IAC-10.B2.5.12

PROJECT AGORA: SIMULTANEOUSLY DOWNLOADING A SATELLITE SIGNAL AROUND THE WORLD

Ghulam Jaffer
IKS, Graz University of Technology, Graz, Austria, ghulam.jaffer@student.tugraz.at

Cmdr. Ronnie Nader
Ecuadorian Civilian Space Agency - EXA, Guayaquil, Ecuador, rnader@exa.ec

Dr. Andrew Klesh
JAXA/JSPEC, Sagamihara, Japan, andrew.klesh@jaxa.jp

Prof. Otto Koudelka
IKS, Graz University of Technology, Graz, Austria, koudelka@tugraz.at

ABSTRACT

The Ecuadorian Space Agency has recently provided the civilian world with an Internet-to-orbit gateway (HERMES-A / MINOTAUR Space Flight Control Center) available for public and educational use. This gateway connects Internet users around the world with the capability to remotely operate and listen to a satellite ground station, providing a broad platform for educators and amateurs to connect to LEO orbiting satellites live.

Around this gateway, the Project AGORA user community was established such that knowledge, assistance and training could be shared among participants. Through this community, users around the world can simultaneously control and download real-time signals from satellites passing over Ecuador, passing control of the station off to each other as each user learns how to operate the system. This paper details the operations of Project AGORA and the results of simultaneous connections from users around the world: North America (Michigan), South America (Ecuador), Europe (Graz-Austria), and Asia (Japan) as they worked together to listen to passing satellites.

From this experience, it has been found that there is a direct link between synchronization losses and the number of simulation programs running with high priority. Moreover, the use of Satellite Toolkit simulations in observations significantly improves all real time results. Results of these studies are presented within this paper.

The HERMES ground station is capable of relaying signals between any computer on the Internet and spacecraft in orbit using one of the four modes of operation, from passive signal listening, to active voice interaction. Here we detail only the reception modes used by the Project AGORA team.

Finally, this paper details the February 5th, 2010 near-miss collision between Iridium-33 34891 debris and the SwissCube cubesat. During this event, the HERMES gateway was a key ground station and relayed live data directly to the EPFL SwissCube center.

Key words: EXA, HERMES, MINOTAUR, AGORA, Operational Modes, Telemetry, AMSAT, N/POES, APT, Image processing, Real-Time, Near-miss Event, Simulation.

I. INTRODUCTION

Project AGORA, through the use of the recently developed Ecuadorian Space Agency's Internet-to-orbit gateway, HERMES-A, has provided Internet users around the world the ability to receive live spacecraft data from orbiting satellites. The user community built by AGORA has allowed for collaborative and educational programs that have benefited both experienced and novice satellite operators (a class of Ecuadorian 2nd graders has now learned to downlink and analyze NOAA weather image data).

Our main objective for the AGORA project has been to demonstrate synchronous round-the-world testing of the HERMES system for a distributed team receiving NOAA APT and amateur satellites signals (in receive-only mode). The team has taken advantage of the fact that licenses are not needed for reception only operation. This setup has also allowed for an international team, and in this paper, the ground station (GS) was operated and controlled by remote users residing in Graz-Austria, Michigan-USA and Kanagawa-Japan.

Weather Satellite Network

The network of operational geostationary weather system comprises hundreds of satellites including the European METEOSAT, the American GOES, the Japanese GMS, India's INSAT series and the Russian GOMS. Some weather satellites, however, are not geostationary. The Polar Earth Orbiting Satellites (POES) including NOAA 15, 17, 18 and 19/N', as well as the ESA provided MetOp satellite operated by EUMETSAT, orbit the earth in approximately 102 minutes at an altitude of 800 km in Sun Synchronous orbit.

Most weather satellites offer two kinds of picture services: a digital transmission format with high-resolution picture data (HRPT), and an analog transmission format of lower resolution called Automated Picture Transmission (APT). This latter transmission format needs limited technical resources for reception and decoding. With the launch of next generation NPOESS[1] in 2014 and, based on the typical life expectancy of the satellites, APT will be replaced by digital services on NOAA satellites. These services, such as low-rate picture transmission (LRPT) on MetOp, would be made available to the public after the 18th month of successfully deployment. Current APT versus future data format LRPT is tabulated in table 1.

