TFE4850 - EiT - Student satelite

Groundstation network

Group 2

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April 23, 2013

Abstract

The NTNU Test Satellite will be using amateur radio and will therefore have a very limited transfer rate of 9600 bps. Combined with the limited access time to the satellite this means a limited amount of data can be downloaded per day.

The aim of this project was to consider some possible networks and set up a ground station network at the student ground station here at Gløshaugen.

Acknowledgements

Thanks Mum!

Roger, Bjørn, ...

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Chapter 1

Introduction

This chapter will contain a short introduction to our project. That means what we're doing and what people are working on the project. It will also be discussed some short background on why we're doing this project.

1.1 The Project group

The project group consisted of 6 people from 5 different institutes, so we have competency in a variety of fields. The group members can be seen in Table 1.1.

1.2 Network

The problem today is that the transfer rate for a satelite using amateur radio is low and the the number of pases are limited. We wanted to look more into this problem and find a solution. Since the transfer rate is limited by the antenna its hard to increase the transferrate without changing the antenna itself. We therefore chose to dive more into how we could increase the number of downstream per pas. We looked into how we could utilize a network of ground stations. We needed to find a existin network that had

Name	**Background**
Marius Ekerholt	Computer technology
Eirik Skjeggestad Dale	Computer technology
Hanne Thorshaug Andresen	Energy and Environmental technology
Leif-Einar H. Pettersen	Electronics and Telecommunications
Børge Irgens	Theoretical Physics
Hallstein Skjølsvik	Electronics and digital design

Table 1.1: Group members

other ground stations already conntected. Carpcom had seemingly a well established network and was one of the main reason for why we chose it.

1.3 NUTS

NUTS is a student driven sattelite project at NTNU. The goal of the project is to design and build a dobbel Cubesat. The student satellite project is organized under the Department of Electronics and Telecommunications.

Chapter 2

Theory

Before we started our project, we did quite alot of prestudy, covering which technology was available, to determine which fit our project best. This chapter will contain a summary of the different technologies, and also some theory behind the reasoning for having multiple ground stations listen to our satelite.

2.1 Communicating with the satellite

Since we don't know when the satellite will be launched we don't know the exact orbit. The project manager, Roger Birkeland, told us that we can assume the orbit will have a height above the Earth somewhere between 450km and 650km and inclination of 98 degrees.

The height above the earth dramatically changes the time the satellite is seen by the ground station, see Fig. 2.1. The signal will be weaker when the satellite is further away, it is therefore necessary to increase the minimum elevation angle ϵ, see Fig. 2.2, to maintain SNR. Previous work[8, 9] has calculated the minimum elevation angle, for a ground station here in Trondheim, for satellites with different altitudes and found that these effects cancel each other out. In the following we'll assume that the altitude is 500 km and the minimum elevation angle is 28 degrees.

The result of this is that the ground station can communicate with the satellite whenever the ground track is inside a rough circle centered on the ground station, see Fig. 2.3 for the estimated "range" of the ground station at Gløshaugen operating with these constraints. The efficency of a network of ground stations is reduced when the ranges overlap, so to have a efficient network the nodes must be geographically far apart. In this case the ground stations must be more than 1600 km apart to have maximum efficency.

The Gløshaugen ground station will on average be able to communicate with the satellite 520 seconds per day. With a bitrate of 9600 bps 600kB can be downloaded per day on average.

