1. Setup the RFID reader so it is operating at full power output.
2. Select a number of different materials to mount your RFID tags on such as wood, cardboard, metal, plastic, fabric and glass.
3. Mount the first tagged sample of material on the tripod at a distance of about 500cm away from the reader antenna and find the strength of the return signal from the tag. Repeat this step for all samples.
4. Move the test sample a further 500cm away from the antenna and repeat step 3 until the tag is no longer read. This will give you a detailed understanding on how each material affects the operation of tags placed on it.

3.2.2.2 Speed testing

The nature of the system being developed requires a reader that can read a tag that is moving. The tagged items would rarely be moving any faster than the speed of a human walking or running [10.35 m/s – 200 m 19.32 s Michael Johnson (US) Atlanta, Ga 08/01/1996]. Armed with this information, the development of a test for a reader's speed at reading a tag and also a number of tags is a simple matter.

Equipment:

1. RFID reader and attached antenna.
2. A number of RFID tags of identical design.
3. RF transparent material to mount RFID tags onto cardboard [must be dry] or plastic is suitable for the job.

Single tag method:

1. Setup a read zone to cover the maximum area possible. The reader should be tested first using only one antenna. Testing can then be expanded with the addition of an extra antenna with each cycle of the test.

2. Apply the RFID tag to the RF transparent material.
3. Attach the RF transparent material to the developed RFID tag holder.
4. First walk through a fully functional RFID reader's read zone and note how many if any reads of the tag occur.
5. The next step requires the wearer of the RFID tag holder to run through the interrogation zone. Note the number of reads of the RFID tag.

Multiple tags method:

1. Setup a read zone to cover the maximum area possible. The reader should be tested first using only one antenna. Testing can then be expanded with the addition of an extra antenna with each cycle of the test.
2. Apply a number of tags to the RF transparent material.
3. Attach the RF transparent material to the developed RFID tag holder.
4. First walk through a fully functional RFID reader's read zone and note how many if any reads of the tags occur.
5. The next step requires the wearer of the RFID tag holder to run through the interrogation zone. Note the number of reads of any of the RFID tags.

3.2.2.3 Connectivity

While not something you would consider as a major aspect of testing when you are thinking of RFID systems, without the right connectivity options the deployment of a medium to large scale RFID system can become difficult. With the nature of the system and the requirement for the deployment of a large number of readers throughout one or more buildings, the ability to connect the reader back to the middleware server is an important factor to consider. The following are the most prevalent options for communications provided by reader manufactures:

1. Universal Serial Bus [USB] / Personal Computer Memory Card International Association [PCMCIA]

This is great for the connection of a reader to a laptop or other portable device but limited in their use for the deployment of a large scale RFID system.

2. Serial/RS232/RS485

This is great for small scale systems where the number of readers required is small and the distance between the readers is short.

3. Ethernet

A requirement for a RFID reader to be used in most medium to large scale deployments, most companies already have a network infrastructure installed (Ethernet). The addition of extra network points to reader deployment location is cheap and once tested is reliable and quick. Another very useful addition to any RFID reader is Power Over Ethernet [POE], with the addition of POE injectors to the network. It would allow for the removal of the need to install power points with each network access point, making your deployment a step simpler and maybe even a little cheaper.

4. Wireless

Wireless network connectivity has become an option on many readers. While it removes the need to install any extra cabling or access points, they require the installation of a wireless network infrastructure if one does not already exist. If one is already present, the deployment of the RFID reader should be made one step easier but would probably not make the deployment any cheaper due to the extra cost of the reader. While wireless networking standards are always improving, this does not solve the development of new and faster ways to gain illegal access to a wireless network encrypted or otherwise.

3.2.2.4 Clean RF output

An important test to determine if the RFID reader is working within specification.
Why run this test?

1. To test to see if there could be problems for the RFID tags trying to synchronise with the reader. RFID readers emit a carrier signal; RFID tags use this carrier signal to synchronise communication between the reader and tag. If the carrier goes outside of the tolerance for the RFID tag it is trying to interrogate, then the tag's clock could fail causing the process to have to restart.
2. Dirty signals or unwanted RF signals coming from the RFID reader. These

signals can cause problems for both the interrogation of tags and getting equipment licensed.

Equipment:

1. RFID reader and antenna.
2. Spectrum analyser and ½ wave antenna.

Method

1. Setup the reader and antenna. Set the reader to maximum power output.
2. Setup the spectrum analyser with a centre frequency of 866MHz and a span of 50MHz. This will allow you to view the entire frequency range that the RFID reader will be transmitting on and will also give a little room either side of this band.
3. With the RFID reader operating at full power, monitor the spectrum analyser for at least 60 minutes and record any signals outside the allotted bandwidth (865MHz to 868MHz).

What to do if the reader does not meet standards:
While it would make the deployment process one test shorter, it is recommended to test all readers prior to their deployment to any installation. It could prove to be a costly mistake if it was proven that a reader operating outside of its specification was causing any sort of difficulties for a customer.

3.2.2.5 Reader selection

During the course of this project I was asked a great deal of questions regarding what reader should be used in different types of situations. All of these questions were answered by defining what problem the reader was going to address and what they expected from the reader. Most of the time expectations of what the technology could achieve were exaggerated.

1. Hand held
    1. Passive

A short read range and if coupled with the wrong tag on the wrong type of surface, then you're as well off using bar codes. This type of reader is also not suited to high volumes of tags.

2. Active

A medium to long range reader that operates like a fixed position active reader which is mobile. This category of reader was not available to the project, but it could have been useful in the detection of lost items that have been tagged but are outside the normal RFID covered site.

2. Fixed location
    1. Passive

A short to medium range reader, they can deal with high tag volumes, but once again tag read rates are very dependant on proper tag selection and placement.

2. Active

A medium to long range reader, they can deal with high tag volumes and is best suited to the system that was being developed for the project as active readers were shown to be better able to deal with the kind of items that were being tagged.

3.2.3 Tag characterization test

The aim of this type of testing is for quality assurance of the tags coming from the vendors. Due to a lack of quality standards for the tags coming from vendors, testing of a large sample size of tags can prevent some head scratching during the deployment of a RFID system. From this test you can determine the minimum read range provided by a certain type of RFID tag and also their expected failure rate.

Equipment:

1. RFID reader and antenna.
2. Attenuator.
3. Large sample of a type of tag to be tested [100 is recommended].
4. Measuring tape.
5. RF transparent surface to mount the tags on.

Method:

1. Setup the reader and connect the antenna to the reader through the attenuator so that the adjustment of the attenuator adjusts the power output from the antenna.
2. Mount the RF transparent surface on a tripod to allow the attachment of tags onto it's surface. Setup the antenna 500cm away from its surface.
3. With the above setup, mount your first tag onto the flat surface. Slowly turn up the attenuation until the tag can no longer be read. Record the level of attenuation required for the tag not to be read and note your results. Repeat for the other 99 tags in your sample.
4. The last step in this testing involves testing the maximum read range provided by a number of tags within the 100 tag sample. Take a representative sample from the tags with the best, worst and median attenuation value. With the selected tags, measure the maximum distance that they can be read from.

3.2.3.1 Optimal tag

From the experience gathered during my extensive testing with the deployment of tags for the partner company, it became very apparent that the selection and placement of a RFID tag is of great importance. The wrong tag on a metal surface is nearly unreadable. This was demonstrated quite well when the partner company deployed label type tags to a customer's site. The customer's site had a large number of computer workstations. These workstations had metal cases; 90% of the time the tags were unreadable with the result that the operator of the hand-held reader looked quite foolish as they moved the reader around trying in vain to get a read from the tag. The partner company's help in this area of the project was of enormous value to the project team. It allowed myself to get first hand knowledge of the most common types of assets encountered on a customer's site. From this research I could determine the types of tags to use and how important it is to test any new types of tags for the optimal tag placement and orientation.

3.2.3.2 What are you applying the tag to?

The importance of this question cannot be stated enough, whether reading tags at a short distance or at the maximum range of the reader, the placement of a RFID tag onto a type of material that the tag is not designed for is a recipe for disaster. A tag designed to work while mounted on a metal surface may return pretty dismal results if mounted on an RF transparent material; it also goes without saying that vice versa is true. A tag designed for wood, plastic or other RF transparent materials will fail miserably when mounted on metal [RF reflective/refractive surfaces].

3.2.3.3 Categories materials can fall into

Absorption types.
Normally caused by liquids, the energy being transmitted from the reader's antenna is absorbed by a liquid [water is a common example, but objects containing water such as the human body or wet cardboard can also cause the same problems]. The loss of energy caused by the absorption results in less energy for the operation of the tag attached to the material (Daniel Dobkin. The RF in RFID. Passive UHF RFID in Practice. Sep.2007) and (Patrick J. Sweeney. RFID for Dummies. 2005).

Reflection/refraction.
RF waves can be reflected or refracted and many surfaces act like a mirror for RF waves "concrete which has a refractive index of around 2.5 at microwave frequencies" (Daniel Dobkin. The RF in RFID. Passive UHF RFID in Practice. Sep.2007). The reflected or refracted wave takes a detour before arriving at the tag allowing the tag to operate. The process of reflection or refraction can distort the RF signal coming from the reader. This can cause the tag to not recognise the signal or have a reduced response to the reader (Daniel Dobkin. The RF in RFID. Passive UHF RFID in Practice. Sep.2007) and (Patrick J. Sweeney. RFID for Dummies. 2005).

Dielectric effect.
A dielectric is an insulating material which does not allow electrons to move freely through them. When a RFID tag is mounted onto the surface of a dielectric material, the

electric field used for the transmission of data between the tag and reader can become focused. This effect can detune the antenna of the tag resulting in poor communication capabilities between the reader and the tag (Daniel Dobkin. The RF in RFID. Passive UHF RFID in Practice. Sep.2007) and (Patrick J. Sweeney. RFID for Dummies. 2005).

Propagation effects.

The propagation of an RF wave between the reader antenna and the tag antenna is never a simple matter. In the real world, the transmitted RF signal from the reader will interact with many other objects on it's travel to the tag as well as scattered or reflected RF signals coming from the RFID reader transmission. Even when deploying a RFID system to a large empty warehouse with just four walls and a roof to deal with, there is still a high possibility of interference to the RF signal from the reader to the tag. The interference can come from a number of sources:

Scattered or reflected RF signals.

Once the RFID reader has transmitted an RF signal, the part of the RF wave that goes directly to the RFID tag is called the direct wave. The journey of direct wave from the reader antenna to the tag antenna is a journey fraught with many hazards. The original RF signal transmitted from the RFID reader does not travel directly to the RFID tag avoiding all obstacles in it's path. Some of the original RF signal will scatter away from the RFID tag due to meeting an object in its path on the way to a RFID tag. The RF signal that gets scattered can cause great problems for the direct wave as it is of the same frequency. If the direct wave coming from the RFID reader meets a scattered or reflected wave, then depending on the phase of this wave it can have a number of different effects on the direct wave (Daniel Dobkin. The RF in RFID. Passive UHF RFID in Practice. Sep.2007) and (Patrick J. Sweeney. RFID for Dummies. 2005).

1. If the direct wave is in phase (0 degrees) with the scattered or reflected wave, then the two waves will have constructive interference.
2. If the direct wave is out of phase (180 degrees) with the scattered or reflected wave, then the two waves will have destructive interference resulting in a weaker signal or in the worst case scenario cancel each other out completely.

