Tracking poachers using The Internet of Things [BLE]

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Abstract

Tracking technologies are currently limited to relying on satellites or cellular towers, for environments that do not permit access to these signals very few viable alternatives exist. This project implements and extensively tests the use of Bluetooth low energy(BLE) as a method to track vehicles. It works by mounting Bluetooth beacons beside a road and placing a receiver concealed somewhere inside the vehicle. As the vehicle drives past the beacon the receiver and beacon are momentarily in range, the receiver then stores a unique ID from the beacon and when the vehicle is then in an area with GSM signal an SMS is sent containing the unique IDs of the beacons that have been detected. The design of the tests is based on deploying the system into a jungle environment as this project is to be prototyped with the Danau Girang Field Centre in Sabah, Malaysia. The results offer insights for how effective Bluetooth beacons are in a detection situation for where the beacon and receiver are in range for a short period of time as well as how different obstructions will affect the range and strength of the signal.

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Chapter 1

Introduction

The decline of the natural world has become one of the biggest talking points in the global news in the past decade. Poaching is one of largest impacting reasons for affecting not only the animals that are being poached but the entire surrounding ecosystem. These poachers operate in outlawed organised gangs as it is an extremely profitable industry. These organised gangs are extremely well structured, and thus difficult to track. Due to the limited technological options, it is currently almost impossible to track the poachers without them knowing once they enter the jungle.. This project will build a solution using Bluetooth beacons situated around the jungle and a receiver placed discretely inside the vehicle. The receiver will be mounted unbeknown to the poachers, allowing them to be tracked as they pass certain locations. This project is to be prototyped for the Danau Girang Field Centre in Sabah, Malaysia to give them the means to track poachers to further understand how they operate within the inner jungles.

A BLE based location and tracking system also provides an alternative method to the limited technologies currently available on the market, this method will allow tracking in remote environments where other technologies have little to no signal available. This project would also be suitable to be utilised in other locations where other tracking methods are unsuitable.

Chapter 2

Background and Related Work

Poaching impacts far more than just the species which are being killed, it has a huge impact on the environment, economy ,and crime of local areas. Like any industry, poaching only exists because there is a demand for it. This demand is primarily from Asian countries as the animals are often used for medicines and their skins used for clothing and rugs. (14)

Poaching is often the most lucrative industry in a local environment. The average salary in Sabah is 1,240 RYM which is 1.98 times lower than the average national salary, those without any formal education are earning an average of 1000 RYM (6). Poaching gives those in the lower societal classes an opportunity to earn significantly more money than traditional employment options.

The effect of poaching on a local environment is huge as it has been shown to cause entire species to become extinct and in turn disrupt the entire ecosystems. This is an important demonstration of why poaching is significant as this effect in the jungles of Sabah would be devastating, to the local environment. If poaching was to escalate in the jungles of Sabah it would have disastrous national effects.

There are many countries, groups ,and individuals that are actively trying to stop those involved and break the poaching market. This project is intended to be implemented in the Lower Kinabatangan Wildlife Sanctuary in Sabah, Malaysia to be used as a tool for the Danau Girang Field Centre(DGFC) to prototype to track these poachers to gain a further understanding of how the networks of poaching gangs operate. The main environment tha poaching happens is where animal life is densest, in the deep jungle. This jungle surrounds the huge Kinabatangan river which runs for 560km and has a basin area of 16,800km (Figure 4.1). The roads which the poachers drive within the jungle are underdeveloped and are made of mud, therefore they will be uneven causing them to drive at low speeds which allow the solution more time to detect them. (Figure 4.2)

Fig. 2.1 Satellite view of the surrounding area of DGFC

Fig. 2.2 An image of a road in the jungle

(Gardner and Goossens)

Other projects regarding tracking technologies have been completed. The use of sending GPS coordinates to a mobile phone via SMS based on GPS technology seemed to be an especially popular and interesting method; (15) this method provided the user with an accuracy of 0.57m thus proving itself to be a very accurate tracking method.

Another method is using a GPS based vehicle tracking system which will inform a system where the vehicle is and how long it has been there. The system uses geographic position and time information from the GPS satellites. This method would have an on-board module which would be situated inside the vehicle consisting of a GPS receiver and GSM modem. The GPS receiver will allow the location of the vehicle to be accurately determined and the SMS model would send that information to a purpose-built vehicle tracking system for the vehicle to be tracked. (Kodavati et al.)

Bluetooth Low Energy(BLE) is a wireless standard to be used in a Wireless Personal Area Network (WPANs) , it operates at 2.4GHz and has a theoretical maximum range of up to 100 meters (8) .BLE is a low cost and a low power technology which makes it suitable for use in this project. Bluetooth low energy has two main ways of operating:

1. Central and Peripheral: The central device allows multiple peripheral devices to connect to it which allows transmissions to be sent and received between the peripheral devices and the central device.

2. Broadcaster and Observer: This method does not require the devices to connect to communicate. It works by the broadcaster which is also commonly referred to as a beacon sends out a signal at set intervals, this signal can contain a small packet, the observer in range will "observe" the message sent by the broadcaster meaning the observer has received the packet.

(11)
For this project, we will be using the broadcaster and observer method as we require the transmission to be very fast and one way.

Global System for Communications(GSM) is the second generation digital cellular network, it is the most used standard for mobile telephone systems being used in countless countries including the UK and Malaysia. GSM hosts the Short Message Service(SMS) which allows users to send up to 160 characters per message for this project this is sufficient to send the location information. SMS works by communicating with cellular towers. When the message is sent from device 1 an uplink signal is sent to the cellular tower, the tower then sends a downlink signal which will be at a different frequency than the uplink to the recipient device. The main causes of a weak signal are:

- Non-conductive materials (Wood, plastics, glass)
- Organic Materials (Mountains, hills, large pools of water and dirt mounds)
- Weather(Fog, rain and humidity)(Dal)

Chapter 3

Limitations and Approach

This section will contain information on why the technologies which have been chosen to be used are the best suited to the project and give a high-level description what the project will do and how it is expected to work

There are many more technologies that are used for location-based services that could be considered, the table below gives a comparison of the relevant attributes of these technologies. For this project, we require a relatively low cost, low power technology that is suitable to be used outdoor

Technology	Range	Cost	Power Consumption	Suitable Environment
GPS	Global	Medium	High	Outdoor
GSM	<45 miles from tower	Low	Medium	Indoor and Outdoor
Infared	1-5	Low	Medium	Indoor
Acustic Signal	2-10	Low	Medium	Indoor
RFID	1-10	Low	Low	Indoor
WIFI	20-59	Low	High	Indoor
Bluetooth	1-30	Low	Medium	Indoor and Outdoor
BLE	1-100	Low	Low	Indoor and Outdoor

Table 3.1 Comparison of technologies that could be used in this project

(16) (12) (3)

Due to the nature of this project, the limitations of the technologies which are available to use are bounded. For most tracking projects the initial route to take would be to use some type of GPS based system, for this project this is not a viable option for this project as the environment is unlikely to have sufficient GPS coverage to connect to the above satellites due to the overhanging trees and foliage, GPS modules also consume a lot of power, this would mean battery life would be very short, potentially too short to get any meaningful data from the receiver.