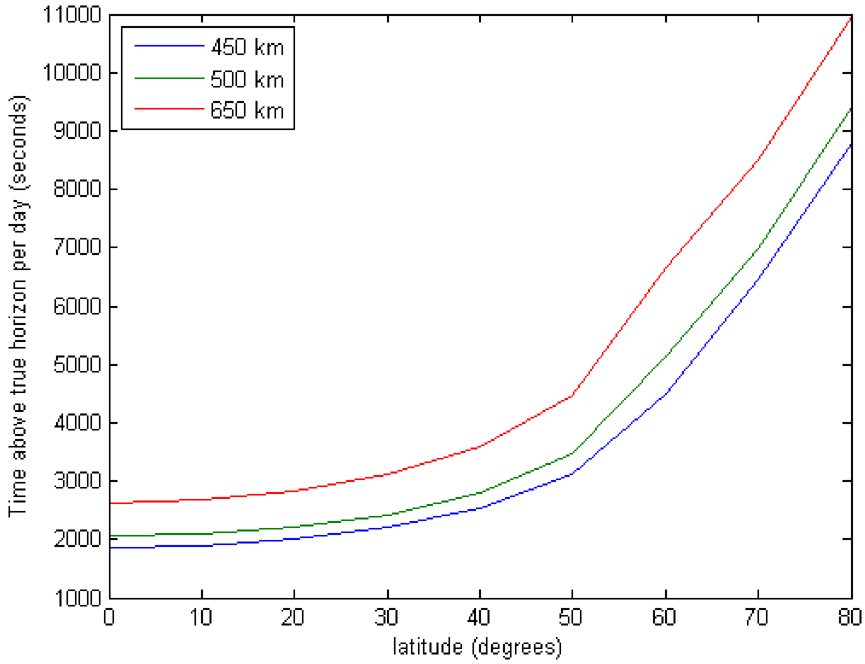

Figure 2.1: Time above the horizon for a satellite with altitude $h = 450km$, $h = 500km$ and $h = 650km$ as a function of ground station latitude

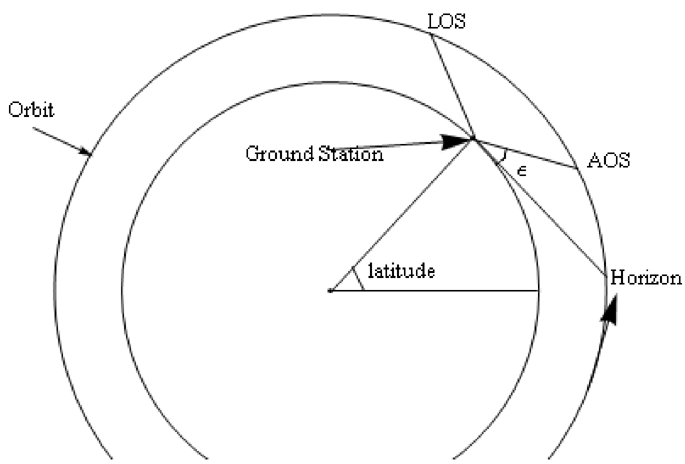

Figure 2.2: Illustration of geometry between a ground station and a satellite

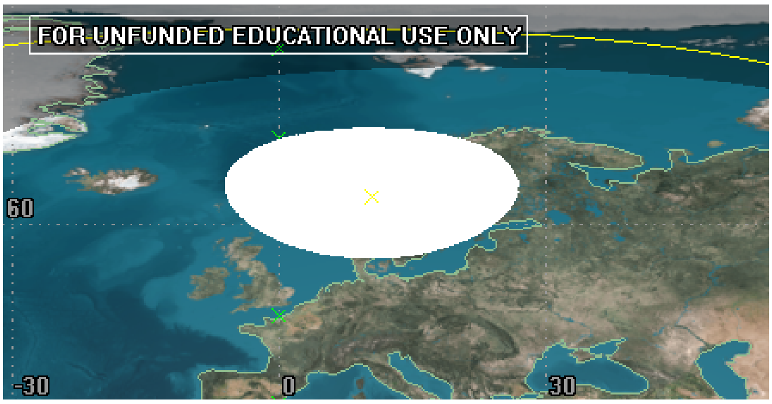

Figure 2.3: NTNU ground station range

2.1.1 Other ground stations

Fig. 2.1 shows that the access time for a (near) polar satellite is almost latitude independent for ground stations at latitudes below 45 degrees. The access times of a ground station those low latitudes are about about 280 seconds/day, i.e. half the duration we get here in Trondheim. For higher latitudes the access time increases dramatically. And the average access time for a ground station in Longyearbyen (78N) is in fact as high has 1300 seconds/day.

2.2 Network technology for ground stations

When we decided to work on a network of ground stations, we first looked into four different ground station network technologies. We first hoped to work on a BlueBox, but this would require support from Aalborg that we couldn't get, as they were busy with a satelite launch of their own. Because of this, we decided to look into Carpcomm, that seemed more complete and doable than connecting to PYXIS with a BlueBox.

2.2.1 Pico

2.2.2 Genso

GENSO is an abbreviation for Global Educational Network for Satellite Operations. As the name suggest GENSO is a network where satellite operators across the world can utilize each others ground stations. GENSO provides a stable network by the use of several Authentication Servers (AUS), that will synchronize with each other. This will make the network resistant to single point failures. As user of GENSO a software applications is available.

