The Design and Role of a Low Cost Semi-Automated Mobile Ground Station in the Tracking and Commanding of Low Earth Orbit Satellites

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Abstract. The traditional ground station consists of a building full of specialized hardware and a large stationary antenna operated by a group of on-site personnel. Reduced budgets have forced project managers to re-evaluate this concept in search of ways to save money. To this end, PC-based systems have been developed that reduce hardware costs and the number of machines and personnel necessary to perform station tasks.
In this paper, we will take this concept to the next level. By improving on the current PC-based systems we will further reduce the hardware and personnel costs, and by introducing the concept of a mobile ground station for low earth orbit (LEO) satellites we will reduce real estate costs while conceivably reducing the number of ground stations required. Together these ideas form the basis for the future of low cost ground station support.

Introduction

In the coming years, the number of low earth orbiting satellites deployed and operated is expected to skyrocket. This is due in large part to the increase in global satellite communications constellations such as INMARSAT, IRIDIUM, and GLOBALSTAR. With this expansion, the current environment of reduced operational budgets and standard requirements for improved performance, the use of a low cost semi-automated telemetry and command system becomes a viable solution for unique one time use or remote site supports.

One example of the need for remote ground station support came with the launches of the Mars Pathfinder and the Mars Global Surveyor. These two ambitious spacecraft were launched with Delta launch vehicles that used a new electronics package. The launch profiles had significant events scheduled to occur over Africa. A temporary support installation was established to cover these launches. Considerable effort was required to get the system installed and working in time for the first launch.

The case of the Mars missions is not at all uncommon. Often scheduled spacecraft and launch vehicle critical events occur at locations where there are no ground stations within the required ground track view area due to launch trajectories. In the past the National Aerospace and Space Administration (NASA) has used mobile ground stations such as the Vanguard tracking ship or created small single purpose tracking stations such as the Dakar station or more recently the LEO-T systems to handle these unique support cases.

The LEO-T system is relatively inexpensive compared to past options, but with recent technological advances, a newer, faster, more flexible and far cheaper implementation of a similar system can be created. Small portable antennas now exist which can be packed into small containers for easy transport. Higher speed processors also now make it possible to handle the telemetry and command requirements of a typical LEO satellite using a single inexpensive PC system outfitted with commercial off the shelf (COTS) telemetry cards. The widespread availability of reliable Internet resources is now the world's preferred data and voice communications medium. This data network provides geographical transparency and eliminates the need for the installation of custom data lines. The combination of these new off the shelf technologies only requires integration to become the answer for short term LEO satellite telemetry and command support at remote locations. This paper will describe the design of one of these systems.

Using the proposed system, it would be possible to handle the case of the Mars missions with ease. The system could simply be flown to the remote location in several small suitcases. The antenna would then be unpacked and aligned and the portable Tracking, Telemetry and Command (TTC) systems would be connected. After that, the only step remaining before support begins would be the running of an interface test.

System Design Goals

The proposed system has a few, ambitious design goals. Firstly, the system should operate as a ground station for low earth orbit satellites and encompass all normal ground station functions. The system should also be very small. Ideally it should be contained in one PC chassis that can easily be moved from place to place. The antenna should also be small enough to be moved from place to place with a minimum of hassle. Finally, the system should have the capability of being controlled from a remote location. These goals define an effective ground station.

Meet the Usual Ground Station Requirements

At first glance this goal seems to be common sense, and to a certain point it is. Of course a ground station must handle satellite downlinks as well as the uplinking of commands. In the course of doing this, a ground station must also do some data processing and control the pointing of its own antenna. How complex these operations become is entirely dependent upon the format of the aforementioned data and commands and the amount of processing that the ground station is required to complete. Because of these differences from satellite to satellite, it is important to make sure that the system is flexible as well as powerful enough to handle whatever special needs a particular satellite may have.

Size Does Matter

These days everything is becoming smaller. Palm sized scheduling and email systems hold the lives of many professionals while fitting inside of their shirt pockets, notebook computers are less than an inch thick and weigh almost nothing, and you can even buy high-resolution monitors that are only three inches deep.

Following this trend in the design of ground stations is only logical. The traditional ground station required racks of specialized systems to handle its everyday, pass to pass tasks. Modern systems can replace most, if not all, of those older systems with small, generic PC cards tied together by a common bus. The antenna has always been one of the largest and most important parts of a ground station. While its importance has not been diminished, new technology has shrunk even this large piece of equipment to a small manageable size.

Is There a Ground Station Button on the Remote?