GSM as the main component within the jungle would have a similar problem to GPS as it requires connection to cellular towers. The natural environment around it consists of dense woodland, with high humidity ,and a large river, All of these are conditions that individually causes GSM to not perform well. For these reasons GSM is not a viable technology to use within the jungle.

Infrared, acoustic signal, RFID and WiFi are all technologies that are best suited for indoor use and therefore are not suitable in this case as they are not technologies that would work effectively outdoors.

BLE is the clear best option shown in table 3.1 due to its low cost and power consumption. It also bypasses the problem of having to rely on a signal from coming from outside of the jungle such as GSM or GPS. BLE does, however, have a smaller range than these technologies but during the implementation of this project we hope to find a way to ensure it can work reliably and prove to be the best option (2)

This project intends to work through 3 parts:

1. A receiver which is placed on a poachers vehicle
2. A Bluetooth beacon which will be strategically placed beside a road within the jungle
3. computer method to log where poachers vehicles have been spotted.

3.1 Receiver

The receiver part of this system will contain BLE functionality which will act as the observer which will be 'listening' out for the beacons signal. In a fully functioning model, the receiver will also contain SMS capabilities which would be used to send SMS messages to a specified number for the user to upload to the computer for the computer to plot on a map which beacons have been spotted. The information on the text messages regarding the beacons that have been detected will correlate to the locations where the poachers have been detected.

Thanks to the relationships in the local area that the staff of DGFC has already set up, an informant would place the receiver on a specific discrete part of the vehicle which will be specified by the testing. The poachers will then continue their journey unaware that there is a receiver on their vehicle. When the vehicle passes one of the Bluetooth beacons the receiver will pick up the unique name of the device. The vehicle will then continue their journey passing more beacons which the receiver should detect and log. When the vehicle leaves the jungle to go to the city to sell the poached animals the GSM module will then send an SMS containing the unique names of the beacons which have been detected to a phone number which will have been set.

Requirements	Acceptance Criteria
Detect Bluetooth beacons in range	Beacon is detected every time the vehicle travels past in range
Store Beacon name	Read the information from the HC-05 to the Arduino
Send SMS	SMS is send to a set person containing which beacons have been detected

Table 3.2 Requirements for the receiver

3.2 Bluetooth Beacons

The BLE beacons will be placed at specific locations on the road. The beacon will display a unique identifier so that it cannot be confused which beacon has been seen by the receiver. Due to the possibility of the receiver travelling at speeds which could cause the beacon to not be detected the beacons will be placed specifically in locations where a vehicle would have to drive extra slow such as a tight bend to try to maximise the amount of time the receiver has to read the beacon. In testing, I will investigate the best places to place a beacon such as the height of the beacon and the distance to the road. (13)

3.3 Visualising the beacons

The data that is received from the vehicle is more effective if the users can visualise where the poachers have been detected. This visualisation should allow the user to see where beacons are placed within the jungle so when the user receives the SMS they can see geographically the points in the jungle that the vehicle has been detected. have been spotted. Figure 3.1 shows a drawn representation of approximately what the user should be able to see.

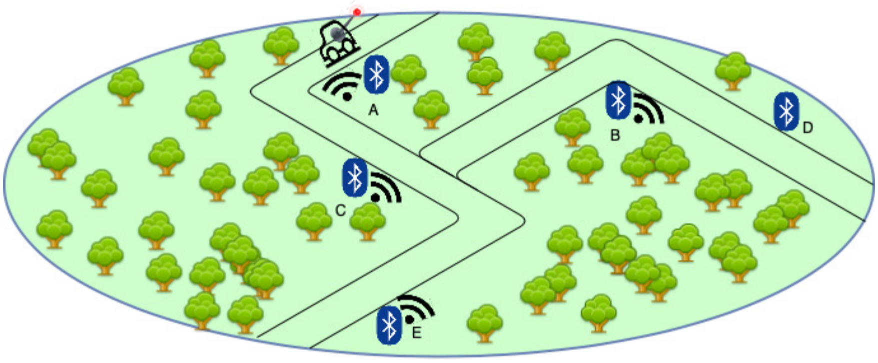

Fig. 3.1 Drawing of the receiver interaction with the beacon

Requirements	Acceptance Criteria
1) It must have an easy way to add new beacons	There is an input option of some type that allows the user to add newly deployed beacons
2) The user must be able visulise the information recieved in the SMS	The user must be able to identify beacons corresponding to the information in the SMS
3) The information entered by the user must be mapped accurately	The point plotted on the map must be geographically close to where the beacon is situated

Table 3.3 Requirements for the visualisation of detected beacons

Chapter 4

Implementation

This chapter will focus on the technical aspects used to implement this project. The chapter is broken into 3 sections, each regarding one of the core components developed for this project. In this chapter, I intend to provide justification for the hardware that is used and to describe the main processes that occur in the solution used to help with the implementation process.

4.1 Receiver

The receiver part of this system is made up of a Ardunio, HM-10 module and in the full working solution a SIM900A module.

An Arduino is a microcontroller which is designed to be used for building digital devices which are interactive and can sense and control. The Arduino is programmed to through its open source IDE which I have used to program to the various components that I have attempted to use throughout this project.

The HM-10 module is a Bluetooth 4.0 Low-energy module which is used to act as an observer to 'listen' for the beacons which it will come into range of. The HM-10 will receive the transmissions from the beacons and save the MAC address of the beacon which it has come into range of. The HM-10 module runs on 2.0-3.7 volts and draws 8.5mA when active. (DSDTech) The module has 4 pins: RX,TX,GND,VCC. All of these pins are connected to the arduino as such:

- RX > D10

- TX > D11
- GND > GND (Any GND on the Arduino)
- VCC > 3.7v

The HM-10 implementation starts by sending the HM-10 a few initialisation commands, AT commands, are instructions used to control a modem. AT is short for ATtention, it was originally made for use with modems and every command line starts with AT. The snippet of code below shows the setup commands which are used to put the HM-10 in the correct mode ready to start receiving data when told.