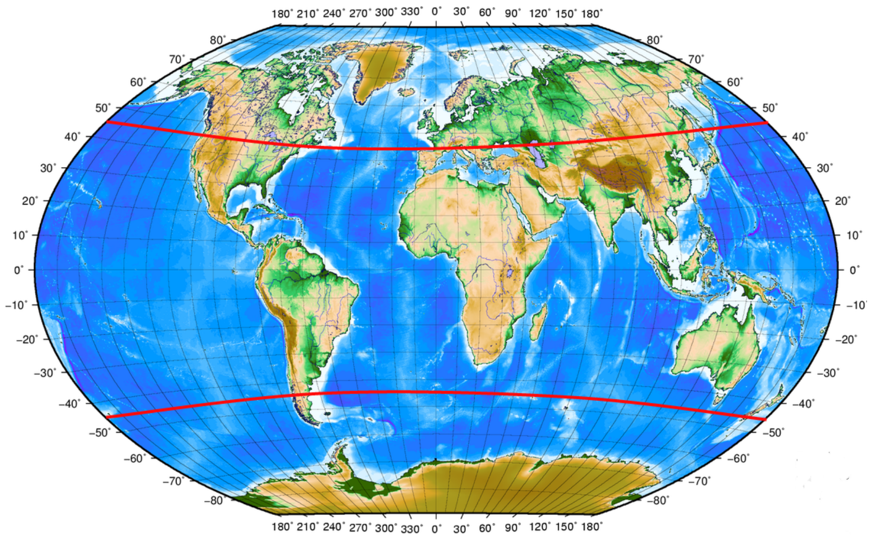

Figure 2.4: Map of the World

This is the Ground Station Server (GSS). A GSS application allows Mission Control Clients (MCC) in the GENSO network to connect to the ground station and download data from space crafts. If the space craft is able, and local laws permit, it is also possible to upload data[7]. Figure 2.5 illustrates this set up.

At first glance GENSO seems like a well organized ground station network which corresponds to the network we want to join. However it is difficult to find anything about the development of the project since September 2010. In addition the GENSO home page "GENSO.org" is not operational. Due to the difficulties with finding information of the current state of GENSO, we chose to look for other alternatives.

2.2.3 Carpcomm Space Network

Carpcomm is a private company that delivers a plug and play ground station [3] that costs $700. The software for the ground station is open source and is provided pre.compiled for x86 and arm debian. It is compatible with the Carpcomm Space Network [4]. The advantage of using this solution is that the network is actually functioning, though there are few other operational ground stations.

2.2.4 PYXIS

The BlueBox is part of a distributed ground station network called PYXIS, developed primarily for the AAUSAT3 by Aalborg University (2013 [2]).

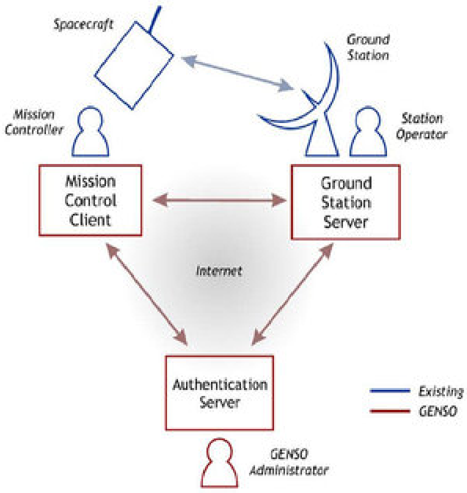

Figure 2.5: Illustration of the GENSO network.

The PYXIS goal is to offer a robust and effective ground station network for satellite developers, and one of the key factors is that everyone is free to setup a ground station using the open source BlueBox hardware.

The PYXIS concept includes a backend server, BlueBox hardware and a Ground Station Server (GSS). The backend server runs an individual instance for each satellite utilizing the BlueBox, and is operated by the persons responsible for the ground station.

The BlueBox itself is hardware to recieve and transmit signlas from the satellites.

Control of the BlueBox and ground station mechanics is handled by the GSS, and both the BlueBox and the GSS is operated by the responsible for the Ground station.

