Collaborative Mapping using a Resilient Mesh Network

Corey Wallis
Serval Project - Flinders University

Supervisors:
Dr Paul Gardner-Stephen - Shuttleworth Foundation Fellow (Flinders University)
Ms Romana Challans - Senior Developer, User Experience (Serval Project)

November 24, 2011

Submitted in partial fulfillment of the requirements for the degree of Bachelor of Science (Honours) at Flinders University - Adelaide Australia

This report does not contain any material previously published or any material written by another person, except where due reference is made in the text.

Signed:

Abstract

This report provides an overview of the development of a prototype application, that supports collaborative mapping activities without relying on traditional telecommunications infrastructure. The prototype application uses a resilient Ad Hoc mesh network, provided by software from the Serval Project, to share information between instances of the application. The prototype application has been developed to run on Android powered smartphones.

The primary use case for the prototype application is, to assist users in the field who are responding to a disaster or emergency event. The knowledge that is collaboratively constructed by the users can be used to assist them in undertaking and coordinating their tasks. Additionally the knowledge can used by those managing the response to improve their overall understanding of the event. Additional use cases are explored, including environmental monitoring and the integration of the application with data collection devices which can be used in the field.

The development of the prototype application is also documented, including the design considerations and an overview of the user experience. Lastly options for expanding the testing of the application are outlined, and possible avenues for future research and development are explored.

Keywords: mapping, collaboration, android, smartphones, ad hoc mesh networking, serval project

Acknowledgements

My thanks to my supervisors for providing support and direction during this research project. In particular my thanks to Romana Challans for proofreading and editing. Any grammatical errors, especially in relation to commas, are entirely my own. The other members of the Serval Project team have been wonderful to work with and I look forward to continuing working on the project with them. A core tenent of the Serval Project is that *communication is a human right*, may we succeed in making mobile telephony via a resilient Ad Hoc mesh network using mobile phone available to all.

Lastly my everlasting gratitude to my wife and baby daughter, who arrived during the writing of this thesis, for providing distractions when I needed them and for keeping me grounded.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

This exploratory research project is concerned with developing a mapping application, that can be used collaboratively by people responding to a disaster or emergency event using their mobile phones. The intent of the application is to assist in building geographic knowledge of a disaster or emergency event from people in the field which can assist them in undertaking their tasks. The knowledge collected in the map can also be used by those managing the response, to improve its effectiveness and assist in having a greater understanding of the event. This is the basis of the research question for this exploratory research.

1.1 Research Question

A key requirement to forming an effective response to a disaster event is the ability to communicate. Those responding to the event need to be able to communicate with each other to coordinate their activities. On a larger scale, those coordinating the overall response need to be able to communicate with individual teams. Additionally there is the need to understand where teams are geographically located, where incidents are occurring and also where infrastructure used in the disaster response is located. This infrastructure includes such things as evacuation centres, food drops, or other equipment. Additionally this may also include existing infrastructure that has survived the disaster and may be used by those responding to the disaster.

While the focus of the research question is on the use case of personnel responding to a disaster or emergency event it has become clear, during the literature review component of this exploratory research, that there is a need to expand the scope of the use case to other users as well. For example people who live in the effected area who can contribute local knowledge to the map. This could also be extended to users who are outside the affected area, for example internationally based volunteers contributing information gained from other information sources such as the media, or even from inter organisation cooperation. To keep this exploratory research project focused, and in particular the development of the prototype application, the use case is focused on those in the field responding to an emergency or disaster event.

The Serval Project software addresses the need for communication by providing a resilient Ad hoc mesh network that supports voice communication in an infrastructure independent manner. As it is infrastructure independent the network can continue to support effective communication when the traditional telecommunications infrastructure may be damaged or otherwise unavailable. Importantly the network can, where possible, extend its capabilities by integrating with existing telecommunications infrastructure, or specialised Ad hoc mesh network infrastructure. This infrastructure includes small and ultraportable mesh potatoes (independently powered WiFi devices which can be used to extend the mesh) or a mobile device attached to the end of a telescopic pole. In this way the coverage of the network can be extended, for example via a cellular or satellite network to places outside the area affected by the disaster. The Serval Project software also supports communication where the installation of infrastructure is deemed to be not cost effective by telecommunications providers. This type of capability addresses the core tenet of the Serval Project, which is that *communication is a human right*.

As well as supporting voice communication the Ad hoc resilient mesh network powered by the Serval Project software can be used to support arbitrary network traffic that can in turn support a variety of applications. In the case of this research project the network is used to support a prototype collaborative mapping application. Therefore the research question for this project is as follows:

> *Is it possible to provide collaborative mapping services on mobile devices in an infrastructure independent manner?*

There are three main components to this research question; collaborative mapping, mobile devices and infrastructure independence.

1.1.1 Collaborative Mapping

Collaborative computing is a concept that can be defined as the "use of computer tools that make it easier for groups of people (possibly geographically separated) to work together as teams" [1, p. 108]. Using this definition the goal of the research project is to develop software that can be used by geographically separated users to collaborate on a map. Specifically the software will allow users to:

1. have the users own geographic location displayed on a map;
2. add incidents, represented by a marker, onto a map;
3. be able to see the geographic location of other users of the application on the map; and
4. share details of incidents with other users of the application on the network.

By achieving these four objectives users of the system will be able to collaborate on a shared experience, and build knowledge about a disaster or emergency event via the map. It is intended that users of the software will undertake these actions in the field and therefore the software is designed to be used on mobile devices.

1.1.2 Mobile Devices

It is intended that the primary use case for the software that is developed as part of this research will be users responding to a disaster or emergency event in the field. As such the software must be available on devices that have a small form factor, are easily transportable, and provide a well known user experience. Additionally to make the use of the system as ubiquitous as possible the software must work with devices that are readily available and do not need to be custom built.

For this reason the target device for the prototype application is a mobile phone, and in particular the type of mobile phone known as a smartphone. For the purposes of this exploratory research a smartphone is defined as a phone with more advanced computing capability and connectivity than an ordinary mobile phone, also known as a feature phone. Examples of smartphones include phones that use the Android platform[1] from Google or the iOS platform from Apple[2]. The larger screens, the ability to use a WiFi network and, especially the inclusion of Global Positioning System (GPS) hardware make smartphones an ideal platform for a mapping application. In particular the GPS capability is critical as the coordinate information provided by GPS is used to determine the users location and associate incident information with a location.

The Android operating system has been chosen as the development environment for the Serval Project software and this is the platform that is also used for the development of the prototype mapping application. In April of this year the technology research firm Gartner, used widely in the reporting on technology, released a report that determined that by "the end of 2011, Android will move to become the most popular operating system (OS) worldwide and will build on its strength to account for 49 percent of the smartphone market by 2012" [2]. In a recent survey mobile phones were found to be increasingly important in emergency situations with 40% of mobile phone owners saying that they had "found themselves in an emergency situation in which having their phone with them helped" [3].

The Serval Project software provides the underlying network and the ability to make voice communications possible between handsets without using traditional infrastructure. The network is in then used in turn by the prototype mapping application to share data among users and facilitate collaboration. Importantly, by using the Serval Project network communications can be achieved independently of existing telecommunications infrastructure.

1.1.3 Infrastructure Independence

As mentioned earlier the Serval Project software provides a resilient Ad hoc resilient mesh network that provides telecommunication and network services without relying on existing infrastructure. This is important in all tools and services, including software that is designed to be used in a disaster event where it is likely the existing infrastructure is damaged or non existent, and services will either be restricted or disabled entirely. Conceptually the Serval Project software is a platform for a resilient Ad hoc resilient mesh network that uses mobile phones as its primary form of network node. As such the Ad hoc resilient mesh network can use the capabilities of the mobile phone to integrate with existing infrastructure where available to provide greater coverage for the network.

Each network node is part of a number of mesh interconnections. A mesh interconnection is defined as:

> *"set of network connections in which there is more than one route between any two nodes on the network, thus giving resilience against the failure of any link between any pair of nodes"* [4, p. 315].

In a network powered by the Serval Project software the current primary form of network node is an Android[3] powered mobile phone. Each mobile phone maintains a list of inter-

[1] http://www.android.com/

[2] http://www.apple.com/iphone/

[3] Porting to other platforms, such as iOS from Apple or Symbian from Nokia, are longer term goals of the Serval Project.

connections and is able to support communication between nodes. Or as Gardner-Stephen writes, the Serval Project software is an:

> *"... implementation of a mesh mobile telephony system that is compatible with some existing mobile telephone handsets, and can be integrated into many more models without changing handset hardware designs or costs. This technology allows mobile telephones to directly communicate with one another, and allows telephone calls to be made without infrastructure beyond the telephones themselves"* [5].

As has been stated previously, the network not only supports telephone calls, the network also supports the use of arbitrary data. The resilient Ad hoc mesh network is used by the mapping software to share information and in turn support the collaborative map based activities. In the event of a disaster or other emergency event access to network infrastructure, other than that supplied by the Serval Project software, has a high likelihood of being either limited or non existent. Therefore the mapping software must be as self contained as possible and the data used to render a map must be available on the device itself. This is in contrast to such services as Google Maps for Mobile[4] which are constructed with the assumption that an Internet connection is always available for the retrieval of information and data pertaining to the map.

It is for this reason that the mapping software uses data sourced from OpenStreetMap[5] which is licensed using the reuse friendly Open Data Commons Open Database License (ODbL) license[6]. As such the prototype mapping software can store map tile data locally on the device. To use this cached data the mapping software uses the mapsforge[7] library to render a map and manage the user experience of interacting with the map. Additionally by using cached map tile data it is possible that a future version of the software will be able to use the Rhizome technology, a component of the Serval Project software currently under development, to share map tile data with other devices and thereby enhance the users experience. These concepts will be explored more fully later in the report.

1.2 Motivation

A core tenet of the Serval Project is that *communication is a human right*. This is especially true in the case of a disaster or other emergency event as effective communication directly contributes to the efficacy of the response to the event. It is this desire to help those affected by, and those responding to, an emergency or disaster event to communicate which motivates this exploratory research project. More broadly the Serval Project is motivated by its core tenet and a desire to help anyone communicate using telecommunications who may otherwise not be able to do so. The development of the mapping services software builds on this foundation by enabling geographic information to become part of the conversation.

Anecdotal evidence suggests that during the Black Saturday bush fires that ravaged Victoria in early 2009, communication was lost with some fire crews for an extended period of time during the response. It is this type of situation that was one of the catalysts for starting the Serval Project [6]. Additionally the Queensland Commission of Inquiry Interim

[4] http://www.google.com/mobile/maps/
[5] http://www.openstreetmap.org/
[6] http://opendatacommons.org/licenses/odbl/
[7] http://code.google.com/p/mapsforge/

Report shows that relying on telecommunications infrastructure for communication during a disaster or emergency event can be problematic:

> "*SMS alerts are . . . not a reliable method of providing flood warnings in parts of Queensland which experience problems with telephone coverage. That difficulty is compounded during a flood, when telephone reception can be affected by flood related power outages and congested telecommunications networks*" [7, p. 130].

