SPECIAL ISSUE: Improving Space Operations Workshop (May 03-05, 2019), Part I.

From the Editor-in Chief

This quarterly issue is dedicated to the recapture of ideas from technical papers presented and discussed during the recent "Improving Space Operations Workshop" in Santa Clara, CA, May 02-03, 2019. In addition to long-term 5^{th} generation wireless networking, the forum included topics on current space communication and navigation initiatives, alternative communication technologies, spacecraft monitoring systems. Risk mitigation of data losses with anomaly detection and fault diagnosis indicated more efficient telemetry analysis using learning algorithms. Automated data processing and integration of multiple knowledge domains enable intelligent systems to manage multi-failure responses. Just as importantly discussed, pre-launch mission planning and project management of multiple system operations to sustain and protect communications and navigation were topics discussed emphasizing a required advancement of technologies and smart implementation of their respective applications. A future quarterly issue will be dedicated for its overview. Impressive with the workshop presenters was the fact they were all subject matter experts having been intimately engaged in both the trials and successes of what they presented at the workshop. Providing an overview of the workshop forum has been a personal beneficial opportunity to conceptualize distinct topics into a composite construct showing a contemporary outlook on space operations. Thank you, readers.

Ronald H. Freeman, PhD

Improving Space Operations Workshop 2019: Photos

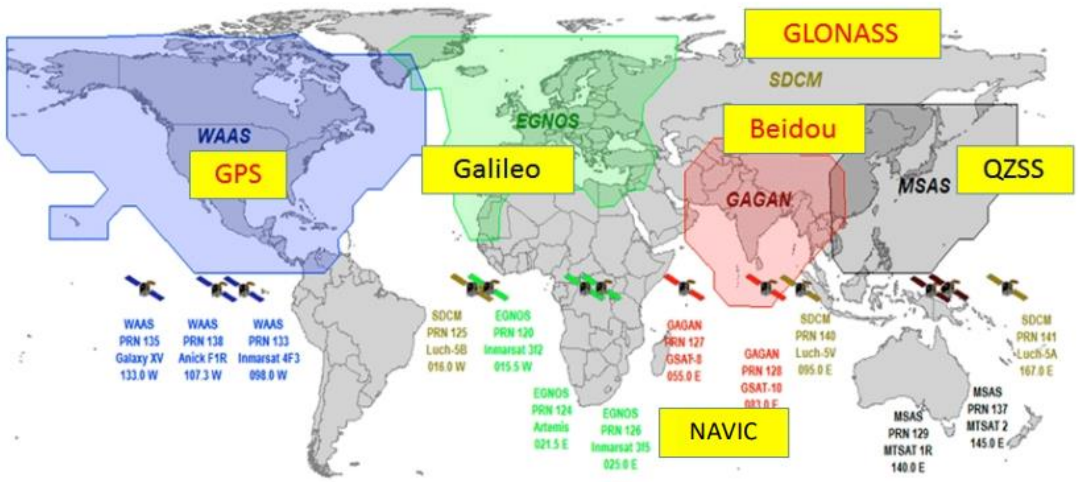

Launch and Early Operations
Launched December 15, 2016
– Second attempt
Two 13-hour shifts for initial two weeks
SwRI:
– First Built Satellite[s]
– First Mission Operations Center
KSAT
ACCESS TO SATELLITES
ANYWHERE, ANYTIME.


