Implementation of recursive internetworking architecture (RINA) over wireless on Android

Mathieu Devos

Supervisors: Dr. ir. Koen Casier, Prof. dr. ir. Mario Pickavet
Counsellors: Prof. dr. ir. Didier Colle, Dr. Dimitri Staessens, Sander Vrijders

Master's dissertation submitted in order to obtain the academic degree of
Master of Science in de industriële wetenschappen: elektronica-ICT

Department of Information Technology
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Permission of consultation

Mathieu Devos
June 2014

Preface

This Master's Thesis would not have been possible without the help of those who aided me during the production process. For this reason I would like to specifically thank a few people.

First and foremost I would like to thank my counselors: Dr. Dimitri Staessens and Sander Vrijders. Without their close guidance right from the start of the thesis up until the very last moment, this thesis would not have been possible. Thanks to their support I was able to learn invaluable knowledge about the relevant subjects concerning this Master's Thesis.
Beside my counselors I would like to thank my promotor: Dr. Ir. Koen Casier. He provided helpful advice with the writing of the Thesis. Furthermore was he an immense help with the logistics that came coupled with the combination of an exchange program and this Master's Thesis.

A huge thanks goes out to my friends who helped me proofread my Master Thesis. Furthermore I wish to extend my gratitude towards the many people who helped me during the process of acquiring information. This includes the many people over at XDA-Developers, the Linux Wireless Kernel mailing list, the i9100 Cyanogenmod team, ...

Finally I would like to thank my family who supported me during this Master Thesis. They did not ask any questions when I turned my room into a technology lab and inflated the energy bill. For your patience during this year: thank you.

Mathieu Devos
June 2014

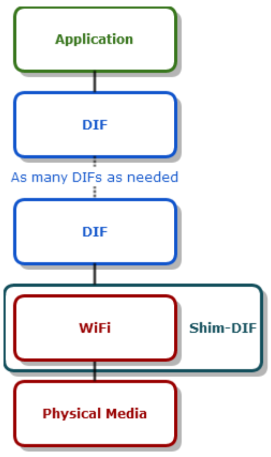
Abstract

The current version of the Internet is a jungle of protocols. Generic protocols interfere with each other, modern protocols overlap with their outdated versions, old issues such as multihoming, layer boundaries, ... were never solved. It is clear we need a new architecture.

With the Internet being born out of ARPANET, instantly several issues became noticeable. ARPANET was a proof of concept, it was never a research net. This means it was never suitable to be the foundation of the current Internet. Several research networks were constructed but were discontinued when ARPANET was moving towards a public network. Several protocols were added to ARPANET and finally it stepped out of its infancy and moved towards a public net. None of the issues were solved though. Protocols were added on top of this, issues that rose during the early stage were never addressed, but the expansion continued anyway. Recursive InterNetworking Architecture, RINA is an alternative architecture that offers an entire new architecture instead of one more protocol meant to patch one specific problem. RINA starts from the basic rule: ´´Networking is Inter Process Communication (IPC) and IPC only". Every IPC has IPC processes that wish to communicate with each other. These IPC processes are bundled in a Distributed IPC Facility (DIF). These DIFs are stacked recursively on top of each other. Every DIF has the same mechanism, but different scopes and policies make these DIFs different.

RINA is a theoretical architecture, without a technical implementation its use cannot be proven. The technical implementation we will be cooperating with is: "Investigating RINA as Alternative to TCP/IP", IRATI. This project aims to provide an implementation of RINA at the lowest possible layer that is currently feasible. While the lowest layer is simply the physical layer, for testing purposes this would prove to be fairly useless as this layer is not directly available in operating systems. This means placemet of the project's code has to be right on top of the link layer. The current existing prototype al-

ready provides a working Shim DIF for Ethernet. A Shim DIF is a DIF which uses the functionality from the lower layer (e.g. Ethernet) and presents this as a DIF to the upper RINA DIF. Note that these Shim DIFs are not fully functional DIFs, but are needed to implement the code as low as possible. The goal is to construct a Shim DIF over WiFi on Android, based on the Shim DIF over Ethernet on Debian Wheezy.



In Linux kernels and Linux-like kernels WiFi frames are being reconstructed as Ethernet frames. After this reconstruction these frames are presented to the kernel. This means that WiFi frames are inaccessible for the user, even the admin (root). In the future this could change or people who currently write the code for the devices which handle this reconstruction could be willing to add implementation for RINA. For this reason a specification will be written which stipulates how the Shim-DIF over WiFi should be constructed. This implementation is specific for the IRATI project.

The implementation on Android is composed through different approaches and a plethora of iterations. After the construction of the base kernel the attempt to add the IRATI specific code to the kernel is made. This proved to be impossible without drastic changes to the code. Other issues arise here as well, such as the addition of system calls to this Android kernel. Further obstacles, such a userspace implementation, package installation, C library incompatibility, . . . all added to the difficulty of implementation. With the current timeframe, manpower, and knowledge the success of implementation on Android fell outside the scope of this Master's Thesis.

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Chapter 1

Introduction

With the Internet evolving at an ever increasing rate it seems to be ossifying. Is this evolution actually a positive aspect though? With a plethora of new protocols, legacy protocols, . . . it would seem that a fundamental look needs to be taken at the current Internet. Starting at the origin of the Internet we move through the history and note that several issues have risen with the Internet that have never been properly addressed. We note that items such as: multihoming, layer boundary violation, . . . are all issues that have been talked about, but never been resolved. The current Internet is a slow, outdated design that needs constant patching to properly function instead of truely evolving. An alternative is needed.

John Day noticed this problem with the current Internet and decided to do some research to what could be changed for this. This lead him to the conclusion that:

> *'Networking is Inter Process Communication (IPC) and IPC only' (Day, 2008)*

Based on this a new architecture was developed. This architecture has been named: **Recursive InterNetwork Architecture**, or in short: **RINA**. This new design takes us back to a very simple basic concept and builds recursively further on this. Old issues that still plague the current Internet vanish with this new design. The essence of the idea is quite simple: use only one repeating layer, a DIF. Every IPC is provided by IPC processes. These IPC processes are brought together in a Distributed IPC Facility, a DIF. This DIF provides IPC servives over the DIF's scope to the distributed applications above. The DIF below is the point of attachment. When applications on the machines want to communicate they utilise these DIFs to set up communication, no static amount of DIFs is required.

The IRATI project has a clear goal to design a basic functional RINA. This means that low level layer support needs to be provided. A working Ethernet implementation has been realized already. In recent light it has become clear that the Internet is moving towards mobility instead of the static desktops. An implementation is needed for WiFi. This is where this Master Thesis is situated. It will try to provide RINA over WiFi. Added to this all is implementation for mobile devices, thus this thesis will handle WiFi on Android. The choice for Android was quickly made as it is partially open source and thus most of the code is publicly available.

In this thesis we will start with a literature study that will take us through the history of the Internet. Following this brief history, the study will state the research question and provide the basic information on where to start the actual research. Once the literature study has been concluded with its placement in the Master Thesis, we will describe the specification of RINA over WiFi. The next step is the actual implementation of the current IRATI prototype on an Android test device. Finally a conclusion will be written with added notes for future steps in this project.

Chapter 2

Literature study

In this chapter we will clearly state the research question. Before we can get to the research question we need to find out why we need to even ask this question. This is done with a small reflection on the current Internet and the evolution throughout history up to this point of the Internet. When this has been handled, the research question can be posed. Following this question the literature study will initiate with acquiring needed information to be able to provide a baseline for the question. Finally we conclude this chapter with a conclusion and a subsection about the placement of this literature study in the thesis. It also points in the direction of the needed items and information that need to be acquired before being able to answer the research question.

2.1 Architecture and origin of the Internet

Starting of this study is done with a small introduction. Since the thesis and the research question 2.2.2 focus on the networking aspect and more specifically on Internet we will first dedicate a section of this chapter to this. We will study the origin and evolution of the Internet, other alternatives to Internet and discuss some of the issues with the current Internet.

2.1.1 Origin and evolution of the current Internet

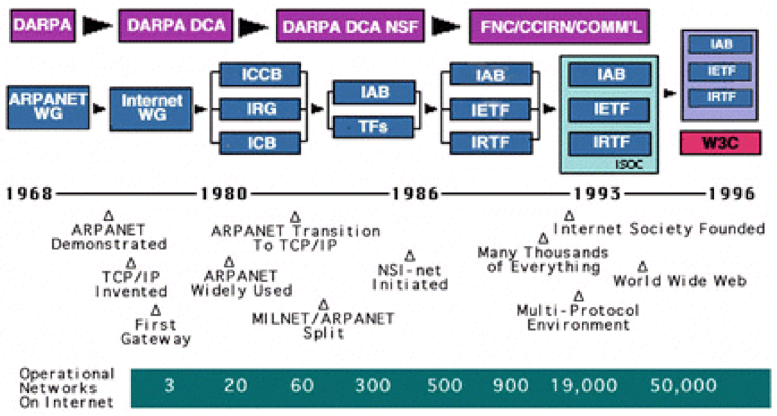


Figure 2.1: Timeline of the Internet (internetsociety.org, 2014)

Internet started out as research aimed at packet switching in the early 1960s. The name of the very first packet switching network was called ARPANET (Advanced Research Projects Agency NETwork), this was a data network established in the USA. While research began early 1960s, it was first established in 1969. The main difference between circuit switching and packet switching is that in packet switching one line of communication can be used for many different packets. These packets can have different sources and/or different destinations, this formed the base of packet switching networks. The first ever packet switched network was set up in California on 29 October 1969 (Salus, 1995). It was commonly thought that ARPANET was set up to survive a nuclear blast, but in fact it was set up as a proof-of-concept and could handle a partial network failure (Hafner, 1998). Later it became clear that this type of network was very robust and was praised for it's ability to withstand partial network failures (Abbate, 2000).

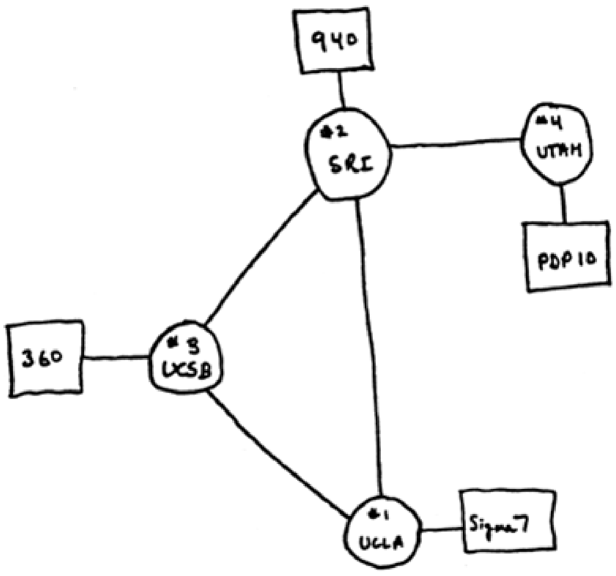


Figure 2.2: Early version of ARPANET (computerhistory.com, 2014)

After the first proof of concept ARPANET quickly expanded during the 1970s. It both expanded on the protocol it used and on the amount of connected nodes. We must first notice that in ARPANET there was no talk of client/server, it was originally designed as a peer-to-peer network (Berners-Lee, 2000; Salus, 2008). ARPANET also went outside the boundaries of the USA when it connected to a Norwegian node in 1973. Later other nodes were included such as a node in Britain, Sweden, ... (see image 2.3. The packet switching network left the proof-of-concept phase in 1975 when it was declared operational (Salus, 2008). While the technology that ARPANET was run on is currently unimportant, the significance of the protocol that was used in this early network deemed to be humongous.

When ARPANET was first launched in 1969 it used the 1822 protocol (Heart et al., 1970), it was named after the report number. This protocol was designed to work cross-architecture and consisted of several fields: a message type, host address (numerical), and a data field. Messages were sent across the network using early routers, called: *Interface Message Processors.* The entire system worked with either a direct, local link where messages were unicasted or were further broadcasted to other IMPs. Once the message had been successfully delivered and acknowledgment was sent back across the network to the sender. ARPANET was entirely designed for this protocol but on top of this protocol the NCP (Network Control Program) protocol was added which in essence meant that more layers were added. These protocols were deemed outdated in 1983 when the transition was made to TCP/IP. This caused a huge requirement of changes[1].

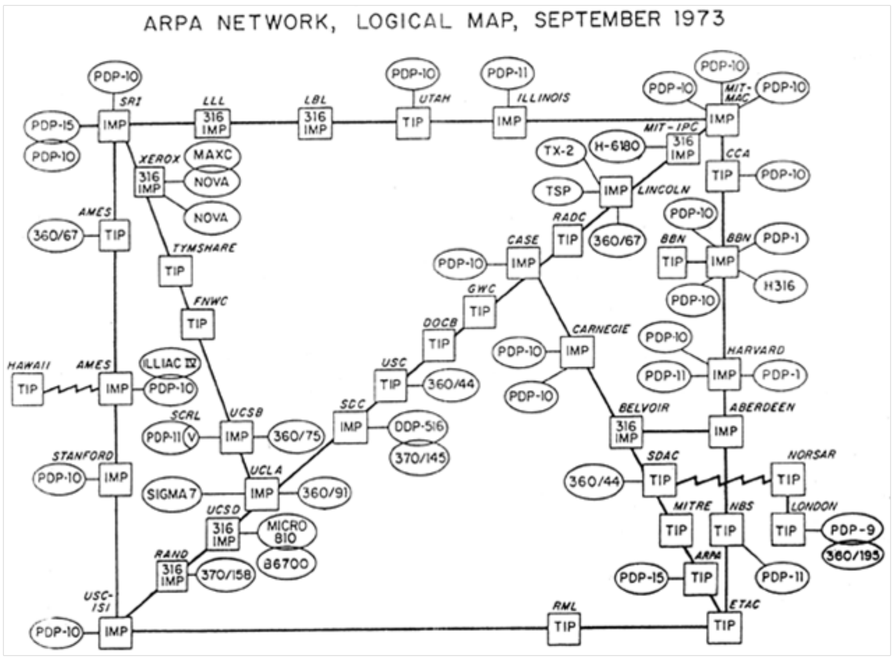


Figure 2.3: Late version of ARPANET (computerhistory.com, 2014)

In 1983 the transition was made towards the currently used TCP/IP protocol. This marked the start of the early *Internet*. TCP/IP stands for Transport Control Protocol / Internet Protocol. This means it is in fact two protocols, transport layer protocol (TCP) and Internet Layer protocol (IP). ARPANET also allowed for layering of higher-level protocols and this is where the OSI model was born. ARPANET decommissioned in 1990 when the transition towards the current Internet had been made. This was mainly due the rise of ISPs (Internet Service Providers) in the late 1980s and 1990s. We can see that ARPANET was essential in the birth of the current Internet.

In later years the Internet became a standardized product. Several standardization bodies regulate the current Internet. The one responsible for the TCP/IP standards is the Internet Engineering Task Force (IETF[2]). While ISO (International Organization

[1]Hence why this is one of the most notable *flag days* in history of software

[2]`http://www.ietf.org/`

for Standards) is responsible for the overarching 7-layer model. Since the bottom part of the 5-layer model and the 7-layer model is exactly the same and we will be working close to the bottom, we will not be discussing the differences between these models further.

2.1.2 Previous alternatives

One of the most notable alternatives to ARPANET was the French-developed CYCLADES. It was created shortly after the birth of ARPANET. The main reason of this research project was to explore alternatives to ARPANET. The core principle was still the same though as also this network was a packet switching network. Some concepts from CYCLADES were later applied to the current version of the Internet, such as: host-responsibility and end-to-end protocol.

At the time in the 1970s several research networks were developed. While all these networks were packet switching, the main point of argument was the role of network or host. Either the network or the host had to be responsible to deliver the packet and this divided the early networks in two groups. Other early research networks on packet switching were: DECnet, EIN nee COST II, EPSS, GEIS, IPX/SPX, Merit Network, ... These networks were very similar to ARPANET and did not feature any noticeable new changes. The most important of these alternatives was CYCLADES and most of the flaws that ARPANET showed were filled by using technology and research from CYCLADES.

