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GLOBAL SATELLITE OPERATORS ASSOCIATION

New Satellite Technologies for Transformative Connectivity

A guide to the technologies and innovations that are enabling satellite communications to become more versatile and cost-effective.

Global Challenges | Satellite Answers

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1. Overview

This paper highlights how innovative solutions in satellite communications, such as multi-orbit satellite networks, inter-satellite links, software-defined satellites and in-orbit satellite servicing, are helping meet the growing needs of enterprises, governments and other users for increased capacity and connectivity.

Satellite communications have long been at the forefront of global connectivity, providing critical Internet, broadcast television and communication services to users at home, in the office and on the move. Satellites support weather forecasting (providing real-time information about weather patterns and storm systems), remote sensing (collecting data and monitoring events on the Earth's surface, such as oceanic and coastal phenomena and wildfires), defense and security, and PNT (positioning, navigation and timing). Satellites provide lifelines for remote regions, disaster-stricken areas, and maritime and aviation industries.

Satellite technology enables people, enterprises, governments and things to connect to the rest of the world. The evolution of standards and the introduction of non-terrestrial networks (NTN) into the 3rd Generation Partnership Project (3GPP) is now playing a major role in the integration of satellites into 5G and 6G ecosystems. The ability to provide connectivity to small antennas, whether in smartphones or fixed terminals at homes and businesses, and antennas integrated into vehicles will extend connectivity capabilities even further in the near term.

2. New Satellite Technologies - Satellite Evolution

The satellite industry is at the leading edge of innovation. Almost daily we see new technologies bringing increased choice for connectivity and more competition in the telecommunications industry offering greater capabilities to users.

Together, these developments contribute to the advancement of satellite technology, enabling scalable, cost-effective and reliable connectivity solutions that can respond to a plurality of needs.

These services include:

- providing direct broadband communications for enterprises and people,
- delivering secure and resilient solutions for government and institutions,
- extending the reach of telcos,
- connecting flights, ships and land vehicles,
- providing supervisory control and data acquisition (SCADA)/Internet of Things services for agriculture and environmental monitoring,
- supporting logistics, transportation and smart cities.

2.1 Non Terrestrial Networks - NTNs

A non-terrestrial network (NTN) refers to a 3GPP-defined concept involving the integration of satellite and terrestrial networks for the support of seamless service continuity in diverse environments. NTNs encompass satellite-based networks operating in frequency bands allocated to mobile satellite services (MSS) or fixed satellite services (FSS). They leverage the 3GPP-defined mobile system, technology and waveforms. Thanks to this technology commonality, economies of scale can be achieved for IoT, broadband, voice and emergency services, for example, at the terminal level.

2.1a Satellite IoT

Satellite technologies are well-suited for large-scale, global IoT deployments, providing coverage across wide geographies. Standards bodies, like 3GPP and the LoRa alliance, have embraced satellite technology, allowing cost-effective deployments and operations worldwide. Satellite IoT opens the door to transformative applications in a range of sectors, such as smart cities, precision agriculture and environmental monitoring, by overcoming existing connectivity challenges. Satellite NB-IoT (Narrowband IoT) solutions employ small, low-power and low-cost IoT modules designed for efficient operation with satellite networks, making applications more affordable and sustainable.

The integration of NTN and terrestrial networks will provide seamless connectivity and roaming capabilities for IoT devices transitioning between ground-based and satellite coverage areas. As IoT and satellite technologies converge, they promise to reshape how we connect, communicate, and interact with the world, ushering in a new era of global connectivity and possibilities.

2.1b Satellite Direct-to-Device Connectivity

Another sub-category of NTN is direct-to-device (D2D) connectivity, which involves connecting satellites directly to smartphones. One approach utilizes spectrum already allocated to mobile satellite services (MSS) and leverages the 3GPP NTN specifications. This ensures compatibility and interoperability across platforms by aligning with standardized protocols and frameworks. It offers a seamless transition between terrestrial and satellite networks for voice, data and messaging services, allowing users to benefit from connectivity regardless of their location. It requires mobile chipset vendors to support relevant MSS frequencies and 3GPP NTN air interfaces. This approach has been authorized in various countries without the need for additional regulatory frameworks to protect terrestrial carriers.

An alternative approach is for D2D to operate in the same frequency bands as those used by mobile network operators (MNOs), serving as a complementary solution to terrestrial mobile coverage. While this approach can leverage the installed base of smartphones and eliminates the need for specialized NTN-compatible chipsets, there are still significant technical challenges. It requires modifications to the radio access network (RAN) and core infrastructure of satellite-based systems, as well as enhancements to increase range and Doppler tolerance, manage interference and potentially establish exclusion zones or transmit power limitations.

As stakeholders navigate these challenges and opportunities, collaboration between satellite operators, mobile network operators and regulatory bodies is required to realize the full potential of satellite D2D connectivity to usher in a new era of ubiquitous and seamless communication. This opportunity is driving parallel developments in other industry bodies, such as the GSMA, which is updating its frameworks to support network convergence and ensure global interoperability for devices and services across terrestrial and non-terrestrial networks.

