Combination of CP & CSA

D5.4- Synthesis Report

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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the Consortium (including the Commission Services)	
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Publishable Executive Summary

A central goal of the Virtual Instrumentation work package was to demonstrate the feasibility and the potential of transforming the data loggers deployed in the INTERACT stations into networked devices that can be connected to the Internet, and thus transformed into virtual instruments.

This deliverable synthesizes the results of two deployment and measurement campaigns conduced at Zackenberg and Abisko. We report on the efforts we have conduced to establish wireless radio links to data loggers deployed in the field, on the quality of these radio links in the harsh arctic environment, and we discuss the merits of delay tolerant networks to achieve resilience in the presence of low quality radio links.

Our work shows that there is a huge potential in establishing various forms of radio links to enhance existing monitoring infrastructure in the INTERACT stations.

1 Introduction

A central goal of the Virtual Instrumentation work package was to demonstrate the feasibility and the potential of transforming the data loggers deployed in the INTERACT stations into networked devices that can be connected to the Internet, and thus transformed into virtual instruments.

But what kind of radio link can be established in the harsh environmental conditions of the INTERACT consortium? What kind of techniques can be used to plan a deployment? What kind of technology is best adapted to the arctic conditions? What is the actual impact of the meteorological conditions on performance? How to overcome the limitations of low quality radio links?

These are the issues we tackle in this deliverable. We synthesize the results of two campaigns conduced at Zackenberg and Abisko. We report on the efforts we have conduced to establish wireless radio links to data loggers deployed in the field, on the quality of these radio links in the harsh arctic environment, and we discuss the merits of delay tolerant networks to achieve resilience in the presence of low quality radio links.

2 Zackenberg Deployment

2.1 Context

At Zackenberg, the challenge is to transform the stand-alone data loggers into virtual instruments, available on-line. In terms of connectivity, the problem is twofold. First, the data loggers need to be made accessible via wireless radio links. Second, the Zackenberg research station needs to be connected to the Internet via some form of satellite link.

We surveyed in Deliverable D5.1 the architectures, protocols and tools available for networking data loggers. In this report, we report on the progresses we have made in Zackenberg and we draw perspectives for the issues that still need to be investigated.

Overall, our work shows that (1) the radio link models we built with open source tools are a very precious tool to guide for further deployments, and that (2) state of the art technology is well suited for deploying effective radio links at Zackenberg.

2.2 Prototype Deployment

In August 2011, Joel Granados and Javier Gonzalez went to Zackenberg Research Station in North-East Greenland. Their task was to evaluate the status of the Capoh System deployed for lake monitoring with a buoy equipped with a water quality sensor connected via a short range communication link with an embedded gateway installed on the shore[1]. They extended the Capoh system with a mid-range wifi communication link to connect the gateway to the research station 5 km away.

[1] See http://javigongon.files.wordpress.com/2011/12/mana.pdf for details.

For the extended communication link, we performed a range of experiments in Copenhagen so that we used the appropriate combination of hardware and software to be deployed in Greenland. We decided to use the Ubiquiti Bullet M2[2], and a custom linux distribution called openwrt. It was the extensibility of Openwrt[3] that made us choose this distribution, and the hardware compatible with it. The final decision was a combination of the reasonable price of the Bullets, their resistance to extreme weather conditions and our previous good experience with Ubiquity[4].

In order to test our system, we designed a set of experiments in Copenhagen, adopting the same restrictions as the ones we knew from Zackenberg: The link distance was 5 km, and there was line of sight. Given these requirements we designed our experiments in two different dimensions: hardware and software. Since we were not familiar with the performance of the different types of antennas under the expected Zackenberg conditions, we decided to try all three basic types of antennas we could find: directional, semi-directional and omnidirectional. We built all three models ourselves based on the recommendations from the "green book", i.e., the reference for cheap yet reliable wireless networking deployments[5]. In the software dimension, our experiments were all based on a set of scripts that sent a predefined amount of packets with an incrementing payload. After the scripts run, we compared the original payload sent by the transmitter and the payload collected by the receiver. The goal is of course that the payload received corresponds exactly to the payload that is sent. We measure data loss in our experiments as the percentage of the payload, which is not transmitted.

Our test resolved that we could get a 0% data loss rate if using a biquad directional antenna. We carried out our experiments in Københavns Havnebade, since this was the only place we found where we could control the 5 km line of sight requirements. In Figure 1 we can see the Bullet M2 configuration as printed in the openwrt console (for debugging purposes[6]).

```
 BUOY                          BOX                                          ROOF                       LAB
/////////                  /////////////                                 //////////////              //////////
///SCB/// ---------------- ///Bulet1////      )))      802.11      (((    ///Bullet2//// ---------------///SBC////
/////////                  /////////////                                 //////////////              //////////

  192.168.1.150   /  192.168.1.1  -  192.168.4.220         /         192.168.4.1  -  192.168.3.1  /  192.168.3.150

> Coordinates.
        Lakes:
                52165048 East
                826775334 North

        Camp:
                512690 East
                8264475 North
```

Figure 1: Network Physical Configuration for the Ubiquity Bullet M2

While in Zackenberg our work was to tweak our Bullet M2 + Openwrt system to work in the field. Our approach was once again very much experimental. By means of a compass and a pair of binoculars we could effectively locate the antenna attached to the solar panel present in the Capoh Base Station. We then carried out the same experiments described above. Since

2 http://www.ubnt.com/bullet

3 https://openwrt.org

4 http://dl.ubnt.com/datasheets/bulletm/bm_ds_web.pdf

5 http://www.amazon.com/Wireless-Networking-Developing-World-Edition/dp/0977809366

6 SBC makes reference to a TS-7260 board running the main computation in a Linux Lenny

the conditions were slightly different in Zackenberg, we decided to try all three types of antennas there. The results were very similar, so we stayed with the biquad direction antenna.

When we were ready to deploy the system, including the wetlab's water quality sensor, we realized that it was damaged. Data could not be collected properly through the serial port, and the data stored inside of the data logger did not match the manual measurements we took as ground truth. After some consideration, we decided to bring the sensor back to Copenhagen, but we decided then to deploy the Capoh System without it so that we could test our wireless link design. We designed in-situ a simple logical sensor that would emulate the data produced by the water quality sensor and send it to the base station. Since the objective was to emulate the data ow as much as possible, we decided to use a string of data originally produced by the water quality sensor as the payload for our emulator. Figure 2 shows it. A program located in the sensor node originally attached to the water quality sensor in the Capoh Buoy, would send strings of data points to the Capoh Base Station as if it was the sensor itself. Once the data had been collected, it would be sent to Zackenberg Base Station. From the Capoh Base Station's point of view, the data it collects is legitimate, and therefore our experiment is comparable to the response of the system in production. Figures 3 and 4 show the system deployed.

```
WQM,005,031511,140135,0.01032,17.3677,0.04,0.060,11817.7,9.520,8.878,92,0.529,1035,6.237\r\n
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WQM,005,031511,140138,,,,,,,,,,,\r\n
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WQM,005,031511,140143,0.01032,17.3677,0.04,0.060,11817.7,9.520,8.878,92,0.529,1035,6.237\r\n
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WQM SN:  33\r\n
CTDO SN:  5031\r\n
DOSN=0\r\n
Soc=1.420000e-04\r\n
FOffset=-3.256790e+03\r\n
A52=-1.746900e-03\r\n
B52=1.329700e-04\r\n
C52=-2.309200e-06\r\n
E52=3.600000e-02\r\n
Optics SN:  856\r\n
FactoryCHL=0.012        40      Scale and Offset\r\n
UserCHL=0.012   40      Scale and Offset\r\n
NTU=0.006       46      Scale and Offset\r\n
Beta=0.000      46      0       Derived Scale and Offset\r\n
<EOH>\r\n
33,4,052308,133543,0.00000,0.0000,0.00,0.0,0,0\r\n
33,4,052308,133543,0.00000,0.0000,0.00,0.0,0,0\r\n
```

Figure 2: Data Points generated by Wetlab's Water Quality Sensor

2.3 Deployment in the Field

Figure 3: Biquad Antenna in Zackenberg Research Station

Our system was deployed at Zackenberg for 2 months. The USB stick containing the data transmitted to Zackenberg Research Station was collected by Mikkel Tamstorf before the station was closed for the winter season. The data collected shows that all scheduled transmissions (once a day) took place, and all the data was transmitted. We thus used state of the art wireless technology to build a data link that did not lose any data over a two months period. A very encouraging result!

Figure 4: Capoh Base Station placed in Sommerfugles_

2.4 Further Radio Links

How can we build on the positive results from our experiments? There are two directions for further work: (1) how to establish radio links to the existing data loggers already in place at Zackenberg, and (2) how can we connect Zackenberg to the Internet via a satellite connection.

2.4.1 Connecting Zackenberg Data Loggers

Most of the data loggers deployed at Zackenberg are CR1000 from Campbell Scientific (CS). This reduces the range in which we can choose the technology to support a wireless radio link, since CS develop their own protocols. Since our goal is to provide an out-of-the-box solution, we will explore which of the different products supported by CS matches our requirements. The whole set of hardwired for radio communications or Spread Spectrum Radios in Campbell Scientific's terminology can be found in their webpage[7].

We will divide our analysis into devices operating at 900MHz and devices operating at 2.4GHz.

[7] http://www.campbellsci.com/spread-spectrum-radio

The products available for 900MHz are:

- RF401 900-MHz Spread-Spectrum Radio[8] and RF430 900-MHz Spread-Spectrum Radio[9]. This Spread-Spectrum Radio is within the 900MHz radio frequency allowed in Europe (910MHz - 918MHz) and its specifications match the ones we have used in the simulations. The reason for having 2 products is that one is equipped with a RS-232 serial interface that facilitates the connection to data-loggers such as the CR1000, and the other is equipped with an USB, which facilitates the connection to a computer. Technical specifications are available online[10].
- RF450 900-MHz, 1-W Spread-Spectrum Radio[11] This Spread-Spectrum Radio operates also in 900MHz (902MHz - 928MHz) and is suitable for long-range communications. Simulations run using the specifications provide better results than the one using the devices mentioned above. Besides, the simulations we have provided in this document have been carried our using this configuration. Given that this Radio counts on a wide operating temperature range and is optimized for high data transfer speeds (the weak point of 900MHz), we strongly recommend its use over the radio presented above. Technical specifications are available online[12].

We therefore recommend RF450 900-MHz, 1-W Spread-Spectrum Radio

The only product available for 2.4GHz is:

- RF416 2.4-GHz Spread-Spectrum Radio[13] and RF432 2.4-GHz Spread-Spectrum Radio. This Spread-Spectrum Radio is within the 2.4GHz radio frequency allowed in Europe (2.45GHz - 2.460GHz) and its specifications are the one used for running the 2.4GHz simulations. The reason for having 2 products is that one is equipped with a RS-232 serial interface that facilitates the connection to data-loggers such as the CR1000, and the other is equipped with an USB, which facilitates the connection to a computer. Technical specifications are available online.

Which frequency to use (900 MHz or 2.4 GHz) depends on:

1. Characteristics of the wireless link between nodes (distance, line of sight, geographical features, humidity, etc)
2. Throughput: How much data we need/want to send per second
3. Power consumption

Since we only count on limited information concerning the size of the data we are dealing with, we will present simulations for both frequencies. It is interesting to explore both in order to establish whether we can grant spatial coverage and good signal for all our devices. We will finally put this together with the rest of our analysis to get a final design proposal. It is worth mentioning that we can make a first design of what we think should be done and then run the simulation using different radios (frequencies) or antennas. This is the approach we are going to take.

8 http://www.campbellsci.com/rf401

9 http://www.campbellsci.com/rf430

10 http://s.campbellsci.com/documents/us/product-brochures/b rf401-rf430.pdf

11 http://www.campbellsci.com/rf450

12 http://s.campbellsci.com/documents/us/product-brochures/b rf450.pdf

13 http://www.campbellsci.com/rf416

From Figure 1 it can be seen - as we mentioned before - that most of the devices are located within a circle. We decided then on an omnidirectional antenna positioned in the main station. Then, we need to run simulations using directional antennas and probably repeaters in order to connect the so-called problematic devices. We will divide our simulations by frequency.

900 MHz

The first simulation we are going to run represents the scenario where all the devices within the circle we mentioned above - this is: M2, M4, M5, MM1, MM2, Linux Machine and CNansen (refer to Table 1) being the gateway located in House 4 - are equipped with an omnidirectional antenna. In Figure 5 we see the signal coverage under the assumption of the antenna being positioned 3 meters above the ground. Responding to a realistic scenario, the antenna in the base station should be positioned up to 5 meters high, being the ones in the data-loggers almost at ground level. This means around 0.5 meters in order to minimize disturbance from the ground.

