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Simple Automatic File Exchange - SAFE - to Support Low-Cost Spacecraft Operation via the Internet

Presentation to the Workshop:

Satellite Networks Architectures, Applications, and Technologies, June 2-4, 1998, Cleveland, Ohio, USA

Authors:

Paul Baker (GST) (pbaker@gst.com)

Max Repaci (GST) (repaci@gst.com)

David Sames (NASA/GSFC - Code 588)

Outline

Brief Introduction

Operations Concept

Implementation and Tests

Conclusions

Additional Details

Contact Information

Paul Baker and James Maxwell Repaci
Global Science and Technology, Inc.
6411 Ivy Lane, Greenbelt, MD 20770 USA
301-474-9696

James Rash
Advanced Architectures and Autonomy Branch
Code 588
NASA Goddard Space Flight Center
Greenbelt, MD 20771
301-286-5246

The Context of the Project

Packet telemetry is acceptable for spacecraft.

End users rely heavily on Internet IP networks for scientific data exchange and collaborative research.

Emphasis on cost reduction characterizes all phases of future space missions.

Distinctive Features of the Project

Simple - SAFE provides only a few basic functions.

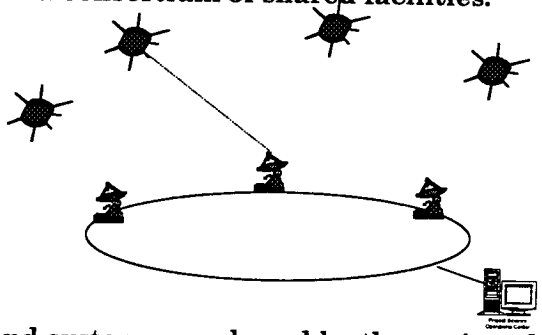
- Simple Automatic File Exchange is only that! Nevertheless, it is sufficient for commands and data.
- Provides a major benefit for space scientists with only a minor investment in development.
- Aims to use commercial equipment and practices.
- Solves well known problems affecting IP in space by avoiding features that expose the problem.

Technical Features

- Pulls data files across the Internet with a read operation (like file read operation in NFS).
- Prearranged file names - no file discovery mechanism.
- UDP packets
- Congestion control at application level
- Simple solution to the Mobile IP problem

Final Goal

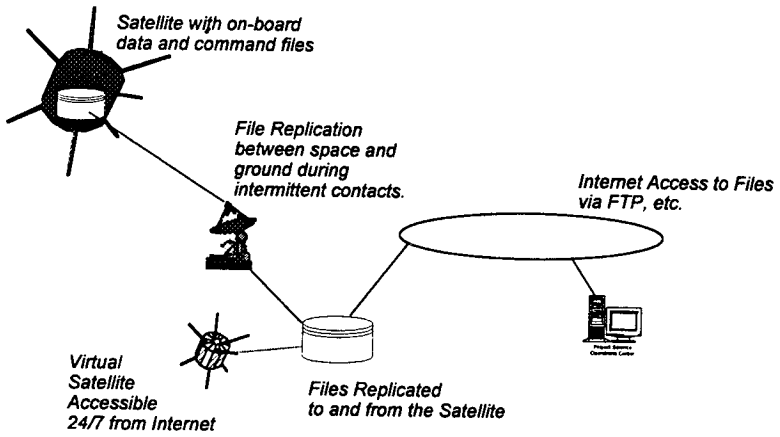
Fleets of Small Satellites will report back to data centers operated directly by the project by means of occasional communication contact with ground stations in a consortium of shared facilities.



The ground systems are shared by the project data centers and all are connected via an Internet. There are no operational costs for routine command uploads or instrument data downloads.

Operations with a Replicated File Protocol

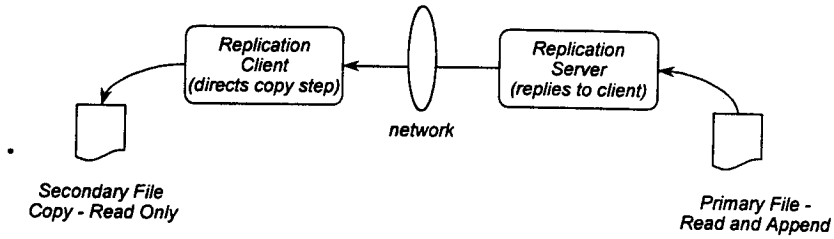
Space-ground data operations require no manual scheduling and supervision. Projects manage data processing over the Internet.



Fundamental File Exchange Operation

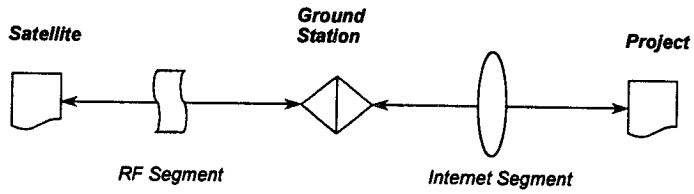
SAFE copies files and copies them successfully even over intermittent connections with a high `bandwidth*delay` product and high bit error rate.