Listing 4.1 HM-10 setup

```
mySerial.write("AT");
    delay(100);
    mySerial.write("AT+ROLE1"); // Master mode
    delay(100);
    mySerial.write("AT+IMME1"); //Wait for connection
    delay(100);
    mySerial.write("AT+RESET");
```

The "AT+DISI?" command is then sent which then tells the module to begin scanning for beacon advertisements. When I first developed this the output was displayed as figure 6.1. In figure 6.1 you will notice that the data that we want is very sparsely spread out, surrounded by many 0's. This incoming data is intended to be sent by SMS which can only contain 160 characters per message which would result in inefficient use of the message and too much data being stored.

```
mySerial.write("AT+DISI?");
```

The AT+DISI? command which can be seen above sets the HM-10 to scan for all beacons, it reads in the advertisements from the beacon as such:

- Factory ID (8 bytes)
- Beacon UUID (32 bytes)
- Transmission information (10 bytes): Major Value(4) Minor Value(4) Measured Power(2)
- MAC Address (12 Bytes)
- RSSI (4 Bytes)

The beacons transmit a 66 byte ASCII string, which we can be seen in Figure 4.1. The 12 bytes of that transmission that contain data is the MAC address of the beacon, this is the information that we want as it tells us which beacon the receiver has been in range of. It is a good source of information to differentiate between beacons as it is unique to every device.

Note: The output in figure 6.1 prints all devices in range on to the same line, therefore, some of the devices which were detected are cut out of the figure.

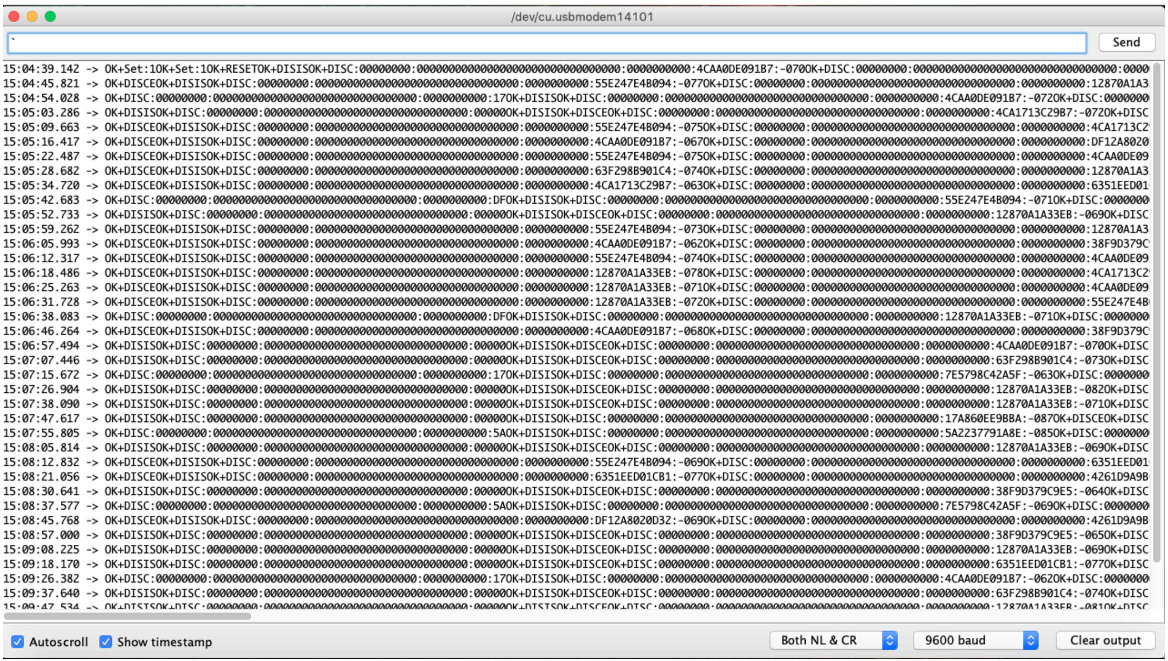

Fig. 4.1 Beacons detected

Figure 6.2 shows an output that was taken from another HM-10 located in the same place minutes apart from the data from Figure 6.1 being taken. This was done to try to keep the same advertisers surrounding it. This time the code has been updated to use regular expressions to only take in and display the MAC address of the beacons which the receiver has come into range of, this makes the information far more readable and wastes less space for both memory and sending as an SMS.

The code below shows the implementation of the regular expression. It reads the data taken from the serial port and records all of the bytes as they pass through, as we know the format of the packets and we know that the MAC address that we wish to keep comes after the FactoryID(eight 0's):BeaconUUID(thirty two 0's):TransmissionInformation(ten 0's) when that format is read in to the port it is filtered through but not saved, the code then knows that it is the next 12 bytes that we want to save as the result, this is then printed to the serial output and the position is updated to repeat. process

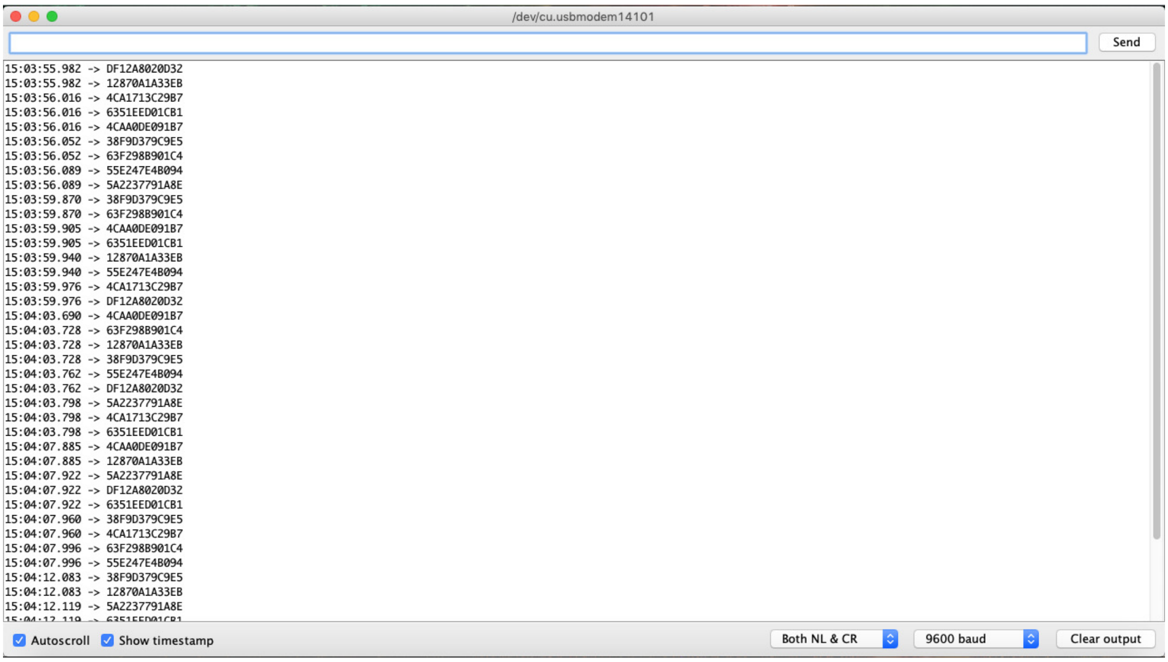

Fig. 4.2 Beacon information read in regular expression

```
inputTXT = mySerial.readString();
int pos = 0;
String result = "";
const String regx = "
    00000000:00000000000000000000000000000000:0000000000:";
const int regx_len = regx.length();
while ((pos = inputTXT.indexOf(regx, pos)) != -1)
{
    // This takes the substring from <starting point> to
        starting point + 12
    result = inputTXT.substring(pos + regx_len, pos + regx_len +
        12);
    Serial.println(result);
    // move starter point to end of last result
    pos = pos + regx_len + 12;
}
```