2.1.3 Flaws of the current Internet

The current model of Internet shows quite a few shortcomings. The main reason here is that the original protocols were never revised or alternatives were never considered. This static approach has lead to the use of a lot of hacks, patches, band-aids, ... A very recent and obvious example is the need currently required to change from IPv4 towards IPv6. The reason for this is that we are simply running out of IPv4 addresses and thus we need another protocol to handle this. The question then rises: why do we need so many changes to a system that should be scalable? This questions can easily be answered when we look at the history of the Internet. It is based on a rigid system with very little science behind it. When we take a close look at the OSI model (see figure 2.4) we see a huge number of protocols who all have to work in conjunction with each other and overlap in several occasions[1].

[1]Example: IPv4 and IPv6 overlap

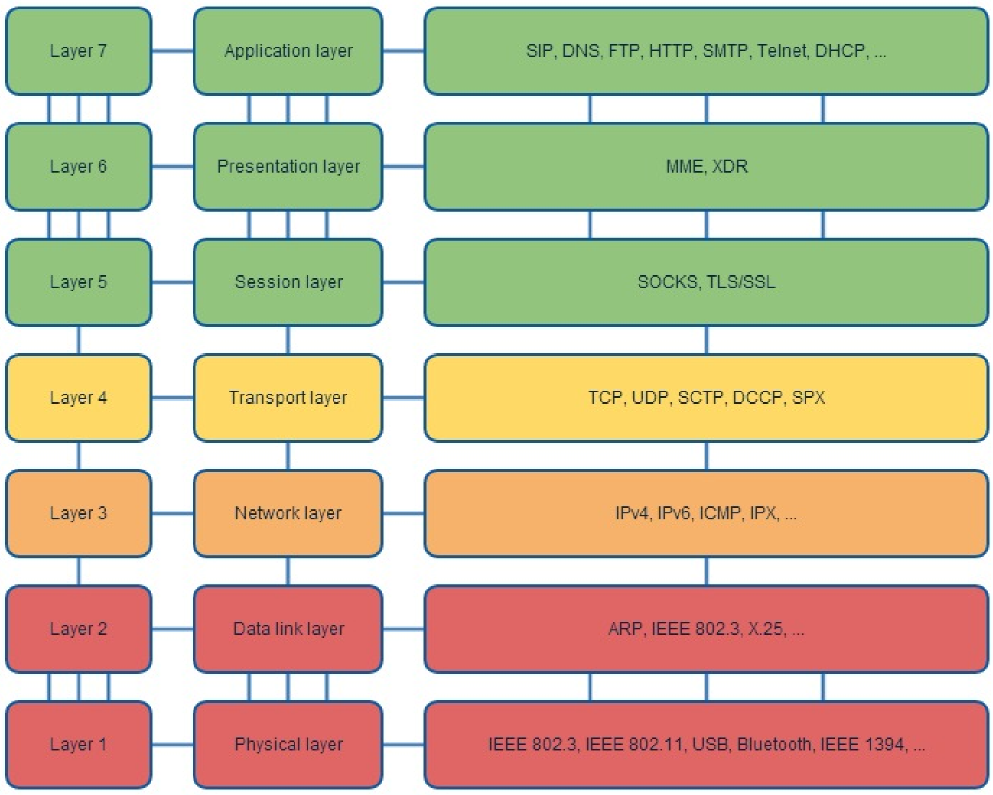

Layer 7
Application layer
SIP, DNS, FTP, HTTP, SMTP, Telnet, DHCP, ...
Layer 6
Presentation layer
MME, XDR
Layer 5
Session layer
SOCKS, TLS/SSL
Layer 4
Transport layer
TCP, UDP, SCTP, DCCP, SPX
Layer 3
Network layer
IPv4, IPv6, ICMP, IPX, ...
Layer 2
Data link layer
ARP, IEEE 802.3, X.25, ...
Layer 1
Physical layer
IEEE 802.3, IEEE 802.11, USB, Bluetooth, IEEE 1394, ...

Figure 2.4: OSI model with examples

Some examples of these issues in the current Internet are: multihoming, denial-of-service, port mapping, NAT (Network Address Translation), IP geomapping, ... While some of these issues are solvable, they require a number of band-aids on the current Internet. This stems from the origin of the Internet. While it started out as a research net it was almost instantly made to be a production network. This was done while other networks, such as CYCLADES, were still researching and solving obvious problems. Due to faulty decisions the Internet continued to be build on these protocols and thus became flawed from the start. For example it is currently fairly difficult to send a packet with multihoming, this requires you to send two different packets. This also causes problems with mobility where targets change IP addresses quickly when running through different Internet providing cells. Handovers from routers is a big hassle for mobile users and slows down the entire process of staying online permanently. While short interruptions are not an issue when loading a website, it can prove fatal when using this Internet for live communications, monitoring, ... Proper multihoming can potentially fix this issue, but this is currently very hard to achieve in the current state of the Internet.

Another example is the use of NAT, Network Address Translation. This is needed because we are currently running out of IPv4 addresses and it enables small networks to have multiple nodes connected to the Internet at the same time. The problem is that this only solves issues in one direction. Nodes outside the network are in essence locked out of the network utilising NAT. While it might provide some basic safety benefits, it causes issues for several applications, such as peer-to-peer applications and many others. It also means that the router is actually breaching the model because it alters packets (specific port number and ip). In the normal model this is never changed between end hosts.

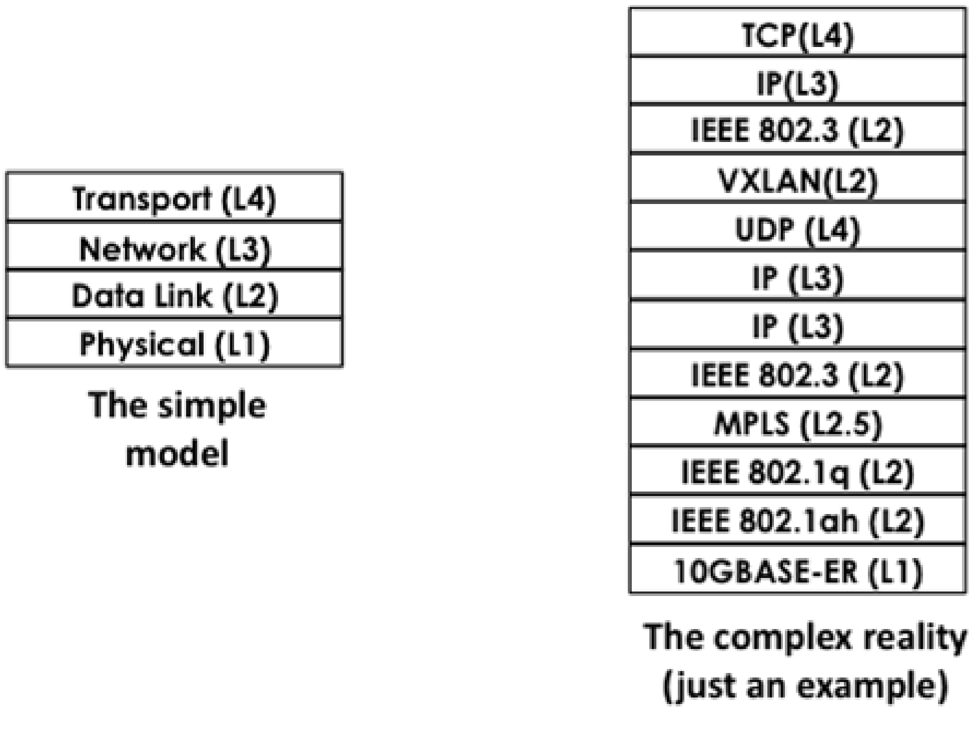


Figure 2.5: Example of the current Internet layer system (Vrijders et al., 2014)

Further issues become apparent when looking at common items in some layers. We see that it is possible to map IP-addresses to geological information, thus violating privacy of the people using the Internet. Secondly when an attacker obtains an IP-address it becomes quite easy for this attacker to spam this IP with data causing a disruption in the service of the host. This is known as: Denial-of-Service Attack. Other mapping problems are the common application-port mapping that occurs. When anybody intercepts a packet he can read the port number and deduce for what application that packet can be used. This leads to more privacy issues and limits applications in their use as they are not free to choose a port number.

We see that the current Internet has quite a lot of issues and can use a general, uniform model or architecture as an answer. Continuing down the road of constantly applying band-aids to a already broken system is clearly not an answer. A clear slate is needed and this is what the research question will try to find an answer for.

2.2 RINA alternative

"Networking is Inter Process Communication (IPC) and IPC only"

John Day, *Patterns in Network Architecture: A return to fundamentals*

In this section we will address the alternative for the current Internet. This alternative is called *Recursive InterNetworking Architecture* (RINA). We will start this section off with explaining the basics of RINA. Both the function and the history will be discussed. Following this the main research question will be posed and we state how this question will be answered. The followup subsection will delve further into RINA and look towards the current technical implementation we are researching, *Investigating RINA as Alternative to TCP/IP* (IRATI).

2.2.1 RINA basics and origin

Before we go any further we initiate with clearly stating what *Recursive InterNetwork Architecture* (RINA) is, how it functions and what the origin of RINA is. As has been shown in subsection 2.1.3, the current status of the Internet is facing a long list of issues. This is where RINA provides an adequate answer, it looks at previous network architectures and tries learn from those. In the end RINA proposes a basic, clear, and adequate answer for the networking needs.

RINA is a proposed architecture by John Day in his 2008 book: "Patterns in Network Architecture: A return to fundamentals" (Day, 2008). Let us start by explaining the full name of RINA: *Recursive InterNetwork Architecture*, first the last part: *Architecture*, this states what the actual goal of this is. To implement an architecture that provides support for Network communication. One of the most important words in RINA is definitely: *Recursive*. Recursive is defined as: "pertaining to or using a rule or procedure that can be applied repeatedly." (dictionary.com, 2013), this instantly shows that the entire architecture is build on a base that can be repeated as many times as needed. It does not involve a static amount of layers, instead it can use as many or as few as needed to set up communication between application processes. The middle part: *InterNetwork* shows that this architecture involves communication between and on networks and is not limited or restricted to single networks.

The main principle in RINA is that networking is simply and only: *Inter-Process Communication* (IPC) (Day, 2008). This is the premise on which entire RINA is founded. An IPC is provided by IPC processes, a group of these coherent IPC processes forms a *Distributed IPC Facility* (DIF) through enrollment. Every DIF is managed and has its own scope, it provides a way for processes to communicate between each other. DIFs have the same mechanism but are configured to different policies and thus have their own sets of rules. A DIF can ultimately be seen as a layer. For example the top DIF provides IPC directly to user applications. Below that you have a DIF that takes care of the communication between user A and the router user A is connected to. Every DIF has their own scope and once it becomes clear what the scope is for the DIF, the function of this DIF will be evident and be tailored to that scope. This repetition of DIFs goes on recursively until the entire chain of communication can be formed and finally the application from user A is interacting with the application from user B.

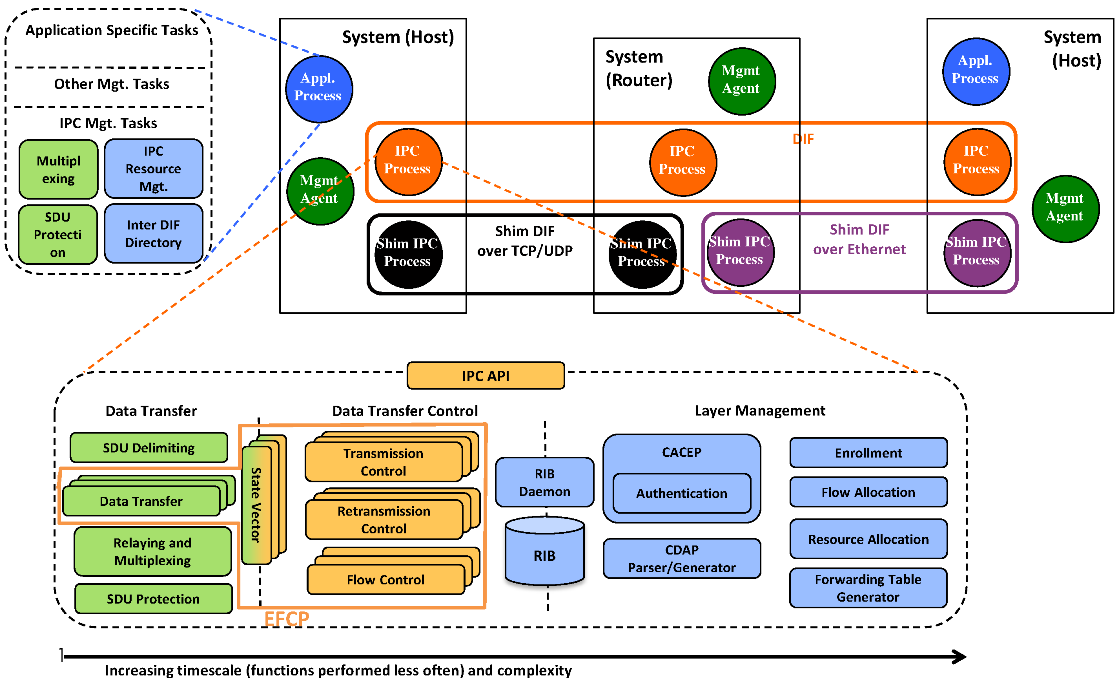


Figure 2.6: Recursive InterNetworking Architecture example (Vrijders et al., 2014)

An example how communication between two processes is established with RINA can be seen in the image 2.6 above. Here we see application S on the host trying to communicate with application D on the other side of the communication chain. We see that for this specific example 3 levels of DIFs are used. These DIFs stack recursively from the bottom level (1st level) up till the DIF that actually takes care of the communication between the IPC and the application process.

In this architecture we see that every application process, which also includes the IPC processes, has a name that is unique in that DIF. This is the way routing is ultimately done, but it no longer forces users to link applications to port numbers or specific IP addresses. While IP addresses can still be used in lower level DIFs for routing, we are no longer restricted to this protocol. Naming stays within the DIF and is not visible outside that layer. In every DIF is a directory that contains the IPC process names and associates these to the application names (layer above the DIF). This is where we instantly see the possibility for multihoming. One application process can have communicate with different IPC processes in the DIF below. An IPC process on the same machine in the DIF below is called a Point of Attachment. The architecture will choose the most optimal routing and provide communication between the application processes in the layer above that requested it. Finally we must name the way a DIF sees its surroundings. An IPC process on the layer above within the same machine is the application process.

2.2.2 Research question

We will clearly state the research question as this will clarify what will be researched, what should be developed and what answers we are looking for. This is applicable for both the literature study as well as for the entire thesis.

The research question is stated as follows:

How to run RINA on Android over WiFi?

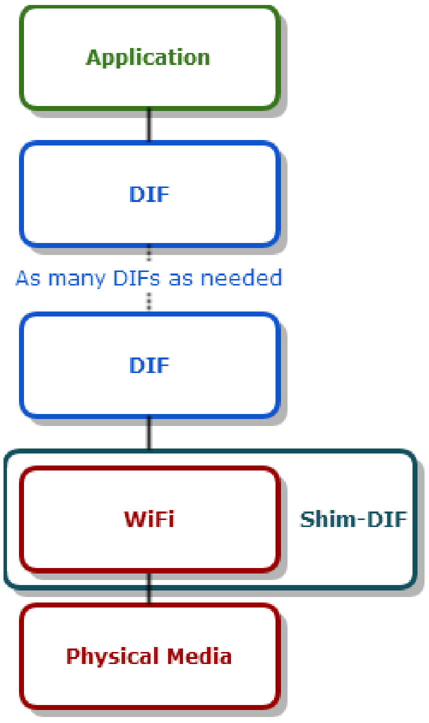


Figure 2.7: RINA over WiFi

This is ultimately the question we are trying to answer. This question alone does not provide enough background and will need some further elaboration, which will be provided in this subsection.

First we must note that RINA is the theory, actual working models are currently very scarce. We thus require a technical implementation of RINA. This will not be self constructed, we will be building further on a provided codebase. This project is *Investigating RINA as Alternative to TCP/IP* (IRATI) (irati.eu, 2013a; Vrijders et al., 2014). This European project is a collaboration between:

i2CAT Foundation `http://www.i2cat.net/en`

Nextworks `http://www.nextworks.it`

iMinds `http://www.iminds.be/en`

Interoute `http://www.interoute.com/`

and is trying to bring a codebase for RINA upon which commercial implementations can be based. A working Recursive InterNetworking Architecture has already been developed for Linux operating systems. Since the Android platform is based on a trimmed and edited version of the Linux platform we will use the previously established code as a base.

