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Overview of In-Space Internet Node Testbed (ISINT)

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August 2000

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OVERVIEW OF IN-SPACE INTERNET NODE TESTBED (ISINT)

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SUMMARY

The Satellite Networks and Architecture Branch has developed the In-Space Internet Node Technology testbed (ISINT) for investigating the use of commercial Internet products for NASA missions. The testbed connects two closed subnets over a tabletop Ka-band transponder by using commercial routers and modems. Since many NASA assets are in low Earth orbits (LEO's), the testbed simulates the varying signal strength, changing propagation delay, and varying connection times that are normally experienced when communicating to the Earth via a geosynchronous orbiting (GEO) communications satellite. Research results from using this testbed will be used to determine which Internet technologies are appropriate for NASA's future communication needs.

INTRODUCTION

The need for in-space Internet technology arose as a result of NASA's implementing the "faster, better, cheaper" paradigm. The space agency had begun to move away from proprietary special-purpose government communication systems and until recently had been producing its own unique hardware and software for space communications because there were no other producers of space-qualified equipment, except for the Soviet space agency. Now, in addition to many proposed commercial space communications systems that might be available, standard Internet protocols are especially attractive for near-Earth communication.

NASA uses the custom-built Tracking and Data Relay Satellite System (TDRSS) to communicate with such space assets as the space shuttle (i.e., the space transportation system (STS)) and the International Space Station (ISS). The TDRSS, a geosynchronous constellation that provides global coverage for all NASA Earth-orbiting missions, has satellites with tracking antennas to follow low-Earth-orbiting (LEO) and medium-Earth-orbiting (MEO) satellites. Two TDRSS satellites in conjunction with their ground station in White Sands, New Mexico, provide near-global, real-time user satellite coverage (ref. 1). For data uplink and downlink, TDRSS uses Consultative Committee for Space Data Systems (CCSDS) formatted telemetry packets. These may contain instrument science data, platform ancillary data, and housekeeping or engineering data. The telemetry packets are time stamped, but the data quality is not guaranteed.

To improve the accessibility of spacecraft data and operations, NASA is moving toward implementing Internet protocol (IP) and transmission control protocol (TCP) and is likely to implement asynchronous transfer mode (ATM). Using TCP/IP as the communications protocol between in-space computers and the end users on the ground will reduce operating costs, increase transmission bandwidth capabilities, and provide faster response times to end users. Switching to commercial satellite networks will also reduce NASA's space communications operation costs in that day-to-day operational costs for a commercial satellite system are absorbed by the provider and are passed on to the users at a fraction of the total cost.

The Satellite Networks and Architecture branch at the NASA Glenn Research Center is conducting research into implementing TCP/IP to and from space assets via a single-hop, geosynchronous Earth orbit (GEO), Ka-band satellite. The entire system is contained in a laboratory using the Advanced Communications Technology Satellite (ACTS) proof-of-concept radiofrequency (RF) transponder and a variety of computers. The research project is called the In-Space Internet Node Testbed (ISINT).

The appendix contains the acronyms used in this report.

SATELLITE NETWORKS AND ARCHITECTURES BRANCH HISTORY IN SPACE COMMUNICATIONS AND INTERNET PROTOCOLS

The Satellite Networks and Architectures Branch conducts advanced research and development of next-generation, space-based information systems to enhance the role of satellite communications in the national and global information infrastructure (NII/GII), to maintain the preeminence of the U.S. satellite communications industry, and to meet future NASA mission communication needs by utilizing emerging global broadband satellite and hybrid networks. Because the NII/GII is based on global heterogeneous communication networks, standards and interoperability are an important consideration in the definition of the branch programs, which are carried out through partnerships with the satellite communication industry and academia.

The research and development deal with the following broad categories: next-generation architectures, applications, internet protocols, asynchronous transfer mode (ATM), and satellite projects. The objectives of the branch are to achieve seamless interoperability between satellite and terrestrial networks, to study next-generation, space-based, highly interoperable NII/GII architectures, to conduct experiments on hybrid satellite network testbeds, and to develop critical precompetitive satellite network technologies.

