An Investigation into the Monitoring of Pest Control Devices using Wireless Communication

A report proposing innovative methods of low-level communication for pest control operations - control device status monitoring

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ABSTRACT

The monitoring of animal control devices (animal traps) in remote areas currently requires field workers to visit each device on a regular basis, which is costly and time consuming. Better monitoring practices could allow DOC to increase their trapping practices through reduced costs. Essentially, the aim of this paper is to reduce the number of man-hours, and hence resources, required to check each trap. An attempt will be made to use wireless communications to check the status of each trap, and hence decide whether or not it will need to be checked, bringing benefits of efficiency and cost savings to the Department of Conservation.

It is recognised that the environment is very difficult for traditional wireless communications to operate reliably and therefore new methods or technologies were investigated for this application. A system operating at 27MHz using a modified pulse position modulation scheme was found to be an appropriate solution; however the success of wireless communications in pest control management is dependent upon the trapping location, patterns and terrain.

DOCUMENT CONTROL

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APPROVALS

Date	Signature	Recipient	Company
		Piet Beukman	MEM (Course Director)
		Graeme Woodward	Project Supervisor
		Fred Samandari	Sponsor

DISCLAIMER

Any and all potential Intellectual Property (IP) developed in this project is the property of the University of Canterbury.

Acknowledgements

I would like to start by acknowledging the continuous and valuable support provided by my technical supervisor, Kelvin Barnsdale. Further to this acknowledgement I would like to thank Piet Beukman and Graeme Woodward who have helped to keep the project on track with timely and constructive interventions. Finally, I would like to thank Thomas Harding for the hard work he has put into the intersecting areas of our projects.

EXECUTIVE SUMMARY

"How can the New Zealand Department of Conservation implement wireless communication into their pest management programme?"

This project is aimed at answering the above question. It involved significant research, culminating in the design of an appropriate wireless communication prototype. A cost benefit analysis found that the New Zealand Department of Conservation (DOC) may benefit from such monitoring networks which led to the development of an implementation guideline. This report concludes with strategic recommendations that focus upon using wireless communication to make pest control management more efficient.

The Wireless Research Centre, at the University of Canterbury, was approached by Landcare Research to investigate the introduction of one way wireless communication from its pest control devices. An initial issue facing the researcher was the substantial scope of the project. A literature review, in combination with investigations into current systems and new technologies, suggested the following ways in which the scope could be appropriately narrowed:

- Use a field trip site near Little River, Akaroa, as the targeted scenario, summarised as:
  - Dense bush terrain, with patches of open undulating land.
  - Block elimination trapping technique used over five days.
  - Traps placed in three lines, roughly 1.5km long.
  - Approximately 200 traps, suggesting an average gap of 20m between traps.
- Split the communication into two stages. The first leg links each trap to an on-site receiver. The second stage links this receiver to a ranger. Focus upon the first of these two steps.
- Use a frequency below 200MHz, a general consensus in literature.

Forest and bush propagation modelling suggested that 140MHz and 169MHz were well suited to the terrain, however 27MHz was found to be the most appropriate. Further results found that 27MHz could be modelled using the Free Space Path Loss model with an added attenuation of 35dB.

A modified Pulse Position Modulation (PPM) scheme was chosen to provide the link from traps to the receiver. This method, which has yet to be found in literature, uses pulses of various duty cycles to receive information from multiple sources. Mathematical simulations (using MATLAB software) showed that modified PPM is a viable solution. A prototype built using this scheme will benefit from power efficiency, hardware simplicity and less dependence upon clock synchronisation. The novelty of this scheme suggests it could be patentable.

Implementation of a proof of concept further demonstrated the viability of modified PPM. A simple test system, consisting of one receiver and five transmitters was able to accurately detect the status of each trap. The whole test system, without including a handheld receiver, cost less than NZ$150, with the full system estimated to cost around $4,500. A Cost Benefit Analysis (CBA), using the Little River site suggested that the entire system, consisting of 100 traps and one receiver, would need to cost less than $5,000 to ensure a one year payback period.

An Implementation Guideline suggests six steps to be followed in the situation that this system is released as a commercial product, comprising of:

- Making the product ready for release
- Building product demand
- Releasing the product
- Looking for potential markets
- Continuing development
- Creating contingency plans

Evaluation of the project showed that delays did occur, but were negated through efficient time management and a flexible plan. Lessons learnt focussed upon these facts while also promoting greater communication between involved parties. The discussion of the potential for a patent on the modified pulse position modulation scheme resulted in advice to keep it as a trade secret, rather than actively patent it.

It was also determined that the project came down to solving several dilemmas. The first was a suitable reduction in scope. This required a shift of focus from simply completing tasks to deciphering what the customer really needs. For this reason a focus was placed upon satisfying the needs of a single site first, then expanding the scope from there. A pest control cycle was developed that uses technology, Near Vertical Incidence Skywave (NVIS) and modified Pulse Position Modulation (PPM), to both monitor and trap pests.

Another issue was faced in the form of accurate timing, with any improvements in clock accuracy offset by increases in cost. Solutions included more accurate, yet expensive, microcontrollers or cheap clock hardware that can be attached. One more quandary was the compromise between lower frequencies and smaller antenna, with a middle ground unavailable due to a lack of available frequency bands. A suggested solution was to investigate acquiring channels in the 40MHz to 70MHz range which will soon become available as a result of the digital changeover.

Specialisations made during this 4bits/day prototype development have meant that the resulting product would translate poorly to a 1kbits/day situation. NVIS, also investigated in the course of this report, could be a potential solution to this data transmission rate.

Recommendations have been put in place, as a result of this report, including:

1. Transmit at a frequency of around 27MHz.
2. Use the modified pulse position system described in this report.
3. Make use of cheap and compact microprocessors.

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1 INTRODUCTION

1.1 STAKEHOLDERS

1.1.1 DEPARTMENT OF CONSERVATION (NEW ZEALAND)

The Department of Conservation (DOC) is a New Zealand state sector organisation that deals with the conservation of New Zealand's natural and historic heritage. DOC has a leading role in conservation work that contributes to NZ prosperity. This includes hands-on work with species and ecosystems as well as leading conservation research and science (DOC), bringing Landcare Research into the mix.

1.1.2 LANDCARE RESEARCH – MANAAKI WHENUA

One of eight Crown Research Institutes (CRIs), Landcare Research's core purpose is to drive innovation in the management of terrestrial biodiversity and land resources. It is for this reason that the University of Canterbury (UoC) Wireless Research Centre (WRC) has been employed to investigate wireless communication from its pest control devices. (Landcare Research)

1.1.3 UOC WIRELESS RESEARCH CENTRE

The Wireless Research Centre, of the College of Engineering, joins together leading academic researchers from around the world, technology and communication based companies, students and Government to undertake ground breaking research in the field of wireless communication. (UoC WRC) Once the WRC are given a project they find the researcher(s) best suited to develop it.

1.2 BACKGROUND

1.2.1 REMOTE PEST CONTROL DEVICE MONITORING

The monitoring of animal control devices (traps) in remote areas currently requires field workers to visit each device on a regular basis, which is costly and time consuming. The researcher is charged with developing a system that remotely monitors the status of these devices, with a goal to bring benefits of time efficiency and cost savings to DOC.

It is recognised the environment is very difficult for traditional wireless communications to operate reliably and therefore new methods or technologies should be investigated for this application. It is for this reason that the project will focus upon control device status monitoring, with data rates of down to 4 bits/day.

1.2.2 RELATED PROJECT – THOMAS HARDING

A related, but still distinct, project will focus upon animal behaviour video monitoring, with a data rate of between 1 and 4MB/day. The project will concentrate on transmission methods only. There are related areas within the project, which are defined in the following Technical Objectives section.

1.3 Technical Objectives

The project can be summed up into two all-encompassing objectives, as seen in the Original Project Outline in Appendix A. The first is to investigate new methods for remotely monitoring the status of animal control devices. This then leads to the second, which is to make recommendations based upon the results, and test any new methods using a proof of concept system. These were then further clarified, by Kelvin Barnsdale (Technical Supervisor), into the following task list.

- To be performed co-operatively with the parallel project described in the previous section, as there are large areas of intersection of knowledge:
  1. Literature review for current research in this application area.
  2. Collect data on the current wireless systems in use, and the constraints imposed by the environment on the installations. Assess if and why existing "off the shelf" methods of wireless communication cannot be used, and identify areas of weakness.
  3. Investigate new low power wireless technologies that may be applicable to this application, both with and without reliance on networks. This will include new modulation types for low signal applications and antennas.
- To be performed jointly, where requirements between the two projects are shared:
  4. Investigate methods to predict wireless propagation through forest using terrain models.
  5. Investigate the relationship between radio frequency, forest type and propagation.
- To be performed individually, where research has led to different outcomes and technologies:
  6. Propose a new system of low power wireless communication for this application.
  7. Analyse the system robustness and research ways to predict link failure rates.
  8. Design and assemble a proof of concept system, capable of being tested in the target environment for a short period.

One of the most important activities within this report, not specifically mentioned above, is narrowing the scope through research and appropriate assumptions. The overall objective of this project can be summed up in the form of a single question:

"How can the DOC implement wireless communication into their pest management programme?"

1.4 Deliverables

The student is expected to deliver a thesis on the work carried out on 4 bits/day control device status monitoring. This will include a model relating radio frequency, forest type and propagation, a proof of concept system, a cost benefit analysis, and an implementation plan. It will then conclude with comment on potential for an environmental sensor network, with data rates of 1k bit/day.

2 PROJECT PREPARATION

With the project initiated near the start of 2012, but limited resources available until October, it was decided that preparation should be undertaken in the meantime. This allowed for time to plan the entire project, gather suitable background material and even participate in field trips.

2.1 PROJECT PLAN

In order to ensure the time over the year was managed appropriately a plan was developed. It consisted of nine major milestones, with all but Project Administration resulting in a progress report. These major milestones were then broken down into minor milestones. Each minor milestone was then quantified with expected completion times. These were then assigned to dates, providing the below basic schedule. More detailed information, including minor milestones, can be viewed in Appendix B.

Task #	Major Milestones	Planned		
		Start Date	Finish Date	Time (hrs)
1.1	Project Administration	23/03/2012	29/01/2013	78
Contact initiated, specifications drawn up, agreement made. This includes meetings throughout the project.				
1.2	Literature Review	02/04/2012	09/07/2013	70
A report detailing the research completed as part of the literature review.				
1.3	Current Systems	09/07/2012	10/09/2012	45
A report listing current processes in place and similar situations where wireless communications are in place. This report will also include a review of off the shelf products available.				
1.4	New Technologies	10/09/2012	12/10/2012	55
A report investigating emerging technologies that could be applied to the situation.				
1.5	Propagation Model	15/10/2012	08/11/2012	150
A report investigating current propagation models, detailing why they are unsuitable. Find a suitable model by building on existing models, confirming it with field testing.				
1.6	Prototype Development	12/11/2012	08/01/2013	200
Evaluate proposed concepts, select one, analyse the system, then design and build a proof of concept system.				
2.1	Cost Benefit Analysis	17/12/2012	13/01/2013	100
A report comparing the proposed prototype with similar systems and the process currently in place.				
2.2	Implementation Guideline	04/01/2013	20/01/2013	100
A report detailing the step by step process of deploying the product throughout DOC's projects.				
3.1	Thesis Submission	24/01/2013	29/01/2013	35
A report collating all research and recommendations for the project.				
Project		**23/03/2012**	**29/01/2013**	**833**

Table 1: A table consisting of major project milestones along with their associated dates and duration.

2.2 Literature Review

A literature review was performed in order to demonstrate knowledge of the related fields while establishing a theoretical framework. Below is a review summary, to help the reader build a basic technical understanding, with more information relating to this section is available in Appendix C-1.

2.2.1 Pest Control

There are many animals considered pests within New Zealand, all of which threaten native New Zealand plants and animals. It is mainly native bird species, including the takahe, kokako and kaki that are fighting for survival against these introduced predators. Ground control methods are particularly effective and DOC spends over $5 million a year on stoat and rat trapping with a network of 180,000 traps.

2.2.2 Radio Communications

Radio waves are the basic unit of wireless communication. By varying the characteristics of a radio wave—frequency, amplitude, or phase—these waves can be used to communicate information. The process of modulation then allows the radio waves to carry information. In this process the message is impressed onto a “carrier” radio wave that is then transmitted. When a radio signal is received, the information is converted back into its original form via a process called demodulation.

2.2.3 Low Power Radio Communications

The definition of Low Power Radio depends upon the frequency at which you are transmitting, but it is typically around 1 Watt. The most effective method for reducing power consumption is by employing a duty cycle, which enables the device to be on only a fraction of the time. This restriction on power consumption is not uncommon in wireless communications and various options are available for power generation through wind or solar energy. Without mains power or another form of power generation the only reasonable option left is batteries.

2.2.4 Antenna Construction

The complexity of antenna design means that it is often left to last during the design of a communication system. The antenna determines the range, performance and legality of an RF link. An antenna is used to convert electric currents into electromagnetic waves and vice versa. Any given frequency corresponds with a wavelength, and the best antenna is related to the wavelength. This resonance occurs at multiples or fractions of the frequency and hence smaller or larger aerials can still be used to pick up a signal.

2.2.5 *Propagation Loss Models*

The transmission of radio signals, at different frequencies, can be affected by many different factors. Attenuation refers to the weakening of a radio signal as it passes through a specific medium. All radio signals are attenuated as they pass through rain or clouds, but radio signals at higher frequencies will be attenuated more than those at lower frequencies. Radio waves are also bent as they pass through the atmosphere because of changes in atmospheric density. This bending is called refraction.

There are many propagation loss models that are used to estimate these losses. Several commonly used options are the Free Space Model, the CCIR Model and the (Okamura-)Hata Models. The accuracy of these models depends on the terrain and frequency in which the system is operating.

2.2.6 *Propagation Through Forested Environments*

A signal is heavily affected by obstacles in its path, particularly those which have a similar length to the signals wavelength, or a gap of a wavelength between obstacles. Objects with a length larger than the wavelength will cause attenuation of the signal as it passes through the object. If the wavelength is greater than the length of the object then the signal will pass through or around the obstacle relatively un-attenuated. There have been many attempts to model propagation loss in forested terrain; however the variation in terrain means that each model must be adjusted to be accurate.

2.3 Current Systems

After an understanding of the technology involved had been gained, the next step was to look into the practices currently employed by DOC. The information below was collected through field trips, interviews and background reading, with a full report, containing more detail, in Appendix C-2.

2.3.1 *Present Arrangements*

2.3.1.1 Pest Control Processes

After shadowing two trappers implementing their respective pest control processes, the information was compiled into a report. Both of these field trips were taken to the Akaroa (Banks Peninsula) region of Canterbury, New Zealand. The process typically begins with the trappers following pre-designated lines laying traps at intervals of 20 metres. These tracks appear to be about 1.5km in length, and are often parallel with each other. A feeder is then placed above the trap, drawing the possum into the trap. This type of trapping is called “block elimination”, and the process is continued until a sufficiently small number of possums remain in the area.

2.3.1.2 Existing DOC communication methods

DOC operates a VHF radio network covering the majority of conservation land in New Zealand. It has however been indicated (Cockburn, 2012) that the primary use of the network is for emergency services. There are two groups of frequencies available to DOC, ones they have licensed and others that can be used with a General Users Radio License. DOC own over 500 licenses at frequencies less than 500MHz, which are specific to certain areas and power levels. Many of these frequencies may be reserved for emergency operations and, hence, must be checked before used.

2.3.1.3 Environmental Constraints

While researching into this topic we found three main sources of information for the type of terrain the system is expected to operate in. These sources were interviews with Bruce Warburton and Stuart Cockburn of Landcare Research, a previous report for DOC by Julian and Derek Carver and field trip experiences. We can expect dense bush coverage, without line of sight between monitoring stations, and variations in both area size and undulation.

2.3.2 *"Off The Shelf" Methods Of Communication Available*

Research was performed in order to find commonly used wireless communication methods. It was found that no "off the shelf" methods were applicable to this project, and the reasons for each have been listed in Table 2, seen below.

Method	Why won't it work?
Wi-Fi	High frequency leads to poor propagation in expected terrain.
WiMAX	High frequency leads to poor propagation in expected terrain.
Cellular	Poor coverage in required areas and high frequency.
Bluetooth	High frequency leads to poor propagation in expected terrain.
ZigBee	High frequency leads to poor propagation in expected terrain.
Satellite Communications	Expensive and link unreliable, due high frequency conflict with weather.

Table 2: "Off the shelf" methods of communication, and why they cannot be used in this project.

2.3.3 *Similar Systems With Alternative Applications*

Research parameters were then extended to include examples where similar applications have been implemented. These systems, along with the reason for unsuitability, are below in Table 3.

Application	Why won't it work?
Bird Monitoring Habitat	Requires on-site computer within short range.
Vineyard Sensor Network	Inadequate terrain, foliage to uniform and low.
Lawn Monitoring Network	Inadequate distance, at inappropriate frequency.
Animal Movement Tracking Network	Does not lend itself to multiple transmitters in one channel.
Industrial Process Automation	Inadequate terrain, too little foliage.

Table 3: Similar systems with alternative applications, and their applicability to this project (Willis, 2007).

2.4 NEW TECHNOLOGIES

Once we have looked into current technologies that could applied to this project we need to look at new technologies that could potentially affect the best solution. A summary of these technologies has been provided below; however a full report relating to new technologies is available in Appendix C-3.

<table>
<tr><th>Technology</th><th>Applicable?</th><th>Details</th></tr>
<tr><td>A24 Trap</td><td>Yes</td><td>Unrelated to core project requirements.</td></tr>
<tr><td colspan="3">The A24 traps can repeatedly kill and re-set themselves before they need to be serviced. These traps can trigger 24 times before they need to be serviced, compared with the current traps which must be manually re-set.</td></tr>
<tr><td>Wi-Fi (802.11ah)</td><td>No</td><td>Inappropriate frequency.</td></tr>
<tr><td colspan="3">"Wi-Fi" is short for Wireless Fidelity, and is a high speed internet and network connection without the use of wires. A new Wi-Fi standard is expected in 2013 which aims to provide an ultra-low-power option at sub 1GHz.</td></tr>
<tr><td>4G</td><td>Yes</td><td>Limited coverage expected in required regions.</td></tr>
<tr><td colspan="3">As the technology behind mobile phone technology improves, the performance also develops. While the technology may be suitable for this project, it relies on existing infrastructure being able to cover the region.</td></tr>
<tr><td>Flexible Spectrum Management</td><td>No</td><td>Complexity requires high levels of power, which is unavailable on each node.</td></tr>
<tr><td colspan="3">The concept of flexible spectrum management refers to a set of new and dynamic procedures and techniques for obtaining and transferring spectrum usage rights and dynamically changing the specific use of frequencies.</td></tr>
<tr><td>New Modulation Schemes</td><td>No</td><td>Complexity requires high levels of power, which is unavailable on each node.</td></tr>
<tr><td colspan="3">While a new modulation scheme may help improve the effectiveness of the system in this project the low power availability will limit the level of processing capability.</td></tr>
<tr><td>Smart Antenna</td><td>No</td><td>Currently too complex and expensive for this project.</td></tr>
<tr><td colspan="3">Smart antennas are antenna arrays with smart signal processing algorithms which calculate beam forming vectors, to track and locate the antenna beam on the mobile/target.</td></tr>
<tr><td>NVIS</td><td>Yes</td><td>Antenna requirements are long for “in the field” applications.</td></tr>
<tr><td colspan="3">Near Vertical Incidence Signal (or Skywave), or NVIS, transmits radio waves upwards into the ionosphere, where they are refracted back down and can be received within 650 km of the transmitter. While not a new technology, it does not appear to have been considered for this type of application.</td></tr>
<tr><td>Smart Dust</td><td>No</td><td>Not yet commercial/technically viable.</td></tr>
<tr><td colspan="3">"Smart dust" devices are tiny wireless micro-electro-mechanical sensors (MEMS) that can detect everything from light to vibrations.</td></tr>
</table>

Table 4: New technologies that could relate to this project, along with reasons they may not be applicable.

3 PROPAGATION TESTING AND MODELLING

With a suitable level of knowledge gained on fields related to the project, the project moved on to modelling the attenuation experienced in various terrains, helping to decide on a suitable frequency for a prototype. See Appendix C-4 for the full report relating to this section.

3.1 CONSTRAINTS

Constraint	Description	Decision
Test sites	These sites were chosen to incorporate some of the different terrains expected for trapping, including an open field control performed at Ilam Fields.	• Ilam Fields • Riccarton Bush • Victoria Park
Frequency Range	The following frequencies through a combination of recommendations from research and frequency availability.	6.2MHz, 27MHz, 50MHz, 80MHz, 140MHz, 169MHz
Power Limit	The amount of transmit power possible is limited by equipment and legal regulations.	Equipment limited (3.15mW)
Antenna	An antenna has a zone of frequencies it is suited to, so the use of one antenna for all tests may skew the results.	Design and construct an antenna for each freq.
Polarity	Polarity of the signal (antenna angle) can change the attenuation of a signal.	Both vertical and horizontal recorded.

Table 5: A list of constraints enforced during the testing phase to ensure appropriate data collection.

3.2 PHASE 1: FREQUENCY SELECTION

3.2.1 TEST PROCEDURE

The following process was repeated at each test site, varying both frequency and polarity:

- Set up the Receiver approximately 500m from the Transmitter. Locations found using GPS.
- Transmit a plain carrier at a pre-defined power level.
- Measure, and record, the signal power level at the Receiver. Calculate change in power level.

3.2.2 SELECTION PROCESS

Five main factors, including test results, we then used to select a frequency.

Freq. (MHz)	Performance	Frequency Popularity	Portability	Frequency Availability	Ease of Use	Total
6.2	**5**	**18**	**8**	**42**	**12**	**85**
27	**40**	**48**	**32**	**63**	**24**	**207**
50	**35**	**18**	**48**	**14**	**30**	**145**
80	**25**	**30**	**56**	**14**	**36**	**161**
140	**20**	**24**	**64**	**56**	**36**	**200**
169	**15**	**24**	**64**	**56**	**36**	**195**

Table 6: Summarised frequency decision matrix, with full weightings and scores in Appendix C-4.

It is clear that 140MHz and 169MHz are strong candidates, however 27MHz has been found to be the most appropriate frequency.

3.3 PHASE 2: MODELLING ATTENUATION IN BUSH

3.3.1 TEST PROCEDURE

The following process was repeated at four distances between 33m and 500m, at 27MHz:

- Set up the Receiver at required distance and measure the location using GPS.
- Transmit a plain carrier at a pre-defined power level.
- Measure, and record, the signal power level at the Receiver. Calculate change in power level.

3.3.2 RESULTS

Distance (m)	FSPL Attenuation, A_t (dB)	Measured Attenuation, A_m (dB)	Error, $[A_t-A_m]$ (dB)
33.3	22.1	57	34.9
68.8	28.4	70	41.6
209	38.0	74	35.0
486	45.4	78	32.6

Table 7: Comparing Free Space Path Loss attenuation with measured values, for 27MHz, over varying distances.

3.4 MODEL DEVELOPMENT

The results gathered seem to suggest that the environment at Victoria Park, Christchurch, adds approximately 35dB in losses to the expected Free Space Path Loss attenuation at any given distance for a 27MHz signal. This has been modelled, as seen below in Figure 1.

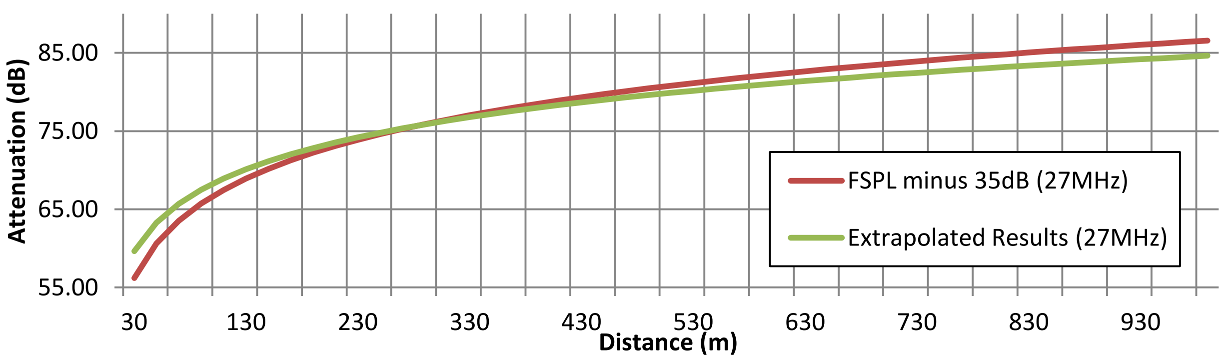


Figure 1: A graph comparing expectations from the model with an extrapolation of measured results.

3.5 LIMITATIONS

There are limitations with the model developed above. While the model could be used as a guide for other sites, a major drawback is that it is specific to this one site. A greater number of recordings would have provided a smoother model by reducing the effect of anomalies. The measurements recorded were estimated from the display of a spectrum analyser which consisted of a "hovering" power level, where continuous variation in the signal level was visible. The model only applies to distances exceeding 25m, with near field complications expected within that distance. The average height of each antenna may have changed between frequencies during testing, leading to bigger antennas (and hence lower frequencies) benefitting from greater heights.

4 Prototype Development

Now that appropriate information has been collected relating to the proposed product we can begin developing a prototype. The process involves making some informed design decisions followed by the suggestion of three prototype designs. Once a design has been selected we can construct a proof of concept and test it. A full report concerning the prototype development process is available in Appendix C-5.

4.1 Requirements

As with any new development there are certain conditions that the product must fulfil in order to be considered successful, listed in Table 8. With such a wide range of trapping scenarios possible the design was focussed to suit the block elimination process witnessed during the first field trip.

Condition	Description	Parameter
Good Range	A greater range allows better flexibility for trappers.	Greater than 500m in bush.
Longevity	Through more power availability and better efficiency.	Operates for min. of 5 days.
Size/Weight	A smaller and lighter transmitter device would make the product portable.	Less than 150 cm^3 and 500grams. (Excluding Antenna)
Transmission Rate	Makes use of the abundant time available.	Increasing accuracy or sensitivity over time.
No. of traps	More traps per system can be beneficial for trappers.	Min. of 100 traps per system.
Cost Effective	A cheaper product is more likely to be adopted.	Less than $5,500 per system.

Table 8: Suggested requirements the prototype should fulfil in order to be considered successful.

4.2 System Infrastructure Decisions

Some choices, regarding the design of the product, were decided before potential prototype designs were developed, and are listed below in Table 9. These decisions were based upon the extensive research and analysis conducted earlier in the project and helps to simplify the prototype design process.

Decision	Result	Why?
Frequency	Below 200MHz.	These lower frequencies operate better in bush conditions.
Antenna	Less than 2m.	A large antenna will make the product less portable.
Network Design	"Star" network	Allowed simple low power transmitters to be used with cheap microprocessors. This narrows the scope and allows a focus to be placed upon communication from trap to a central receiver.
Processing Hardware	Arduino/PICAXE Microprocessors	Low power consumption, easy to use, small size, cheap.

Table 9: Decisions made about the system design before prototypes are suggested.

4.3 Potential Prototype Designs

With the scope now narrowed it becomes easier to suggest prototype designs. Taking into account the limitations and decisions made earlier in this section the following designs are suggested.

4.3.1 Prototype Design 1 – Dual-Tone with Time Division

The first design, which was developed early in the project, aimed to make full use slow data transmission rate needs. A dual tone, as in two separate transmit channels, would be used to detect the trap status, set or sprung. There are products available online that will fulfil the dual channel communication aspects, at 27MHz, required for this prototype.

In order to differentiate between traps, each device would be assigned a time period during the day. With 1440 minutes per day the system can hold 144 traps with ten minutes for each trap to transmit. As the device clocks are likely to run at slightly different speeds it is likely that some "slip" will occur. To minimise the chance of slip causing an overlap into another traps timeframe, which is possible with cheaper microprocessors with poorer quality crystals, we can insert a guard time between each trap. A guard time of five minutes will allow the receiver five minutes to pick up the incoming signal. This technique can be viewed graphically in Figure 2 below.

