Telecommunications for the Consolidated Space Operations Contract (CSOC)

An Internet Interface to NASA Satellites

Jeff Hayden
CSOC Spacecraft Chief Engineer - Retired

303-779-6179 - jlhayden@earthlink.net

NASA Problem - CSOC Solution - Vision for the Future

Autonomous IP in Space

Segment	Problem: Today's Operations	Solution: CSOC Introduces	Vision: Future Operations
Space	■ Data transmitted in various formats ■ Dependent on ground-generated commands ■ Intensive communications coordination	■ TCP/IP Protocols ■ Artificial intelligence ■ LAN-connected processors ■ Push Ka-band	■ Data transmitted in standardized protocols ■ More autonomous onboard control ■ Software reconfigurable from ground ■ On-demand access to ground ■ Onboard orbit/attitude determination ■ High rate comm reduces network load
Ground	■ Complex, manual-intensive mission and science planning ■ Orbit parameters determined ■ Commands for station keeping and instrument pointing ■ Complex network scheduling ■ Data reformatted for users ■ Data stored at each location ■ Multiple interfaces & operators	■ COTS-based standard systems ■ Standardized processes ■ Consolidated operations ■ Internet-based open architecture ■ Artificial intelligence	■ Automated mission management ■ No data reformatting ■ Single data storage ■ Simple data distribution ■ Minimized planning and scheduling ■ Autonomous Antenna Operations
User	■ Complex interface for planning ■ Received data passes through many unique processes and buffers ■ Data stream intermixed with rest of payload	■ Automated planning ■ On-demand bandwidth ■ Internet data distribution	■ Simplified planning interface ■ Simplified data retrieval ■ Self-sufficient control and data retrieval capability ■ Data retains user formatting

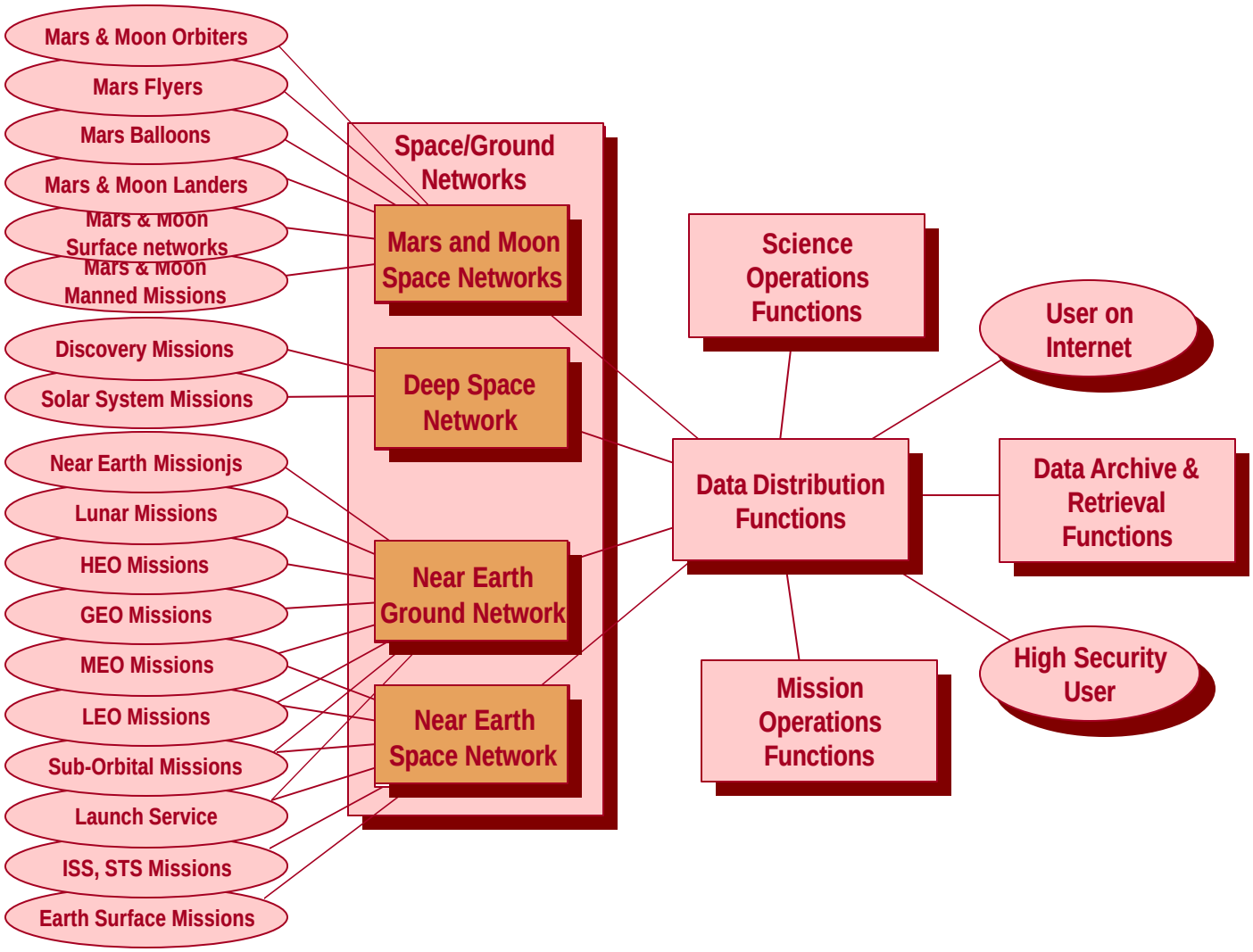
Strategies for Ground and Spacecraft Functional Evolution

Autonomous IP in Space

- **CSOC's initial architecture:**
  - Based on NASA's existing heterogeneous infrastructure,
  - Not easily shared between disparate missions.
- **CSOC Unifies and Standardizes this architecture**
- **CSOC modifies existing systems and adds new systems to:**
  - Improve bandwidth,
  - Simplify the handling of data, and
  - Obtain autonomy in operations.
- **Service to the NASA customer is significantly improved:**
  - Higher data rates reduce service time and/or enable improved science.
  - Data routed between user and instrument by "Internet"
  - Evolved CSOC architecture operates autonomously at much lower cost.

CSOC Unified Functional Structure

Autonomous IP in Space



CSOC Unified Functional Structure

Autonomous IP in Space

- **CSOC's Data Distribution Functions and Space/Ground Networks enable communications between**
  - Space-borne hardware,
  - Mission Operations,
  - Science Operations,
  - Data Archive and Retrieval,
  - High Security Users, and
  - Internet Users.
- **The keys to the structure are in the**
  - Higher Bandwidths
  - Standardization of the Data Distribution Functions
    - CSOC will utilize standard Internet Protocols (IP's) for data movement throughout the system and
    - IP is extended to spacecraft through the Space/Ground Networks to achieve interface, data, and control uniformity throughout the system.
  - Extensive use of autonomous operations - CSOC will:
    - Actively pursue and develop autonomous ground operations.
    - Participate with missions to attain autonomous on-board spacecraft operations.

Strategy for the space/ground functional areas

- **Maximize efficiency of operation with:**
  - Very high bandwidth wireless networks,
  - Ka-band RF to obtain 100-600 Mbps near earth transfers, 1 Mbps Mars transfers.
  - Enables shorter transfer times, thus more transfers per asset.
- **Autonomous operation of those networks,**
  - Service rendered on-demand.
  - No scheduling activities.
  - Add inexpensive ground stations as missions grow.
- **New spacecraft use**
  - Small, high-rate Ka-band steerable dish and low-rate near-omni antenna.
  - Autonomous control of RF to support demand access operations.
  - High-speed, IP compliant, autonomous on-board LAN.
  - IP compliant instruments and subsystems.
  - Autonomous navigation.
  - Task assignments rather than commands.

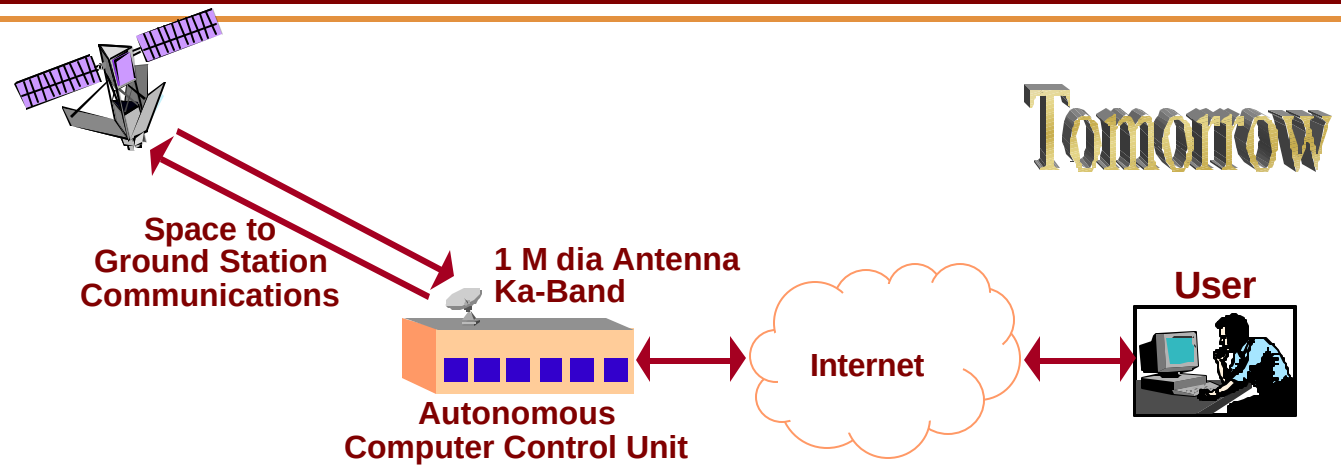
Changing the Spacecraft Paradigm

- **A spacecraft is just another node on the "Internet of Intranets"**
  - Servers flying in zero g intranet
  - Spacecraft computer is spacecraft server
  - MyInstrument@spacecraft.nasa.gov
  - Subsystem1@spacecraft.nasa.gov

