AIAA SciTech Forum
9 - 13 January 2017, Grapevine, Texas
55th AIAA Aerospace Sciences Meeting

AIAA 2017-1334

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Reference Ground Station Design for University Satellite Missions with Varying Communication Requirements

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The Georgia Institute of Technology will support five small satellite missions within a two year frame (2017 to 2019). Each satellite has different communication requirements because the mission requirements and hardware components are different for every mission. This paper discusses a common ground station architecture which will support every small satellite mission from Georgia Tech. Georgia Tech will use a network of three different ground stations, utilizing commercial off the shelf (COTS) operations software, software defined radios (SDR), and open source tracking software. This paper describes the Georgia Tech ground station and how challenges were addressed to meet the multi-mission communication requirements.

I. Introduction

Over the past decade, many universities have successfully launched small satellites and are continuously participating in various university small satellite programs[1,2]. The Georgia Institute of Technology (Georgia Tech) is one school that is actively involved with small satellite missions. Five small satellite missions are planned to be operated from Georgia Tech within next two years from 2017 - 2019 (Fig. 1). Because every satellite has a different requirement and utilizes different radio components, the communication requirements (frequency, modulation, encoding, etc.) to support each mission varies. For example, while CubeSats have traditionally stayed within the domain of VHF/UHF communication bands, more missions are requiring higher frequency such as S-, X-, or even Ka-Band due to the demand for a higher downlink data rate and the trend toward intersatellite small satellite missions[3].

One of the biggest challenges for universities with multiple satellite missions is planning for ground operations. Many missions need to share a limited amount of ground station resources when they are operated during the same time period. In order to prevent modifying the physical ground station hardware and operation software for every mission, there needs to be a versatile ground station architecture which may support most small satellite missions without modification and could be easily inherited to future missions as well. This paper describes the current ground station architecture at Georgia Tech to operate small satellites with different communication requirements flexibly using the integrated technology elements of distributed ground station sites, commercial off-the-shelf (COTS) small satellite operation software, software-defined radio (SDR), and open-source satellite tracking software. The purpose of this paper is to document the Georgia Tech ground station design that is intended to support a wide range of satellites in a university setting.

II. Communication Requirements for Georgia Tech Small Satellite Missions

Georgia Tech is scheduled to fly five small satellites within next two years (Fig. 1). Considering the fact that the small satellites are usually expected to last from six to twelve months, there will be time overlaps between periods of time when the different missions operate. The communication hardware each satellite mission flies will be different, but they will communicate through a common ground station architecture. Therfore, Georgia Tech ground station needs to be able to process various types of communication signals. In this section, the various small satellite missions operated by Georgia Tech are briefly reviewed (Table 1).

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A. RANGE

RANGE (The Ranging And Nanosatellite Guidance Experiment) is the first mission which will be operated by the Georgia Tech ground station. The mission was selected by a Terra Bella University Cubesat Partnership for launch in April, 2017[4]. Two 1.5U CubeSats will be deployed to study positioning capabilities. Absolute positions of the RANGE satellites will be validated using GPS receivers and ground-based laser ranging measurements, and relative positions will be validated through intersatellite optical ranging between each other. The intersatellite optical ranging will also double as low-rate optical communication link. For radio frequency communication, both RANGE satellites use the NanoCom AX100 half-duplex UHF transceiver from GomSpace, with Gaussian Frequency Shift Keying (GFSK) modulation and AX.25 data link layer protocol. The data rate will be 9.6 kilobits per second (kbps). Because RANGE is a two satellite mission, communication requirements for RANGE include simultaneous contact with two satellites during each ground station overflight.