It is for this type of reason the team developing the Serval Project software are motivated to develop an Ad hoc resilient mesh network that can provide telecommunications capabilities during an emergency or disaster event. Not only does the Ad hoc resilient mesh network support voice telephony, it supports arbitrary data and therefore can be used by other applications. The prototype mapping software is also an example of the Ad hoc resilient mesh network supporting data other than voice telephony data.

Importantly in developing use cases with interested parties, and undertaking the research into this project, it became clear that there is an opportunity to develop the mapping software further and have an impact on areas other than disaster and emergency response. These areas include research into fields such as the management of mass gatherings, or environmental management.

1.3 Contribution

The primary contribution that this research makes is in the development of the prototype application that supports collaborative mapping activities on an Ad hoc resilient mesh network. The initial testing of this application provides an affirmative answer to the research question outlined earlier. Undertaking the research and exploring the use cases has also shown that the Serval Project software can form the basis for an ecosystem of applications that can be used with an Ad hoc resilient mesh network. Development of the prototype application has also effected changes to Serval Project software which will make the development of this type of ecosystem easier.

Importantly in answering the research question this research has contributed to closing a gap in the literature discovered during the literature review phase of this research. Specifically this research has shown that an Ad hoc resilient mesh network, on commodity hardware, can support a collaborative application. Additionally the research into existing systems, especially the Ushahidi[8] system which provided the base model for the application, highlighted a number of use cases that had not been previously considered. As such this research project has shown that a distributed, collaborative mapping application on mobile devices has the potential to have an impact in a number of different areas.

1.4 Research Area

The primary research area is in collaborative systems on mobile devices, with a particular focus on the tools and technologies which support the functionality of the mapping services application. Research has also been undertaken into a number of supporting areas, including Ad hoc mesh networking, as well as exploring the various use cases that have been developed. For example applying collaborative mapping to other areas such as environmental management, or mass gathering research.

[8] http://www.ushahidi.com/

Importantly as initial investigative and exploratory research, this project has the potential to act as a springboard for future research into areas such as user experience design, the use of collaborative systems in emergencies, and the continued expansion of the use of Serval Project powered Ad hoc resilient mesh networks.

1.5 Project Summary

This project is an initial investigative study that sought an affirmative answer to the research question stated earlier and as such show that it is possible to use a collaborative system to build shared knowledge on a map in a infrastructure independent manner. As a result use cases have been explored and documented, and a prototype application has been developed. Investigation into the supporting technologies has been carried out as well as areas of future research highlighted. Lastly, and perhaps most importantly, this research has helped build awareness amongst project stakeholders of the potential uses of mapping software when combined with an Ad hoc resilient mesh network.

1.6 Report Structure

The structure of this report is as follows:

- Chapter one, this chapter, provides an introduction to the project and its research question.
- Chapter two, provides context and background to the project, including examining use cases and the motivation for the project.
- Chapter three, provides detail on the prototype application, the design considerations, as well as system internals.
- Chapter four, provides an overview of the testing conducted to date, as well as a more in depth proposed testing plan.
- Chapter five, concludes the exploratory research project and identifies possible avenues for future work

Chapter 2

Context and Background

A core tenet of the Serval Project is that *communication is a human right*. This is particularly important during times of disaster and emergency, where communication has been identified as a critical factor in the effectiveness of the response to a disaster or emergency event by the relief organisation that was involved in formulating the use case below. This use case in turn lead to the development of the research question for this project. As has been identified previously the research question is as follows.

> *Is it possible to provide collaborative mapping services on mobile devices in an infrastructure independent manner?*

The three main components of this research question; collaborative mapping, mobile devices and infrastructure independence and the discussion of the use case form the basis for this chapter.

2.1 Primary Use Case

The use case developed in conjunction with representatives of the relief organisation define a system that users could use to improve their geographic knowledge of a disaster or emergency event. The use case defined four main activities that users would need to undertake:

1. determine their own geographic location by having it represented by a marker on the map;
2. be able to see the geographic location of other users of the application on the map;
3. add incidents, represented by a marker, onto a map; and
4. share details of incidents with other users of the application on the network.

Using the GPS capabilities of the mobile device, in this case an Android powered smartphone, the users geographic location can be determined. This is represented on the map with a marker. As the user moves around the landscape the position of the marker changes to reflect their new location. In this way the user can improve their situational awareness by improving their knowledge of the landscape and their position within it. As the users location changes, updates are sent across the resilient mesh network to other users of the system. As such a user can see their own geographic location as well as other users.

To help distinguish between users two coloured markers are used. One for their own location, and another for the location of others. In this way a user of the system can see their own location in relation to the landscape and to the other users of the system. This means for example that members of a team responding to the disaster or emergency event can monitor the location of each other and improve the coordination of their efforts. In a planned future release of the system more complex iconography is planned which would allow a user to distinguish between the markers for other users and identify a specific user. Currently a user must touch the marker of another user to see some information about that user.

For the purposes of the research project an incident is defined as an event happening in the area affected by the disaster or an emergency. A user can add an incident to the map at their currently location by specifying a title and brief description of what is occurring. Example incidents include such things as “The bridge at this location is out”, “The building at this location has suffered significant damage”, or “The disaster response control centre is located here”. Associated with the information about the incident is the geographic coordinates and the phone number of the user who added it to the map.

Once the incident is added to the users map, the information is sent across the network to other users of the system. Features for a planned future release include the option to include a image with an incident report, applying different categories to incidents including enhanced iconography, and the ability to add an incident by touching an area on the map and using this location rather than the location of the user. Additional planned features also include implementing encrypted packets using the mechanisms provided by the Serval Project software, as well as filtering information based on criteria such as a trusted user list. Even without these enhanced features the prototype application supports the activities of the users in collaboratively building a map which enhances their understanding of the geographic layout of the disaster or emergency event.

2.2 Collaborative Mapping

Collaborative mapping for the purposes of this exploratory research project, is defined as undertaking the tasks as outlined in the use case presented in the previous section. By facilitating the four main activities and supporting collaboration the users of the system can help individual team members in their response to the event and increase the information available to those tasked with managing the response. Importantly these activities can be undertaken in real time and without reliance on existing telecommunications infrastructure. The main inspiration for the software is a platform known as Ushahidi (subsection 2.2.1) which provides similar functionality to that provided by the prototype application with some key differences.

2.2.1 Ushahidi

Ushahidi is a collaborative mapping system that is widely used to collate information about disasters, emergencies and other crisis events. The term ‘Ushahidi’ means ‘testimony’ in Kiswahili (Swahili) and was developed during a period of post-election violence in Kenya in late December 2007 and early January 2008 [8]. At the time of its first deployment the system allowed users to anonymously report incidents of violence online or via SMS (Short Messaging Service) message and have these reports added to a map so that people could visualise what was occurring.

The main point of differentiation between the Ushahidi platform and the prototype application developed by this exploratory research is that Ushahidi is infrastructure dependent. Telecommunications infrastructure is required to report incidents, either via SMS or by visiting a website directly, and the map is displayed on a website which must be viewed over the Internet. In contrast the prototype application is infrastructure independent and can provide access to the map without the use of telecommunications infrastructure. Even with this dependence on infrastructure the Ushahidi platform has been shown to provide invaluable information during an emergency or disaster event.

Ushahidi was used during the response to the earthquake that struck Haiti in 2010 where information was gathered from news reports and more importantly directly from individuals about the most acute needs of people affected by the disaster. Reports included information about the need to be rescued, food, shelter, water as well as issues of security [9]. Initially the reports were primarily sourced from phone calls and news reports. In time the use of SMS, even though access to the telecommunications infrastructure was erratic, increased and the reports sourced from the Ushahidi instance were used by many relief organisation, the U.S. Coast Guard and the U.S. Marines. Importantly many of the reports were of direct assistance to those responding to the disaster event as they included geographic information [10].

A planned feature of the prototype application is to encrypt the information sent and received by the application using the mechanisms provided by the Serval Project software that are currently under development. Using these mechanisms it would also be possible to introduce the ability to apply trust levels to users and by extension their incident reports. In this way the information added to the map gains some authority depending on who had added it to the map. Us trust levels it would also be possible to filter out information from users if necessary, for example if a particular user was found to be untrustworthy or if the map was only to show information from members of a single organisation for example.

The use of SMS, while critical to the construction of the map, showed the difficulties in relying on traditional telecommunications infrastructure during a disaster event. For as Nelson et. al. write:

> *"Haiti's overwhelmed cell phone providers made their systems available for the relief efforts, but often could not handle the volume. In some cases, SMS broadcasts from a relief organisation crashed a cell phone network for over four hours at a time"* [10, p. 24].

Ushahidi was also used in the response to the earthquake in Christchurch, New Zealand in 2011. Within 6 hours of the earthquake occurring an international team of volunteers had set up an instance of Ushahidi that in a few days following the event had collected 779 reports on 781 different locations and received 69,143 unique visitors [11]. The knowledge in a Ushahidi map was contributed by a wide range of stakeholders on a wide variety of topics. Some of which may not be classed as sufficiently important to warrant inclusion in an official government publication. For as McNamara writes:

> *"It's unlikely that the nearest open cafe will ever appear on a civil defence publication. However, these community assets are important too. Proving a neutral space for crowdsourced information meant that we could combine official information about essential services with less critical information, such as locations of free BBQs that were established by neighbours helping each other out"* [12].

Crowdsourcing is defined as the act of "delegating a task to a large or diffuse group, usually without substantial monetary compensation" [13]. Information collected in this way has proven effective in managing responses to other disasters. During the response to the earthquake and tsunami that occurred in Japan on March 2011, crowdsourced information was shown to assist patients in accessing medicines, and facilitated discussion between patients and health care workers which may not have been possible otherwise [14].

During the recent crisis in Libya an instance of Ushahidi was used by the United Nations to collate data and share it with other organisations and relief workers both within and outside the country. In a 48 hour period the team was able to collect 100-plus incidents and have them displayed on a map. The same amount of information used to take between 2 and 4 weeks to compile [15].

Ushahidi can be used in other circumstances other than disasters and emergencies. A group of Egyptian women are using a Ushahidi instance, named HarassMap[1], which tracks instances of sexual abuse in Cairo. The map allows the volunteers to visualise hotspots and then contact shop keepers or others in the area about ways to make the area safer for women. Figure 2.1 shows a screen capture of the HarassMap map which shows how incidents can be categorised and displayed on the map. It is possible to envisage a use case where a mesh network could be used to provide information to users of a service like HarassMap in realtime so that they could adjust their travel plans as they moved through an area. This would be especially useful in times of unrest such as during a protest. During the recent protests as part of the "Arab spring", many groups contacted the Serval Project with interest about the ability to communicate without the reliance on telecommunications infrastructure and expressed interest in the possibility of mapping for use in just this type of scenario.