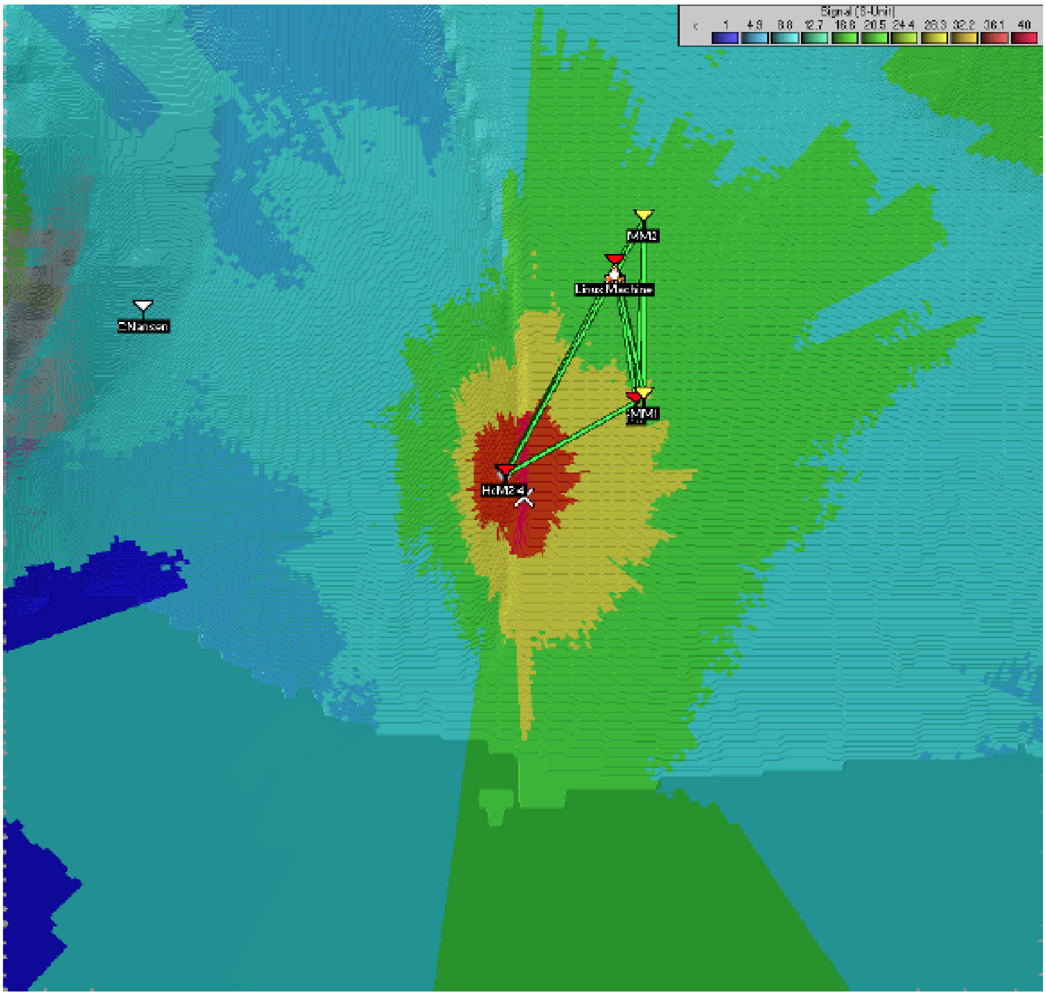


Figure 5: Signal coverage for 900MHz and omnidirectional antennas nearby House 4.

What we observe in this Figure is that, as we predicted, all the devices mentioned above are covered with a very good signal, except for CNansen. In this case, we would recommend a directional antenna pointing at House 4 if we intend to guarantee a good connectivity. Since we have line of sight this will improve the quality of the signal dramatically. We believe though that this approach is enough for a fairly good connection (in case we want to consider budget too). Figure 6 shows in more detail the quality of the radio link between House 4 and the camera CNansen.

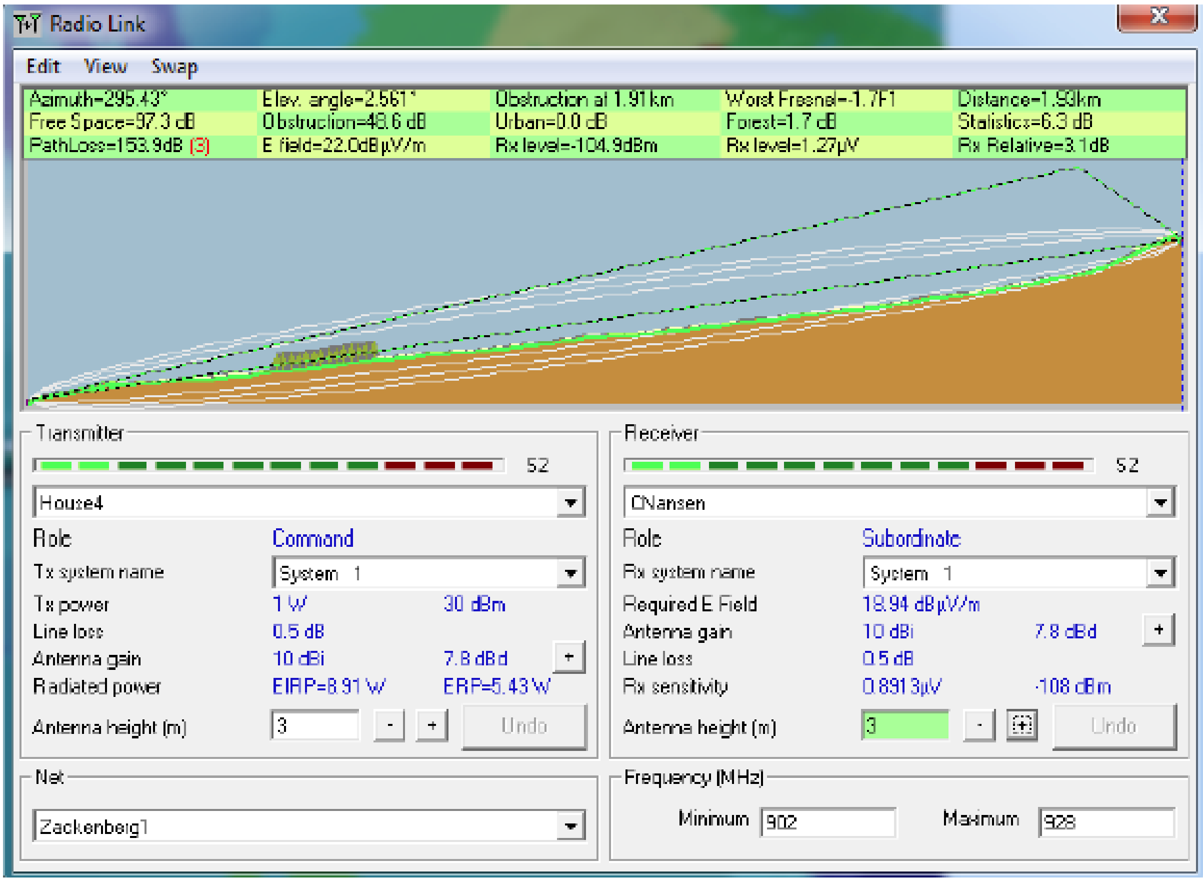


Figure 6: Link quality between House 4 and device CNansen

If we now keep this configuration and zoom out, we see that - because of the terrain elevation - device M3 is also under what we would define as good coverage. This leaves devices M6 - which we can see is totally out of reach - and M7 - which does not even appear in the map - as our main concern in terms of designing a reliable wireless network. Figure 7 represents the zoomed-out map, and Figures 8, 9 and 10 support our argument.

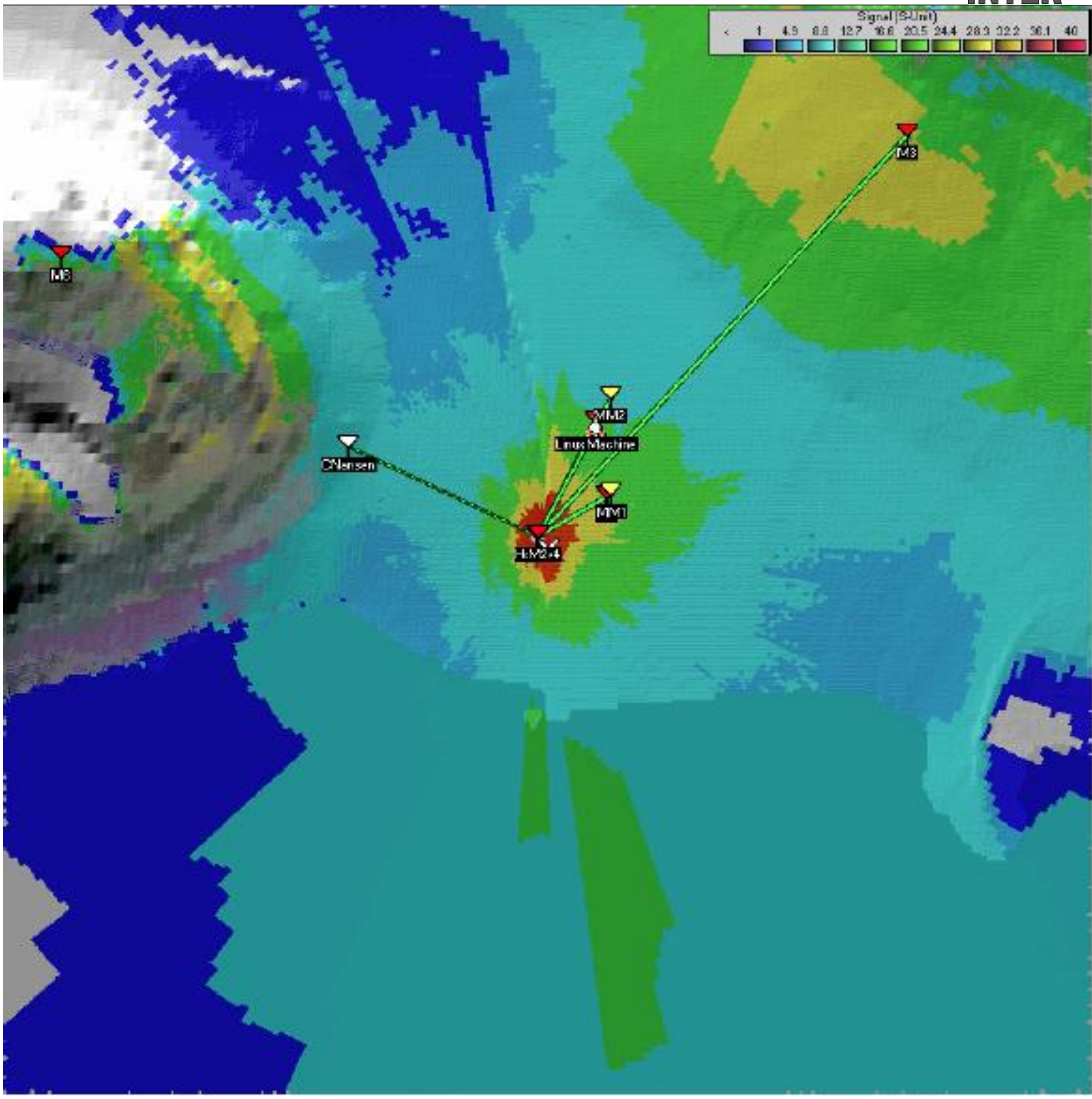


Figure 7: Signal coverage for 900MHz and omnidirectional antennas. Zoom out.

