Ad-hoc Cellular Hybrid Opportunistic Network to Promote Local Routing

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Declaration

I certify that this dissertation does not incorporate, without acknowledgement, any material previously submitted for a degree or diploma in any university and to the best of my knowledge and belief, it does not contain any material previously published or written by another person or myself except where due reference is made in the text. I also hereby give consent for my dissertation, if accepted, be made available for photocopying and for interlibrary loans, and for the title and abstract to be made available to outside organizations.

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Abstract

A summary of your dissertation, with emphasis on the conclusions. This should fit in about 3/4 of this page. Do not cite references or put lists here. It can be 2-3 paragraphs.

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Keywords: DNA, RNA, Amber

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1.1 Introduction

The popularity of mobile devices has grown rapidly in recent years. Report from ICT facts has shown that in 2015 alone there are more than [number] of mobile devices are used worldwide. That translates to having 1 mobile device for every 100 people. The competitive nature of the mobile phone manufacturers caused the capabilities of these devices to improve in a very rapid phase.

Nowadays mobile devices have multiple interfaces with different characteristics for their communication. These interfaces can be infrastructured networks like cellular or infrastructure-less networks like wifi or Bluetooth. The availability of these vastly different network interfaces and communication protocols in mobile devices has open new research opportunities in providing reliable, lowcost, high bandwidth connections without any additional cost.

With mobile devices, internet traffic surpassing that of computers/cite the need for a reliable, lowcost high bandwidth mobile connection is apparent more than ever. In the past, this problem has been addressed by implementing ad-hoc networks. This is a good solution as we have a high density of mobile devices in most of the crowded place. But the thing about the ad-hoc network is that they can be very unpredictable in nature. As ad-hoc infrastructure-less in nature wifi and Bluetooth connections are better suited than their cellular counterpart. The use of Bluetooth connection is not ignored due to the low bandwidth connections they make.

In the past researchers have tried to solve this problem by implementing an ad-hoc network using only the wifi interface. To my knowledge, the most important part of an ad-hoc network is to keep track of information about the nodes in real-time. In the past researchers have used a separate channel in the ad-hoc network./citation hear Due to the ad-hoc network being unreliable this is not a good solution.

These days the mobile devices have become very sophisticated. They possess multiple network interfaces with considerable processing power. Technologies like GSM and wifi had become matured technologies. Nowadays GSM networks can provide good coverage in a very reliable manner.[]. With the introduction of wifi p2p technologies like wifi direct it has become very easy to form a peer to peer networks using wifi interfaces. So this shift of paradigm provides a unique research opportunity in developing a hybrid network that uses wifi peer to peer networks as its data plane and cellular network as its control plane and the backup data plane.

Let me elaborate on the architecture of this hybrid network in detail. The proposed architecture has two network interfaces working in a multiplexing manner to provide network connections.[image] Every device consists of a demon that calls to an API endpoint giving metadata about the node. It processes those data and comes up with routing paths for the ad-hoc network. Then the server transfers back the relevant data for the available nodes to provide an optimized routing path. So when we need to transfer data to a device in the ad-hoc network it uses wifi p2p rather than cellular saving the valuable bandwidth. Traffic that is gong to the internet is routed to the GSM network using the cellular interface without any change.

Due to wifi networks having greater bandwidth than that of the gsm network we can actually improve the speed drastically than that of the cellular connection. As we are using a much reliable GSM network for our control plane we can provide a stable connection than that of the pure ad-hoc network. Due to the usage of local routing provided by the ad-hoc network, this will provide a cheap reliable high bandwidth low latency connection in some scenarios. We are going to analyze the efficiency of this with the previous android MANET implementation's ads current GSM connections to further justify the significance of this solution.

1.2 Motivation

Even though the current mobile devices are heavily reliant on the data connection to function they underutilize the network resources available to them. This is shown in the Cisco(2017)Global Mobile Data Traffic Forecast Update, 2017 to 2022[1] Eg: If we need to transfer the file to a friend we need to do so using a data connection rather than transferring them peer to peer using wifi. Even To communicate with multiple people in the same room there should be a cellular connection. But they are in the communication range of each other. If there was a direct connection between two devices we can achieve much higher bandwidth without any additional charge. With the local routing, we can have a redundant connection between devices. This can be very helpful for a situation where there is bad reception. If the cellular connection breaks there is a path through the ad hoc network. So our motivation is to reduce the cost of the data connection while increasing the quality using the readily available resources of the mobile devices.

