TFE4850 - EiT - Student satellite

Ground Station networks

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May 2, 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 very limited 600 kB of data can be downloaded per day.

The aim of this project was set up a ground station network at the student ground station here at Gløshaugen and increase the download capacity. To achieve this several ground station network were explored and the Carpcomm Space Network was selected as the most suitable for this project.

We have set up a Raspberry Pi as a ground station and connected it to the Carpcomm Space Network. However we've found that it lacks support for many kinds of radios and the rotor control functionality is still experimental. And in addition it can't transmit to the satellite, so it can't be used to initiate downloads.

Our simulations show that even a small network will drastically increase the amount of data that can be downloaded. Calculations on the power supply for the satellite shows that there is sufficient power available to connect and communicate with a ground station network. If the challenges related to the rotor functionality can be overcome the improvements on data obtained from the satellite can be substantial.

Preface

This report is a part of the result of the Experts in Teamwork village TFE4850 Student Satellite, spring 2013. EiT is a interdisciplinary course, where students from different study programs work together to achieve a common goal.

We would like to thank the NUTS project leader Roger Birkeland, the facilitators and all the other village groups for many good ideas and advice. Many thanks also to Knut Magnus Kvamtrø for help with connecting to the ground station.

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Introduction

The students here at NTNU will be building and launching a double Cubesat in the near future. It will have a scientific payload consisting of a infrared camera, which will be used to study gravity waves in the atmosphere. One problem is that the transfer rate for a satellite using amateur radio is low and the number of passes are limited. We wanted to look more into this problem and find a solution. The download capacity is limited by the amateur radio protocol, antennae and the amount of time the satellite is above the horizon. We don't want to change the former, but can increase the latter by joining a ground station network.

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.

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

Chapter 2

Ground Station Networks

This chapter will present some theory and simulations regarding ground station networks and power supply and information about some of the available technologies are explored. The reason why we chose a particular network, our implementation of it and our results are also presented.

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[7, 8] 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 efficiency of a network of ground stations is reduced when the ranges overlap, so to have a sufficient network the nodes must be geographically far apart. In this case the ground stations must be more than 1600 km apart to have maximum efficiency.

