RF Modeling and measurement of the performance of the Xbee radios using high-gain dish antennas

Prepared by: Jessica Celeste Nowak Bustamante de Haro
Prepared for: Dr. Mike MacGregor

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ABSTRACT

This work is based on an experiment conducted southwest of the city of Edmonton as a part of the sensor network project led by Dr. Mike Macgregor for the University of Alberta. The experiment attempts to analyze the maximum distance that a point-to-point link can have using high-gain antennas and placing sensors on the antennas, one that acts as a transmitter and the other as a receiver. The transmitter sensor extracted values of the received signal intensity (RSSI) each time the receiver was moved few hundred meters apart. Additionally, we used certain variables and introduced them in the simulation software called SPLAT! This software predicted RSSI values for the same distances that we used in the field. These values were compared with those taken in the test to model the behavior of a signal radiated by the sensors using Zigbee technology. The simulation shows that the tool used in this study is limited in its analysis for short distances (few hundred meters) and therefore we had to calculate the RSSI values with the free-space path loss formula. The results of the simulation sustain Inverse Square Law while those taken in the field demonstrate inconsistency with the law, most likely due to the phenomenon known as multipath.
INTRODUCTION

Because climate change and the impact of the activities of human beings in the environment are becoming an issue we can no longer ignore. It becomes imperative to have more sophisticated technology tools that allow us to obtain accurate information of what it is happening in our environment, particularly in the most sensitive areas of our planet. Artificial satellites are one of the tools that are used today to capture some data that may help scholars and scientist in the field of environmental engineering. Even though, this system is not effective enough because it can only take samples when the satellite is positioned over the point of interest, as long as the environmental conditions allow it, that is, there are no clouds that are covering the area. Additionally, we can take samples of large tracts of land, but if we want to assess a specific space in a forest where the vegetation is much denser, we could not capture accurate natural phenomena alone this area.

Due to this need for more accurate and reliable data, we have seen the implementation of sensor networks an optimal solution that promises real-time measurement, and further detailed in several scientific factors concerning environmental aspects. To meet these needs of the scientific community, it has been thought in the use of wireless sensor networks. These networks are made up of small low cost devices, long range and low power consumption. These characteristics have made possible the obtaining of environmental data in hostile environments like a forest or a glacier where human being cannot continuously access. The nodes of the network perfume measurements Xbee radios using the Zigbee protocol based on the IEEE 802.15.4 protocol.

One of the unknowns in implementing these sensor networks is to identify where to place gateway from the nodes to be able to collect data and send it to the engineers for further analysis. A simple analysis can be implemented by building a simple point-to-point link between two sensors. There are some considerations to take into account when implementing a point-to-point link, such as obstacles that may interfere with the link, the curvature of the Earth, the lost signal by several factors such as refraction of the transmitted signal, weather conditions, etc. To avoid these drawbacks, engineers tend to establish a line of sight between the transmitter and receiver antennas which avoid all possible obstacles. Despite of this, the links cannot be infinitely long, as
there are also the losses of power of the signal transmitted by propagation in the air that limit the maximum range of the link. This is the scope of our investigation: to determine the intensity of the signal between transmitter and receiver, at different distances.

The received signal strength indicator (RSSI) is a measurement of the power present in a received radio signal. Every receiver has a determine sensitivity, which is the minimum magnitude of input signal required to produce a specified output signal having a specified signal-to-noise ratio, or other specified criteria. In other words, indicates how faint an input signal can be to be successfully received by the receiver, the lower power level, the better. So, if we can calculate the RSSI of a link before it is lower that the sensitivity of the receiver, we can determine the maximum range of the link for future implementations.

Thus, this project aims to measure the performance of the Xbee radios using high-gain dish antennas of point to point links using the prediction software SPLAT! To generate RSSI values at different distances from the transmitter (every 100m for 1km). As well as, checking the performance of the transmission system by comparing the values taken in the field with the values generated in the modeling.

To determine the performance of these Xbee radios we proceeded to take measurements of the received signal strength indicator (RSSI) in open field. This measurement indicates the signal strength as a function of distance and environmental variables. Field measurements were conducted in small distances (hundreds of meters) for the purpose of being a guide for subsequent modeling.

This paper presents data on the intensity of signal taken in the open field of a point to point link. In this study, sensors, created by a company called Libelium where connected to high-gain antennas. The sensors incorporate the Zigbee wireless communication protocol and XBee transmission radios. These measurements were compared later with the results obtained with a RF modelling tool. Data was taken in a considered flat terrain southeast from the city of Edmonton in the province of Alberta, Canada.