	NOAA-APT	MetOp-LRPT
Signal	Analog	Digital
Imagery Channels	2	3
Spatial Resolution	4km/pixel	1km/pixel
Security	N/A	Compressed, can be encrypted
Expected Life	NOAA 15/17 – while operational Others - ~ 2012	Deployment 2006 through 2015

Table 1 : A comparison between current NOAA APT and future LRPT like data format

APT data is transmitted continuously as an analog signal using amplitude modulation (AM) of a 2.400 kHz sub-carrier on FM carrier in 137MHz. A new line of data is transmitted each half a second, containing a line of image data from two Advanced Very High Resolution Radiometer - AVHRR[2] channels Visible (VIS) and Infrared (IR) together. The APT frame format is shown in fig. 1.

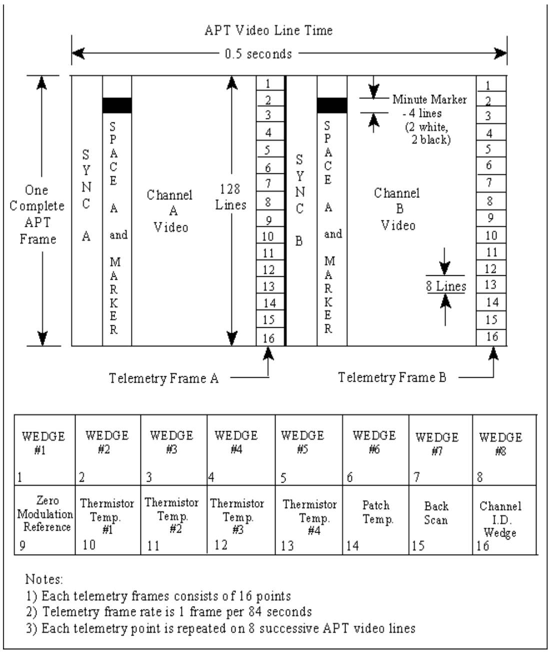

Fig. 1: The APT frame format.

As each image frame is received, synchronization patterns show up as vertical black lines to the left of each image, while telemetry data is shown as gray scale wedges carrying calibration and other information. Any two of the AVHRR[2,3] channels can be chosen by the NOAA GS for dissemination. A visible channel is used to provide visible APT imagery during daylight, and one IR channel is used constantly (day and night). A second IR channel can be scheduled to replace the visible channel during the night-time portion of the orbit. To measure various environmental parameters, the data from two channels is compared. The three channels operating entirely within the infrared band are used to detect the heat radiation from and hence, the temperature of land, water, sea surfaces, and the clouds above them.

HERMES-A Ground Station

HERMES-A/MINOTAUR[4,5] was built by the Ecuadorian Space Agency (EXA)[4] for receiving NOAA APT telemetry signals, housekeeping data and half-duplex (HDX) voice signals from Amateur[6] satellites. Other existing systems providing some remote operation like HERMES are Mercury GS[7] and GENSO[8] but they do not allow remote users to receive the signal in real-time at their home location. A typical APT receiving station is shown in fig. 2.

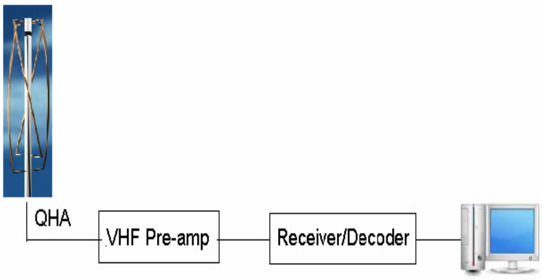

Fig. 2: Typical standalone APT Receiving system

HERMES-A/MINOTAUR is based in the coastal city of Guayaquil and works in broad ranges of frequency bands like VHF, UHF, 900MHz and 2.4GHz. It has two main components: the HERMES-A server matrix, which processes the signal and serves the Internet gateway functions and MINOTAUR sensor array, which receives the signals from the spacecraft. The MINOTAUR array is a 12 m tall sensitive sensor array with the capability of detecting signals as faint as 0.2 watts at a distance of more than 22000km (e.g. a Molnya satellite), but also has a high discrimination capability. It is dual polarity, variable frequency resonator operating from 1.2 MHz to 2.4 GHz, with a 130dB gain, while the GORGON-B is a secondary array operating in the VHF narrow band, 137-138MHz, well suited for NOAA satellites reception. The radiation pattern of this antenna system is shown in fig 3.

