A Wireless Communications Radio Frequency Scanner for Signal Measurement

ECE 4011 Senior Design Project

Section L05, Wireless RF Scanner Team

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Executive Summary

The team is designing a wireless communications scanner that will be used in a mobile environment for measuring the RF performance of mobile telephone networks. This device is being prototyped for a company called DasPoint Inc., which uses these transceivers to optimize distributed antenna systems. The current device they use is bulky and is heavy to carry around to perform vehicle-based or walk-based tests. This product will integrate various components needed for the scanner and will transmit all the results on an Android device. This will make the whole testing process less bulky. It will also provide a much more user-friendly interface to the people conducting these tests, and will give them much more control and debugging tools on-site while they are conducting the tests.

The scanner will consist of five major components, namely, RF front end board, software-defined radio receiver, control system, Android mobile application and the power source. The signal will first go through an RF front end board which will clean up the signal and pass the data to a software-defined radio. The software-defined radio will convert the analog signal into digital form and apply digital filters to the signal. After this, the control system will run different algorithms on the data to generate final results. Finally the Android application will display the data in a simple user interface.

The device would cost about $1500 which includes the cost of the parts and development. The market value for the device would be about $8000. The cost of the device would be about the same as the current products in the market, but efficiency of the device would save companies a lot of cost. Using this device would require less manpower and time to analyze a specific network; therefore, reducing operating costs for the companies using this device.

A Wireless Communications Radio Frequency Scanner for Signal Measurement

1. Introduction

The Wireless Signal Measurement Scanner team will be designing a scanner which will be a portable and an affordable way for companies to measure and optimize wireless signals. The team will be working with DasPoint to gather the necessary parts for the project. The total cost of the parts will be about $1500.

1.1 Objective

The team will design and prototype a device that can tune to frequencies from 300Mhz to 3.8Ghz and gather data to analyze a specific network. The front-end RF board will input the wireless signals and process it using various DSP filters into digital form on a software-defined radio. Then, the data will be transferred to the control system, where it will go through algorithms to output specific parameters such as signal strength, quality, power level, interference to noise ratio etc. which will help the end user gather valuable data about the network status. This data will be displayed in form of plots and excel sheets on an Android platform based mobile application.

1.2 Motivation

The motivation for this project comes from the fact that the team will be designing a prototype product that will be used in the industry after testing and debugging. Working with a company that already has a strong presence in the industry assures the team that the scanner will be used in real world applications. The device will offer companies an easy way to analyze networks since it will require little training because of the simple user interface. This device will save companies time and money, as opposed to using more complex tools that require a trained user to operate.

1.3 Background

DasPoint, Inc. has developed a scanner that they currently use for testing. There isn't much competition in the market due to small demand for such services. DasPoint has focused on distributed antenna systems to step into the market. The device is based off the current device which is bulky, slow, and hard to operate. The team aims to fix all those problems by redesigning the device.

The scanner will consist of five major components, namely, an RF front end board, a software-defined radio receiver, a control system, an Android mobile application and the power source. The signal will first go through a RF front end board which will clean up the signal and pass the data to a software-defined radio. The software-defined radio will convert the signal into digital form and apply digital filters to the signal. Then, the control system will run different algorithms on the data to generate final results. Finally, the results will be sent to an Android application via Bluetooth, which will display the results in a simple user interface.

2. Project Description and Goals

The team will design and prototype a working device that will be able to give signal parameters based on a given frequency.

- Dynamically tune anywhere from 300MHz to 3.8 GHz
- Dynamic bandwidth selection from 50Khz to 20 MHz
- RF Snapshot recorder capability

- GSM/CDMA/UMTS/LTE decoding
- Signal measurements
- Using a GPS module provide accurate timing and location data with outputs
- Android-based control with API for further development

3. Technical Specifications

3.1 Quantitative Specifications

The five major modules of the system are RF front end board, software-defined radio receiver, control system, Android mobile application and power source. The tables from 1 through 4 below show the specifications of all the modules except power source.

Table 1. RF front End Board Module Specifications

Feature	Specification
Frequency Range	300 MHz – 3.8 GHz
Number of filter paths	34
GPS resolution	5m
Input	Signal through antenna
Output	Filtered analog signal, GPS signal

Table 2. Software-defined Radio Receiver Module Specifications [1]

Feature	Specification
Frequency Range	300MHz – 3.8 GHz
Size	5” by 3.5”
FPGA	Altera Cyclone 4 FPGA
Processor	ARM 9 (200 MHz)
RF Transceiver	LimeMicro LMS6002D
Sampling	12-bit 40MSPS Quadrature Sampling
USB	USB 3.0
USB Micro-controller	Cypress FX3
Inputs	Power, Analog Signal & GPS Signal
Outputs	Digital Signal, GPS Signal