Demand access improves overall system efficiency

Autonomous
IP in Space

Nothing happens until it's generated, validated, and scheduled by humans



Demand Access allows users to directly access their own spacecraft and the spacecraft to directly access the network services

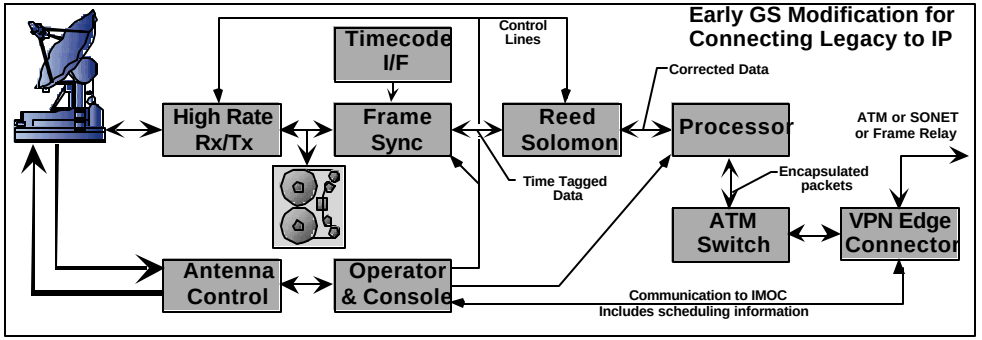
The Proposed Solutions

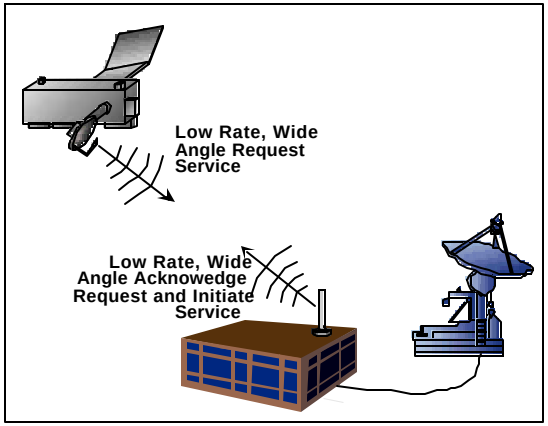
- Ground Network (GN)
- Space Network (SN)
- Deep Space Network (DSN)
- Spacecraft

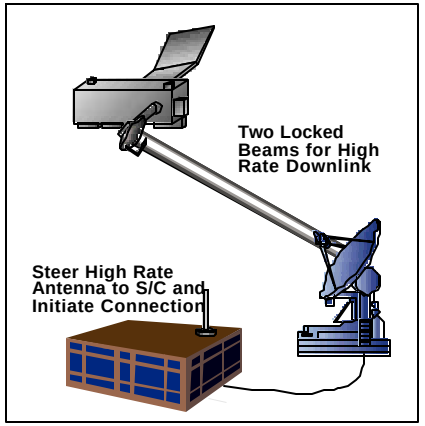
Ground Network (GN) - CSOC near term modifications

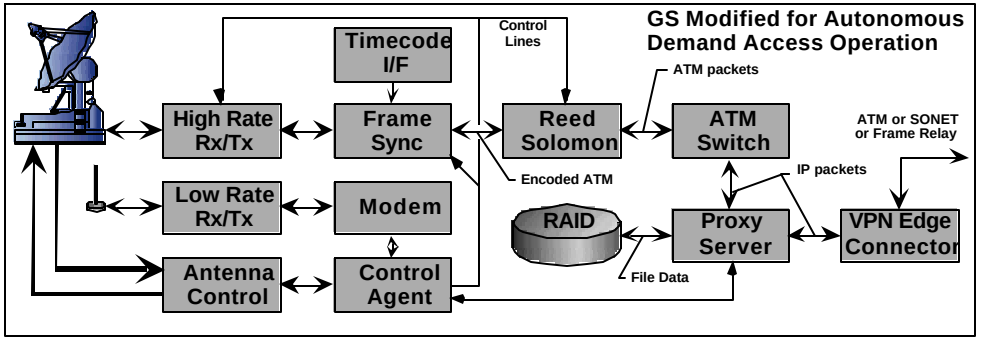
Autonomous
IP in Space

- Top – Early modification for automation and IP connection.
- Left – Spacecraft demands service, GS acknowledges.
- Right – Spacecraft and GS move high rate data down and up.
- Bottom – Later GS modification for autonomous demand access operation.





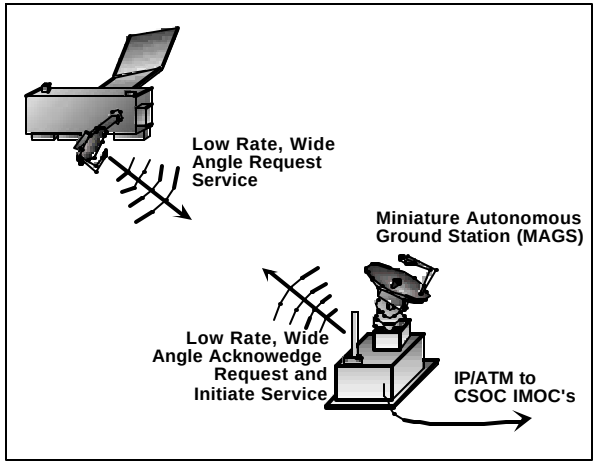


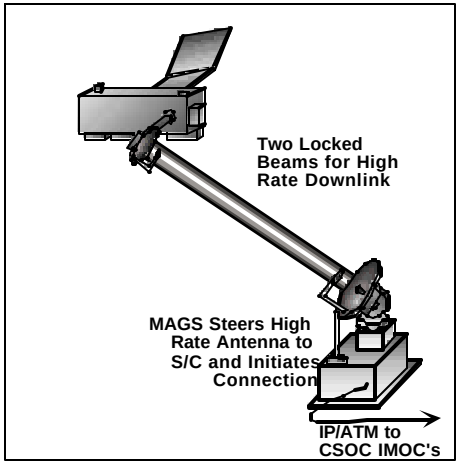


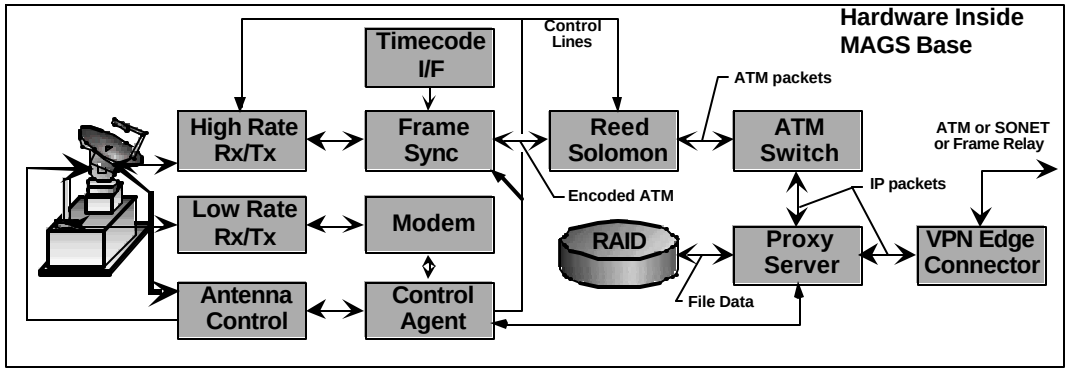
Ground Network (GN) - CSOC future modifications

Miniature Autonomous Ground Station (MAGS) concept

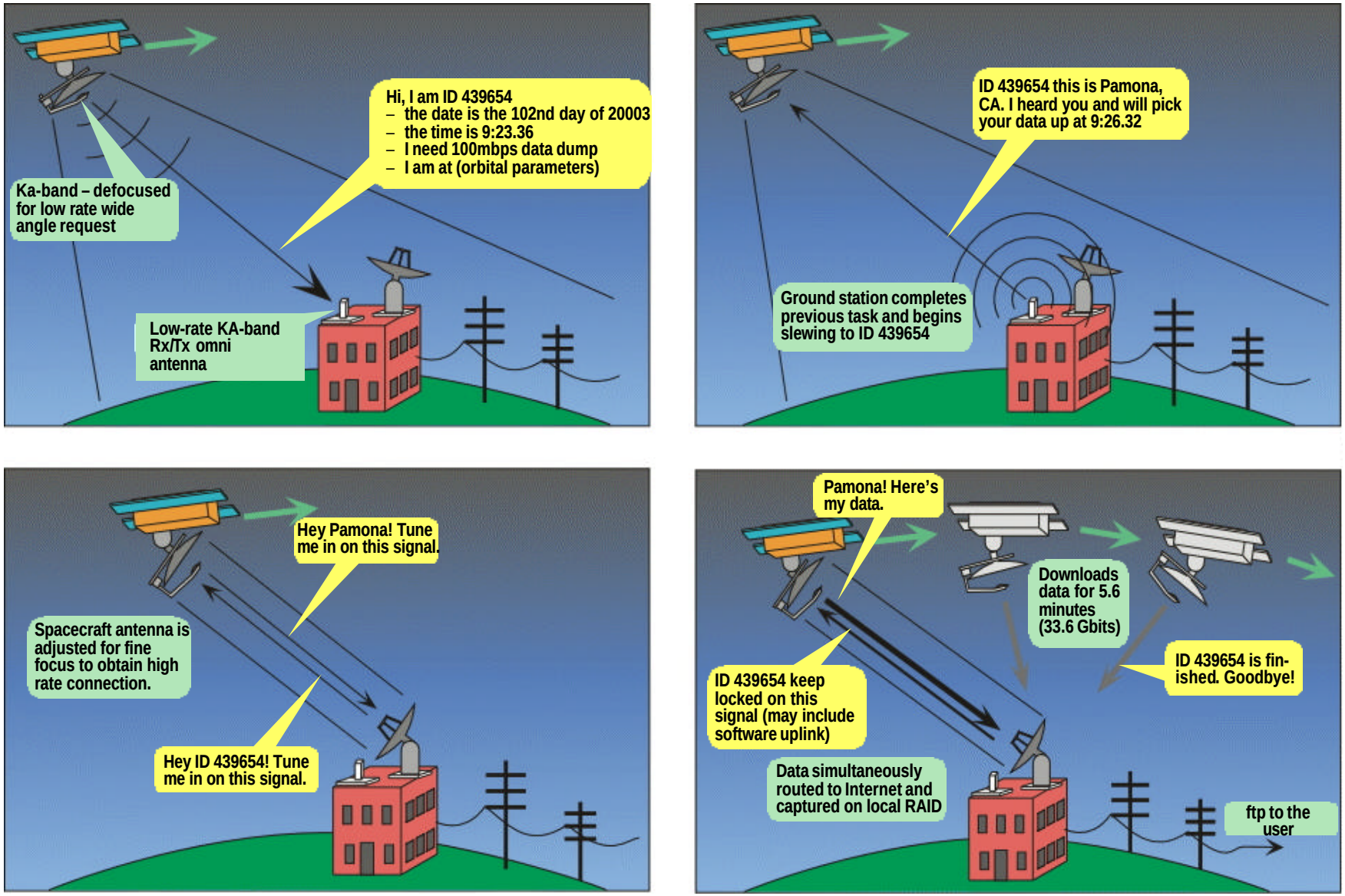
- **Left – MAGS acknowledging a request for service.**
- **Right – Ka-band high rate down- and uplink.**
- **Bottom – Equipment in the base of a MAGS.**