Multipath propagation.

Multipath interference occurs when a signal propagating from a RFID tag to a reader is reflected or refracted off an object or a number of objects within its environment. The part of the signal that travels the most direct route (direct wave) to it's destination will suffer less absorption, attenuation and are the first waves to reach the reader, while the rest of the signal may bounce around it's environment until one of two results occur:

1. The signal is absorbed

If the above occurs then no further problems can be caused.

2. The signal finally reaches it's destination and is read by the RFID reader.

The second option can cause signal attenuation and distortion which is a common phenomenon in all radio systems. It can be a serious problem in RFID systems due to the RFID system transmitting a very narrow spectrum with essentially only one frequency (during the continuous wave part of the transmission). With this very narrow spectrum transmission, near perfect cancellation can occur between the direct wave and indirect wave if they meet with the correct magnitudes and they interfere destructively. UHF RFID readers implement a number of different methods of reducing the effects of multipath propagation. These include frequency hopping; these changes in frequency could reduce the degree of cancellation that could occur between the direct and indirect waves (Daniel Dobkin. The RF in RFID. Passive UHF RFID in Practice. Sep.2007) and (Patrick J. Sweeney. RFID for Dummies. 2005).

3.2.3.5 Optimal tag type.

Each type of material which is unfriendly to RF signals has an optimal tag type designed and developed with it in mind; metals and liquids are the most obvious materials. There are two ways to minimise the effects of absorption and reflection/refraction:

1. To raise the antenna off the surface of the material (works best for liquids and other absorbent materials).
2. Tuning the tag antenna to work specifically on that type of surface.

A combination of both of these options should offer the best compromise between a tag that can operate on both metals and liquids, but won't be easy to remove from the item that it is attached to.

3.2.4 Tag placement and orientation

The placement and orientation of a RFID tag can play a big part in the successful read of the tag. If a "slap it on as quick as possible" method is chosen, then problems will be encountered in the future. A more scientific approach must be taken when deploying a tag to an item and this approach must start when assessing RFID tags for specific purposes.

3.2.4.1 Testing RFID tags for the optimal placement

There is little or no point applying a RFID tag to the bottom of a computer tower where the RFID signal has little hope of reaching it. This is why it is of great importance to determine the composition of the customer's assets before the process of deployment begins. During the site survey, it is important to make a quick note of this composition, weather the majority of the assets to be tagged are metal bodied computers or plastic bodied office equipment, but in most cases it will be a mixture of both RF friendly and RF hostile assets. Once a breakdown of what types of equipment the tags are going to be attached to, the process of selecting the correct tag placement for each type of asset can begin.

1. Computer tower.
   A computer tower is basically a big metal box even though it looks like it is plastic, most of the time it is a thin layer of plastic placed over a metal surface (sides and top on newer Dell cases). From tests the most desirable place for a RFID tag is at the top of the front bezel as it is normally made of plastic and allows a good stand of point for the tag. Testing has shown that if this bezel is greater than 2cm (as in the case of most Dells), then a tag designed for metal surfaces is not needed.

2. Laptop

   While the outside of the laptop may be made of plastic, it is what's inside that counts. Due to the design of most laptops, space inside the plastic is at a premium. This means all sorts of electronics and metal shielding are placed against the outside casing. Tests have shown that tag placement on a laptop can be very difficult and can vary widely between laptop models, but from tests the best results have been gained from the placement of the tag onto the top of the laptop screen cover.

3. Printers.

   The large quantity of plastic used in most printers provides a near optimal surface for the placement of a RFID tag. Placement of the tag onto the feed tray doors or onto the very top cover is the optimal position for most laser jet printers, while optimal placement on ink jet is normally on the door covering the internals of the printer.

4. Monitors.

   CRT monitors proved easy to tag, with the surface above the CRT tube itself provides the best location for tag placement due to the large gap between the outer casing and the internals of the monitor.

   Flat panel monitors can be a bit more troublesome; like laptops results can vary depending on the make and model. Tests have shown that the area above the screen but below the top of the casing gives the best results.

5. Industrial equipment (all metal surfaces)

   The sort of equipment encountered during the project included moulding machines, microscopes and other equipment from a clean room environment. Due to this it was impossible to conduct tag placement tests on the equipment, but from simple trial and error a number of guide rules were developed.

   1. Check if the line of sight from the tag to the reader is clear.
   2. Place the tag as high up on the equipment as possible but not facing the ceiling.

3. Expect the unexpected in a clean room environment due to the metal walls and ceiling tiles.

3.2.4.2 Tag orientation testing.

The orientation of a RFID tag affect it's read range by more than 50% on tags that I have tested in the lab. So before deploying any new tag to a customer's site, the optimal orientation for the tag must be determined.

Equipment

1. RFID reader and antenna.
2. Square cardboard box.
3. RFID tags.

Method

1. Setup the RFID reader and antenna. Set the reader to maximum power output.
2. Place the cardboard box in front of the antenna at a distance of 200cm.
3. On the tag draw an arrow pointing up.
4. Place the RFID tag on the cardboard box with the arrow pointing towards the ceiling.
5. Get the reader to interrogate the tag. If the reader succeeds then move the box 200cm further away from the antenna and repeat the interrogations again.
6. Keep repeating the above until the interrogation fails. Note the maximum distance that the interrogation succeeded.
7. Turn the box so the arrow is now pointing at the floor and repeat steps 5 and 6.
8. Repeat step 7 until the arrow on the tag has pointed in all the possible directions (24 in all).

3.3 Analysis of the partner company's system from solely a RFID hardware point of view.

The partner company's system is a thin client system developed by a third party developer for the partner company. The main aims of the system were to provide processing of assets, calculation of depreciation and the display of the information regarding these assets. The main aim of the partner company's system was to tie together RFID information coming from a network of RFID readers spread throughout the customer's site, with financial information coming from the customer's financial system. The partner company's system would then process this information, calculating depreciation and monitoring the current location of the asset. This information would be displayed to the customer via a browser based interface (thin client solution). The main part of the partner company's system that falls within my part of the project was the design, development and deployment of the RFID system, the design and development of the reader interface and filtering of the incoming data streams.

3.3.1 Design and development of the RFID system.

The initial design, development, deployment and further fine tuning was undertaken by a third party contractor hired by the partner company.
The design of the RFID system called for the deployment of an active reader at all exit doors throughout the building. These active readers were to cover all traffic entering and exiting the building. Further to this, all non mobile assets and less expensive assets would be tagged using passive RFID tags. These tags would be scanned on a weekly or monthly basis using a hand held RFID reader and the results uploaded to the partner company's system.

3.3.2 Reader software

The design of the software interface to the readers was supplied by the reader manufacturer; this software polled each reader in the system in turn. When a reader was polled, it would return all tag information held in it's buffers. This information was then converted into a set of Extensible Mark-up Language [XML] files, one file per tag read by the reader. Filtering of this data for multiple tag reads and other unwanted events was originally not dealt with and a further modification to the software was required. The result was that all tags read more than once within the space of 20 seconds counted as one tag with just the time and date stamp updated; no other filtering of the incoming stream of data was carried out.

3.3.3 Reader and tag deployment

The deployment of the system to the first customer took a matter of hours, the active readers were deployed without performing the necessary testing (AEN tests and Read zone design) and the entire system was deployed and fine tuned within a day.

3.3.4 Problems with the system identified with the first customer

A number of problems were quickly identified with the system, the primary one being that it didn't work as expected. The design of the system and total lack of proper filtering of the incoming data streams meant that multiple tag reads were a daily occurrence resulting in the partner company's system telling the customer that assets had entered or left the building many times depending on how fast the tagged asset had moved through the read zone. As the read zone had not been designed properly, they covered large parts of the internal area of the building, so even assets moving around the building were flagged by the system as having left or entered the building.
Some of these original problems were overcome with the removal of the equipment installed by the third party contractor and replaced by the project team with newer more accurate equipment. Due to the now rather tight nature of the budget for this project, it remained with the original design of covering the exit points only. The reasoning behind this was that the equipment costs that would be required to redesign the partner company's system were too high. This approach improved performance of the system resulting in fewer multiple reads from the smaller read zones but not solving the entire problem.

3.3.5 Solutions proposed from this project

The main aim of my part of the project was to develop the required knowledge for both the thorough testing and deployment of all aspects of a RFID system. Once the project commenced there were relevant results produced to correct mistakes made by the partner company during the design and deployment of the initial RFID system to their first customer. Some of this work has been listed above and other major parts are listed later in this thesis.

1. Design of a better RFID system.
2. Testing of the readers and tags to aid in the design of a better RFID system.
3. Compilation of the correct deployment guidelines for both the readers and tags.

3.4 Summary

This chapter set out the required tests to develop a test bed for the further testing of the overall system. This was done by the development of a number of tests for the development and deployment of the test bed. The test bed would then be used to perform subsequent testing that would be required for all further RFID equipment to be used in the asset tracking system. While these tests were developed for the deployment of the test bed, it was also envisioned that these tests should be used in the deployment of all further RFID systems by the partner company.

The final part of this chapter briefly dealt with the deficiencies that were present in the RFID system that was being deployed by the partner company, explores the problems that arose from this and the solutions that were provided by the project team to rectify these problems.

Chapter 4

System analysis and design

This chapter will deal with the analysis of the partner company's system, it's requirements, design, development and operation. From the research done on the original system, a better understanding of the requirements of the RFID system for Juno could be developed, this could lead to the design and development of a better RFID system and interface software for the Juno system.

4.1 Analysis of partner company's system

The analysis of the RFID system for the partner company's system was done using a number of sources of information:

1. The requirements developed for the partner company's system
2. The RFID system deployed for the first customer as part of the partner company's pilot system
3. Subsequent deployments of the system
4. Customer requirements for the system
5. Talking to the partner company's employees

With these main sources of information about the partner company's system in hand, a detailed examination of the partner company's RFID system could be produced. The detailed analysis of the partner company's RFID system was required so that the project team did not make the same mistakes that the partner company made while the partner company's RFID system was in design and development.

4.1.1 Analysis of the partner company's customer requirements

Analysis of the partner company's customer requirements documentation was very in-depth regarding the requirements for the partner company's software system, but very slim on the requirements for the RFID system. Potential customers had unrealistic expectations of what passive RFID could achieve. The main expectation was for passive RFID to be able to read tags at extreme distances. Using the customer requirements the following was develop:

1. Mobile passive readers that can read RFID tags from 2 to 3 meters, enabling the reading of all tags in a small size office from the centre of the floor space.
2. Real time operation of the partner company's software on the mobile RFID reader.
3. The ability to track paperwork using active RFID tags and locate the paperwork even if the paperwork is located inside a metal filing cabinet.

After performing this research, the researcher felt that while the customers had an unrealistic expectation of what RFID could offer, most of these unrealistic expectations were down to the partner company's sales staff who promised anything to make a sale. It was then a problem for the engineering team to meet these requirements. In all the customer requirements offered very little usable data.

4.1.2 Analysis of requirements for the RFID system

While the researcher made every effort to acquire the RFID system requirements document from the partner company, he was unable to as the document did not exist. The partner company acquired a third party company to perform the entire process. Unfortunately this did not include the development of requirements documentation for the proposed system.

