FACTORS AFFECTING NETWORK HANDOVER ON MOBILE DEVICES

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STATEMENT OF CANDIDATE

I, Michael Bauer, declare that this report, submitted as part of the requirement for the award of Bachelor of Engineering in the Department of Electronic Engineering, Macquarie University, is entirely my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualification or assessment an any academic institution.

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ABSTRACT

People are constantly on the move and in consistent need of communication. Mobile devices and internet connectivity have now become an integral part of our way of living. To best accommodate the moving person, mobiles need to switch between available networks in an attempt to avoid a break in connection. In an effort to minimise the break in connection and optimise handover, an improved location-based handover algorithm can be developed, taking advantage of cheaper, faster internet and modern day mobile processing. Such a system could map wireless networks and upload data to a server from users as they travel throughout their day to day life. This data may then be processed into an optimised model that can be downloaded as the user passes through an area, improving upon the decisions made by the algorithm. The benefits that could be gained out of mapping networks are currently not known and modern day technology may or may not be suitable to collect high-quality data necessary to produce an accurate model. This leads to the primary focus of this project which is to determine the quality of data that can be collected from a mobile device and in what ways can a model produced using this data can benefit the algorithm. Through the development of a system which mirrors its data collection capabilities, the merits of the collected data is analysed to determine the feasibility and benefits of developing this improved location-based handover algorithm. In this project, it is discovered that the data may not be of high enough quality yet particular situations were found to be potentially beneficial to the algorithm

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Chapter 1

Introduction

Ever since the commercialization of the internet, societies hunger for a greater range of information and a need for high-speed communication has grown as fast as the exponential growth in internet speeds and bandwidth [9]. Along with the advent of Mobile technologies allowing people to communicate while on the go, consistent internet connectivity is a critical part of today's society which leads to further rapid developments within the industry. Ever since the first generation (1G) was released in 1982, each subsequent generation is released approximately every 10 years, each exponentially faster than the last [2].

As each new generation is phased in and the older ones (eventually) phased out, the results are a very modern day problem requiring mobiles to switch between different networks as the user is on the move. In order to maintain a continuous high-quality internet connection, handover needs to be seamless and quick to prevent streaming videos or international video calls from losing connection and dropping out.

The problem explored in this document is less to do with the process of handover but rather the decision making behind it. In some cases, switching networks can be quick and in other cases less so. In the static case when the user is standing still, the decision generally would be to switch to the fastest available network. This does make the assumption that the user them self has no preference, whether it be for financial or personal reasons. When the user is mobile the situation is different, signal strength and the available networks are now not constant requiring consistent monitoring to quickly react to changes.

As smart phones become increasingly computationally powerful, this decision-making process can incorporate more sensory data such as GPS coordinates and memorised locations to make predictions about the future state of all the available networks. As such the mobile will make more informed decisions as to which network will be best and when switching to it will result in a minimal interruption to the user.

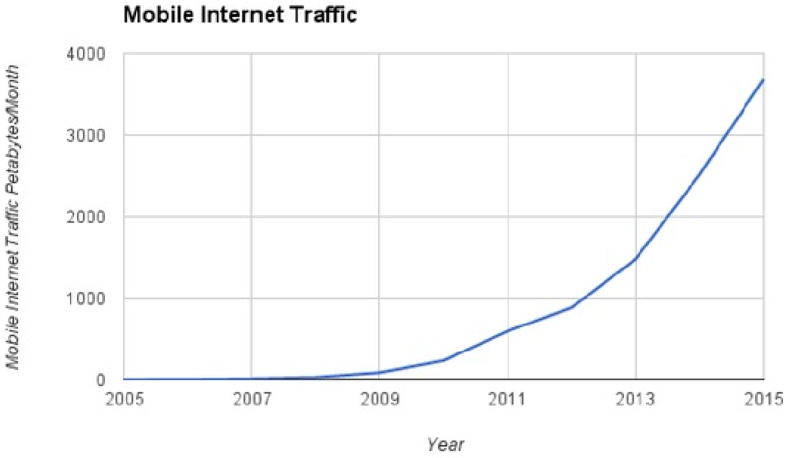

Figure 1.1: Exponential increase in mobile internet usage. [8]

1.1 Project Goal

In order to understand the extent to which handover could potentially be improved by proposing an improved location based handover technique in which signal data is mapped modelled to allow the mobile to understand the surrounding area and better decide on the best state of the network. The primary question being explored is the feasibility of the proposed technique. This question can be broken down further into two questions, what is the quality of the data that can be collected and how useful can it potentially be.

These questions are explored by mapping local networks then analysing the resulting data for patterns, inefficiencies, quality of data and other environmental oddities. This experiment is to be achieved through the development of a system which allows for easy data collection and storage as well as a platform for the automated generation of useful plots and allow the easy exporting of specific sets of data for further analysis.

Other questions around the proposed technique will also be explored, particularly how it may be implemented by developing a mapping application consisting of an Android application and a Web application in to collect data and process it. The challenged faced during development of this system will be similar to those faced while developing an implementation of the proposed handover technique.

1.2 Definitions and Abbreviations

1.2.1 Abbreviations

A number of abbreviations are used throughout this paper, a list of what each of them stands for are below. Those that are not as self-explanatory or isn't a system or product is defined further within the definitions section.

LAN Local Area Network

WAN Wide Area Network

GSM Global System for Mobile Communication

CDMA Code division multiple access

WCDMA Wideband Code Division Multiple Access

LTE Long Term Evolution

OFDMA Orthogonal Frequency-Division Multiple Access

RSSI Received Signal Strength Indicator

RSRP Reference Signal Received Power

UHF Ultra High Frequency

SHF Super High Frequency

MAC Media Access Control

SSID Basic Service Set Identifier

BSSID Service Set Identifier

GPS Global Positioning System

SDK Software Development Kit

HTTP Hyper Text Transfer Protocol

JSON JavaScript Object Notation

CSV Comma Separated Values

XML eXtensible Markup Language

API Application Programming Interface

REST Representational State Transfer

UI User Interface

AJAX Asynchronous JavaScript and XML

KML Keyhole Markup Language

IMEI International Mobile Equipment Identity

1.2.2 Definitions

A list of important definitions of physical objects, processes and protocols related to this paper are provided below.

Handover The process in mobile communications of switching from one network type to another including from within one access point within the network to another.

Access Point A physical object which acts as a gateway connection to the internet such as a Wireless router. In the case of this paper it will always refer to Wireless Access Points and also include Cell Towers.

ISM band Industrial, Scientific and Medical (ISM) radio bands are a set of internationally recognised radio bands reserved for usage in a particular field. It is enacted to improve harmonisation in spectrum utilisation.

Cell Tower A physical tower part of the mobile networks infrastructure which act as an Access Point for one or more of the 2g, 3g or 4g networks.

Decibel(s) A unit of measurement to measure sound or electromagnetic intensity. It is measured on a logarithmic scale meaning negative numbers do not have a negative intensity but rather represents small fractions of an intensity.

REST API A special type of API that enabled connection to the systems functions via the Internet, usually using HTTP.

JSON A standard file format specification commonly used for internet communications. It is useful for communication to REST API's.

CSV Similar to a JSON file, CSV is a standard file format specification commonly used to store and transfer data from a database or table. It's layout makes it somewhat human readable and along with JSON a widely used format.

KML Keyhole Markup Language is an XML based specification for displaying geographic data. Used by Google Maps API.

A number of products and services are both mentioned a used throughout this paper and the development process. A quick explanation of the product or service and what it's used for is provided below.

Wi-Fi Managed and named by the Wi-Fi Alliance, Routers equipped with this technology enables them to wirelessly add other devices to the local network and facilitate communication between them and the rest of the network which may include ethernet wired connections and a connection to a model allowing the network to also access the internet.

Android A smart phone operating system developed by Google.

Bottle A lightweight Web application framework written in Python that automates and aids in the creation and management of Web applications.

Bootstrap A free and open source frontend web framework allowing the rapid development of good looking websites.

PythonAnywhere An online service that provides the facilities to run and manage web applications on the internet along with a connection to a database.

MySQL Is an open source SQL database management system developed by Oracle Corporation

Chapter 2

Background and Related Work

2.1 Mobile Networks and Wireless Communication

Mobile devices have two primary ways of accessing the internet, via wireless connection to a local area network (LAN) such as Wi-Fi or a connection to a wide area network (WAN) such as GSM, WCDMA and LTE. Mobiles can thus choose which network is preferred based on a number of factors, primarily due to the quality of connection which is not to be confused with quality of service. The quality of connection depends on how well the mobile can communicate effectively with the access point however the quality of service depends on how effectively and quickly the mobile can communicate over the network. As the quality of service is difficult to reliably measure it tends not to be used in the decision-making factor in mobiles. One caveat, however, is that the potential capabilities of each type of network are well defined thus more advanced technologies will get a higher priority.

Decision-making factors such as user preferences or quality of service are out of the scope of this document. User preference should always trump the mobiles opinion as some networks cost money or may be a security risk to the user, both of which cannot be easily determined by the mobile. The quality of service cannot be used as while it is difficult to measure, Wi-Fi networks can potentially provide a much better connection than WCDMA or some LTE connections. Wi-Fi, however, will often not be better than LTE and in some cases worse than WCDMA depending on the user's equipment, distance to their wireless access point or their plan with their internet provider. Due to the variation and that much of the variation cannot be controlled for the data will not be suitable for analysis.

2.1.1 Local Area Networks

Wi-Fi is the only widely used Wireless LAN supported by mobile devices and while the network capabilities of Wi-Fi are thus clear but they depend heavily on the owners quality of service. Wi-Fi can easily provide high-speed internet however it is very common that the speeds available to that network are a lot slower. This results in the actual internet speed being very unpredictable.

Due to Wi-Fi's potential for a high-speed connection and that it tends to be a cheaper source of internet, a mobile is more likely to give it a high priority. What Wi-Fi has in speed, it loses in signal range, with a reliable connection typically extending up to 100m and half that indoors. Because of its short range, a mobile may only be in the range of one Wi-Fi access point with good quality. As Wi-Fi is common it is also likely to be in the range of a neighbours access point however with a less reliable connection. Wi-Fi is also highly susceptible to environmental factors such as brick walls and metal sheets.

Due to this potential for wide variations in quality of connection in relatively small areas particularly indoors a user may be faced with constant network switching between the LAN and any available WAN resulting in network interruptions. Network Handover itself takes some time and is dependent on which network is being switched to, yet even when a connection has been made, a mobile application may not detect and handle it. If the handover occurred when it was in the process of uploading or downloading information, whether it be a video call or a loading a website, an error may occur and the application will fail to function correctly.

2.1.2 Wide Area Networks

Wide Area Networks consist primarily of GSM, WCDMA and LTE, with many other types and variants which are generally unused or not as popular. These networks are also split into different generations which the three networks listed earlier being 2g, 3g and 4g.

Each of these generations is inherently different architectures from the last giving it a new set of capabilities along with advantages and disadvantages. Historically however those networks with mostly only advantages are the ones that find widespread usage. One consistent advantage that each generation has is the exponential increase in internet speeds and as such quality of service [2].

The second and third generation networks are consistently slower than Wi-Fi while the fourth generation capable of similar speeds yet still at a higher cost per Gigabyte, resulting in Wi-Fi being a preferable option. WAN networks, however, have a much larger range and signal quality is limited by the local topology and large buildings over many kilometres as opposed to Wi-Fi being affected by a single brick wall. Cell towers often also overlap meaning patchy black spots from one cell tower can be covered by another.

As the architecture differs greatly between the generations it results in costly and time-consuming infrastructure to set up the network making it common to have the different generation networks run in parallel with each other. A further consequence of the infrastructure costs is that an individual network will not have complete coverage, as a network becomes established it may get close but the introduction of the next generation will result in more irregular coverage. This then leads to the problem of handover between the networks.

	2.4 GHz	5 GHz
Interior Drywall	3-4	3-5
Cubicel wall	2-5	4-9
Wood Door (Hollow-Solid)	3-4	6-7
Brick/Concrete wall	6-18	10-30
Glass/Window (not tinted)	2-3	6-8
Double-pane coated glass	13	20
Bullet-proof glass	10	20
Steel/Fire exit door	13-19	25-32

Figure 2.1: The difference in attenuation between 2.4GHz and 5GHz signals. [17]

2.1.3 Access Points

An access point is a piece of equipment that when connected to, allows communication over that particular network. More specifically for this document, an access point is connected to wirelessly via a mobile device and provides access to the internet. Each type of network utilises a different type of access point and is limited to a specific range of frequencies in order to minimise interference with other networks.

Wi-Fi Wireless Router

A wireless router that adheres to the IEEE 802.11 standards serves as the access point for a Wi-Fi network. Often for home networks, the wireless router will be built into the modem. Each Wi-Fi access point has an SSID which is the name of the network and a unique BSSID. The BSSID is also known as the devices MAC Address which every Wi-Fi enabled device must have. [1]

Wi-Fi access points mainly operate on 2.4 GHz UHF and 5 GHz SHF ISM bands, with most devices supporting only 2.4 Ghz and newer devices supporting 5 GHz. While 2.4 GHz originally sufficed, the rapid increase of that frequency has led to a large amount of interference limiting its maximum transfer speed. By utilising the 5GHz band, higher speeds can be achieved. In addition, the two frequencies complement each other well due to their different properties.

5 Ghz signals are more prone to attenuation from different materials, reducing its maximum range and making it more susceptible to the environment compared to 2.4 Ghz. This means that with a strong signal, high speeds can be attained without the interference from neighbouring networks. This suits well with 2.4 Ghz signals as with its longer range it can cater for more users, however, it suffers and contributes to the suffering of other Wi-Fi access points because of the interference.

Mobile Cell Tower

A cell tower serves to be the access point for all mobile networks. Each tower can contain a number of antennas to serve one or more service providers such as Telstra, Optus and

Generation	Frequency
2G	900MHz
3G	900MHz
3G	2100MHz
4G	700MHz
4G	1800MHz
4G	2300MHz
4G	2600MHz

Table 2.1: Frequency Bands used by Optus for mobile communications. [5]

Vodafone in Australia. The can also support one or more networks such as 2G, 3G or 4G.

The frequencies used by the cell towers vary depending on the service provider and the frequencies they are licensed to use, for example, the frequencies used by Optus are in table 2.1. The frequency used by each tower is also determined by the licences as only some frequencies are licensed for specific areas.

In order to better manage each tower's available bandwidth as a particular tower is becoming busy, it reduces its power output decreasing its range. By doing so all the mobiles connected to it that are now outside of the tower's range must undergo handover to another tower [20]. This system relies on the fact that the neighbouring tower may be less busy. This means that the output of a particular cell tower may vary greatly throughout the day, although it can be predicted by understanding when the area is most likely to be busy.

As cell towers have a much larger range than Wi-Fi access points, they are spaced out a lot more. This leads to issues such as building shadows, areas where the radio waves from a particular cell tower are blocked by a large building or experiences a large amount of interference due to reflection and diffraction around surrounding buildings and local topography. This results in service providers installing smaller cell towers aimed specifically at any large shadowed areas. This increases cell coverage but will force the user to switch to the smaller cell tower for only the period of time they are inside the shadow.

Shadows tend not to always be a big problem as radio waves can flow around buildings. The lower the frequency, the easier it is for radio waves to pass around buildings as they curve around more. Higher frequencies curve a lot less around buildings increasing the size of the shadow, both are however susceptible to producing interference patterns. This is the same reason why 5Ghz Wi-Fi is affected more by environmental factors than 2.4Ghz. The area behind an object that is blocking a cell tower would contain an interference pattern causing a large spike in the variance of signal strength over small areas. A conceptual way of picturing this can be seen in figure 2.2.