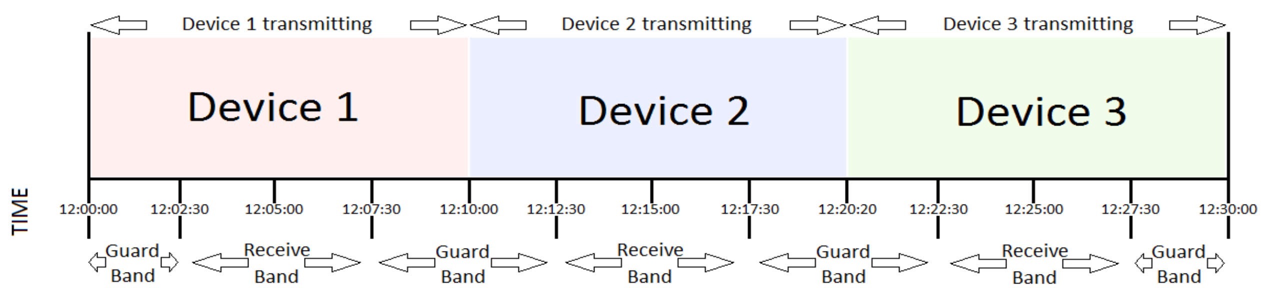


Figure 2: An explanation of the Time Division suggested for Prototype Design 1.

4.3.2 Prototype Design 2 – Near Vertical Incidence Skywave (NVIS)

Murray Greenman, an amateur radio specialist and author of "Digital Modes for all Occasions" (Greenman, Digital Modes for all Occasions, 2002), was contacted and a conference call was set up. The call was very insightful but did not lead to any immediate revelations. A few weeks later Murray released a journal article which had a lightly veiled response to our situation. That section focussed upon a low power, and low-bandwidth, link from a series of collection points in a forest and suggested NVIS as the solution.

NVIS works by sending radio signals upwards into the ionosphere. These waves are then refracted back down and can be received within a radius of up to 650km from the transmitter. The most common frequencies used in this method are 3.5MHz at night and 5MHz during the day. These values change, depending upon the time of the day, due to changes in ionosphere level densities.

One of the great advantages of NVIS is the direction of transmission, which removes the effect of mountainous terrain; a common issue in DOC patrolled regions. Another positive in regards to NVIS as a potential design is its range and speed of transmission. Murray was kind enough to set up an experiment to test the methods aptitude. It involved a transmission distance of 15km, over hilly terrain, and a signal power of 200mW at 3.549MHz. The test was successful, but one major deterrent is the large antenna in use. It is not feasible to set up a 40m half-wave dipole on each trap. This method uses more power than the other designs but has a significantly longer range.

4.3.3 *Prototype Design 3 – Modified Pulse Position Modulation using AM Pulses*

Design 3 has been derived from the control methods used by Radio Controlled (RC) cars at 27MHz. These use pulses of various lengths to determine the speed and direction of the car in a method called Pulse Position Modulation (PPM). Unfortunately the receiver can only take input from one transmitter at a time. It was then theorised that each pulse length could relate to a different trap, however this still meant that multiple signals would get confused, especially when 200 (100 for "sprung" and 100 for "set") were needed to fulfil the 100 trap requirement. To fix this the next step was found to be to vary the length of time between each pulse, rather than the length of each pulse.

This made sense; however, pulses could easily be misinterpreted. A pulse every two seconds would be confused with a pulse every second, making the first impossible to detect if they were appropriately aligned. A natural progression suggested the pulse frequency be dependent upon prime numbers, with each device assigned its own prime number. This method could be transmitted and received on cheap microprocessors. The unusually low data transmission rate of this system may be the reason it has not been developed, and hence cannot be found in literature. It is for this reason that the concept may be potentially patentable, and is covered in section 7.2.

4.3.4 *Prototype Design Decision*

This decision will be based upon a number of different factors, which each carry a different weighting. It is for this reason that a decision matrix, shown below, has been developed in order to find the best solution.

Prototype Design	**Score**					**Total**
	Range	**Longevity**	**Size**	**Cost**	**Trap #**	
1. Dual-tone	**48**	**48**	**15**	**32**	**48**	**191**
2. NVIS	**60**	**56**	**0**	**48**	**6**	**170**
3. PPM	**36**	**72**	**40**	**64**	**36**	**248**

Table 10: Summarised prototype design decision matrix, with full weightings and scores in Appendix C-5.

It is clear, from the decision matrix above, that a modified PPM scheme is best suited to this project.

4.4 Prototype Construction

Once a final design has been settled the prototype construction can begin.

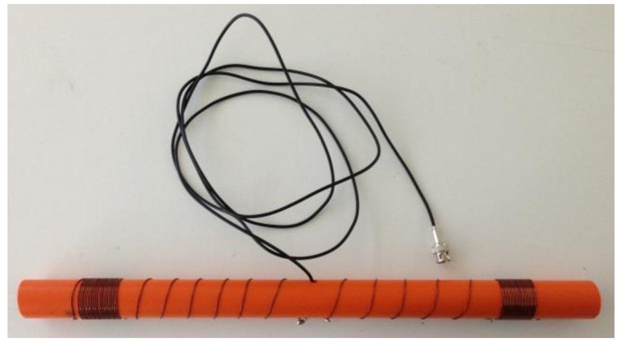
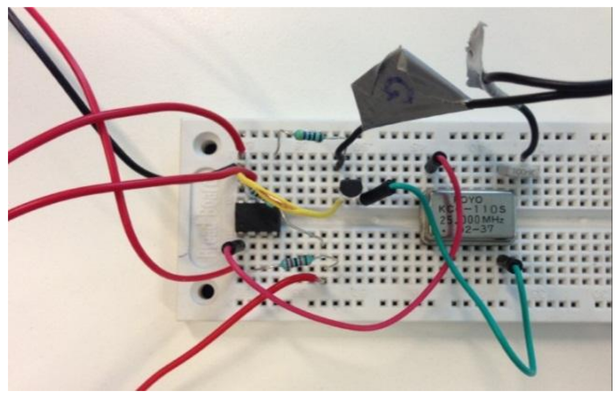
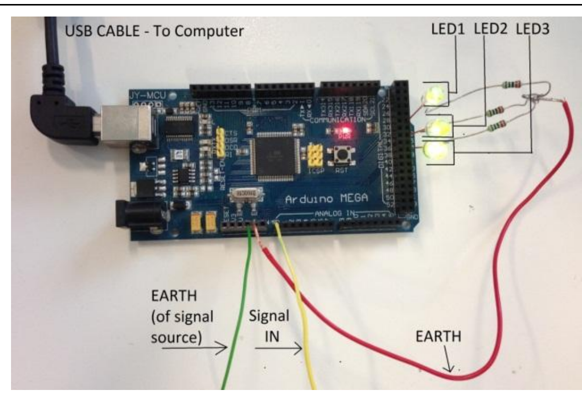
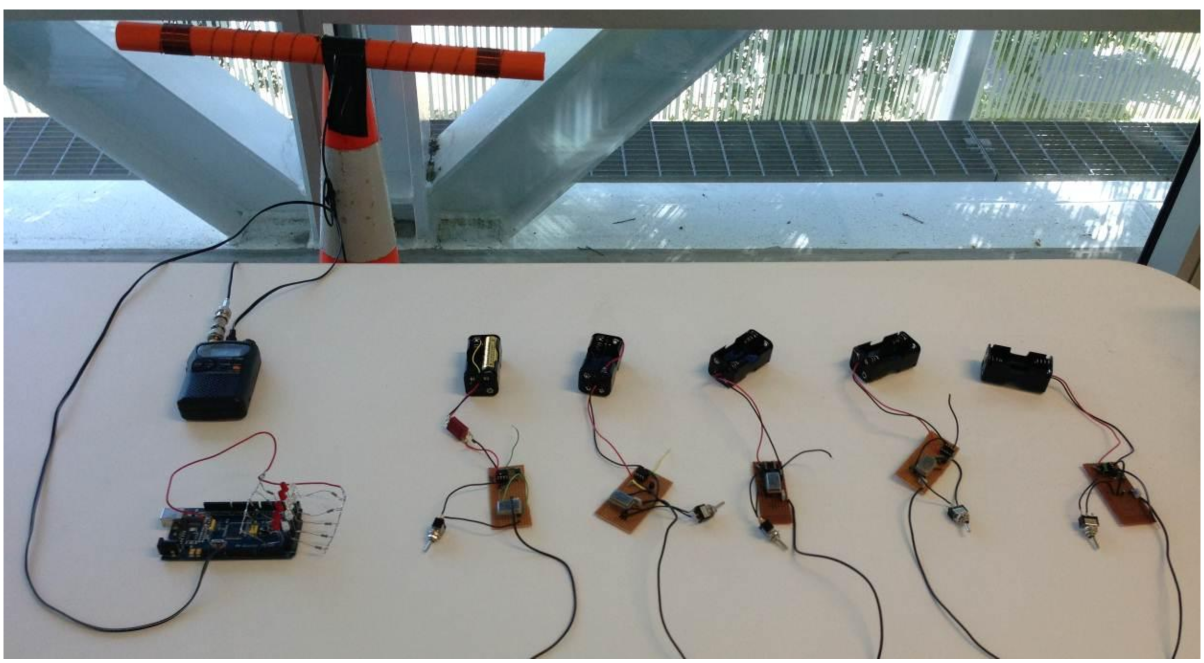
Unit	Description	Resulting Component
Antenna	With portability being a major concern in this project we decided to build the more compact helical design, as even a half-wave dipole would be over 5m for 27MHz. A detailed explanation of the antenna construction process is available in Appendix C-4.	
Transmitter	The brain of this circuit is the PICAXE microcontroller, which creates the required pulse. This pulse is then sent to the oscillator which essentially converts this electric signal into a radio signal. The black cable can then be connected to an antenna to properly radiate the signal. More information regarding the workings and construction of the transmitter is available in Appendix C-5.	
Receiver (RF)	This handheld device is able to convert the incoming radio pulses into audible clicks. The connection of a sound jack means that the clicks are now output as a varying voltage which can be passed onto the decoding section of the receiver.	
Receiver (Decoding)	A simulation was then created in MATLAB to find appropriate methods for decoding the incoming signal. Three fundamentally different decoding techniques were developed until one was able to work with the limited memory available in a microprocessor. For more information regarding these processes, and the signal decoding as a whole, see Appendix C-5.	

Table 11: A table describing components of the prototype.

4.5 Prototype Testing

In order to test how well the system performs the testing process was split into four steps. This allowed better distinction between over- and under-performing parts.

Section	Description	Result
Transmitter	This step focusses upon ensuring the transmitting device sends out the correct pulse rate. It uses the PICAXE microprocessor to output a pulse at designated times. These pulses are directed towards a 25MHz oscillator which then transmits for the duration of the pulse. A switch is attached to the PICAXE that changes between two duty cycles, suggesting a "set" or "sprung" status.	Success, with some calibration, the correct signal was output from the PICAXE.
RF Link	This section continues on from where the last section stopped, testing that the link between transmitter and receiver works correctly. The audio jack on the receiver was un-plugged to listen for the "clicking" associated with the transmitting signal.	Success, "clicking" sound received with 20m gap between antennas.
Decoding (Receiver)	As the transmitter has found to be working correctly we can attach the combined output of several PICAXEs to the receiver. This removes the effect of any potential issues caused by the RF link.	Success, but still plenty of scope for improved receiving methods.
Complete System	The final step looks at the whole system. Flicking the switch on a transmitter should cause one LED on the receiving unit to turn off, while another turns on. Each of these LED's will be associated with a prime number.	Success, with lower prime number values taking longer to react to a switch change.



The receiver is visible on the far left, with five separate transmitters to the right.

Table 12: The different stages of testing and their outcomes.

5 Cost Benefit Analysis (CBA)

A CBA is significantly more valuable when the assumptions it makes are accurate. These assumptions then rely heavily upon the situation it is being applied to. Thus a case by case method for applying a CBA to DOC device monitoring site has been used upon the Little River field trip site.

5.1 Existing Cost Benefit Analysis Models

A model for estimating the financial viability of the implementation of trap monitoring system was found during early research. The model, which takes the form of two equations, can be used to identify situations in which the introduction of a trap monitoring system could provide cost savings. Another report, funded by DOC, then modified the model to make it appropriate for DOC trapping procedures and is explained in detail in Appendix C-6. (Julian Carver, 2011)

5.2 Cost Benefit Analysis of Field Trip Site

A CBA, with the assistance of the above model, was then established for a site visited during a field trip. With the scenario and assumptions based upon experience, gained while shadowing a trapper for a day, it was possible to show the financial benefits of introducing a trap monitoring system. The model was based upon three trappers undergoing five days of “block elimination”, using 200 traps.

The analysis estimated that drop of approximately 11% in labour costs could be expected. The size and shape of the location would require two systems. We can assume the devices would be used once a week, at varying locations, for 45 weeks of the year with similar savings. In order to provide a payback period of one year the device would need to cost less than $5,275, assuming trappers are currently paid $45/hour. A rough estimate puts the prototype device cost at about $40 per transmitter, where cost reductions through bulk production are expected to be offset by the cost to include an amplifier. Assuming the receiver costs $500, a system with 100 traps would cost $4,500.

5.3 Limitations

In order to obtain useful financial estimations many assumptions had to be made, where the accuracy of the result is only as good as the assumptions made. It must also be understood that this CBA is only applicable to the block elimination trapping process. There is also the possibility that some non-financial benefits or costs may become apparent once implemented, such as improved trapping patterns by studying the frequency each trap location is sprung. It is also worth noting that this does not take into account travelling to and from the site, where a 3 hour round trip may not be worth 45 minutes of work. The analysis has also assumed that trappers are paid per hour, when they are paid $60/hectare in reality, to make the process simpler.

6 IMPLEMENTATION GUIDELINE

Any good implementation guideline begins by looking at previously introduced technologies, analysing both the strong and weak factors of the product roll-out. This step is followed by a clarification of the goals involved with the project, including a list of actions required. The aforementioned list is then moulded into a plan. Two of the most important properties of an implementation plan are that is must be flexible and reviewed regularly. See Appendix C-7 for the full report relating to the Implementation Guideline, including the process outlined above.

6.1 IMPLEMENTATION AND MONITORING

#	Step	Implementation	Monitoring
1	Ready for Release	Write datasheet. Define and resolve potential legal/permission/IP issues. Test the final product. Find a suitable manufacturer.	Regularly redefine potential legal and IP issues, including competitor products that could infringe on demand. Have modified PPM scheme patented.
2	Build Demand	Display at conventions (wireless technology or pest control). Advertise to appropriate audience. Create an online profile, making your product easily searchable. Press releases. This stage is important to ensure that the product "crosses the chasm".	Strong product recognition among targeted customers. Easily searchable online, preferable the top hit for product related searches on Google. Consider using Google Trends to measure search frequency.
3	Product Release	Find appropriate paths of distribution, including retailers, salesmen and online purchasing availability.	Reasonable level of product uptake. Strong network of product representatives.
4	Potential Markets	Look at ways to reach non-customers, potentially through personal use. Look at other potential uses for the product, including other status monitoring options.	Remain open to developments that could increase product reach. Taking active measures to test alternative uses.
5	Continued Development	Investigate what the consumer wants improved, which could include extending the range, increased duration capabilities, alternative power supply, more traps per receiver and cheaper components. Potential smartphone connectivity.	Responses and action after customer feedback. Advances in suggested capabilities. Wider range of uses from improved capabilities. Looked into reducing transmitter size through on-chip design.
6	Contingency Plans	Develop plans for "What if" scenarios, including demand increase/decrease, supplier issues and increased competition.	Update these plans regularly to keen them current. Be vigilant for potential "What if" scenarios to ensure preparedness.

Table 13: The steps suggested for product implementation, including how they can be monitored.

7 Project Evaluation

7.1 Project Management

This section has been broken into two separate parts. One looks at how the objectives within this project have progressed. The other focuses upon practices that were found to be very beneficial and others that would have been implemented in hindsight.

7.1.1 *Task Progression*

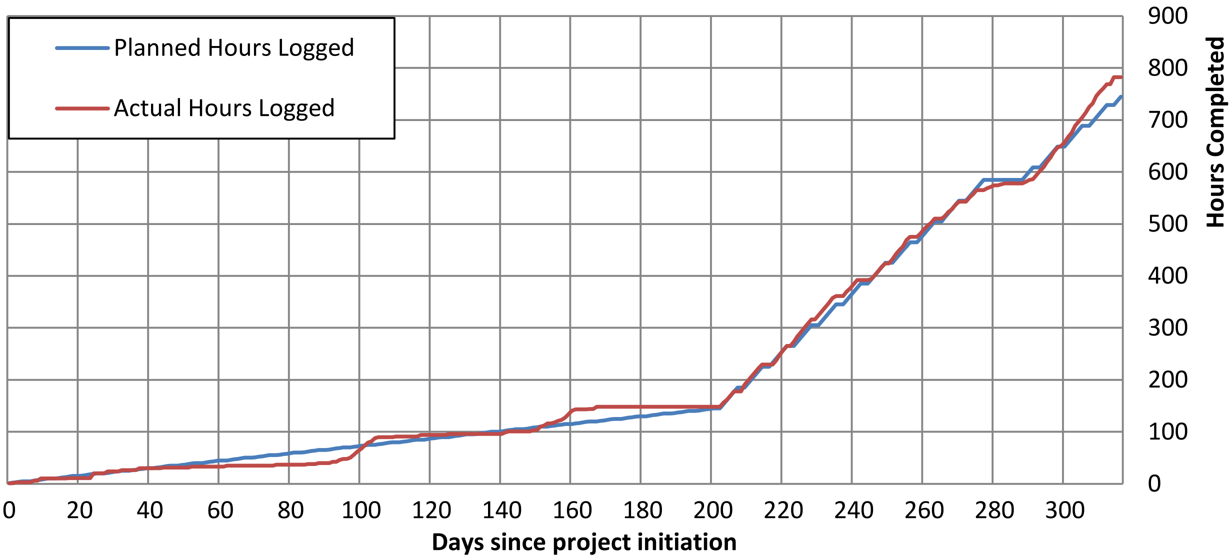


Figure 3: A graph comparing the progression of hours logged against planned hours.

The graph in Figure 3 shows that the actual hours logged by the student followed closely with expectations. There are three noticeable deviations. Two are in the first half of the project and correlate to the hand in of progress reports. The final is at the end of the project where a strong push was required to make up time losses before the Christmas break. This delay, of approximately three weeks, was caused by an unexpected complication within the project, antenna design and construction.

Impacts from this delay were minimised through parallel progress on other tasks and overtime during weekends. Employment of these two methods has allowed the project to be completed on time. It was during this period that a flexible plan proved to be invaluable as the potential to work on other parts of the project was made obvious. The lopsided nature of progress was due to class attendance requirements, with class finishing around day 200. In financial terms, the project costs have been minimal, with approximately $400 spent on hardware components (antenna, receivers and transmitters). The major reason this number is lower than expected is that a majority of the equipment used was either owned by WRC or borrowed from their industrial partners.

7.1.2 *Key Lessons Learnt*

Experience gained during this project has given the following tips that will help in future projects:

- **Do not underestimate the benefits of an in-depth plan**. The plan used during this project clarified the scope for each student and provided "wake-up calls" when needed.
- **Keep communication channels strong.** Regular correspondence between individuals involved with a project will keep expectations aligned.
- **Never make excuses.** A much more productive attitude is to present actions that will resolve the situation.
- **Allow time to have the final project report reviewed.** This project only allowed two days, which put unnecessary pressure on those performing the reviews.

The planning and time management skills learnt during this year through the MEM course and this project will be invaluable experience for future endeavours. The ability to summarise larger issues into manageable sections, learnt during the MEM course, has helped immensely during this project.

7.1.3 *Personal Reflection*

This project was undertaken to give the student a glimpse into real life project management as well as method of displaying skills learnt during the Masters of Engineering Management (MEM) course. The MEM course is focussed upon bridging the gaps between engineering, technology and business. My undergraduate degree in Electrical and Electronic Engineering has provided a strong engineering and technology background, with MEM providing key business lessons. Some of these business aspects can be broken down into:

- Basic economic and accounting awareness.
- Marketing knowledge, focussing upon strategies.
- An ability to see beyond project requirements and hence discover what is actually required.

It is the last of these that has proven to be particularly useful in this project.

The biggest highlight, for myself, from this project was not the discovery of a potentially novel communication technique, but rather the investigation into potential commercial opportunities. In the future I think I would benefit from:

- Greater confidence. Experience will lead to more confidence, especially when making decisions, and hence resulting in more successful projects.
- Better analysis procedures, in both technical and commercial terms.

7.2 Patent Potential

The modified pulse position modulation scheme described in this report has been suggested as a patent candidate. Initial literature searches could not find references to this scheme, although the fact that it sends information slowly and one way make it unsuitable for most communication. Potential commercial uses for the scheme are the reason a patent is being considered.

Initial steps would be focussed upon collating information, explaining the concept ensuring that the key features and benefits are obvious. Any evidence related to the development of the concept would also be beneficial. The next step would be to meet a Patent Attorney to help decide upon an appropriate IP (Intellectual Protection) strategy, investigating all forms of intellectual protection and perhaps even using a combination of these IP forms. In reality the only options in this situation are a patent or keeping it as a trade secret

As with any decision the application for a patent is dependent upon the benefits outweighing the costs. There are five key factors influencing patent decisions, including risk of appropriation, detection of infringement, impact of publication, efficacy of alternatives and degree of protection. It is also important to remember that patents are location specific and varying in how long they last.

The potential benefits, which at this point are minimal with little commercial likelihood, do not outweigh the costs, such as hiring a Patent Attorney and maintaining the patent, it becomes impractical to file for a patent. A request to have this report embargoed for 24 months will allow time to file for a patent if a commercial prospect is discovered, as publication will automatically make the intellectual property public.

7.3 Conclusion

7.3.1 Project Conclusions

The research and modelling sections brought about several key conclusions. Early on in the project it became apparent that lower frequencies would suffer less attenuation than higher frequencies in forested terrain, with 200MHz considered the highest applicable frequency. Research also resulted in the discovery of no existing systems that could be transferred to this project, and hence purchasing a commercial solution was not a viable resolution. In addition to the lack of existing systems, it was found that no recently released technology was found to be appropriate to the given situation.

The prototype development and testing sections of this report found that the properties of the modified PPM scheme, on 27MHz, appear to fit in well with the requirements of a remote monitoring pest control system. These beneficial properties include:

- Lower power use, through the use of lengthy duty cycles.
- No need for clock synchronisation between transmitters and receiver.
- Very simple and cheap transmitters.
- Receiver-heavy design, where most processing is on receiving side of data transmission.

It was found that remote monitoring of block elimination sites should be profitable for DOC; however this suggestion is based upon many assumptions that could change the resulting recommendation. It is also likely that other costs or benefits will only be obvious once the system is in place, and putting a financial value on these externalities can be difficult.

7.3.2 Major Dilemmas

The first major dilemma faced in this project was the massive scope involved. Pest control can vary hugely, with variables including terrain, trap longevity, distance intervals and trap type. Thus the first step was to apply various assumptions to focus the objectives and allow a sensible outcome. It was for this reason that block elimination, as seen in the first field trip, was used as a typical situation. This simplification has allowed a useful result to be reached, but makes it more difficult to apply to other situations.

Rather than thinking along the lines of how wireless communication technology can help pest control, the best approach was to ask how pest control and wireless communication can best be combined to reduce the issues pests cause. Gas-power traps that reset automatically, such as the A24, could be integrated with a Near Vertical Incidence Skywave transmitter (NVIS). By placing one of these in the centre of each block elimination zone, information regarding spring frequency can be relayed back to base.

If the frequency increases above a predetermined threshold then block elimination can be implemented in that area. The long-term A24 trap can then act as a receiver for the status of each leg hold trap used in block elimination. It can then relay the status of each trap back to base through its NVIS link. This method would fulfil both the monitoring and number control requirements in this area.

Network design was a deceivingly complex part of this project. Time was first devoted to attempts at communicating directly from each trap to a distant receiver. However common sense suggested that the aim should be to minimise the aggregate distance of transmission. These minimal distances were achieved through a mesh network scheme.

Further research suggested that this solution may not be the most suitable proposal as each transmitter also needed to be a receiver. The minimum distance assumption was soon disproved as it was, in fact, the path that required the lowest portable power needs would be most appropriate, which lead to a star network approach, where each node only needs to transmit and travel 500m.

One of the major issues currently faced by the decoding process is microprocessor clock accuracy. Cheaper devices tend to suffer greater clock drift, caused by poorly calibrated oscillators. A potential solution could the attachment of an external clock, which has better accuracy. Another possibility would be to use the set or sprung logic to choose the most likely value. This would make it a relative decision, rather than based upon an absolute value, and would also improve the devices transmission range.

Another major dilemma faced was the compromise between lower frequencies and smaller antennas. Lower frequencies perform better in New Zealand bush terrain, but require a larger antenna. The lowest frequency DOC owns rights to, above 15MHz, is 139MHz. This cuts out a large number of channels that would be particularly appropriate to bush terrain communication. The only frequency found in that range was 27MHz, under a General User Radio License. A frequency within this range would help to solve the "Lower Frequency vs. Smaller Antenna" dilemma.

A potential solution is on the horizon with several channels, in the 40MHz to 70MHz range, are becoming available New Zealand wide, as analog television moves to digital. This could be a valuable opportunity to make use of cheap transmission technology driven by the historic demand for television.

One major limitation facing the potential development of technology in this area is power availability. Power requirements are currently fulfilled through time constrained batteries which induces the need for more regular site visits and reduces potential benefits of remote monitoring. An alternative could be the consideration of local power generation using natural energy, including wind or solar.

7.3.3 Further Research

The prototype design decisions made during this report mean that the result is highly specified to a low data transfer rate, and hence would translate poorly to 1,000 bits per day. This is due to the fact that each time a signal is sent it only transfers one bit of information. Scaling up the data transfer to 1,000 bits per day for 100 traps would require different 100,000 (1000 bits/trap) prime numbers, rather than just the first 200 (currently 2 bits/trap). The NVIS prototype design could be investigated as a potential solution to this higher data rate, but would need to operate in a more long term situation to be viable.

There are still questions that remain unanswered, but are outside the scope of this investigation. It is for this reason that the following areas are suggested for further research:

- Better decoding methods for modified PPM scheme, taking into account the lower memory availability in microprocessors.
- Optimise prime number use in the modified PPM scheme, weighing up clock inaccuracy against better defined results for the receiver.

7.4 Recommendations

There are several key recommendations stemming from this report, aimed at providing an appropriate wireless link from a pest control device.

4. Transmit at a frequency of around 27MHz, which is available under a General Users Radio License. This frequency was found to be best suited to the project, taking into account forest attenuation, availability and portability.
5. Use the modified pulse position system described in this report, as its power efficiency, cheap build costs and receiver-heavy design make it ideally suited to this application.
6. Implement both the transmitting and receiving sections of the system with micro-controllers, which benefit from being both compact and cheap.

These recommendations will ensure a cost-effective solution to the project requirements.

REFERENCES

Update Camalie Networks Wireless Sensing. (2008, June 3). Retrieved January 20, 2013, from Camalie: http://camalie.com/wirelesssensing/wirelesssensors.htm

Ballon, S. D. (2007). Flexible Spectrum Management and the Need for Controlling Entities for Reconfigurable Wireless Systems. *New Frontiers in Dynamic Spectrum Access Networks*, (pp. 347-362).

Bluetooth. (n.d.). *A Look at the Basics of Bluetooth Wireless Technology*. Retrieved November 4, 2012, from Bluetooth: http://www.bluetooth.com/Pages/Basics.aspx

Circuits Today. (2011, January 18). *Smart Antennas*. Retrieved November 20, 2012, from Circuits Today: http://www.circuitstoday.com/smart-antennas

Cockburn, S. (2012, 08 06). DOC Science & Research Unit, Electronics Lab, HO. (T. Harding, Interviewer)

DOC. (2010). *VHF radio course*. Retrieved 08 22, 2012, from Department of Conservation: http://www.doc.govt.nz/upload/training-courses/vhf-1/index.html

DOC. (n.d.). *Overview of DoC's role*. Retrieved 01 11, 2013, from Department of Conservation: - http://www.doc.govt.nz/about-doc/role/vision-role-overview-and-statutory-mandate/overview-of-docs-role/

Encyclopedia Britannica. (2012). *satellite communication*. Retrieved November 7, 2012, from Britannica: http://www.britannica.com/EBchecked/topic/524891/satellite-communication

Greenman, M. (2002). *Digital Modes for all Occasions.* Radio Society of Great Britain.