4.1.3 Analysis of the data requirements of the partner company's system

The data required from the RFID system was established from a detailed review of the partner company's requirement documentation for the software system. The following data is required from the RFID readers for the partner company's system to operate correctly:

1. Tag ID: The RFID tag identification; this corresponds to the tag number that will be contained in the asset register.
2. Name: Free text description of the asset; this is similar but not necessarily the same as the asset register asset name.
3. Zone: This is the reader's name; the reader that reads the tag.
4. Activity: This is the current internal RFID tag status not used by the partner company's system.
5. Date: This is the date of the read.
6. Time: This is the time of the read.
7. Tag Cell: This is information of the battery life of the active tag not used by the partner company's system.

4.1.4 Analysis of the operation of the pilot deployment of the partner company's system

The initial pilot scheme's main aim was to demonstrate how RFID and the partner company's software could be utilised to streamline the asset management process, giving the finance department an easy to operate system that would provide soft real-time information about the company's assets. The system was designed and deployed prior to the start of this project by a third party company.The system consisted of two parts:

4.1.4.1 Active RFID system

The active system consisted of four XTAG RFID readers and about 30 active tags. The thirty active RFID tags were placed on high value items such as recording and mixing equipment. The four active RFID readers covered the four exits from the building. These four active RFID readers were to catch all RFID tagged items leaving and entering the building.

4.1.4.2 Passive RFID system

The passive RFID system consisted of a mobile RFID reader [Psion Walkabout pro with the TSL snap on UHF RFID reader]. The passive side of the system was basically to replace the already deployed bar code system being used. So the bar codes were replaced with RFID tags and the mobile RFID reader took over the functionality of the bar code reader. All assets within the pilot scheme were tagged with passive RFID tags.

4.1.4.3 Pilot scheme system performance

Due to the design of this system, it did not operate correctly resulting in tagged items disappearing and reappearing from the system indicating they had left or entered the building. The design flaw in this system was from two sources; a budget that was too small to realistically implement the desired system and the second was an improper site survey done during the design and deployment of the system. These two points led to a system that did not operate correctly.

4.1.4.4 Flaws with the active RFID system

The equipment selected and used for the pilot scheme deployment was supplied by the third party installer and all of the equipment used was XTAG in origin. The problem with all the XTAG readers deployed were they had built in antennas. The built in antennas resulted in a system that was not very flexible and not the correct choice for the location and requirements of the partner company's system.

Soon after the start of the project, members of the project team were asked to see if they could rectify the problems being encountered with the pilot scheme system. The project recommended the deployment of new RFID readers and tags that would better suit the requirements and location of the pilot scheme installation. The greatest change recommended to the system was the movement of the readers from the inside of the building to the outside, thus eliminating the overlapping read zones and moving them away from the internal corridors of the building where people transverse everyday, causing the disappearing and reappearing tagged items. Shortly after these recommendations had been made, there were difficulties between the partner company and the original RFID system supplier. This resulted in the removal of all of the XTAG equipment from the pilot scheme. While this was seen as a setback for the partner company, it also provided the necessary funds to replace all the XTAG equipment used in the pilot scheme with more flexible Wavetrend equipment. With the deployment, testing and tuning of this equipment completed, there was a vast improvement in the pilot scheme system. But even with the improvement, it was clear from the start of the project that the current design of the system was flawed and needed to be redesigned as tagged items were still disappearing and reappearing on the partner company's system although at a lower rate than before.

4.1.4.5 Flaws with the passive RFID system

While the active system showed potential for asset tracking from day one, the passive system showed less potential, especially if the company had already deployed a bar code system, as the RFID tag just replaced the bar codes and the passive RFID reader just replaced the bar code reader with a large increase in cost. The initial system used a type of tag that was designed to be placed onto a metal surfaces. These tags gave a dismal read range of less than a meter for a price of a few Euro per tag [€3 per tag was the purchase price for these tags]. So replacing an existing bar code system for a company with this type of RFID system did not show the desired cost to performance ratio. The problem was compounded further when the partner company started cutting corners by placing RFID tags not designed for metal surfaces onto metal surfaces, thus reducing the read range from under a meter to a few centimetres at best and at worst causing the tags to be unreadable.

4.1.5 Analysis of the subsequent deployments of the system

At the time of writing, there were a number of the partner company's systems deployed mostly in the health care industry. All of these installations were of the same basic principle as the original pilot scheme; to locate RFID readers at entrances and exits from a building and catch all RFID tagged items leaving or entering the building. This design had been proven to be flawed in operation during the initial pilot scheme and all members of the project team recommended against the deployment of this design again. The design did have one critical factor in it's favour; cost. Due to the cost factor most companies selected this design over other designs recommended by the project team. While in the short term it saves the company's money, over the long term it would prove to be a bad decision as the system would fail to meet any of the requirements set out by the company in it's original specification.

4.1.6 Customer system 1

The first customer to purchase the partner company's system was a health care company in county Waterford. The project team were asked to submit a number of designs for this customer but all the designs submitted were thought to be expensive. This resulted in the submission of the old designs to the customer. The two designs submitted were one consisting of both active and passive RFID being used and the second design was just passive RFID being deployed. The second design was selected by the customer.
The second design consisted of the deployment of about 6,000 passive tags to all assets of a certain value on the asset register. While this would have resulted in a working system if implemented correctly, the recommendations of the project team were ignored in favour of saving money and cutting corners. These tactics resulted in the deployment of about 2,000 to 4,000 passive RFID tags that were not designed for mounting on metal surfaces. They were deployed on computers and other metal clad objects. The resulting system was a complete disaster not functioning most of the time.
Following on from the deployment of the standard RFID label, the project team was once again approached to resolve the problems with the RFID system for the customer. There was one limitation placed on the project team before a solution could be found. There was no room in the project budget to purchase RFID tags specifically designed

for metal surfaces.

After careful research and testing of a number of ideas, the following solution was settled upon. All deployed RFID tags would need to be placed onto a stand-off of at least 2 to 4 millimetres. Following on from this, a number of tests were conducted on different types of material to be used for the stand-off [cardboard, plastic or foam backing]. After much testing, the most suitable stand-off was created from the foam backing, not because they offered the best increase in performance, as all stand-off tested [cardboard, plastic, foam backing] offered the same performance increase due to being RF translucent, but because the foam backing could be bought with glue applied to both sides and cut to the proper length. This was chosen to speed up the redeployment of the RFID tags that required the foam backing. The stand-offs were deployed resulting in an improvement in the operation of the system.

4.1.7 Customer system 2

Another health care company was sold the partner company's system and once again the designs of the project team were ignored for the old design used in the pilot scheme. This was submitted to the customer in a number of different forums:

1. Complete RFID system using both passive and active RFID, covering all exit points for 4 buildings.
2. Complete RFID system using both passive and active RFID, covering all exit points for 3 buildings.
3. Complete RFID system using both passive and active RFID, covering all exit points for 2 buildings.
4. Complete RFID system using both passive and active RFID, covering all exit points for 1 building.
5. Passive RFID system only.

For the second customer that the partner company's system was deployed to, every effort was made by the project team to ensure that the partner company understood the consequences of deploying the original design used for the previous pilot system. Unfortunately this information fell on deaf ears. While both the partner company and the project team knew that the original RFID system design was flawed, the design options that were given to the customer meant that anything other than the first and last option on the above list would result in a system that did not operate correctly. The designs between 1 and 5 resulted in a system partially covering the entire company site. This meant that an asset could leave one of the buildings that was not completely covered and vanish completely without the system detecting it.

In the end a combination of two options were selected. It covered all three buildings but only partially covered the fourth building. This left the door wide open for assets to disappear off the system easily.

Following on from the deployment of the system, problem after problem was discovered by the customer mostly to do with the system reading tags that were not moving. Throughout the entire course that the partner company was with the project, these problems were never solved to the customer's satisfaction. The problems stemmed from the old design of just covering the exit and entrance points of a building. The partner company intended on redeploying the readers at a later date when the customer had agreed to spend more money on the project, so that the readers would cover the entire inside of the building complying with the original project team's recommendations. It is unknown if the project ever made it to that stage.

4.1.8 Customer system number 3

Since the partner company's system original deployment, it had been redeveloped. This redevelopment focused on the functionality of the partner company's system. It did not in any way improve the problems identified in the system installed at the first customer's site. The additional functionality added to the partner company's software at this stage just compounded the weaknesses already identified in the partner company's system. This came in the form of Short Message Service [SMS] or text messages.

One particular piece of functionality that was added to the partner company's system was the ability for the system to send a text message when an asset entered or left a building. It was this one function that showed how badly the system had been designed. By the time the third customer had contracted the partner company to supply them with an asset tracking system, I had learned a number of important lessons from the original customer's installation. These lessons were put to good use when it came to design the

RFID system for the second customer.

Project team recommendations for the second customer's system were as follows:

1. A full site survey and testing of the environment where the readers were being deployed.
2. The second and most important recommendation was a choice between two approaches to the RFID system:
    1. Either cover the internal area of the building using RFID and make the necessary changes to the partner company's software
    2. Keep the readers covering just the doors but implement the necessary filtering of the incoming data streams.
3. Select the correct passive RFID tags for deployment onto metal surfaces and be clear on the expected read range of the passive handheld RFID reader to the customer.

Unfortunately the project teams' recommendations were not implemented. This resulted in the partner company's system sending hundreds of text messages in the space of 20 minutes when the system was initially switched on due to false reads.

4.1.9 Analysis of the overall partner company's RFID system design

During the course of the research performed on the design, development and deployment of the RFID system for the partner company's system, a number of important lessons were learned:

1. Planning is essential for any RFID system to operate properly.
2. Cutting corners in the short term regarding deployment costs and design will cause untold amounts of trouble in the near future.
3. A system designed to cover only the exit and entrance points of a building will not operate with enough accuracy for it to track assets properly resulting in unhappy customers and engineers.
4. Testing is very important.

All of the above points are important to keep in mind when designing, developing or deploying another RFID system. A lot of problems with the partner company's RFID system could have been avoided by following some common sense and the advice of the project team.

4.2 Gathering and development of requirement for the Juno RFID system

After researching the current RFID system, the researcher had a good foundation on what direction the design of the RFID system for Juno should take and also what pitfalls to watch out for.

4.2.1 The partner company's expectations for active and passive RFID systems

4.2.1.1 Passive system

During numerous meetings with the partner company's employees, the requirements for a passive RFID system for the partner company's system were established. The main focus of the partner company in the passive RFID area was on mobile hand-held RFID readers. The hand-held reader would be used like a bar code reader with a greater range, allowing the user to read all the RFID tags deployed in a small size office space of about 4 to 10 Meters squared. Beyond the read range, certain other requirements were developed from the meetings with the partner company regarding the formatting of data stored on the reader and the transfer methods of data from the reader to the partner company's server.

4.2.1.2 Active system

The active system is seen as the backbone type of RFID to be used in the partner company's system due to the extended read ranges and wider range of tag types available. The initial requirement for the active system was to cover an area the size of a normal double office door [approximately 1 – 2 meters wide]. This was in keeping with the design of the original RFID system to cover all exit points of a building and read all RFID tags as they passed through the exit point.

4.2.1.3 Requirements for the active system hardware.

1. One active reader to cover an open space of about 15 to 20 meters squared. While the coverage of an open space of those measurements by an active reader should be achievable for an open and unobstructed space, the project team recognises that this would have to change depending on the dimensions, shape and contents of a room.
2. Be able to read up to 100 unobstructed tags within its read zone within a 1 to 2 second window.
3. All communication with the reader should be via Transmission Control Protocol/Internet Protocol [TCP/IP] over Category 5 cable [Cat5] based cable and have the correct 8P8C/RJ-45 connection jack.
4. Allow for the changing of the reader antenna without the need to modify the reader housing.
5. Easy to read fault and operation indicators/light emitting diodes.
6. Well documented API and supplied SDK for at least Java/C#.
7. Be able to provide RSSI as part of the returned data from a tag read.