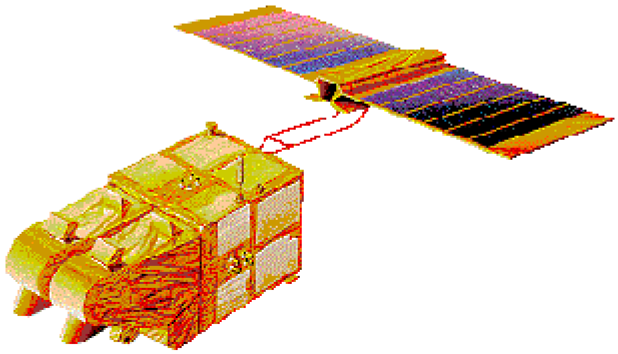
There's a remote control for your television, your stereo, and your VCR. Why isn't there a remote control for your ground station? Remote control of a system allows for convenient everyday operation even when the system being controlled is located thousands of miles away. Modern data networks make communication between geographically distant systems almost transparent and instantaneous. This technology can be used to allow operational control centers to coordinate multiple, remote ground stations from one location. With today's reduced budgets the cost savings achieved through the reduced travel costs and staffing levels that remote ground station control provides make this feature a "must have."

Satellite / System Specifications

The Satellite

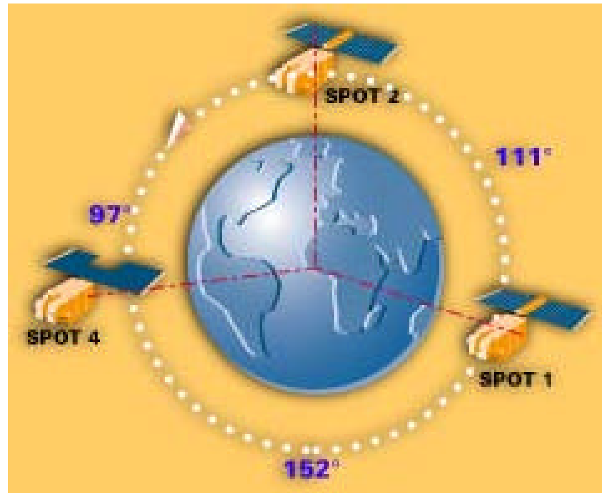
For the purpose of this paper, we will describe a system with hardware to support a real-world satellite. The SPOT (Satellite Pour l'Observation de la Terre) satellites of France's CNES (Centre National d'Etudes Spatiales) are typical low earth orbit satellites used for Earth observation and imaging and have the following characteristics:

Altitude:	832 km (at equator)
Orbit:	Circular at 98.7 degrees
Period:	101 minutes



The SPOT Satellite

Downlink	
Carrier Frequency:	2.206 GHz
Subcarrier:	65.536 kHz
	S-Band
Modulation:	Pulse Code Modulation (PCM) / Phase Shift Key (PSK) / Phase Modulation (PM)
Transmission Power:	0.2 W
Transmission Bandwidth:	140 kHz
PCM Format	
Bit Rate:	2.048 kbits/sec
	Bi-Phase-L Code
Words / minor frame:	256
Minor frames / Major frame:	16
Bit Synchronizer	
Code:	Bi-Phase-L
Bit Rate:	2.048 kbits/sec
PSK Demodulation	
Loop Band:	2
External / Internal Filter:	Internal
Bandwidth:	6.15 kHz
Subcarrier:	65.536 kHz
Uplink	
Carrier Frequency:	2.031 GHz
Loop Bandwidth:	Medium
Modulation Mode:	PM
Transmission Power:	180 W (Wallops) 1 kW (Santiago and Goldstone)
Command	
Baseband Modulation:	NRZ-L/PSK/PM
Subcarrier:	8 kHz
Clock Frequency:	2 kHz



The SPOT Constellation

The Telemetry

The proposed system described in this paper would handle a downlinked Time Division Multiplexed (TDM) telemetry data stream. This is one of the most common spacecraft telemetry formats that ground stations support. A typical downlink telemetry data rate of ten megabits per second will be used in all bandwidth calculations and board selections.