Figure 1: List of Georgia Tech Small Satellite Missions

Table 1: Georgia Tech Small Satellite Missions Overview

Mission	Features	Program	Size	Frequency Band (Uplink/Downlink)	Launch Year
RANGE	Laser ranging, optical intersatellite communication	Terra Bella University CubeSat Partnership	Two 1.5U	UHF/UHF	2017
Prox-1	Automated trajectory control and inspection of a deployed CubeSat	Air Force UNP – 7	22’’x 24’’ x 12’’	UHF/S-band	2017
ARMADILLO (U. Texas)	Dust and debris characterization and radio-occulation	Air Force UNP – 7	3U	VHF/UHF	2017
RECONSO	Detect and track small space objects	Air Force UNP – 8	6U	UHF/UHF	2018
USIP	Inflatable LiDAR target imaging	NASA USIP	3U	UHF/UHF	2018

B. Prox-1

Prox-1 is a nanosatellite with size of 22 by 24 by 12 inches (66.5 kg) selected by University Nanosatellite Program (UNP) - 7 from Air Force Research Laboratory (AFRL) [5]. It is planned to be be launched on the SpaceX Falcon Heavy rocket in Fall 2017. The main objective of Prox-1 is to deploy a 3U CubeSat solar sail built by The Planetary Society and demonstrate automated trajectory control based upon relative orbit determination using infrared imaging technology. It will also downlink photos of the solar sail deployment. The communication requirement for Prox-1 includes UHF uplink and S-band downlink. Its hardware includes a RX-445 UHF receiver and TX-2400 S-band transmitter from SpaceQuest Ltd., along with a KPC-9612 terminal node controller from Kantronics to apply Frequency Shift Keying (FSK) modulation and AX.25 protocol on signals. Prox-1 will utilize an S-band ground station located fifteen miles away from campus for downlink and UHF station on campus for uplink.

C. ARMADILLO

ARMADILLO (Attitude Related Maneuvers and Debris Instrument in Low Orbit) is a 3U CubeSat built by University of Texas at Austin (UT-Austin), in collaboration with Baylor University and University of Stuttgart[6]. Like Prox-1, it was selected for flight by UNP – 7 from AFRL and will launch as a secondary payload on the same SpaceX Falcon Heavy rocket in Fall 2017. While it is a mission from UT-Austin, it is planned to be operated by the Georgia Tech ground station. ARMADILLO will characterize in-situ sub-millimeter level dust and debris particles in Low Earth Orbit using a Piezo Dust Detector developed by Baylor University and demonstrate ionospheric radio-occulation with a FOTON GPS receiver developed UT-Austin. ARMADILLO communicates with the ground station through a Helium 100 UHF downlink/VHF uplink radio from Astronautical Development LLC (Astrodev), with GFSK modulation and AX.25 data layer link protocol.

D. RECONSO

RECONSO (RECONnaissance of Space Objects) is a 6U CubeSat selected for flight by UNP-8 from AFRL[7]. It is planned to launch as a secondary payload in 2018. The goal of RECONSO is to demonstrate space surveillance capabilities by detecting and tracking resident space objects in the 1-10 cm regime using a visible lens and CMOS imager. RECONSO will both uplink and downlink at UHF, using a PI-1310 UHF radio from Tyvak Inc.

E. NASA USIP

Georgia Tech has been selected by NASA USIP (Undergraduate Student Instrument Project) to develop an imaging LiDAR CubeSat mission for planetary applications. This satellite is planned to launch in late 2018 or 2019. CubeSat will deploy a LiDAR target which will unfold and inflate after detaching from the top of the CubeSat. The CubeSat will then acquire images of the target through LiDAR until the target is out of range. This mission will use the NanoCom AX100 half-duplex UHF transceiver from GomSpace.

III. Georgia Tech Ground Station Architecture Overview

The Georgia Tech ground station is a network of three different stations: the S-band station at the Cobb County Research Facility (CCRF station), the VHF/UHF station on the Van Leer building at the main campus (VL station), and the UHF station on the Montgomery Knight building at the main campus (MK station). All three of these stations are controlled by a central server located in the Engineering Science and Mechanics (ESM) building. These stations can operate independently or in concert for the various upcoming missions. For example, the Prox-1 mission will require an uplink in UHF from MK station, but will downlink in S-band to the CCRF station. The RANGE mission has two satellites, which initially will be close together and thus possible to track with a single station, but as they drift apart, the MK station and the VL station will be used simultaneously to communicate with them both. Fig. 2 shows the three ground stations and their approximate locations in the Atlanta area.

