TECHNOLOGY EVOLUTION AND INNOVATION IN SPACECRAFT COMMUNICATIONS

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ABSTRACT

This paper discusses the evolution of the ground satellite communication systems and the efforts made by the Goddard Space Flight Center's (GSFC) Advanced Architectures and Automation (AAA) branch, Code 588 to bring satellite scientific data to the user's desktop. Primarily, it describes the *next generation* desktop system, its architecture and processing capabilities, which provide autonomous high-performance telemetry acquisition at the lowest possible cost. It also discusses the planning processes and the applicability of new technologies for communication needs in the next century. The paper is presented in terms simple for those not very familiar with current space programs to understand.

KEYWORDS

Desktop Satellite Data Processor, telemetry processing, telemetry acquisition, PC based telemetry.

INTRODUCTION

The English mathematician Isaac Newton, as a consequence of his work on the theory of gravitation, had mentioned the theoretical possibility of establishing an artificial satellite of Earth, in 1687. Only in the early 20th century, however, did the theoretical work of the Russian Konstantin Tsiolkovsky and the experimental work of the American Robert Goddard confirm that a satellite might be launched by means of a rocket. The space age dawned with the launching of Sputnik 1 by the Soviet Union on Oct. 4, 1957. A year later on October 1, 1958, National Aeronautics and Space Administration (NASA) was born

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by a congressional act signed by President Eisenhower. The Vanguard project team and other employees from the Naval Research Laboratory were transferred to NASA, and this group became the nucleus of the Goddard Space Flight Center (GSFC). Later, other NASA facilities were established.

Currently, more than 3,500 satellites orbit the Earth generating an enormous amount of data. The scientific community and other interested users have easier access to satellite data either directly from satellites or over the Internet. This access facility is as a result of the world space agencies' commitment to using Consultative Committee for Space Data Systems (CCSDS) standards and the availability of direct-broadcast data from Low Earth Orbit (LEO) spacecrafts. Figure 1 depicts in simplicity the system's context.

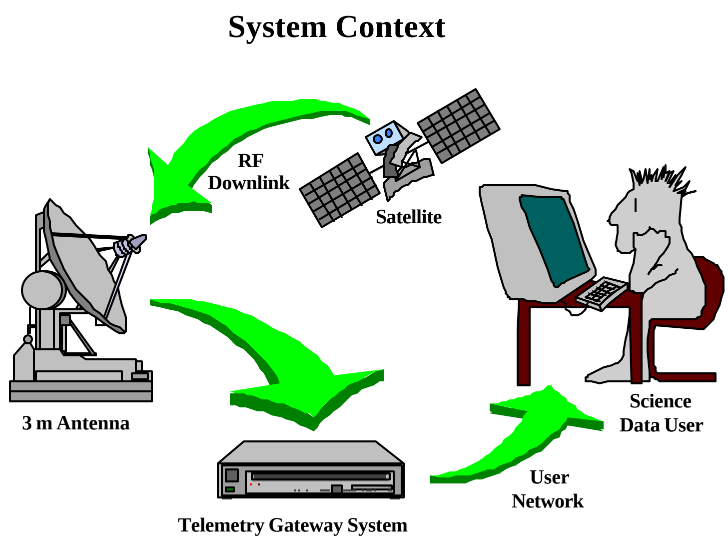


Figure 1. Satellite to User system context

The focus is now on migration from expensive and massively integrated ground control systems to ultra-low cost systems, small enough for a desktop. Through the use of technological innovations in power computing, Very Large Scale Integration (VLSI) Application Specific Integrated Circuits (ASIC), and advanced software development these goals are attainable. These technologies have dramatically increased the speed of data acquisition and processing.

THE NEED OF INNOVATION

Satellites are designed to serve one of three purposes: space science, applications, or communications. Their basic operation is to relay signals to tracking station facilities, mainly through the use of an electronic device called a *transponder* (transmitting responder).