A current working Shim-DIF (more about specific working of RINA in 2.2.1) has been constructed for 802.1Q (Ethernet) on Linux operating systems. A big portion of this thesis is how to port the IRATI prototype on Android, more specifically to extend the prototype towards a working WiFi Shim-DIF. A key point for this Shim-DIF and the thesis as a whole is the need to be dependency free. When this Shim-DIF is dependency free it will guarantee the full and seamless working of RINA on mobile devices, specifically on the Android platform. Other physical connection mechanisms for Android such as: 3G, 4G, . . . are not part of this thesis.

Another part of the research is dedicated towards the differences between the Linux and Android platform. IRATI is built in C in kernelspace and C++ and Java in userspace. These coding languages are well supported in Linux and in various other platforms. The issue here rises that the library that handles C++, *glibc*, is not available in the Android operating system. On Android a variant of this library is available, called *bionic*, this library however has more limited functionality, specifically some alterations on how C++ is handled.

One final piece of research that will be completed is to figure out how to optimally map RINA API to the current WiFi standard. For this we will take a closer look at the current WiFi standard (Ortiz, 2009; Paul and Ogunfunmi, 2008; Perahia, 2008). Since the current WiFi standard is constructed out of several protocols: LLC 802.2, MAC 802.11 and PHY 802.11, we will investigate these further.

This research question is now clearly stated and throughout this literature study we will try find the needed background information to help us formulate an answer in the thesis. The answer will not only be limited to pure text form, but shall also include working code for the prototype of the *Shim-DIF over WiFi on Android*.

2.2.3 IRATI implementation

In this part we will address the technical implementation of the RINA model. The implementation that we will be using is developed in the IRATI project.
In this subsection we will further explain the current development status of IRATI, the future goals and give a brief explanation of the technical aspects of this project.

The IRATI project is building a working, open source, technical implementation of the Recursive InterNetwork Architecture in Linux with parts in both kernel and userspace (irati.eu, 2013b). The technical roadmap towards this goal has been divided in 3 parts.

1. Restricted prototype (November 2013)
2. Open source prototype (June 2014)
3. Open source prototype, further development (December 2014)

These different phases show the current plan of action for the project. They represent the coarse lines along which the project will guide itself. More specifically the project aims to have a technical implementation that features both parts in kernel space and in user space. These should be loosely coupled and functionalities that take part in both user and kernel space should be avoided. The reason that this currently has to be done is that for the entire architecture to work optimally we would need to have a brand new kernel based on this architecture. This is not within the confinement of the project and thus IRATI opts for a loosely coupled, although less optimal, system. Within this project is also a big part that represents the application programmable interface (API), this is situated within the user space. It acts as an adaptor in the project and presents the RINA stack towards the applications as a common interface. This is of utmost importance because thanks to this the applications quickly become versatile and cross platform. When the same API functions are offered on different platforms it becomes irrelevant for the application which operating system it is running on. As long as API functions presented to the the applications stay the same. This API currently offers bindings for C and C++ for the applications. However bindings for other programming languages can be quickly implemented when using tools such as SWIG. SWIG stands for Simplified Wrapper and Interface Generator and can, when prompted present the C/C++ bindings as other programming language bindings. A working example of this is the currently operational Java bindings for RINA.

The first phase of the project focuses on having a working prototype of RINA. This prototype should be as low as possible within the current Internet stack. Due to not being able to fully redevelop a brand new kernel, outside the project's scope, the option has been made that the lowest feasible is the Ethernet stack. More specifically virtual LAN (vlan) Ethernet, 802.1Q. This requires one special DIF, a Shim-DIF over Ethernet that presents Ethernet in such a way that DIFs on top of this Shim-DIF can use it as part of RINA. This entire architecture is presented in the following figure 2.8. This provides a technical proof-of-concept for RINA. It will also add functionality to current Internet, such as multihoming and improved mobility (Vrijders et al., 2014). During this phase of the project the code is not publicly available.

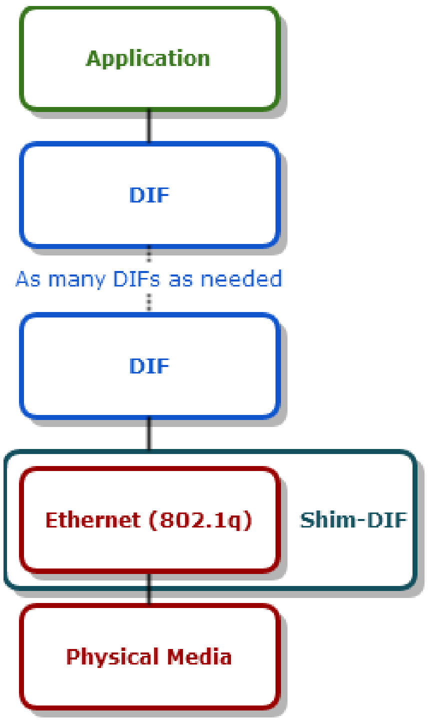


Figure 2.8: Recursive InterNetworking Architecture example over Ethernet

After the first phase of the project has been completed and several iterations over the current code have been completed, it can move towards the open source phase. This should be around June 2014. In this phase functionality should be supplemented to the existing codebase. Not only should the previously working parts of the project be improved upon and publicly released, but new functionalities should be added. These items can be different levels of support on top of different layers of the current Internet. Expansions could be made towards other protocols than UDP or IP. Other platforms could be explored such as Android which is a minimal deviation from the current Linux Operating Systems that are being focused on.

The final phase is to further iterate upon the currently existing codebase. This means fixing bugs and further improving functionality. These steps lead towards a well-developed technical project that clearly shows a proper implementation of RINA. During this phase further spread towards other operating systems and protocols is the main target. This will lead to a strong interoperability between different architectures and protocols using RINA. From the second phase on the project will be open sourced and aim to set up a strong developing community around the technical implementation of RINA.

Finally we will briefly touch on how the thesis utilises the IRATI project. The thesis is focused on the WiFi implementation on Android operating systems (figure 2.7). More specifically the thesis will aim to port the IRATI stack on the Android platform over WiFi. For this code will be used that was produced during the first phase. The code will be made publicly available when the second phase is reached, which should be at the end of this Master Thesis.

2.3 RINA over WiFi

Following the introduction to the RINA alternative in section 2.2 we will now take a closer look to RINA over WiFi on Android. What the exact needs are for this implementation and where special focus will be needed. We kick this section off with a piece about IEEE 802.11 MAC protocol. Followed by the WiFi Shim-DIF. Finally we will take a closer look at the Android restrictions (compared to Linux).

2.3.1 IEEE 802.11 Media Access Control

In this subsection we will address the WiFi MAC[1] (Gast, 2005). Since the 802.11 protocols covers both layer 1 (physical layer) and a part of layer 2 (Media Access Control) we will limit ourselves here to the layer 2 interaction. The IRATI project code will have to fit seamless on this protocol to ensure maximal optimization for wireless communication. In normal operation mode the device drivers for user devices will be set to *STA* mode (Station infrastructure mode). This enables basic device functions, however two devices in STA mode will not be able to communicate with each other unless an Access Point (AP) is presented to communicate with. As can been seen in figure 2.9.

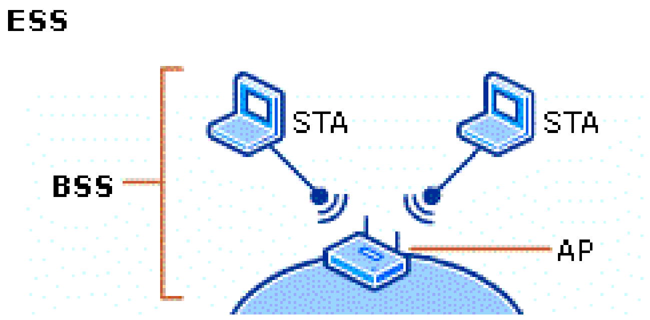


Figure 2.9: 802.11 Infrastructure mode (STA and AP) (technet.microsoft.com, 2014)

Drivers can also function in other modes, some of which will be handled later in this thesis, some who will not be handled at all. Other modes that drivers are capable of are (wireless.kernel.org, 2014):

AccessPoint (AP) infrastructure mode Access Point for a master device in a network, normal mode for WiFi router. *Not handled further*

Monitor (MON) mode A passive mode that allows monitoring of all packets the device receives, can be double used in some devices. *Used in testcases*

Ad-Hoc (IBSS) mode Enables communication between other ad-hoc devices without AP (figure 2.10). *Used in testcases*

[1]802.11 Media Access Control

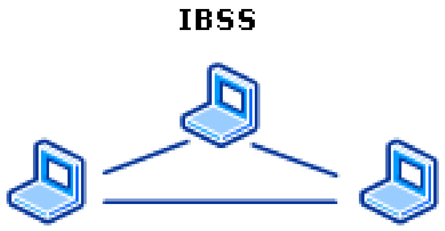


Figure 2.10: 802.11 Ad-hoc mode) (technet.microsoft.com, 2014)

Wireless Distribution System (WDS) mode Enables communication between devices (mostly APs in a single ESS), uses the 4-addresses from the layer-2 header[1]. *Not handled further*

Mesh Enables communication in Wireless Mesh Networks, used to set up intelligent, dynamic routes. *Not handled further*

For the initial part of this thesis we will leave the device in either STA or IBSS mode. This means that the drivers will *translate* the 802.11 MAC-headers to 802.1Q MAC-headers when in STA mode. If this happens in IBSS mode we will have to test or ask authorized sources[2]. The difference can be seen in the figure below (figure 2.11). We see that the entire header (Ethernet) becomes quite a bit easier to understand in STA mode. Since the IRATI project already has a working Ethernet Shim-DIF this will, under normal conditions, fit on this MAC header in STA mode. When expanding further down the road we will have to implement a Shim-DIF capable of handling the 802.11 MAC header.

[1]Other modes only use these partially and mostly leave one or more fields empty

[2]Linux Wireless Kernel group for example

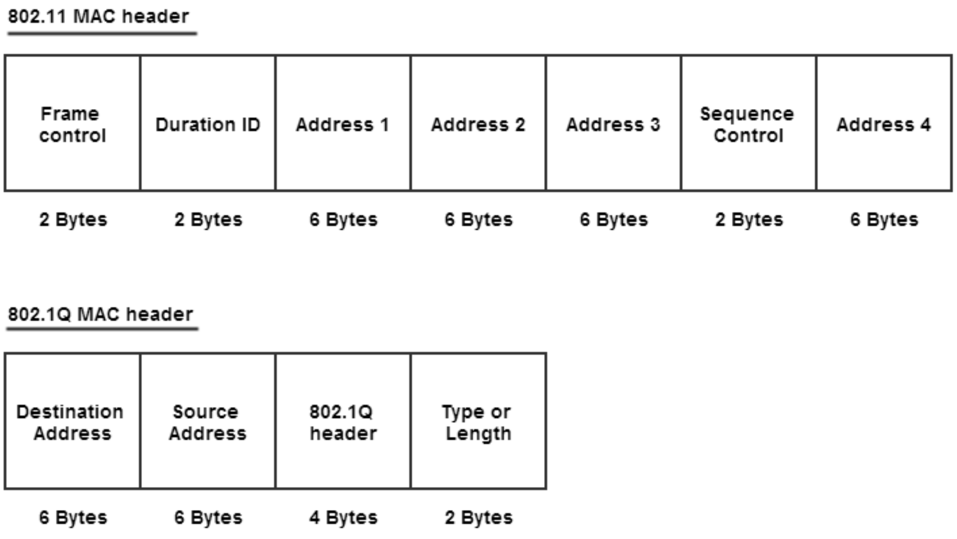


Figure 2.11: 802.11 and 802.1Q MAC headers

Since WiFi MAC headers (802.11 MAC) have quite a lot more functions (30 bytes compared to 802.1Q's 18 bytes) we will have to adjust the code for this. The functions that are added can potentially prove useful for the architecture and thus further study should be implemented. This research will focus on the overlap of functions between the MAC header and the functions provided by the IPC API. It can ultimately prove advantageous to use the full WiFI header alongside with RINA instead of having drivers reform this header to a more easy to comprehend Ethernet MAC header.

2.3.2 IEEE 802.2 LLC

Since the WiFi protocol consists of 3 different layers, we require research to each of these. In the table below the WiFi protocol is further explained in its different protocol parts.

802.2	LLC
802.11	MAC
802.11	PHY

Table 2.1: Overview of WiFi protocol parts

As stated in the previous subsection we do not cover the 802.11 Physical protocol as this is outside the scope of this thesis. The LLC header does over some interesting aspects. While it is a quite old protocol (IEEE Computer Society, 1998a), it might still have its uses. A typical LLC header is represented in the table below.

DSAP address	**SSAP address**	**Control**	**Information**
8 bits	8 bits	8 or 16 bits	M*8 bits

Table 2.2: 802.2 LLC PDU format

A LLC frame has a source address and a destination address. In the current version of the Internet it acts as an interface which situates itself between the Data link layer and the Network layer. It was originally designed to provide flow control and error management. However, given the age of the protocol, these functions are now almost exclusively done by Transport layer protocols. While always attached to WiFi protocol, it is almost never used in today's networking environment. Error management and flow control are handled by 802.11 MAC protocols and LLC is simply added on top of this. LLC provides 3 types of operation:

Type 1 Operation The simpelest operation. The protocol only uses the source and destination service access point (SSAP and DSAP). These addresses are used to indicate which type of packet the header is transporting.

Type 2 Operation This operation mode builds further upon Type 1 operation. Each SAP has 2 possible states and when both are in Operation mode, communication can be provided between these SAPs. Type 2 Operation also requires ACKing of every packet. However, the ACKing done through means of numbering each packet, with a maximum of 128 possibilities. A very low number considering current high bandwidth communication links.

Type 3 Operation A combination of the modi aforementioned. This operation mode requires ACKing, similar to type 2, but provides no state vectors for the SAPs.

The conclusion about this protocol is fairly simple: it is old and provides very little use for the WiFi protocol. It might offer some functionality for the RINA specification over WiFi in the next chapter.

2.3.3 Shim-DIF for wireless

While under normal operation of the research question we delve further into the Shim-DIF over WiFi (see figure 2.7). However, after research (see Appendix 5.2), we see that WiFi frames are reconstructed to Ethernet frames before they are passed to the kernel.

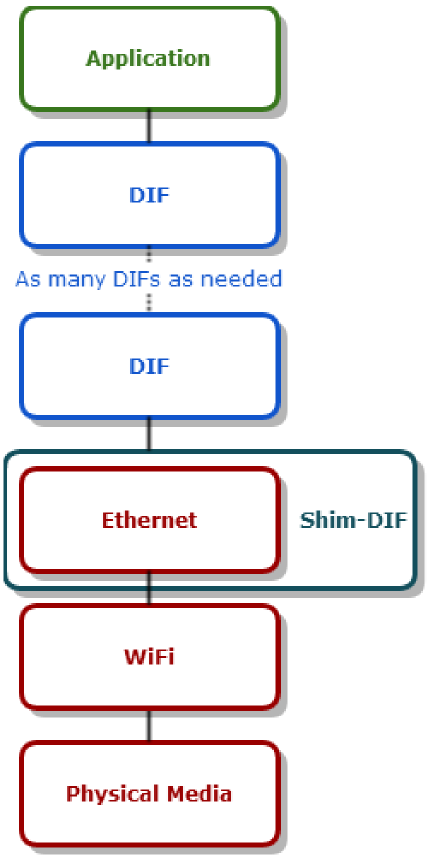


Figure 2.12: RINA over WiFi (updated)

In normal conditions this means we can fully copy the code from IRATI, we must remind ourselves that we are still working on another Operating System and this comes with consequences. These are handled in the next component. We will take a closer look at the WiFi packets and provide a Shim-DIF for the WiFi standard. This provides a base for other developers who wish to update drivers further down to road to make said drivers compatible with RINA.

2.3.4 Android restrictions

While Android is a UNIX-like operating system and based on Linux, it does come with some restrictions. In this subdivision we will be comparing Android OS to the Linux OS. The reason for this is that the IRATI project already has a working RINA implementation on Linux and this will be used for the further work of this thesis. Secondly, because Android is based on Linux operating system and its kernel. At one point in history the two operating systems shared a common kernel and while this common component is planned, it is currently not the same kernel.