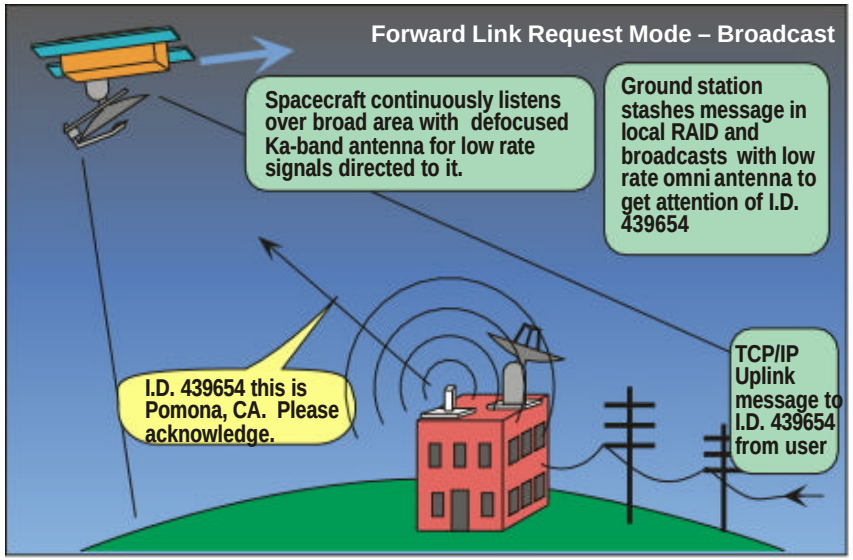


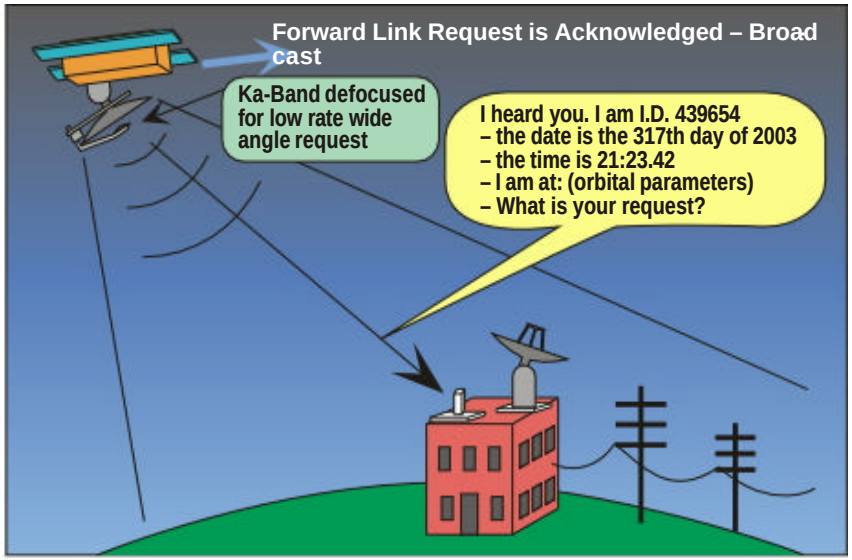
Return link demand request using beacon mode