1.3 Research significance

Short-range wifi communication offers higher data transfer rates. As the white paper about wifi 802.11ax standard by (Cisco,2019).[2]suggests, we can get up to 4.8 Gbps of max data rate by this wifi standard. As we try to route the data locally users will get a faster internet connection without any additional infrastructure cost. And we can also reduce the cellular charges of the user significantly. By implementing this kind of hybrid cellular-ad-hoc network we get additional high bandwidth without any additional cost to the user.

1.4 Background

1.4.1 A peer-to-peer (P2P) network

According to (Schollmeier,2001)[3] peer-to-peer network is a network of interconnected nodes ("peers") serving resources amongst each other without the use of a centralized administrative system.

1.4.2 What is ad-hoc network

According to Toh, C. (2002). Ad hoc wireless networks: Protocols and systems. [4] an ad hoc network is a network that is comprised of individual devices interacting with each other directly. The term(ad-hoc) implies spontaneous or impromptu construction because these networks often bypass the central access point such as a router. Many ad hoc networks are local area networks where devices are enabled to send data directly to one another rather than going through a centralized access point.

1.4.3 Mobile ad-hoc network:(MANET)

According to Toh, C. (1997). Wireless ATM and ad-hoc networks: Protocols and architectures.[5]These are wireless ad-hoc-networks which can self-configure dynamically to create a wireless mesh network. Nodes of this network can move freely so they have the ability to make and break the connection on the fly.

1.4.4 What is wifi direct?

According to Wi-Fi Alliance(2019,Aug) www.wi-fi.org/discover-wi-fi/wi-fi-direct [6], Wi-Fi Direct is a Wi-Fi communication standard that facilitates device connections without requiring a wireless access point (WAP). The devices are connected using Wi-Fi, thus achieving Wi-Fi level connection and transfer speeds from the connectivity.

The basic function of Wi-Fi Direct is to enable the connection between devices and facilitate data transfer through the use of built-in wireless modules without

the aid of a dedicated access point

1.4.5 Wi-Fi peer-to-peer (P2P)mode in android

Wi-Fi peer-to-peer (P2P) allows Android 4.0 (API level 14) or later devices with the appropriate hardware to connect directly to each other via Wi-Fi without an intermediate access point (Android's Wi-Fi P2P framework complies with the Wi-Fi Alliance's Wi-Fi Direct™ certification program). Google (2019,Aug) Android API documentation https://developer.android.com/guide/topics/connectivity/wifip2p.html[7] An API's is provided to discover and connect to other Android devices when each device supports Wi-Fi P2P.

Even though the new standard by WIFI-alliance includes a wifi ad-hoc mode Android open-source [6] project haven't implement it. So if we were to use it we need to implement it our self.

1.4.6 Virtual Private Network(VPN)

A virtual private network (VPN) is the extension of a private network that encompasses links across shared or public networks like the Internet. VPN enables us to send data between two computers across a shared or public internetwork in a manner that emulates the properties of a point-to-point private link. (Microsoft,2019)[8]

1.4.7 VPN Services of Android OS

Android VPN service is an application interface that gives application developers to create VPN services. Different with this method is that they can automate the device configuration process by using this API.Google (2019,Aug) Android API documentation https://developer.android.com/ [9]

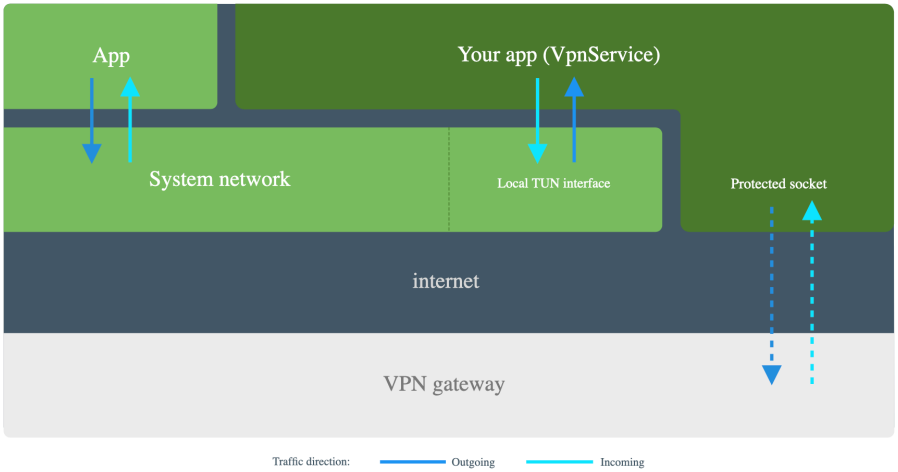

Figure 1.1: How VpnService connects Android networking to the VPN gateway

Chapter 2

Literature Review

To better understand the current progress in mobile ad-hoc network technology, let's look into the current findings and ongoing research in the fields of networking. There are some interesting researches done in these fields which can be used to find an answer to the above research problem.