Before we can further inspect the Android operating system, compared to Linux OS, we first need to identify the differences between the *Android kernel* and *Linux kernel.* For most of this information we will be using a talk by John Stultz, comparing Android to a stock Linux kernel (Stultz, 2011; Wiki, 2013a). The amount of changes is not that large as it comprises of around 25 000 lines of changes, compared to the entire 15 millions lines of code for the full kernel. This places the changes around ~0.2% of the total code. Of course some of these changes can have large impacts on the actual kernel itself. These changes will be discussed here. Some of the items in the Android patches include:

- Ashmem
- Binder
- Pmem
- Logger
- Early suspend
- Wakelocks
- Various small *hacks* to facilitate a mobile OS
- ...

Because a Linux kernel is meant for desktop and server hardware (both very similar), Android aims to improve in the hardware department. This allows the use of more and varied hardware through its kernel. A second large point of interest for Android is the power management. While traditional systems are just plugged in with the cable and thus don't need to worry as much about power. The opposite is true for mobile, battery powered devices where power management is of utmost importance. Another change

between the two kernels is the way error reporting is done and the attempt to increase security on the Android kernel. Finally the Android kernel aims to improve performance, especially for its intended users, mobile platforms.
Some of these changes to the original kernel have been talked about quite a bit, such as the wakelocks. However we find that these changes will not impact the current implementation of the IRATI stack into Android. Further down the road additional optimization can be acquired between the Android kernel and the IRATI stack.

Android kernels are very specific to the target devices. This adds an increase in difficulty when trying to implement a general code, which RINA's technical implementation aims to provide. Since the devices are small, CPU speeds are low, RAM and storage are limited, these kernels are reduced to the bare minimum. Because of this it is fairly difficult to clone one kernel to another device. The drivers are specifically selected for that device and might simply be replaced by other hardware on the second device. This is an issue that we will have to consider during the implementation phase of this thesis. Working with the bare minimum of a kernel means that dependecies might not be met when adding new code to this kernel. Finally we see that the version of these Android kernels is quite far behind the most recent Linux kernels. While the most recent Linux kernels (at the time of writing) are 3.16.x, our test device's most recent kernel is 3.0.101. More recent devices have kernel versions as high as: 3.4.x.

As shown above, the current version (and future versions) of the Android kernel might pose problems for the IRATI prototype. In addition to this, an operating system does not only comprise of its kernel. This is an important part and the aspect where we see the biggest change between Linux and Android. When looking at a structured overview of an operating system (UNIX-like), we see that libraries play a big part in the undertaking of an operating system. Here we find the biggest change between Android and Linux. Linux uses glibc (gnu.org, 2013) and Android uses the Bionic library (Contributers, 2013; Wiki, 2013b).

The restrictions from the Bionic library that affect the inclusion of the IRATI stack on Android are mostly limited to the C++ language. The way Bionic handles C++ is quite unique as it aims to alter the use of C++ as a whole. This issue here is the following: IRATI stack is build on C++. For the most part C++ is still supported by the library, but it does come with some restrictions. Before we inspect those restrictions we must first look at the reason why the glibc was not used in the first place. This can be declared very fast and accurate. Glibc is a *slow* and *huge* library. While this is not an issue for systems that run on Linux (desktops, servers, . . .) it does form a problem for small-scale mobile platforms. Another issue with glibc is that it falls under GPL (GNU General Public License) and the smaller version, uClibC falls under LGPL (Lesser GNU General Public License). This implies that everything that uses these libraries also falls under these licenses, something Google was looking to avoid. Hence the option to use a new library, Bionic, which uses BSD license and thus can shield its applications from the GPL and LGPL licenses. Finally we must note that glibc is quite large and meant for high frequency processors, where bionic is a lot smaller and works very fast, even without high speed processors[1].

Because the C++ restrictions of the Bionic library are of utmost importance to this IRATI project inclusion we will now take a closer look at these restrictions. The most profound and important restriction is the lack of support for C++ exceptions. Google engineers deemed these exceptions bloated and largely impractical for use thus the support for this was entirely cut. When people still want to use exceptions they are advised to try another library, add a library that does support these or switch to Java programming language in the userspace. This is an important change as the current IRATI project does use C++ exceptions and thus the code will need to be retailored to fit seamless on the Android platform. Another option is to try and implement changes on Android so that the current IRATI project can be ported over. Secondly, Bionic does not contain a C++ Standard Template Library. This is for obvious reasons to try and keep Bionic as small as possible. When applications wish to use a C++ STL they will have to include one with the application or acquire it beforehand. Other changes bionic made can be viewed at Pthreads. These are threads that are standardized and should be compatible cross-platform. Some changes bionic made to these threads include: cancellation, pthread_once(), pthread_atfork(). Here it is recommended that when these functions are used in the original code, to revise the code and work around these changes. The changes are in place again to reduce the bloated code in glibc and endorse optimized coding. The final changes that bionic implements are the lack of support for wide and locale characters and some user-account-related functions.

2.4 Conclusion and placement of the study in the thesis

In the final segment of this literature study we will draw a conclusion and show where the literature study will fit in the master thesis. The relevance of this entire literature study

[1]High frequency CPUs are becoming available for mobile platforms at this very moment

will be shown throughout the rest of thesis. It might become obsolete or perspectives might change, but this is a needed study. The study provides a baseline on which the Master's Thesis will build further. Several tests need to be conducted and code needs to be programmed, this means that the conclusion will be quite different. This also means that the literature study will be purely that and no conclusions will be drawn from only this aspect, the conclusions will be multi-faceted.

2.4.1 Conclusion literature study

As we can see from the initial chapter the Internet is not perfect. It was built on a proof-of-concept with a very basic set of rigid protocols. This has lead to several disadvantages that currently require heaps of work for just temporarily repairs. For other issues we just require a plain new protocol to solve this issue. A clear answer is needed and this is what we present: Recursive InterNetworking Architecture, RINA. This new architecture requires quite a bit of initial work to set up a technical project to take over all the functions of the current Internet. After this initial work it will require minimal maintenance and prove to be very scalable in the long run. The main reason for this is the recursive function in the entire architecture.

RINA is an architecture that stands on one basic principle: networking is an InterProcess Communication (IPC) and IPC alone (Day, 2008). This IPC is provides an IPC process. A group of these coherent processes (same layer) forms a Distributed IPC Facility (DIF) when these processes are enrolled. These DIFs stack recursively until the application on host A can communicate with the application on host B. Every one of these DIFs has a unique set of functions and operates in its own scope.

This shows the way RINA functions, but since RINA is only a model we need a technical implementation. This implementation we will be using and supporting is the IRATI (Investigating RINA as Alternative to TCP/IP) project. This European project focuses on a technical implementation of RINA for UNIX-like operating systems. It already has a working Shim-DIF for Ethernet (802.1q). In this thesis we will try to port the IRATI stack to Android. Finally we will try to make a working Shim-DIF for WiFi on Android.

Finally we take a closer look to the DIF that will be researched in this thesis. The Shim-DIF for wireless. This Shim-DIF will use the Ethernet MAC header as its main pillar and build further upon this. In research from this literature study we have concluded that 802.11 (WiFi) MAC headers are not available because drivers reform these to 802.3 headers. This means that the initial research question is altered in a manner that reflects these findings. To illustrate this with images: we initially started with image 2.7 and after this study we came to the conclusion that we will have to work on a model represented in image 2.12. When all the above questions have been answered and submitted, we can assume the research question (2.2.2) has been solved.

2.4.2 Placement of the literature study in the master thesis

This literature study functions as a background study for the master thesis. In this study we have looked at the cause of the problem, clearly stated the research question, and finally we have provided adequate research to start the thesis. The background study and information has thus been provided to the researchers. This information shall be used to continue the thesis from this point on. Several research topics and points of importance have been pointed out in this study.

Chapter 3

SHIM DIF for WiFi

3.1 Introduction

In this chapter we will stipulate the Specification of the Shim DIF over WiFi. This DIF will only provide support for RINA DIFs. Given that a RINA DIF expects a RINA API as the lower API, the purpose of a Shim DIF is to create as thin a veneer as possible over a legacy protocol (WiFi) to allow a RINA DIF to use it without modification. The goal is not to make legacy protocols provide full support for RINA and so the shim DIF should provide no more service or capability than the legacy protocol provides.

802.2	LLC
802.11	MAC
802.11	PHY

Table 3.1: Overview of WiFi protocol parts

WiFi consists of 3 main parts and the adaptor will try to span over all these. On top we have the 802.2 LLC layer, below that is the 802.11 MAC layer and finally we have the 802.11 physical layer. We must note that the LLC layer is an old protocol that has been reused for WiFi, it is not likely to be updated soon. The LLC layer is currently being used to differentiate between different higher level data packets. The MAC layer has been changed as recently as 2007 with 802.11e. It has several fields reserved for future use and could be changed later on. Finally, the physical layer is presented at the bottom of the WiFi scope. We instantly note that this changed quite often but provides no additional use towards the Shim DIF. The physical layer of WiFi is not within the scope of the Shim DIF.

The Shim DIF over WiFi is not a fully functional DIF. This means that some limitations apply to this protocol:

- Limited amount of flows due to the usage of the LLC header for flow differentiation (802.2 standard(IEEE Computer Society, 1998a)).
- Only type 1 operation of LLC is useable, this means no Flow Allocation with LLC is possible.

The reason why we can only use Type 1 operation is because the other types (2 & 3) require constant ACKing of packets. These packets are then marked with ACK numbers, limited to 128 different values. This is considered too low in the current high bandwidth traffic that can occur. Thus only Type 1 operation, which has no ACKing, but also Data State vectors, can be used. Even with these restrictions the Shim DIF provides enough support at the bottom layer of the architecture that other DIFs can build further upon. The Shim DIF provides QoS-cubes, flow differentiation and other options such as fragmentation possibilities. The Shim DIF presents the WiFi stack towards upper layer DIFs as a DIF.

3.2 Mapping of 802.11 MAC header

In this section we will show how we will use WiFi. We will start the mapping from the 802.11 MAC layer. Here we focus on 802.11e, this IEEE standard from 2005 implements the most recent version of MAC. This includes the introduction of QoS, used later on in this specification.

The fields in the 802.11 MAC header (shown in figure 3.1) that will be used are the Address Fields and Payload field.

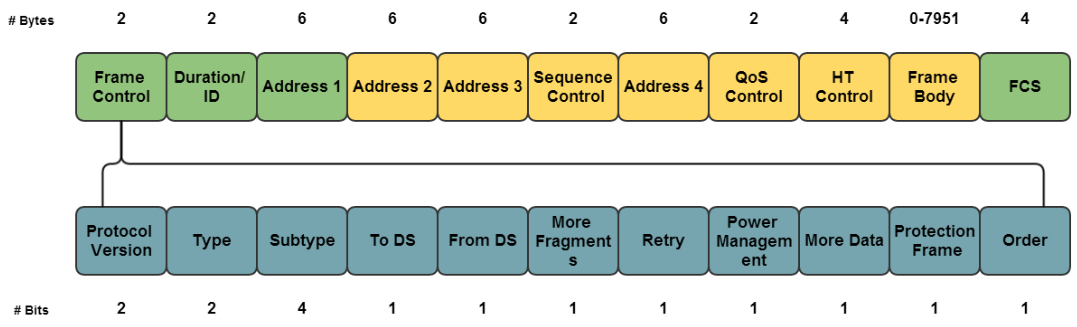


Figure 3.1: 802.11 MAC frame

These 4 address fields will be used according to the 802.11 MAC standard (IEEE Computer Society, 2012). This means the following address fields will be mapped:

Address fields The MAC addresses used to identify shim IPC Processes to.

Network Type	**To DS bit**	**From DS bit**	**Address 1**	**Address 2**	**Address 3**	**Address 4**
IBSS (ad hoc)	0	0	DA	SA	BSSID	*N/A*
BSS (infrastructure)	0	1	DA	BSSID	SA	*N/A*
BSS (infrastructure)	1	0	BSSID	SA	DA	*N/A*
WDS	1	1	RA	TA	DA	SA

Table 3.2: Overview of Address Fields[2]

Destination Address (DA) The Shim IPC process address corresponding to the WiFi interface that the destination Shim IPC Process is bound to.

Source Address (SA) The Shim IPC process address corresponding to the WiFi interface of this Shim IPC Process.

[2]Only DA and SA are used in the Shim IPC Process

Note that these address fields are static in the Shim and are determined according to the values in the Frame Control field, further details shall not be provided for this as this is provided in the IEEE standard(IEEE Computer Society, 2012).

Frame Body This is the SDU it received from the upper DIF. An SDU can be fragmented as 802.11 supports fragmented payload[3]

The DIF name is the SSID (Service Set Identifier). This name is provided by periodical advertisement in a beacon frame.

3.3 Mapping of 802.2 LLC header

DSAP address	**SSAP address**	**Control**	**Information**
8 bits	8 bits	8 or 16 bits	M*8 bits

Table 3.3: 802.2 LLC PDU format

The 802.2 LLC header will primarily be used for differentiating between different connections for the upper layer DIF. For further information and documentation on this standard we refer to the IEEE document (IEEE Computer Society, 1998a).

3.3.1 SAP addressing

SAPs will be used to distinguish between different connections, the current address assignments for SAP can be found in the table below. These SAP assignments only have to be unique within their scope and are not required to be globally unique. Every SAP is a CEP-id, during flow allocation they are mapped to a port-id. This port-id forms the boundary between the 0-DIF (Shim DIF) and the 1-DIF.

[3]More Fragments subfield in the Frame Control field

< Least significant bit								< Least significant bit							
I/G	D^{ISO}	D	D	D	D	D	D	C/R	S^{ISO}	S	S	S	S	S	S

I/G	0	=	Individual DSAP
I/G	1	=	Group DSAP
C/R	0	=	Command
C/R	1	=	Response
I/G	`0 DD DDDD`	=	DSAP address
C/R	`0 SS SSSS`	=	SSAP address
I/G	`1 DD DDDD`	=	Reserved for ISO definition
C/R	`1 SS SSSS`	=	Reserved for ISO definition

Table 3.4: SAP Address Assignment

This leaves 6 bits per address field free to choose. The least significant bit is always on the left. We will only use individual SAPs and discard the Command/Response bit due to not having Data State Vectors available. The second least significant bit will also be left 0, due to the ISO definition. This means we can only use {0, 4, 8, C} for our last hex symbol. This leaves the following possibilities free to choose from: 0x{XY}. With X = {0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F} and Y = {0, 4, 8, C}. In total, 64 SAP addresses can be used within the Shim DIF.

3.3.2 DSAP address field

The Destination Service Access Point will be used to identify the flow on the destination IPC Process. For correct mapping on addressing we currently store a mapping between application-naming and connection address locally.

3.3.3 SSAP address field

The Source Service Access Point will be used for to identify the flow on the current IPC Process. For correct mapping on addressing we currently store a mapping between application-naming and connection address locally.

3.4 Use of Address Resolution Protocol

Because the RINA Flow Allocator is unavailable at this low level, the Shim DIF reuses ARP in a request/response mode to perform Flow Allocation. ARP (IEEE Computer Society, 1998b) will be used to map an application-naming (1-DIF) to the address of a Shim IPC Process (0-DIF). Currently ARP is used to map a hardware address to an IP(v4) address.
Below is the ARP frame represented by the RFC826 implementation[4].

Bit 0-7	**Bit 8-15**
Hardware type	
Protocol ethertype	
Hardware address byte length	Protocol address byte length
Opcode (ARP Request or ARP Response)	
Hardware address sender (n bytes)	
Protocol address sender (m bytes)	
Hardware address target (if known) (n bytes)	
Protocol address target (m bytes)	

Table 3.5: ARP frame format

In the chart below we show how ARP is used in the Shim DIF. Locally an ARP table is kept with entries which map Shim IPC Process Addresses (MAC addresses) to Application names. When data transfer is required, the Shim IPC Process asks the ARP protocol to send out an ARP request to find the Shim IPC Process Address which corresponds to the application name of the destination.