IN-SPACE INTERNET NODE TESTBED (ISINT)

Goal

The goal of ISINT research is to provide current and future NASA missions with the fundamental architecture for accomplishing in-space Internet communications (fig. 1). Information about the behavior of TCP/IP over links subjected to high latency, handoffs, and variable delays will indicate the appropriateness of using TCP/IP for near-Earth communication needs. Because the testbed is contained in a lab environment, commercial-off-the-shelf (COTS) and government-off-the-shelf (GOTS) products are being used. Ultimately, users of the ISINT-tested technology will have to obtain and/or manufacture flight-worthy components after the technology has been tested and verified in the laboratory.

Objectives

The first objective is to integrate, develop, and demonstrate the technology needed for direct communication with space assets via standard Internet protocols using commercially available components. Thus, NASA can reduce the cost of obtaining data from and operating its space vehicles (e.g., scientific satellites and manned spacecraft, such as the space shuttle and the International Space Station). The second objective is to experiment with sending command and control sequences to devices through the testbed to determine where problems might exist. Embedded web technologies, such as Tempest software, will be used to test the feasibility of a principal investigator (PI) from a personal workstation directly controlling a spacecraft device (ref. 2).

Changes are currently being considered to implement Internet protocols and technology to the space shuttle and the International Space Station. For example, reference 3 states that "Station LAN's can be routed to PI's directly through future satellite systems." Also, The Pressurized Payload Interface Requirements Document (ref. 4) is being updated to allow the use of TCP/IP addresses and protocols within the onboard network. The Space Operations Management Office (SOMO) at the NASA Johnson Space Center has awarded the Consolidated Space Operations Contract (CSOC) to a group of companies led by Lockheed-Martin. One of the essential elements in CSOC is to provide "transparent IP service worldwide" and "immediate remote access to spacecraft and instrument data via IP connectivity" (ref. 5). The ISINT testbed can make valuable contributions to this effort.

Using standard Internet protocols will make scientific satellite data more readily available to researchers. Currently, the satellites utilize custom-built and/or proprietary protocols to communicate with NASA ground stations. There is no error correction performed on the telemetry data. The ground station receives the telemetry and then forwards it to users within the NASA network. Changing to standard Internet protocols will permit lost or corrupt packets of data to be detected during the downlink process. Mechanisms in the handshaking between the sender and receiver detect missing or corrupt packets, so retransmissions are made automatically. The result is better quality data reaching the end user.

Test Plan Overview

The majority of the tests deal with bulk file transfers between the space and terrestrial nodes. These transfers are monitored by tcpdump (ref. 6), which collects data from TCP/IP activities. The resulting dump files are then processed by a tracing program that plots throughput and provides other statistical results.

Streaming video, telephony, and web server hosting will also be tested for demonstration purposes. All three of these are understood in a standard point-to-point TCP/IP over satellite architecture. The introduction of one of the points as a moving LEO is expected to introduce some new issues.

TESTBED CAPABILITIES

Commercial- and government-off-the-shelf products are being integrated in a testbed to validate that space-to-the-Internet communications provide an end-to-end system solution to NASA, DOD, and industry. The terrestrial and satellite network simulator enables laboratory-based verification of advanced components and system architectures. Through hardware and software, the testbed integrates many proof-of-concept components in the flexible simulation tool of a satellite system at Ka-band frequencies. Among the satellite system environment variables to be simulated are rain fade, range delay, handoffs, and antenna tracking. To accommodate the simulation of proposed global satellite constellations, Ku-band capability will be added in the future.