4.2.1.4 Requirements for the passive system hardware.

1. Read all unobstructed, properly positioned and orientated RFID tags travelling in front of an antenna at a distance of 1.5 meters or greater.
2. Be able to read up to 100 unobstructed tags within it's read zone within a 1 to 2 second window.
3. All communication with the reader should be via TCP/IP over Cat5 based cable and have the correct 8P8C/RJ-45 connection jack.
4. Allow for the changing of the reader antenna without the need to modify the reader housing.

5. Easy to read fault and operation indicators/light emitting diodes.
6. Well documented API and supplied SDK for at least Java/C#.
7. Be able to provide RSSI as part of the returned data from a tag read.

4.3 Design of the RFID system

During the course of the project, the project team had many opportunities to see how not to design a RFID system. After the gathering and development of the necessary requirements for the Juno system, the design phase was entered.
Throughout the project, the project team has always endorsed the deployment of a RFID system that covered the internal area of a building rather than covering only the exit and entrance points of a building. The researcher has always seen this design, while not perfect, to be more reliable than covering the entrance and exit points alone. The reasoning behind this is that when covering the entrance and exit points of a building, you get one chance to detect a tag entering or exiting a building. With the design proposed by this research, the system will know that the tag is still there until it leaves the building.

4.3.1 Active RFID design

The design chosen for the active RFID system would consist of the deployment of one active RFID reader per lab. This reader would be set up to cover all of the lab area. Testing would be preformed to test that the system did in fact cover the entire lab area. Other tests would be carried out to ensure that it met the requirements for read range and rate.

4.3.2 Passive RFID design

While the active system would be deployed to cover the entire area of the labs, the limited read range of the passive RFID readers prevented their deployment in this configuration. Hence they would be utilised to cover the entrance and exit points of the lab. While this is going against all recommendations that the project made about the deployment of a RFID system, the read range of the readers was considerably too short to cover the area of the labs. The passive system would also be tested so ensure that it met the requirements set out earlier in the design process.

4.4 Drivers [including mobile reader software]

For each of the readers selected for the RFID test bed, a driver would have to be developed for its connection to the Juno asset tracking system that would utilise the data coming from these readers. The development of this software fell into two categories; the fixed readers and the mobile reader [Psion walk about pro].

Note: Regarding the mobile reader software development during the course of the development of this software, the partner company had to leave the project. This left the development of this software without the necessary hardware to test the software, as the mobile reader belonged to the partner company and was unavailable for the project once the partner company had departed from the project.

4.4.1 Fixed readers driver

The driver design and development for all fixed readers took into account that while the readers the project team would be using for the project were of a very good quality and met all of the desired requirements for the project, they might not always meet the requirements for future projects. With this fact in mind, the drivers were all designed and developed to have loose coupling with the Juno system, allowing for new readers to be added to the Juno system with ease. This was achieved by using an abstraction layer. The abstraction layer design required all reader drivers to use a common set of commands and responses, so that readers could be substituted without the need for changing the layer above the abstraction layer.

The abstraction layer is a simple but very effective idea, allowing for further expansion to the system with only a small amount of work required to the underlying driver for the reader.

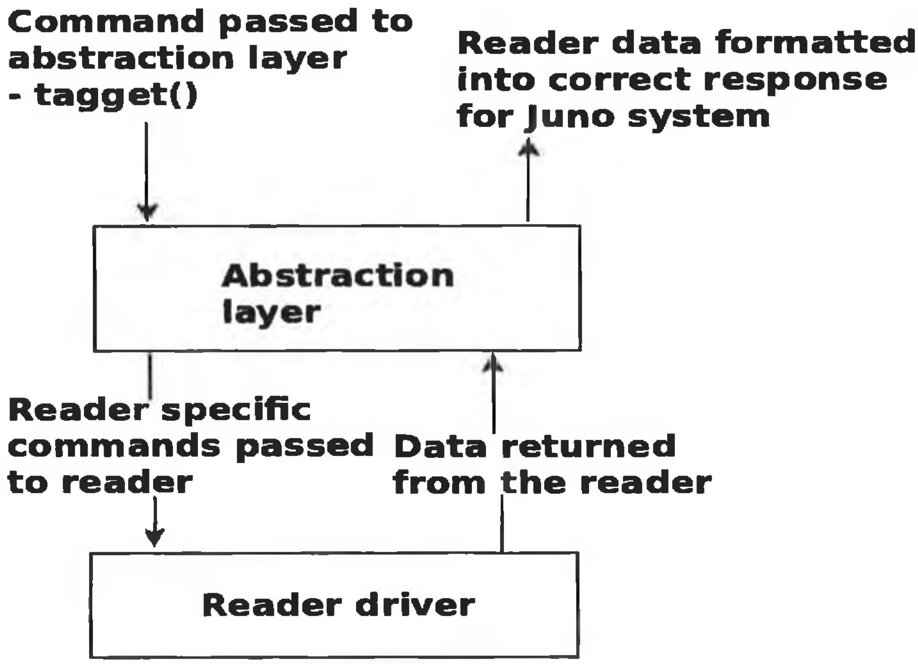

Figure 6 – Abstraction layer diagram

Abstraction layer I/O

Input command	Output from command
gettag	reader_id – the reader identifier
	tag_id – tag number
	Timestamp – time the tag was read at
	Rssi – the signal strength between the tag and reader
	antennae_number – which antenna attached to the reader read the tag
	Error: "message" – this value is returned only when an error occurs, the "message" portion of this changes depending on the cause of the error.
status	Ok – reader is operating as expected and no errors have been encountered
	Error: "message" – this value is returned only when an error occurs, the "message" portion of this changes depending on the cause of the error.

Figure 7 – Reader command I/O

4.4.1.1 Wavetrend RX900

Driver design

The driver design started with the creation of a list of all the commands that the RX900 reader use and that would be used in normal operation of the reader and not set up of the reader. This list was then used to create a list of commands and the respective data sent to the reader as the command. The data being sent to the reader was read using a network utility called Wireshark. This allowed the researcher to view individual packets going to the reader. While this may seem like a long and arduous process to get the necessary data that is also available in the reader's documentation, it was found that when testing the sending and receiving of the commands from the documentation that some of the commands were inaccurate and the cause of some great headaches. Once the necessary commands and return data formats had been retrieved from the reader's network stream, the design process proceeded.

The design of the reader's driver was made as light as possible as not all the commands were required for the day to day operation of the reader and they were not implemented. The two main commands that were implemented were to get data from the reader and to get the status of the reader.

Get tag data or status

1. Set up a socket connection to the reader.
2. Wait for the connection to establish.
3. Send the necessary command in Byte format to the reader.
4. Wait for the data to be returned from the reader.
5. Once data has been returned from the reader, parse the data into the necessary format as laid out in the abstraction layer design document.

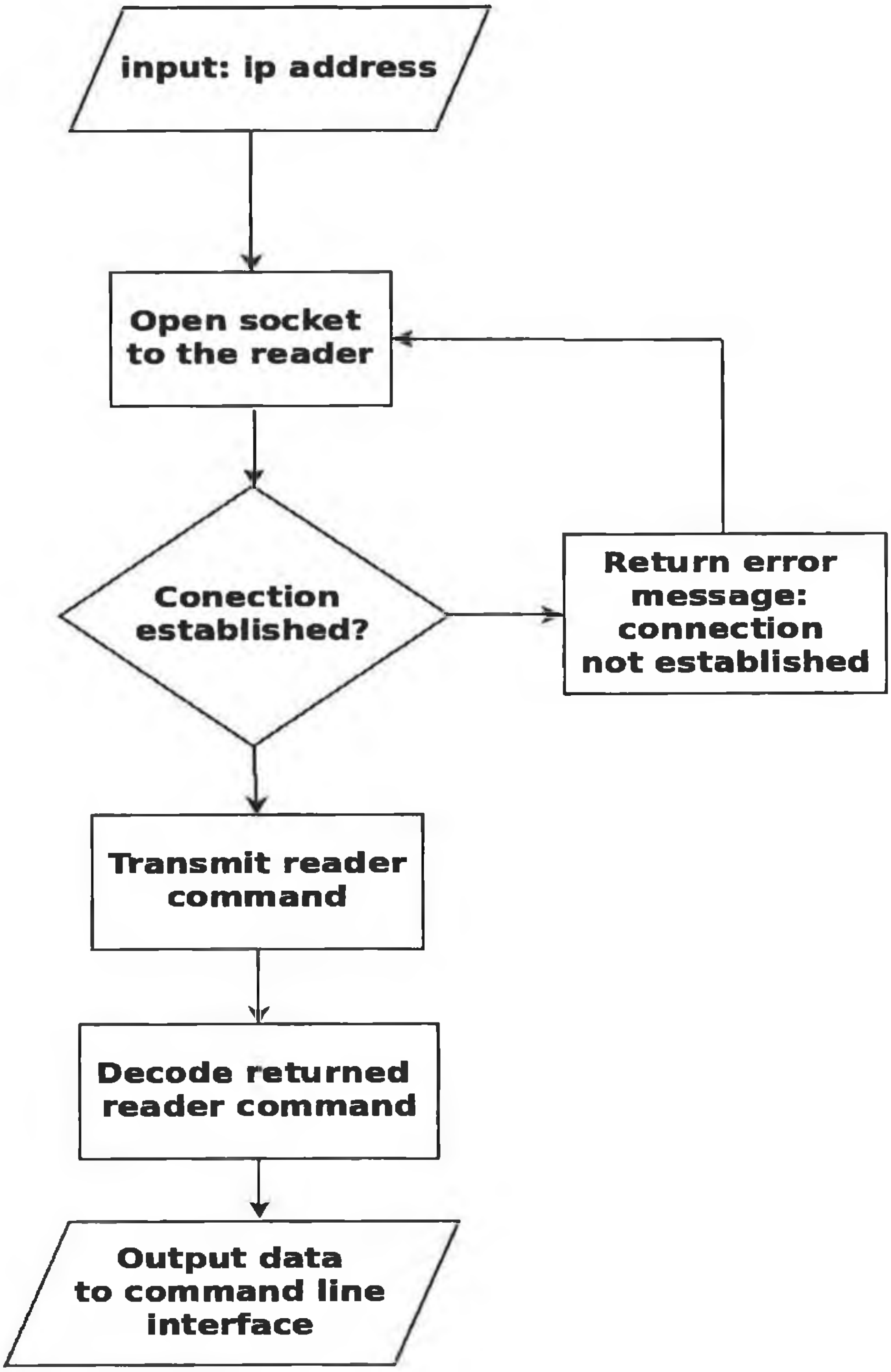

Figure 8 -Get tag data or status

4.4.1.2 Sirit Infinity 510

Driver design

While the Wavetrend RX900 reader buffered all tags read in a first in first out [FIFO] buffer allowing for the retrieval of all of the tag information easily with a simple command, the Infinity 510 did something similar but would not allow the retrieval of all of the necessary tag data. After some research of the Infinity's documentation, it was concluded that the development of a client server architecture was the way forward for the development of the required driver for the Infinity 510. The client server architecture would require the development of a server daemon to run on the Infinity 510 and collect all the necessary data from the reader. This data would be stored in a ring buffer [a ring buffer was chosen due to the limited memory of the device]. It would also have to provide the necessary server to allow the client to gain access to the data stored in the ring buffer.