[4]`http://tools.ietf.org/html/rfc826`

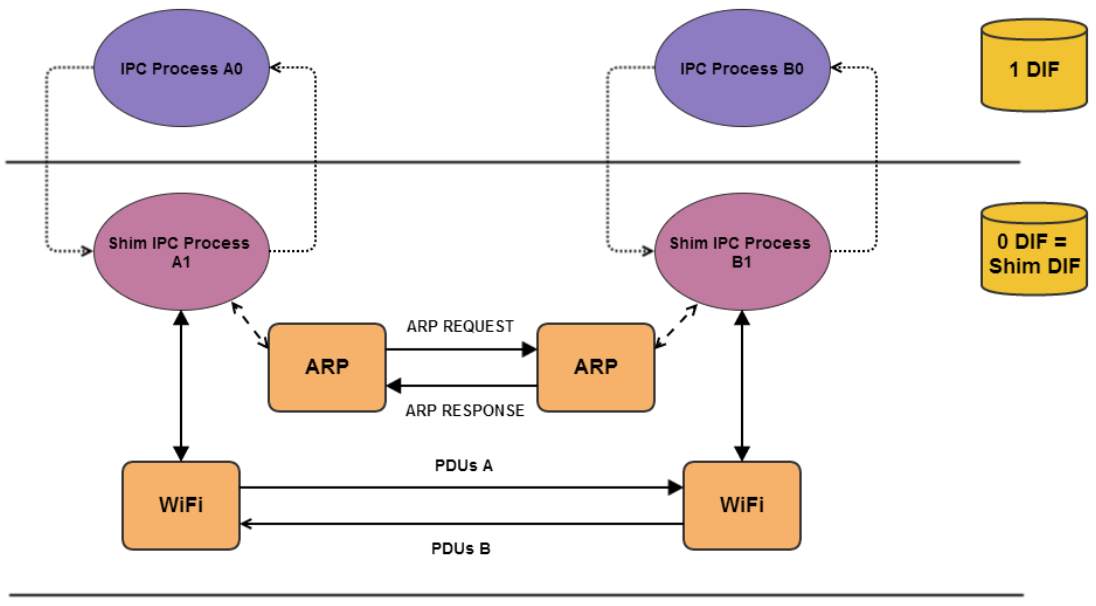


Figure 3.2: ARP example

ARP has a 1 byte length field for the network protocol address. For the Shim DIF we will be using ASCII coding, this leaves us with a maximum of 255 characters for the length of the network protocol address. Due to RINA specifications, a name can consist of 4 parts, which will be encoded in this network protocol address. The encoding we use is bencoding. It is defined in the specification[5] with the bittorrent protocol.

Process name	Echo-IPC-Process
Process instance	1
Entity name	Data
Entity instance	1

Table 3.6: Application-Naming information

Encoded this becomes: "16:Echo-IPC-Process1:14:Data1:1". Note that these are all strings. As an alternative we can also use a synonym for the application name. A synonym is the name of the Application Process instance with a default Application

[5]`https://wiki.theory.org/BitTorrentSpecification#Bencoding`

Entity instance.
Since we need to send the source and destination application name, but we only have one network protocol length field, we choose the longest application name. The other, shorter application name is then filled with padding (zero bytes, 0x00) which are removed by the receiving IPC Process. This causes some overhead, but this overhead stays very small because these ARP frames only need to be sent during the flow allocation phase.

3.5 Service Definition

In this section the different QoS-cubes that are supported will be addressed.

3.5.1 QoS-cubes supported

The WiFi protocol supports several QoS-cubes, they are a combination of following possibilities.

Because QoS-cubes are separated in 4 categories we will offer 4 QoS-cubes. The categories are the following: voice, video, background, best effort. This gives us the following QoS cubes:

ID	1
Name	Voice
Average bandwidth	Depends on 802.11 physical standard
Average SDU bandwidth	Depends on 802.11 physical standard
Peak bandwidth-duration	Depends on 802.11 physical standard
Peak SDU bandwidth-duration	Depends on 802.11 physical standard
Burst period	Depends on 802.11 physical standard
Burst duration	Depends on 802.11 physical standard
Undetected bit error rate	Depends on 802.11 physical standard
Partial delivery	Allowed
Order	Depends on 802.11 physical standard
Max allowable gap in SDUs	Depends on 802.11 physical standard
Delay	Depends on 802-11 physical standard
Jitter	Depends on 802-11 physical standard
Ack policy	Depends on kernel settings

Table 3.7: QoS cube for traffic categorized as Voice

ID	2
Name	Video

Table 3.8: QoS cube for traffic categorized as Video

ID	3
Name	Background

Table 3.9: QoS cube for traffic categorized as Background

ID	4
Name	Best_effort

Table 3.10: QoS cube for traffic categorized as Best effort

Note that we do not provide full tables as below the Name section these are all the same, dependent on the physical standard over which communication is done.

3.6 Configuration

Every Shim IPC Process is assigned to a WiFi interface. Before the Shim DIF can become operational it needs a basic amount of information. This information is comprised of:

3.6.1 Shim IPC Process info

The Shim IPC Process needs information on the device to which it is bound. This information is: name of device (wlan0, . . .), hardware address of the device, state of the device (UP/DOWN). Furthermore it requires information to interact with the wireless network this device is part of. This information consists of: SSID, Encryption, Channel, Encryption-key.

3.6.2 Port-id to CEP-id directory

The WiFi Shim DIF has different flows available through the use of CEP-ids. In the subsection 3.3.1 about SAP mapping we saw that 64 connections can be differentiated.

Each one has a 1-byte long address. This SAP address is a Connection EndPoint-Identifier (CEP-id). The CEP-id is locally mapped on the port-id. The port-id is a transfer point on the boundary between the 1-DIF and the 0-DIF.

3.6.3 Application to SAP mapping

Since no explicit flow allocation is possible, it is currently not possible to choose the SAP addresses freely. They will be mapped to applications locally in a file. This file contains a mapping for application naming info to SAP addresses. When communication is set up the Shim IPC Process retrieves the right SAP address from this file based on the requesting application. Or the Shim IPC Process delivers to the correct application process based on the SAP address.

3.7 Bootstrapping

Upon creation of the Shim IPC Process, the Shim IPC Process assumes its position in the DIF. This DIF name is the same name as the SSID. First the Shim IPC process is bound to the interface and assumes the Shim IPC Process address is the same as the hardware address of the wireless device. When this wireless device becomes part of the network, the Shim IPC Process is considered to be part of the DIF. When these conditions have been met, we assume that all traffic will be RINA traffic and should be handled by the Shim DIF.

3.8 Application (un)registration

If an Application Process (AP) registers with the Shim IPC Process. Upon registration of the application, the Shim IPC Process's directory adds an item. This item maps the AP name to the MAC address. The MAC address is bound to the Shim IPC process. Finally when an AP un-registers the Shim IPC Process removes the entry in the ARP cache. If future queries of the application name are triggered, they will be ignored if the entry is not present in the cache.

3.9 Enrollment

All members with an interface active in the same SSID are assumed to be in the same Shim DIF. When a new member enlists in this Service Set it is enrolled in the Shim DIF.

3.10 WiFi Shim IPC Process Definition

The Shim IPC process over WiFi assumes the following API from ARP:

arpAdd(netaddress).submit Adds a mapping of network address, in RINA the application name, to the MAC interface in the ARP table of the interface. In essence this maps the application process to the Shim IPC process address. The function returns: 'success' when the mapping was added, 'failure' when it was not.

arpRemove(netaddress).submit This is the inverse of the action of the previous function. It removes a mapping of the application name to the MAC address in the ARP table. If this entry is removed it returns: 'success', otherwise 'failure' is returned.

arpMapping(netaddress).submit Requests ARP for a mapping of a network address to a MAC address. When the mapping is found, arpMapping(netaddress, hwaddress).deliver is called.

These 3 functions are provided by ARP.

Port-ids are linked to CEP-ids and are tristate variables. The 3 states of a port-id are the following:

NULL The port-id is unusable in this state

PENDING-SAP This state of the port-id can originate from two possibilities. The application process has initiated the flow allocation, requested sapMapping and is idle in the PENDING-SAP state until it receives an sapMapping.deliver. The other option is that it has received a request to create a flow and is currently waiting for the sapMapping.submit function to finish, it stays in the PENDING-SAP until it receives sapMapping.deliver.

PENDING-ARP This state of the port-id can originate from 2 possibilities. The port-id has received the sapMapping.deliver(+) function and the arpMapping.query has been called. The port is idle in the PENDING-ARP state until it receives the arpMapping.deliver. The other possibility is that the request to create a flow has delivered the sapMapping.deliver(+) and is waiting for the allocateResponse.submit to finish the flow allocation.

ALLOCATED This state indicates that the flow has been allocated and the port-id can be used to read/write data to/from.

Below are all the possible functions for the Shim IPC process and finally a state diagram with said functions is presented.

3.10.1 applicationRegister(naming-info).submit

When invoked

This primitive is invoked to register an application on top of the shim IPC process. The application becomes available in the shim DIF. This primitive has to be invoked before all other functions. ARP does not differentiate between client/server, which means every application has to be available in the ARP table, even clients.

Action upon receipt

The naming-info is transformed into a single string (application-name), with the method described in segment 3.4. arpAdd(application-name).submit is called. If successful, a mapping of the application name to the hardware address of the device is added in the ARP table of the interface. The other primitives become usable. If it failed, they are not and an error is generated.

3.10.2 applicationUnregister(naming-info).submit

When invoked

This primitive is invoked to unregister an application on top of the shim IPC process. This unregisters the application in the shim DIF. No other primitives can be invoked until applicationRegister(naming-info).submit is called again.

Action upon receipt

The naming-info is transformed into a single string (application-name), with the method described in section 3.4. arpRemove(application-name).submit is called. If successful, the mapping of the application name to the hardware address of the device is removed from the ARP table of the device. If it fails, an error is generated.

3.10.3 allocateRequest(naming-info).submit

When invoked

This primitive is invoked by a source application to request a new flow. Naming-info consists of the destination upper layer IPC Process name <AP name, AE name> (AP-name if there is a single Shim-DIF; AP-ApplicationEntity if there is more than one).

Action upon receipt

If there is already a flow established to the destination application (the port-id is in the ALLOCATED state), or there is a flow pending between the source and destination applications (the port-id is in the PENDING-SAP or PENDING-ARP state), a negative allocateResponse(reason).deliver is returned. If the port-id is in the NULL state, sapMapping(void, port-id,netaddr).submit is called. The port-id transitions to the PENDING-SAP state.

3.10.4 allocateResponse(reason).submit

When invoked

This primitive is invoked by the destination application in response to an allocateRequest(naming-info).deliver which is invoked by a positive sapMapping(reason).deliver.

Action upon receipt

If the port-id is not in the PENDING-ARP state, an error is generated. If it is and if the allocate response is positive a flow has been established for this port-id; any queued frames are delivered to the destination application. The port-id transitions to the ALLOCATED state. If it is negative the flow creation has failed and reason indicates the failure reason, all queued and future frames from this combination of source MAC address and source SAP are dropped. The port-id transitions to the NULL state.

3.10.5 arpMapping(netaddr,hwaddr).deliver

When invoked

This is invoked by the ARP protocol machine when a requested mapping becomes available in the ARP table. The Shim IPC process is supplied with the mapping of a network protocol address, application name in RINA, to a hardware address (hwaddr).

Action upon receipt

If the port-id is in the PENDING state, (there is an outstanding allocateRequest(naming-info).submit), an allocateResponse(reason).deliver is invoked, and the hardware address

(MAC address) is stored for this flow. In this case the port-id transitions to the ALLOCATED state. If the port-id is in the ALLOCATED state, nothing happens. If it is in any other state, an error is generated.

3.10.6 sapMapping(CEP-id,Port-id,Naming-info).query

When invoked

This can be invoked by the reception of a WiFi frame when the port-id is in the NULL state. The port-id transitions to the PENDING-SAP state and the Shim IPC process awaits the sapMapping(reason).deliver response. It can also be invoked by the allocateRequest.submit function. The port-id transitions to the PENDING-SAP state and awaits the sapMapping(reason).deliver response. If the port is in the ALLOCATED nothing happens.

Action upon receipt

When received, the locally stored "SAP to naming-information" database is queried. The response is the sapMapping(reason).deliver response.

3.10.7 sapMapping(CEP-id,Port-id,Application-naming).submit

When invoked

When a mapping is found by sapMapping(CEP-id,Port-id,Naming-info) this function is invoked.

Action upon receipt

Requests the Shim IPC Process to look in the provided table to find a mapping between the CEP-id and the Application-naming. If successful this adds an entry to the "Port-id to CEP-id directory" and consequently calls a positive sapMapping.deliver(+). If the unsuccessful a negative sapMapping.deliver(-) is called and no mapping is added to the CEP-id to Port-id directory. Note that this function always requires a Port-id and either a CEP-id (receiving Shim IPC Process) or Application-naming (sending Shim IPC Process).

3.10.8 sapMapping(reason).deliver

When invoked

This is invoked as a response to the sapMapping(CEP-id,Port-id,Naming-info).query after the "SAP to naming-information" has been inquired.

Action upon receipt

If the naming-info is an error (sapMapping.deliver(-)) then the port-id transitions to the NULL state. If the information is genuine and the port-id was in the PENDING-SAP state then it transitions to the PENDING-ARP state.

3.10.9 Frame

When invoked

When the port-id is in the ALLOCATED state, a frame may be sent. Otherwise the frame is dropped.

Action upon receipt

When there is no flow for the combination of the MAC address that sent the frame and the receiving CEP-id, the sapMapping.query function is called and the port-id transitions to PENDING-SAP. If there is a flow for the sender's MAC address and the receiving CEP-id, and the port-id is in the ALLOCATED state, write.deliver is called. If it is in the PENDING-SAP or PENDING-ARP state, the packet is queued. If it is in the NULL state, the packet is dropped.

3.10.10 read.submit

When invoked

This is invoked by the application when it wants to read a SDU.

Action upon receipt

When the shim IPC process receives this primitive and the port-id is in the ALLOCATED state, it will create a frame, and pass it to the OS for delivery. It is assumed that neither fragmentation nor concatenation is performed by the shim IPC Process. This is done because the WiFi protocol provides the functions below the Shim-DIF. Therefore shim IPC Process uses a different frame for each SDU passed to it. If the port-id is not in the ALLOCATED state, an error is generated and the frame is dropped.

3.10.11 write.submit

When invoked

This is invoked by the application when it wants to send one or more SDUs.

Action upon receipt

When the shim IPC process receives this primitive and the port-id is in the ALLOCATED state, it will create a frame, and pass it to the OS for delivery. It is assumed that neither fragmentation nor concatenation is performed by the shim IPC Process. This is done because the WiFi protocol provides the functions below the Shim-DIF. Therefore shim IPC Process uses a different frame for each SDU passed to it. If the port-id is not in the ALLOCATED state, an error is generated and the frame is dropped.

3.10.12 deallocate.submit

When invoked

This service primitive is invoked by the application to discard all state regarding this flow. It is the responsibility of both the source and destination application to invoke this primitive. It is a local event.

Action upon receipt

When the shim IPC process receives this primitive, the port-id transitions to the NULL state.

3.10.13 Corresponding state diagram

A "/" represents a following, or void, function that is being called by the preceding function.