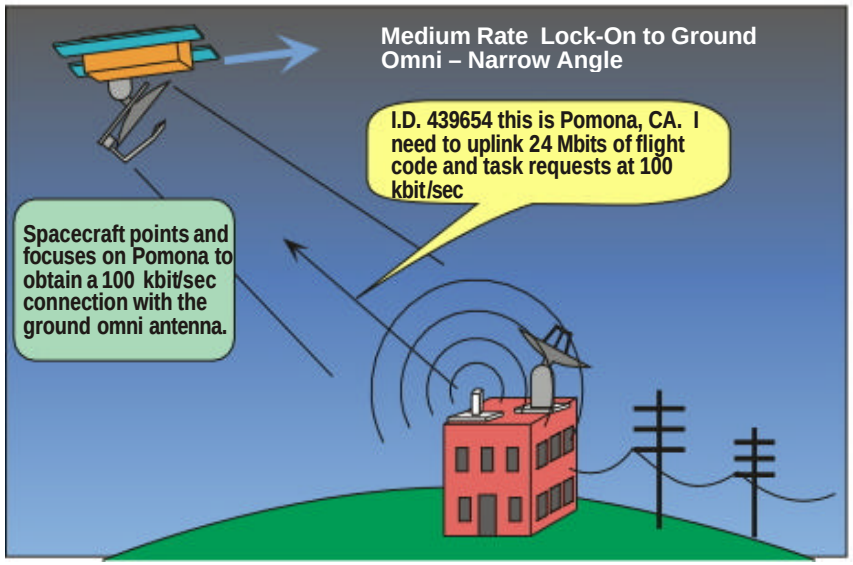


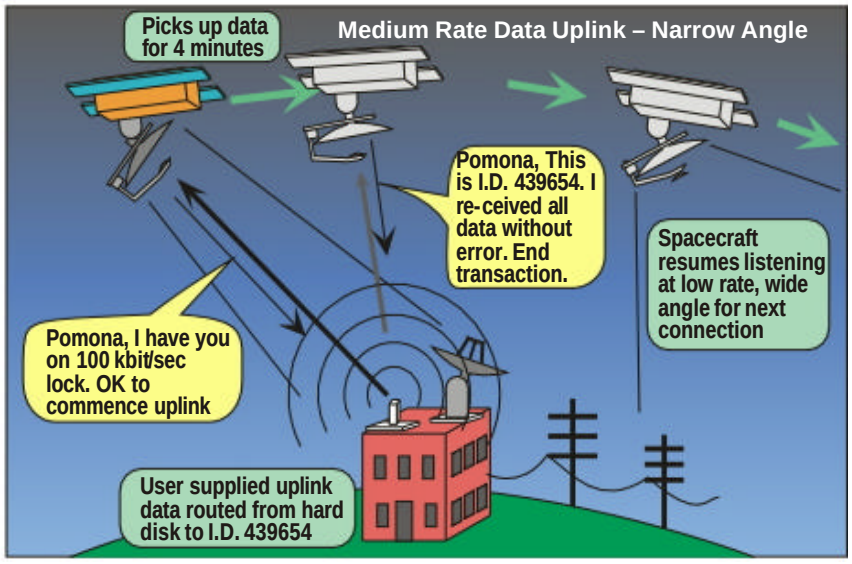
Forward link demand request from ground

Autonomous
IP in Space



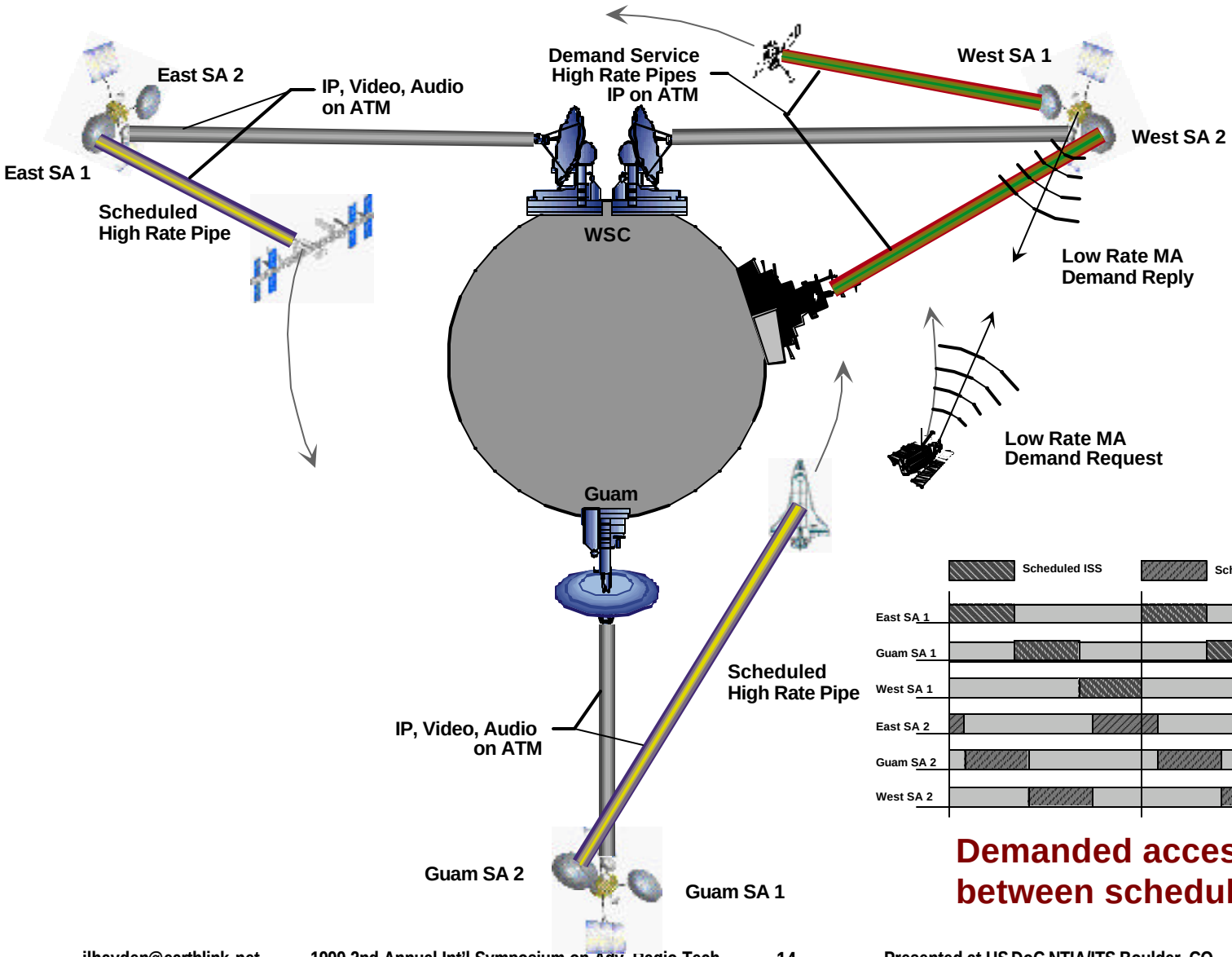






Space Network (SN)

Autonomous IP in Space

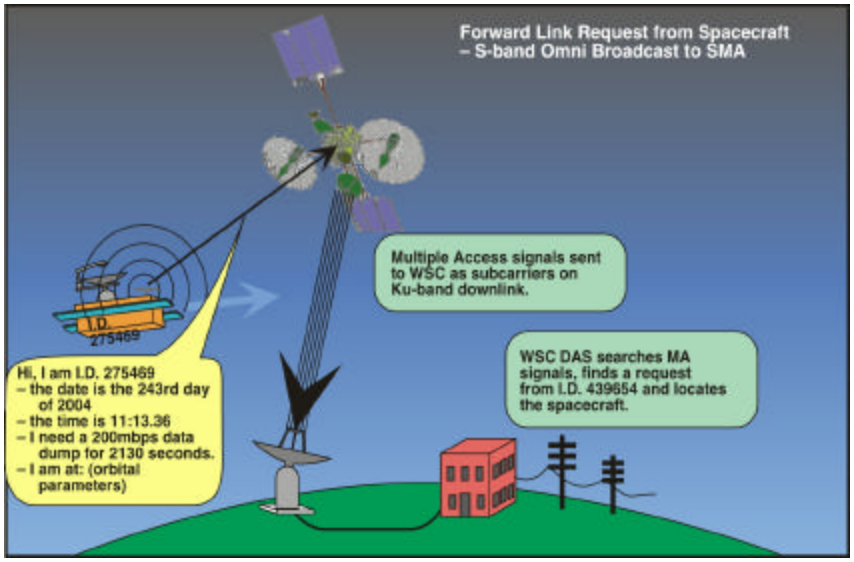


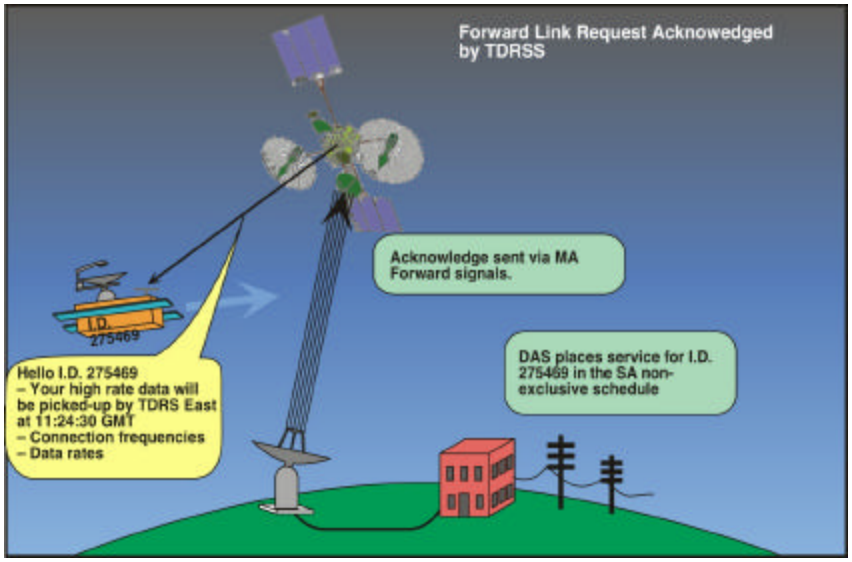
The TDRSS is shown providing scheduled and demanded access

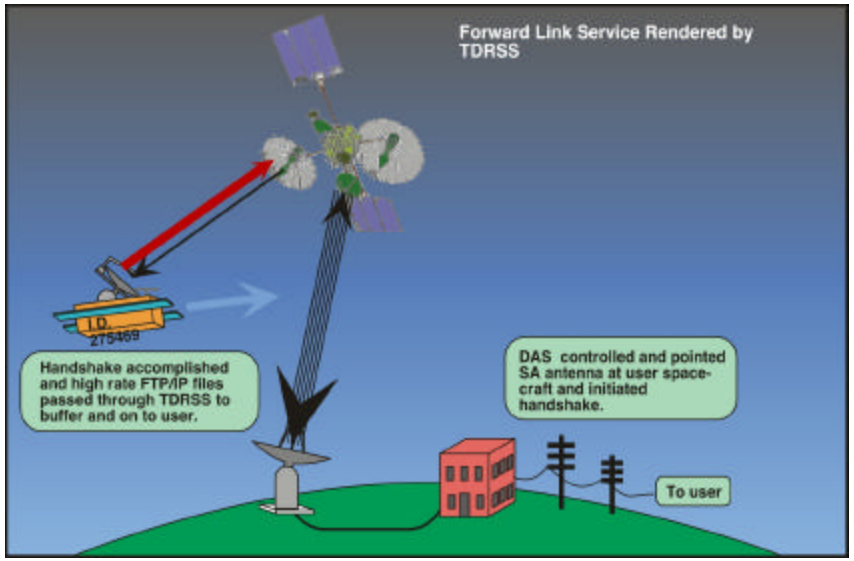
Demanded access fits between scheduled services.