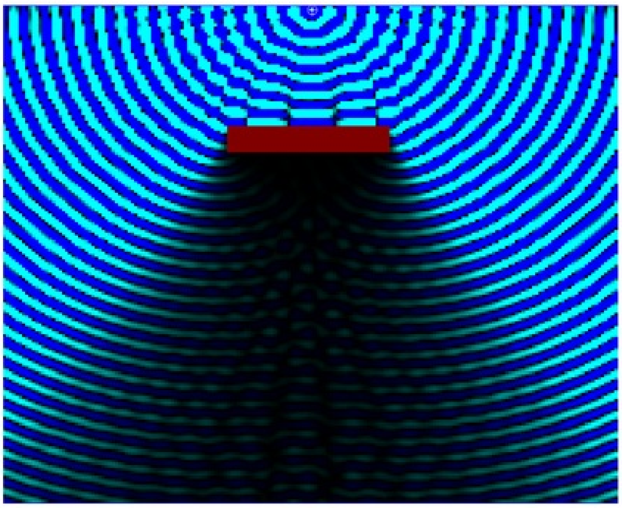

Figure 2.2: A conceptual example of interference patterns forming along with a shadow. Made using the Ripple Wave simulation at http://www.falstad.com/ripple/

2.2 Types of Network Handover

Network handover is a well-established component in modern day mobile networks resulting in a number of classifications and techniques in order to describe different sorts of handover and carry it out.

Hard and Soft Handover

One method of differentiating between types of handover is whether the current connection to the cell tower is broken before or after a connection has been established with the destination tower.

Hard handover is when the mobile disconnects from the current cell tower before negotiating a connection with the destination tower resulting in a break in internet connection as the new connection is being negotiated.

Soft handover is when a connection is first negotiated with the destination tower before breaking the connection with the original tower ensuring the handover process is executed without any break in connection. This type of handover requires a particular architecture that allows multiple towers to communicate the same data to one mobile at the same time.

Out of the three WAN technologies covered, only WCDMA can support soft handover [3] as both the current tower and destination tower can communicate with the mobile on the same frequency but different scrambling codes [15]. GSM and LTE both do not support soft handover. The reason why LTE doesn't support it even while being a later

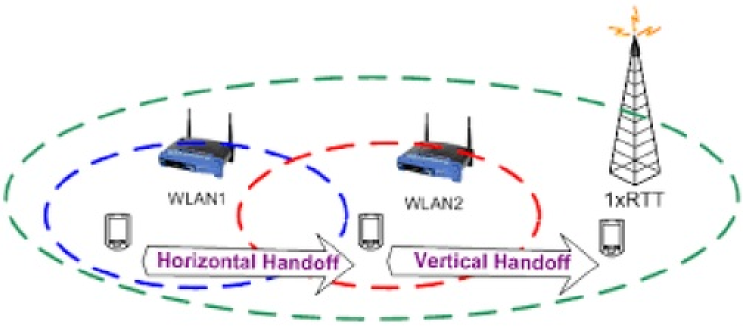

Figure 2.3: Horizontal and Vertical Handover, here called Handoff. [14]

technology is because based on OFDMA which makes it necessary for the mobile to retune to a different set of frequency subcarriers to connect to the new tower. The connection process in LTE is much faster than GSM making it nearly seamless.

Horizontal and Vertical Handover

Horizontal handover is the label given to instances of handover when the current network and the destination network are of the same type, either WAN to WAN or LAN to LAN [13].

Vertical handover occurs when the source access point is a LAN network and the destination is a WAN network or vice versa. [16].

Cost of Handover

The time it takes for handover to occur is highly variable depending on which network is handover over to which and if it's even properly implemented. Horizontal handover from an LTE tower to another LTE tower can mean a break in connection for around 1 second. This break in connection will often not disrupt communications as missing packets of data are able to be re-sent and is an example of low-cost handover.

Vertical handover, however, requires a more time as it requires renegotiating for a new IP address, this is an example of high-cost handover. The time it takes for this handover to complete depends highly on the quality of the service being connected to, resulting in slower reconnection times when connecting to a slow Wi-Fi access point. In addition packet recovery will not be possible due to the new IP address. Any download or streaming service will fail, requiring the application that initiated the download to continue only when reconnected to the internet. Badly written applications may have to restart the download from the beginning while applications such as WhatsApp may decide to drop a voice call before the reconnection has occurred.

While the general idea that horizontal handover is low cost and vertical handover is high cost, there are still a number of complexities that make the true cost of handover

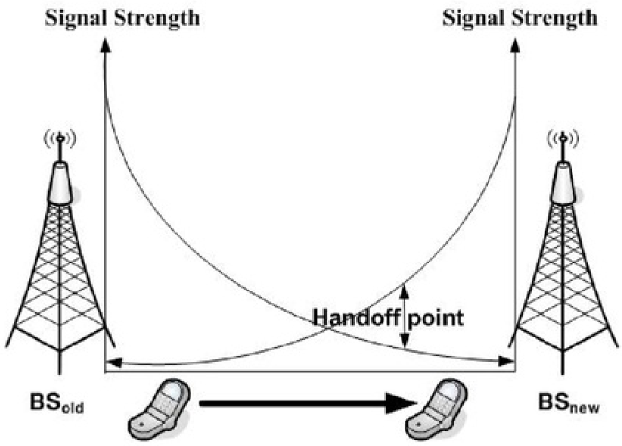

Figure 2.4: A Standard non-predictive handover algorithm. [21]

difficult to quantify. For instance handover from 4G to 3G whilst in the middle of a download is low cost. Handover from 3G to 4G is simply not possible whilst in the middle of a download requiring the data stream to stop completely before it can resume [10], similar to what occurs during handover from 4G to Wi-Fi. This means that while handover from 4G to 3G is low cost, handover from 3G to 4G is high cost simply due to the fact that the feature isn't implemented in most cases.

2.3 Algorithms Governing Handover

Whether a mobile device undergoes handover or not depends on the algorithm it's using. The algorithms task is to decide on the best network state of the phone, where the simplest case it will only look to handover to the current best network, up to more complex analysis on the user's activities in order to know the best network now and predict the best state in the near future. It in important to note that for Android devices the handover algorithm is vendor specific with each vendor having their own implementation of which is not usually publicly accessible. [11]

2.3.1 Greedy Handover Algorithm

The simplest and likely the most widely used handover algorithm throughout mobile devices is the Greedy algorithm. This algorithm knows only of the current state of the available networks without any memory of the previous state or any interest in the future. Using a variety of measurements, it then decides on which network is best and initiates handover should the current network not be the best and the better network is beyond a

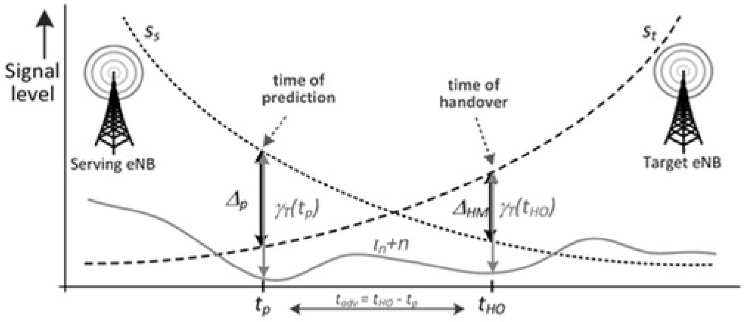

Figure 2.5: A Standard predictive handover algorithm. [18]

predefined threshold. [22]

2.3.2 Predictive Handover Algorithm

The predictive handover algorithm extends the functionality of the greedy handover algorithm by caching the previously recorded values allowing the algorithm to be aware of current trends. By looking at these trends the future state of the network can be predicted. [18]

2.3.3 Location Based Handover Algorithm

Location based algorithms extend on the predictive handover algorithm by also collecting GPS data if available. The location data can then be used to estimate the physical speed of the phone allowing better approximations into the near future as fast moving users will experience faster rates of decay than slower users. [12] This data can also be cached such that areas that are commonly travelled by user will be known by the algorithm and once near or travelling towards a cached location again, the data collected previously can then be used to calculate the best outcome.

2.3.4 Proposal of an Improved Location Based Technique

By taking advantage of modern day smartphones, it is possible to improve on the location based handover algorithm. Surveying surrounding areas in an automated fashion and storing the measured results, adds a new source of data into the decision-making process.

Given more accurate GPS systems, higher processing capabilities, more memory and cheap high-speed internet access, it may be possible to develop a service where cached results and processed into a model of every network in the local area.

Depending on the complexity of computing such a model or if enough data can be collected this may be extended to be an online service. All collected data can be uploaded to a server which could then build the model. Excluding any privacy issues, a service such

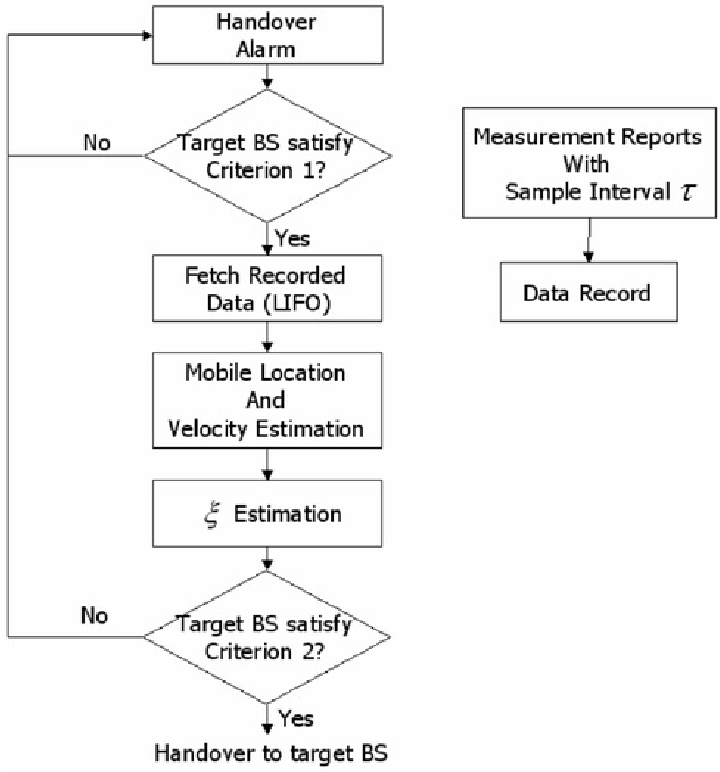

Figure 2.6: A Standard location based handover algorithm. [12]

as this would benefit the user through a more detailed model and it wouldn't require the user to have already travelled through an area to benefit from its potential improvements.

Chapter 3

Development of the Network Mapping System

In order to collect, store and analyse the data efficiently a network mapping is needed. Simply named Signal Mapper, it would compromise of two primary components, an Android application for collecting all the relevant data and a Web application which will store the data and allow for an easy platform to use for the latter part of this project, data analysis. The overall workflow of the system is that multiple android devices with the application installed can be used to collect data then after all desired measurements have been made the data can then be uploaded to the Web application for storage in the database. The user can then view the data, download specific sets for analysis and quickly view useful plots within Google Maps.

3.1 Development Process

As one of the goals of this system is to explore the challenges faced when implementing the proposed handover technique, all of the specifications and requirements must evolve as the system progresses and initial data is collected. This limits the ability to predict the outcomes or even the final set of requirements. As such, this system will be developed using a Prototype model whereupon the successful completion of enough components to collect data, data will be collected and then analysed to test the effectiveness of both components. Improvements can then be decided upon and then implemented, returning to the testing step. The primary emphasis is not on a polished bug-free version of the system but rather speedy development to fit the time constraint and for complete functionality.

3.1.1 Constraints

The development of this system is subject to a couple initial constraints which had influenced the development of the system.

- There exists a time constraint of 12 weeks for both development and the analysis stages of this project.
- The mobile component of the system must be developed on an Android device due to hardware accessibility.
- The mobile can only be polling 3g or 4g at any one time. Either one of them plus Wifi is possible.
- Only the Optus network can be surveyed due to limited access to SIM cards and the fact only one can be used at once.

3.1.2 Requirements

As touched on before, the system requires evolved during the course of development. The final version of the system requirements are listed and briefly described in Appendix A, tables A.1 and A.2.

3.2 Android Application Specification

The Android platform provides many useful services allowing a developer to retrieve and manage data from all of the mobiles sensors, even at a relatively low level. The application serves as the primary tool used in collecting data and is designed so such that it's easy and intuitive to use, speeding up the time it takes to collect data and minimizing the chances of user error while also providing two main modes allowing the user to without effort collect a huge amount of data with automatic mapping or collect less but more detailed and specific data with the manual mapping mode.

Android applications are programmed primarily in Java with the user interface specified with XML files. Along with the expansive Android SDK providing access to the mobiles sensors it allows most of the development time to be focused developing a solution without needing to create any supporting architecture. That being said, applications can vary greatly in complexity resulting in many components that require partial reinventing to achieve the specific goal. This is more analogous to having the wheels and an engine but without the axles and drive shaft.

The primary goal of the Android application is to seamlessly collect Wi-Fi and Mobile network data. Once the data has been collected, it will be uploaded to the Web application to be processed and analysed.

3.2.1 Usage and Use Cases

The application is designed around a particular workflow. The user will first choose one of the two collection modes, provide a name or tag for this particular dataset then undergo sampling the networks in the local area. Once data collection has been finished, the data

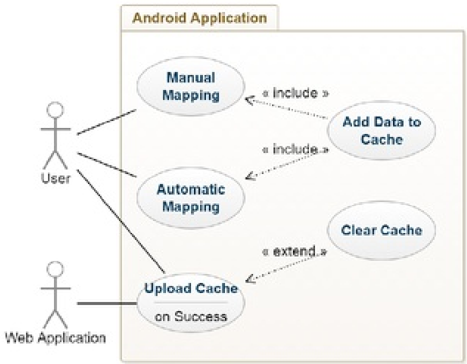

Figure 3.1: Use Case Diagram for the Android Application.

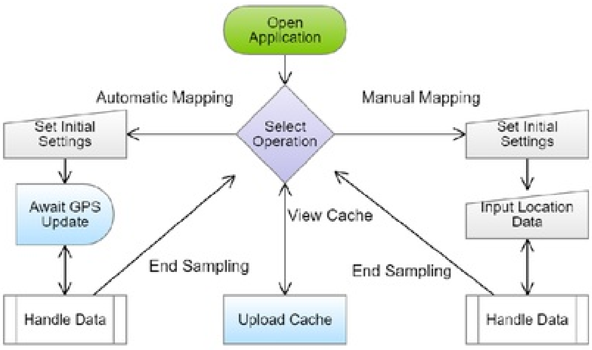

Figure 3.2: Flow Chart for Android Application.

can be observed with some initial statistics and uploaded to the web application. Upon a successful upload, the cache will be cleared in order to preserve memory.

The particular use case for the application could vary, however, it revolves around the concept of needing to understand the layout of wireless signal strength over a specific area. Some examples of the variety of use cases is a prospective new home buyer checking to see if the 4G signal in the house is acceptable, a university looking to optimise the placement of Wi-Fi access points or even a final year engineering student searching for potential improvements in mobile handover technologies.

Manual Mapping

The manual mapping sub-process sacrifices automation by ignoring GPS data for higher quality data. Manual Mapping allows the user to select their location from a display map (provided by Google Maps) providing more accurate and detailed measurements. The primary idea is if a small area needs to be mapped in detail or the GPS reception is horrible then the user can still collect data. Depending on the intended usage of the data, while this sort of mapping results in fewer data, it would prove to be more useful than the data collected automatically as it allows for highly controlled experiments.

Pros: Accurate, reliable and highly detailed data.

Cons: Tedious and requires manual labour.

Automated Mapping

The automated mapping sub-process sacrifices quality of data for sheer quantity relying on the accuracy of the GPS to map the data to their respective locations. This allows the user to relax, go about their day to day life as data is recorded or provides an easy way to poll a large area while going for a nice stroll. Quality is only sacrificed in two ways, both mitigable depending on the exact situation. For example, while going about the day's business in the area, the mobile may be kept in a pocket or held in an inconsistent way damaging the quality of the measurements. This can be fixed should the mobile be mounted or held in a particular but consistent way. The second way the data could lose quality is that it's dependent on what could be fallible GPS results caused by bad reception making indoor data practically useless, yet of high quality when mapping an open area.