Greenman, M. (2010, February 17). *Amateur Radio*. Retrieved November 21, 2012, from QSL: http://www.qsl.net/zl1bpu/

Hachman, M. (2012, May 16). *What's Next for Wi-Fi? WiGig, 802.11ah Wait in the Wings*. Retrieved November 20, 2012, from PCMag: http://www.pcmag.com/article2/0,2817,2404479,00.asp

Hoffman, T. (2003, March 24). *Smart Dust*. Retrieved November 21, 2012, from Computer World: http://www.computerworld.com/s/article/79572/Smart_Dust

International Telecommunication Union. (2008, March 7). *Invitation for submission of proposals for candidate radio interface technologies.* Retrieved November 20, 2012, from http://wirelessman.org/liaison/docs/L80216-08_008.pdf

Julian Carver, D. C. (2011). *A Review of Wireless Sensor Networks for Pest Control Operations.* Christchurch: DOC.

KIDSON, S. (2012, November 3). *War on predators takes big leap*. Retrieved November 20, 2012, from Stuff.co.nz: http://www.stuff.co.nz/the-press/news/7903223/War-on-predators-takes-big-leap

Landcare Research. (n.d.). *About the Organisation*. Retrieved 01 11, 2013, from Landcare Research: http://www.landcareresearch.co.nz/about/about-landcare

Love, D. (2013, January 9). *The Original iPhone Was Introduced 6 Years Ago Today*. Retrieved January 20, 2013, from Business Insider: http://www.businessinsider.com/original-iphone-introduction-2013-1

Markham, A. (2008). *On a Wildlife Tracking and Telemetry System:.* Cape Town: University of Cape Town.

Michael Kapp. (n.d.). *New Product Development Process*. Retrieved January 20, 2013, from Product Strategy: http://www.productstrategy.net/product-development-process/

Networking Tutorials. (2007). *Introduction to Mobile Technology and Communications*. Retrieved November 7, 2012, from Networking Tutorials: http://www.networktutorials.info/mobile_technology.html

Peter. (2009). *What Is Wifi? A Guide To WiFi For Beginners*. Retrieved November 1, 2012, from Squidoo: http://www.squidoo.com/what-is-wifi

Remote Control Technology. (n.d.). *Medium Range Wireless Switch System*. Retrieved January 20, 2013, from Remote Control Technology: http://www.remotecontroltech.com/product/MedSwitch.aspx

Sutter, J. (2010, May 3). *'Smart dust' aims to monitor everything*. Retrieved November 21, 2012, from CNNTech: http://articles.cnn.com/2010-05-03/tech/smart.dust.sensors_1_smart-dust-sensors-kris-pister?_s=PM:TECH

Szewczyk, R. (2004). *An Analysis of a Large Scale Habitat Monitoring.* Berkeley: The Intel Research Laboratory.

UoC WRC. (n.d.). *WRC Welcome*. Retrieved 01 11, 2013, from Wireless Research Centre: http://www.wrc.canterbury.ac.nz/

WiFi Alliance. (n.d.). *Discover and Learn*. Retrieved November 20, 2012, from WiFi Alliance: http://www.wi-fi.org/discover-and-learn

Willis, S. L. (2007). *Investigation into long-range wireless sensor networks.* Townsville: James Cook University.

WiMAX. (n.d.). *What is WiMAX?* Retrieved November 4, 2012, from WiMAX: http://www.wimax.com/general/what-is-wimax

Zigbee Alliance. (n.d.). *ZigBee Technology*. Retrieved November 5, 2012, from Zigbee Alliance: http://www.zigbee.org/About/AboutTechnology/ZigBeeTechnology.aspx

8 APPENDICES

APPENDIX A – ORIGINAL PROJECT OUTLINE

LOW POWER WIRELESS MONITORING FOR WILDLIFE MANAGEMENT

University of Canterbury Wireless Research Centre
K.P.Barnsdale
Date 21March 2012

BACKGROUND

The monitoring of animal control devices (animal traps) in remote areas currently requires field workers to visit each device on a regular basis, which is costly and time consuming. A system of remotely monitoring the status of these devices would bring benefits of efficiency and cost savings to the Department of Conservation. It is recognised the environment is very difficult for traditional wireless communications to operate reliably and therefore new methods or technologies should be investigated for this application.

OBJECTIVES

Investigate new methods of remotely monitoring the status of animal control devices. Make recommendations as a result of the above, and test any new methods using a proof of concept system. These tasks will be shared by two Post Graduate students.

TASKS

1. Literature review for current research in this application area.
2. Collect data on the current wireless systems in use, and the constraints imposed by the environment on the installations. Assess why existing "off the shelf" methods of wireless communication cannot be used, and identify areas of weakness.
3. Investigate new low power wireless technologies that may be applicable to this application, both with and without reliance on networks. This will include new modulation types for low signal applications and antennas.
4. Investigate methods to predict wireless propagation through forest using terrain models.
5. Investigate the relationship between radio frequency, forest type and propagation.
6. Propose a new system of low power wireless communication for this application.
7. Analyse the system robustness and research ways to predict link failure rates.
8. Design and assemble a proof of concept system, capable of being tested in the target environment for a short period.

Information gathering

The students will collect information by literature search and by contact with the relevant expertise within the customer's organisation. The students will also partake in field trips to gather information on current systems.

Application performance variations

There are three possible applications for the target system(s):

1. Control device status monitoring – up to 4 bits/day. "Kill traps" can just send information when the trap has been sprung. "Restraining traps "must send trap status every day.
2. Animal behaviour video monitor – 4MB/day. With some video compression this may be reduced to 1MB/day, but the project will concentrate on transmission methods only.
3. Small environmental sensor network – 1kbit/day

The project will decide on the priority of these applications, as any system will only be truly optimised if just one target application is chosen.

Deliverables

Student 1 to deliver a thesis on the work carried out on Application 1 above, and suggestions on how it can be extended into Application 3, including a cost benefit analysis, an implementation plan and a proof of concept system.

Student 2 to deliver a thesis on the work carried out on Application 2 above, and suggestions on how it can be extended into Application 3, including a cost benefit analysis, an implementation plan and a proof of concept system.

Deliver dates

Thesis and final report to be delivered by 15th January 2013.

Interlectual property

All IP developed during this project will remain the property of UC, as outlined in Interlectual Property sections of the contract between UC and Landcare Research. Use of IP will be subject to agreement at the end of the project.

Payment

There are two scholarships involved with this project. The funding from Wireless Research Centre will be paid monthly to each student over the course of one year. The "top up" UC scholarship of $5000 will be paid to each student on delivery of the final thesis.

Appendix B – Project Plan

This appendix contains the work breakdown structure predicted during the planning stages of this project.

Project Administration

Task #	Minor Milestones	Deliverables	Planned		
			Start Date	Finish Date	Time
1.11	Specification of Requirements	Contact initiated, specifications drawn up, agreement made.	23/03/2012	30/03/2012	5
1.12	Project Plan developed	Draw out a detailed project plan with all notable milestones detailed.	17/09/2012	11/11/2012	10
1.13	Project Charter developed	A statement of the scope, objectives and participants involved with the project. It will provide a preliminary delineation of roles and responsibilities, outline the project objectives and identify the main stakeholders.	17/09/2012	11/11/2012	10
1.14	Project Proposal developed	A project proposal will be written, with the aim of making an offer to the supervisor/customer. It will state that, in exchange for money, we will perform the research and guide them on how to use and implement the results of the study.	9/04/2012	11/11/2012	15
1.15	Fortnightly Meetings	Eight fortnightly meetings with Kelvin Barnsdale and Graeme Woodward (Supervisors)	23/03/2012	29/01/2013	8
1.16	Academic Progress Report 1	A progress report submitted to ensure suitable gains have been made.	23/03/2012	26/10/2012	10
1.17	Academic Progress Report 2	A progress report submitted to ensure suitable gains have been made.	29/10/2012	30/11/2012	10
1.18	Academic Progress Report 3	A progress report submitted to ensure suitable gains have been made.	3/12/2012	21/12/2012	10
1.1	**Project Administration**	**Contact initiated, specifications drawn up, agreement made. This includes meetings throughout the project.**	**23/03/2012**	**29/01/2013**	**78**

Table 14: A breakdown of minor milestones relating to project administration.

Literature Review

Task #	Minor Milestones	Deliverables	Planned		
			Start Date	Finish Date	Time
1.21	Select topics	Select the topics to be explored by the literature review.	02/04/2012	09/04/2012	5
1.22	Select sources	Look into different sources for related information, particularly when gathering information regarding pest control processes.	09/04/2012	16/04/2012	5
1.23	Investigate Pest Control	Collect and collate information regarding pest control, from proposed sources.	16/04/2012	30/04/2012	10
1.24	Investigate Basic Radio Comms.	Collect and collate information regarding basic radio communication theory, from proposed sources.	30/04/2012	07/05/2012	5
1.25	Investigate Low Power RC	Collect and collate information regarding low power radio communication, from proposed sources.	07/05/2012	21/05/2012	10
1.26	Investigate Propagation Loss Models	Collect and collate information regarding existing propagation loss methods and models, from proposed sources.	21/05/2012	28/05/2012	5
1.27	Investigate Propagation through Forested Environments	Collect and collate information regarding propagation models, focussing on work in forested terrain, from proposed sources.	28/05/2012	11/06/2012	10
1.28	Write Literature Review	List all of the information collected from the above sources and provide a short summary of each. Summarise all the useful information collected.	11/06/2012	09/07/2012	20
1.2	**Literature Review**	**All the above factors combined, to make a comprehensive literature review on related topics.**	**02/04/2012**	**09/07/2013**	**70**

Table 15: A breakdown of minor milestones relating to the literature review.

*5 hours a week.

CURRENT SYSTEMS

Task #	Minor Milestones	Deliverables	Planned		
			Start Date	Finish Date	Time
1.31	Field Visit 1	A day-trip to Akaroa (specifically, near Little River) to shadow and interview trappers on the job.	09/07/2012	09/07/2012	5
1.32	Field Visit 2	A day-trip to Akaroa (specifically, near Le Bons bay) to shadow and interview a trapper on the job.	16/07/2012	16/07/2012	5
1.33	Investigate current DOC practices	Look into methods and processes that DOC currently use to control pest populations, and elaborate on why they need to be re-evaluated. (Does not include field trips)	23/07/2012	30/07/2012	5
1.34	Investigate existing DOC infrastructure	Explore existing methods of communication hat DOC use and/or own, and determine whether or not they could be applied to the current requirements.	30/07/2012	06/08/2012	5
1.35	Investigate "Off-the-shelf" products	Determine whether there are any readily available products that could be amended to this situation, and elaborate on why some may not be appropriate.	06/08/2012	20/08/2012	10
1.36	Similar applications	Find and investigate similar situations (low power, low data), and determine whether or not they are applicable in this situation.	20/08/2012	27/08/2012	5
1.37	Write Current Systems Review	Write up a report detailing the above investigations, concluding with the best direction for DOC requirements.	27/08/2012	10/09/2012	10
1.3	**Current Systems**	**A report listing current processes in place and similar situations where wireless communications are in place. This report will also include a review of off the shelf products available.**	**09/07/2012**	**10/09/2012**	**45**

Table 16: A breakdown of minor milestones relating to current systems.

*5 hours a week.

NEW TECHNOLOGIES

Task #	Minor Milestones	Deliverables	Planned		
			Start Date	Finish Date	Time
1.41	New Technology	Investigate newly released technology, such as 802.11ah, 4G and Mesh Networks.	10/09/2012	24/09/2012	10
1.42	Emerging Technology	Investigate technologies that are still being developed and would have the potential to impact on the given situation.	24/09/2012	01/10/2012	5
1.43	Processing Related Technology	The previous sections focus on physically sending the signal. This section will investigate potential benefits that could be achieved through processing the data, through modulation and/or coding.	01/10/2012	08/10/2012	10
1.44	Technical Expert Research	Determine whether or not research from technical advisors could have an impact on the given situation.	08/10/2012	09/10/2012	10
1.45	Summary	Summarise the above, including which could be suitable for the given situation.	09/10/2012	10/10/2012	10
1.46	Write New Technologies Review	Collate all the information above into a report that clearly depicts which technologies could influence this project.	10/10/2012	12/10/2012	10
1.4	**New Technologies**	**A report investigating emerging technologies that could be applied to the situation.**	**10/09/2012**	**12/10/2012**	**55**

Table 17: A breakdown of minor milestones relating to new technologies.

*5 hours a week until 08/10/2012, where becomes 8 hours a day.

PROPAGATION MODEL

Task #	Minor Milestones	Deliverables	Planned		
			Start Date	Finish Date	Time
1.51	Test Sites	Investigate areas that could be used for collecting data.	15/10/2012	16/10/2012	15
1.52	Test Variables	Define which frequencies, power levels and distances will be used during testing.	16/10/2012	18/10/2012	10
1.53	Testing Controls	Set out the parameters required for testing. This will include legal investigations into requirements for testing at various frequencies.	18/10/2012	19/10/2012	10
1.54	Perform Testing	Implement the testing procedure set out in earlier sections, storing information in the form of a matrix for easy analysis.	19/10/2012	29/10/2012	50
1.55	Analyse Test Data	Use the collected data to develop a propagation model for the given terrain. It is expected that this result in the modification of an existing model, however it is possible that an entirely new formula may be generated.	29/10/2012	06/11/2012	50
1.56	Write Propagation Model Review	Use the above information to write a review detailing the results, and explain how said results compared to expectations.	06/11/2012	08/11/2012	15
1.5	**Propagation Models**	**A report investigating current propagation models, detailing why they are unsuitable. Find a suitable model by building on existing models, confirming it with field testing.**	**15/10/2012**	**08/11/2012**	**150**

Table 18: A breakdown of minor milestones relating to propagation modelling.

*8 hours a day.

Prototype Development

Task #	Minor Milestones	Deliverables	Planned		
			Start Date	Finish Date	Time
1.61	Potential Concepts	Narrow down the combinations of technology that would best suit the requirements, and evaluate the positives and negatives of each selection.	12/11/2012	15/11/2012	20
1.62	Choose Concept	Decide which of the potential applications will be implemented.	16/11/2012	19/11/2012	10
1.63	Predict System Robustness	Investigate potential weaknesses involved with the Proof of Concept. Predict the robustness of specific parts of the system, commenting on the systems overall robustness. These will be used to help decide whether or not the concept has been properly constructed.	20/11/2012	23/11/2012	20
1.64	Design the Proof of Concept	Set out a procedure that details how each part of the system will be constructed, followed by the integration of these parts into one product.	26/11/2012	04/12/2012	60
1.65	Build the Proof of Concept	Implement the design procedure outlined above.	05/12/2012	14/12/2013	40
1.66	Test the Proof of Concept	Test the capabilities of the system, ensuring that it has fulfilled its requirements adequately.	14/12/2012	08/01/2012	50
1.6	**Prototype Development**	**Evaluate proposed concepts, select one, analyse the system, then design and build a proof of concept system.**	**12/11/2012**	**08/01/2013**	**200**

Table 19: A breakdown of minor milestones relating to prototype development.

*5 hours a day on prototype development (with 3 remaining hours a day on cost benefit analysis or implementation guideline)

COST BENEFIT ANALYSIS

Task #	Minor Milestones	Deliverables	Planned		
			Start Date	Finish Date	Time
2.11	Current method	Describe, in detail, the current process. Include valuations, short term and long term.	12/11/2012	20/11/2012	20
2.12	Chosen method	Describe, in detail, the chosen process. Include valuations, short term and long term.	20/11/2012	28/11/2012	20
2.13	Establish alternatives	Find and describe each of the alternatives to the chosen design/method. Include valuations, short term and long term.	28/12/2012	12/12/2012	30
2.14	Write Cost Benefit Analysis	Collate the above information, providing an explanation and recommendation as to which system should be implemented.		04/01/2013	30
2.1	**Cost Benefit Analysis**	**A report comparing the proposed prototype with similar systems and the process currently in place.**	**17/12/2012**	**13/01/2013**	**100**

Table 20: A breakdown of minor milestones relating to cost benefit analysis.

IMPLEMENTATION GUIDELINE

Task #	Minor Milestones	Deliverables	Planned		
			Start Date	Finish Date	Time
2.21	Investigate past introductions	Look into previous technological rollouts through DOC.	07/01/2013	10/01/2013	20
2.22	Formulate methods	List and describe possible methods of implementation, giving pros and cons for each method.	10/01/2013	11/01/2013	10
2.23	Implementation method	Decide which of the above methods of implementation would best suit the given situation.	11/01/2013	14/01/2013	10
2.24	Write Implementation Guideline	Detail the chosen process of distributing and installing the product. Look into options regarding production materials and locations.	14/01/2013	24/01/2013	60
2.2	**Implementation Guideline**	**A report detailing the step by step process of deploying the product throughout DOC's projects.**	**04/01/2013**	**20/01/2013**	**100**

Table 21: A breakdown of minor milestones relating to the implementation guideline.

*3 hours a day on cost benefit analysis and implementation guide till 08/01/2013, and 8 hours a day after this date.

THESIS SUBMISSION

Task #	Minor Milestones	Deliverables	Planned		
			Start Date	Finish Date	Time
3.11	Collect Information	Collect all relevant information from previous sections of this project.	24/01/2013	25/01/2013	10
3.12	Write Thesis	Formulate the information collected into a presentable and easy to read form. The document should pay particular attention to being clear and well organised.	26/01/2013	29/01/2013	25
3.1	**Thesis Submission**	**A report collating all research and recommendations for the project.**	**24/01/2013**	**29/01/2013**	**35**

Table 22: A breakdown of minor milestones relating to thesis submission.

*8 hours a day.

APPENDIX C – TECHNICAL PROGRESS REPORTS

Each of these reports included a Project Status and Appendix section which have been removed due to their redundancy. All references are available in References section of the main report.

1. LITERATURE REVIEW

RADIO COMMUNICATIONS

A suitable place to start is a good overview of radio communications, helping with the understanding of reviews later in this report. It is important that propagation, antennas and the difference between analog and digital communications.

- "Appendix A: Radio Communication Basics", Princeton University, 1995.
    - A great introduction to radio communications, including definitions and explanations of basic concepts.
- "Inside the radio wave spectrum", Telecomcircle.com, 2009.
    - An informative poster in regards to different uses within the radio spectrum, including its position within the electromagnetic spectrum and a brief introduction to using Hz.
- "Understanding Antenna Specifications and Operation", Linx Technologies, 2012.
    - Provides a handy introduction to the workings of antennas, and describes the fundamentals particularly well. Also explains how half- and quarter-wave antennae function as well as how antenna direction can affect the shape of the resulting radiation pattern.
- "Introduction to Communication Systems – Analog Communication Techniques", Upamanyu Madhow, 2011.
    - A strong introduction into what analog communication involves, including types of modulation and how they are performed.
- "A Foundation in Digital Communication", Amos Lapidoth, 2009.
    - Essentially a textbook for digital communication, laying out important notation and theoretical concepts used in this method of communication. It also lays out the many different types of digital communication in a relatively easy to understand manor.
- "Comparing and Contrasting Analog and Digital Two-Way Radios", BearCom, 2010.
    - A useful comparison between analog and digital communications, clearly stating the technical issues as well as political reasons behind the move (or lack of) from analog to digital.
- "Review of Radio Spectrum Policy in New Zealand", Ministry of Economic Development – Radio Spectrum Management.
    - The Review is designed to inform the Associate Minister of Communications on:
      •The radio spectrum management environment in New Zealand and its effectiveness;
      •The factors that influence that environment; and
      •Existing and emerging policy issues warranting consideration in 2004/2005 and beyond.

Low Power Radio Communications

With the remote location of most trapping locations in New Zealand it is sensible to investigate low power methods of communication.

- "Investigation into Long-Range Wireless Sensor Networks", S. Willis, 2007.
    - While this report mainly focusses on development for Wireless Sensor Networks it has been useful in suggesting methods of increasing the range of an existing low-power network. Some of these suggestions will be particularly useful in any non-WSN based applications developed, particularly in Chapter 3. The report also includes examples of many propagation modelling methods currently in use.
- "Using Wireless Sensor Technology to Schedule Irrigations and Minimize Water Use in Nursery and Greenhouse Production Systems", J. Lea-Cox, A. Ristvey and G. Kantor, 2008.
    - Irrigation management has traditionally been a very difficult task, however this report uses wireless sensor networks to provide real-time data to aid in this process. It looks at two different wireless sensor network options, implements them, and analyses the data collected.
- "Range of Low-Power Radio-communication", M. Callendar, 1947.
    - Gives a good overview of factors affecting the achievable range of low-power radio-communications, focussing on areas where low-power communication is realistically possible. It then follows with approximations of ranges where communication can still be achieved, despite the lower power levels.
- "Low-Power Radio Communication in Industrial Outdoor Deployments: The Impact of Weather Conditions and ATEX-compliance", C. Boano, J. Brown, Z. He, U. Roedig, T. Voigt, 2009.
    - This paper gives a summary of factors affecting reliability in low power systems, particularly looking at the variability of the environment. This includes rain, fog and temperature changes. It also looks into the affect that casing has on communication links.
- "Ultra Low-Power Radio Design for Wireless Sensor Networks", C. Enz, N. Scolari, U.Yodprasit, 2005.
    - A paper that looks into different methods for reducing power usage in a wireless sensor network. The overall aim of this report is to find the potential capabilities of system-on-chip products in WSN situations. A large focus is placed on the physical design of the product, rather than specifying on communication methods.

Propagation loss models

When deciding upon the frequency that would be best suited to the environment we need a suitable method of finding out how well a signal would propagate through a given terrain.

- "RF Path Loss & Transmission Distance Calculations", W. Debus, 2006.
    - Good summary of popular models available for modelling path loss over various terrain types, including the Free-Space Model, CCIR Model, Hata Models and Walfisch-Ikegami Models. It also provides useful measurements, comparing each model against real situations.

- "Prediction of Received Signal Power and Propagation Path Loss in Open/Rural Environments using modified Free-Space Loss and Hata Models", W. Shittu, B.Bajoga, F.Anwar and M. Salami, 2008.
    - This report describes how the Free-Space Loss and Hata models work, in a way that makes adaption realistic. It suggests ways in which these models can be modified to provide better results, which may be used later in this project.
- "Impact of Clutters on Quality of Service in Mobile Communication Using Walfisch-Ikegami Propagation Model", N. Sah and T. Thakur, 2005.
    - Clearly states and explains QoS (Quality of Service) factors of wireless networks. Explains the Walfisch-Ikegami model and suggests methods which can be used to modify it to specific tasks, which is been considered in this project. It also summarises the reasons for path loss in wooded areas as a result of the absorbing effect of trees, and the scattering and diffraction caused by trees. It continues by removing tree height and rainfall (above zero) as significant factors affecting loss.

PROPAGATION THROUGH FORESTED ENVIRONMENTS

This section follows on from the previous, focussing upon forested regions.

- "Implementing ZigBee Network in Forest Regions – Considerations, Modelling and Evaluations", V. Harvanova and T. Krajcovic, 2011.
    - Provided a great knowledge basis on forest-type terrain modelling and distances achievable by ZigBee devices (868MHz). The report also gave an insight into energy consumption levels of current systems, allowing a sensible target for power consumption to be found.
- "Radio Wave Propagation Along Mixed Paths in Forest Environments", T. Tamir, 1977.
    - Many papers on this topic are based on this report which attempts to model the propagation mechanism taken by radio waves in a forest, taking into account paths that are not completely wooded. It has helped to understand the way in which waves propagate through vegetation.
- "Propagation Modelling of VHF Radio channel in forest environments.
    - Builds on the paper above by proposing a Parabolic Equation algorithm, rather than a canonical case, to allow the computation of an impulse response of stationary determinist channels. It has further helped to understand the way in which waves propagate through vegetation.
- "A Full Wave 3 Dimensional Analysis of the Interaction of a Low Frequency Electromagnetic Wave with a Forest", L. Angot, H. Roussel and W. Tabbara, 1999.
    - The report shows an interesting method for modelling a forest environment, specifically over the 20 to 30 MHz range. It takes into account interaction between the EM waves and both the ground and trees. The major limitation of this model is that it considers the forest as an infinite array of trees.
- "VHF propagation over hilly, forested terrain", M. Meeks, 1983.
    - Interesting report that attempts to develop a computer-based propagation model in forest terrain, at 110.6 MHz, over a long distance.

- "A Wireless Sensor Network for Orienteering Competitions", M. Zoller, 2011.
    - A useful guide to the development of test equipment within the VHF band. Details both hardware and software involved in the development of a prototype radio device.
- "Using Wireless Sensor Technology to Schedule Irrigations and Minimize Water Use in Nursery and Greenhouse Production Systems", J. Lea-Cox, A. Ristvey and G. Kantor, 2008.
    - An interesting article on wireless sensor capabilities, especially when related to low data requirements. The document also reports on systems that are being used two test two different sensor network designs.
- "Calculation of Radio Loss in Forest Environments by an Empirical Formula", H. Chen and Y. Kuo, 2001.
    - This report suggests and confirms, through rigorous testing, that loss can be accurately estimated using an empirical formula. Unfortunately the article is focussed upon the 1GHz-100GHz range, providing very little help to the current application.
- "Propagation Analysis and Deployment of a Wireless Sensor Network in a Forest", J. Gay-Fernandez and J. Sanchez, 2010.
    - Guides the reader through the process of implementing a wireless network in forest terrain. Also contains a propagation model for the sensor network, with conclusions comparing expected results with the actual outcomes.

Summary of Literature Review

Pest Control

"Nine out of ten North Island brown kiwi chicks born in the wild will die before they are 1 year old"

There are many animals considered pests within New Zealand, which all threaten native New Zealand plants and animals. Below is a list of these animals, where those in bold are especially applicable to this project.

- Argentine Ants
- Deer
- Feral Goats
- **Ferrets**
- Fish
- **Hedgehogs**
- Kaimanawa Horses
- Kawau Island Wallabies
- **Pets (domesticated and feral)**
- **Possums**
- Rainbow Lorikeet
- Rainbow Skinks
- **Rats**
- **Stoats**
- Tahr
- Wasps
- **Weasels**

The control of many others on this list could be helped through the development of this tool.

Dozens of native bird species, including the takahe, kokako, kaki and kakariki karaka, are fighting a desperate battle for survival against introduced predators, which have been listed above. Some of these species are now only found in specially designated island sanctuaries. Stoats, rats, cats and possums are the main culprits for these casualties, through nest raiding and defoliation of native forest. Targeted pest control campaigns have been proven to work, with the increase to 70% survival rates for kiwi in the Tongariro Kiwi Sanctuary after intensive predator control the year before. There are a wide range of methods for controlling these pests, but it depends upon the other animals living in the area and the type of terrain.

Ground control methods are particularly effective, including the use of traps, bait stations and culling, but rely on suitable terrain and regular checks. DOC spends over $5 million a year on stoat and rat trapping with a network of 180,000 traps being maintained. When trapping possums DOC require the number trapped to fall below 5 trapped for every 100 traps laid. Another common form of ground control, poison bait stations, are one of the most effective methods but pose some risk to non-target species (dogs, native wildlife and farm stock). This is the most widely used pest control approach used by DOC, and is very labour intensive and expensive. When ground methods are not possible DOC tends to employ an aerial drop of 1080, which can be as low as a quarter of normal costs. This method is used for less than 2% of public conservation land, whereas ground control is performed on 4% of conservation land.

Radio Communications

Most of the information in this section is heavily referenced from "Appendix A: Radio Communication Basics", Princeton University, 1995.

The radio frequency spectrum covers the range between 3 kHz and 300 GHz, in the lower half of the electromagnetic spectrum. A breakdown of separate zones within the radio spectrum has been provided below, in Figure .

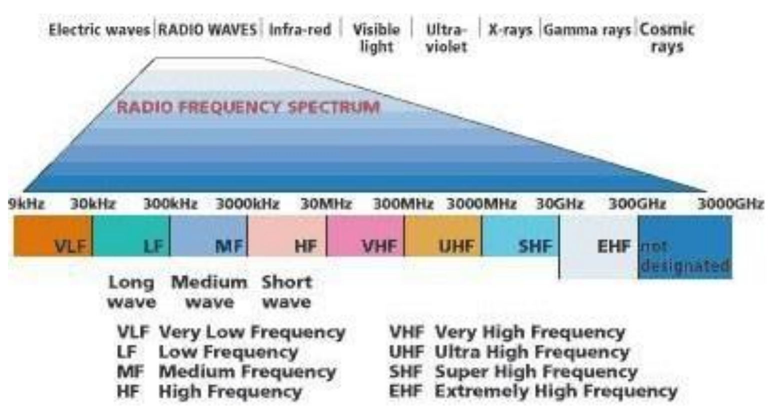


Figure 4: A breakdown of the radio frequency spectrum.