The major Earth tracking stations, typically comprised of:

- an antenna about 30m in diameter,
- a receiver cooled to 14 Centigrade in order to reduce its noise, and
- a radio transmitter with a power output in the range of several hundred to several thousand watts of power to send signals to high orbit satellites.

A large demand is being created for low-cost processing systems. Conditions that have contributed to this demand include the imminent deployment of the Earth Observing System (EOS) satellite constellation, the international collaborative efforts at the Russian Space Station Mir, and the expected launching of hundreds of scientific and commercial LEO satellites within the next several years.

Modern satellites like the EOS-AM generate enormous amounts of data at an orbital average of 18 megabits per second (Mbps) and require that over one terabyte (1024 gigabytes) of data per day is collected and processed. The continuously expanding user base imposes near real time requirements to access this massive amount of scientific data over the Internet, rather than after days or weeks.

Ground data systems must have the ability to both capture and process the telemetry data as it is received and distribute the data over a network with lower capacity than the space-ground link. More efficient ground systems must be developed now to provide data communication from the satellite to the user at a fraction of the cost of traditional methods.

CURRENT TECHNOLOGICAL DEVELOPMENTS

In response to NASA's demand for high-performance, low-cost telemetry ground communication systems, the AAA branch has designed and developed a variety of generic hardware and software processing elements used to capture, process, and distribute space telemetry data. The main elements in this approach are VLSI ASIC, card-level components, and advanced highly integrated, real-time software system environments.

Technical Summary

To support initiatives for cheaper, faster, better ground telemetry systems, the development of new VLSI ASIC's will dramatically lower the cost of hardware components and increase the performance. In the early 1990's, the first generation hardware cards based on large 9U Virtual Module Eurocard (VME) Buses (approximately 15x7 inches) processed data at a rate of 20 Mbps. Using a newer VLSI technology, performance has increased to 150Mbps. Soon performance is expected to increase to 300Mbps, and eventually up to an astonishing 500 Mbps using the new 0.6 to 0.4 micron CMOS technology components under design.

The size of the hardware form factor (physical size of the hardware) has also been significantly reduced. As a single chip it integrates most of the functionality contained in three high-density 9U VME cards. To understand the magnitude of such technological innovations, imagine a personal computer and a 3-meter antenna replacing many of the functions traditionally provided by a ground station that usually requires a whole building for its operations.

DESKTOP SATELLITE DATA PROCESSOR

The Desktop Satellite Data Processor (DSDP) system (also referred to as the Next Generation Desktop System) is being developed for extremely high performance processing of telemetry data by utilizing VLSI ASIC’s, parallel architectures, and pipeline data processing. The objective of the DSDP is to provide advanced low-cost integrated ground system solutions for the acquisition of data from low-earth orbiting satellites and delivering this data to users over standard commercial network interfaces [1].

System Description

Conceptually, the DSDP can serve as a stand-alone telemetry processing system to support a mission (shown in Figure 2.)
A spacecraft passing over a ground station will constitute a "session." The maximum session period that can be handled by the DSDP will be a function of the input data rate, the capacity and configuration of the storage subsystem, the network interface rate, and the operational scenario being demonstrated. The DSDP will:

- Receive modulated RF signals from the antenna/downconverter,
- Perform all CCSDS AOS services (frame and packet processing),
- Provide uplink processes, and
- Output processed science and Internet data to a user network (Ethernet, ATM, FDDI, Internet, others).
-

The DSDP Control Software is being developed in object-oriented design as a generic software package. A graphical user interface enables the scheduling and control system operations, monitoring system status, generating system quality and accounting reports, logging system events, and data distribution.