KSAT
ACCESS TO SATELLITES
ANYWHERE, ANYTIME.
EXIT

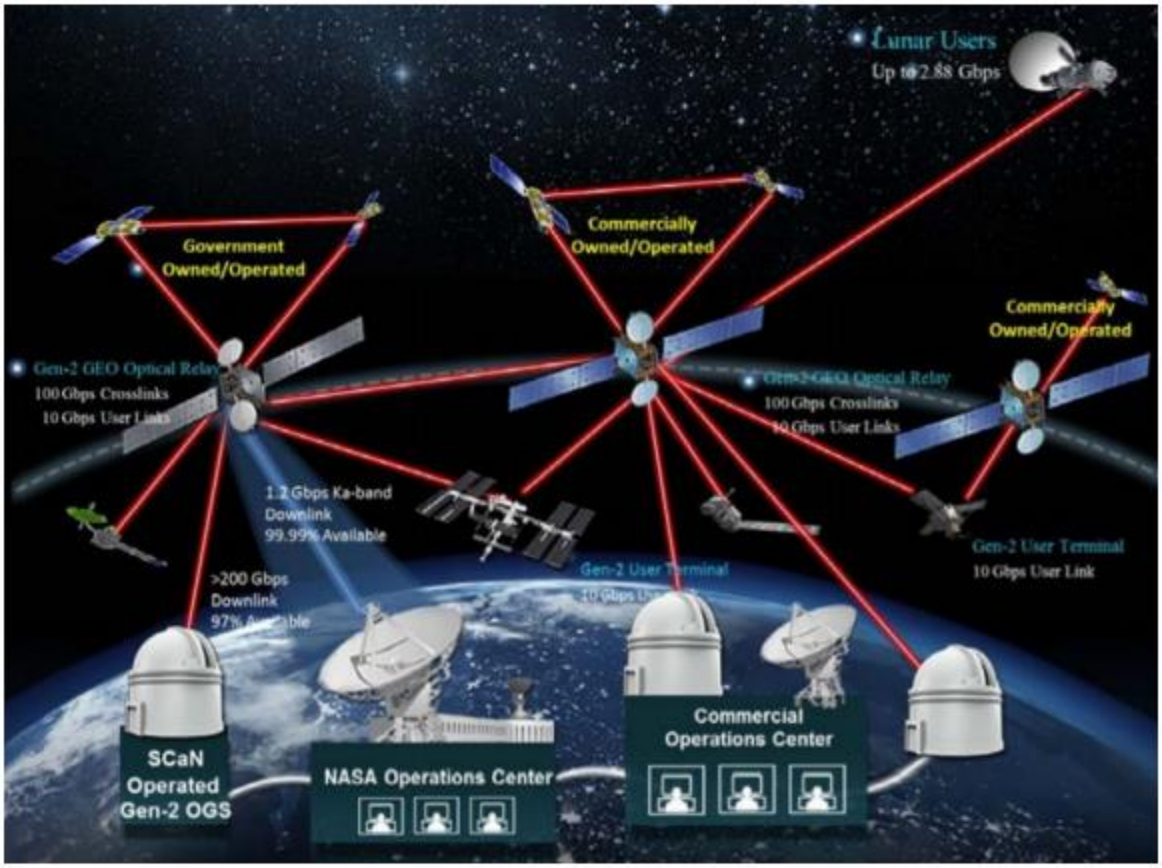

Over 300,000 people connected

ISOW 2019: Overview 1.

- GNSS is an umbrella term for satellite constellations that broadcast signals from space for radionavigation
  - Systems with global coverage: GPS (United States), Galileo (European Union), GLONASS (Russia), BeiDou (China)
  - Systems with regional coverage: NAVIC (India), QZSS (Japan)

