

NASA 26 GHz Polar Subnet in 2020+

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The next generation Earth observing satellites will face challenges in supporting high rate space communications from the increasingly sophisticated instruments. Emerging applications will need space-to-ground links with data rates forecasted to be in the 1-20 Gbps range. To meet these challenges, NASA is designing and integrating a 26 GHz Polar Subnet to support space communication needs in 2020 and beyond. This paper describes the current effort of the Space Communications and Navigation Program's Near Earth Network (NEN), managed out of Goddard Space Flight Facility (GSFC), to deploy a 26 GHz Polar Subnet including the implementation, topology, capabilities, architecture design, operations and key design trades.

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I. Introduction

OVER the next several years, National Aeronautics and Space Administration (NASA) plans to launch multiple earth-science missions, including the NASA-Indian Space Research Organisation (ISRO) Synthetic Aperture Radar (NISAR) and Plankton, Aerosol, Cloud and Ocean Ecosystem (PACE) missions, which will send data from low-Earth orbits to ground stations at 1-3 Gbps, to achieve data throughputs of 5-40 terabits per day. These transmission rates exceed the capabilities of S-band and X-band frequency allocations used for earth-science mission downlinks. The International Telecommunications Union (ITU) has allocated 1.5 GHz from 25.5 GHz to 27.0 GHz (referred to in this paper as 26 GHz) for Ka-band Earth Exploration Science Service (EESS) and Space Research Service (SRS) direct downlinks. Accordingly, NASA is exploring enhancements to its space communication capabilities to implement a 26 GHz Polar Subnet that will provide NASA's first wideband high data rate Ka-band downlink capability. This Ka-band downlink capability will primarily support Ka-band polar low Earth orbit (LEO) missions by the fourth quarter of calendar year 2020 (4Q20).

Ref. 1 proposed a NEN Ka-band network architecture in 2010 to support Ka-band near-Earth missions consisting of ground stations at Fairbanks, Alaska; Svalbard, Norway; Wallops Island, Virginia; White Sands, New Mexico; and McMurdo, Antarctica. This proposed Ka-band network was envisioned to provide simultaneous reception of left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP) downlinks from the Surface Water and Ocean Topography (SWOT) and Hyperspectral Infrared Imager (HypSIIRI) missions with a maximum of 1 Gbps data rate per polarization, offset quadrature phase shift keying (OQPSK) modulation, low-density parity-check (LDPC) Rate = 7/8 channel coding, a 3 dB link performance margin, and a minimum ground antenna elevation angle of 10°.

Ref. 1 determined the NASA Deep Space Network (DSN) or National Oceanic and Atmospheric Administration (NOAA) SafetyNet network would not provide support to Ka-band near-Earth missions. Also in Ref. 1, the NASA Space Network via multiple Tracking and Data Relay Satellites (TDRSs) would provide support to a third Ka-band mission, Deformation, Ecosystem, Structure, and Dynamics of Ice (DESDynI) (since renamed as NISAR). However, NASA has determined that a ground-based high data rate 26 GHz Polar Subnet to be integrated with the NEN is the most cost-effective solution for supporting Ka-band polar-orbiting LEO missions, based on the refined trade studies discussed below for the NISAR and PACE missions and advancements in space communications technology.

Ref. 2 identified several benefits of using the 26 GHz band for LEO-to-ground communications links: 1) higher data rates and higher science data return, which enable scientific sensors with higher resolution and wider coverage; 2) a less congested spectrum environment; 3) no difficulties during operations for missions using the 26 GHz band in other orbits or for space-to-space communications; 4) existing technology and standards for 26 GHz operations, which facilitates interoperability; and 5) additional incentive for infrastructure/service providers to upgrade their equipment as more missions use the 26 GHz band, thereby encouraging interagency cross support. Ref. 2 also identified challenges associated with operations in 26 GHz when compared with existing S-band and X-band operations, including greater propagation losses and the need to improve infrastructure availability especially in polar regions.

NASA performed various trade studies, including loading and coverage analyses, link design analyses, and technology assessments, to provide the technical basis for the design of the high data rate NASA 26 GHz Polar Subnet. Loading and coverage considerations included ground station locations, ground antenna elevation angles, downlink data rates, and contact times. The ground station locations were chosen based on total daily contact times to polar-orbiting spacecraft to increase daily downlink data throughput and connectivity to long-haul fiber optic networks for enabling high speed backhaul communications. Link design considerations included ground station locations, ground antenna gain-to-noise-temperature (G/T), ground antenna elevation angles, and downlink coding, modulation, and data rates, as well as impacts of Ka-band propagation effects, user transmitter distortions, and user filtering to comply with the Space Frequency Coordination Group (SFCG) out-of-band emissions mask. The technology assessment identified candidate commercial-off-the-shelf (COTS) and non-developmental item solutions for the NASA 26 GHz Polar Subnet ground station components, including: antenna subsystems capable of accurate pointing and rapid antenna acquisition of customer spacecraft; high data rate receivers; data rate buffering and playback subsystems; and monitoring and control subsystems capable of supporting automated operations.

To provide Ka-band services to the NISAR, PACE, and future Ka-band polar-orbiting LEO missions while addressing the challenges for 26 GHz operations noted in Ref. 2, the high data rate NASA 26 GHz Polar Subnet changes the Ka-band network proposed in Ref. 1 to a three-node network with ground stations at Fairbanks, Alaska; Svalbard, Norway; and Punta Arenas, Chile. The ground stations will have tri-band (Ka-, S-, and X-band) ground

antennas enclosed in radomes. NASA is including an X-band ground antenna feed to enable a backup capability for supporting existing X-band customer missions.