2.2 Multi-orbit Satellites

While satellite constellations are already operating together across various orbits today, further value can be created by optimized routing of traffic over multi-orbit networks. A multi-orbit approach utilizes a combination of satellites at various orbits to best exploit their unique characteristics in terms of coverage, throughput, latency or operational ease. The aim is to optimize the system to meet customers' service level requirements.

Combining both GSO (geostationary orbit) and NGSO (non-geostationary orbit) satellites can leverage the advantages of various orbits to best meet specific users' needs. There is also increasing interest in employing multi-orbit networks to relay the large amounts of data generated by earth observation and satellite imagery.

2.3 Software-defined Satellites

Software-defined satellites (SDS) introduce flexibility and programmability into traditional telecom networks, which simplifies management, uses network resources more efficiently and reduces operating costs. The industry is moving towards the creation of a global network ecosystem for software-defined satellites, modems, antennas, wave forms and the interoperability required to realize the full potential of future applications and connectivity needs. This software-based approach gives satellite networks massive scale, agility and the right cost structures for meeting coverage and capacity demand anytime and anywhere.

New generation SDS are designed for flexibility for:

- Superior Connectivity: Beam shapes and power allocation can be constantly adapted to optimize coverage and link performance;
- Flexibly Capacity Availability: Dynamic bandwidth allocation based on demand – the satellites adjust capacity availability to follow traffic;
- Seamless End-to-End Networking: Dynamic software-based interaction with user terminals and central networks to enable end-to-end service orchestration.

The development of a unified network that uses a multi-orbit, multi-layer, multi-band system, which is software-defined and supported on the ground by smart edge terminals, can help unlock the true potential of satellite communications.

2.4 Ground Segment


Image by Hughes

The satellite system ground segment is evolving with the changing nature of both GSO and NGSO satellite constellations. With the proliferation of NGSO constellations and satellites in inclined orbits, the need for antennas that track the satellites has become essential. This can be served by traditional parabolic antennas, often operating in pairs to ensure a "make before break" connection, or by flat panel antennas (FPA).

Another industry trend is towards an agnostic ground ecosystem where interoperability is key. The Digital Intermediate Frequency Interoperability [DIFI] initiative utilizes an existing ANSI standard as a means to achieve this by presenting the signal for onward processing in a generic form. This is being used in hub architectures and there are moves to have it more widely implemented in terminals.

Meanwhile, satellite user terminals have been reduced in size, weight, power consumption and cost, and provide a wide array of solutions for the end user. For instance, significant improvements in small form factor antennas have created terminals that are more portable, while providing a better performance than earlier generation models. These improvements are facilitating the wider deployment of user terminals that facilitate greater connectivity to the global network.

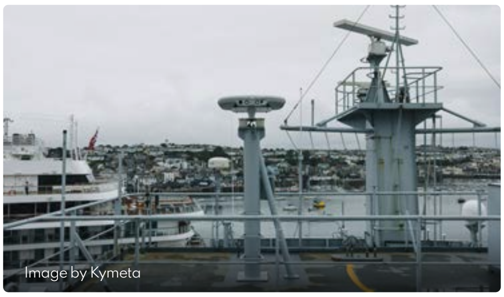


Image by Kymeta

2.5 Inter-satellite Links

Satellite-to-satellite links, also called inter-satellite links, can facilitate enhanced services, such as realtime offloading of the earth imaging and IoT traffic from low-earth-orbit (LEO) satellite constellations. This is valuable because LEO satellites can only communicate with ground stations within a restricted view of the Earth. Inter-satellite links, both radio and optical, can overcome this limitation, as data can be relayed to and from the ground via other satellites, including those located in a different orbit. Thanks to the communication links established amongst satellites, IoT traffic is deliverable in real time everywhere, and Earth-observation satellites are able to transmit high-quality images or other data back to the ground in real time. Similarly, crewed space stations will be able to communicate with the Earth at any time, even when over water and out of sight of land.

Optical communications technology enables high-speed connections and provides resiliency between platforms. Technological advancements, wider adoption and a downward trend in the cost of optical terminals are transforming inter-satellite optical links, by providing greater security, less interference and the reduction/ elimination of gateways.

In the future, widespread adoption of optical inter-satellite links by satellite operators is likely to encourage mass manufacturing of components, reducing their size and costs, and furthering adoption. Like RF communications, optical technologies can be optimized to meet specific customer needs and applications, giving them a critical role in the future of satellite communications.

2.6 Life Extension and In-orbit Servicing

Life extension services enable satellite operators to reuse existing assets beyond their original lifespan. The cost to deploy a single satellite in GSO can be well over US$200 million, underscoring the value of servicing, repairing or upgrading such satellites, rather than replacing them. In-orbit servicing therefore presents a compelling value proposition to GEO satellite operators: life extension and other in-orbit satellite services will generate more than US$4 billion in revenues by 2028, according to some estimates.