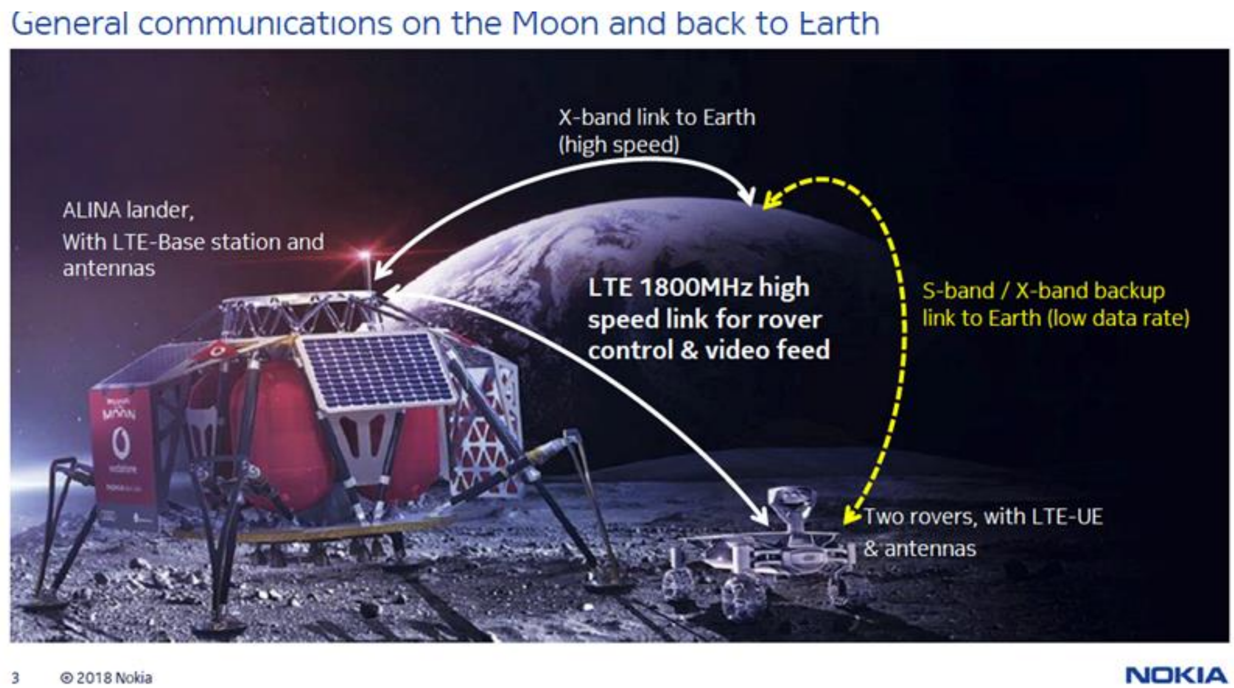


Modern LTE/5G wireless networking architectures improve wireless broadband speeds to meet increasing international demands. Long-term evolution to improve wireless broadband speeds is possible through the integration of large numbers of antennas into future 5th generation (5G). The 71-76 GHz (70 GHz) band was identified at the International Telecommunication Union (ITU)'s World Radio-communication Conference (WRC) 2015, as a possible band for future 5G wireless system deployments.[1] Interference level was developed when considered power limited, yet satellite networks tend to be interference limited.[2] NASA has set the standard for connecting data-gathering satellites with ground stations on Earth, through global communication networks. In the 28 GHz band, Fixed Satellite Service (FSS) uplink–i.e., the communication links from Earth Stations (ESs) to Space Stations (SSs)–is in wide use, whereas in the 70 GHz band, the Fixed Service (FS) Wireless Backhaul (WB) for other cellular systems–e.g., the 4th generation (4G)–is the predominant incumbent. Future mission communication service demands for higher and faster data rates are expected to increase. According to ISOW 2019 presenters, Subray and Gifford, LTE/5G meets increasing demand for faster wireless broadband speeds and that 70 GHz band will be possible for future 5G wireless system deployments.



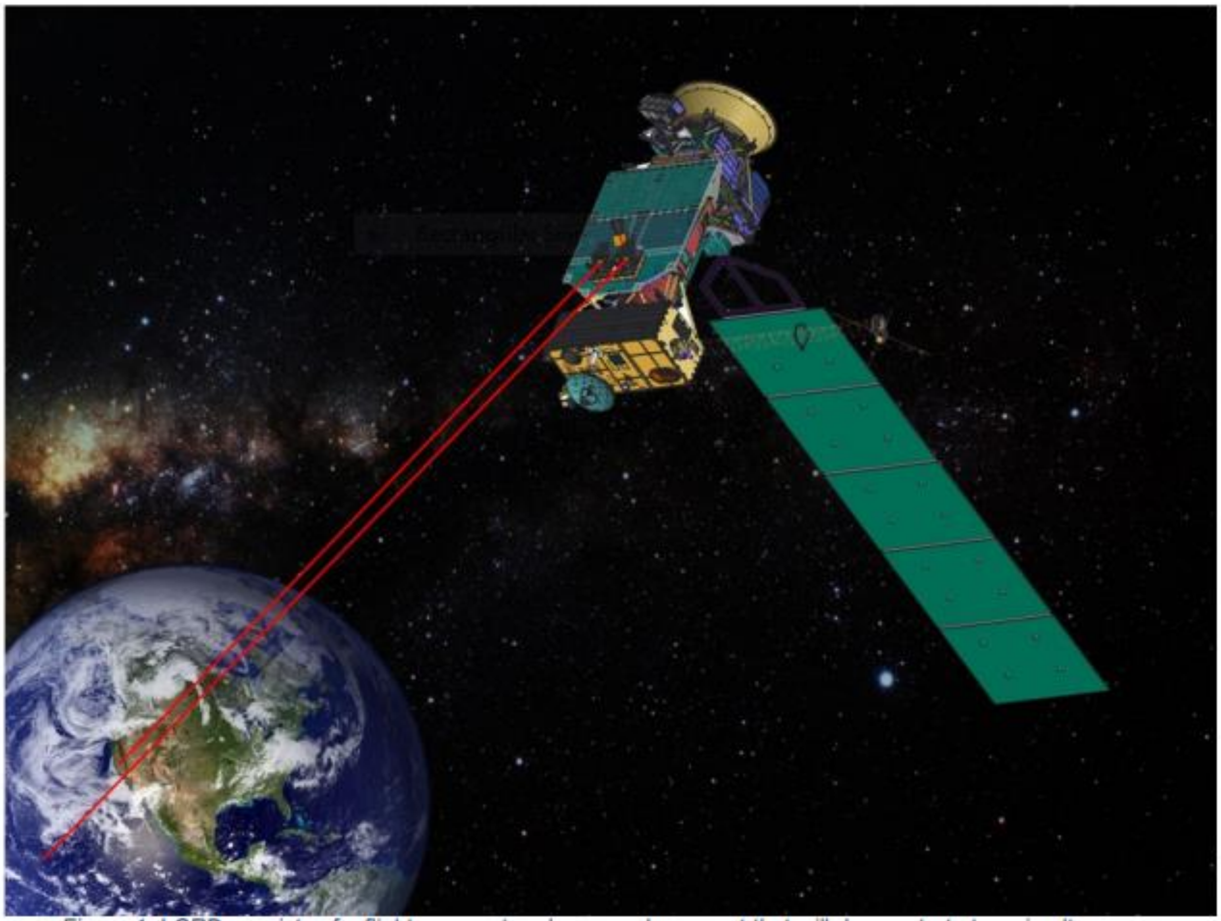
Sean Casey of Atlas Space Operations, noted how shared costs and risks foster greater interoperability and sustainability satellite communications. Sending/receiving data on Earth from any spacecraft is a difficult task, mainly because of the large distances involved. NASA's Space Communications and Navigation (SCaN) manages 3 communication networks for transmitting and receiving signals across large distances that contain space relay satellites and distributed ground stations: Near Earth Network (NEN), Space Network (SN), and Deep Space Network (DSN).