The variables used in the field were analyzed with the Signal Propagation, Loss, And Terrain analysis tool, SPLAT!. Due to limitations of SPLAT! on the analysis of signal loss over short distances, this study assumed obstruction-free path, i.e., free space.
The results obtained in the analysis of signal loss (path loss) match the theoretical calculations of the law of free space. SPLAT! used as data the transmission power, the transmission frequency, the link distance and gains of the antennas (lost by the connectors was considered negligible). After we obtained the value of free-space path loss by SPLAT! We proceeded to calculate the RSSI. The data obtained from this math operation differ from those taken in the field. It is estimated that these differences could have been given due to ground reflections adding to the signal received directly by the transmitter, a phenomenon known as multipath propagation.
CHAPTER 1

THE ZIGBEE PROTOCOL

The rise of the creation of new and innovative devices has created the need to define a new category of computer networks known as personal area networks. The area coverage of this networks are no bigger than 30 meters between devices and can be seen in homes and even be limited to the human body. The need for mobility has made these personal networks be supported by wireless technologies. For personal wireless network or WPAN we have three general trends that are contradictory: low data rate, medium data rate and high data rate. A result of the low data rate trends is the Zigbee protocol.

Built on top of the IEEE 802.15 standard, Zigbee is the perfect example of what IEEE wanted to achieve with the standard: low-cost, low-power consumptions and small digital radios. The low power usage allows longer life with smaller batteries making them last even for years. Because of these characteristics, in particular the long lasting battery, makes Zigbee ideal in the implementation of sensor network.

1. Technical specifications

Some of the technical features found in the Zigbee protocol are:

– Data rates from 20 to 250 Kbps

– Different topologies such as conventional star and mesh operation

– Addressing based on short 16 bits or normal MAC (64 bits) addresses

– Support of simple access and slotted allocation with guarantees

– Support of acknowledged data transfer, and an optional beacon structure

– Energy detection (ED)
– Link quality indication (LQI)

– Multilevel security.

Because Zigbee takes advantage of the physical and the data link layer of the 802.15.4, we are going to discuss some of the 802.15.4 characteristics.

1.1. 802.15.4 and Zigbee

In contrast to the IEEE 802.15.4 standard, that works in the first two layers of the OSI model, Zigbee defines the communication layer from the third to upper layers in the stack. These upper layers have the purpose of creating a hierarchical network topology in which devices can communicate between each other and also enable features such as authentication, encryption, and some services such as discovery of nodes.

Figure 1.1 shows the two layers of the 802.15.4 standard, the Zigbee protocol layers on top of the layer 2 in comparison with the OSI model.

![Layer comparison between 802.15.4/Zigbee and the OSI Model](http://sensor-networks.org/index.php?page=0823123150)
1.2. 802.15.4 transmission frequencies and data rates

802.15.4 operates in the industrial, scientific and medical (ISM) radio bands. The frequencies defined in the standard are spread among 27 different channels divided in three main bands:

- 868.0 - 868.6MHz -> 1 channel (Europe)
- 902.0-928.0MHz -> 10 channels (EEUU)
- 2.40-2.48GHz -> 16 channels (Worldwide)

The commercial Zigbee radios work in the following frequencies:

- 868MHz -> XBee 868MHz OEM
- 900MHz -> XBee 900MHz OEM
- 2.40GHz -> XBee 802.15.4 OEM / XBee ZB

The data rate for the above frequencies is:

- 868.0 - 868.6MHz -> 20/100/250 Kb/s
- 902.0-928.0MHz -> 40/250 Kb/s
- 2.40-2.48GHz -> 250 Kb/s

1.3. Transmission characteristics

The 802.15.4 standard has the characteristic of being resistant to noise. This is achieved because it uses Direct Sequence Spread Spectrum to encode the signal (pre-modulation). Basically the DSSS is a technique that adds a redundant bit pattern for each one of the bits that make up the signal, the higher the bit pattern, the greater the strength of the signal to interference. Also, this process causes the total information to be transmitted to occupy a larger bandwidth but it uses a lower spectral power density for each signal.
1.4. Low battery consumption

The 802.15.4 standard specifies that devices work with low-duty cycles. This means that the transmitter or receiver can be sleeping most of the time (for hours or even days), this will depend also on the communication model used because the nature of communications between a sensor node and a hub has a great impact on the power consumed. Representative times as follows:

- 30 ms (typical) = new slave enumeration
- 15 ms (typical) = sleep slave to active
- 15 ms (typical) = active slave channel access

During the inactive period (if it exists), all nodes may enter in a sleep mode, thus saving energy.

2. Topologies and device types

Zigbee have different topologies that can range from a centralized star or a cluster-tree-based architecture to a complete mesh network. The mesh networking provides high reliability and more
extensive range. The standard provides specifications that depend on the device capability. For that purpose there are two kinds of capacities or types of nodes: a full-function device (FFD) and a reduced-function device (RFD). Normally the FFD can be a master (coordinator) and a PAN coordinator while the reduced-function one is normally a slave or simply a regular node if there is no master–slave communication.

