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# Distributed Operation of a Military Research Micro Satellite Using the Internet

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**PICOSat is a micro-satellite carrying four research payloads for the United States Air Force – two ionosphere measurement payloads, a vibration damping system, and a polymer battery. It was built by Surrey Satellite Technology Ltd (SSTL) under contract to the Space Test Program of the United States Air Force and is based upon SSTLs standard micro-satellite bus.**

**PICOSat was launched in September 2001 and is operated by SSTL from its control center in Guildford, UK under contract to the USAF. To increase the data return from the mission, a second groundstation was installed at the USAF Academy in Colorado Springs, which is remotely controlled from the SSTL operations center via the open Internet. SSTL provides low cost access to space with its range of nano, micro and mini satellites, and this philosophy requires low cost spacecraft operations. Networking a number of low cost groundstations via the Internet can provide a cost effective solution to increase the data return from the mission, and increase operations flexibility. This paper will discuss the PICOSat spacecraft and the operations concept for operating the mission. An overview of the protocols will be presented along with the issues regarding the use of the open Internet for control of a spacecraft.**

## I. Introduction

Surrey Satellite Technology Ltd has installed a number of ground stations for customers worldwide and has collaborative operations agreements with these customers for spacecraft operations. Individually these ground stations are capable of commanding and recovering data from many of the SSTL spacecraft. Each ground station will have a maximum visibility of less than 2 hours per day for each spacecraft, thus limiting the data recovery capacity from each station.

By networking these stations together with the Surrey Mission Operations Centre, data capacity may be increased considerably, thus benefiting all parties and maximizing the capability of the spacecraft. An additional possibility is to have the satellites operated from one central station, using the antennas and equipment of the remote station as an extension of the main ground station. This allows not only more visibility, but it also allows operation of spacecraft using communication bands that may not be available in the geographic area of the main station, but that are available in the area of the remote station.

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## II. Groundstation Networking

A spacecraft in an 800km Low Earth Orbit is travelling at approximately 7.5km per second and has a visibility circle of approximately 6000km. This means that any ground station will be able to receive the spacecraft for a maximum period of 15 minutes per pass. In such an orbit, the spacecraft will orbit the Earth 14 times per day, and the latitude of the ground station will determine how many orbits are visible at each station. For a polar orbit, a station at high latitudes (i.e. near the poles) will have visibility during all passes, where-as a station on the equator will only have visibility for approximately 4 passes per day.

The following chart shows the duration that a spacecraft is above a given elevation angle for various latitudes. This chart has been calculated for an 800km polar orbit and assumes a radio horizon of 0 degrees at each station. If the local radio horizon is higher than 0 degrees, the visibility time will decrease considerably.