The battery life of the devices in this solution are points of interest as the receiver needs to last from the time the informant puts the receiver on the vehicle, for the duration of their journey throughout the jungle, until the vehicle arrives back into the vicinity of the GSM signal of the city or nearby towns. Good battery life for the receiver would be 3 days for this project to allow the poachers to stay in the jungle for up to 2 days. The Arduino Uno has a typical current consumption of 45mA, by using 3 AA batteries which have 1.5v and 2500mAH capacity each, this would give the Arduino 4.5V to run the Ardunio and HM-10. The HM-10s current consumption is between 8.5mA when active, we can assume for this use it will draw the maximum current so we can calculate how the battery life by $(2500mA * 3)/(45mA + 8.5mA) = 140hours$. This shows that the receiver can be powered by this setup theoretically for approximately 5.8 days which should be long enough to power the receiver for at least one trip in and out of the jungle.

The GSM part of this project which was intended to send an SMS containing the MAC addresses of the beacons detected. This was intended to work by scanning approximately every 45 minutes to see if there was 2g signal. The reason for scanning so rarely is that the GSM module would be in sleep mode to conserve battery. When the module did have signal, messages would be sent containing all of the beacons that have been sent since the last send. After this set of messages had been sent the memory would then be deleted ready to take in more beacon information. In this section, I tested both SIM900A and SIM800L. The sim cards that both of these modules require are the old 2G sim cards without the 2g sim cards the module does not connect to the network which meant I could not test any code. I sim cards advertised as old 2g sim cards on ebay, one of which even claimed to be for a GSM device tracker but contained the new type of microchip, I also asked friends and family to use the old sim cards they could find around their homes. This was unsuccessful as all of the sim cards that I tested were either locked or deactivated where companies cannot reactivate an old deactivated sim card without specific account detail which the owners could not remember the details for.

Although I could not get this to work in the UK due to not being able to get the right part, Sabah runs on a 3g network so in deployment it should be extremely easy to source the right sim card. Through my research, I have found a lot of similar code to send a message online. To implement this in deployment should potentially be easier as once I have an active 2g sim card. In preparation of getting a sim card, I have implemented the GSM part of the receiver without being able to test it. When I get the sim card it should be as easy as plugging the sim card in and maybe changing a few lines of code to make it work.

The code below demonstrates a function that allows the Arduino to turn on the module without any human interaction, this would wake the module up to scan for a signal. This is an important function as the receiver needs to work autonomously

```
    digitalWrite(4, HIGH);
    delay(1000);
    digitalWrite(4, LOW); //turns the module on without having to touch
        it
    delay(5000);
```

The snippet of code below is the main function for sending the SMS. It uses an if statement to see if the timer conditions have been met, this is used as an alternative to the delay function as this method does not delay the entire code running, the condition when not met will cause the BLE scan to re-run. The interval is set to 270000ms which is 45 minutes as it will conserve battery as the GSM module when active draws a high current, up to 2mA when transmitting data. When the time interval has been met the signal quality will be tested to see if the signal quality is good and there is at least one beacon address stored a message will be sent. The result variable is then set to 0 to reset the memory to allow for more beacon data to be recorded

```
if (currentMillis - previousMillis >= interval) {

  previousMillis = currentMillis;// save the last time you blinked the
     LED
  signal = Serial.write("AT+CSQ=?\r");//Test signal quality
  if(signal = 1 && result.length() >= 12) //Minimum of 1 address in the
       variable is 12 bytes
  {
    sendSMS(); //sends all data in the result variable, will send in
        mutiple messages if longer than 160char
    delay(8000)
    result = 0
    }
}
```

4.2 Bluetooth Beacons

For the beacons, there were 2 implementation options, either to develop my own or buy off the shelf. I started this part of the project by purchasing a BLE 5.0 beacon made by Jinou. This particular beacon was of interest to me as it is configurable thus for testing the broadcast interval can be changed and tested. Another advantage of using a Bluetooth 5.0 beacon is that Bluetooth 5 is backwards compatible which should allow the solution to utilise the improvements that have been made to transmission speed and range. This Beacon costs £12.99 and uses a CR2032 battery which sells for about 50p each. With this implementation, each beacon would cost £13.50 each to deploy - if this solution was to be deployed into a working product potentially hundreds of beacons would need to be deployed around the jungle, this would result in an expensive solution.

During testing, it was clear that the receiver was picking up other Bluetooth devices slightly more frequently than the beacon even with toggling with the broadcast interval. For this reason, I configured a HM-10 module to act as a beacon through the use of AT commands- this will allow me to have options to implement whichever beacon proved to be more successful. Having two different beacons also gives me a tool to know how well they are performing as they can directly be compared against each other. The price of this implementation is £7.99 for the HM-10 module and 11.25 for the Lithium Polymer(LiPo) battery which is being used to power the battery. A LiPo battery is not necessarily needed, for cost reasons this could be run on a nickel metal hydride battery pack which cost less than £5, the HM-10 modules can also be bought for £2.50 from China. This however, would incur a 1 month delivery time which was estimated by couriers which made it infeasible for the cheaper module to be ordered for this project. Due to the cost of the HM-10 beacon being half of that of the off the shelf beacon if it proves to be as good or better in testing then the HM-10 beacon would be implemented. (4)

The battery life of the beacons are a paramount concern as it may be difficult for DGFC staff to go back into the jungle to replace the batteries regularly, The main factor which can be changed to increase battery life is the broadcast interval. The off the shelf beacon has been broadcasting at 1600ms for the last 2 months and has currently got 80% battery. The battery consumption can be thought to decrease linearly as the broadcast interval is shortened which can be visualised by figure 6.3. Apple recommends a broadcast interval of 100ms, this would give an estimated 18.75 days of battery life. This could prove to be infeasible due to the battery not being able to be frequently replaced. In testing, it will be worthwhile to test the

