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5G Satellite Communications Market and Design Trends

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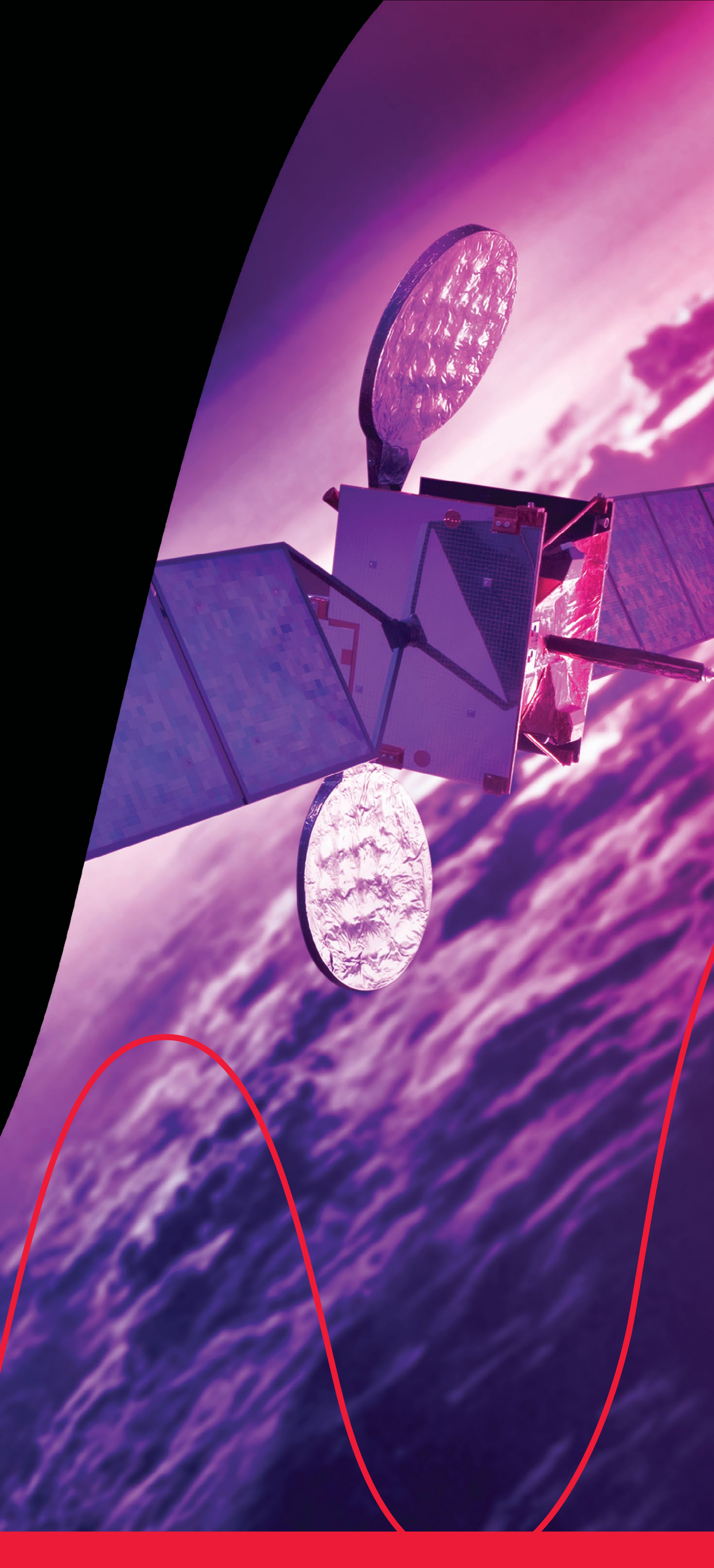

Introduction

5G Satellite Communications Market and Design Trends

With direct-to-satellite connectivity, unmodified cellular smartphones and IoT devices can now leverage satellite communications networks. A market report from Kaleido Intelligence recently found that direct-to-satellite connectivity will see revenues for connectivity services reach over $9 billion annually in 2030. MarketsandMarkets expects the satellite IoT market size to grow from $1.1 billion in 2022 to $2.9 billion in 2027, with a CAGR of 21.9% during that period. These new capabilities will meet the needs of many applications for connectivity in remote areas where cellular service is unavailable while supplementing them in areas with cellular service already available.

This eBook looks at various satellite communications trends along with the challenges and solutions related to device and system simulation and testing for these markets. Keysight Technologies, the sponsor of this eBook, presents end-to-end capabilities for testing and evaluating devices, subsystems, and systems for the growing satellite market.

A new Keysight paper discusses using next-generation optical communication links to transmit data in space — with higher data rates, improved security, and less energy dispersion. It predicts that COTS components will enable you to quickly integrate proven optical technologies, reducing cost and speeding up deployment. You will also learn about current GEO and LEO communication capabilities, including the current state of broadband communications networks, mobile and personal communications LEO networks, and combining GEO satellite and wireless transports into a low latency internet service. Another article discusses the coexistence of military-grade 5G with radar and satellite, non-terrestrial network communications.

We hope that this eBook will aid engineers in understanding the challenges ahead in satellite communications while highlighting the tools available to help overcome these challenges. We would like to thank Keysight for sponsoring this eBook and offering it free to our audience. Keysight has all the tools needed to simulate and test your designs, many of which are covered in this educational eBook.

Patrick Hindle, *Microwave Journal,* Media Director

A Review of the Current Broadband Satellite Communications Market

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Since 2012, the broadband satellite industry has evolved at an unprecedented and unfathomable rate. This article discusses the major historical milestones, system developments and challenges of the past decade, focusing primarily on constellations in non-geostationary (NGSO) low Earth orbit (LEO), while also mentioning developments in the geostationary (GSO) sector.

An April 2022 study conducted by researchers in the Olin Satellite + Spectrum Technology & Policy (OSSTP) Group found that more than 20 unique entities have filed U.S. Market Access applications with the Federal Communications Commission (FCC) for a total of 70,000 fixed satellite service (FSS) satellites operating across Ku-, Ka- and/or V-Bands.[1] Of these systems, several entities (Starlink, OneWeb, Kepler) have started deploying satellites, with OneWeb and Starlink totaling more than 4000 NGSO FSS satellites in orbit as of December 1, 2022, as seen in ***Figure 1***.

Much of the regulatory and technical framework that has enabled these systems to come to fruition was established in the late 1990s or early 2000s for systems like Skybridge and Teledesic. While these 1990s networks were not commercially successful, they moved the satellite industry forward. These efforts helped establish GSO interference mitigation techniques at the International Telecommunications Union (ITU) and refined the processing round filing framework within the FCC. These networks also drove technological advancements like low-cost user terminal antennas, along with gateway and teleport architectures that have been pivotal stepping stones for today's industry.

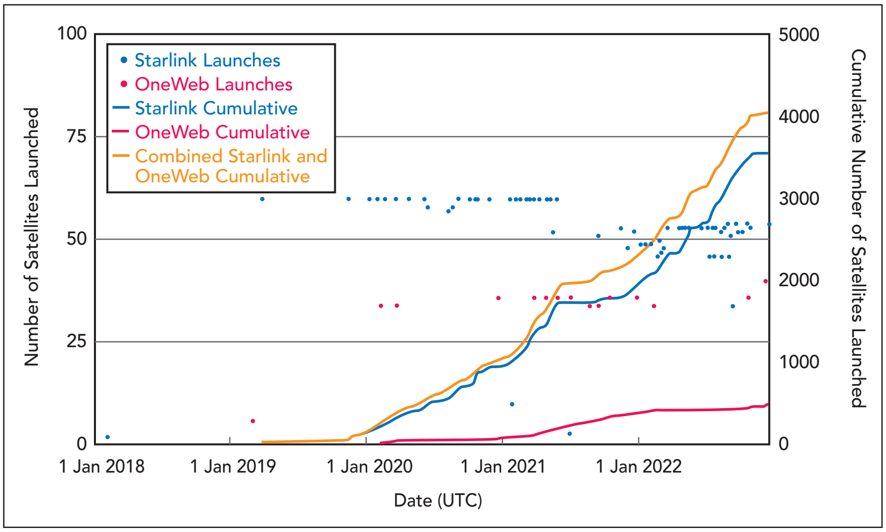

Fig. 1 Number of U.S. NGSO FSS launches over time.

SATELLITE BROADBAND HISTORY: A DECADAL REVIEW

An assessment of the latest generation of NGSO systems like OneWeb, Starlink, Lightspeed and Kuiper, begins in November 2012 as shown in ***Figure 2***, when Greg Wyler filed for Ku-Band frequencies at the ITU. These frequencies had been studied at numerous World Radio Conferences (WRCs) in the 90s and were set aside for NGSO systems. In this same period, GSO high-throughput satellite (HTS) networks like Viasat-1 and medium Earth orbit (MEO) O3b, also founded by Wyler, were beginning to provide services. O3b was commonly described as the most successful satellite network to that point because it offered high capacity and it had never filed for bankruptcy.

As shown in ***Figure 3***, Wyler brought his NGSO project to Google and for a brief period, he worked with a team in Google's Access Division. After leaving Google and bringing the NGSO FSS project with him, Wyler and Elon Musk collaborated on the constellation effort but later split in 2015 giving birth to today's OneWeb and Starlink constellations.

At WRC-15, studies addressing NGSO protection criteria for GSO systems, referred to as equivalent power flux density (EPFD) limits, were evolving in V-Band along with NGSO bringing into use (BIU) requirements, high altitude platforms (HAPS) frequency allocations and terrestrial frequency allocations for 5G systems. The rules defined at WRC-15 would establish the framework for the future NGSO revolution. The same year, Wyler informed Telesat CEO Dan Goldberg of his LEO broadband constellation plans. Despite being initially opposed to LEO constellations, Goldberg filed through Canada for access to COMMStellation, an existing ITU network. When he was awarded spectrum, Goldberg formed what would eventually become Telesat's Lightspeed NGSO constellation.

This started a rush as mainstays in the satellite industry, new startups and tech conglomerates began filing for NGSO constellations. In 2016, SES found their foothold in this race by acquiring O3b while Amazon announced their plans to launch the Kuiper constellation of LEO satellites. This is shown in ***Figure 4***.

In 2017, Iridium upgraded their messaging service on their NEXT line of satellites launched through SpaceX. Despite some early success, LEO constellations were not without risk. Greg Wyler's OneWeb, one of the largest players in the new landscape, declared bankruptcy in March 2020 due to funding uncertainties, but emerged from bankruptcy eight months later in November 2020. OneWeb managed

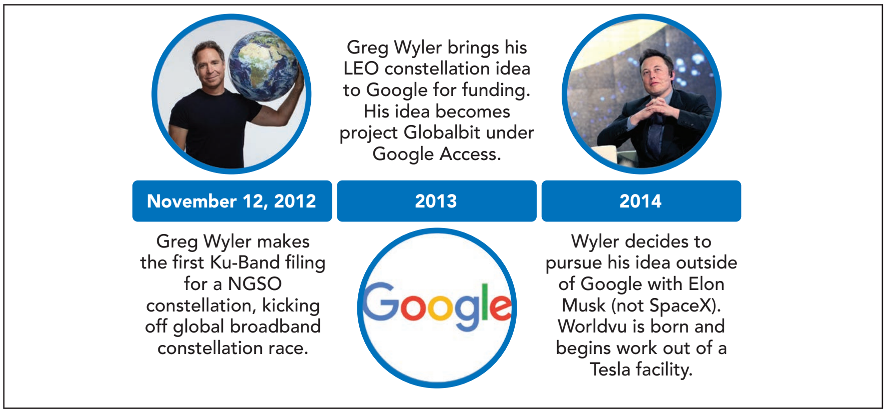

Fig. 2 **Timeline for Greg Wyler's satellite efforts.**

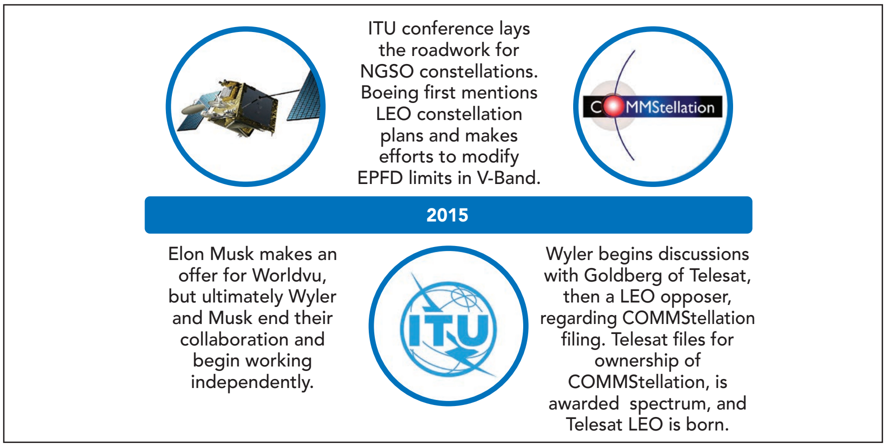

Fig. 3 **The evolution of LEO satellites.**

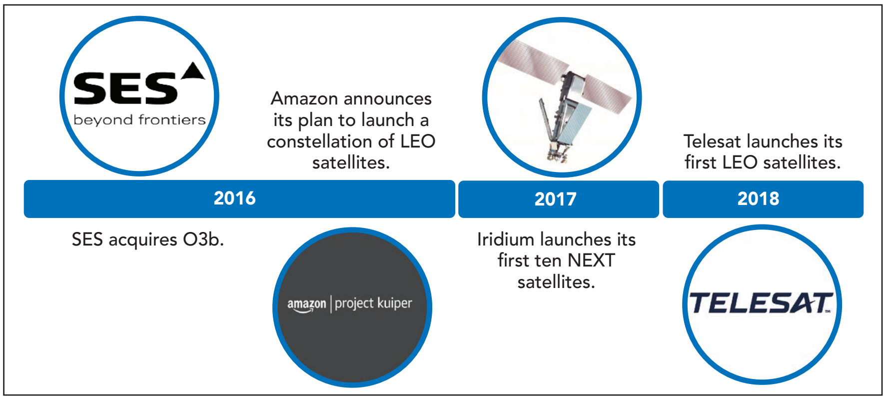

Fig. 4 **NGSO satellite activity after 2015.**

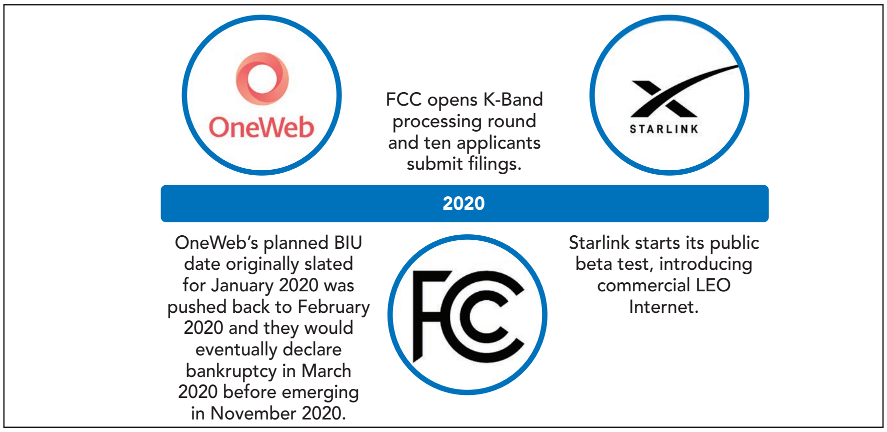

Fig. 5 **The satellite industry speeds up.**

to find new funding and they emerged from bankruptcy in November 2020, as shown in ***Figure 5***.