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

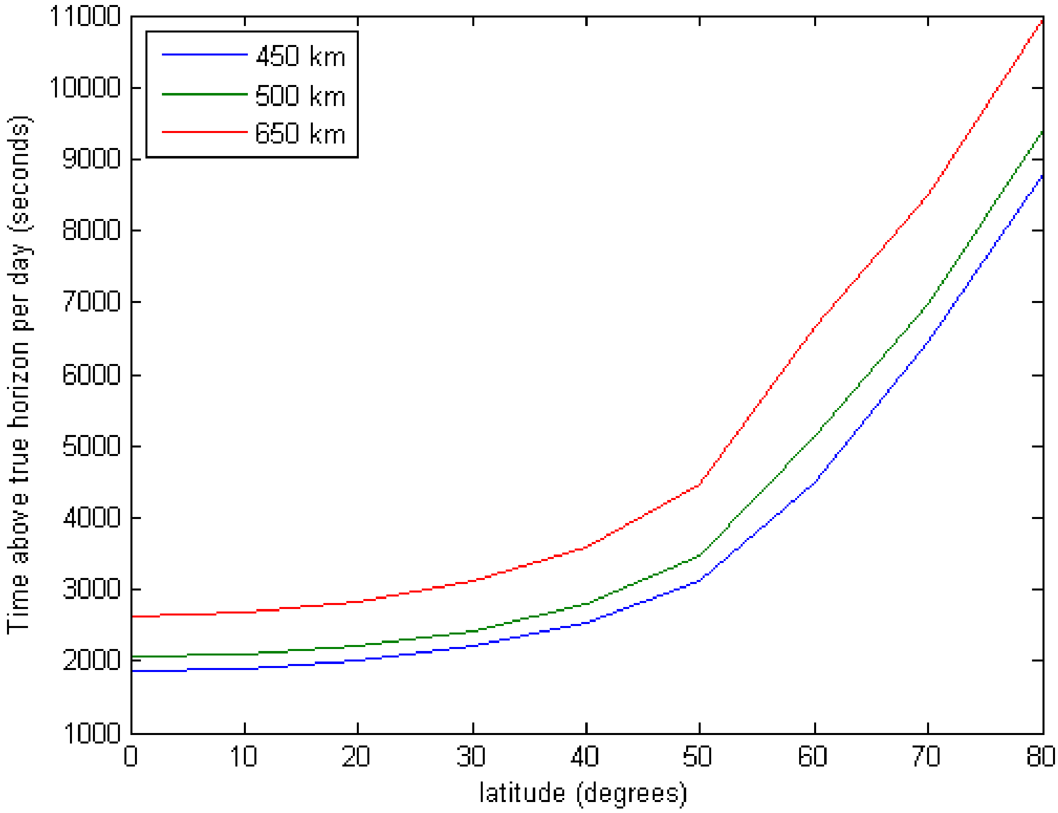

Figure 2.1: Time above the horizon for a satellite with altitude $h = 450km$, $h = 500km$ and $h = 650km$ as a function of ground station latitude