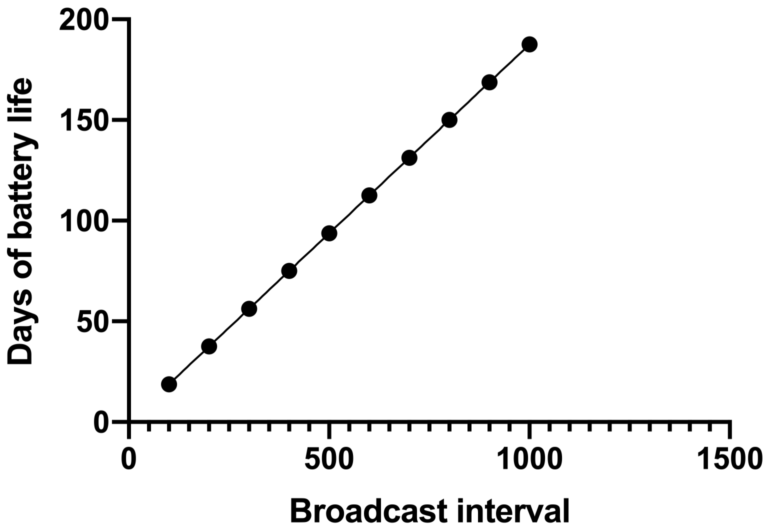

Fig. 4.3 A graph to show the effect on battery life when differing broadcast intervals

trade-off between battery vs broadcast interval.

4.3 Visualising the beacons

For this part of the project, the intention was to extend an open source tracking software called Traccar, due to time constraints I did not manage to complete this part of the project. However, to fit the requirements Google Maps functionality can be used to fit the requirements.

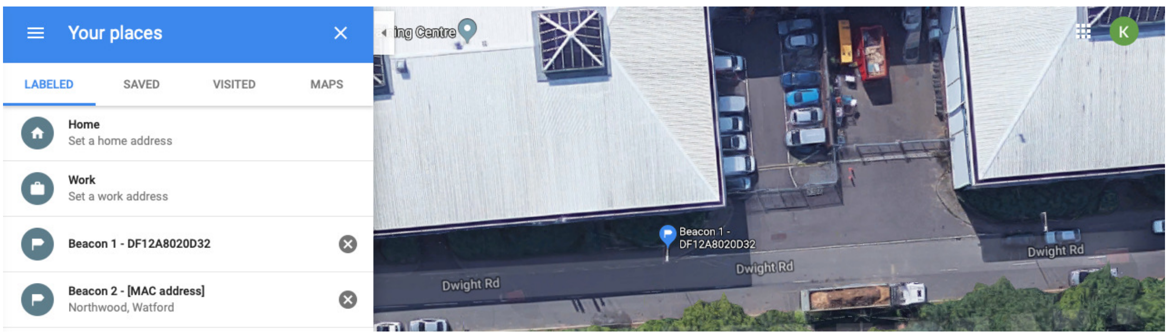

Fig. 4.4 Visualising the beacon locations using Google Maps

In this method as beacons are being deployed their coordinates are being recorded, after deploying all of the beacons and a user on the computer can use the recorded MAC address/ coordinate pairs and upload them to the computer in the list that has been made to store beacons the user can add the coordinates into Google Maps and add the beacons coordinates to the list of beacons, each beacon added should be added with the corresponding MAC address so when the user gets the SMS from the receiver it can be easily known which beacons have been detected and their locations.

Chapter 5

Evaluation and Results

5.1 Testing

5.1.1 Test 1: Off the shelf beacon versus HM-10 beacon

There were 2 different beacons to test for all of the parameters, Beacon A which was a HM-10 module that was powered by a LiPo battery which I had configured using AT commands to act as a beacon. The second beacon was an off the shelf module purchased on Amazon. To test the range of the beacons the first test that I conducted was designed to test the range of the beacons. The test works by placing a beacon in a fixed position with varying obstructions of different materials to simulate both potential casing materials and objects which could affect the performance of the signal between the beacon and the receiving device in the

Fig. 5.1 HM-10 beacon mounted on a tree

jungle. I took measurements of the receiver testing the RSSI every 2 meters. RSSI stands for Received Signal Strength Indicator, it is a measurement of how well the receiver can hear the signal from an access point or router it is useful as it can tell us how good of a connection the receiver will get to the beacon at any given point. Both beacons RSSI are meant to be set at -70dBm at a 1-meter range from the beacon.

The first test was to test the range of both beacons. The test works by placing a beacon in a fixed position with no obstructions between the beacon and the receiving device.

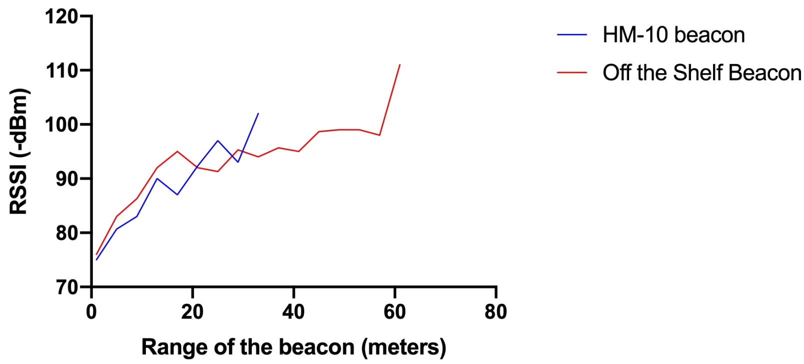

Fig. 5.2 A graph to show the RSSI from the beacons at increasing distances

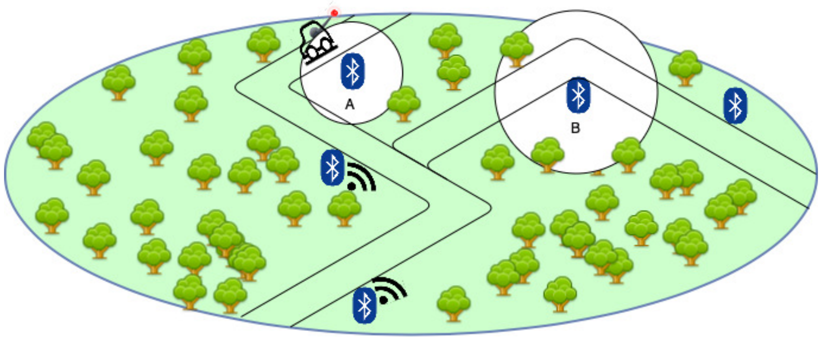

Fig. 5.3 A visualisation to show the difference in range between the HM-10 module(A) and the off the beacon (B)

I tested in a large field where no other devices could be detected and tested one beacon at a time to ensure no interference this is important to isolate the results of the test to ensure a fair result. I tested 3 times and averaged the results, figure 5.2 graphs the results. In the graph we see RSSI on the Y-axis, the lower the RSSI the stronger the signal. On the X-axis we see the range of the beacons. In the graph shows that the range of the off the shelf beacon is 84% larger, and throughout that range, the signal strength remains to be strong until 41 meters as RSSI begins to deteriorate in reliability from the beacon after 95 RSSI which the HM-10 beacon reached at 25 meters. This shows that the off the shelf beacon has a significantly longer range while maintaining a good signal. This can be better be visualised by 7.3 where beacon A is the HM-10 beacon and beacon B is the off the shelf beacon.