In May 2020, the FCC announced the Ka-Band processing round with ten applicants filing for LEO constellation access. SpaceX also announced its public beta test in October 2020, introducing fast, low latency LEO internet for the masses. Even with its inherent risks, the NGSO satellite industry was expanding and evolving at a rapid pace.

In 2021, this pace continued with Canada committing $1.15 billion to Telesat's NGSO Lightspeed Constellation. But 2022 brought challenges to the satellite industry. The COVID-19 pandemic had already created logistical headaches and the war in Ukraine compounded these challenges. Telesat responded by decreasing their LEO satellite fleet by a third and OneWeb experienced launch delays.

Despite the headwinds, the industry experienced several noteworthy accomplishments; Starlink and OneWeb reached a spectrum coordination agreement and Starlink and AST announced plans for low-data rate (not broadband) services directly to cell phones with their next-generation satellites. ViaSat and Inmarsat, two of the largest GEO satellite services and broadband providers agreed to merge in a $7.3 billion deal (see ***Figure 6***).

Table 1 provides a summary of the mission lifetime, orbital altitude, number of planned satellites (as submitted in filings), frequencies and current number of orbiting satellites for primary LEO, MEO and GEO players.

To conceptualize the various orbits of these networks more easily, a single OneWeb, Kuiper, SpaceX and Telesat satellite orbit is depicted in ***Figure 7*** using AGI's Systems Tool Kit (STK). ***Figure 8*** adds the Mangata and Kuiper MEO systems to the LEO satellites of Figure 7. ***Figure 9*** adds the geostationary orbit of a satellite like EchoStar, Intelsat and ViaSat, in green, to the LEO and MEO networks of the previous orbital representations.

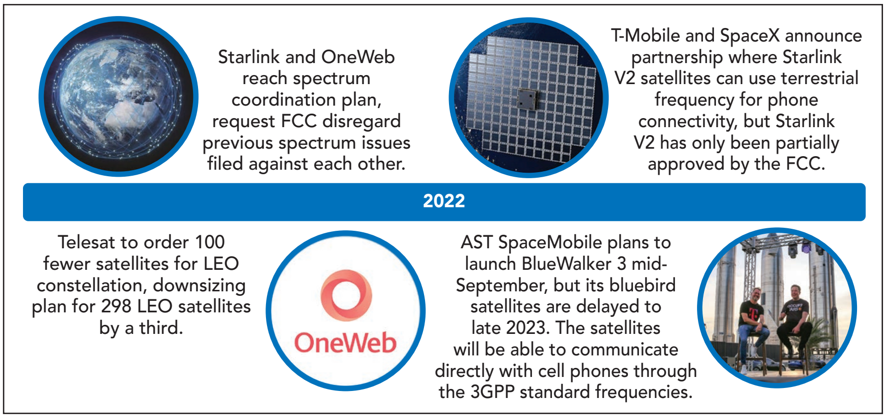

Fig. 6 Recent developments in the satellite industry.

TABLE 1

SUMMARY OF SEVERAL LEO, MEO AND GEO SYSTEM STATISTICS AS OF DECEMBER 3, 2022

	Mission Lifetime (Years)	*Altitude (km)*	*Frequency Bands*	*No. of Planned Satellites*	*No. of Orbiting Satellites*
SpaceX Starlink	5-7	328.3 - 614	Ku Ka E	>30,000	3347[2]
OneWeb	10	1200	Ku Ka	47,844	428[3]
Telesat Lightspeed	10	1000-1325	Ka	198	2
Amazon Kuiper	7	590-630	Ka	3236	0
SES O3b	10	8062	Ka	20	20
SES mPower	12	8062	Ka	11	0
Mangata	10	6400 1215-3800 9000-11,585	Ka V	0	791
ViaSat	15	35,786 (GEO) 8400 1300	Ka V	3	
EchoStar	15	35,786 (GEO)	Ku Ka S	9	
Intelsat	15+	35,786 (GEO)	Ku Ka C	50	
Inmarsat	15	35,786 (GEO)	Ka L S	14	

TECHNICAL AND REGULATORY CHALLENGES

The incredible achievements of the LEO, MEO and GEO broadband satellite sectors over the past decade would not have been possible without overcoming technical and regulatory challenges. The primary technical challenges are the availability of low-cost, user terminals (UTs), efficient solid-state power amplifiers (SSPAs) and

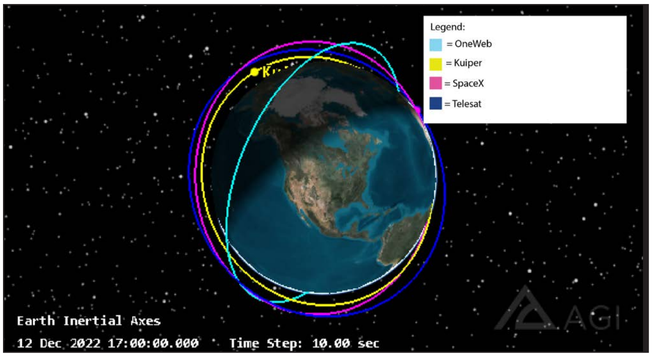

Fig. 7 Orbital representation of satellite constellations in LEO.

launch vehicle supply. The primary regulatory challenges have centered on interference mitigation (EPFD), BIU deadlines for ITU filings and an update of FCC NGSO licensing rules and sharing frameworks.[4]

TECHNICAL CHALLENGES

Due to tracking requirements for NGSO systems, user terminal technologies consist of a pair of traditional parabolic dishes or a flat panel phased array.[5] While the parabolic dish is less expensive, it requires a second dish to support make-before-break satellite-to-satellite handoffs. The phased array antenna simplifies this process by electronically scanning a single beam or multiple beams, but it is considerably more expensive than the parabolic dish alternative.[6] Starlink is currently selling its terminals at $599 and they are suspected to be selling them at a loss.[7] It is also worth noting that these technologies must comply with ITU and FCC regulations such as power flux density (PFD) limits, earth station gain masks and equivalent isotropic radiated power (EIRP) density limits.[8]

Another critical piece of technology is the SSPA, which is located on the satellite payload. These power amplifier devices have evolved from being largely silicon-based to GaAs and GaN.[9] Over the past few years, we have seen solutions like GaN-on-diamond being developed at companies like Akash Systems.[10] Increasing the efficiency of these devices from today's approximately 30 percent levels to upwards of 50 percent would result in dramatically improved overall system performances, and help close business cases more easily.

The industry is expecting a spike in launch demand starting in 2024, a year in which a potential launch shortage may occur. Out of the four medium and heavy lift launch vehicles available today (SpaceX's Falcon 9, ULA's Atlas V, Arianespace/Roscosmos' Soyuz-2 and Arianespace's Ariane 5), only one is available due to vehicle retirement and U.S. sanctions. Rocket Lab's Electron and Virgin Orbit's Launcher One have successfully delivered payloads to orbit and are expected to be operational with more than ten launches a year by 2024, but these are considered small launchers. The long development time of new vehicles might leave the industry with only one medium-lift launch vehicle able to deliver more than ten launches in a year in 2024. This development poses a major risk to the satellite communications industry and it suggests that a launch supply shortage could lead to higher launch prices and substantial delays that might prevent NGSO systems from achieving their milestone requirements.

REGULATORY CHALLENGES

Satellite systems are governed internationally under the United Nations (UN) via the treaty-based ITU. Every three to five years, the ITU hosts the WRC, which is the culmination of a three-to-five-year regulatory review cycle. During the years between WRCs, working parties (WPs) and study groups (SGs) collaborate to conduct analysis and put forth proposals about topics like spectrum allocation, licensing, interference management and future studies. Country delegations to the WRC consist of national regulators, such as the FCC in the U.S. and Ofcom in the U.K., along with industry players like Intelsat, EchoStar, OneWeb, ViaSat, SpaceX and Amazon and government entities like National Telecommunications Information Administration (NTIA), National Oceanographic Atmospheric Administration (NOAA) and National Aeronautics and Space Administration (NASA).

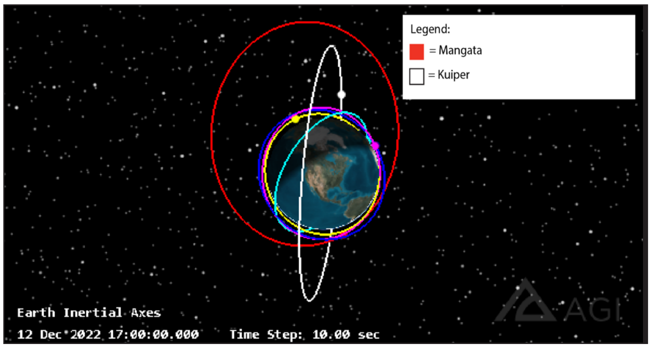

Fig. 8 Orbital representation of satellite constellations in MEO.

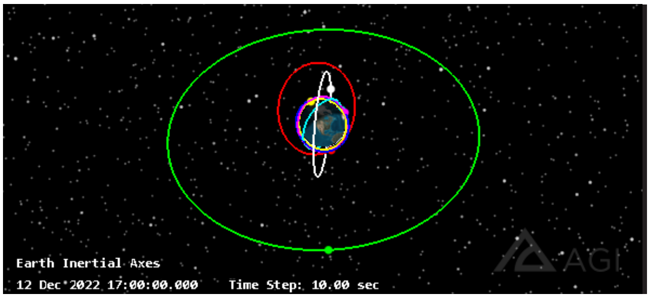

Fig. 9 Orbital representation of satellite constellations in GEO.

Over the past decade, international and local regulatory discussions have centered around a handful of topics. High on the list have been interference mitigation techniques for protecting incumbent terrestrial networks via PFD limits and geostationary systems through time-based, statistical EPFD limits.[11] BIU requirements, which define the number of satellites necessary to prevent expiration of an ITU filing. Other important issues for the satellite industry revolve around the terrestrial spectrum allocation for 5G and 6G technologies, along with coordination rules.

In the U.S., the FCC functions to regulate "interstate and international communications through cable, radio, television, satellite and wire. The goal of the Commission is to promote connectivity and ensure a robust and competitive market."[12] To facilitate spectrum sharing, the FCC authorizes the right to transmit signals over specific bands of spectrum. Unlike terrestrial systems, the FCC implements a processing round approach for satellite spectrum allocation.[13]

FCC processing rounds were held in 2016, 2017, 2020 and 2021, with these rounds alternating to cover either Ku-/Ka-Band or V-Band. Over the course of these processing rounds, more than 20 unique applicants submitted market access requests seeking authorization for over 70,000 total satellites. Since the end of 2019, the FCC has seen the number of NGSO satellites in orbit increase 31.4x with the introduction of FSS NGSO systems. Unfortunately, this unprecedented level of activity has resulted in increasingly long waiting times for FCC approval. The 2016 Ku-/Ka-Band Processing Round took an average of two years from the point at which an operator first submitted their application to the time the FCC made their First Action. In the March 2017 V-Band round, this delay increased by nearly a year to 2.9 years.[1] To address this issue, the House Energy and Commerce Committee introduced bipartisan legislation in the Satellite and Telecommunications Streamlining Act and the Secure Space Act on December 8 to reform FCC licensing rules.[14]

This trend of increasing wait times, coupled with the scarcity of spectrum resources has created a competitive environment among stakeholders leading to questions about how the FCC should consider its sharing rules.[15] Fortunately, some of the major players in the satellite field have reached coordination agreements that allow their current and second-generation broadband networks to coexist. On June 13, 2022, OneWeb and Starlink requested that the FCC dismiss the previous coexistence complaints they had filed against one another and that the Commission instead focus on approving both second round systems as quickly as possible.[16,17] Similarly, on September 24, 2022, Amazon and Telesat reached an agreement.[18]

CONCLUSION

The accomplishments of the satellite industry over the past decade are a true cause for celebration. Given that more than 4000 satellites are operational across Starlink and OneWeb alone, it is likely that these networks will continue to make technological history in the coming decades. However, it is also the case that advances in user terminal, power amplifier and launch availability will be imperative as these networks continue to roll out to ensure financial viability and affordable service offerings. It will also be critical that our national and international regulators continue to review existing regulations and update outdated policies promptly to encourage innovation and enable new entrants into the sector.■

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Military-Grade 5G Pushes Coexistence Boundaries with Radar and Satellite

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Coexistence grows as radar and satellite systems use the same or nearby frequency bands with 5G, creating the need to assess coexistence and mitigate potential interference as new 5G networks are deployed.

5G cellular promises new applications for military and government communications, including high-definition video; 3D or augmented reality; ultra-reliable, low latency communications; and massive machine-type communications. These capabilities will enhance intelligence, surveillance and reconnaissance, command and control and supply chain procurement and logistics. With new bands specified for 5G, however, coexistence with existing services poses a dual-edged challenge. Radar and satellite systems using the same or nearby frequency bands can reduce the capacity in 5G systems, while 5G can impair radar performance and damage satellite ground stations. Only by assessing and mitigating the potential impact among 5G, radar, satellites and other systems, can all these coexisting systems deliver their intended performance.

For example, in the U.S., the spectrum between 3.1 and 3.5 GHz is shared between federal and non-federal radio location services, with federal services having the primary allocation or priority. Similarly, both C-Band and extended C-Band frequencies are used for fixed satellite services and 5G, with potential interference issues between them.

WHAT IS COEXISTENCE?

Coexistence refers to the situation when two or more signals have the right to occupy the same or nearby spectrum. Usually, one of the services has priority. Radar typically has priority over 5G. If there's a conflict, the 5G transmitter must shut off or move to a different frequency. With satellite systems, 5G interference can be severe: receiver front-ends in ground stations are highly susceptible to interference from high-power 5G base stations.

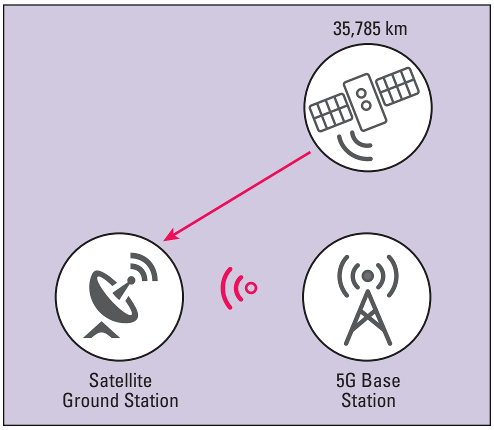
5G operating bands are currently grouped into frequency ranges below 6 GHz (FR1) and mmWave spectrum around 28 or 39 GHz (FR2). To provide the bandwidth for 5G, new operating bands have been allocated, with most of the initial deployments in the 3.6 to 3.8 GHz and 26 to 27.5 GHz bands and more bands planned. The 5G services in these bands must coexist with the downlink range used by satellite ground stations, from 3.4 to 4.2 GHz, and the military satellite bands from 27.5 to 29.5 GHz and the fixed satellite service downlinks from 37.5 to 40 GHz.

Some of these coexistence issues are unique to the U.S., according to a report published by the Congressional Research Service.[1] The report says, "Although Department of Defense (DOD) uses certain mmWave frequencies for high-profile military applications such as advanced extremely high frequency satellites that provide assured global communications for U.S. forces, it extensively uses sub-6 frequencies—leaving less sub-6 availability in the United States than in other countries. The Defense Innovation Board (DIB) advised DOD to consider sharing sub-6 spectrum to facilitate the build-out of 5G networks and the development of 5G technologies used in the sub-6 band."