The Pentium workstations use the Linux operating system, kernel version 2.2.1. This kernel's TCP implementation incorporates the standard "good-practice" features for transport layer control, specifically the Internet Engineering Task Force (IETF) Request For Comments (RFC) 1323, "TCP Extensions for High Performance;" RFC 2581, "TCP Congestion Control;" and RFC 2018, "Selective Acknowledgment" (refs. 7 to 9). Although RFC 1191, "Path MTU Discovery," is an important feature, the ISINT configuration has not implemented it (ref. 10). The ISINT's Linux TCP has been configured to use the largest packet size available (1500 bytes/packet). The testbed accuracy was demonstrated by running the same file transfers through the actual ACT satellite and comparing the results. A comparison of the results was performed and documented in a contractor report (ref. 11).

TESTBED SETUP AND APPROACH

The ISINT consists of two local area networks (LAN's) that communicate with each other over an RF satellite simulation. One LAN represents terrestrial users on the Internet and the other, a set of computers on a space platform. Modems, routers, and hubs connect these LAN's to the RF satellite simulation. Figure 2 shows the current configuration of the testbed, and figure 3 is a generic diagram of the testbed setup and capabilities. Details of hardware and router configurations are given in table I.

The satellite simulation is currently configured as a GEO-based, Ka-band transponder. Static range delay will be simulated using the buffers in the modems. For simplicity, the initial configuration simulates a hypothetical stationary LEO spacecraft communicating via a GEO bent-pipe satellite to an Internet user on the ground.

Initial tests involved file transfers over the satellite simulation using TCP/IP with standard good practice features enabled (see Testbed Capabilities section). Transfer rates for a 1-gigabyte (GB) file are near the theoretical limits of the system, using a 500-ms satellite latency time and T1 rate (1.544 Mbps). The current equipment supports speeds up to 8 Mbps.

After the system is verified to correctly simulate realistic stationary point-to-point (LEO-GEO-ground) communications, additional capabilities will be added to simulate a moving LEO spacecraft that periodically passes through the GEO's zone of coverage. Planned upgrades to the system include the use of modems and routers capable of supporting transmission speeds of 45, 155, and 622 Mbps. Up and down converters will be replaced to support Ku-band simulations. The static range delay simulation will be replaced with a dynamic range delay implemented in software. Other enhancements can be added to accommodate experiments as needed.

TESTBED RADIOFREQUENCY LINK CHARACTERISTICS

An RF link consists of the modems, up and down converters, antenna systems, and transponder(s) used to communicate between two end points. The ISINT incorporates COTS modems and up and down converters in the testbed. Antenna system tracking and pointing are emulated in the ISINT testbed. The RF transponder is the Advanced Communications Technology Satellite's (ACTS') proof-of-concept hardware.

The atmosphere, hardware, and relative motion and distance of the end stations exhibit physical link characteristics, which include contact time, gain variation, and propagation delay variation. The testbed has accounted for each of these characteristics through the use of simulators and COTS and GOTS hardware.

Contact time is emulated by switching the communication signal on or off. The Ohio Network Emulator (ONE) software enables and disables the communication flow based on a predefined connection scenario. Connection scenarios are developed using Satellite Tool Kit, modeling the connection times of a given space platform communicating over a specified GEO to the specific groundstation. Initially, ISINT will model shuttle communication over a TDRSS satellite to White Sands.

Gain variations occur due to Doppler motion, rain fade, and other atmospheric effects. The Doppler motion effect is experienced in any spacecraft communication network that has motion as an element. Ka-band communications through rain decreases signal strength. These effects are emulated using programmable attenuators and RF switches.

Propagation delay variation is attributed to moving communication platforms, such as orbiting spacecraft or perhaps objects during launch conditions. The distance changes between a LEO spacecraft and its GEO communications satellite as the spacecraft passes within view of the GEO. For links up to 10 Mbps, variable delay emulation will be performed by software using a dedicated workstation. The ONE software is being enhanced to perform delay variation and insert various bit error rates (BER's). This emulator will be used until it can no longer match the hardware's maximum operational speed. The operational limit of ONE has not been determined at this time.