Table 3. Control System Module Specifications [2]

Feature	Specification
Processing Units	Exynos 5 Octa Cortex-A15 1.4Ghz quad core and Cortex-A7 quad core.
IO Ports	USB 3.0 Host, USB 2.0 Host, USB 3.0 OTG, PWM for Cooler Ethernet RJ-45, Headphone Jack, 30 Pin : GPIO/IRQ/SPI/ADC
HDMI Out Port	HDMI 1.4a output Type-D connector
Storage	Micro-SD slot, eMMC 4.5 module connector
DC Input	5V / 4A input, Plug specification is inner diameter 2.1mm and outer diame 5.5mm
Memory	2Gbyte LPDDR3 RAM PoP

Table 4. Android Mobile Application Specifications

Feature	Specification
Login	Username, Password, Submit Button
Signal measurement plots	Signal strength vs. time, quality level vs. time, Signal strength vs. location

3.2 Qualitative Specifications

- Intuitive menu screens on Android
- Easy to find error faults on Android
- Easy to interpret results
- Protective case for the entire system

4. Design Approach and Details

4.1 Design Approach

System Overview

The wireless communications scanner will consist of a RF front end board module, a software-defined radio receiver, a single-board computer, an Android based cell phone and a power module. The front end board, the software-defined radio and the single-board computer help capture and process the signal. After all the calculations have been done, results will be transmitted to the cell phone using

Bluetooth. The following figure shows the hardware block diagram of the entire system and how they interact with each other.

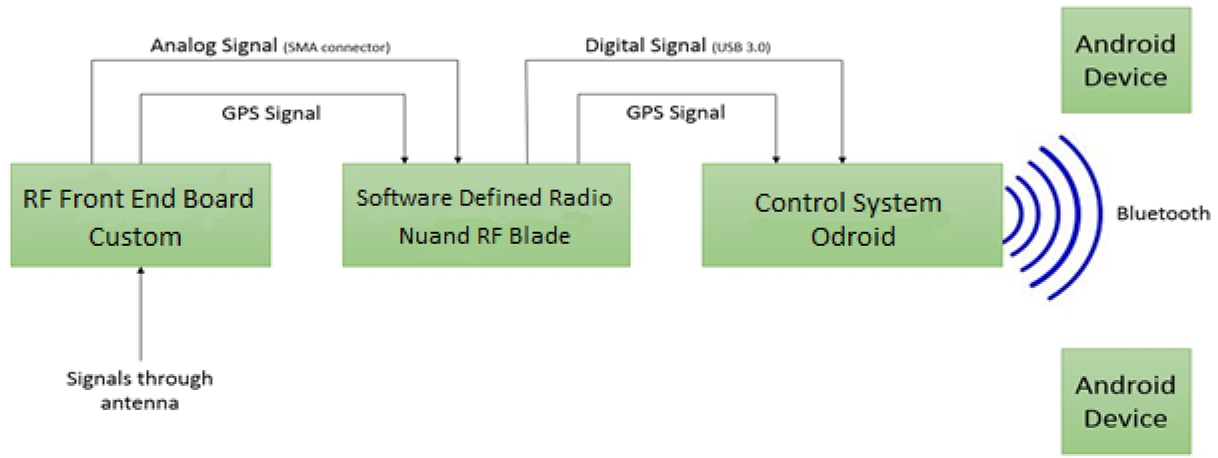


Figure 1. Hardware Block Diagram of the entire system.

RF front end board

The RF Front end board is the first component of the Wireless Communications Scanner**.** This will be a custom board developed by DasPoint Inc. It has an antenna attached to it that can read the analog signals in the air. It can read anywhere from 300 MHz to 3.8GHz signals and thus can cover all the network protocols (GSM/CDMA/UMTS/LTE) that we will be concerned with in this project. The analog signal then goes through various band-pass filters to remove noise and to only keep bandwidth we are interested in. Then, the frequency we are interested in analyzing is selected by a series of switches. This signal is then passed on to the software-defined radio board through a SMA connector. The front end board also has a GPS device on it. The GPS signal performs two major roles. First, the GPS signal passes on the latitude-longitude information, which is used to map signal strength with location. Secondly, the GPS's clock is used to synchronize all the different modules (except cell phone) by sending a reference signal to the entire system. Thus, it helps maintaining the frequency accuracy. The RF front end board outputs the analog signal and the GPS signal.

