Global Educational Network for Satellite Operations (GENSO)

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Abstract

The GENSO project is an international project that officially began in October 2006. The main goal of the project is to improve educational spacecraft communications by creating an international network of university and amateur ground stations. With the realization of such a network, more experimental data can be downloaded, a greater number of students can participate in realtime spacecraft mission operations with a hands-on approach, and new scientific missions can be realized.

1 Introduction

Since the cost of launching something into space is extremely high, many universities around the world are developing micro-class satellites, nano-class satellites, and pico-class satellites called CubeSats [3]. These satellites are extremely small at only 1 kg and 10cm by 10cm by 10cm in a cubic configuration [3]. Thus, there is every little room to put highly sophisticated radios and antennas. The current data rates for many of these university built spacecraft are only 1200 bits per second or 9600 bits per second. Finally, to further reduce costs universities tend to launch their satellite as a cluster of secondary payloads. As a result, most of the recently launched university satellites have been placed into low-earth high-inclination orbits. These orbits allow the satellites to be visible from any spot on earth multiple times a day, allowing universities from all over the world to participate in the same launch. Additionally, universities tend to build a single primary ground station on or near their campus in order to communicate with their satellite. However, communications with the satellites can only occur while the satellite is visible, giving most universities a communications window of only 30 to 45 minutes a day. This small window combined with the extremely slow data rates means that many university Cubesat missions are limited by the amount of data that they can download from their spacecraft. Thus, some scientific missions that could physically fit inside of these university satellites cannot be pursued and many that do fit are extremely data constrained.

During the majority of the day the university ground stations are inactive. Thus, if the many universities developing satellites around the world shared their ground stations, all participating university satellite missions could increase their net data downloads. The GENSO project intends to develop a system that could achieve this by virtually connecting existing ground stations that are located in physically different places around the world via the existing internet infrastructure.

2 Project Overview

The GENSO project was initiated under the International Space Education Board (ISEB), which consists of the Education Departments of the Canadian Space Agency (CSA), the European Space Agency (ESA), the Japan Aerospace Exploration Agency (JAXA), and the National Aeronatics and Space Administration (NASA). The project is managed by the Education Projects Division of ESA and was initiated on the 5th October 2006 when the assessment study was presented to ISEB the implementation plan was accepted and is now well under way [15]. The current members of the project include California Polytechnic State University in the United States, University of Tokyo and UNISEC in Japan, Aalborg University in Denmark, Technical University of Vienna in Austria, Lulea University in Sweden, AMSAT-UK in England, and the SSETI-Association in France.

Many of the university spacecraft that have recently been launched and that are currently being developed are using amateur radio frequencies. For university spacecraft that qualify these frequencies are inexpensive to obtain and are located in a globally coordinated set of frequency bands. Thus, these spacecraft can communicate with ground stations all over the world including both university ground stations and radio amateur stations. The GENSO project intends to release the system as open source (with the exact license still to be determined). This will allow future modifications and improvements by radio amateurs and students from around the world in addition to participation in the network.

The GENSO project has many different main objectives including the following [13]:

- Unparalleled near-global access to educational and radio amateur spacecraft in orbit.
- Remote access for operators to real-time mission data, even in cases when their local. groundstation is experiencing technical difficulties
- Scheduling of remote uplink sessions via trusted ground stations.
- Optional automatic remote control of all participating ground stations.
- Downlink error-correction by comparing multiple data streams.
- A global standard for educational ground segment software.
- An optional well-defined standard solution for educational ground-segment hardware (in order to expedite participation in GENSO).
- An optional well-defined standard design solution for educational space-segment communications hardware (in order to expedite participation in GENSO).
- Close collaboration with the Amateur Radio community to support a common interface for applying for frequency allocation and coordination.

Even though the GENSO project officially started in October of 2006, much of the project is significantly based on the work of other projects such as the Ground Station Network project at the University of Tokyo [5] and the Mercury Ground Station at Stanford University [2]. The project is expected to last two years in the active development stage, with the first year ending in September 2007. Additionally, workshops are held often in order to help ease the issues associated with the members being so dispersed. So far there have been three workshops, with one in Tokyo, Japan, and two at the ESA-ESTEC center in Noordwijk, The Netherlands. There is a forth planned to be held at Cal Poly University in San Luis Obispo, USA. Future workshops are planned for Sweden and other locations in Europe.

3 System Architecture and Design

The GENSO system architecture comprises of three main parts: a Mission Control Client (MCC), a Ground Station Server (GSS), and an Authentication Server (AS). The MCC is the gateway for a satellite application to the GENSO network. The MCC exposes a virtual RS-232 interface and a socket interface. This will allow legacy applications that are already developed to interface directly to a hardware Terminal Node Controller (TNC) to use the GENSO network without software modification.