Pros: Low quality data mitigated by sheer numbers and great for large open areas.

Cons: Potentially inconsistent and unreliable data.

Data Caching and Upload

As sampling potentially weak and unreliable network connections make it difficult to upload data the instant it's gathered it is best to instead store the collected data locally in a cache until the user is in a position to upload it in chucks. Due to potentially large amounts of data stored in the cache, the user may also prefer to wait until a reliable unmetered network is available before commencing the upload. The upload will transfer the data in chunks in order to reduce the chance of a failure. Single chunks can also be automatically uploaded during connection given a suitable connection and activated in the settings. Upon successfully uploading the data the local cache will be cleared in order prevent a build up in memory usage. This serves as the last action the user undertakes before either repeating the application's work flow or moving to the Web application to view and analyse the new data.

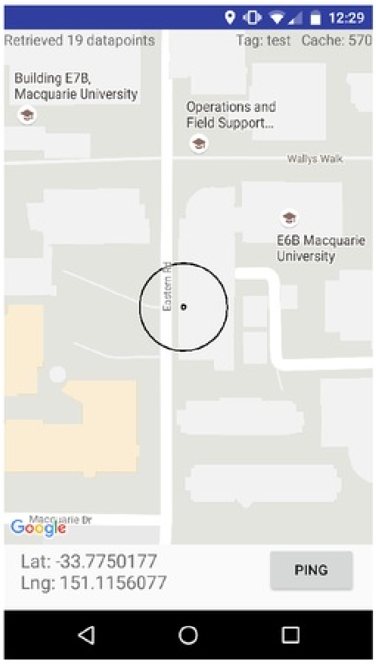

Figure 3.3: Example of network polling screen where all data is collected. Currently set to Manual mode.

3.2.2 User Interface

The User Interface aims for a simple and intuitive layout using an Android standard navigation and layouts organised by different levels of progress in the workflow. Furthermore, the actual collection of data is either automatic or is collected at the touch of a button meaning the data is collected from different sources and processed while being abstracted away from the user's experience. Other than a quick initial setup or selecting a location while undergoing manual mapping, everything is simply the touch of a single button.

Making the application very user-friendly minimises the risk of misclicks and user fatigue resulting in lost or unreliable data. It also serves to make the application look more outstanding when available for public use. Navigation throughout the application utilises a sidebar with a link to each screen minus the data collection screen which is only accessible via the Network Polling setup Screen. Screenshots of each screen can be found in the Appendix B.

Network Polling Setup Screen

This screen serves as the starting point for each survey. It provides the user with the ability to select the collection mode, a minimum GPS accuracy (for Automatic mode) and allows the user to select a previously used tag or enter a new one. This list of tags also has the number of data points within that tag to give the user an idea on how much data has been collected and allows them to know when recently collected data has been ingested.

Data Collection Screen

The data collection screen is what the user has open while conducting a survey. The screen consists mostly of a view of Google Maps. Below the view the user's current longitude and latitude are displayed and to the right will be a button which either polls all networks if in manual mode or acts as a pause/resume button when in automatic mode.

Further details are present with 2 circles overlaid on the maps view, one small circle of constant size to accurately display what the mobile thinks is the user's location and another also centred on the same location however with a varying radius. The radius depicts the GPS accuracy, indicating that your actual position is within the larger circle with a probability of 68%.

At the top of the screen over the maps the user can see the number of data points most recently collected, how many data points are in the cache, what the selected tag is and should it be active, some text to indicate when a chunk of data is being uploaded and its result. A failed chunk upload will produce a menu box suggesting the user can for this survey only disable automatic uploading.

Cache Screen

The cache screen provides a number of functions relating to cache management. It displays in large numbers the number of data points within the cache as well as an option to clear the cache should bad data be accidentally collected. The clear cache function is only run after a confirmation is provided by the user. Three more buttons are present, the first two send the data to the Web application, the latter of which sends them in chunks. The third button allows the user to preview the cached data, which upon activation the data will be printed below the button.

Settings Screen

The settings screen provides access to three settings along with a number of test functions. The three available settings are to change the chunk size for uploading data, to change the URL of the Web Application and toggle Auto Chunk upload. These options are placed in this window as they should seldom be changed and the defaults function adequately.

There also exists 6 test functions, each with their own button. The results are printed below similar to the cache preview button in the Cache screen. Two buttons test sending sample JSON data to the Web application which can server to test the mobiles internet connection, the correctness of the web application URL and also functionality the REST API. The four following buttons prints out all available Mobile data, Wi-Fi data, Last known location data and also all cache data. The final button displays the same data as the preview cache button in the Cache screen, however, makes the UI seem more complete.

About Screen

The about screen serves to briefly inform the user about the application and its purpose.

3.2.3 Components

The Android application is split into a number of subcomponents which provide all of the individual functions the application needs to fulfil its requirements. Their purposes range from data collection to storage and management.

Location Manager

The Location manager is the application's connection to anything GPS related. It uses Androids Location Services to subscribe to regular updates from the GPS and stores the updated data so it can easily be gathered. It is the source of the longitude, latitude and accuracy fields of the data and provides a function to easily get the last known data as well as another function that forces an update for more current data.

In addition to the location data, it also collects the phones speed, altitude and bearing. While potentially less useful for the purpose of this project, it comes with the location data and can mean the data can be used to study topographical features or how signal data is affected when going at certain speeds.

This component follows a singleton design pattern to avoid multiple instances unnecessarily subscribing to receive updates and ensure the same data is accessible everywhere. It is important to note that the accuracy value provided by Android is given in meters and represents the 68% confidence interval meaning the provided value has a 32% chance of being less accurate.

Network Manager

The Network Manger provides access to all signal measurements for all the different available networks. It also contains functions to request Android to connect to a specific network. It connects to Androids Wi-Fi services for details about Wi-Fi networks and the Telephony services for details about the available mobile networks.

It provides two primary functions for collecting the data, one for the Wi-Fi data and the other for data on the currently connected mobile network. They both then return relevant filtered information about their networks formatted in an easily accessible way. As Android provides the ability to simultaneously retrieve information from all access points on a particular network, these functions return a list of these values, each to be made into an individual Data Point and stored in the cache.

Web Adapter

The web adapter component manages the connection between the Android application and the Web application via HTTP. The primary function that it needed to be performed is to asynchronously upload a chunk of data in a JSON format to the Web Application's REST API. This is done by opening a connection to the Web Application and sending it an HTTP POST with the attached data; the application then waits for a response indicating the success or failure of the communication.

The Web Adapter accepts Data in a number of different formats to make using it convenient, it then reformats the provided data into the JSON data and sends it upon request. It is designed as a Singleton to always use the one established connection and managing that, rather than creating and mismanaging many connections. Retrieving the single instance is statically available and all communications are managed asynchronously.

The Web Adapter also serves a secondary function of testing the connection to the Web application as well as getting useful information such as a list of all tags along with their current data point count. This allows the user to confirm data has been uploaded successfully and easily select from previously used tags to continue that particular survey.

Cache

The Cache acts as a temporary form of persistent data storage statically available from all parts of the application. All data that is collected when stored in the cache is kept in Memory. The Cache also provides a convenience function that passes all the data to the Web Adapter for uploading. Once the upload is a success, it will clear the cache to free up memory.

Should the application be closed while some data has not yet been sent, it will then pack all the data into a JSON format and save it using Androids Shared Preferences Service.This service is a lightweight key-value based system that saves the data in an XML file on the phone so it can be loaded later. When the application has been started up again, if any data was saved it will be reloaded into memory.

The primary reason why a Cache is needed in this system as opposed to uploading the data as it's collected as those areas being surveyed may contain areas of very weak signal strength resulting in an unreliable connection making it impossible to map such areas. The secondary reason is that uploading thousands of data points individually will result in an excessive amount of overhead, but grouping them together into chunks the upload speeds are considerably improved. Should data not be temporally be stored, a failed attempt at uploading the data means it's lost.

Data Point

This component contains the class that acts as a container for a single measurement of all the data. This class allows the creation of new Data Points while ensuring the data is valid and managing defaults. It also allows the easy conversion of all the data into a format useful for making JSON files.

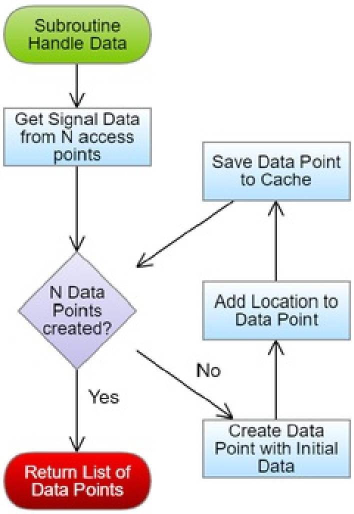

Figure 3.4: Flow Chart describing the generation of a Data Point.

This component also contains the statically available function which creates a Data Point by polling all the other sensory components of the system then adding it to the cache.

3.3 Web Application Specification

The Web application provides access to all the collected data as well as a number of useful tools to search and filter the data for download and further analysis or to dynamically generate visualisations over a Google Maps panel.

It is programmed primarily in Python using the Bottle framework allowing for a rapid development of this lightweight application. While the server side code is executed in python, the client side is coded primarily in HTML and CSS along with some javascript. Bootstrap is used in order to aid in rapidly creating a clean, well-designed user interface making the application more intuitive to use. It is hosted with PythonAnywhere which provides access to a MySQL database, a URL to access the application as well as support for executing schedules programs to ingest or backup data.

3.3.1 Usage and Use Cases

As the Web Application is part of the overall system, the use cases are similar to the Android Application in the sense that all use cases revolve around the need to understand the layout of wireless signal strength over a specific area. The application, however, can serve two different groups of users, those with technical skill and those without. The lay

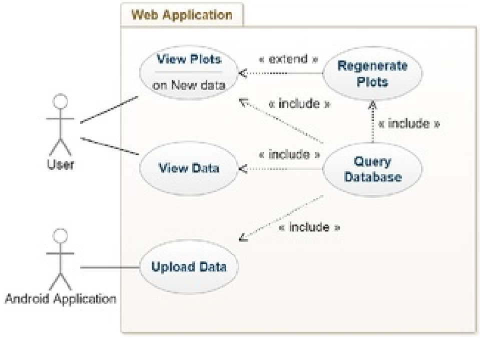

Figure 3.5: Use Case Diagram for the Web Application.

user would use the Android application in the same way a technical user will, however once up to the data analysis stage, the lay user would be able to use pre-made scripts to easily visualise the data. The technical user will find a use in these visualisations, however, in addition, can create their own scripts or download the data to analyse the data with themselves.

To make the distinction clear between the two types of users, while the difference in technical skills plays a part this does not prevent a technical user from just the Maps with the pre-made scripts. The true difference is in the original intention. As covered in the Android applications usage section, a new home buyer would only need the generated visualisations to determine if the 4G surrounding the house is suitable. The university wanting optimised layout of access points would benefit from the visualisations but will necessarily require some more detailed surveys in some areas and would naturally have a more complex wireless network. This would require more detailed analysis not provided by this system.

3.3.2 User Interface

The User Interface will be kept simple and intuitive and consist of only three main pages: A Search page that serves as a gateway into the raw data described in the Data Search component and the Maps page which acts as the main page of the Dynamic Data Visualization component and an Editor page which provides the tools for creating scripts to be run on the Maps page. For the purpose of this project, a login page will not be needed although it will need to be included in any public release in order to protect user's privacy.

Through the use of Bootstrap, creating a sleek and professional template is simple allowing the focus of the UI development to be in the creation of each page. Screenshots of each page can be found in Appendix B.

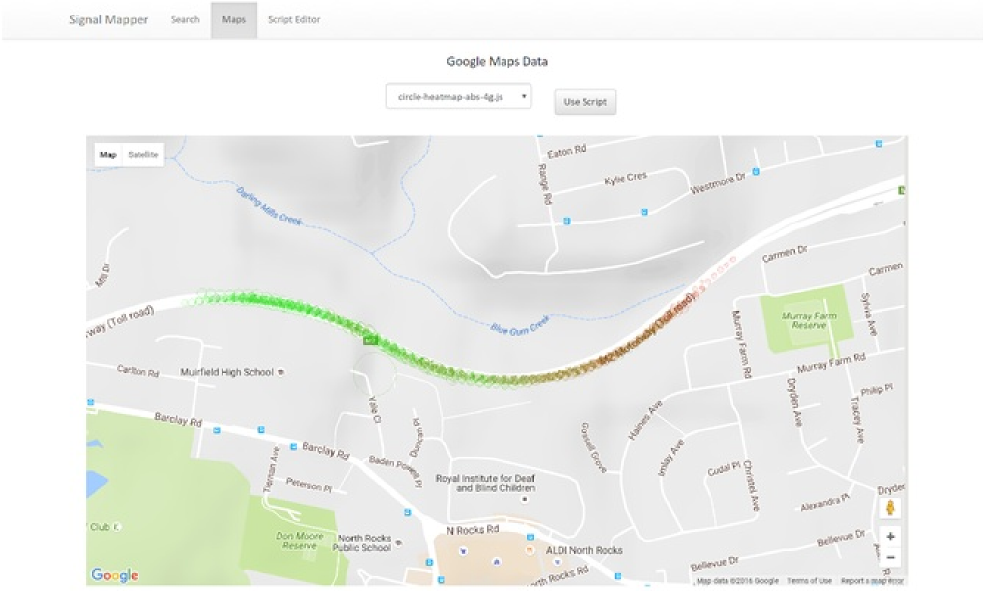

Figure 3.6: Maps page displaying results from a single 4g tower along the M2.

Home Page

This page serves to contain general information about the project similar to the about page in the Android application. It also displays the total number of data points in the database.

Search Page

The search page allows the user to browse the data within the database. It contains some filtering options such as allowing the user to select a specific Tag and/or SSID. All selected data is displayed in a larger column to the right-hand side, while the left column contains a number of lists, listing all the Tags, SSID's, BSSID's, CID's and network types along with the number of data points with that field.

The filtered data is remembered by the application so it can be used on the Maps page to visualise the data.

Maps Page

The Maps page acts as a quick and intuitive way of viewing the data in the database. It consists primarily of an instance of Google Maps along with all its functionality. In addition, the user has a drop-down box where they can select a script that can be used in processing the data which is then output into the Map. The ability to create or modify scripts allow this to be quite a powerful tool however, there is a memory limit that will limit the amount of objects that can be drawn on the map depending on the browser being used thus making it suitable for initial analysis.

Script Editor Page

The script editor page consists of an editor tuned with Javascript highlighting as well as the ability to save the script under a particular name and load other scripts to be modified.

3.3.3 Components

The Web application also has a number of sub-components each serving to manage a particular aspect of the system. While it has fewer components than the Android application the Web application is still a crucial and large part of the system.

Database Adapter

One of the major components in the web application is the database adapter. It acts as an adapter to allow Python to send SQL statements to the database and manage the responses. It also has a container class for a Data Point implementing similar functions to the Android application's Data Point. Functions such as validating data and to a lesser extent formatting it.

REST API

The REST API acts as the other end of the connection from the Android application's Web Adapter component. It receives chunks of data in the form of JSON files, decodes them into the Web Interface's implementation of a Data Point and uses the database adapter to submit the new data into the database. Upon completion, it then responds with either a success or failure. Failure responses are more detailed specifying which data points had the issue in case corrupt data made it through the verification on the Android side and isn't able to be inserted into the database. On top of this, it provides access to the database in order to retrieve filtered data in a JSON or CSV format to be used with third party applications.