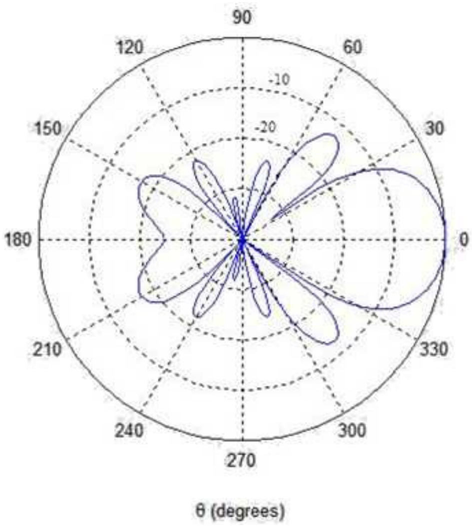

Fig. 3: MINOTAUR antenna radiation patterns

The Minotaur array has 2 IP cameras[9], one on-board and one outside, pointing to the array. Fig. 4 shows both camera views.

Fig. 4: The Minotaur Array onboard and external camera view

Contrary to standalone APT GS, HERMES receives the APT audio frequency (AF) from NOAA satellites and relays it in real-time to remote users all over the world through the Internet. The decoded images are then post-processed locally by a weather-decoding program WXTOIMG[10] and/or APTDECODER[11]. For online reception of APT feed, the only requirement is VRS Remote Monitor (VRS-RM)[12] Listen Connection running on user PC with broadband Internet. The user must have a public IP address authenticated by EXA to access HERMES, track the current operational satellites and receive telemetry signals. In this way the HERMES project transforms a simple laptop computer into a full space-qualified ground station, 'a GS on-the-move'. One of the four operational modes, 'Delta mode', is shown in fig. 5.

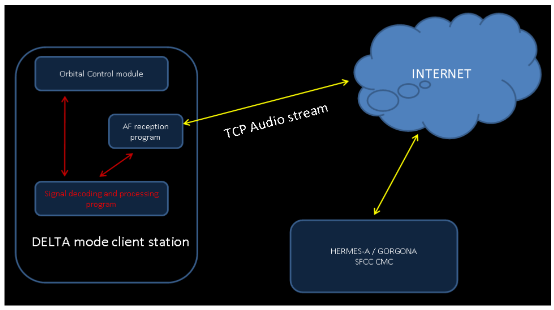

Fig. 5: HERMES Delta mode client station. The APT from NOAA is received and relayed to remote users in real-time through Internet

To avoid any noticeable latency in remote connections, a 512kbps connection was found to be good enough for clear reception. We verified multi-user test runs where each participant was able to track the satellite, control the ground station, and receive telemetry from a NOAA satellite. All remote users decoded received AF signals which provided 1) APT with WXTOIMG and 2) telemetry / housekeeping data using HRD[13]-DM780 and/or MixW[14]. We found that most Internet connections were capable of handling the AF input load.

The software used for decoding included WXTOIMG[9], a fully automated weather satellite recording, decoding, editing and post processing software with the enhanced features like map overlays, 3-D imaging, animations, projection transformation etc. Its automatic processes featured the ability to decode and create images, anaglyphs, animations and movies. Similarly, MixW has an advantage over HRD-DM780 to use its notch filter feature for easy processing.

II. OPERATIONAL MODES

The HERMES does not include terminal node controller (TNC) as it is developed to work as an internet-to-orbit gateway (I-2-O)[5] for Internet user to connect satellites in space. So the TNC resides at the user end. Since operative in Sep. 2009, many users around the world has tested and verified its full remote GS operational capabilities. The only one of four HERMES modes (Delta) does not need a control interface to track the satellite for data reception. HERMES is an Open System Interconnection (OSI) model gateway and the software-TNC (HRD-DM780 or MixW) on the user end has the big advantage to vary according to user needs.