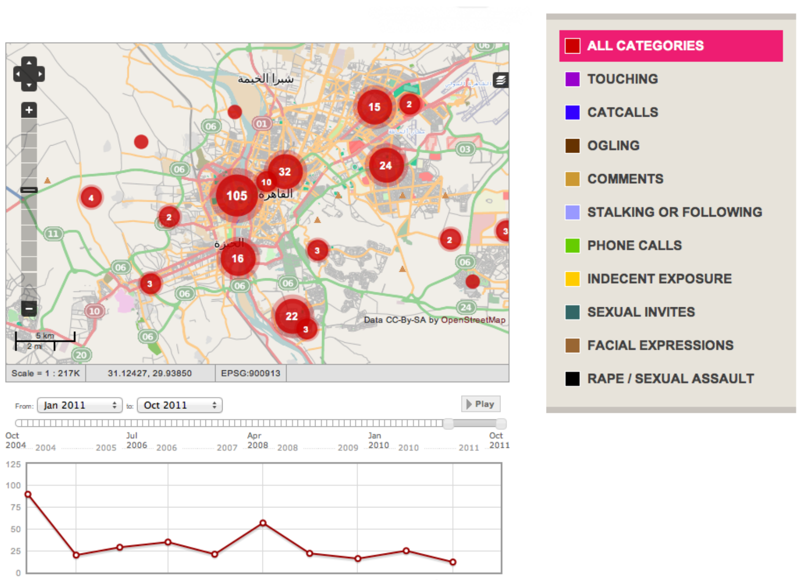

Figure 2.1: A screen capture from the Egyptian HarassMap

There are three main points of comparison between Ushahidi and the prototype applica-

[1] http://harassmap.org/

tion. First is the reliance on telecommunications infrastructure, either in the use of SMS to send in incident reports or an Internet connection to access the website and view the map. In instances such as Haiti or Libya the Ushahidi instance has been setup by people outside the affected area and has been used to coordinate the response. In contrast the prototype application is designed to be used by people in the field on their mobile devices. A future research opportunity is in exploring how the two systems could be connected. For example using mobile devices on the mesh resilient network to collect information and then link in with existing infrastructure to send data out of the area for inclusion on a website such as a Ushahidi instance.

The second is in the use of crowdsourced data. By sourcing data from potentially unreliable sources the knowledge represented in the map map be compromised. Many of the projects that have used a Ushahidi instance have developed a team of volunteers to filter incident reports and to look for corroborating evidence. The prototype application is particularly susceptible to this as no filtering mechanisms are in place. As mentioned earlier a planned feature of the application is to leverage the encryption capabilities of the Serval Project software, currently under development, to improve the security of the system and to assist in filtering messages by sender phone number, or group affiliation.

Related this second point is the retention of users who contribute to the map. Typically the number of users who actively contribute content for the map make up a very small percentage of the overall user base, for as Kobia writes:

> *"a mere 1 percent of participants actively contribute new content, 9 percent interact with it, and the other 90 percent are mere viewers. These ratios slide further towards passive viewing once an event is no longer front-page news"* [16].

It is hoped that by providing a system that can be used in the field higher retention rates would be seen. Field testing of the application is a particularly important future avenue of research once these and other additional features are included.

The third and final point of comparison is the functional perspective of the user interface. A map that aggregates data into a series of markers can appear to over simplify the data. This over simplification either leads to knowledge loss or user who are more likely to disengage from the map. For example the map produced by Ushahidi or the prototype application can be seen simply as a map with a series of markers on it. It is important to remember that as Kobia notes *"behind each of those dots [markers] is a human experience - perhaps a life or lives that have been touched by disaster"* [16]. This is particularly evident in the HarrasMap mentioned earlier where an example incident stated:

> *"A man followed me in his car as I walked by McDonalds. He got out of the car ... asked me for directions, pinned me to the side of the bridge and grabbed me in inappropriate places"*" [17].

In the use case presented at the start of this section this point of comparison is less of an issue as the map produced by users of the system is designed to be used in the field during their response to the disaster and emergency event, typically by those responsible for responding to the event such as emergency relief organisations. During the research component of this research the potential benefits of using crowdsourcing to collect information was highlighted and features to assist in this have been added to the roadmap for future development of the mapping software. The literature review phase of this project also highlighted a number of other systems that have provided insight into other use cases for the application.

2.2.2 Other Geographic Systems

The prototype mapping application has been developed with a focus on the use case outlined earlier. As such it provides the main functionality identified in collaboration with the disaster relief organisation for use in the field. The literature review phase of this research project has highlighted a number of other potential use cases and other projects working in the area of mapping with mobile devices, although the resilient mesh network aspect of the project remains unique. One such use case that has been identified is environmental monitoring.

A recent study has looked at using a mesh network to track tigers in India [18]. In this use case the tigers are fitted with a collar that include a GPS receiver and includes mesh network capabilities. The position of the tiger is tracked over time by the collar and the data stored. When a tiger comes in range of a "anchor node", the data is transmitted to a base station. Once received at the base station the data can be plotted on a map to determine where the tigers have travelled. Alternatively ranges can use a mobile device which is part of the mesh network to retrieve data and provide analysis in the field.

The main point of differences between this project and the prototype mapping application is that the collar on an individual tiger only stores the data for that tiger and the data is transmitted back to a central point for analysis. In the prototype mapping application each device on the network contains a copy of the incident and location data. The data is sent over the network either as it is collected or periodically resent so that nodes that have joined the network also collect the data. In this way there is no central repository of data that must be relied upon and this is as a result of the infrastructure independent nature of the project.

A further example of the use of mobile devices with mapping capabilities being used for environmental management is the Water Canary[2]. This devices uses a proprietary techniques to undertake spectral analysis of a water sample to determine its quality. The device can then use any open wired or wireless network to transmit the geocoded results of the analysis. This data can then be put on a map that displays positive tests using green markers and negative tests in red. Visualising the data in this way allows users of the map to more easily identify areas where a significant number of tests have failed. These areas may then be targeted for further analysis by a team using more extensive water testing apparatus [19].

There are two main points of contrast between the Water Canary and the prototype application. The first is that the Water Canary doesn't support its own network. To transmit data back to a centralised repository the device must be connected to an open wired or wireless network. Secondly the map isn't available on the device, it must be viewed using a computer or other mobile device. By pairing the device with a smartphone that was sharing its Internet connection this issue could be alleviated.

It is worth noting that an increasing number of Android powered smartphones support integration with accessories via the Android Open Accessory platform[3]. This allows accessories to be plugged into the smartphone and to communicate with software on the device. In this way it is possible to envisage a smartphone that is used to provide access to a mesh network and map based software that can be used with a variety of different accessories such as a water quality testing device for environmental monitoring. Such a system could not only transmit data back for later analysis it could also be used to support analysis and advanced data gathering in the field. This capability is not restricted to Android powered

[2] http://www.watercanary.com/

[3] http://developer.android.com/guide/topics/usb/adk.html

devices, for example a young researcher has developed a device which can be used with an Apple iPhone that can detect radiation and uses the iPhone to display the readings [20].

A smartphone can also be used to support in the field medical analysis. For example researchers at the University of California, Berkeley have devised a way to integrate a mobile phone into a device that turns the camera on the device into a diagnostic-quality microscope known as the CellScope[4]. The goal of the project has been to *"demonstrate the feasibility of creating an entirely integrated and portable mobile phone microscopy system"* [21].

Whether the data is collected by observations undertaken by the user, collected from an accessory, or even simply by moving around the landscape, the key aspect is the ability to visualise on the map information that could not be readily understood before. It is this ability to visualise information on a map that has had ramifications in a number of different disciplines including the humanities where a new form of scholarship is under development known as Spatial Humanities[5]. By visualising data on a map, especially data that is also time coded, a researcher can gain insights into their chosen field that were not possible before. As Knowles states:

> *"Mapping spatial information reveals part of human history that otherwise we couldn't possibly know ... It enables you to see patterns and information that are literally invisible"*" [22].

The goal of visualising information on the map is to take data, transform it into information and from there build knowledge. This is a common thread between the exploratory research of this project and the research projects outlined in this section. The key factor for this research is in the use of mobile devices, in particular smartphones, to collect, analyse and map the data. The use of smartphones and mobile devices is the topic of the following section.

2.3 Mobile Devices

The primary use case for the prototype software is that it is used in the field during the response to a disaster or emergency event. As such the software needs to be available on a device which is small, portable and is capable of supporting the mapping activities. The device needs to have a screen capable of displaying a map, include a GPS receiver so that the geographic location of the device can be determined, and support access to an Ad Hoc network using WiFi (Wireless Network). Additionally to have the best chance of being used in the field the device must be readily available, for example the device cannot be custom manufactured. It needs to be readily available and for a reasonable cost. Especially if the goal of the prototype software is to expand the use of the system into areas such as crowdsourcing information.

For these reasons the use of a mobile phone, specifically a smartphone, as the device for the prototype application is a natural fit. The term smartphone, for the purposes of this exploratory research is defined as a mobile phone with more advanced computing capability and connectivity than a basic mobile phone, also known as a feature phone. Consequentially a smartphone powered by the Android operating system from Google was chosen as the target device. While some Android powered devices can cost many hundreds of dollars for a high end smartphone, there is a market segment that includes smartphones that cost less

[4] http://cellscope.berkeley.edu/index.html
[5] http://www.scholarslab.org/announcements/frontiers-in-spatial-humanities-video/

than one hundred dollars as well. Making them readily available for a reasonable cost. An example of such a device is the Huawei IDEOS u8150[6] which has been the primary testing platform for the Serval Project to date.

There are three main technical reasons for this choice. The first is that a smartphone running the Android operating system has been chosen by the Serval project as the initial target for the development for their resilient mesh network software. The Android operating system was chosen because at its core it uses a Linux based kernel. This is important for as Gardner-Stephen notes "Our research group already has extensive UNIX development experience, enabling us to leverage the opportunity to manipulate the WiFi hardware on Android phones at a low level" [23]. Figure 2.2 provides an overview of the Android operating system and shows the Linux kernel at the bottom of the stack [24].

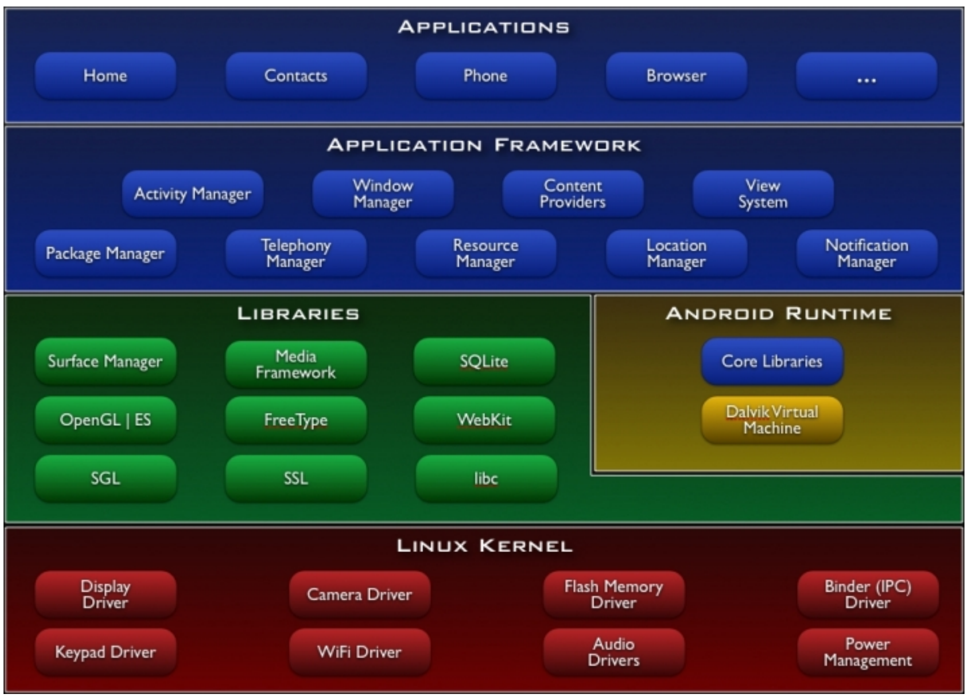

Figure 2.2: The Components of the Android Operating System

The second technical reason is that the Android operating system includes the Android runtime and application frameworks. These provide a rich environment in which to develop an application and the Android runtime provides a familiar development experience by using the Java programming language. Also, the Android operating system provides a touch based user experience that users are becoming increasingly familiar with due to the increasing popularity and availability of touch based devices. The Android framework provides relatively straight forward access to the data and services necessary for a map based application including access to GPS coordinates, creating and managing databases and as well as accessing file and network resources.