Both the backend server and the GSS is already in place at each ground station, and to join the PYXIS network we would only have to make a BlueBox, and test that it works.

2.3 Raspberry pi

Raspberry Pi is a small computer, with everything gathered in one board. In our project we will be using the B model, revition 2, which have a 700MHz ARM CPU, 512MB of RAM and a SC-card reader, in addition to the leads to connect to different devices, for the full overview, see figure 2.6. The recommended operating system is Raspbian, a linux distribution based on Debian.

The Raspberry pi was originally intended to help teach programming,

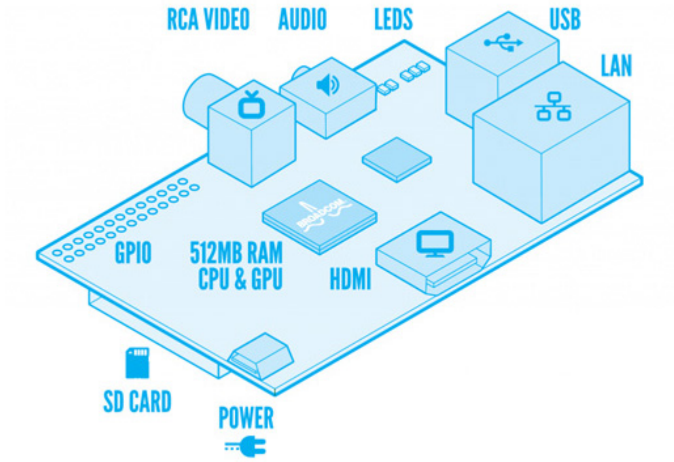

Figure 2.6: A highlevel schemantic of the Raspberry pi, mobel B rev 2

but it can also perform many of the standard computer tasks, and it can be connected to a monitor or tv using an HDMI lead. In our project we hope to be able to use a Raspberry pi to run the software required to control the ground stations. The software provided by the carpcomm project has Raspbian as one of its supported plattforms, so we hope this will work well.

To control the movement of the antennas, an serial port is needed. Raspberry Pi has an serial port included in its gpio (general purpose input/output) connector. This serial port uses ttl-standard for its voltage levels, this is 0/3.3V while RS232 which is the standard used in computers uses (3V-15V)/-(3V-15V). Because of this an converter is needed. We chose to make an custom circuit board using the MAX3232 RS232 line driver. The circuit board is designed to be mounted on the gpio connector, because of small space in the case for the Raspberry Pi, the output is connected with cable to the external connector.

2.4 SunPower

Communication with the satellite through the groundstation network demands power from the satellite. Without any electrical power a satellite will not be able to support its payload or radio communication. NUTS double CubeSat uses sunlight as an energy source through solar panels.

Solar panels base their operation on the ability to convert sunlight into electricity. By using semiconductors the photovoltaic effect can be exploited. The convertion process where the suns radiation is converted into an electical current is achieved by creating mobile charged particles in the semiconduc-

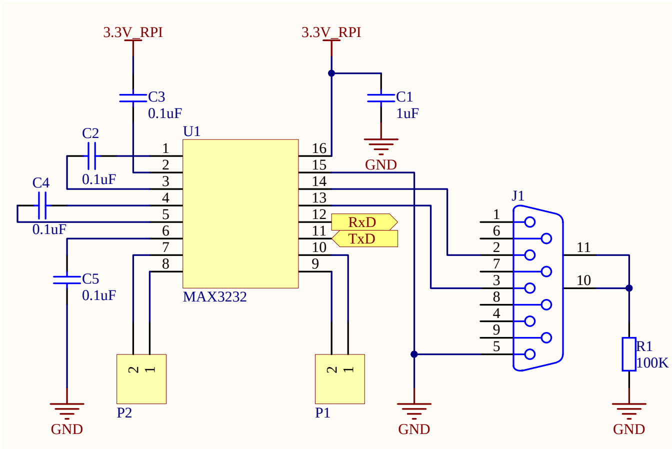

Figure 2.7: Schematics for the RS232-converter

tor. They are in turn separated by the device structure and produce the electrical current.(kilde)

Batteries are used to store power during eclipse and support the payload. When the satellite is in eclipse the earth blocks the solar radiation and the battery must supply the power.

Identifying the satellites communication necessary to establish if a ground-station network is profitable. Forthcoming calculations are based on an estimate done by De Bruyne [10].