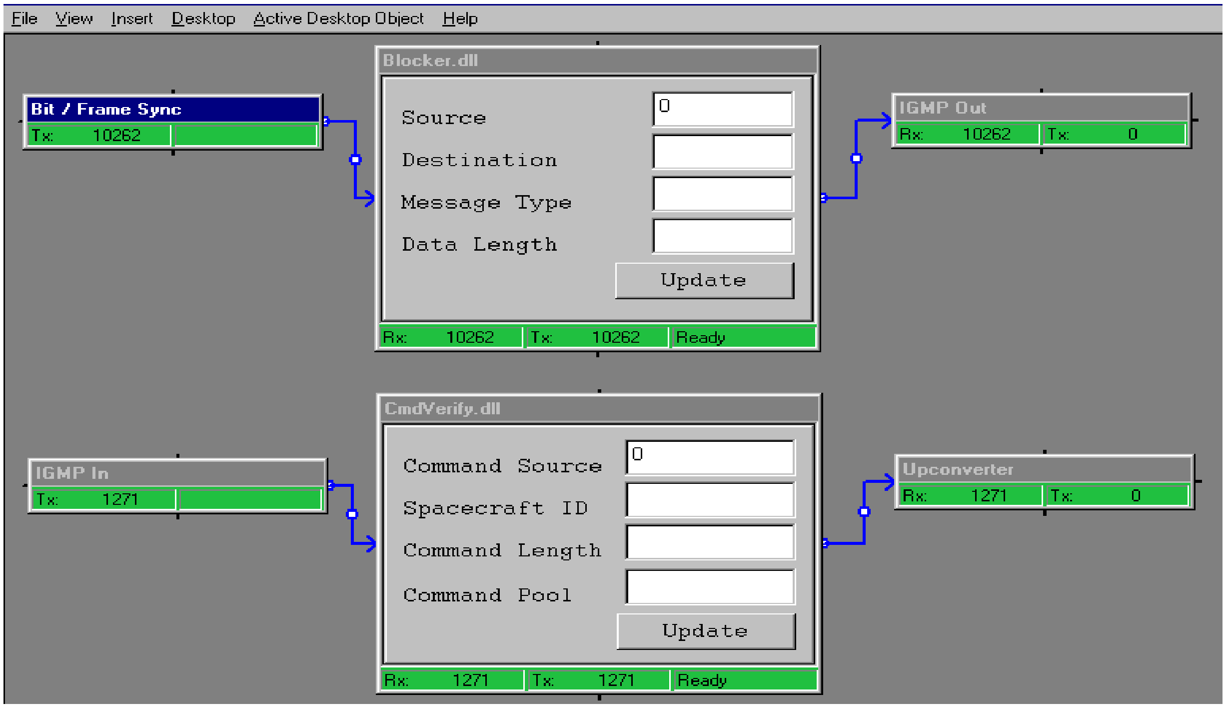
<u>System Design</u>

The design for our system can be broken down into two separate and distinct parts: the foundation application and the antenna and control system. Both rely heavily on COTS pieces to implement the system in as simple and as cost-effective a way as is possible.

Every Reliable System is Built On a Solid Foundation

Our system design is based upon a “foundation application”. A foundation application is a kind of software container that provides the basic functionality found in all applications (i.e. configuration, printing, device interface support, disk access, etc.). Into this container can be placed software components, specialized devices, and program extensions.

The software components are small, efficient libraries that provide specific functionality such as data item monitoring and data encapsulation. The devices are also interfaced with through small libraries. These components and devices can be chained together to provide the complete functionality required by a



A Sample Foundation Application View

system. Program extensions are add-ons to the basic functionality of the foundation application that can provide capabilities such as automated scheduling.

The particular foundation application that this system is designed around runs on the Microsoft Windows NT operating system. It runs well on a COTS PC with at least a 300 MHz processor 128 megabytes of Random Access Memory (RAM). Out-of-the box, users are provided with a graphical representation of system data flow, raw data views, and an event history as well as "What You See Is What You Get" (WYSIWYG) printing. This is all presented to the user with a standard Windows interface making system use intuitive and training a snap. In order to create a system, a user simply inserts components and devices onto the application's window. Dragging lines between the components and devices connects the data flows. This newly created layout can then be configured and saved for later use.

Our foundation application also provides us with several extra features that make implementing a ground station fairly straightforward. First, the foundation application has a built-in real-time data switching capability. This allows us to change from a prime device to a backup device during a pass without a loss of data. The second nice feature that is provided is built-in remote control. This meets one of the system design goals out of the box. The remote operator is provided with a graphical user interface (GUI) exactly like the one that is seen on the local system. The overhead data transmission that this requires is very minimal, around five to ten kilobytes per second, and can easily be handled by even a low-bandwidth Internet connection. The final extra feature provided is device transparency. This means that devices of different makes and models that provide the same functionality can be swapped in and out of the system without any software rewrites providing that the device objects for all of the swapping devices are written. An example of this would be swapping a high data rate frame synchronizer for a lower data rate model. This feature is extremely useful both when the system needs to be upgraded and when a device needs to be replaced and the exact same device isn't readily available.