2.0.1 COMONet: Community Mobile Network

One of the focuses of research being conducted in the field of ad-hoc networks is in making networking more flexible, both on the physical network side and the application side, as with most applications nowadays being developed with infrastructure networks and always-on connectivity in mind.

When smartphones were introduced, there were no open software devices like Android available to the public. Smartphone industry was dominated by closed echo system devices. back then Symbian Ltd(2019,Aug)What is Symbian OS https://www.symbianos.org/ [10] was the go-to OS choice for mobile devices. originated from EPOC32, an operating system created by Psion in the 1990s. In June 1998, Psion Software became Symbian Ltd. It was a major joint venture between Psion and phone manufacturers Ericsson, Motorola, and Nokia. So due to the close nature in software and hardware of those devices, modifying them to create an ad-hoc network was not an easy task back then.

Project COMONet(Wijesekera and Keppitiyagama 2007)[11] was undertaken in this kind of environment back then. COMONet was a Community based Mobile Network which utilizes Wi-Fi and Bluetooth interfaces to build ad-hoc network among mobile phone users to bypass GSM base stations whenever possible. It provided the functionality to make voice calls without the help of a carrier network.

To use this functionality caller and the callee does not have to be within the Wi-Fi or Bluetooth range of each other to make a call since the COMONet(Wijesekera and Keppitiyagama 2007)[11] is capable of routing calls through the other mobile nodes that are participating in the network. It can switch in between mesh connection and the cellular connection on the fly without breaking the connection.

Let us dig deeper into the implementation of the COMONet. What the researcher has done hear was to implement a mobile ad-hoc mesh network using the readily available network interfaces of the mobile devices. COMONet uses different networking stacks to implement the vice call functionality as below

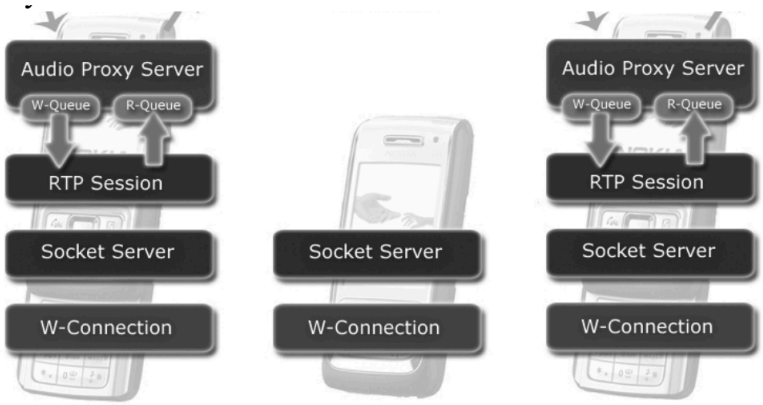

Figure 2.1: Wireless View of COMONet

Most of the functionalities in the above stack are not readily available to the application developer. So to get access to the networking interfaces to ring 0 privileges is a must. What the researcher had done is to use a hack to get into kernel mode and passing that data out to the application layer to use with his device. Believe me, this is no easy task to do. One way to do this is to read the machine code of the os and modifying the relevant bits so that it gives the elevated (ring 0) privileges to the Comment app. To my knowledge, this is not a good design because if the COMONet application crashes, then the whole os crashes. But at that time this was not feasible to in the proper manner due to the closed nature of the Symbian ecosystem.

2.0.2 The SPAN project: SmartPhone Ad-Hoc Networks

The SPAN project(Thomas, et al.2012)[12] utilizes MANET (Mobile Ad-Hoc Network) technology to provide a resilient backup framework for communication between two devices when all other infrastructure is unavailable or unreliable. The MANET based solution is a headless, infrastructure-less network that allows common smartphones to link together in a dynamic way to create a mobile ad-hoc network.