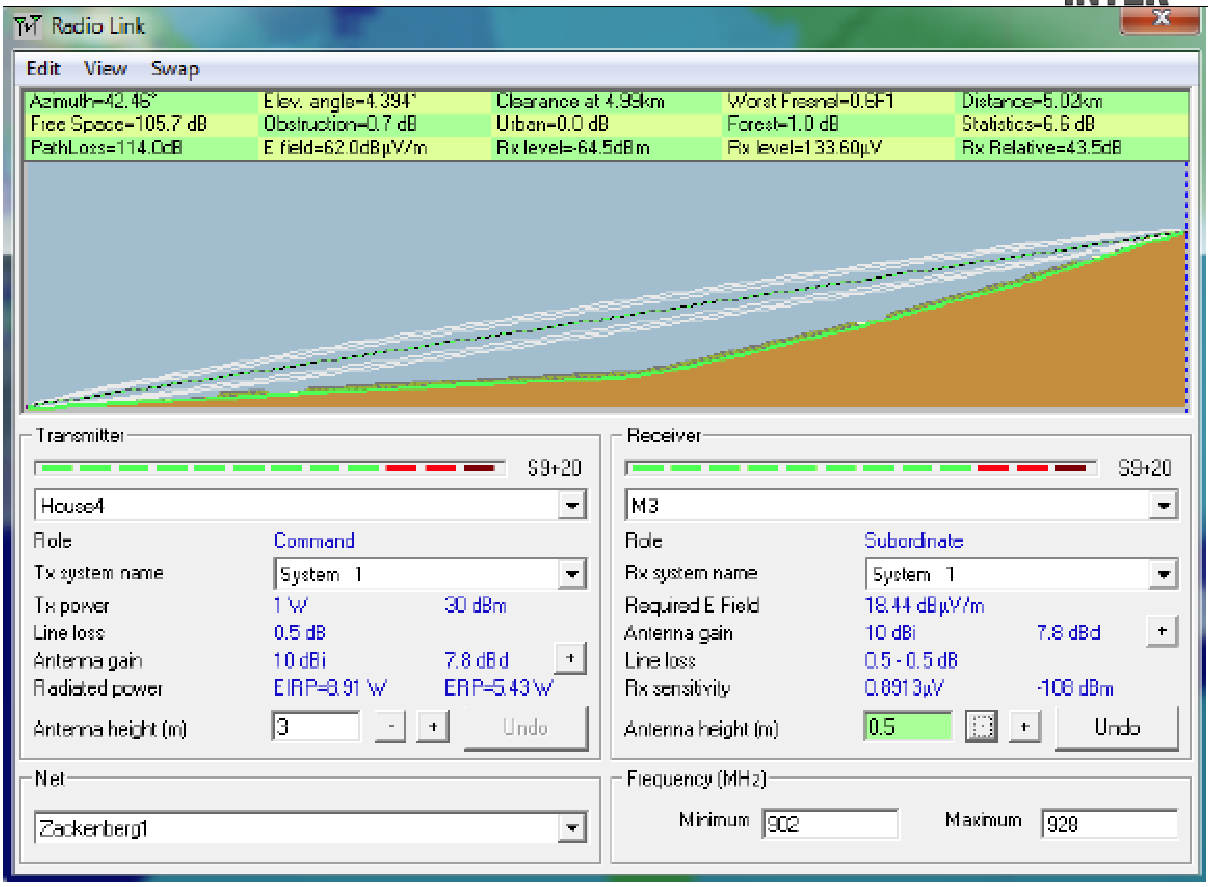


Figure 8: Link quality between House 4 and device M3

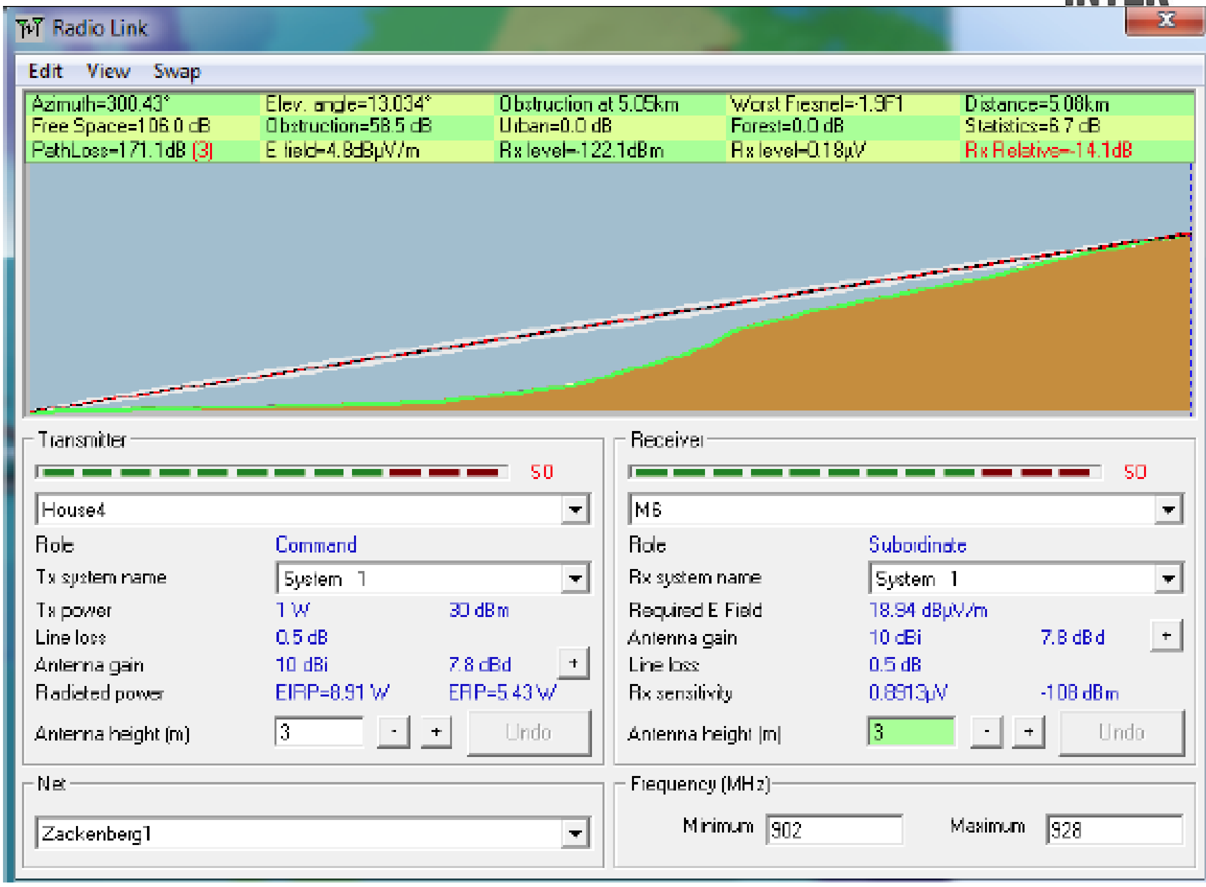


Figure 9: Link quality between House 4 and device M6

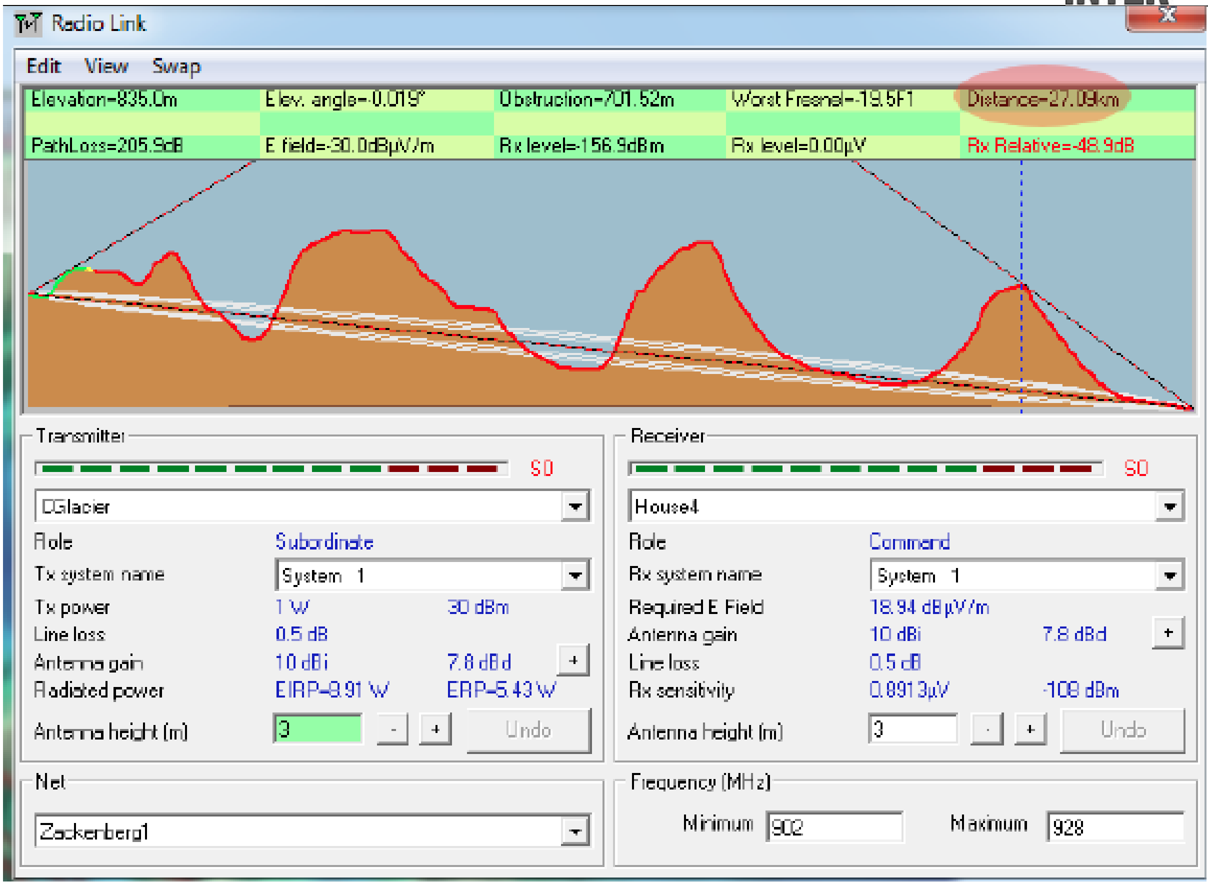


Figure 10: Link quality between House 4 and device CGlacier

Now that we focus on connecting 2 devices to an already functional wireless network, we will make use of the concepts we defined before under Section 4, and more specifically multi-hop networks. As we will see in the next section, the hardware we are using for wireless communications allows us to configure the radios inside of them to retransmit data. This means that we can reuse the radio that sends wireless data from one device to the base station to forward data coming from another device which cannot reach the base station by itself. This widens our possibilities since we do not necessarily need to use additional hardware.

We explored different alternatives for connecting device M7 reusing our hardware. The one we have selected - which provides the better connectivity for device M7 – requires the antenna connected to device M3 to act as a repeater as well as a transmitter for device 3. Also, we need a directional antenna connected to device M7, pointing at device M3. In this way, Figure 11 represents the signal cover from device M3.

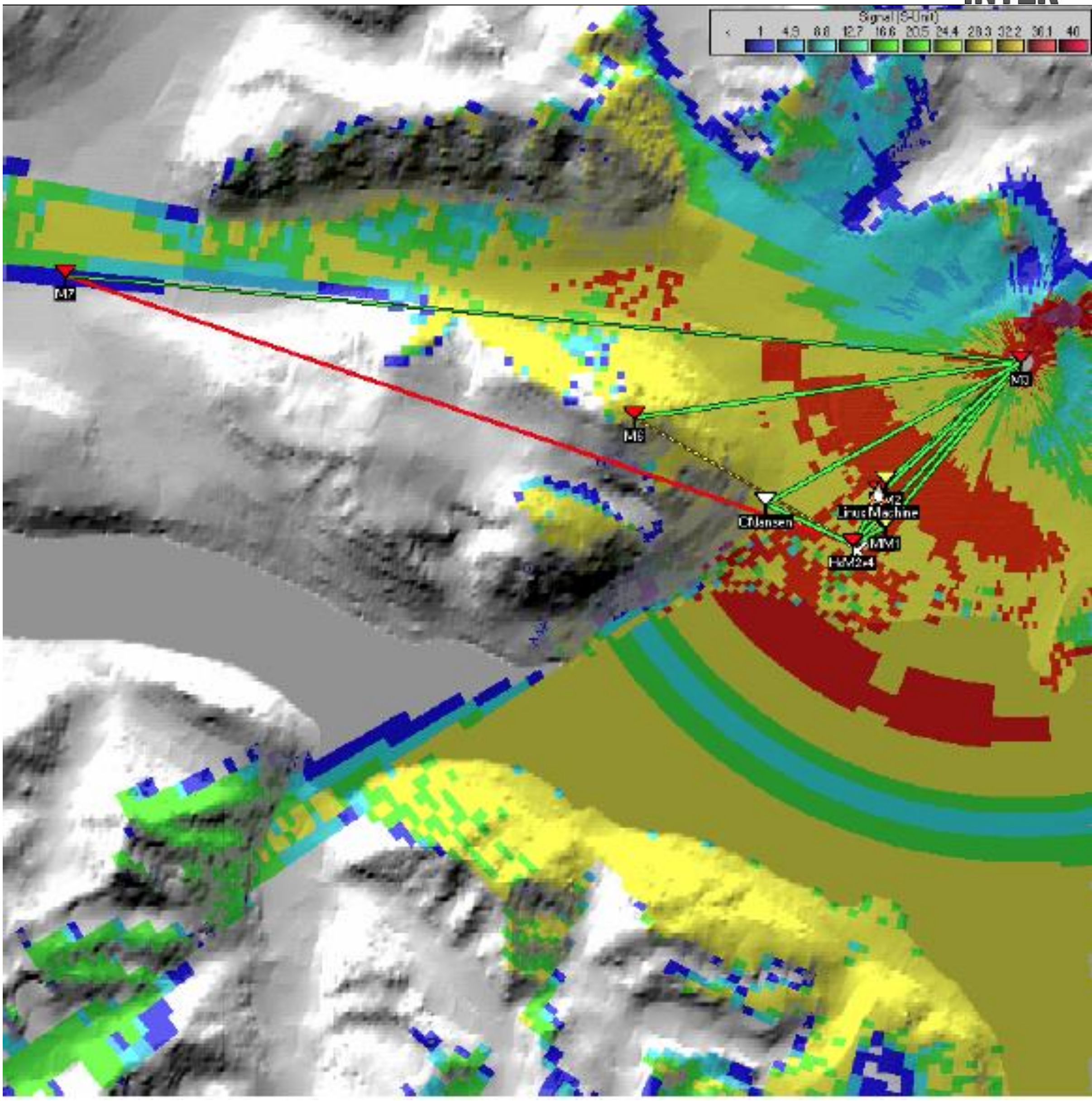


Figure 11: Signal coverage for 900MHz from M3's point of view.

Even if this image does not imply a very good signal connection between M7 and M3, we should remember that this signal coverage map is set from M3's point of view. If we measure the quality of the link between these two devices, we see that the quality is good enough for our purposes. Figure 12 shows this.

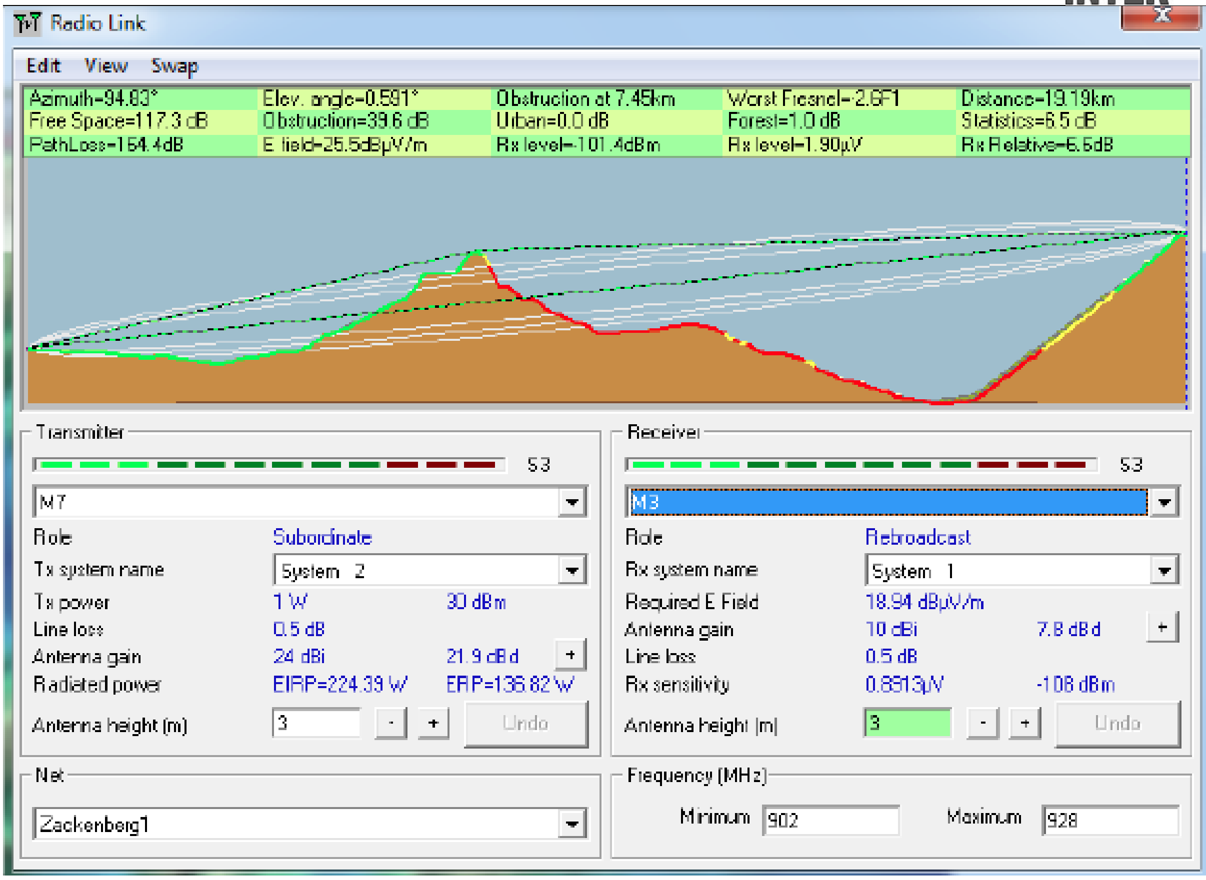


Figure 12: Link quality between M3 and M7.