Data Search and Selection

This component consists of the search page containing a number of options allowing the user to filter and select the data they wish to visualise. Upon each modification of any of the filters, the results will be listed in the right-hand column so the user can quickly determine if their selected parameters match their expected output. It will also contain two buttons to download the data, either as a CSV file or a JSON file and a third button which linking the user to the Maps page to visualise the selected data.

Here the user interface requires a bit more care to keep it user-friendly as having every search option will make the page highly cluttered. In order for this component to get the data, it needs to decode the user's input into a format into data the Database adapter can parse. Once the database adapter responds with the result, it is displayed to the user.

Dynamic Data Visualization

Dynamic Data Visualization consists of two components of the system however it covers a wide range of potential functions depending on the desired of the user. It provides the user with two interfaces, one for each sub-component.

The first subcomponent is an embedded Google Maps panel allowing the user the easily visualise the data selected in the search page from the Data Search Component. The user can then select an appropriate script to customise how the data is exactly represented and act as a last filter over the data. The embedded Maps panel comes with all the capabilities of a standard Google maps screen providing the user with more visualisation options.

The second sub-component is a script editor allowing the user to modify or create new scripts to be run as the Google Maps panel is loaded. The Ace web text editor is used along with its JavaScript code colouring and completion module is used as the primary script editor. This allows the user to take advantage of the full Google Maps API.

User created scripts are run client side only and have API access by using AJAX. Due to the limitations of most browsers, however, it is difficult to load more than 10,000 objects in the map depending highly on memory management however through the use of KML layers.

3.3.4 Data Validation

While high-quality development and testing should avoid the need for a second layer of verification, the nature of the Android operating system it is run on many different brands of phone relying on each brand to create a proper implementation of the adapter between Androids services and the hardware sensors. While uncommon among popular devices, not all devices can be tested on and particular devices having a bug due to an error in the vendor's implementation. One such of these known bugs is related to a function required by the Android application's Network Manager component [6]. While tests have not revealed any issues, the bug only appears on some devices.

3.4 Testing And Quality Assurance

In order to ensure the quality of the data, assuming no human factors involved its collection, it is important to ensure a high degree of live testing is performed and the code is well documented for peer review.

JavaDoc will be used extensively throughout the Android application as well as inline comments for more complex or messy tasks. This will enable reviewers and those who may want to modify the application to understand the code but also spot any inconsistencies between the documentation and the code meaning either a mistype in the documentation or the code is performing the wrong task resulting in potentially unreliable data.

Both the Location Manager and Network Manager are tested by collecting live data and displaying it, then comparing it to the physical surroundings to ensure it and the data are consistent. This includes going to a specific longitude and latitude and ensuring the retrieved data is accurate to within the measured accuracy at least 68% of the time.

The Web Adapter requires less physical effort and involves sending different sets of test data to the Web application and retrieving the expected result. This, however, works hand in hand with the Web Adapter's REST API and it is entirely possible that an error could exist in both requiring testing of also the Database Adapter in the Web application and visual inspection of the MySQL database.

Due to the prototype development approach, time constraints and the fact that the system consists of two smaller parts automated testing isn't used. The end result will not be a polished bug-free application yet will still be completely functional hence the emphasis on live testing, as a result data can be collected at an earlier stage in development.

Chapter 4

Data Collection

Data Collection consisted of using the system defined earlier over a range on different areas and situations to cover as many different cases as possible increasing the chances of discovering interesting findings. Data is collected both spatially and temporally in order to experiment with not only how the networks change throughout different areas, but how it also changes for a stationary device under different conditions.

The quality of data is also observed thoroughly through the controlling of particular variables and repeated surveys. Repeated surveys of the same or very similar situations also serve to show how the data naturally varies thus providing a way of differentiating between random noise and interesting phenomena.

The exact details of the data being collected, why each piece of data is important and how it's collected is also an important component to this section as it directly related to how and what data would be collected by a mobile device running an implementation of the improved handover technique.

4.1 Collected Data

The primary measures being collected by the mobile is signal strength measured in decibels (dBm), longitude and latitude as well as extra data about the specific access point, a timestamp and metadata from the GPS such as accuracy and speed . In total 14 fields are collected for each data point as seen in table 4.1 plus a unique identifier (primary key) added when inserted into the database.

There are numerous ways of measuring the quality of a wireless network connection such as timing the time it takes to ping a server, timing how long it takes to download a file, counting the number of failed connections over a period of time and measuring the signal strength which correlates to how 'loud' the connection is. They all measure fundamentally different aspects of a network and can be used to make two primary measurements, quality of signal and quality of service. For the best results, they all should be used if possible with only the latter indicating the quality of signal and the others indicating the quality of service.

Name	Data Type
Id	SERIAL PRIMARY KEY
Timestamp	DATETIME
Longitude	DOUBLE
Latitude	DOUBLE
Accuracy	DOUBLE
Bearing	DOUBLE
Speed	DOUBLE
Network type	INT
Network strength	INT
SSID	TEXT
BSSID	TEXT
CID	TEXT
Tag	TEXT

Table 4.1: Fields Stored in the MySQL database

These measurements all have their drawbacks as well. Measuring signal strength is reliable and is easy to measure, in particular, considering this can be measured over multiple access points at one time. The downside is that it provides no reference to the quality of the available server. For example, two Wi-Fi networks are available to the user, one with high signal strength and one with medium signal strength, both enough to communicate reliably on. It may be the case that the access point with better signal strength is connected to the internet via ADSL while the access point with medium signal strength is connected with Fibre Optic. In such a case only measuring signal strength does not provide the bigger picture.

Pinging a server and measuring it's response time multiple times and averaging the time result provides some information on how busy the access point is. Its downside, however, is that it is difficult to distinguish if it is the server that may be busy or the access point. Such measures also change based on usage making it very difficult to serve as a control, in particular, if the use case is for the mobile to take these measurements in the background as part of an implementation of the handover technique. The user may return later that day and what was once a busy unreliable network may be quiet and have the best quality of service. This measure also has the downside that it can only be run on the access point that it's currently connected to.

A file download serves to indicate the potential maximum download speeds providing the necessary information to know the better network in the example used previously. This can also be extended to also uploading a file to measure upload speeds, yet it also faces similar issues that pinging a server has. The mobile cannot know if a slow download is due to the network being slow or the server the file is downloaded from, it can only perform this with one access point at a time and will usually take longer to test than the pings will.

The final measure for quality of service is to count the number of failures during a download or while streaming data. This serves to reveal how variable the network quality of service is. While this can be implemented in the same way as the file download, in order to conserve network usage and focus only on keeping an open data stream, a slow download would prove to be useful. This has the downside of taking time, can be done only on one access point at a time and is also highly susceptible to local traffic.

For the reasons stated measuring signal strength only serves to be the most feasible solution given time constraints on data collection and the difficulty of ensuring the quality of service measures are accurately controlled resulting in what may just be noise. This argument is only strengthened considering at any one point in a network dense area such as Macquarie the number of access points can exceed 100. To connect to enough access points individually to measure the quality of service for a representative sample is not feasible.

4.1.1 Hardware and Network Provider

The Mobile used for this experiment is a D820 Nexus 5 running Android 6.0.1 and with an IMEI of 359250054210917. The only mobile network used for testing is the YES OPTUS network. Different mobiles and models will likely produce different results depending on the inbuilt transceiver, in the case of this experiment the transceiver used by the Nexus 5 is the Qualcomm WTR1605L.

4.2 Database and Formatting

To store the collected data a MySQL database hosted by PythonAnywhere is used. Only one table as described in table 4.1 is needed to store the data each field and their function is listed below. A database is deemed more suitable to store the data as opposed to using a spreadsheet or a .csv file as it is easily scalable to large sizes, easily modifiable, well supported and allows the usage of SQL statements which are well optimised.

Id A Unique Identifier for each data point, allowing the management of each individual data point.

Timestamp The exact time of the creation of the data point.

Longitude Longitude component of the Users position as retrieved from the devices GPS.

Latitude Latitude component of the Users position as retrieved from the devices GPS.

Accuracy The radius of a circle depicting the 68% confidence area for the users position. The center of which is the given longitude and latitude. No data or manual polling results in a value of 0.0. The Accuracy is important in determining the validity of the GPS data where a higher value results in less accurate speeds, bearings and altitude in addition to positional data.

Bearing The Bearing is the horizontal direction of travel of the mobile device measured in degrees with a range from (0.0-360.0]. 0.0 serves as no data.

Speed The Speed is how fast the device is moving measured in meters per second. 0.0 indicates no value.

Network type An integer representing each network type. 0 Indicating Unknown, 1 for Wi-Fi, 2,3 and 4 for 2g,3g and 4g networks respectively.

Network strength An Integer value representing signal strength as measured in dBm.

SSID The identity of a particular Wi-Fi network which may span over one or more access points.

BSSID The identity of a particular Wi-Fi access point. The BSSID is also known as the MAC address of a Wi-Fi access point.

CID The identity of a particular Mobile network tower. It consists of a number of available values depending on the network generation delimited by a semicolon. For 4g this consists of the Mobile country code (Mcc), Mobile Network Code (Mnc), Local Area Code (Lac), Cell ID (CID), Personal Communications Service (Psc). For 4g it consists of the Mcc, Mnc, Cid, Physical ID (Pid) and the Type Allocation Code (Tac). 2g consists of Mcc, Mnc, Lac and the Cid.

Tag Some identifying text to aid in the filtering of data in order to differentiate particular areas or experiments.

Each field minus the speed, bearing and altitude plays a key role in identifying each data point or is the measure being collected itself. Speed, bearing and altitude are provided by the GPS in addition to location and accuracy and so collection came at little cost. In addition to collecting the above data, it is important to note that only one mobile is used in the collecting of data. Should any further mobiles be used and any other people undergo surveys, three more fields should be added to this table.

IMEI A 15 digit unique Identifier for each mobile phone. Modern phones tend to have an IMEI/SV (Software Verification) which consists of 16 digits. The First 8 digits of the IMEI and IMEI/SV consits of a Type Allocation Code (TAC) unique to each wireless device. The next 6 digits are manufacturer defined used to uniquely identify each individual mobile of the particular make. The final digit for the IMEI is a checksum digit, the final two digits of the IMEI/SV is the Software Verification Number. [4]

Service Provider An identifier for the particular mobile network being used. In the case for Australia, the three network providers with mobile infrastructure are Optus, Telstra and Vodafone. All other service providers would use one of these networks, for instance a user with Amaysim would have the Optus network in this field.

UserName A unique identifier for each user conducting surveys. For a larger system this is suggested to be a numeric identifier yet a string will suffice for smaller systems.

As all data is public there is little need for security however, to prevent the malicious deletion of data, all access to the database must be done via the Web Application or directly from the host server. The host server is inaccessible to the public and the Web application doesn't contain any delete function. In addition, all data being input is sanitised to prevent SQL injection or Cross-site scripting (XSS) attacks.

4.3 Expectations and Hypothesis

In exploring the factors that affect handover and how they can be used to improve location based handover it proved difficult to predict what could be found in the data. In addition, it is difficult to determine the quality of the collected data with little data of a similar enough sort to compare it to. As a result, all development followed a Prototyping workflow to continuously improve in the correct direction based on collected data.

Aside from how difficult to predict the results would reveal it is expected that certain situations would influence network strength heavily. Some examples would be the topography of the local area, the location of buildings and time of day, more specifically busy periods verses non-busy periods. It is important to explore the potential effects of such situations and how it would show up in the data if the prediction proves correct.

While many factors would effect network coverage, only those of which the mobile can easily predict can prove useful, for instance, the weather may have an effect on network coverage, while the weather is predictable in the short term the resulting effect may chaotic in nature. Another example would be network usage during daytime verses night time, where the result will differ per location and subjected to special occasions however a general pattern may emerge that can result in more accurate predictions.

4.3.1 Buildings as Signal Obstructions

The primarily explored situation would be how buildings affect network coverage in a general way and if mapping particular areas would prove useful in predicting their effects and adjusting the network state accordingly. The expectation is that a path travelling perpendicular to the direction of three access points, two of which are blocked by buildings in some areas as depicted in figure 4.1.

It is clear in figure 4.1 that there is one large building that affects only tower 1, then a series of smaller buildings affecting both tower 1 and 2. Tower 3 remains unobstructed however distant from the starting position of 0. Should data such as this or similar be found without there being too much noise it could prove highly useful to the proposed handover technique.

An example of how it could be useful is assuming the mobile started connected to tower 1, starting at position 0 and moving towards the right. The algorithm would notice the sudden drop in signal at position 15. It would notice that tower 1 would return to

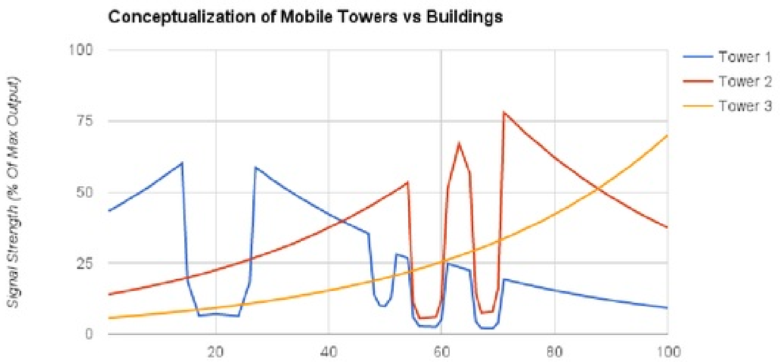

Figure 4.1: An example of what the signal strength along a path may look like for 3 access points that are obstructed by buildings.

strength however with reducing signal until red takes over at position 42. This would provide two handover techniques to use depending on the cost of undergoing handover.

The first assuming a low cost of handover, the best option would be to undergo handover at each intersection of tower 1 and tower 2 until position 42 where it would continue undergoing handover to stay on the maximum path. The second case assumes a high handover cost where a more stable tower with less signal strength would prove better than unstable to high strength towers. In this case handover would occur only at the first intersection of tower 1 and 2 and then again to tower 3 at the first signal drop from tower 2.

In contrast, a standard predictive algorithm would first undergo handover at the first intersection of tower 1 and 2. It would the connected to tower 2 for which if the cost of handover was low would prove to be inefficient. It would then upon facing the first intersection between towers 2 and 3 switches to tower 3 and switch back to tower 2 soon after before switching back to tower 3 until the end of the trip. Should the cost of handover be high, the bouncing between towers 2 and 3 would prove to be the inefficient option, thus the improved algorithm utilising the figure 4.1 as a model would perform better than a standard predictive algorithm regardless of the cost of handover.

Realistically however measured signal strengths may contain a high level of variance, building may not completely block signals as described or a slight change of wind may make the model lacking leading to incorrect decisions resulting in the simple predictive algorithm performing better in general. As such by looking at these factors, the feasibility of using such a model as a key component of an improved location-based handover algorithm can be explored.

4.4 Controls and Methods of Collection

To ensure the quality of the collected data and ensure a sufficient range of situations are surveyed two particular areas and types of collections were performed and each survey is conducted with similar conditions in order to minimise interference from unwanted sources.

Mobiles in the real world often face interference from many sources, of which many will not be a result of the surrounding environment but the actions of the user themselves. The way the user can hold the phone can mean a significant difference in measured signal strength depending on the type of phone with up to 15dBm variance across many mobiles [19]. Such a variance in just the way the mobile is being held could cause a loss of 1-2 bars of reception in LTE with each bar being 10dBm [7].

As a result of every survey, the mobile performing the data collection is always held horizontally facing up. It is also always held where possible with the tips of the fingers and at the very least never with the palm grasping the mobile. Whilst inside of vehicles the mobile is held nearest to the window and if possible kept away from metallic materials.

Even with these controls, it's expected that some of the variances in the collected data would be a result of how the mobile was handled, the aforementioned actions would reduce its impact allowing for environmental variances to have a larger impact in the retrieved signal strength.