They have injected the framework into the existing Android network stack between OSI layers 2 and 3. Privileges needed to create the ad-hoc network is gained by accessing the wireless chip drivers directly to set the parameters of the wireless interface. They have configured the wireless chip to work in ad-hoc mode by using the iwconfig Linux command-line utility.The Debian Project(2019,Aug) Official WIKI page https://wiki.debian.org/iwconfig [13]

They have customized the device network drivers in this implementation. By doing so they have limited the generalizability of the technology in different devices. Plus side of implementing the network in this manner is that it can change the routing protocol in a dynamic passion. To my knowledge, most of the ad-hoc implementations cannot achieve this feature.

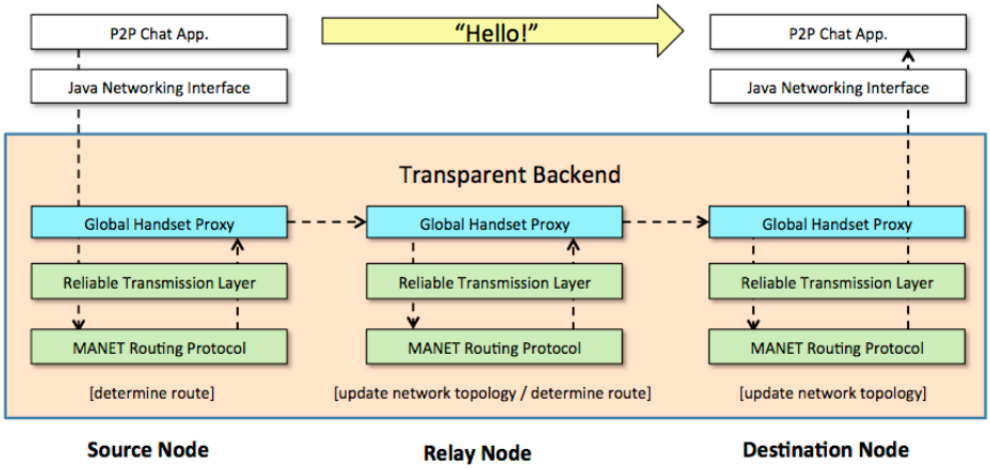

Figure 2.2: Cross-sectional view of the network

2.0.3 Better approach to mobile ad-hoc networking

BATMAN project:Better approach to mobile ad-hoc networking B.A.T.M.A.N.(better approach to mobile ad-hoc networking)[14] by Open Mesh is a routing protocol for multi-hop ad-hoc mesh networks. People at Open-Mesh have implemented this framework to support local routing on top of the ad-hoc enabled kernel.Open Mesh (2019,Aug) B.A.T.M.A.N. project https://www.open-mesh.org/projects/batman-adv/

This system works on top of the kernel to support ad-hoc routing by modifying the messages passed inside the network environment. Initially, they flood the network with announcement messages. So every node knows who their neighbors are. Due to this if there was a missing node we only need to change the routing data of the local nodes. Besides routing, the framework provides other functionalities such as benchmarking the network and node visualization.

As they have to implement the platforms on top of an ad-hoc enabled kernel this cannot use with a normal stock Android device. To use this framework we need a custom Android OS like Lineage OS. Lineage OS Team(2019,March)Changelog 23 - Brilliant Backgrounds, Versatile Volume and Terrific Tiles[Web post] https://lineageos.org/Chang 23/[15]. They haven't automated the process of creating the network yet. So this is not a user-friendly solution as well. The efficiency of their protocol has been discussed in their documentation. To my knowledge, this is pretty efficient at routing data. We cannot use this in our research due to the limited number of the devices that they support.

2.0.4 Mobile Ad-hoc Networks over Wi-Fi Direct

Development of Mobile Ad-hoc Networks over Wi-Fi Direct with Off-the-Shelf Android Phones (Liu,et al.2016)[16]

In this paper, researchers try to introduce a novel method to achieve multi-hop communication among open-source, non-rooted Android devices using Wi-Fi Direct Technology. This solution tries to preserve the ad-hoc property of the network while using minimum privileges.(Liu,et al.2016)[16]

Let us analyze this method. They have chosen the wifi interface for their communication. Bluetooth interface has been discarded due to its low bandwidth rates. The protocol he had chosen here is the wifi-direct. It allows them to create groups inside the network. Initially, all the nodes become group owners. When it is time to transfer the message some becomes clients. After the message has been transferred node revert back to its initial state.