If we want to provide better connectivity for device M7, we can place a repeater. The optimal position for it is on top of the mountain that separates these two devices, as we can see in the figure above. The coordinates for the repeater are 74.49944 and -20.789441302.3. The signal strength increases when making use of these additional devices as we can see in Figure 13. Also, Figures 14 and 15 show the quality of the individual links M7 - Repeater and Repeater - M3.

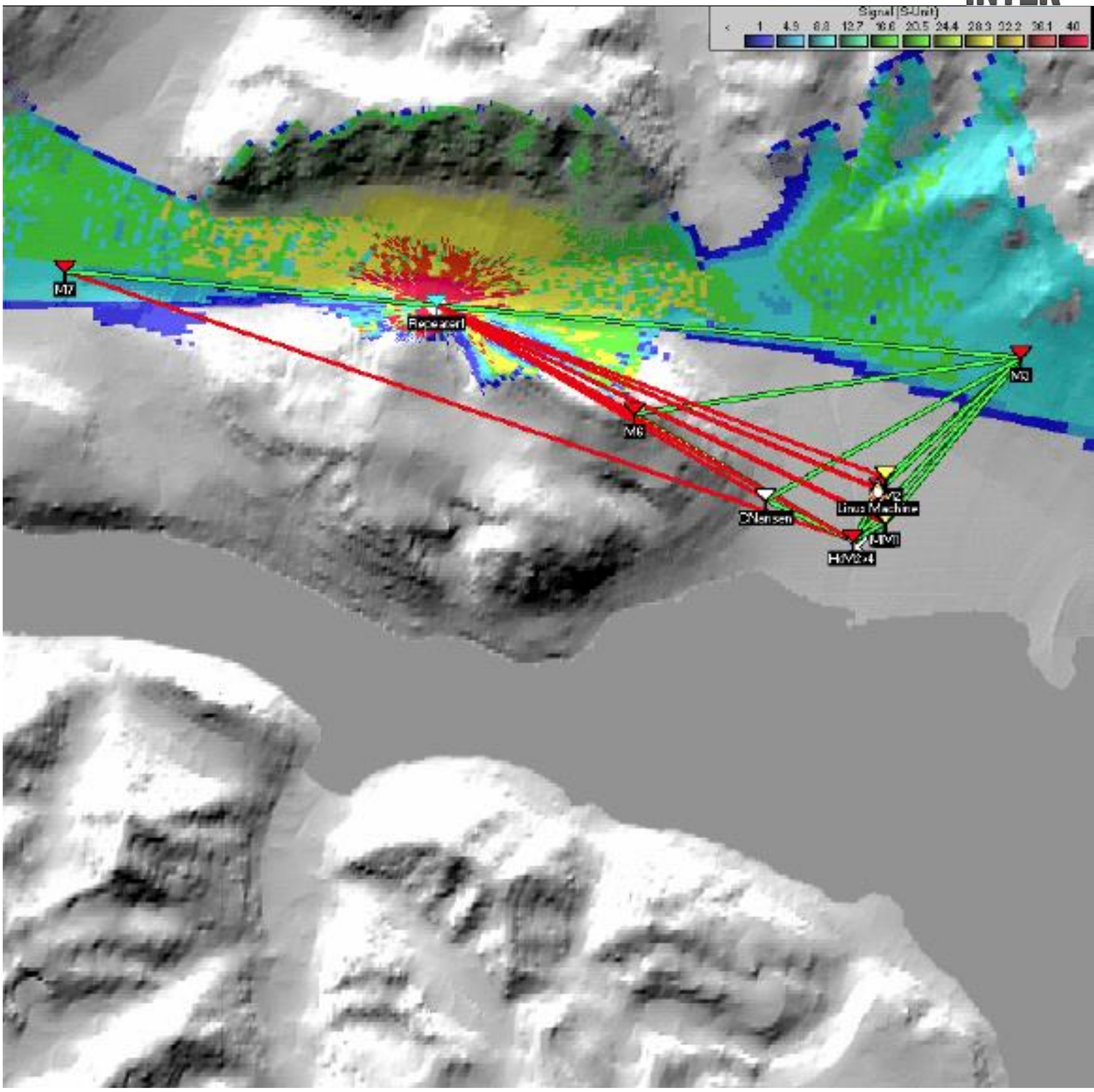


Figure 13: Signal coverage for 900MHz from Repeater's point of view.

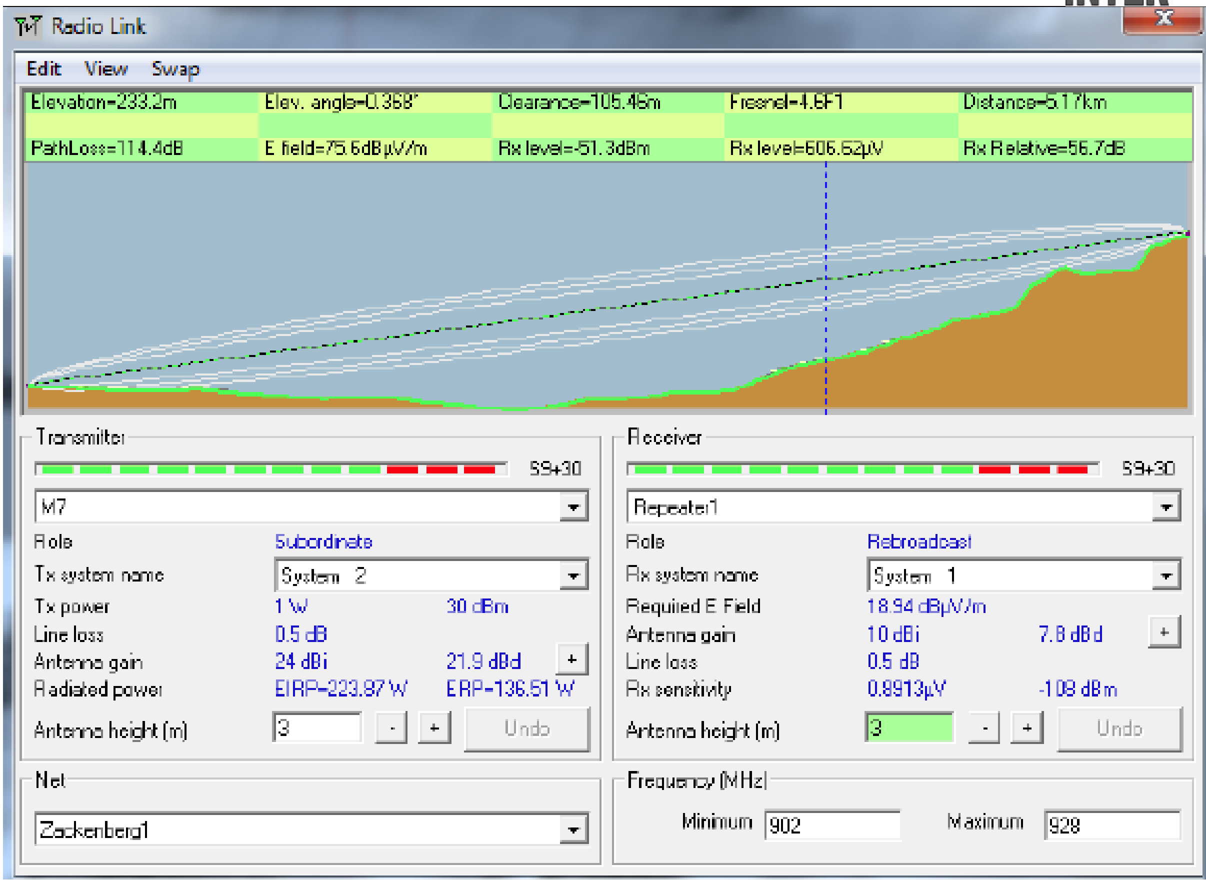


Figure 14: Link quality between M7 and Repeater1 using 900MHz.

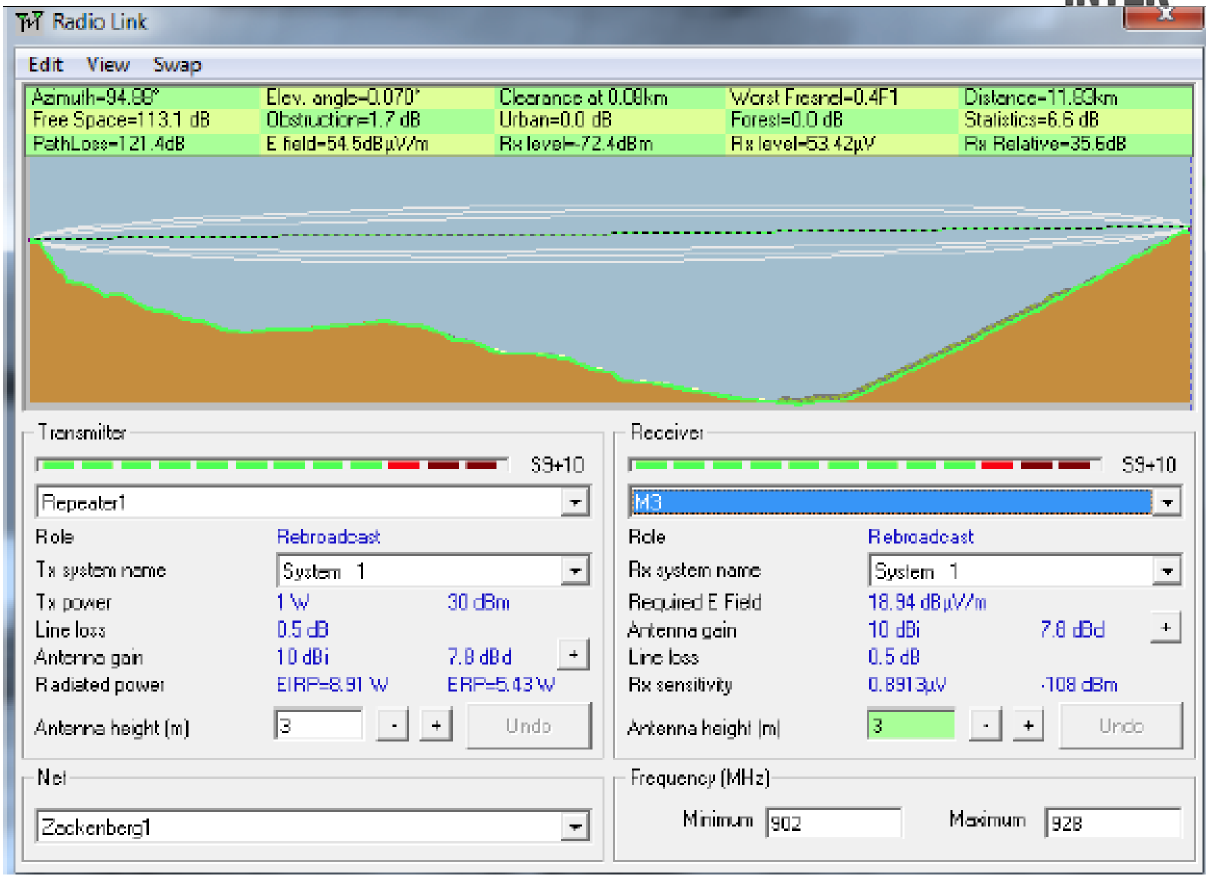


Figure 15: Link quality between Repeater1 and M3 using 900MHz.

The last device we need to provide remote access to is the Glacier Camera (CGlacier). This one is much more difficult to connect, since, as we can see in Figure 10 a semi-direct link is impossible due to terrain elevation. Moreover, since the device itself is placed next to a small peak, we will need to use at least one additional repeater in order to guarantee radio coverage. Increasing the number of repeaters violates the final budget and also requires more maintenance, which is always not well received. However, since we have been given the position of the data-loggers and we assume it as non-modifiable, we need to adapt our design to these requirements.

In our first approach, we try to reduce the amount of repeaters to the minimum. In this way we introduce 1 repeater in order to allow the signal to "get out" of the valley in which it is located and then we reuse the infrastructure we had before. Figure 16 represents this scenario. Please note that the figure explicitly shows the network topology. The red lines are the paths that are infeasible due to poor signal and the green ones are the paths with good connectivity. We can see that every node can reach the base station (House 4) by using a "green path", which implies that the node (device) is connected.