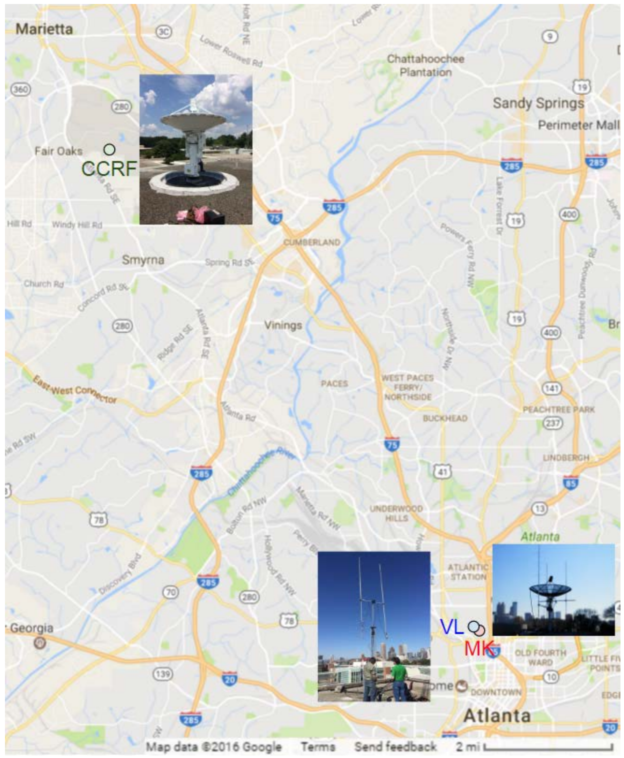

Figure 2: Locations of Georgia Tech ground stations throughout Atlanta

While each station operates in different frequency bands, they share a common architecture. Every station is equipped with a software defined radio (SDR) for uplink and downlink. Each station is controlled by a server computer, which controls antenna pointing, monitors station health data, and runs the digital signal processing software to drive the software defined radio. Because each station uses different hardware, the drivers for these operations are different, but each server has a common external interface, so the central system will interact with each station in the same way. Fig. 3 shows a block diagram of the interaction between the central system and a single remote facility.

QuantumCMD is a mission operation software package which will be explained in a later section. Because QuantumCMD is designed to interface with only a single ground station, a custom program, called the clearinghouse, will be used to route messages from QuantumCMD to the different remote stations. This clearinghouse will also timestamp and save all data being sent in both directions, which will act as an additional backup. In total, three full copies of all uplink and downlink messages will be archived, one in QuantumCMD, one in the clearinghouse, and one in the remote station's server. This gives several different backups to prevent data loss, and to trace problems that may arise in data handling chain.

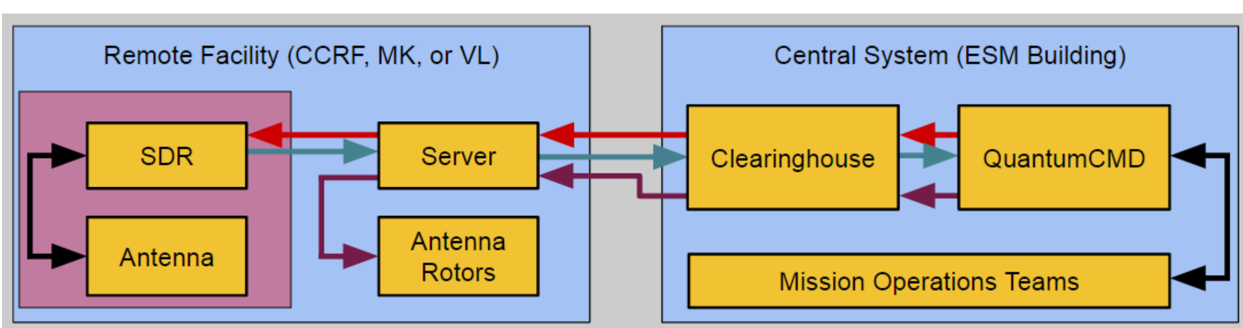

Figure 3: Block diagram of central server interaction with a remote station: all three remote stations have the same connection interface

A. Station Hardware

Because no single antenna may transmit in all bands, different antenna systems are used at different remote stations. Each remote station has a different set of hardware designed to communicate on different frequency bands.