This result could have been expected however as the HM-10 uses Bluetooth 4.0 where the off the shelf beacon uses Bluetooth 5.0 which has been developed for an increased range. After this test I stopped testing the HM-10 beacon as the off the shelf beacon had proved itself to be significantly better so the results that I would get for the HM-10 module would not be of as significant as the off the shelf beacon was certainly going to be used for the project following those results

5.1.2 Testing the effects of obstructions of various materials on the beacon signal

The next test that was carried out was to test the various types of obstructions that the signal would face in deployment. I tested plastic and cardboard cases which were intended to simulate the effect that adding a case would have on the signal. I again did this test 3 times and tested the RSSI at distances increasing by 4 meters starting at 1 meter. The images below show the boxes that I put the beacons into for testing.

Fig. 5.4 Beacon in a plastic case

Fig. 5.5 Beacon in a cardboard case

In figure 7.6 you can see the outcome of the test. The graph contains the data from the unobstructed signal to allow for easier comparison. We can see that for the plastic case the RSSI is higher at one meter than in the unobstructed and the cardboard, from this we can tell instantly that plastic affects the signal strength significantly. Towards the 25 meter range, the effect of the plastic seems to level out as all of the results were very similar at this range. The case materials did show to affect the range however with the plastic losing signal at 45 meters resulting in a loss of range versus the unobstructed signal of 44% and the cardboard losing signal at 57 meters resulting in a loss of 14%. This leaves an interesting trade-off for the casing as a plastic casing would have been the ideal material as it is waterproof and discrete.

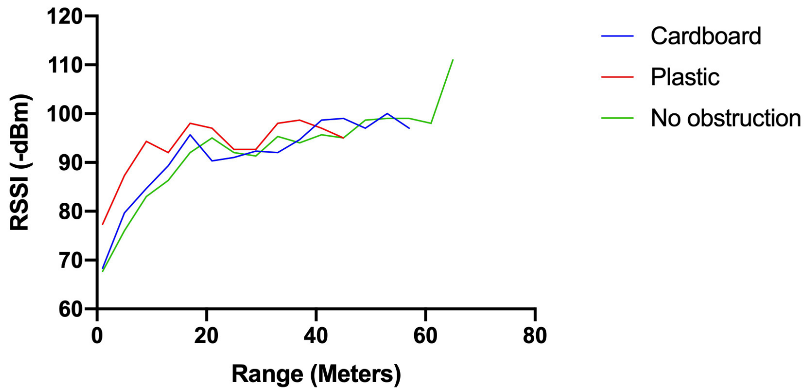

Fig. 5.6 A graph to show the affect on RSSI at distances when the beacon is obstructed by various materials

5.1.3 Testing the effects of elements that would effect the signal in the jungle

The next test I did was to see how the signal would be affected within a jungle environment. Sabah receives 2500–3500 mm of rainfall annually, for comparison Cardiff receives 991 mm of rain annually. It is also up to 100% humidity in the jungle so it is important to know how water would effect the signal strength. This proved to be a difficult test as any container that held the water would add to the obstruction of the signal which would make it difficult to test the affect of water without the container. For this, I chose a sandwich bag as it is extremely thin plastic which would have the least effect on the signal as possible. It would be naive to say that the obstruction from the sandwich bag did not effect the results on the signal at all, for this reason before testing the water I put the beacon in sandwich bags and tested this individually to understand the affect of the plastic bags on the signal so we can better understand the effect of the water.

I filled this with 1 litre of water and submerged the beacon to try and replicate the wetness of the surroundings in the jungle. The graph below shows the results of the data. For the "just water" data as I had the data for the water and plastic bag combined, and for the plastic bag I took the difference of the data for the unobstructed signal and added it on to the water data to try and get a gauge for how water alone would affect the signal. The graph below shows that the plastic bag had a small impact but the water itself had the biggest impact on the signal of any material we have tested having a range of only 33 meters. From the trends that we have seen in the previous graphs, based on the results of the just water we could expect another 4 meters of range based on the RSSI strength of 29 and 33 meters, bringing the range of the water up to 37 meters.

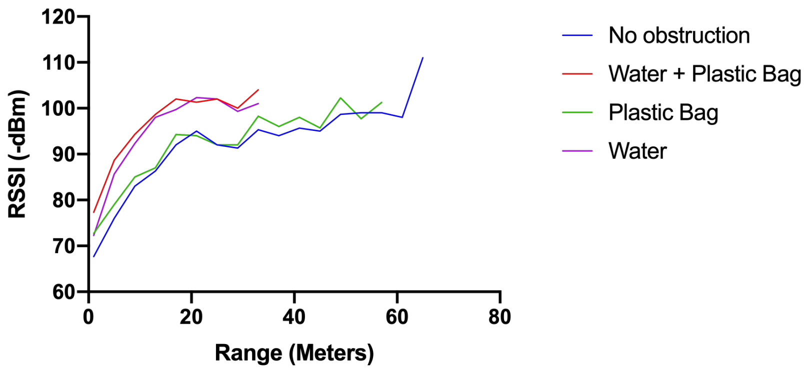

Fig. 5.7 A graph to show the affect on RSSI at distances when the beacon is obstructed by water

5.1.4 Testing how changing the broadcast interval and vehicle speed affects beacon detection

The driving test is the next experiment which was needed. As the beacon is to be placed in the jungle onto a tree or similar surface, I mounted the beacon on to a tree similar to how a beacon would be mounted in the jungle. Figure 5.8 shows the first road which I tested on, I tried to test in the closest environment to the jungle as possible, this road is in Watford, England. The road is pictured below and the mounted beacon is identified. In this experiment, we are driving at various velocities to see whether the receiver picks up the signal from the beacon. The estimated max velocity was 70 KPH which is approximately 43.4 mph so testing was planned to go up to 45 mph although it was not expected to be successful at the higher speeds. For each speed, the broadcast interval would be increased to test what the highest broadcast interval we could set the beacon on while getting reliable results to ensure the beacon is detected every time that the vehicle is in range. The test recorded whether when the vehicle drove past the beacon it was detected or not. This was tested 3 times for each velocity and beacon interval with the receiver placed on the dashboard.