When estimating the period of the satellite the Earth and satellite orbit is assumed to be spheres. Kepler‘s third law for circular orbits is used:

$$\left(\frac{2\pi}{T}\right)^2 = \frac{GM}{R^3} \tag{2.1}$$

Where T is the period of the satellite, G is the gravitational constant[1], M is the mass of the Earth[2] and R is the distance between the centers of mass of the Earth and the satellite.

$$T = 2\pi \left(\frac{R^3}{GM}\right)^{\frac{1}{2}} \tag{2.2}$$

where $R = R_\oplus + h$ where $R_\oplus$ is the radius of the earth[3] and h is the altitude of the satellite. Since it is uncertain what altitude the satellite will settle in after it is launched, two heights are used in the calculations and it’s

[1] $G = 6.6742 \cdot 10^{-11}\,\mathrm{km^3/s^2}$
[2] $M = 5.9736 \cdot 10^{24}\,\mathrm{kg}$
[3] $R_\oplus = 6371\,\mathrm{km}$

assumed that the satellite wil settle somewhere within interval $h_1 = 450\,\text{km}$ and $h_2 = 650\,\text{km}$. Which gives

$$T(h_1) = 5610s \tag{2.3}$$

$$T(h_2) = 5850s \tag{2.4}$$

when inserted into Equation 2.2.

From De Bruyns equations [10] the longest possible time in eclipse can be calculated. The worst case average power is approximately $P_{avg} = 5.42W$ from by De Bryens calculations. This power is claculated when the satellite has its longest time in eclipse.

$$t_{ecl,max} = 2R_{sat}\left(\frac{R_{sat}}{R \times M}\right)^{\frac{1}{2}} \tag{2.5}$$

$$P_{avg,orbit} = P_{avg} \times \frac{(t - t_{ecl,max})}{t} \tag{2.6}$$

This becomes for each of the possible heights:
equation 2.5 $t_{ecl,max_1} = 2151.1s = 35.9min$
equation 2.6 $P_{avg,orbit_1} = 3.34W$
equation 2.5 $t_{ecl,max_2} = 2118.9s = 35.3min$
equation 2.6 $P_{avg,orbit_2} = 3.46W$

These are simplified calculations where the teperature changes of the solar cells is not taken into account. As the satellite moves through orbit the temperature will effect the solar cells, but this requires more extensive calculations. The average power calculated here is based on worst-case estimate from De Bruyns [10] and the real average power can be calculated with the exact orbital parameters.

The battery used in the NUTS Cubsat wil consist of lithium-ferrite-phosphate cells ($LiFePO_4$) [11]. These cells have a typicall voltage of 3.3 V. The Cubesat has $4 \times 1.1Ah$ cells, where two is in serie and two is in parallel. This means a total of $2.2Ah$ at $6.6V$ [10]. This is used to calculate the worst-case Depth Of Discharge (DOD). The DOD represents the percentage of the discharged battery capacity expressed as a percentage of maximum capacity. It indicate the state of charge where 100%= empty and 0% = full (KILDE).

Total capacity: $C_{tot} = 2.2Ah$
The battery capacity used during eclipse:

$$C_{ecl} = \frac{P_{avg,orbit}}{V_t ot} \times t_{ecl,max} \tag{2.7}$$

$$DOD_{max} = \frac{C_{ecl}}{C_{tot}} \tag{2.8}$$

Calculted with the different hights give:
equation 2.7 $C_{ecl_1} = \frac{3.34W}{6.6V} \times (\frac{35.9min}{60\frac{min}{hour}}) = 0.3Ah$
equation 2.8 $DOD_1 = 0.136 = 13.6\%$
equation 2.7 $C_{ecl_2} = \frac{3.46W}{6.6V} \times (\frac{35.3min}{60\frac{min}{hour}}) = 0.31Ah$
equation 2.8 $DOD_2 = 0.141 = 14.1\%$
The battery capacity will decrease with the number of charge-discharge cycles. Discharge of at least 80% is refered to as deep discharge. When the critical DOD is reached it will be in risk of battery failure. From our calcultations the DOD is not in the critical region.

To establish the communication time a simplified power balance is used.