Software-defined radio receiver

The analog signals sent by the front end board are then received by a software-defined radio. In this project, the Nuand bladeRf is being used as the software-defined radio, since it has very good processing power, has USB 3.0 support and is relatively cheap for its functionality. The analog signals go through an Analog to Digital converter in the bladeRF, and get digitized. This A to D converter resides in the LimeMicro LMS6002D integrated circuit which is embedded on the bladeRF board. The LMS6002D is field programmable and covers frequency ranging from 300MHz to 3.8GHz, thus ideal for our project. [3] The digitized signal then goes through various digital filters to further process the signal. The bladeRF has an Altera Cyclone 4 FPGA which controls the logic for these filters. This FPGA has a single-cycle access embedded memory and hard 18x18 multipliers, which makes the signal processing much faster. Under the current implementation, the FPGA is being under-utilized. The team plans to program more on the FPGA, if time permits, as processing signals through a DSP-dedicated FPGA is much faster than on a computer. The digital signals, after going through the filters, are then transferred to a single-board computer through a USB 3.0. The USB 3.0 interface is provided by a Cypress FX3 microcontroller with an ARM9 processor [4]. USB 3.0 has a full duplex operation with low latency and increased power delivery, allowing up to 5 Gbit/s. Other than the digital signal, the bladeRF also passes on the GPS signal to the control system.

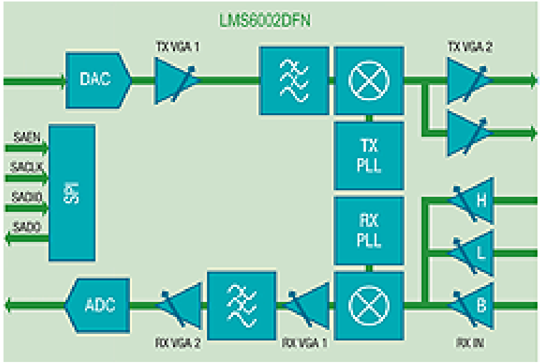


Figure 2. Lime Micro LMS6002D.

Control System

ODROID acts as the control system which will take the input of the captures from the Nuand BladeRF and process the signals using certain DSP algorithms. The ODROID is primarily aimed at Android developers that need a device on which to develop Android applications without the contract or a data plan. Therefore, the captures that are sent from the Nuand bladeRF can be suitably transferred to the ODROID. The block diagram below is a schematic of the ODROID. As can be seen, there are several different inputs and outputs that can be used to facilitate the flow of data. These include USB 3.0 ports, a Micro SD slot, and I2C and SPI buses. The ODROID has 2 GB of memory, and the data from the bladeRF can be transferred to the ODROID via USB 3.0 interface [5].

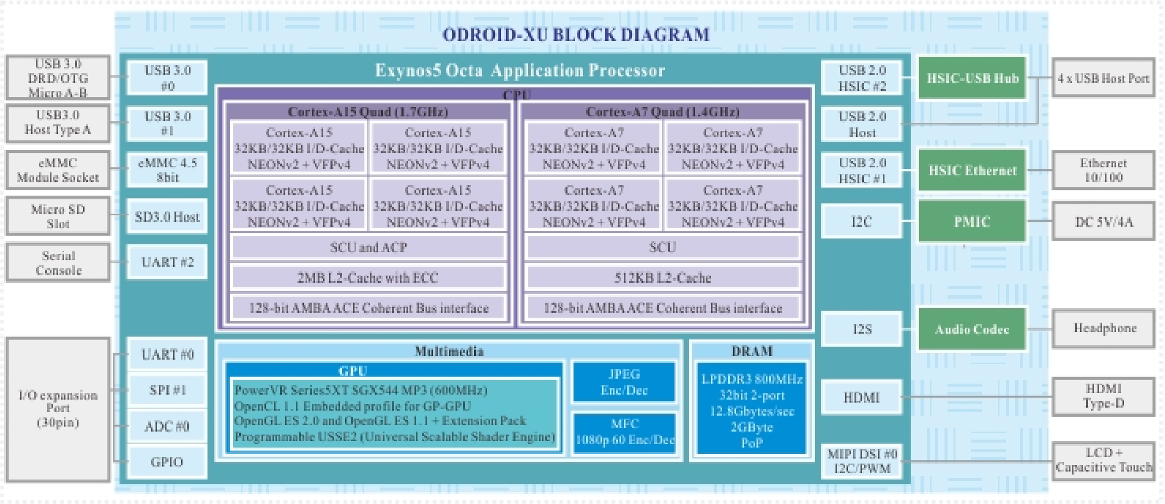
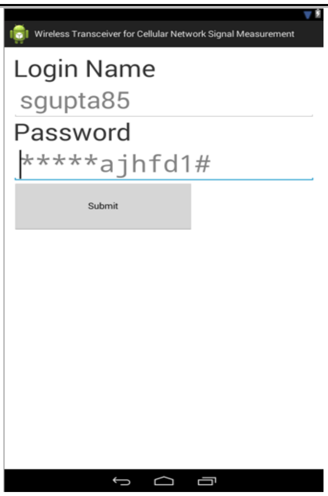


Figure 3. Block Diagram of ODROID.