NASA MISSION CLASSES

The research of the Satellite Networks and Architectures Branch is applicable to all four NASA enterprises: Human Exploration and Development of Space (HEDS), Space Science, Mission to Planet Earth, and Aeronautics and Space Transportation Technology. Some HEDS and Mission to Planet Earth missions have similar operational scenarios: space assets operating in LEO that need to downlink data to ground users. The ISINT simulations will initially address these mission classes. The unique operational issues of Aero-Space and Space Science missions will be addressed after the basic LEO-GEO-ground model is accommodated.

NASA MISSION REQUIREMENTS

The NASA Mission Requirements Document guides the modeling of each testbed scenario and must be obtained. The document describes the operation of the communication system for specific NASA missions and also identifies their critical communication issues (networking, protocol, RF, antenna pointing, etc.). The following minimum information is needed for each NASA mission to be simulated:

1. Communication system characteristics
2. Network architecture
    a. Network topology
        i. Block diagrams
        ii. Interfaces
        iii. Data rates
        iv. Protocols
    b. Control and data distribution
3. Link characteristics
    a. Modulation and coding
    b. Bit error rate
    c. Connect time
    d. Intermittence
    e. Data rates
4. Antenna System

ISINT SIGNIFICANT TECHNICAL RESEARCH PROBLEMS

Transmission control protocol is a reliable, connection-oriented, byte-stream, transport-layer service; TCP over satellite, point-to-point on the ground, is fairly well understood and can be enhanced by several mechanisms (ref. 12). The initial ISINT model is a low-Earth-orbit (LEO) spacecraft primarily downlinking data via GEO satellite to an Internet user on the ground. Typical space science traffic consists of bulk data transfers to the ground with short bursts of uplinked commands and operational parameters.

Research issues to be addressed using the ISINT testbed include

(1) Exploring scenarios using a communication satellite constellation with intersatellite links (ISL)
(2) Maintaining and resolving IP addresses while potentially downlinking to a variety of groundstations
(3) Determining an effective way to maintain or re-establish a TCP/IP session during handoffs from one satellite to another or from one groundstation to another

Adequate coverage from a commercial satellite constellation is an issue for space-to-ground Internet technology but is outside the scope of ISINT lab work. Current commercial satellite constellations are not designed to track independent spacecraft such as the shuttle, the International Space Station, and scientific satellites (ref. 1). Next-generation commercial satellite systems may provide the needed capabilities to support government enterprises such as NASA and the Department of Defense.

CONCLUDING REMARKS

As of May 1999, the testbed was configured and tested at T1 line rates (1.544 Mbps) end-to-end. Space-based files were transmitted through the simulated satellite to the ground Intranet at rates near the theoretical limits. The TCP congestion and recovery mechanisms performed as expected during slow-start and steady-state phases of transmissions. The testbed is currently being reconfigured to accommodate higher capacity modems and routers.

APPENDIX—ACRONYMS

ACTS	Advanced Communications Technology Satellite
ATM	asynchronous transfer mode
BER	bit error rate
CCSDS	Consultative Committee for Space Data Systems
COTS	commercial off the shelf
CSOC	Consolidated Space Operations Contract
DHCP	dynamic host configuration protocol
GEO	geosynchronous orbiting
GII	Global Information Infrastructure
GOTS	government-off-the-shelf
HEDS	Human Exploration and Development of Space
IETF	Internet Engineering Task Force
IP	internet protocol
ISINT	In-Space Internet Node Testbed
ISL	intersatellite link
ISS	International Space Station
LEO	low Earth orbiting
MEO	medium Earth orbiting
NASA	National Aeronautics and Space Administration
NII	National Information Infrastructure
ONE	Ohio Network Emulator Software
RFC	Request For Comments
SOMO	Space Operations Management Office
STS	space transportation system (space shuttle)
TCP	transmission control protocol
TDRSS	Tracking and Data Relay Satellite System