Beyond the radio and microwave portions of the electromagnetic spectrum and towards the near-infrared and in the realm of light photons, NASA uses lasers for space communications. Lunar Laser Communications encodes data onto a beam of laser light to enable optical communications for data transmission up to 622 Mbps. Space laser communications technology has the potential to provide 10 to 100 times higher data rates than traditional radio frequency systems for the same mass and power. Hosted onboard a U.S. Air Force spacecraft as part of the Space Test Program (STP-3) mission, Lunar Communications Relay Demonstration (LCRD) demonstrated this 1,244 Gbps technology in a 2-year mission to geosynchronous orbit – 22,000 miles above Earth's surface.



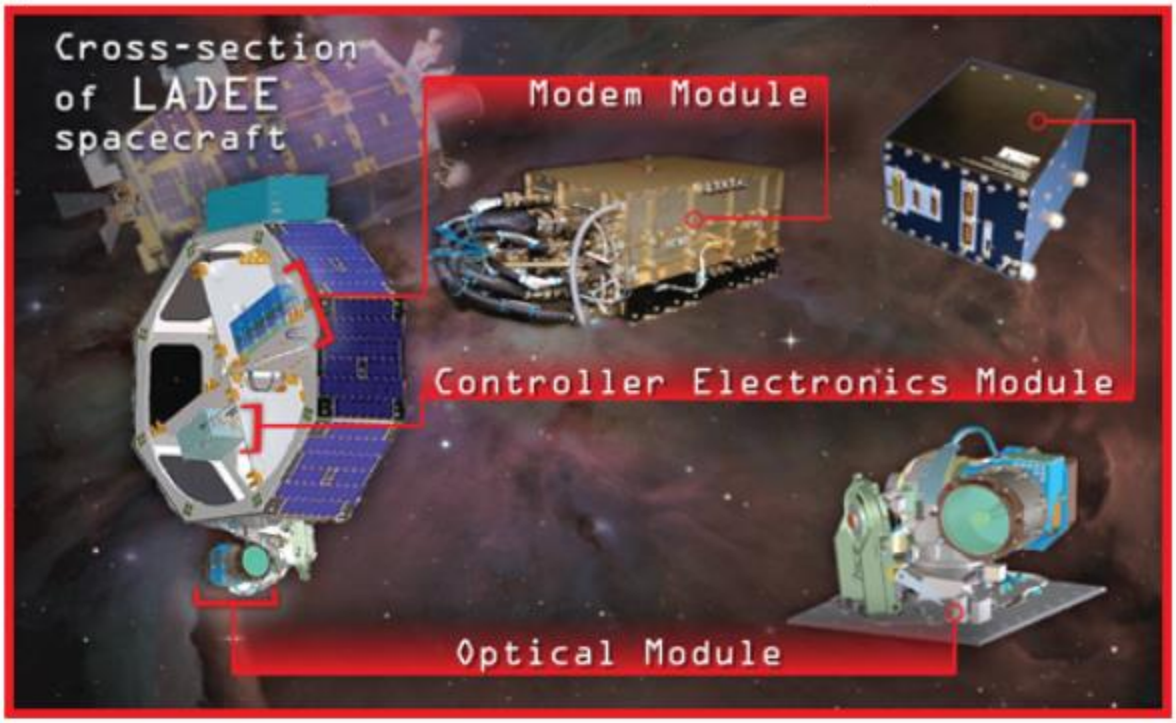
One solution for NASA was to look beyond the radio and microwave portions of the electromagnetic spectrum towards the near-infrared and in the realm of light photons. Light photons are small packets of electromagnetic waves, and when many are transmitted together "in synch," they form what is commonly known as a LASER beam. NASA ventured into a new era of space communications using lasers, beginning with the Lunar Laser Communications Demonstration (LLCD). LLCD established the ability to encode data onto a beam of laser light and validated a new form of communications from space, "optical communications." The term "optical communications" refers to the use of light as the medium for data transmission. LLCD has the capability to transfer data at a rate of up to 622 megabits per second (Mbps). It will demonstrate two-way, high-rate laser communications from lunar orbit aboard the Lunar Atmosphere Dust Environment Explorer (LADEE).

Laser Communications Relay Demonstration (LCRD) mission is a testbed for bidirectional optical communications and associated communication techniques, including adaptive optics, symbol coding, link layer protocols and network layer protocols. LCRD will test the functionality in various settings and scenarios of optical communications links from a GEO payload to ground stations in Southern California and Hawaii over a two-year period following launch in 2019. The LCRD investigator team will execute numerous experiments to test critical aspects of laser communications activities over real links and systems, collecting data on the effects of atmospheric turbulence and weather on performance and communications availability. LCRD will also incorporate emulations of target scenarios, including direct-to-Earth (DTE) links from user spacecraft and optical relay providers supporting user spacecraft.