The copy operation is connectionless - there is no time lost establishing and maintaining TCP connections.



Ground Station Acts As Gateway

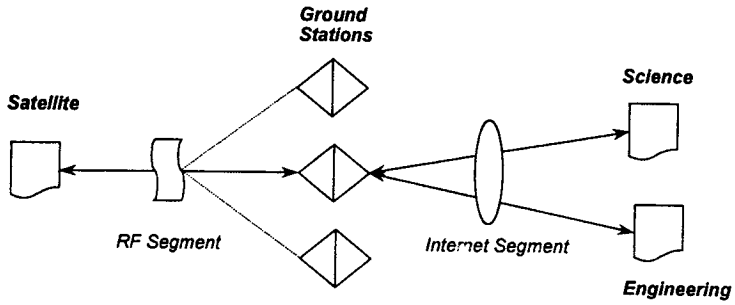
Each connection passes through the ground station, which acts as an intermediate connection point.



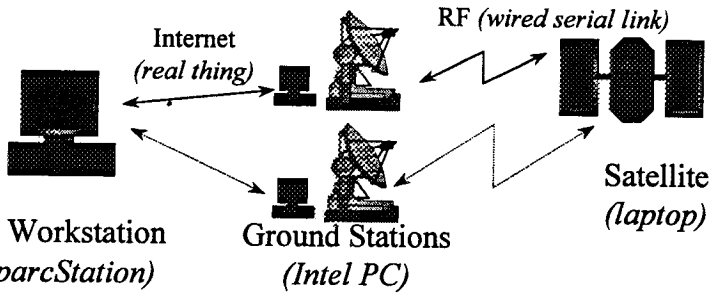
Multiple Ground Stations and Destinations

A satellite may connect with multiple points on the Internet, e.g., the scientists at one location and spacecraft bus engineers at a second.

Moreover, a satellite may use several ground stations at different points in its orbit. Conversely, a ground station may serve several satellites in turn.



Demonstration of SAFE



The demonstration simulates a scientist accessing instrument data and sending commands via file replication.

- **Satellite instrument writes data to onboard file which is automatically replicated to the scientist's workstation.**
- **Scientist writes instrument commands to local file which is replicated to satellite.**

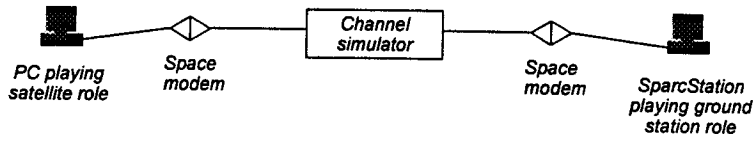
Testing SAFE

Purpose:

- Run file transfers with realistic light-travel-time delays and bit-error rate and study the effect on the data transfer rate.

Equipment:

- Provided by the IPIC project (TCP-over-satellite test suite).
- Satellite Modems for IP are COTS but not space-qualified.
- FYI, we are using PC to play the satellite role but IPIC runs a single-board embedded computer for better realism during TCP tests.



Lessons Learned from Implementation

The low-cost operational scenario is realistic and easy to implement with the automatic file exchange system.

UDP is reasonably effective - on a par with other alternatives.

Congestion control is essential but troublesome.

- Congestion control is built into TCP, but TCP assumes all packet loss is due to congestion and the control overreacts when packets are lost due to line noise and data drop-outs.
- No congestion control built into UDP - the nodes can saturate routers.
- Congestion control is built into the file exchange software of SAFE and has been optimized for connections that have line errors as well as congestion.
- Optimization for a noisy space-link connected to a congested Internet is a difficult problem that needs further research - or better - an avoidance mechanism.

Feedback

The implementation has been demonstrated for many engineers - who had important comments:

- The key impediment is the lack of space-qualified hardware that supports any commercial network protocol.
- Many existing satellites systems have an uplink bandwidth that is too small to allow an error-correcting protocol of any kind. Tradition is slow to change.
- There is an important type of mission cannot be accommodated by an Internet connection because the required bandwidth during a pass is too high. The Internet bandwidth is adequate for the average data rate but not the peak bandwidth during a pass.

Future Initiatives

Create Opportunities for Use in Space

- Need to proselytize for IP so that there are customers for commercial, space-qualified, IP hardware.

Specification of SAFE

- leading to an acquisition of an implementation from a commercial vendor who currently markets similar SW (any vendor with NFS or RPC protocols).

Small systems demonstration to show feasibility for very small satellites.

- Current demonstrations use 486 PCs.
- Considering implementation for single-board VxWorks computer.
- Considering demonstration on palmtop computers.

Applications with high bandwidth requirements

- low priority - imaging sciences tolerate packet losses.
- no "simple" solution, see "Details"

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We thank David Sames for his support and contributions to this work. He has recently left the project.