The third and last technical reason is that the prototype application must used map data cached locally on the device in order to achieve the third goal of the research project,

[6]http://huaweimobile.com.au/u8150

infrastructure independence. To achieve this the prototype application is built around the mapsforge[7] library. This library manages the rendering of the map and provides a robust API for adding markers and other overlays to the map, as well as capturing the actions of the user. The data for the map is sourced from OpenStreetMap[8] which is licensed using a reuse friendly Open Data Commons Open Database License[9]. Under the terms of the Creative Commons license it is not only possible to cache data locally on the device, it is possible to share the data with other devices on the network. These are two attributes that are necessary to achieve infrastructure independence.

Additionally there are a number of non-technical reasons as to why Android has been chosen as the development platform for the prototype application. First among them is the potential number of smartphones running the Android operating systems. Recent research by Gartner as shown that in the third quarter of 2011 Android devices accounted for 52.5 percent of total smartphone sales, more than doubling the market share seen in the same quarter last year [25]. There are a number of different versions of the Android operating system currently in use on devices. Android 2.1, also known as “Eclair”, was chosen as the version that would be used for the development of the prototype application. As such the software can potentially run on over 90% of all of the Android powered smartphones that have accessed the Android marketplace in late October - early November 2011 [26].

This is not to say that developing on the Android platform is without its challenges. The first is that at the time of writing there is no API in the Android runtime or framework to configure the WiFi hardware in Ad Hoc mode. This is the preferred mode when constructing a WiFi resilient mesh network using the Serval Project software. To configure the hardware it is necessary to gain root privileges on the device and configure the hardware at the Linux kernel level. The root, or super user, level of access to the operating system is typically disabled by the manufacturer of the smartphone. To gain this level of access it is necessary to undertake various activities that are collectively known as “rooting” the device[10]. Once the phone is “rooted” it is possible to undertake the low level tasks using the elevated privileges.

Unfortunately each different WiFi chipset needs to be configured differently in order to support an Ad Hoc WiFi network. Differences in chipsets, firmware and drivers mean that different options need to be used when loading or configuring the WiFi kernel module. This limits the number of devices that the Serval Project software can be used with as each chipset and firmware combination must be analysed to determine the appropriate options. An exploratory research project that is being undertaken at the same time as this one is looking into ways in which this process can be automated, either by guessing the correct settings or at the very least providing feedback to the Serval Project development team. A recent developers only build[11] of the Serval Project software includes this functionality and at the time of writing is undergoing testing by the developer community.

This challenge can be seen as a symptom of a larger problem. With a few exceptions the source code for the Android operating system has been released as open source and can be downloaded[12] by anyone who is interested in developing an Android powered device. While releasing the source code can be seen as an opportunity, in that any interested manufacturer can download the source code and use it to build their own device, it does cause fragmentation in the Android ecosystem. Fragmentation occurs at two levels, at the hardware level

[7] http://code.google.com/p/mapsforge/
[8] http://www.openstreetmap.org/
[9] http://opendatacommons.org/licenses/odbl/
[10] http://en.wikipedia.org/wiki/Rooting_(Android_OS)
[11] http://groups.google.com/group/serval-project-developers/browse_thread/thread/801f5ef6523d6446
[12] http://source.android.com/source/downloading.html

and the software level. An example of the hardware fragmentation is the issues caused by the different WiFi chipsets to the Serval Project. An example of the software fragmentation is that many phones aren't updated to the latest version of the Android operating system. Possibly due to incompatibilities with the hardware used to build the device, or other market pressures such as building demand for the next new device. A recent investigation showed that up until the end of 2010 seven of the eighteen phones studied never ran a current version of the operating system, and that twelve of the eighteen phones ran a current version for a few weeks or less [27], this can be seen more clearly in Figure 2.3.

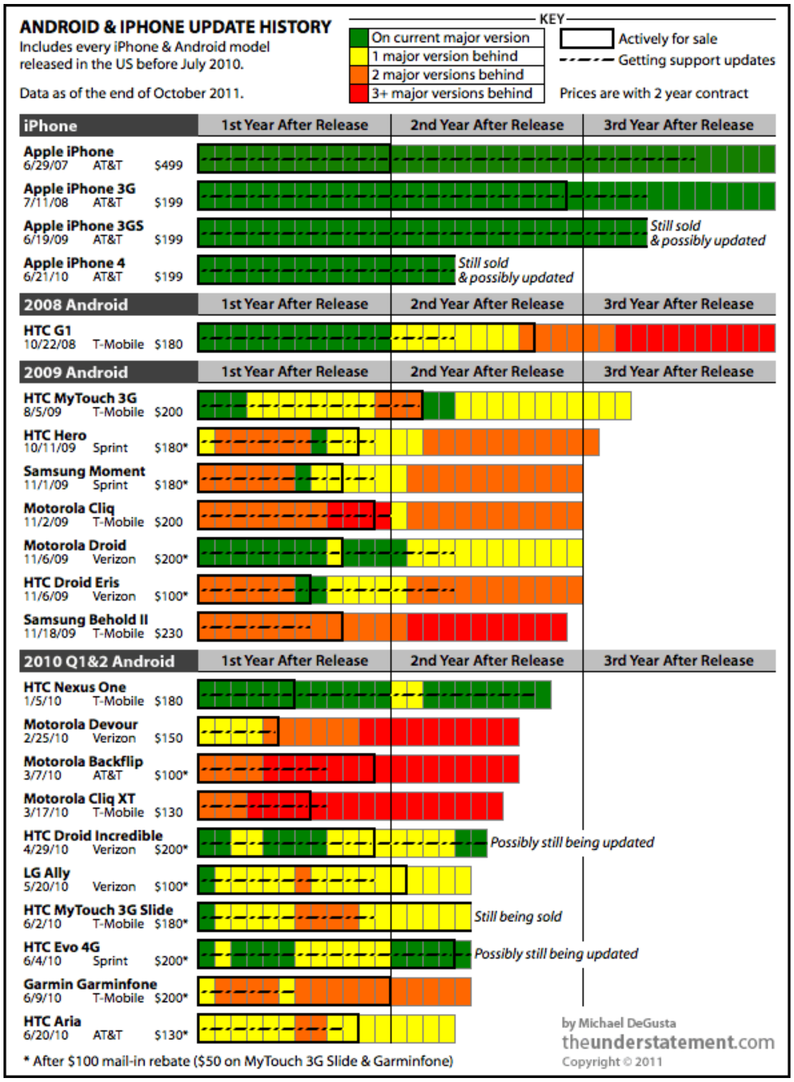

Figure 2.3: An infographic detailing Android fragmentation over a 3 year period

The problem of fragmentation is compounded by the fact that there are many third parties that have developed their own versions of the Android operating system for installation on various devices. One of the more popular examples of this is CyanogenMod[13]. Ultimately what this means is that while the current version of the prototype application can potentially be used with a large number of phones, as its development target is a relatively old release of the Android operating system, care will need to be taken in the choice of the next development target to ensure that it continues to have the possibility of working with as wide a range of smartphones as possible.

Putting these issues aside the smartphone still presents a compelling case for the platform for the prototype application within the use cases outlined earlier, and in particular in the main use case of the response to a disaster or emergency response. A smartphone typically travels within the user wherever they go, so that it is likely to be with them when a disaster or emergency event occurs. When not used in the response to a disaster or emergency event the user can access their email, browse the Internet and undertake many other tasks related to their working lives. Finally they can use it as a phone to keep in contact with colleagues, family and friends. As it is a device that the user is has used extensively it is anticipated that the user experience will continue to be familiar even under the high cognitive load during an emergency or disaster.

Prior to entering the area affected by the disaster or emergency the required map data can be loaded onto the device so that the map can be used without the need for any existing infrastructure. Alternatively the map data can be updated in the field using the Rhizome functionality provided by the Serval Project software. Rhizome is defined by Gardner-Stephen as a:

> *"mesh file distribution protocol that allows user-created content and software updates to spread hop-by-hop over the mesh. This hop-by-hop approach elegantly solves many of the problems with mesh-wide file transfer, in particular bandwidth starvation and instability of long links"* [28].

In this way map data can be updated as required, for example when a user moves into an area where their phone does not have map data, or alternatively where updated map data is available. For example if the disaster or emergency event has changed the topography of the landscape in some way and the map needs to be updated to reflect this. In essence when not used as part of the response to a disaster or emergency event the smartphone can be used to support the day to day activities of the user. During the response, it can be used as an infrastructure independent communication device that is part of a resilient mesh network.

2.4 Infrastructure Independence

The research question and primary use case, require the the prototype application be able to provide the required core collaborative mapping activities in an infrastructure independent manner. Therefore the application cannot use existing telecommunications infrastructure to share information between user, or use the Internet to retrieve map data in order to render a map. The primary use case for the application is during the response to a disaster or emergency event, and as such traditional telecommunications infrastructure may be damaged or overloaded. Additionally in the other possible use cases access to infrastructure may be limited, for example due to the remote location where environmental monitoring is being undertaken. To this end the prototype application uses the resilient Ad Hoc mesh network provided the main Serval Project software to share information.

[13] http://www.cyanogenmod.com/

2.4.1 Ad Hoc Mesh Networking

The prototype application is integrated with the main Serval Project software, in order to use the resilient Ad Hoc mesh network to transfer information between instances of the application. Specifically information related to the geographic location of users, and the incidents that they add to the map must be shared in order to facilitate the four core collaborative mapping activities identified earlier. A resilient Ad Hoc mesh network can be defined as:

> *" a decentralized [sic] type of wireless network. The network is ad hoc because it does not rely on a preexisting infrastructure, such as routers in wired networks or access points in managed (infrastructure) wireless networks. Instead, each node participates in routing by forwarding data for other nodes, and so the determination of which nodes forward data is made dynamically based on the network connectivity"* [29].

The main Serval Project software uses the wireless network interface of an Android powered smartphone, to form a resilient Ad Hoc mesh network with other smartphones or specialised mesh infrastructure. Such infrastructure includes small and ultraportable mesh potatoes (independently powered WiFi devices which can be used to extend the mesh) or a mobile device attached to the end of a telescopic pole. A mesh potato may also be used to form a bridge between the mesh network and a Broadband Global Area Network (BGAN) terminal to provide satellite based access to the Internet.