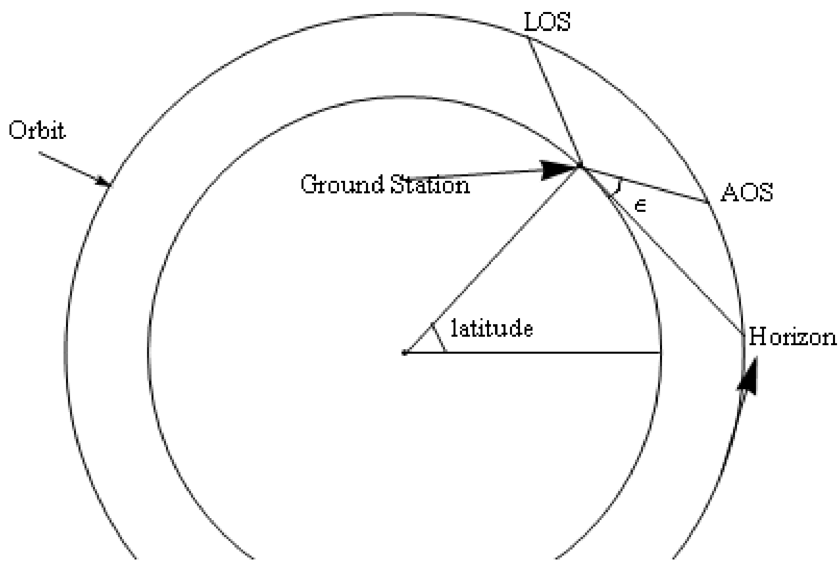

Figure 2.2: Illustration of geometry between a ground station and a satellite

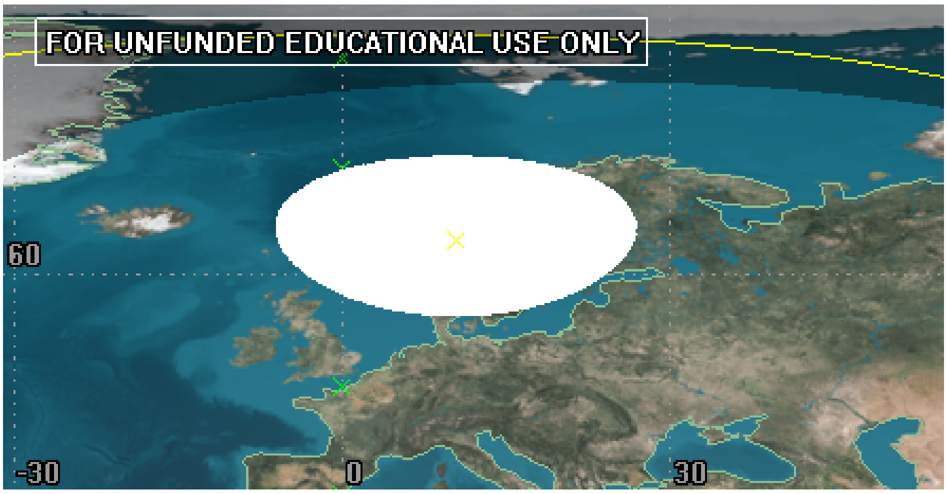

Figure 2.3: NTNU ground station range

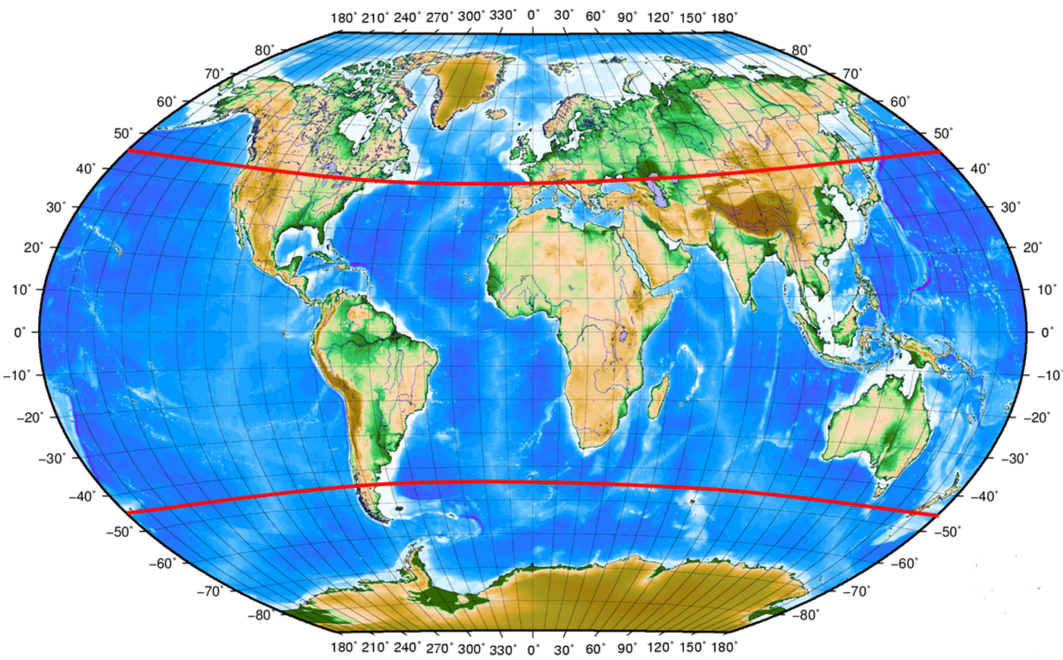

Figure 2.4: Map of the World

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 as 1300 seconds/day.

2.2 Satellite Power System

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.

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 time based on the power available is necessary to establish if a groundstation network is profitable. Forthcoming calculations are based on an estimate done by De Bruyne [9].

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

$$T(h_1) = 5610\,\mathrm{s} = 93.5\,\mathrm{min} \tag{2.3}$$

$$T(h_2) = 5850\,\mathrm{s} = 97.5\,\mathrm{min} \tag{2.4}$$

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

when inserted into Equation 2.2.

From De Bruyns equations [9] the longest possible time in eclipse can be calculated. The worst case average power is approximately $P_{avg} = 5.42W$ from by De Bruyns calculations. This power is calculated when the satellite has its longest time in eclipse.

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

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

Putting in $h_1 = 450\,\text{km}$ and $h_2 = 650\,\text{km}$ gives:

$$t_{\text{ecl},max_1} = 2151.1\,\text{s} = 35.9\,\text{min} \tag{2.7}$$

$$P_{\text{avg},h_1} = 3.34\,\text{W} \tag{2.8}$$

$$t_{\text{ecl},max_2} = 2118.9\,\text{s} = 35.3\,\text{min} \tag{2.9}$$

$$P_{\text{avg},h_2} = 3.46\,\text{W} \tag{2.10}$$

These are simplified calculations where the temperature changes of the solar cells is not taken into account. As the satellite moves through orbit the temperature will effect the solar cells, but including this effect requires more extensive calculations. The average power calculated here is based on worst-case estimate from De Bruyns [9], the real average power can be calculated with the exact orbit parameters.