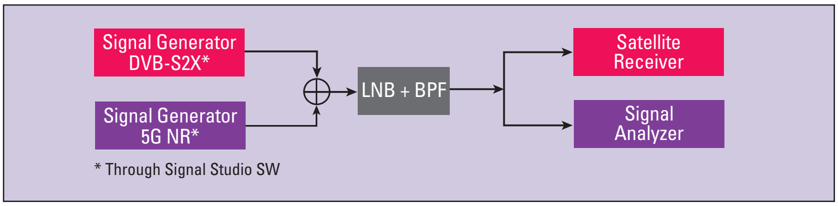
The solution to these challenges is spectrum sharing, which makes coexistence conflicts likely.

IMPACT OF COEXISTENCE

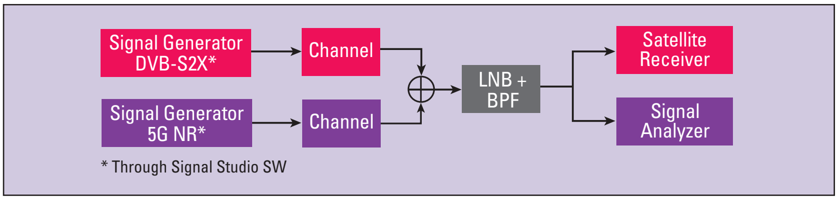
Coexistence is a concern when two or more signals have the right to occupy similar spectrum. However, the signals don't have the right to interfere with each other. For communication systems, coexistence issues may degrade the service by decreasing the data throughout or totally disrupting the link, which will create a financial



▲ **Fig. 1 5G base stations can interfere with the sensitive receivers in satellite ground stations if they use nearby spectrum.**



▲ **Fig. 2 Test setup for assessing the coexistence performance of a satellite receiver in the presence of 5G signals.**



▲ **Fig. 3 Emulators add channel effects to coexistence lab testing.**

problem from higher operating costs and lower revenue. Ensuring coexistence can be challenging, as the respective systems have different functions, designs, signal characteristics and locations.

Several approaches can be used to minimize potential problems: The frequency regulator, such as the FCC, can define guard bands and frequency spacing between services. Services can be required to maintain minimum distances from transmitters. As an example, the minimum separation between shipborne radars and terrestrial 5G base stations can be defined. Transmit power can be restricted—indoors versus outdoors, for example—and antenna type, angle and elevation defined to restrict the level and direction of the radiated power.

Arguably the most challenging is the coexistence of 5G with satellite systems (see ***Figure 1***). Satellite ground stations have sensitive RF front-ends designed to receive the low-level signals from satellites orbiting at 35,785 km. The low noise amplifier in the receiver can be overloaded by nearby terrestrial sources, such as the much higher-power 5G signals from base stations—both operating in C-Band.

HOW TO MEASURE

The potential of coexistence interference can be assessed in the lab using a tailored test system that enables adjusting parameters such as signal strengths, center frequency, frame structure, modulations, etc. (see ***Figure 2***). In the figure, which shows the satellite-5G example, the signal generator provides the satellite DVB-S2X signal, using software to create the digital video that is downloaded to the hardware.

Some common metrics are used to assess signal quality and the impact of coexistence. One is error vector magnitude (EVM), with units of percent or dB. This measures the difference between a measured symbol and a reference (theoretical) symbol in I and Q. As the demodulation of a signal in the receiver becomes poorer, the EVM increases. A perfect signal will have 0 percent EVM.

The 3GPP standard for 5G details the EVM requirements for various modulations, with the modulation changed to maximize what the channel can support. With lower noise and distortion, the channel can support higher-order modulation, which transmits more symbols in a given time. QPSK is the lowest order and accommodates the highest EVM. As the channel quality improves, the modulation steps to 16-, 64- and 256-QAM.

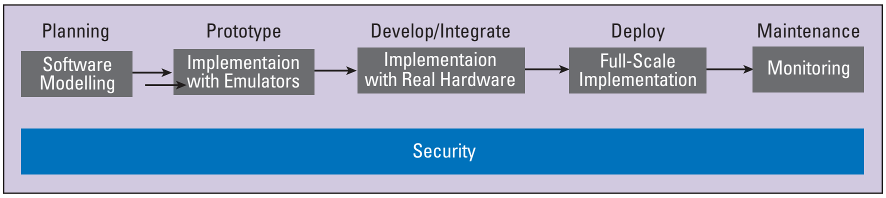
As 5G is deployed, coexistence will remain a prominent concern, extending from consumers to militaries and governments as private 5G networks are rolled out on bases, in government facilities and conflict zones. In addition to satellite networks, the coexistence risk will need to be assessed for military radar and non-5G communications systems.

Typically, coexistence problems cause service disruptions or performance degradation. Often, however, the consequences remain unknown until a problem occurs. To avoid surprises, a best practice is to prototype scenarios in the lab and look for coexistence issues. Once systems are deployed, 24/7 monitoring in the field can help identify sporadic issues and lead to resolution.

DIGITAL TWINS

Digital twin technologies can be used to plan for and simulate coexistence scenarios. Scalable channel emulators can support up to 64 channels and 400 MHz bandwidth and will cover mmWave bands with external hardware for up- and down-conversion. Emulators work with various software packages to implement 3GPP 5G and custom channel models. These systems can simulate Doppler shift and delay in the channel, which adds more realism to lab tests (see ***Figure 3***).

When designing and deploying a new 5G network, a "crawl-walk-run" approach is recommended to identify and mitigate coexistence issues (see ***Figure 4***). Begin with software to create a digital twin and model the current transmitters and receivers and see the effects from



▲ **Fig. 4** Recommended development flow, beginning with software modeling.

the new system. Hardware prototyping follows, using available devices and systems with commercial off-the-shelf (COTS) hardware emulators to mimic a small-scale system in a lab or anechoic chamber. COTS emulators enable the frequency, bandwidth and power to be varied, which may identify corner cases where coexistence issues arise.

Outside the lab, plan field testing with deployed 5G, tactical or public safety networks and radar or satellite ground stations. Field tests can measure transmit power, signal strength, EVM, throughput with modulation and MIMO, latency, block error rate and beamforming quality. In some cases, drones can be used for fly testing to determine 3D coverage, measuring signal strength, signal quality and throughput.

SUMMARY

To assure the performance of a military or government 5G network, coexistence must be planned and assessed up and down the stack from layer 1 to 7. Testing must span from the chipset to the full network and include multiple RF channels, carrier mechanisms, data protocols and waveforms, such as 3GPP 5G New Radio, pre-5G and custom OFDMA. When assessing the impact of coexistence issues, consider these questions:

- How will the interfering waveforms interact?
- How much suppression is required, in-band and out-of-band?
- How much guard band is necessary?
- What metrics should be used to assess impact?
- Is lab testing sufficient or should it be supplement with field test?

With the ability to assess the coexistence of networks and services, issues can be identified and resolved to achieve reliable communications. Many approaches are available from the lab to the field to assess potential issues that may degrade the performance of military and government systems. Once deployed, ongoing monitoring will reveal new coexistence issues, safeguarding the 5G network and, more importantly, the individuals depending on its performance.■

Reference

1. Congressional Research Service, "National Security Implications of Fifth Generation (5G) Mobile Technologies," April 5, 2022, Web: sgp.fas.org/crs/natsec/IF11251.pdf.

Keysight, Qualcomm Accelerate 5G Non-Terrestrial Network Communication

Keysight Technologies Inc., Santa Rosa, Calif

Keysight Technologies, Inc. announced it has collaborated with Qualcomm Technologies, Inc. to establish an end-to-end 5G non-terrestrial network (NTN) connection. Based on this successful demonstration of call signaling and data transfer using orbit trajectory emulation, Keysight and Qualcomm Technologies aim to accelerate 5G NTN technology to provide affordable broadband connectivity in remote areas.

NTNs based on 5G satellite-to-ground communication bring secure, reliable and high bandwidth connectivity to remote areas that do not have terrestrial network coverage. Widespread 5G NTN deployments can provide critical health, safety, and financial benefits to rural populations while improving economic conditions for industrial sectors such as agriculture, energy, health and transportation.

The end-to-end 5G NTN connection, based on modeling constellations of low Earth orbit satellites, was made in Qualcomm Technologies' San Diego laboratory by combining Keysight's 5G base station and aerospace emulation solutions with a Qualcomm Technologies 5G mobile test platform (MTP). The Qualcomm Technologies MTP is a smartphone reference design that acts as a proven test device for implementing and verifying the most advanced features available from Qualcomm Technologies research labs. The collaboration enables device makers to speed development and verification of 3GPP Release 17 compliant designs.

Keysight's high performance emulation capabilities make it possible to compensate for high Doppler effect and time delay as satellites move at speeds up to 7500 kilometers per second and at altitudes as high as 750 kilometers. The aerospace industry uses Keysight's software-centric design and validation solutions to launch thousands of satellites that are used for aeronautical, maritime and mission-critical communications as well as environmental monitoring.

Keysight integrates 5G network and real-world channel emulation hardware and software to create an end-to-end mixed terrestrial and space lab-based test bed to realistically simulate a wide range of orbit trajectories. The solution uses dynamic multipath propagation to emulate ground-to-satellite, satellite-to-ground and ground-to-ground satellite links. This provides holistic performance verification of terrestrial and non-terrestrial infrastructure as well as 5G NTN devices.

Tingfang Ji, vice president of engineering at Qualcomm Technologies, Inc., said, "Our research with Keysight drives many innovations with significant positive impact across a multitude of sectors that rely upon robust wireless connectivity. We are pleased to leverage Keysight's expertise in 5G emulation platforms to help the validation of our research and development for satellite-driven 5G NTN communications."

Cao Peng, vice president and general manager for Keysight's Wireless Test Group, said, "Together with Qualcomm Technologies, Keysight is making significant leaps in digitally connecting the world's unconnected areas where deploying terrestrial cellular networks is not a viable option. Keysight is excited to provide industry-first emulation capabilities to Qualcomm Technologies, enabling the world-leading wireless technology innovator to comprehensively address a wide range of complexities that arise as advanced space and terrestrial technologies are combined onto a single modem platform."■

Architecture of ORBCOMM Little LEO Global Satellite System for Mobile and Personal Communications

Dimov Stojce Ilcev,
University of Johannesburg, Johannesburg, South Africa

This article describes the ORBCOMM system, a wide area packet switched and global two-way data transfer network providing mobile satellite communication (MSC), tracking, monitoring, control and logistics services between mobile, remote, semi-fixed units and other mobile or fixed subscribers via ORBCOMM space and ground segments. It includes the concept of the ORBCOMM Little low earth orbit (LEO) MSC System as well as the architecture of the ORBCOMM Little LEO MSC Network Space, Ground and User segments. ORBCOMM satellite communication, tracking and monitoring terminals, heavy equipment management terminals and ORBCOMM maritime satellite automatic identification system (S-AIS) terminals are also described

The ORBCOMM MSC system concept originated in 1989 by Orbital Sciences Corporation. The $810 million ORBCOMM Company became operational in 1998 and then filed for Chapter 11 bankruptcy protection in September 2000. Shortly thereafter, ORBCOMM Company was purchased by a new group of investors in April 2001 for an estimated $5 to $10 million

The ORBCOMM Global, L.P. Company, Dulles, Va., U.S., equally owned by Teleglobe and the Orbital Sciences Corporation, provides global services via the world's first Little LEO satellite-based data and messaging satellite communications system. The U.S. Federal Communications Commission granted ORBCOMM a commercial license in October 1994 and commercial service began in 1998. Orbital Sciences is the prime contractor for satellite design.

The ORBCOMM Company owns and operates a network consisting of Little LEO satellites and several ground earth stations (GES) deployed around the world, connecting small, low power and commercially proven subscriber terminals to private and public networks, including the Global System for Mobile Communication (GSM), cellular systems and the internet.

ORBCOMM is one of the first LEO commercial communications satellite systems to reach orbit and begin service. Offering paging, messaging and data transfer services, the first two of a planned 36-satellite constellation were launched in April 1995.

The constellation was designed to maximize coverage over heavily populated regions, particularly between 60 degrees North and 60 degrees South latitudes. Trade studies were performed to evaluate an optimal constellation configuration for coverage of this region. A total of 35 first generation satellites (OG1) were launched between 1995 and 1999 using the Pegasus and Taurus launch vehicles, establishing the operational satellite constellation for the ORBCOMM Global communications infrastructure. The unlaunched satellite, original designation ORBCOMM FM-29, was cannibalized for parts for a capability demonstration satellite and then rebuilt as TacSat-1 for the U.S. military.

ORBCOMM Generation 2 (OG2) second generation satellites supplement and will eventually replace the first generation constellation. Eighteen satellites were ordered by 2008 nominally intended to be launched in three groups of six from 2010 to 2014, and by 2015 have all 17 satellites launched. These satellites were launched by SpaceX on the Falcon 9 launch vehicle.

ORBCOMM provides constellations of Little LEO communication satellites for mobile applications, such as maritime, land (road and rail) and aeronautical communications. Apart from service for mobile applications, ORBCOMM provides service for fixed applications, industrial IoT, machine-to-machine (M2M) communications hardware, software and services designed to track, monitor and control fixed and mobile assets in markets including transportation, heavy equipment, maritime, containers, oil and gas, utilities and government. The company provides hardware devices, modems, web applications and data services delivered over multiple satellite and cellular networks.[1]

ORBCOMM SYSTEM

As of 30 June 2021, ORBCOMM had more than 2.3 million billable subscriber communicators, serving original equipment manufacturers such as Caterpillar Inc., Doosan Infracore America, Hitachi Construction Machinery Co., Ltd., John Deere, Komatsu Limited and Volvo Construction Equipment, as well as other corporate and private customers, such as J. B. Hunt, C&S Wholesale Grocers, Canadian National Railways, C.R. England, Hub Group, KLLM Transport Services, Marten Transport, Swift Transportation, Target, Tropicana, Tyson Foods, Walmart and Werner Enterprises. ORBCOMM Company is headquartered in Fort Lee, New Jersey and has a Network Control Center in Dulles, Va.

By means of a global network of LEO satellites and accompanying ground infrastructure, ORBCOMM's low-cost and reliable two-way data communications products and services track, monitor and control mobile and fixed assets in four core markets: commercial transportation, heavy equipment, industrial fixed assets and marine/homeland security. The company's products are installed on trucks, containers, marine vessels, locomotives, backhoes, pipelines, oil wells, utility meters, storage tanks, small craft, camera cargo sensors, tractor ID sensors for trailers, wireless door sensors, wireless temperature sensors, next generation of cellular and IoT telematics and other assets.

ORBCOMM is continuously updating its network to improve global coverage and enhance its performance and reliability for customers around the world. With the launch of new and more capable next generation OG2 satellites, ORBCOMM took its service to the next level. Each OG2 satellite is the equivalent of six OG1 satellites, providing faster message delivery, larger message sizes and better coverage at higher latitudes, while significantly increasing network capacity.

ORBCOMM owns and currently operates a global network of 31 LEO communications satellites and accompanying ground infrastructure including 16 GESs, or gateways, in 13 countries to track and establish two-way satellite communications, tracking and monitoring systems.

From robust web reporting applications to turnkey IoT solutions and enablement, ORBCOMM's portfolio includes the tools developers, system integrators, value added reseller (VAR) partners and enterprise users need to remotely monitor and control fixed and mobile assets around the world. These include trailers, reefers, containers, cargo ships, fishing vessels, cargo security and fleet management.

In addition, ORBCOMM's Satellite Automatic Identification System (S-AIS) is an important solution for ship tracking and safety and security in navigation. Taking into consideration all mentioned services, the ORBCOMM system could be classified as a subsystem of the Global Maritime Distress and Safety network and its equipment.