It is possible to create signals that oscillate at these frequencies, allowing the creation and manipulation of radio waves. Radio waves are the basic unit of wireless communication. By varying the characteristics of a radio wave -

frequency, amplitude, or phase - these waves can be used to communicate information. Radio waves that carry information are called radio signals, and the process of modulation allows the waves to be moulded into signals. In the process of modulation, the message is impressed onto a "carrier" radio wave that is then transmitted. When a radio signal is received, the information is converted back into its original form by a receiver, a process called demodulation. Frequency represents the number of cycles a radio wave completes in one second, and is the most common description of a radio communication signal. Hertz (Hz), which represents one cycle per second, is the standard unit of Frequency.

Radio signals can also be identified by their wavelength. Signals with long wavelengths have lower frequencies, while those at higher frequencies have shorter wavelengths, displaying their inverse relationship. The radio spectrum is divided into "bands" that correspond to various groups of radio frequencies. These bands are identified by their frequencies, or by descriptive terms that have been adopted over time. Several types of descriptive names have been attached to various portions of the spectrum.

The transmission of radio signals, at different frequencies, can be affected by many different factors. Attenuation refers to the weakening of a radio signal as it passes through the atmosphere. All radio signals are attenuated as they pass through rain or any kind of water in the air (clouds, snow, sleet), but radio signals at higher frequencies will be attenuated more than those at lower frequencies. This makes radio communication, especially over long distances, extremely difficult in the upper (above 10 GHz) frequencies. Radio waves are also bent and/or reflected as they pass through the atmosphere. Because of changes in the density of the atmosphere with elevation, radio signals bend as they pass from one atmospheric layer to the next. This bending is called refraction.

The amount of refraction, or bending, experienced by a radio signal is related to its frequency. Lower frequencies bend easily and can be reflected back to Earth. Higher frequency signals experience less refraction than those at lower frequencies, and at progressively higher frequencies, there will be less and less bending. At a certain frequency, atmospheric conditions will be such that there is so little refraction that the signal will not be reflected back to Earth. The point at which this occurs is called the maximum usable frequency (MUF), and is generally in the range of 10 to 15 MHz, although it can be as high as 30 or 40 MHz or as low as 6 MHz, depending on time of day, season, and atmospheric conditions. At higher frequencies, above the MUF, radio signals travel in almost straight lines from the transmitter to receiver, a transmission characteristic referred to as "line-of-sight."

One of the most overlooked parts of RF design is the antenna, which is probably due to its complexity. The antenna determines the range, performance and legality of an RF link. Many systems leave this part of the design until the end, causing lower than expected performance levels or redesigns. When looking into low-power communication there are two main designs preferred, the dipole and monopole whips. The main function of an antenna is to convert electric currents into electromagnetic waves and vice versa, essentially becoming a complex RLC (Resistor, inductor and capacitor) circuit with variations between inductive reactance and capacitive reactance, depending upon frequency. The aim is to maintain the inductive and capacitive reactance at the same level, making impedance purely resistive, where the antenna will be resonant. This frequency will correspond with a wavelength, and an antenna with the same length as the incoming wave will best pick up the signal. This resonance will occur at multiples or fractions of the specific frequency and hence smaller or larger aerial can still be used to pick up a signal.

The decision between Analog and Digital methods of transmission is very complex. A typical analog signal will continuously deteriorate as it advances toward its maximum range, until only white noise is heard. In contrast, a typical digital signal will stay strong and clear until it reaches its maximum range, at which point it will completely die. Below is a summary of each.

Analog: These signals have a sinusoidal, or continuous, value. Today's analog systems use frequency modulation (FM). The frequency modulation produces a continuous wave with the voice signal. By integrating such a simple system into a single chip, the cost of this radio has dramatically reduced. Analog signals are still used in many systems today, but the uses for analog signals are declining with the introduction of the more reliable digital signal.

Digital: Digital signals are represented by binary numbers: 1 or 0. The 1 and 0 values can correspond to different discrete voltage values. Any signal that doesn't quite fit into the scheme is rounded off. By using a binary signal, error correction embedded signalling and control bits are possible in each packet transmitted. A packet contains an assembly of bits. The software contains an algorithm that understands the differences between voice and background noise, and in return, cancels the unwanted background noise and unwanted audio. The wireless digital signal provides the same levels of reliability and control as a wired digital signal.

Low Power Radio Communications

The definition of Low Power Radio depends upon the frequency at which you are transmitting, but is typically around 1 watt. In New Zealand residents are allowed to broadcast, license-free, at a maximum of 1 watt EIRP in some FM bands (87.6 to 88.3 and 106.7 to 107.7) under a General User Radio License.

The most important challenges faced, when designing WSN radios, are size and power consumption. Reductions in power usage requires the optimisation of all layers of the given communication system. Even when these layers have been mostly optimised it is still the transceiver that consumes the most power, and hence improvements of this aspect will result in large gains for WSN's as whole. The most effective method for reducing power consumption is employing a duty cycle, which enables the device to only be on part of the time, hence reducing the power required.

Another part of the system which often consumes considerable levels of power, when included, is the processing unit. These are included when high levels of modulation and encoding are required. The communication distance achievable at these low levels of power suggests that sensor networks should be employed to reduce the distance each signal must travel. Due to the remoteness of these nodes it is unrealistic to get a wired power supply to them. The size and quantity of these nodes also removes the option of generating power, however it is possible that wind/solar energy could be harnessed. This leaves just battery supplied power, which is limited to the capability of the battery. With a limited amount of power available, it would make sense to reduce power consumption in order increase its operational time. This would reduce the number of times that battery must be replaced.

Propagation Loss Models

A typical RF transmission system takes the following form.

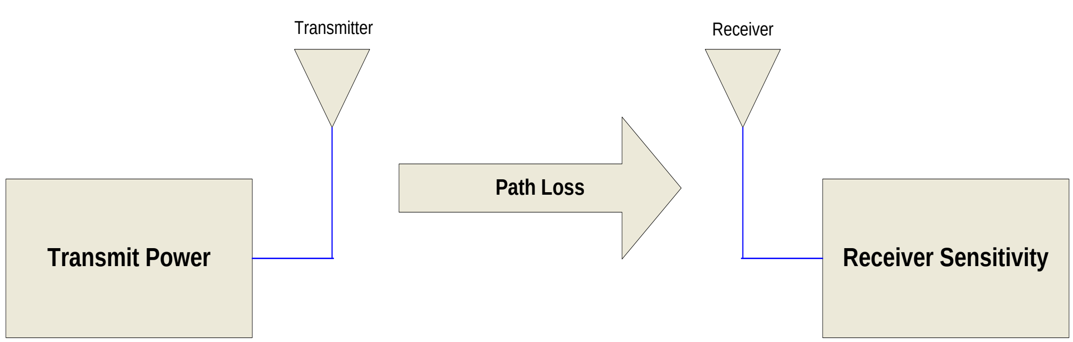


Figure 5: A diagram depicting typical losses during transmission.

As long as the Receiver Sensitivity is higher than the Transmit Power, minus the Path Loss, then reliable communication can be maintained. This path loss is broken up into several main reasons, including free space path loss, absorption losses, signal diffraction, multipath effect, varying terrain and buildings/vegetation/atmospheric conditions.

When a radio transmission is designed there are two questions that are always asked.

- How far apart can the transmitter and receiver be placed without affecting performance?
- How can we increase this separation distance?

This is where a method of modelling propagation losses becomes useful. There are many propagation loss models which are commonly used. We can narrow this down to several realistic options, which are:

- Free Space Model - Free Space propagation is an ideal propagation environment where transmission of radio waves from a transmitter antenna to a receiver antenna is free of all objects that might interact in any way with the electromagnetic energy. This is the most basic model available.
- CCIR Model - An acronym for Comite Consultatif International des Radio-Communication, who first published it, that provides a formula for the combined effects of free-space path loss and terrain-induced path loss.
- (Okamura-)Hata Models - The Hata models are empirical formulae for the computation of propagation path loss based on Okumura results.
- Walfisch-Ikegami Models (WIM) - A model for propagation that has been shown to be a good fit for frequencies between 800-2000 MHz of distances up to 5km.

The accuracy of these models depends heavily on the terrain and frequency in which the system is operating.

Propagation through forested environments

A transmitted signal is heavily affected by obstacles in its path, particularly obstacles which have a similar length to the signals wavelength. Any objects with a length larger than the wavelength will cause attenuation of the signal as it passes through the object. If the wavelength is larger than the length of the object then the signal will pass through the obstacle relatively un-attenuated.

Following on from the previous section, we apply the models found to a forest terrain. The models mentioned are heavily directed towards predicting mobile phone transmission, particularly through urban environments. With the increase in obstacles and decrease in frequency it would be sensible to assume that these models would underestimate the level of attenuation. There have been many attempts to model propagation loss in forested terrain, however the variation in said terrain means that each model must be heavily specified to be accurate.

While some models attempt to model each tree as an object and statistically estimate the loss this project will aim to adapt existing models to the terrain through the introduction and specification of variables into the equations. It quickly becomes obvious that there are systems set up in similar situations, giving the project the option of basing a possible system on existing products.

2. Current Systems

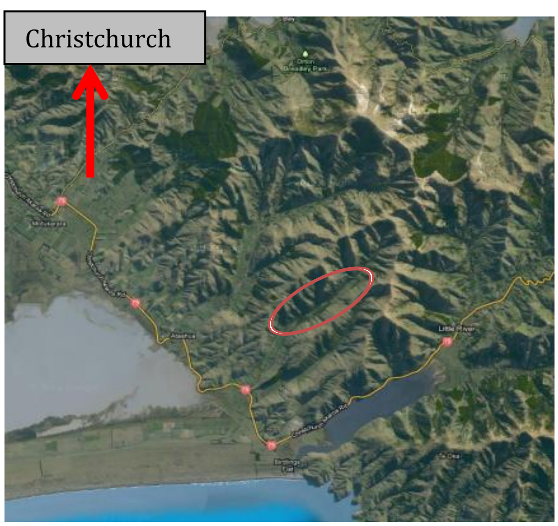
This section looks at systems that are currently in place with DOC, potential technologies that could be put in place and similar situations where wireless monitoring is used.

Present Arrangement

Research has been performed looking into current practices employed by DOC. A summary of current trapping and communication methods used by DOC has been provided below.

Pest Control processes

After shadowing an individual implementing the current pest control process, two reports were compiled detailing the information collected. These Field Trip reports can be seen in Appendix A. Both of these field trips were taken to the Akaroa (Banks Peninsula) region of Canterbury, New Zealand, in the areas circled below in Figure 6 and Figure 7.



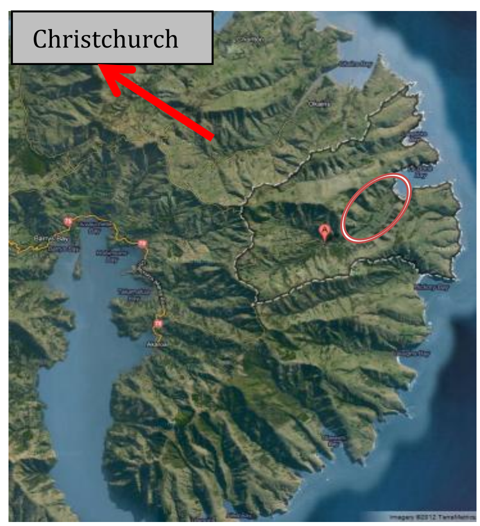


Figure 6: Field Trip 2 - Le Bons Bay

Figure 7: Field Trip 1- Birdlings Flat

Possum Trapping

The typical process begins with the trappers following pre-designated lines leaving a chew card every 5-20 metres. These tracks appear to be between 500m and 1km in length. Each chew card is made up of layered plastic with peanut butter in the gaps, with an example below in Figure 8.

Figure 8: A chew card, used to determine if possums are in the vicinity.

The trappers then return the following day. If the chew card has bite ma **Reference source not found.** has, then the trapper knows that a possum set next to the chew card. The trap may also have a feeder placed above it, which will draw the possum into the leg trap, leading to the configuration shown on the left in Figure 9. Flour was spread around the trap as experience had shown it attracts possums.

Figure 9: A feeder, placed above a leg trap, used to catch possums.

Those employed to trap then return the next day to check the traps, which is a legal requirement with this method of trapping. Most areas require less than 2% of traps to contain possu otherwise it continues. For example, if 10 of 200 traps contain possums, the process until the day that they catch less than 4 possums with those traps. The percentage required can change from region to region, and made the whole set up temporary. This type of trapping is called "block elimination".

General Trapping

The second field trip was not focussed on possum trapping, and was a more permanent set up. Rather than leg traps, the trapper employed larger wooden kill traps, pictured below in Figure 10.

Figure 10: A larger, more permanent, trap used for smaller pests (stoats, possums, rats, etc).

With the semi-permanent set-up the process was simple, empty the trap (if required) and reset it with bait.

Existing DOC communication methods

The Department of Conservation already has various communication systems in use as well as many frequencies licensed. This section will define these systems, through which this project could operate, as well as discover frequencies available to DOC that could be used with a new communication system.

VHF Operations

DOC operates a VHF radio network covering the majority of conservation land in New Zealand. It has however been indicated (Cockburn, 2012) that the primary use of the network is currently for emergency services and as such was deemed undesirable for the network to be used for transmitting large amounts of data at the risk of impeding this service. The network currently operates in three distinct ways as follows:

Simplex, Figure 11 (DOC, 2010)

- For direct communication between radios.
- Used over short distances
- Line of sight
- Range up to 10km

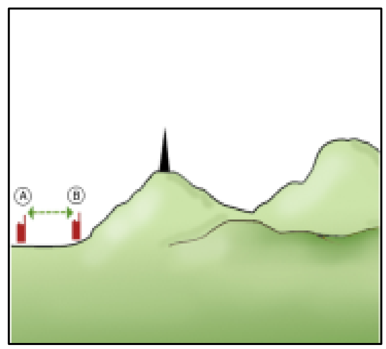


Figure 11: Simplex VHF Communication.

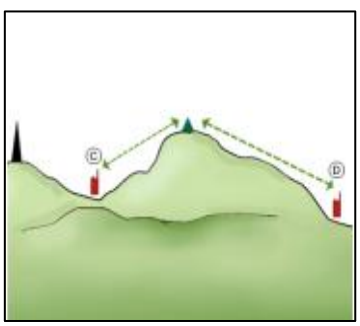


Figure 12: Portable Repeater VHF Communication.

Portable Repeaters, Figure 12 (DOC, 2010)

- Used for areas not covered by fixed repeaters
- For emergencies and general operation support
- Field kits containing long lasting external batteries and solar panels

Fixed Repeaters, Figure 13 (DOC, 2010)

- Non line of sight
- Repeater receives incoming signal and re-broadcasts it
- Typical range up to 50 – 60km (terrain dependant)

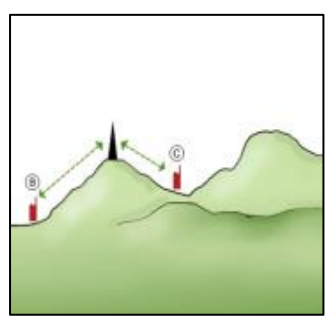


Figure 13: Fixed Repeater VHF Communication.

- DOC has a network of fixed repeaters to provide radio coverage over key areas of conservation land

The DOC fixed repeater network is comprehensive, with coverage over a large percentage of conservation land. Coverage is broken down into regions over the country with all regions covered to some degree, Figure 14 (DOC, 2010).

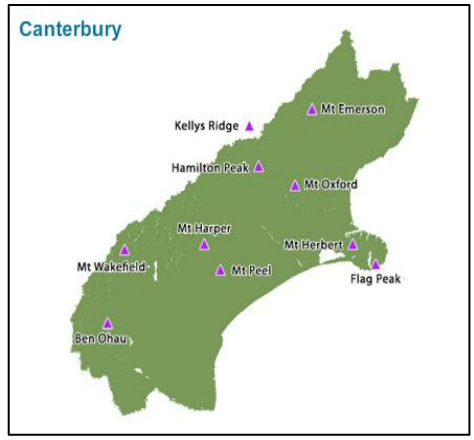


Figure 14: Fixed Repeater Locations - Canterbury Example.

It is recommended that this frequency range be investigated to determine its suitability in the given terrain as the existing infrastructure would make this an attractive option financially.

The VHF frequencies licensed by DOC are listed below, in Table 1, as suggest by S. Cockburn (Cockburn, 2012)**.**

Licence Type	Licence ID	Spectrum Details			
		Low (MHz)	High (MHz)	Power dBW (EIRP)	Polarisation
Mobile transmit	114812	169.168750	169.181250	14.0	Vertical
Mobile transmit	106354	169.256250	169.268750	14.0	Vertical
Mobile transmit	106355	169.418750	169.431250	14.0	Vertical
Mobile transmit	114820	169.481250	169.493750	14.0	Vertical

Table 23: VHF frequencies licensed by DOC in New Zealand.

Other Frequencies available to DOC

There are two groups of frequencies available to DOC, ones they have licensed and others that can be used with a General Users Radio License. DOC own over 500 licenses for frequencies under 500MHz, which are specific to certain areas and power levels. Many of these frequencies may be reserved for emergency operations and, hence, must be checked before used. For a detailed list of these channels see Appendix B.

The General Users Radio License is the licence covering the operation of amateur radio equipment in New Zealand, and is presided over by the Ministry of Economic Development. A general user radio licence is granted for the transmission of radio waves by amateur radio operators in New Zealand, for the purpose of communications in the amateur radio service. Realistically, the GURL license has ranges from 3.5 MHz to 150MHz available, with a strong concentration of channels from 26-28MHz. While it may actually entail many more frequencies, there are strict reservations for distinct types of communication in certain channels. For appropriate frequencies that are available with a GURL see Appendix C.

Environmental Constraints

While researching into this topic we have found three main sources for the type of terrain the system is expected to operate in, field trip experience, interview with Bruce Warburton of Landcare Research and a report by Julian Carver.

Field Trip

The two field trips have presented very different types of terrain, as shown in Figure 15 and Figure 16, which can have a considerable effect on propagation losses.

Figure 15: More open but (generally) more undulating terrain.

Figure 16: Field Trip 1 - Denser foliage.

The type of bush will also have an effect on propagation, with pine needles known to cause unusual levels of attenuation at certain frequencies.

Bruce Warburton

In order to ascertain a worst case landscape environment a series of questions were posted to the Landcare project correspondent, Bruce Warburton around the expected animal monitoring set up (Warburton, 2012):

- Location (or description of the type of vegetation/ terrain in the area)
    - Worst case is steep sided valleys covered in dense forest. Best case if McKenzie basin relatively flat and tussock country.
- Spacing of cameras
    - Well this depends of species. For feral cats and stoats that have large home ranges devices might be spaced at 800-1000m apart, but I think 400m would be OK. For rats and possums you could have the spaced at 100m apart. Depending on survey design you might had a group (block) of cameras at say 100-m spacing and then groups of them at wider spacing (say up to 200-5—m between groups).

- Number of cameras in any one area.
    - Again, no hard and fast rule as it depends on the variability of the index and precision you need. But I would say for any one survey area 30 would be a good (max) number. Or you might have say 10 in each of 3 blocks that are randomly allocated across the area of interest.

A Review of Wireless Sensor Networks for Pest Control Operations – Julian and Derek Carver

This report investigates the varied landscapes in which DOC conducts pest control operations, which are most often not ideally suited to wireless signal transmission. Involving dense bush coverage, without line of sight between monitoring stations, the DOC landscapes expected to be used for operations, vary in both size and terrain as described by the subset of DOC operations below (Julian Carver, 2011):

- **Whangarei** – A 2,000 hectare site comprising mixed pastoral landscape, wetlands, and forest margins.
- **Te Urewhera Mainland Island** – very large scale operation of around 40,000 hectares, with a 2,500 hectare Kiwi Sanctuary inside it.
- **Boundary Stream Mainland Island** – 800 hectares of lowland to montane forest on the eastern flanks of the Maungaharuru Range.
- **Tasman predator control project** – a 25,000 hectare project in the McKenzie basin near Twizel. Primarily braided river beds, wetlands, and surrounding tussock land.

The main focus of this report, which is also beneficial to the current project, was to look potential opportunities and benefits for the use of wireless sensor networks (WSNs) in pest control operations at the Department of Conservation. It focuses on determining the operational contexts in which WSN technologies may be of benefit and the different operational variables that impact on cost/benefit ratios. It discusses only in very general terms the selection of particular WSN technologies, and how they will be deployed in the field from a detailed technical perspective. (Julian Carver, 2011)

Important findings included that fact that in addition to direct financial savings through reduced labour and vehicle costs, there is potential benefit in the use of WSNs to gather more data to optimise trapping network design, more rapidly responding to unpredicted changes in trap availability in large remote kill trapping networks, to ensure more robust testing of new approaches to trapping, and in improved outcomes through enabling use of live catch traps in new places where they would otherwise have been too expensive to service. The report concluded that further work should be conducted on evaluation of particular WSN technologies, understanding their costs, and testing and piloting them in the field. (Julian Carver, 2011)

“Off the shelf” methods of communication available

There are many options for wireless communications available commercially. Many of these are collected, explained and dismissed for this purpose below.

Wi-Fi (802.11a/g/b) a.k.a Wireless LAN

"Wi-Fi" is short for Wireless Fidelity, and is a high speed internet and network connection without the use of wires. (Peter, 2009)

Description

Wi-Fi is easier and cheaper to set up and run than a wired network - mainly due to the lack of cables, and allows you to move your computer quickly and easily around the area. It also allows you to connect multiple devices to the one point connection, with minimal hassle. Wi-Fi works, in essence, exactly the same way a Television or Cell Phone works. Wi-Fi typically uses radio waves to transmit information to and from the internet or your computer network. Your device interprets the radio waves with the help of installed hardware/software (specifically for wireless networking). The reverse process occurs when your device needs to communicate back. One of the fundamental differences between Wi-Fi and a Cell Phone is that Wi-Fi operates on a much higher frequency (2.4GHz or 5GHz), as opposed to Cell Phones which work below the 1GHz level. The higher the frequency the higher the amount of data that is able to be transferred. (Peter, 2009) The latest and most prominent form of Wi-Fi is 802.11n (n-type), with a new standard, 802.11ah, expected soon.

Advantages

- Easily obtainable technology, making hardware cheap and reliable.
- Can integrate with many other devices, allowing for phone and computer connectivity.

Disadvantages

- Frequency is ineffective in forested terrain.

WiMAX (Worldwide Interoperability for Microwave Access)

WiMAX is a wireless broadband access technology that provides performance similar to 802.11/Wi-Fi networks, with the coverage and quality of service of cellular networks. (WiMAX)

Description

WiMAX is a wireless digital communications system, also known as IEEE 802.16, which is intended for wireless "metropolitan area networks". WiMAX can provide broadband wireless access up to 50km for fixed stations, and 5-15km for mobile stations. In contrast, the 802.11 wireless local area network standard is limited in most cases to only 30-100m. With WiMAX, Wi-Fi data rates are easily supported, but the issue of interference is lessened. WiMAX operates on both licensed and non-licensed frequencies, providing a regulated environment and viable economic model for wireless carriers. (WiMAX)

Advantages

- Enables the adoption of advanced radio features.
- Readily available hardware, which is both flexible and durable.

Disadvantages

- Intended for metropolitan areas, and hence, are ineffective in forested terrain.

Cellular

Mobile phones and their network vary significantly between providers and countries. However basic communication is maintained, through electromagnetic microwaves, with a cell base station. Most cellular companies have large antennae, which are usually mounted on hills, buildings and poles. The mobile phones have low-power transceivers that transmit voice and data to the nearest site, usually within 8 to 13 km away. (Networking Tutorials, 2007)

Description

When a mobile device or phone is turned on, it registers with its closest cell base station. It sends a unique identifier, and hence is alerted by the central switch point when there is an incoming phone call or text. When a user moves, the mobile device reselects the nearest cell phone site. Cell sites broadcast their presence and relay communications between the mobile handsets and the central switch point. The dialogue between the mobile phone handset and the cell phone site is a stream of the digital data, which includes a digitized for of the audio message for voice calls. (Networking Tutorials, 2007)

Advantages

- Strong existing network, world-wide.
- Hardware is readily available.

Disadvantages

- Limited coverage in low population areas, where this project will focus.

Bluetooth

Bluetooth technology is a short-range communications technology that is simple, secure, and everywhere. It is found in billions of devices worldwide, from mobile phones and computers to medical devices. It is intended to replace the cables connecting devices, while maintaining suitable levels of security. (Bluetooth)

Description

Bluetooth technology is based on three core factors, namely robustness, low power, and low cost. When two Bluetooth enabled devices connect to each other, this is called pairing. The nature of Bluetooth technology means any Bluetooth enabled device can connect to another Bluetooth enabled device located in its proximity. Connections between Bluetooth enabled electronic devices allow these devices to communicate wirelessly through short-range networks. Each device in a network can also simultaneously communicate with up to seven other devices within that single network and each device can also belong to several networks simultaneously. The range of Bluetooth technology is application specific, with a minimum range of 10 meters, but there is no set limit and manufacturers can tune their implementations to provide the range needed. (Bluetooth)

Advantages

- Popular form of communication, with many proven examples of success.

Disadvantages

- Inadequate range, especially in areas with many obstacles.

ZigBee

ZigBee is a standards-based wireless technology designed to give a low-cost, low-power wireless option for a variety of situations. (Zigbee Alliance)

Description

ZigBee can be used almost anywhere, is easy to implement and needs little power to operate, promoting itself as a useful option for this project. ZigBee uses the 2.4 GHz radio frequency to deliver a reliable and easy-to-use communication method. Its reliable wireless performance and battery operation gives ZigBee the freedom and flexibility to work anywhere. (Zigbee Alliance)

Advantages

- Can transmit high volumes (video).

Disadvantages

- Inadequate range in forested terrain, given its high frequency.

Satellite Communications

Satellite communication, as part of the telecommunications industry, is the use of artificial satellites to provide communication links between various points on Earth. Satellite communication plays a vital role in the global telecommunications system. There are approximately 2,000 artificial satellites orbiting the Earth, which relay data to and from one or many locations worldwide. (Encyclopedia Britannica, 2012)

Description

Satellite communication has two main components: the ground segment, which consists of fixed or mobile transmission and reception, and the space segment, which primarily is the satellite itself. A typical satellite link involves the uplink of data from an Earth station to a satellite, where the satellite then receives and amplifies the signal. The satellite then transmits that same signal back to Earth, where it is received. Satellite receivers on the ground include handheld devices, which could be applicable to this project. (Encyclopedia Britannica, 2012)

Advantages

- Extremely long range and world-wide coverage.

Disadvantages

- High frequency means device would need direct line of sight to a Satellite.
- Heavily affected by weather conditions.

Similar Systems with Alternative Applications

This section looks at other monitoring networks where the technology could be applicable to this project. (Willis, 2007)

Bird Habitat Monitoring

A bird habitat, located on Great Duck Island off the coast of Maine, USA, is home to a wireless sensor network. It is used to monitor the movement of a species of bird which lives in burrows around the island. Environment settings (temperature, moisture, etc.) were periodically sent to an on-site computer located nearby, which then relayed them to a research office by means of a satellite link. The advanced processors and software algorithms used made the availability of an on-site computer a requirement. (Szewczyk, 2004)

Vineyard Sensor Network

Similar technology to the previous section allowed the monitoring of environmental conditions in a vineyard. Growing techniques were then altered, with the help of the network, to improve the quality of the product. The terrain traversed in this situation was on a clear hillside, apart from the vines, making propagation considerably easier than this project. (Update Camalie Networks Wireless Sensing, 2008)

Lawn Monitoring Network

As an already available product it has been tested and has a transmission range of approximately 15m, at a frequency of 916MHz. The system uses battery powered sensor nodes, which have been push into the lawn, to monitor soil moisture levels. These nodes then pass the information on to a control unit which dictates the operation of relevant sprinklers over the area. (Willis, 2007)

Animal Movement Tracking Network

This system was set up to locate specific animals by their calling sound, and is able to locate the approximate position of an animal within 250mm. Unfortunately the areas covered are relatively small and the expected terrain was quite open. Each node was made up of a pocket PC, a set-up which would be both power hungry and expensive. (Markham, 2008)

Industrial Process Automation

It is not uncommon for wireless sensor networks to be implemented in industrial processes, helping to increase automation. The network of nodes is used to monitor temperature, fluid levels or pressure, all in order to maintain perfect working conditions for machinery. The environment however, is urban and consists of relatively short distances, making this set-up inadequate for forested terrain. (Willis, 2007)

Summary of Current Systems

Below is a summary of “Off the shelf” methods, and why they are not appropriate to this application.