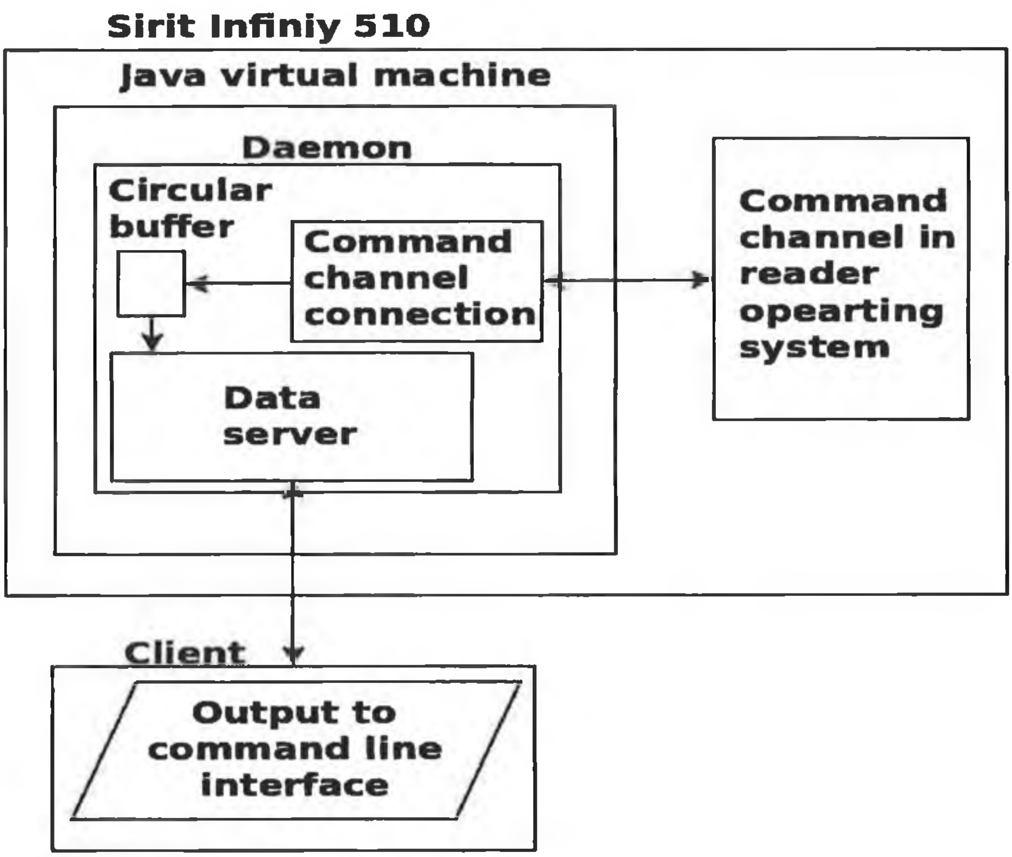

Figure 9 – Sirit Infinity 510 top level block diagram for deamon

With these design parameters in mind, the design of the client server architecture was created. The design was broken down into 3 main parts;

1. Collecting data on the reader
    1. Set up the reader to get the necessary data from the incoming RFID tag stream.
    2. Store this data in the ring buffer.
    3. Error and exception handling.
2. Serving Data from the reader
    1. Bind to the necessary port and wait for connections.
    2. When a connection is received, check the right command has been sent and reply with the appropriate response [accept or close connection].
    3. Transmit data stored in the ring buffer and send the end character.
    4. Close connection.
3. Client to connect to the server
    1. Establish connection to server daemon.
    2. Send correct command.
    3. Receive data from the reader.
    4. Parse data into the correct format in accordance with the abstraction layer documentation.
    5. Disconnect and close connection.

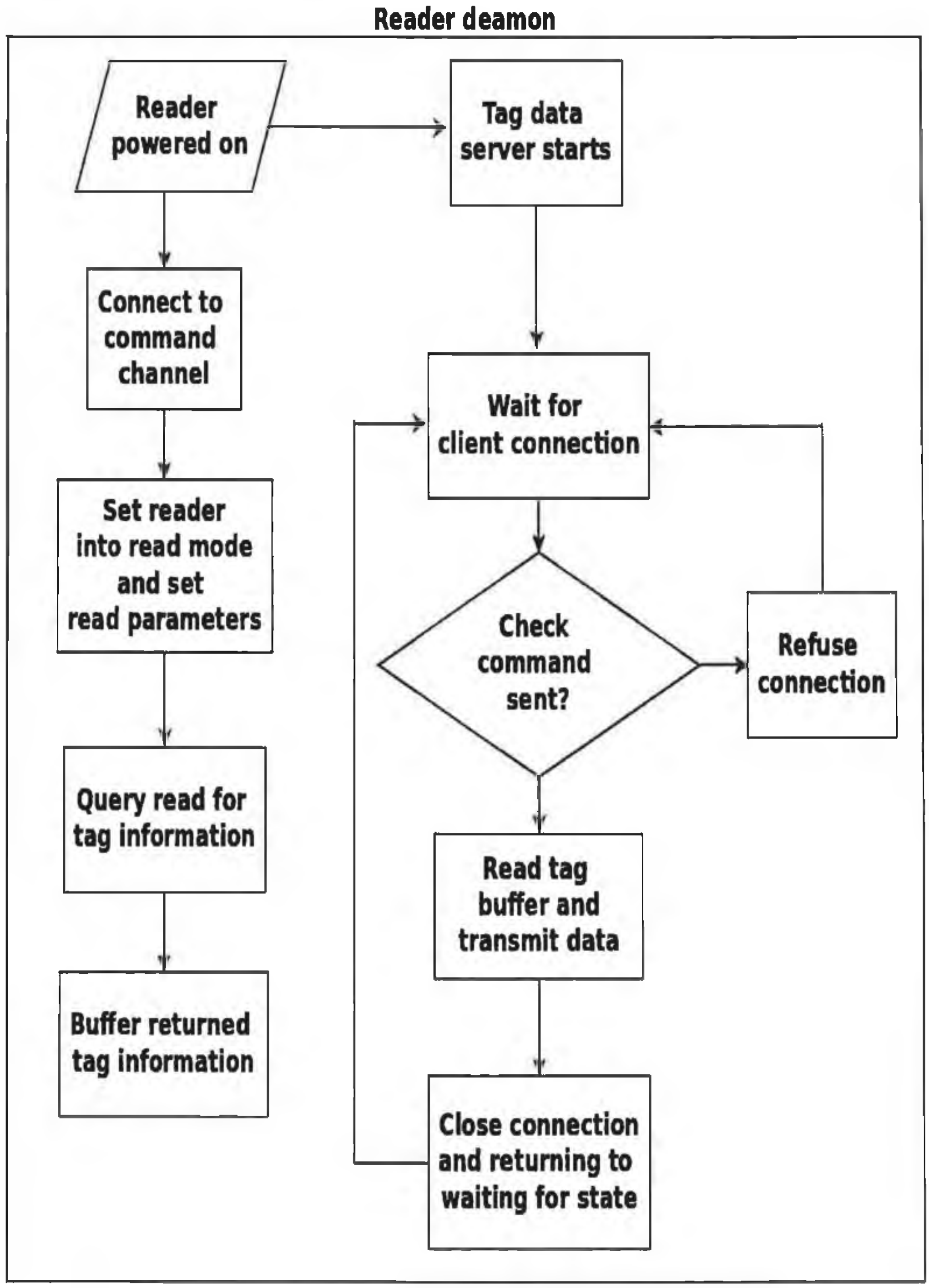

Figure 10 – Reader deamon block diagram

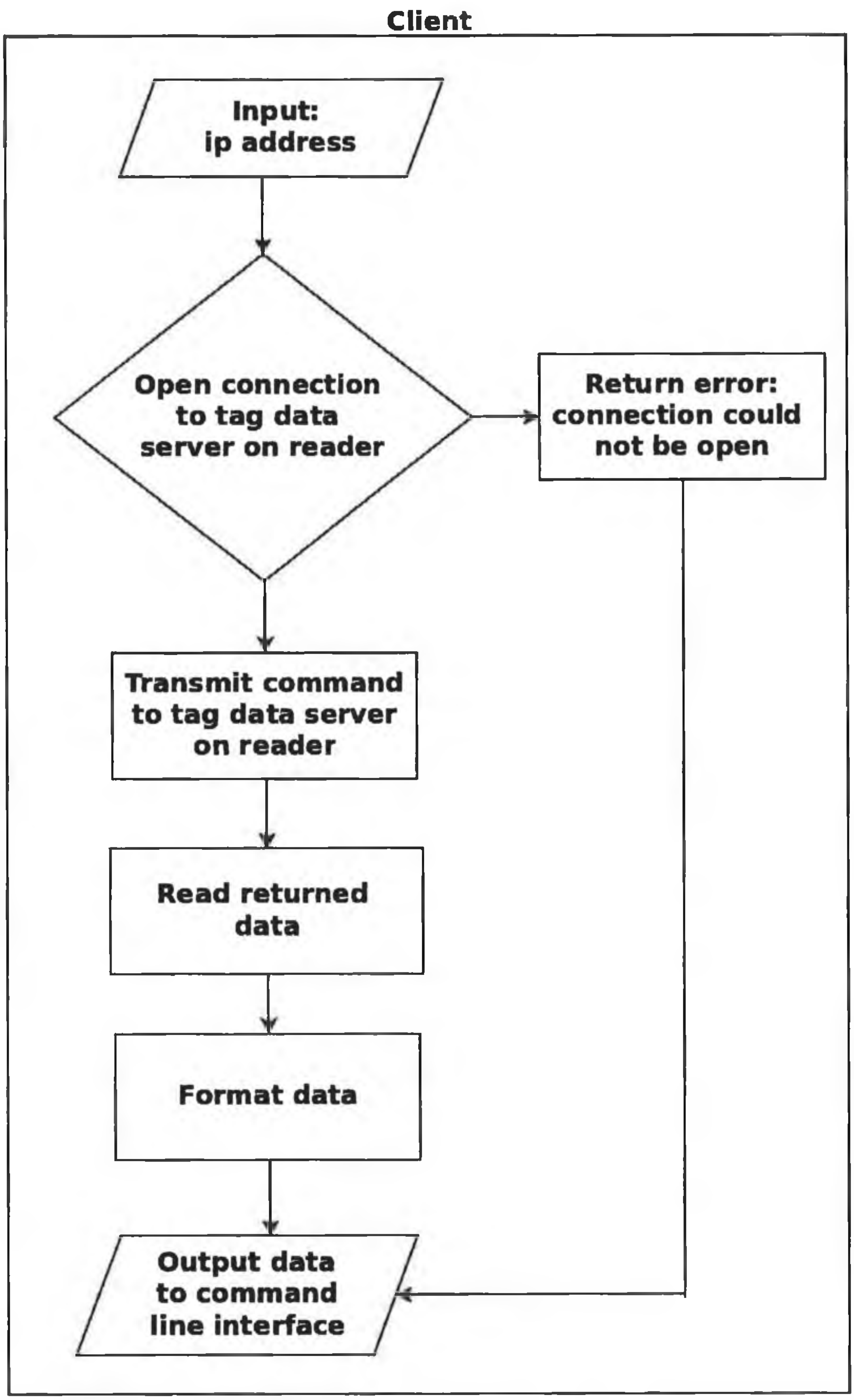

Figure 11 – Sirit Infinity 510 client block diagram

4.4.2 Mobile reader software development

Development of the software for the mobile RFID reader was very different from the development of the required software for the fixed position RFID readers. Once the correct RFID reader had been identified [Symbol 1223 HP], it was a matter of getting the correct software development kit [SDK]. At the same time as locating the SDK for the mobile reader, I also found the source code for the demo program that came with the reader. The demo program allows for the reading of tag data but not for the storing of this data. As the reader required to be operational in a short period of time, a short term solution was to modify the source code of the demo application. This proved to work and the reader was put into operation. Unfortunately this led to problems as without the reader further development of the software for it was difficult and with the exit of the partner company from the project, the further development of this software was sidelined without the necessary hardware to test it on.