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TABLE I.—ISINT COMPUTER AND ROUTER CONFIGURATIONS

System	Installed operating system software	Installed hardware/option
Terrestrial 1	Windows NT 4.0 server service pack 4.0	Dell OptiPlex Pentium II, 450 MHz RAM, 384 MB Video ram, 8 MB Ethernet interfaces (2), 3Com 10/100 MB Mouse, PS2 Intellimouse
	Redhat Linux 5.2 with 2.2.1 kernel	SCSI hard disk, 18 GB SCSI JAZ drive, 2 GB Monitor, Dell UltraScan 1600 HS, 21in. CD-ROM drive, 17/40X Connectix video camera Speakers/sound card
Terrestrial 2	Windows NT 4.0 workstation service pack 4.0	Dell OptiPlex Pentium II, 450 MHz RAM, 384 MB Video ram, 8 MB Ethernet interfaces (2), 3Com 10/100 MB Mouse, PS2 Intellimouse
	Redhat Linux 5.2 with 2.2.1 kernel	SCSI hard disk, 18 GB SCSI JAZ drive, 2 GB Monitor, Dell UltraScan 1600 HS, 21in. CD-ROM drive, 17/40X Connectix video camera Speakers/sound card
Space 1	Windows NT 4.0 workstation service pack 4.0	Dell OptiPlex Pentium II, 450 MHz RAM, 384 MB Video ram, 8 MB Ethernet interfaces (2), 3Com 10/100 MB Mouse, PS2 Intellimouse
	Redhat Linux 5.2 with 2.2.1 kernel	SCSI hard disk, 18 GB SCSI JAZ drive, 2 GB Monitor, Dell UltraScan 1600 HS, 21in. CD-ROM drive, 17/40X Connectix video camera Speakers/sound card
Space 2	Solaris 2.7	Sun Sparc 2 Sun graphics adapter and monitor CD-ROM drive RAM, 64 MG Cartridge tape drives (2), 4 and 8 mm Hard drives External, 1.2 GB Internal (2) 400 MB
Floater 1	Windows 98	Dell Latitude laptop, 300 MHz CD-ROM drive, 24X RAM, 128 MB Hard drive, 6.4 GB LAN card, 3Com 10/100 Global modem card, 56 kB
Space	Cisco 3640 IP Plus	Cisco 3640 router RAM, 128 MB Modules 4-port serial 1-port fast Ethernet 2-slot voice/fax FXS voice interface card
Terrestrial	Cisco 3640 IP Plus	RAM, 128 MB Modules 4-port serial 1-port fast Ethernet 2-slot voice/fax E&M voice interface card