This method preserves the ad-hoc nature of the network. But because in each transfer of data it needs to make and break the structure of the network transfer rates becomes low. Due to this, it is pretty hard to keep a continuous stream of data using this network.

2.0.5 Enabling multi-hop ad-hoc through wifi direct multi-group networking

Enabling multi-hop ad hoc networks through wifi direct multi-group networking (Funai,Tapparello and Heinzelman)[17]

In this paper, they(Funai,Tapparello and Heinzelman)[17] and have proposed and analyzed different practical solutions for supporting the communications between multiple WiFi Direct groups using Android OS devices. They have analyzed the WIFI Direct standard and the limitations of the current implementation of the Android WiFi Direct framework and presented some possible solutions to interconnect different groups to create multi-hop ad hoc networks.

Let us consider their proposed method to create multi-hop ad hoc networks. In this method near devices are connected using wifi-direct architecture (Group owner and Client). Intergroup communication is achieved using this wifi-direct protocol. They have used the hotspot functionality of the Android to achieve intergroup communication. To do this they need to allocate a node to provide

hotspot functionality to other groups. To enable inter-group communication they have modified the routing table of relevant devices. To do this the root access to the device is needed.

In this implementation, they have done no modifications to the operating system.They have modified the routing tables of certain devices to achieve intergroup communication. This needs root access for modification of the routing table. This limits the usability of this system in personal devices as rooting voids the warranty of most of the Android devices.

2.0.6 infrastructure-less Communication Platform for Android

infrastructure-less Communication Platform for Off-The-Shelf Android Smartphones : (Takuma,Toru and Takuo)[18]

In this research, they are trying to implement an ad-hoc network without modifying the OS or rooting the Android device. They have introduced new topology for the network and relevant routing protocols to go along with that. They have used wifi-direct and wifi interfaces to implement the network.

The researchers(Takuma,Toru and Takuo)[18] have made some interesting trade-off between architecture, performance and the required privilege levels when implementing this network. They have used a tree architecture rather than a graph architecture when designing the network. They proposed a relay node to do the inter-cluster communication. This relay node uses the wifi connection to transfer the data from one device to another. Other message transfers use the wifi-direct protocol.

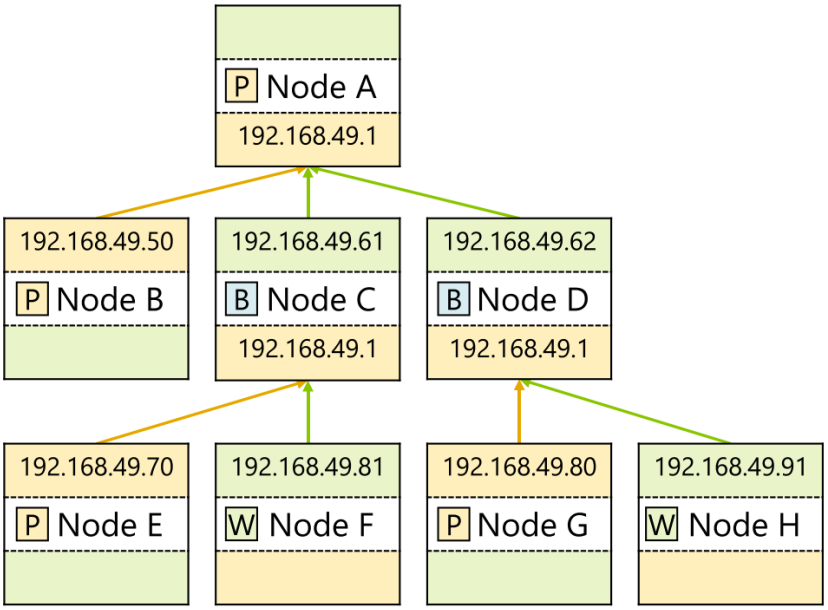

Figure 2.3: Example of topology construction

Because of the topology, they proposed the network will have a low latency connection and high bandwidth. But due to the non-distributed nature of the relay node, it takes some time to recover from a node failure. Implementing this network does not need any OS level modifications or root privileges. Allocation of a relay node is not a good approach because that device cannot be a user in this network.