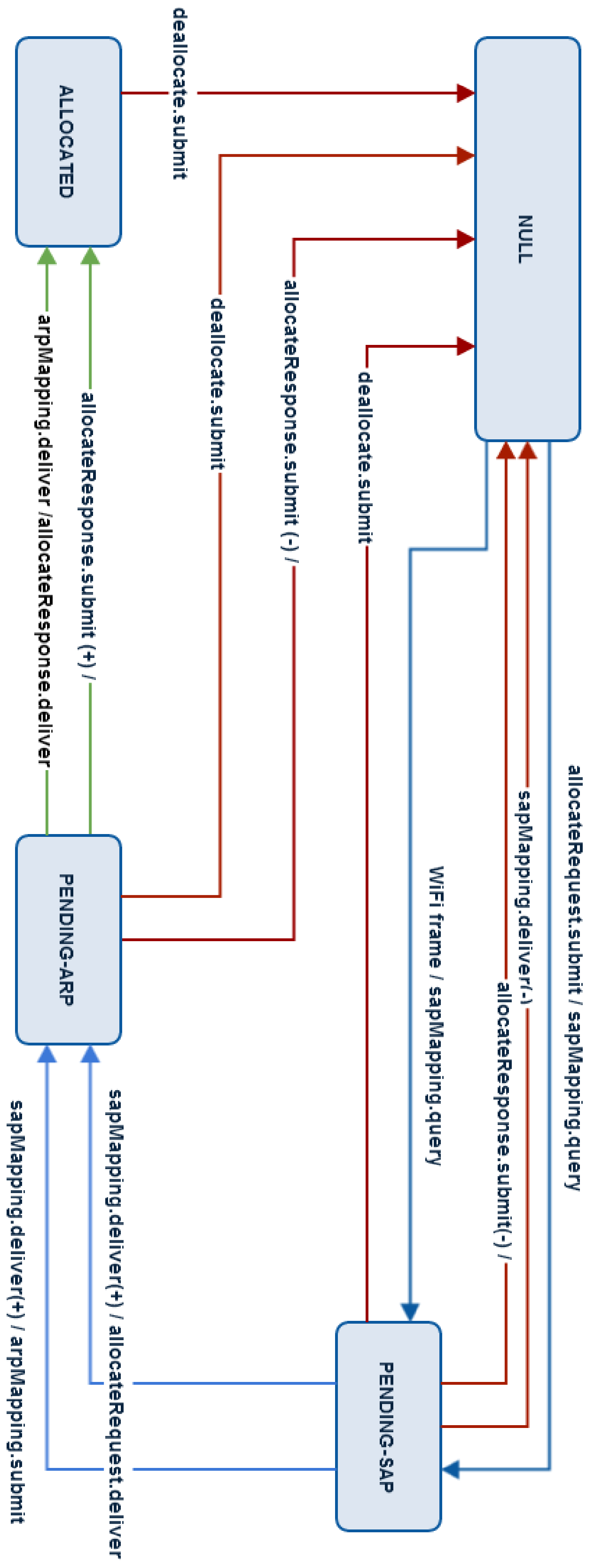

ALLOCATED
NULL
PENDING-ARP
PENDING-SAP
deallocate.submit
deallocate.submit
allocateResponse.submit (-) /
deallocate.submit
allocateRequest.submit / sapMapping.query
sapMapping.deliver(-)
allocateResponse.submit(-) /
WiFi frame / sapMapping.query
arpMapping.deliver /allocateResponse.deliver
allocateResponse.submit (+) /
sapMapping.deliver(+) / allocateRequest.deliver
sapMapping.deliver(+) / arpMapping.submit

Figure 3.3: Corresponding state diagram

Chapter 4

Implementation

Ensuing the chapter about the specification over WiFi, we will now address the implementation of the prototype. This chapter has been divided in 3 sections, each containing a number of subsections. We initiate with the plan of action which clearly states the trajectory this implementation will follow. Secondly we focus on the implementation of a Shim DIF prototype over WiFi. Finally we approach the subject of the Android implementation.

4.1 Plan of action

In this section we will give the reader a short introduction to the implementation topic. After this introduction we have the procedure of implementation. This subsection will detail the path followed for this entire implementation and will clearly show the milestones on the path. The section can be seen as a guide to understand the different steps taken in the implementation part.

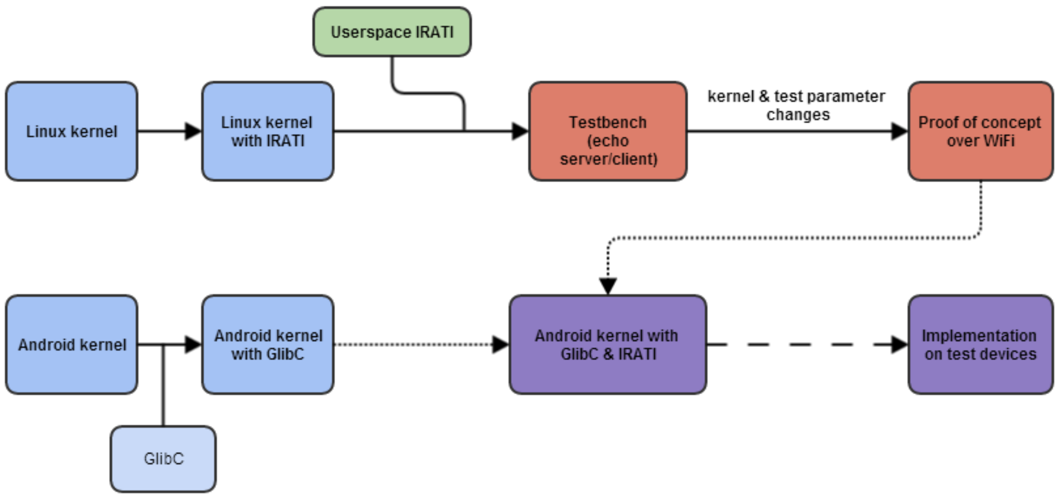
4.1.1 Introduction

The research question states: "How to run RINA on Android over WiFi?". Now that the background of this question has been clearly evaluated we can move towards the implementation. This chapter seeks to find a way towards a technical implementation of this research question. The chapter will not instantly address the question, but will start with some basic proof of concepts and already working implementations. After these have been carefully explained on how they were achieved, we move further towards the WiFi part of the research question and finally altering the operating system (OS) to Android.

In the end we hope to have a working, technical implementation of the IRATI project code that can be constructed and applied to the given test devices[1].

4.1.2 Procedure of implementation

In the final part of this section we will discuss in detail how the implementation will be addressed. For this, we reference to figure 4.1. This figure shows us clearly all the steps that will be talked about in this chapter. The steps with higher importance to this thesis will be specified and will be addressed in greater detail.



Userspace IRATI
Linux kernel
Linux kernel with IRATI
Testbench (echo server/client)
kernel & test parameter changes
Proof of concept over WiFi
Android kernel
Android kernel with GlibC
Android kernel with GlibC & IRATI
Implementation on test devices
GlibC

Figure 4.1: Procedure of implementation - flow chart

First we start with a proof of concept over WiFi. For this we use 2 linux machines who communicate through a simple echo program using RINA. This is an initial proof of concept that is needed to prove the capability of using RINA on top of WiFi. The point is here to prove that even though the WiFi frames are reformed to Ethernet frames by the drivers we can use these Ethernet frames for RINA. This is done by adding a VLAN interface (802.1Q) and using the Ethernet Shim DIF on top of this. This Ethernet Shim DIF and its functions are provided by the IRATI project.
The section initiates with an explanation on kernel compilation, where we briefly touch on how to build and install kernels. This a very basic step in the implementation that will see further use throughout the rest of the implementation chapter. Following this

[1]Test devices = 2x Samsung Galaxy S II smartphones

we prove the functionality of the Ethernet Shim DIF by setting up two virtual machines with RINA-enabled kernels that have the Ethernet Shim DIF. These are basic linux kernels with additions from the IRATI project. Finally we realize the proof of concept over WiFi. For this we use the linux kernels with both RINA and the IRATI additions enabled, plus the wireless parts added.

After we have implemented a working RINA on pure linux machines, we initialize the process again on Android. We first note that also in Android the WiFi frames are transformed to Ethernet frames and only after this has been handled the user can use these frames. Specifically this means that once the kernel has been sufficiently modified for functionality on Android, that the wireless part is in essence the same as on pure linux computers.
Initially we explain how to build a basic android kernel and the differences to building a pure linux kernel. Secondly we explain how the IRATI-specific kernel parts are added to this base Android kernel. After this step we move towards adding the userspace implementation of the IRATI project. Because of previously mentioned limitation we require certain libraries so the addition of glibc or a similar library will be required. Following this, we explain how the required userspace packages are added and how the userspace is configured. Once we are able to insert the modules and turn on the ipcmanager we can call this implementation a success. For the final part we explain the changes required to move from this basic Android kernel to a device specific kernel and run the echo experiment on the two test devices.

We provide steps along this route on how we got to these parts, why we chose certain items over their respective alternatives and finally provide initial results to prove the functioning aspects of these implementations.

4.2 Proof of concept over WiFi

In this section we will explain the implementation of the proof of concept of RINA over WiFi. This includes the compilation of a Linux kernel, the irati test bench setup and finally we show the proof of concept.

4.2.1 Compiling a kernel

The first step of the implementation is building a base kernel. For this step we have several possibilities and guides available. While we will not go into details such as listing exact commands we intend to give a clear structure on how to build a basic kernel for a Linux Operating System. The reason we choose Linux is fairly straightforward:

- Stable basic versions
- Under GNU General Public License, thus opensource code
- Big development community
- Crossplatform interoperabilities
- ...

We choose the most recent kernel version which can be found at `http://www.kernel.org`. After downloading and extracting this kernel we acquire all the needed packages to build this kernel. For a Debian based system, these include:

- kernel-package
- libncurses5-dev
- fakeroot
- wget
- bzip2
- bc

These packages are Debian specific, but a quick online search should state which packages are required for the specific Linux system. After acquiring these packages one can follow a few simple steps, set up the configuration file and have the kernel built. Consequently you can install the kernel next to the current one and select which kernel you prefer on boot. This has several advantages which include always have a stable base kernel to fall back upon. It also allows the addition of new code to the kernel in several, testable stages. Further information on how to build kernels can be found in Appendix B 5.2.

4.2.2 Test bench irati

The current IRATI implementation consists of a Linux Kernel with RINA added in kernelspace and some additions to the Userspace which are closely linked to the Kernel. The modifications to the kernel are mostly additions to the *net* section of the kernel.

This is in essence the RINA implementation. Because this implementation is the Shim DIF over 802.1Q we also need to add the VLAN option in the configuration file. After adding these kernel files and selecting their options in the config file we can build the kernel in the same manner as in the previous subsection. Finally we are also required to add the wireless drivers for to this kernel. For this we first find out which WiFi device our hardware has by running a simple *lpci* command. A quick Google search gives us the needed kernel drivers and these options are selected in the configuration file.
The files needed to for this kernel are provided in addendum on physical storage alongside this thesis. However for optimal results we recommend acquiring the most recent files directly from the source. For general kernel files this is `www.kernel.org` and for the irati project this is `www.irati.eu`.

The userspace part requires some added specific packages before it can be built and installed. These packages are:

- maven
- libnl-genl-3-dev
- libnl-3-dev
- libtool
- autoconf
- openjdk-6-jdk
- git
- swig (>2.0.8)

The packages are again Debian specific and the correct packages should be acquired for the relevant Linux system. Because this code is still very sensitive to changes we refer to the IRATI project again for the most recent requirements. After acquisition of the these packages we can run the commands to install this userspace section.

Initial test for this are run on 2 32-bit Debian Wheezy virtual machines. After we install both the correct kernel and add the IRATI userspace implementations to that, we set up the network between the two virtual machines. For this we add a virtual Ethernet device to both virtual machines and put them both in the same virtual network. As an additional test we also supply them with IP addresses which allows us to test basic ping commands to be sure that the machines can reach each other. While it is not necessary for RINA, it adds an extra check to confirm the connection between the network devices of the virtual machines.

Following the setup of the network devices we insert the Loadable Kernel Module (LKM), *802.1q*. This can be done when the system is booting or when the user requires it. When this module is up we can create a new network between the devices with a virtual tag (number). This tag acts as the DIF name for the Shim DIF. Once the link has been set up between the two devices, we initiate the RINA aspects of the test. We insert *shim-eth-vlan* and *normal-ipcp*. If these modules are activated properly, which can be checked in the log file of the kernel, we can move to the next step. This step involves running the ipcmanager, which is located in the userspace folder. Once this us brought up successfully on both devices, we can start communication between these machines. For testing purposes we use a simple echo-server on one machine and an echo-client on the other. This lets us test the communication between the two machines.

4.2.3 Proof of concept over WiFi

Finally we implement the proof of concept over WiFi. For this we need to note that in Linux and Linux-like kernels, WiFi frames are reconstructed to Ethernet headers. This is done by the drivers, either accomplished in hardware (hardmac) or by software (softmac). Once these frames have been transformed they are presented to the kernel. The kernel has in essence no knowledge that these frames are WiFi frames. In our proof of concept this can be seen as an advantage because we can reuse the IRATI code and create a virtual interface (802.1Q) that is directly linked to the WiFi device. Normally the wireless device is called *wlan0*, after the creation of the virtual device we simply add a virtual device: *wlan0.number*, where the number is the VLAN tag. This VLAN tag is the Shim DIF name.

The setup for the proof of concept over WiFi is fairly similar to the one with the virtual machines. However for this we add the wireless device drivers in the kernel and use two physical devices. The reason we use physical devices is because virtual machines cannot have virtual wifi devices. The reason for this is that virtualization software packages such as VirtualBox, which was used for this thesis, cannot present WiFi frames to the virtual machine.

After the setup of both kernels and the relevant userspace, we can run the test. This test is the same test we ran on the virtual devices and proves the communication between the two physical devices over WiFi. For this test we set up an ad-hoc network with static IP addresses (unrelated to RINA) which gave us certainty that the devices could reach each other. The proof of communication can be found on the physical media in the logfiles.

4.3 Android implementation

In this section we will address the implementation of RINA on Android. We initiate with a subsection about Android kernels, more specifically moving towards the device specific kernel. This includes the judgments that had to be made when selecting kernels, the issues that arose during these processes and finally the proof of implementation. After this subsection we move to the Android compilation with the irati kernel stack and which complications presented themselves during this process. Following this section we address the Android compilation with glibc, a requirement to run the userspace section of the IRATI codebase. We then move towards the final step of the Android implementation with both the kernel and userspace implementation. Here again we note the issues, choices and obstacles that present themselves when implementing this subsection. Finally we offer the alternative possibilities to the implementation, their advantages and their disadvantages.

Note that we have set up an implementation process that might not be suitable at this time of implementation. This could be due to arising problems, which would force us to search for alternatives. This does not mean that implementation is impossible, but simply not possible within the current scope of the Master's Thesis. A similar note had to be made when it came to the Wireless stack, which had to be abandoned because implementing full hardware drivers for entire 802.11 was outside the scope of this Thesis.

4.3.1 Android kernel

The first subsection is dedicated to the implementation of an Android kernel. While this process is very similar to the basic Linux kernel, some very specific additions are required to build these kernels.
Unlike the Linux kernel, is the Android kernel fairly device specific. Android kernels are provided by the producer of the smartphone and are iterated upon from that point on. In most cases this means that the kernel is almost never updated compared to the more recent Linux kernels. This can be instantly noted with our kernel. The version of this kernel is 3.0.101, at the time of writing (June 2014) the most recent Linux kernel is

3.16.x. The only update that was brought to this kernel during the entire Thesis was an upgrade from version 3.0.64 to 3.0.101. A fairly minor update in essence. These Android kernels are specifically tailored to each device. Most changes in these kernels comes from optimization processes by community developers who try to squeeze a bit more out of the kernel. Examples of this could be: updating specific files, changes hardware settings, adding modules to improve functionality, ... Since Android devices are almost never modular, adding different device drivers quickly becomes useless these developers. And while the newest kernels could support the newest hardware, this is simply not needed for these "older" devices which rely on a basic, stable kernel.

For our device, *Samsung Galaxy SII - i9100*, we opted to go for the Cyanogenmod ROM with a modified Apolo[1] kernel. The following reasoning was used: cyanogenmod was chosen because several reasons. These are:

- Large development community
- Most recent version of Android supported (4.4.2) (stable)
- Decent guide to construct the ROM yourself
- Many kernels specifically designed for this ROM

The most recent build, with explanations on how to construct it yourself can be found here: `http://wiki.cyanogenmod.org/w/I9100_Info`. The build we use in this thesis is Milestone 7 (M7), which is considered stable. With this ROM (Operating System) also comes a prepacked kernel. However for the purpose of this Master's Thesis we want to build our own kernel. The reason for this is fairly simple: we want control over the kernel so we can later add further code to it. In this environment this code is the IRATI code alongside the requirements to run the IRATI code, such as VLAN and the correct wireless network devices.