Method	Why won’t it work?
Wi-Fi	Distance achievable is inadequate.
WiMAX	Frequency leads to poor propagation in expected terrain.
Cellular	Poor coverage in required areas.
Bluetooth	Inadequate maximum achievable distance.
ZigBee	Does not provide suitable distances in expected terrain.
Satellite Communications	Link unreliable, due high frequency conflict with weather.

The following table lists similar systems which serve alternative applications, along with why they are not appropriate to this situation.

Application	Why won’t it work?
Bird Monitoring Habitat	Requires on-site computer within short range.
Vineyard Sensor Network	Inadequate terrain, too little foliage.
Lawn Monitoring Network	Inadequate distance, at inappropriate frequency.
Animal Movement Tracking Network	Permanent set-up, uses too much power.
Industrial Process Automation	Inadequate terrain, too little foliage.

3. NEW TECHNOLOGIES

A24 TRAP – A NEW TRAPPING PRODUCT

Figure 17: The GoodNature A24 trap, designed for rats and stoats.

The A24 traps, which have passed animal welfare standards, can repeatedly kill and re-set themselves before they need to be serviced. The self-setting, gas-powered, rat and stoat trap is being trialled for two years at the Nelson Lakes National Park. The new traps can be activated 24 times before they need to be serviced, compared with the DOC 200 traps which are currently used. Once a DOC 200 is sprung, it has to be manually re-set. DOC is already one year into a trial involving another gas-powered trap that targets possums. Some innovative ideas including modifying the tunnel used for the DOC 200 trap to use with the A24 are helping to prevent non-target species, like weka, from getting caught. The new traps would allow DOC staff to divert more energy into other aspects of preservation. (KIDSON, 2012)

While the technology itself has no impact upon the communication aspect of the project it may be useful to have a fixed device on to which the communication aspect is attached. The shift from short term trapping to a more long term alternative is promising for the communications requirements as a fixed location and time frame will allow more flexibility of its design. This could range from longer antenna to more powerful batteries.

WI-FI – 802.11AH

"Wi-Fi" is short for Wireless Fidelity, and is a high speed internet and network connection without the use of wires (Peter, 2009). Wi-Fi connects mobile phones, computers, media players and other devices, without the need for cables. These networks use a radio technology called 802.11 to provide wireless connectivity. A Wi-Fi network is usually used to connect electronic devices to each other. They operate in the 2.4 and 5 GHz radio bands, with some versions able to use both bands. These bands are designated as "license-free", which use of these bands without a government license. Because the Wi-Fi bands are "license-free", it becomes more important for manufacturers to ensure that their products pass the standards of interoperability set by the Wi-Fi certifications. Interoperability means that products from different manufacturers will work together (WiFi Alliance).

Every few years a new Wi-Fi standard is released. Expected in 2013 is the 802.11ah standard which aims to provide an ultra-low-power version of Wi-Fi at a sub 1GHz frequency. While the low power opportunities with 802.11ah are attractive it is expected that the frequency chosen for this standard, just under 1GHz, with be inadequate for the given terrain. (Hachman, 2012)

4G – Latest in Mobile Phone Technology

Mobile phones and their network vary significantly between providers and countries. However basic communication is maintained, through electromagnetic microwaves, with a cell base station. Most cellular companies have large antennae, which are usually mounted on hills, buildings and poles. The mobile phones have low-power transceivers that transmit voice and data to the nearest site, usually within 8 to 13 km away (Networking Tutorials, 2007). As the technology behind mobile phone technology improves the performance also develops. Once certain parameters are met the technology is said to be a new generation. In March 2008, the International Telecommunications Union-Radio communications sector (ITU-R) specified a set of requirements for 4G standards, which set peak speed requirements for 4G service at 100 Mbit/s for high mobility communication and 1 Gbit/s for low mobility communication (International Telecommunication Union, 2008).

While the technology may be suitable for this project, it is heavily reliant on the ability of existing infrastructure being able to cover the required regions. It is also likely that frequencies used in 4G communication may become unreliable in forested areas. It is for this reason that 4G/Mobile technology will be kept in mind during the project, with inclusion dependent upon cellular coverage within given the regions.

Flexible Spectrum Management

While Mesh networks are not particularly new, the introduction of flexible spectrum management is. Tremendous efforts on research of frequency-agile techniques are being performed for increased efficiency. The concept of flexible spectrum management, which refers to a set of new and dynamic procedures and techniques for obtaining and transferring spectrum usage rights and dynamically changing the specific use of frequencies, plays an important role in fully exploiting the advantages of cognitive, reconfigurable networks and terminals. (Ballon, 2007)

While this technology may benefit the transmission of data, it would require greater levels of processing for both sending and receiving. This increase in processing requirements will lead to an increase in power requirements, which are unavailable in the given environment.

NEW MODULATION SCHEMES

When looking into possible modulation schemes we are limited by the power capabilities of the project. This will limit the number of bands available, unless extremely narrow bands are used. Unfortunately the reduction of band size will lead to a greater affect from the multipath affect, and hence the received data will be less reliable. While a new modulation scheme may help improve the effectiveness of the system in this project the low power aspect will limit the level of processing capability. As most new schemes incorporate complex processing it is unlikely that they could be used in this project.

SMART ANTENNA

Smart antennas (also known as adaptive array antennas, multiple antennas and, recently, MIMO) are antenna arrays with smart signal processing algorithms used to identify spatial signal signature such as the direction of arrival (DOA) of the signal, and use it to calculate beam forming vectors, to track and locate the antenna beam on the mobile/target.

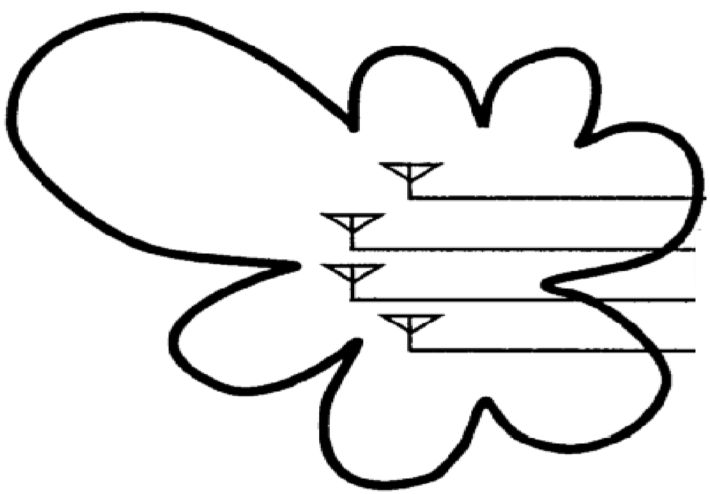


Figure 18: An array of aerials configured to provide lower levels of attenuation in a certain (upper left) direction.

Smart antenna take advantage of the diversity affect, in the transceiver sections of a wireless system, at both the source and the destination. The term diversity effect refers to the transmission and reception of multiple radio frequencies that are used to decrease the error during data communication and also to increase data speed between the source and the destination. The main difference between smart and regular antenna is related to the way both the systems deal with the problems caused by multipath wave propagation. When a wireless signal is sent to a large distance it may have to pass many barriers like tall buildings, mountains, utility wires and so on.

Thus these signals' wave fronts will be scattered and will take multiple paths to reach the receiver. In a conventional Wi-Fi communication system, a method called single input single output [SISO] is used, that is one antenna will be connected to the source and another one will be connected to the destination. When the signals arrive late at the destination, they may arrive faded or cut-out. This is one of the basic problems of a SISO system. All these problems can be solved with the help of Smart Antennas, through estimating the direction of arrival and employing the beam forming method. (Circuits Today, 2011)

Unfortunately this type of system is expensive, large and diversity of incoming signals must be taken into account (from multiple antennae). The complexity and number of antenna involved with smart antenna are unsuitable for the given environment, especially considering that those setting up the traps will have very little knowledge of communications theory.

Murray Greenman Option (NVIS)

Murray Greenman (ZL1BPU) is an amateur radio enthusiast who writes a column ("Digital Modes") on various new communication technologies and runs a website where much of the same information is also posted. The website is designed to include information on new, different, and specialized radio communication modes. The emphasis is on modes which have influenced him in some way during development. There are digital chat modes and visually readable modes for LF, HF and VHF. After discovering his interest in transmission of low-power and low-bandwidth data, contact was made and a Skype meeting was organised. The meeting consisted of a brief introduction about experiments he has been performing and he then delved into deeper technical detail regarding both the 4bits/day (Richard) and 4Mbits/day (Thomas) requirements. (Greenman, Amateur Radio, 2010)

After this meeting, Murray wrote about the predicament faced in this project and suggested that it could be completed with each transmission taking under a minute. Murray chose a frequency of 3.549MHz with a 200mW carrier, which is producible with a single CMOS chip and a 1W solar panel. He then goes on to test the suggested system and appears to receive the signal without many issues. The relevant part of the article has been included in Appendix 1.

While the information he has provided has been very useful, there is one major issue with the set-up he has suggested. The antenna size is restricted in this project, in order to maintain mobility and ease of set-up, yet Murray has experimented using much longer antenna. Of particular interest was the information on solar powered communication, even when direct sunlight was not achieved.

Smart Dust

"Smart dust" devices are tiny wireless micro-electro-mechanical sensors (MEMS) that can detect everything from light to vibrations. Recent and future breakthroughs in silicon and fabrication techniques could allow these "motes" to eventually be the size of a grain of sand, though each would contain sensors, computing circuits, bidirectional wireless communications technology and a power supply. Motes would gather data, run computations and communicate that information using two-way radio at distances approaching 350m (Hoffman, 2003). A researcher, in the 1990s, named Kris Pister dreamed of a future in which people would sprinkle countless tiny sensors around the earth, no larger than grains of rice. The latest advances have come from Hewlett-Packard, which announced work on a project called the "Central Nervous System for the Earth." In coming years, the company plans to deploy a trillion sensors all over the planet. The wireless devices would check to see if ecosystems are healthy, detect earthquakes more rapidly, predict traffic patterns and monitor energy use (Sutter, 2010).

While this technology would be idea for animal tracking, and could even be transferred to this project, it is not yet technically or commercially viable, and hence must be ruled out for this project.

Summary of New Technologies

These potentially useful technologies have been summarised in the below table, where, if they are not applicable, a reason is provided.

Technology	Applicable?	If not, why not?
A24 Trap	Yes	Unrelated to core project requirements.
Wi-Fi (802.11ah)	No	Inappropriate frequency.
4G	Yes	Limited coverage expected in required regions.
Flexible Spectrum Management	No	Complexity requires high levels of power, which is unavailable on each node.
New Modulation Schemes	No	Complexity requires high levels of power, which is unavailable on each node.
Smart Antenna	No	Currently too complex and expensive for this project.
Murray Greenman Option (NVIS)	Yes	Antenna requirements are long for “in the field” applications.
Smart Dust	No	Not yet commercial/technically viable.

Table 24: A summary of the new technologies suggested in this report.

4. Propagation Modelling

Constraints

Suitable Test Sites

Several sites in the Canterbury region have been selected as possible initial test sites. These sites were explored in order to select the most suitable. (See Appendix A for more a more detailed view at these areas.)

Test Site A – Bottle Lake

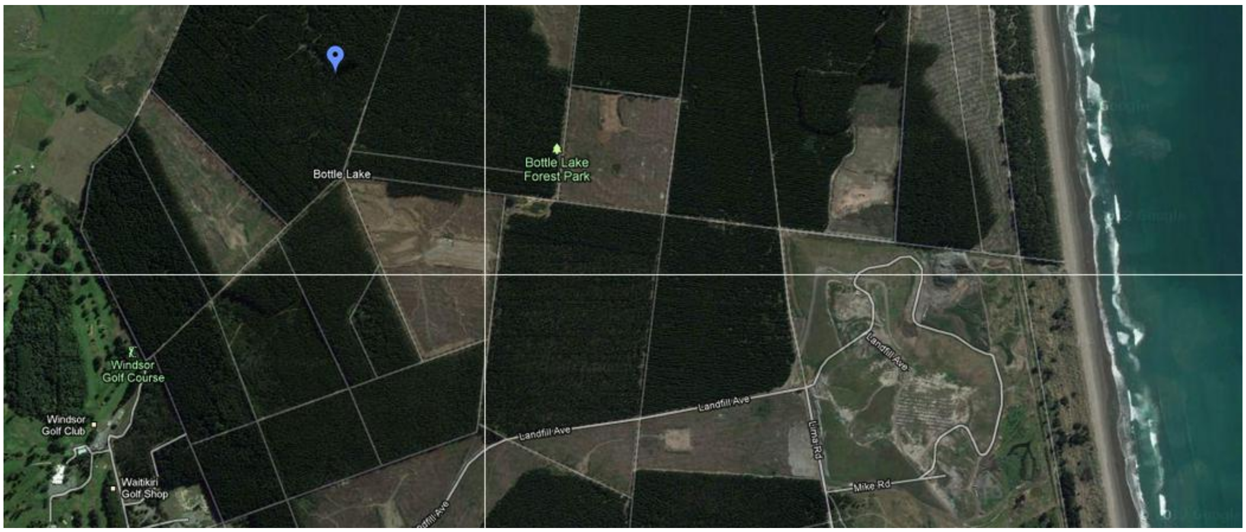


Figure 19: A map detailing the area in Bottle Lake Forest Park that has been proposed.

Distance: 13km (23 mins)
Maximum test range: 2km+

Test Site B – Little River

Figure 20: A map detailing the location of Test Site B, near Little River (to the east).

Distance: 46km (50 mins)
Maximum test range: 700m

Test Site C - Westmoreland

Figure 21: A map detailing the location of Test Site C, just south Westmoreland (Christchurch).

Distance: 11km (18 mins)
Maximum test range: 600m

Test Site D – Riccarton Bush

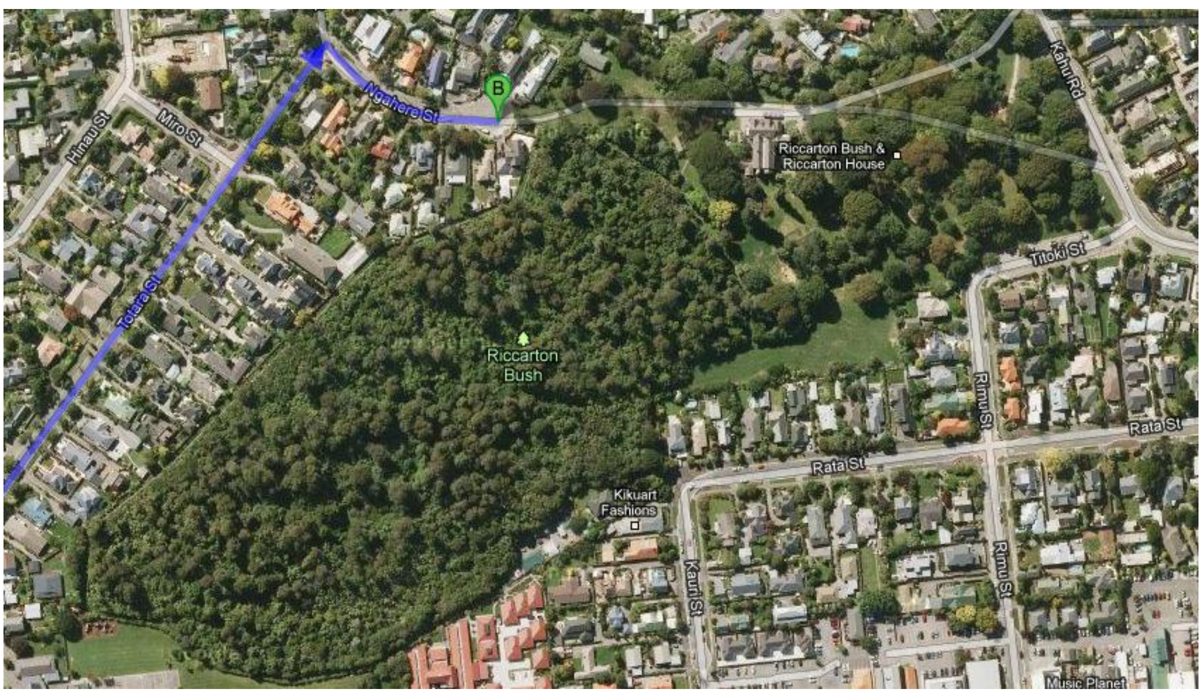


Figure 22: A map detailing the location of Test Site D, in the Riccarton suburb of west Christchurch.

Distance: 1km (2 mins)
Maximum test range: 600m

Test Site E – Mcleans Island Road

Figure 23: A map detailing the area on Mcleans Island Road that has been proposed.

Distance: 15km (20 mins)
Maximum test range: 600m

Test Site F – Kennedy's Bush

Figure 24: A map detailing the area Kennedy's Bush that has been proposed.

Distance: 17km (30 mins)
Maximum test range: 1.2km

Test Site G – Victoria Park

Figure 25: A map detailing the area in the Port Hills that has been proposed.

Distance: 13.6km (23 mins)
Maximum test range: 500m

Test Site Decision

In order to choose which site is best suited to this round of testing a decision matrix has been created. This will take into account distance from university, the available range of distance testing, the appropriateness of bush type, the density of bush and undulation within the area. They have then been weighted, in order, with proximity of test area being the most important, and undulation mattering less, in this situation.

		Distance	Test Range	Undulation	Bush Density	Bush Type	Total
Weighting		**9**	**7**	**4**	**5**	**7**	
Test Site	A	6	10	2	4	2	166
	B	2	8	9	8	8	206
	C	6	7	7	7	7	215
	D	10	5	1	7	6	206
	E	6	7	2	5	3	157
	F	5	8	4	4	6	179
	G	6	7	6	8	7	**216**

Table 25: A decision matrix designed to find the most appropriate test area.

The decision matrix shown above suggests Victoria Park is the most suitable test site, using Ilam Fields (next to the University) as a control site. Further testing will need to be further afield to find the best conditions.

Frequency Range

Literature has strongly suggested that an upper limit on frequency should be placed around 200MHz as higher frequencies are strongly affected by tree sized obstacles. Further restrictions limit the range to frequencies that are available to DOC, including channels owned by DOC and those available under General User Radio Licenses. Two channels, 50MHz and 80MHz, potentially open to DOC were also included. Thus the below frequencies were included as frequencies to be investigated.

6.2MHz, 27MHz, 50MHz, 80MHz, 140MHz and 169MHz

Power Limit

There are two main ways in which power levels are limited. The first is legally, where power limit rules are enforced to guarantee paying users a channel that has as little noise as possible. The second, which applies in this situation, is equipment capabilities. In this case we are limited to just 3.15mW.

Antenna Design

In order to ensure equality between frequencies it has been decided that each will have an antenna designed especially for it. The below table, of given frequencies and their equivalent wavelengths, has been provided as a reference.

Frequency (MHz)	6.2	27	50	80	140	169
Wavelength (m)	48.35	11.1	6	3.75	2.14	1.77

Table 26: A list of frequencies tested in this section, along with their associated wavelengths.

6.2MHz

A 6.2MHz signal has a wavelength of 48.35m, which roughly corresponds to a 24m half wave dipole. Such an antenna is impractical, especially when taken out into the field. It was for this reason that a helical antenna was employed. With a mixture of research and advice from antenna experts (Hi-Tech Aerials, in Christchurch), two antennas, of length 3m, were constructed and tuned. Copper wire wrapped around drain piping was used to build the antenna, seen below.

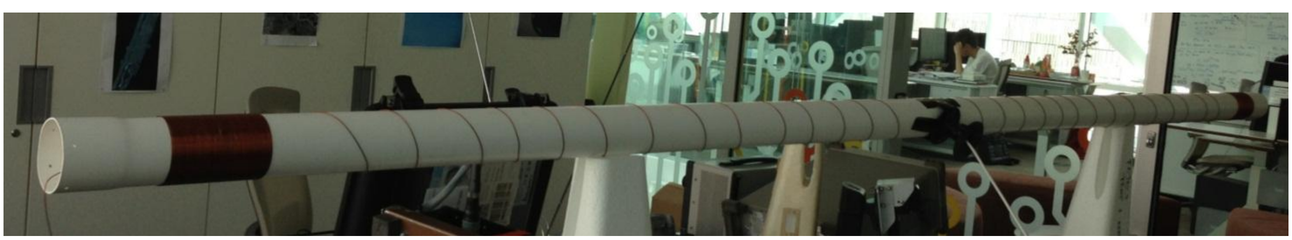


Figure 26: An image depicting the 6.2MHz Antenna.

The first version of the antenna gave a particularly low frequency, suggesting that the length of wire on the antenna had to be shortened. One side of the antenna is active, receiving the signal, while the other acts as a ground. It was then tuned by removing approximately half the turns at each end of both antennas, giving an optimum frequency of 6.2MHz.

27MHz

A signal at 27MHz will have a wavelength of 11.10m and hence would require a half wave dipole of length 5.55m. While still long, this is reasonable for testing purposes. Thus the below antenna was constructed, using electrical conduit with a coaxial cable down the middle.

Figure 27: A 27MHz half wave dipole.

The co-axial cable was then cut down until the appropriate frequency resonated. This was found, as with the 6.2MHz example, using a network analyser.

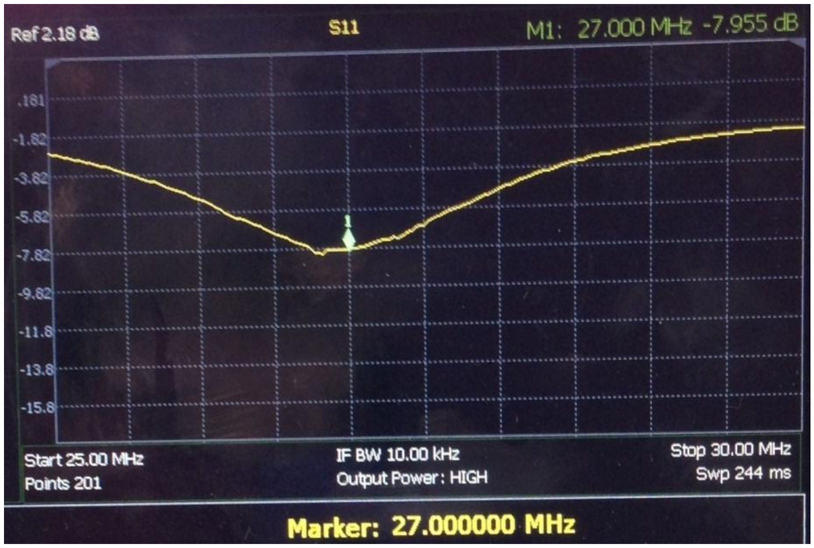


Figure 28: The network analyser displaying a tuning to 27MHz.

A second pair of 27MHz antennas was then constructed, but this time in the form of a helical antenna, with a length of just 50cm. Theory suggests that this would provide just 10% performance relative to the full length antenna.

50MHz

Two previously constructed and tuned antennas were sourced by Kelvin, project supervisor. Both were half-wave dipoles. A coaxial cable was then attached, with the shielding (ground) connected to one arm of the dipole, and the core connected to the other half.

Figure 29: The 50MHz antenna being used in Riccarton Bush.

The rest (80MHz – 169MHz)

A standard set of extendable “Bunny Ears” television aerials is capable of transmitting and receiving at the remaining frequencies. The antennas were then tuned to each of the required frequencies, with their lengths recorded. Each aerial was shortened from the outside inwards, with the outer most sections compressed first, to ensure a better connection at the base of the antenna, where larger currents are expected.

Figure 30: The extendable "bunny ears" used initially for frequencies above 80MHz.

Unfortunately, these antennas proved to be particularly unreliable. It was for this reason that new antennas were constructed to specifically for each frequency. Half wave dipoles were constructed for each frequency, as seen below in Figure 31.

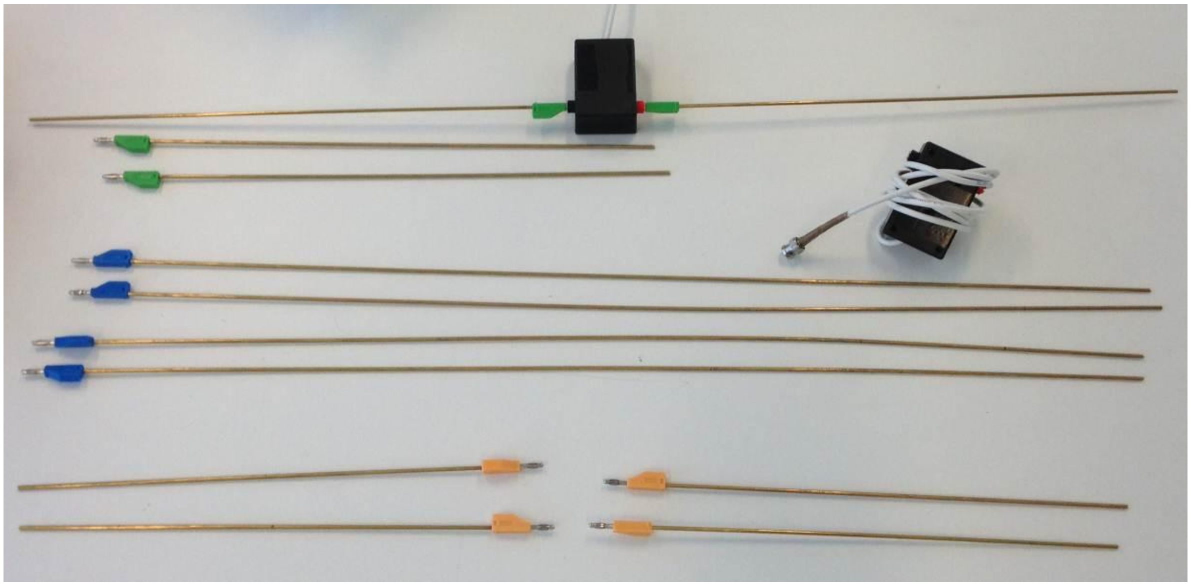


Figure 31: The latest antennas used for the 80MHZ - 169MHz range.

Signal Polarity

When a signal is transmitted it has a polarity, which is the orientation of the signal. This polarity can be in any direction, but this testing phase will only use vertical and horizontal polarised signals.

This polarisation can be dictated by changing the antenna orientation. A vertical antenna will produce a vertically polarised signal, and vice versa.

Phase 1: Frequency Selection

Test Procedure

The following process was repeated at each test site, varying both frequency and polarity:

- Set up the Receiver at 500m from the Transmitter. Measure the location using GPS.
- Transmit the signal at a pre-defined power level (3.5 mW).
- Measure, and record, the signal power level at the Receiver. Calculate change in power level (signal attenuation).

Results

Ilam Fields

Antenna	Frequency (MHz)	Receive Power (dBm)		Attenuation (dB)		Transmit Power (dBm)
		Vertical	Horizontal	Vertical	Horizontal	
Loaded Dipole	6.2	-86	-94	91	99	5
Loaded Dipole	27	-97	-106	102	111	5
5.5m dipole	27	-66	-85	71	90	5
3m Dipole	50	-84	-94	89	99	5
Tuned Dipole	80	-79.8	-91	84.8	96	5
Tuned Dipole	140	-100	-100	105	105	5
Tuned Dipole	169	-87.5	-95	92.5	100	5

Table 27: The test results for Ilam Fields (Control).

Victoria Park

Antenna	Frequency (MHz)	Receive Power (dBm)		Attenuation (dB)		Transmit Power (dBm)
		Vertical	Horizontal	Vertical	Horizontal	
Loaded Dipole	6.2	-115	-109	148	142	33
Loaded Dipole	27	-105	-98	138.4	131.4	33.4
5.5m dipole	27	-88	-76	93	81	5
3m Dipole	50	-106	-82	111	87	5
Tuned Dipole	80	-107	-88	112	93	5
Tuned Dipole	140	-123	-103	128	108	5
Tuned Dipole	169	-126	-111	131	116	5

Table 28: The test results for Victoria Park.