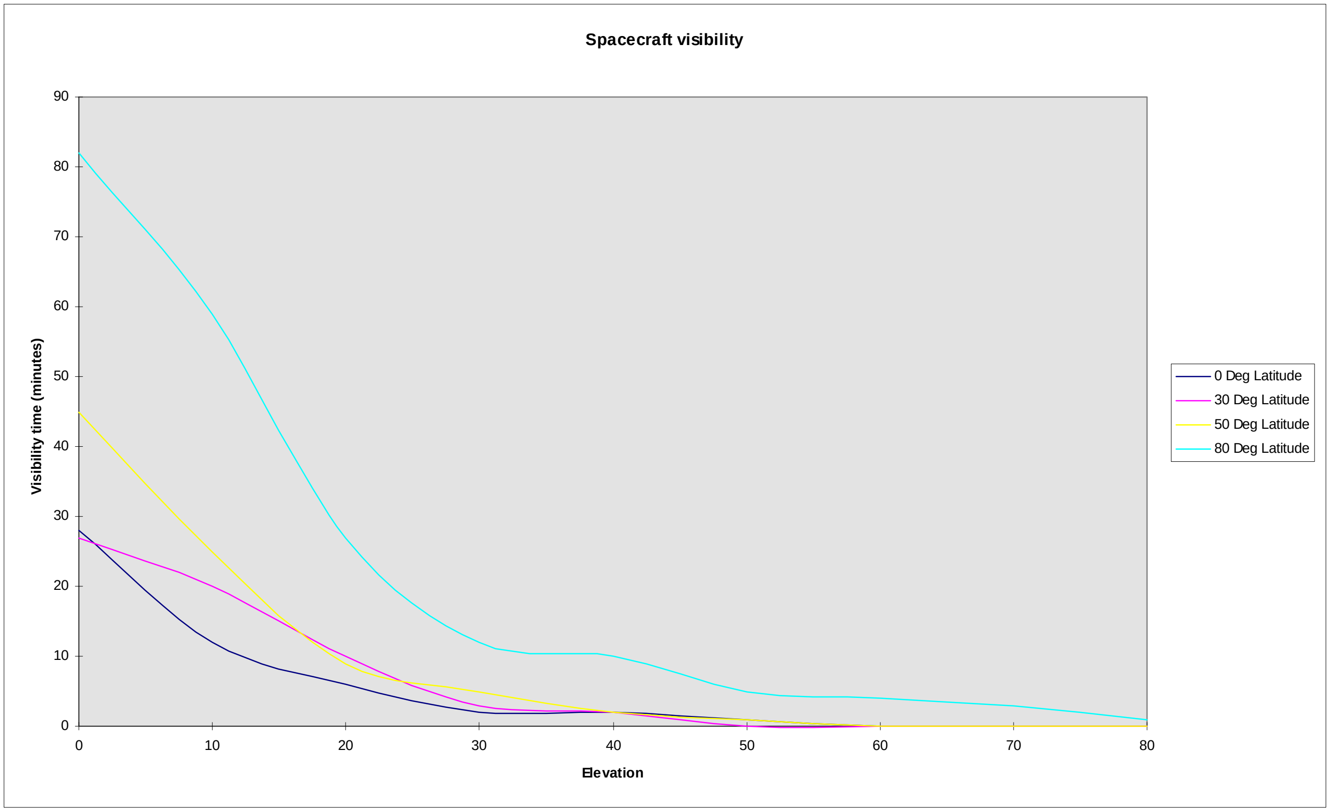


**Figure 1. Spacecraft visibility with respect to latitude and ground station antenna elevation**

The latitudes graphed above equate to the following geographic locations -:

| Latitude | Geographic region |
|---|---|
| 0 Deg Latitude | Malaysia, Thailand, Singapore, Nigeria |
| 30 Deg Latitude | USA, China, Australia, Chile, New Zealand |
| 50 Deg Latitude | Europe |
| 80 Deg Latitude | Spitsburgen, McMurdo |

The maximum total daily visibility time for each area is as follows -:

| Latitude | Visibility (minutes) |
|---|---|
| 0 Deg Latitude | 55 |
| 30 Deg Latitude | 63 |
| 50 Deg Latitude | 91 |
| 80 Deg Latitude | 206 |

By networking ground stations, the total visibility, and therefore the data recovery capacity of the network, can be increased considerably. The following chart shows the maximum possible visibility for each region simply by networking the local ground station with the Surrey Mission Operations Centre.