Image by Astroscale

With the support of life extension services, GEO services can continue to operate even after a satellite runs out of fuel, key bus subsystems fail or a replacement is delayed. In future, a wide range of new in-orbit services, from refurbishment to removal, across all orbits, are set to help ensure that orbital highways remain safe, secure and available for continued economic development.

2.7 Artificial Intelligence / Machine Learning

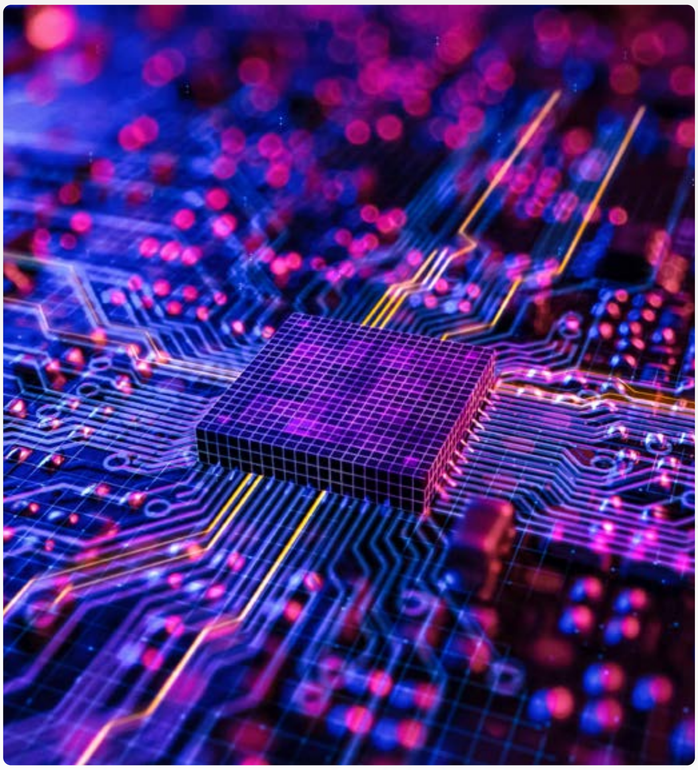
Artificial intelligence (AI) can make satellite communications more efficient, reliable and secure by optimizing space operations and network performances. By improving data analysis, AI can further enhance predictive maintenance and prevent satellite system failures. AI may also play a critical role in dynamic resource allocation (e.g. radio spectrum), as well as for interference detection and mitigation, ensuring clearer communication channels. It could even enhance data compression and transmission, leading to more efficient use of bandwidth and reduced latency. At the same time, AI could enable advanced security measures that better protect satellite communications against cyber threats.

2.8 Open Radio Access Networks

The open interfaces introduced through open radio access networks (O-RAN), and the addition of radio access network intelligent controllers (RICs), can be used to manage spectrum resources and enable seamless interoperability between terrestrial and satellite networks, as well as increasing satellite network efficiency.

Open RAN allows for different parts of the radio access network to be serviced by a variety of trusted vendors. Competition amongst vendors of each component fosters innovation and quality while lowering prices, and network supply chains become more diverse and less prone to a single point of failure. ORAN networks are more upgradable over time, more resilient, and more secure than traditional radio access networks. If one component or vendor in a network represents a threat or risk, an operator can find a replacement vendor without having to rebuild its entire infrastructure. In addition to the security benefits of modularity, the software-driven functions of O-RAN allow operators to customize their networks and respond quickly to security threats or performance issues.

2.9 Quantum Technologies



Quantum technologies are likely to greatly improve satellite communications by enhancing security, precision and global connectivity. Quantum key distribution (QKD) already provides virtually unbreakable encryption, ensuring secure key exchanges and detecting eavesdropping attempts.

Satellite operators are now investing in next generation end-to-end system testbeds that include a spacecraft, a ground segment and an operational segment to demonstrate that quantum technology can actually be used to protect existing networks, by adding a layer of security that is unbreakable with quantum computers.

Quantum sensors will also offer high-precision measurements and improved signal detection, bolstering navigation and communication systems. Additionally, the integration of quantum computing can optimize satellite operations and data processing, leading to more efficient and reliable communication systems.

3. Conclusion

The dynamic evolution of satellite communications is transforming global connectivity. The ongoing development of multi-orbit satellite networks, inter-satellite links, and the integration of nonterrestrial networks exemplify the industry's commitment to expanding and enhancing connectivity solutions. These advancements are pivotal to meet the increasing demand for reliable, secure and high-capacity communication services. The deployment of these cutting-edge technologies is driving a new era of satellite communications that is bridging the digital divide and fostering global inclusivity.

The convergence of these innovative technologies positions the satellite communications industry to play a crucial role in the future of global connectivity, ensuring an inclusive digital future for all. This ongoing transformation highlights the industry's commitment to creating a more connected and secure world.

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