The high data rate NASA 26 GHz Polar Subnet will provide the following services to Ka-band polar-orbiting LEO customer missions: Ka-band downlink communications; S-band uplink and downlink communications; and tracking, including antenna angle tracking, two-way tone ranging, and one-way and two-way range rate (Doppler) tracking. The high data rate NASA 26 GHz Polar Subnet will be capable of supporting Ka-band downlink data rates up to 1.75 Gbps per polarization at a bit error rate (BER) of 10^{-12} , and at a minimum ground antenna elevation angle of 5° . The high data rate NASA 26 GHz Polar Subnet includes the following features: antenna acquisition and tracking of customer missions based on customer orbital dynamics; simultaneous Ka-band downlink communications services and S-band uplink and downlink communications services; automated failover to redundant equipment to maintain service continuity and reduce lifecycle costs; and channel access data unit (CADU) processing and fill frame removal. NISAR and PACE will require delivery latency for telemetry data as follows: 15 seconds for time critical engineering data; 30 seconds for quick look or time critical science data; and 30 minutes for science data. These latency requirements drive the need for the following additional high data rate NASA 26 GHz Polar Subnet capabilities: attachment of an earth-receive-time (ERT) time tag to the end of each telemetry transfer frame; and data rate buffering, recording, storage, and retransmission.

II. Emerging Ka-Band Customer Mission Requirements

The NISAR mission, with a launch readiness date (LRD) of December 2021, is expected to be the first LEO polar-orbiting user of the high data rate NASA 26 GHz Polar Subnet, followed by the PACE mission with an LRD of August 2022.

The NISAR spacecraft has a 24-cm wavelength (L-band) synthetic aperture radar (SAR) and a 12-cm wavelength (S-band) SAR. NISAR will take measurements to reveal information about the evolution and state of Earth's crust, help scientists better understand Earth's processes and changing climate, and aid future resource and hazard management. Additional details on the NISAR mission are found at <https://nisar.jpl.nasa.gov/>.

The primary instruments planned for PACE are the ocean color instrument (OCI) and the multi-angle polarimeter. PACE will advance the assessment of ocean health and continue systematic records of key atmospheric variables associated with air quality and Earth's climate. Additional details on the PACE mission are found at <https://pace.gsfc.nasa.gov/>.

Table 1 summarizes NISAR and PACE mission requirements.

Table 1. NISAR and PACE Mission Requirements.

Parameter	NISAR	PACE
Orbit	747 km altitude, 98° inclination	675 km altitude, 98.4° inclination
Polarization	LHCP & RHCP, simultaneous	RHCP
Daily Data Volume	26 Tbits/day	5 Tbits/day
Contact Requirements	1 contact per orbit	1 contact per 6 hours
Minimum Pass Duration (assumed)	3 minutes	3 minutes
Daily Contact Time (derived)	123.8 minutes	138.9 minutes (600 Mbps) 69.4 minutes (1.2 Gbps)
Ka-Band Downlink Data Rate (derived) (Note 1)	3.5 Gbps (1.75 Gbps per polarization)	600 Mbps or 1.2 Gbps (single polarization)
Bit Error Rate (BER)	10^{-8}	10^{-12}
Spacecraft Tracking (Position, Velocity, & Time) (Note 2)	On-board GPS Receiver	On-board GPS Receiver
Notes:		
<ol style="list-style-type: none"> The NISAR (1.75 Gbps for right-hand and left-hand circular polarization) and PACE (600 Mbps and 1.2 Gbps) data rates do not include the Consultative Committee for Space Data Systems (CCSDS) Low-Density Parity-Check (LDPC) encoding overhead. NISAR and PACE will use OQPSK modulation with LDPC Rate = $7/8$ channel coding. The NISAR and PACE spacecraft are equipped with on-board Global Positioning System (GPS) receivers that are expected to provide earth-centered, earth-fixed (ECEF) spacecraft position, velocity, and time with 1 sigma ephemeris accuracy < 100 ns to the customer MOC via the telemetry downlink. In normal operations, the customer MOC will provide their daily spacecraft ephemeris to the NEN to support accurate antenna acquisition and tracking of NISAR and PACE spacecraft. 		

The required daily contact times and data rates shown in Table 1 drive the the number of ground station locations needed support the NISAR and PACE missions. The data rates and BER shown in Table 1 drive the design and functionality of the high data rate NASA 26 GHz Polar Subnet.

PACE will require simultaneous Ka-band and S-band services from NASA. S-band services include uplink and downlink communications, one-way and two-way tracking, and contingency services. At the present time, NISAR will only require a Ka-band downlink service from NASA.

NISAR and PACE spacecraft have on-board Global Positioning System (GPS) receivers that are expected to provide adequate spacecraft ephemeris data to support rapid antenna acquisition and tracking, even with the narrow beamwidth of the Ka-band ground antenna.

Both the NISAR and PACE missions are planning to use the advanced orbiting systems (AOS) space data link protocol as defined in Ref. 3 for Ka-band downlink communications. The high data rate NASA 26 GHz Polar Subnet will be designed to support AOS transfer frames; perform CADU processing, including derandomization, LDPC decoding, separation by virtual channel, discarding fill frames; and produce virtual channel data units (VCDUs) with attached metadata headers. Metadata includes the receiving station identifier and ERT time-stamps.