A GSS is installed at every ground station node in the network and primarily functions as a way to control the ground station hardware such as the radio and the antenna. The second major role is to internet-enable these hardware functions and to encapsulate satellite data packets in XML messages.

The final major component of the GENSO system is the AS. The AS is used to keep track of the current state of the GSS and MCC nodes in the network. Thus, the AS can be queried by MCC nodes for a list of GSS currently available GSS nodes that could support the required radio frequency (RF) modes (e.g. frequency shift keying (FSK) ultra high frequency (UHF) uplink at 9600 bps vs. audio frequency shift keying (AFSK) very high frequency (VHF) downlink at 1200 bps), their locations on the internet, their locations on the globe, and their current status (e.g. available, busy, experiencing problems, etc). The AS also provides authentication so that only authorized communications can occur between the proper GSS and MCC nodes. The current plan is to initially have three Authentication Servers in the GENSO network, with one located in Europe, the second in the USA, and the third located in Japan. This will not only provide redundancy but also allow GSS and MCC nodes to communicate with the AS having the smallest network delays.

After the initial query to the AS and authentication, the GSS and MCC communicate with one another in a Peer-to-Peer (P2P) fashion. Thus, the GENSO system architecture is a hybrid between a P2P network and a centralized network, addressing both scalability and security.

As shown in Figure 1, the GENSO system can aslo be thought of as an additional layer between the network layer and the application layer. The red solid lines show the data path for data downloaded from and uploaded to the spacecraft. The blue solid lines show the GENSO control data path. The red dashed line shows how the Satellite Application can behave as if it were directly connected to the remote ground station hardware, providing a virtual link to the spacecraft.

Since the GENSO project is being developed by students and amateur radio enthusiasts with a small budget, it is essential to keep costs low. Thus, commercial off the shelf (COTS) components, open source software, and widely used web technologies are leveraged throughout the project. The project is largely being developed in Java with some parts being developed in C# and C. Initially only drivers for COTS ground station hardware such as radios, TNCs, and antenna rotor controllers will be supported in large part by utilizing the Ham Radio Control Libraries (Hamlib) [8] and GNU Radio open-source projects [9]. Instead of trying to develop a custom network for communication between the nodes the open internet is used. XML messages over sockets will be used to both encapsulate spacecraft data and for control messages within the network. Finally, for security and authentication standard internet protocols and technologies such as HTTPS (secure HTTP), encryption with a secure sockets layer (SSL), and X.509 certificates will be used.

At the time of this writing the GENSO project still has yet to go through the preliminary design review (PDR) phase and thus, might have significant changes that will differ from the architecture and design that was described above. For the most up to date and more detailed design documents please refer to the GENSO project website [15].

4 Related Work

The GENSO project has grown out of two other previous projects that started at two universities. These were the Mercury Ground Station Network project (MSGN) at Stanford University and the Ground Station Network (GSN) projet at the University of Tokyo. These two projects are described in the next two sections.

4.1 Stanford University

Stanford University's Space Systems Development Laboratory (SSDL) started development of the Mercury Ground Station Network (MSGN) around 1999.