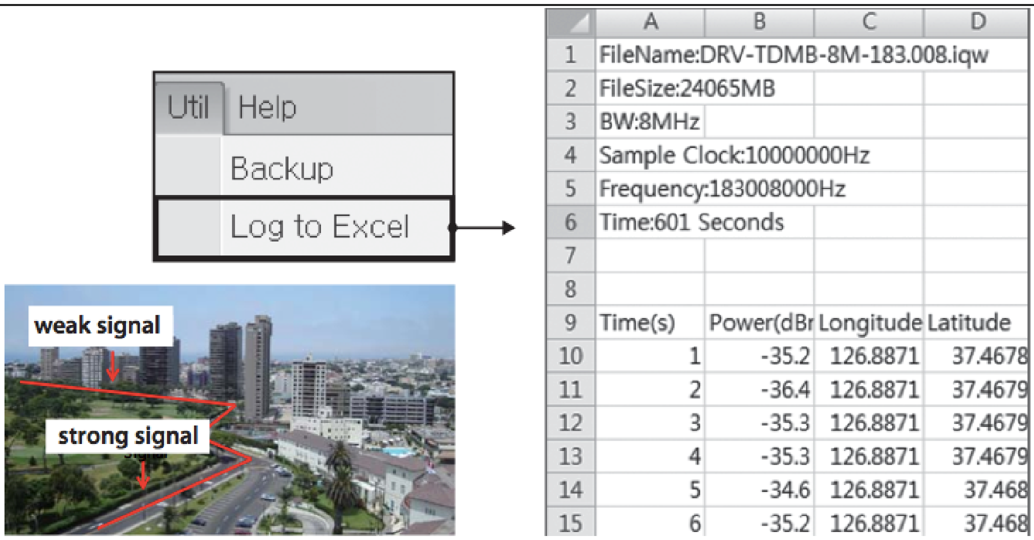
An Android-based cell phone with mobile application

The Android application will run on the smartphone of the user and communicate with the ODROID board through Bluetooth. This application will be developed on Android 4.3 Jellybean using java. After receiving the data regarding signal measurement, strength, quality level, location of the transceiver/MS from the ODROID board, the application will display several plots regarding signal measurement through its interface. The figures from 4 through 7 below show the proposed UIs and graphs for the application.



Login Name
sgupta85
Password
*****ajhfd1#

Figure 4. Login page GUI of the android application.



	A	B	C	D
1	FileName:DRV-TDMB-8M-183.008.iqw			
2	FileSize:24065MB			
3	BW:8MHz			
4	Sample Clock:10000000Hz			
5	Frequency:183008000Hz			
6	Time:601 Seconds			
7				
8				
9	Time(s)	Power(dBr	Longitude	Latitude
10	1	-35.2	126.8871	37.4678
11	2	-36.4	126.8871	37.4679
12	3	-35.3	126.8871	37.4679
13	4	-35.3	126.8871	37.4679
14	5	-34.6	126.8871	37.468
15	6	-35.2	126.8871	37.468

Figure 5. Qualitative comparison in signal strength between two locations will be possible to view via the android application [6].

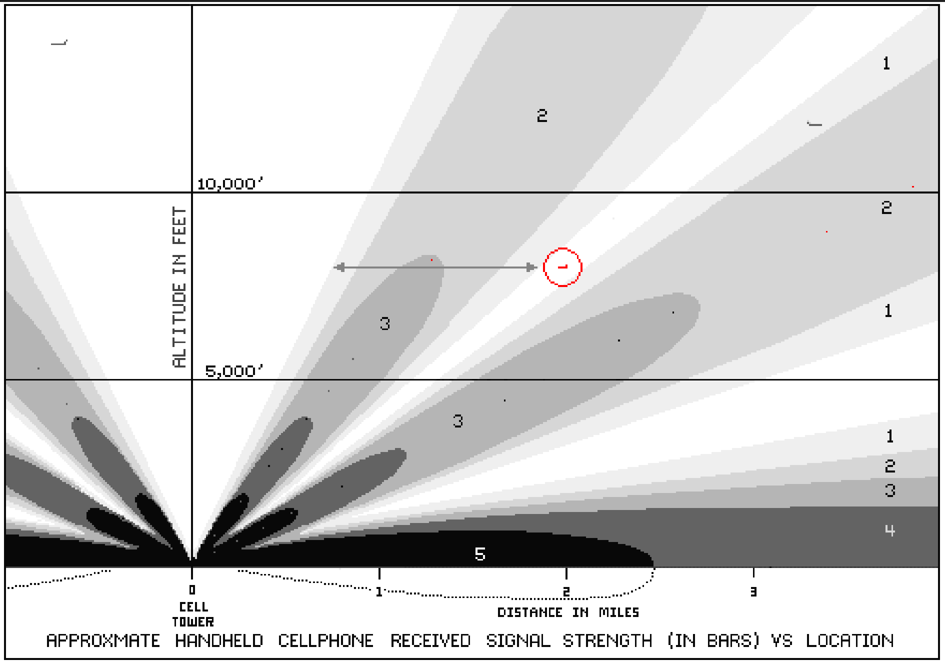


Figure 6. An example plot of received signal strength versus location.