Spacecraft demands and obtains access through TDRSS

Autonomous
IP in Space

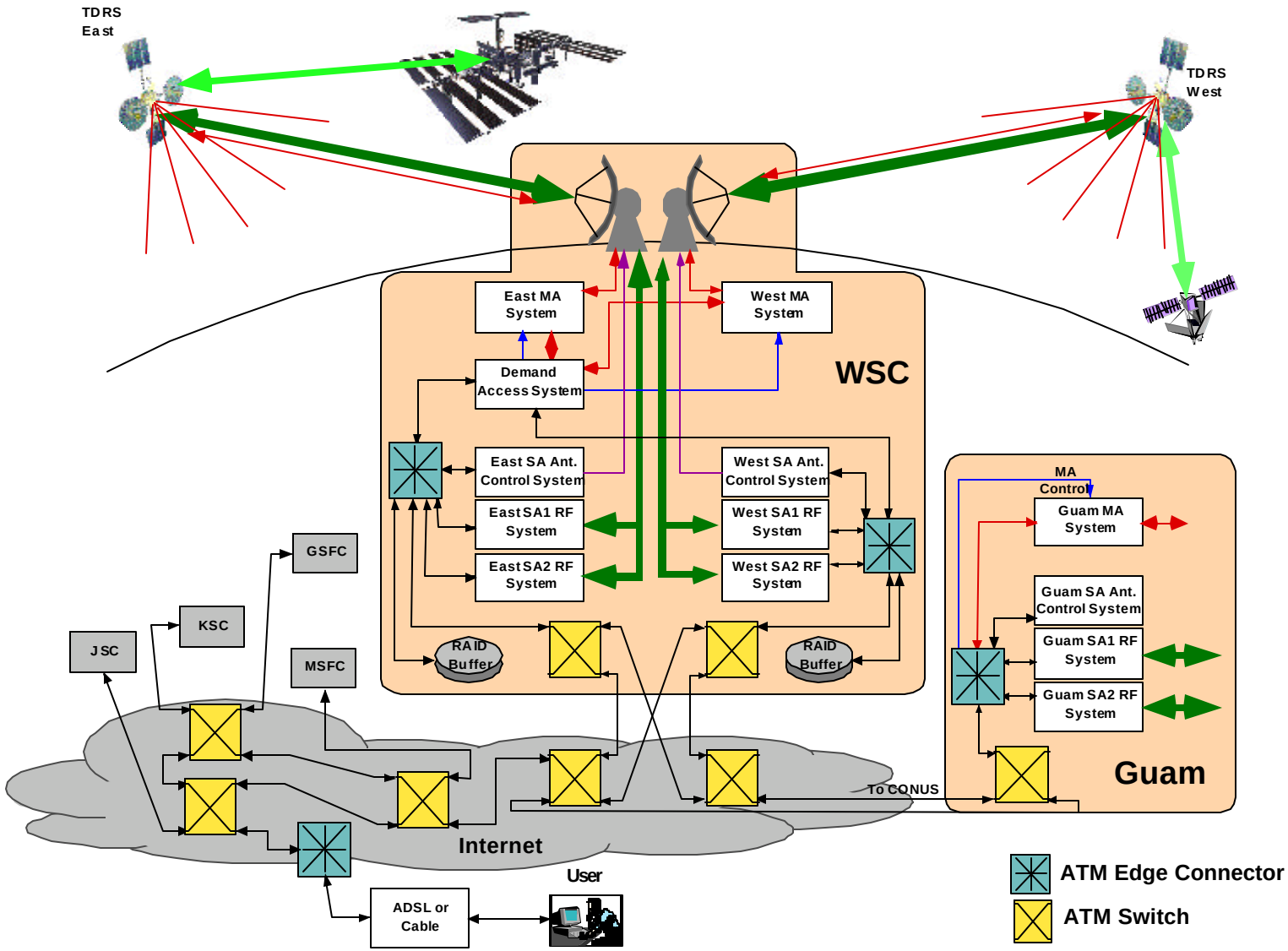






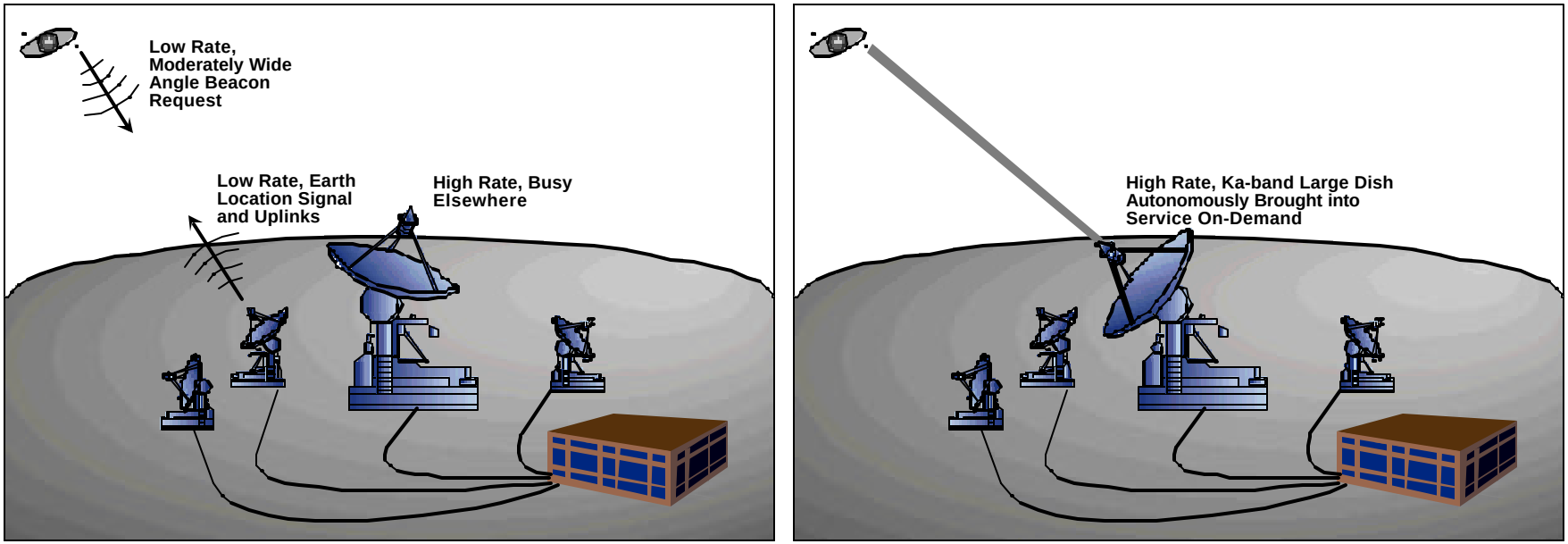
TDRSS modifications for IP/ATM and demand access

Autonomous
IP in Space



Deep Space Network (DSN)

DSN beacon mode facilitates autonomous demand access



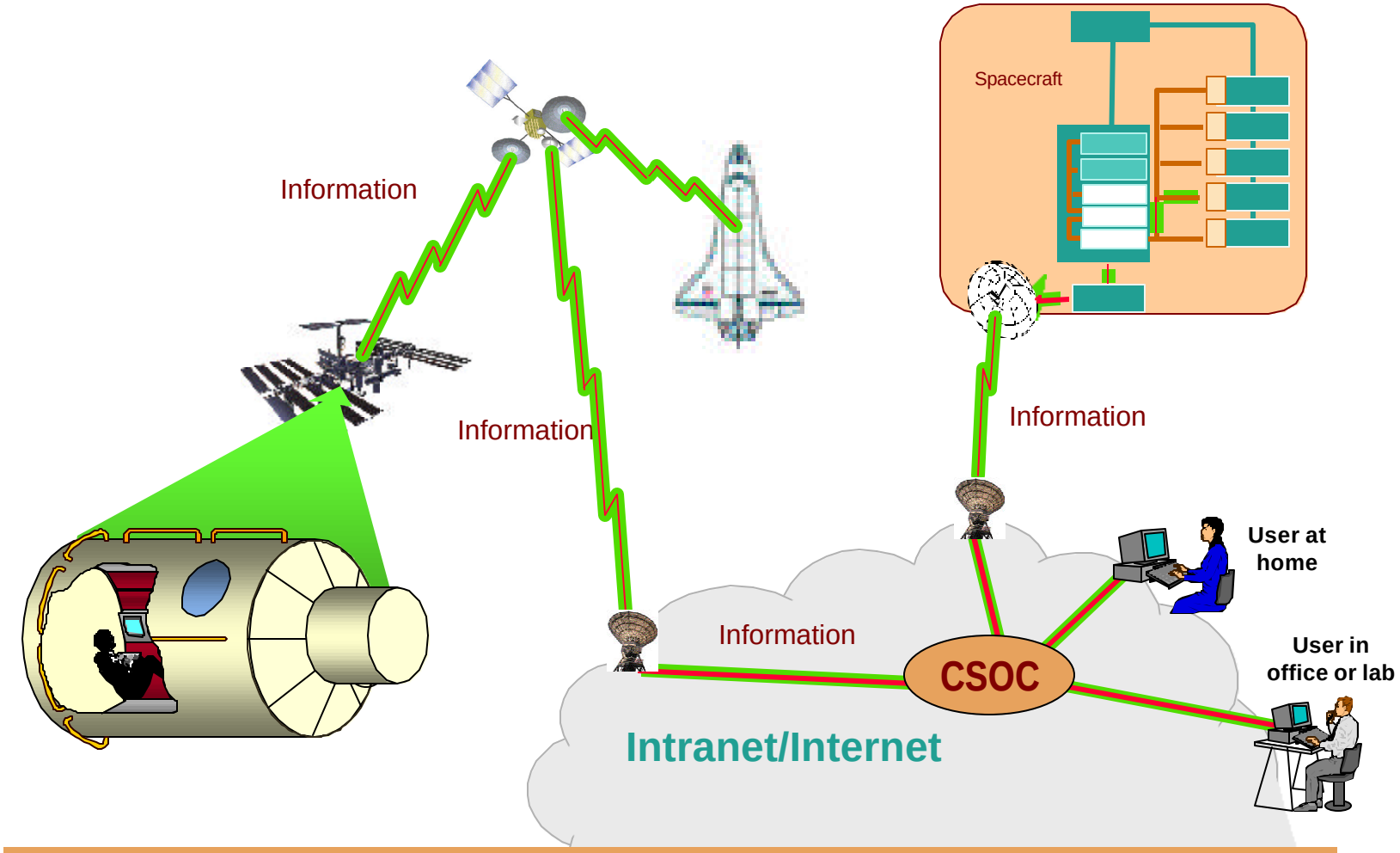
- Small antennas autonomously scan skies, listen to beacon signals, and send Earth position lighthouse signals.
- When access is requested, DSN autonomously brings in large antenna to collect data.
- Cell phone-like Time Division Multiple Access (TDMA) can resolve same frequency contention for service.

Spacecraft

- International Space Station (ISS)
- Space Transportation System (STS - Shuttle)
- Robotic Spacecraft
- Spacecraft Constellations

ISS and STS

Autonomous
IP in Space



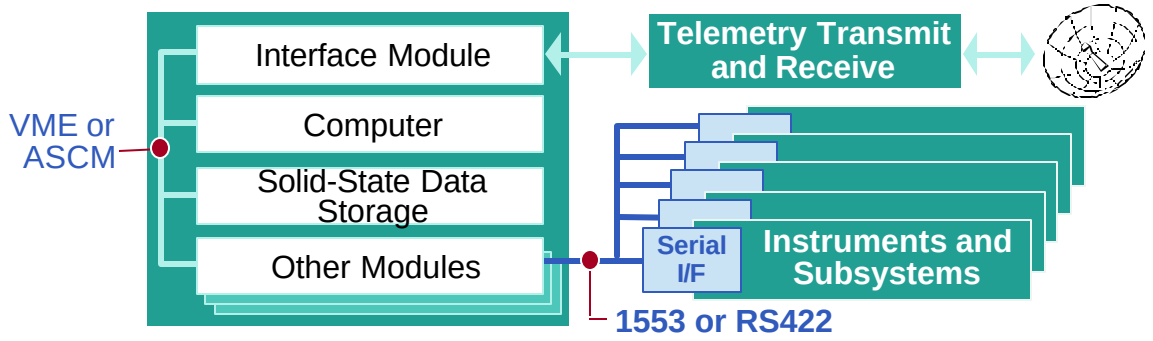
Science on ISS or STS can be interactive and synchronized with experiments on the ground or robotic S/C via the GN and SN