III. Trade Studies

The NASA 26 GHz Polar Subnet will support customer missions at the highest data rate planned by a civilian space agency to date, based on Ref. 2. NASA performed various trade studies, including loading and coverage analyses, link design analyses, and a technology assessment, to provide the technical basis for the design of the high data rate NASA 26 GHz Polar Subnet. Loading and coverage considerations included ground station locations, ground antenna elevation angles, downlink data rates, and contact time requirements. Link design considerations included ground station locations, ground antenna G/T including radome effects and wind, ground antenna elevation angles, and downlink coding, modulation, and data rates. Link design analyses also considered impacts of Ka-band propagation effects, user distortions, and user filtering to comply with the Space Frequency Coordination Group (SFCG) out-of-band emissions mask. The technology assessment identified candidate solutions for NASA 26 GHz Polar Subnet ground station components, including: antenna subsystems capable of accurate pointing and rapid antenna acquisition of customer spacecraft; monitoring and control subsystems capable of supporting automated operations; high data rate receivers; and data rate buffering and playback subsystems.

A. Loading and Coverage Considerations

NASA performed loading and coverage analyses to identify minimum number of ground stations capable of meeting NISAR and PACE daily data volume and contact time requirements. Minimizing the number of ground stations will reduce lifecycle costs of the high data rate NASA 26 GHz Polar Subnet, since fixed expenses for backhaul communications are a major cost driver. NASA considered several candidate ground station locations for the high data rate NASA 26 GHz Polar Subnet, including Fairbanks, Alaska; Svalbard, Norway; Punta Arenas, Chile; Wallops Island, Virginia; White Sands, New Mexico; Matjiesfontein, South Africa, and McMurdo, Antarctica. All of these ground station locations, with the exception of Punta Arenas and Matjiesfontein were considered in Ref. 1.

Fairbanks, Alaska and Svalbard, Norway provide high daily contact times to polar-orbiting missions and have connectivity to long-haul fiber-optic networks for high data rate backhaul communications. Punta Arenas, Chile has connectivity to long-haul fiber-optic networks as well and can provide additional coverage to polar-orbiting missions. The high data rate NASA 26 GHz Polar Subnet will comprise these three ground station locations.

NASA determined that ground stations at White Sands, Wallops, and McMurdo were not adequate candidates to provide high data rate services to Ka-band polar-orbiting LEO missions. NEN currently has Ka-band antennas at White Sands, New Mexico and Wallops Island, Virginia. However, neither of these ground stations provide sufficient daily contact times for polar-orbiting LEO missions. In addition, the slewing rate of the Ka-band antenna at White Sands is not sufficient to support polar-orbiting LEO spacecraft, and the G/T of the Ka-band antenna at Wallops Island is not sufficient to support high data rate Ka-band downlinks. Finally, while McMurdo provides high daily contact times to polar-orbiting LEO missions, this site does not have connectivity to a long-haul fiber optic network. The location at Matjiesfontein needed significant development and infrastructure, which could potentially impact the subnet readiness date. This site remains a viable future expansion option.

Figure 1 a) illustrates the average daily coverage times at 5° and 10° ground antenna elevation angles for NISAR from Fairbanks (ASF), Svalbard (SGx), and Punta Arenas (PA), and Figure 1 b) illustrates the average daily coverage time for PACE from ASF, SGx, and PA. NASA will consider supporting Ka-band customer missions at a 5° minimum ground antenna elevation angle in the future to provide increased daily contact times. Decreasing the minimum ground antenna elevation angle from 10° to 5° significantly increases daily contact times from each ground station to a

customer satellite by approximately 40%, reducing the total number of sites needed to support Ka-band customer missions.

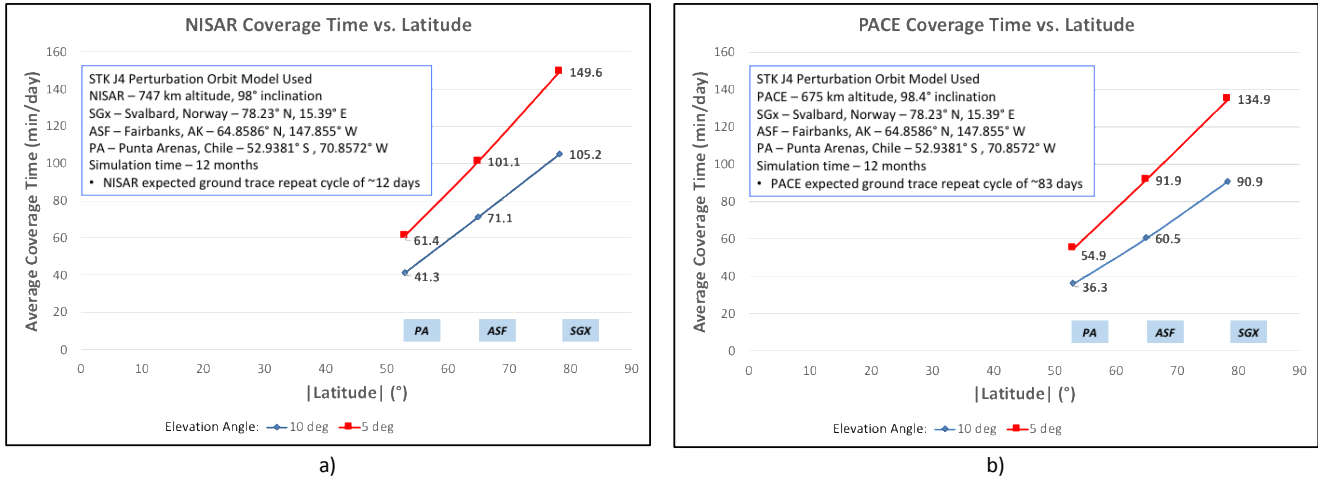


Figure 1. Average Daily Coverage Times from Fairbanks, Svalbard, and Punta Arenas to NISAR and PACE.