With so much of the overall system coming from this COTS foundation application, the only software that is needed is just four device objects and two software components.

Devices

The four device objects that are needed are a decommutator/bit synchronizer, a modulator, and transmitting and receiving Internet Protocol (IP) devices. The IP devices that we need are included with the COTS foundation application so they do not need to be custom-built. The remaining two devices can be created quickly and easily. All that needs to be done is to take the provided skeleton device object and map its well documented interfaces to the specific calls in the hardware's device driver.

The IP devices we will use in this design operate using a network protocol that has been accepted by NASA for data transport. This protocol is the standard Internet Group Multicast Protocol (IGMP). The protocol is useful for the transmission of data packets to multiple users simultaneously. IGMP is a message-based, connectionless protocol. NASA Communications (NASCOM) also appends a Real Time Protocol (RTP) header to every message inside of the IP message wrapper. The RTP header contains a sequence count inside that is checked by the receiving system to ensure the receipt of all data packets in the correct order.

The decommutator/bit synchronizer can be implemented by using any board that meets the particular data rate requirements of the particular satellite that is being monitored. Examples that meet the requirements of our specific LEO satellite are the SBS Technologies 4422-PCI Decommutator with Bit Synchronizer Daughtercard and the L3 Communications DSM720-32-PCI High-Performance Decommutator/Simulator Module. Both cards plug into the PCI bus found in all modern PCs and have maximum data rates of twenty megabits per second, providing plenty of speed to handle bursting data at our ten megabit per second data rate.

The modulator can likewise be implemented by any board that meets the particular satellite's requirements. For this specific LEO satellite, we chose the SBS Technologies 4437-P Modulator which supports data rates between one kilohertz and two point five megahertz and supports PSK and PM modulation.

It is important to remember that the specific devices can be swapped in and out of the system with ease because of the device transparency feature provided by the foundation application.

Software Components

There are only really two software components that our system will need to meet the design goal of implementing typical ground station tasks. The first component is a telemetry processing component. This component takes as its input the raw TDM data stream that comes out of the system's bit synchronizer and frame synchronizer card and will perform all of the data processing required by our system. When a telemetry frame is transferred to the input of this component, the component wakes up and begins to process the new data. This component's main function is that of table driven data extraction. There will be an extraction table defined and built for each telemetry format. The table contains the location of the telemetry word to be extracted and its location in the output data block. This table can be modified to handle changing extraction requirements. ID frame parameters in the display allow for the specification of the frame ID synchronization counter. This counter is used to identify each individual minor frame for the data extraction operation. This component could be broken up into several smaller components if the complexity of the processing is great enough, but in most cases this component will be performing simple operations such as data stripping.

The second component that is required is a command validation component. This component will take as its input commands received from the operational control center. It will check the commands for validity, perform any modifications that need to be done before output to the satellite through the antenna, and provide error feedback to the command source.

The system will communicate with its remote sites via a TCP/IP (Transmission Control Protocol / Internet Protocol) connection. Using this type of communication allows for complete geographic transparency while providing reliable data transmission and avoids the costs associated with running dedicated data lines from the ground station to the satellite's control center.

The TCP/IP connection can be supplied in a number of ways. If an ethernet connection is available, a network interface card should be used. If a network connection is unavailable but reliable phone lines are present, a simple internal, external, or cellular 56kHz modem can be used. To completely meet the design goals, the system has been designed using the INMARSAT (International Maritime Satellite Organisation) Sat-B HSD satellite communications system. This system relies on a satellite constellation to provide 64 kilobit per second data communications bandwidth over ninety-eight percent of the globe in a system that is the size of a small computer.

Is That an Antenna or a Tennis Racket?

To say that antenna technology has come a long way in the past few years would be a significant understatement. Driven perhaps in part by the increasing home digital television market and its "mini dish" antennas, the satellite communications that once required a dish big enough to sit in can now be handled by an antenna who, along with its needed receiver, RF converters, and transmitter, can fit in a large suitcase.

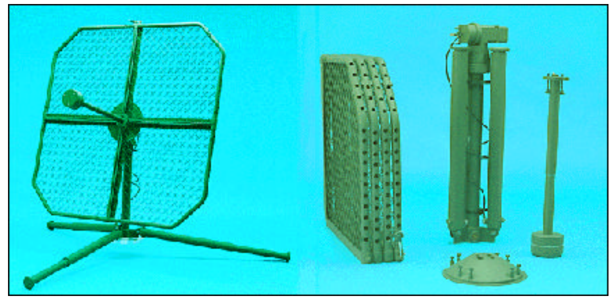
Antennas

As was the case with the COTS PC cards that we discussed in the *Devices* section of the design, there is a wide market for antennas that meet the needs of a typical LEO satellite. We chose two systems from Malibu Research that provide us with a great deal of flexibility.