The CCRF station has an S-band (2200-2310 MHz) antenna system, manufactured by Orbital Systems Ltd. The system includes the antenna, a low noise amplifier (LNA) for the receiver, a high power amplifier (HPA) for transmit, positioning rotors capable of driving the antenna at 60 degrees per second in azimuth and elevation, and a control computer. These components are all integrated into the antenna pedestal, and no external equipment is required besides the radio.

The VL station is a VHF/UHF station, built using amateur radio equipment. It is configured to uplink in the VHF (144-148 MHz) band. The uplink uses two different amplifier stages, one to bring the less than 10 mW SDR output to 1 W, and another to bring that signal up to 50 W. A two stage architecture was chosen because of the very large amount of amplification required; it was more cost-effective to use two amplifiers rather than a much larger amplifier. Both the transmit and receive antennas are circularly polarized Yagis. The received signals are sent to a band pass filter then to a LNA mounted on the antenna mast before heading to the SDR, the VL station uses an SP-70 preamp with a 0.7 dB noise figure.

The MK station uses the same receiver components as the VL station, but it transmits at UHF (430-438 MHz). The MK station's UHF uplink is a similar two stage amplifier setup as the VL station. The two UHF yagi antennas at the MK station are combined as a phased array to increase the antenna gain, both used for receive and transmit with an RF switch. A spare VHF antenna and a dish antenna are attached for backup/future use if necessary. Fig. 4 describes the flow of RF signals between the SDR and the antenna for the VL and MK stations.

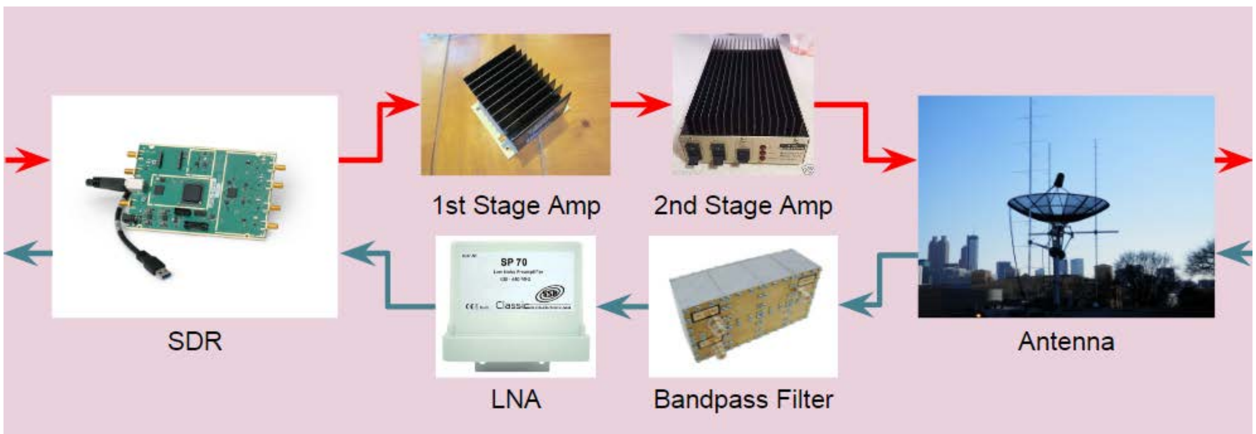

Figure 4: Flow of RF signals between the SDR and the antenna at the VL/MK stations

B. QuantumCMD

To control this network, Georgia Tech is using the QuantumCMD software, developed by Kratos Defense & Security Solutions, Inc. for spacecraft command and control. Using COTS software for mission operations reduces the risk of writing different operation software for fast turnout small satellite missions and provides a common user to machine interface. It also has a user-friendly visual interface (Figure 5), automation features, and easy access over the internet. QuantumCMD is capable of parsing incoming messages and generating responses using user-created mission scripts. QuantumCMD can store a large number of such scripts, which will be developed for each mission by the mission specific operations team. Uplink commands are sent from QuantumCMD to the central server, which routes them to the appropriate ground station for transmission, along with pointing commands for the rotor and signal power level settings. Downlinked telemetry is automatically scanned for any variables that may indicate off-nominal performance, for example, low battery voltage or high current draw. These red flags can trigger automatic notifications to the relevant operations team. The telemetry is also provided to QuantumCMD's web interface for customizable visualization.