Web Sites:

Global Science and Technology: http://www.gst.com

Project Working Papers: http://abita.gst.com/node.htm

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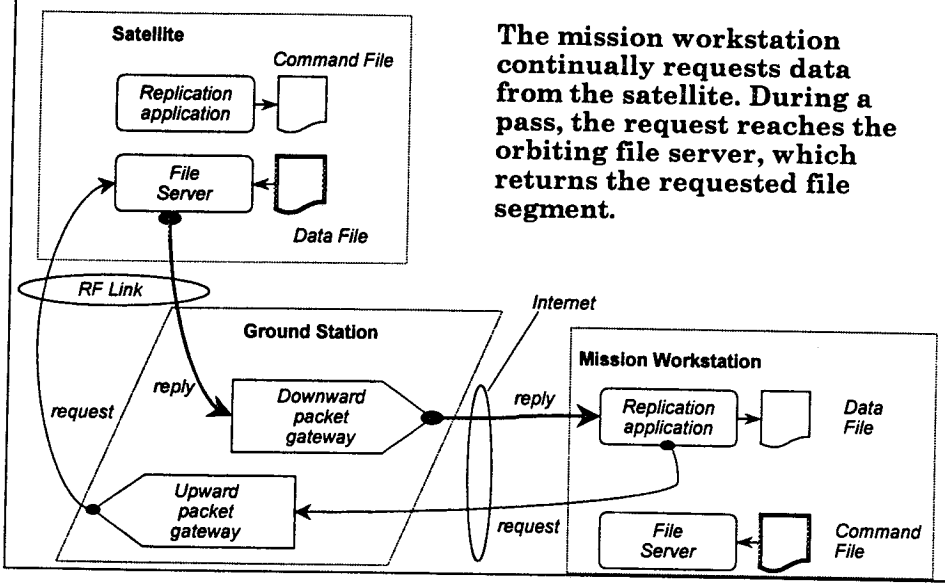
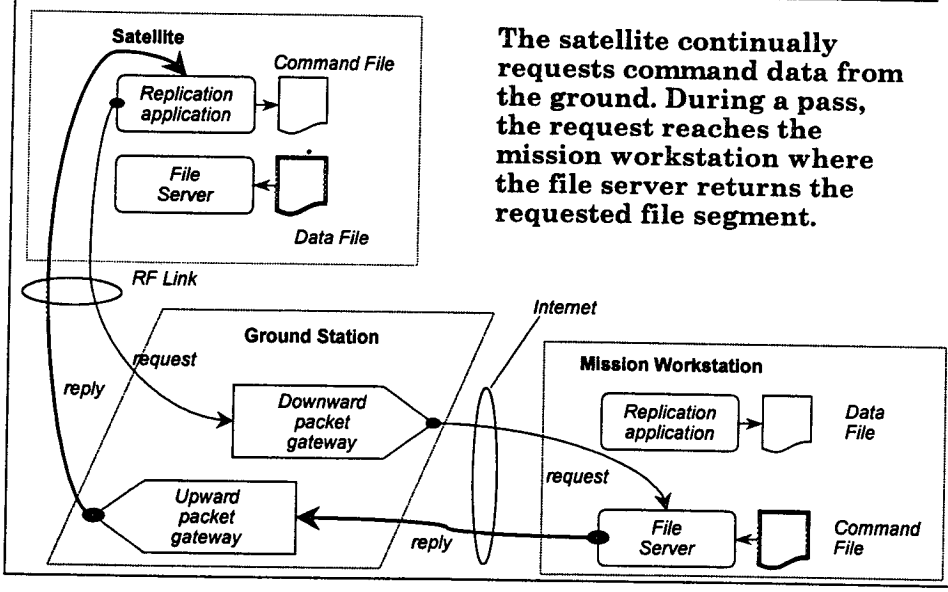
- **File Exchange Operations**
- **Mobile IP Solution**

File Exchange for Satellite to Ground



The mission workstation continually requests data from the satellite. During a pass, the request reaches the orbiting file server, which returns the requested file segment.

File Exchange for Ground to Satellite



The satellite continually requests command data from the ground. During a pass, the request reaches the mission workstation where the file server returns the requested file segment.

Basic Gateway Functions

Upward Packet Gateway:

- Identify packet as intended for satellite. (Use port number and optional security verification)
- Convert to space link format (if different) and forward.

Downward Packet Gateway:

- Convert to IP format (if different).
- Insert IP address of gateway as source address of packet.
- Forward packet to recipient's address on Internet.

Packet conversions

- None required if satellite link uses IP Modems.
- Generally need to add/remove IP headers if IP was not used on the link to the satellite.

Mobile IP for SAFE

Problem:

- The satellite connects to the Internet at the ground station and must use a local IP address.
- The satellite's IP address changes from one ground station to another.
- Future enhancements to IP protocol have been slow to arrive.

Interim solution

- Ground station applies local address to packets from satellite.
- The file server in the Mission computer notifies the replication application when it learns the current IP address of the satellite.