A framework for opportunistic navigation with the multi-constellation ORBCOMM Little LEO satellite signals is proposed via Doppler. A receiver architecture suitable for processing both time division multiple access (TDMA) and frequency division multiple access (FMDA) signals from ORBCOMM can produce Doppler frequency measurements from multi-constellation LEO satellites. An extended Kalman filter based estimator is formulated to solve for a stationary receiver's position using the resulting Doppler measurements.[1,2]

LITTLE LEO MSC NETWORK ARCHITECTURE

The ORBCOMM system and network is a wide area packet switched network with two-way data transfer and messaging providing satellite communication, tracking and monitoring services between mobile, remote, semi-fixed or fixed satellite communication units (SCUs), GESs or gateway control centers (GCCs) accomplished via the constellation of Little LEO satellites and network control centers (NCCs).

An ORBCOMM mobile or fixed terminal delivers information to and from virtually anywhere in the world on a nearly real-time basis via ground and space segments to the terrestrial telecommunication network and its ground subscribers. The ORBCOMM OG1 ground segment and subscriber transmitters (Tx) are capable of providing a continuous 4.8 Kb/s stream of uplink packet data and 9.6 Kb/s stream of downlink packet data to the receivers (Rx) and vice versa.

At first, the OG2 satellites operated at an uplink speed of 4.8 Kb/s and a downlink speed of 7.2 Kb/s, while the currently the OG2 satellites can provide higher data rate transmission capabilities, with subscriber downlink speeds of up to 86.4 Kb/s in the uplink and up to 172.8 Kb/s in the downlink. More importantly, a proposed modified OG2 satellite deployment plan will improve overall network coverage and capacity (particularly in mid and higher latitude coverage areas), so ORBCOMM can meet an expected increased demand for its services.

RF communication within the ORBCOMM network operates in the very high frequency (VHF) portion of the frequency spectrum between 137 and 150 MHz. The system can send and receive two-way alphanumeric packet messages, like well-known two-way paging, SMS or e-mail transmissions.

The ORBCOMM network enables two-way monitoring, tracking and messaging services through the world's first commercial Little LEO satellite slow data communications system. Applications include tracking mobile assets such as oceangoing ships, fishing vessels and barges, containers, vehicles, trailers, locomotives and rail cars, heavy equipment and small craft as well as monitoring and controlling fixed sites.

Fixed services include supervisory control and data acquisition (SCADA) or M2M of electric utility meters, water levels, oil and gas storage tanks, wells, pipelines and environmental projects and a two-way messaging service for consumers, commercial and government entities.

Small, low power and commercially proven SCUs can connect to private and public networks, including the Internet, via ORBCOMM satellites and gateways. Through this network, ORBCOMM delivers information to and from virtually anywhere in the world on a nearly real-time basis.

Vital messages generated by a variety of applications are collected and transmitted by appropriate mobile or fixed SCU terminals to a satellite in the ORBCOMM constellation. The satellite receives and relays these messages down to one of four U.S. GES terminals. The GES then relays the message via satellite link or dedicated terrestrial line to the NCC station. The NCC routes the message to the final addressee, through the Internet via e-mail to a personal computer or through terrestrial networks to a subscriber communicator, pager, dedicated telephone line or facsimile.

The ORBCOMM space and ground network with GESs, GCCs and SCUs and with the OG1 and OG2 generation of satellites is shown in ***Figure 1***. Messages originating outside the U.S. are routed through international GCCs in the same way to their final destinations. Messages and data sent to a remote SCU can be initiated from any computer using common e-mail systems, internet and X.400. The GCC or NCC then transmits the information using ORBCOMM's global telecommunications network.

ORBCOMM serves customers through VARs that provide expertise in specific industries. These ORBCOMM VARs provide whole-product solutions and customer support to end-users. Different customers from around the world rely on the ORBCOMM satellite network for a wide range of mobile, farming and fixed site data applications including:

1. Monitoring and controlling assets at remote or rural sites for oil/gas extraction, pipeline operations, storage, custody transfer and electric power generation and distribution;
2. Messaging for truck fleets, owner operators and remote workers;
3. Tracking and managing construction equipment, locomotives, rail cars, trucks, trailers, containers, vessels, small craft and locating and recovering stolen vehicles and cargo and
4. Weather data for general aviation.[2,3,4]

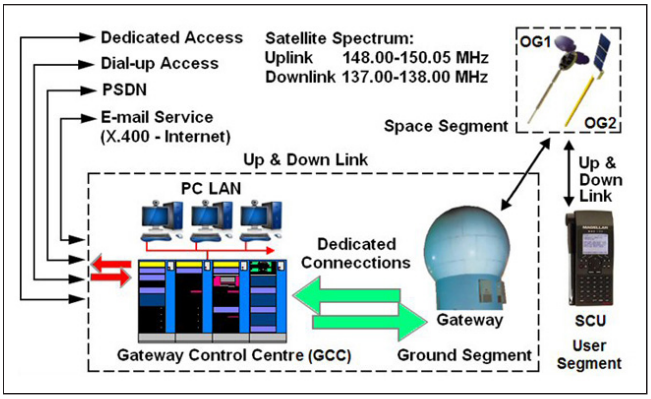
SPACE SEGMENT

The ORBCOMM system allows users to track, monitor and control remote assets via a satellite network that provides near global coverage with OG1and OG2 satellite constellations.

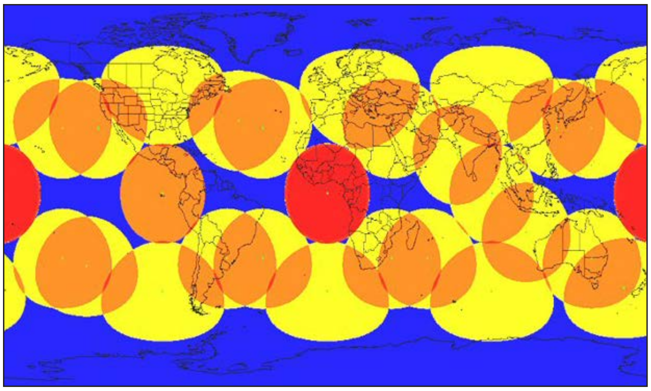
FIRST GENERATION OF ORBCOMM OG1 SATELLITES

Through a network of LEO OG1 satellites and regional GESs, users can communicate with their mobile or fixed assets anywhere in the world (see ***Figure 2***). ORBCOMM offers low-cost and high-quality service dedicated to fulfilling the specific needs of all potential users.

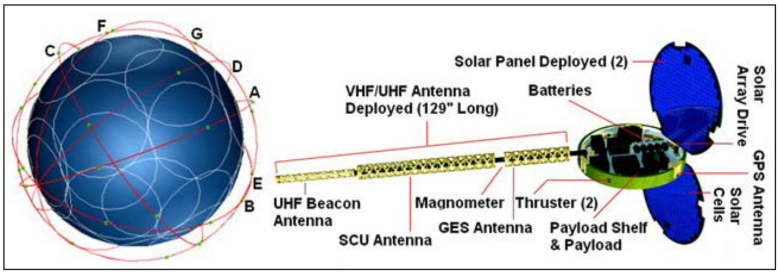
The ORBCOMM communication network's first generation operational OG1 satellites are in Little LEO orbit at about 825 km above the Earth's surface (see ***Figure 3a***). The main function of ORBCOMM's satellites is to complete the link between an SCU and the switching capability at the NCC in the U.S. or a licensee's GCC in other countries.



▲ Fig. 1 ORBCOMM system overview.[2]



▲ Fig. 2 ORBCOMM OG1 satellite coverage.[5]



▲ Fig. 3 ORBCOMM OG1 satellite constellation (a) and components of the OG1 satellite (b).[2]

1. Planes A, B and C are inclined at 45 degrees to the equator and each contains eight satellites in circular orbits at an altitude of approximately 815 km.
2. Plane D is also at 45 degrees containing seven satellites in circular orbits at an altitude of 815 km.
3. Plane F is inclined at 70 degrees and contains two satellites in a near-polar earth orbit (PEO) at an altitude of 740 km.
4. Plane G is inclined at 108 degrees and contains two satellites in a near-PEO at an altitude varying between 785 km and 875 km. Plane E is in circular equatorial orbit.

Figure 3b shows the main parts of a fully deployed OG1 satellite. Each spacecraft carries 17 data processors and seven antennas, designed to handle 50,000 messages per hour.

Undeployed, the ORBCOMM OG1 satellite resembles a circular disk and weighs about 43 kg. It measures approximately 1 m in diameter and 16 cm in depth. Circular panels hinge from each side after launch to expose solar cells. These panels articulate on one axis to track the Sun and provide 160 W.

The satellite's electrical power system is designed to deliver about 100 W, on an orbit-average basis, near its expected end-of-life in a worst-case orbit. The satellite solar panels and antennas fold up into the disk (also called the "payload shelf") with the remainder of the payload during launch and deployment. Once fully deployed, the spacecraft length measures about 3.6 m from end-to-end with a 2.3 m span across the solar panel disks. The spacecraft long boom is a 2.6 m VHF/UHF gateway antenna.

The ORBCOMM network depends on the number of satellites and gateways in operation and the user's location. As the satellites move with the Earth, so does the approximately 5.100 km diameter geometric footprint of each satellite. This system provides redundancy at the system level, due to the number of satellites in the constellation. Thus, in the event of a lost satellite, ORBCOMM will optimize the remaining constellation to minimize time gaps in satellite coverage. Consequently, the constellation is tolerant of degradation in the performance of individual satellites.

ORBCOMM satellites constantly move, so large obstructions do not prohibit available coverage in remote rural areas. In comparison, GSM (cellular) coverage depends on tower location, usually centered on major highways and cities and cannot reach remote areas, and the geostationary earth orbit (GEO) satellite system requires large space constructions and costly/ power-intensive hardware. Due to slow data transfer, however, large data files (such as graphics) or emergency response latencies are not appropriate applications for ORBCOMM.

Its satellite transponder receives 2400 b/s at 148 to 149,9 MHz and transmits 4800 b/s at 137 to 138 MHz and 400.05 to 400.15 MHz. The OG1 satellite system uses X.400 of the Consultative Committee on International Telephony and Telegraphy (CCITT 1988). Addressing and message size is typically 6 to 250 bytes (no maximum).

The communication subsystem is the principal payload flown on the satellite, consisting of five major parts:

1. The Subscriber Communications Section is the main payload part consisting of one subscriber Tx, seven identical Rxs and associated Rx and Tx filters and antennas. Six of the Rxs are used as subscriber receivers and the seventh is used as the Data Center as a Service (DCAAS) Rx. The subscriber Tx is designed to transmit an operational output power of up to about 40 W, although the output is less during normal operation. The power of each Tx can vary over a 5 dB range, in 1 dB steps, to compensate for aging and other lifetime degradations. Symmetrical Differential Phase Shift Keying (SDPSK) modulation is used on the subscriber downlink at a data rate of 4800 b/s. (It is capable of transmitting at 9600 b/s.). The satellite uplink modulation is SDPSK with a data rate of 2400 b/s. Raised cosine filtering is used to limit spectral occupancy.

2. The ORBCOMM Gateway Communication Section contains both the gateway satellite's Tx and Rx. Separate right-hand circular polarization antennas are used for Tx and Rx functions. The gateway Tx is designed to transmit 5 W of RF power. The 57.6 Kb/s downlink signal to the GES is transmitted using an offset quadrature phase shift keying (OQPSK) modulation in a TDMA format. The gateway Rx is designed to demodulate a 57.6 Kb/s TDMA signal with OQPSK modulation. The received packets are routed to the onboard satellite network computer.

3. The Satellite Network Computer receives the unlinked data packets from the subscriber and the ORBCOMM gateway Rxs and distributes them to the appropriate Tx. The computer also identifies clear uplink channels via the DCAAS Rx and algorithm and interfaces with the GPS Rx to extract information pertinent to the communications system. Several microprocessors in a distributed computer system aboard the satellite perform the satellite network computer functions.

4. The UHF Tx is a specially constructed 1 W Tx that emits a highly stable signal at 400.1 MHz. The Tx is coupled to a UHF antenna designed to have a peak gain of about 2 dB.

5. The Satellite Subscriber Antenna Subsystem comprises a deployable boom containing three separate circularly polarized quadrifilar antenna elements.

The attitude control system is designed to maintain both nadir and solar pointing. The satellite must maintain nadir pointing to keep the antenna subsystem oriented toward the Earth. Solar pointing maximizes the amount of power collected by the solar cells. The satellite employs a three-axis magnetic control system that operates with a combination of sensors, which also obtains its position through its onboard GPS receiver.

Satellite planes A/B/C are designed to maintain a separation of 45 ± 5 degrees between satellites in the same orbital plane. Planes D/E provide 51.4 degrees spacing between satellites, while highly inclined satellite planes (F/G) are spaced for 180 ± 5 degrees apart.

The springs used to release the satellites from the launch vehicle give them their initial separation velocity. A pressurized gas system is used to perform braking maneuvers when the required relative in-orbit satellite spacing is achieved. An Orbital Sciences Corporation formation-keeping technique maintains the specified satellite intra-plane spacing. One of the benefits is that, unlike GEO satellites, it does not affect the satellite's life expectancy in fuel usage.[2,4,5]

SECOND GENERATION OF ORBCOMM OG2 SATELLITES

ORBCOMM in May 2008 signed a next generation satellite constellation contract with Sierra Nevada Corporation (SNC) to build 18 modern ORBCOMM Generation 2 (OG2) satellites with an option to purchase up to 30 additional OG2 satellites to augment its existing satellite constellation (see ***Figure 4***).

As prime contractor, SNC is an experienced integrated space team with unique and established space heritage, resources and performance record, including Boeing Intelligence and Security Systems (I&SS), ITT Space Systems and MicroSat Systems. The integrated space team also includes several other key subcontractors and industry leaders with unparalleled experience in both the design and construction of complex communications systems and satellites.

SNC, Boeing and ITT provide oversight, systems engineering, technical management, integration and mission assurance functions to assure the successful performance of the OG2 program. MicroSat Systems (MSI), a wholly owned subsidiary of SNC, leveraged its experience on the TacSat-2 mission to design the spacecraft and perform integration and test activities for the OG2 satellites.

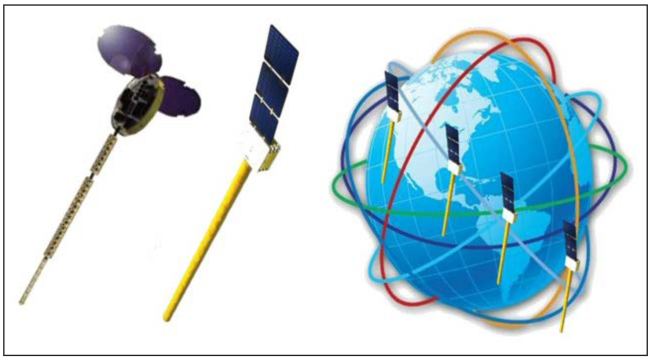
In June 2008, SNC selected Argon ST to develop and deliver the satellite payloads for the OG2 satellite constellation. Each OG2 satellite is equipped with an enhanced communications payload designed to increase subscriber capacity by up to 12 times over the OG1 satellites. ORBCOMM customers can transmit data over the OG2 satellites at greater speeds and send larger data packets using future modems.

From 8 October 2012 to 22 December 2015, 18 next generation OG2 satellites were launched, but only 17 became operational. ***Figure 5*** shows the ORBCOMM OG1 spacecraft (a), ORBCOMM OG2 spacecraft (b) and ORBCOMM OG2 orbital satellite constellation (c).

The OG2 satellites are backward compatible with OG1, so that existing subscriber communicators function seamlessly with the OG2 satellites. In addition, all OG2 satellites are designed with S-AIS payloads to receive and report transmissions from AIS-equipped oceangoing vessels. In fact, ORBCOMM markets this S-AIS data to the USA and international coast guards and government agencies, as well as maritime companies engaged in security or logistics businesses for tracking shipping activities or for other navigational purposes.