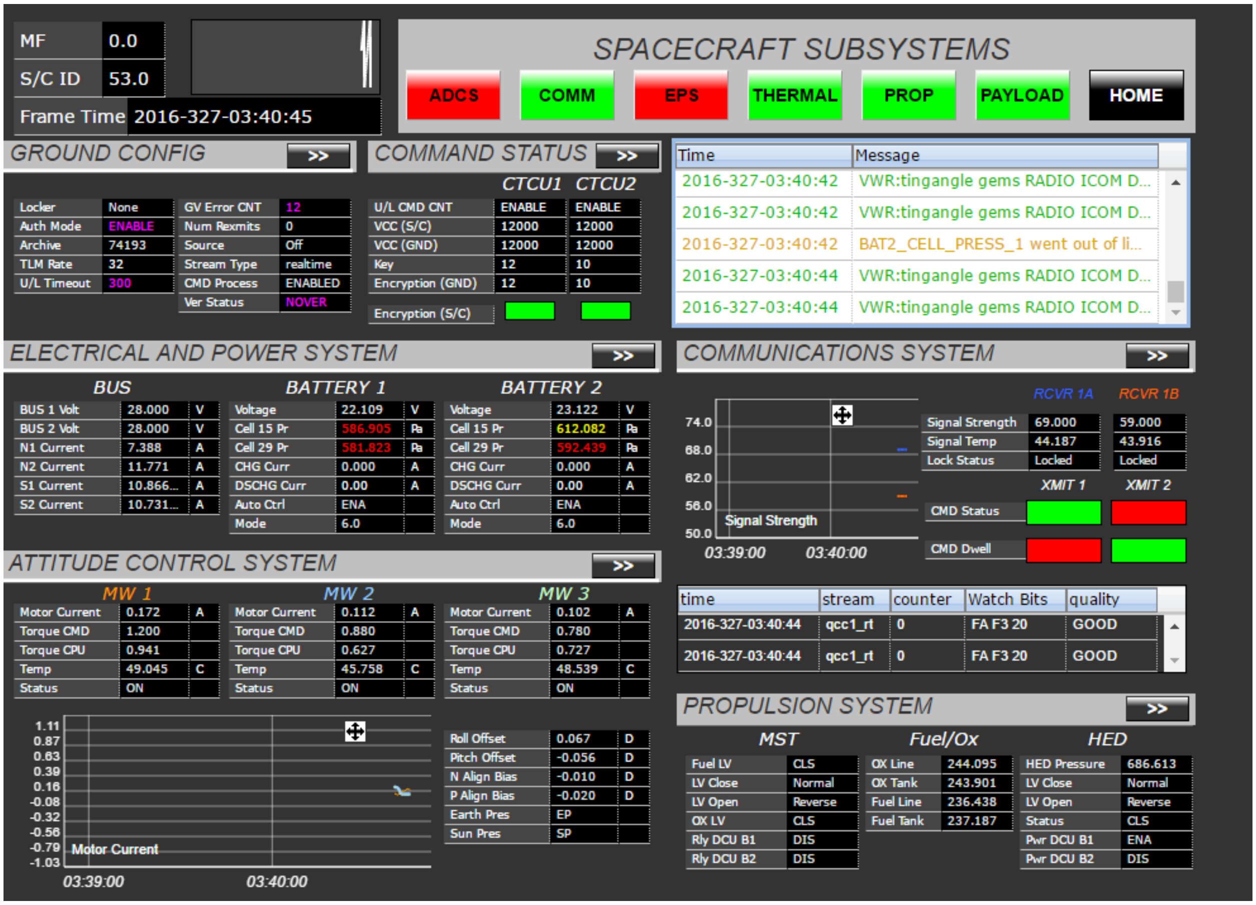

Figure 5: QuantumCMD web interface

C. Digital Signal Processing

The digital signal processing is performed using GNU Radio (Fig. 6), an open source project to provide support for the use of SDRs. It provides libraries for basic DSP functions, like signal filtering and common modulation schemes. These libraries are user-extensible, and many custom functions are used in the GT ground station. GNU Radio also provides a flow control manager to regulate the program in real time, and a graphical interface similar to LabView for prototyping. The GT ground station software is capable of using CCSDS and AX.25 packet protocols, and can perform GFSK and Quadrature Phase Shift Keying (QPSK) modulation/demodulation. Once the signals are modulated, the baseband signal is sent to the SDR, where it is upconverted to the correct frequency and transmitted. The SDR used in all three stations is the Ettus Universal Software Radio Peripheral (USRP) B210. The B210 is a very capable radio, with two input and two output channels, 56 MHz of real-time bandwidth, and RF coverage tunable from 70 MHz to 6 GHz.