HERMES is capable of handling four modes of operation i.e., Delta, Alpha, Beta and Gamma[15]. The two modes (receive only) Delta and Alpha are detailed in the following section.

Delta Mode: Weather Satellite AF Receiving

In this operating mode, the user receives the AF signal input from a passing NOAA satellite transmitting an APT signal and decodes it to translate into an image.

The mode is 'AF receive-only' and uses a Quadrifilar Helical Antenna (QHA)[16] which does not require tracking as it has a broad reception pattern from almost horizon-to-horizon. The radiation pattern of this antenna is shown in fig. 6.

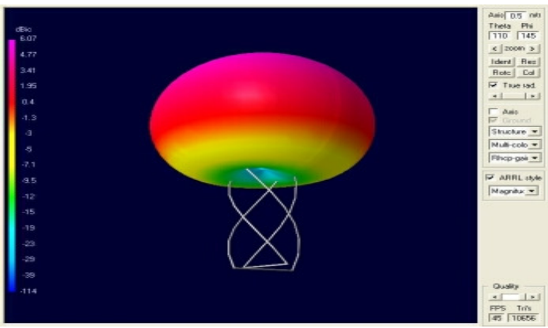

Fig. 6: QHA RHCP radiation pattern. Adapted from http://homepages.ipact.nl/~pa1are/QHA.html[16]

Among other findings, two captured and post processed images are shown in fig. 7 and 8. The image shown in fig. 7. is a composition of images from NOAA 15, 18 and 19, received by HERMES from the satellites directly during the heavy South American rainfall of March 2010. It is a thermal enhancement. We can see the high temperatures on Atacama Desert of Chile and in Venezuela stresses the problems it has of blackouts due to dependence on hydroelectric power. This image was showcased on the IAF website as an image of the day on 13th April 2010. The image depicted in fig. 8. is enhanced with 'MCIR - with precipitation' during the thunderstorm season. The cloud charging effect can be observed easily.

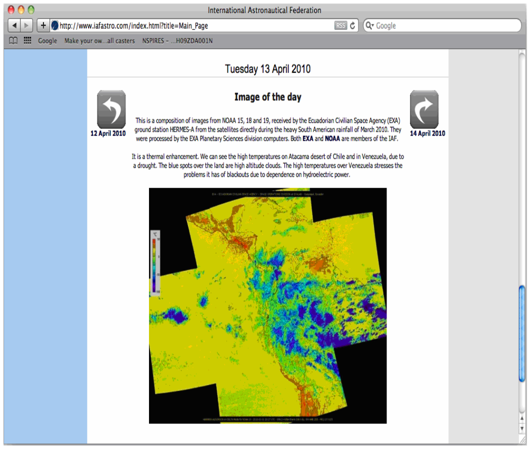

Fig. 7: Composite image from NOAA 15, 18 and 19 with Thermal enhancement

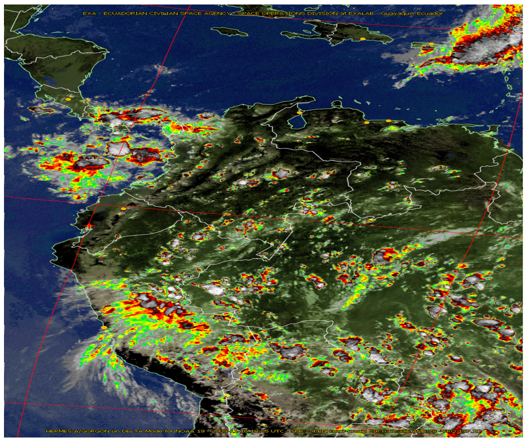

Fig. 8: Multi Spectral Analysis (MSA) - with precipitation enhancement showing cloud charging during high thunderstorm activity in Ecuador. With this enhancement, high cold cloud tops are coloured to indicate the probability and intensity of precipitation.