LCRD consists of a flight segment and a ground segment that will demonstrate two simultaneous bidirectional optical links

Another motivation for exploring laser communications was the development of more efficient, cost-effective space communications equipment. Because RF wavelengths are longer, the size of their transmission beam covers a wider area (about 100 miles); therefore, capture antennas for RF data transmissions must be very large. Laser wavelengths are 10,000 times shorter, allowing data to be transmitted across narrower, tighter beams. The smaller wavelengths of laser-based communications are more secure, delivering the same amount of signal power to much smaller collecting antennas. NASA’s LLCD mission will test this concept. Flight Terminal Data, transmitted in the form of hundreds of millions of short pulses of light every second, will be sent by LLST, aboard the LADEE spacecraft. For example, using S-band communications, the LADEE spacecraft would take 639 hours to download an average-length HD movie. Using LLCD technology, download times will be reduced to less than eight minutes.



Lunar Laser-communications Space Terminal (LLST)

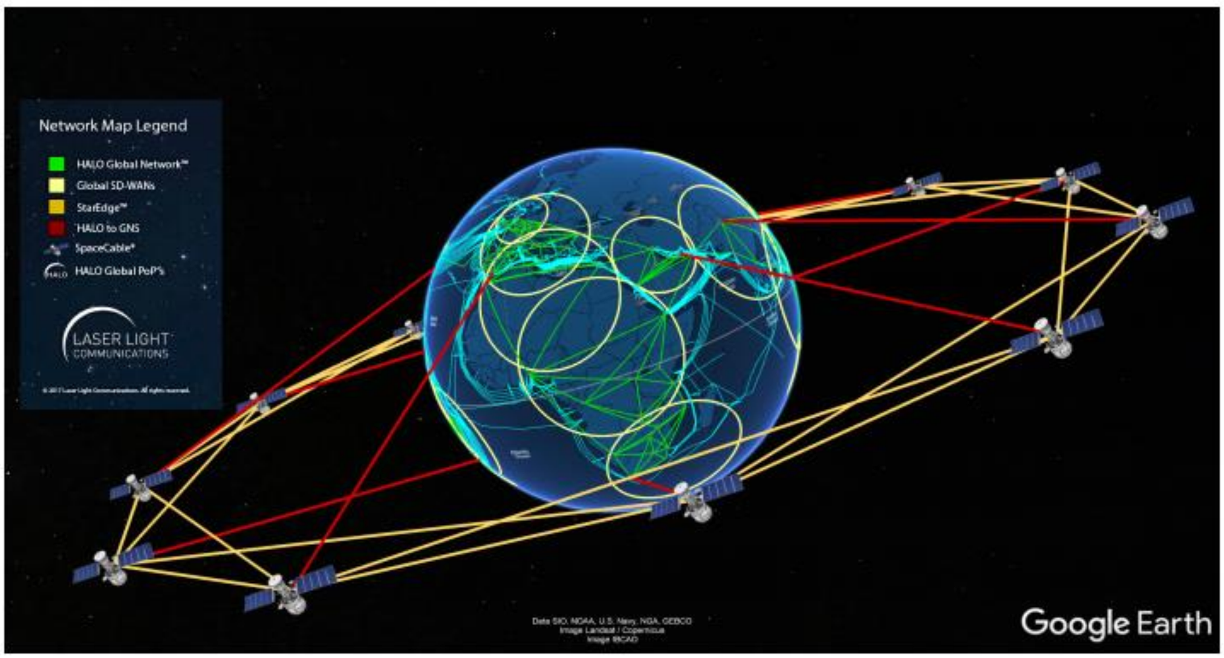
Laser communication terminals can support higher data rates with lower mass, volume and power requirements, a cost savings for future missions. Flight Terminal Data, transmitted in the form of hundreds of millions of short pulses of light every second, will be sent by Lunar Laser-communications Space Terminal (LLST), consisting of an telescope-containing optical module for Earth-pointing beams, a modem module containing both transmitter and receiver, and a controller electronics module telescope (transmits and collects the signals transmitted to and from Earth by fiber-optic cables). The data transmissions will be down-linked to any one of three ground telescopes in New Mexico, California or Spain.

Lunar Laser Communications Ground Terminal (LLGT)

The Lunar Lasercom Ground Terminal (LLGT) is the primary ground terminal for NASA's Lunar Laser Communication Demonstration (LLCD), which demonstrated for the first time high-rate duplex laser communication between Earth and satellite in orbit around the Moon. The LLGT employed a novel architecture featuring an array of telescopes and employed several novel technologies including a custom PM multimode fiber and high-performance cryogenic photon-counting detector arrays. LLGT consists of an array of eight transceiver and receiver telescopes mounted on a single gimbal. The telescopes and gimbal are connected to the control room where ground-based optical transmitters, receivers and associated electronics reside. The four, 6-inch refracting telescopes are used to send both a beacon and data to the LLST. Four, 17-inch reflective telescopes collect and focus the faint optical data signals from the LLST to optical fibers leading to detectors in the control room. All eight telescopes are housed in a fiberglass enclosure for stability to maintain their alignment and operation.