One of the many advantages of using an SDR is that it may produce various waveforms based on the mission's needs. For example, to communicate with two satellites in close proximity, the antenna is aimed at the midpoint, and the radio can create create two simultaneous uplink messages by adding the baseband waveforms of each individual message, provided the uplink frequencies are within 56 MHz of each other. It is also capable, through the GNU Radio, of employing any modulation and encoding scheme. This flexibility is very important when supporting many different missions, each with a different spacecraft radio.

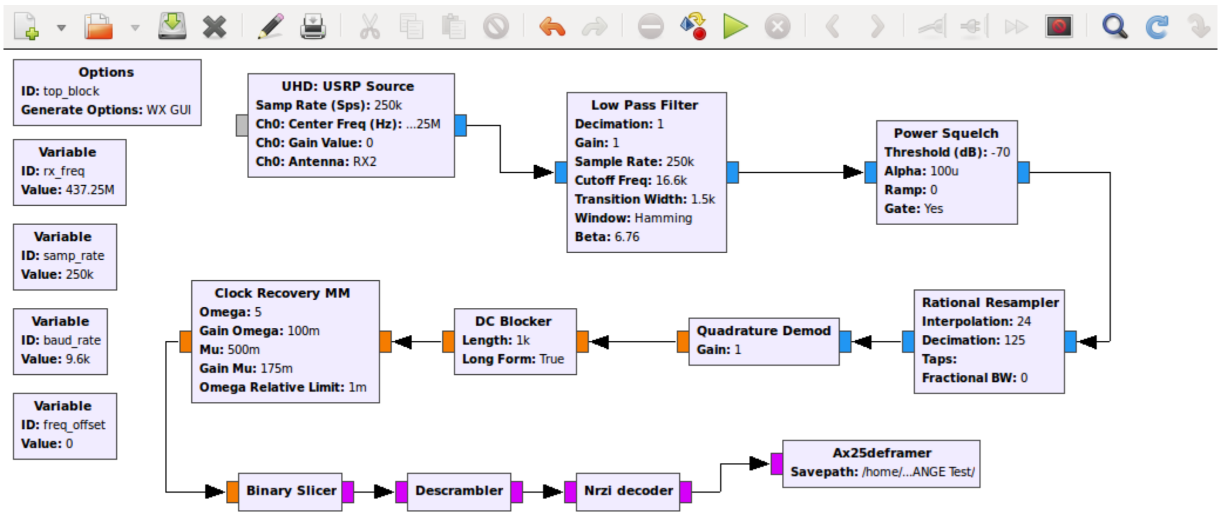

Figure 6: An example of a GNU Radio flowgraph processing downlink signal with GFSK modulation and AX.25 framing

D. Uplink/Downlink Summary in Each Remote Station

For uplink, commands from the QuantumCMD are sent securely over the GT network to the station server. A copy of the command is timestamped and saved locally, to maintain a transmission log. The message is then encoded and modulated using GNU Radio, and the baseband signal is sent to the SDR for upconversion and transmission. Each groundstation has amplifiers downstream of the SDR to bring the signal power up to the appropriate level for transmission. In the case of the MK and VL stations, these amplifiers are UHF and VHF amateur radio equipment, and in the case of the CCRF station they are built into the antenna system.