The access provided by a BGAN terminal is expensive and provides a relatively small amount of bandwidth and therefore should be considered a precious resource. The smartphones themselves can also provide access to the traditional cellular telephony infrastructure where possible. The variety of connectivity options that can be used with a resilient Ad Hoc mesh network managed by the main Serval Project software can be seen in Figure 2.4 [30].

The resilient Ad Hoc mesh network is used by the prototype application to support the four core collaborative mapping activities, in areas where access to traditional telecommunications infrastructure is not possible or unreliable.The use of the resilient Ad Hoc mesh network, when combined with the use of map data stored on the smartphone, makes the application predominantly infrastructure independent. The one piece of infrastructure that the software must continue to rely on is non terrestrial and it is the Global Positioning System (GPS).

2.4.2 Global Positioning System

The Global Positioning System is critical to the operation to the prototype application, as it provides the the geographic coordinate information used to identify where markers must be placed on the map. To use the capabilities of the GPS a receiver is used on the smartphone to receive signals from four or more GPS satellites, of the 31 currently in operation, that are orbiting the Earth. Using these signals the receiver is able to calculate the geographic location of the smartphone on the Earth. The geographic location of the smartphone is used to infer the location of the user as well as the incidents that they add to the map.

Many smartphones can also make use of Assisted GPS (A-GPS) to provide geographic information. For example where an insufficient number of satellites can be seen by the GPS receiver on the smartphone, or to achieve a fix on the location faster. A-GPS is a system where:

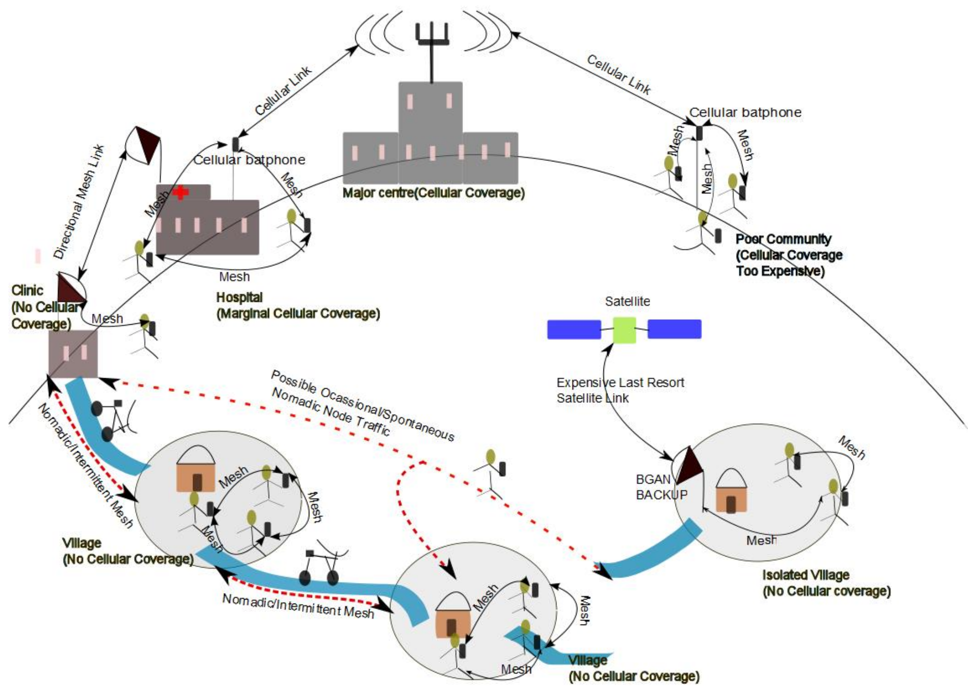

Figure 2.4: The various components of a Serval Project powered network

> *"many of the functions of a full GPS receiver are performed by a remote GPS location server. This remote server provides the A-GPS mobile device with satellite orbit and clock information; the initial position and time estimate; satellite selection, range and range date; and position computation."* [31, p. 6].

Additionally a smartphone may also use WiFi position or cellular positioning as a means of providing geographic location information. Using these types of techniques involves communicating with a remote server details about the WiFi access points, or cellular telephony towers, that can be seen by the device. The remote server maintains a list of these pieces of infrastructure with known coordinate information. Using this information the remote server is able to calculate an approximate geographic location of the smartphone.

From the perspective of the average user, these systems may be a preferred option as they are capable of providing an initial first fix on a geographic location in less time and using less power from the battery, than the full GPS system. The downside, from the perspective of this exploratory research project is that an active Internet connection is required in order for these types of system to work. In the event of a disaster or emergency event the required infrastructure may be damaged or unavailable meaning that the required Internet connection is not available. Or alternatively not enough of the infrastructure is operational to provide enough information to calculate a fix. Additionally in testing undertaken by Zandbergen it was found that these techniques do not provide geographic information with the same accuracy as full GPS [31].

One further complication, from the perspective of this exploratory research, is that some manufactures of the cheaper Android powered smartphones reduce the cost of manufacture by only A-GPS capabilities in their devices. Using devices like this, without access to telecommunications infrastructure means that geographic information is either not available, or a fix may take significantly longer to achieve than devices which include full GPS capability.

A final concern with regards to GPS is that it is a single system and therefore represents a single point of failure. If the system were to fail in any way, for example if the satellites started to fail, the ability for the smartphone to provide geographic information would be compromised. Fortunately there is an alternative system known as the Global Navigation Satellite System (GLONASS) which has been put in place by the Russian government. Some manufacturers are including support for the GLONASS systems in their smartphones, such as Apple and the recently released iPhone 4S [32]. Having multiple sources of satellite based geographic information not only improves redundancy, as one study has shown it can be used to increase the accuracy of the information in difficult terrain [33].

Chapter 3

Prototype Application

The prototype application has been developed using the Java programming language, using the Android framework and Android runtime. It has been released as Open Source using version 3 of the GNU General Public License[1] (GPL). In keeping with the Open Source nature of the prototype application the source code is available on a public GitHub repository[2] where interested developers can download the source code and contribute changes if they so choose. It is planned that additional documentation, samples, and other information will be made available as development of the application progresses. It is intended that this thesis will contribute to the set of documents and information.

This chapter examines the prototype application, and considers the design of the application, the development of supporting applications, the users experience when using the application, the format of the network packets used by the application, and lastly the binary map file format used to render the map and cache data on the smartphone.

3.1 Design Considerations

As has been stated previously the main use case for the prototype application is to provide an environment that supports collaborative mapping on mobile devices during the response to a disaster or emergency event. It is this use case which has influenced the development of the application to date within the requirements of this exploratory research and the related constraints on time and resources. The primary use case also stipulates that the application must work in the absence of traditional telecommunications infrastructure, as in a disaster or emergency event this infrastructure may be unavailable due to damage or over subscription. For these reasons, the prototype application is designed be installed on a Android powered smartphone and used in conjunction with the main Serval Project software.

The main Serval Project software manages all aspects of the resilient Ad Hoc mesh network: it provides a list of peers to the prototype application, which it then uses to send location and incident packets as the mechanism to share information between instances of the prototype application running on smartphones that are part of the network. Currently the prototype application, uses the User Datagram Protocol (UDP) to send plain text packets. The path that these packets take through the network to reach the other network peers is dependent on the main Serval Project software and the way that it manages the network.

[1] http://www.gnu.org/copyleft/gpl.html
[2] https://github.com/techxplorer/ServalMappingServices

As each location and incident packet is sent as plain text, this has been identified as a security concern, as packets can be intercepted by unauthorised parties and potentially modified in transit, or sent and received by unauthorised applications. The plain text packet format was chosen as it made the initial development of the networking components of the prototype application easier, time and resources could then be spent on other aspects of development, such as gaining an understanding of the Android environment itself. A considerable amount of time and resources was spent on understanding how user interfaces are developed, and the way in which components of an Android application are constructed and managed by the Android framework and runtime. UDP was chosen as the transport for the packets as it is a much more efficient way of transferring small amounts of data, especially when the amount of data is limited to that which can be contained in only one packet. Lastly the use of a plain text packet format allowed for the construction of a number of supporting applications that were used during the initial development phases of the prototype application.

To address these security concerns, a future version of the prototype application will use the encryption functionality of the main Serval Project software which is currently under development, to encrypt the content of packets and ensure that packet content cannot be accessed by unauthorised users or applications. Additionally more advanced measures may be taken, for example using shared encryption keys so that a group of users who have access to the appropriate credentials can decrypt the packet, and the use of cryptographic hash in the content of the packet to ensure that the content is unchanged and was indeed originally sent by the specified user. The main benefit of using the main Serval Project software is that the resilient Ad Hoc mesh network allows the use of the prototype application without relying on traditional telecommunications infrastructure.

The one piece of infrastructure that the prototype application is reliant upon is the Global Positioning System (GPS), as this is the source of geographic information that specifies the location of the smartphone, and by extension the location of the user themselves. Geographic location information is requested using the standard methodology as outlined in the Android developer documentation[3]. Only information sourced from the GPS location provider is used as the other location providers are infrastructure dependent, for example using the cell-id of telecommunications infrastructure to determine an approximate location based on the triangulation of signals from a number of telecommunications towers.

A benefit of this approach is that a more accurate location can be determined using GPS, which has a direct positive influence on the accuracy of the information added to the map. The downside to this approach is that it can take a relatively long time to determine an initial location fix, in testing this was shown to be as much as 3 minutes in some cases depending on the GPS chipset used and environmental conditions. Additionally it was discovered using the GPS hardware exclusively increases the drain on the battery of the smartphone as it is necessary to keep the GPS hardware powered on during the time that the application is in use. Further testing needs to be carried out to determine the optimal model for managing the location requirements of the application.

The data used to construct the underlying map must also be stored on the device. In keeping with the requirement of infrastructure independence it is assumed that there is no reliable Internet connection to source map tiles from third party servers, for example those that power the native Google Maps capabilities. Therefore the maspforge library (section 3.5) is used as a replacement for the standard Google Maps component provided as part of the Android framework. This library is able to use data that is stored in a relatively

[3]http://developer.android.com/guide/topics/location/obtaining-user-location.html

efficient manner on the SD card using a mapsforge specific binary file format. Additionally as the data is sourced from the OpenSteetMap which uses the reuse friendly Open Data Commons Open Database License. This permissive license means that data can be shared amongst users of the application if required using the forthcoming Rhizome component of the main Serval Project software.

3.2 Supporting Applications

Three supporting applications were constructed during the early stages of the development of the prototype application. These applications were designed to support testing of components of the prototype application. All three applications have been released as Open Source under the terms of the GPL.

The first supporting application was designed to send a UDP packet in order to testing the packet receiving capabilities of the prototype application. The content of the packet can either be sourced directly from the user via the console or alternatively from a packet script. The packet script is essentially a plain text file that specifies a delay, in seconds, and the content of the packet. The specified delay is used to space out the sending of the packets as specified by the script. For example a packet may be sent by the application, then a delay of 10 seconds is observed, and then the next packet is sent. By making the delay part of the script packets could be sent with differing amounts of delay. This application was used primarily to send packets to the prototype application while running within the Android emulator and to observe how the application behaved. It was not used once the testing of the application moved to using actual devices. The source code for the application is available via a GitHub repository[4].