4.4.1 Spatial Collection

The most common form of data collection is performed spatially whilst moving from one point to another. Whilst due to nature being locked into a specific direction of time there also exists a small temporal element to these surveys as specific locations are revisited.

Macquarie University

The university campus serves as a nearly ideal place for surveying signal strength as it contains a large variety of differing locations, an extensive Wi-Fi network and is partially covered by a 3g and 4g black spot.

The campus contains numerous areas at different levels of building density, for instance, areas closely surrounded by large buildings such as the E6A courtyard, areas with more distant buildings and nearby smaller buildings such as the areas between the campus and Macquarie centre and large fields with little to no obvious obstruction. While these fields are very open, they happen to lay partially on the black spot and many areas may be affected by the topography. This may seemingly complicate that particular scenario of what an ideal area to be used as a control, to which is does, however, it does add more scenarios which may prove useful.

Motorway 2

The Motorway 2 in Sydney connects the City to the Western suburbs, it also happens to run directly next to Macquarie University proving to be a convenient motorway to survey a much longer path yet potentially building some interesting charts when mapped by longitude. Through the repeated travel through a section of the motorway, it can serve as a basic control in order to study the amount of experience variation. As many areas are revisited it also serves to be useful for studying temporal effects such as travelling during peak hour compared to travelling late at night.

4.4.2 Temporal Collection

Temporal collection studies the surrounding networks over time in or around the same location. It's useful in studying internal mobile timing such as how often particular sensors automatically update and how networks change over a short amount of time.

Chapter 5

Data Analysis

In order to make sense of the collected data, it must be analysed in a number of different ways. In doing so a better understanding of the nature and processes of signal strength and distribution over space and time can lead to the determination of the feasibility of the proposed location based technique improving handover and thus improving the quality of service for the user.

5.1 Metadata

Over 500,000 data points had been collected during the duration of this project of which 430,000 data points were from the network dense areas around the Macquarie University campus, 65,000 data points were from the M2 motorway.

Wi-Fi made up the most commonly collected network also with around 430,000 data points, LTE made up 65,000 data points. Of the Wi-Fi networks, eduroam, Macquarie Public and Macquarie Onenet consisted of 100,000 data points each.

5.2 Methods of Data Analysis

To effectively analyse the data two programs were used for analysis, the developed web application and Tableau. The web application serves to provide quick and up to date metadata as well as some initial visualisation of the data over Google maps, Tableau is then used for more in-depth analysis and visualisation. While the Web Application search page provides useful metadata, the maps page proves to be more resourceful for visualising the data.

5.2.1 Google Maps API Scripts

Google Maps provides a simple yet powerful API for placing objects within a Maps object. Through using different scripts and selecting the desired set of data the Maps page provides quick access to the data and some initial information. The simplest of the created scripts displayed one specific dimension such as accuracy of each data point represented as the radius of a circle, however, the most used script displayed a number of useful dimensions.

The scripts beginning with "circle-heatmap-" displays a circle for each data point and coloured depending on its signal strength. The colour is interpolated from red to green, the greener the stronger the signal. The colour range depends on the selected script, one such script makes red to be the weakest value and green to be the strongest, three other scripts are created with ranges specifically for Wi-Fi, 3g and 4g. In addition, the more inaccurate the data point is the larger the circle's radius and the more transparent it becomes. This makes each circles radius clear but the more inaccurate the data point, the less of an effect its colour has on the map thus the deeper the colour on the map, the more reliable those measurements are.

5.2.2 Tableau

Tableau is an advanced data visualisation program created by Tableau Software. Once data has been imported into Tableau, it allows for rapid analysis and makes it simple to create different visualisations with an intuitive drag and drop interface. The fact that it provides in-depth analysis and makes creating visualisations quick it serves as a suitable method of analysis considering time constants.

The Maps in Tableau are not as detailed as Google Maps making it not very useful when interested in how buildings affect network strength, in particular when compared to Google's satellite view. Aside from less detailed maps, Tableau is able to handle much larger datasets and able to display data on a map in a much more varied manner thus making the two complement each other.

5.3 Results

By analysing the collected data for particular ways that it can be used to improve a location based handover algorithm, the feasibility of developing such a system can be determined. In addition to the number of situations the data could improve on the algorithm, the quality and variance of the data needs to also be analysed in depth to make sure that the algorithm can determine if a particular state in the surrounding network is the result of a specific and predictable event or just random noise.

5.3.1 Variance and Quality of Data

Wi-Fi

Variance can be best measured by analysing the same place or path temporally. Figure 5.1 is the result of leaving the mobile still in the Courtyard just outside of the campus hub for a number of minutes, polling the network approximately once per second. Here we can see that the Wi-Fi access points in blue consist of primarily straight lines and

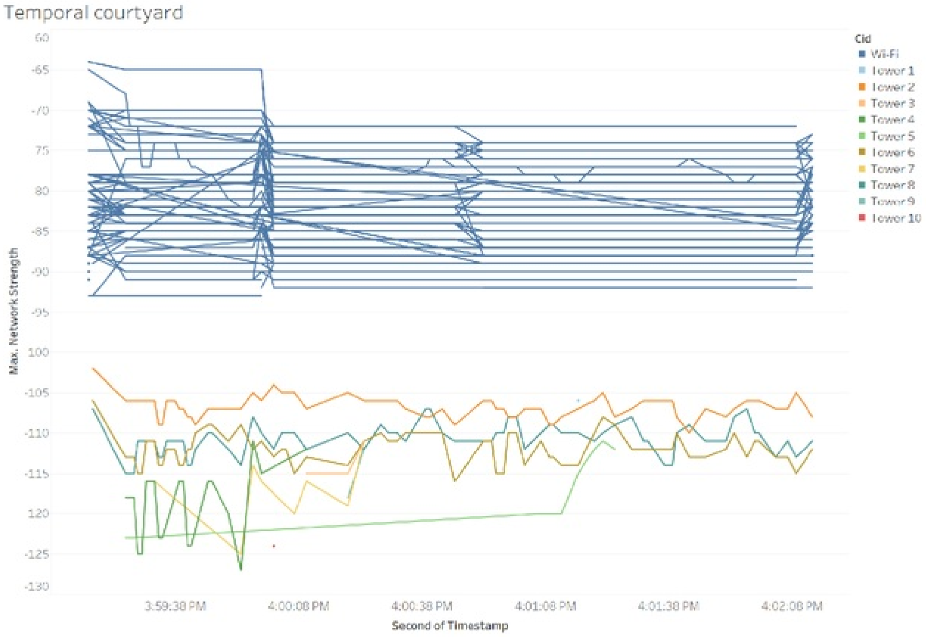

Figure 5.1: Variance in 4G and Wi-Fi signal strength over three minutes.

generally updated four times. It's unlikely that the variance in Wi-Fi happens to be very sure and more likely that the mobile doesn't scan the Wi-Fi signal strength as often. It does, however, seem that one Wi-Fi access point updates a lot more often and may be the Wi-Fi access point that the mobile is currently connected to.

This is a clear indication that Wi-Fi may not be very well suited to be used to create a model without more dedicated surveys forcing the mobile to rescan each time. To get a better idea on how much a Wi-Fi network may vary in a small area a much larger time frame is required. Figure C.1 in the appendix looks at the difference in Wi-Fi signal over a number of access points near the E6A courtyard revealing the actual Wi-Fi variation to be on average 13dBm. As the mobile has passed through the area many times and not in the exact same spot and occurred over a longer period of time, it's difficult to truly know its variance.

Mobile Data

Mobile access points are evidently rescanned more frequently than Wi-Fi due to clear variation in the signal. This is a clear indicator that surveying mobile networks are a lot more feasible with everyday mobile phones. The question then becomes how much variation is there in mobile networks and will it be small enough to distinguish clear and repeatable trends. A notable observation is that the area has poor 4G reception and that the strongest access point (the orange line, named later on as Tower 138) is likely to be the cell tower on top of the Optus headquarters towards the south.

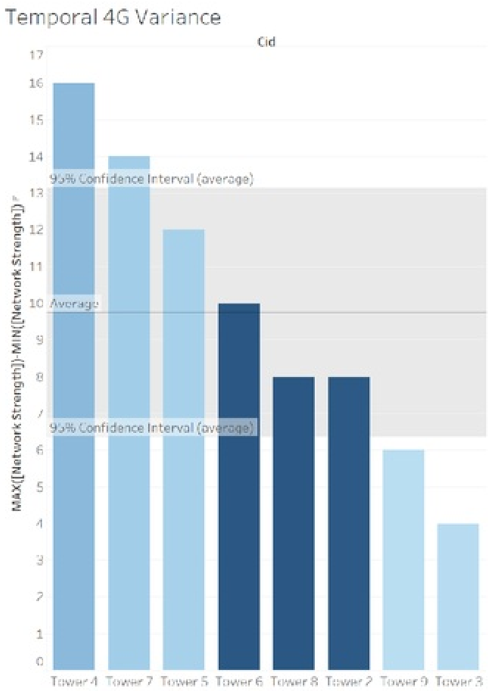

Figure 5.2: The total variance per 4G cell tower from 5.1.

By looking at the total difference in signal strength of each tower as seen in figure 5.2 we can see that 4G networks vary on average by 10dBm over a short period of time. The actual cause of this variance is difficult to pinpoint as it could be a natural variance of the tower, interference from people or objects moving around or even due to the inaccuracies in the mobiles transceiver. Similar arguments can be made for the variation in Wi-Fi as well.

The exact cause of the variance does not matter as it's a close representation to the variance that will be experienced by most mobile phones. This means that any unique features of a signal strength map must be distinguishable from the measured natural variation, otherwise, any constructed model will be prone to both type 1 and type 2 errors (False positives and false negatives respectively) resulting in incorrect decisions made by the handover algorithm and by extension affecting user experience.

5.3.2 Shadows

Due to the fact that using the proposed handover technique building shadows may be a key area of improvement, it is a crucial component in determining how useful the improvement may be and whether the gains from predicting shadows are worth of costs of development.

Building Shadows

The search for building shadows did not yield any conclusive results as it was difficult to differentiate between the natural variation measured earlier with any building shadows or interference caused by them. As covered earlier it is possible the variation measured consists of the interference that is being searched for however it is impossible to understand the true origin becoming the causation issue.

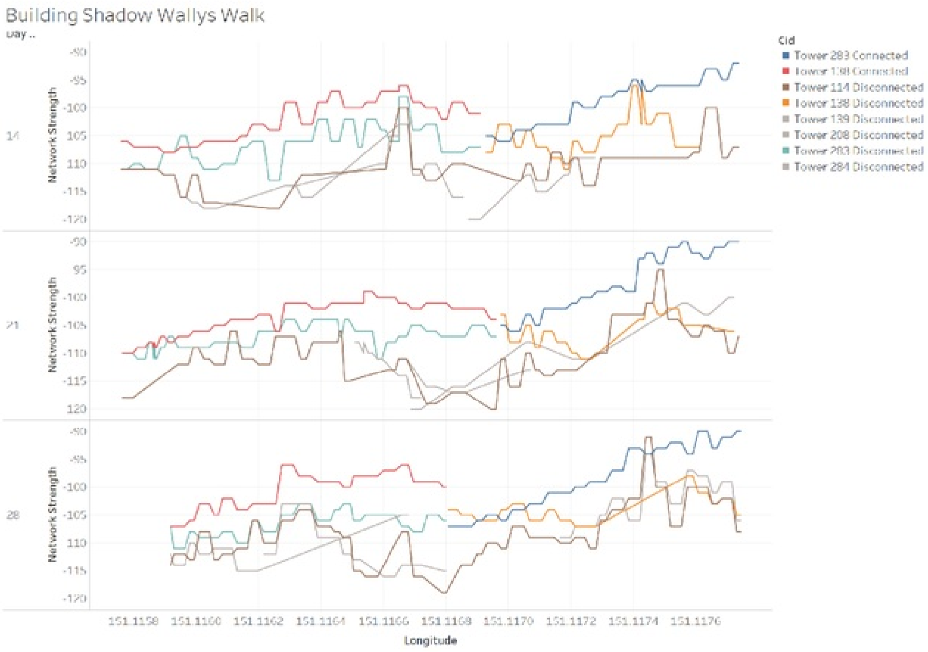

Figure 5.3: 4G signal strength of each cell tower while walking along a path. The towers labelled as 'connected' represents the time the mobile was connected to that particular tower. The 'disconnected' label represents towers when they weren't currently connected to.

One area located in the Macquarie does, however, seem to be more clearly caused by building shadows and interference however it isn't consistently found. Figures 5.3 and 5.4 do match similarly to the 'ideal' scenario as seen in figure 4.1 with Tower 283 placed along a path, somewhat unobstructed and Tower 138 to the south obstructed by a number of buildings and car parks.

In figure 5.3 when travelling from the right to the left, it is clear that Tower 283 is consistently slowly declining with little variation. Eventually, tower 138 becomes more dominant, the mobile hands over to it and stays with it for the rest of the path. With the exception of the middle section, tower 138 seems to have a higher amount of variation. This is however with within the measured range of normal variation.

The primary source of evidence of building shadows is with the other weaker towers with a few areas, although also somewhat inconsistent, where more than one tower has a sudden spike or drop in signal strength in the same area. If these towers are in approximately the same direction this could be the result of interference patterns.

Should these be as a result of building shadow it still will not be an example of an area where the improved handover technique will beat a standard handover algorithm as the towers that experience the interference aren't the strongest towers in the area making them undesirable anyway. Further data will need to be collected to determine if building shadows can be mapped accurately using only a mobile device until then the evidence points otherwise.

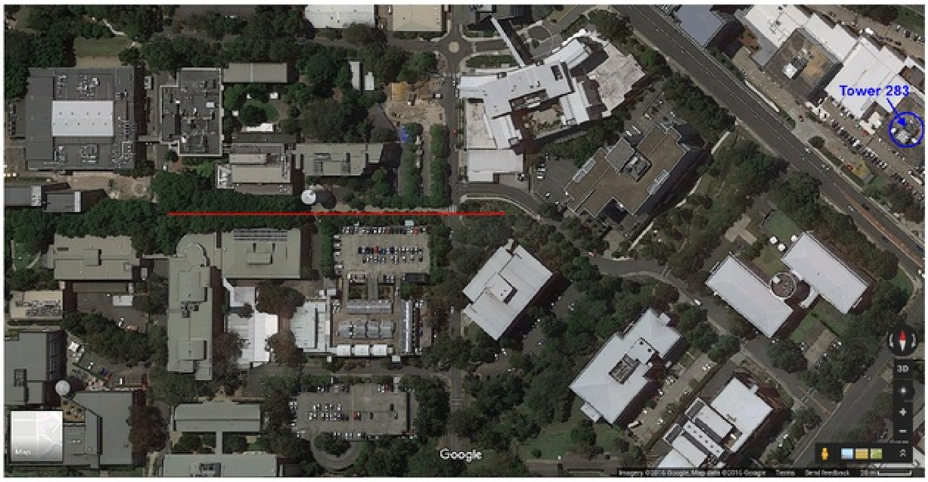

Figure 5.4: Map displaying the area represented in 5.3. The red line represents the path taken. In this map tower 283 is marked, tower 138 is a couple kilometres south in the direction approximately perpendicular to the path travelled.

Topography Shadows

Shadows due to the topography of the area may be easier to detect as the side of can be much larger than a building, in particular when it comes to the width preventing the radio waves from moving around the sides causing interference patterns. As the radio waves can only go over, no interference patterns are created as on a large scale they require two sources.

In figure 5.5 this may be visible although due only partially to the local topography and partially to local infrastructure. This is because it occurs in a part of the motorway that is both an exit and is cut through a hill, see figure 5.6 more details on the location and surrounding towers.

The areas where this is first seen in just under the bridge and it at times continues just past the bridge and can be seen in the data as a large gap in the 4G signal where the only nearby 4G towers are on either side of the motorway labelled 3 and 4.