The battery used in the NUTS Cubesat will consist of lithium-ferrite-phosphate cells ($LiFePO_4$)[10]. These cells have a typical voltage of 3.3 V. NUTS will have 4 × 1.1 Ah cells, where two are in series and two series are in parallel. This means a total of $C = 2.2\,\text{Ah}$ at 6.6 V[9]. 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 indicates the state of charge where DOD = 100% is a empty battery and DOD = 0% is a full battery.

The battery capacity used during eclipse:

$$C_{ecl} = \frac{P_{avg,orbit}}{V_t ot} \times t_{ecl,max} \tag{2.11}$$

$$DOD_{max} = \frac{C_{ecl}}{C_{tot}} \tag{2.12}$$

Calculated with the different heights gives:

equation 2.11 $C_{ecl_1} = \frac{3.34\,\text{W}}{6.6\,\text{V}} \times (\frac{35.9\,\text{min}}{60\,\text{min} hour}) = 0.3\,\text{Ah}$

equation 2.12 $DOD_1 = 0.136 = 13.6\%$

equation 2.11 $C_{ecl_2} = \frac{3.46\,\text{W}}{6.6\,\text{V}} \times (\frac{35.3\,\text{min}}{60\,\text{min} hour}) = 0.31\,\text{Ah}$

equation 2.12 $DOD_2 = 0.141 = 14.1\%$

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. We assume that the radio uses $P_{\text{radio}} = 2.5\,\text{W}$ and the payload uses $P_{\text{payload}} = 5\,\text{W}$ for ninety seconds. The standby power is unknown, but a microcontroller in standby running of 18.5mA and 3.3V uses $P_{\text{standby}} = 0.0612\,\text{W}$

These numbers come from various NUTS/NTNU publications are only rough estimates of what can be expected.

$$P_{\text{avg,orbit}} \cdot t - P_{\text{payload}} \times 90s - P_{\text{standby}} \times t = P_{\text{radio}} \times t_{\text{communication}} \tag{2.13}$$

Equation 2.13 is a simplified model for computing the amount of time the satellite can broadcast. Inserting h_1 and h_2 gives:

$$t_{\text{communication}} = 7172.12\,\text{s} = 110.5\,\text{min} \tag{2.14}$$

$$t_{\text{communication}} = 7778.77\,\text{s} = 129.6\,\text{min} \tag{2.15}$$

The calculations on power- and orbit estimates results in long communication time. There are several simplifications done during these calculations. The power drawn from the satellite are rough estimates and the available communication time will likely differ from the these results. Since $t_{\text{communication}} > T$ we think that there will be enough power for communication even without these simplifications.

2.3 Ground station networks

The actual performance of any future network will depend on the participants, their location and hardware. All of this is currently unknown. In Figure 2.5 and Table 2.1 some different networks are illustrated and their access time simulated.

These results show that even cooperating with other norwegian/scandinavian universities will result in significant gains in download capacity, even though there will be a certain overlap in coverage. Cooperating with other universities further afield will also increase download capacity, but if they are located at lower latitudes the decreased number of passes observed will decrease their contribution.

