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Satellites Provide Distant Connections

The growing number of artificial satellites—notably those with low earth orbits—is a sign of the essential roles that they will play in many emerging communications applications, including IoT, 5G, and connected cars.

Satellites have become a well-established contributor to modern electronic communications. RAF officer and science fiction writer Arthur C. Clarke is often credited (in 1945) with the concept of communications by means of relaying signals back and forth between the earth and orbiting artificial satellites. Satellite communications (satcom) systems have evolved a great deal from that early idea, growing into the many different satellite constellations at different orbiting altitudes that are currently serving many different markets and applications.

Today's satellites are commonly categorized as the earliest geosynchronous earth orbit satellites (GEOS), medium earth orbit satellites (MEOS), and the latest, low earth orbit satellites (LEOS). The latter are soon to become key parts of the emerging 5G wireless communications network, which will promise delivery of high-speed, wideband data anywhere and anytime, and those satellites will help make it anywhere. Satellite is the only electronic communications technology that can reach 100% of the earth's population.

A satellite's payload defines the type of application for which it is best suited, such as military signal intelligence (SIGINT), commercial communications or broadcast, and specialized applications such as weather forecasting. A communication satellite's payload includes a transponder, which is a transmitter and receiver operating at a designated frequency band. Satellites can have circular or elliptical orbits, maintaining the same distance above the earth in a circular orbit and having that height above the earth vary with an elliptical orbit. The height above the earth provides satellites with the capability to transmit and receive radio waves over great distances compared to communications systems using line-of-sight (LOS) signals.

Early satellites had mostly passive payloads, serving essentially as repeaters for signals transmitted from earth and redirecting the signals back to earth at much lower power levels, due to the attenuation from free-space signal loss. Most current satellites employ active transponders with high-gain amplifiers on board to overcome free-space path loss and typically increase the power level of signals being retransmitted to earth.

The antennas onboard a satellite must receive uplink signals from earth with high sensitivity and transmit downlink signals back to earth with high gain. A number of different antenna types are used on satellites, including dipole antennas for omnidirectional transmissions and reception, and highly directional antennas for telecommunications and broadcasting. Directional antennas are usually more recognized for their associated surrounding reflector assemblies (as in direct

1. Artificial satellites were once entirely geosynchronous-earth-orbit (GEO) types at high altitudes and with larger cover areas, but the current trend is for using larger numbers of smaller low-earth-orbit (LEO) satellites at lower altitudes and smaller coverage areas. *(Courtesy of Telesat)* broadcast television antennas), which support antenna gain and directivity.

A satellite's antenna patterns are designed to cover a specific area on the earth. On the earth's surface, earth stations are designed to control the satellite should it drift from its designated position due to various external forces, including the gravitational forces of the moon and the sun. Due to the distance from the surface of the earth, the gravitational force of the earth has no effect on a geosynchronous satellite. There is some centrifugal force due to the rotation of the earth that can cause them to deviation from their position.

A satellite's elevation angle, ε, is typically defined as the angle from the center of the satellite's radio beam and a plane tangential to the earth's station. A satellite's footprint is the area on the earth within which receivers with standardized specifications can receive and process signals from the satellite. Satellites at different orbital heights, such as a GEOS and a LEOS, will achieve different footprints, requiring a different number of satellites in a constellation to achieve a given coverage area for an application.

2. The Iridium constellation of 66 LEO satellites will be the world's largest constellation of communications satellites, used for many other global services. *(Courtesy of Iridium Communications)*

For example, geosynchronous satellites have circular orbits that follow the movement of the earth. For a stationary observer on the surface of the earth, a geosynchronous satellite will appear to be fixed in space. Because of its height above the surface of the earth (just over 22,000 miles in altitude in an orbit that is at 0 deg. latitude, at the equator), a geosynchronous satellite has an extremely large footprint. As a result, it is possible to achieve total coverage of the earth with only three geosynchronous satellites in a constellation.

Such satellites orbit with the same rotational speed as the earth and in its eastward direction of motion, fixing them in their designated location above the earth's surface. The inclination of a geosynchronous satellite with respect to earth is 0 deg. Such high-orbiting satellites are commonly used for radio and telephone broadcasting, as well as for wireless telephone networks.