The Zigbee Coordinator is normally the most capable device. All Zigbee network must have one (and only one) coordinator and forms the root of the network tree. In a Star topology, the coordinator is in the center and in the tree or mesh topology, it is the top node (root) of the network. The coordinator have the initialisation tasks such as select the frequency channel to be used in the network, start the network and allow other devices to connect to it. It also stores repository for security keys. The Zigbee router works as an intermediate device passing data from other devices. Networks with Tree or Mesh topologies need at least one Router. Note that a Router cannot sleep. The last type of node is an end device and because this device cannot relay data to other devices, it can have long periods of sleep, making the batteries last longer. The main tasks of an End Device at the network level are sending and receiving messages. In figure 1.3 be can see the position of each device in a different topology.

![Zigbee topologies](image)

*Figure 1.3. Zigbee topologies and position of devices.
Dark-blue: coordinator, light blue: end device, orange: router.*
3. Media Access Control

In a network, node may be silent, in a contention free or in a contention access period (CAP). To prevent interferences between nodes when they want to transmit, they use two techniques: CSMA-CA and GTS.

Carrier sense multiple access with collision avoidance (CSMA –CA) is very similar to the one used for medium access control by the standard IEEE 802.3 (Ethernet). The difference is that CSMA-CA adds additional steps to avoid any possible collision. Basically, in this process each node senses the medium energy levels (feature called channel energy scan), i.e., check if any other node is transmitting. If so, a counter within the node starts giving a random waiting time before sensing the medium again. When the medium is free, the node sends a short frame to the receiving node (may be an access point) requesting permission to transmit (RTS-Request To Send). The receiver responds with another frame indicating that it is free to receive (CTS -Clear To Send) or occupied receptor (RxBUSY). If a CTS was received the source computer transmits the data frame (DATA). If the destination computer receives the message correctly frame responds with positive acknowledgment (ACK) and if it did not receive correctly answers with a negative acknowledgment frame (NAK) and origin device will try to resend it again. This whole process is called the Contention Access Period (CAP) in the whole transmission process defined by the standard.

The second one is Guarantee Time Slots (GTS). Form an allocation point of view, the GTS allocation is similar to a Time Division Multiplexing Access (TDMA), this means that a reserved amount of bandwidth is allocated to a node in a by a duration of a time slot. The big difference, which makes GTS better, is that the bandwidth is adjusting accounting to the time slots and also the time slots are variable. This system uses a centralized node that will be the PAN coordinator, which gives slots of time to each node so that any knows when they have to transmit. The stage where the node asks the PAN coordinator for slot allocation is called Contention-Free Period (CFP). Upon receiving this request, the PAN coordinator checks whether there are sufficient resources and, if possible, allocates the requested time slots. These time slots are called Guaranteed Time Slots (GTSs), if the resources are not available the GTS request fails.
It is important to point that the IEEE 802.15.4 and ZigBee Alliance continue to work closely to ensure an integrated and complete solution for the market especially for sensor networking-based applications.
4. Wireless Sensor Networks (WSN)

Due to the lower-power, low cost and low consumption features that the IEEE 802.15.4 and Zigbee, the standards are ideal for the construction of nodes for wireless sensor networks. A WSN consist in autonomous devices using sensor to monitor and capture data from the environmental conditions. The network consists in a gateway that establishes the connectivity between the wired world and the distributed nodes.

People have created WSN applications for areas including health care, utilities, environmental monitoring and remote monitoring. In the health care, sensors are created to be implanted into patients or wear them as accessories. The objective is to monitor the individual by collecting information such as vital signs to check the health of the patient. The most widely developed application is environmental monitoring. These networks are placed in cities, refineries, forests, rivers, etc. to collect information on environmental variables such as CO2 in the air or water, humidity, temperature, acidity, soil salinity, solar radiation, etc. to assess, predict and even prevent natural disasters, environmental pollution or simply evaluate the speed in regeneration of natural resources in specific areas. Anyhow, the latter implementation has many applications in the environmental and human sphere.

5. Libelium’s sensor solution: Waspmote

Due to the rise of the Internet of all things and man’s need for control over their environment, many companies have focused on creating sensors. Libelium is one of these companies. According to their webpage “Libelium delivers a powerful, modular, easy to program open source sensor platform for the Internet of Things enabling system integrators to implement reliable Smart Cities and M2M solutions with minimum time to market.”