For downlink, radio messages from a spacecraft are received by the antenna, filtered by bandpass filter, and amplified by Low Noise Amplifier (LNA) before reaching the SDR. After the RF signal is downconverted into baseband at SDR, it is demodulated and decoded using GNU Radio to extract messages from the packets. A copy of each message is timestamped and saved locally before being sent to the ESM central server. The messages are then processed by the QuantumCMD software as described in the above section.

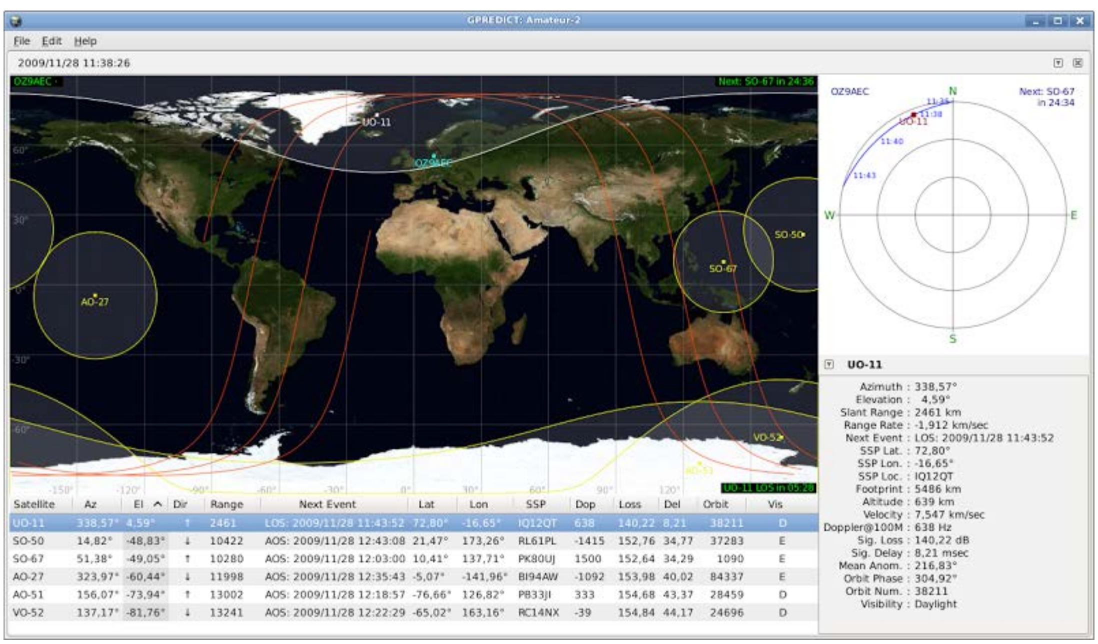

Figure 7: Gpredict Screenshot

E. Tracking

For tracking software, the Gpredict open-source software[8] is used to monitor and track multiple satellites in real time at the MK and VL stations (Fig. 7). Gpredict contains a satellite database with known Two Line Elements (TLE). It may update TLE information, group chosen satellites into modules, and control antenna rotor from different vendors. It also provides a user-friendly visual interface, where an operator may position ground station antennas and observe satellites nearby. In the CCRF station, the antenna system is preinstalled with its own tracking software.

IV. Conclusion

Georgia Tech's satellite ground station network is composed of three individual ground stations to support the varying communication requirements of small satellite missions from Georgia Tech and other academic institutions. The ground station is planned to debut when the RANGE satellites are launched in April 2017. While RF components for VHF/UHF systems on campus are supported by COTS amateur radio equipment, the S-band system is supported by a specialized ground station company. The overall structure of the Georgia Tech ground station is flexible enough to support various mission requirements with the use of easily customizable operations software, software defined radios, and user friendly open source tracking software. The station also has plans to upgrade the UHF station to have a four element phased array and modify the S-band antenna feed to use X-band feed if any missions with frequencies above S-band need to be supported. Partnering with other ground stations to expand the network is another possibility in the future.

Acknowledgments

The authors would like to thank Guggenheim School of Aerospace Engineering at Georgia Tech for supporting this project. The authors also thank Georgia Tech Ground Station Working Group, Georgia Tech Amateur Radio Club (W4AQL), and other personnel who have helped build this ground station.

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