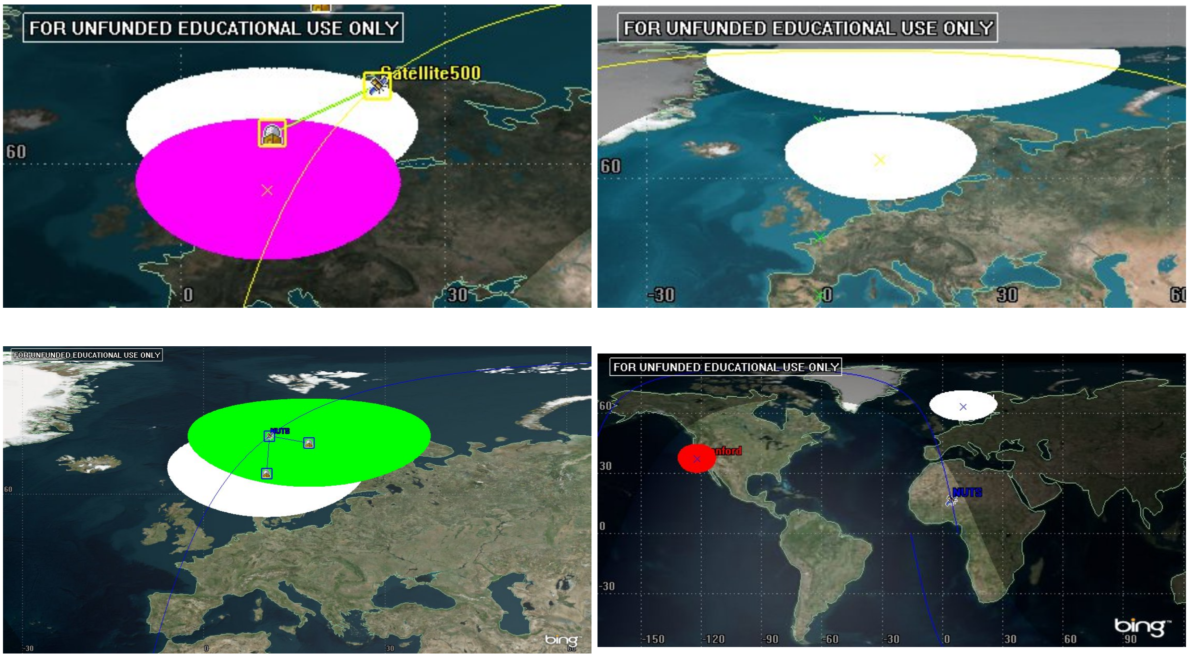

Figure 2.5: Some possible ground networks

Other locations	Time	Improvement
Aalborg	790s	50%
Longyearbyen	1900s	260%
Narvik	900s	73%
Stanford	800s	54%

Table 2.1: Results of simulations

2.4 Network technology for ground stations

2.4.1 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 other's 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. A program called the Ground Station Server (GSS) is made available to the participants. The 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[6]. Figure 2.6 illustrates this set up.

At first glance GENSO seems like a well organized ground station network which would suit the project's needs. 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.

2.4.2 PYXIS

The BlueBox is part of a distributed ground station network called PYXIS, developed primarily for the AAUSAT3 by Aalborg University (2013 [1]). 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 back-end 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 receive and transmit signals 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.

2.4.3 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 precompiled for x86 and arm processors. CarpSD, the software from Carpcomm connects to an server where it can upload data from satellites. From an web interface at this server the groundstation can also be controlled remotely, it can also be set up to control the groundstation automatically.

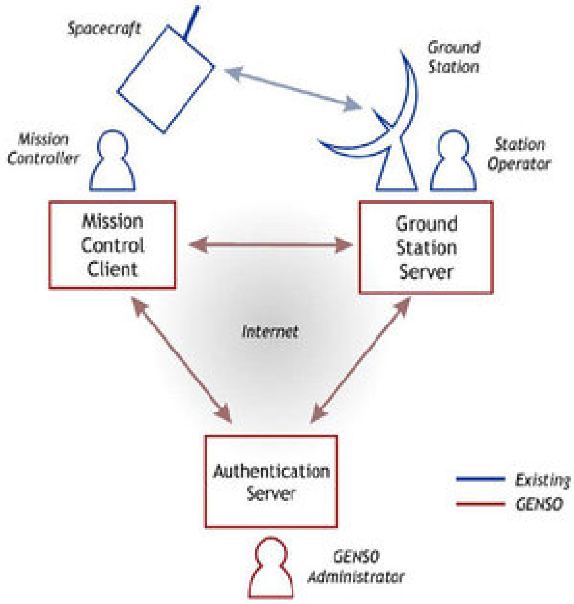

Figure 2.6: Illustration of the GENSO network.

The advantage of using this solution is that the network is actually functioning, though there are few other operational ground stations.

Why we chose Carpcomm After exploring the different alternatives, BlueBox seemed to be a good choice. However this would require some support from Aalborg University. This was impossible, as they were busy with a satellite launch of their own. GENSO is not up and running yet, so it is not suitable for our purposes. The Carpcomm Space Network is a network of ground stations that already have participants. This network is actually up and running and all the necessary resources are available at their web site. We wanted to test this ground station network without interfering with the system already in place. The solution was to use a Raspberry pi to connect the ground station at Gløshaugen to the Carpcomm Space Network.