Free Space Path Loss Modelled Result

Antenna	Frequency (MHz)	Receive Power (dBm)	Attenuation (dB)	Transmit Power (dBm)
5.5m dipole	27	-45.63	50.63	5
3m Dipole	50	-50.98	55.98	5
Tuned Dipole	80	-55.06	60.06	5
Tuned Dipole	140	-59.92	64.92	5
Tuned Dipole	169	-61.56	66.56	5

Table 29: Free Space Path Loss Predicted Results.

Comparison

Upon inspection, the results obtained through the Ilam field testing did not appear to match closely with the predicted behaviour. A comparison with the FSPL model revealed a large discrepancy in the obtained result, Figure 32.

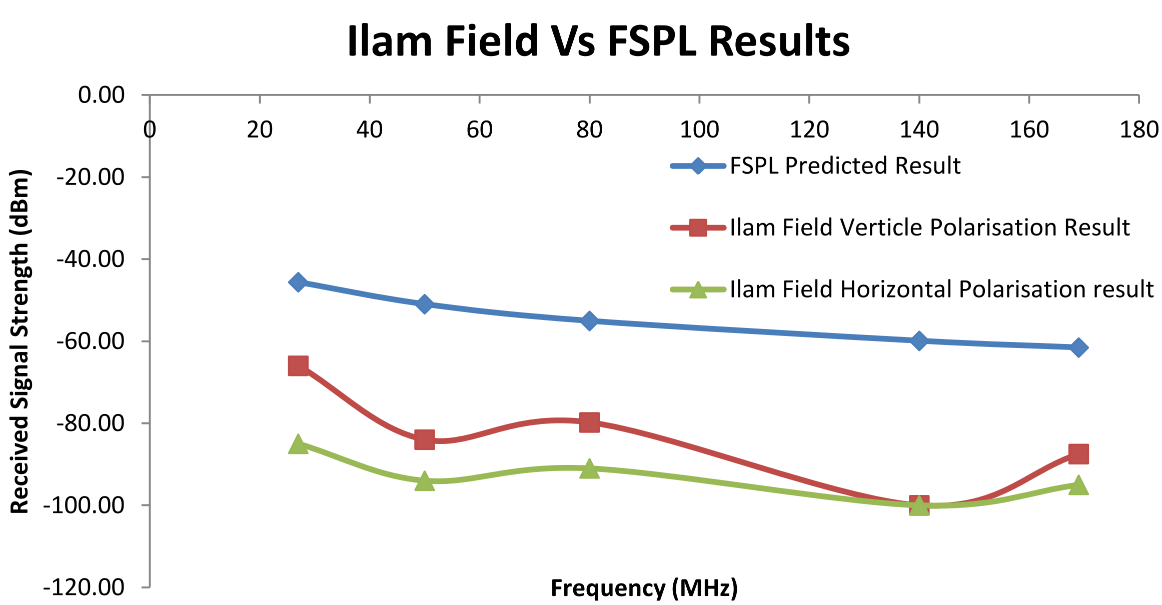


Figure 32: Ilam Field vs. FSPL Model Test Results

One phenomenon that went some way to explaining the unexpected result is the effect of multipath cancellation. When the direct wave and reflected ground wave reach the receiving antenna out of time phase cancellation may occur, leading to reduced signal strength at the receiver. Unfortunately due to the limited time available to the project this phenomenon was not able to be confirmed or explored further. As such the open field results were discounted for the time being and the FSPL model was subsequently used as the reference measure in further testing.

Comparison of the Victoria Park and FSPL model generated significant more reliable results. Upon analysing the test data form the forested terrain field trial it was immediately apparent that the horizontally polarised antenna was achieving much higher received signal strength than the vertically polarised antenna, Figure 33. This result is believed to be due a number of effects, with the single greatest contribution arising due to the vertically polarised radio waves strongly attenuating with the also vertically orientated trees in the signal path.

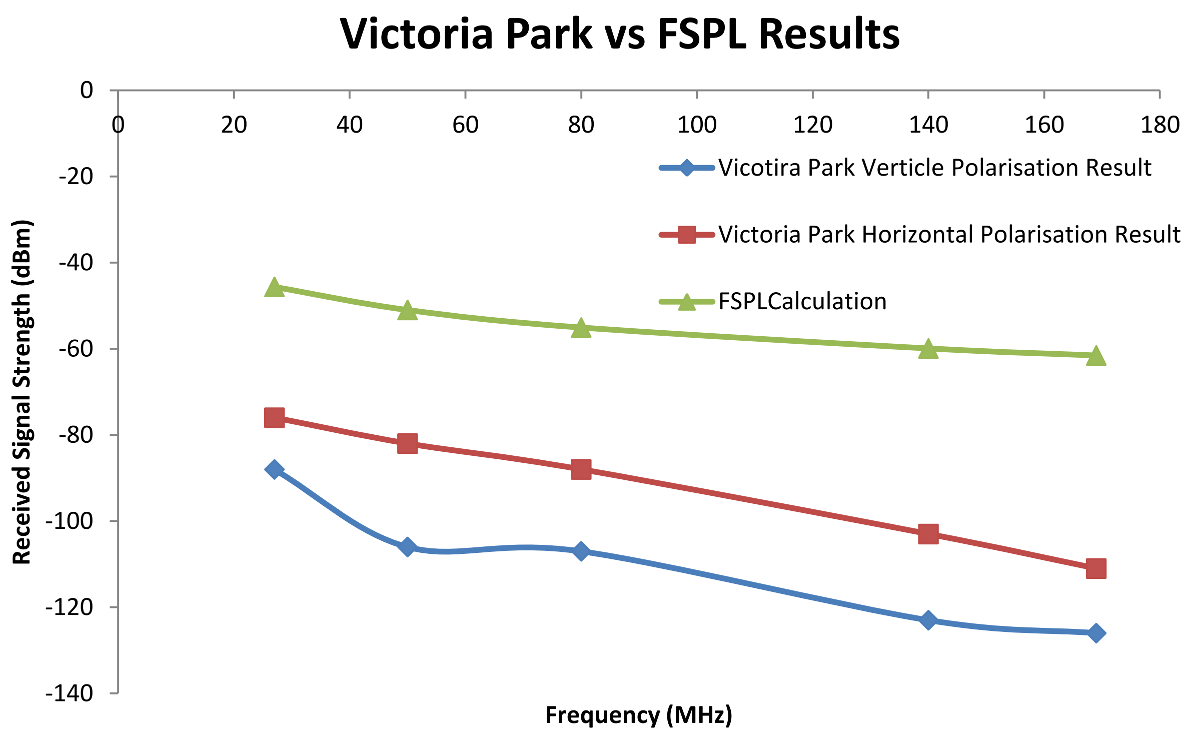


Figure 33: Victoria Park vs. FSPL Model Test Results

When vertically polarised signals are sent, Figure 34, the effective diameter of trees becomes equal to its total length. Radio waves then become much more prone to complete reflection off the tree surface and the total attenuation of the radio signal increases. It is for this reason that it can be concluded that in forested terrain, horizontally polarised waveforms will have greater performance than vertical.

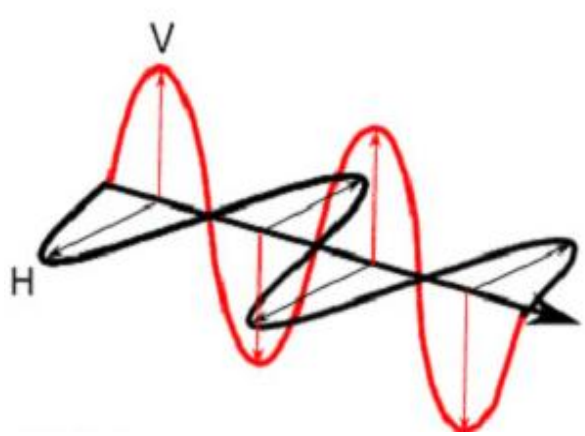


Figure 34: Radio Wave Polarisation

Selection Process

Attenuation performance in bush terrain was only one of the factors affecting the frequency decision. Below, in Table 30, is a decision matrix detailing why 27MHz was chosen as the frequency to recommend for modelling and use in the prototype.

Freq. (MHz)	Performance			Frequency Popularity			Portability			Frequency Availability			Ease of Use			Total
	S	W	T	S	W	T	S	W	T	S	W	T	S	W	T	
6.2	1		**5**	3		**18**	1		**8**	6		**42**	2		**12**	**85**
27	8		**40**	8		**48**	4		**32**	9		**63**	4		**24**	**207**
50	7		**35**	3		**18**	6		**48**	2		**14**	5		**30**	**145**
80	5	5	**25**	5	6	**30**	7	8	**56**	2	7	**14**	6	6	**36**	**161**
140	4		**20**	4		**24**	8		**64**	8		**56**	6		**36**	**200**
169	3		**15**	4		**24**	8		**64**	8		**56**	6		**36**	**195**

Table 30: A decision matrix designed to find the most appropriate frequency to model.

Phase 2: Modelling Attenuation

Now that a frequency has been chosen the test procedure can be modified to help build a model that predicts attenuation, in that terrain, at a given distance.

Test Procedure

The following process was repeated at four distances between 33.3m and 486m:

- Set up the Receiver at required distance and measure the location using GPS.
- Transmit the signal at a pre-defined power level.
- Measure, and record, the signal power level at the Receiver. Calculate change in power level.

The process was repeated with 50MHz and 140MHz for comparison purposes.

Results

		Attenuation (dB)					
	Frequency (MHz)	27		50		140	
	Polarisation	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal
Distance (m)	**33.3**	70	62	88	68	75	67
	68.8	81	75	95	81	83	78
	209	90	79	107	85	101	86
	486	102	83	120	91	115	104

Table 31: The attenuation measured at various frequencies and polarisations, over different distances.

Data Manipulation

Comparison of the 27 MHz vertical and horizontal polarisation, Figure 35, was used to further confirm the selection of horizontal polarisation as the better performing waveform orientation.

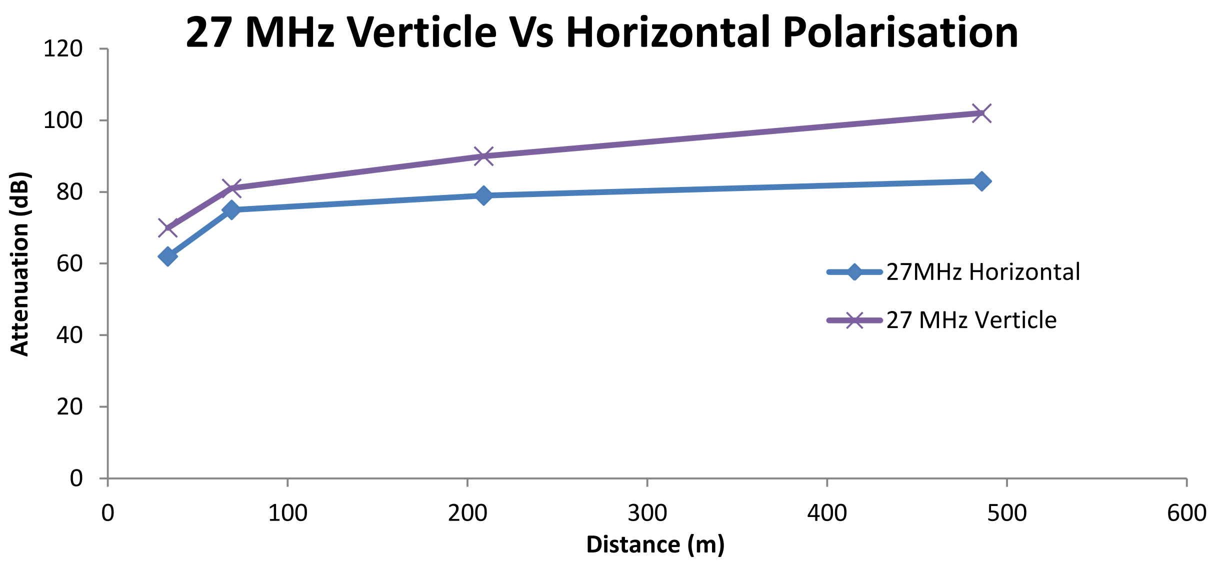


Figure 35: 27 MHz Vertical vs. Horizontal Polarisation

Model Development

The attenuation of the transmitted signal was calculated and then compared to the free space signal, Figure 36. Using a logarithmic regression model, a coefficient of determination of 0.86 was realised, indicating a reasonable goodness of fit, 1.0 being perfect, 0.0 indicating no correlation (Steel, 1960). An obvious limitation to this model is the distinct lack of data points, however it should be noted that further testing is currently planned post-completion of this project.

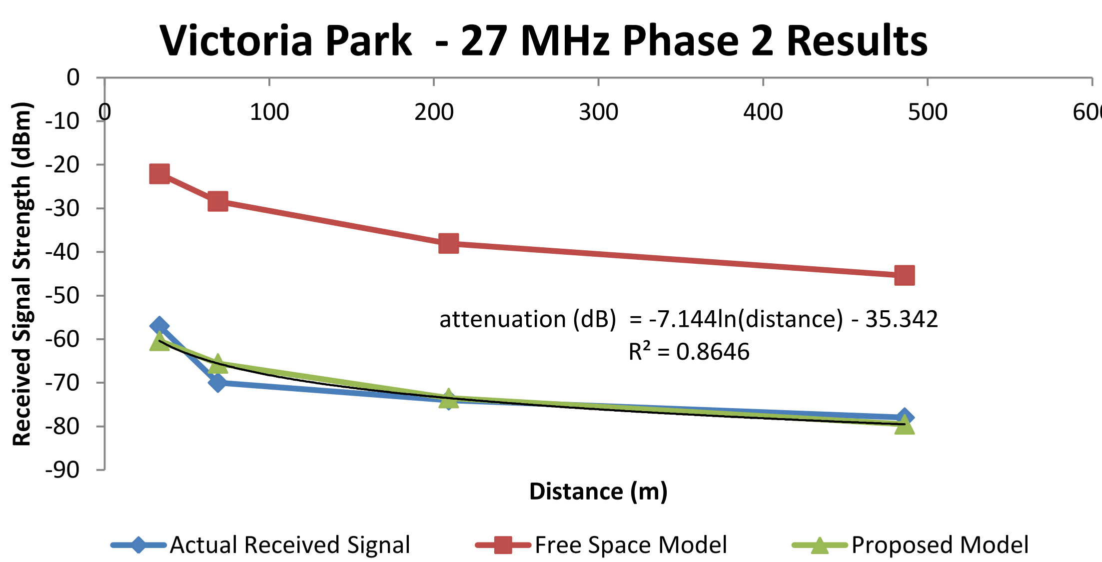


Figure 36: Victoria Park Phase 2 Test Results

An interesting observation on the Victoria Park field test occurs when the FSPL model calculation is subtracted from the test data, Figure 37. Over 500m, the result is an approximation of a simple offset of 35 dB from the free space model (at a fixed transmitter power level). Further testing is however required to further validate this finding.

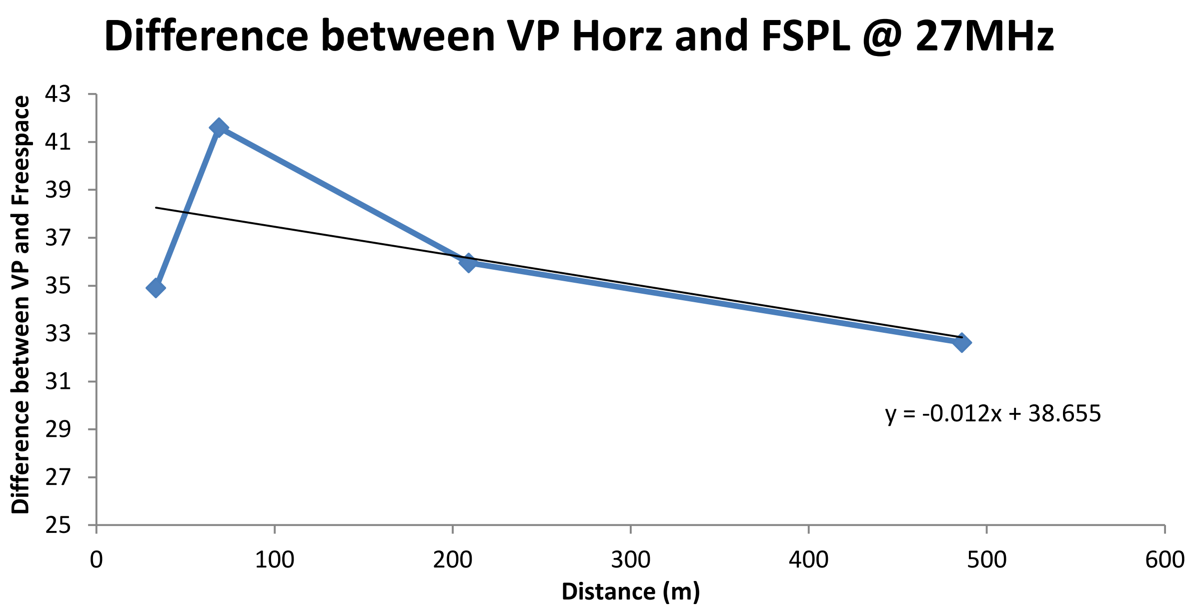


Figure 37: Victoria Park less FSPL at 27 MHz

5. Prototype Development

Requirements

As with any new development there are certain conditions that the product must fulfil in order to be considered successful. The design has been focussed to suit block elimination trapping.

Range

A larger range will allow fewer receivers in each given section of pest control. With receivers expected to cost more it is sensible to reduce the frequency with which they are required. A range of 500m should be achievable.

Longevity

In order to ensure the final product lasts in the field a mix of good efficiency and strong power availability is required. Using the five day block elimination programme as an example would suggest a minimum operation length of five days.

Size

With portability and discretion important factors in the success of this product, its size is very important. This predominantly applies to the transmitter, and for this reason the transmitter volume has been limited to 150 cm^3. This does not include the antenna.

Transmission Rate

This is not necessarily a requirement, being more of an allowance, and suggests that the prototype makes use of generous time availability. As long as 4 bits are transferred per day, as stated at the project outset, then this requirement will be fulfilled.

Number of Traps

Assuming a range of 500m, in any direction, two receivers would be required to cover the 1.5km long field trip site. With 200 traps set up it is reasonable to assume that each receiver should be able to operate a minimum of 100 traps. A greater number of traps would be beneficial for areas with thicker bush and would allow flexibility in trapping processes.

Cost

A cheaper system will lead to better likelihood of product development as it becomes cheaper than alternatives. As transmitters vastly outnumber receivers it is obvious that a system with cheap transmitters would be preferential. Allowing $50 per transmitter and $500 per receiver would suggest a maximum cost of $5,500 for a system with 100 traps.

System Infrastructure Decisions

Further decisions can be made, prior to prototype design decisions, in regards to the infrastructure around the system.

Frequency

A combination of propagation modelling and research has suggested that a frequency of less than 200MHz would be appropriate for terrain containing dense bush. A general consensus has been found, that a lower frequency leads to less interference from trees and bush as the signals wavelength approaches the gap between (and diameter) of obstacles.

Antenna

To ensure product is portable a limitation is being placed upon antenna length. Carrying multiple antennas in dense bush can be difficult and taking multiple trips would be unacceptable. It is for this reason that a limit of 2m has been set for antenna length.

Network Design

The type and shape of network is a surprisingly complex part of implementing a wireless monitoring system. There are many systems available, each with its own benefits, however very few have been developed with bush terrain in mind. One could look into direct communication between trap and the ranger/base station; however common sense suggested minimising the total distance travelled by all the signals. This could be achieved through first collecting the signals together then sending them all as one combined signal for the longest section of transmission.

A mesh network would perform this collection of signals, but a new issue then surfaced, in the form of power availability. Thus a new design was needed that would redistribute power use to areas where power would be more readily available. It was at this point that the final design was decided to be a star network design. All designs mentioned have been detailed below.

Single Node

Figure 38: An example showing the single node solution, where each star is a node.

The single node design relies on an external communication infrastructure to communicate. Such infrastructure is regularly available in the form of Satellite Communications or Cellular networks. Unfortunately these communication methods would struggle in the given terrain, with Satellite Communications severely affected by the tree canopy and cellular networks unavailable in many remote trapping areas. By, instead, using a Near Vertical Incidence Signal system this approach may become practicable but it would require large semi-permanent antenna. This design could be plausible, but is inefficient.

Linear Nodes Network (Mesh Network)

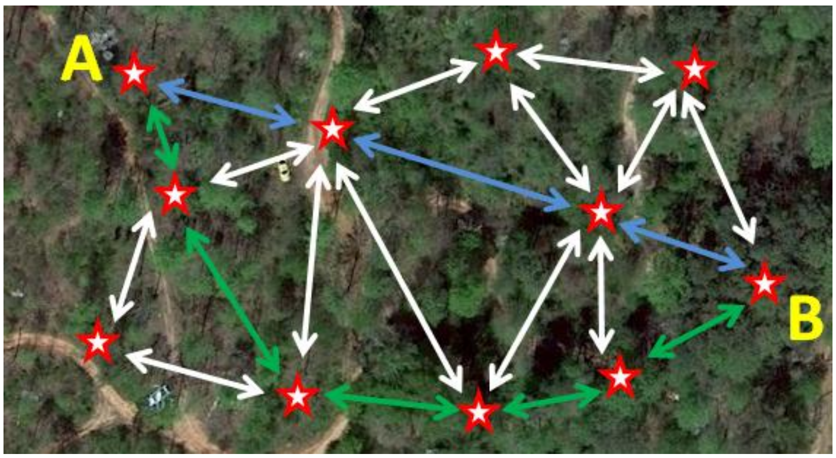


Figure 39: An example showing the paths available in a Mesh Network, where each star is a node.

Early research into existing technology availability suggested that Mesh Networks could be a promising solution. Mesh networks essentially contain many “nodes”, where each has the capability to both transmit and receive. A signal then takes the most appropriate route through the network. Unfortunately, the receiving capabilities add greater power usages and size to each node, both of which are limited in this project. This is exacerbated by the fact that only one way communication is needed.

This network design would also limit the flexibility and reliability of the whole system. Bigger gaps between nodes cannot be tolerated and, with current trapping methods, the failure of any one node will cause any connected to it to be un-contactable. Even if these issues were corrected the existing systems are not supplied at adequately low frequencies. This design is not adequate.

Star Network

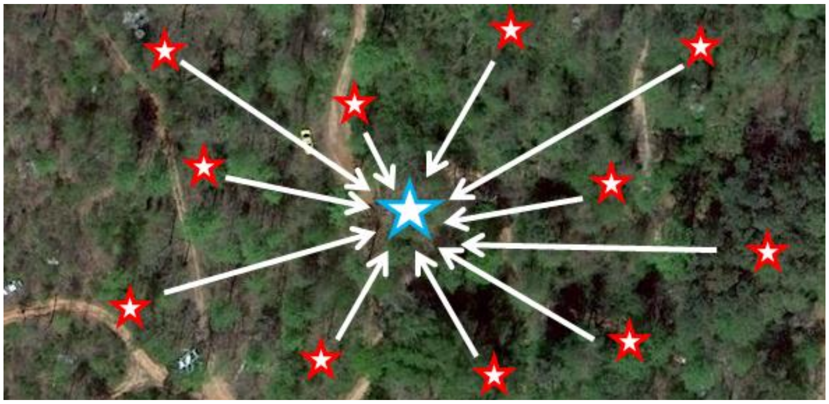


Figure 40: An example showing a Star Network, where each red star is a node and blue star is the receiver.

This design allows both the separation of communication environments and transmitter simplicity. Each node consists of just a transmitter, leaving a majority of power consumption and complexity at one point, the receiver. In this situation the main priority becomes the distinction between trap signals.

Processing Hardware

Several options were looked at as potential hardware to process both outgoing and incoming signals. Laptops would be both too large and expensive. Smartphones are too expensive and do not typically have the battery power required to last five days. Both of these options were considered overkill given the required processing. The obvious solution was the use of microprocessors. Popular options include Arduino boards, which contain Atmel chips, and PICAXE chips.

Potential Prototype Designs

The research performed so far in this project has suggested many solutions to this project. A large amount of advice has suggested the adoption and modification of existing systems, while information gathered has suggested that other technologies translate poorly to this situation. The three most appropriate designs have been collected and detailed on the following pages.

Prototype Design 1 – Dual-Tone with Time Division

The first design, which was developed early in the project, aimed to make full use of the relaxed time constraints. A dual tone, as in two separate transmit channels, would be used to detect the trap status, set or sprung. There are products available online that will fulfil the dual channel communication aspects, at 27MHz, required for this prototype.

In order to differentiate between traps, each device would be assigned a fixed time period during the day. With 1440 minutes per day the system can hold 144 traps, allowing ten minutes for each trap to transmit. As the device clocks are likely to run at slightly different speeds it is likely that some "slip" will occur. To minimise the chance of slip causing an overlap into another traps timeframe we can insert a guard time between each trap. A guard time of five minutes will still allow the receiver five minutes to pick up the incoming signal. This technique can be viewed graphically in Figure 41 below.

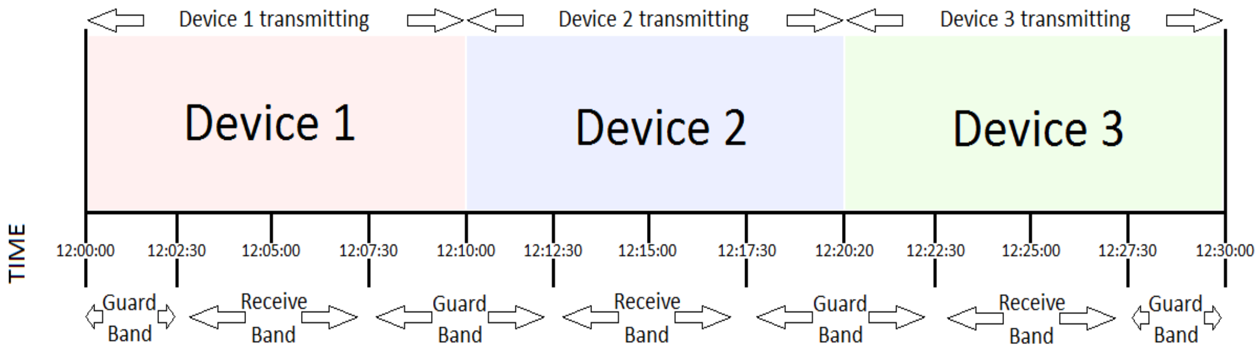


Figure 41: An explanation of the Time Division suggested for Prototype Design 1.

The most appropriate method of monitoring these times is through the use of a microcontroller. Assuming only clock drift (minimal programming related delays), it was found that a PICAXE microcontroller loses just over five minutes per day. This suggests that either the guard time needs to be increased or the microcontroller needs a more accurate clock.

A simple 2-channel wireless switch system would suffice in this situation. The microcontroller suggested above would connect to a transmitter, telling it when to turn on and which switch to flick. The associated switch would then turn on at the receiver, which another microcontroller would read. This microcontroller would then output the status of each trap. These devices are expensive, large and consume relatively high levels of power. (Remote Control Technology)

Prototype Design 2 – Near Vertical Incidence Signal/Skywave (NVIS)

Murray Greenman, an amateur radio specialist and author of "Digital Modes for all Occasions", was contacted and a conference call was set up. The call was very insightful but did not lead to any immediate revelations. A few weeks later Murray released a journal article which had a lightly veiled response to our situation. That section focussed upon a low power, and low-bandwidth, link from a series of collection points in a forest and suggested NVIS as the solution.

NVIS works by sending radio signals upwards into the ionosphere. These waves are then refracted back down and can be received within a circular region of up to 650km from the transmitter. The most common frequencies used in this method are 3.5MHz at night and 7MHz during the day. These values change, depending upon the time of the day, due to changes in ionosphere level densities.

One of the great advantages of NVIS is the direction of transmission, which removes the effect of mountainous terrain; a common issue in DOC patrolled regions. Another positive in regards to NVIS as a potential design is its range and speed of transmission. Murray was kind enough to set up an experiment to test the methods aptitude. It involved a transmission distance of 15km, over hilly terrain, and a signal power of just 200mW at 3.549MHz. The test was successful, but one major deterrent is the large antenna in use. It is not feasible to set up a 40m half-wave dipole on each trap. Further to the suggestion of NVIS, Murray Greenman performed some initial testing. His write-up on the subject has been provided below.