4.5 Summary

From the in-depth review of the partner company's system requirements, design, deployment and operation. The design and development of the RFID system for the Juno system could be undertaken using the research done on the partner company's system as a starting point and a good source of data on a currently operating system. This research led to the design decision to utilise a system that covered as much area as possible rather than covering the entrance and exit points of a building. It also provided the necessary requirements for the design and development of the RFID system for Juno so that it could meet all of the present requirements made by the partner company's system. The final part of this chapter dealt with the development of the necessary interface drivers to the readers being deployed for the Juno system and the design decisions taken during the course of the design and development process.

Chapter 5

Implementation

The two main objectives behind the research done in this part of the project was to design and develop an improved RFID configuration for the Juno system and to create the necessary software interface drivers and abstraction layer. The following chapter gives the results of the research.

5.1 Equipment selection

Following on from the RFID system analysis performed in chapter 4 where the requirements for current RFID system was developed, the following equipment was selected as it best fit the requirements for the partner company's system. While meeting other important factors, it was reasonably easy to acquire [there is no point using equipment that is very difficult to source or has large lead time before delivery]. With these factors met, the following equipment was selected and purchased:

Active

- Wavetrend L-RX900 Active Reader

Passive

Fixed

- Feig LRU 2000A
- Sirit Infinity 510

Mobile

- Psion Walkabout Pro model with the TSL snap on UHF RFID reader

Note: The mobile reader was on loan from the partner company due to the partner company leaving the project midway through the project. The research using the mobile was not completed as purchasing a unit for the project was outside the specified budget.

Prior to the departure of the partner company, a good deal of work had been done on the development of the necessary software to provide the required RFID data in a format that could be processed by the partner company's software. This software was in use by the partner company prior to their departure.

5.1.1 Initial equipment test

The initial equipment test was a simple run through of the equipment's documentation and test of the equipment's features and operation.

5.1.1.1 Active

Wavetrend L-RX900 Active Reader
I checked for the correct operation and functionality. Everything worked after a little struggle with an internet protocol [IP] address problem. The read range was impressive even with the small stub antenna provided.

5.1.1.2 Passive

Fixed

Feig LRU 2000A
The most difficult of the two passive readers to setup, it consisted of a Xilinx board running a version of Busybox [Linux] but after much struggling the reader had a basic setup configured and was reading tags.

Sirit Infinity 510
This reader proved to be the easiest to configure, setup and program for. During initial testing, it performed well and on running through the feature list it was found to offer a Java virtual machine [JVM] and Python interrupter for the development of reader applications.

Mobile

Psion Walkabout Pro model with the TSL snap on UHF RFID reader
A more in-depth check of the mobile reader was performed. This included checking the operating system [OS] version and performing any necessary updates to the OS. The supplied RFID reader that was attached to the Psion walkabout Pro was checked for the model number and other necessary information to obtain the correct advanced programmer interface [API].

5.2 RFID lab site survey

After the test bed location had been selected, a thorough site survey was conducted. The lab environment test plan was created a number of months before the final delivery of the RFID equipment. This gave plenty of time for the necessary research to be performed to create a short but yet thorough set of rules to follow when conducting a test plan. The test plan was then implemented and a full site survey was conducted as set out in chapter 3 [3.1.2 Lab environment test plan].

5.2.1 RFID lab site survey results

The results from the sites were a mixture of expected and unexpected results. The first test preformed in the site survey was to identify all possible sources of AEN; this test had an unexpected result. The test was performed over the course of 11 hours [a full 24 hours was not feasible due to the college closing at 21:00] and due to the location of the lab a great deal of AEN was expected. The results showed that the level of noise within the bands that the RFID was operating in, was relatively quiet over the course of the entire 11 hours, with records of the level of noise being taken every hour.
AEN data collected is shown in the table below:

AEN test results				
Time	Peak noise level measured in dBm			
	center frequncy of 866 MHz		center frequncy of 499 MHz	
	Lab 1	Lab 2	Lab 1	Lab 2
09:00:00	-105	-112	-94	-114
10:00:00	-101	-105	-96	-107
11:00:00	-103	-102	-102	-111
12:00:00	-104	-106	-98	-102
13:00:00	-98	-101	-102	-111
14:00:00	-102	-100	-95	-99
15:00:00	-106	-115	-88	-98
16:00:00	-99	-110	-107	-115
17:00:00	-96	-111	-113	-111
18:00:00	-110	-103	-107	-113
19:00:00	-98	-112	-116	-111
20:00:00	-108	-109	-104	-112
21:00:00	-100	-110	-103	-107

Figure 12 – AEN data table

5.2.2 RF path loss contour map

The RF path loss contour mapping of each interrogation zone was performed as per the site survey plan developed. This test was performed only for the passive readers as the active reader's read range is so great that it would prove impossible to perform without the need for a large open space like a warehouse, which was unavailable to this project at the time of testing.

Results:

The results below are from the average of a number of different readings taken at each of the eight points.

Angle	0	45	90	135	180	225	270	315
Frequency	All reading taken in dBm.							
865.5 MHz	-78	-94	-87	-88	-86	-49	-53	-49
866.8 MHz	-83	-85	-82	-94	-79	-46	-48	-51
868 MHz	-71	-84	-80	-83	-88	-52	-47	-53

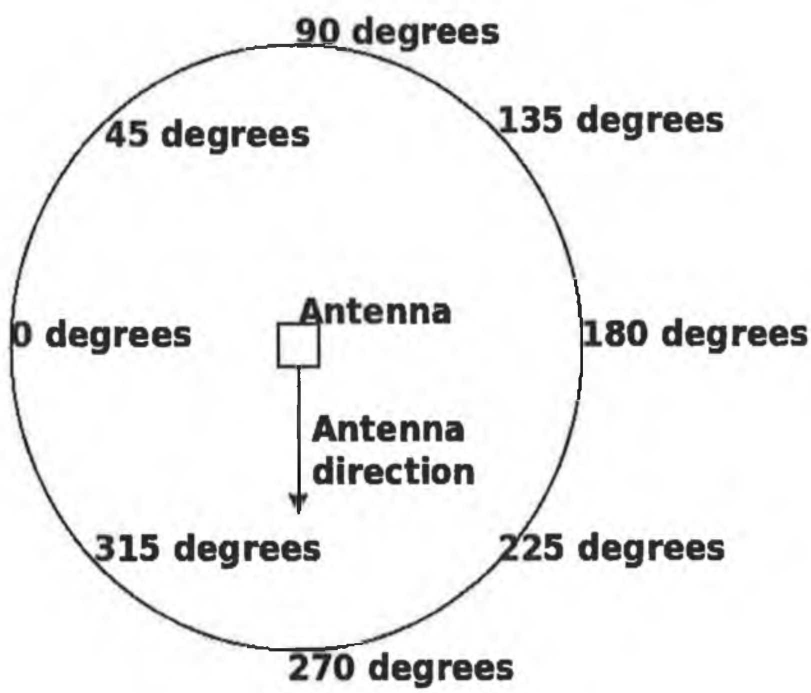

Figure 13 – RF path loss data table

5.3 Readers, antenna and tag testing within the lab

5.3.1 Antenna patterning test

The antenna pattern testing was performed for the passive RFID readers only. A grid was set-up and the antenna was placed in the centre of the grid. The following table shows the results obtained from a number of runs of the test. Due to the variations of the read range obtained over the number of runs of this test, an average read range has been given.

Angle	0	45	90	135	180	225	270	315
Maximum read range	300 to 400 cm	200 to 300 cm	200 to 300 cm	200 to 300 cm	300 to 400 cm	700 to 800 cm	700 to 800 cm	700 to 800 cm

Figure 14 – Antenna pattern test data table

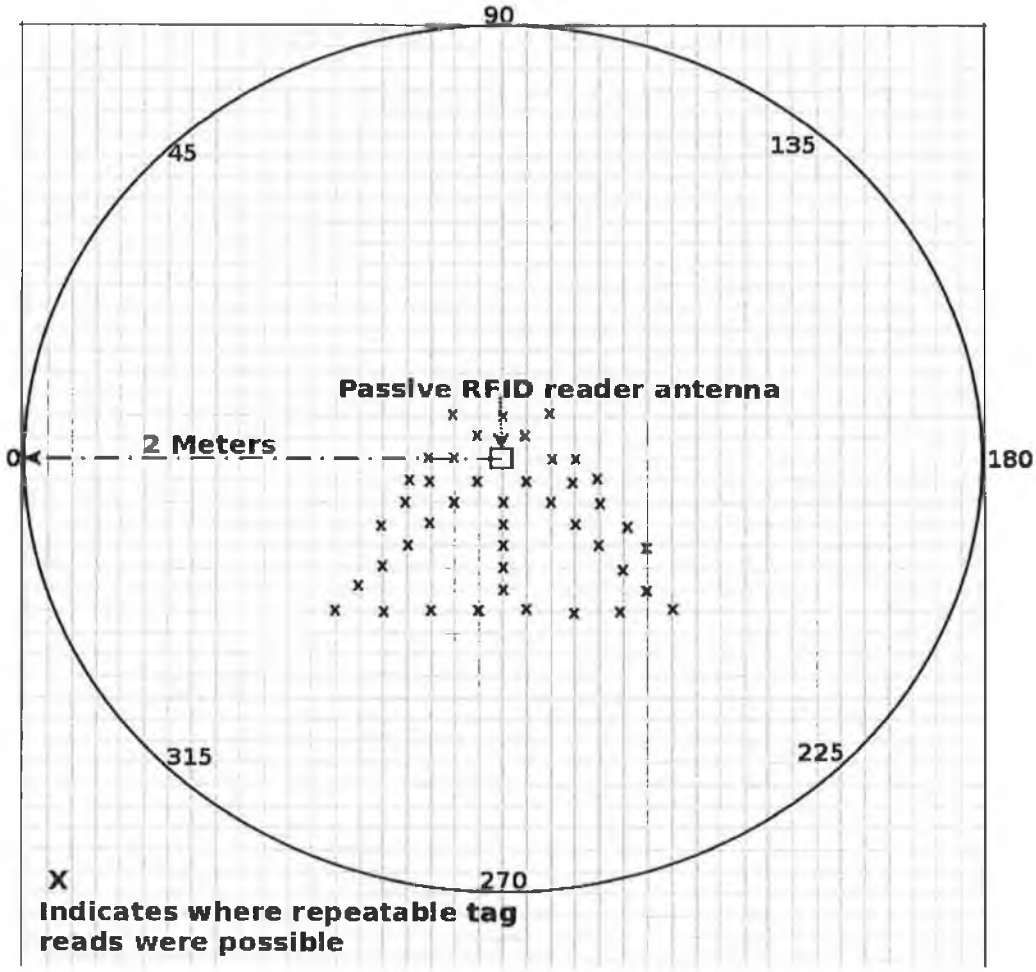

Figure 15 – Antenna pattern test map

5.3.2 Reader performance test (for distance and speed)

5.3.2.1 Distance testing

Testing was carried out as per the test plan. The following table shows the results.