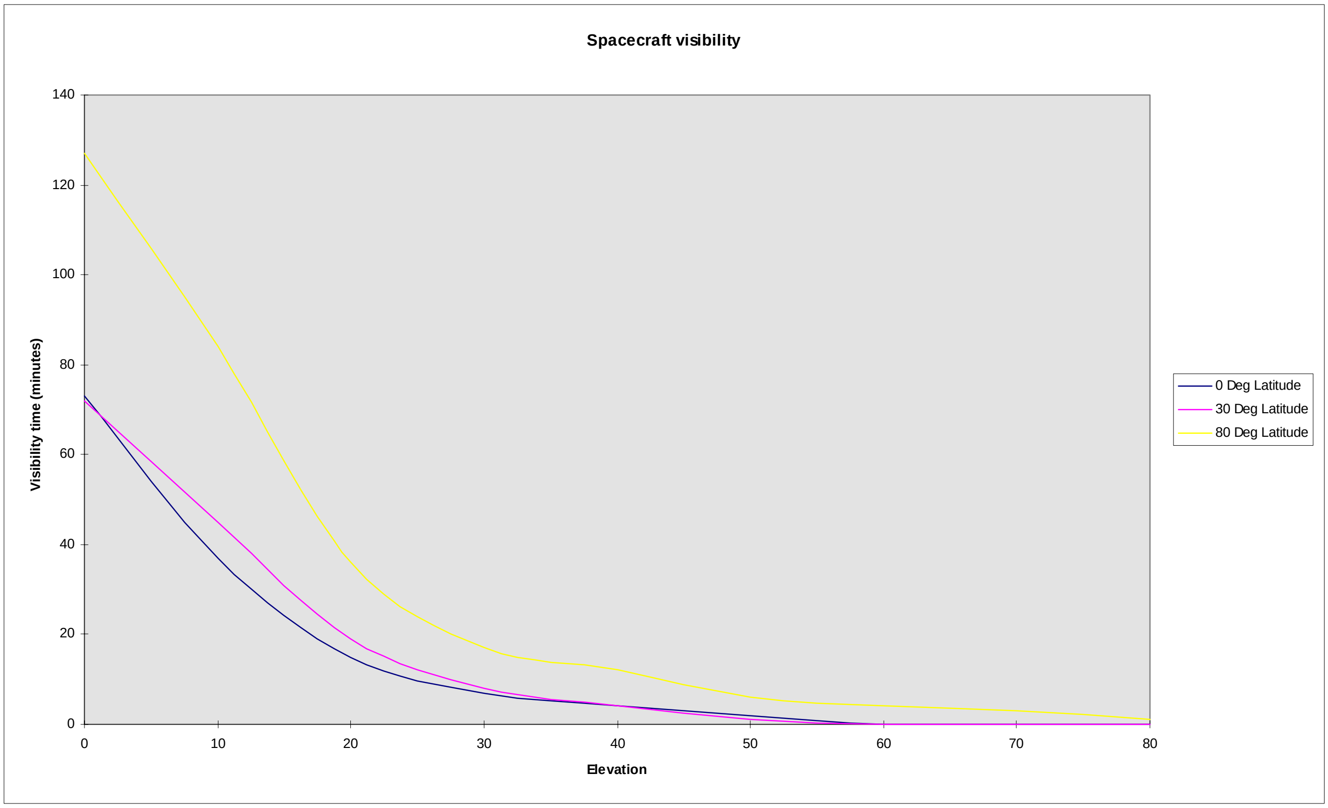


**Figure 2. Spacecraft enhanced visibility after networking with Surrey**

The maximum total daily visibility time and approximate download capacity for each area when networked with Surrey is displayed below.

| Latitude | Stand alone | | | Networked | | |
|---|---|---|---|---|---|---|
| | Visibility (minutes) | Capacity (9600bd) | Capacity (38400bd) | Visibility (minutes) | Capacity (9600bd) | Capacity (38400bd) |
| 0 Deg Latitude | 55 | 3.25MB | 13MB | 146 | 8.75MB | 35MB |
| 30 Deg Latitude | 63 | 3.75MB | 15MB | 154 | 9.2MB | 36.5MB |
| 50 Deg Latitude | 91 | 5.25MB | 21.5MB | | | |
| 80 Deg Latitude | 206 | 12MB | 49MB | 297 | 17.5MB | 71.2MB |

The above shows a clear advantage in networking ground stations with the Surrey Mission Operations Centre and shows that stations operating in equatorial regions may increase their data capacity by 150%. Networking additional ground stations for each spacecraft may provide additional increases, however it should be noted that where the ground station visibility circles overlap, the advantages of the system drop off and the complexity increases considerably.
In addition to the increased data capacity, there are additional benefits of the system -:

Timely command access. Since the spacecraft will be in view of one of the networked ground stations more often, commanding may be carried out more regularly, and at more appropriate times.

Regular telemetry acquisition. Telemetry may be acquired more regularly by one of the ground stations in the network and distributed within the network. This allows closer monitoring of the spacecraft especially during critical operations.

## III. Managing Shared Resources

The management of antenna resources within a traditional ground network may be the single largest problem to be overcome. Agencies require high availability of antennas, and exclusive (or high priority) access to the antenna during passes of their space assets. These requirements traditionally afford a high price, and may not be compatible with low cost operations concepts.

SSTL spacecraft operate a highly autonomous operations concept, which can support multiple ground stations capable of recovering data. This allows unscheduled downlink sessions to be made at any time, which in turn permits the sharing of ground resources on an ad-hoc basis. In such instances, agreements for resource sharing between station managers can easily be achieved. Each station in the network will effectively get whatever the remote station is able to supply.

For spacecraft with higher operational requirements, an agreement can be made between managers so allow priority availability of ground resources for a specific mission. The Surrey Mission Operations software supports mission prioritization, and by correct setting of these parameters, mission requirements should be ensured.

## IV. Implementation

The Surrey Mission Operations Software requires modification to support station networking, however many features have been designed into the software from the start. The software already uses the TCP/IP protocol for communicating between local modules and this may be easily extended onto the Internet.