When used for voice communications, the lower orbital heights of LEOS and MEOS provide advantages in terms of signal delay times. Because of the significant distances that a signal must travel from the ground to the satellite and back down to the ground, there is considerable delay time for satellite communications signals from a GEOS, which is most noticeable during satellite telephone voice calls. The shorter distance that a signal must travel from the earth's surface to a LEOS and back again translates into considerably less latency for a LEOS than for a GEOS. The smaller footprints of LEOS compared to GEOS allows for better frequency reuse in a LEOS constellation than in a GEOS system—although for a given coverage area, a GEOS system can be implemented with considerably fewer satellites and earth stations.

SORTING SATCOM FREQUENCIES

A wide range of frequencies has been allocated for satellite use by global standardization organizations such as the U.S. Federal Communications Commission (FCC) and the International Telecommunication Union (ITU). Allocations must be with international agreement to prevent frequency overlaps and interference. Frequency bands are allocated for fixed satellite services, mobile satellite services, broadcast services, meteorological satellite services, and navigational services using GPS satellites, with allocations covering a wide total frequency range from VHF and UHF through millimeter-wave (30 to 300 GHz) frequencies and higher.

For example, late last year, the FCC granted a petition from Canadian-based Telesat (www.telesat.com) for access to the U.S. satcom market using Telesat's growing LEO satellite constellation *(Fig. 1)*. With this FCC approval, and prior rights from the ITU, Telesat has obtained worldwide rights to about 4 GHz of Ka-band frequency spectrum for their LEO satellite system. This is enough bandwidth to support numerous broadband services.

The company has stated its intention to create a massive LEO satellite constellation of around 120 satellites by 2021; as part of reaching that goal, the company is planning to launch two satellites in 2018: Telestar 18 VANTAGE over Asia and Telestar 19 VANTAGE over the Americas. The LEO satellite system is being assembled to provide broadband voice, video, and data services for government, business, and individual users, as part of a business decision to build upon LEO satellites rather than GEO satellites as a more flexible and practical satcom solution.

"Telesat applauds the FCC's ruling, which will bring manifold benefits to the U.S. market, including improved access to the internet as well as the potential to enhance opportunities for U.S. workers and consumers, U.S. industry, and the U.S. technology base," said the company's president and CEO, Dan Goldberg. "Next-generation LEO satellite constellations have great promise for erasing the digital divide, and Telesat encourages the FCC, as it reviews its spectrum allocation policies, to ensure that satellite operators have sufficient access to the spectrum necessary to deliver on that promise." It should be noted that, although Telesat is a Canadian company, 62.7% of the company is owned by a U.S.-based satcom company, New York-based Loral Space & Communications (www.loral.com).

LEOS LOOM LARGE

The Telesat LEO satellite constellation will offer competition to the current state-of-the-art LEO satellite constellation managed by Iridium (www.iridium.com). The company's second-generation Iridium-NEXT satellites *(Fig. 2)* form the world's largest satellite constellation. Its 66 cross-linked LEO satellites, providing mobile voice and data service across the entire planet, including the oceans and the polar regions. The Iridium NEXT LEO satellites are deigned to provide seamless coverage and a dynamic mesh network, with each Iridium NEXT satellite linked to four nearby satellites, two in the same orbital plane, and one in each adjacent plane.

This mesh network routes traffic among satellites to ensure a continuous connection, everywhere. Each satellite communicates with nearby satellites to create a totally continuous satcom network. Combined with redundancies across the network, secure, dedicated ground infrastructure, and low interference at L-band frequencies, this unique configuration will allow services using the Iridium network to continue to remain unaffected by natural disasters—including hurricanes, tsunamis, and earthquakes that can cripple terrestrial infrastructure. These LEO Iridium satellites are typically placed in orbit by rockets that carry as many as 10 satellites at one time *(Fig. 3)*.

The trend away from GEO satellite constellations and towards LEO satellite constellations is quite clear with these activities by Telesat and Iridium Communications. In addition, LEO satellites will play important roles in the infrastructure of emerging 5G wireless communications networks, especially as service providers look to the satellites to provide affordable wireless communications services in remote regions that are not practically serviced by the erection of terrestrial cellular-type base stations.

Many of these LEO satellites contributing to 5G services may also be sending and receiving signals at millimeter-wave frequencies, requiring specialized antenna designs and high-frequency transponders in addition to lower-frequency equipment. Since LEO satellites have relatively small footprints compared to GEO satellites, the visibility for a mobile communications user on earth to be within range of a LEO satellite in a 5G network will be only minutes per satellite, requiring efficient, high-speed switching and seamless connectivity between satellites to make such switching invisible to mobile users on earth.

3. Up to 10 LEO satellites comprising the massive Iridium satellite constellation are launched at one time, with the support of business partners such as SpaceX. *(Courtesy of Iridium Communications)*