2.0.7 Integrated Cellular and Ad Hoc Relaying Systems

In this paper, they have proposed the idea of using ad-hoc and cellular connection side by side to improve the quality of the connection. In this architecture, the two networks do not talk to each other. But in my research cellular connection is used to make the ad-hoc network. And in the above research, they are concerned only on the theoretical aspect of the network.(Hongyi,Chunming,Swades and Tonguz 2001)[19]

2.0.8 WiFi Direct and LTE D2D in Action

In this paper, they have proposed the method of using the wifi direct and cellular connection side by side to improve the bandwidth of the connection. But here they

are more interested in the implementation aspects of the network rather than the theoretical aspects. In this paper, they have analyzed the nature of the connection using different criteria as well.(Arash and Vincenzo 2013)[20]

2.0.9 A Unified Cellular and Ad-Hoc Network Architecture

UCAN: A Unified Cellular and Ad-Hoc Network Architecture (Haiyun,Ramachandran,Prasun and Erran,2003)[21]

In this research (Haiyun,Ramachandran,Prasun and Erran,2003)[21] have introduced an implementation of a hybrid ad-hoc cellular network. It answers the question can these two networks be synergistically combined to leverage the advantages of each other.

2.0.10 Routing protocols in an ad-hoc network

Routing protocols in an ad-hoc network (Casetti, et al.2015)[22]

In the paper by (Casetti, et al.2015)[22], they have proposed a content-centric routing algorithm that can be used in a mobile ad-hoc network. In this method, the content delivery leverages the forwarding scheme through a content-centric approach.

In the paper by (Philippe,Muhlethaler,Clausen and Laouiti)[23], they have analyzed the use of OLSR(Optimized Link State Routing) protocol in an ad-hoc routing environment. This is a proactive routing protocol for mobile ad hoc networks.OLSR protocol is an optimization of a pure link-state protocol for mobile ad hoc networks. This technique significantly reduces the number of retransmissions in a flooding or broadcast procedure.

The paper A Study of Ad-Hoc Networks by (Alshaer and El-Rabaie)[24] does some higher-level analysis of the routing protocol that can be used with a mobile ad-hoc network. In this paper, researchers analyze how different aspects of the network affect these protocols.

2.0.11 Secure Key Establishment for Device Communications

Secure Key Establishment for Device-to-Device Communications (Wenlong,Weisheng,Xianghui and yin)[25]

In this paper, they (Wenlong,Weisheng,Xianghui and yin)[25] investigate the security requirements and challenges for a device to device communications and present a secure and efficient key agreement protocol, which enables two mobile devices to establish a shared secret key for D2D communications without prior knowledge

2.1 Summary

Several efforts are in development to address many of the requirements to achieve decentralised mobile ad-hoc networking. Some researchers are based on implementation aspects of the network and others are focused on the theoretical aspects of the network. Initially, we discussed different ways we can make an ad-hoc network.

This can from complete OS modification, routing table modification to application-level modification with no additional privileges(no root). Most recent implementations rely on wifi direct protocol to implement ad-hoc networking. When designing the architecture we need to concern the modification that needs to be done on an Android system because of this affect the reach of our research.

In the later part, we discuss different kinds of cellular ad-hoc hybrid network and their performance in a theoretical and practical manner. The current implementations of ad-hoc network targets on Android devices relying on new and/or proprietary standards, ignoring the existing standards used across many existing implementations. This limits their usefulness unless they gain mass-market adoption

Chapter 3

Research Design

Let us consider the research question first. It consists of two parts. The first part consists of How to deploy an ad-hoc network using the infrastructure network as a control plane. The second part of the research question is on finding what are the performance implications to the nodes of such a network.

I have fallowed the constructive research approach do my research. So to find the feasibility of deploying this kind of network first need to analyze our problem thoroughly. Initial problem we face is to deploy an ad-hoc mobile network using readily available resources in the mobile devices. To do this we need to do some literature survey on this field.