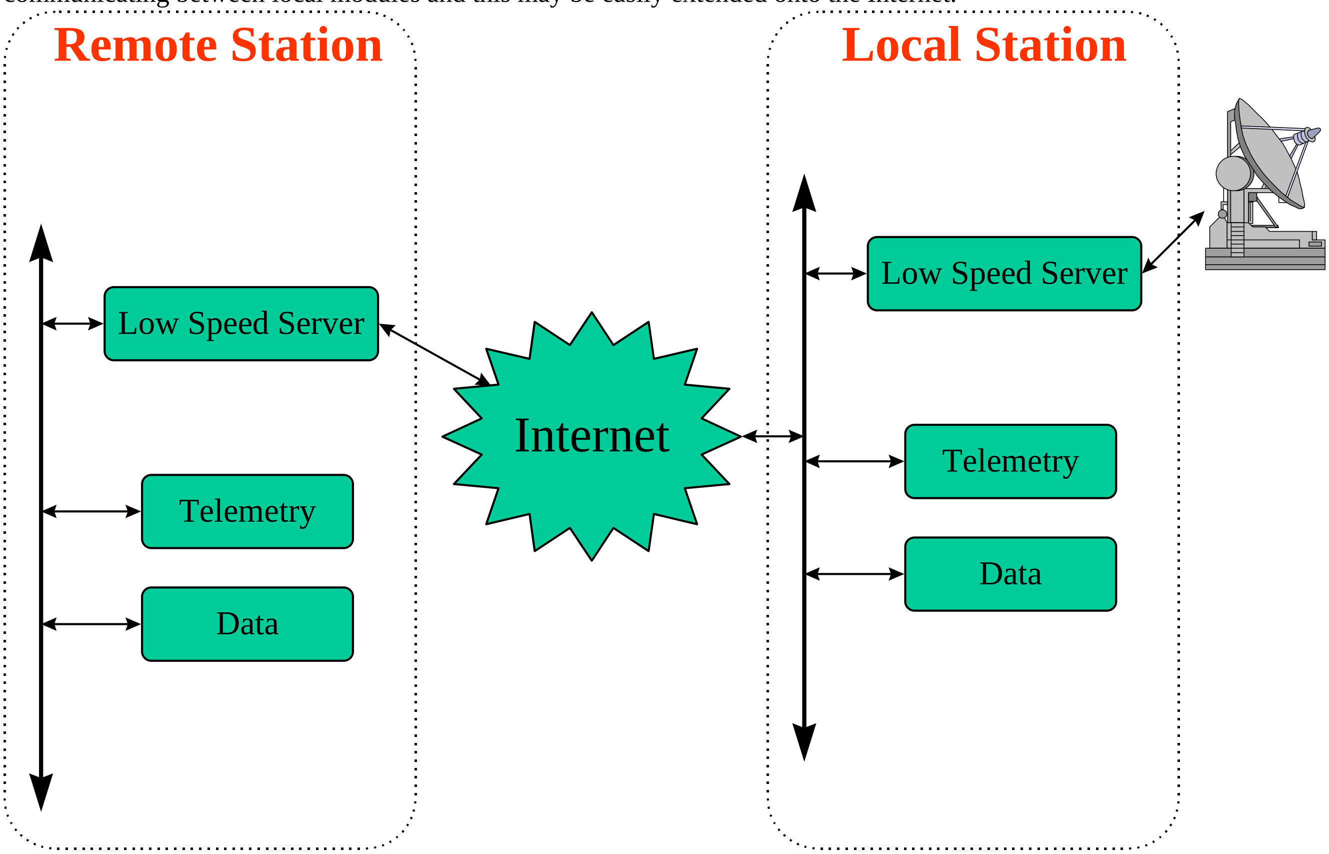


**Figure 3. Implementation of spacecraft control over the Internet**

### A. Low Speed Server

The Low Speed Server is a standard part of the Operations Centre Software and currently interfaces various software components to the station hardware. This allows many applications to access the spacecraft data links (both uplink and downlink) simultaneously by multiplexing requests and distributing data.

SSTL space link protocols use packetised communication protocols, and the Low Speed Server provides the extension of the space link over the ground network. The software supports services to return all received packets, or to filter packets based on destination address.