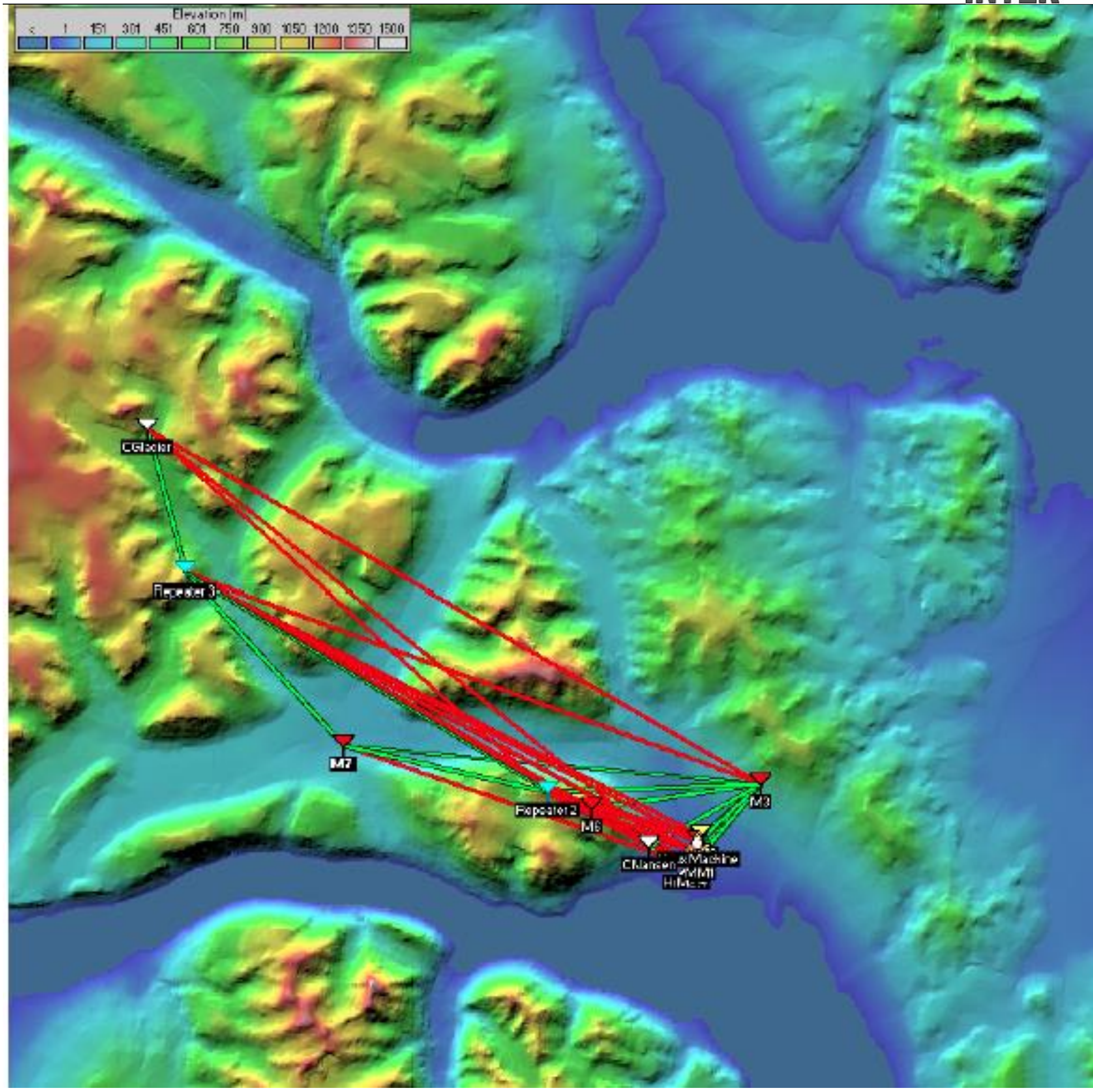


Figure 16: Network topology for the entire network using 1 additional repeater for the Glacier Camera

This solution is theoretically possible. However we can see that we are using the radio in device M7 as a repeater. This is the weak point of this design. Generally we should not worry about it, since there is no reason for anything to go wrong, however, it would be better to use repeaters as repeaters and end devices only as end devices. Applying this paradigm we propose another solution where we use another repeater in order to avoid the use of M7 as such. The coordinates for Repeater 2 are 74.50166 and -20.887221068.6. Figure 17 represents this network topology.

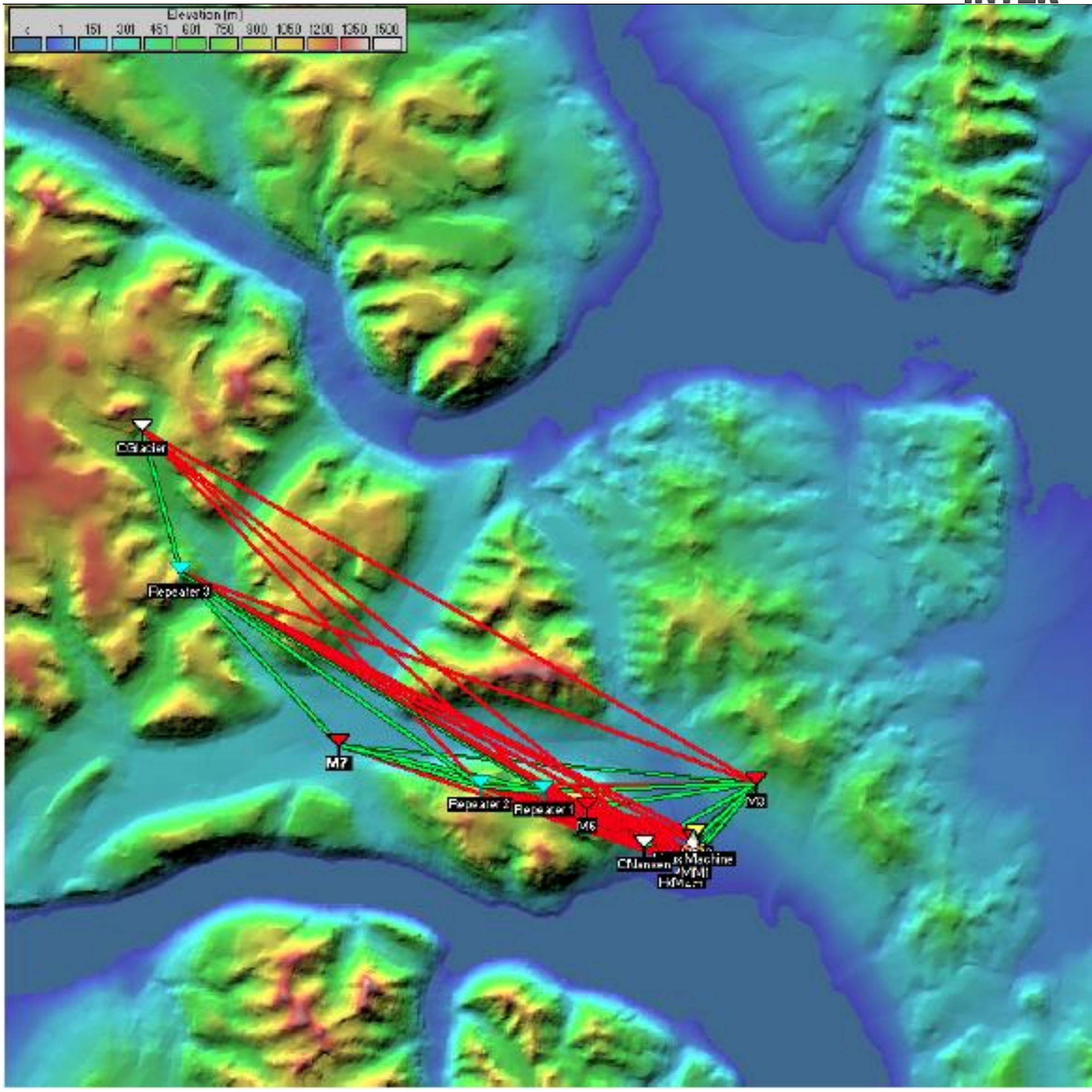


Figure 17: Network topology for the entire network using 2 additional repeaters for the Glacier Camera

Both designs are equally feasible, and should solve the problem we have defined in the beginning. We wanted to give more than one solution in case budget is not a problem or there is another requirement not stated here that would make one of the designs above not functional.

The topologies shown in Figures 17 and 16 are then our two designs for the sensor network using 900MHz.

2.4 GHz

As stated before, our intuition and experience points us towards 900MHz as the best solution for this network. Nonetheless we will run the simulations modifying the out-of- the-box networking devices operating at 2.4GHz.

As in the section above, we will start by covering the devices within the circle and short range of House 4 by means of an omnidirectional antenna. Figure 18 shows this. Also Figure 19 shows the Fresnel Zone of the point-to-point connection between the CNansen and House 4. This explains visually why 2.4GHz behaves worse over long distances.

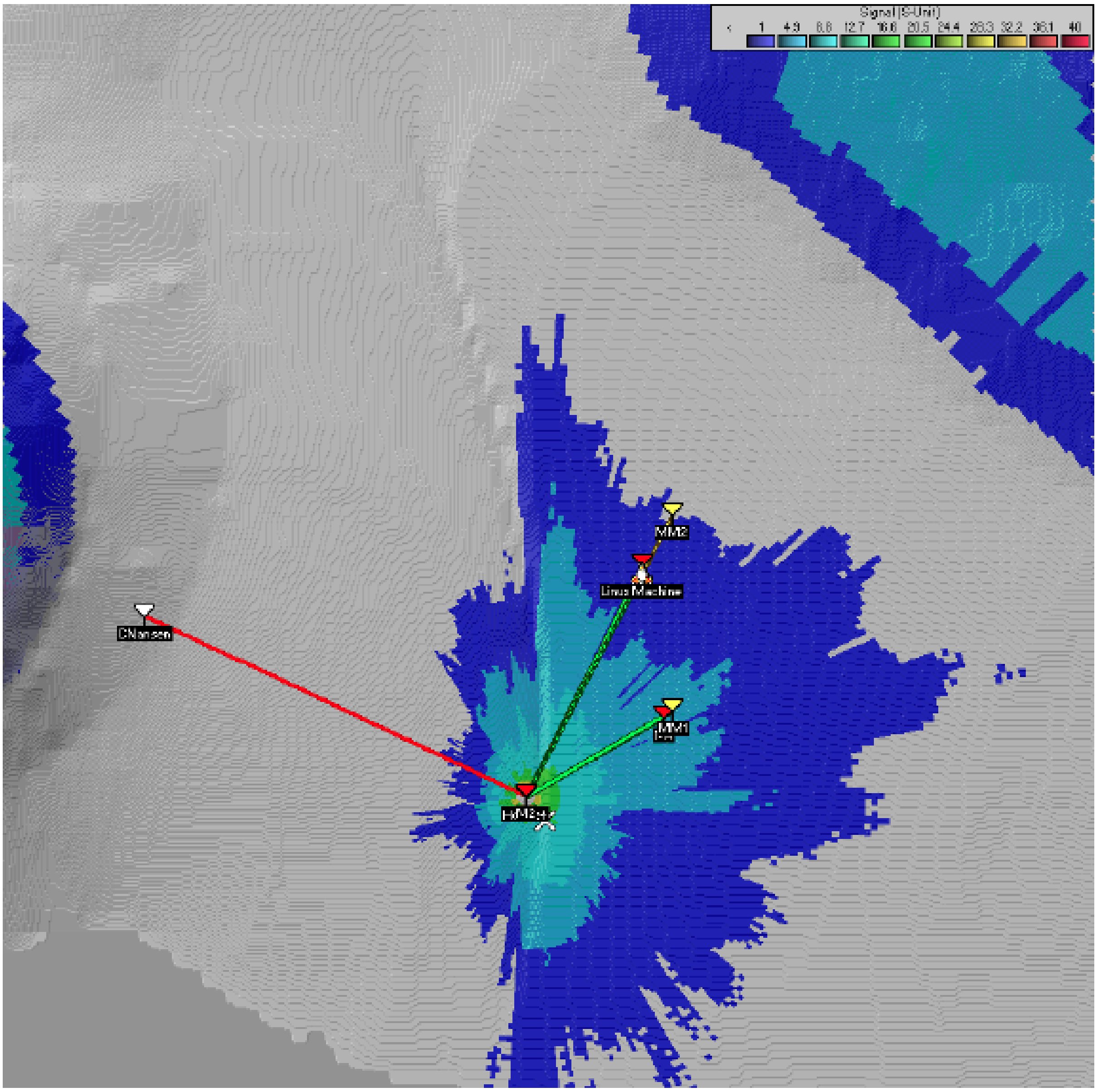


Figure 18: Signal coverage for 2.4GHz and omnidirectional antennas nearby House 4.

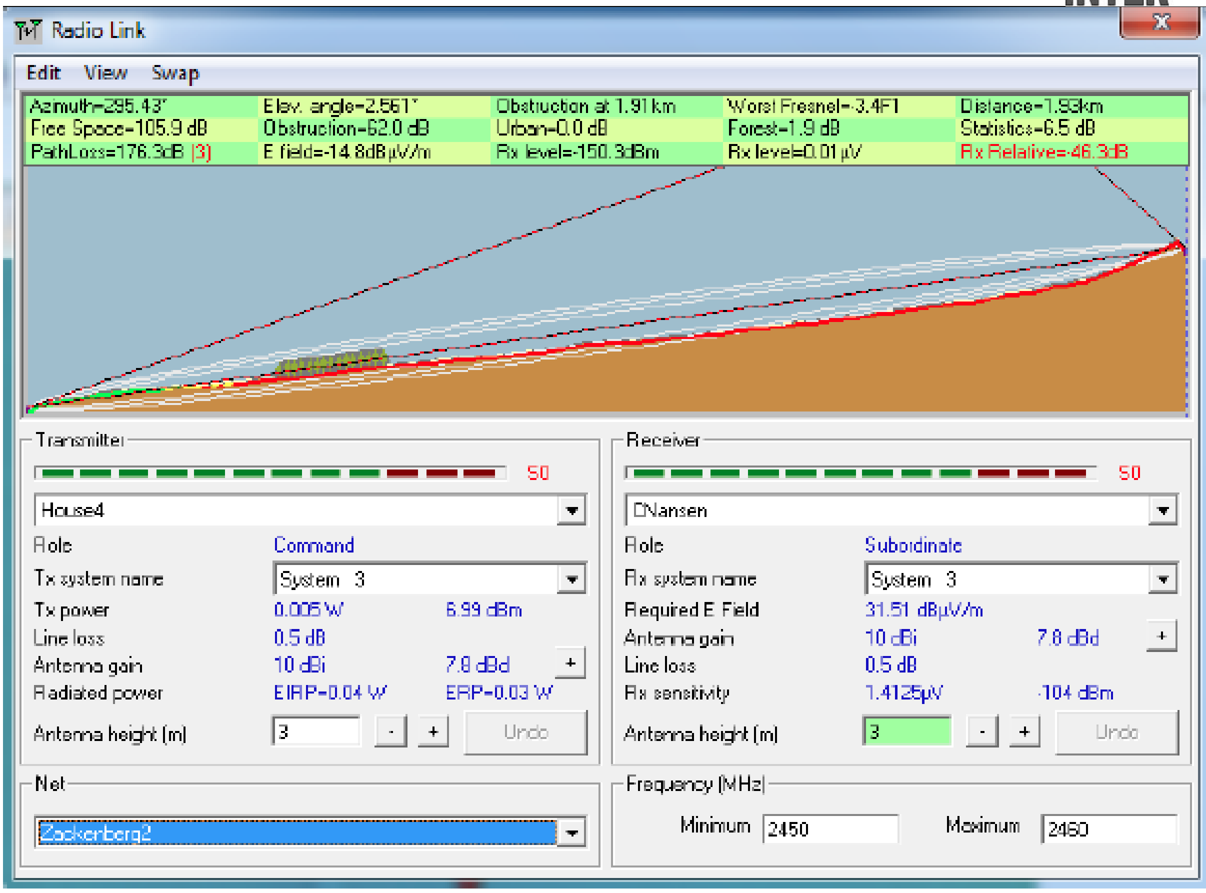


Figure 19: Link quality between CNansen and House 4 using 2.4GHz.