Robotic Spacecraft - Evolution

Autonomous IP in Space

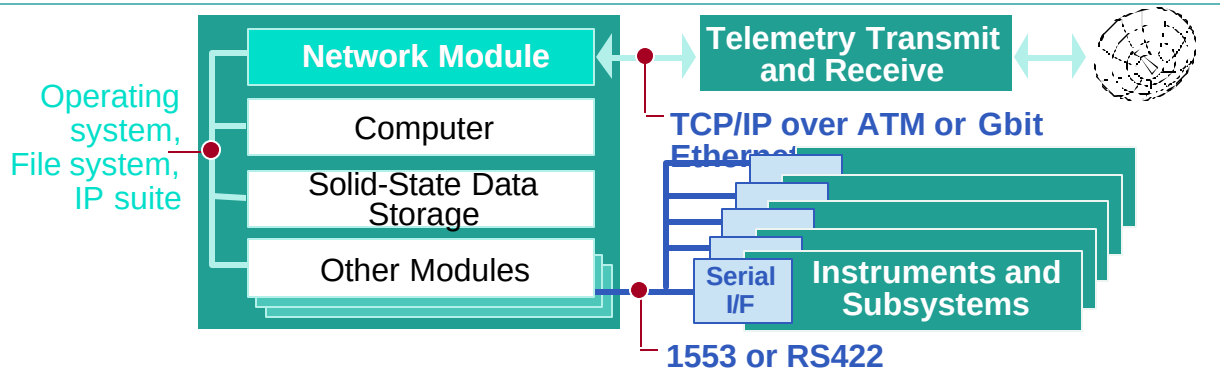
Current Spacecraft

- Specialized, space-qualified computer
- Embedded real-time software
- Data collected from serial bus and commutated into telemetry
- Scheduled communications



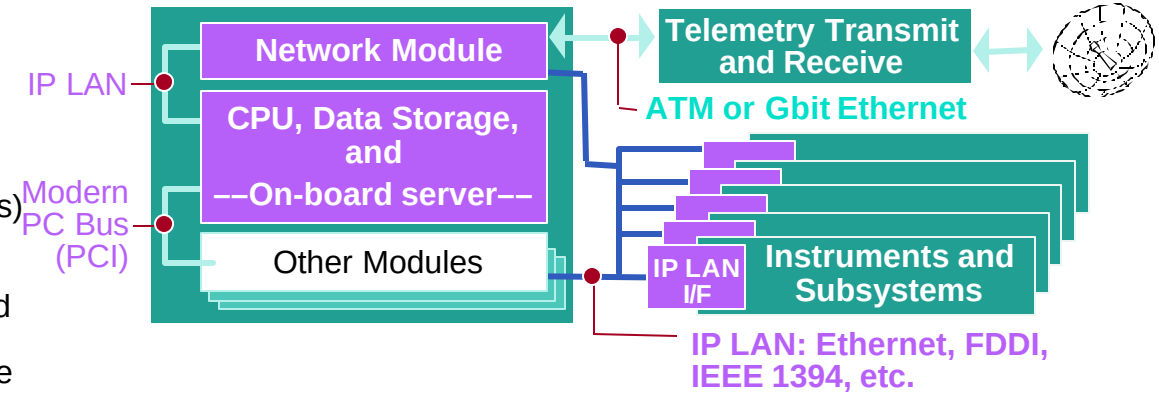
Transitional Spacecraft

- Entire spacecraft acts like a network node
- Space-qualified commercial computer with OS and files allows handling data in files (eliminated LZP)
- COTS autonomy software can be used



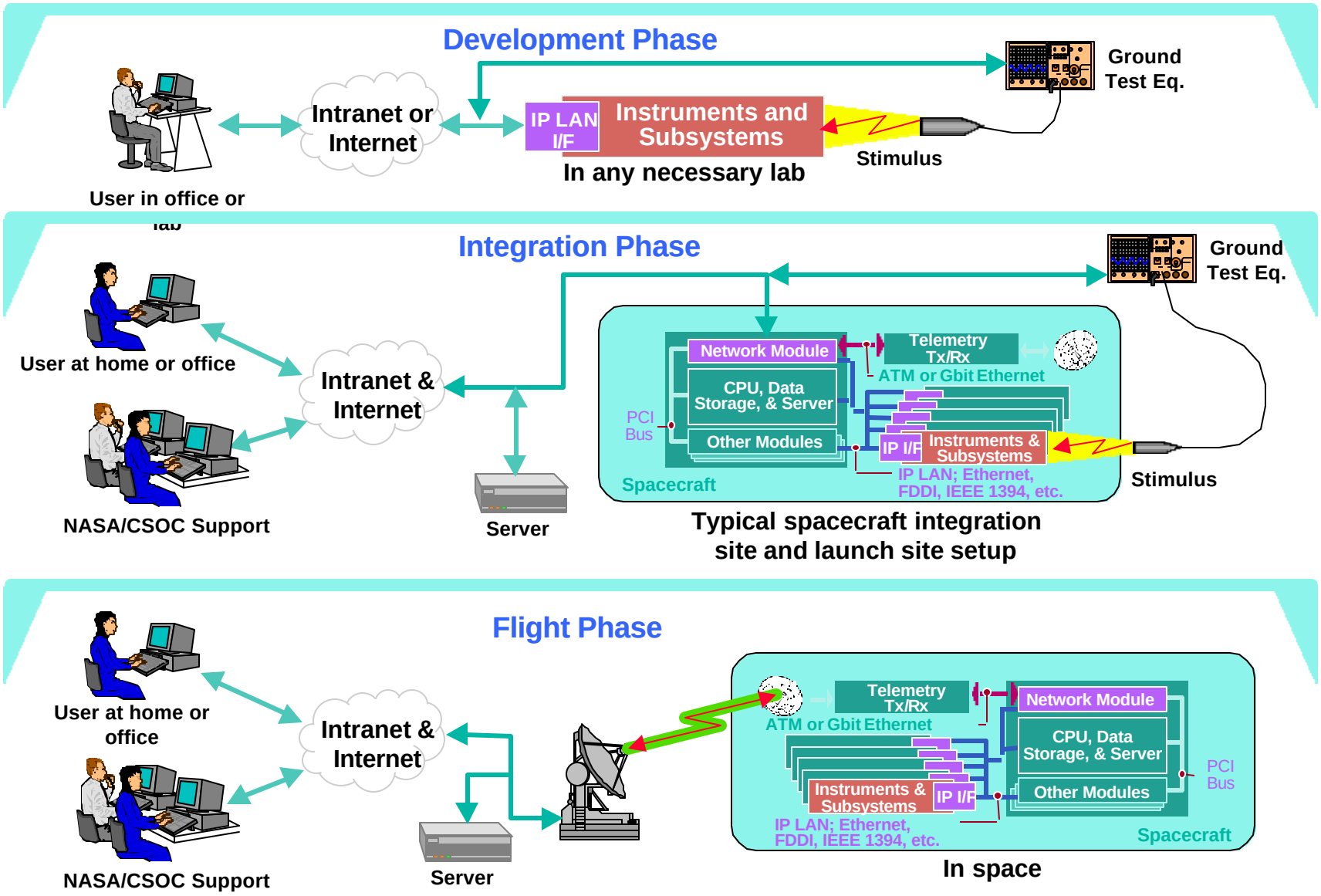
Future Spacecraft

- On-board LAN enables direct access to components
- Large memories provide server cache
- High-level autonomy (e.g., agents) on board the spacecraft
- Spacecraft given goals and schedules instead of commanded
- HW/SW for demanding or providing communications service

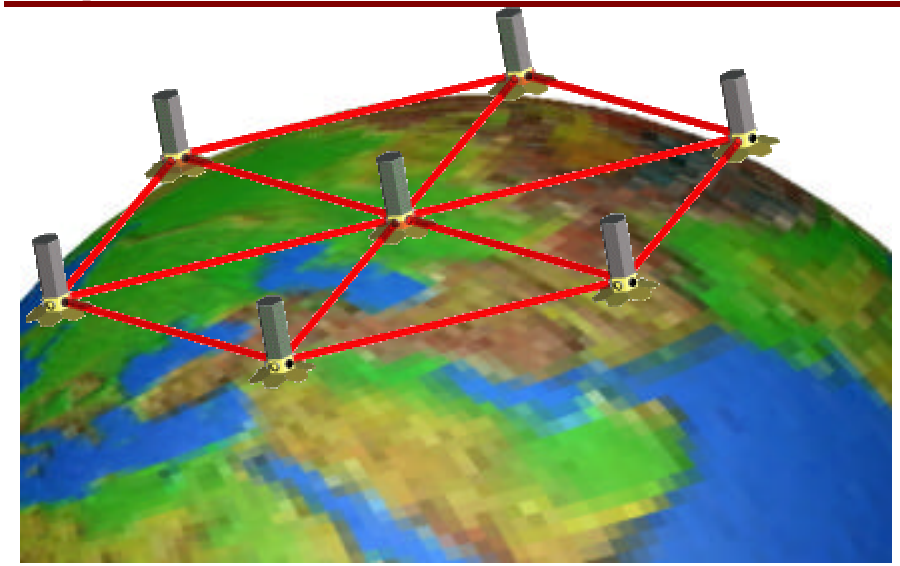


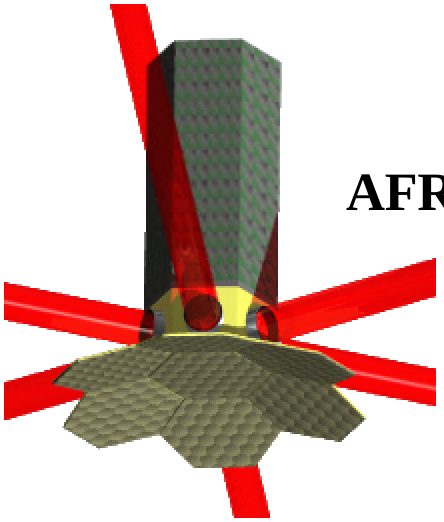
IP interfaces are constant throughout instrument life cycle

Autonomous
IP in Space



Spacecraft Constellations





Example
AFRL's TechSat21

- **IP/ATM facilitate constellation coordination**
  - Multicasting assists in time synchronization
  - Server S/C correlates constellation data
  - Any S/C can provide server function for constellation
- **Cross links**
  - High Rate provided with Ka & up or optical
  - Cross links will also assist in constellation geometry alignment