Alpha Mode: A Near-Miss Event

On February 5th, 2010 at 05h20.23 -5:00 UTC, the HERMES-A/MINOTAUR Space Flight Control Centre monitored the pass of SwissCube-35932 an Iridium-33DB-34891 that could pose a threat of collision. The pass occurred without incident, however the only GS in view of SwissCube and able to monitor was HERMES-A.

The live signal was routed via Internet to the EPFL[17] Space Center and the Space Operations Division (SOD) crew at EXA could hear the SwissCube signal loud and clear from acquisition of satellite (AOS) till loss of satellite (LOS) at a range of 3115km northbound using HERMES. Signal analysis indicated the distance between the objects was 1058 m at closest approach.

The EXA-SOD continued to monitor the objects when within range for the next few days and found that SwissCube remained safe. The STK simulation made at EPFL shown in fig, 9 was verified by HERMES results.

The near miss event made evident the need of this online and real-time tracking and monitoring as HERMES-A/MINOTAUR team did by tracking the satellite signal over the Internet in real time to monitor if the collision was to happen. In coordination with EPFL, users around the globe were able to watch the pass in real-time.

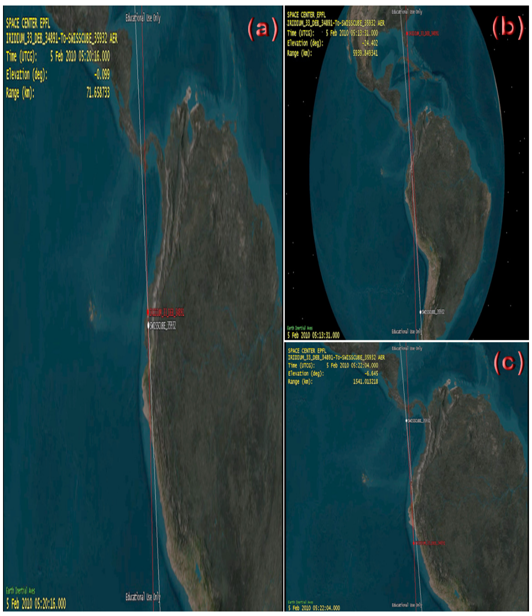

Fig. 9: February 5th, 2010 a near-miss collision between Iridium-33/COSMOS 34891 debris and the SwissCube cubesat occurred. Fig. 1 (a) shows the angle between the two orbiting/approaching bodies ~ 0.09 deg. (b), approaching (c), after the event. Adapted from EPFL[17]

III. IMPLEMENTATION

The relative movement between LEO satellites and the Earth requires tracking with the most common method 'program tracking'. The Keplerian elements of satellite and GS location are known, so the actual position of spacecraft any given time can be calculated by applying orbital mechanics.

These Keplerian elements are provided in the form of two line elements (TLE), which allows for a standard update to the satellite database in the program. Five of the six orbital elements are quasi-stable over time, leaving only a single parameter varying with time. The computational advantage makes TLEs a near-universal tool used by space agencies to describe the orbits of their satellites[18].

The PC running this tracking program determines azimuth / elevation angles of antennas versus time and drives antenna rotators to compensate for spacecraft movement. As a result, the antenna points correctly to the spacecraft and follows its movement in the orbital velocity vector above horizon, from AOS till LOS.

The tracking system also compensates for Doppler shift on transmit and receive frequencies due to the significant relative movement between spacecraft and GS. These frequencies are shown on the HRD-Sat Track software as VFO-B and VFO-A respectively.

Satellite tracking, remote controlling of communication radio, acquisition of data and post processing are generally too complicated to be processed and displayed by one or two computers alone. The remote users have generally distributed processing of the entire setup using several PCs with multiple displays. While this setup has been run on a single laptop, a common distribution is as follows.

1st PC performs communications control using HRD-Radio and HERMES web interface[19] IP antenna cameras (onboard and external) and antenna polarity selection. The interface is shown in figure 10.

2nd PC functions orbital control using HRD-Sat Track, HRD-Antenna Rotator (AlphaspidRAS; working on local PC at EXA but results are shown remotely at user end) on 1st monitor display and Google Earth (GE)[20] on the other.