Fig. 5.8 Road 1 which was used for testing

This road which had a similar build to go a jungle road was difficult to drive on over 20 mph so on this road we would test at 20 mph to maintain safety, if the beacon was not detected, then we would decrease speed to see what the maximum speed the beacon was detected at that broadcast interval. I started the broadcast interval at 200ms and the receiver picked the beacon up every time. I repeated this test for broadcast intervals up to 1600ms, increasing in 100 intervals. The receiver detected the beacon every time without fail. Due to the success of this test, a tarmac road where a vehicle could get to higher speeds was needed. For this I travelled to Dwight Road, Watford, England. It is a road at the back of an industrial estate and as I was testing on a bank holiday weekend it was perfect as there were no cars. I attached a beacon to a lamp post and began conducting the test. The closest the vehicle was to the

	1000ms	1100ms	1200ms	1300ms	1400ms	1500ms	1600ms
5 mph	Y	Y	Y	Y	Y	Y	Y
10 mph	Y	Y	Y	Y	Y	Y	Y
15 mph	Y	Y	Y	Y	Y	Y	Y
20 mph	Y	Y	Y	Y	Y	Y	Y
25 mph	Y	Y	Y	Y	Y	2/3	2/3
30 mph	Y	Y	Y	Y	2/3	2/3	1/3
35 mph	Y	Y	Y	Y	2/3	1/3	1/3
40 mph	Y	Y	Y	Y	2/3	1/3	N
45 mph	Y	Y	2/3	2/3	1/3	N	N

Y: the beacon was detected every time
1/3: the beacon was detected in 1 out of the 3 tests
2/3: the beacon was detected in 2 out of the 3 tests
N: the beacon was not detected in any of the tests

Table 5.1 Table to show the effect of different broadcast intervals and speed of vehicles for detection

beacon at its peak was approximately 2 meters away.

On this road, I conducted the same experiment as the previous experiment on the dirt road but with the difference that the vehicle would now be travelling up to 45 mph. This worked with flawlessly at 45mph until the beacon interval was increased to 600ms, with the lower beacon intervals the receiver had detected the beacon before passing it. As it went to 800ms it was detected but about half a second after passing the beacon each time. 1000ms was also detected far after the beacon but now about 1.5 seconds after passing the beacon. The 1200ms broadcast interval is where the receiver started to not detect the beacon. As the test was repeated 3 times the beacon was detected 2 out of the 3 times tested, one of the times tested the beacon was detected approximately 25 meters after passing the beacon. This is due to the probability of beacon advertising and the HM-10 scanning while the vehicle is in range. The probability that detection will occur decreases exponentially as the broadcast interval increases.

Table 5.1 gives a partial set of results from this test as all of the results from 200ms to 1200ms were Y's as the beacon was detected every time. The table shows when the reliability of the solution starts to deteriorate. As there are two variables in this connection the beacon and the receiver it is important to note that the receiver is set on the fastest reliable loop cycle which is 2500ms. This is the fastest loop from my testing that works reliably as SoftwareSerial the library which I am using to communicate with the Arduino, this is because as the Arduino is communicating with the computer through the serial port it is unable to do anything else including reading in from the HM-10 module, this can result in overflowing which has proved to corrupt incoming data.

5.1.5 Testing how changing the broadcast interval and vehicle speed affects beacon detection while the receiver is mounted under the bonnet

For the final test, we needed to fully simulate how the beacon and receiver would communicate in the jungle, due to the fact we do not want poachers to find the receiver it has to be placed somewhere hidden. After inspecting my car, a 2005 Ford Focus there was very few places where the receiver could put discretely. I believe the best place would be under the wheel arch however the wheel arch on my car was too small to fit a receiver. As we assume poachers will drive 4x4 vehicles the wheel arch gap will be a lot larger. To complete the test I needed somewhere with similar obstructions so I fastened the receiver to the bonnet which can be seen in the image below. A bonnet will have more of an impact on the signal as it is surrounded by far more and thicker metal being that close to the engine, this also would not be a feasible location to put the receiver in deployment as the heat of the engine could potentially damage the receiver.

Fig. 5.9 An image of the beacon mounted on to the inside of the bonnet for testing

	600ms	700ms	800ms	900ms	1000ms	1100ms	1200ms	1300ms	1400ms	1500ms	1600ms
5 mph	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N
10 mph	Y	Y	Y	Y	Y	Y	Y	Y	2/3	N	N
15 mph	Y	Y	Y	Y	Y	Y	Y	Y	2/3	N	N
20 mph	Y	Y	Y	Y	Y	Y	Y	2/3	1/3	N	N
25 mph	Y	Y	Y	Y	Y	Y	Y	2/3	1/3	N	N
30 mph	Y	Y	Y	Y	Y	2/3	2/3	1/3	N	N	N
35 mph	Y	Y	Y	Y	2/3	1/3	2/3	N	N	N	N
40 mph	Y	Y	2/3	Y	2/3	2/3	2/3	N	N	N	N
45 mph	Y	Y	2/3	2/3	1/3	1/3	N	N	N	N	N

Table 5.2 Table to show the affect of different broadcast intervals and the speed of vehicles for detection while the receiver is mounted under the bonnet

I completed the same test with the receiver inside of the bonnet. A segment of the results of can be seen in the table below, the results from 200ms to 700ms were all Y's which means that the receiver detected the beacon on each of the 3 tests. The results were significant showing the huge impact that concealing the receiver has on the signal strength. The results at 800ms were similar to the results of the previous test at 1200ms and the results at 1000ms in this test were similar to that of 1400 in the previous test. This shows a result that with the receiver concealed the signal is approximately as effective as if the beacon was set to -400ms less than any broadcast interval with it concealed.

Chapter 6

Analysis

Following the results of the receiver under the bonnet test, it shows that under the bonnet the signal strength is greatly affected. However detection can occur with the right beacon interval. This is a good thing because as under the bonnet is the most heavily obstructed part of the vehicle it gives us the ability to give the informant the choice of where to put the receiver on the vehicle depending on the vehicle. Placing the receiver on the side of the vehicle could have a big effect on the signal. If the receiver is placed on the left wheel arch and the beacon on a tree to the right of the road, the obstruction will be the entire width of the vehicle. As we have tested under the bonnet, we can be confident that with a low enough broadcast interval, detection would still happen every time.

To choose the broadcast interval for the beacons we need to consider the trade-off of battery life vs effectiveness. Detection every time the receiver comes in to range of the beacon is a requirement so we must choose the highest beacon interval that gives us a reliable solution and maximise battery life. The max speed would be 60-70 km/h (45 mph) as the roads are very slippery and there are a lot of bumps and holes on the dirt roads, the average speed is 40 - 50 km/h (30 mph). As 30mph is the average speed, we can immediately rule out broadcast intervals of 1100ms or higher as the results at this speed shows that detection only occurred 2 out of the 3 times it was tested. To get a reliable solution to work for the max speed a broadcast interval of 700ms would be the lowest, which would give an estimated battery life of 131.25 days.