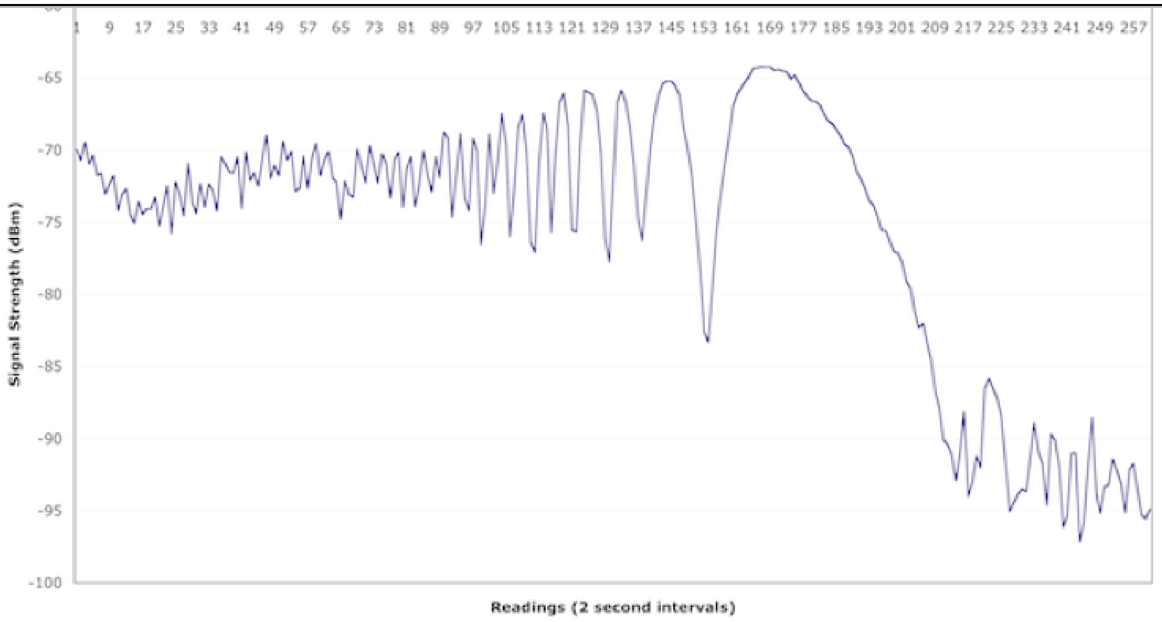


Figure 7. An example plot of signal strength vs. readings at 2 second intervals.

Power source

Currently the team has not selected the source to power all the modules. The team is currently considering using lithium ion batteries for powering all the modules independently. Another good alternative to these batteries is ODROID's Smart Power extension which will allow the team to power the ODROID board along with all the other modules which will be connected to ODROID. This extension has an output DC voltage of 3.00V~5.25V and maximum DC output current of 5A. Smart Power can also enable us to optimize energy consumption by showing voltage, current, watt and watt-hour consumption of the modules. Downside to using Smart Power will be cost as it is expensive and can cost up to $70 whereas lithium ion batteries will cost only $30.

4.2 Codes and Standards

There are several codes and standards that apply to the project:

1. Nuand bladeRF captures radio frequencies of various network protocols. LTE, EDGE, HSPA, HSPA+, UMTS and CDMA are the network protocols that need to be monitored. These protocols will be used to calculate the signal strength of the signal.

2. Universal serial bus (USB) 3.0 is used between the RF front end board and ODROID for sending unprocessed data. USB 3.0 features 5 Gbit/s transfer speed and has increased bandwidth as USB 3.0 is a full duplex as compared to USB 2.0 being a half-duplex. [7]

3. WiFi, also known as IEEE 802.11 standard will provide a wireless communication interface for nearby communication with cell phones or PC. It will allow transmission of data from ODROID to Android/PC. WiFi uses 2.4 GHz UHF and 5 GHz

4. JDK, or Java Development Kit library will be used with math and hardware management functions to control the ODROID.

5. The RF front end board also uses GPS (Global Positioning Service) for clock as it is very accurate. GPS is also used to determine the location.