Delay/Disruption Tolerant Networking (DTN)

NASA's previous mission used single relay or point-to-point links to communicate with low-Earth orbit as well as deep space spacecraft. However, future exploration concepts will include several hops via satellite and other intermediate nodes, building the foundation for a "Solar System Internet". Knowing the state of the network allows one to apply decisions for optimizing and adapting communication to the context. Monitoring over a DTN network provides a method to reduce the significant amount of data that is needed to characterize some network feature or parameter. This may be useful to improve DTN algorithms.
For example, Laser Light Global Limited (Laser Light) intends to be "First to Market" with the All-Optical HALO Global Network System™. The hybrid network design will converge infrastructure of a "global viewing" satellite constellation with the location diversity of existing undersea cable and terrestrial fiber networks.



The complete +33Tbps HALO hybrid network will be made up of 12 optical satellites expected to deliver service speeds of 200 gigabits per second, bi-directionally, or 100 times faster than conventional space-based radio downlinks. Laser Light's StarBeam™ OS is a US patent, proprietary, next-generation, software-defined, all optical communications system. StarBeam™ is intended to be an automated and robust cognitive based computing system using Artificial Intelligence (AI) and Machine Learning (ML) algorithms to sense, predict, and infer network conditions and weather patterns, configured to dynamically manage transmission of data between optical communications nodes – both terrestrial and orbital - to form a hybrid mesh global network topology. This newly patented StarBeam™ network system is intended to make autonomous traffic routing decisions across the entire hybrid network – satellites and ground service networks, offering multiple "real time" service options to eliminate slowdowns from network congestion, outages, or weather interruptions.

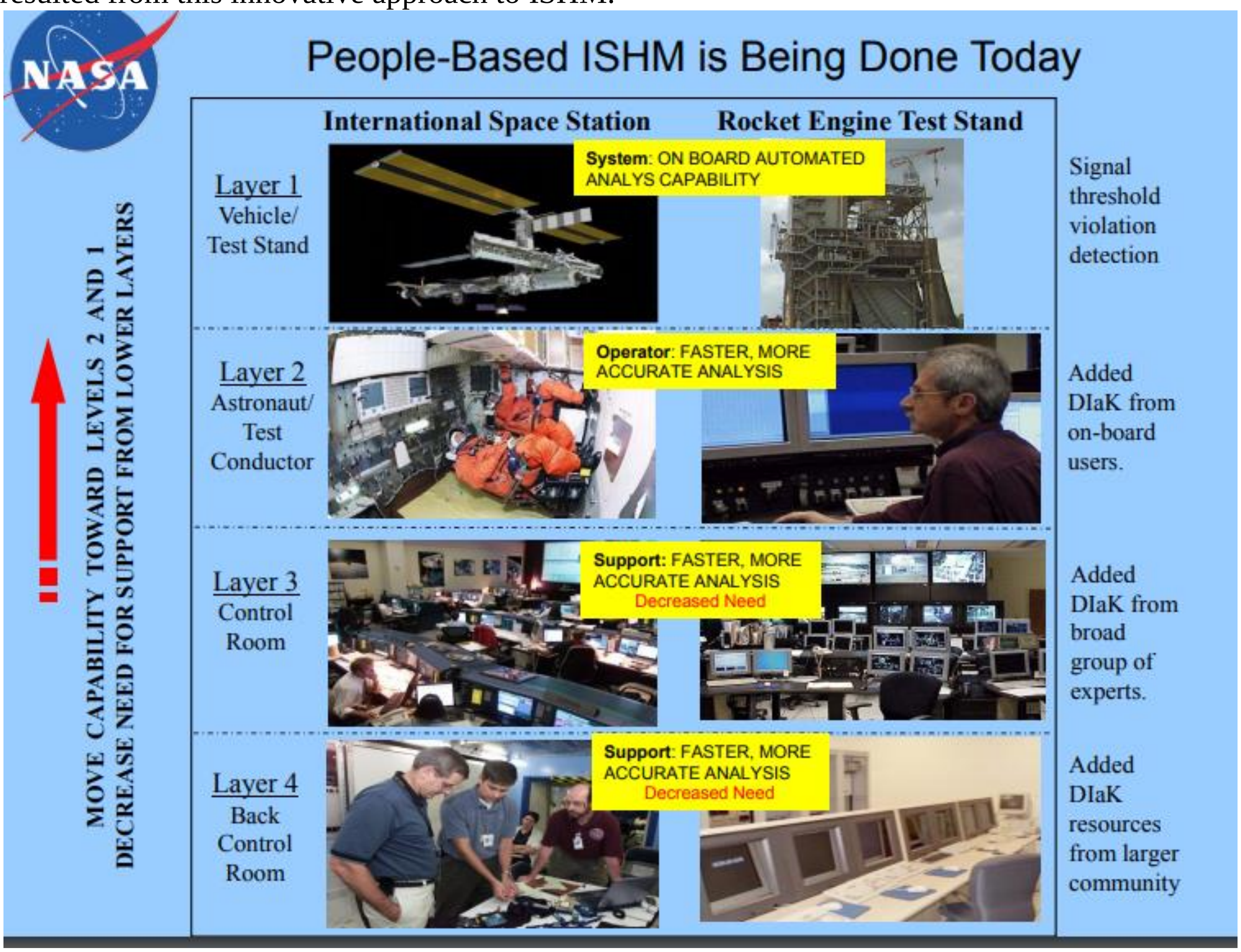
Anomaly Detection (AD) and Fault Diagnosis Methods