System Overview

Desktop Satellite Data Processor Context Diagram

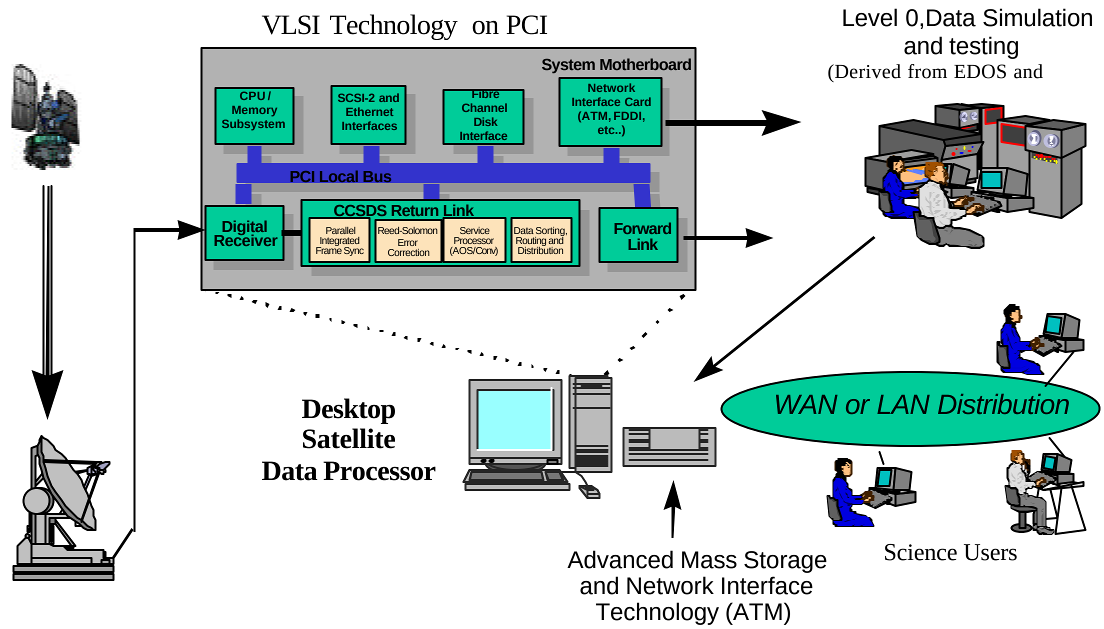


Figure 2. The Conceptual Operation

System Architecture

The system architecture is based on the PCI local bus and VLSI ASIC's that perform frame synchronization, bit transition density decoding, Cyclic Redundancy Code (CRC) error checking, Reed-Solomon error correction, data unit sorting, packet extraction, annotation and other service processing. The Host System is a standard PC or workstation that supports the PCI bus architecture and can process the data at 50Mbps to 150Mbps sustained rate, depending on its CPU power.

The system architecture (Figure 3) provides a framework to integrate all system elements necessary to provide project-specific functionality, while allowing for future performance and functional upgrades. The DSDP consists of three AAA branch developed, custom designed PCI bus modules, and integrated software running on a PC Windows NT environment.

The *Digital Receiver Card* core engine consists of two identical AAA branch specialized ASIC's (the high-rate CMOS Digital Receiver Chip). The Digital Receiver Card receives an IF signal and then performs BPSK or QPSK demodulation, Viterbi decoding, and bit synchronization. The serial clock and data is then output via a 100K ECL interface to the Return Link Processor Card.