4.3 Constraints, Alternatives, and Tradeoffs

Constraints

There were several constraints associated with the choice of devices. For one, the battery life of the transceiver needs to last for least six hours, and therefore lithium ion batteries will be used. Additionally, the transceiver should be small and light to increase portability. The cost of the device is not a primary concern, as the total cost is expected to be under $2,000. The most important constraint, however, is the processing speed. The capacity of the processing units in the system need to be analyzed carefully to ensure that the signal processing load is balanced correctly in order to achieve the required rates.

Alternatives

In order to establish communication with the mobile device, USB 3.0 could have been used instead of Bluetooth. The wireless capability of Bluetooth over USB 3.0 was considered to be a bigger factor to take into consideration than the vast superiority in the transfer rate of USB 3.0 over Bluetooth. Therefore, despite USB 3.0's transfer rates ranging in the gigabits as compared to Bluetooth's transfer rate of 24 Mbps, the portability and convenience of Bluetooth is preferred. [9] Finally, in alternatives between software-defined radio platforms required, bladeRF and HackRF had to be looked into. Eventually, bladeRF was chosen due to its higher bandwidth, sample size as well as superior power consumption as compared to HackRF. [10]

Tradeoffs

The first major tradeoff that had to be taken into consideration was that between cost and processing power. The device that we chose for the development board was the ODROID. While the ODROID is a lot more expensive than the popular development board, Raspberry Pi, it has a clock speed of 1.7 GHz as compared to the 700 MHz of the Raspberry Pi. However, the processing power was considered a more important factor than the cost difference. [11] Also, comparisons also had to be drawn between memory and power. The Nuand bladeRF uses Altera chips which have less RAM available per logic element than the Xilinx chips, which are used by HackRF. However, bladeRF is better than HackRF in terms of power consumption. It was determined that the power consumption is more important than the available RAM. [12]

5. Schedule, Tasks, and Milestones

The wireless transceiver team will be designing and implementing this prototype over the next 4 months. Appendix A lists all the tasks and milestones, the person(s) assigned to those tasks, duration and their relative difficulty level. Appendix B contains the Gantt chart with the specific tasks and their associated timeline.

6. Project Demonstration

The capabilities of the Wireless Communications Receiver can be demonstrated in a classroom environment through the use of an android interface on a tabloid/PC/Android/Chrome Book.

- The Receiver will be powered on and there will be a display on the android interface.
- The Receiver will collect metadata that is being broadcasted in the air (no particular cellular network is being accessed) and display useful information about the network being accessed on the android interface.
- For a specific frequency, the power level and interfering will be displayed along with longitude and latitude of the testing location.

7. Marketing and Cost Analysis

7.1 Marketing Analysis

The target market consists primarily of individuals or corporations who wish to measure, record and graph the signal and connection quality of a cellular network. As it stands, there is no single device that is capable of measuring and displaying this data in a portable and easy to use way. There are however other RF scanning devices that can measure signal power at specific frequency ranges, but the data they provide is limited. One device from a company called DRTI has a similar device that can scan cellular data and display it but the interface is not as user friendly as we envision [13].

7.2 Cost Analysis

The cost of hardware for a prototype of this device is approximately $640. The main costs include the Nuand RF board and ODROID development boards because of their relative complexity. The DasPoint front-end interface board will be provided by DasPoint at no cost. The user must provide a mobile phone to access the information, so the user will have to handle the cost of the phone separately.

Table 5. Equipment Costs

Product	**Quantity**	**Unit Price**	**Total Price**
Nuand RF Blade	1	$450	$450
DasPoint Front End Interface Board	1	$250	$250
ODROID Development Board	1	$140	$140
Android Mobile Phone	1	$0	$0
Misc. Wires, Tools, Solder	1	$50	$50
TOTAL COST			$890

The development costs were determined by assuming a labor cost of $40 per hour. Fringe and overhead costs are included in the final estimate. A significant amount of time will be devoted to coding the algorithms that connect to the cellular network and communicate with the towers to get signal statistics.

Table 6. Development Costs

Project Component	Labor Hours	Labor Cost
Planning		
Group planning	60	$2,400
Group meeting	60	$2,400
Hardware		
Building/Assembly	12	$480
Testing	12	$480
Wireless Communications		
On-board programming	170	$6,800
Code debugging	170	$6,800
Android App		
Programming & Debugging	150	$6,000
Demonstration		
Preparation/setup	20	$800
Total Labor	504	
TOTAL COST		$26,160

With a conservative fringe benefit cost of 30% of the total labor and overhead costs of roughly 120% of the material and labor costs, the total development cost for the prototype is estimated to be $59,065.