The ORBCOMM LEO satellites are "orbiting packet routers" ideally suited to "grab" small data packets from mobile or fixed sensors and relay them through a tracking Earth station and then to a GCC.

▲ Fig. 4 ORBCOMM OG2 satellite coverage.[6]



▲ Fig. 5 ORBCOMM OG1/OG2 satellites: OG1 spacecraft (a), OG2 spacecraft (b) and ORCOMM OG2 orbital satellite OG2 coverage (c).[8]

The current satellite constellation, OG1 and OG2, provides one central location for the two-way delivery of data over multiple carriers to customer back-office applications via the Internet, cellular wireless, satellite and dual-mode cellular and satellite services; however, more than 42 percent of the market share of ORBCOMM's current satellite system provides M2M service to users for fixed and mobile applications.[6-8]

GROUND SEGMENT

The ORBCOMM ground segment, which contains most of the system intelligence, comprises gateways or GESs, control centers and both mobile and fixed SCU customer terminals. The space segment of satellite constellations and orbits are controlled by one satellite control center (SCC).

Gateways, which include the GESs, GCCs and the NCC, are located at ORBCOMM headquarters in Dulles. Within the USA, there are four other GESs located in Arizona, Georgia, New York State and Washington State. The NCC also serves as North America's GCC and manages the overall system worldwide. ORBCOMM gateways are connected to dial-up circuits, private dedicated lines or the Internet. The SCU handheld devices for personal messaging are fixed and mobile units for remote monitoring, control and tracking applications.

GES

ORBCOMM continues the deployment of additional regional GESs to provide near-real-time service for all major areas of the world, as well as developing and launching a new generation of satellites that will enhance and expand the current system's capabilities. All ORBCOMM's GES terminals link the ground segment with the space segment and are in multiple locations worldwide.

The GES acquires and tracks satellites based on orbital information from the GCC, links ground and space segments from multiple worldwide locations, transmits and receives transmissions from the satellites, transmits and receives transmissions from the GCC or NCC, monitors the status of local GES hardware and software and monitors satellite system level performance "connected" to the GCC or NCC (see ***Figure 6***).

The GES terminal is redundant and has two steerable high-gain VHF antennas that track the satellites as they cross the sky. It transmits to a satellite at a frequency centered at 149.61 MHz at 56.7 Kb/s with a nominal power of 200 W. It receives 3 W transmissions from the satellite in the 137 to 138 MHz range. These up-and-downlink channels have 50 KHz bandwidths.

The mission of the GES is to provide an RF communications link between the ground and the satellite constellation. It comprises medium gain tracking antennas, RF and modem equipment and communications hardware and software for sending and receiving data packets. An ORBCOMM licensee requires a gateway to connect to satellites in view of its service area. Namely, the gateway consists of a GCC and one or more GESs, as well as the network components that provide interfacility communications.[2,9,10]

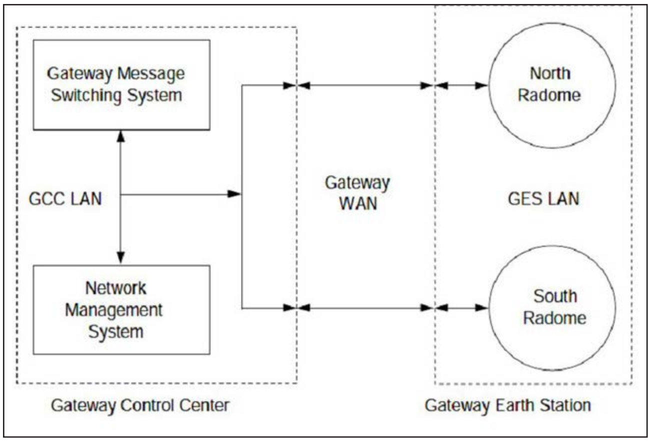
GCC

The GCC is the operations center for ORBCOMM gateway activities. Auxiliary systems such as subscriber management and business support systems are typically located in the GCC. GCC terminals are in territories licensed to use the ORBCOMM system. They locate wherever ORBCOMM is licensed, link remote SCUs with terrestrial-based systems, communicate via X.400, X.25, leased line, dial-up modem, public and private data networks and E-mail networks including the Internet and efficiently integrate the ORBCOMM infrastructure with new or existing customer management information system solutions.

The GES transmits messages over a dedicated line to the GCC that places them on the public switched network for delivery to the receiver subscriber's PC Internet provider. The GCC Local Area Network (LAN) and GES LAN are considered part of the global OCCNet Wide Area Network (WAN).

The OCCNet is the overall, worldwide WAN hardware network that ties together the ORBCOMM LAN hardware in GCC stations of ORBCOMM gateways established throughout the world. Thus, it consists of the routers, bridges, modems and interconnecting circuits over which command and control telemetry passes.

Within the context of an ORBCOMM gateway, the OCCNet also consists of the routers, bridges and modems by which the ORBCOMM gateway elements (in particular, the NMS, GMSS, and GES) are interconnected. The OCCNet functions include: 1) providing message transport between an ORBCOMM gateway, GMSS and NMS, 2) providing message transport between an ORBCOMM gateway, GCC and its GES terminals and 3) providing message transport with the GCC.[1,2]



▲ **Fig. 6 Diagram of ORBCOMM GES.**[10]

NCC

The NCC is responsible for managing the ORBCOMM communications network elements and the USA gateways through telemetry monitoring, commanding and mission system analysis. It monitors real-time and back-orbit telemetry from the ORBCOMM satellites, sends real-time and stored commands to the satellites, provides the tools and information to assist engineering with resolution of satellite structure and ground anomalies, archives all satellite and ground telemetry data for analysis and monitors performance.

The NCC manages the entire ORBCOMM satellite constellation and its processes and analyzes all satellite telemetry. It is responsible for managing the ORBCOMM system worldwide. Through OrbNet, the NCC monitors message traffic for the entire ORBCOMM system and manages all message traffic that passes through the U.S. gateway. The NCC is staffed 24 hours a day, 365 days a year from Dulles, Va. A backup NCC system was established in 2000, which permits the recovery of critical NCC functions in the event of an NCC site failure.[1,5]

SCC

The SCC serves in territories licensed to use the ORBCOMM system and provides control of the ORBCOMM Little LEO satellite constellation. The SCC terminal is owned and operated by ORBCOMM and co-located with the U.S. NCC in Dulles, Virginia.

SCU

The SCU equipment comprises both mobile and fixed terminals used for connection to the ORBCOMM satellite network through gateway stations. The SCU terminal is a wireless VHF modem that transmits messages from a user to the ORBCOMM system for delivery to an addressed recipient and receives messages from the ORBCOMM system intended for a specific user.

Manufacturers have different proprietary designs. Each model must be approved by ORBCOMM and adhere to the ORBCOMM Air Interface Specification, Subscriber Communicator Specifications and ORBCOMM

Serial Interface Specification (if an RS-232 port is available). Different versions of SCU terminals are currently available, which include "black-box" industrial units that have RS-232C ports for data uploading and downloading. Current options on several SCUs include internal GPS receivers and/or additional digital and analog input and output ports

▲ **Fig. 7 ORBCOMM second generation of SCU modems: Stellar DS300 (a) and Quake Q4000 (b).**[11,12]

USER SEGMENT

The ORBCOMM satellite system is designed to enable short communications between different, often unmanned remote fixed or mobile modems, positions and customer information hubs as a part of the User Segment. The main unit is an SCU. ORBCOMM hardware and software components comprise a global, packet switched two-way data communication service optimized for short messages and small file transfers.

The ORCOMM SCU mobile or fixed satellite terminals are full-feathered compact, light-weight devices with their own power supplies, or are supplied from other sources if installed on some mobile means of transport, such as ships, road or rail vehicles and small craft. Many have RS-232 data ports and some are integrated (black-box versions) with GPS receivers, lap-tops and palm-top computers and other systems.

Data transmissions can be encrypted by application software using standard digital encryption standard computer chips using the same methodology used by STU-111s to encrypt classified conversations over the public telephone network.

The ORBCOMM system provides a less accurate geolocation capability that combines the Doppler frequency shift available from a LEO satellite with the satellite onboard GPS receiver to calculate position within less than 100 meters. This may be sufficient for many U.S. or other country armed forces requirements.[1,5]

SECOND GENERATION OF ORBCOMM SCU TERMINALS

There are many first and next generation SCU satellite terminals that use the ORBCOMM satellite network, but in this context, two terminals from ORBCOMM's second generation of SCU terminals will be introduced. Before that, the Magellan GSC 100 satellite modem was developed as the first generation of handheld satellite terminals in the world that allows sending and receiving text and e-mail messages to and from anywhere in the ORBCOMM coverage area (see Figure 4).

1. Stellar DS300 Terminal – The DS300, designed by Stellar and Delphi Electronics, and Safety and manufactured by Delphi, is a two-way satellite communicator for use with the LEO ORBCOMM satellite network. It is a complete hardware solution combining a satellite transceiver and GPS receiver for companies using a wide variety of applications to track, monitor and communicate with their fixed and mobile assets around the globe (see ***Figure 7a***).

The DS300 terminal is a complete hardware solution for companies using a wide variety of applications to track, monitor and communicate with fixed and mobile assets around the globe. It features a satellite modem using a VHF transmit frequency of 148 to 150.05 MHz and a receive frequency of 137 to 138 MHz. Dynamic Range is 40 dB minimum. Its power supply is 12 VDC for both the transceiver and GPS receiver. It transmits at a speed of 120 Kb/s, and has a user-programmable application processor, an integrated 16 channel GPS receiver, adequate software configurable input/output (I/O) options and a battery charger packaged in a rugged, automotive-grade enclosure.

The design and stable performance make the DS300 a reliable satellite device for transportation, heavy equipment, marine, aeronautical and many other markets. The satellite modem is configurable with eight input or output digital channels, four input analog channels and 8 GPS receiving channels.

2. Quake Q4000 Terminal – This satellite three-mode (ORBCOMM, Iridium and GSM) mobile terminal is one of the initial generations of cost effective and fully programmable ORBCOMM transceivers and GSM (cellular) receivers. It operates at a VHF transmit frequency of 148.000 to 150.050 MHz and a receive frequency of 137.000 to 138.000 MHz with a 50-channel GPS receiver for a global tracking capability (see ***Figure 7b***).

It uses the ORBCOMM satellite network and it has almost the same technical characteristics as the Iridium Q4000i for the Iridium Big LEO satellite network. It can be used for SCADA (M2M) and business-to-business Internet links with marine, land (road and rail) or aeronautical based assets and fixed M2M heavy equipment, transportation and oil and gas applications anywhere in the world.

This is a robust industrial modem in a compact form factor that is small enough to hold in one's hand. It is also designed to meet exacting standards regarding automotive power conditioning requirements and features a low power draw load for battery operated applications of 10.5 VDC.

The Q4000 uses an application programming interface (API) that empowers developers to integrate its functions and build customized onboard mobile applications. Various mobile and fixed clients are given a wide array of fully customizable options, including multiple inputs/outputs, antenna detection, J1939 CAN Bus, memory and network accessibility based on their M2M technical and functional requirements.[11, 12]

NEXT GENERATIONS OF ORBCOMM SCU TERMINALS

1. ORBCOMM OG2-GPS Modem – This tracking unit delivers connectivity over the LEO ORBCOMM VHF satellite network for transportation maritime, land (road and rail) and aeronautical, heavy equipment, agricultural and other markets (see ***Figure 8a***). It measures 40 × 70 x 0.5 mm and has a Mini PCI Express 52-pin edge connector with a 0.8 mm pitch. Its input voltage is 2.8 to 15 VDC. Input current in transmit mode is 1.6 A, GPS draws 35 mA and receive mode uses 70 mA.

ORBCOMM's OG2 and OGi satellite modems share the same electrical and application interfaces. This allows for seamless plug-and-play satellite connectivity over either network with no additional time or resources spent on development and integration. The OG2 satellite modem supports low power consumption for improved longevity in battery-powered applications, and its modems do not require a fixed line of sight with the satellites. The GPS version includes a built-in accelerometer and is well-suited for use in mountainous terrain and dense urban areas.

2. ORBCOMM GT 1100 Modem – This unit enables full control of mobile assets and containers (see ***Figure 8b***). It allows complete visibility and control of fixed and mobile assets. As part of a comprehensive solution that includes sensor technology, powerful Web and mobile applications and reliable cellular and satellite connectivity options, the GT 1100 helps businesses optimize operational efficiencies and reduce costs. It is available as a cellular or dual-mode satellite-cellular version powered by solar rechargeable batteries for low power consumption and long service life in the field. It operates autonomously and requires minimum maintenance, no battery changes and can externally interface to a GPS receiver.[13,14]

3. ORBCOMM MT 5000 Modem – This is reliable small craft and shipborne tracking device for safety, security and compliance that ensures secure, consistent and reliable M2M vessel fleet location (see ***Figure 9a)***. The MT 5000 is a class B transmitter, broadcasting Radio – AIS (R-AIS) messages to nearby vessels and coastal AIS stations, along with ORBCOMM's S-AIS network. This unique combination delivers more reliable and comprehensive fleet location data. It brings the power of reliable tracking to smaller vessels.

It uses rechargeable lithium manganese batteries with very low self-discharge. It can be charged from 9 to 32 V DC or by means of universal 12 V AC/DC adapter. It operates at 4 VHF AIS frequencies, two for R-AIS and two for S-AIS with a minimum 2 to 3 W EIRP. It also uses 50 Global Navigation Satellite System (GNSS) channels for GPS satellite-based augmentation systems, such as WAAS, EGNOS and MSAS and non-augmented GNSS networks such as GPS, GLONASS, Galileo and BeiDou.

4. ORBCOMM GT 700 Modem – This unit provides reliable satellite-based asset detection, tracking and security in the transportation and distribution, oil and gas and other industrial markets (see ***Figure 9b***). It supports a security cable that wraps around container-locking bars or other latching mechanisms to ensure cargo security. The device delivers alarms when the cable seal is broken or disconnected to help deter theft.

It uses a lithium internal (primary battery) that lasts five years at two messages per day. It provides simplex (one way) transmission via circular polarization division multiplexing and adaptive transmission modulation over the LEO satellite constellation and tracking with a GPS receiver operational to 1,000 knots (515 m/s) in service for ships and aircraft tracking as well.[15,16]

▲ **Fig. 8 OG2 and GT 1100 SCU terminals: OG2-GPS Modem (a) and GT 1100 Modem (b).**[13,14]

▲ **Fig. 9 MT 5000 (a) and GT 700 (b) SCU terminals.**[15,16]

▲ **Fig. 10 Heavy equipment and transport management: PT 7000 Modem (a) and RT-6000 Terminal (b).**[17,18]

SATELLITE COMMUNICATION, TRACKING AND MONITORING TERMINALS

To enhance safety and security in transportation systems it is necessary to implement satellite asset tracking (SAT) for all mobile solutions, especially for ships and small craft via two-way data transfer devices in portable sizes. With their reduced power consumption of main, solar or battery power, these portable units are an effective way of remotely collecting position, velocity and time (PVT) data from ships, containers, vehicles, locomotives with wagons and small craft for transmission to the tracking control station (TCS). In this article only two ORBCOMM SAT and fleet management terminals will be discussed, global transportation management and heavy equipment management terminals.

1. ORBCOMM PT 7000 Modem – This unit integrates cellular and optional satellite trackers in cases where monitoring units are outside of ORBCOMM satellite coverage (see ***Figure 10a***). It provides comprehensive monitoring and control for heavy equipment and vehicles used in the construction, mining, rail and utility industries. As part of a comprehensive telematics solution that includes sensors, connectivity and applications, the PT 7000, available as a cellular or dual-mode satellite-cellular version, gives customers complete visibility and control of their heavy equipment fleet and allows them to manage their operations more effectively by enabling access to real-time data and analytics.