The second application was designed to receive UDP packets and to echo their content to the console and alternatively to a text based log file. The application was used primarily to test the prototype application while running within the Android emulator and to observe how packets were being sent by the prototype. It was not used once the testing of the application moved to using actual devices. The source code for the application is available via a GitHub repository[5].

The third and final supporting application was designed to use a list of geographic coordinates as input and construct a packet script that could be used with the first supporting application. The content of the script was designed to be a series of location packets, each packet using one of the sets of geographic coordinates from the supplied list. This packet script could then be used to test the prototype application while it was running within the Android emulator to see how the application behaved to a stream of incoming location packets. Additionally a number of instances of the first supporting application could be used, each with different packet scripts, to see how the prototype application behaved with multiple incoming streams of location packets. The source code for the application is available via a GitHub repository[6].

Construction of these three supporting applications was made relatively easier due to the use of a plain text packet format, and were used during the early stages of the development of the prototype application. They were not used once testing of the application progressed to using actual smartphone devices and the resilient Ad Hoc mesh network provided by the

[4]https://github.com/techxplorer/UdpSender-App
[5]https://github.com/techxplorer/UdpLogger-App
[6]https://github.com/techxplorer/CoordsToLocations

main Serval Project software. They were also used in undertaking early testing of the user experience of the prototype application.

3.3 Prototype Application User Experience

In order for a person to use the prototype application, they must have an Android smartphone that works with the main Serval Project software. As this is Open Source software it is possible to either build the software from source, available via a GitHub repository[7], or download and automatically install the compiled version of the software via the Android Market[8]. The most recent version of the software will always be available via the GitHub repository, while developer only release candidates of the compiled software may also be announced to the Serval Project developer mailing list[9].

The prototype application is available as source code via its own GitHub repository and this is currently the only distribution channel for the software. It is possible that a future release may be made available via the Android Market when it is deemed to be feature complete, or it may be incorporated into the main Serval Project application. Therefore at the moment to install the prototype application on a device a user must download and compile the source code themselves. Additionally to fully experience the capabilities of the prototype application at least one map data file (section 3.5) must be copied to an SD card that is installed in the smartphone into a specific directory. Detailed installation instructions are beyond the scope of this document and will be added to the Serval Project wiki when appropriate.

After the main Serval Project software has been installed, configured, and it has been confirmed that the smartphone is capable of forming a resilient Ad Hoc mesh network with at least one other phone, the prototype application can be used. The prototype application is started by the user touching its icon, accessible from the users application launcher. Importantly the prototype application must be started after the main Serval Project software so that the resilient Ad Hoc mesh network is available.

The first screen that the user sees upon application launch is a disclaimer screen. This screen informs the user that this experimental prototype software and also that any data that is sent by the application is in plain text and may be accessed by third parties. Additionally the user is informed that no information collected by the application is collected centrally by the Serval Project. The user is required to acknowledge , and accept the terms of, this disclaimer by choosing the confirmation button before the application will continue. If they do not agree with the terms of the disclaimer they can quit the application at this point.

If more than one map data file is found on the SD card, in a predetermined location, the user is prompted to select which file best suits their current location. Alternatively if there is only one map file available the application will use this file by default. If no files are found the user is asked if they wish to continue without a map data file. In this instance the application will still work, markers will still appear on the screen, but there will be no underlying map information to add context.

The users geographic location is determined by accessing the GPS hardware of the smartphone. Once a fix of acceptable quality and accuracy has been determined a blue coloured marker is added to the map to represent their location. As the user moves around the landscape and the geographic location information from the GPS hardware changes the position

[7] https://github.com/servalproject/batphone
[8] https://market.android.com/details?id=org.servalproject
[9] http://groups.google.com/group/serval-project-developers/

of the marker will be changed to reflect the new location. A complete log of the users movements is stored by the application for later possible analysis. At the time a new geographic location is determined for the user a location packet is sent across the mesh network to all of the network peers as identified by the Serval Project software. In this way other users of the prototype application will see the movements of the user around the landscape.

The location of other users on the map are represented on the map by a burnt orange coloured marker. The position of another users marker is changed when new location information is received in the form of a location packet. The user of the prototype application can also add an incident to the map at their current location. Incidents are represented by a yellow marker on the map. When a new incident is added to the map an incident packet is sent to all known peers on the resilient Ad Hoc mesh network as determined by the main Serval Project software. Each type of marker is in a different colour in order to help the user understand the information that is displayed on the map. An example map can be seen in Figure 3.1.

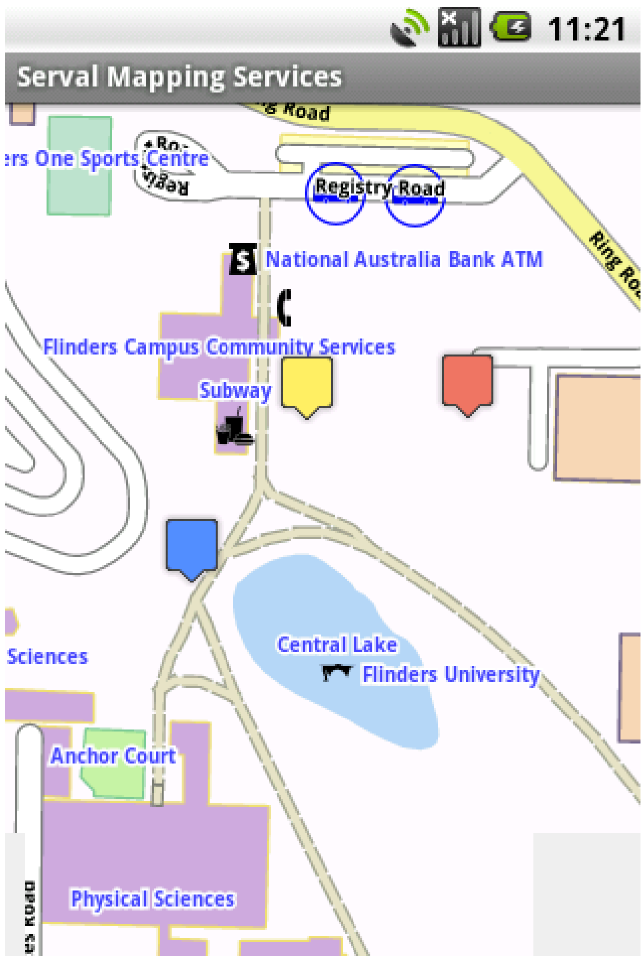

Figure 3.1: A screen capture of the map from the prototype application

More complex iconography is planned for a future release, for example where different categories of incident are used a different marker will be used. Additionally different iconography will be explored to see if it is possible to impart additional information to the user such as the age of the information used to put the marker on the map, so that the user can readily determine what is old information and what is new information.

If a user touches the marker for another user on the map they are presented with a screen that allows them to contact the user either via a phone call over the resilient Ad Hoc mesh network or via a Short Message Service (SMS) style message. If a user touches the marker for an incident the details of the incident are displayed. A sample incident can be seen in Figure 3.2. This screen is similar to the one used to solicit the information from a user when they add an incident to the map except the incident details are not editable. Additionally the user is able to use familiar touch controls in order to pan and zoom the map, similar to the way that users can use popular mapping application such as Google Maps.

Figure 3.2: A screen capture of an incident from the prototype application

When a new packet is received by the application it is first validated to ensure that it is valid. Validation rules include checking to ensure that the right number of fields are present and that the right data type is used for each field. For example the fields used to represent geographic coordinates are checked to ensure they are numeric values that are within the bounds of valid geographic coordinates using the decimal degree notation. Once validated the content of the packet is stored in an SQLite database: one database is used for location information and another for incidents, using the standard content provider model[10] that is part of the Android framework. These same databases are used by other portions of the application, for example when the map refreshes.

It is planned for a future release that some of this information be made available to third party applications using the content provider mechanism if this is found to be useful. Additionally it is planned to provide a mechanism for third party applications to add content to the map by using a content provider. For example the main Serval Project application could use such a mechanism to add information to the map such as the signal strength related to network peers, in particular peers which may not be running the mapping application such as mesh potato network nodes. Location and incident data can be exported from these databases to a plain text file on the SD card for further analysis should that be required. The user can also delete all data in the databases at their discretion.

The map display updates every thirty seconds redrawing the map with the updated location of markers by sourcing data from the aforementioned databases. Any marker information that is more than twenty minutes old is not displayed. A planned future release of the prototype application will make this timeout value a user configurable option. Additionally as a means of spreading incident data as far as possible through the resilient Ad Hoc mesh network an incident data record is randomly selected every thirty seconds by each device for retransmission across the network.

Initially it was intended to use UDP broadcast packets for the transmission of information by the prototype application, however this was found not to be viable and an alternative strategy developed. It is believed that the root cause of this issue is the way in which the main Serval Project software must configure the network interface to support the resilient Ad Hoc mesh network. This is a non standard network configuration from the perspective of the Android framework which is higher up the software stack and can cause some issues. As an alternative every thirty seconds the main Serval Project software is polled for a list of known network peers. This list is iterated over one record at a time when a new packet needs to be sent over the network. Further investigation will need to be undertaken to determine a more efficient mechanism for sending packets at the same time that the packet format is reconsidered.

3.4 Packet Format

As outlined earlier location and incident information is shared between instanced of the prototype application by sending packets across the resilient Ad Hoc mesh network using UDP. The packets are constructed using plain text and contain a number of fields, each field is separated by a delimiter. Care has been taken in the development of the fields to take into account planned future enhancements. This includes the additional encryption and security features mentioned earlier as well as matching the incident fields to those used by the Ushahidi system. In this way it will be easier to integrate the prototype application with a Ushahidi instance should that become a required feature.

One type of packet is used for geographic location information, the other contains incident information. Each field is separated by a pipe character and some fields are common to both

[10] http://developer.android.com/guide/topics/providers/content-providers.html

packet types, while some fields are not actively used by the prototype application at this time. The common fields are as follows:

1. The phone number and subscribe ID fields are sourced directly from the main Serval Project software. These are used to identify a user a on the resilient Ad Hoc mesh network;

2. The latitude and longitude fields are expressed using the decimal degree notation;

3. The timestamp field is used to represent the local time as determined by the smartphone when the location was determined or the original incident packet sent. The time is expressed as the number of seconds since January 1, 1970 00:00:00 UTC; and

4. The timezone field represents the local timezone as determined by the smartphone. The field contains one of the timezone identifiers as defined by the Android framework.

The timestamp and timezone fields are used to represent the local time of the original device that sent the packet. This information is used to convert the time to UTC internally before any comparisons are made between time values. For example determining the age of incident information while refreshing the map.

As already discussed the signature field is not currently used by the prototype application. This field is designed to contain a cryptographic hash of the packet content specific to the original user who sent it. It is anticipated this field will be used in a future release once the encryption functionality provided by the main Serval Project software is available and integrated with the application. The fields contained in both packet types are outlined in the following two sections.

3.4.1 Location Packets

A location packet contains the geographic coordinates that represents the geographic location for the specified user at a specific point in time. Each packet is sent using UDP on port 4012 to all of the known resilient Ad Hoc mesh network peers as determined by the main Serval Project software. A location packet contains each of the fields as outlined in the table below (Table 3.1).