$P_{radio} = 2.5W$
$P_{payload} = 5W$ in $90s$
Mikrokontroller is in standby and with 18.5mA and 3.3V it uses:
$P_{standby} = 0.0612W$
These numbers are supplied from NUTS and are rough estimates of what can be expected.

$$P_{avg,orbit} \times t - P_{payload} \times 90s - P_{standby} \times t = P_{radio} \times t_{communication} \tag{2.9}$$

Communication time h_1:
equation 2.9 $t_{communication} = 7172.12s = 110.5min$
Communication time h_2:
equation 2.9 $t_{communication} = 7778,77s = 129.6min$
The calculations on power- and orbit estimates results in long communication time. There are several simplifications done during this calculations that must be taken into account. The power drawn from the satellite are rough estimates and the available communication time will likely differ from the these results. The calculated communication time provides a good indication and it can be seen that it is time available to connected to a groundstation network.

Chapter 3

The project

3.0.1 Ground station networks

There are a lot of unknowns in this area. We don't know what network will be used, who will be participating or what kind of radio equipment will be used. A part of this project is to simulate some different possible ground networks to find how much data we can realistically download. Simulating a network consisting of NTNU and Aalborg University is interesting, since Aalborg University are the developers of the BlueBox satellite network.

A ground station network consisting of NTNU and Aalborg University is not very efficent, see Fig. 3.1.

The results are summarised in Table 3.1.

The problem today is that the transfer antenna on the NUTS satellite is limited. We started looking for network that connects ground stations to Internet. From there we wanted ground station that was portable and easy to use (plug and play). We therefore decided to try out Raspberry Pi

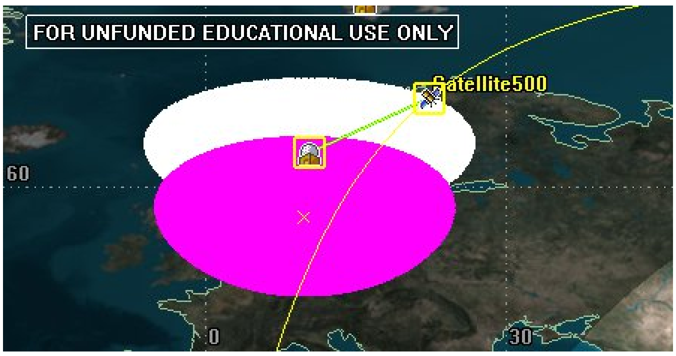

Figure 3.1: Ground station network: NTNU and Aalborg

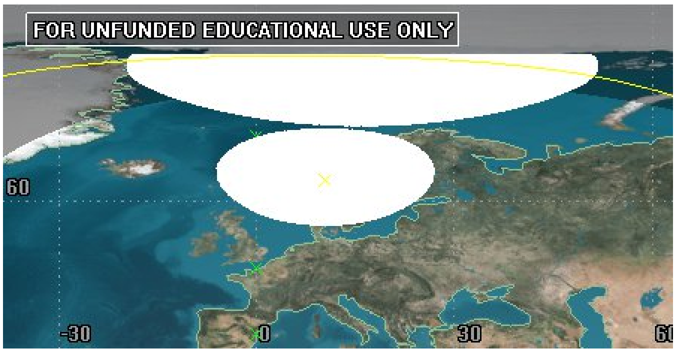

Figure 3.2: Ground station network: NTNU and UNIS

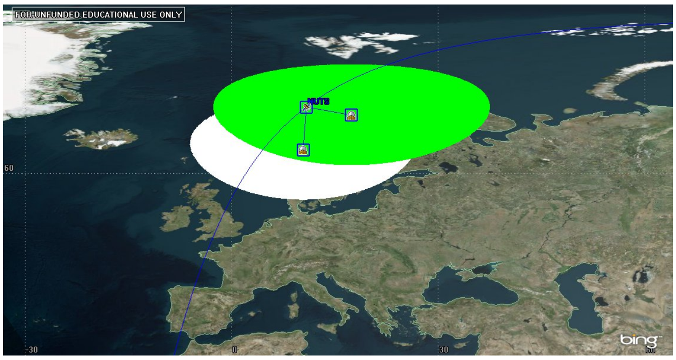

Figure 3.3: Ground station network: NTNU and UiN

Other locations	Time	Improvement
Aalborg	790s	50%
Longyearbyen	1900s	260%
Narvik	900s	73%

Table 3.1: Some data

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