1. Read – tag was read at the specified distance.
2. Not read – tag was not read at the specified distance.

	Materials	Wood	Cardboard	Metal	Plastic	Power supply	Oscilloscope
Distance	Readers						
200 cm	Active	Read	Read	Read	Read	Read	Read
	Passive fixed	Read	Read	Read	Read	Read	Read
	Passive mobile	Read	Read	Not read	Read	Not read	Read
400 cm	Active	Read	Read	Read	Read	Read	Read
	Passive fixed	Read	Read	Read	Read	Read	Read
	Passive mobile	Read	Read	Not read	Read	Not read	Not read
600 cm	Active	Read	Read	Read	Read	Read	Read
	Passive fixed	Read	Read	Not read	Read	Not read	Not read
	Passive mobile	Read	Read	Not read	Read	Not read	Not read
800 cm	Active	Read	Read	Read	Read	Read	Read
	Passive fixed	Not read	Read	Not read	Read	Not read	Not read
	Passive mobile	Not read	Not read	Not read	Not read	Not read	Not read
1 Meter	Active	Read	Read	Read	Read	Read	Read
	Passive fixed	Not read	Not read	Not read	Not read	Not read	Not read
	Passive mobile	Not read	Not read	Not read	Not read	Not read	Not read
1.5 Meters	Active	Read	Read	Read	Read	Read	Read
	Passive fixed	Not read	Not read	Not read	Not read	Not read	Not read
	Passive mobile	Not read	Not read	Not read	Not read	Not read	Not read
2 Meters	Active	Read	Read	Read	Read	Read	Read
	Passive fixed	Not read	Not read	Not read	Not read	Not read	Not read
	Passive mobile	Not read	Not read	Not read	Not read	Not read	Not read
5 Meters	Active	Read	Read	Read	Read	Read	Read
10 Meters	Active	Read	Read	Read	Read	Read	Read

Figure 16 – Distance testing data table

While the results of the active system was as expected, the results of the passive systems was very poor. A number of measures were taken to try and boost the read range of the passive system, but little improvements were made.

5.3.2.2 Speed testing

Active:
This worked consistently at all speeds that the researcher was able to generate.

Passive:
The fixed passive reader preformed with very good results in this test as long as the tag was correctly orientated, on the correct side of the researcher and within the limited read range of the reader.

5.3.2.3 Clean RF output

The output from each reader [both passive and active] was checked over the course of an hour and nothing irregular was displayed on the spectrum analyser for the duration of the test.

5.3.2.4 Tag characterization test

Due the low quantity of both passive and active RFID tags, the results of our testing does not give a usable representation of the read range and failure rate of the tags.

Active

Only about 20 active tags were available as a test sample. All active tags were operating correctly at the time of testing so a failure rate of 0% was recorded. The average read range recorded for the test sample was approximately 20 meters.

Passive

The test sample size for this test was 30 tags. While this is below what we would recommend as an ideal test sample size, it was all the tags available to the team. Testing of both failure rate and read range was conducted using this test sample.

Failure rate

The recorded failure rate for the test sample was 0%, I felt this was a reflection of the test sample size rather than the quality of the tags tested.

5.4 System deployment

The system deployment was done in two phases;
Phase 1: Reader deployment.
Phase 2: Tag deployment.
Following on from the system deployment, in-depth testing of the system was conducted to ensure that it operated to the design parameters specified in the design of the system.

5.4.1 Reader deployment

Following on from the execution of the RFID lab test plan, the RFID system was deployed to the labs. The design that was developed for the lab called for the deployment of the active and passive readers as follows.

5.4.1.1 Passive readers

The deployment of the passive reader best suited to the labs' design was to deploy one reader at each door of the lab [two doors], with one antenna on either side of the door. One Sirit Infinity 510 and one Feig LRU 2000A were deployed. While the Sirit reader performed without any trouble, the Feig reader was troublesome.

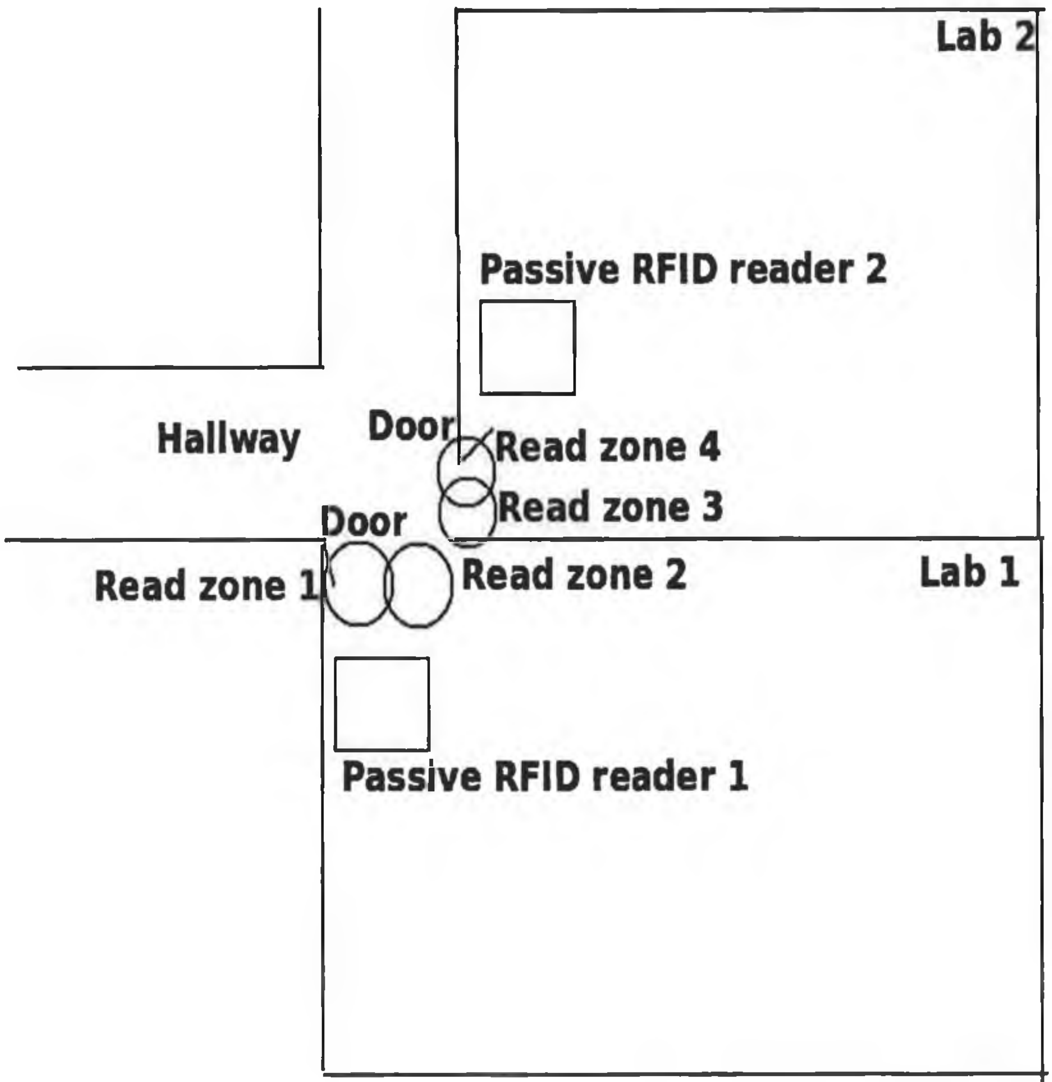

Figure 17 – Passive reader set up

5.4.1.2 Active readers

Two active readers were deployed; one active reader per lab. One active reader could comfortably cover the entire area of the test lab. This design suited the test environment perfectly, allowing for the total coverage of the labs and also allowing for the creation of an overlapping read field. This would be important to cover all aspects of testing the entire system.

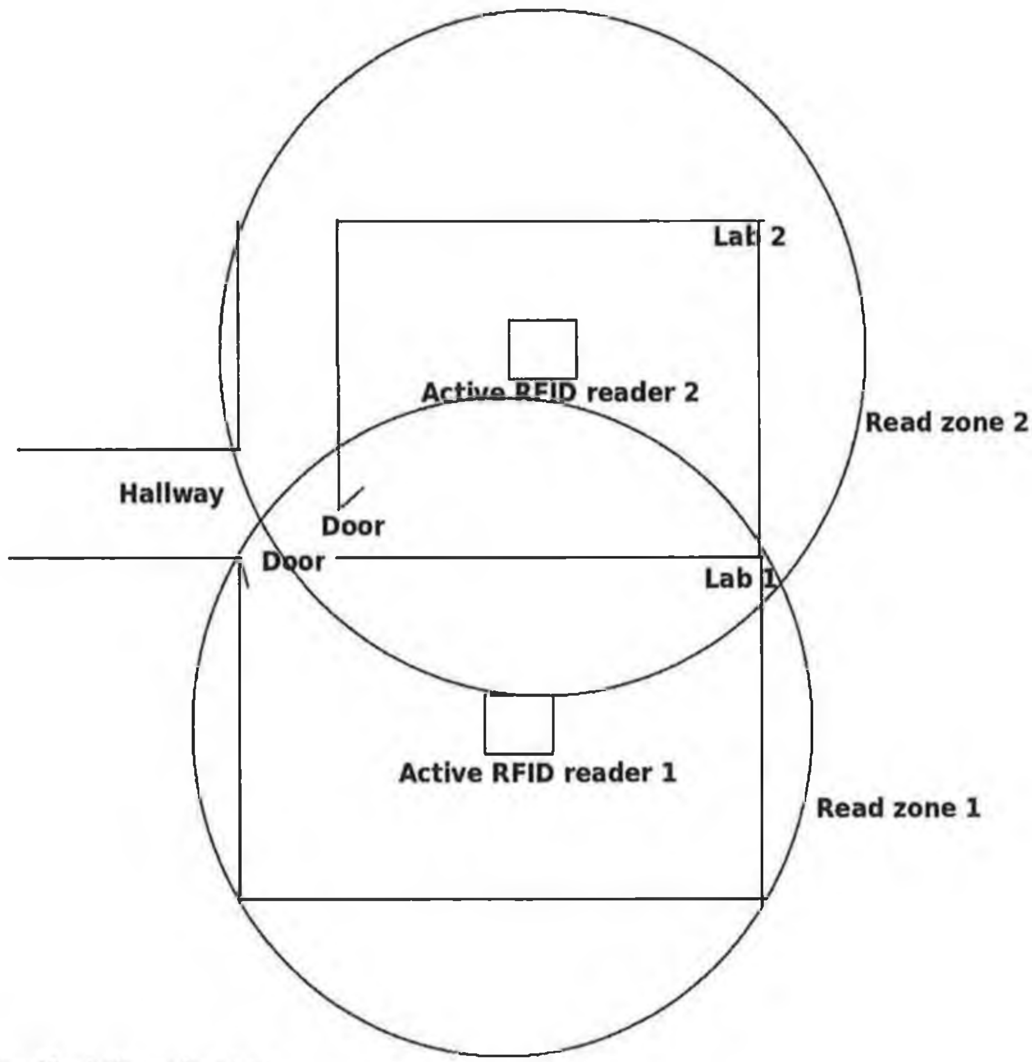

Figure 18 – Active reader set up

5.4.2 Tags

The tag deployment encompassed a number of fields, finding the correct tag for a range of different materials and finding the best orientation for each selected tag. The tables below show the results from the testing performed in this section.