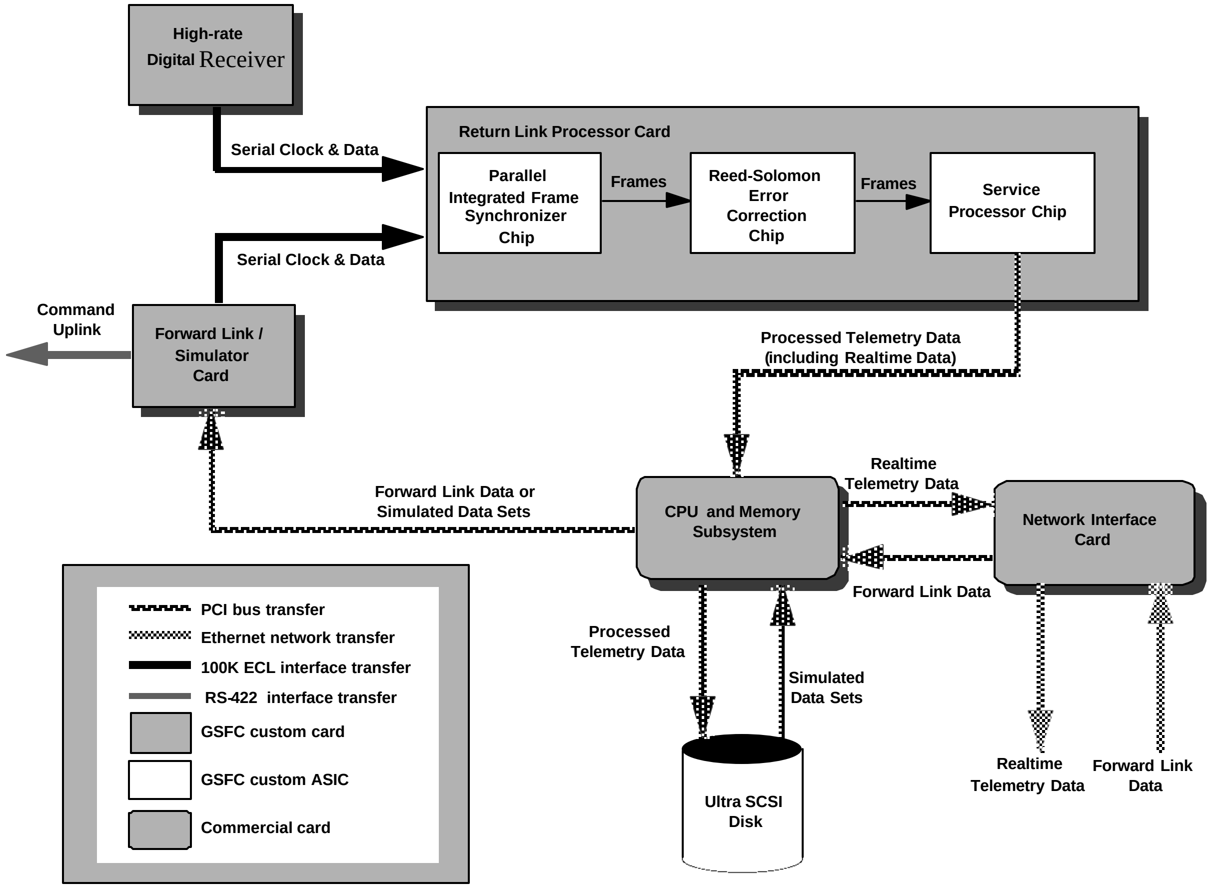


Figure 3. System Architecture

The *Return Link Processor Card* (RLPC) integrates three AAA Branch designed ASIC's shown in Figure 3. The RLPC receives telemetry clock and data, and then frame synchronizations occur according to a specified synchronization pattern and strategy. Reed-Solomon error detection and correction is then optionally performed on the synchronized frames. Data pieces are extracted from the frames and source packets are reassembled. Data is then output, via Direct Memory Access (DMA), to the host memory for storage to system disk and/or output over an Ethernet network.

The *Forward Link / Simulator Card* provides spacecraft command data uplink and spacecraft data simulation. Spacecraft command data is received via user input or over the network.

Major Goals

DSDP's major goals are to:

- Prototype and demonstrate autonomous high-performance telemetry acquisition and data processing.
- Develop the base set of functional reusable components.
- Develop custom hardware and control software portable to any PCI bus architecture.
- Commercialize components via technology transfer.
- Provide data process system performance to 150Mbps with a capability in the near future to increase to 450Mbps.