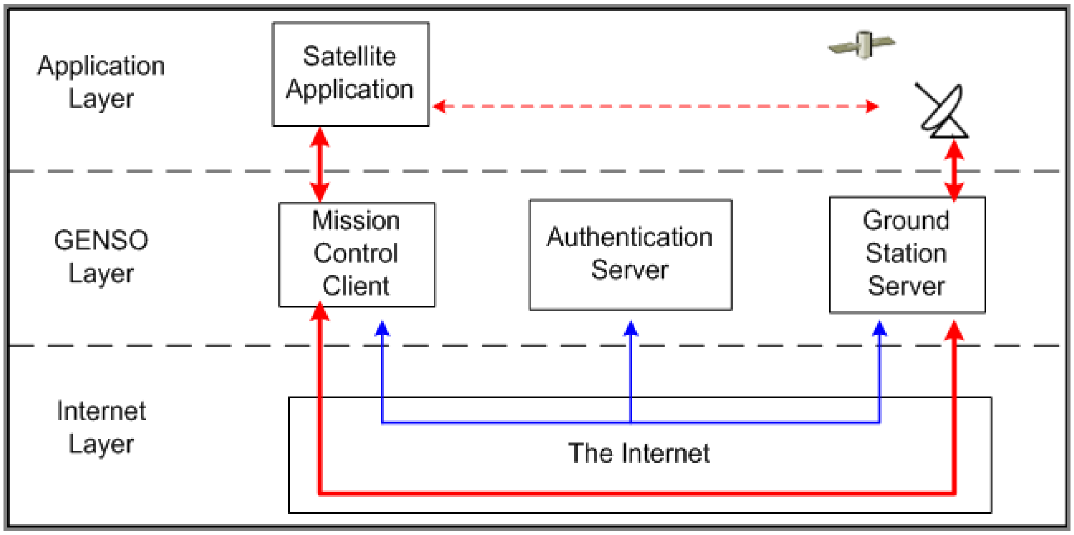

Figure 1: Layer Model of the GENSO System

The MSGN was first developed as a test bed to work with Stanford University's Orbiting Picosatellite Automated Launcher (OPAL) micro-satellite, which operated using amateur radio frequencies [11]. Developed initially as a way to reduce mission operations cost, MSGN was built upon a variety of open-source projects and technologies including Linux, Java, Apache, and MySQL [2]. Access to a remote ground station was initially done through a command-line interface using SSH [11]. Again, the initial focus was to develop software that would allow remote operator access to a ground station, control the ground station hardware (such as antenna rotors and radios), automatic pointing of antennas and frequency tuning due to orbital prediction, and finally parse and present data through a web interface.

After the OPAL mission was over and Stanford University's SSDL began work on the Quakesat Cubesat sometime about 2001, it was decided that the MSGN would become more useful as a Federated Ground Station Network (FGN) [12]. Thus, the project shifted to address new concerns such as security, hardware virtualization, reliability, and recoverability [10]. The MSGN project then developed a command and control language for the ground station network using an XML framework and created the Ground Station Markup Language (GSML) [7]. Additionally, the use of Virtual Machines (VM) was added. The Virtual Machines were used to address concerns of both security and configuration changes if multiple satellite operators wanted to use the same ground station [6]. After the GSML was incorporated into the MSGN project, the Quakesat was launched in 2003. After Quakesat stopped working in early 2004, no significant developments have been added to the MSGN project [2].

As of 2004 there were about half a dozen nodes on the MSGN network, consisting of 3 Stanford ground stations and one station in Norway, Denmark, Germany, and Iowa [7]. The MSGN software itself is free open-source and can be downloaded online [2].

4.2 University of Tokyo

The University of Tokyo is leading an effort called the Ground Station Network (GSN) project, which is trying to connect various Japanese university ground stations together via the internet [5]. There are currently 9 Japanese universities networked together including Hokkaido Institute of Technology, Nihon University, University of Tokyo, Tokyo Institute of Technology, Soka University, Tokyo Metropolitan College of Aeronautical Engineering, Takamatsu National College of Technology, Yamaguchi University, and Kyushu University (as of September 2005) [16].

Two Japanese CubeSats were launched during the first Cubesat cluster launch which happened in June 2003 from Plesetsk in Russia on a Russian Rockot launch vehicle [1] [14]. After the launch, both of the Japanese universities experienced considerable problems with operations. Congested amateur frequency bands and short visible pass times caused even further limitations to the amount of data that could be downloaded from their CubeSats. Additionally, any malfunctions in their individual ground stations would cause a complete suspension of communications with their individual satellites [16]. Thus, the two Japanese universities decided to start a project that would help combat these problems. The Ground Station Network (GSN) project was then born in 2004.

The GSN project has four main goals [16]:

- use the internet instead of dedicated network lines for data transmission
- creation of an autonomous operation system
- creation of an open architecture
- creation of an open system (framework)

By using the established infrastructure of the internet costs will be reduced. Additionally, the initial costs to have new ground stations join the GSN will be reduced. An autonomous operation system would determine, once a satellite operator logs onto the network, which ground station would be the best choice at that time for communication with the satellite. The autonomous operation system would also allow for autonomous control of the remote ground station devices (such as tuning the radios, and pointing the antennas). Finally, the autonomous operation system would provide automatic routing of any received data from the satellite back to the satellite operator across the network. The creation of an open architecture would create a protocol or specification of how hardware equipment would be controlled. Thus, if future new types of radios or antenna controllers be come available, the ground stations that use these new hardware types would be able to create software drivers that only need to be run on the local ground station, no changes to the GSN would have to be made. Finally, the creation of an open system, meaning a freely downloadable software framework, would allow more universities to easily join the GSN.

Development of the GSN is still continuing. Two more Japanese CubeSats have been launched after the first launch in 2003. Thus, the GSN is currently used to track and operate 4 Japanese University satellites. The XI-IV and XI-V CubeSats were developed by the University of Tokyo and the Cute-1 and Cute-1.7 satellites were developed by the Tokyo Institute of Technology [4].

5 Conclusion

With more and more universities actively developing and operating spacecraft, in large part due to the CubeSat community, universities have realized that networking their ground stations together could provide large improvements in communications performance. Furthermore, projects such as GENSO, MSN, and GSN are proving that nontrivial ground station network systems can be developed today cheaply by utilizing current internet and web technologies. Finally, these networks will allow university and high school students direct hands-on education with university spacecraft developed by other institutions, hopefully attracting more students to the aerospace engineering and related fields.

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