The kernel we chose for this project is the Apolo Kernel, branch 7.0b, specifically tailored to Cyanogenmod (CM). The kernel can be found here: `http://forum.xda-developers.com/galaxy-s2/development-derivatives/kernel-t2291756`. The reasons for choosing this Apolo kernel are the following:

- Stable base kernel with minor branching for user based optimization
- Updated codebase for the most recent CM build

[1]`http://forum.xda-developers.com/galaxy-s2/development-derivatives/kernel-t2291756`

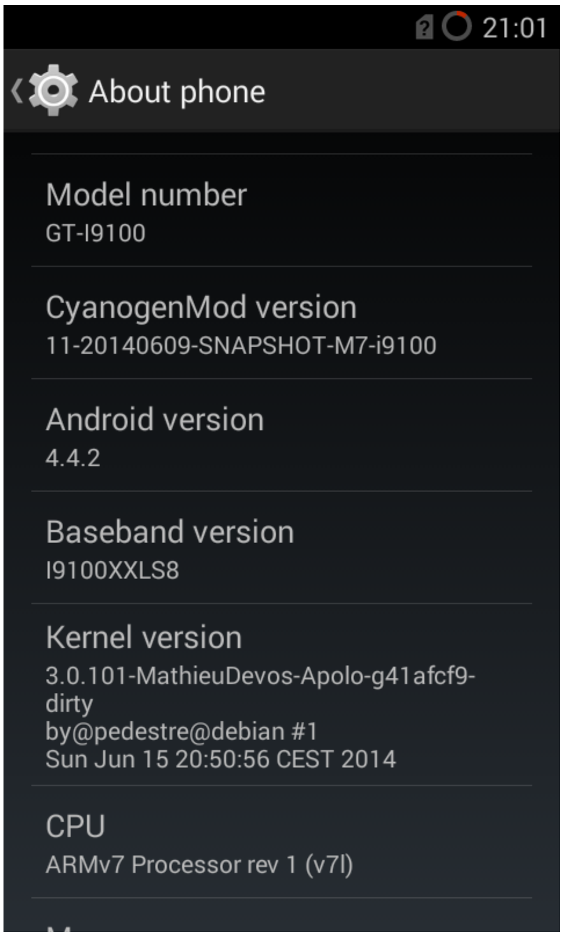
- Large development community
- Good explanation on how to build the kernel yourself

This clearly shows the reasons why we chose this kernel. We have to note that other kernels that are built for Cyanogenmod Milestone 7 are fairly similar and could be considered almost equal to this kernel. Since we plan to add code to the kernel we first have to be able to build this basic kernel from scratch ourselves. This involves forking the repositories of both the initramfs and the kernel to our own github. These repositories can be found at: `https://github.com/mathieudevos/Kernel-smdk4412` and `https://github.com/mathieudevos/Initramfs_CM_4.4.x`.

Before we can build these kernels we should briefly explain what initramfs is. Initramfs is the abbreviation for: "initial ram file system". This is the first file system that gets loaded into RAM on start-up. For basic Linux systems these are fairly straightforward. For Android they are very specific, up to the point where you need to exactly match your kernel and ROM with this initramfs. For this reason we select the initramfs based on Cyanogenmod for Android 4.4.x. When we take a closer look at the kernel in the github repository, we note a mk.sh file which automatically makes the correct zImage. This zImage is the image of our kernel that we need to flash over the current kernel. This image depends on the constructed kernel and on the initramfs. Some minor changes are required before we can run this shell script. These steps include, but are not limited to:

1. Switch to the wip-md branch in the kernel repository. This is the work in progress branch which contains some minor changes.
2. Change the name of the initramfs folder to match the forked repository. Thus changing it to "initramfs".
3. Further steps involving kernel building on Android (see Appendix 5.2)

The changes that are made to this kernel involve two patches. These patches affect the cypress keyboard device drivers, which is needed to utilize the hardware keys and the cl_cfg80211 file. After these patches are applied, one can run the mk.sh file and acquire a new zImage that can be flashed as a kernel on the devices. When successful, you should see similar information in the "About phone" section of settings menu:


21:01

About phone

Model number
GT-I9100

CyanogenMod version
11-20140609-SNAPSHOT-M7-i9100

Android version
4.4.2

Baseband version
I9100XXLS8

Kernel version
3.0.101-MathieuDevos-Apolo-g41afcf9-dirty
by@pedestre@debian #1
Sun Jun 15 20:50:56 CEST 2014

CPU
ARMv7 Processor rev 1 (v7l)

Figure 4.2: Screenshot of "About phone" section of settings

Before we can move on to other subsections we have to note that this step is a very large step in the process and depending on the device, the support, the community, . . . this can be a very lengthy process. We remark that this subsection, while now described simple, was quite a time-sink before we got to a working base kernel. This subsection is no longer as simple as just running the commands exactly as described on a website, so patches are needed, changes of files, and most of all: testing if the kernel will actually boot. If you find that the kernel gets stuck on boot, we note that Android does have any early boot warning system. However to access this system we need to set up a serial console with USB-to-UART converter. For this reason we strongly recommend to use matching code (kernel $\leftrightarrow$ ROM) which has been recently updated.

4.3.2 Android kernel with IRATI kernel code

When we finally obtain the basic stable Android kernel with the code to build it, we can move towards adding the IRATI code to it. This subsection is only dedicated to the IRATI kernel code addition. Before we can implement the userspace, we first need a working kernel with all the correct kernel-specific code.

To add to this base kernel we use the git repository from IRATI over linux. Since Android is based on Linux we consider this to be a good starting point. The IRATI stack uses a base kernel and builds further on upon this. This means that when we create a patch that finds the differences between the base kernel and the IRATI kernel, we only have IRATI specific changes. This patch can then be applied to the base Android kernel in steps.

The patch will try to create new files when needed, change files or delete files which are no longer needed. However several issues arise here. In the current implementation of Linux, one can add system calls to the syscall table, called syscall_32.tbl or syscall_-64.tbl depending on the architecture. These tables can be found in *arch/x86/syscalls/*. However, this simply does not exist in our Android kernel. Not only does the file not exist, the map is simply non-existent. According to a guide[1] we found on the Internet, we should be able to add these to unistd_32.h. This is currently untested as we simply did not get this far yet because we have found issues with other files.

During the Make phase of the kernel we found ourselves stuck with the *rmap.c* file. This calls for a hashtable function. This is where the first issue shows up. Hashtables are not implemented in Android, at least not in C. The solution to this was a fairly quick hack where we copied the hashtable.h file from a standard Linux kernel to the Android kernel. Now the function could be found, but we still had issues with one of the functions. The function: *hlist_for_each_entry_safe* gives us the following error during compilation:

```
net/rina/rds/rmap.c:87:68: error: macro "hlist_for_each_entry_safe"
    requires 5 arguments, but only 4 are given
```

A quick glance at the code shows us that we are in fact passing 5 arguments to this function. Together with the previous issue of having difficulties of having to add system

[1] http://www.techipost.com/2012/08/30/steps-of-adding-system-call-to-linux-kernel/

calls to the kernel, we are required to note that this might require an alternative approach. Since the user space implementation requires this kernelspace implementation to be functioning, the userspace subsection below has not been implemented in code as of yet. Due to the complexity of implementation that arose we are required to look for alternatives that will address both kernel- and userspace issues.

4.3.3 Android compilation with glibc and IRATI userspace

In this subsection we address the implementation of GlibC alongside Android. The reasons why we cannot stay with the same standard C library is fairly logic. Bionic, the C library for Android, does not provide full fledged support for C++, more on this can be read in the literature study 2.3.4. Simply said, if we want to install the userspace of IRATI, we will need access to a full C library. Several options are available here:

- GNU C Library (glibc)
- dietlibc
- μclibc
- EGLIBC

We opted to for the most common library GlibC, because after further research we noted that this was the only one that had been implemented in Android. However it has never been done for the test devices, thus no previous experience could be relied upon.
After the implementation of the library we face another problem. Before the installation of the userspace can commence, we need some additional packages. The packages are freely available on Debian Wheezy systems. The packages are listed in the subsection, test bench irati (4.2.2). While these packages can be simply acquired from the source by running the standard “apt-get install” command (on Debian), this is unavailable in Android. The problem here is not that this command is OS-specific, it is that this command will also automatically check all dependencies for these packages. Furthermore is it possible that these packages do not support the ARM architecture, or are simply incompatible with the Android Operating System.

Fixing this would require recompiling shell with GlibC so we would have a fully fledged shell with all commands. Next we would have to cross-compile every package and their dependencies separately. Then we would have to carefully install these packages on an alien system and hope that we would have the full functionality and commands available from these packages. This is clearly outside the scope of this Master's Thesis. Again, we need to look for an alternative. If this alternative is implementable within the timeframe of this Thesis is unknown.

A final remark about this userspace section of IRATI code. Currently the userspace section of IRATI provides RINA through the use of C++ code. This can be seen in the figure 4.3 below. We note that these C++ functions are mapped to JAVA with the use of SWIG. SWIG is an interface compiler which connects C and C++ code to other languages, in our case: JAVA.

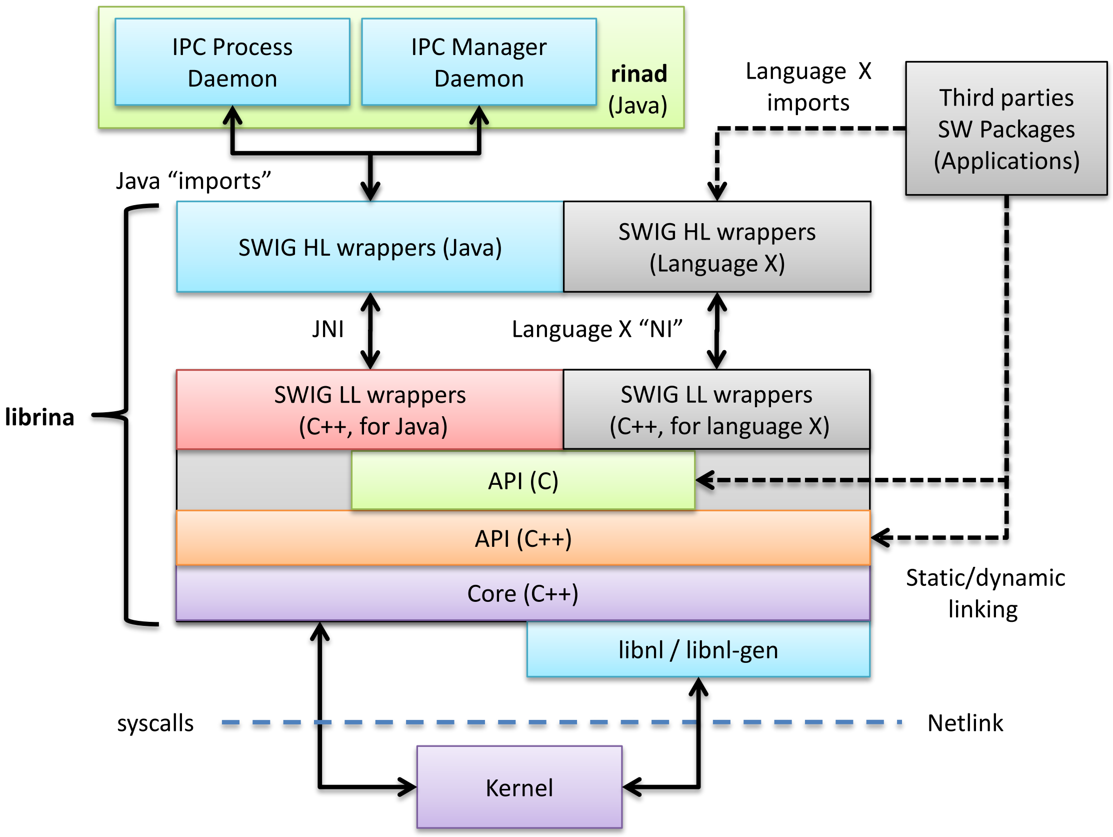


Figure 4.3: Overview of IRATI

We see that the section of librina is mostly written in C++ and then translated to Java functions through SWIG. This is the exact functionality that Android NDK also provides. It provides a environment that allows the developer to code in C or C++ and translates this code to native libraries which can then be packed in *.apk* files. These are Android specific files which represent programs. However, Android NDK comes with some limitations, as it is built for Android, it is specifically tailored to the Bionic library and does not support glibc. A solution for this is to use a different NDK, such as Crystax NDK[1]. These provide full support for C++ and would thus perfectly fit for librina. If the kernel could be successfully implemented, the RINA userspace code that is written in C++ (librina) should be imported in this NDK, adapted to the NDK and then produced as an .apk file. The rinad section (see figure 4.3 above), is written in Java, thus can be copied to Android and be presented as a simple program. Of course, the librina can be imported as a native library then in one bigger program, which would also contain rinad. Given the current state of the IRATI project, this seems the most feasible solution towards implementation on Android.

4.3.4 Android specific implementation

Following the previous subsections, this subsection is dedicated to an representation of the entire process. However, as we have noted we have encountered a plethora of difficulties in both kernelspace and userspace. This means that the actual implementation on the physical devices could not be realized and thus the test can not be completed. We do believe that while the original research question states: "How to implement RINA on Android over WiFi", we have proven that the WiFi aspect does not matter in this equation and that Android is a very strict platform.

Because Android is such a specific platform we can see this research question in a different light. How to expand the IRATI codebase on different Linux-like Operating Systems, possibly with different architectures. In the final subsection of the implementation we address the alternatives that could prove to be helpful. Finally we attempt to show brief implementation processes that could be feasible for these alternatives, concerning RINA.

4.3.5 Alternative implementation possibilities

The final subsection is dedicated to alternatives of implementation. As we have shown during the previous (sub)sections, Android is very restricting. Within the current time-frame it is not possible to acquire a fully working RINA implementation with the IRATI codebase on Android. However we note that while Android is very restricting, other systems might be more viable for implementation of IRATI code. The goal is to stay on the same architecture, ARM. We see that different options become viable alternative paths. These options are:

[1]`https://www.crystax.net/en/android/ndk`

- Ubuntu Touch
- Debian next to Android
- Debian on Android
- Sailfish Operating System
- More recent device

A quick glance over these options show that we are moving closer to less strict environments while still staying on the ARM architecture. While the most promising is most likely Ubuntu Touch, recently the entire development has been halted for the devices (i9100). This makes the Ubuntu Touch option a fairly unpredictable one as no backup or help can be found for the implementation of this. In its current form it is not possible to get the screen working and while Debian and Ubuntu are fairly similar, they are not exactly alike.

The second option of running Debian next to Android in its own space is a viable one, but has not been done for the device. This means that the same issues arise as the previous option: no help, no developing community, ... While if it would be fairly easy to acquire this might be the best option, but as previously stated: this option falls short when paying respect to the limited timeframe.

The third option, Debian on Android, might turn out to be the most interesting one. It has been done and can easily be implemented through Google Play Store. Several options are available such as:

- Linux on Android
- Debian Kit
- Linux Deploy
- Complete Linux Installer
- . . .

Given the limited timeframe we will attempt to test several of these devices and add our findings later. What we actually require from this: being able to construct our own kernel, if we get a base kernel and modify the IRATI kernel-specific code into this we can move towards the next step. Install this with Debian and attempt to install all the required userspace packages through “apt-get install”, finally add swig through manual installation. This means that the packages will have to specifically run on ARM, or will have to be general and run on all architectures. Finally we have to note that this means that we are running Debian as a virtual machine on top of Android. This means that even if we can set up VLAN interfaces in the virtual machine, this does not mean that the Android device will use VLAN. More probably: we would have to set up RINA in such a way that we no longer care about VLAN tags, and instantly assume that all traffic is RINA traffic. Only if all these conditions are met will we be able to communicate between the two devices.

The second to last option that we will address here is the option of looking towards other operating systems that support ARM. Sailfish OS is such an operating system. It is built for ARM devices but ships with a fully fledged glibc library. Furthermore does it still support Android application through an adaptor layer. However, since no such device is physically available for this Master’s Thesis we have to consider this option as an alternative, however not a viable alternative at this point of time.

The final option is simply to update the test devices. They run on kernel version 3.0.101, while newer devices easy run on 3.4.x. The newest devices will soon also start to be built for ARMv8 instead of ARMv7, which could open the doors further for technological improvements. Not only do new devices have more technological options, since they are newer most of these devices will have a bigger, more recent developing community, eager to get their hands on extra implementations. One of these implementations could be to acquire a working RINA on Android.

We can conclude that even with different alternatives we do not have one clear alternative that offers us the entire solution. While we have acquired plentiful knowledge about the subject and all relevant options, alternatives, ... We have to consider the limited timeframe and scope of this Master’s Thesis. The alternatives will be tested but we have to consider the downsides to each of these implementation alternatives.

Chapter 5

Conclusion

The final chapter presents the conclusion of the Master's Thesis. Here we show the path of operation we took starting from our introduction, through the literature study with the research question. Following this we conclude the specification and the implementation and finally we answer the research question in the final section.