2.5 Raspberry pi

Raspberry Pi is a small computer, with everything gathered in one board. In our project we will be using the B model, revision 2, which have a 700MHz ARM CPU, 512MB of RAM and a SD-card reader, in addition to the leads to connect to different devices, for the full overview, see figure 2.7. The recommended operating system is Raspbian, a linux distribution based on Debian. The Carpcomm home page lists Raspbian as one of its supported platforms.

The software provided by the Carpcomm project has Raspbian as one of its supported platforms, so we hope this will work well.

To control the movement of the antennas, a serial port is needed. Raspberry Pi has an serial port included in its gpio (general purpose input/output) connector. This serial port uses

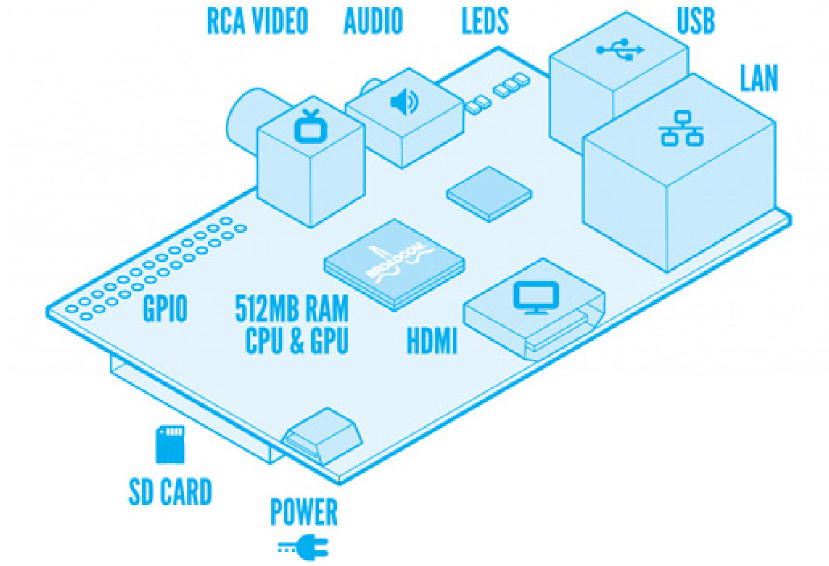

Figure 2.7: A highlevel schematic of the Raspberry pi, model B rev 2

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. A custom circuit board was made using the MAX3232 RS232 line driver.The circuit board is mounted on the gpio connector and, because of the small case, a cable is used to connect to the external connector.

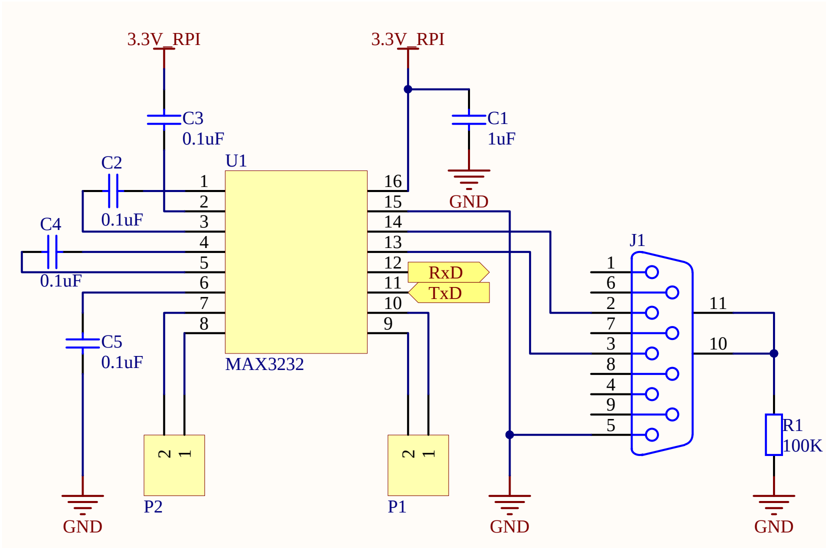

Figure 2.8: Schematics for the RS232-converter

2.6 Connecting to the Network

To connect the ground station to the Carpcomm Space Network the Carpcomm software was installed on the Raspberry pi. The CarpSD ground station control software used is an open-source program primarily developed by the team behind Carpcomm. The purpose of this software is to make it possible to connect to the Carpcomm Space Network server. The software runs as a background process and makes it possible to control the ground station if you have access to an internet browser. The software runs continuously in the background making it possible to connect remotely at any time and start receiving data from satellites.