NVIS Experiments

I was recently asked to comment on the best way to send low-power, low-bandwidth data from a series of collection points in a forest. There are several problems with this type of activity. The most important are forest attenuation, range and power budget, but of course equipment size, portability, cost, complexity, reliability, operational details and so on also need to be considered. I thought that the best approach to this problem would be to use a low power MEPT technique. I knew from past experience that NVIS (Near Vertical Incidence Signal) propagation provided good range during early evening and most of the morning, and decided to test the idea under realistic conditions. My calculations on power budget told me that a small 1W solar panel would provide enough power for daily transmissions without direct sunlight.

While I couldn't quickly plant an instant forest, I could at least try out the idea over hilly rural land, and chose the path between my place and that of Andrew ZL1WJQ at Patumahoe. The range, about 15km, was outside ground wave range on 80m, where I planned to test. The setup was really cute: Andrew's transceiver is CAT operated, and he placed his computer on the Internet via a VNC (Virtual Network Computer) server. This meant that I could access his computer remotely, operate software on his computer, control his rig (using HRD), and of course see what I was doing via a replica of his computer screen on my own computer!

Continued…

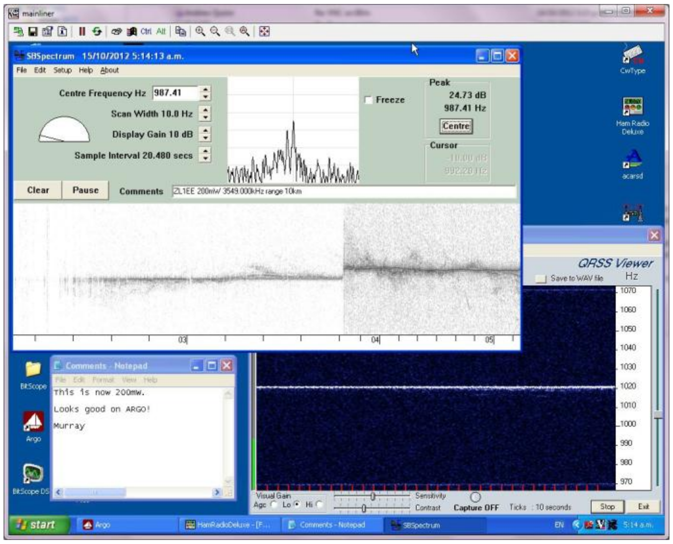


Fig. 2. Remote view of computer screen.

In Figure 2, which is a local screen-shot of what I saw on Andrew's computer, you can see that I've arranged two spectrogram programs on the screen (I ran them remotely from shortcuts on his screen). Top left is the specialized Doppler-measurement program SBSpectrum by Peter Martinez G3PLX. Beneath it on the bottom right is the familiar screen of ARGO by Alberto deBene I2PHD. Bottom left I've opened a small Notepad window, in which I was able to type comments for Andrew to read, and of course for him to reply at his leisure.

Although not shown here, there was also a Ham Radio Deluxe window open, through which I could control everything on Andrew's transceiver.

At the time of the screenshot I was running a 200mW carrier on 3549.000kHz, which you can see on the ARGO trace. The trace looks a little wobbly, sometimes a bit 'thready' but that's about all you can tell. However, if you look at the much slower and higher resolution SBSpectrum trace, you can see that my carrier, as received, has numerous components. As well as the very weak ground wave signal there is a strong E-layer signal and 'clouds' of F-layer energy, which do not show as a focused ray at this slow recording speed since the F layer changes quite quickly.

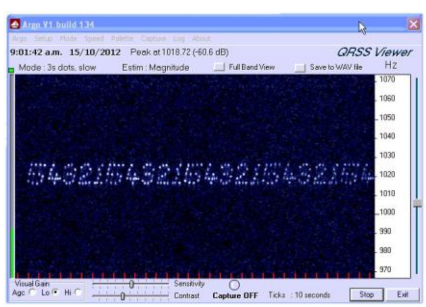


Fig. 3. ARGO via VNC 1.

Continued…

This next picture, also via the VNC, shows my transmitter sending Sequential MT-Hell with one-second dots, still at 200mW, received on ARGO as QRSS3. At this time of the day (9AM) the F-layer signal is quite strong and you can see how it would be quite easy to send and receive telemetry with this setup. I imagined up to 1200 field stations with two-letter/number callsigns sending five bits of data in three-character bursts. Each transmission would take under one minute. This visually decoded mode can easily be transmitted by a very simple micro-controller, and all it takes to generate 200mW efficiently is a single CMOS chip. Of course you need a fair sized antenna for such an application, but I don't see that as a problem in a fixed location in the bush. Even better, because of the nature of NVIS, reception improves the further away you are from the field stations!

While I have yet to test the idea again using a true digital mode (I will next time the VNC is running), I also know that DominoEX works very well under similar circumstances. This mode is very immune to both drift and NVIS propagation problems, and was designed for 80m. Some years ago Clayton VK1TKA (at the time ZL2TKA) developed a very sophisticated one-chip DominoEX telemetry transmitter based on a 3.58MHz TV crystal, and I was able to copy its signal day and night! It ran 100mW and used DominoEX4. Reception during the day was not perfect, but I received good data frames several times each hour. At night reception was perfect.

Digital Modes – Murray Greenman, ZL1BPU <zl1bpu@nzart.org.nz>

Prototype Design 3 – Modified Pulse Position Modulation using AM Pulses

Design 3 has been derived from the control methods used by Radio Controlled (RC) cars at 27MHz. These use pulses of various lengths to determine the speed and direction of the car in a method called Pulse Position Modulation (PPM). Unfortunately the receiver can only take input from one transmitter at a time. It was then theorised that each pulse length could relate to a different trap, however this still meant that multiple signals would get confused, especially when 200 were needed to fulfil the 100 trap requirement. To fix this the next step was found to be to vary the length of time between each pulse, rather than the length of each pulse.

This made sense; however, pulses could easily be misinterpreted. A pulse every two seconds would be confused with a pulse every second, making the first impossible to detect if they were appropriately aligned. A natural progression suggested the pulse frequency be dependent upon prime numbers, with each device assigned its own prime number. This method could be transmitted and received on cheap microprocessors.

The best way to describe this technique is through an example. Say we have three transmitters. The first transmits one pulse, for 1 millisecond, every 5 milliseconds. The second transmits one pulse every 7ms, while the final transmits every 11ms. These have been plotted below in Figure 42, and it is obvious that the signal sometimes overlap.

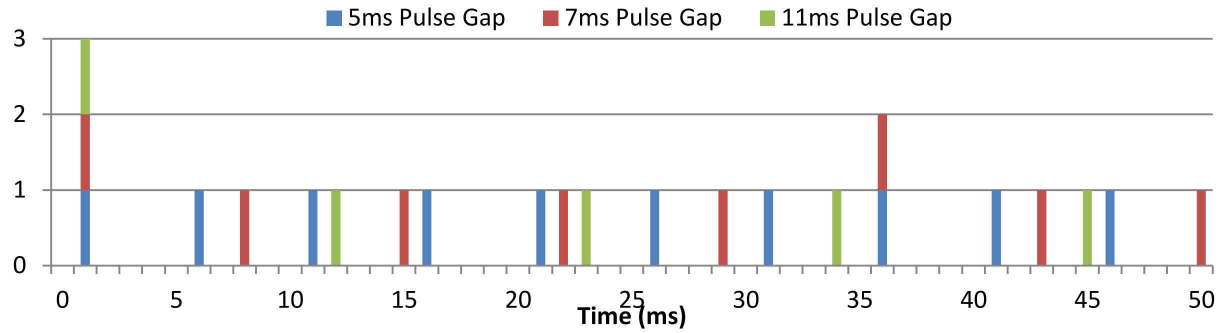


Figure 42: A plot showing the signal from three separate transmitters.

Unfortunately, the receiver cannot detect where these signals are coming from, only that they are occurring at certain times. It can detect the size of each of these pulses, but that ability is unused in this situation as the receive power is relative to the distance between the transmitter and receiver. Thus the receiver can see the signal shown below in Figure 43.

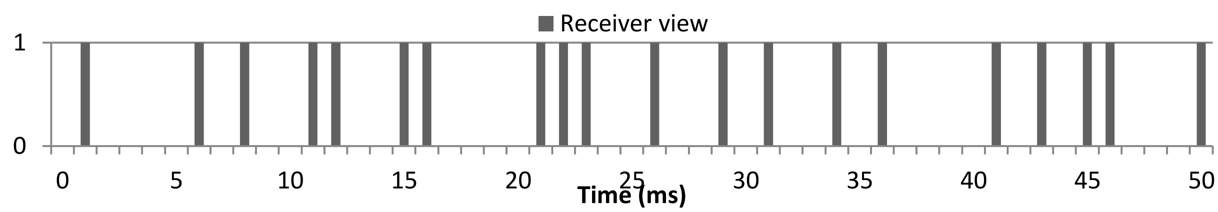


Figure 43: The incoming signal, from the point of view of the receiver.

The gaps have not been chosen randomly, they are prime numbers, ensuring that one signal does not continuously overlap with another. An example of this overlap would be the use of 2ms and 4ms as the gaps, as seen below in Figure 44.

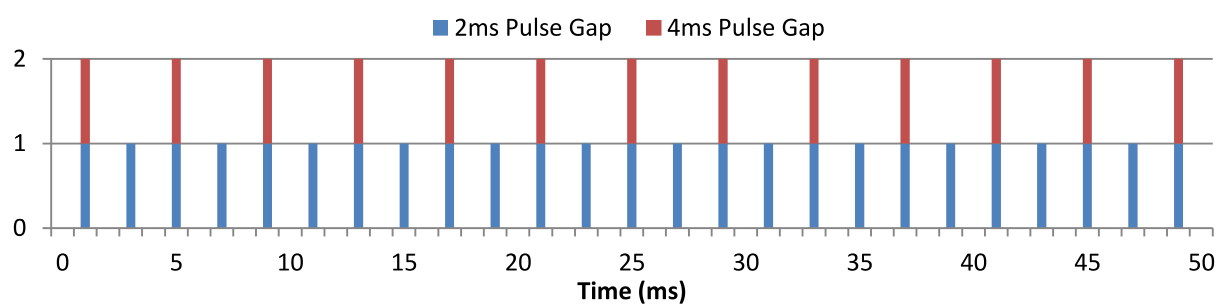


Figure 44: Two separate transmitters, at 2ms and 4ms

The 4ms gap signal would be completely invisible to the receiver, as seen below in Figure 45, with only the 2ms signal detectable. This would apply to any multiple of 2ms.

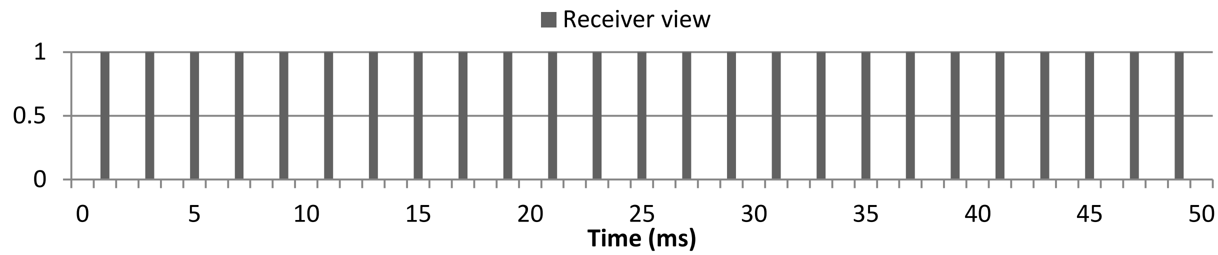


Figure 45: Two separate signals, at 2ms and 4ms, with only 2ms visible at the receiver.

With prime numbers, by definition, not able to repeat like this it is much less likely to confuse multiple signals. It is possible that one signal could appear without being transmitted, however enough repetitions (time) will then disprove the existence of this signal. The combination of time and prime numbers will also remove the need for signals to begin, and finish, at certain times.

By checking the correlation between these points a receiver is then able to decipher which prime numbers are being transmitted. In this situation each transmitter would send one prime number when it is set, and then a separate prime number when it has been sprung, allowing the receiver to know the state of each trap. There are several notable benefits that relate this design strongly to the requirements set in this project, including:

- Low power requirements, through the equivalent of very low duty cycles.
- Very cheap and simple transmitter design.
- Synchronisation of microprocessor clocks is unnecessary.
- Receiver-heavy design, where most processing is on receiving side of transmission.
- Accuracy increases over time, making use of significant time allowances.

Prototype Design Decision

Using the requirements previously mentioned it is possible to create a decision matrix that weighs up each option and suggests the most appropriate.

Prototype Design	Range			Power Consumption			Size			Cost			No. of Traps			Total
	S	W	T	S	W	T	S	W	T	S	W	T	S	W	T	
1	8	6	**48**	6	8	**48**	3	5	**15**	4	8	**32**	8	6	**48**	**191**
2	10		**60**	7		**56**	0		**0**	6		**48**	1		**6**	**170**
3	6		**36**	9		**72**	8		**40**	8		**64**	6		**36**	**248**

Table 32: A decision matrix to decide which prototype design is most appropriate.

The decision matrix above strongly suggests that Prototype 3, Modified PPM, is best suited for development in this project.

Prototype Construction

As a prototype has now been selected its development can begin. This process can be broken down into three main components, the antennas, transmitters and a receiver.

Antenna

With portability being a major concern in this project we decided to build the more compact helical design, as even a half-wave dipole would be over 5m for 27MHz. While a purchased antenna may provide better results we decided, at this stage, to use the antenna we constructed during our propagation modelling phase. This allowed us to maintain control over size and frequency range.

Figure 46: The Helical 27MHz antenna chosen for prototype construction.

A spread sheet was designed to help in the construction of these helical antennas. Begin by measuring the proposed base material, in this case thin plastic piping, into six equal portions.

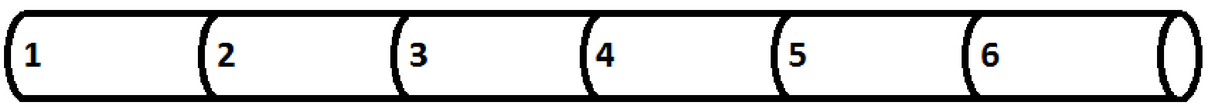


Figure 47: Antenna base material split into 6 equal portions.

A rough assumption is that a half wavelength should be wound onto each side of the antenna (side A – sections 1 to 3, side B – sections 4 to 6). Approximately 90% of each half wavelength should be in the out most section of that side, with the last 10% split over the other two sections on that side. A spread sheet can be used to calculate these winding numbers by working out the piping circumference. Approximately 10% of a wavelength of wire should be left hanging out each end on top of the length in the windings.

A coaxial is then connected to the centre of the antenna, with the wire from one side attaching to the inner wire and the other side attaching to the shielding (ground). A network analyser is then used to detect the current active range of the antenna. The antenna can be considered as a complex RLC network. At some frequencies it will appear as an inductive capacitance while at others it will seem to be a capacitive reactance. The key in antenna construction is to find the area where these two values are equal, but in opposite directions, and hence cancel each other out. It is at this point that the antenna will be resonant. This resonance at 27MHz is visible in Figure 48 below.

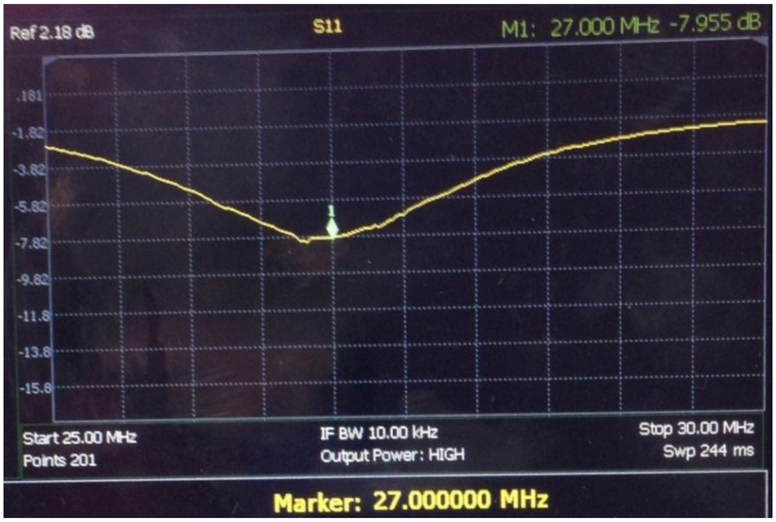


Figure 48: A network analyser screenshot when connected to an antenna that is tuned to 27MHz.

With the construction details given above it is likely that the network analyser is showing resonance at a lower than expected frequency. In this case windings should be removed from the end of each side. The number of windings to remove is proportional to the gap still left between measured and expected values. If you have 50 windings in sections 1 and 6 and find that it is resonating at 24MHz then you will to remove ((27-24)/27)*50 [=5.55] windings. Each antenna size and frequency was made in a pair, with the second one made to the exact same size and proportions, resulting in a very similar active range.

Transmitter

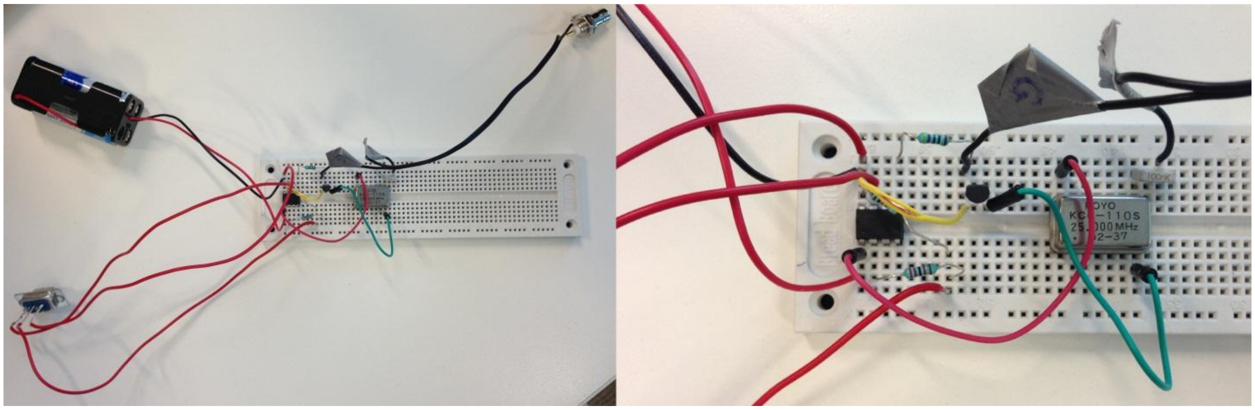


Figure 49: A simple circuit designed to transmit the PPM signal.

The brain of this circuit is the PICAXE microcontroller, which creates the required pulse. This pulse is then sent to the oscillator which essentially converts this electric signal into a radio signal. The black cable in the top right of the diagram can then be connected to an antenna to properly radiate the signal and improve transmitting distances.

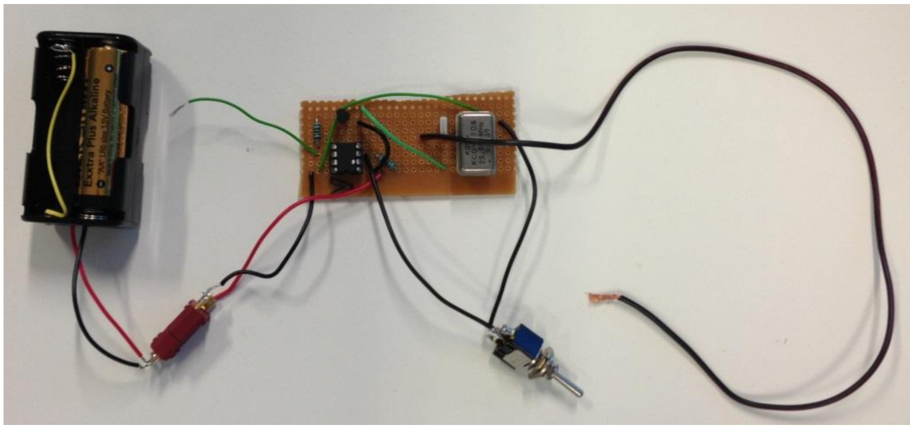


Figure 50: The finished transmitter circuit on a Vero board.

Once tested upon a breadboard the final design was built on a Vero board, as seen above in Figure 50. The black wire to the right is the antenna. The switch is used to tell whether the trap is "set" or "sprung", and lets the PICAXE know which prime number to send. Once the circuit was complete and lightly tested four replicas of it were fabricated. This gives the proof of concept five receivers to work with.

Receiver

To simplify the actions performed by the receiver we have split it into two sections. This first focuses upon receiving the signal and putting it in the form of a variable voltage. The second section then works on using this variable voltage to output the signals being received.

RF Signal

This part of the process is quite basic as the handheld receiver device, shown below in Figure 51, does most of the work.

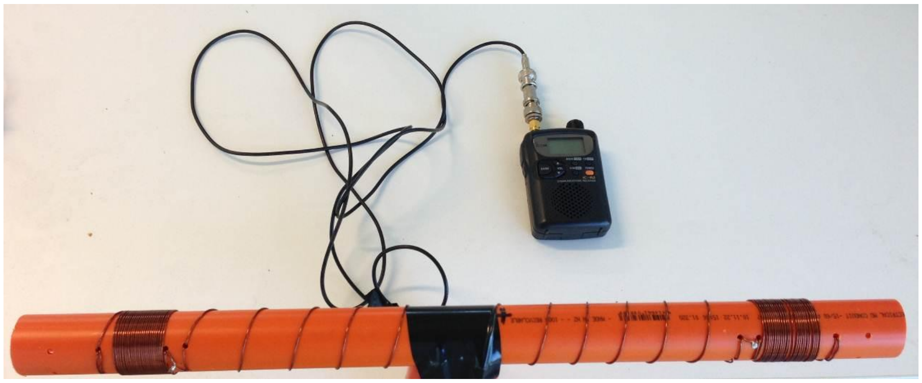


Figure 51: The antenna and handheld receiver device used to acquire the RF signal.

The receiver device picks up any pulses sent out by the transmitters and they appear as audible clicks. These clicks are turned into a variable (pulsing) voltage by attaching a headphone jack and then connecting this to the Arduino device set up to decode the signal.

Signal Decoding

The first step in this process is the choice of appropriate hardware. Essentially we will have:

- One wire bringing the variable voltage (signal) into the system.
- One wire providing the earth value of the receiver, giving a comparison value for the signal in.
- Three LED's, each chosen to depict the status of an incoming signal (e.g. if a signal is there then the LED will be on). The LED's are then connected to an output and, through a resistor, to earth. More LED's can be attached to these digital pins if required.
- A microprocessor to process the signal in and activate the appropriate LED. In this case the Arduino Uno was chosen, followed by the Arduino MEGA, after memory space issues.

The configuration used can be seen in Figure 52, shown below.

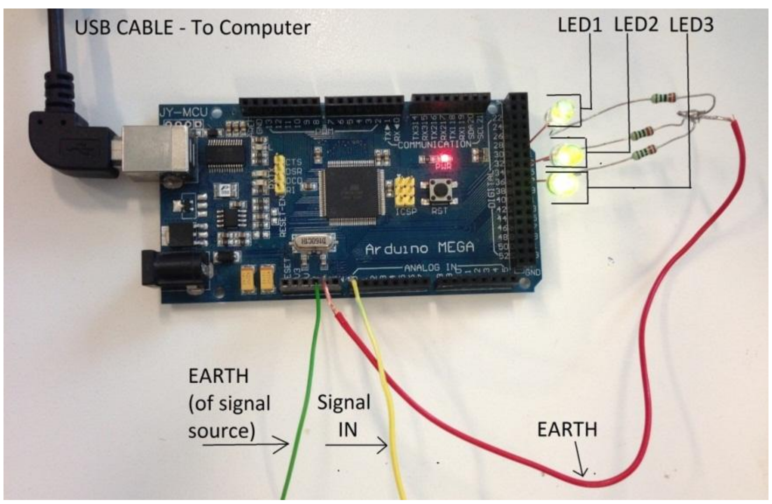


Figure 52: The Signal decoding set-up constructed.

A simulation was then created in MATLAB to find appropriate methods for decoding the incoming signal. Three fundamentally different decoding techniques were developed until one was able to work with the limited memory available in a microprocessor. The code was then translated onto the Arduino (from MATLAB code to C). The board essentially takes a variable voltage in from the yellow wire (from receiver) and stores it in order to attempt to decipher it.

The final decoding method stores the last 1225 cycles as a “1” or “0”. Each time a “1” is received it checks back to see which prime numbers have a “1” in the past. Thus, for the prime number 29 it checks for a “1” 29 cycles previously. If there is one then it adds 100 to a counter, if not then it adds 1 to another counter. We can then divide the first counter by the second and a higher result would suggest that the prime number is being received.

PROTOTYPE TESTING

In order to test how well the system performs we have split it into steps. This allowed better distinction between over- and under-performing parts.

Transmitter

This step focusses upon ensuring the transmitting device sends out the correct pulse rate. It uses the PICAXE microprocessor to output a pulse at designated times. These pulses are directed towards a 25MHz oscillator which then transmits for the duration of the pulse. A switch is attached to the PICAXE that changes between two duty cycles, suggesting a “set” or “sprung” status. Thus, there are two basic checks we can do to ensure it is working correctly.

Expectation: Pulse at output of PICAXE, at predetermined duty cycle.
Result: Success (some initial calibration needed with poor PICAXE clock capabilities)

Expectation: Pulse at output of oscillator, at predetermined duty cycle.
Result: Success

RF Link

This section continues on from where the last section stopped, testing that the link between transmitter and receiver works correctly. The audio jack on the receiver was un-plugged to listen for the “clicking” associated with the transmitting signal.

Expectation: Pulse at output of PICAXE, at predetermined duty cycle.
Result: Success (some initial calibration needed with poor PICAXE clock capabilities)

Signal Decoding Software

In order to test the effectiveness of the signal decoding software a simple circuit was constructed. This circuit comprised of three PICAXE microcontrollers, each assigned a prime number, to represent a different trap. These then output the variable voltage signal that would be expected from their equivalent transmitter. The signals are then combined and fed directly into the Arduino MEGA kit. Due to clock inaccuracies in the PICAXE devices each needed to be calibrated. The set-up has been illustrated below in Figure 53.

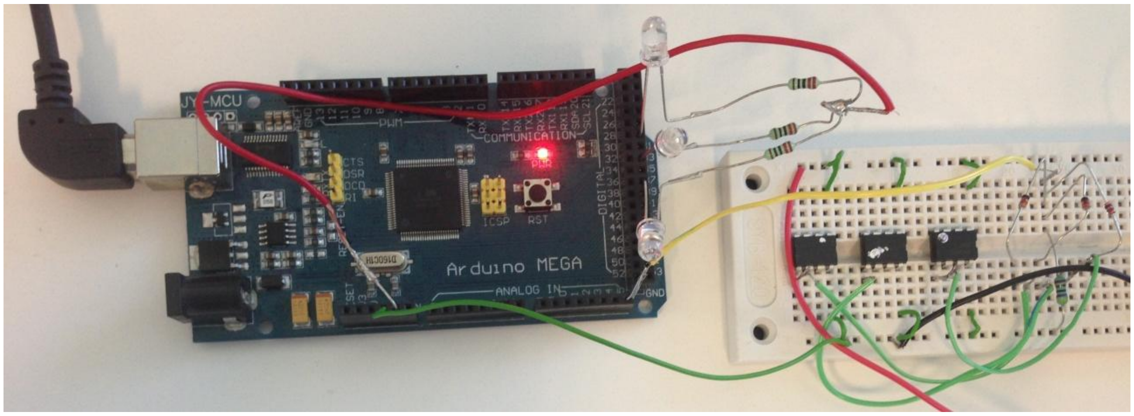


Figure 53: The full set-up involved with testing the signal decoding software.