The Low Speed Server permits access to the spacecraft for all communications via the flight computers. It does not (currently) support asynchronous operations formats that are generally only employed for commissioning and emergency operations. This support will be added in the near future to allow SSTL to undertake full spacecraft operations support from a remote location.

| **Service** | **Description** |
|---|---|
| Return all frames | All AX.25 packets are returned to the task |
| Return specified address(es) | Only frames destined to the AX.25 the addresses specified during link initialisation |
| Transmit frame | Transmits an AX.25 frame |
| Return async. | Return all asynchronous data |
| Transmit async. | Transmits asynchronous data |

For operations within an operations centre, the Low Speed Server distributes its data to a number of applications, such as Telemetry/Telecommand, payload data download, and time synchronisation software. While most applications use the “return specified addresses” service, there is still some duplication of data transmission to a number of applications since m many applications require the same status frames.

To support efficient station networking, the Low Speed Server has been upgraded to also take its data stream from another Low Speed Server, which may be resident at another physical station. This allows a single data stream to be transmitted from the remote station to the local station, and for the local Low Speed Server to provide the dissemination functions.

### B. Tracking and Control

The Tracking and Control application is the primary control task for the SSTL Mission Operations Centre station. It is responsible for controlling the station automation, and tracking spacecraft. The control software employs NORAD Two Line Elements (TLE) to predict spacecraft visibility over a ground station, and can dynamically allocate a spacecraft pass to a system depending on antenna availability.

The station Tracking and Control tasks has been upgraded to support multiple remote stations. This requires modification to the pass scheduler and additional configuration windows to allow the remote station parameters to be entered. This includes security features to ensure that only specified stations may remotely acquire data.

## V. Security

SSTL employs an end-to-end security system for spacecraft command. This system ensures that any parties eavesdropping to any or both sides of command sessions are (easily) not able break the code and access the spacecraft. Connection to the Internet does not unduly reduce this security since the commands are already transmitted via an open link (i.e. the RF links).

Payload data transmissions are generally transmitted in the open and are in any case transmitted via an open link (i.e. the RF link). Should secure data transmissions be required, data should be encrypted on the spacecraft prior to downlink, and therefore transmission via the Internet does not unduly reduce security.

Data transmitted between ground stations may be encrypted using a router employing Virtual Private Network (VPN). This ensures that all data transferred across the open Internet is encrypted, and is only transmitted unencrypted within the participating stations. VPN technologies are widely used to connect networks in a secure manner using authentication, encryption and tunnelling services provided by IP protocols.

## VI. Requirements

For a ground station to participate in the network, there are certain requirements. A permanent connection to the Internet with reasonable capacity, and upgraded Mission Control software are the minimum requirements. To support security and VPN, a router with these features is required.

*1. Network link requirements*

The network connectivity requirements are as follows -:

- Full time connectivity.
- Fixed IP addresses for all ground station computers.
- Data rate at least 1½ times that of the downlink data rate.

*2. Router requirements*

To support secure connections between stations, a router with VPN (Virtual Private Networking) support is required. Such a router may also support additional security features such as a firewall, to allow a full security policy to be enforced.

SSTL has recently implemented the use of Internet Protocols (IP) for space use. In such a scheme, the router may act as a bridge, to pass data from the network directly onto the uplink/downlink. To support this, the router must have a synchronous serial port (HDLC) that can be configured to use Frame Relay. This type of interface is commonly used for WAN (Wide Area Network) applications.

## VII. Hardware Configuration

The following diagram presents a possible network configuration to support standard AX.25 protocols, asynchronous bootload protocols, and Internet Protocols.