Table 3.1: Location Packet Field List

Field Name	**Description**
Type	The type of location packet
Phone Number	The phone number associated with the users device
Subscriber ID	The subscriber ID associated with the users device
Latitude	The latitude geographic coordinate in decimal degree notation
Longitude	The longitude geographic coordinate in decimal degree notation
Timestamp	The local time reported by the device when the coordinate information was determined
Timezone	The timezone id reported by the device
Signature	A cryptographic hash of the packet content

The type field is specific to location packets and it is envisaged that this field will, in a future release, represent different location information in order to facilitate new functionality. For example it is envisaged that a user could configure the application to send a location packet with a different type when they arrive a specific destination. In this way fellow users of the application could be alerted to the fact that the individual had arrived. This could be extended with the encryption functionality to ensure that only a subset of users saw the alert, for example members of the same disaster or emergency response team.

3.4.2 Incident Packets

An incident packet is designed to contain the details of an incident that the user has added to the map that represents a particular event or condition at a specified time and geographic location. Each packet is sent using UDP on port 4013 to all of the known resilient Ad Hoc mesh network peers as determined by the main Serval Project software. A location packet contains each of the fields as outlined in the table below (Table 3.2).

Table 3.2: Incident Packet Field List

Field Name	**Description**
Phone Number	The phone number associated with the users device
Subscriber ID	The subscriber ID associated with the users device
Title	The title of an incident
Description	The description of an incident
Category	The category of an incident
Latitude	The latitude geographic coordinate in decimal degree notation
Longitude	The longitude geographic coordinate in decimal degree notation
Timestamp	The time reported by the device when the coordinate information was determined
Timezone	The timezone id reported by the device
Signature	A cryptographic hash of the packet content

In the current implementation of the prototype application the category field of an incident packet is not used. It is envisaged that this field will be used, in a future release, to distinguish between different types of incidents. For example in the case of environmental monitoring, the field may be used to distinguish between a location where a large cactus infestation has occurred, as opposed to a small cactus infestation. It is also possible, given the broadening scope of the prototype application that these packets will be renamed as Point of Interest (POI) packets to recognise the increased scope and numerous use cases for the application.

3.5 Cached Map Data

To achieve the goal of infrastructure independence the prototype application must be able to render a map on the smartphone using map data that is stored on the device. To this end the prototype application uses the mapsforge library to render the map and manage the various aspects of user interaction. For example the library provides the necessary functionality to add markers to a map and be able to respond when a user touches one of them. The mapsforge library uses its own binary format [11] for its map data. The data used to construct these files is sourced from the OpenStreetMap which provides data under a reuse friendly Open Data Commons Open Database License.

The conversion process from the OpenStreetMap format to the mapsforge binary format requires two pieces of software. The first is the Osmosis[12] application, this is officially

[11] http://code.google.com/p/mapsforge/wiki/SpecificationBinaryMapFile
[12] http://wiki.openstreetmap.org/wiki/Osmosis

supported software from OpenStreetMap which is used to read, write and manipulate data from the OpenStreetMap. For example the application is capable of taking an export from the OpenStreetMap data and constructing a local version of source PostgreSQL database. Crucially the Osmosis application employs a plugin based architecture that allows its functionality to be extended by including additional optional component in the data manipulation pipeline. One such component is the mapfile-writer plugin[13], which is used to create the binary map files for use with mapsforge.

With the Osmosis application, the mapfile-writer plugin and supporting libraries installed it is possible to convert data from the OpenStreetMap format to the binary format used by the mapsforge library. It is important to remember that smartphones have comparatively limited processing power and storage capacity and therefore it is necessary to keep the map data files as small as possible. The easiest way to achieve this, in the context of the primary use case, is to convert only the data required to represent the area affected by the disaster or emergency event. Additionally smaller files are easier to transfer across a resilient Ad Hoc mesh network.

Therefore the simplest approach is to download one of the many country or area extracts from one of the OpenStreetMap mirrors[14] and use this as the basis for the conversion. Testing has revealed it is possible to convert areas as large as New Zealand or South Africa or as small as the Flinders University campus. If converting a small area it is possible to start with a larger country or area extract of the OpenStreetMap data and select a smaller portion for the inclusion in the binary map file.

One the binary map file is converted it can copied to the SD card used with the smartphone into a specific location so that it can be found by the prototype application. As previously mentioned more than one file can be stored on the SD card and the user will be prompted to select which file they wish to use when they start the application. A future planned feature is to have the application dynamically chose the most appropriate map file based on the current location of the user and in particular change map data files if necessary between map rendering cycle and the next. This would be particularly useful where the Rhizome component of the main Serval Project software was used to share map data among network peers. In this way if a particular user didn't have the map data for their location they could request the data from another peer who did have it.

Importantly the prototype application has shown that it is possible to build an application that supports collaborative mapping activities in an infrastructure independent manner and this has been successfully tested in small scale experiments. The testing of the application, and future testing plans is the topic of the next chapter.

[13] http://code.google.com/p/mapsforge/wiki/MapFileWriterOsmosis
[14] http://wiki.openstreetmap.org/wiki/Planet.osm#Country_and_area_extracts

Chapter 4

Testing the Prototype Application

Testing of the prototype application has been limited to small scale testing using the Android emulator and a small number of Huawei U8150 smartphones. In particular medium to large scale testing has proven to be beyond the scope of this exploratory research project. Testing of the application must be carried out on smartphones due to the close integration with the main Serval Project software which cannot be used within the Android emulator. It is intended that as the development of the application continues beyond the prototype stage further testing will be carried out, in particular as interest in the application grows and opportunities for testing during disaster and emergency response exercises become possible. This chapter provides an overview of two possible experiments that could be used for testing in the future.

4.1 An Orienteering Style Experiment

An orienteering style experiment is proposed to test the application in relation to the main use case that has driven development of the application up to this point. The underlying principle of the experiment is to have a number of teams explore an area looking for a series of control points. The control points are analogous with incidents that may be added to the map if the application was used during the response to a disaster or emergency event. Example control points include indications that food or water is present, that shelter is available, where a dangerous situation exists, and where people need assistance.

During the experiment the teams will need to record that they have found a particular control point. The effectiveness of the application will be determined by three main factors; the users experience in using the application, the number of control points identified, and the time taken to complete the task. Each team must visit as many control points as possible and record the team specific unique identifying mark for control point. If teams meet each other during the experiment they can share information about the location of control points that they have found. A team cannot record and share the unique team specific control point identifier for another team.

In the first phase of the experiment the teams are provided with a map, a compass and notepaper. The teams must use the map and compass to navigate the defined area and locate as many control points as possible in a set time period. The team uses the notepaper to note the team specific unique control point codes, including the time that the control point was discovered. Teams will also be encouraged to record any observations that they may have during the experiment.

In the second phase of the experiment the teams are provided with an Android powered smartphone that provides access to the standard Android mapping application. As in the first phase of the experiment the team is also provided notepaper to record their observations and the team specific unique control point codes. The team must used the standard Android mapping application to help navigate the defined area. To ensure that a teams recollection of control point placement does not effect the outcome of the experiment the control points will be relocated before the start of this phase of the experiment. As in the first phase of the experiment teams are encouraged to share information with each other if they meet.

In the third phase of the experiment the control points are relocated for a third time. This time the teams are provided with an Android powered smartphone that has the prototype mapping application installed. Each team must use the prototype application to record the location of control points that they discover including the unique team specific control point code. In this phase of the experiment the location of control points will be shared with the other teams automatically using the resilient Ad hoc mesh network provided by the main Serval Project software. Team will also be encouraged to use the voice telephony and messaging aspects of the main Serval Project software to communicate if they wish.

It is anticipated that this experiment will provide data points such as the time taken to find control points, the total number of control points found during the specified time period and if the teams completed the course. Additionally the observations made by the teams will provide insight into their experiences during the three phases of the experiment. Teams will also be encouraged to make observations about their experiences in using the prototype application to assist in determine how the application behaves during a test in the field.

It is anticipated that this experiment will show that when the users of were able to use the prototype application they were able to locate control points more effectively and that the sharing of information became easier. It is hoped that the final phase of the experiment in particular, will show that the prototype application supports an improved user experience by making it easier to collaboratively build knowledge about an area using the map on the device. The second experiment is designed to evaluate the impact that the application has on the ability for two people to coordinate their rendezvous behaviour.

4.2 Testing the Impact on Rendezvous Behaviour

The goal of the prototype application is to enhance the ability of users to collaboratively build knowledge about a particular geographic area, such as an area affected by a disaster or emergency event. By collaboratively building knowledge it is anticipated that the user of the prototype application will be better able to coordinate their activities. One such activity is the ability for users to rendezvous at a particular location. To test if the prototype application can have a positive impact on this type of behaviour an experiment similar to employed by Dearman et al. is proposed [34].

During this experiment, participants were given a mobile device that displayed a map that was capable of showing three different types of markers. The first marker was a predetermined rendezvous point. The second marker was the geographic location of the user, and the third marker represented the geographic location of a person that they were required to rendezvous with. Experiment participants were required to participate in three different rendezvous scenarios.

In the first scenario the experiment participant was instructed to rendezvous with another person, as represented by the third marker, at a predetermined time and location. This location was displayed on the map and during the experiment participants could see their location, the rendezvous location and the location of the other person on the map.

In the second scenario the experiment participant was instructed to meet with the other person not at a predetermined time or location. When instructed the experiment participant was required to locate the other person on the map and navigate their way across the landscape to the location of the person. During this time the other person was always in motion.

In the third scenario the experiment participant was instructed to meet with the other person at a predetermined location at a specified time. Unlike the first scenario the other person appeared to get lost and so would not arrive at the predetermined location. Therefore the experiment participant would be required track the other person down when it became clear that the person would not be arriving at the specified location.

Using these scenarios it can be possible to observe how a user interacts with the map and the impact that this has on their ability to rendezvous with another person. In the case of the study undertaken by Dearman et al. it was found that:

> *Participant usage suggests the importance of the relation- ship between their personal location, the location of their partner, and the location of the rendezvous. Additionally, we observed a consistent trend of continual manual refinement of the visible map detail as the proximity between the participant, their partner and the rendezvous decreased. It is evident from this study that there are many different ways to use both a location-aware map application and the application specific features (zoom and pan).* [34, p. 5].

In particular it was found that users would use the map to maintain awareness of their own location relative to that of the rendezvous point and the other person. It was also found that "the majority of participants ... actively refined the map as they progressed through the scenario, zooming into the map to gain greater region specific detail" [34, p. 6].

Using these types of scenarios it is anticipated that the ability for the prototype application to enhanced the ability of users to rendezvous with each other will be evaluated. Additionally the experiment will provide an insight into the way in which users interact with the application which may suggest user interface improvements, and the need for new functionality or changes to existing functionality.

It is intended that both this experiment, and the one outlined in the previous section, will be undertaken using real Android powered smartphones using the prototype application and the main Serval Project software. As a side benefit these experiments will also provide an insight into how the resilient Ad hoc mesh network behaves in terrain such as the pine forest (Figure 4.1) on the Flinders University campus. Additionally it will provide an opportunity to field test the ability for smartphones to receive GPS signals in near to real world conditions.