3rd PC carries out decoding/data processing using HRD-DM780 or MIXW, as a network client of the 1st and 2nd PC, so the decoding program can track the frequency changes.

4th PC works orbital simulation running Satellite Tool Kit (STK)[21] simulation of the current NOAA satellite showing the orbital mechanics data in real-time. The STK real time simulations are well synchronized, so that when the footprint border of the satellite, in full 3D simulation, touches the antenna,

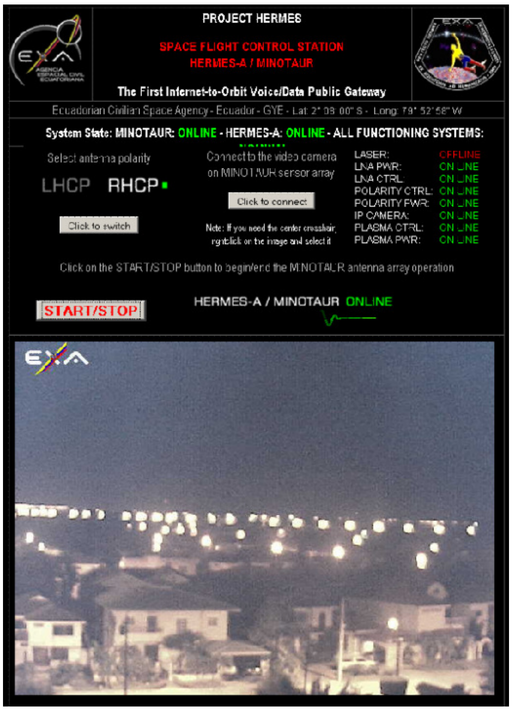

Fig. 10: The communications control using HERMES Web Interface to run/stop, antenna polarity change and onboard IP camera. The most important interface for remote users.

the AF is received to all participating remote users. Initial setup for weather decoding and processing can be found on the Project Agora website[22].

If a faster PC is used, then both HRD-Radio and HRD-Sat Track can be run on a single computer. A real-time STK simulation is shown in fig. 11.

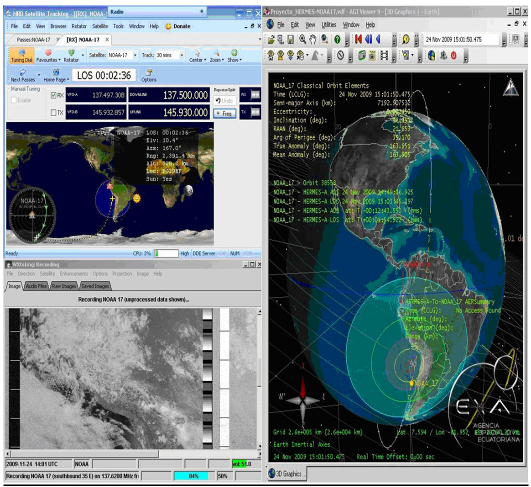

Fig. 11: A real-time STK simulation shows Keplerian elements while capturing NOAA-17 in delta mode operation.

IV. CONSTRAINTS

There were a few constraints found in the execution of this project.

VRS-RM/ Port Blocking/ Firewall

It has been observed that VRS-RM freezes due to saturation at EXA end and requires a reset every few months. Secondly, one remote user in Japan had an issue with port blocking due to firewall security at their organization. Because of this, they could not access HERMES remotely.

To resolve these problems at both ends and as a redundant protocol, a 'Broadwave Interface' was created as an alternative to VRS-RM but not a complete replacement. HERMES typically allows access through the "HERMES Broadwave Interface", meant to be used over port 80, when access to port 264 is not possible due firewall issues. It requires static IP (authenticated by HERMES) to use as this provides a layer of security on the router

The other option is Skype[23], for delta mode when using MINOTAUR. It works in all modes, but as stated earlier, VRS-RM is the first option in all cases.

As an alternative: The remote users can receive AF signals by accessing a remote interface on port 94 to process the images after the pass is completed. The AF .wav of all NOAA satellites for the previous seven days passes are available on the EXA server.