It is also evident that in the 5 selected trips displayed on figure 5.5 that the mobile at times had difficulty choosing between 3G and 4G with the 3rd trip handing over 5 times. This proved to be an example where the improved handover technique will improve the user experience. Note that the 4th trip was chosen as it was an example of the mobile being forced into 4G, and while many other trips had been made, all the other trips had closely resembled one displayed in the figure.

5.3.3 Cell Tower Breathing

Cell tower breathing can potentially be a useful source of predictive behaviour, if at least over time. This, however, wasn't observed over any of the longer term temporal analysis such as figures C.2, C.3 and C.4 along the M2 or shorter term ones such as figure 5.1. It is suspected that should this phenomenon be observable it will require a temporal study in between the longer and shorter term ones as it may only be visible during specific hours of a weekday or it may be always visible but oscillating over a larger period of time.

5.3.4 Handover Between 3G and 4G

As explored earlier on while transmitting or receiving data, handover from 4G to 3G is low cost yet the reverse is high cost. Such an oddity would mean that the proposed handover technique may perform better than a standard predictive handover algorithm by avoiding handover to 3G when the 3G is likely the run out in the near future.

Evidence of this high-cost handover can be seen in figure 5.5 within the 5th Trip wherein an area with clearly adequate 4G signal the mobile stuck with 3G. Out of 12 trips allowing the mobile to switch naturally to its preferred network, this occurred three times.

It wasn't recorded whether data was receiving or transmitting data at any particular time so it is possible that at it was either transmitting or receiving only during the three times handover to 4G failed to occur. As such it would be a useful measure for the future.

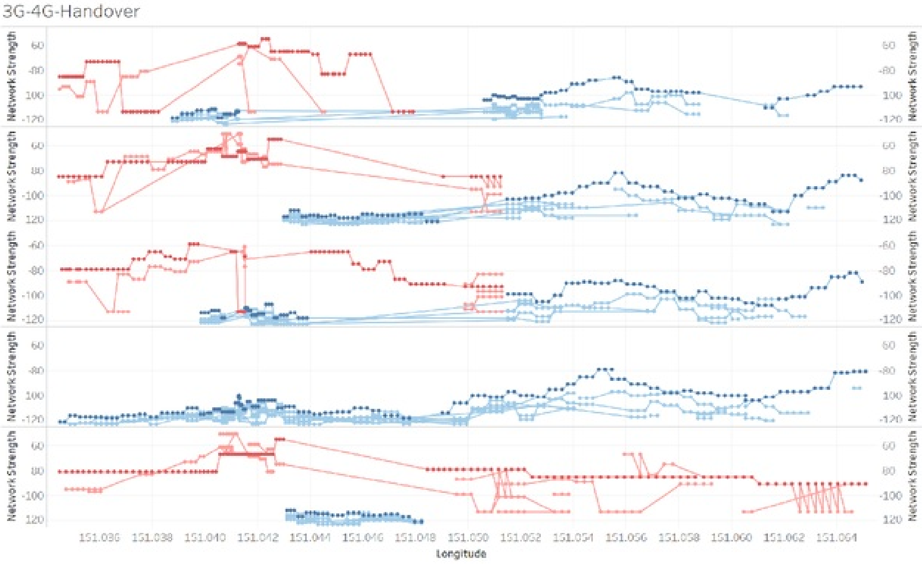

Figure 5.5: Every dot represents a single data point and the line connects each cell tower. Red represents 3G while Blue represents 4G, the darker dots indicate which network it's currently connected to and although not shown each each dot with the same Longitude represents a different cell tower.

Figure 5.6: Map displaying the area represented in 5.5. Each red circle represents the location of a cell tower and each arrow indicates a nearby tower. The Yellow circle indicates a common handover location as seen in Longitude 151.043 of figure 5.5.

5.3.5 Further Observations

In addition to the results above, a couple other interesting observations were found in the data that may also have an effect on the feasibility of developing the improved handover technique.

M2 Consistent Results

By observing figures C.2, C.3 and C.4 it becomes easy to see how the 4G signal over the M2 changes over time. Through visual inspection some areas are consistently highly variable while others are consistently constant over a single trip and this picture doesn't change much whether it be looked at over specific days or specific hours, with the biggest changes being the area described in 5.3.4 where the gaps are just when the mobile was connected to 3G.

Naturally, any longer term changes must require more data over a longer period, however, considering its consistency it shows that an individual mobile device can reliably map the mobile networks in any particular areas.

Mapped Mobile Signal Strength

A more visual map of mobile signal strength around Macquarie can be found in figure C.6. Interestingly enough even though multiple towers can be seen from the campus, there is a clear shift from green to red making the black spot in the area starkly obvious. Not only this, it seems to be a fairly gradual border rather than a messy one as one may expect from an area dense with buildings.

This can be partially explained away by the fact that the only areas with 'Good' reception are or nearly line of sight with one of the two towers primarily servicing the campus. Deep within the campus there still seems to be 'Poor' signal, perhaps due to both interference patterns as signals pass around as well as reflections off of buildings.

Cell Tower Coverage

Cell tower coverage around Macquarie is evidently poor due to the fact it's in a black spot but is for the most part services by only two towers, as opposed to the M2 for instance in which an area of similar size will often have more than two good signal towers overlapping.

As mentioned the M2 along the areas surveyed are well covered with the exception of the one place which serves as the strongest way the improved handover technique can beat out a standard handover algorithm. The fact that it must rely on a component of handover between two specific systems not being implemented isn't very promising as the cheapest fix may be to simply upgrade the local towers and install new ones rather than developing an improved handover algorithm.

Chapter 6

Conclusions and Future Work

6.1 Discussion

By looking at the results, the prospect of developing an improved location-based handover algorithm that utilises downloaded models built from data it has collected is not very promising. Benefits for such a system does exist but only in specific cases which may or may not be common.

More data over a larger range of areas is needed to produce a more conclusive result. Since the largest found benefit of the improved handover technique takes advantage of the overlap and the gaps of different generation systems, only when the distribution of both systems are about equal will any worthwhile effect be noticed, however in the areas surveyed, 4G coverage seems to be near complete with the black spot in Macquarie having good reception with neither network.

This means the signal strength along the M2 and within the university campus can be improved by adding new cell towers and upgrading existing towers with 4G. This may prove to be cheaper than developing the proposed handover technique and provide similar benefits making a standard predictive handover performing just as well as the improved location-based algorithm.

There also exists a number of privacy other issues with regards to the collection of location and signal data as users go about their day to day life and uploading it to a server. As it's clear that for effective models to even be created to maximise any benefits from the system, models need to be created from huge amounts of data which would prove too costly and time-consuming to gather.

The one cost effective solution to this is to collect data from the phones of all the users, however, this data could reveal more than just signal quality but the location and day to day activities of all its users. Even if the data is collected by a benevolent company, gathering active and willing users will be difficult and any security failures leading to a data leak would be catastrophic to users privacy and irreversibly damage the reputation of the company.

In addition to the feasibility and risk issues stated there are also still some technological limitations, all data was collected to minimise the effect the user has on their mobile device by holding it out away from the body, held only with the tips of the fingers and with the same orientation. In reality, users will have mobiles in their pockets, bags or even in the palms of their hands, all of which will reduce the quality of the signal measured. This reduction will not be constant either as holding a mobile in a hand affects the measured signal differently to when it's in a pocket or a bag.

Battery life is also a technological issue that will be faced as in order to get very accurate location data, the GPS must be both active and running continuously for at least a short amount of time. A mobile may survive a day with standard usage however once the GPS needs to be activated more than usual, mobile batteries may only survive a matter of hours. This can be mitigated by only collecting data more rarely, a couple times an hour for 30 seconds maybe but it will significantly reduce the amount of collected data. A much smaller battery life will result in a negative user experience that may outweigh any positive experience from more effective handover.

Wi-Fi also proved to be an issue as the mobile doesn't automatically rescan the signal strength as often leading to low-quality data. Wi-Fi access points are also more difficult to map as they have a lower range and higher density, requiring a much lower amount of variance in the collected data. The variance over Wi-Fi, however, appeared to be greater than that of mobile networks making it undesirable to map. This can be worked around by manually rescanning however data collection will not be seamless and become very slow which isn't suitable for background mapping as the user goes about their daily business.

Considering the time constraints for this project it is not conclusively clear that more undiscovered benefits don't exist and those situations that work well for the algorithm aren't as commonplace. This means even though this is likely a negative result for the feasibility of developing a system and its improvement on user experience, more data over more locations will lead to a more conclusive result.

6.2 Conclusion

The goal of this project was to determine the feasibility of developing an effective improvement over current handover techniques by using a location-based approach improved with a detailed model of the wireless networks surrounding the mobile device as measured by the device itself. Furthermore, the potential benefits of this system were explored to determine to determine if producing a model will allow the proposed technique to perform better than current handover algorithms and to get an idea of the required quality of the data.

In order to determine this, an application was prototyped to collect the data the same way that an implementation of this technique must then upload the data to a web service connected to a database. As development progressed, early sets of data were collected and analysed to better understand what data should be collected. The result is a system which can collect data, process and upload it in a way that will mirror the data collection for the proposed handover technique.

Starting during development, areas were surveyed when possible to collect large amounts of data. Each survey was conducted with controls in mind to preserve the quality of the collected data. Particular areas and paths of interest were also revisited numerous times to explore how the signal changes over time as well as space.

Once sufficient data has been collected, it can then be analysed for different situations where the model of the area would outperform the current handover algorithms. In addition, the data was analysed for quality and consistency in measurements to determine if the found situations can be reliably distinguished from background noise and interference.

The results lead to the conclusion that the benefits compared to current systems may be too little to outweigh its costs and a potential hindrance to the user. While areas of potential improvement over current handover algorithms were found, those specific situations may not be common and can be fixed through other and cheaper means such as upgrading a cell tower from 3G to 4G or adding new cell towers.

More data over a larger variety of areas will be needed for a more conclusive result and a number of other areas into this system can be explored with more depth. There exists a large chance that the particular areas surveyed over this project are not representative of most situations in general. This means that should areas of mixed generation networks be more common, the cheaper option may be to collect data and build a model leading to a recommendation of more widespread surveys of different areas.

Based on the results of the analysis and with the root goal of the project to improve handover thus to improve user experience, there is a lack of clear and consistent areas of general improvement over current handover algorithms. The few areas of potential improvement are either inconsistent or are not commonplace. This means that at this time is it not worth approaching the issue of improving handover through the use of a model built from data collected from the mobiles owned by the users. Another approach will need to be explored and may simply be improving network coverage.

6.3 Future Work

During this study, only a few aspects of this improved handover technique was explored, primarily surrounding the data available to be collected and how it can be managed. There are a number of other areas that may prove to shed some more light on the benefits of this system such as much larger surveys to collect more data and studies into making and prototyping a model of the wireless networks. Mobile and Wi-Fi networks are also very dynamic over longer periods of time as infrastructure is consistently improving and access points are being added or removed.

As 4G coverage around Sydney is extensive with only a few areas with only access to 3G, it is likely that areas of mixed generations are unlikely. This means that conducting larger surveys may not be necessary and little more may be found. The caveat is that 5G arriving in the near future which may lead to network changes and patchy coverage for a time making the improved handover technique more useful to users.

Prototyping an actual model of mobile networks is an interesting next step. As technology improves and changes over time, the results become outdated and new situations and network phenomena can be explored. If the data be highly reliable and areas of potential improvement are found in abundance, then the next issue that must be tackled is building and prototyping the model. This model will also have uses in other fields such as providing detailed information about the network resulting in more informed placement of access points leading to better network coverage.

Appendix A

Signal Mapper System Requirements

A.1 Overview

All functional and non-functional requirements for both the Android and Web application can be found here. It is important to note that there is a considerably smaller number of non-functional requirements as the developed system is not intended to be bug-free or a polished final version. As a result, there are no few requirements related to the quality of its functionality rather than it should just function adequately. The few non-functional requirements relate to particularly disruptive issues such as data upload times and for the quick and intuitive usage of the application.

A.2 System Requirements

Name	Functional Requirement	Reason
FR.1.1	A Manual collection mode should be available.	Allows more detailed and accurate surveys to be produced.
FR.1.2	An Automatic collection mode should be available.	Allows larger areas to be surveyed more quickly.
FR.1.3	All collected data must not be permanently stored on the mobile.	This restricts access to the data and storage will be limited to a SQLite database.
FR.1.4	All collected data must be cached on the mobile device.	While mapping, many areas of poor to no signal will be passed resulting in no connection to send the data.
FR.1.5	All cached data must have the ability to be uploaded in chunks	While mapping, it is likely that handover is to occur often causing larger uploads to fail if they should coincide.
FR.1.6	Upon successful data upload, the data must be removed from the mobile.	This is to prevent a build up of data in the mobile.
FR.1.7	The GPS can only be active during data collection.	This will conserve battery life as GPS is a major consumer of power.
FR.1.8	An option for Automatic chunk uploading during collection.	This prevents the cache from growing too large while mappings network dense areas.
FR.1.9	An option for a minimum accuracy during automatic collection.	This can avoid uploading bad data which would be filtered out anyway.
FR.1.10	The ability to add a tag to each survey should be present.	This will aid in sorting and filtering the data later.

Table A.1: Android Application Functional Requirements

Name	Non-Functional Requirement	Reason
NFR.1.1	The user must be able to begin data collection within 10 second of starting the application.	This means minimizing set-up time and resulting in a quick intuitive work-flow.
NFR.1.2	The User Interface must be intuitive enough for first time users to easily navigate and start collection.	This means no training should be required and anyone can use the application.
NFR.1.3	All methods of deleting data should not allow accidental activation.	This aids in the prevention of accidental data loss.

Table A.2: Android Application Non-Functional Requirements

Name	Functional Requirement	Reason
FR.2.1	The REST API must support the uploading and ingest of data chunks in a JSON format.	Data needs to be sent to the database, the JSON format is a standard and well supported format
FR.2.2	The REST API must provide a list of tags and their data count.	This aids the Android Application in satisfying NFR.1.1
FR.2.3	The REST API must allow access to the database and return filtered results in either CSV or JSON format.	Required for getting and analysing the data with third party applications.
FR.2.4	The Web Application must not facilitate the deletion of any data.	Prevents accidental deletion and is the only required security measure.
FR.2.5	The Web Application must provide an interface to browse filtered data.	Allows quick access to the data.
FR.2.6	The Web Application must provide an interface to provide some initial visualization and analysis methods.	Allows the user to quickly answer simple questions about the data.
FR.2.7	The interface described in FR.2.6 must allow user customization.	Due to too many different interesting ways to look at the data, this allows the user decide for themselves.
FR.2.8	The entire database must be backed up daily.	Safety First.
FR.2.9	All JSON uploads must be backed up after they have been ingested.	In case of database corruption, allows uploaded data from after the last backup to be re-ingested.
FR.2.10	All JSON uploads must go to a Cache before being ingested.	Required for Satisfying NFR.2.1
FR.2.11	Any cached uploaded data must be processed via a script run hourly	Required for Satisfying FR.2.1 and NFR.2.1

Table A.3: Web Application Functional Requirements

Name	Non-Functional Requirement	Reason
NFR.2.1	Data uploads must perform minimal processing.	This allows chuck uploads to be done quickly and make it less likely for the HTTP connection to be broken due to Handover.
NFR.2.2	The User interface must be intuitive enough for first time users to navigate.	This does not include the development of scripts, but includes filtering data and using scripts in the maps page.

Table A.4: Web Application Non-Functional Requirements

Appendix B

User Interface

Screen shots of Android application and the Web Application are displayed below. Each page and screen along with some variants depending on user settings is displayed.