Figure 4.1: An example of the terrain in the pine forest at Flinders University

Chapter 5

Conclusion and Future Work

This exploratory research project has been focused on the development of a prototype mapping application. The intent of the application is to provide a platform for user to collaboratively build knowledge on a map using their Android powered smartphone. The primary use case for the application has been identified as, users who are responding to a disaster or emergency event. The application shows the location of each user on the map, and allows them to add incidents to the map. This information is shared between instances of the application using the resilient Ad Hoc mesh network, that is powered by the main Serval Project software. The research and software development has been undertaken to seek an answer to the following research question:

> *Is it possible to provide collaborative mapping services on mobile devices in an infrastructure independent manner?*

The research has provided an affirmative answer to the question. It has been demonstrated that the prototype application supports collaborative mapping on Android powered smartphones in an infrastructure independent manner. As with any exploratory research, further avenues of investigation have been identified. It is also the nature of prototype software development that additional features and changes to functionality have been discovered. It is these two topics that are the focus of this final chapter.

5.1 Further Research

The literature review component of the exploratory research highlighted how systems such as Ushahidi (subsection 2.2.1) have been successfully used in the response to a disaster or emergency event. The information that has been added to these types of map has been crowdsourced, and came from a wider user base than what was proposed in the primary use case. It can be seen that the prototype applications has a potential role to play in these types of crowdsourcing activities and that this should be explored.

Additionally the research into other use cases (subsection 2.2.2) highlighted some potential scenarios where collaborative infrastructure independent mapping may also be able to play a role. For example in environmental monitoring, or in the integration with data collection devices that could be used in conjunction with a smartphone. These wider user cases need to be identified and more fully explored.

The current iteration of the prototype application uses a very simple iconography scheme to represent the three different data points that are displayed on the map. The use of more complex iconography, in particular to support the exploration of the additional potential use cases, needs to be explored. The power of visualising data on a map comes from visualising it in such a way as to highlight trends, and make it easier to identify areas that may need further assistance or investigation. As Kobia [16] noted it is important to remember that behind each marker is a human experience - and this is particularly true of the examples provided by the HarrasMap project [17] . Therefore a balance between simplifying the display of information, without trivialising or reducing the significance of the information, would need to be found.

As part of this exploration into more advanced iconography, different strategies need to be explored in order to represent different categories of information, the age of the information and in particular the authenticity of the information source. In relation to the primary use case this would include different markers for different categories of incidents, indicating how recently an incident was identified, and the authority of the user who added the information. In light of the need to explore the potential for crowdsourcing information the need for determining authority is particularly important.

Environmental monitoring has already been identified as a possible area where collaborative mapping could be used. Other additional areas include research at mass gatherings, and other scenarios where distributed data collection of information related to geographic locations can be used. Before the use of the prototype application can be expanded further testing (chapter 4) needs to occur and the functionality of the application needs to be expanded to support these research activities.

5.2 Prototype Application Enhancements

The four key objectives for collaborative mapping (section 2.2) that were defined during the early stages of this exploratory research have been implemented in the prototype application. Additionally the primary use case (section 2.1) has influenced the development of the application and narrowed its scope. To expand the number of potential use cases that the prototype application can be applied to, additional features and enhancements need to be developed.

The first new feature is to make use of the encryption capabilities of the main Serval Project when available, to encrypt the content of the packets used to share information between instances of the application. This would replace, or at least augment, the plain text format (section 3.4) currently in use. Additionally the encryption capabilities can be used to include a cryptographic hash of the packet content. In this way users can be positively identified and the information used to construct the map can be secured against modification.

This supports the potential research avenue in using crowdsourcing techniques to collect information as users can be identified with some confidence which is the basis for addressing the concerns of authenticity. For example identifying information from relief team members versus information crowdsourced from individuals. This can also be extended to identifying individuals who have provided crowdsourced information which has been of consistently high quality and therefore have a higher degree of authority.

Provision in the packet format has been made for different types of location packets, and different categories of incident packets. In order to make the application more useful to other research areas these fields need to be actively used by the application. A solution to managing different lists of categories for incident information will also need to be addressed. It is possible that a more flexible approach will need to be taken where incidents become more generic points of interest. These changes are aimed exploring the issues of alternate iconography and finding a balance between complexity and simplicity in the display of information.

Lastly the mapsforge library has been used to render the map, and the capability of the library to used cached map data (section 3.5) is a corner stone of the applications ability to operate independently of traditional telecommunications infrastructure. The current version of the prototype application allows only one map data file to be used to render a map which is chosen when the application starts. A proposed new feature for the application is to support the use of multiple map data files dynamically, choosing the most appropriate map data file depending on the current location of the user. In this way smaller map data files could be used to support the application. For instance map data could be generated for the entire world using a grid based system and shared amongst devices as required, rather than generating map data based on country or geographic area which may cause the file to include information that is not required.

5.3 Conclusion

In conclusion, this exploratory research project has shown that it is possible to provide collaborative mapping services on mobile devices in an infrastructure independent manner. It has done this by developing an Android based application that can be used to support the four core activities required for a collaborative map that uses cached map data and a resilient Ad Hoc mesh network for connectivity. Additionally it has shown that the prototype application can be used to address the primary use case, and that will some modifications additional use cases can also be explored. Lastly it has shown that geographic information can be added to the conversation that results from addressing the core tenet of the the Serval Project, which is that *communication is a human right*.

Bibliography

[1] F. Hargrave, *Hargrave's Communications Dictionary.* No. 0-7803-6020-6, 3 Park Avenue, 17th Floor, New York, NY 10016-5997: IEEE Press, 2001.

[2] "Gartner says android to command nearly half of worldwide smartphone operating system market by year-end 2012." http://www.gartner.com/it/page.jsp?id=1622614, April 7 2011.

[3] A. Smith, "Americans and their cell phones." http://www.pewinternet.org/Reports/2011/Cell-Phones.aspx, August 15 2011.

[4] J. Daintith and E. Wright, eds., *Oxford Dictionary of Computing.* Great Clarendon Street, Oxford OX2 6DP: Oxford University Press, 6 ed., 2008.

[5] P. Gardner-Stephen, "Sustaining telecommunications capability and capacity during acute phase of disasters and disaster responses," in *17th World Congress on Disaster and Emergency Medicine*, pp. s101 – s102, 2011.

[6] P. Gardner-Stephen, "The serval BatPhone: making mesh mobile telephony practical, anywhere, any time.," in *linux.conf.au 2011*, Janurary 29 2011.

[7] Queensland Floods Commission of Inquiry, "Queensland floods commission - interim report." http://www.floodcommission.qld.gov.au/publications/interim-report, August 1 2011.

[8] O. Okolloh, "Ushahidi, or 'testimony': Web 2.0 tools for crowdsourcing crisis information," *Participatory Learning and Action*, vol. 59, pp. 65–70, June 2009.

[9] A. Nelson and M. Patel, "How mapping, sms platforms saved lives in haiti earthquake." http://www.pbs.org/mediashift/2011/01/how-mapping-sms-platforms-saved-lives-in-haiti-earthquake011.html, January 11 2011.

[10] A. Nelson, I. Sigal, and D. Zambrano, "Media, information systems and communities: Lessons from haiti." http://www.kflinks.com/haitireport, February 21 2011.

[11] H. Leson, "Launching eq.org.nz for the new zealand earthquake." http://blog.ushahidi.com/index.php/2011/02/24/launching-eq-org-nz-for-the-new-zealand-earthquake/, February 24 2011.

[12] T. McNamara, "eq.org.nz - the power of ushahidi." http://www.nzcs.org.nz/newsletter/article/94, March 18 2011.

[13] "crowdsourcing." http://en.wiktionary.org/w/index.php?title=crowdsourcing&oldid=13937541, September 28 2011.

[14] Y. Tamura and K. Fukuda, "Earthquake in japan," *The Lancet*, vol. 377, p. 1652, May 14 2011.

[15] UN Integrated Regional Information Network, "Online media mapping aids libya crisis response," *BBC Monitoring*, May 2011.

[16] D. Kobia, "Communicating during a crisis: social software, says david kobia, can help during a catastrophe - and after," *Technology Review*, vol. 113, p. 11, Sept-Oct 2010.

[17] O. Ward, "Egyptian women put sexual harassment on the map." http://www.thestar.com/News/World/article/1026060, July 17 2011.

[18] Y. B. Adimulam, R. Banothu, G. C. Babu, B. S. Babu, and S. Jagirdar, "Tracking indian tigers using adhoc networks & GIS," *International Journal of Computer Applications*, vol. 26, no. 11, pp. 12–14, 2011.

[19] A. Ostrow, "New device uses gps & crowdsourcing to identify world's water problems." http://mashable.com/2011/07/14/water-canary/, July 14 2011.

[20] "Japanese company unveils iphone geiger counter." http://www.abc.net.au/news/2011-11-16/firm-makes-iphone-geiger-counter-for-worried-japanese/3674890, November 16 2011.

[21] D. N. Breslauer, R. N. Maamari, N. A. Switz, W. A. Lam, and D. A. Fletcher, "Mobile phone based clinical microscopy for global health applications," *PLoS ONE*, vol. 4, p. e6320, July 2009.

[22] P. Cohen, "Digital maps are giving scholars the historical lay of the land," *The New York Times*, p. C1, July 27 2011.

[23] P. Gardner-Stephen, "The serval project: Practical wireless ad-hoc mobile telecommunications." http://developer.servalproject.org/site/docs/2011/Serval-Introduction.html, August 3 2011.

[24] "What is android?." http://developer.android.com/guide/basics/what-is-android.html, November 17 2011.

[25] "Gartner says sales of mobile devices grew 5.6 percent in third quarter of 2011; smartphone sales increased 42 percent." http://www.gartner.com/it/page.jsp?id=1848514, November 15 2011.

[26] "Platform versions." http://developer.android.com/resources/dashboard/platform-versions.html, November 3 2011.

[27] M. Degusta, "Android orphans: Visualizing a sad history of support." http://theunderstatement.com/post/11982112928/android-orphans-visualizing-a-sad-history-of-support, October 26 2011.

[28] P. Gardner-Stephen, "Photos and update from nigeria - and introduction to rhizome." http://servalpaul.blogspot.com/2011/10/photos-and-update-from-nigeria.html, October 6 2011.

[29] "Wireless ad-hoc network." http://en.wikipedia.org/w/index.php?title=Wireless_ad-hoc_network&oldid=461607757, November 20 2011.

[30] S. Palaniswamy, "Wifi multi model management," November 2011.

[31] P. A. Zandbergen, "Accuracy of iphone locations: A comparison of assisted gps, wifi and cellular positioning," *Transactions in GIS*, vol. 13, no. S1, pp. 5–25, 2009.

[32] C. Sorrel, "iphone 4s supports russian glonass satnav." http://www.wired.com/gadgetlab/2011/10/iphone-4s-supports-russian-glonass-satnav/, October 20 2011.

[33] S. Ji, W. Chen, X. Ding, Y. Chen, C. Zhao, and C. Hu, "Potential benefits of gps/glonass/galileo integration in an urban canyon – hong kong," *The Journal of Navigation*, vol. 63, no. 04, pp. 681–693, 2010.

[34] D. Dearman, K. Inkpen, and K. Truong, "Mobile map interactions during a rendezvous: exploring the implications of automation," *Personal and Ubiquitous Computing*, vol. 14, pp. 1–13, Jan 2010.