Expectation: Pulse at output of PICAXE, combined into one signal.
Result: Success

Expectation: Correct LED's activated, corresponding to the prime number being entered.
Result: Success

Expectation: Check the actual values for each prime number through serial link (USB). Confirm that the only numbers with high hit rates are the prime numbers being generated.
Result: Success

Complete System

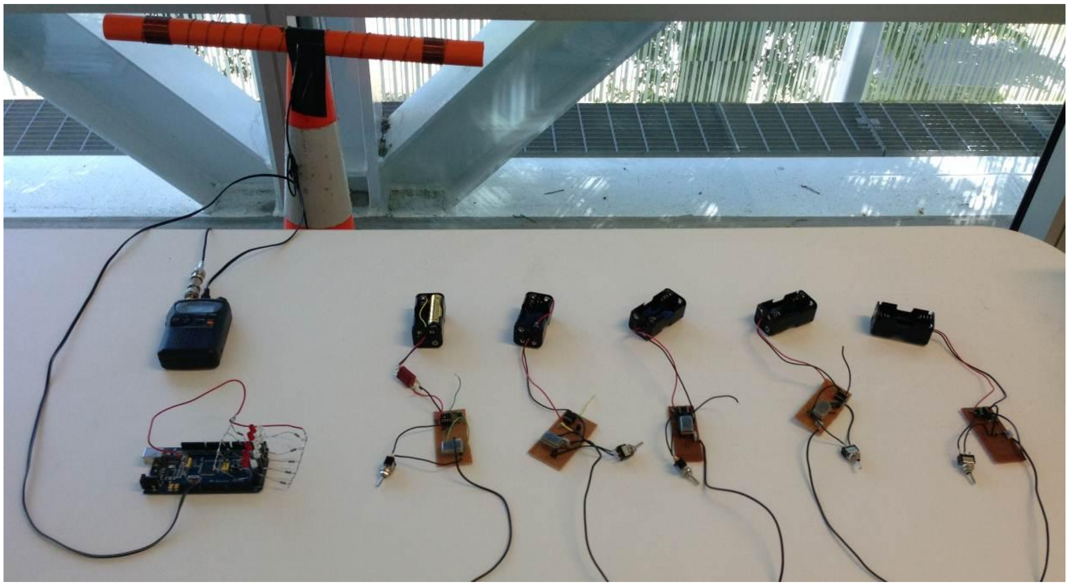


Figure 54: The whole system set-up, including antenna, receiver, 5 transmitters and one Arduino decoder.

Expectation: Red ("set") or White ("sprung") light show up when system online.
Result: Success

Expectation: Associated lights switch status (Red on and white off, or vice versa)
Result: Success

6. Cost Benefit Analysis

There are two fundamental reasons that this project has been requested. The first is the strong legislation in place that ensures trapping practices are humane. The regulations require leg hold traps, used in block elimination trapping, to be checked every 24 hours. Such protocols ensure that the animal in a trap does not suffer more than needed.

The second reason driving this project is the continual increase in technological ability at a reduced price. Better technology will increase the chance of a result working to specification while the drop in price will make it more attractive when compared to alternatives.

The introduction of wireless pest control management will bring many obvious benefits, and other that may not be quite so palpable. Thus benefits can be split into two types, the first of which are financially obvious, including:

- More efficient Labour costs, through lower labour costs (less time) or larger capabilities for that labour cost.
- Reduced vehicle use.
- More trapping without increasing overall costs.
- Less trapping equipment per site with knowledge of "popular areas".

The second type includes benefits that are not so obvious, and are much harder to financially quantify, including:

- Could help collect data about specific trapping locations, allowing better trapping practices to be developed. (i.e. which site populations grow faster)
- Associate weather types with varieties of pest caught or even the number of false alarms.
- Collect data to pest routines. (i.e. types of bush layout they prefer and at what times they get trapped, leading to more accurate tracking programmes)
- Collect data about the effectiveness of trap types, leading to employment of those that are more effective.
- Trappers changing their habits to adjust to the new technology (i.e. setting up in star formation, rather than on lines.

A cost benefit analysis, where only the financially quantifiable benefits and costs are used, can be used to determine if the tipping point has been reached. This represents the situation where the introduction of the technology would be cheaper, in the long term, than the current system.

Existing Cost Benefit Analysis Models

A model for estimating the financial viability of the implementation of trap monitoring system was found during early research. The benefit model, which takes the form of an equation, can be used to identify situations in which the introduction of a trap monitoring system could provide cost savings.

The paper begins by looking at travel scenarios involved with trap checking. This is described by a simple diagram, shown in Figure 49, where they leave the track at point A, to check traps at T_1, T_2, T_3 and T_4. (Julian Carver, 2011)

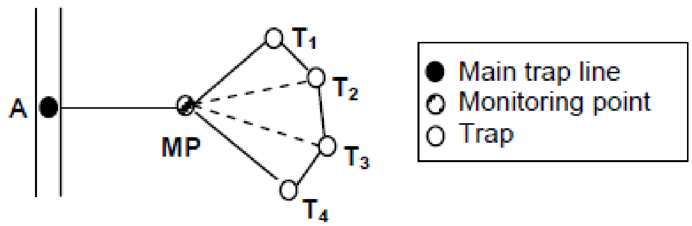


Figure 55: Graphical representation of a trapping pattern.

By monitoring at point MP the trapper is able to skip walking the full route (A->MP->T_1->T_2->T_3->T_4->MP->A) and potentially just walk a shorten route (A->MP->T_1->T_2 ->MP->A), or even the shortest route (A->MP->A) if no traps are sprung. The benefits are heavily dependent upon the gaps from MP to T_X and between each T_X.

The paper then defines an equation for the calculation of total benefit (TB) in dollar terms, as:

$$TB = t(d/c)(1 - \rho)[(x_b m)+(h_b w)] - d/s[(x_b m)+(h_b w)]$$

where:

- α is the number of trap checks required during a defined time period
- ρ is the probability of the trap being sprung
- $x_b m$ is the roundtrip distance between MP and T, or T_1, T_2 etc (x_b) multiplied by the rate used for reimbursement of non-labour costs for different modes of travel (m).
- $h_b w$ is the number of hours required for roundtrip travel between MP and T (h_b) multiplied by the ranger's wage rate (w).
- t - the number of traps
- d - the number of days in the defined time period for the benefit calculation
- c - the maximum number of days between trap checks for each trap
- s - the maximum number of days between trap servicing (e.g. re-baiting) for each trap

Constraints on Effectiveness

It is expected that a pest control device monitoring system will save DOC in man-hours, however there are several issues resulting from such time savings. (Julian Carver, 2011)

- **Labour units** – The lessened need for man-hours may not in fact lead to reduced labour costs. A trapper may only be required for 45 minutes of work, but needs to travel an hour to get there. In this case the trapper would be reluctant to work. This could be outweighed by asking the trappers to lay more or longer lines, as well as using a denser trapping pattern.
- **Trapping patterns** – Trappers typically lay traps in relatively straight lines, where they carrying all the equipment with them. This leads to a similar pattern of checking traps. In order to access traps in the middle of the line the trapper would have to walk the same distance as the current situation. This makes any benefits trap pattern specific.
- **Bait Longevity** – Pests are lured to traps using bait, however the bait is sometimes eaten before the trap is set off. A trapper would normally refill these lures as part of their rounds, which would not occur if traps were skipped.
- **Signal strength variations** – The nature of the environment that trapping occurs will mean that much longer distances are sometimes possible. Thus we can expect trappers to attempt to get as close to these maximums as possible. Any time this is estimated incorrectly the trapper will have to go out and re-lay that one trap. It is also possible that a trap may have signal when it is laid, but loses it before the end of the pest control session. Moisture, through rain, would have a strong effect on communication range.
- **Trap inspection definition** – Legal requirements say that certain traps must be inspected once every 24 hours. Whether or not this wireless method of inspection is adequate is unclear, and hence the system may become obsolete if the clarification requires of eye contact with the trap.

Product Cost Estimations

Rough estimations of the products cost, based upon prototype development, have been predicted below in Table 33.

Part	Quantity	Estimated Price	Total
Transmitter	100	$35	$3,500
Transmit Antenna	100	$5	$500
Receive Antenna	1	$60	$60
Receiver	1	$400	$400
Decoder	1	$40	$40
		TOTAL:	**$4,500**

Table 33: Estimated costs associated with the fabrication of each system.

CBA of Little River Site

This example uses information gathered during the first field trip in this project, from an area near Little River, Akaroa. The trapping in this area, called “block elimination”, targets possums using leg traps. These do not necessarily kill the animal, and it is for this reason that legislation has been put in place requiring the traps to be checked once every 24 hours. The trapping continues until less than 2% of the traps in place contain a pest, but typically lasts 5 days.

Trapping area

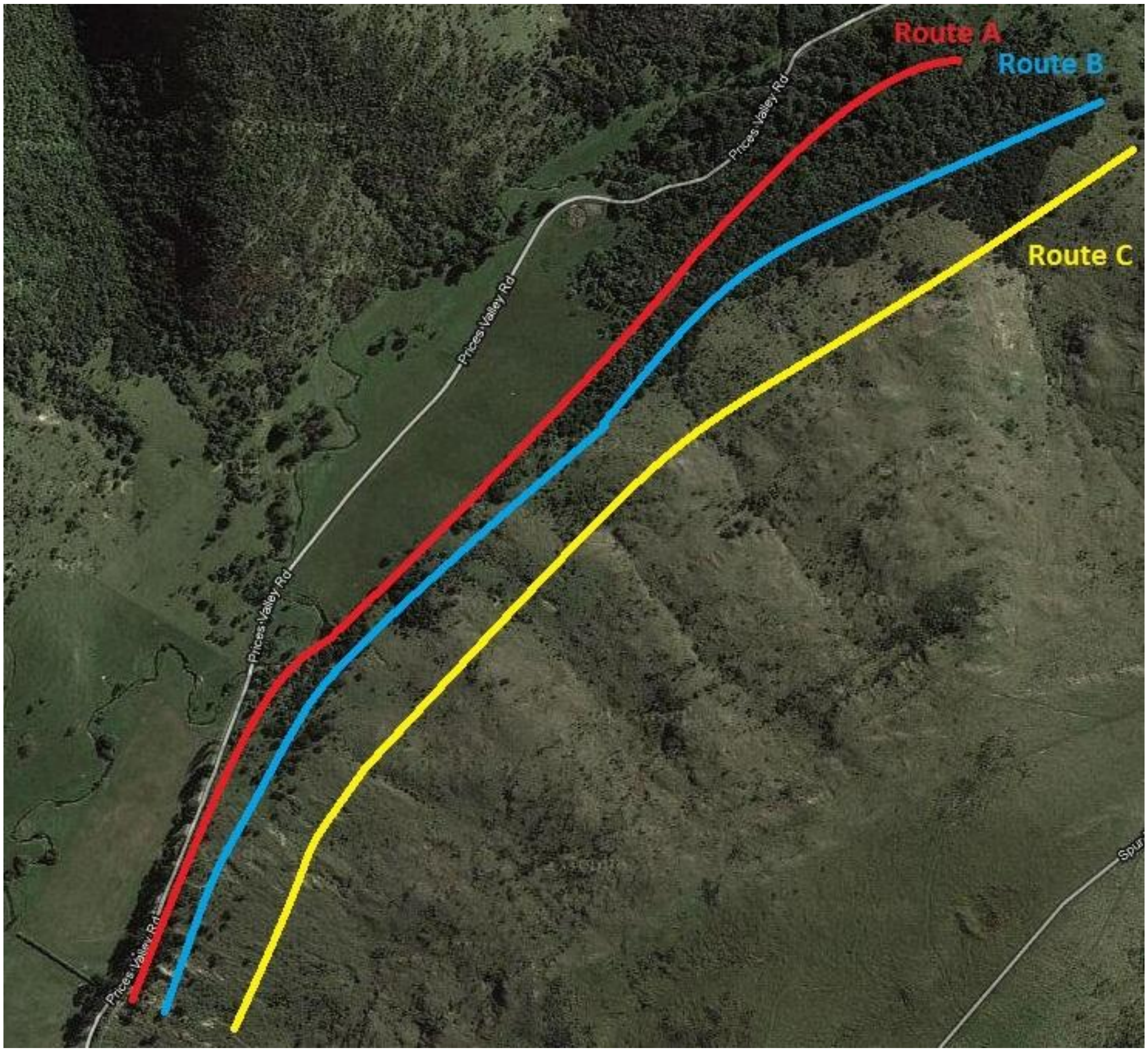


Figure 56: The field trip site being used as an example for a Cost Benefit Analysis.

The whole operation consists of 3 lines, with one trapper operating each line. Each trapping line is approximately 1.5km long, with 65-70 traps spaced about 20m apart. The site is located in a valley on the Christchurch site of Little River and trapping at this site does not appear to be uncommon.

Assumptions

- Walking speed of 5km/h, a.k.a 84m/minute. It should therefore take 15s to walk 20m.
- Trappers are paid $45/hour (75c/minute).
- It takes 5 minutes to set up a trap without a sensor device.
- It takes 5.5 minutes to set up a trap with a sensor device.
- An un-sprung trap will take 30 seconds to check.
- A sprung trap will take 5 minutes to empty, re-bait and reset.
- It takes 3 minutes to collect a trap without a sensor device.
- It takes 3.5 minutes to collect a trap with a sensor device.
- The number of traps sprung drops by 2/3 every day.
- That the trappers will take the original pattern if more than 25% of traps have been sprung.
- Assume 2/3 sprung traps are grouped, so 2/3 of checks involve a 15s walk between each trap after a five minute walk to the area, followed by a 5 minute walk from the area. The remaining 1/3 of checks will involve just a 10 minute walk to and from the trap. This can be summarized as the following equation:

  Walking Time = ((2/3)*S) + A + ((1/3)*S*A) + LR

  where S = No. traps sprung
  A= Average distance from road
  LR = Length of the road walked/driven.

  This assumption is based upon the fact that possums tend to follow similar tracks up and down a slope, a path that is taken during feeding periods at dawn and dusk.

Existing method costs

This method does not take into account the addition of a wireless monitoring section.

Day	Mins/trap	0	1	2	3	4	5	Total
Traps set-up	**5**	200	0	0	0	0	0	-
Walking	**0.25**	200	200	200	200	200	200	-
Check: No Reset	**0.5**	0	133	178	193	198	0	-
Check: Reset	**5**	0	67	22	7	2	0	-
Traps collected	**3**	0	0	0	0	0	200	-
Total time (mins)		1050	452	249	182	159	650	**2741**
Total cost		$788	$339	$187	$136	$119	$488	**$2,055.75**

Table 34: Costs associated with the current method of block elimination.

The existing method, detailed in Table shows a high hour count on the first and last days, with the four middle days dropping in a consistent manor. A total of 2,741 minutes, or slightly less than 46 hours, are devoted to the project.

New method costs

This method takes into account the addition of a wireless monitoring section.

Day	Mins/trap	0	1	2	3	4	5	Total
Traps set-up	**5.5**	200	0	0	0	0	0	-
Walking	**0.25**	200	200	98	38	18	0	-
Check: No Reset	**0**	0	133	178	193	198	0	-
Check: Reset	**5**	0	67	22	7	2	0	-
Traps collected	**3.5**	0	0	0	0	0	200	-
Total time (mins)		1150	385	135	44.5	14.5	700	**2428.5**
Total cost		$863	$289	$101	$33	$11	$525	**$1,821.38**

Table 35: Costs associated with the new method of block elimination suggested.

The new method suggests a higher hour count than the existing method, on the first and last days. Countering this variation is the more rapid drop in hours during the four middle days. A total of 2,428.5 minutes, or slightly just over 40 hours, are devoted to the project using the new method.

Comparison

While each site is different, it is estimated that this site would save approximately 5 labour hours per project, equivalent to a drop of 11% in labour costs. The size and shape of the location would have required two device monitoring systems. We can then assume the devices would be used once a week, at varying locations, for 45 weeks of the year with similar savings. This would suggest a saving of 235 labour hours a year. Assuming a trapper wage of $45/ hour we get a financial saving of almost $10,550. In order to provide a payback period of one year the device would need to cost less than $5,275.

Limitations

In order to obtain useful financial estimations many assumptions had to be made, where the accuracy of the result is only as good as the assumptions made. It must also be understood that this CBA is only applicable to the block elimination trapping process. There is also the possibility that some non-financial benefits or costs may become apparent once implemented, such as improved trapping patterns by studying the frequency each trap location is sprung. It is also worth noting that this does not take into account travelling to and from the site, where a 3 hour round trip may lessen the willingness of trappers to visit the site if only 45 minutes of work is available. The analysis has also assumed that trappers are paid per hour, when they are paid $60/hectare in reality, to make the process simpler.

7. IMPLEMENTATION GUIDELINE

Any good implementation guideline begins by looking at previously introduced technologies, analysing both the strong and weak factors of the product roll-out. This step is followed by a clarification of the goals involved with the project, including a list of actions required. The aforementioned list is then moulded into a plan. Two of the most important properties of an implementation plan are that is must be flexible and reviewed regularly.

PAST TECHNOLOGY INTRODUCTIONS

Stages of Development

Shown below are the phases any new product will follow to release. Knowing these stages will help to point out such stages within the release of other products, assisting in the analysis of product roll-outs. Organizations typically tailor the new product development process to their own needs. (Michael Kapp)

Concept Phase

The first requirement, even before the concept is started, is a product champion. This individual will provide the push behind the product, using support from others in the organisation as needed. A concept phase will typically contain a product description, market and technical assessments, proposed schedules and recommended resources requirements.

Once approved at the concept review, the product program will be assigned adequate resources and move onto the next stage in the cycle.

Definition & Business Case Phase

This stage will focus upon clearly defining the product to be developed, while also completing the business plan for the product. Market research and competitive analysis are used to verify assumptions made during the concept stage. Design and feasibility experiments will help to clarify technical assumptions made.

This stage should result in clear product requirements, a complete business plan and a project schedule. Once approved, the product will move onto the next step.

Implementation Phase

Building on the previous phase, this stage aims to develop the product to within specification of the development plan. It essentially starts at finalising design and finishes at prototype construction. A typical implementation phase will result in:

- Software and hardware development completed
- Prototype built
- Manufacturing processes and test schedule completed
- Technical documentation written
- Packaging requirements complete
- Final costs estimated

A successful review will then lead onto the next stage in the new product development cycle.

Testing Phase

This phase will include validation of the manufacturing process, through pilot manufacturing, and the completion of testing. It essentially analyses the products readiness for release. Once complete, the product should receive the go ahead to launch, leading to the next stage.

Deployment Stage

The deployment stage encompasses the remaining steps to a full release of the product. This will include an increase in product, marketing and the formulation and distribution of a launch plan. Following a launch it is standard procedure to review the whole procedure, assessing the overall product performance. A finished review means the new product development cycle is complete.

Product A – Apple iPhone

The design and introduction of the Apple iPhone, dubbed "Project Purple 2", has undoubtedly rewritten the rules for technological product implementation. Once the design had been completed, and production begun, Steve Jobs famously announced it to the world at the Macworld 2007 convention on January 9 2007. (Love, 2013)

There are three core public notification methods commonly used by technology companies to drum up demand, namely, press releases, advertising and convention sneak peeks. Until the iPhone release there was a definite focus upon advertising, while conventions were usually aimed at creating hype in the early adopter community. So much excitement had been built around the product that it was estimated that 60% of people knew about it and much of the tech press left the International Consumer Electronics Show to visit the Apple event instead. (Love, 2013)

Figure 57: The Apple website homepage upon release of the iPhone in 2007.

While a typical technological release is seen to "cross the chasm", Apple has done much more than this. The fact that it was estimated that 60% of all people knew about the product suggests that their jump to cross the chasm has actually placed them into the late majority. This jump is no doubt due to Apples ability to attract non-customers. A strong marketing team has managed to promote Apple as the "cool" and "superior" product, even where this may not be true. This assumption is further backed up by the incredible uptake in smartphone technology. The jump, both expected and actual, has been illustrated below in Figure 58.

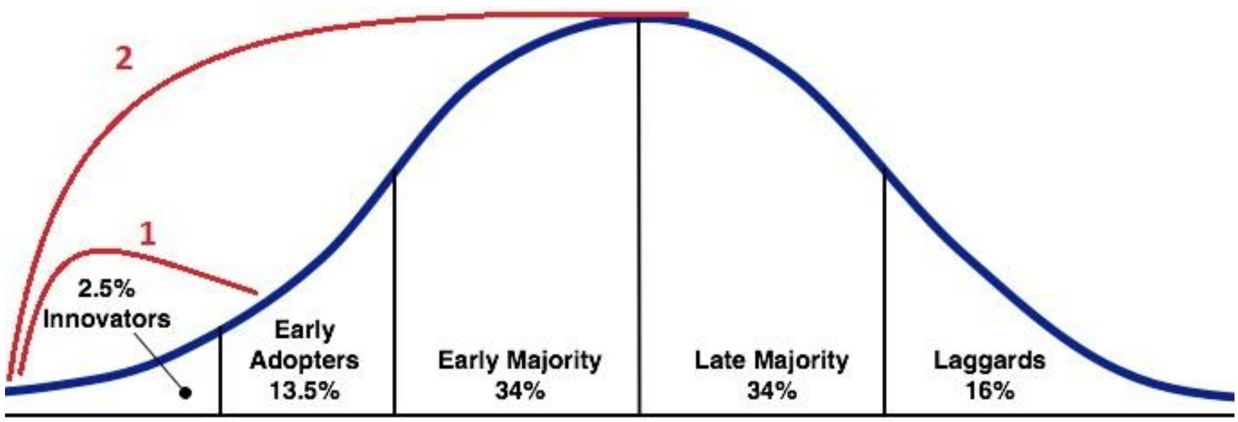


Figure 58: An illustration of Apples expected technology adoption (1), along with the actual adoption (2).

Along with any profitable product release we see other similar releases attempting to gain a share of those profits. It is for this reason that we have seen many legal cases with Apple trying to protect both their technical innovation and market share. This innovation can vary from physical likeness to touch screen actions. While court decisions may have varied, it has all been based upon the protection of intellectual property.

Product B – A12/A24 pest control traps

The A24 and A12 pest control traps have recently being released and are considered a complementary good to the communications device being developed in this report. This trap, designed and manufactured by GoodNature, is considered the latest tool in the fight against pest numbers in New Zealand (GoodNature). The major benefit this trap brings to the trapping procedure is its self-resetting nature, using compressed carbon dioxide gas canisters, and high hit-to-kill ratio. It was the resetting nature that allowed fourteen possum kills from seven traps in just one night, double maximum possible with the currently used leg traps. (Isobel Ewing, 2012)

The traps are currently in a testing phase where their ability to effectively kill pests is being investigated. This testing could result in a trap that requires considerably fewer ranger visits and surpasses the legislation that requires daily checks. At $145 per trap it is an effective method of pest control, with one gas canister allowing up to 24 resets before a ranger visit is needed. Overall, this could prove to be a particularly strong tool in the fight between DOC and pests that threaten natural habitats. (Wardle, 2012)

Product C – Oracle – IT Infrastructure Transition

This final example looks at the introduction of a technology, Oracle IT infrastructure, at an existing company; much like the upgrade situation DOC will be found in with its monitoring system. Oracle introduces technologies, such as cloud computing, tape storage and specialised servers, to a company in an attempt to improve their bottom line. This upgrade process does not always go as planned. (Oracle)

The example outlines a process that expected to take three months, but was in fact found to take closer to three years. Oracle provides powerful technologies, which are scalable, and have flexible object oriented architecture to allow continuous growth and integration. Yet the upgrade did not go to plan. A useful analogy was given as attempting to upgrade a car engine, without looking at other parts of the car. Would the new engine require a better transmission? Does the engine work differently and hence require new training to drive it? Does the steering wheel come separately?

The extra time, design and development costs, and employee training are not included in the cost of the system introduction. Although a cost benefit analysis may have suggested profitability, it may have made incorrect assumptions or being given conflicting data. In essence, Oracles sells the powerful engine, not the steering wheel or driver. It is for this reason that several suggestions are made when planning the introduction of technology. (Mehrmann)

- Be Aggressive – Ensure that the technology gives a genuine competitive edge.
- Be Cautious – If the upgrade could affect core competencies and hence the revenue of your business then the transition should be well planned.
- Be Quick – Implement small yet quick changes, allowing efficient monitoring of progress and effects.
- Be Slow – Large changes in business sustaining areas should be implemented slowly, especially since these areas are normally already streamlined.
- Be Safe – Especially important when it comes to technology as growing interconnectivity means it is possible that gaps in security may open up during upgrades.

Key Points from Past Technology Introductions

It has been difficult to find a precedent so only the applicable lessons have been drawn from the examples explained above. The following lessons can be learnt from these investigated cases:

- Product A – Apple iPhone
  - Implementation plan is heavily dependent upon proposed customer.
  - Ensure adequate demand before product release.
  - Address all available routes to increase product awareness.
  - Find ways to communicate with non-customers.
  - Protect your intellectual property, through legal means if necessary.
- Product B – A12/A24 pest control traps
  - Ensure a well-designed product before release.
  - Allow time for extensive testing prior to the product release.
  - Look at legal issues related to product use, such as the definition of "investigating traps every 24 hours".
  - A cheap product is very important when looking at the scale of pest control in NZ.
- Product C – Oracle IT infrastructure
  - Ensure that the technology gives genuine benefits to the company.
  - Be careful when making changes around core competencies.
  - Apply these upgrades in small and quick steps.
  - Larger changes to business sustaining areas should well-researched.
  - Watch for security issues when opening new connections to DOC computer hardware.

DEVELOPING AN IMPLEMENTATION GUIDELINE

Goal Clarification

This step combines the lessons learnt in the conclusions section with standard practices to create a list of goals for the product release cycle.

1. Have product ready for release.
2. Build hype around product with appropriate audience.
3. Release the product.
4. Explore other potential markets.
5. Continue development to ensure product improvement.
6. Strong contingency Plans.

List of Actions

We can then break these goals down into specific actions.

1. Have product ready for release.
    - Define and resolve potential legal/permission/IP issues.
    - Settle on complete design.
    - Test on small scale.
    - Design/Locate appropriate casing.
    - Find a suitable manufacturer.
    - Test Design in the field, on a larger scale.
    - Build a datasheet to help with set-up.
2. Build hype around product with appropriate audience.
    - Display at wireless technology/pest control conventions.
    - Appropriate advertising.
    - Online profile.
    - Press releases.
3. Release the product.
    - Find appropriate retailers.
    - Provide online buying option.
4. Explore other potential markets.
    - Personal use?
    - Other status monitoring options?

5. Continue development to ensure product improvement.
    - Longer lasting.
    - Better range.
    - Alternative power supply.
    - More traps.
    - More information communicated.
6. Contingency Plans. What if:
    - Demand increases?
    - Demand decreases?
    - There are supply issues?
    - Other products enter the market?
    - A fault is detected in the product? (Product recall?)

Develop Actions into Plan

These actions can then be formulated into an easy to read implementation plan, as seen below in Table 36.

#	Step	Implementation
1	Ready for Release	Write datasheet. Define and resolve potential legal/permission/IP issues. Test the final product. Find a suitable manufacturer.
2	Build Demand	Display at conventions (wireless tech or pest control). Advertise to appropriate audience. Create an online profile, making your product easily searchable. Press releases. This stage is important to ensure that the product "crosses the chasm".
3	Product Release	Find appropriate paths of distribution, including retailers, salesmen and online purchasing availability.
4	Potential Markets	Look at ways to reach non-customers, potentially through personal use. Look at other potential uses for the product, including other status monitoring options.
5	Continued Development	Investigate what the consumer wants improved, which could include extending the range, increased duration capabilities, alternative power supply, more traps per receiver and cheaper components. Potential smartphone connectivity.
6	Contingency Plans	Develop plans for "What if" scenarios, including demand increase/decrease, supplier issues and increased competition.

Table 36: A table containing the implementation guideline for wireless pest control device monitoring.

Monitoring the Implementation Guideline

Each of the steps in an implementation guideline will need to be monitored to ensure their continued success. For this reason, methods for monitoring the guideline have been suggested below in Table 37.

#	Step	Monitoring
1	Ready for Release	Regularly redefine potential legal and IP issues, including competitor products that could infringe on demand.
2	Build Demand	Strong product recognition among targeted customers. Easily searchable online, preferable the top hit for product related searches on Google. Consider using Google Trends to measure search frequency.
3	Product Release	Reasonable level of product uptake. Strong network of product representatives.
4	Potential Markets	Remain open to developments that could increase product reach. Taking active measures to test alternative uses.
5	Continued Development	Responses and action after customer feedback. Advances in suggested capabilities. Wider range of uses from improved capabilities.
6	Contingency Plans	Update these plans regularly to keen them current. Be vigilant for potential "What if" scenarios to ensure preparedness.

Table 37:A table containing suggestions for monitoring the implementation guideline.