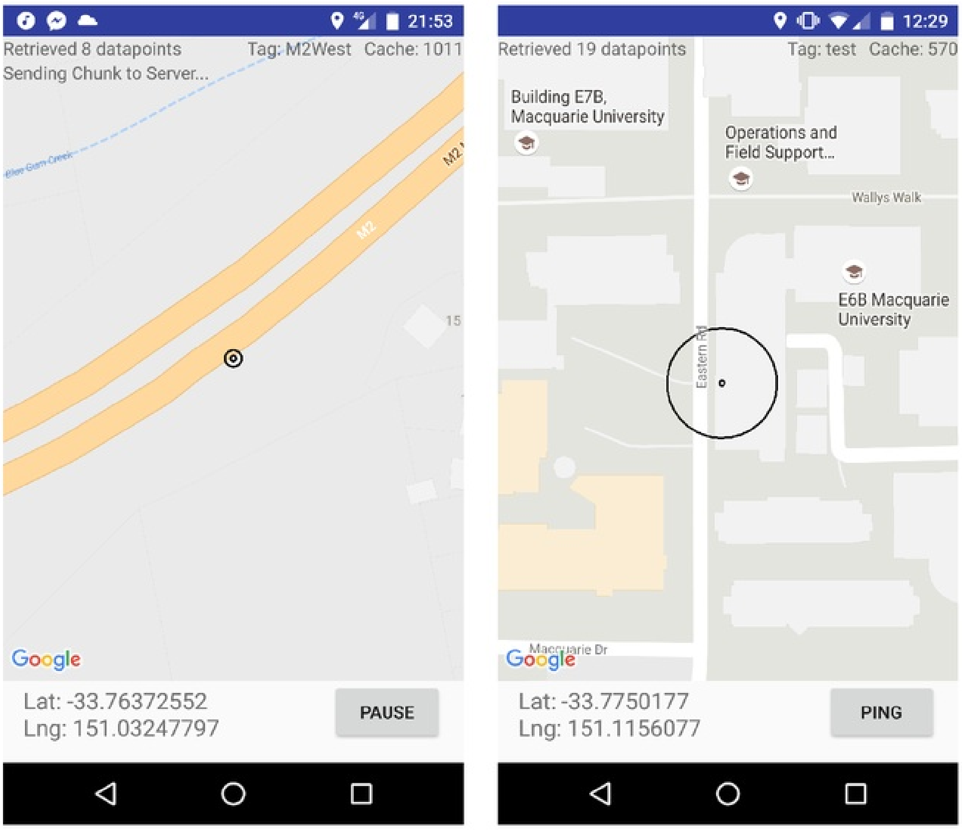

Figure B.1: Polling screen in Automatic mode (left). Polling screen in manual mode (right).

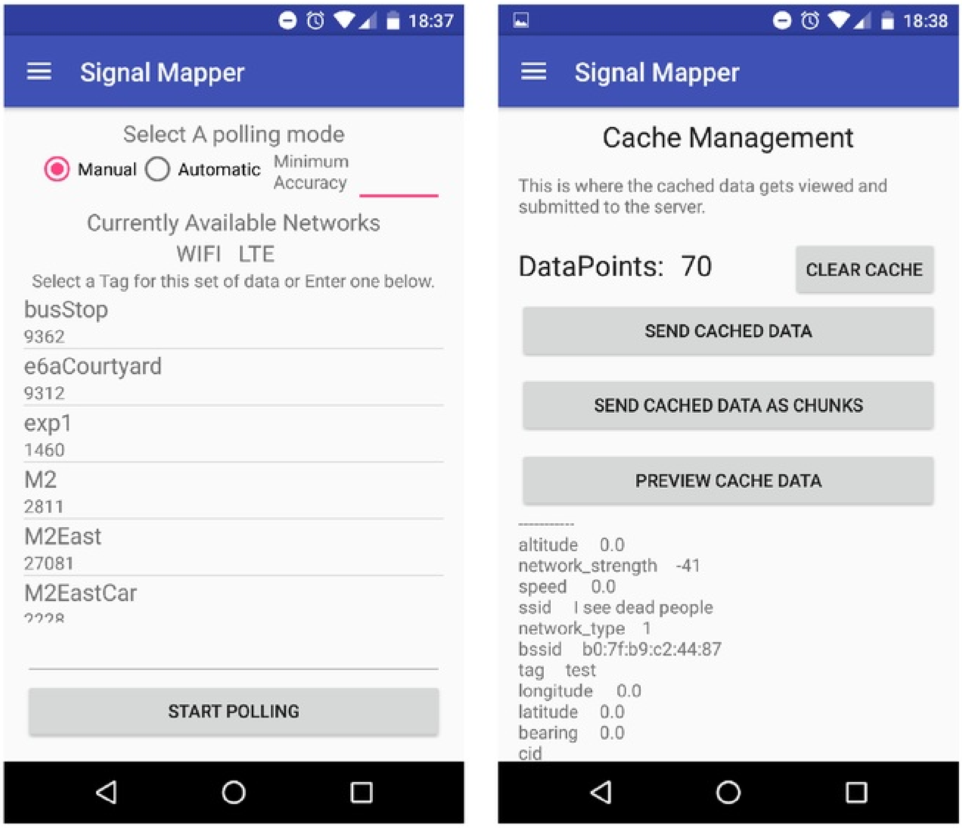

Figure B.2: Survey setup screen (left). Cache screen (right)

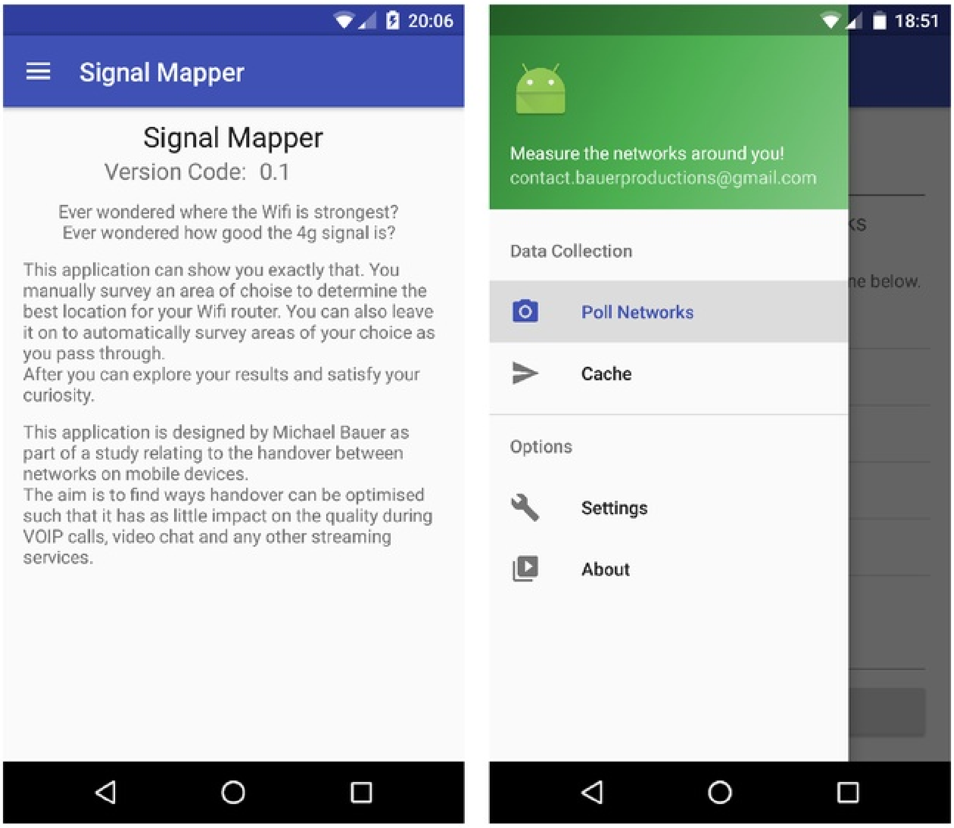

Figure B.3: About screen (left). Navigation sidebar (right).

Figure B.4: Settings Screen with sample Wi-Fi, Mobile and Location data from top left to bottom right.

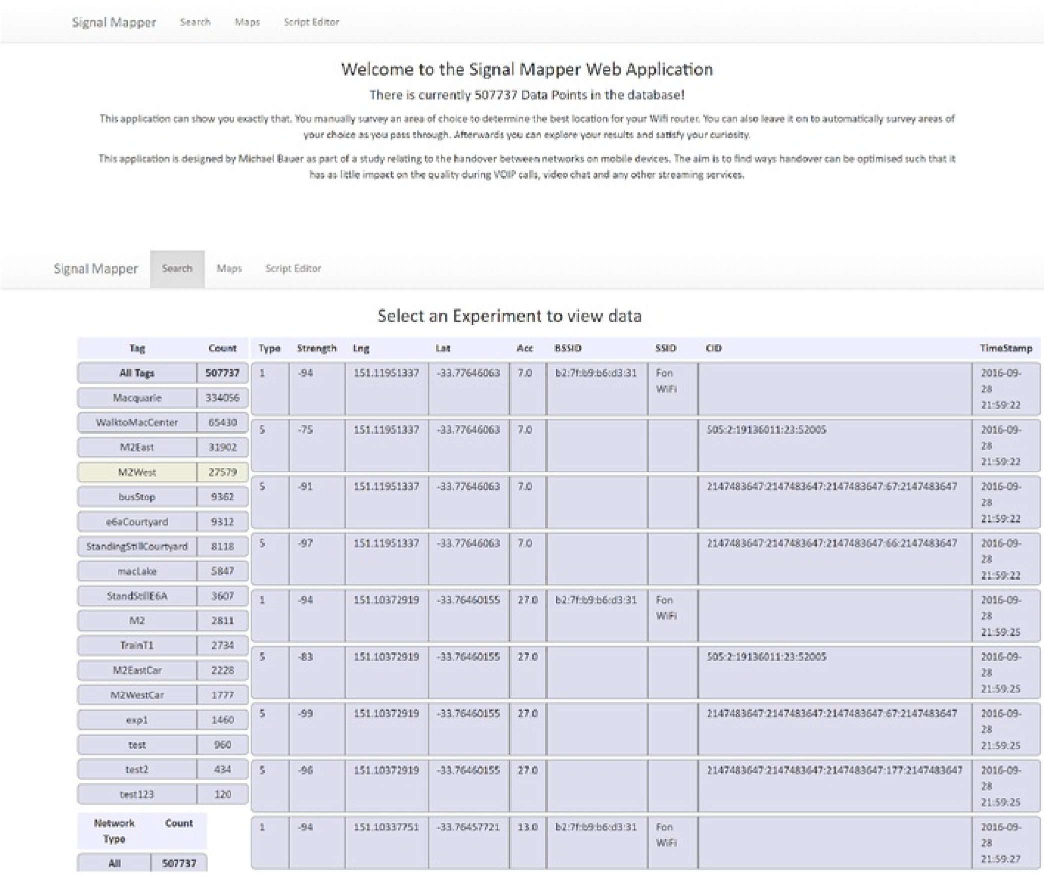

Figure B.5: Home page with description on top, search page below.

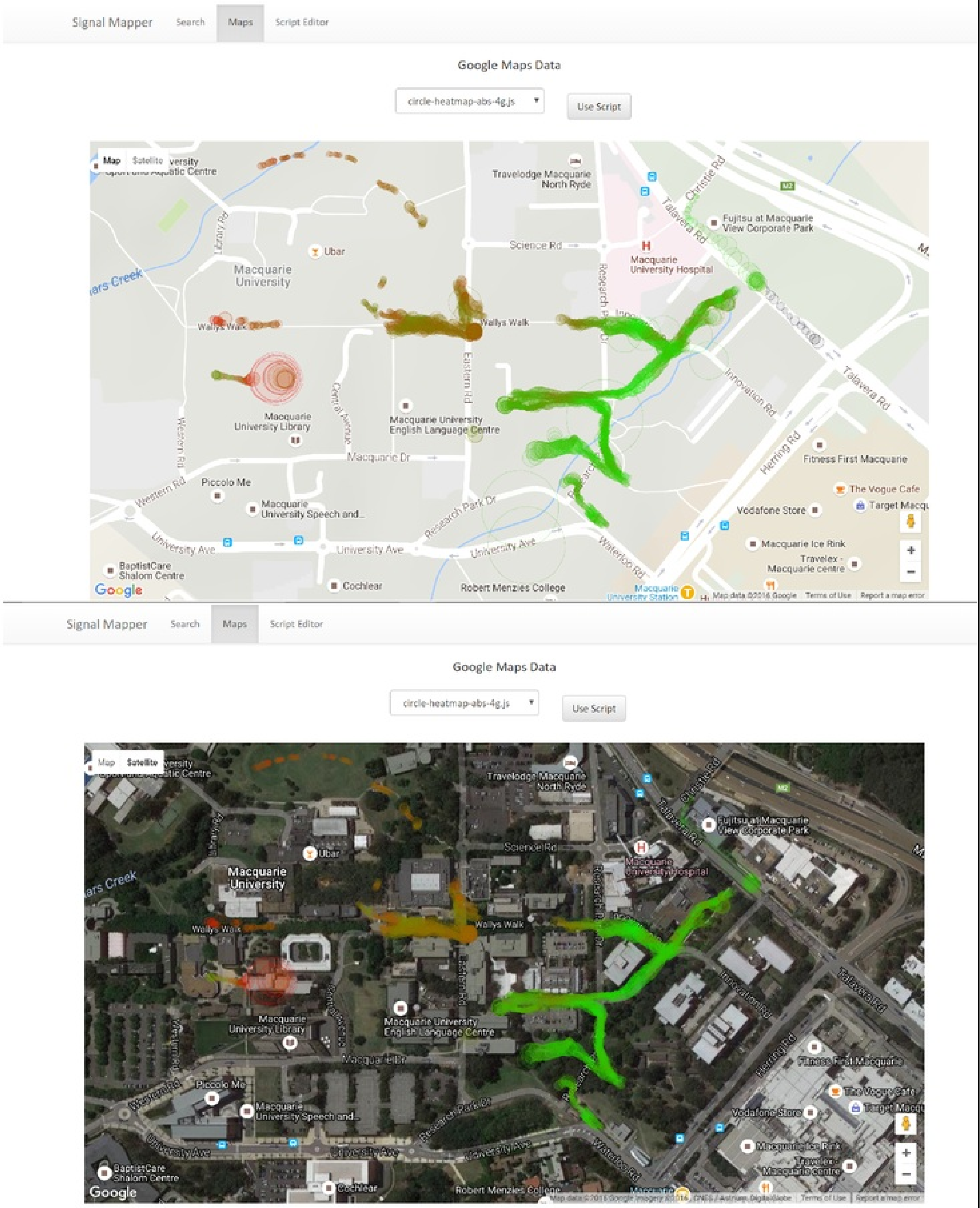

Figure B.6: Maps page displaying results from a single 4g tower. Maps view on top and Satellite view below.

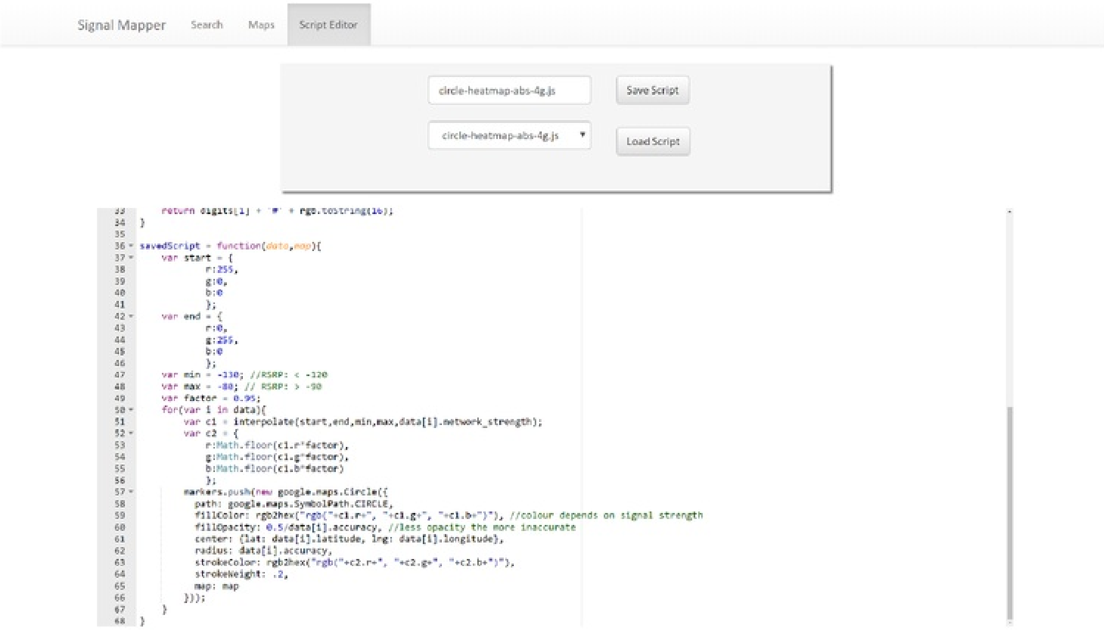

Figure B.7: The script editor page loaded with a script that displays coloured circles with a range that corresponds to RSRP scale.