Waspmote is one of the products that the company provides. This small sensor comes with it’s own API and it was built to be modular. On top of the main aboard that is provided we can integrate Zigbee or 802.15.4 radios, 3G board to enable connectivity to the cellular network, and

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1 http://www.libelium.com/company/
great amount of sensors to measure environmental variables like gas level (SH2, Methane (CH4), CO, and air pollutants), solar radiation (PAR), humidity, temperature, etc. In figure 1.6 we can see a Wasp mote board and couple of sensors that can be connected to it.

Figure 1.6. Wasp mote board and sensors
CHAPTER 2

POINT TO POINT LINKS, RSSI AND FREE-SPACE PATH LOSS

In telecommunications, a communication link is a channel that allows the connection between one or more devices. This link can be a physical medium such as air, copper or fiber; or it can be a logical link. The purpose of the link is to transmit and receive information between the devices connected to it. When we only need to connect a transmitter with a receiver (only two devices) a point to point link is used. A simple example of a point-to-point link is a telephone call where both devices are connected to each other and what is sent only one can hear the other.

We said already that telecommunications links can be both physical and logical and that physical links have several means for transmitting information. In this study we have focused on using microwave links that uses air to send radio frequency signals. The point to point microwave technology provides a connection using directional antennas and the link uses a determined transmit frequency range, called spectrum, to send video, voice or data between locations. The transmitter and the receiver can be few meters or even several kilometers apart. These point-to-point links also require a direct line of sight (LOS), this means there are no obstructions in the link so that they can transmit between antennas. A simple one-way microwave link includes four major elements: a transmitter, a receiver, transmission lines, and antennas. We can see in figure 2.1 the components of the link and how they need to be obstacle free to assure a proper communication.
Some of the technical features found in a point-to-point microwave are the range, data rate, the frequency bands and modulation methods. A microwave link can support up to a maximum distance of 100 km, but this number can vary according to the terrain. Do not forget that the point to point link requires line of sight and perhaps in the field where we will put the antennas it is not possible to establish such a long link. The bond length also depends on the height of the antennas.

To know the minimum height of the antennas you can perform calculations of the Fresnel zone. The Fresnel Zone “provides means to calculate where the zones are—where a given obstacle will cause mostly in phase or mostly out of phase reflections between the transmitter and the receiver... The strongest signals are on the direct line between transmitter and receiver and always lie in the first Fresnel zone.”\(^2\) So if we calculate the first Fresnel Zone we can determine the height of the antennas to preserve the LOS and the signal strength for the point-to-point link.

1. **Multipath propagation**

If unobstructed, radio waves will travel in a straight line from the transmitter to the receiver. But because in a real deployment we cannot find a real unobstructed path the signal can get from the TX to the RX via a number of different propagation paths. These different paths are created due to

\(^2\)Fresnel zone. URL: http://en.wikipedia.org/wiki/Fresnel_zone
the reflection of the electromagnetic signal by Interacting Objects (IOs) in the environment such as houses, mountains, lakes, windows, walls and even the curvature of the Earth. So at the end, the number of the possible propagation paths is very large. As shown in Figure 2.2, each of the paths has a distinct amplitude, delay (runtime of the signal), direction of departure from the TX, and direction of arrival; most importantly, the components have different phase shifts with respect to each other.

A receiver cannot differentiate between different multi path components, so it just adds them all, causing interference between them. Such interference can be constructive or destructive. A destructive interference is the one that cause fading by cancelling with the original signal. This effect – namely, the changing of the total signal amplitude due to interference of the different MPCs – is called small-scale fading.

![Figure 2.2. Multipath propagation](image)
2. Free Space Attenuation

The attenuation is the loss of power when the signal is transmitted from one point to another and it is a function of the distance. The analysis of the attenuation of the signal strength through the free space path loss approach is used in many areas to predict the strength of the received signal strength (RSSI) that might be expected in a radio system. Although this analysis does not take into consideration the concept of multipath, discussed above, it is useful as a basis for understanding many real life radio propagation situations.

![Figure 2.3. Free Path loss attenuation representation](image)

To be able to determine the free space propagation we need to take into consideration that the transmitter and receiver have a clear line of sight path between them. We have to make sure there are no other sources of impairment. To calculate the free space power received by an antenna, which is separated from a radiating antenna by a distance, we use the Friis free space equation.
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\[ P_r = P_t G_t G_r \frac{\lambda^2}{(4\pi d)^2} \]

Figure 2.4. Friis Free Space Equation

\textit{Gt and Gr are the transmit and receive antenna gains}
\textit{\(\lambda\) is the wavelength}
\textit{d is the Tx-Rx separation}
\textit{Pt is the transmitted power}
\textit{Pr is the received power}
\textit{Pt and Pr are in same units}
\textit{Gt and Gr are dimensionless}
CHAPTER 3

RSSI DATA COLLECTION IN THE FIELD

This research project will be the precursor for environmental measurements like the incidence and reflection of single light (photosynthetically active radiation - PAR), air temperature, relative humidity and soil moisture at various depths - 5 cm, 10 cm and 20 cm. This data collection will be done by a highly qualified group of staff CEOS (Science Center Earth Observation of the University of Alberta) in the forests and towns of the province of Alberta and Manitoba in Canada with high environmental impact. The main objective of CEOS in the implementation of sensor networks in recent sites is to measure the rate of forest regeneration.