As spacecraft send back increasing amounts of telemetry data, improved anomaly detection systems are needed to lessen the monitoring burden placed on operations engineers and reduce operational risk. Current spacecraft monitoring systems only target a subset of anomaly types and often require costly expert knowledge to develop and maintain due to challenges involving scale and complexity. Spacecraft are exceptionally complex and expensive machines with thousands of telemetry channels detailing aspects such as temperature, radiation, power, instrumentation, and computational activities. Monitoring these channels is an important and necessary component of spacecraft operations given their complexity and cost. In an environment where a failure to detect and respond to potential hazards could result in the full or partial loss of spacecraft, anomaly detection is a critical tool to alert operations engineers of unexpected behavior. Monitoring 1,350 mnemonics developed from Long Short-Term Memory (LSTM) recurrent neural networks (RNNs) help to achieve high prediction performance while maintaining interpretability throughout the system. Therefore, a metric indicates how "unusual" a mnemonic's behavior is at a given time. A metric indicates how "unusual" a mnemonic's behavior is at a given time. In one approach, the metric indicates how "unusual" a mnemonic's behavior is at a given time. Simple forms of anomaly detection consist of out-of-limits (OOL) approaches which use predefined thresholds and raw data values to detect anomalies, the most widely used AD in the aerospace industry.[3] Anomaly detection systems need a mechanism to tolerate unpredictability.

Telemetry Analysis with Learning Algorithms (TALA) is a prototype AD system in use at Landsat 8, used daily for engineering reviews. The algorithms learn to predict a system's behavior based on historical data and produce alerts in case of behavior changes. Most anomaly detection systems do not monitor long-term trends, yet researchers at Telnor Satellite and L3 communications have experimented with predicting seasonal trends. TALA detects anomalies that last longer than three minutes compared to others that detect instantaneous anomalies. Patterns that repeat every orbit are easy to predict. By designating several "predictive" mnemonics, mode mnemonics are used to predict other spacecraft behavior. Mnemonics such as command counters steadily drift that produces false positives. Excessive false positives produce alarm fatigue indicating a filter for certain mnemonics. According to Paul Hudgins, TALA produces 4 – 10 false positives per day for Landsat 8 – out of 1350 mnemonics monitored. Researchers at Arctic Slope Technical Services consider the TALA advantages to include increased situational awareness due to greater efficiency to inspect mnemonics and detect subtle changes than human capability, and time saving due to reduced human plot reviews.

Integrated Systems Health Management (ISHM) Enabling Intelligent Systems

Failure events require adapting a procedural response to a system fault. Jim Ong noted fault diagnosis and restoring the system's functionality are the procedures designed to resolve single failures. When procedures interact with faults to be corrected, mission controllers negotiate the response procedure. Ong proposed a multi-failure response tool by combining and adapting single-failure procedures. Anomaly detection, diagnostics, prognostics, and comprehensive system awareness have not been considered traditionally in the context of autonomy functions such as planning, scheduling, and mission execution. ISHM as a capability integrates data, information, and knowledge (DIaK) is applied to achieve a degree of functional capability level (FCL) to help manage the health of the system. The data is processed with a set of specialized algorithms of Health and Usage Monitoring System (HUMS). ISHM incorporates an automated analysis of failure trending to predict if critical data streams approach out-of-norm values. Knowledge, normally resident in individuals, is crucial to achieve high FCL. On-board ISHM is implemented with a collection of algorithms that detect specific anomalies during specific regimes of operation. The problem-space analyzed off-line by experts, subsequently results in pre-defined solutions. The domain platform for both the problem- and solution- spaces needs to be embedded and applied to a comprehensive knowledge model in order to develop ISHM capability and autonomy. NASA Platform for Autonomous Systems (NPAS), software platform, which encompasses integrated technologies to achieve hierarchical distributed autonomy, resulted from this innovative approach to ISHM.[4]



Since knowledge normally resides in individuals, the lower layers include the most people and the most knowledge. If the spacecraft could accommodate a large number of people to operate it, people could do the job (analysis, conclusions, and operational decisions). But that is not the case, and most operators and support personnel are on Earth (on the ground) while the ISS is on orbit (in space). At the top layer (Layer 1) is the system itself with some automated capability to manage its health; generally detection of signal range/limit violations that activate alarms. At the next layer down (Layer 2) are the astronauts who can directly operate the station. They represent the local knowledge and have local data and information to manage the Station's health. At the next layer down (Layer 3) are the individuals in the control room. Additional DIaK is accrued with the control room personnel, and issues can be resolved faster and better in support of the crew. Here, diverse knowledge is employed regarding each subsystem and their interactions.