To register our ground station with the network an entry for our station, plotting the latitude, longitude and elevation, were created. Before starting testing, the software controlling the antenna had to be installed. The Hamlib rotator library was chosen since the ground station already uses it and CarpSD supports it.

With everything set the testing of the station could start. The testing was started of with connecting to a small TV-antenna to register the signal. On the station page at the Carpcomm website the frequency was set to 433.3 MHz. This frequency was chosen because it is used by the police in Trondheim, and there are likely to be a lot of transmissions there. Data (see Figure ??) was successfully received and sent to the Carpcomm Space Network. After receiving data from the TV-antenna, a full-scale antenna was used.

2.6.1 Results

The Carpcomm software is easy to install and set up, as long as the hardware, e.g. radio and rotors, is supported. The supported radios are all small and inexpensive, which makes them suitable for radio amateurs who want to help with receiving satellite transmissions. These

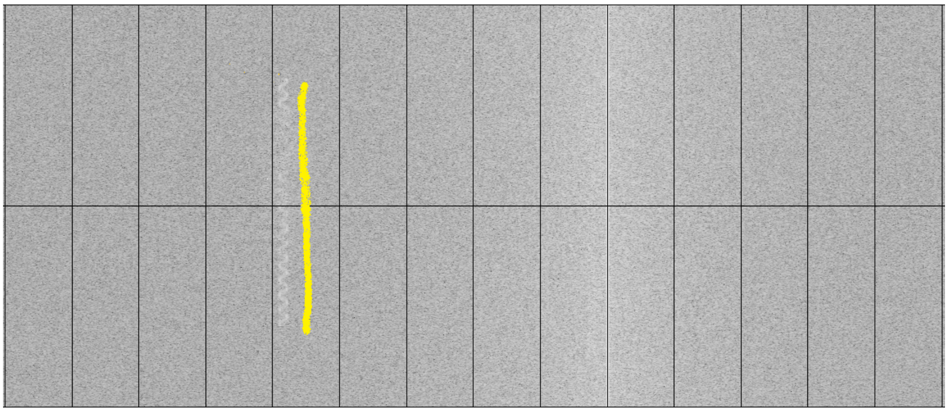

Figure 2.9: A signal recorded by the Carpcomm Space Network
The x-axis is the frequency and the y-axis is time. Black and gray is noise and the white line to the left of the yellow line is the signal.

smaller radios can only use one antenna, and since only one radio can be used Carpcomm can only receive either UHF or VHF signals. Unfortunately this makes it less suitable for us, since we want to use a more advanced radio which is not supported.

Since we could not get the software to control the antenna rotors to work properly we can only receive data from satellites in a small area of the sky, which makes the station less useful.

Since the network can not be used to tell remote stations to transmit commands to the satellite, it is only suitable if data can be transmitted automatically or continuously.

All this means that the Carpcomm Space Network is suitable for radio amateurs who wants an inexpensive way to help the micro satellite community. For professional usage it lacks important features and hardware compatibility.

2.7 Summary

The NTNU Test Satellite is using amateur radio and the transfer rate will therefore be very limited, of only 9600 bps. Combined with the limited access time to the satellite this means a very limited 600 kB of data can be downloaded per day.

Different ground station network are today available, but a network is dependent on other ground stations as participants to be beneficial. Carpcomm Space Network is an existing network which is already connected, and therefore seemingly the best choice.

To connect the ground station at Gløshaugen to the Carpcomm Space Network a Raspberry Pi were used to run the required software. During our work we discovered that it lacks support for many kinds of radios and that the rotor control functionality is still experimental. In addition it cannot transmit to the satellite, and can not be used to initiate downloads.