As indicated in the introduction of this paper, it must be clear how the sensors may be dispersed between them and the gateway to perform their proper placement in the field when building the WSN. Thus, an experiment took place southeast of the city of Edmonton in the province of Alberta, Canada. A point-to-point link using high-gain antennas and sensors equipped with Zigbee radios was used. The sensors are part of a platform called Arduino WaspMotes manufactured by the company Libelium. These WaspMotes were acquired with a range of sensors and expansion cards to mount the various sensory circuits and wireless cards using the Zigbee communication protocol. There functionality and programmability are out of the scope of this project.

In this chapter we will see how the RSSI measurements were made in the field and the data that was collected. It is noteworthy that some of these data will then be input variables for the simulation software that we will discuss in more detail in Chapter 4.

The antennas used in this study are high-gain antennas comprising 60 cm spun aluminium dish and patch feed, together with all necessary mounting parts. In summary, the characteristics are:

- Frequency 2250-2450 MHz
- Gain 21 dbic
- -3db beamwidth 16°
- -10 db beamwidth 28°

3 http://www.jrmiller.demon.co.uk/products/s_ant.html
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- SWR $< 1.2:1$
- Axial ratio 1.05:1
- Polarisation RHCP
- Connector N-male [Option: N-female]
- Impedance 50 ohm
- Overall diameter 590 mm (23”)
- Weight 1.4 kg (3 lb)

The sensors were placed in the patch feed of each antenna, one for transmission and one for reception. Then the receiving antenna was moved every n-meters and the RSSI was collected for each distance.

Below we present the RSSI values obtained in the field:

<table>
<thead>
<tr>
<th>Samples</th>
<th>RSSI (dBm)</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>-36</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>-36</td>
<td>249</td>
</tr>
<tr>
<td>3</td>
<td>-37</td>
<td>341</td>
</tr>
<tr>
<td>4</td>
<td>-48</td>
<td>403</td>
</tr>
<tr>
<td>5</td>
<td>-60</td>
<td>485</td>
</tr>
<tr>
<td>6</td>
<td>-57</td>
<td>564</td>
</tr>
<tr>
<td>7</td>
<td>-66</td>
<td>644</td>
</tr>
<tr>
<td>8</td>
<td>-67</td>
<td>725</td>
</tr>
</tbody>
</table>

Figure 3.1. High-gain antenna-60 cm spun aluminium dish.
RF Modeling and measurement of the performance of the Xbee radios using high-gain dish antennas

To get these measurements under the following conditions:

- Flat terrain at the southeast of the city of Edmonton.
- No obstacles where between the transmitter and the receiver.
- The transmitter was placed in the following coordinates:

<table>
<thead>
<tr>
<th>UTM</th>
<th>Latitude/Longitude</th>
<th>Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>12U 381411m E 5913391m N</td>
<td>53°21'22.86&quot;N / 112°46'54.70&quot;W</td>
<td>TX</td>
</tr>
</tbody>
</table>

- The receiver was moved in an average of 90 meters to obtain the above RSSI values. The coordinates are as follow:

<table>
<thead>
<tr>
<th>UTM</th>
<th>Latitude/Longitude</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>12U 381411m E 5913491 N</td>
<td>53°21'26.05&quot;N / 112°46'54.83&quot;W</td>
<td>1</td>
</tr>
<tr>
<td>12U 381411m E 5913640 N</td>
<td>53°21'31.06&quot;N / 112°46'54.99&quot;W</td>
<td>2</td>
</tr>
<tr>
<td>12U 381411m E 5913732 N</td>
<td>53°21'33.76&quot;N / 112°46'55.15&quot;W</td>
<td>3</td>
</tr>
<tr>
<td>12U 381411m E 5913794 N</td>
<td>53°21'35.85&quot;N / 112°46'55.24&quot;W</td>
<td>4</td>
</tr>
<tr>
<td>12U 381411m E 5913876 N</td>
<td>53°21'38.50&quot;N / 112°46'55.35&quot;W</td>
<td>5</td>
</tr>
<tr>
<td>12U 381411m E 5913955 N</td>
<td>53°21'41.05&quot;N / 112°46'55.46&quot;W</td>
<td>6</td>
</tr>
<tr>
<td>12U 381411m E 5914035 N</td>
<td>53°21'43.22&quot;N / 112°46'55.48&quot;W</td>
<td>7</td>
</tr>
<tr>
<td>12U 381411m E 5914116 N</td>
<td>53°21'46.02&quot;N / 112°46'55.67&quot;W</td>
<td>8</td>
</tr>
</tbody>
</table>

NOTE: The coordinates of the different positions of the receiver were calculated adding the distance to the transmitter position towards north.