Case Study 1: Disrupted Data Collection

The Jupiter Energetic Particle Detector Instruments (JEDI) on the Juno Jupiter polar-orbiting, atmosphere-skimming, mission to Jupiter will coordinate with the several other space physics instruments on the Juno spacecraft to characterize and understand the space environment of Jupiter's polar regions, and specifically to understand the generation of Jupiter's powerful aurora. Three JEDI instruments have been operating in interplanetary space for close to 1 year, mostly in their "energy modes" with the high voltages turned off. During early commissioning, the high voltages on JEDI-A180, JEDI-90, and JEDI 270 were operated for about 1 day, 12 days, and 16 days, respectively. These high voltages were autonomously turned off by alarms within the instrument generated by a new circuit introduced into the JEDI design that senses small transients on the current outputs from the MCPs (non-heritage, microcircuit plate). The cause of these "micro-discharges" has been determined to be high fluxes of solar ultraviolet light entering the sensor. During most of the first year of operation within the interplanetary environment, the JEDI instruments have been in the energy mode and have obtained outstanding measurements. Of substantial interest is that, because of the "non-operational" orientation of the Juno spin axis relative to the sun, the JEDI-A180 field of view actually looked right at the sun once per spin and directly observed the X-rays coming from the solar flare that accompanied the generation of the interplanetary event. A set of valves in the fuel pressurization system — components that help facilitate the firing of the main engine — were a bit sluggish when scientists executed a command sequence. Holding off on the scheduled burn, Juno went into safe mode several hours before the specified flyby. Safe mode is what's *supposed* to happen when the spacecraft senses something unexpected. It battens down the hatches: The spacecraft ensures that it's facing the sun to receive solar power, then turns off its scientific instruments and any nonessential components to protect them for several hours or day. The safe-mode procedure kept Juno from collecting any scientific data during Wednesday's flyby.

Case Study 2:

Omitron/NASA flight operations engineer Jesus Orozco demonstrates a novel trajectory design model updated for labor and cost savings. Certain trajectory missions are classified as variable when yaw, steering target specific orbit planes. With current legacy criteria, such missions FDF and WSC analysts spend over 175 hours to provide acquisition data for 100+ trajectories per launch resulting in a total 4900 vector components. By updating criteria used in the model: half-beam to < 0.90 degrees and differenced Doppler offset to < 4.1 kHz.

GSFC Flight Dynamic Facility is the world leader in innovative mission analysis, trajectory design, and maneuver planning expertise. Space Exploration Engineering (SEE) and Applied Defense Solutions (ADS) needed a flight-dynamics system (FDS). As AGI software has proven successful in so many missions and is in use at most centers, the LADEE team felt confident using it for their FDS in trajectory design, maneuver planning and orbit determination—as well as acquisition data and product generation. Astrogator supports an unlimited series of events for modeling and targeting a spacecraft's trajectory, including impulsive and finite burns and highfidelity orbit propagation, while providing the ability to target specified and optimized orbit states that reference customizable control and result parameters.

- ***Assuming 3 maneuver sequences per launch, the analysis discussed here would have the following implications for the FDF***

Cases	Criteria	Process (hrs)	Products (hrs)	Delivery (hrs)	QA (hrs)	Total (hrs)
60	Legacy	45	51	6.9	2.1	**105**
4	Updated	3	3.4	0.4	0.2	**7.0**

- ***WSC would see similar results in their processing of FDF data***
  - For 60 trajectory cases, WSC would have to input a total of **2940** vector components vs **196** vector components for 4 trajectory cases
  - For 60 trajectory cases, WSC would have to manage a total of **180** maneuver sequences vs **12** maneuver sequences for 4 trajectory cases

- ***With updated criteria, effort is reduced by 93.3%!***

References

1. *Report and Order and Second Further Notice of Proposed Rulemaking Use of Spectrum Bands Above 24 GHz for Mobile Radio Services*, Jul. 2016.

2. Resolution COM6/20: Studies on Frequency-related Matters for International Mobile Telecommunications Identification Including Possible Additional Allocations to the Mobile Services on a Primary Basis in Portion(s) of the Frequency Range Between 24.25 and 86 GHz for the Future Development of International Mobile Telecommunications for 2020 and Beyond, Geneva, Switzerland, 2015.

3. Hundman, K., Constantinou,V., Laporte, C., Colwell, I., and Soderstrom, T. *Detecting Spacecraft Anomalies Using LSTMs and Nonparametric Dynamic Thresholding*. In KDD '18: The 24th ACM SIGKDD International Conference on Knowledge Discovery & Data Mining, August 19–23, 2018, London, United Kingdom.

4. Figueroa, F. and Walker, M. *Integrated System Health Management (ISHM) and Autonomy* Retrieved from http://ntrs.nasa.gov/search.jsp?R=20170012201

Technical Articles