5.1 Plan of operation

When we were originally presented with the Research question we were quite intrigued. A new architecture to replace the entire current Internet, that seemed like quite the task. Being part of this meant that we might be able to leave our mark on the pages of the Internet history. This is where we started this Master's Thesis, with the history of the Internet. It became quickly clear that the current version of the Internet had a lot of shortcomings, none of which could be addressed properly. A clear, new architecture was needed, RINA was born. A recursive architecture which reimplemented the same structure(s) over and over again, only changing their policy and scope. While RINA was purely theoretical, the IRATI project aimed to make a technical implementation at the lowest possible level for RINA.

This is where the Master's Thesis is slotted in. After the research question we could fully launch our literature and technology study. This quickly brought us to an important milestone. A part of the research question, the wireless part, was unavailable in its current implementation. We had to drop this part from our implementation. We did provide a specification for the Shim DIF over Wireless. This specification provides enough information to the reader to implement a full wireless implementation of the IRATI code. Given the current Linux kernel code, this implementation can be seen as writing a driver for a network device. This was outside the scope of this Master's Thesis, thus we assumed the specification to be an adequate substitution for the lack of implementation over wireless medium.

After providing the theoretical specification, we moved towards the implementation. Here we note that this implementation step was not initiated after the specification, but was already started during the preparation of the thesis. Initial base kernels were already constructed for both Linux and the Android devices (i9100 - Samsung Galaxy SII). Over the course of this Master's Thesis we have been acquiring information and learned how to practically apply this knowledge. However, we have to remark that even with the added knowledge, the amount of obstacles that presented themselves for this implementation piled up as well. Not only was finding a groundwork kernel for the devices a fairly specific and difficult task, which only proved to be successful after adding several manual patches to the code. We note that after the basic kernel we encountered many more problems, which, given the timeframe were simply not solvable. While we encountered these problems in both userspace and kernelspace, we opted to look for alternatives that could provide some relief to the implementation of the code. After careful research we have come to the conclusion that even these alternatives prove extremely difficult to implement given the current timespan of the thesis.

5.2 Research question answer

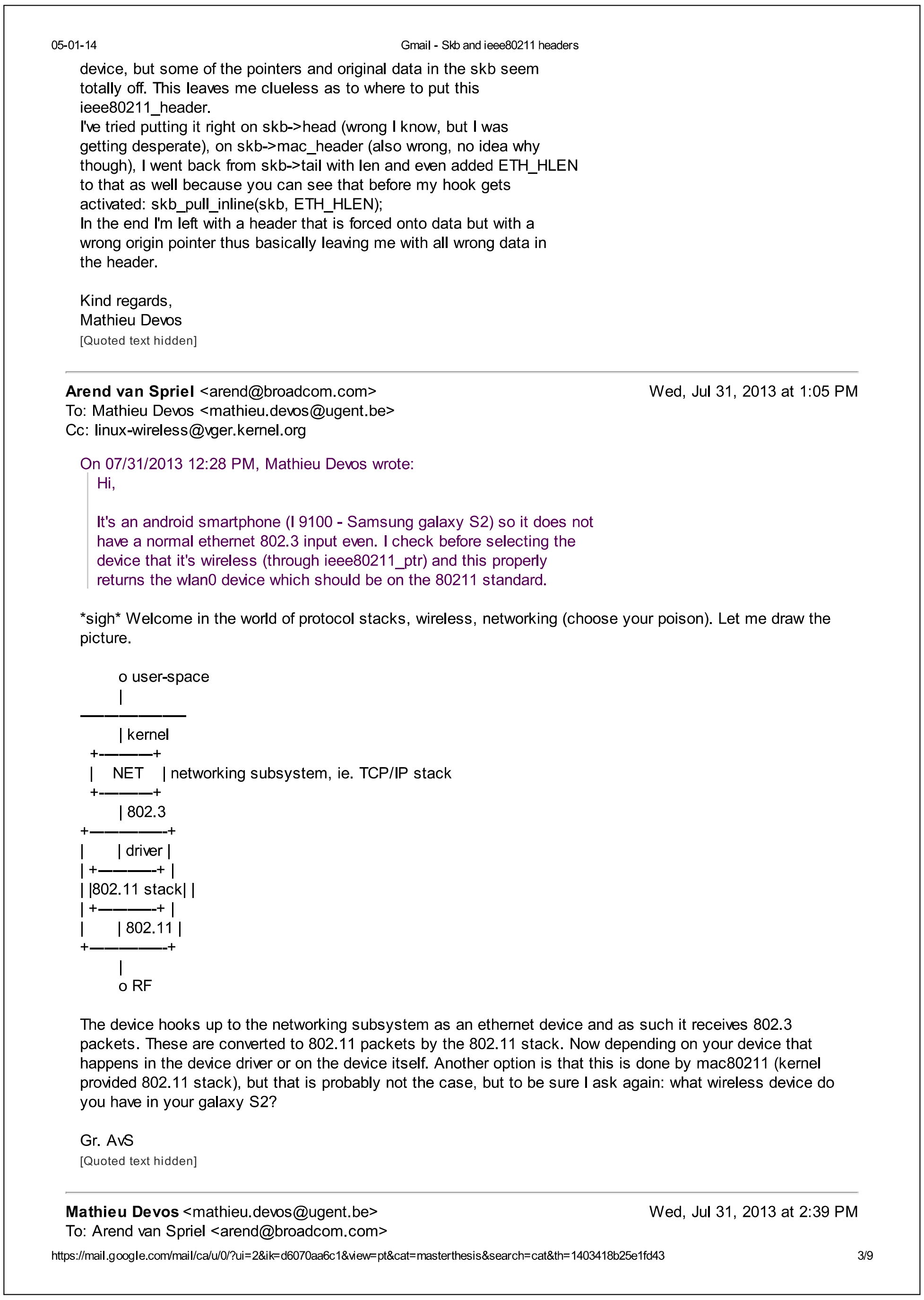
The research question states:

How to run RINA on Android over WiFi?

We have to conclude that with the current implementation we are not able to run RINA on Android over WiFi. With the current Linux, and Linux-like, kernel the part about WiFi becomes irrelevant because the user is locked out of this process. A theoretical specification has been provided to answer the WiFi section. Furthermore have we shown extended research and implementation processes towards the Android part of the research question. However due to several, time-consuming difficulties, the implementation has proven to be a insufficient. The biggest issue we have here is a time issue. Given more time with added manpower and supplemented with additional knowledge, this implementation is feasible. Further research is required to acquire a working implementation of RINA on Android.

Appendices

Appendix A: Emailconversation Linux Wireless mailing list



device, but some of the pointers and original data in the skb seem
totally off. This leaves me clueless as to where to put this
ieee80211_header.
I've tried putting it right on skb->head (wrong I know, but I was
getting desperate), on skb->mac_header (also wrong, no idea why
though), I went back from skb->tail with len and even added ETH_HLEN
to that as well because you can see that before my hook gets
activated: skb_pull_inline(skb, ETH_HLEN);
In the end I'm left with a header that is forced onto data but with a
wrong origin pointer thus basically leaving me with all wrong data in
the header.

Kind regards,
Mathieu Devos
[Quoted text hidden]

Arend van Spriel <arend@broadcom.com> Wed, Jul 31, 2013 at 1:05 PM
To: Mathieu Devos <mathieu.devos@ugent.be>
Cc: linux-wireless@vger.kernel.org

On 07/31/2013 12:28 PM, Mathieu Devos wrote:
> Hi,
>
> It's an android smartphone (I 9100 - Samsung galaxy S2) so it does not
> have a normal ethernet 802.3 input even. I check before selecting the
> device that it's wireless (through ieee80211_ptr) and this properly
> returns the wlan0 device which should be on the 80211 standard.

sigh Welcome in the world of protocol stacks, wireless, networking (choose your poison). Let me draw the picture.

```
       o user-space
       |
------------
       | kernel
  +--------+
  |   NET   | networking subsystem, ie. TCP/IP stack
  +--------+
       | 802.3
+-----------+
|      | driver |
| +---------+ |
| |802.11 stack| |
| +---------+ |
|      | 802.11 |
+-----------+
       |
       o RF
```

The device hooks up to the networking subsystem as an ethernet device and as such it receives 802.3 packets. These are converted to 802.11 packets by the 802.11 stack. Now depending on your device that happens in the device driver or on the device itself. Another option is that this is done by mac80211 (kernel provided 802.11 stack), but that is probably not the case, but to be sure I ask again: what wireless device do you have in your galaxy S2?

Gr. AvS
[Quoted text hidden]

Mathieu Devos <mathieu.devos@ugent.be> Wed, Jul 31, 2013 at 2:39 PM
To: Arend van Spriel <arend@broadcom.com>

Appendix B: Construction of kernels guide

This guide stipulates how to create kernels for Linux, Android in general and specificcaly to the Samsung Galaxy SII device (i9100). We assume the person operating these systems to be utilizing a Debian or Debian-like system. Other systems might require different commands.

Kernel compilation for linux

First, lets get a kernel from `http://www.kernel.org` we recommend just getting a long term kernel that is based on your current kernel. For this guide we'll be using the *3.2.49 linux kernel*[1].

Now you'll want to extract

```
tar -xvf linux-3.2.49.tar.xz
```

and move to the directory of this kernel.

```
cd linux-3.2.49/
```

Before we go any further we'll need some packages to ensure a proper build and help us down the road. To get these packages run:

```
sudo apt-get install libncurses5-dev gcc make git exuberant-ctags
```

Note that for pure kernel building you can follow the guide from KernelNewbies[2], this section will follow this guide quite a bit but will show where you can make changes.

[1] `https://www.kernel.org/pub/linux/kernel/v3.x/linux-3.2.49.tar.xz`

[2] `http://kernelnewbies.org/KernelBuild`

If you do not wish to download a .tar you can opt to get the code directly from the git as shown on KernelNewbies with the following command:

```
git clone link.git && cd map
```

After this you might still need to check out to the correct branch. To list them run:

```
git branch -a
```

Check out the branch you want (stable, longterm, ...) with:

```
git checkout -t origin/branchname
```

Now we need a configure file for this kernel, several options are available here.

Copy current configure file

This is most likely the simplest and fastest way to set up your config file. Simply copy your current config file and place it in the kernel folder (named *.config* - this means it's an invisible file). This can be easily done with the follow command:

```
cp /boot/config-‘uname -r‘* .config
```

Note that this command will have to be run from inside the kernel directory. The part *uname -r* basically prints your current kernel version thus it will select the config for your current active kernel (important if you have multiple kernels).

Making default configuration

This is the very default configuration. If you run this you and instantly try to compile your kernel you will get a huge number of questions trying to figure out how to set up your kernel. This can take a while and could leave you without some important options (it's easy to miss them). Hence why we recommend to copy your own config and make changes to it (see subsection menuconfig below). If you want to create a default config, just run this code from the kernel directory:

```
make defconfig
```

Making non-default configuration

Some kernels provide more base configuration files, you can find these in *arch/your_-architecture/configs*. If you are unsure what your architecture is, just run

```
uname -m
```

Lets say you have a config file name x86_64 in there that is a config file. To prepare your build with this configuration file, just run

```
make x86_64
```

from your kernel base directory.

Change configuration file

Once you have your configuration file (through copy or make defconfig) you can edit this through a simple visual editor with the following commands:

```
make menuconfig
```

or

```
make nconfig
```

Kernelcompilation

The actual kernel compilation is done by running the following command from your kernel base directory:

```
make
```

This can take a while and if you have a multicore processor you can advantage of this by adding an option to this make. The command becomes:

```
make -j‘nproc‘
```

Nproc will return the number of cpu cures thus this will run make with just as much threads as you have cpu cores.

Kernel compilation for android

For android a small part is different, but it’s the general idea that stays the same.

Toolchain

Android needs to be build with a custom gcc toolchain. This toolchain can be found at: `https://github.com/mathieudevos/arm-eabi-4.6`. With git this becomes

```
git clone https://github.com/mathieudevos/arm-eabi-4.6.git
```

Note that you should **NOT** be in your kernel directory, it is recommended that you run this git command in the parent folder of the kernel. This would end up with one folder named linux-3.2.49 and one named arm-eabi-4.6.

Older toolchains might not work on your system as 4.6 is the first one to be written for 64bit operating systems (note that this entire process is written for 64bit). Once you have the toolchain we now need to point the Makefile to this toolchain.

Initramfs for android

Since this can not be automatically copied from your current kernel you need to specify your own initramfs. While you can build your own initramfs with following script: *kernel/scripts/gen_initramfs_list.sh*, we do not recommend it as you need a very specific set of parameters for this.

If you are only building your kernel for the sake of kernel modules (thus just matching version) you can use the default initramfs file by just running

```
./gen_initramfs_list.sh -u 0 -g 0 -d > default_initramfs.list
```

For a normal kernel build that you intend to install we recommend you “steal” an initramfs file from an existing kernel. For the I9100 device we will provide our own initramfs that should work, it can be found here: `https://github.com/mathieudevos/android_kernel_samsung_smdk4210/blob/cm-10.1/usr/galaxys2_initramfs.list`.

After you have acquired your initramfs file you just need to make your kernel point towards it, this is done in the *.config* file, change the follow field:

```
CONFIG_INITRAMFS_SOURCE="./usr/galaxys2_initramfs.list"
```

Kernel build preparation

Open the *Makefile* in your kernel folder with a text editor. Find and change to the following data fields:

```
ARCH ?= arm
CROSS_COMPILE ?= ../arm-eabi-4.6/bin/arm-eabi-
```

After this is done you can open your *.config* file and change your

```
CONFIG_LOCALVERSION=""
```

If you have a very similar kernel to the one you are currently running and only wish to use this kernel for building kernel modules you must make sure this name reflects your kernel name. The versions should match (see on top of Makefile) and also the localversion should match.

Sometimes however, it is easier to build a kernel from scratch and install said kernel and only after that is done start building your kernel modules on this kernel. This will insure good integration between your kernel modules and your kernel.

Kernel installation for linux

The linux kernel that you just compiled can easily be installed into your current system by running following commands from the base kernel directory:

```
sudo make modules_install install
```

This will install your kernel to the */boot/* folder, install your modules (the ones shipped with your kernel, we will make our own) and update your grub bootloader. To use this command you do need an installkernel script, which grubby provides.

If you want to be sure your grub bootloader will present you with the option of choosing your kernel on boot you should make a few modifications in the grub file. This file can be found at */etc/default/grub*. To ensure that you are always presented with the option of choosing your kernel, delete the following line:

```
GRUB_HIDDEN_TIMEOUT_QUIET
```

If you want you can still change the timeout timer so you have a bit more time to choose your kernel. Just edit:

```
GRUB_DEFAULT timeout
```

After you modified this file, just finish with the command:

```
sudo update-grub2
```

This concludes the Linux kernel building and installation. You should now be able to build your own linux kernel and boot into it.

Kernel installation for android

Android is quite a bit harder to install your own kernel. After you are done with building your kernel with the toolchain you will find a zImage (or similar name) in your *kernel/arch/arm/boot* folder. This is the image that we want to flash onto our device.

Depending on your device this is done after you unlocked your bootloader (general setup) or for instance with a specific tool (heimdall) for older devices like *Samsung Galaxy S2 - I9100*. After you have your zImage ready we now need to overwrite your old zImage.

☞ **unlocking your bootloader and/or installing new kernels can void your warranty, we cannot be help responsible for any damages caused by following this guide**

General install on newer devices

After you have unlocked your phone (google this) you should install android sdk which should give you access to fastboot. You can confirm this by plugging your device in and running

```
fastboot devices
```

For this command to work you have to be in fastboot mode, this is mostly done by a hardware key combination on boot, google this for your phone. This command should show your device in the terminal window. Once you have this, lets move to our zImage folder and try to boot with this kernel (but not flash it).

```
fastboot boot zImage
```

If your phone boots properly into your new kernel and you can check this within settings that this is actually your kernel, you can repeat the process but now flash your kernel.

```
fastboot flash zimage zImage
```

This concludes installing your zImage through fastboot.

Specific installation on galaxy S2

If you do not have a galaxy S2 you should skip this part as it uses a custom program that only works for this device.

Boot your phone into download mode (press volume down, power and menu for 10 seconds). Once you have your phone in this mode, go to download mode. From this mode run the heimdall command with:

```
heimdall print-pit
```

This should return the partition points with the images attatched to them. We're looking for the zImage here, it'll be called *kernel* or *KERNEL*, this is important because it's case sensitive. Once you have this information, get ready to flash your zImage on the device with:

```
heimdall flash --KERNEL zImage
```

After this your phone should reboot with your new kernel on it.

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