Network Latency

A good Internet connection with Round Trip Time (RTT) < 50ms was assumed to be required for remote operations, but many ISPs between a remote user node and HERMES are not offering up-to-the-mark connections as revealed by traceroute and observed in all four modes of operations. It was found that the RTT is usually greater than 300ms which does not allow for synchronous links to HERMES. The RTT and is shown in fig 12 and traceroute in fig. 13.

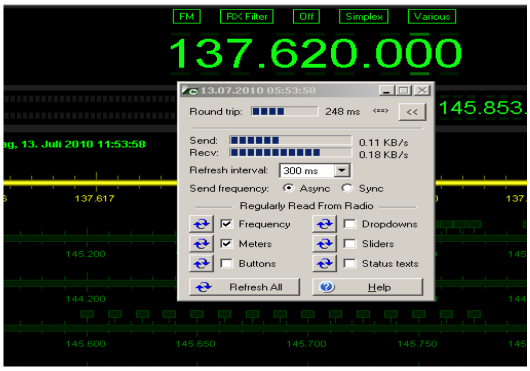

Fig. 12: The round trip time on July 13, 2010, between Graz, AUSTRIA – HERMES, EXA.

Fig. 13: The current traceroute on June 14, 2010, between Graz, AUSTRIA – HERMES, EXA.

As Internet speed is never constant and checked results are always different, there are a few spots the Internet connection will jump through to get to Ecuador, so it is likely to have changes in the latency. The immediate effect is observed with freezing HRD during satellite pass acquisition. From command and control point of view, HERMES is tested for Alpha and Beta[15] mode with satisfactory results, but Voice Mode (Gamma[15]) is difficult to accomplish with such an issue for remote operations. None of participating users was able to reduce RTT less than 150ms (with a 50ms requirement). The traceroute points out that the bottleneck is somewhere just before Ecuador. The HRD, ping and traceroute all validate that the round trip time (RTT) is ~ 250ms even when the Internet usage is not so high in Graz, Austria and other remote users' sites.

Synchronization Loss

We observed the synchronization losses very often during NOAA image capturing process. The problem is due to some high priority processes running in the client computer while receiving the NOAA signals. The effects are shown in fig. 15.

To overcome this problem, we cut those processes and gave high processing priority to the VRS-RM and WXTOIMG and the processor affinity on both CPUs (dual processor PC). Moreover, use of resync option during acquiring and processing NOAA images is of great help.

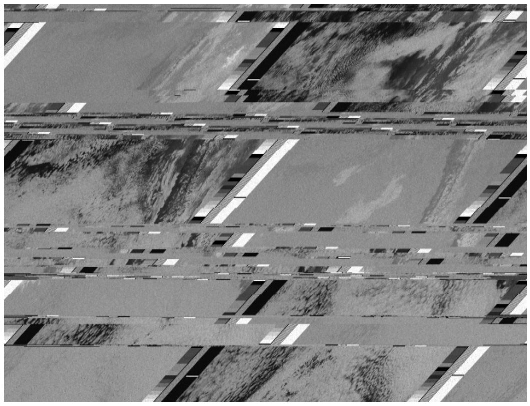

Fig. 15: Image is 'slanted' due to under-sampling frequency and has 'Synchronization losses' due to high priority program running on the machine.

V. AMATEUR LICENSE REQUIREMENT

The advantage of both receive-only modes, Delta and Alpha, is that there is no requirement for obtaining amateur license for all remote users participating in the project AGORA. The Amateur license is needed to transmit on Amateur entitled bands (e.g. 2m, 70cm), where most of the AMSAT or/and university class nanosatellites are/will be communicating with their nanosatellites like RAX[24], TUGSat1[25] and LiNSAT[26, 27]. The same is true for remote users who want to participate in transmissions to amateur/university satellites in "Mode Beta" and "Gamma". The HERMES accepts all transmissions encapsulated in AF. Furthermore, as a redundant confirmation, remote users were all times in contact with local GS operators in Ecuador who were responsible to turn off the system if required (as per US, Ecuadorian, Austrian and Japanese law). For mode "Alpha and Delta", certainly, ANYONE can receive with or without a license, thus the magnetism of project AGORA. The relevant observed information is tabulated in table no. 2.