It receives asset status updates and engine alerts, configures reporting intervals, responds to requests for asset positions and more. A satellite connectivity option is available for critical applications to ensure alarm delivery and response. It also receives real-time alarms when specific conditions are detected or thresholds are exceeded and an asset has been turned on, an engine reading has exceeded a threshold, an asset has entered or exited a geofence, low oil pressure is detected and more. It provides accurate status and position information along with key operational metrics so all users can proactively manage their fleets anywhere in the world.

By leveraging equipment utilization and maintenance reports, customers know where their equipment is, if it is productive or needs maintenance, if oil pressure is within limits and how it is being used to better allocate resources and improve operational efficiency. In addition, equipment alerts including unauthorized movement or out-of-spec sensor readings such as loss of oil pressure or high coolant temperature can be quickly communicated to a mobile device to ensure a timely response.

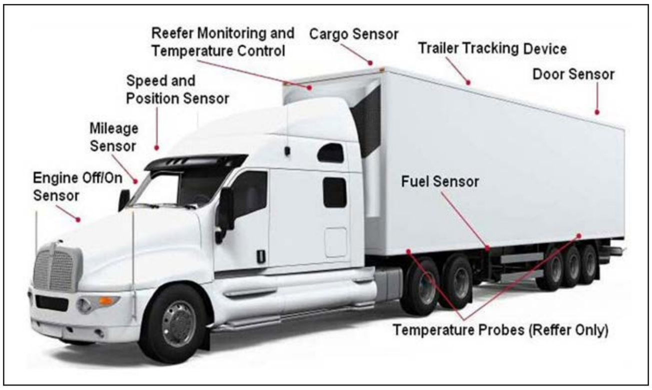
Necessary time to provide alert delivery is 30 seconds and poll response time is 2 to 3 minutes. The terminal provides reporting interval position, motion start/stop, condition-based fault codes, engine/idle hours, fuel consumption, battery voltage, antenna connect/disconnect and pre-defined event triggers. It interfaces four digital inputs, two digital outputs, two pull-up, two pull-down, four analog inputs, 4 1(/2) CAN/J1939 bus ports, 2(/1) Serial ports, LED and Bluetooth low energy.[17,18]

2. Global Transportation Management RT-6000 Terminal – This terminal can be used for integrated GPS with dual-mode cellular and satellite tracking and management and has many interfaces for monitoring sensors (see ***Figure 10b***). The ruggedized RT 6000+ provides visibility, control and decision rules to dispatch and operations centers, maintenance organizations and operational managers of transportation companies worldwide.

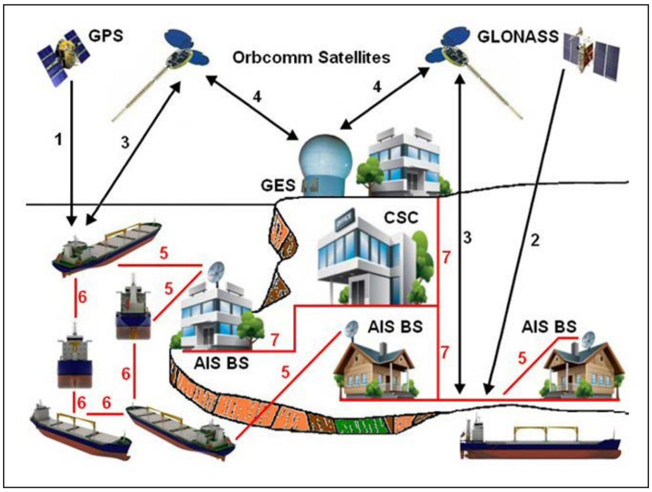
Using a unique direct interface to any refrigerated asset it provides comprehensive temperature and fuel management, maintenance, logistical and management applications services to revolutionize refrigerated transportation operations (see ***Figure 11***). Transport customers can make immediate, important decisions about their reefers or any other vehicles, allowing for smarter investments in transportation system operations, logistics and immediate savings as well as improved end-to-end operations. With two-way interfaces, this solution delivers the most effective refrigeration and fleet management tools in the industry for maximum compliance, efficiency and return-on-investment.[2,10]

MARITIME SATELLITE AIS (S-AIS) TERMINALS

The ORBCOMM LEO operator provides a new and more reliable satellite automatic identification system (S-AIS) via VHF frequencies for oceangoing ships with onboard broadcast systems. Ship identification, position and other critical data received from the GES can be used to assist in navigation and improve maritime safety and security at sea. In a similar way, the S-AIS system can be used for aeronautical applications so that aircraft position and other critical data can be used to assist in-flight operations and improve aeronautical safety.



▲ **Fig. 11 Tracking sensors onboard a truck.**[2]



▲ **Fig. 12 ORBCOMM Satellite AIS (S-AIS).**[2]

The most current terrestrial-based Radio AIS (R-AIS) system implemented by the International Maritime Organization provides only VHF limited coverage nearby shorelines; it is not able to provide global coverage. The ORBCOMM satellite system overcomes this due to a fully Satellite AIS (S-AIS) data service that can monitor maritime vessels well beyond coastal regions and the horizon in a cost effective and timely fashion and send this data via GES to the Coastal Surveillance Center or TCS.

An AIS receiver using satellites can extend the VHF range of R-AIS systems considerably and makes it easier to monitor ship ocean navigation and fishing areas. ORBCOMM was the first commercial satellite network to begin operations with S-AIS data service. In 2008, ORBCOMM launched the first LEO satellites specially equipped with the capability to collect AIS data with plans to include these capabilities on all future satellites for ongoing support of global safety and security initiatives.

Figure 12 shows the space and ground configuration of S-AIS integrated with R-AIS. In fact, all ships receive GNSS PVT signals from the US GPS (1) or Russian GLONASS (2), then ships out of R-AIS coverage send via service link (3) PVT data to an AIS satellite. This data is transmitted via a feeder link to the GES (gateway) terminal (4).

All ships inside of R-AIS coverage send GNSS PVT data to the R-AIS base station (BS) via radio link (5), while all ships have AIS data communication via inter-ship links (6). Received AIS data from the GES and AIS BS is forwarded via terrestrial links (7) to the SCS terminal for processing. In this way, AIS data with positions of all ships in a certain sailing region can be displayed on a radar-like screen and used for collision avoidance.[1,2]

CONCLUSION

The versatile ORBCOMM products and Little LEO satellite constellation support multiple modes of communication, leveraging extensive experience to provide a broad portfolio of satellite, cellular and dual-mode IoT connectivity. The platform's capacity has been expanded exponentially to process more than 100,000 messages per second, which is an increase of over 1000x in message throughput over legacy systems. With the ORBCOMM satellite network, it is possible to provide increased processing capability. Customers can continue to expand their deployments, access a higher level of visibility and enable more sophisticated solutions in a 5G sensor-enabled IoT ecosystem integrated with satellite solutions.■

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Optical Communications the Next Frontier for Satellite Communication

Keysight Technologies Inc., Santa Rosa, Calif.

THE ERA OF THE SPACE GOLD RUSH

Over the past 50 years, the space industry has been transformed from government-led exploration through a period of commercialization to the current day, where entrepreneurs are fueling explosive growth and innovation, creating a gold rush in space. Technology advancements have been the catalysts for much of the development. This new era of exploration is driving a tectonic shift resulting in the global space economy being valued at $424 billion in 2022. (Euroconsult).

Space missions are now commonplace, with SpaceX alone carrying out more than one voyage per week in 2022, nearly doubling the number in 2021. The industry is rapidly evolving, with private organizations pushing the boundaries of innovation, from building the next generation of reusable rockets, to scaling low earth orbit (LEO) communication satellites and reaching planets deeper in the solar system with the ultimate goal of sending humans to Mars!

The increase in competition has upended the space economy and costs have come down significantly. The growth has been fueled by the barriers to entry lowering, including:

- The cost of hardware plummeting
- Reusable launch rockets
- The densification of electronic components
- More standardization when connecting satellites to rockets

The resulting gold rush has organizations striving to be first and the disruption has created an array of opportunities that were impossible a decade ago.

GROWTH IN SATELLITE CONSTELLATIONS

The need to access space for navigation, communication, surveillance and reconnaissance, remote sensing, internet access, and space experimentation has

never been greater and shows no sign of abating. This is driving demand for satellite systems which play a pivotal role in the aerospace and defense industry along with a multitude of commercial applications.

Currently, the military relies on satellite connections that are not always robust and lack the necessary bandwidth. This can cause challenges for soldiers in the field or the navy trying to navigate the seas. With the rollout of satellite networks in LEO, these challenges will be obliterated.

There are currently more than 4,550 satellites in orbit, with over 3,000 in LEO. The lowering of the barriers to entry has fueled the new wave of LEO mega-constellations, creating an opportunity for optical communications as the need for bandwidth grows exponentially.

Optical communications — the use of light to transmit information — provides the aerospace and defense industries with several advantages over traditional radio frequency (RF) communications, including increased bandwidth, higher frequencies, improved security, and the ability to transmit data over longer distances without signal degradation. Deploying optical links connects satellites to create a resilient and secure network for flexible data transfer over longer distances. With the bandwidth and latency issues associated with traditional satellite systems eliminated, the industry is turning to optical links.

As the space gold rush intensifies, organizations are striving to be first to market. They are turning to commercial off-the-shelf (COTS) components widely deployed in other sectors to facilitate this. However, the risks and costs within the space industry are unique and can't be underestimated. So, before a COTS component goes into orbit, it must be tested to ensure it can reliably perform in space. From an engineering perspective, overcoming the harsh environment of space is a significant challenge.

PITFALLS IN SPACE

Space is an extreme environment, presenting the ultimate challenge for humans and technology to survive. The hostile setting creates an array of pitfalls that must be factored in when designing and building solutions.

1. Launch

The G-force and vibration encountered during the ascent into orbit can reach 5Gs and range from 5-200 hertz. This pressure from the sound waves can damage or detach any components not built to withstand the impact.

2. Temperature Extremes

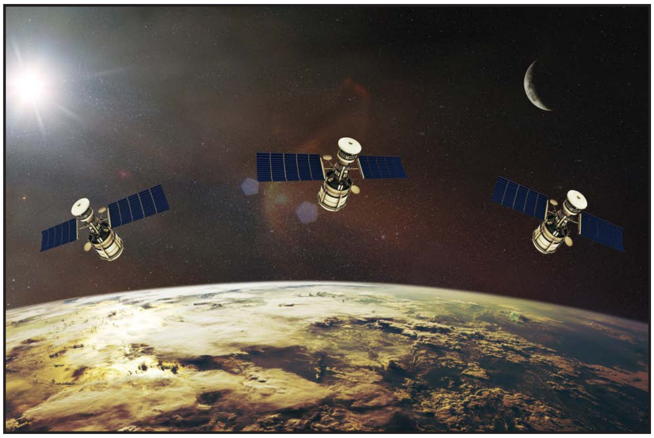
Once a satellite is orbiting, it has to be able to tolerate extreme temperatures. The climate is determined by the proximity and orientation to the sun, which can range from -170°C to 123°C in LEO. In addition to variable temperatures, dissipating heat through convection is not possible. Instead, radiation is the only viable method in the vacuum of space. In the case of satellites, a heat pipe regulates the temperature and keeps the system operating.

3. Radiation Damage

Cosmic rays harm not only people but equipment. The radiation comes from rays, solar flares and radiation belts and can result in the degradation and failure of electronics and electrical systems in vehicles, rockets, or satellites. The level of exposure varies depending on the orbit. For example, the impact is limited in (LEO), while it's much higher in geosynchronous and polar orbits. However, there are risks in LEO from solar outbursts and geomagnetic storms. For example, a solar storm in 2022 caused 40 Starlink satellites to be destroyed—an incident that is estimated to have cost approximately $100 million.

4. Power

Every piece of equipment in space must be self-sustaining. For satellite systems, each unit must generate and store enough energy to power the entire mission. There is no room for error as any power outages will result in an operational satellite becoming another piece of space debris that will, at some point, return to earth and burn up on reentry.



5. Outgassing

Outgassing is not a significant issue on earth, but in the vacuum of space, it can increase the volume of trapped gasses. Outgassing occurs in materials like the plastics used in electronic components. As the vapor condenses, the materials start to degrade, which can ultimately lead to catastrophic failure in equipment like satellites and spacecraft. As a result of the risks, NASA has developed guidelines to limit outgassing levels of components used in space applications.

6. Communication

The Doppler effect impacts satellite communications in space as the motion between the satellite and the ground station changes. As satellites are in constant orbit, the Doppler shift of the signal is always changing. Therefore, it must be continuously accounted for to maintain accurate communication.

As satellites are in constant orbit, signals are impacted by variable fading, latency and Doppler shifting. For inter-satellite links, there is minor fading between terminals in the vacuum of space, latency is more stable and the Doppler shift for satellites is lower in a similar orbital plain. With terrestrial communication, the attenuation is proportional to the distance traveled, as well as cloud cover and humidity that will scatter or absorb signal energy. A communications system must adapt to minimize the impact of these differences.

7. Space Debris

Another emerging environmental hazard resulting from the surge in activity is space junk. More than 30,000 pieces are orbiting the earth, and the debris consists of fragments of out-of-service rockets and satellites stuck in orbit. And as the number of satellites in space continues to grow, so will the amount of debris, increasing the likelihood of a catastrophic collision between the junk and a functioning satellite.

STATE OF TECHNOLOGY DEPLOYMENT

The space arms race is accelerating the need to deploy new technologies and systems quickly. This is driving the adoption of COTS components to reduce costs and speed up deployment. As the industry becomes more commercialized, the need to quickly integrate proven technologies will continue to grow.

For example, as new satellite systems are deployed

in LEO to speed up data transfer, COTS components are being integrated. These elements are already battle-tested in the telecommunications and industrial sectors. However, they now need to be evaluated to ensure they are fit for purpose in space. This is creating the need to emulate the space environment to assess the performance of each component.

Without incorporating COTS technologies and ensuring they are space reliable, it will be almost impossible to keep up with and prosper in the space gold rush.

SATELLITE COMMUNICATIONS

Just as the last few decades have seen significant transformations in space exploration, satellite technology has undergone numerous changes.

Figure 1 displays the entire communications chain of a simplified SatCom system. This bent-pipe transceiver's function is to:

- Receive the transmitted signal
- Filter and down-convert it to a lower RF frequency
- Amplify and retransmit the same signal down to a receiver station

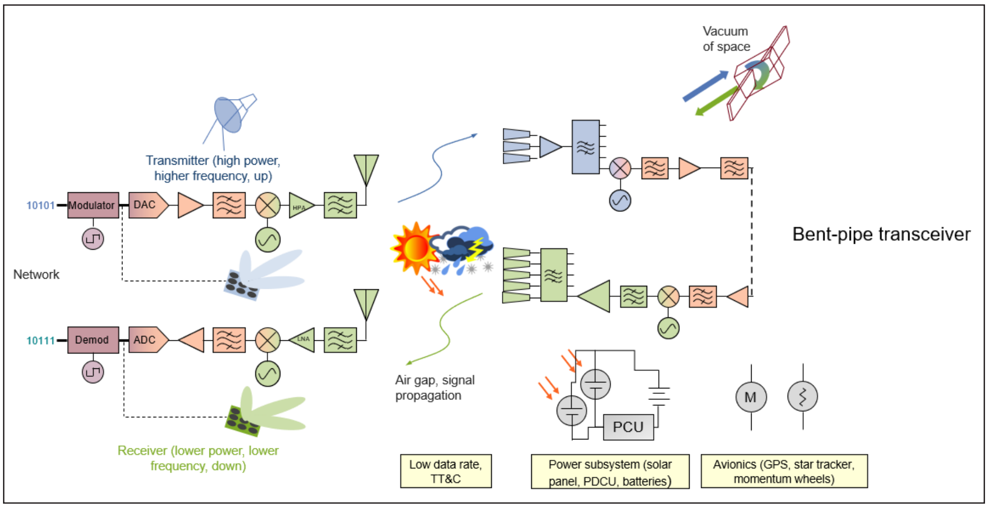
The signal is then amplified, filtered, and demodulated so that the data can be passed into the network. These simplified systems have some limitations, including spotty connectivity. This can cause challenges across industries but is a particular issue in the defense sector if military personnel can't access mission-critical insights on the battlefront or in remote locations.