Loading and coverage analyses were used to determine whether NISAR and PACE daily data volume and contact time requirements shown in Table 1 could be simultaneously supported by either a 3-node network (Fairbanks, Svalbard, and Punta Arenas) or a 2-node network (Fairbanks and Svalbard). The analyses illustrated that a 3-node network will be capable of providing simultaneous support to NISAR and PACE with a 10° ground antenna elevation angle for support to both missions and PACE operating at 600 Mbps. The analyses further illustrated that a 2-node network will be capable of providing simultaneous support to NISAR and PACE with a 5° ground antenna elevation angle for NISAR support and PACE operating at its higher data rate of 1.2 Gbps.

B. Link Design Considerations

NASA performed link design analyses for the downlink from NISAR and PACE to the NASA 26 GHz Polar Subnet ground stations, considering ground station locations, ground antenna gain-to-noise-temperature (G/T) including radome effects, ground antenna elevation angles, and downlink coding, modulation, and data rates, as well as impacts of Ka-band propagation effects, user distortions, and user filtering to comply with the SFCG out-of-band emissions mask. Table 2 shows the assumptions used to perform the link design analyses. The equivalent isotropic radiated power (EIRP), coding schemes, and modulation schemes shown in Table 2 were assumed to be fixed. The link design analyses were used to calculate the ground antenna G/T (including radome effects) necessary for a 0 dB downlink performance margin at the ground stations.

Table 2. Link Design Analyses Assumptions.

Parameter	NISAR	PACE
Orbit	747 km altitude, 98° inclination	675 km altitude, 98.4° inclination
Minimum Ground Antenna Elevation Angle	5°, 10°	10°
Satellite Equivalent Isotropic Radiated Power (EIRP)	38 dBW	23.13 dBW
Ka-Band Downlink Data Rate	1.75 Gbps per polarization	600 Mbps or 1.2 Gbps
Annual Availability	95%	95%
Channel Coding	LDPC Rate = 7/8	LDPC Rate = 7/8
Modulation	OQPSK	OQPSK
Bit Error Rate (BER)	10 ⁻⁸	10 ⁻¹²

As noted earlier, NASA will consider supporting Ka-band customer missions at a 5° minimum ground antenna elevation angle in the future to provide increased daily contact times. Ref. 4, which describes a three-year Ka-band

propagation characterization effort conducted by NASA's Glenn Research Center and sponsored by NASA's Space Communications and Navigation (SCaN) Program, presented a comparison of measured and ITU-modeled propagation loss (not including scintillation) at Svalbard at 26.5 GHz for a 5° ground antenna elevation angle. The accompanying conference briefing also presented the results of measured and modeled propagation loss at Fairbanks at 27.5 GHz for an 8° ground antenna elevation angle. The results of the comparisons validated the ITU propagation loss models; measured propagation losses at Fairbanks and Svalbard were within 0.5 dB of propagation losses predicted by ITU models for 95% annual availability. In addition, Ref. 5 indicated that multipath effects on a satellite downlink signal are negligible as long as the elevation angle to the satellite is much larger than the half-power beamwidth of the ground antenna. The NASA link design analyses employed International Telecommunications Union (ITU) models to compute propagation losses, including atmospheric loss (ITU-R P.676-8), rain attenuation (ITU-R P.618-10), and cloud loss (ITU-R P.840-4).

The NASA link design analyses also considered the impact to end-to-end downlink performance due to transmitted signal distortions, including phase noise, amplitude modulation to amplitude modulation (AM/AM) conversion, AM to phase modulation (AM/PM) conversion, and spurious outputs, in conjunction with intersymbol interference due to band-limiting effects from transmit filtering to comply with the SFCG out-of-band emissions mask as defined in Ref. 6. To account for the impact of the transmitted signal distortion and band-limiting effects on the end-to-end downlink performance, the NASA link design analyses included a receiver implementation loss of 3.5 to 4.0 dB. These impacts are discussed in Ref. 7, Ref. 8, and Ref. 10.

Ref. 7 presented the results of an analytical evaluation of receiver performance degradation for binary phase shift keying (BPSK) and quadrature phase shift keying (QPSK) signals due to the cumulative impact of nine transmitted signal distortion parameters: frequency offset; filter amplitude and phase ripple; phase noise; spurious PM; AM/AM and AM/PM conversion; incidental AM, and spurious outputs. This evaluation illustrated that transmitted signal distortions increased the signal-to-noise-ratio (SNR) degradation in a receiver by up to 4-5 dB for QPSK signals with a BER of 10^{-5} .

Ref. 8 presented the results of a simulation of receiver performance degradation with and without adaptive equalization due to band-limiting conditions and several transmitted signal distortion parameters (I/Q channel skew, data asymmetry, modulator gain and phase imbalance, AM/AM, and AM/PM) for a Tracking and Data Relay Satellite System (TDRSS) 300 Mbps uncoded link with QPSK modulation in a 225 MHz channel. This combination of data rate, modulation, channel coding, and channel bandwidth equates to a bandwidth-time (BT) product of 1.5, which is the same BT product for the NISAR downlink of 1.75 Gbps with LDPC Rate = 7/8 channel coding in a 1.5 GHz channel. This simulation illustrated that the receiver performance in the presence of transmitter distortions and band-limiting effects is degraded by up to 6-7 dB and noted that adaptive equalization techniques, such as those defined in Ref. 9, can compensate for the effects of intrachannel and interchannel interference in QPSK systems caused by channel filtering and nonlinearities.