APPLICATIONS

These technological innovations are the building blocks that allow for migration from the bulk and expensive ground station computer systems to very versatile PC-based systems. Previous data collection and analysis efforts involved the physical transfer of data to a central site for processing, and analysis was performed on an overnight and multi-day effort. Moreover, final analysis results are documented in a report published weeks or months later [3]. Using new technological innovations, the ground station equipment will be affordable and the data will be accessible to the largest possible user base as distributed timely (seconds instead of days) over commercial networks and the Internet.

Multiple missions identified in Figure 4 will continue to push downlink data rates up to 300Mbps thus creating opportunities to reduce cost and provide more distributed ground processing system for specific area research [4].

Technology Infusion Opportunities			
Satellite System	Launch Date	Downlink Rate (Mbps)	Multiple Ground Stations
Earth Observer 1	1999	105	Possible
GATES (proposed)	1999	150-320	Yes
RADASTAT	2000	105	Yes
EOS AM	1998	150	Yes
ESSP's	2000-2010	?	Yes
ADEOS II	1999	60	Yes
U.S. RADASTAT	2000	105+	Yes

Figure 4 Possible applications

Earth Observation System (EOS)

The EOS constellation of remote sensing satellites in low Earth orbit is a cohesive national effort to study Earth's global change [6]. The first of these satellites is scheduled to be launched this year. Each mission requires a number of CCSDS data systems for various functions including data acquisition, compatibility testing, spacecraft simulation, and data quality monitoring and spacecraft control. EOS's direct broadcast technology will allow distributed ground terminals to receive and process data. End users who stand to benefit from this capability include:

- Scientists require real-time data to conduct or validate field observations, to plan correlative campaigns or to observe rapidly changing conditions in the field,
- Meteorological and environmental agencies that require real time atmospheric analysis, storm and flood status, water temperature and vegetation stress, and
- International partners who require receipt of data from their high volume EOS instruments at their own analysis centers.

DSDP systems will provide substantial savings in development, test and simulation, maintenance and operations costs. Aside from producing state-of-the-art telemetry data acquisition, capture, distribution and analysis for NASA centers, the system will be an affordable educational tool able to provide regional science centers, institutes, and universities the capability to examine real-time scientific data.

Advanced Internet Applications

Ambitious plans have been set forth for the next century, to place in orbit constellations of several hundred LEO satellites for global broadband Internet communications. To that end, a very large company has already expressed interest in hardware components and processes implemented in the DSDP.

The aim is to enable high-quality voice, video, and other data communications from anywhere on Earth [5]. According to the company: "On Day One of service, we will enable broadband telecommunications access for businesses, schools and individuals everywhere on the planet." This is the first proposed broadband LEO satellite network that will compete with fiber terrestrial cable.