Info-Issues/Modes	Alpha	Delta
Modulation	CW, USB	AM, FM
Data reception	Telemetry AF Receive-only	Weather AF receive-only
Amateur License	No	No
Sync. Loss	No	Yes
Network Latency	Yes	No/Yes
Satellite Tracking	Yes	No/Yes
Doppler Shift (Detectable at AF)	Yes	No
Accomplished	Yes	Yes

Table 2 : The information related to two of four modes, Alpha and Delta

VI. CONCLUSIONS

We have demonstrated a synchronous round-the-world test of the HERMES by a distributed team which was able to track, download and decode NOAA and other amateur satellites transmissions using a suite of free softwares. Among many constraints, synchronization loss was addressed and network latency issues were discussed.

The SwissCube near-miss event was only possible through the use of this gateway for a live relay to satellite owners and after determination of SwissCube rotation rate.

Project AGORA has provided many users the ability to receive signals from spacecraft in orbit who would not otherwise have access to a ground station. It is hoped that this system will help to inspire a new generation of scientists and engineers in countries, otherwise disconnected from space exploration.

VII. ACKNOWLEDGEMENTS

We are grateful to EXA and Cmdr. Ronnie Nader for providing access to the HERMES. This work is partially funded by HEC-Pakistan and FFG-Austria.

VIII. REFERENCES

[1] NPOESS: Future NOAA Satellites, http://noaasis.noaa.gov/NOAASIS/ml/future.html

[2] NOAA KLM User's Guide, http://www.ncdc.noaa.gov/oa/pod-guide/ncdc/docs/klm/html/c4/sec4-2.htm

[3] Advanced Very High Resolution Radiometer (AVHRR) http://noaasis.noaa.gov/NOAASIS/ml/avhrr.html

[4] Ecuadorian Civilian Space Agency (EXA), http://www.exa.ec

[5] R. Nader, "The HERMES, Internet-to-Orbit Gateway" UNOOSA, Graz, Austria 2009

[6] AMSAT, http://www.amsat.org

[7] Mercury GS Network, http://mgsn.sourceforge.net/index.php

[8] GENSO, http://www.genso.org/

[9] The MINOTAUR, http://minotaur.exa.ec/

[10] WXTOIMG, http://www.wxtoimg.com/

[11] APT-Decoder, http://www.poes-weather.com/

[12] VRS Remote Monitor Listen Connection, http://www.nch.com.au/vrs/remote.html

[13] Ham Radio Deluse, www.ham-radio-deluxe.com/

[14] MixW, http://mixw.net/

[15] G. Jaffer et. al., "Using a virtual ground station as a tool for supporting higher education", IAC-10.E1.4.11, Prague Czech, 2010 (accepted)

[16] Quadrifilar Helical Antenna (QHA), http://homepages.ipact.nl/~pa1are/QHA.html

[17] SwissCube, http://swisscube.epfl.ch

[18] Satellite Orbit Analysis, http://www.wmo.int/pages/prog/sat/cgms/directoryofapplications/en/ap1-08.htm

[19] The HERMES Project, http://hermes.exa.ec/

[20] Google Earth, http://earth.google.com/

[21] Satellite Tool Kit, http://www.stk.com/

[22] Project Agora http://sites.google.com/site/projagora/instructions/image-translation

[23] Skype, http://www.skype.com/intl/en/home

[24] UoM RAX Satellite, http://rax.engin.umich.edu/

[25] O. Koudelka et. al. "TUGSAT-1 / BRITE-Austria - the first Austrian nano-satellite" IAC-06-b5.2.6 pp. 8, 2006.

[26] G. Jaffer et. al., "Detection of Sferics by a nano-satellite", IAC-08.B4.2.12, Glasgow, UK, 2008

[27] K. Schwingenschuh and G. Jaffer, et. al., "Feasibility study for the future Austrian nano-satellite", 37th COSPAR Scientific Assembly 2008, Montreal-Canada

-The date of access to all URLs in the references is Sep. 6th, 2010