Table 7. Total Development Costs

Parts	$890
Labor	$26,160
Fringe Benefits (30% of Labor)	$7,848

Subtotal	$34,898
Overhead (120% of Parts, Labor & Fringe)	$41,877
TOTAL COST	$76,775

A production version of the complete system may include a faster, more capable front-end board with an FPGA that has more memory. This would allow for all of the computation and signal processing to be moved off of the ODROID and onto the FPGA, effectively eliminating the need for the ODROID. This would increase performance and reduce cost, but would take significantly more development time. The final product is expected to be sold to the public at a price from $8,000 to $12,000.

8. Current Status

Currently, the project specifications have been determined and it's in the research phase. This semester once the parts are received, the team will start working on the prototype.

9. References

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[13] "Products", drti.com [Online]. Available: http://www.drti.com/products.htm [Accessed Dec 2, 2013].

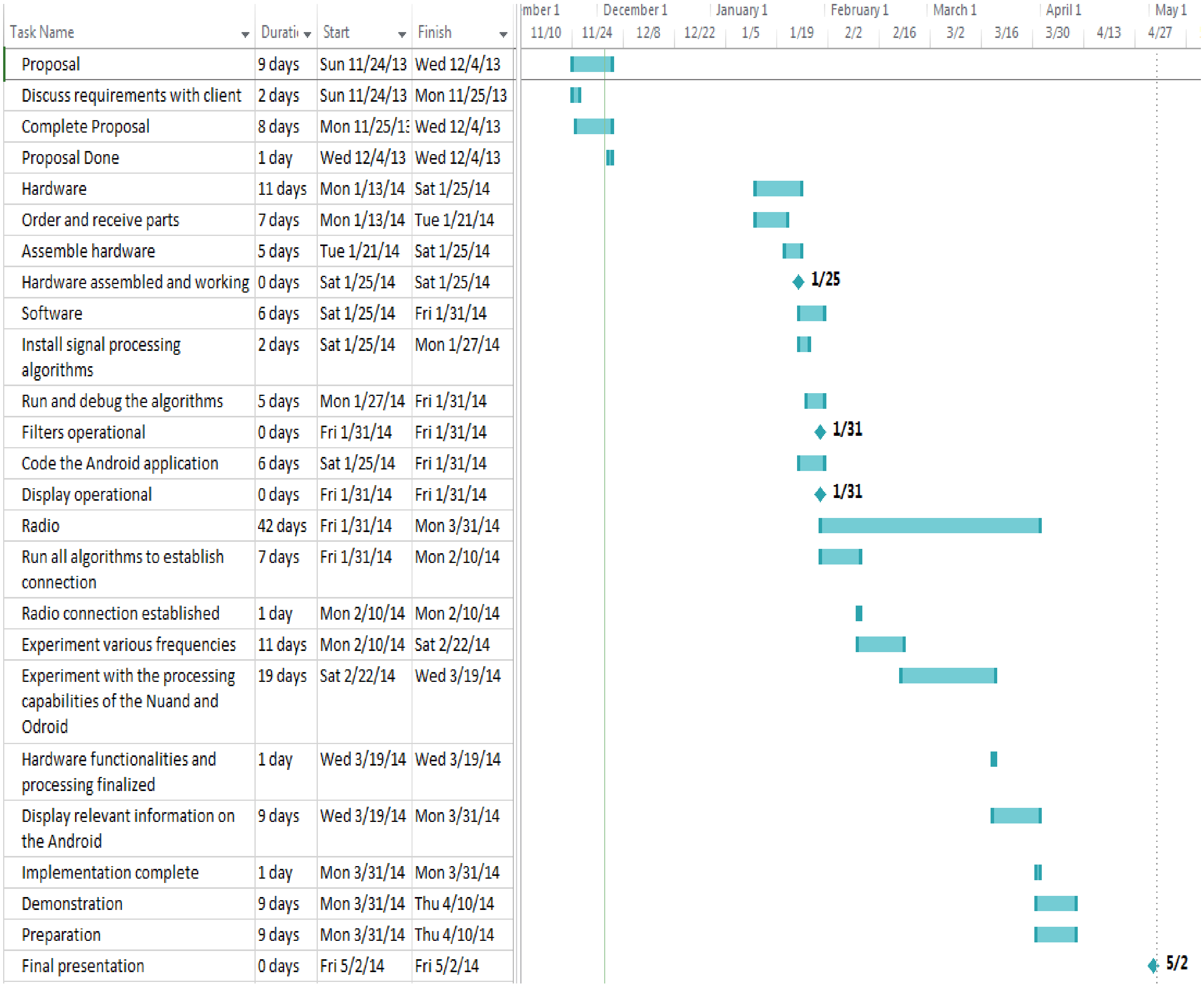
Appendix A

Task Name	Duration	Start Date	Due Date	Responsible	Difficulty
Proposal	***10 days***	**11/24/2013**	**12/4/2013**		
Discuss requirements with client	*1 day*	11/24/2013	11/25/2013	Group	Low
Complete Proposal	*9 days*	11/25/2013	12/4/2013	Group	Medium
Proposal Done	*0 days*	12/4/2013	12/4/2013	Group	*Milestone*
Hardware	***12 days***	**1/13/2014**	**1/25/2014**		
Order and receive parts	*8 days*	1/13/2014	1/21/2014	Vatsal	Low
Assemble Hardware	*4 days*	1/21/2024	1/25/2014	Vatsal, Pooja	Medium
Hardware assembled and working	*O days*	1/25/2014	1/25/2014	Vatsal, Pooja	*Milestone*
Software	***6 days***	**1/25/2014**	**1/31/2014**		
Install signal processing	*2 days*	1/25/2014	1/27/2014	Prahlad, Cameron	Medium

algorithms					
Run and debug the algorithms	*4 days*	1/27/2014	1/31/2014	Prahlad, Cameron	Medium
Filters Operational	*0 days*	1/31/2014	1/31/2014	Prahlad, Cameron	*Milestone*
Code the android application	*6 days*	1/25/2014	1/31/2014	Sahil, Avnish,	Medium
Display operational	*0 days*	1/31/2014	1/31/2014	Sahil, Avnish,	*Milestone*
Radio	***59 days***	**1/31/2014**	**3/31/2014**		
Run all algorithms to establish connection	*10 days*	1/31/2014	2/10/2014	Group	High