The first antenna is the Model P352 Broadband Deployable Telemetry Tracking System. This system is comprised of a six-foot reflector, Electrical Conical Scanning Feed, and a Model HD 50 Harmonic Drive El/Az positioning head. The entire system is built of modular construction so any broken parts can quickly and easily be replaced in the field. The entire system breaks down into small packages suitable for mailing to any remote location. All but one of the packages weighs less than 78 pounds. The required downconverter and pedestal electronics can be placed in a box that also serves as the antenna's counterweight. The P352 is capable of both programmed and automatic tracking modes and was designed for use over S-Band and L-Band frequencies. If portability is required, the P352 can be assembled on a trailer and driven from location to location.

The P352

The second antenna is even more lightweight and portable. The Man Portable S-Band Satellite Tracking System was designed to meet needs similar to the Mars mission situation where the antenna needs to be deployed in one location for a small period of time, such as during launch, and then moved to another location for reuse. The antenna is designed using Malibu Research's Flat Parabolic Surface (FLAPS™) technology. High-strength, lightweight composites are assembled in a "tennis-racket" grid to provide a five-foot square antenna that along with its pedestal, pedestal electronics, and downconverter still weighs only a mere 32 pounds. The entire system stores in a soft case that is the size of an ordinary backpack.



The Man Portable S-Band Tracking System

The P100 Antenna Control Unit controls both antennas. This system can either be used in its own Pentium-based computer or as two controller cards in our "foundation application" system using Malibu Research's proprietary software. The control unit allows for remote operation and has built-in password protection. The unit takes care of all antenna control functions.

Receiver

Since the downconverter comes as part of the antenna systems, the only missing part in the downlink operation is the receiver. We chose the Systems Engineering and Management Company's RC-600 series Receiver Combiner since it comes with a choice of nine different RF tuners and twelve existing IF bandwidth modules. This should be sufficient for any particular station needs.

Transmitter

Depending on the exact power requirements for the station we will choose between two ComTech PST Transmitters. The Model CHC29218-250/5650 is a weather-proof S-Band transmitter capable of transmitting at a minimum of 250 Watts output over the frequency range of 2025-2120 MHz. The Model ARD178228-300 Linear Power Amplifier System is capable of transmitting at 300 Watts output over the frequency range of 1750-2120 MHz.

The system that we have just described is very flexible. If the requirements for a particular support operation change, such as between satellites in a constellation, the only changes that need to be made are the swapping in and out of software components and the addition or removal of devices.

Cost Estimates

The cost of a ground station is of course one of the major concerns in any design. Because of our frequent use of COTS products and low software development costs due to the use of the foundation application, our system is less expensive than a LEO-T system.

Top-of-the-line PC with INMARSAT SAT-B interface	$ 5,000
INMARSAT SAT-B System	$ 5,000
Demodulator/Bitsync Card	$ 5,000
Modulator	$ 5,000
Man Portable Antenna With Downconverter and Pedestal	$200,000
Malibu Research P100 Antenna Control Unit	$ 10,000
Two Man-Months of Software Development	$ 50,000
TOTAL:	$280,000

All estimates are based upon averages of the different components discussed in this paper. A similar LEO-T system is priced from $600,000 to $800,000 depending upon the options purchased.

Conclusion

Modern ground stations must be smaller, better, and more cost-effective than their predecessors. In this paper, we have proposed a design for a LEO satellite ground station built mostly from COTS products to meet several ambitious design goals. The first goal was to meet all of the usual ground station operational requirements. By designing the system to handle LEO standard TDM telemetry data at a rate of ten megabits per second, we handled the downlink side of the system, and by providing for command verification and handling we have handled the uplink side of the system. The second design goal was that the system should be small and portable. The system we designed is contained in a single PC and a thirty-two pound antenna. If there is a smaller, more portable system possible, we have yet to see it. The final design goal was that the system should be able to be remote controlled. Our foundation application provided this right out of the box.

Acknowledgments

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References

Antenna specifications can be reviewed at www.MalibuResearch.com.

SBS Technologies, Inc. board specifications can be reviewed at www.sbs.com.

L3 Communications board specifications can be reviewed at www.ti.L-3Com.com.

Cost estimates were derived from averages costs specified by various vendors.