- Antenna gain: 2.1 dBi
- Antenna height: 3 meters
- Transmission frequency: 2.4 Ghz
- Transmission Power: 65mW
- Because there are no exact values for the loss of connectors, we are going to work with 20 dBm including the transmission power and antenna gains.
- Receiver sensitivity: -92 dBm
CHAPTER 4

RADIO FREQUENCY MODELING TO PRODUCE PREDICTIVE VALUES FOR RSSI IN A LINE OF SIGHT LINK

In this chapter we will see how the use of a prediction tool helped us obtain the loss of the received signal and then use this values to calculate the intensity of the signal in the receiver side. Additionally, we will discuss briefly the use of the simulation tool in the different versions that have been created to be used on various operating systems. In this study we only used the original version created by John A. Magliacane for Linux, the version for Windows created by John McMellen and the GUI programmed by Charles Escobar.

1. Prediction Software: SPLAT!

The more accurate definition for the software we can find it in the official web page “SPLAT! is an RF Signal Propagation, Loss, And Terrain analysis tool for the electromagnetic spectrum between 20 MHz and 20 GHz.” that was created by John A. Magliacane. It is a really powerful tool that is command-line driven and reads input data through a number of data files. SPLAT! provides site engineering data such as the great circle distances and bearings between sites, antenna elevation angles (uptilt), depression angles (downtilt), antenna height above mean sea level, antenna height above average terrain, etc. in simple reports and high quality graphs. All this calculations are based on the input files and especially from the digital terrain information that will give the tool the detailed information about the terrain.

SPLAT! is a free software and it is redistributed under the General Public License (GNU License), that is why it is free downloadable from the web page and can be install in any Linux distribution. Due to this property of the license, other pioneers interested in collaborating have created versions of the application for Windows and MAC. These versions obviate the need for manual
installations of the tool in Linux. For this project we used the Windows and two versions of Linux. The Linux version consists in the original version and a GUI that is built in an .iso file created by the Ecuadorian engineer, Charles Escobar. Charles, has also a Spanish web page\footnote{http://www.charlesescobar.com/splat/} dedicated to the software and had written a paper called Calculation of telecommunications using free software SPLAT (Cálculo de Telecomunicaciones usando Software Libre SPLAT) where how he used this tool to do some telecommunication predictions in Ecuadorian territory.

2. Installation of software and versions used

The exact installation of software is not going to be explained step by step because it will be unnecessary. We can find very detailed information in each end user manual that can be found on pages dedicated to each version. Links to these pages can be found at the official website of SPLAT! (http://www.qsl.net/kd2bd/splat.html). What is meant in this section is how these versions used provided data or addition functionalities for the research.

2.1. The original Linux version

This is the version created by the original author John A. Magliacane. It was installed in a virtual machine loaded with Ubuntu Desktop 12.0. For the installation of the necessary libraries use the command:

```
sudo apt-get install gnuplot build-essential libbz2-dev bzip2 zlib1g-dev
```

These libraries have to install before SPLAT!. Installing SPLAT! is straight forward, this is accomplished following the installation guide that comes in the .zip files that we downloaded from the office web page.
This is the version that was used to generate the predicted values of free-space path loss that were used later to calculate the RSSI. These values can be found in the report file with the name “Transmitter-to-Receiver.txt” that is created after issuing the command for point-to-point analysis.

The command used to run SPLAT! was:

```
splat -t /home/jnowak/splat-work/Transmitter.qth -r /home/jnowak/splat-work/Receiver.qth -metric
```

We could also obtain a terrain profiles with the following command:

```
splat -t /home/jnowak/splat-work/Transmitter.qth -r /home/jnowak/splat-work/Receiver.qth -p terrain_profile.png -metric
```

### 2.2. The Windows version

Versions of SPLAT! that run under Windows have been made freely available by John McMellen, KC0FLR, and Austin Wright, VE3NCQ. The installer was downloaded from Austin’s web page [http://www.ve3ncq.ca/wordpress/?page_id=62](http://www.ve3ncq.ca/wordpress/?page_id=62). The installation is really simple, but it didn’t work properly for my Windows 7 PC, but we used the sdf-converter tool (`srtm2sdf-win.exe`) to convert the .hgt files downloaded from [ftp://e0srp01u.ecs.nasa.gov/srtm/version2/SRTM3/](ftp://e0srp01u.ecs.nasa.gov/srtm/version2/SRTM3/) to .sdf. Beware that this Windows tool generates the files with a different file name format that the Linux version can use. If you are going to import this files to the Linux version change the “x” in the name for “.”, for example, the name of the .sdf file for Windows can be: 54x55x125x126.sdf , the Linux version will use: 54:55:125:126.sdf. Windows won’t allow having these types of names in files, so you will have to rename the files inside your Linux.
2.3. Linux GUI

Charles Escobar created a more simple way to use of SPLAT! through a GUI application developed by him in PHP, taking from his own words:

“SPLAT-looking GUI allow the user to use SPLAT!, providing the telecommunications engineer or technician a friendly environment in which he/she can introduce the variables and parameters necessary for calculations of telecommunications without having to worry about interaction with the console GNU/Linux.”