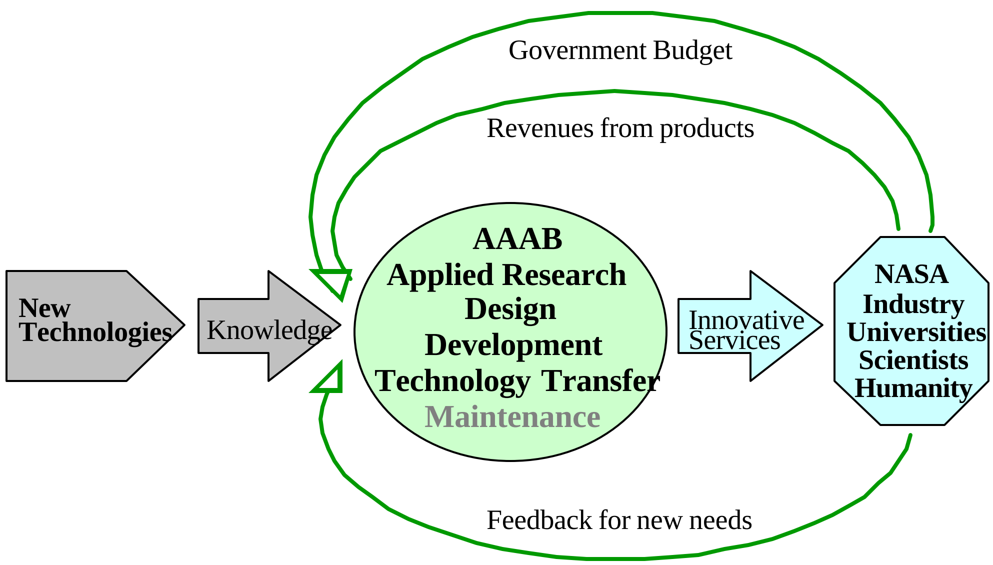
Technology Transfer

The advances in chip integration level and design tools discussed earlier will allow even greater reduction in cost and size while increasing performance. With the *technology transfer* program, all these innovations will be expanded even more and transformed to other technologies. The market size for such innovations has the implications of expanding exponentially by the turn of the century. In the foreseeable future, every scientist will have the capability to examine scientific data at real-time at his or her desktop and Internet access will be ubiquitous.

INNOVATIVE PROCESSES

Innovation is not just a single act of developing a new technique or a system, but rather, it is a series of actions that form a process. Efforts to exploit these new technologies have identified the need to develop an innovation process [2]. A process model is depicted in Figure 5 to help the reader conceptualize the idea of a forward-acting process, which leads to technological innovation.

At the same time, there are important factors that result in both information feedback and monetary gains. Feedback is a very important mechanism, which tells us how our projects are perceived. This helps us to select appropriate new innovative solutions and necessary products for future space projects.



System of Technology Innovation

Figure 5 Technology innovation process in AAA Branch

Technology Development Strategic Planing

The use of costly, dedicated, mission-specific ground stations is becoming increasingly difficult to justify. Therefore, the strategy for the past several years has been to focus on the similarities of functional requirements across programs, rather than differences, using Open Systems architectures. This new approach promotes cross-mission equipment standardization and veers away from the traditional paradigms for spacecraft support. A key part of this approach is the application of high density packaging technology to integrate high performance, low cost elements that can be replicated for use in many different space missions. Great savings can result from using common technology to perform the same functions across missions through the integration and standardization of equipment.

These strategies are in line with the NASA-wide management plan to design an innovative observation and data management strategy. Such a strategy would provide Earth scientists the necessary data to conduct intensive process-oriented research for EOS Mission to Planet Earth (MTPE) and other scientific missions.

Multi-Mission Support

The individual elements of the Functional Component Architecture were engineered to anticipate the requirements for a wide variety of spacecraft, including the International Space Station Alpha, the EOS constellation, and many other missions.

Inter-operability

The adherence to Open System standards is an evident prerequisite for commercial ground support equipment. Its broad range of performance and functional capabilities are intended for use throughout a program’s development cycle: testing, integration, and training through program operation. Testing includes the actual satellite testing during its development, providing simulation environment for its onboard instruments. This testing guarantees the satellite’s correct operation of its instruments when in orbit.

CONCLUSION

The quantum level increase in the amount of space mission data retrieval presents considerable challenges to our analysis methods for technological innovations. This paper has discussed implemented initiatives and pending initiatives within the GSFC AAA Branch for improvement of our existing data retrieval and information dissemination processes. It has introduced products that are engineered to provide cost-effective solutions to the sophisticated, high performance telemetry processing requirements of modern space missions. I would like to acknowledge that these technological leaps would not have been possible without the many talented and resourceful individuals within our organization who take state-of-the-art technologies of the future and utilize them to solve today’s problems. I look forward to continued success as we help NASA meet the challenges of tomorrow in Earth and space exploration.

"NASA is an investment in America's future. As explorers, pioneers, and innovators, we boldly expand frontiers in air and space to inspire and serve America and to benefit the quality of life on Earth."

ACKNOWLEDGEMENTS

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