Figure 2 illustrates a more modern LEO satellite which contains internal processing capabilities that enable it to change its function over time. In addition to the simple bent-pipe transceiver, these systems can also perform data processing within the satellite for data channelization, processing, and even passing intelligence into the space network for optimized data transfer.

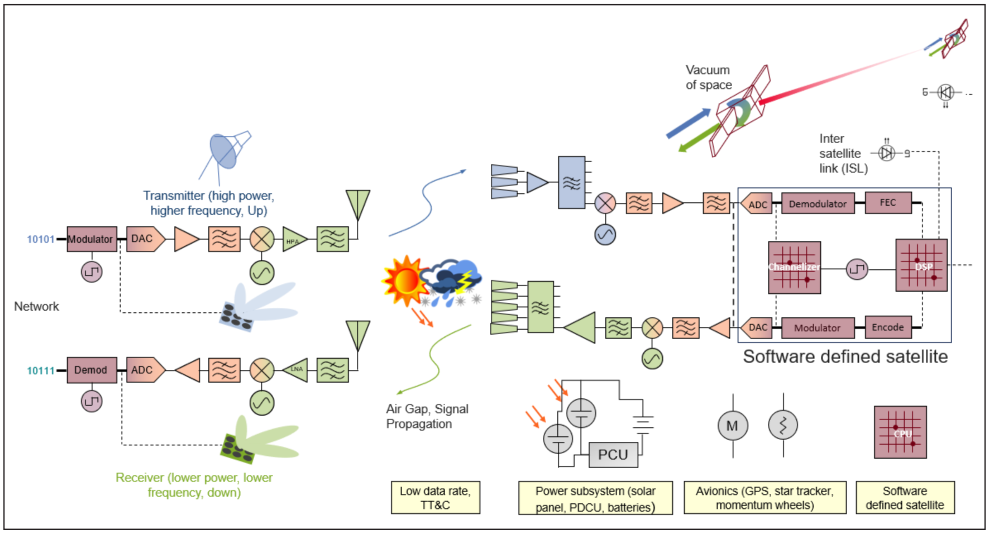
These embedded capabilities are key to the success of networked mega constellations, and the addition of inter-satellite links (ISLs) allows for the implementation of traffic routing in the satellite network.

According to Northern Sky Research, approximately 85% of all satellites launched between 2020 and 2030 will be constellations. These systems will not only be in constant contact with their counterparts on the ground, but many will also be communicating with one another directly. This is ushering in a more mature era for ISLs and making the case for optical communication in space.

Figure 3 depicts an optoelectronic SatCom system. In this model, the laser becomes a localized reference for the ground-station telescope. The laser is fed an electro-optic modulator and the data to be transmitted is encoded into the optical signal. This is then passed through the telescope optics to the satellite, which has its own telescope and local references linked to an op-



▲ **Fig. 1 Simplified SatCom System. Image courtesy of Keysight.**



▲ **Fig. 2 LEO Software Defined Satellite. Image courtesy of Keysight.**

toelectronic receiver. The satellite efficiently converts the data from optical to digital to enable processing, before converting the data back to optical and routing it in the relevant direction.

THE CASE FOR OPTICAL COMMUNICATION IN SPACE

By using light to transmit data, optical communication brings some specific advantages including:

- **Achieving Higher Data Rates**
  Occupied spectrum and interference with other systems are often communication hurdles when working in RF or microwave frequencies. These concerns are alleviated with the localized laser source and A-to-B communication associated with optical photonics, meaning organizations can encode over wider bandwidths and obtain higher data rates.

  This is crucial to achieving the next frontier in satellite communications as demand has recently begun to outpace the bandwidth RF provides. The average transmission is currently tens or even hundreds of gigabits per second, and this can only be expected to grow in tandem with new aerospace and defense innovations. In addition, optical communication will be a critical component of supporting new Earth observation technologies like synthetic aperture radar, as organizations need the ability to send raw data to terrestrial applications in a highly secure manner.

- **Increased Security**

  Synthetic aperture radar is just one use case that underscores the importance of security, and this is another driver behind the rise of optical communication. The technology's tight, precise laser beam is much narrower than RF, meaning that the point-to-point communication of data is thereby more secure. This makes optical links more protected from eavesdropping, more resistant to jamming and spoofing, and better suited for confidential and military communication.

- **Less Energy Dispersion in Space**

  A laser's physical makeup means that optical communication results in less energy dispersion in space. Unlike with RF there is no need for a phased array antenna for beam steering. Instead, optical communication uses fast-steering mirrors along with gimbals to ensure precision pointing with less energy dispersion.

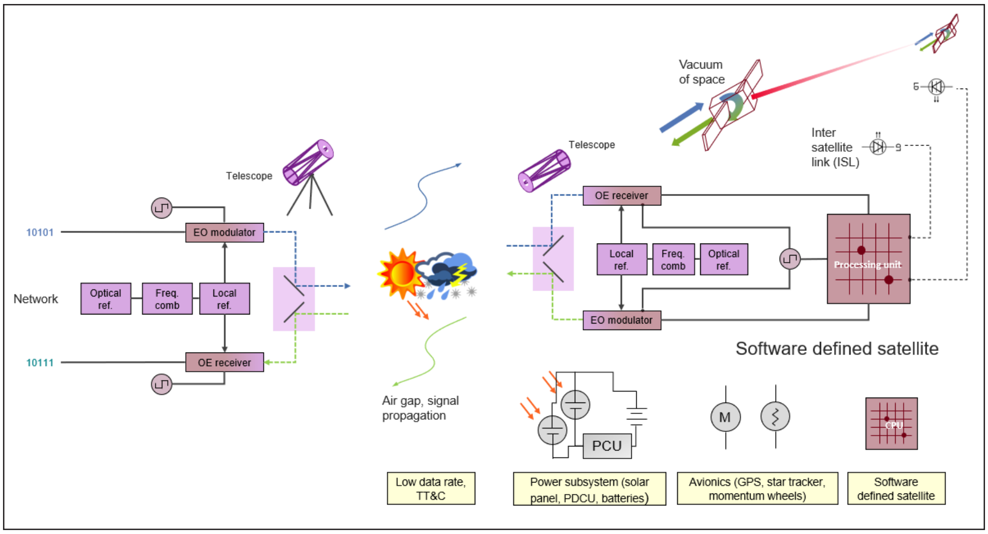


Fig. 3 Optoelectronic SatCom System. Image courtesy of Keysight.

SHINING A LIGHT ON THE SPACE NETWORK OF TOMORROW

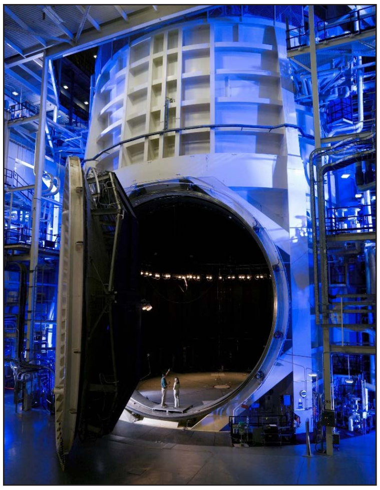
As optical communication is adopted, optical intersatellite links (OISLs) are combining with intelligent routing to form a secure, robust network that rivals the terrestrial internet in terms of speed and efficiency. Data remains in orbit and AI algorithms determine the most efficient ground station on Earth to deliver the information to the end user.

In order for this future to be realized, however, the industry must first deploy new technologies and systems. And as outlined above, the most efficient, proven way to do this is by leveraging COTS components to accelerate deployment while simultaneously keeping costs down.

THE CASE FOR COTS

Utilizing components and technologies used in terrestrial fiber-optic communications is an obvious path to minimize development costs in optical communications. Additional benefits include:

- Proven functionality and durability for communications
- Standards based, so components from different manufacturers can be used together
- Industrialized production, which typically enables rapid assembly and shorter lead times
- Specifications and performance characteristics based on the volume of components and systems manufactured



▲ The larger of two thermal vacuum chambers located at Johnson Space Center. (Photo credit NASA)

1. Minimizing the Risk

The use of COTS comes with one significant caveat, however: these technologies were not designed for space. And as we've discussed previously, space is a harsh environment replete with extreme temperature fluctuations, radiation exposure, and debris. Manufacturers need a way to ensure their COTS components can withstand these and other space-specific conditions without negatively affecting performance or reliability.

2. Simulating Space Conditions on Earth

One of the best ways to achieve this is by replicating space on Earth and testing space performance in the lab. Organizations can create simulated versions of systems and subsystems to ensure their COTS components can withstand any condition that may occur in space.

These emulations, known as digital twins, can significantly accelerate development and decision-making processes by identifying issues that can be addressed in the design phase, rather than once the component has already been incorporated into a space system. Digital twins also can expose mission risks that might not be evident via traditional testing solutions and provide insights into how various COTS components will perform together in space conditions.

Creating digital twins and testing for space's harsh conditions requires specialized equipment and an extensive knowledge of testing best practices. This can be costly for COTS manufacturers to develop and maintain in-house, so many rely on a trusted third-party entity for these and other testing requirements.

KEYSIGHT: MISSION CONTROL FOR AEROSPACE AND DEFENSE INNOVATION

Keysight Technologies has had a front row seat to the space industry's evolution, providing testing support for NASA's Orion spacecraft along with other aerospace and defense organizations. As COTS manufacturers look to capitalize on the space gold rush, Keysight is an ideal testing partner to ensure their solutions can withstand the environment's extreme conditions and perform as required.

Our goal is to help customers accelerate through the early stages of design and prototyping and leverage the data acquired through testing measurements to reduce costs and get to market faster. We do this by bringing space into the lab and creating digital twins as outlined above. This approach helps COTS manufacturers make better models, validate their design as they build hardware, decrease the likelihood of failures in orbital demonstrations and, ultimately, accelerate deployment.

Looking at satellites specifically, power and the dynamic channel are two areas of operation that have a bearing on validating COTS optoelectronic systems.

1. Power System Simulation

As we've established, there is no power source in space for a satellite; it must be self-sufficient once in orbit. Leakages or drains that exceed the satellite's ability to generate and store power are tantamount to equipment failure. To test for this in the lab, solar array simulation can be used to provide realistic power to the systems and subsystems, combined with power analysis hardware that monitors the power distribution and current draw in an emulated environment.

2. Dynamic Channel Emulation

It's critical to look at how Doppler, absorption, and scattering occur over time between communicating terminals—and how these change based on orbits. For example, it may be negligible with ISLs as relative movement between satellites in the same orbit has minimal impact. Linking with satellites in other orbits and to ground stations can impose higher doppler and fading, however. It's important to test for these variances to ensure they won't impede communications once launched.

These are just a few of the space-specific variables against which COTS components must be vetted—it's also important to test for launch vibration and forces, radiation damage, outgassing, space debris, and the technologies' ability to withstand temperature extremes. Assessing performance across these areas and collecting the corresponding measurement data throughout simulation gives COTS manufacturers a solid foundation for in-orbit demonstration and, assuming all goes well, launch.

3. Keysight Solutions

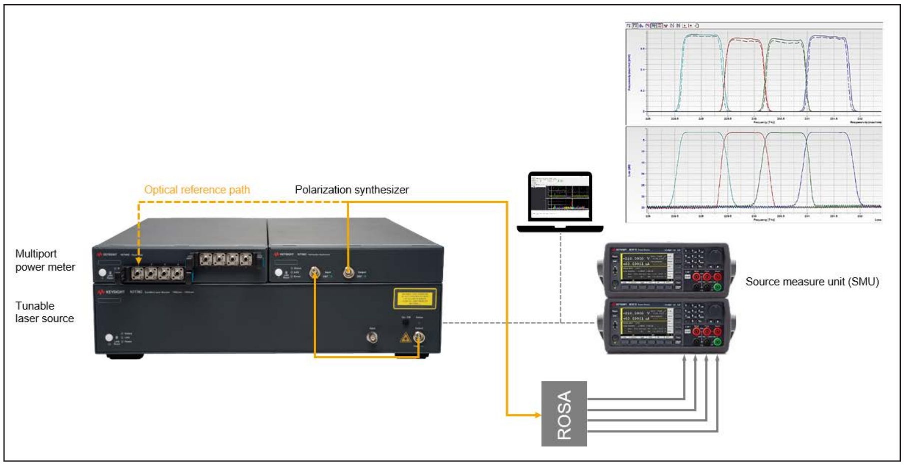
Keysight has numerous solutions that can help ensure optical communications systems are space ready.

The example below illustrates a receiver optical sub-assembly (ROSA), which is designed to convert an optical signal to an electrical one. A typical goal when testing this application is determining the wavelength-dependent responsivity of the photodiode and its polarization-dependent loss.

In the lab, we would excite the receiver with a calibrated optical signal, and in this case where the receiver is sensitive to polarization, a polarization synthesizer.

That signal is split, with one branch measured by a calibration instrument and the other going to the receiver. The electrical output of the latter is then measured with precision SMUs, that allows accurate measurement of both current and voltage from the sub-assembly output.

Keysight automates the entire measurement for fast, user-friendly testing that also provides insight into the isolation of channels, the linearity, and the flatness of the receiver. This is just one example of how our testing approach gives COTS manufacturers a leg up on the competition to lead the space gold rush while also minimizing costs and risk.



▲ **Testing a receiver optical sub-assembly (ROSA). Image courtesy of Keysight.**

THE FUTURE IS COTS

The space gold rush is creating an array of possibilities and organizations are racing to deploy new technologies and systems. The use of optical communication, which is transforming satellite systems, is an example of this. Using light to transmit data in space brings significant benefits, including higher data rates, improved security and less energy dispersion. As these mega satellite constellations are built, COTS components are increasingly being utilized to reduce costs and speed up deployment.