Implications for Communication Systems

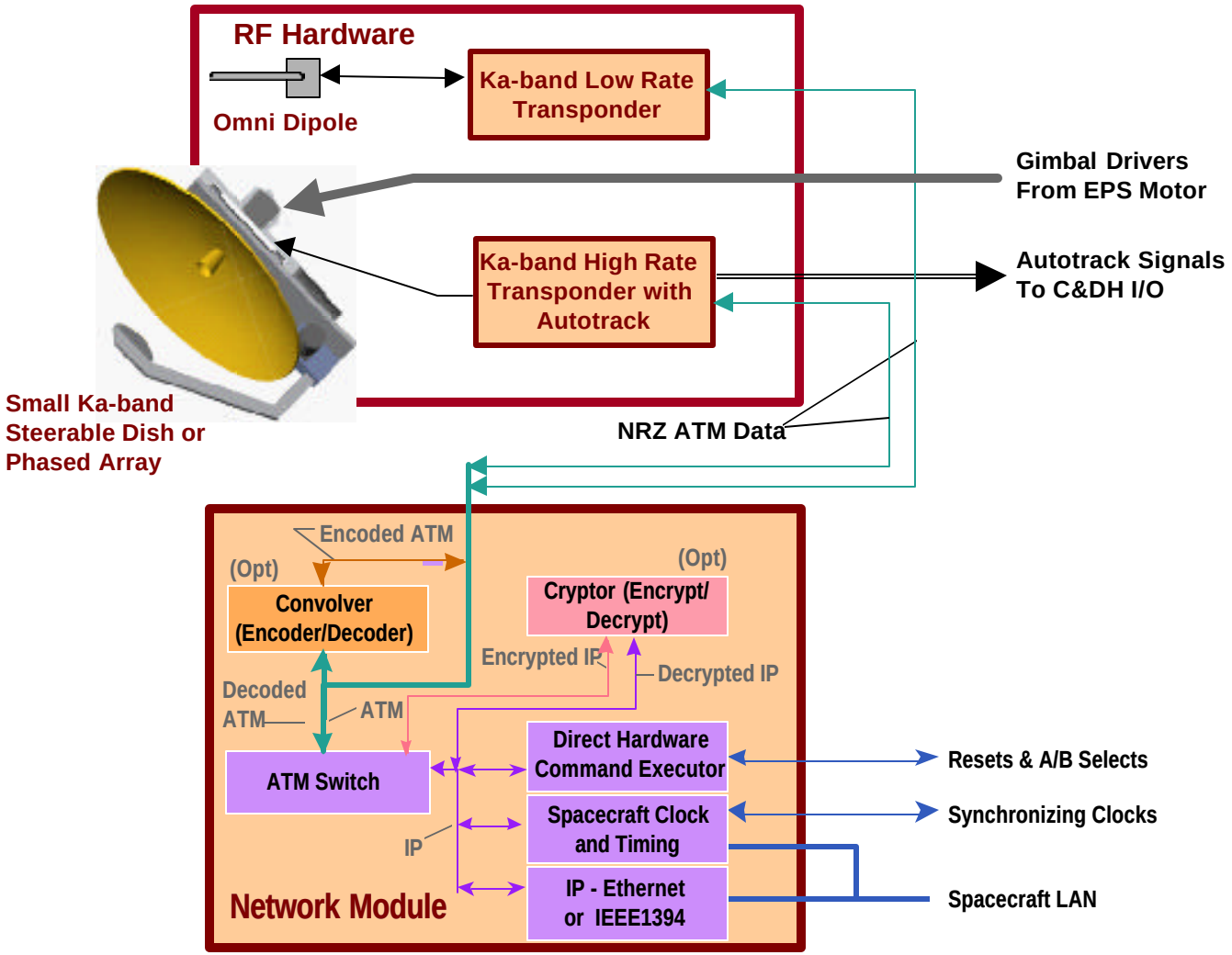
- Implement demand access and IP
- Low rate, wide angle hailing system
- High rate, highly focused data passing system

Implement demand access and IP

- **HW and SW needed to interface with CSOC's IOA**
  - **Standard Wireless Network Connector (SWNC)**
    - High rate (Ka) & low rate RF (X or Ka) for demand access.
    - Dish or Phased Array Antennas
    - S/C & Instrument/subsystem network modules.
    - SWNC SW Controls - demand access, antenna pointing/focusing, data rate.
    - Handle spinners
  - **Standard Awareness Package**
    - Autonomous HW and SW for navigation, attitude, health, task scheduling, etc.

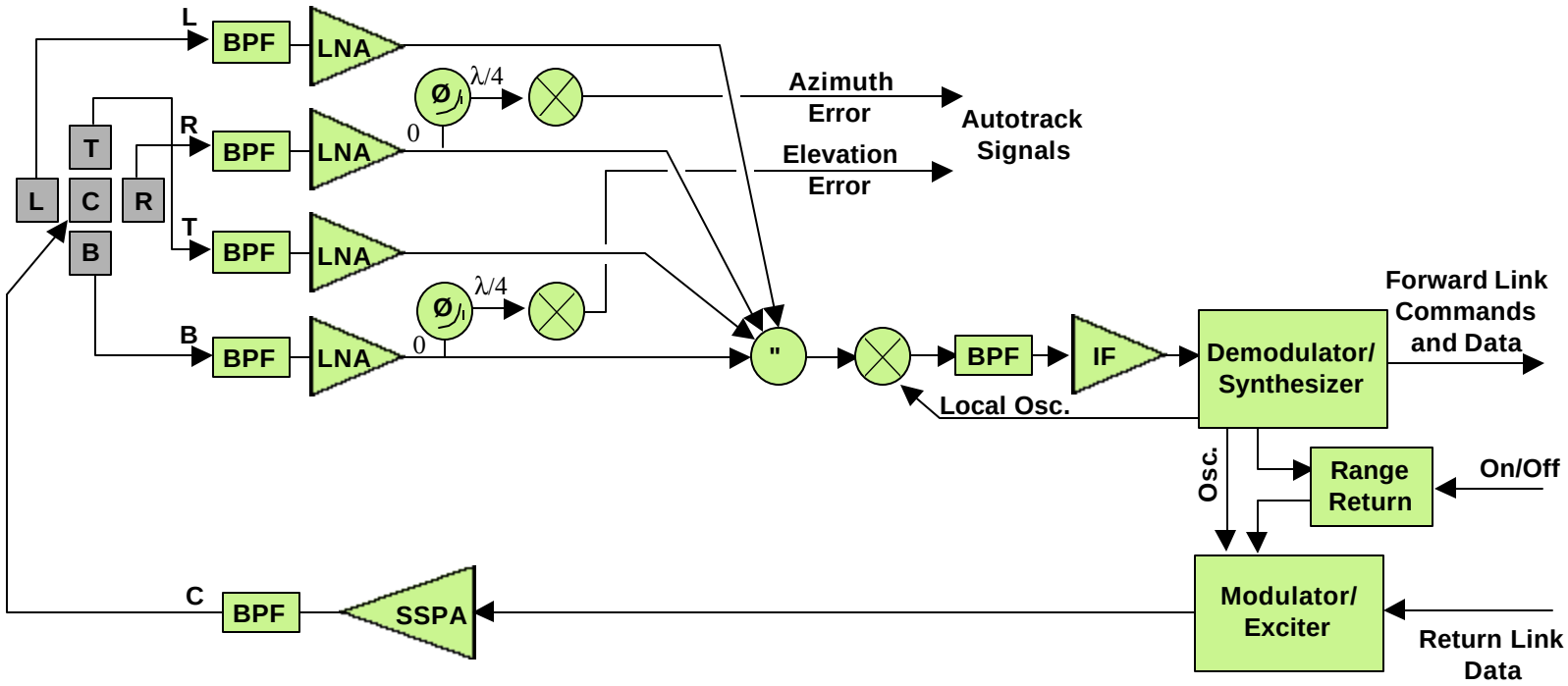
RF & LAN hardware for CSOC network compliant S/C