Alternatively, when beacons are placed a smart phone can be used to use the app the beacon designers created which allows the user to connect to the beacon to change the settings such as the broadcast interval. Table 6.1 has been created for as a guide for the individuals deploying the beacons if they have smart phones available in the jungle. It gives those deploying the beacons the discretion to estimate what the max speed would be for the specific road which they are deploying on, based on this estimate they can see what broadcast interval they should set the beacon to and thus they can determine how long the battery would last, if they do have a smart phone and can use this method it will ensure that the battery life is maximised for each individual beacon while ensuring that the receiver will still be able to detect it.

Max Road Speed (mph)	Set broadcast interval to:	Estimated battery life (Days)
5	1400ms	262.5
10	1300ms	243.75
15	1300ms	243.75
20	1200ms	225
25	1200ms	225
30	1000ms	187.5
35	900ms	168.75
40	700ms	131.25
45	700ms	131.25

Table 6.1 A guide to inform deployers of what to set beacon broadcast interval to based on the maximum road speed

Chapter 7

Discussion

To evaluate the success of the project we must remind ourselves of the requirements which we initially set out to achieve. The requirements for the receiver have been as follows:

- Requirement 1 states that beacons must be detected every time the vehicle travels past with range. This criterion has been met shown by the testing. The beacon is detected every time and based on the maximum speed that a vehicle can travel on a road the broadcast interval of the beacons can be changed to ensure that this requirement is met.
- Requirement 2 states that the beacon information should be read into the Ardunio and stored. This requirement has been met as we saw in figure 6.2 the MAC address of the beacons have been read in a readable format and stored to a variable.
- Requirement 3 declares that an SMS should be sent containing the which beacons have been sent. This has not been met currently due to not being able to source a 2g sim card, this however, is likely to work in Malaysia as they run on a 3g network.

From these requirements, we can see that the BLE part of the project is working extremely well. When starting the testing the table that was drawn to collect results went in increments of 2 mph in the range of 2mph - 20mph. The results proved to be outstanding and showed that with a low beacon interval vehicles could be detected far above 45 mph. The entire BLE part of the project has been extremely successful despite only managing to make the HM-10 work in the last few weeks. The alternative to this part was using a HM-05 module which uses Bluetooth 2.0, as Bluetooth 2 does not contain BLE I implemented it to scan all devices around it and store the values. This worked well however, as it is not the technology's dominant purpose it was unreliable occasionally not detecting devices that were nearby. It would also only detect devices up to 5 meters away. Another problem with the HM-05 solution is that Bluetooth 2 does not have beacons and is not forward compatible thus the 'beacons' that had to be used was another HM-05 in discovery mode to try and simulate how a beacon would act. (9)

The GSM part of the receiver not being functional does not fully take away from the project as the receiver can be collected to get the data, as this is a prototype the main part of the project working well is the important part and hopefully with just the correct sim card the GSM will be made to be functional very quickly as I have implemented the code.

7.1 Future Work

In the future, this project can be developed further, as we now know that the beacon system is viable, when the SMS is sent out of the jungle, the time that the beacon was detected could also be recorded and sent with the MAC address of the beacons. The computer could then be automated to receive the message and read in the data from the SMS. This data could be then uploaded to a software which has the locations of the beacons saved on a map as the Google Maps solution does, but then it could map the journey which the vehicle took based on the MAC address of the vehicles and the times that they were detected. This future work could make the project fully functional and worthy of going to market. The benefit of the data being able to be mapped would allow users to further understand how the poaching gangs have moved and where they have stopped for longer, this would show points of interest to see where the poachers sleep at night in the jungle and the routes that they take.

This project shows that BLE beacons can be used for in cases where the beacon and receiver are only in range of each other for split seconds of each other. This technology could have many more uses such as a new way of paying for parking. This could work by a user who would drive into a car park, the receiver then detects the beacon on the vehicle, when the beacon is no longer detected the vehicle has left, then the user could be charged for that many minute's parking.

7.2 Lessons Learned

One of the main lessons that I have learned from this is project to start early, although my time plan in my initial report was reasonable I did not expect to get stuck for over a month at a time. In future projects, I will assume from the outset that things will go badly wrong to ensure I have planned large buffers and contingency plans if things don't go well. Time management is often the downfall of most projects, with more time I would have been able to complete the visualisation part of the project which would have made the solution more useable.

Most projects struggle at some point, and getting over these problems is a an important lesson, one cannot be afraid to ask for help from those around you and online. Computer Science is a subject where solving problems is one of the main focuses and therefore people seem more willing to help others, before this project I would have never looked to a public forum to ask a question to seek the advice from those that I did not know. Learning to seek advice from those more experienced than myself helped me solve the regular expression problem which I was struggling to implement.

Besides the soft skills that I have developed in this project, I have also developed a lot of technical skills. Throughout my degree program, I have not had anything to do with any hardware or computer engineering so I thought this project would be a good opportunity to learn more about it. I have learned a lot about circuits and how voltage and current is not as simple as it will work or it will not work, for example with the SIM900A module as it would not connect to the network one of the possible ways to fix this would be to give it a greater current regardless of the LEDs working to show it was being powered, this is because as the SIM tries to send a message it draws more current, if there is not enough current supplied the module will restart itself and not send the message.

The Ardunio IDE uses C++, a language I have never encountered before, it is used as it is a lower level language which works closer to the hardware, for all of the Arduino based work I have had to learn to code in C++. This is a very useful skill for me to have learned as I am now more comfortable working in higher level languages as I feel like I understand what is happening under the code.

Chapter 8

Conclusion

This project set out to create a method to detect poachers within the inner jungle, it has successfully completed that task through the use of BLE beacons. This method provides a different way of tracking, without needing to worry about signal strength from satellites or cellular towers, this brings a new tracking method that can be used in any environment regardless of how remote. Following testing, it can also be seen that environments, where water is surrounding the beacons, result in significant range loss. The solution works best if it is possible to have no obstructions in the line of sight between the beacon and the receiver, water and wood proved to be particularly severe obstructions, a beacon surrounded by water reduced the signal range by 43%. The broadcast interval of the beacon has a linear effect on battery life, the higher the beacon interval the longer the battery will last. As battery life is a concern for this project we want to maximise battery life so through testing a guide in the form of a table has been developed to allow the deployer to estimate what the maximum speed is for a given road and tell them what beacon interval to set the beacon to, this ensures the receiver will be able to detect the beacon every time and maximise the battery life of the beacon.

This project could allow for huge amounts of future work; this system could record the time which beacons were detected which could then be used to map a system outside of the jungle, producing an automated route on the map to visualise where the vehicle has been and how long the vehicle was on each road. This would lead to huge amounts of information that could be analysed which would further help with the ambitions of this project to understand how the networks of poaching gangs operate within the jungle.

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