Results from our simulations show that even a small network with Norwegian/Scandinavian universities will result in a significant gain in download capacity. If the weaknesses in the technology can be overcome the improvements can be substantial. Another factor that must be taken into considerations when planning a network of ground stations is the position of the different nodes. The efficiency of a network of ground stations is reduced when the communication ranges overlap. The range of the Gløshaugen ground station covers much of Northern Europe, so efficiency will be reduced to a level more in line with lower latitude stations. A network of ground stations demands more power as the communication time increase. Calculations show that there is enough power available to meet these increased demands.

However, further work must be carried out so that the Carpcomm Space Network can be fully exploited, but if this is done it will bring great benefits.

2.7.1 Further Work

As it stands now the Carpcomm Space Network can not be used at the same time as the rest of the ground station systems. It is fairly simple to implement code to upload data to Carpcomm, so a possible solution may be to integrate Carpcomm Space Network support in the already existing software. Then the existing solution can be used to control the radio and antennas, and data can be uploaded to the network when the ground station is idle.

Alternatively the Carpcomm software can be used. In that case rotor control must be improved. A modification to CarpSD or the driver for the rotor interface will probably be necessary. The existing rotor interface has some quirks that makes the movement very choppy, which can be bad for the antennas and rotors. Because of this it is desirable with a new rotor interface. The Raspberry Pi have the necessary inputs and outputs to act as an interface, it just needs some voltage converters and software to control it.

The solution using the gpio connectors to connect to the rotor control must be improved. Either a more robust cable and connection must be made, or the serial port connector integrated in the chassis.

2.7.2 Social benefits

Carpcomm is a ground station network that connects ground stations all over the world. This makes it possible for ground stations with short or rare satellite passes to get more communication time. Ground stations with broader communication time can obtain data from other satellites and provide it to the ground station in need of this information. The rules for accessing the Carpcomm space network are: for every byte of data you upload, you can download one byte of data from your satellite. This provides a give and take society, and it is important that each ground station has the opportunity to provide data to others.

For ordinary people, it might not be easy to see the great social benefits of a ground station network. As mentioned, a ground station network will increase the number of downstream per pass. This is profitable for Norway since we have a landscape with a lot of mountains, which provides limitations on communication with satellites. With more data available, one can more easily investigate and improve different aspects of a satellite mission like the satellite launch, satellite power system and payload. This will improve the usefulness of satellite projects, such as NUTS. More data will provide greater benefits for those working with smaller satellites, like for example students. Increased knowledge is beneficial for education, and this is very useful to the society.

When connecting to a network all the participants will benefit, in addition to getting more date to your own project other will receive more data as well. Small-scale satellite projects created by countries with limited resources will gain from joining a network of ground stations. By creating a network of ground stations one will achieve collaboration between countries, university and people. Sharing of recourses will give more knowledge to a wider range of people and increase the likelihood of new projects being created.

Bibliography

[1] *AAUSAT3*. February 13 2013. Available at: <http://www.space.aau.dk/aausat3/>

[2] *Carpcomm Space Network*. Available at: <http://carpcomm.com/howitworks.html>

[3] *Carpcomm Ground Station 1*. Available at: <http://carpcomm.com/gs1.html>

[4] *Raspberry pi*. Available at: <http://www.raspberrypi.org/>

[5] Amundsen, Morten et al., Ekstern kommunikasjon, 2011

[6] *The educational part of ESA's home page*. Available at: <http://www.esa.int/Education/Global_Educational_Network_for_Satellite_Operations/>

[7] Marholm, Sigvald, Master Thesis: Antenna Systems for NUTS, July 2012

[8] Bakken, Marianne, Master Thesis: Signal Processing for Communicating Gravity Wave Images from the NTNU Test Satellite, July 2012

[9] De Bruyn, Dewald, Master Thesis: Power Distribution and Conditioning for a Small Student Satellite, June 2011

[10] Birkeland, Roger, Gutteberg, Odd, IAA-CU-13-09-09 Overview of The NUTS Cubesat Project, February 2013

[11] Holberg, Fredrik Sola, Master Thesis: Electrical Power System of the NTNU Test Satellite, June 2012