Ref. 10 presented the results of an end-to-end software simulation and hardware emulation of the LandSat Data Continuity Mission (LDCM) X-band OQPSK 384 Mbps (220 Msps) downlink with LDPC Rate = 7/8 channel coding. This combination of data rate, modulation, channel coding, and channel bandwidth equates to a bandwidth-time (BT) product of 1.7. This study illustrated that a receiver implementation loss of < 2 dB for a BER of 10^{-12} is achievable by using adaptive baseband equalization (ABBE), even with significant amplitude and phase distortions due to spectral truncation (i.e. band-limiting).

Several antenna sizes were evaluated to achieve the G/T necessary for a 0 dB downlink performance margin with the assumptions shown in Table 2 and the impacts of transmitted signal distortion and band-limiting effects to end-to-end downlink performance discussed above. The link design analyses determined that an 11.3-meter ground antenna enclosed in a radome would be sufficient to support NISAR at a 5° or 10° ground antenna elevation angle and PACE at a 10° ground antenna elevation angle with positive downlink margins at Fairbanks, Svalbard, and Punta Arenas.

C. Technology Assessments

NASA performed technology assessments to identify candidate solutions for the NASA 26 GHz Polar Subnet components, including: antenna subsystems capable of accurate pointing and rapid antenna acquisition of customer spacecraft; monitoring and control subsystems capable of supporting automated operations and failover; high data rate ground receivers; and data rate buffering and playback subsystems.

NASA will specify customer orbital dynamics including ephemeris uncertainty to define the ground antenna acquisition and tracking performance. NASA has reviewed solutions from antenna vendors to determine that non-developmental tri-band (Ka-, S-, and X-band) antenna subsystems with acquisition and tracking capabilities required to support Ka-band operations are available. NASA is including an X-band feed for the antenna subsystems to enable a backup capability for supporting existing X-band customer missions.

NASA has reviewed solutions for ground station monitoring and control systems to determine that COTS monitoring and control subsystems capable of supporting automated operations and failover are available.

NASA is coordinating with receiver equipment vendors to design a high data rate ground receiver that can accommodate high data rate Ka-band telemetry and minimize receiver performance degradations due to user transmitter distortions in conjunction with the SFCG out-of-band emissions mask band-limiting effects.

Finally, NASA is developing a COTS-based subsystem called Data Acquisition, Processing, and Handling Environment (DAPHNE) that will provide data rate buffering, recording, storage, and retransmission services to support customer mission latency requirements. This system will have a ingest rate of up to 4Gbps, which meets the needed high data rate for the NISAR mission.

These technology assessments indicate that there is no significant technical risk associated with deployment of the planned high data rate NASA 26 GHz Polar Subnet.

D. Trade Study Observations

The analyses discussed above provides the technical basis for NASA to implement a 3-node high data rate 26 GHz Polar Subnet with a 11.3-meter ground antenna enclosed in a radome at Fairbanks, Svalbard, and Punta Arenas. The high data rate NASA 26 GHz Polar Subnet will fully satisfy daily data volume, contact time, and downlink performance requirements for the NISAR and PACE missions. The ground antenna size was driven by the lower EIRP of the PACE mission, and the need for 3 ground stations was driven by the lower data rate of the PACE mission. The analyses further determined that a 2-node network (Fairbanks and Svalbard) will fully satisfy daily data volume, contact time, and link performance requirements for the NISAR and PACE missions, if PACE operates at its higher data rate of 1.2 Gbps and support to NISAR is provided at a 5° ground antenna elevation angle.

Additional analyses determined that if high data rate NASA 26 GHz Polar Subnet support was required only for the NISAR mission, then a 2-node network with 4.0-meter ground antennas at Fairbanks and Svalbard would be sufficient to meet daily data volume, contact time, and downlink performance requirements. Significant cost savings are possible by reducing the ground antenna size and the number of ground stations.

The link design analyses described above were performed for the worst-case geometry (i.e. at low ground antenna elevation angles). However, as noted in Ref. 2, the received SNR varies greatly during the period of visibility to a satellite from a given ground station, since path losses and atmospheric propagation losses decrease from low ground antenna elevation to zenith by as much as 10 dB or more at 26 GHz. In the future, NASA will consider supporting variable coding and modulation (VCM) and adaptive coding and modulation (ACM) schemes to take advantage of varying received SNR during a customer satellite pass and increase the amount of downlink data received per pass.

IV. Proposed NASA 26 GHz Polar Subnet

This section presents the network architecture, overview, capabilities, ground station design concept, and operations concept of the proposed high data rate NASA 26 GHz Polar Subnet. The network architecture and ground station design concept were based on the results of the analyses discussed in Section III.

A. NASA 26 GHz Polar Subnet Architecture

Figure 2 illustrates the high data rate NASA 26 GHz Polar Subnet architecture.