It is actually a really easy to use application, the user don’t even have to know any command as required for the original version. Charles even created an .iso file with everything pre-installed in a Xubuntu environment, just click on the desktop direct access and input the variables asked by the GUI.

The .iso can be downloaded from:

http://www.charlesescobar.com/iso/xubuntu-splat-12.04.2d.iso

user: splat

password: splat

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5 Taken from http://www.charlesescobar.com/wp-content/uploads/2013/05/splat-gui.pdf and translate to English
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Figure 4.1. SPLAT-GUI desktop
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Figure 4.2. SPLAT-GUI
3. Input data for prediction generation

Some files are mandatory for successful execution of the program, while others are optional. Mandatory files include digital elevation topography models in the form of SPLAT Data Files (SDF files), site location files (QTH files), and Irregular Terrain Model parameter files (LRP files). Optional files include city location files, cartographic boundary files, user-defined terrain files, path loss input files, antenna radiation pattern files, and color definition files.

SPLAT! imports site location information of transmitter and receiver sites analyzed by the program from ASCII files having a .qth extension. QTH files contain the site’s name, the site’s latitude (positive if North of the equator, negative if South), the site’s longitude (in degrees West, 0 to 360 degrees, or degrees East 0 to -360 degrees), and the site’s antenna height above ground level (AGL), each separated by a single linefeed character. The antenna height is assumed to be specified in feet unless followed by the letter m or the word meters in either upper or lower case. Latitude and longitude information may be expressed in either decimal format (74.6864) or degree, minute, second (DMS) format (74 41 11.0).

Our .qth files are:

Transmitter.qth

Transmitter
53 21 22.86
112 46 54.70
3m

Receiver.qth

Receiver
53 21 46.02
112 46 55.67
3m

The Receiver.qth coordinates were changed according to the position to obtain the accurate free-space path loss.
Due to limitations concerning predictions over short distances that the simulator has, we had to consider propagation loss using the approach of free-space loss in the calculation of the strength signal power (RSSI). To obtain these values, we input the following data in the program:

- **Distance of the link**: Coordinates of the transmitter and coordinates of the receiver (run the program for each receiver position)
- **Transmission power**
- **Transmission frequency**

We also generated the profile terrain and the path loss profile diagram with the digital elevation topography models in the form of SPLAT Data Files (SDF files), related to the coordinates where our devices were located.
CHAPTER 5

RESULTS AND CONCLUSIONS

1. Results

We did two types of calculations:

1.1 The free-space path loss of the link simulated in SPLAT! For 1 km every 100 m. Then manually calculating the RSSI with free-space path loss FSPL formula and the received power in free space. SPLAT! Will provide the Signal power level at Receiver using the ITWOM path loss approach.

Free-space loss

\[ FSL = 20 \log \frac{\lambda}{4\pi d} \]

Received power in free space

\[ P_{Rx} = P_{Tx} + G_{Tx} + G_{Rx} + 20 \log \frac{\lambda}{4\pi d} \]