Tag type	Material
Tuned tag [specifically tuned for metal]	Metal
Use of a stand-off or tag with an integrated stand off.	Liquid
As these materials do not cause a problem to RF signal, most RFID tags will operate on them without any problems. The one type of tag that will have problems here are tags designed to operate on metal surfaces as they are tuned to operate with a metal backing.	RF translucent [plastic, wood, cardboard]

Figure 19 – tag type table

5.5 Driver implementation

The development of all of the required drivers for the RFID readers was done using Java SDK 1.6. Java was selected for portability between operating systems. One of the main focuses for the project was to reduce the cost of development and deployment of such a system by using Free Open Source Software [FOSS] wherever possible. This included using Linux as the operating system of choice for deployment to all of the servers used throughout the project.

5.5.1 Wavetrend RX900 driver development and test

Development of the driver was done using a test driven approach. As each block of the code was developed, the relative test that had been developed prior to the start of the development, was executed on the completed block of code.

Code block	Test Unit
Connecting to the reader.	Connection established and return connection established message.
Send necessary reader commands and receive return data.	Receive correct formatted response containing the expected data for the command.
Format data to abstraction layer specifications.	Review of end data and check that it meets the abstraction layer standards.

Figure 20 – RX900 Code block and test table

5.5.2 Sirit infinity 510

The driver development undertook the same test driven development process, with the development of the necessary test units for each block of code before the block of code was written.

Code block	Test unit
Daemon:	
Start running on reader	Print out start up message to reader's buffer
Issue the necessary commands to set reader into the correct operating mode	Reader returns correct command data format
Insert data into circular buffer	Check buffer depth on reader's console
Start client server and wait for connection from client	Print out startup message to reader's console with IP and port number
Send requested tag data to client	Check data output from client
Empty buffer	Print out buffer depth to reader console after data transfer to client
Client:	
Connecting to the reader	Connection established and return connection established message
Send necessary reader commands and receive return data	Receive correct formatted response containing the expected data for the command
Format data to abstraction layer specifications	Review of end data and check that it meets the abstraction layer standards

Figure 21 – Sirit Infinity 510 code block and test table

5.6 Summary of performance, results and observations

Implementation of the active RFID system in the test bed ran smoothly, with few surprises regarding the performance of the overall active system. The overall read rate of the active tags was very high even when the tags were place in obscure locations on laboratory equipment.

In contrast to this, the deployment and testing of the passive system was very troublesome and revealed that passive RFID is not suitable for anything other than the replacement of bar codes within the asset tracking system. Even with this low expectation of passive RFID, one main point must be made; if you do not perform the necessary testing of the tags and readers to be deployed, you should expect major headaches from the system, resulting in read ranges and read rates of the tags to be very low.

Deployment of the reader drivers went very smoothly, with the abstraction layer proving to have been a major achievement of this research as it provides the necessary low level of coupling with the Juno system for the replacement of the current set of readers with new readers with very little extra work required.

The development of the software for the mobile reader proved to be easier than first expected. The modifying of the demo program to perform the necessary tasks was of a major benefit to the partner company as it saved them from losing a customer after missing a number of deadlines with the deployment of the necessary software from a third party developer. It also exposed the researcher to developing software using Microsoft tools [C# and the .Net platform] which was a great experience.

Chapter 6

Conclusion and future work

A look at the results from the project and an in-depth review of those results could lead to the recommendation of future work that would be of benefit to the project.

6.1 Conclusion

During the course of the feasibility study, I got a good grasp of the requirements for the system that the partner company required. It was from this and a thorough review of the partner company's market research, talking to their current client base and dealing with the day to day problems of their current system that helped me get an in-depth view on what the overall system should be able to achieve. The system should allow the tracking of assets in soft real-time, giving a clear and concise view of all of a company's assets.

The main aims of this research were:

1. To develop an understanding of RFID systems, technology and their uses in various forms especially in asset tracking. The development of a number of useful guides on how to research, select, set-up and deploy RFID systems.
2. Development of an interface to a number of RFID readers, along with the implementation of a reader protocol which would allow easy adding of different reader types to the system. The research and development of filtering for the incoming information.
3. Minimise project costs by using open source software wherever possible.

The three aims were met by:
First a full and in-depth evaluation was done on the current state of RFID technology, providing me with the key knowledge to purchase the necessary equipment to proceed with other parts of the project. A large number of visits to the partner company's current

customers provided me with a wealth of knowledge about the different types of real life problems faced when deploying a RFID system in a working environment. This experience would help in the future with the development of both the reader and antenna selection, testing and deployment guidelines. It also gave me an opportunity to get a better understanding of what types of interference sources that would be encountered in a working environment. These visits also gave me the opportunity to gain hands on experience at deploying a working system into a live environment. This would also prove to be useful going forward in the project.

Once I had gained experience in the deployment of a RFID system in the real world, I found that the development and testing of the required lab within GMIT to be a challenging but worthwhile exercise. The development of this test bed provided me with the necessary controllable environment to allow the further development and testing of all the techniques that I have developed while installing equipment for the partner company [i.e. full Faraday cycle analysis and interrogation zone plotting]. When the test bed was finished, it provided a controlled environment to continue the rest of the testing of tags, antennas and readers.

The second aim of the project was to develop a set of tools for the interfacing and collection of data from the edge of the system. As the previous interfacing to all the partner company's readers were serial RS485 in nature, this required the development of a completely new set of tools. These tools were developed using Java [JDK 1.6] allowing for portability. This coupled with Linux running on a virtual machine, allowed for the quick and easy deployment of the system. The use of Java, vmware server and Linux met the partner company's requirement for a low cost solution to their problem.

The third aim of reducing the ov antennas erall expense of such a system was also achieved by utilising free software [JDK and Linux]. This combination led to a reduction in the overall cost of production and deployment of a system.

6.1.1 Performance of the finished system

The performance of the finished system shows a marked improvement over the original system that had been deployed by the partner company. These performance gains fell into a number of categories :

6.1.1.1 A reduction in false reads in the active RFID system

The reduction in false reads of tagged assets was the biggest improvement that the Juno design RFID system offered over the previous system. The Juno design RFID system offered a 60% to 70% improvement in false reads over the previous RFID system. This was tested by having a tagged asset pass through a door in the test bed system. Using the previous RFID system, the tag was read between 60% to 70% percent of the time. The signal strength used for this test using the old system was strong enough to detect the tag leaving the test bed system through that one door but low enough to keep the read range as small as possible. When repeating the same test with the new system, the tag was always within the read zone of the RFID reader, hence no false positives were detected.

6.1.1.2 Improvement in the ability to track tagged assets

The Juno design for the active RFID system also added the ability to track a RFID tag within the test bed facility. While the accuracy of the tracking was low, the tagged asset could be located to one of the two labs that was covered by the active RFID system. It was felt that this was a large improvement over the original system that could only detect the tagged asset when it passed through a read zone but could not detect the direction the asset travelled. The accuracy of the tracking could be improved with the addition of more RFID readers to the system.

6.1.1.3 Performance gains in the use of passive RFID

The performance gains in the passive RFID system are harder to quantify because of their nature. While the project did not improve the design of the original passive RFID system, it was felt that the research performed within this project improved the reliability of the read rate and read range of the passive RFID system. This was achieved by the development of the necessary protocols for the selection, testing, positioning and placement of the passive RFID tags. Following these protocols the passive RFID system should operate more reliably.

6.1.1.4 Abstraction layer

The advantages created by the introduction of an abstraction layer between the middleware system and the RFID readers cannot be quantified until there is a requirement for the development of a driver for a new RFID reader. But it is felt with the well defined set of instructions that are required to operate the system, the development of a driver for a new RFID reader should be shortened considerably. This reduction in development time would have saved both time and money.

6.2 Future work

During the course of the project a number of questions were asked by the partner company regarding extending the read distance of passive RFID. Many avenues of research were viewed, but without greater funding behind the project they proved to be impossible to follow up. One such avenue was research into Mojix STAR System [www.mojix.com]. Research into this type of RFID could provide the necessary savings from the use of cheaper [relative to active tags] passive tags and deploying a Mojix STAR System. Another possible area for research is the use of an all open source RFID reader and tag system. While this would prove to be of great interest to the project, the idea had to be shelved due to time and budget constraints.

Chapter 7

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Chapter 8

8.1 Appendix

8.2 Glossary

RFID

Radio frequency identification, a type of technology that uses radio frequency wave to communicate between a reader and tag.

Passive RFID

Passive indicates that the tag does not contain its own power supply and hence must gather the required power from the readers transmissions.

Active RFID

Active indicates that the tag has its own internal power supply and does not require the readers transmission for power.

RF

Radio frequency is a member of the electromagnetic spectrum between audio and infra-red.

EPC

Electronic product code, a unique number stored on a RFID tag.

LF

Low frequency, a frequency between the range of 30 to 300 KHz.

HF

High frequency, a frequency between the range of 3 to 30 MHz.

UHF

Ultra high frequency, a frequency between the range of 300 MHz to 3 GHz.

ASK

Amptitude shift keying is a method for transmitting data by the modulation of the ampitude of the carrier wave.

PSK

Phase shift keying is a method for transmitting data by the modulation of the phase of the carrier wave.

FSK

Frequency shift keying is a method for transmitting data by the modulation of the frequency of the carrier wave.

ISO

The international standard organisation is an organisation resposible for the development and publishing of standards within a wide range of fields, including RFID.

AEN

Ambient electronic noise is electronic noise produced by the operation of electronic deveice.

dBm

The dB is a logarithmic unit measurement, dBm refers to mili dB.

USB

Universal serial bus, a type of connection interface found on most computers, laptop and electronic devices.

PCMCIA

Personal Computer Memory Card International Association (PCMCIA) is a form of PC Card developed by the standards body Personal Computer Memory Card International Association.

RS232

Recommend Standard 232 is the stand for connecting devices to serial ports.

RS485

Similar to RS232 but for use over longer distances and noisy environments, it allows a number of devices to be daisy changed together.

POE - Power Over Ethernet

A standard for passing electrical power and data over the same ethernet cable.

XML

Ex-tenable mark-up language

SMS

Short message service.

Asset register - what is it?

A list of all the assets a company own, along with their individual value, depreciation and net book value.

Cat5

Categories 5 cable, normally referring to unshielded twisted pair cable used for computer networks.

FIFO

First out, first in. A type of buffer commonly used in electronics and software where the first piece of data into the buffer will be the first piece to get dumped out of the buffer once it is full.

Daemon

A computer program that runs in the back ground, normally started by the user. Call a Daemon in Unix operating systems and called a service in Microsoft Windowz Operating systems.

OS

Operating system.

API

Advanced programmer interface.

SDK

Software development kit

FOSS

Free open source software.

Juno

The asset tracking system that was researched, designed and developed within this project.