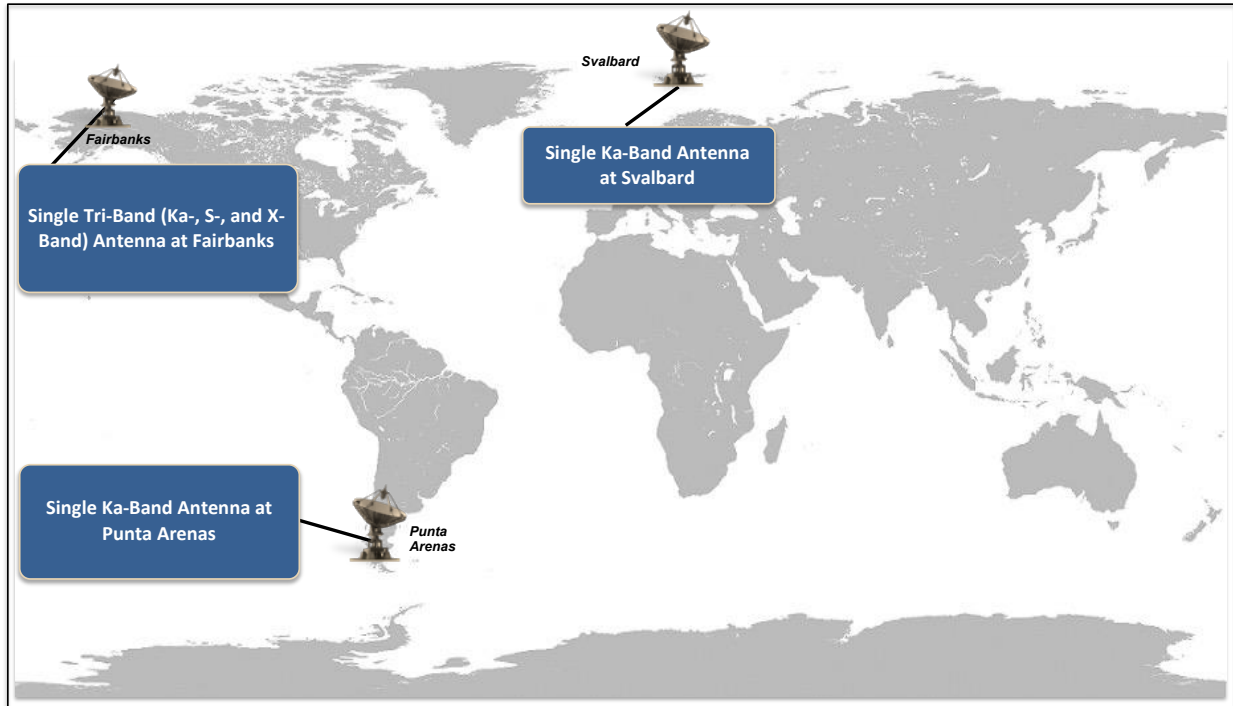


Figure 2. NASA 26 GHz Polar Subnet Architecture

Based on the results of the analyses described in Section III, NASA plans to implement a 3-node high data rate 26 GHz Polar Subnet, with a NASA-owned ground station at Fairbanks, Alaska and augmented by CSP ground stations at Svalbard, Norway and Punta Arenas, Chile, to meet the NISAR and PACE data volume and daily contact time requirements. The NEN Project will design and implement one tri-band (Ka-, S-, and X-band) antenna enclosed in a radome at Fairbanks. The Fairbanks ground station will be operated by the University of Alaska, Fairbanks, the Svalbard ground station will be provided and operated by Kongsberg Satellite Services (KSAT), and the Punta Arenas ground station will be provided and operated by a CSP yet to be determined. The Punta Arenas ground station will provide additional Ka-band service for polar orbiting missions.

B. NASA 26 GHz Polar Subnet Overview

The high data rate NASA 26 GHz Polar Subnet will be integrated into the NEN. Figure 5 shows an overview of the NEN, including the high data rate NASA 26 GHz Polar Subnet and associated ground stations. This figure shows interfaces between NASA 26 GHz Polar Subnet ground stations and: NEN elements, including the Global Monitor and Control Center (GMaCC) and NEN Scheduling System (NENSS); NASA elements, including the Flight Dynamics Facility (FDF) and Communications Service Office (CSO) NASA Ground Communications System (NASCOM); and the customer mission operations centers (MOCs) interface via CSO/NASCOM and the customer spacecraft radio frequency (RF) interface.