Radio connection established	*0 days*	2/10/2014	2/10/2014	Group	*Milestone*
Experiment various frequencies	*12 days*	2/10/2014	2/22/2014	Group	High
Experiment with the processing capabilities of the nuand and ODROID	*25 days*	2/22/2014	3/19/2014	Group	High
Hardware functionalities and processing finalized	*0 days*	3/19/2014	3/19/2014	Group	*Milestone*
Display relevant information on the android	*12 days*	3/19/2014	3/31/2014	Group	Medium
Implementation complete	*O days*	3/31/2014	3/31/2014	Group	*Milestone*
Demonstration	***10 days***	**3/31/2014**	**4/10/2014**		

Preparation	*10 days*	3/31/2014	4/10/2014	Group	Medium
Demonstration	*10 days*	4/10/2014	4/10/2014	Group	*Milestone*
Final Presentation	***0 days***	**5/2/2014**	**5/2/2014**	**Group**	***Milestone***

Appendix B



Task Name	Durati	Start	Finish
Proposal	9 days	Sun 11/24/13	Wed 12/4/13
Discuss requirements with client	2 days	Sun 11/24/13	Mon 11/25/13
Complete Proposal	8 days	Mon 11/25/1:	Wed 12/4/13
Proposal Done	1 day	Wed 12/4/13	Wed 12/4/13
Hardware	11 days	Mon 1/13/14	Sat 1/25/14
Order and receive parts	7 days	Mon 1/13/14	Tue 1/21/14
Assemble hardware	5 days	Tue 1/21/14	Sat 1/25/14
Hardware assembled and working	0 days	Sat 1/25/14	Sat 1/25/14
Software	6 days	Sat 1/25/14	Fri 1/31/14
Install signal processing algorithms	2 days	Sat 1/25/14	Mon 1/27/14
Run and debug the algorithms	5 days	Mon 1/27/14	Fri 1/31/14
Filters operational	0 days	Fri 1/31/14	Fri 1/31/14
Code the Android application	6 days	Sat 1/25/14	Fri 1/31/14
Display operational	0 days	Fri 1/31/14	Fri 1/31/14
Radio	42 days	Fri 1/31/14	Mon 3/31/14
Run all algorithms to establish connection	7 days	Fri 1/31/14	Mon 2/10/14
Radio connection established	1 day	Mon 2/10/14	Mon 2/10/14
Experiment various frequencies	11 days	Mon 2/10/14	Sat 2/22/14
Experiment with the processing capabilities of the Nuand and Odroid	19 days	Sat 2/22/14	Wed 3/19/14
Hardware functionalities and processing finalized	1 day	Wed 3/19/14	Wed 3/19/14
Display relevant information on the Android	9 days	Wed 3/19/14	Mon 3/31/14
Implementation complete	1 day	Mon 3/31/14	Mon 3/31/14
Demonstration	9 days	Mon 3/31/14	Thu 4/10/14
Preparation	9 days	Mon 3/31/14	Thu 4/10/14
Final presentation	0 days	Fri 5/2/14	Fri 5/2/14