Autonomous
IP in Space



Ka-band high rate T/R module

Autonomous
IP in Space



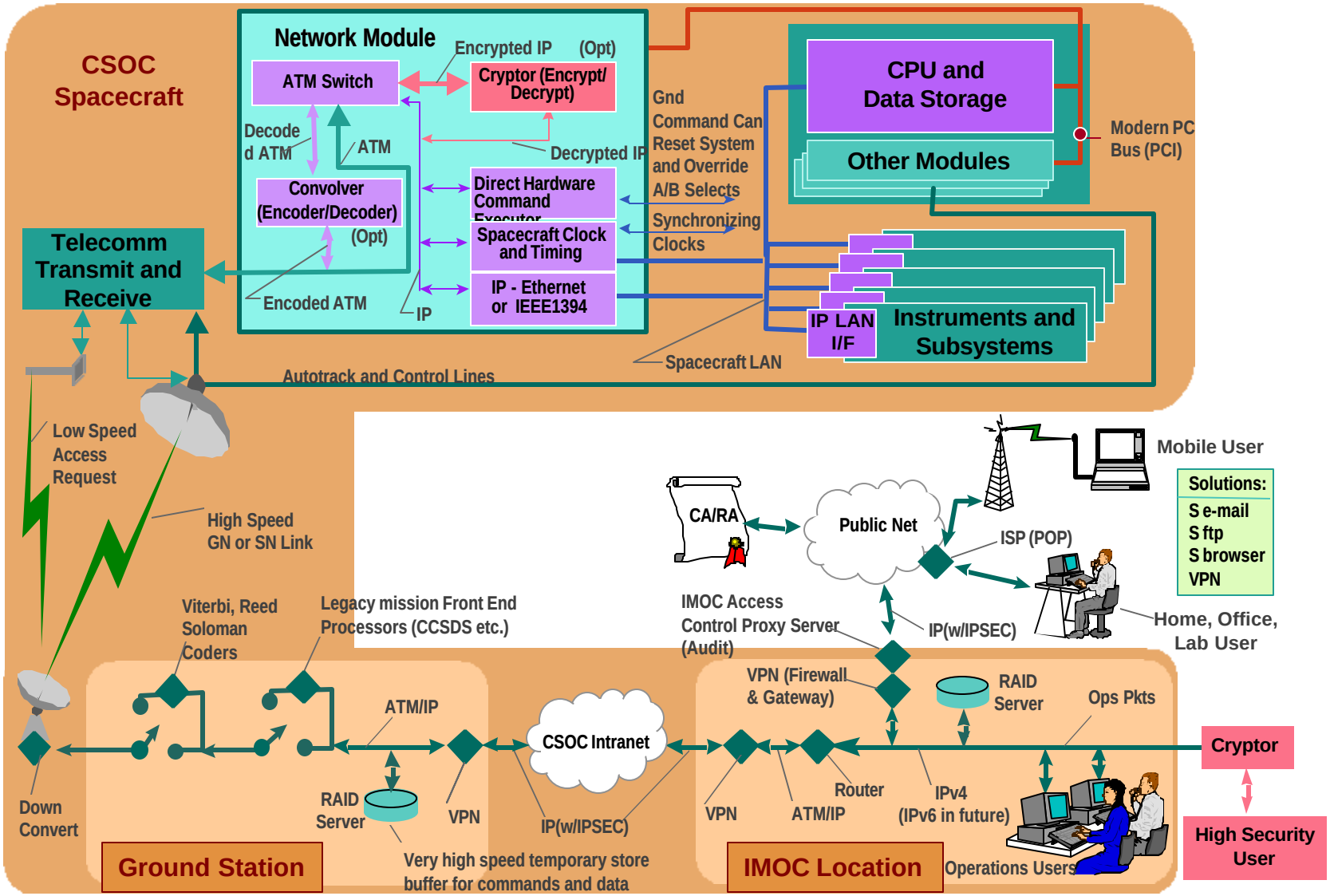
Low rate, wide angle hailing TX/RX systems

- **For GN**
  - S-, X-, Ku-, or Ka-band (preferred)
  - Near Omni for the GN
- **For SN (TDRSS)**
  - S-band Multiple Access (SMA) needed to contact TDRSS
- **For DSN**
  - X- or Ka-band (preferred)
  - 11m to 26m antennas
  - 1° to 10° FOV
- **On-Board Spacecraft**
  - Patch,
  - Dipoles,
  - Horns,
  - Defocused Dish or Phased Array
  - ð /2 to 2ð FOV to GN or SN
  - 1° to 10° FOV

High rate, highly focused, data passing TX/RX systems

- **For GN**
  - Ka-band (preferred)
  - 0.1° to 1° FOV
  - Rates >300Mbps
- **For SN (TDRSS)**
  - Ku-band Single Access system on TDRSS 1-7,
  - Ka-band for TDRSS H,I,J
  - Rates >300Mbps
- **For DSN**
  - X- or Ka-band (preferred)
  - 26m, 34m, 70m antennas (70m cannot do Ka)
  - 0.01° to 0.5° FOV
  - Rates >1Mbps to Mars
- **On-Board Spacecraft**
  - Focused Dish or Phased Array
  - 0.1° to 0.5° FOV to GN, SN, or DSN

CSOC network (spacecraft to GN shown)



CSOC Network

- **New spacecraft network module:**
  - Hub/Router for control of on-board LAN for routing data/commands/tasks between instruments, subsystems, C&DH.
  - Instruments and subsystems incorporate LAN interfaces.
  - Provides a spacecraft clock and auxiliary timing signals.
  - Provides for critical hardware command trapping and execution signals.
  - Can include hardware encryption, if required, or encryption may be provided by an external device.
  - May incorporate an ATM edge connector to handle high rate synchronous data simultaneously with lower rate asynchronous data.
  - May incorporate IP only, depending on mission.
  - Data dropout/noise protection (Viterbi, Reed Solomon) is incorporated for most missions.
- **Wireless RF link**
  - Low rate Ka-band, X-band, or S-band for hailing the network to demand access; for down-linking identification, status, and health data; and, for up-linking low rate command or task assignment data.
  - High rate Ka-band steerable dish antennas (space and ground) with autotrack to ensure high rate lock-on, or steerable beam phased arrays for passing large data sets.

CSOC Network

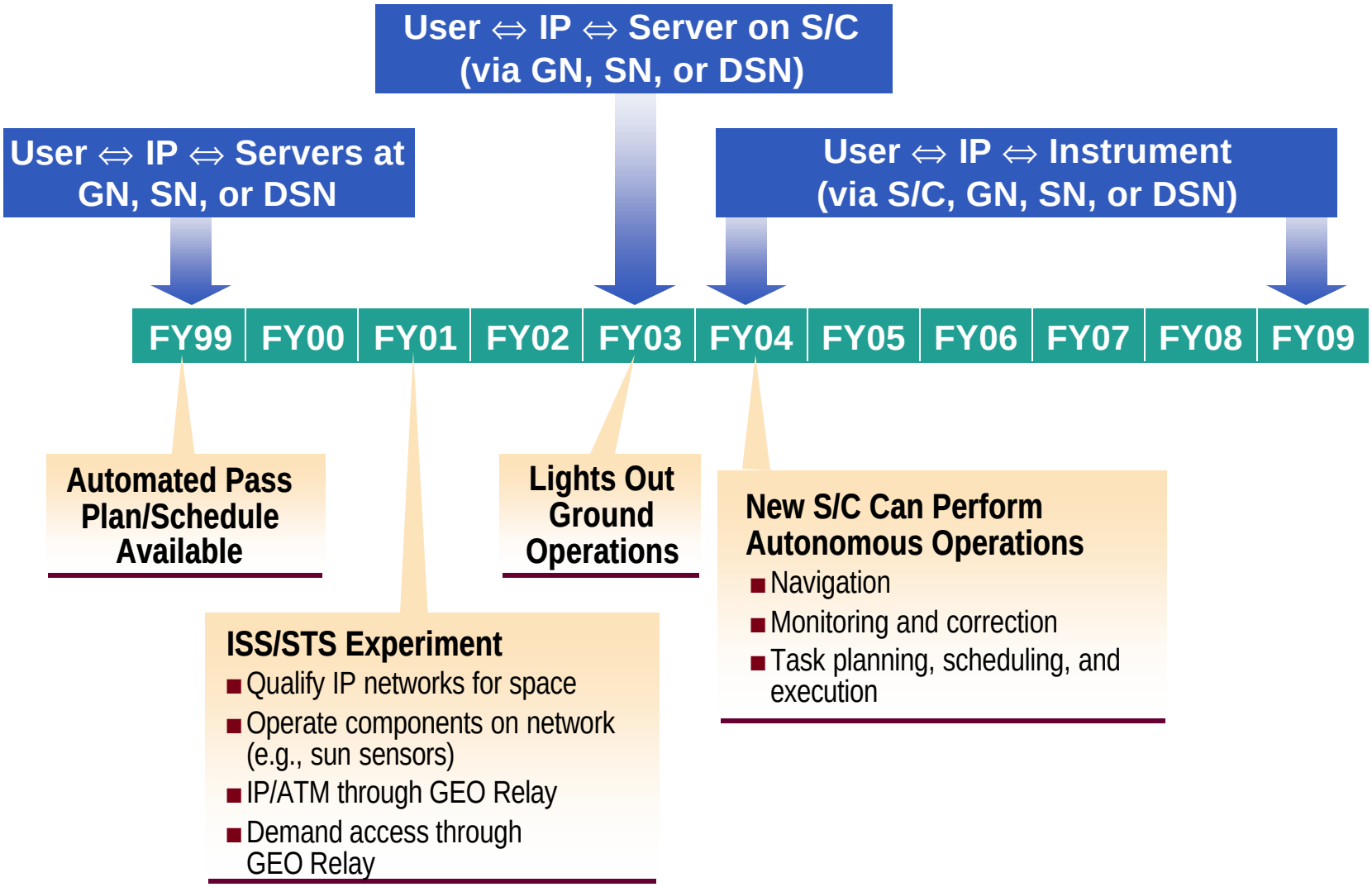
- **Ground Station**
  - Low rate, omni-directional Ka-, X-, or S-band transceiver for receiving requests for access to the network as well as spacecraft ID's, health, and status.
  - High rate Ka-band steerable dish - less than 1 meter diameter for new missions. Larger X- and S-band antennas kept for legacy missions.
  - Viterbi, Reed Solomon, Turbo codes provided for error detection and correction.
  - FEP provided for legacy missions.
  - High speed, high capacity RAID with the IP server computer to provide temporary storage for up-links and down-links.
  - Ground station network routed to VPN.
- **CSOC Virtual Private Network (VPN) Intranet**
  - VPN's set up with telecommunications companies.
  - Data further protected with encryption.
- **IMOC location at NASA center**
  - Data captured in high speed, high capacity RAID with the IP server computer.
  - IMOC personnel perform spacecraft operations through server.

CSOC Network

- **CSOC Intranet to public Internet connection**
  - Via a firewall server at the IMOC site.
  - Data over the Internet uses software encryption/decryption.
  - Authorization service is provided by a specially qualified vendor.
  - Authorized personnel can access their spacecraft or instrument from any connection to the Internet.
  - Internet security will increase significantly due to demand by commercial users.
- **Secure/encrypted connections**
  - Via leased hardlines, if so desired by customer requiring extra security.

The CSOC 10 Year Plan

Autonomous IP in Space



Some pertinent information

- **CSOC web site:**
  - **Http://www.csoconline.com**
    - Introduction
    - Documentation
    - Contacts
- **Documentation**
  - This presentation is based on section 4 and appendix C of the Integrated Operational Architectural Baseline
- **CSOC contacts**
  - Marty Skudlarek 281-853-3335 martin.skudlarek@csoconline.com
  - Bob Gates 281-853-3063 robert.gates @csoconline.com