Appendix C

Figures and Graphics

C.1 Figures

C.1.1 Wi-Fi Signal Variance

Figure C.1 shows the variation of signal strength in the courtyard of E6A for the three main Wi-Fi networks in the area: Eduroam, Macquarie OneNet, Macquarie Public

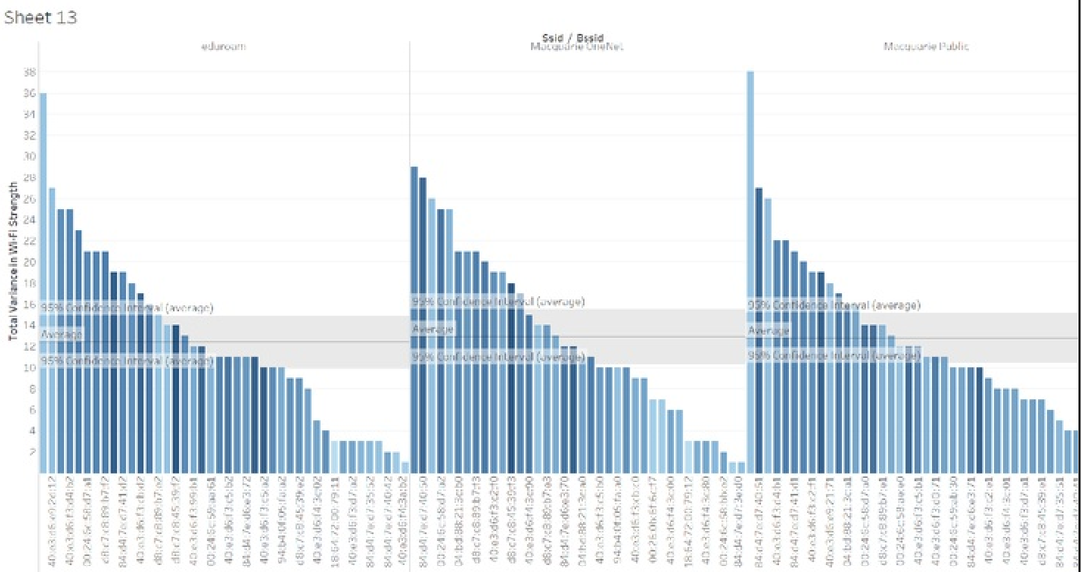

Figure C.1: The variance found across Wi-Fi access points in the courtyard outside of E6A taken over a number of days. Each bar represents the maximum signal strength found from a particular access point minus its minimum signal strength. The depth of the blue colour indicates how often that particular access point was measured.

C.1.2 M2 Signal Variance

The following figures provide an easy way to see how signal strength varies split into different time scales.

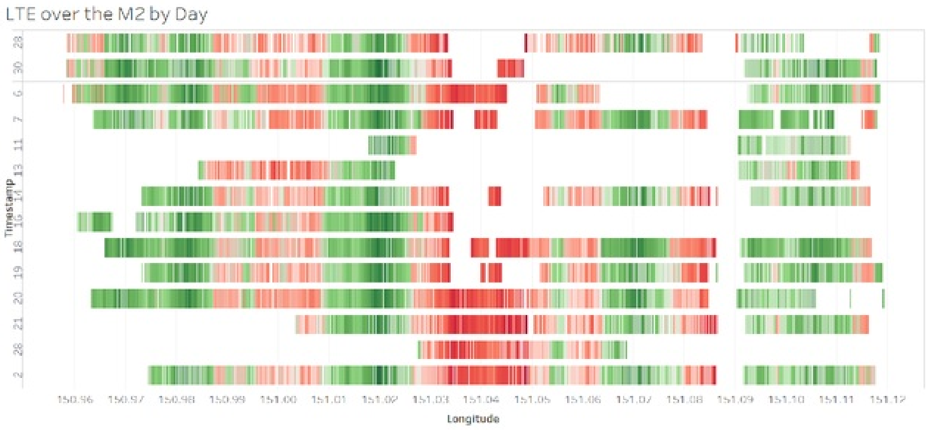

Figure C.2: Signal strength split by day.

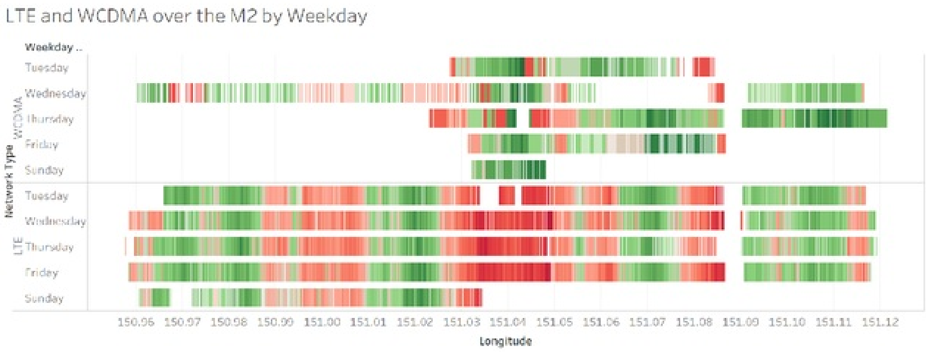

Figure C.3: Signal strength split by day of the week.

C.2 Graphics

C.2.1 Signal Strength Maps

These Maps serve to indicate more specifically each area and path that has been surveyed.

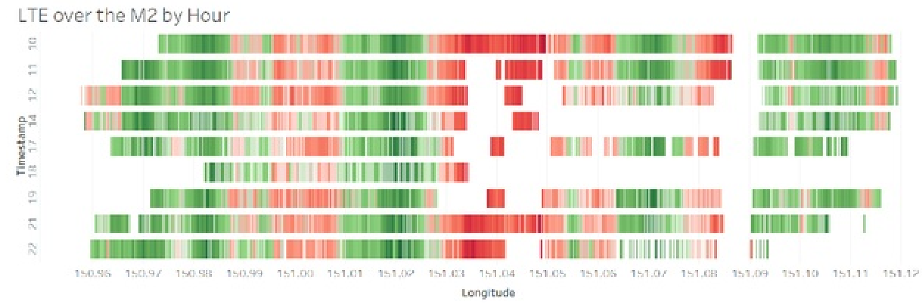

Figure C.4: Signal strength split by hour of the day.

Figure C.5: Maps view of LTE signal strength over the M2 and of the areas covered by particular cell towers.

Figure C.6: Maps view of LTE signal strength over the M2.

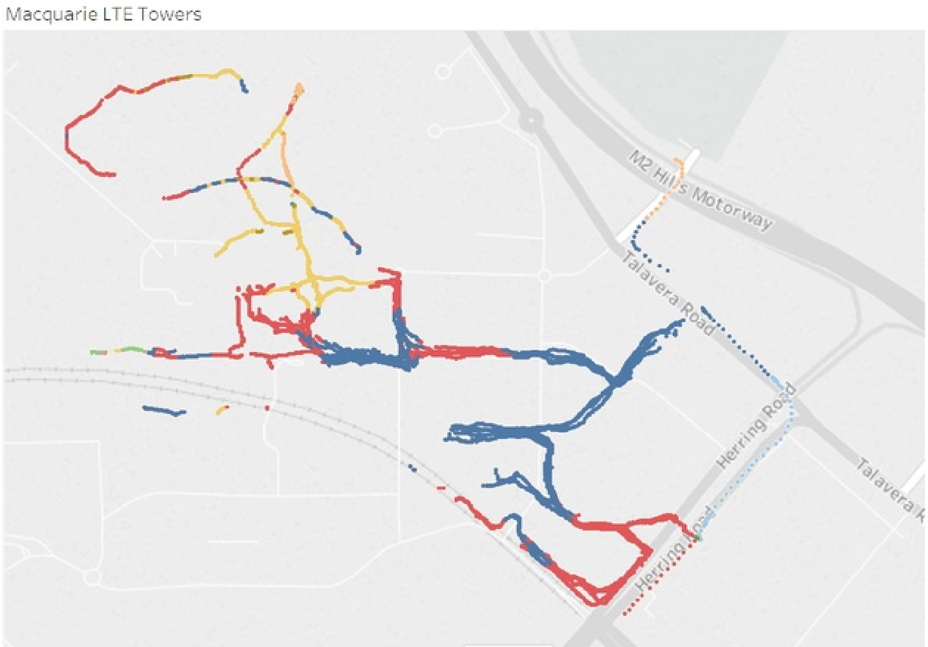

Figure C.7: Maps view of areas covered by particular LTE cell towers.

Appendix D

Code Samples

Any relevant code will be placed under this section. All the code minus the Maps API scripts can be found in the following link to the Bitbucket repository. More Maps API scripts can be found in the editor page of the Web Application linked below.

Repository https://bitbucket.org/MikeBauer/signal-mapper

Web Application http://mikebauer.pythonanywhere.com/

D.1 Maps API Script Example

```
function interpolate(start,end,min,max,val){
    var nval = val-min;
    var nmax = max-min;
    if(min==max){
        return start;
    }
    if(nval > nmax){
    return end;//just in case
    }
    if(nval < 0){
        return start;
    }
    return {
        r : Math.floor(start.r+((end.r-start.r)*(nval/nmax))),
        g : Math.floor(start.g+((end.g-start.g)*(nval/nmax))),
        b : Math.floor(start.b+((end.b-start.b)*(nval/nmax)))
    }
}

//Function to convert to hex format from a rgb color
function rgb2hex(color){
    if (color.substr(0, 1) === '#') {
        return color;
    }
```

```
    var digits = /(.*?)rgb\((\d+), (\d+), (\d+)\)/.exec(color);
    var red = parseInt(digits[2]);
    var green = parseInt(digits[3]);
    var blue = parseInt(digits[4]);

    var rgb = blue | (green << 8) | (red << 16);
    return digits[1] + '#' + rgb.toString(16);
}

savedScript = function(data,map){
    var start = {
          r:255,
          g:0,
          b:0
          };
    var end = {
          r:0,
          g:255,
          b:0
          };
    var min = -130; //RSRP: < -120
    var max = -80; // RSRP: > -90
    var factor = 0.95;
  for(var i in data){
      var c1 = interpolate(start,end,min,max,data[i].network_strength);
      var c2 = {
          r:Math.floor(c1.r*factor),
          g:Math.floor(c1.g*factor),
          b:Math.floor(c1.b*factor)
          };
    markers.push(new google.maps.Circle({
      path: google.maps.SymbolPath.CIRCLE,
      fillColor: rgb2hex("rgb("+c1.r+", "+c1.g+", "+c1.b+")"), //colour depends on signal strength
      fillOpacity: 0.5/data[i].accuracy, //less opacity the more inaccurate
      center: {lat: data[i].latitude, lng: data[i].longitude},
      radius: data[i].accuracy,
      strokeColor: rgb2hex("rgb("+c2.r+", "+c2.g+", "+c2.b+")"),
      strokeWeight: .2,
      map: map
    }));
  }
}
```

Listing D.1: Script to draw to Google Maps configured for LTE

Bibliography

[1] "Wireless LAN medium access control (MAC) and physical layer (PHY) specification," Piscataway, NJ, Tech. Rep. 802.11, 1997.

[2] *2G-5G Networks: Evolution of Technologies, Standards, and Deployment (Second ed.).* Hershey, Pennsylvania, IGI Global, 2008.

[3] 3GPP, "Handover procedures," 3rd Generation Partnership Project (3GPP), TS 23.009, Mar. 2007. [Online]. Available: http://www.3gpp.org/ftp/Specs/html-info/23009.htm

[4] ——, "Numbering, addressing and identification," 3rd Generation Partnership Project (3GPP), TS 23.003, Sep. 2008. [Online]. Available: http://www.3gpp.org/ftp/Specs/html-info/23003.htm

[5] ACMA, "Register of Radiocommunications Licences: Optus Mobile Pty Limited," Australian Communications and Media Authority, Tech. Rep., 2016. [Online]. Available: http://web.acma.gov.au/pls/radcom/client_search.client_lookup?pCLIENT_NO=20007586

[6] Android. (2013-2016) Issue 60430: Telephonymanager.getallcellinfo() returns null or "unknown" values. [Online]. Available: https://code.google.com/p/android/issues/detail?id=60430

[7] ——. (2016) Signalstrength line 785. [Online]. Available: https://android.googlesource.com/platform/frameworks/base/+/master/telephony/java/android/telephony/SignalStrength.java

[8] Cisco, "Cisco visual netowrking index (vni)," Cisco Systems, Tech. Rep., 2008.

[9] ——, "Cisco visual netowrking index (vni)," Cisco Systems, Tech. Rep., 2015.

[10] H. W. C. L.-S. L. G. Tu, C. Peng, "How Voice Calls Affect Data in Operational LTE Networks," MobiCom, Tech. Rep., 2013.

[11] M. Gudmundson, "Analysis of handover algorithms," *Proceedings of IEEE conference on Vehicular Technology VTC*, 1994.

[12] D.-B. L. H-P Lin, R-T Juang, "Improved location-based handover algorithm for mobile cellular systems with verification of gsm measurements data," *IEEE Vehicular Technology Conference*, 2004.

[13] R. P. J. D. Bakker, "Handover in a virtual cellular network," *Proceedings of IEEE conference on Vehicular Technology VTC*, 1999.

[14] B. C. V. R. M. G. L. Chen, T. Sun, "A Smart Decision Model for Vertical Handoff," Department of Computer Engineering University of California, Tech. Rep., 2004.

[15] C.-Y. Liu, "Heterogeneous network handover using 3gpp andsf," *Proceedings of IEEE conference on Advanced Information Networking and Applications*, 2015.

[16] R. H. K. M. Stemm, "Vertical handoffs in wireless overlay networks," *Mob. Netw. Appl.*, 1998.

[17] Motorola, "5Ghz IEEE 802.11a For Interference Avoidance," Motorola, Tech. Rep., 2008.

[18] C. T. U. F. of Electrical Engineering. (2016) 5gmobile research lab overview. [Online]. Available: http://5gmobile.fel.cvut.cz/about/5Gmobile_overview_20161015.pdf

[19] G. Pedersen, "Mobile Phone Antenna Performance 2016," Aalborg University, Tech. Rep., 2016. [Online]. Available: http://www.pts.se/upload/Rapporter/Tele/2016/MobilephoneTest2016-augusti-2016.pdf

[20] Y. C. M. A.-S. C. C. Q. Ye, B. Rong and J. G. Andrews, "User association for load balancing in heterogeneous cellular networks," *IEEE Trans. Wireless Comm.*, 2013.

[21] P. K. S. V. Goswami, "Analytical modeling for handling poor signal quality calls in cellular network," *International Journal of Networks and Communications*, 2012.

[22] T. O. X. Yang, J. Vre, "A survey of handover algorithms in dvb-h," *IEEE Communications Surveys and Tutorials*, 2006.