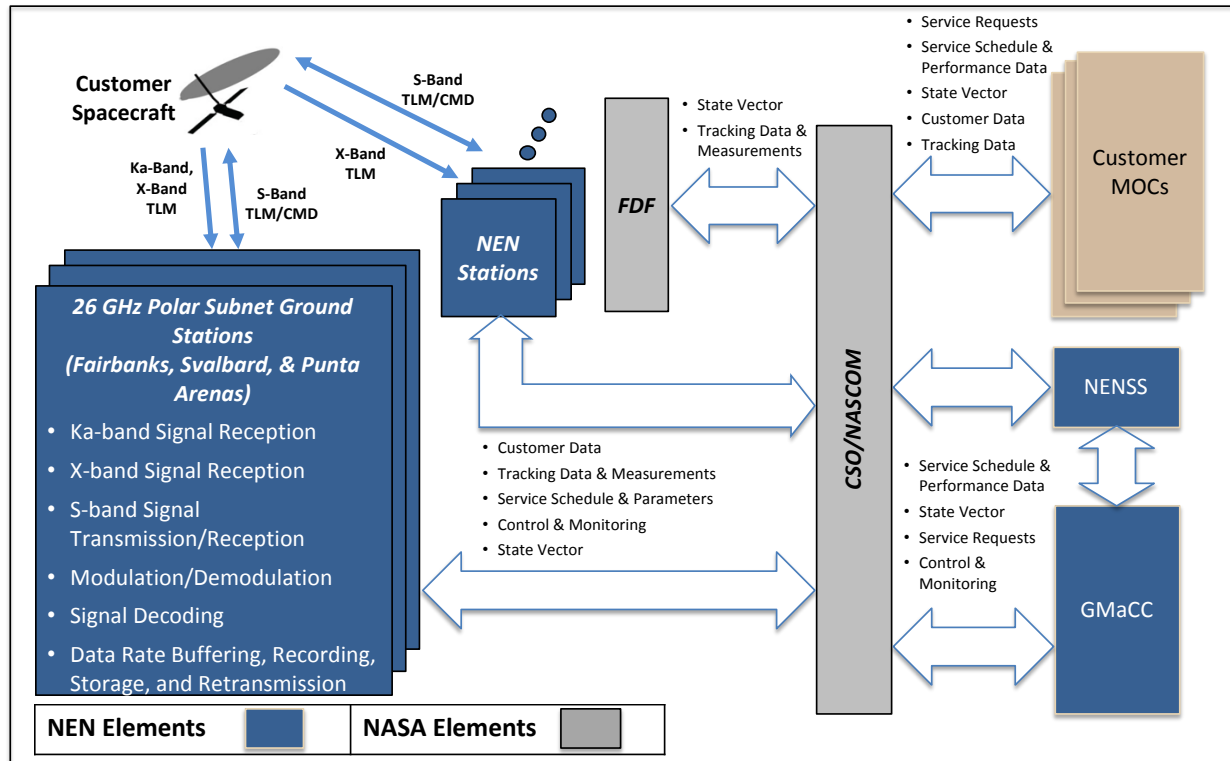


Figure 3. NEN Overview with Integrated NASA 26 GHz Polar Subnet

The high data rate NASA 26 GHz Polar Subnet, as an integrated part of the NEN, provides C&T services to customer missions. The high data rate NASA 26 GHz Polar Subnet consists of a NASA-owned ground station at Fairbanks, and CSP-owned ground stations at Svalbard and Punta Arenas. The CSP-owned ground stations will provide high data rate 26 GHz Polar Subnet services similar to the NASA-owned station at Fairbanks.

The NENSS, located at the White Sands Complex (WSC) in White Sands, New Mexico, will schedule NASA 26 GHz Polar Subnet services, maintain customer configurations used at each NASA 26 GHz Polar Subnet ground station, resolve network scheduling conflicts, and schedule troubleshooting and testing to support customers. The NENSS forwards acquisition data, such as two line element information or improved interrange vectors (IIRVs) provided by the FDF and customer MOC, and the customer service schedules including service configuration parameters to the NASA 26 GHz Polar Subnet ground stations via the GMaCC.

The GMaCC, located at the Wallops Flight Facility in Wallops Island, Virginia, will perform remote control and monitoring of the NASA 26 GHz Polar Subnet ground stations.

The FDF provides acquisition data based on tracking data such as improved inter-range vectors (IIRVs) to the NENSS to support scheduling of NASA 26 GHz Polar Subnet services, if applicable.

The CSO/NASCOM is a global system of communications transmission, switching, and terminal facilities that provide NASA with wide area network communications services. CSO/NASCOM services supporting the high data rate NASA 26 GHz Polar Subnet include real-time and mission-critical IP routed data as well as high rate data connections between the NASA 26 GHz Polar Subnet ground stations, customer MOCs, the GMaCC, the NENSS, the FDF, NASA Centers, and the Jet Propulsion Lab (JPL). The CSO/NASCOM also provides inter-center mission voice communications services for management of the network and customer mission coordination.

C. NASA 26 GHz Polar Subnet Capabilities

The high data rate NASA 26 GHz Polar Subnet will support Ka-band customer missions via the NASA 26 GHz Polar Subnet ground stations, in conjunction with the NENSS and the GMaCC.

The NASA 26 GHz Polar Subnet ground stations will be capable of: performing antenna and signal acquisition of customer spacecraft; providing S-band uplink service to customer missions; providing Ka-band, X-band, and S-band downlink services to customer missions; providing tracking services including antenna angle tracking, two-way tone ranging, and one-way and two-way Doppler tracking to customer missions; providing simultaneous S-band and Ka-band C&T services and simultaneous S-band and X-band C&T services; automatically configuring the ground station

antenna and ground station equipment to provide communications and tracking services to customer spacecraft based on service schedules and service configuration parameters received from NENSS via the GMaCC; providing NASA 26 GHz Polar Subnet ground station status information to the GMaCC; attaching an ERT time tag to the end of each telemetry transfer frame; performing CADU processing and fill frame removal; providing data rate buffering, recording, storage, and retransmission services to customer missions; and supporting an interservice duration of ≤ 3 minutes.

The NENSS will be capable of: receiving customer support requests; and generating and disseminating conflict-free service schedules and service configuration parameters to NASA 26 GHz Polar Subnet ground stations and the customer MOC via the GMaCC.

The GMaCC will be capable of: automatically disseminating customer service schedules including service configuration parameters received from the NENSS to NASA 26 GHz Polar Subnet ground stations; configuring, initializing, and provisioning Ka-band, X-band, and S-band services from the NASA 26 GHz Polar Subnet ground station at Fairbanks to customer spacecraft; monitoring the status of NASA 26 GHz Polar Subnet ground station equipment; providing NASA 26 GHz Polar Subnet service performance data to customer MOCs; and performing service tear down at the end of each scheduled customer spacecraft pass and reconfiguring the NASA 26 GHz Polar Subnet ground station equipment to support the next scheduled customer mission.