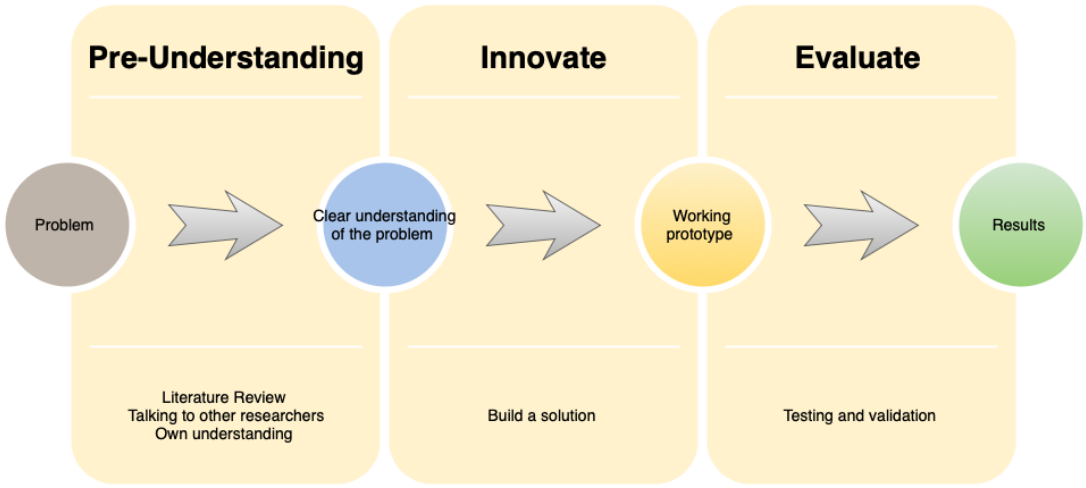

Figure 3.1: Flow of the Constructive Research Design

To answer the first part of the research question, I have used the exploratory research design principle. Reason for choosing this method is because not much research was done in this field. To get insight on to the research problem I have done a thorough literature review on the mobile ad-hoc networking solutions currently available to us.

By doing so I have gained a good understanding regarding the mobile ad-hoc networking. A well-grounded picture on how to implement an ad-hoc network was developed by following the research. I have identified the problem in those implementations and some ways of solving those problems. And another valuable outcome of this research is to find the feasibility of the solution in the future. I have found a new method that can solve these limitations. Insight from the research has shown the next stages as well.

As we have shown that it is feasible to implement an ad-hoc network using readily available devices without making any modifications to OS or acquiring root privileges. Now to the second part of the research which asks the question of what are the performance implications to the nodes of such a network.

For this, we need to analyze the ad-hoc network using relevant benchmarks in this field. To identify relevant benchmark metrics I have used the above literature review. I have identified Throughput, Topology construction time, Latency as valid

matrices for this evaluation processes. Finally, by using these data we can predict the performance of different applications on this network.

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3.1 Research Approach

In here I fallowed the inductive research approach. In here i observed that the current mobile devices do not have a good cellular connection even though they rely heavily on the data connection. Most of the application in mobile devices need an Internet connection to function. The pattern I saw in here was only one network interface at a time is used when connecting to the internet. It is either cellular or wifi, not both. So the theory is that we can improve the bandwidth and latency of the connection if we use multiple interfaces at the same time.

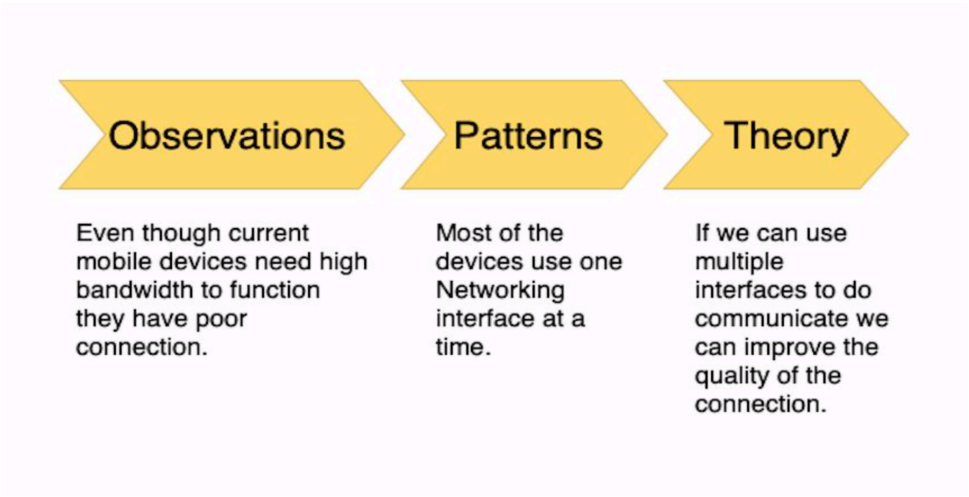

Figure 3.2: Flow of of the Inductive Research Approach

Chapter 4

Implementation

This chapter describes the software solution at a finer level of detail, down to the code level. This chapter is about the realisation of the concepts and ideas developed earlier. It can also describe any problems that may have arisen during implementation and how you dealt with them. Do not attempt to describe all the code in the solution, and do not include large pieces of code in this chapter (detailed source code can be provided in Appendix C and also be included in the CD). Just pick out and describe the pieces of code which, for example: are especially critical to the operation of the solution; you feel might be of particular interest to the reader for some reason; illustrate a non-standard or innovative way of implementing an algorithm, data structure, etc. You should also mention any unforeseen problems you encountered when implementing the solution and how and to what extent you overcame them. Common problems are:

4.1 Preliminary Results and Discussion

By doing a literature review i have come up with a new ad-hoc architecture which can create an ad-hoc network without the need for modifications to OS or needing superuser privileges.This covers the first part of my research question. I am currently working on implementing that architecture using three Android devices.

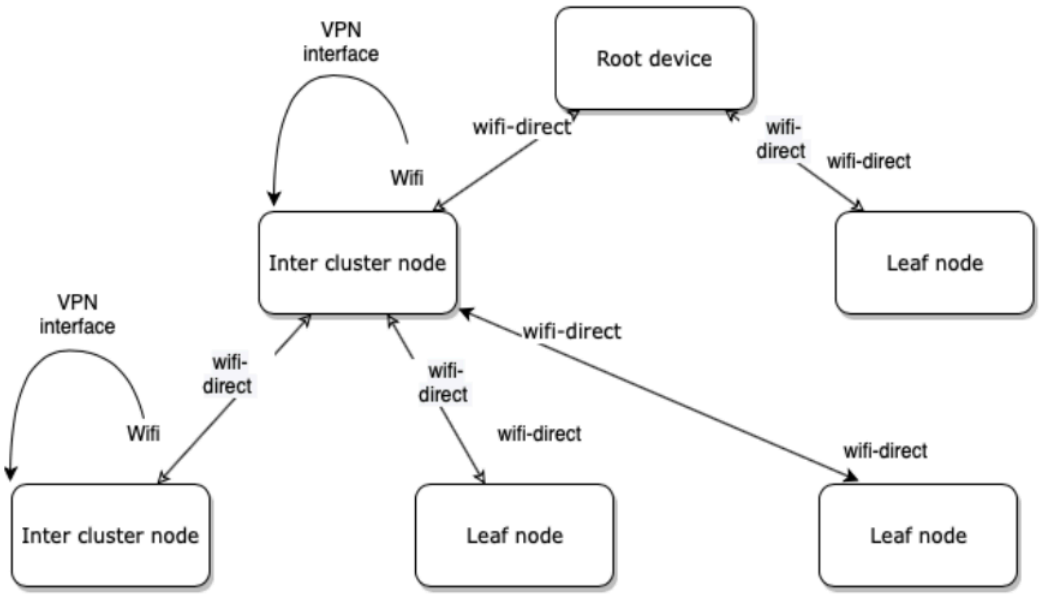

Figure 4.1: Proposed architecture for the ad-hoc network

Chapter 5

Conclusion

This chapter is the most important chapter of the dissertation, for after ensuring the methodology and research processes are sound, the examiners will spend much time studying this chapter.

5.1 Introduction

5.2 Conclusions about research questions (aims/objectives

Findings for each research question or hypothesis are summarized from chapter 5 and explained within the context of this and prior research examined in chapter 2; for example, with which of the researchers discussed in chapter 2 does this research agree or disagree, and why? Disagreement suggests the research is making a contribution to knowledge and this contribution of the research should be clearly developed.

5.3 Conclusions about research problem

Based on section 6.2, implications of the research for furthering understanding of the research problem is explored. You are warned that examiners are careful that conclusions are based on findings alone, and will dispute conclusions not clearly based on the research results. This section concludes with a summary listing of the contributions of the research together with justifications for calling them 'contributions'.

5.4 Limitations

Section 1.7 has previously outlined major limitations of the research that were a deliberate part of the research. This section discusses other limitations that became apparent during the progress of the research.

5.5 Implications for further research

This final section is written to help other researchers in selection and design of future research. Further research could refer to both topics and to methodologies or to both. Removing some limitations mentioned in section 1.7 usually provides opportunities for further research.

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Appendices

Appendix A

One Appendix

This is a appendix. Behaves same as a chapter.

Appendix B

Another Appendix