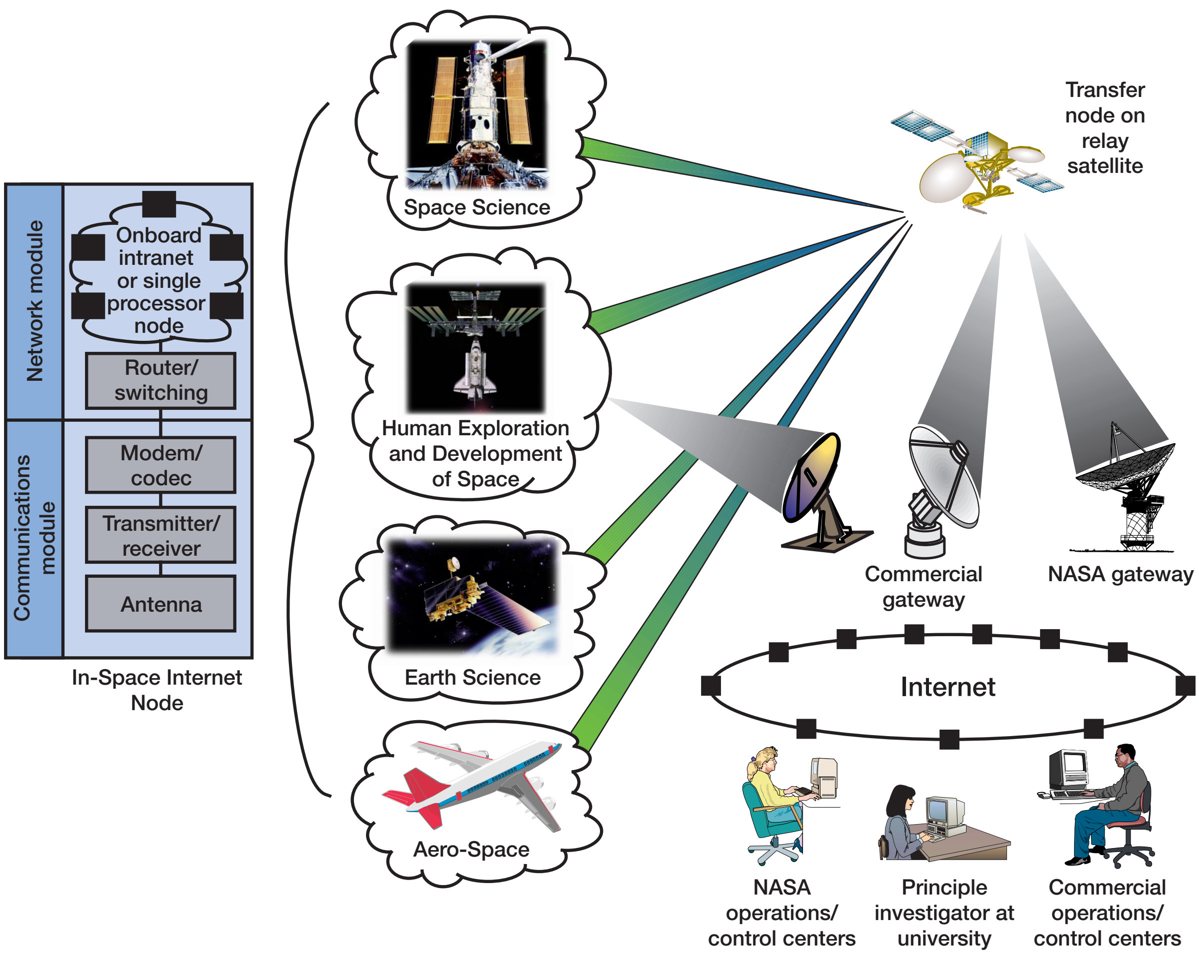

Figure 1.—Space Internet architectures.