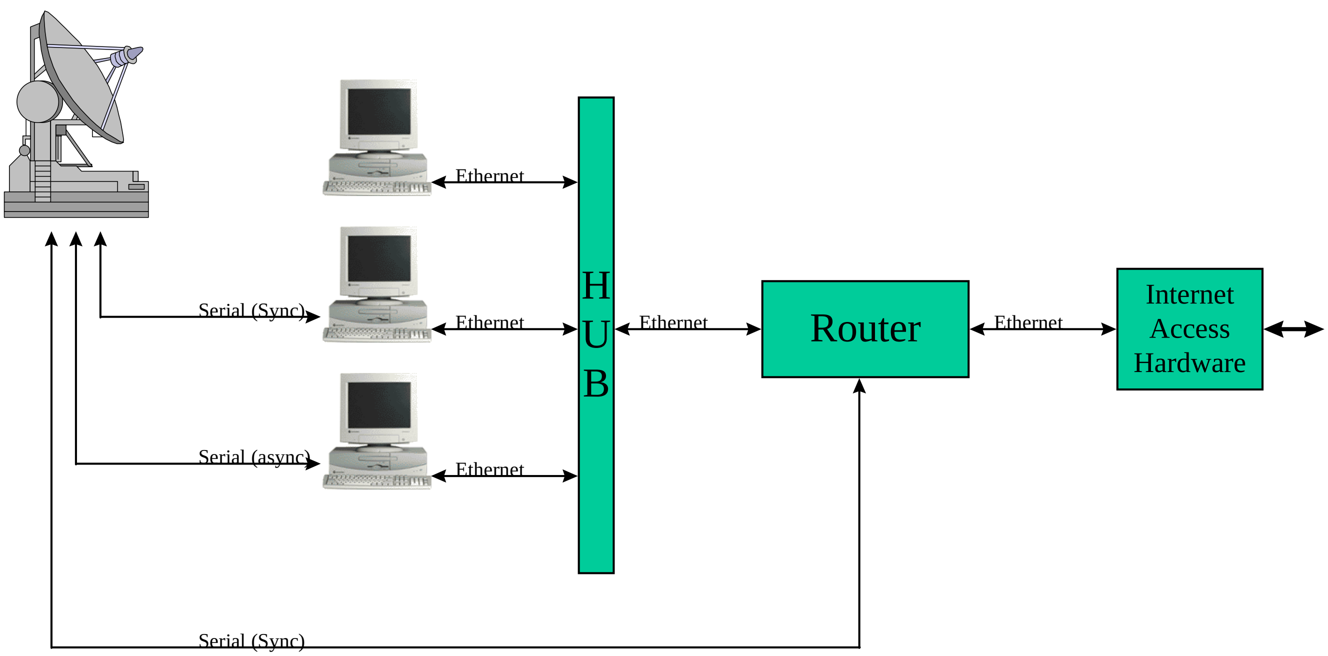


**Figure 4. Spacecraft control local hardware implementation**

In this configuration, the router can provide full security enforcement (firewall and VPN) as well as act as an interface for IP spacecraft access via a synchronous serial interface.

## VIII. Test Configuration

The United States Air Force Academy ground station in Colorado Springs, USA has been used to test and implement the above concepts.

It was installed by SSTL in 1999 to support the USAF PICOSat mission. Initial testing showed that the station can be used as a remote antenna to support operations on SSTL spacecraft. A fully operational system was implemented to support the PICOSat operations from Surrey following launch in September 2001. The USAFA ground station is directly connected to high capacity Internet links capable of supporting spacecraft operations. Security requirements and documentation had to be met before connection to this military installation was authorized.

## IX. Results

The above configuration was tested during June and July 2001 at the United States Air Force Academy ground station.

Tests using the USAFA ground station were only possible using low data rates (9600bd). This operated extremely well and trials were conducted to upload, download and command the UoSAT-5 spacecraft. Initial tests required a temporary security authorization to allow the data through the firewall, however a more suitable permission has now been obtained to operate the system permanently. Due to the high Internet data rates available between the USAFA and SSTL control stations, and the low spacecraft data rate, this system performed at 100% throughput. Some minor delay is noticeable when transmitting commands from the remote station due to the additional round trip delay inherent in the Internet, however this was not an operational problem.

The system has now been operational for almost three years and functions as designed to operate PICOSat from Surrey on a daily basis without needing interaction from USAFA staff other than equipment maintenance.

## X. Conclusions and Follow-up Work

This study has demonstrated the ability to use low cost networking to support a secure and reliable ground network for space operations. Current low-cost Internet software and hardware is available to provide secure communications over public networks.

The work undertaken in this study supported SSTLs standard space protocols (AX.25) and is not directly compatible with standard protocols (e.g. Internet Protocols or CCSDS). A CCSDS standard (SLE – Space Link Extension) is available to perform a similar function and if Internet Protocols are to be supported directly on the space link, Mobile IP may be employed to perform a similar function.

SSTL is currently using Internet Protocols to control a series of spacecraft of the Disaster Monitoring Constellation, an international series of spacecraft designed and built at Surrey dedicated to providing daily imagery of any point on Earth to support disaster relief operations. SSTL is looking into the use of Mobile-IP as part of this work. External companies have already shown an interest in this technology.


## XI. Acknowledgments

The authors wish to thank USAF-STP and AFOSR for their support of the PICOSat project.


## XII. References


Jackson, C., “Groundstation Networking”, SSTL SPBQ-23909-01, 2000.