We can appreciate that the signal still reaches the devices present in the area, but the signal strength is much less than in the case of 900MHz. This relates to our expectations based on theory. Since we would have to make use of at least 5 more repeaters and a great deal of directional antennas in order to achieve the same results as those given using 900MHz radios - all this according to our models. We will not go further into the design of the network using 2.4 GHz.

Proposed Design

Summing up the design we concluded after our analysis, our proposal –once again using 900MHz- is the following:

- Devices: M2, M4, MM1, MM2 and Linux Machine: RF450 900-MHz, 1-W Spread-Spectrum Radio+ Omnidirectional Antennas. We propose to use omnidirectional antennas attached to the RF45 radio in this devices. The omnidirectional antennas used here need to have a considerable gain (+10dBi)
- Devices: CNansen, M6, CGlacier : RF450 900-MHz, 1-W Spread-Spectrum Radio + Directional Antennas. We will used directional antennas attached to the RF45 radio in this devices
- Device M7: Depending on the design will be equipped with RF450 900-MHz, 1-W Spread-Spectrum Radio and a directional or omnidirectional antenna (See below)
- Additionally we will make use of 2 or 3 repeaters (depending on the chosen design (see

Section 6.1 for more information).

For the design with 2 repeaters (Names mapping Figure 16):

- Repeater 2: RF450 900-MHz, 1-W Spread-Spectrum Radio + Omnidirectional Antenna. Device M7 needs to be equipped with an omnidirectional antenna since it acts both as a transmitter and a repeater. This is the reason why the performance of this design will not be as high as the one we propose below.
- Repeater 3: RF450 900-MHz, 1-W Spread-Spectrum Radio + Omnidirectional Antenna. Device CGlacier's directional antenna points at Repeater 3.

For the design with 3 repeaters (Names mapping Figure 17):

- Repeater 1: RF450 900-MHz, 1-W Spread-Spectrum Radio + Omnidirectional Antenna. Repeater 1 acts as a gateway to the first part of our network, allowing both Repeater 1 and M7 to connect to it. Repeater 1 will be a critical point, since a failure in this device will cause that we loose wireless communication with devices M7 and CGlacier.
- Repeater 2: RF450 900-MHz, 1-W Spread-Spectrum Radio + Omnidirectional Antenna. Repeater 2 connects Repeater 3 and Repeater 1 in order to free device M7 from carrying out this task. Therefore, device M7 will be equipped with a directional antenna pointing towards Repeater 1, improving the balance of the network.
- Repeater 3: RF450 900-MHz, 1-W Spread-Spectrum Radio + Omnidirectional Antenna. Device CGlacier's directional antenna points at Repeater 3.

This design has been communicated with the DMU team in charge of long term monitoring at Zackenberg. Test deployments are being performed by the Greenland authorities to evaluate possible solutions.

2.4.2 Establishing a Satellite Connection for Zackenberg

The most obvious approach is to deploy a new satellite connection directly from the Zackenberg station. An interesting alternative would be to establish a wireless radio link between Zackenberg and the Danneborg station where a satellite connection is available all year round. This would simplify the problem of maintenance during the winter months. We modelled the feasibility of a wireless radio link between Zackenberg and Danneborg. Figure 20 depicts the exact location of both stations.

The first things we need to take care of is finding out the exact distance between the two stations, in order to be able to provide precise calculations for Link Budget and Free Space Propagation -which is directly proportional to distance. For this purpose, we are making use of an online tool which transforms GPS coordinates to km (http://www.movable-type.co.uk/scripts/latlong.html). Given the coordinates provided for this assignment, Figure 21 shows the real distance between the two stations.

Figure 20: Zackenberg (A) and Daneborg (B) on a satellite picture.

Once we have the distance, we can calculate the Free Space Propagation, which is defined as follows:

FSL[dB] = C + 20 * Log(D) + 20 * Log(F) / D = distance, F = Frequency [MHz] ^ C = Adjust constant (C=36.3 if D expressed in miles, C=32.5 if D expressed in Km)

In our case, where we are going for 2.45GHz, the FSL's calculation is:
FSL[dB] = C + 20 * Log(D) + 20 * Log(F) =
= 32.5 + 20 * Log(5) + 20 * Log(2450) =
= 32.6 + 13.9794 + 67.7822 = 114.26 dB ≈ 114 dB.

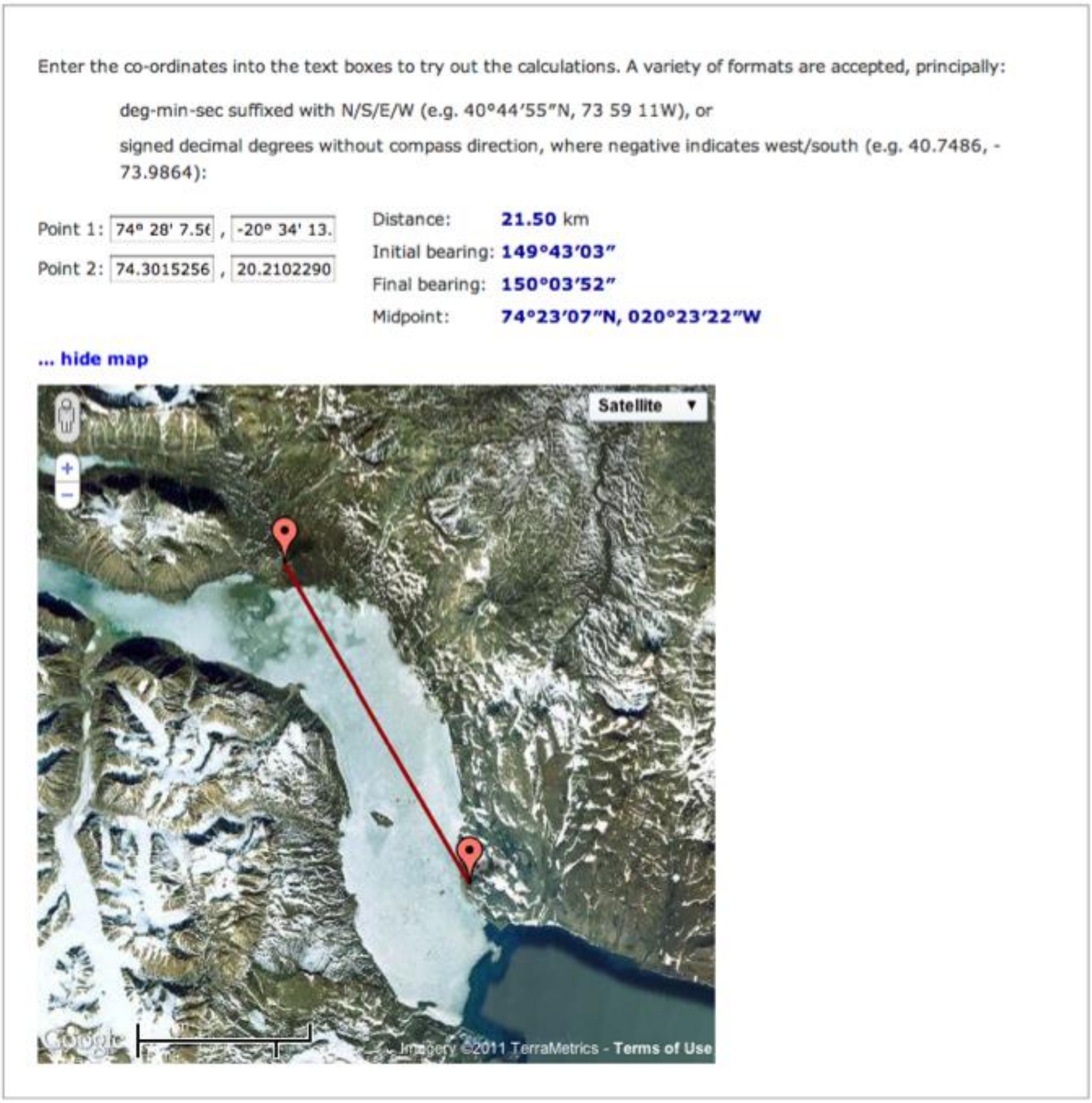


Figure 21: Actual distance between Daneborg and Zackenberg

Now, we choose the hardware components of the wireless link. We have taken two different approaches so that we can compare them afterwards and make a decision based on the trade-off energy consumption vs. throughput.

Our first configuration is (being the hardware components in both points identical):

Transmitting & Receiving device: Ubiquiti 2

3. Up to 24 V
4. In 802.11b (1Mbs - 11Mbs)
   > Tx = 20dBm (+- 1dBm)
   > Rx = -90dBm to -95dBm (+-1dBm)
1. In 802.11g (6Mbs - 24Mbs)
   > Tx = 20dBm (+- 1dBm)
   > Rx = -84dBm to -92dBm (+-1dBm)

Antennas: Dish Antennas

- 24dBi

Cable Loss: We try to take it down by directly connecting the transmitter and receiver to the antenna.

- 2dBm

The calculations are then:

	20 dBm	(Tx)
	+ 24 dBi	(Antenna transmitter)
1.	2 dBm	(Cables&Connectors transmitter)
◦	24 dBi	(Antenna receiver)
1.	2 dBm	(Cables&Connectors transmitter)
	64 dB	

Considering the FSL: 64dB - 127 dB = -63dB
As our receiver's sensitivity is up to -95dBm, our margin is +32dB

This margin should allow us to confront extreme weather conditions such a snow storm and so on. Nonetheless, the fact that we are using Ubiquiti's Bullet2 implies that our energy consumption goes out of the Low Power Consumption paradigm we try to preserve in Greenland. For this reason, we will contemplate the use of other types of transceiver receiver, present in most motes - f.i. telosb or epic platforms- the CC2420.

#Transmitting & Receiving device: CC2420

1. 250 Kbps
2. High Sensitivity: -94dBm
3. 0 to -25 dBm output power - Low Power Consumption

Our calculations are then:

	0 dBm	(Tx)
	+ 24 dBi	(Antenna transmitter)
-	2 dBm	(Cables&Connectors transmitter)
+	24 dBi	(Antenna receiver)
-	2 dBm	(Cables&Connectors transmitter)
	44 dB	

Considering the FSL: 44dB - 127 dB = -83dB
As our receiver's sensitivity is up to -94dBm, our margin is +11dB

This margin is considerably lower than the one using Ubiquiti's Bullet2, nonetheless the saving in terms of power consumption is dramatic. Should we make some fast calculations:

20 dBm = 100 mW

So we are going 2 orders of magnitude down in terms of power consumption when using the CC2420 instead of Ubiquiti's Bullet2. Using one or the other depends of how reliable we need our link to be, and also if Zackenberg Research Station puts some kind of restrictions when it comes to power consumption during the winter season, and therefore the link must be alive running with batteries and a solar panel.

Apart from the manual calculations, we are also providing signal maps created with Radio Mobile that reinforce our calculations. We will provide different maps of the Zackenberg area and explain their meaning in each caption. Besides, this tool provides height information, so we can even notice signal loss caused by refraction or reflection.

In summary, the radio link modelling does not show any problem with a satellite connection based on establishing a wireless radio link between Zackenberg and Danneborg. This remains to be tested in the field.