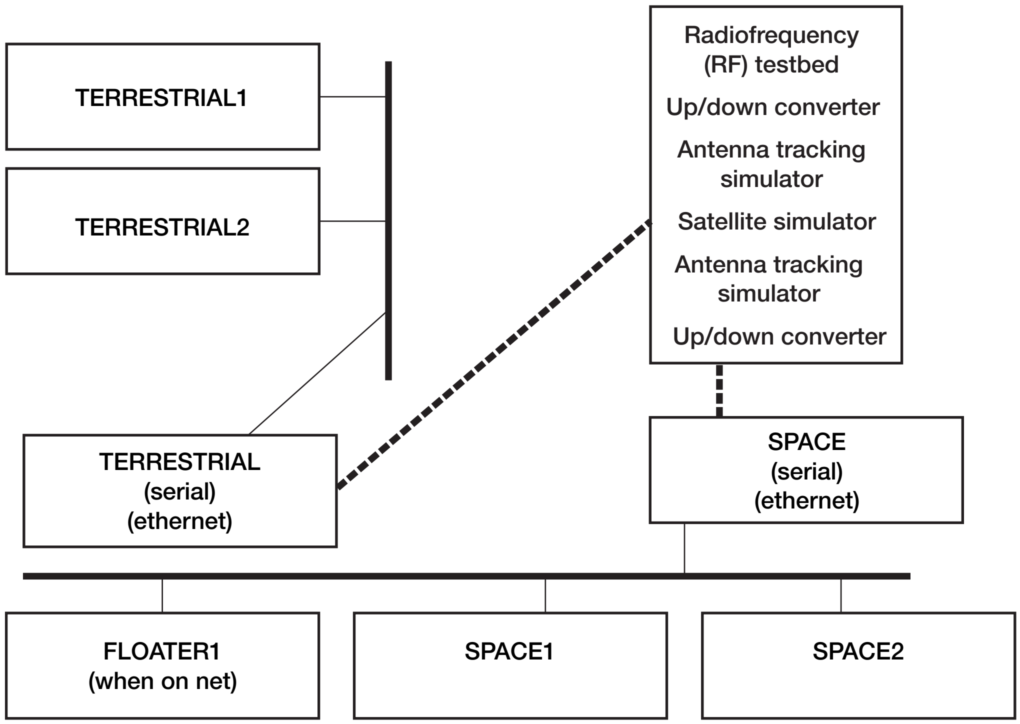

Figure 2.—Current In-Space Internet Node Technology (ISINT) testbed.

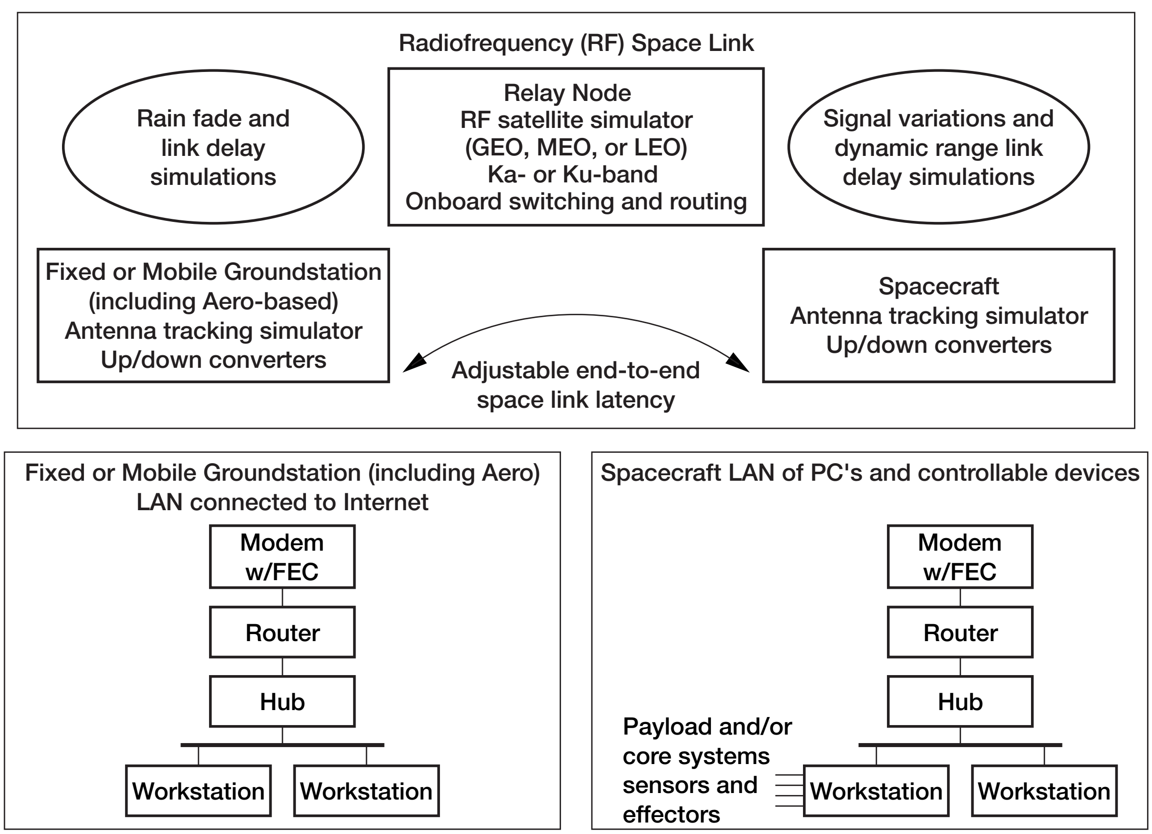

Figure 3.—ISINT generic functional block diagram.

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13. ABSTRACT ***(Maximum 200 words)***

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