For manufacturers looking to harness COTS, the ability to evaluate if those components are space ready is the pathway to taking part in the boom. As the space industry becomes increasingly commercialized, the need to quickly integrate proven technologies that perform reliably in space will continue to grow. By partnering with Keysight, our solutions can help emulate and evaluate that your COTS components are ready for the rigors of space.■

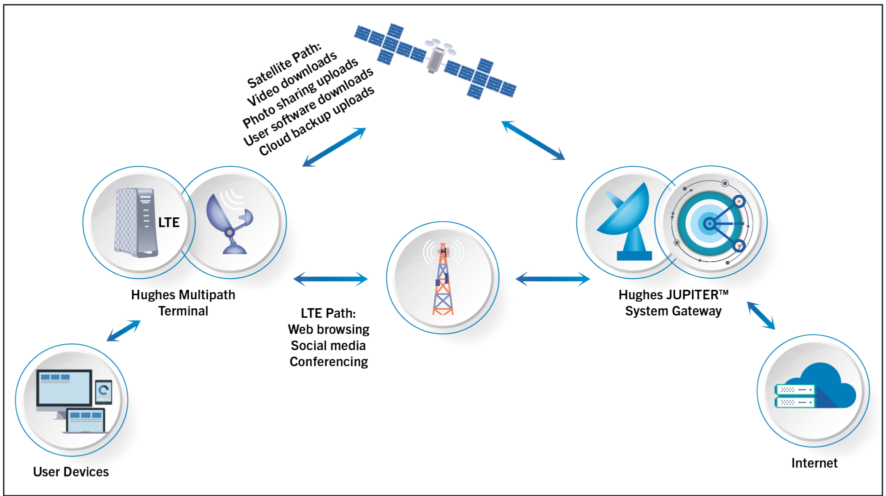
Combining GEO Satellite and Wireless Transports into a Low Latency Internet Service

George Choquette
Senior Vice President, Hughes

In September 2022, Hughes Network Systems, an EchoStar company, launched a new multi-transport consumer offering for U.S. customers that combines the advantages of geostationary (GEO) connectivity with the low latency of a terrestrial wireless transport for a more responsive satellite internet browsing experience. Offered under the HughesNet® brand, the new HughesNet Fusion™ plans leverage innovative enterprise software-defined wide area networking (SD-WAN) techniques to combine the low latency of wireless (specifically LTE) with the high capacity and throughput of GEO satellites into an offering for home and small business users (see ***Figure 1***). Built-in, active optimizing technology balances the responsiveness of LTE and the high capacity and throughput of satellite simultaneously to send data traffic intelligently and transparently over the best transport path.

Named for the fusion of the benefits of LTE and GEO satellite transport, the offering provides excellent performance for video streaming, video conferencing, web browsing, social media, banking and home office applications. It offers a satisfactory real-time gaming experience, which has been a challenge for GEO services. However, gaming applications notoriously consume gigabits of data, which makes them costly to run on any satellite-based service.

The LTE path offers lower latency and better response time for interactive internet applications than both GEO satellites and low Earth orbit (LEO) satellites. While wireless transport can be expensive when used to stream high-definition video, satellite transport is more cost-effective than fixed LTE, especially for users who watch a lot of video. However, satellite incurs higher latency, as data must travel up to a satellite orbiting approximately 37,000 kilometers away and come back down, introducing a noticeable delay in some applications. The new hybrid offering uses both LTE and satellite transports simultaneously on an application and flow-aware, packet-by-packet basis to get the best of each method without the relative cost or latency drawbacks. A HughesNet Fusion service plan includes a volume of LTE service as a cost-effective complement to the GEO satellite service. This specific transport is transparent to the end user, is



▲ **Fig. 1 The HughesNet Fusion network.**

compatible with smartphones, TVs and computers and preserves the privacy of user traffic.

INTELLIGENT INTERNET TRAFFIC MANAGEMENT

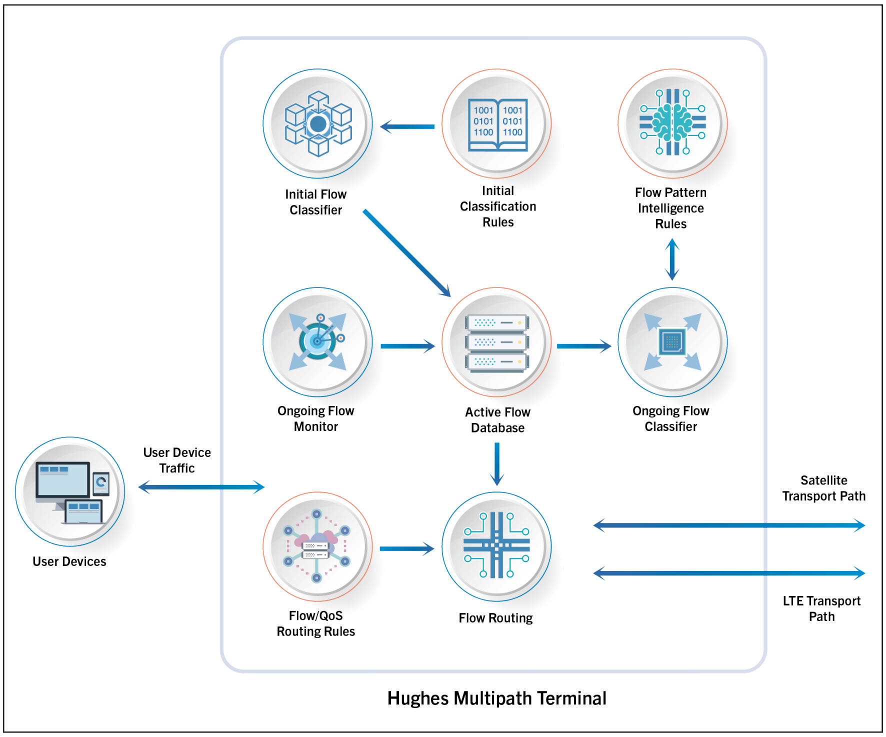
The Hughes ActiveTechnologies™ software forms the core of the Fusion plan (see ***Figure 2***). This proprietary and intelligent software classifies data traffic based on quality of service (QoS) requirements and routes each type of data over the optimal transport path. The software recognizes when the QoS requirements for an active traffic flow change and automatically changes the routing when appropriate.

To make the transition from HughesNet to HughesNet Fusion plans simple for end users, Hughes built ActiveTechnologies software, the LTE device and the wireless antenna into a new self-contained multipath terminal designated as the Hughes WL3000 terminal. Hughes also built its ActiveTechnologies software into multipath gateways connected to internet points-of-presence, as illustrated in ***Figure 3***. Turning on the Fusion offering is as simple as plugging in the new terminal and connecting it to the LAN port in the standard HughesNet router; no parameter entry or expertise is required. The new terminal works seamlessly with the existing router's Wi-Fi access point to serve all the smartphones, computers, smart televisions and other devices within the home. User device traffic travels seamlessly over Wi-Fi into the satellite router and is relayed to the multipath terminal. In the terminal, the ActiveTechnologies software forwards the traffic to the LTE modem or back to the satellite router for transport.

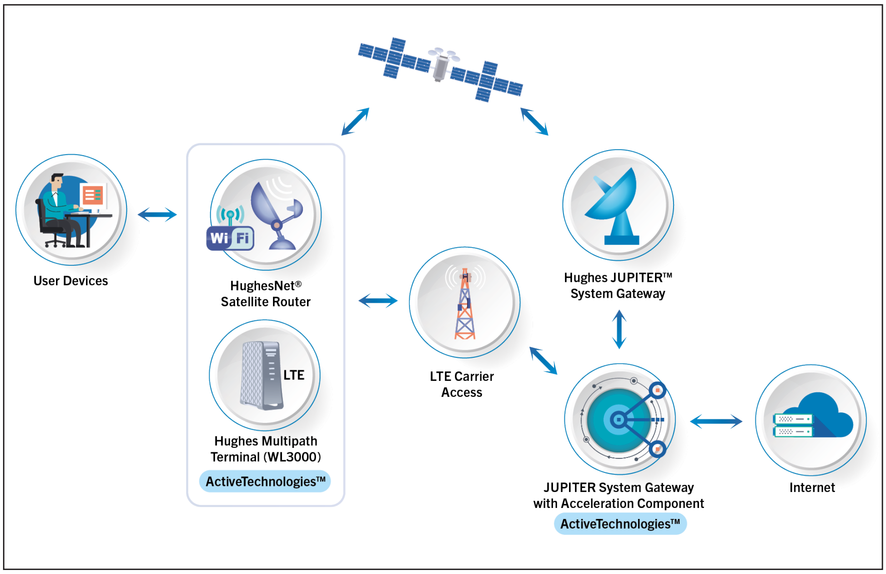
AUTOMATIC TRAFFIC CLASSIFICATION AND OPTIMIZED ROUTING

When a customer accesses the internet using the HughesNet Fusion plan, the traffic classifier function examines the traffic flow to make an initial determination based on the values of fields in packet headers, if available. However, many internet applications like video streaming, web browsing and banking are conveyed using the hypertext transfer protocol (HTTP) and cannot be distinguished by examining packet header fields. As the flow of traffic proceeds, the classifier monitors a set of criteria, such as packet rates and sizes, to determine if a QoS change is indicated.

As an example, video streaming starts with low latency protocol handshakes, security exchanges and a few packets to request the desired video from the internet host, then transitions into a high-throughput video stream download where transport latency is not perceptible by the user. The ActiveTechnologies software classifier detects that change in the traffic pattern and adjusts the flow classification to video streaming so that the appropriate packets in the flow are directed to the satellite path. The use of traffic patterns, rather than traffic content, enables the classification of encrypted flows without compromising user security and privacy. This constant traffic pattern monitoring and reassessment continues for the duration of a traffic flow, accommodating those applications that reuse the same protocol connection to an internet host server for different traf-



▲ **Fig. 2 The ActiveTechnologies software flow.**



▲ **Fig. 3 The HughesNet Fusion network with ActiveTechnologies software.**

fic types. The detection and monitoring function is also useful when an established connection changes during operation. An example of this scenario is when traffic flow changes from fast bidirectional exchanges to extended one-way download or upload. The routing function directs the packets of a given flow to the transport path designated for the classified QoS, routing to either LTE or satellite. This routing is performed independently for traffic in both directions between the user device and the internet host.

Web browsing provides another interesting example of how the HughesNet Fusion offering improves user experience. A typical web page contains dozens to hundreds of objects, like text, GIFs, ads and video clips, that are served by many different internet hosts. Regardless of transport method, the web browser on the end user device requests separate connections to each internet host and sometimes multiple connections to the same host. With HughesNet Fusion, ActiveTechnologies classifies each connection separately, assesses the QoS requirement continuously and routes the data accordingly. Objects such as text and GIFs can travel over LTE, while embedded video clips can transmit over satellite. This optimizes performance and cost, serving the web page over both transport methods and providing a seamless experience to the end user.

ADAPTING ROUTING TO TRANSPORT PATH CONDITIONS AND CAPACITIES

HughesNet Fusion service plans also use ActiveTechnologies to optimize service availability automatically. By constantly monitoring each transport path, the software automatically adjusts traffic for network availability; if one path becomes momentarily unavailable, the system sends traffic flows over the other path. In this scenario, the software prioritizes availability over performance and cost to ensure users can still use the internet for business or entertainment. As soon as the ActiveTechnologies software determines that both transport paths are again available, the system reverts to traffic routing patterns that optimize service performance and cost. The software also adapts traffic routing to conserve the low latency transport for use throughout the month. This adaptation is automatic and gradual, resulting in no disruption to the service user. With the potential for multiple routing adjustments over the course of the month, users reap the maximum benefit of their low latency LTE transport.

RULES OF THE ROAD FOR TRAFFIC CLASSIFICATION

Hughes engineers pre-set the performance, cost and availability parameters that guide the ActiveTechnologies software. The parameter values can be configured from the operations center, enabling real-time tuning of the performance and efficiency of the active service and allowing tailoring of operation for different service plans or transport characteristics. Configuration rules determine how traffic flows are classified for QoS requirements based on initial packet header values and monitored traffic characteristics including packet size, rate and volume. Additional configuration rules determine how transport paths are assessed for real-time characteristics including availability, throughput, latency and packet loss rate. This suite of controls enables ActiveTechnologies to maintain service availability and optimize quality automatically in the presence of changing performance of the underlying transport networks.

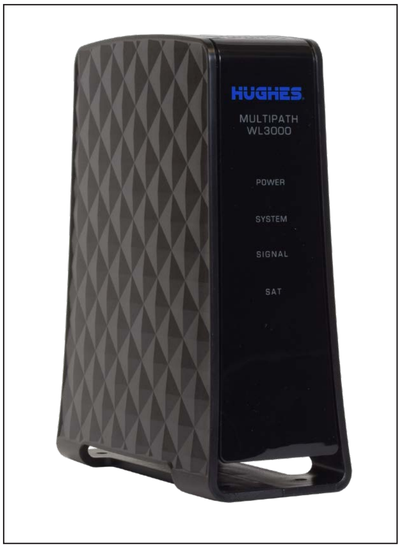


Fig. 4 The HughesNet Fusion WL3000 modem/router.

A NEW MULTI-PATH FORWARD FOR SATELLITE INTERNET

HughesNet Fusion plans meet the needs of rural consumers who live beyond the reach of wireline services, yet within the footprint of wireless networks. In these cases, the wireless service may not be strong enough for single-path service but it is likely sufficient to augment GEO satellite service. This offering leverages the capacity density, rural availability and high-throughput of GEO satellite connectivity along with the low latency of wireless transport to deliver low latency satellite internet. HughesNet Fusion represents the latest of a series of satellite internet innovations from Hughes, the company that innovated the first satellite internet access system, the first high-throughput spot beam satellite for internet access and the first applications of DVBS2 and DVBS2X standards for satellite internet service. Each of these innovations has enhanced HughesNet service, the satellite internet service on which millions of people depend, while enabling the Hughes JUPITER™ System ground platform that the company sells to other operators around the world.

Fig. 5 The HughesNet Fusion indoor antenna assembly.

In September 2022, Hughes introduced HughesNet Fusion to customers in the southeast region of the U.S. Soon after, the company made the offering available to new customers in that region and then quickly expanded the service nationwide. The WL3000 modem/router for this service is shown in ***Figure 4***, while the indoor wireless antenna assembly is shown in ***Figure 5***. ■

Keysight and Samsung Demonstrate 5G NTN Data Connection

Keysight Technologies Inc., Santa Rosa, Calif.

Keysight Technologies, Inc. and Samsung Electronics' System LSI Business have teamed up to demonstrate 5G New Radio (NR) non-terrestrial networks (NTN) enabling satellite-to-smartphone data connections at Mobile World Congress Barcelona 2023 (MWC23). Presented at Keysight's booth, Hall 5 Stand 5E12, the demonstration featured two-way SMS texting and video streaming over a live 5G NTN connection.

Satellite-to-ground communication based on 5G standards is a critical step to building NTNs that deliver ubiquitous mobile connectivity and broadband internet access to populations living in rural areas. The collaboration between Keysight and Samsung demonstrates how this new technology integrates 5G into space communication and speeds up the implementation of 3GPP Rel-17 designs.

The demonstration was conducted by emulating a constellation of satellites in low earth orbit (LEO) through the Keysight PROPSIM Channel Emulator and establishing a 5G connection between the Keysight E7515B UXM 5G Wireless Test Platform and Samsung's Exynos Modem platform. Despite being in lower altitude orbits, LEO satellites move at very high speeds creating high Doppler fluctuations and signal degradations that require compensation to achieve reliable connections and provide end-to-end quality of service.

Keysight's wireless test platform combines 5G NR and narrowband internet of things (NB-IoT) NTN signaling with real-world channel emulation hardware and software to create an end-to-end, mixed terrestrial and space communication testbed. This lab-based platform realistically simulates a wide range of orbit trajectories, including LEO and geosynchronous equatorial orbit (GEO), to address these technical challenges, optimize user equipment (UE) designs, and validate UE implementations prior to network deployments.

Huiwon Je, vice president of the modem development team at Samsung Electronics, said, "Innovation in 5G technology is only possible when working side-by-side with partners like Keysight. Samsung has been at the forefront of 5G modem technology and with Keysight's emulators and test platforms, we are able to quickly develop and evaluate 5G NTN connections using our Exynos Modem development platform."

Peng Cao, vice president and general manager for Keysight's Wireless Test Group, said, "By working closely with partners such as Samsung, Keysight is helping deliver the innovation needed to bring broadband connectivity to areas where terrestrial cellular networks are not a viable option. Through comprehensive, end-to-end emulation solutions, we are able to test early in the design cycle with realistic conditions to address a range of complexities that enable device makers to deliver on the promise of NTN."