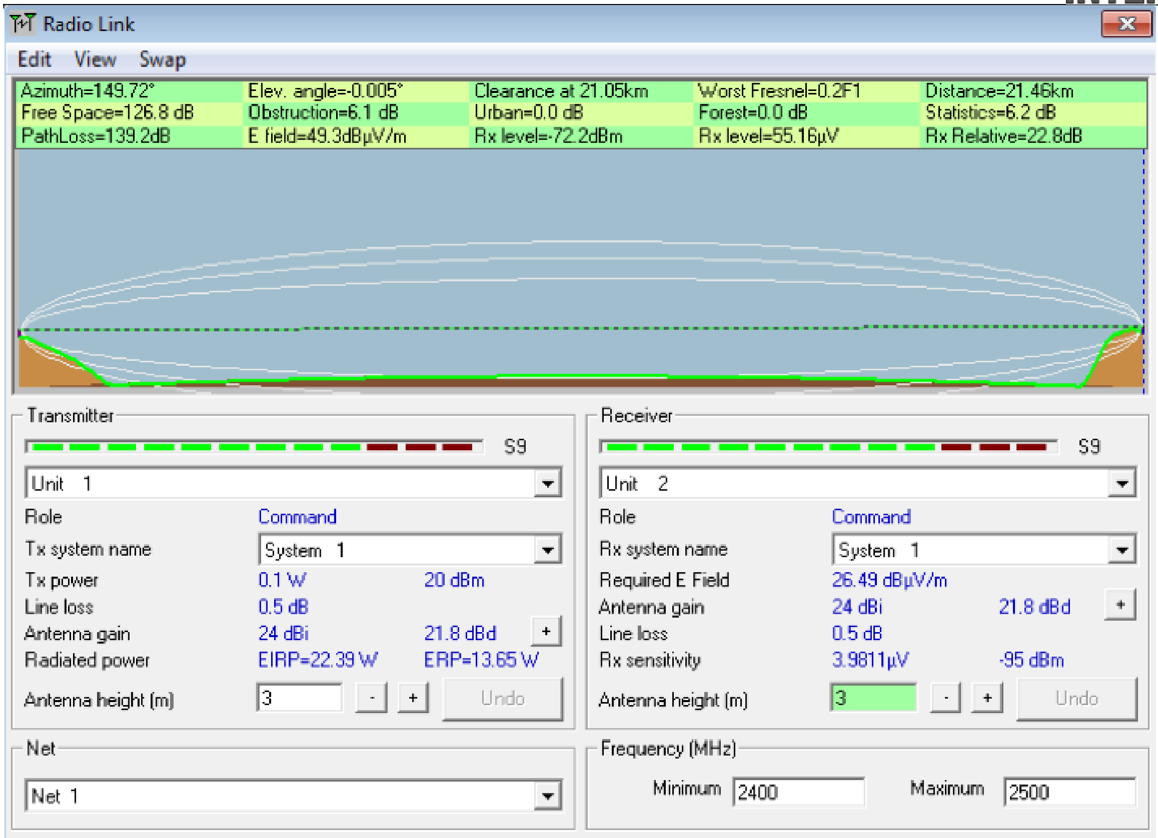
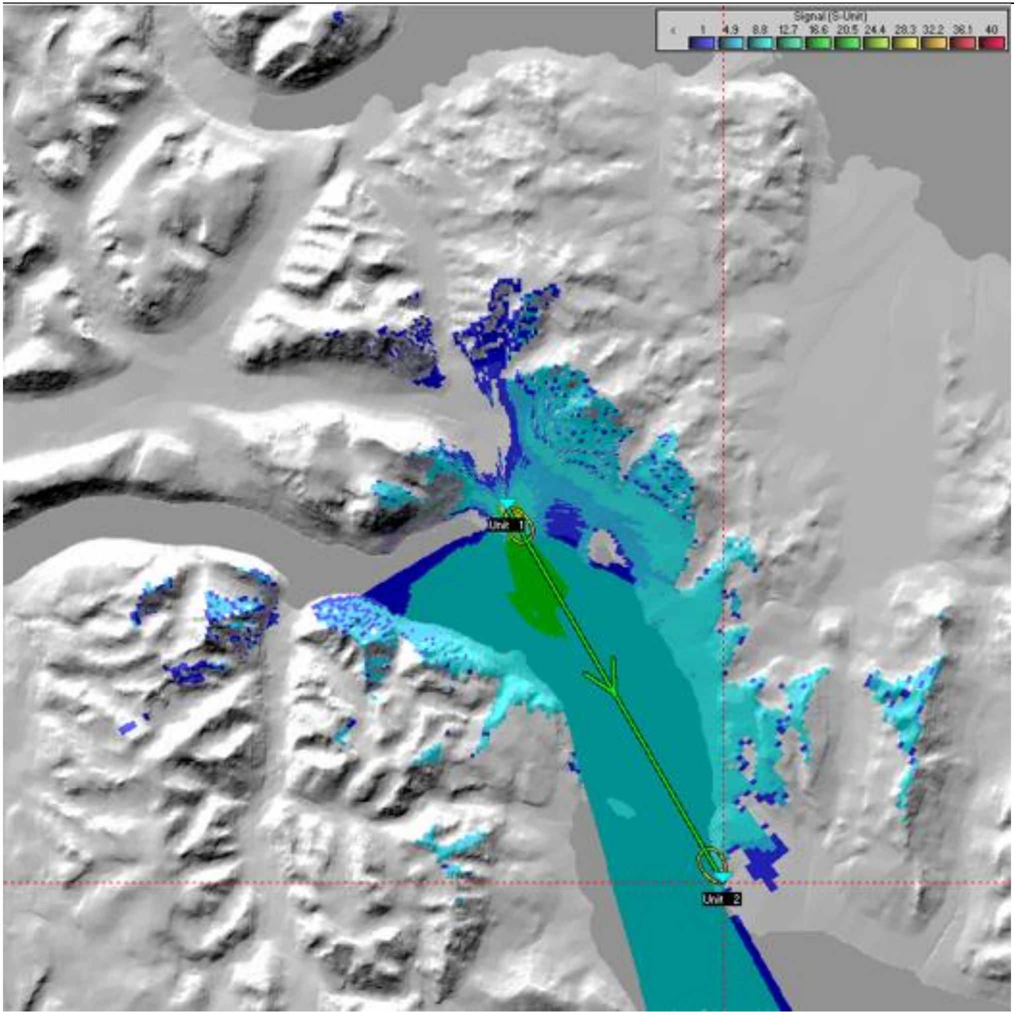


Figure 22: Elevation Map for the Daneborg/Zackenberg link


Signal [S-Unit]
1 4.9 8.8 12.7 16.6 20.5 24.4 28.3 32.2 36.1 40
Unit 1
Unit 2

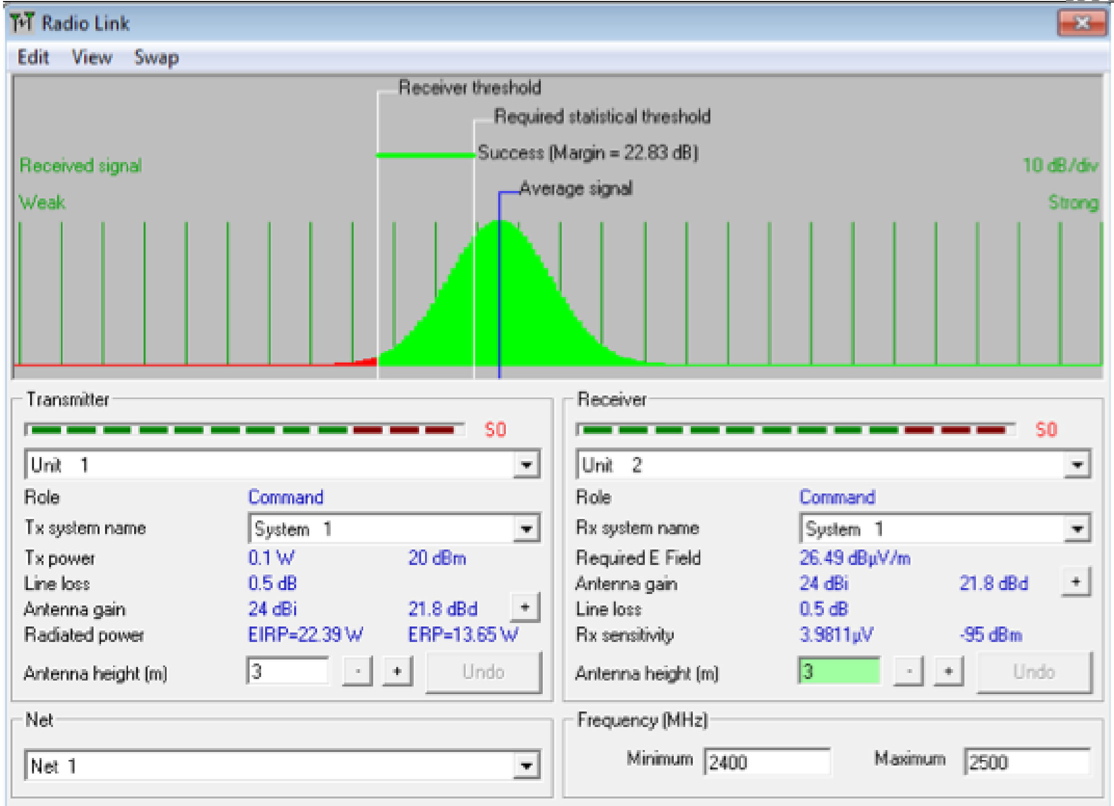


Figure 23: Signal Map for the Daneborg/Zackenberg link

3 Abisko Deployment

At Abisko we had two activities, one related to wireless communication and one related to remote data collection. In a long-term study we measure the impact of meteorological factors on wireless links in the arctic environment. The extreme seasonal changes in temperature, humidity and precipitation in different forms typical for the arctic environment challenge wireless communication, for example with data loggers. We observe a significant seasonal impact on the packet reception rate and show that temperature has the highest correlation to the signal strength and packet reception rate among the meteorological factors measured.
Further, we approach remote data collection using delay tolerant networks; people hiking by remote sensors can pick data up with their mobile devices and carry them towards the research station - either when passing by Abisko themselves, or by passing the data further to other hikers.

3.1 A Long-Term Study of Correlations between Meteorological Conditions and 802.15.4 Link Performance

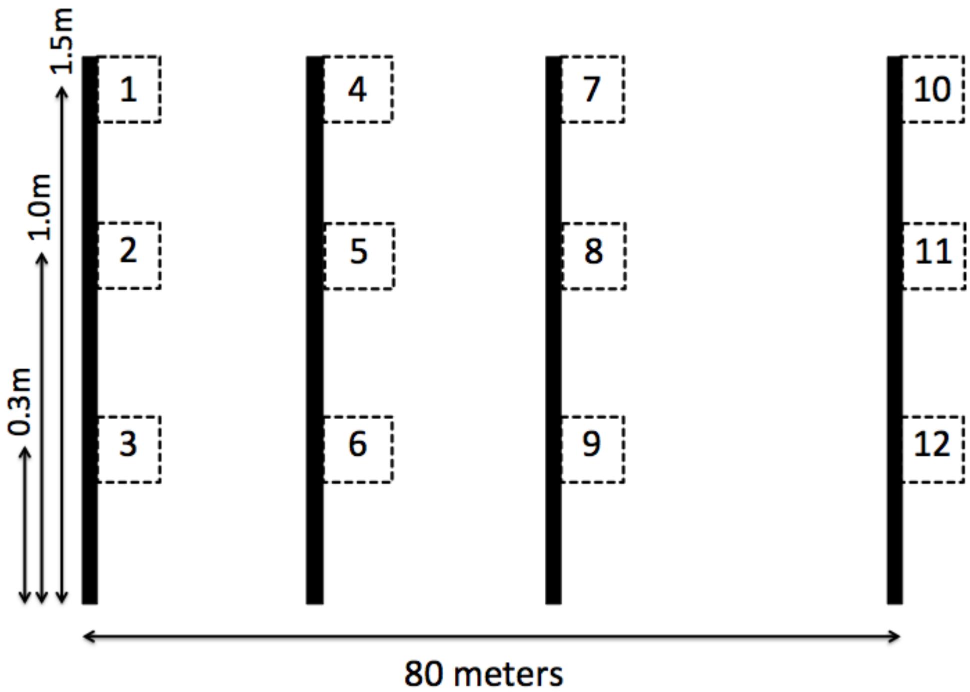
We setup a sensor network at a polar research facility in Abisko, Sweden (68°21'N,18°49'E), which annually has an mean temperature around 0°C and only 300mm of precipitation. It experiences permanent daylight in the summer and an absence of the sun during the winter.

The research station monitors Arctic ecology, meteorology and climate change. The surrounding area is a national park, with 40% of the ground above the tree line and patches of permafrost. Specifically, the network is deployed in an area characterized by a mixture of open space grassland and occasional mountain birch. Except for a few summer months the site is covered by snow and ice. There is an almost total lack of contention and interference for the wireless medium in this environment, being in such an isolated location.

The actual deployment of the network took place in early March 2013. It took us two full days, working 12 hours a day, to get everything up and running. During the deployment the area was covered in snow about 40 cm deep. The majority of the time was spent digging through the snow and drilling into frozen ground.

Sensor Network Deployment --- The network is comprised of 12 sensor nodes, mounted on four poles aligned along an 80 m transect at distances of 0 m, 20 m, 40 m and 80 m. The poles were secured into the ground using special speared metal anchors that had to be hammered into the ground. Nodes are mounted on each pole at heights of 1.5 m, 1.0 m and 0.3 m. These heights were chosen so that the lowest node would potentially be covered in snow, the middle node just above the snow and the high mounted node to ensure good radio communication.

Figure: Four poles with three sensor nodes each are placed along an 80 m transect at distances of 0 m, 20 m, 40 m and 80 m. The sensors are mounted at 0.3m, 1.0m, and 1.5m.



So that the setup would withstand the harsh environment, all the equipment was placed in enclosures with IP68 connectors to avoid any water damage. Furthermore, inside every box we placed bags of silica gel to absorb any excess condensation.

Figure: One of the poles with three sensors attached and the testbed box.

The schematic setup --- The twelve TelosB[14] are attached to our Sensei-UU testbed[15] via a USB backplane, ensuring both reliable data logging and power supply. The sensor nodes, which are among the most commonly used by the research community, are equipped with 802.15.4-compatible CC2420 radio transceivers that operate in the 2.4 GHz ISM band. At each pole we have a testbed box containing a router, USB-hub and Power-over-Ethernet (PoE) splitter. The router is used to control and monitor the nodes, sending commands and handling node resets. The box and its three nodes were powered using a single Ethernet cable, thereby reducing the cabling complexity.

[14] Crossbow Inc. TelosB datasheet, Revision B edition, May 2004.
[15] O. Rensfelt, F. Hermans, L.-A. Larzon, and
P. Gunningberg. Sensei-UU: A Relocatable Sensor Network Testbed. In Procs. of WiNTECH ’10, pages 63–70, September 2010.