<table>
<thead>
<tr>
<th>Samples</th>
<th>Device</th>
<th>Path loss (dB)</th>
<th>RSSI (dBm)</th>
<th>Distance</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>TX</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>53°21'22.81&quot;N / 112°46'54.70&quot;O</td>
</tr>
<tr>
<td>1</td>
<td>RX1</td>
<td>-79.95</td>
<td>-59.95</td>
<td>100</td>
<td>53°21'26.05&quot;N / 112°46'54.83&quot;O</td>
</tr>
<tr>
<td>2</td>
<td>RX2</td>
<td>-86.01</td>
<td>-66.01</td>
<td>200</td>
<td>53°21'29.27&quot;N / 112°46'54.97&quot;O</td>
</tr>
<tr>
<td>3</td>
<td>RX3</td>
<td>-89.56</td>
<td>-69.56</td>
<td>300</td>
<td>53°21'32.51&quot;N / 112°46'55.10&quot;O</td>
</tr>
<tr>
<td>4</td>
<td>RX4</td>
<td>-92.03</td>
<td>-72.03</td>
<td>400</td>
<td>53°21'35.69&quot;N / 112°46'55.24&quot;O</td>
</tr>
<tr>
<td>5</td>
<td>RX5</td>
<td>-94.02</td>
<td>-74.02</td>
<td>500</td>
<td>53°21'38.98&quot;N / 112°46'55.37&quot;O</td>
</tr>
<tr>
<td>6</td>
<td>RX6</td>
<td>-95.61</td>
<td>-75.61</td>
<td>600</td>
<td>53°21'42.22&quot;N / 112°46'55.51&quot;O</td>
</tr>
<tr>
<td>7</td>
<td>RX7</td>
<td>-97.16</td>
<td>-77.16</td>
<td>700</td>
<td>53°21'46.01&quot;N / 112°46'55.45&quot;O</td>
</tr>
<tr>
<td>8</td>
<td>RX8</td>
<td>-98.11</td>
<td>-78.11</td>
<td>800</td>
<td>53°21'48.69&quot;N / 112°46'55.78&quot;O</td>
</tr>
<tr>
<td>9</td>
<td>RX9</td>
<td>-99.14</td>
<td>-79.14</td>
<td>900</td>
<td>53°21'51.92&quot;N / 112°46'55.91&quot;O</td>
</tr>
<tr>
<td>10</td>
<td>RX10</td>
<td>-100.05</td>
<td>-80.05</td>
<td>1000</td>
<td>53°21'55.16&quot;N / 112°46'56.05&quot;O</td>
</tr>
</tbody>
</table>
1.2 Calculate the RSSI using SPLAT! for the distances used in the field and then compared to the ones obtained in the testing.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Device</th>
<th>RSSI-field (dBm)</th>
<th>RSSI-SPLAT!(dBm)</th>
<th>Distance</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>TX</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>53°21'22.86&quot;N / 112°46'54.70&quot;W</td>
</tr>
<tr>
<td>1</td>
<td>R1</td>
<td>-36</td>
<td>-55,621</td>
<td>100</td>
<td>53°21'26.05&quot;N / 112°46'54.83&quot;W</td>
</tr>
<tr>
<td>2</td>
<td>R2</td>
<td>-36</td>
<td>-68,15</td>
<td>249</td>
<td>53°21'31.06&quot;N / 112°46'54.99&quot;W</td>
</tr>
<tr>
<td>3</td>
<td>R3</td>
<td>-37</td>
<td>-70,62</td>
<td>341</td>
<td>53°21'33.76&quot;N / 112°46'55.15&quot;W</td>
</tr>
<tr>
<td>4</td>
<td>R4</td>
<td>-48</td>
<td>-72,14</td>
<td>403</td>
<td>53°21'35.85&quot;N / 112°46'55.24&quot;W</td>
</tr>
<tr>
<td>5</td>
<td>R5</td>
<td>-60</td>
<td>-73,75</td>
<td>485</td>
<td>53°21'38.50&quot;N / 112°46'55.35&quot;W</td>
</tr>
<tr>
<td>6</td>
<td>R6</td>
<td>-57</td>
<td>-75,07</td>
<td>564</td>
<td>53°21'41.05&quot;N / 112°46'55.46&quot;W</td>
</tr>
<tr>
<td>7</td>
<td>R7</td>
<td>-66</td>
<td>-76,07</td>
<td>644</td>
<td>53°21'43.22&quot;N / 112°46'55.48&quot;W</td>
</tr>
<tr>
<td>8</td>
<td>R8</td>
<td>-67</td>
<td>-77,16</td>
<td>725</td>
<td>53°21'46.02&quot;N / 112°46'55.67&quot;W</td>
</tr>
</tbody>
</table>
The terrain profile (Figure 5.3.) will show us the elevation of the terrain where we did the measurements. We can see that actually wasn’t that flat as we believed in the test. This profile was created between the transmitter and the last position of the receiver (position 8).
Figure 5.3. SPLAT! Terrain profile between Transmitter and Receiver

2. Conclusions

One of the most important things that we could notice from comparison between the predictions of SPLAT! and the valued that were took from the field is that we have a difference, in the longest point of measurement, of 10 dBm. This is not a big difference but we can think that this is probably due to ground reflections adding to the signal received by the receiver. It’s very difficult to predict what might happen since the situation is quite complex. Even over short distances, the signal you receive is probably the result of the signal getting to you via 1000 or more separate paths. Also, we could assume that the device sensing the RSSI was not working properly.

Another interesting point is to see that with SPLAT! we can prove that our simulated values meet the Inverse Square Law. The Inverse Square Law says that every time we double the distance between the transmitter and the receiver, the received signal strength will decrease by exactly
6.02 dB. Our values taken from the field defy this law of physics. This could be explained with the situation above.
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