D. NASA 26 GHz Polar Subnet Ground Station Design Concept

The NASA 26 GHz Polar Subnet ground station design concept consists of the following elements: an antenna subsystem enclosed in a radome, which provides a tri-band S-band, X-band, and Ka-band antenna feed, downconverters and upconverters, and an intermediate frequency (IF) switch interface; a signal processing subsystem, which provides a low data rate (LDR) transmit capability, an LDR receive capability, a high data rate (HDR) receive capability, and one-way and two-way tracking capability; a monitoring and control (M&C) subsystem, which provides monitoring and control of NASA 26 GHz Polar Subnet ground stations; a time and frequency reference subsystem (TFRS), which provides time and frequency references to NASA 26 GHz Polar Subnet ground station equipment; and a DAPHNE subsystem, which provides a data rate buffering, recording, storage, and retransmission capability.

The NASA 26 GHz Polar Subnet ground station design concept will include redundant equipment and paths to maintain service continuity in case of equipment failure. The ground station design concept includes an IF service for high data rate (HDR) and low data rate (LDR) telemetry, providing a standard interface to support future service expansion. For example, customer missions will be able implement higher order modulation and coding schemes, including VCM schemes, ACM schemes, and the European Telecommunications Standards Institute (ETSI) Digital Video Broadcast (DVB) S2 standard, by providing receiver and transmitter equipment that is compatible with the IF interfaces at the NASA 26 GHz Polar Subnet ground station.

E. NASA 26 GHz Polar Subnet Operations

The high data rate NASA 26 GHz Polar Subnet will implement automated operations and install redundant hardware with return-to-vendor agreements in the event of equipment failures to reduce lifecycle costs. Generally, NASA 26 GHz Polar Subnet support to customer missions begins when the customer MOC submits requests for services to the NENSS. The customer MOC and FDF provide customer ephemeris and updates to the NENSS to assist with service scheduling. The NENSS generates NASA 26 GHz Polar Subnet service schedules and disseminates these schedules, service configuration parameters, and customer ephemeris to the GMaCC. The GMaCC disseminates the service schedule and customer ephemeris and updates to the NASA 26 GHz Polar Subnet ground stations prior to service start.

Based on GMaCC-provided service schedule and customer ephemeris, the M&C subsystem at the NASA 26 GHz Polar Subnet ground station enables automated, unattended operations of the terminal including automated service configuration setup, initialization, and provisioning, calculation of orbital trajectories, control of the antenna pointing and spacecraft tracking, automated telemetry and command operations, and communication with customer MOCs. Automation features include fault detection, fault isolation, and automatic failover to redundant hardware in order to maintain service continuity. The TFRS provides an accurate timing and frequency reference for all equipment at the NASA 26 GHz Polar Subnet ground stations.

The NASA 26 GHz Polar Subnet ground stations will forward service performance data to the GMaCC. During service, the customer MOC can submit service reconfiguration requests, such as signal reacquisition, to the NENSS and the GMaCC. The GMaCC and NENSS, in conjunction with the associated NASA 26 GHz Polar Subnet ground stations, will execute the reconfiguration request received from the customer MOC.

The NENSS performs NASA 26 GHz Polar Subnet service accounting functions. The GMaCC provides the GMaCC operators the capability to manually control remote equipment setup, failover, service initialization, and

service provisioning. The M&C subsystem at the NASA 26 GHz Polar Subnet ground stations provides local operators the capability to manually control the site equipment setup, failover, service initialization, and service provisioning.

Each NASA 26 GHz Polar Subnet ground station provides data rate buffering, recording, storage, and retransmission services to customer missions.

V. Conclusion and Summary

NASA is planning a 3-node high data rate 26 GHz Polar Subnet with a NASA-owned at Fairbanks and CSP ground stations at Svalbard and Punta Arenas. This network will be capable of accommodating NISAR and PACE downlink communications with a 10° ground antenna elevation angle for support to both missions and PACE operating at 600 Mbps. NASA will provide remote M&C of 26 GHz Polar Subnet ground stations via the GMaCC. The ground stations will be capable of automated failover and service recovery to reduce lifecycle costs.

Loading and coverage analyses showed that support at a 5° ground antenna elevation angle is feasible. Decreasing the minimum elevation angle from 10° to 5° increases the daily contact time between each ground station and customer spacecraft by approximately 40%, thus reducing the number of passes needed to downlink the same data volume. NASA will consider supporting Ka-band customer missions at a 5° minimum ground antenna elevation angle in the future to provide increased daily contact times.

Measurements at Svalbard and Fairbanks validated the accuracy of ITU propagation loss models for Ka-band communications at low ground antenna elevation angles. Ref. 2 noted that the received SNR varies greatly during the period of visibility to a satellite from a given ground station, since path losses and atmospheric propagation losses decrease from low ground antenna elevation to zenith by as much as 10 dB or more at 26 GHz.

Transmitted signal distortions in conjunction with intersymbol interference due to band-limiting effects from transmit filtering to comply with the SFCG out-of-band emissions mask result in significant degradation to receiver performance. Adaptive equalization techniques in the receiver will be required to mitigate the effects of transmitter distortions and band-limiting effects and to reduce the receiver implementation loss.

Future Ka-band missions should consider using advanced modulation and coding techniques such as ACM or VCM to take into account propagation effects over the the full LEO orbit, rather than at worst-case low elevation angle geometries. Advanced modulation and coding techniques in conjunction with operations at low ground antenna elevation angles will increase the daily data throughput to the ground for customer missions.

The NASA 26 GHz Polar Subnet ground station design concept includes an IF service for HDR and LDR telemetry, providing a standard interface to support future service expansion, such as adding receivers with ACM, VCM, and DVB-S2 capabilities to support higher data rates at existing ground stations. This future service expansion capability will ensure that the high data rate NASA 26 GHz Polar Subnet is able to adapt to increasing customer mission data volumes throughout its lifecycle.

Acknowledgments

TBD

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