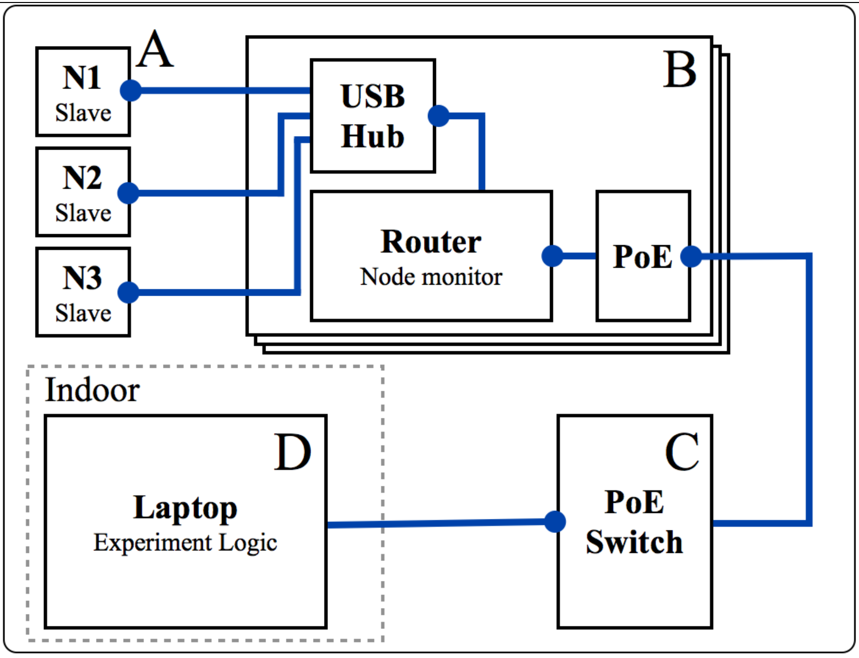
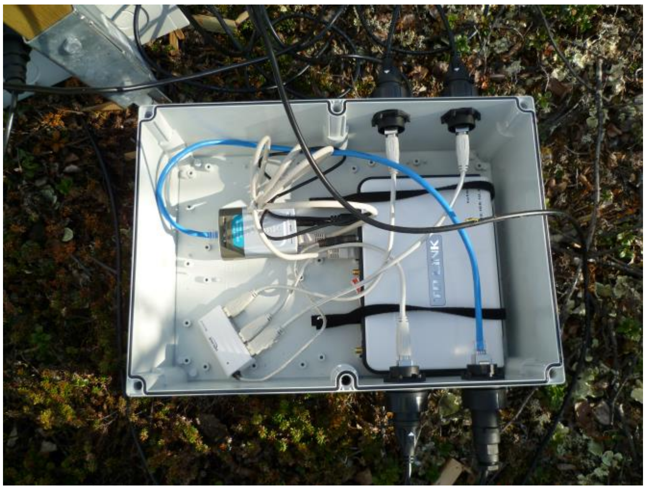


Figure: Schematic system overview

Figure below: Left: TelosB sensor node (A), right: testbed Box (B) equiped with a router, USB-hub, and Power-over-Ethernet splitter.



Each of the four boxes is connected to a PoE switch that is also located outside in the snow. The PoE switch is powered using a durable outdoor power cable and all Ethernet cables are of a gel filled outdoor design to minimise condensation collecting in the Cat5e core. The switch is connected to a laptop indoors that runs the experiment logic. The setup is designed to be easy to deploy and to ensure continuous operations over long periods of time. This is also the reason that the nodes run on fixed power.

Software Logic --- Our experiment consists of cyclically sending packets along each radio link, i.e., sending packets between every possible pair of nodes. The scheme works in a round-robin fashion where each node takes turns being the designated sender, a role that changes every 30 seconds. The sender then transmits one packet per second addressed to each of the other nodes, again in a round-robin manner. When a packet is received by the intended recipient, that node replies with a response packet addressed to the sender. Throughout this process, all other nodes promiscuously receive any packets they overhear and log them accordingly, in effect generating up to 11 packet receptions per sent packet.

To capture 802.15.4 packets containing errors in the payload (i.e., packets whose CRC fails) we have modified the radio driver of the nodes. This allows us to log all packets that have successfully been detected. The payload of each packet is 34 bytes in size and contains, except a two byte start sequence, the fields: packet type, sequence number, source address and destination address. These fields are repeated four times in sequence until the packet buffer is full. The repeated pattern in the payload is used during analysis of broken packets to compute the ground truth. Through a majority vote of the same piece of received data we can deduce what it should be, and identify errors with that information. Packets where we are not able to find consensus (due to many errors) in the voting are disregarded, we note that such packets are very rare (<0.1%) among all broken packets.

Preliminary Results --- Before deploying our testbed in Abisko, we deployed a similar setup at the Marsta meteorological research station outside Uppsala. After one year of successful operation in Marsta we found the system to be ready for the arctic environment. Because of the larger data-set we present results collected in Marsta that we expect to show similar trends as the data from Abisko. For a more complete overview of the results of both stations we refer to two of our publications in international conferences, see appendix.

In summary, our three key findings are:
• Based on a long-term measurement, we show that the overall network performance of our outdoor open space sensor network contains a diurnal cycle and a slower moving seasonal change.
• We show correlations between meteorological factors and the 802.15.4 link metrics received signal strength (RSSI) and packet reception rate (PRR). By decoupling temperature and humidity, we identify that temperature is the dominating factor. In contrast to previous work, we conclude that rain has no observable impact on either RSSI or PRR.
• Through a systematic analysis over different types of links we show that packet reception consistently maintains a negative correlation with temperature, with links at the edge of reception range showing a stronger correlation.

Diurnal cycle: A diurnal variation in PRR is observed with a trend of daytime lows and nighttime highs. PRR can vary as much as 20% in one day.

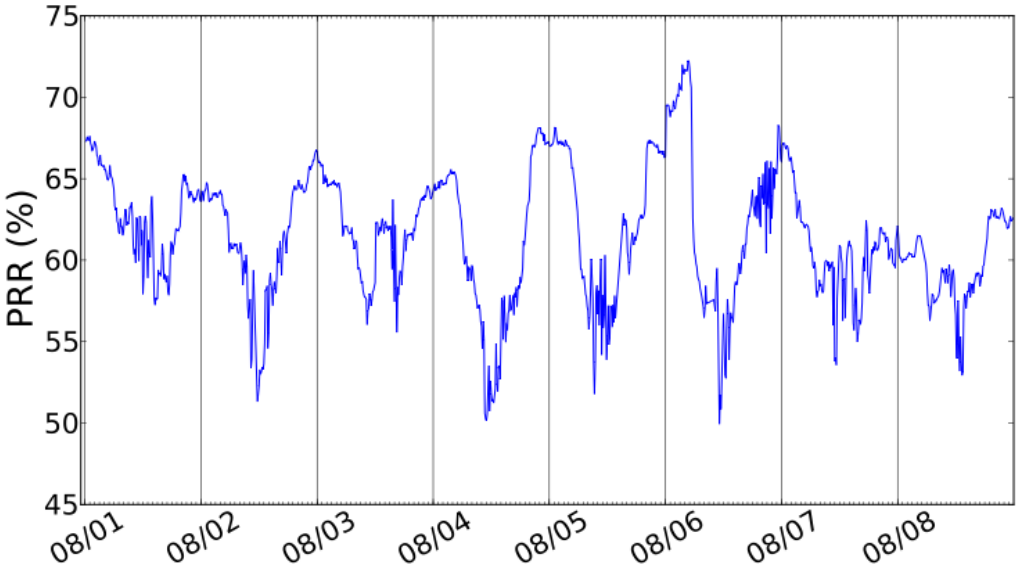


Figure: The packet error rate fluctuates significantly during a day. The figure shows the values for a representative link where reception during night is better than during daytime.

Seasonal change: Previous work has shown that PRR exhibits a cut-off behaviour where it is typically either very good with a PRR above 90% or very poor with a PRR below 10%, and only a small portion of links have a PRR in between. Based on the same categorization, all the links in our deployment are plotted in the following Figure. First of all we see that the categorization matches with the observed daily PRR, where most links are either very strong (PRR > 90%) or very weak (PRR < 10%). Only about one fifth of the links have an intermediate PRR (90% <= PRR <= 10%) throughout the experiment. Note that it is the proportion of strong and weak links that changes throughout the experiment whereas the amount of intermediate links is fairly constant. This can be seen when strong links start to diminish in late May and at the same time the percentage of weaker links increase.

This suggests that there are seemingly strong links, with PRR above 90% that can deteriorate over long time periods and become weaker. It implies that a high PRR during deployment is not necessarily a guarantee for a continued high PRR over time.

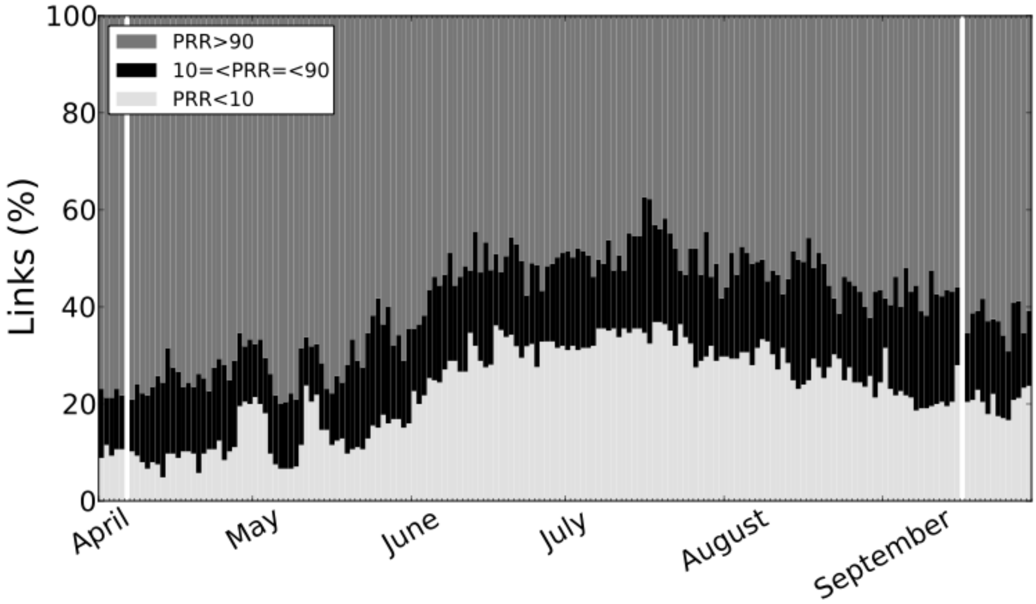


Figure: The number of bad links increases during summer, The number of links with reception rate between 10% and 90% remains constant over the same interval.

Correlations to Meteorological parameters: We analyse the obtained measurements with a focus on correlations between the link measurements RSSI and PRR for the representative link and the four selected meteorological factors. We use Spearman's rank correlation as our metric throughout the analysis. It measures how well two variables monotonically increase (or decrease) in relation to one another. It does this by computing the linear dependence of the ranked variables as opposed to the variable values themselves. The metric emphasises a correlation where the change in one variable results in a change of the other variable, where the change rate might not be linear but steadily increasing or decreasing.
We correlate with four meteorological parameters, namely, temperature, air water content, temporal changes. An overview of the correlations for the representative link can be found in the following Table. For further results we refer to the appendix.

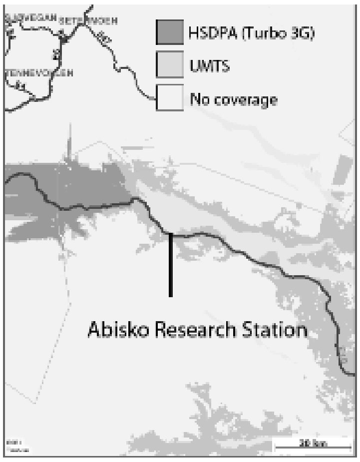
TABLE I: Summary of the correlations between link metrics and meteorological factors for the representative link.

	RSSI	PRR
Temperature	-0.81	-0.54
Relative Humidity	0.12	0.21
Absolute Humidity	-0.72	-0.44
Precipitation	-0.13	0.06
Sunlight	-0.42	-0.33

3.2 Remote Data Collection by Delay Tolerant Networks

Collecting data from remote sensing areas around the Abisko Research Station typically involves a researcher's manual interaction with the sensors on location. Direct communication with a server at the research station is difficult because of the lack of cellular phone coverage and long distances. As an alternative to the technology applied in Zackenberg, we try to involve persons hiking in the area to pick up data and carry it to Abisko using delay tolerant networking. Delay tolerant networking makes use of short distance communication like Bluetooth or IEEE 802.11 to transfer data among mobile devices. Distances are spanned by the mobility of the devices, rather than long range communication. Obviously physical mobility takes time, but the benefits are large data volumes and low error rate.

We see a potential of this technology for INTERACT's outreach activity to involve people into the sensing and interpretation of the data that they collect (e.g., setting the current water-levels into historical perspective, or explaining climate phenomena based on the data).



Left: Remote sensor sites are marked with grey areas (not all sites are included)
Right: Cell phone coverage in and around Abisko

System overview --- We built a mobile phone application for the Android operating system that wirelessly can connect to sensor nodes and transfer sensor data into its database. The same way, when the mobile phone gets into contact with infrastructure networks (e.g., cellular network or wireless access points at the research station), it transfers the data in its database to the server. This way, remote sensing with long distance between sensor nodes and the server at a research station can be bridged by the mobility of users.

Sensor and mobile phone communicate with each other using the Bluetooth technology which is ubiquitous in phones. Sensor nodes have to be extended with Bluetooth modules, preferable of the newest "Bluetooth Low Energy" standard. The modules typically have a serial interface which can directly be connected to sensor nodes.

We also developed a more elaborated system that allows passing of data among mobile phones in the context of the EU/Haggle project[16].

Autonomous UAV --- To be able to retrieve the data from remote sensors without human interaction at all, a quadrocopter-prototype has been developed and evaluated during a master thesis project by Johan Hotby. A quadrocopter is a helicopter with four rotors placed in a cross formation (see picture below). The quadrocopter can navigate autonomously between different GPS-positions that are updated during flight trough Xbee-modules. All levels from sources code, design of the electronics to development of the chassis was performed during the project. The quadrocopter was tested on an open field in Uppsala. During GPS-navigation the quadrocopter was able to achieve a stationary position with a mean stationary offset of less than 0.5 meters even in light winds.

To be able to use the quadrocopter in Abisko, further range testing is needed to guarantee that the quadrocopter can fly out and back again on the same battery. This is a challenge because the high capacity batteries add additional weight to be carried. The flighttime could also be increased by optimizing the quadrocopter's design itself for lower weight. Also, careful planning of the flight routes would be needed to avoid danger for people, animals and nature.

Figure: Quadrocopter to support data collection in remote areas

4 Conclusion

The results of our deployment and measurement campaigns are very promising. The technology for establishing quality radio links for data loggers deployed in the Arctic is rapidly maturing. The key issue is the planning of deployments and the resilience of the deployed solutions. In this deliverable, we have detailed the design of radio links for the Zackenberg station and we have studied the potential of a delay tolerant network, possibly based on the utilization of UAVs for carrying data in the absence of high quality radio links.

[16] http://haggle.googlecode.com

These results are very encouraging and should be followed by further measurement campaigns, to validate our design, and contribute to the development of new forms of delay tolerant networks adapted to the characteristics of the INTERACT stations.