Evolution of Satellite Networks and Antenna Markets

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Abstract

The VSAT (very small aperture terminal) was first developed for commercial use by Hughes Network Systems in the mid-1980s and implemented on the first commercial satellite network for Wal-Mart, operating over a GEO (geostationary) Ku-band satellite. In over 30 years since, there have been dramatic advances in satellite, networking and ground system technologies, solutions, and services, the scope of which go well beyond what can be addressed in this Handbook. The modest objective of this chapter is to provide key insights into the evolution of satellite networks and associated ground systems that today serve all global...
market sectors. It identifies applications for which the transformative potential of electronically steerable phased arrays (described in chapter “Electronic Beam-Scanning Technology for Small Satellite Communication Systems and Their Future Development”) is poised to displace mechanically steered parabolic antennas as large-scale, small satellite constellations are launched. The net result will be an expansion of global satellite markets and diversification of ground systems, as VSATs and flat panel, phased array solutions supplement each other to fuel the expansion.

The world of small satellite constellations in LEO and MEO orbits will extend the reach of satellite communications, particularly in underserved portions of the world. By eliminating mechanical steering, flat panel antennas with electronic tracking will open up new addressable mobility markets through lower cost and compact packaging, whether for airborne, maritime, train, or land vehicle applications. This is not a matter of ground satellite systems being replaced, but supplemented in a very significant way.

**Keywords**

VSAT (very small aperture terminal) · Satellite networks · Ground systems · Global market sectors · Geostationary (GEO) satellites · Low Earth orbit (LEO) constellations · Medium Earth orbit (MEO) constellations · Mechanically steered parabolic antennas · Phased array antennas · Flat panel antennas

1 Introduction

That decision to implement the first enterprise satellite network by Walmart was hailed by Fortune magazine (Fortune 2005) as “one of 20 most strategic business decisions of the twentieth century” because it gave them an “informational competitive advantage.” In particular, it gave Sam Walton, the owner of Walmart, the ability to review progress of his many distributed stores by utilizing the then new medium of video-conferencing with his management team, including sharing up-to-date sales, marketing, and inventory information. Only satellites could reach all of his locations across the country, mostly in rural America, and unlike terrestrial technologies, offering uniform quality of service delivery at costs that are independent of location.

Fast forward more than three decades and these core benefits of satellite networks remain as key drivers in enterprise and government markets globally. Most significantly, advances in satellite architectures and technologies have lowered cost per bit of high-speed service delivery to be competitive with terrestrial, thereby expanding addressable markets to include the billions of consumers unconnected worldwide. Latest market data (Northern Sky Research 2019) shows the total installed base of VSATs globally is approaching seven million sites, with approximately four million being consumer and the aggregate growing at almost 15% CAGR. Today’s largest consumer satellite Internet service, on just one VSAT system, i.e., HughesNet™, spans the Americas with over 1.4 million subscribers.
Invention of the VSAT began the transition from when only large corporations or broadcast networks could afford the large dishes and the extensive real estate required to receive signals from the early C-band and Ku-band GEOs, to today’s world of multi-spot beam, Ka-band, high-throughput satellites (HTS) in which everyday consumers can enjoy the benefits of high-speed Internet access at affordable costs. For example, in the mid-1960s, Intelsat I (http://www.boeing.com/defense-space/space/bss/factsheets/376/earlybird/ebird.html) required a 30-meter Standard A parabolic antenna to receive one TV signal. Just two decades later, this had dramatically changed. The first VSAT emerged as a large briefcase-size box weighing several kilos connected to an external 1.5- to 2-meter fixed parabolic antenna, providing typically a maximum user uplink data rate of 9.6 kbps and costing approximately $10,000.

Today’s GEO satellites can transmit over 200 TV channels into a half meter parabolic antenna and receiver or deliver up to 1 Gbps of two-way Internet data throughput via the latest generations of compact VSAT installations, including modems/routers and a range of fixed/mobile/transportable antennas, virtually all being mechanically steerable parabolics.

As illustrated in Fig. 1, today’s burgeoning multi-billion dollar satellite industry is a core part of a rapidly evolving networking architecture that connects people, enterprises, and things worldwide, delivering video, voice, and Internet access/data services to millions of locations.
2 Satellites Enable High Availability Connectivity

By virtue of operating over wireless channels in space, satellite networks uniquely provide a robust alternative path to terrestrial links, whether fixed (fiber, cable, landlines) or wireless/cellular. High availability, fault-tolerant solutions result when both networking categories are configured together, with either as primary or backup, making them critically important when disasters strike for both emergency preparedness/response and maintaining enterprise or government operations. As a case in point, during the aftermath of Hurricane Maria which hit Puerto Rico and the US Virgin Islands in November 2017, satellite connectivity proved invaluable in recovery operations as terrestrial infrastructure was devastated (Fig. 2).

Hughes and partner, Response Force 1, supported the San Cristobal Hospital in Ponce by deploying VSATs and solar generators, helping to keep it operational and enabling leadership teams to order supplies and medications as well as evacuate patients in critical condition. They also supported businesses, such as wholesalers, pharmacies, retailers, and others to ensure operations could continue, including processing insurance claims, credit card payments, and government-issued food stamp (debit card) purchases – which was critical as cash was difficult to come by following the storms. And not to mention working with federal agencies to reconnect airports in St. Croix, St. Thomas, and San Juan in order to schedule first responder flight cycles to the islands (Fig. 3).

3 Mobility Solutions: From Emergency Response to Telemedicine, Mobile Education, and Banking

In virtually all the application areas illustrated, VSATs and related satellite systems/gateways from the earliest versions to the most advanced have employed primarily parabolic, mechanically steerable antennas operating over Ka or Ku band GEOs, in either fixed, transportable, or mobile configurations. Figure 4 illustrates just one example (C-COM Satellite Systems 2019) of a transportable antenna offering, a category that evolved to serve a wide range of markets by virtue of rapid, self-pointing capability, typically 90 seconds or less, and not requiring specially trained experts – in this case with solar panels and battery backup for rapid deployment virtually anywhere.

Transportable configurations span a wide range of applications globally, from satellite newsgathering, to mobile telemedicine, remote oil/gas and military field operations, cellular towers on wheels, and more, which the reader may find at various vendor websites. Figure 5 shows examples from various countries of mobile clinics configured for different categories of medical care, from basic checkups and nutritional guidance to breast cancer screening – bringing much needed telemedicine services to the public living outside urban areas.

Mobility applications as opposed to transportable have proven extremely challenging when employing mechanically steerable antennas, and all require some form of movable and stabilized platform, including accurate GPS and gyro positioning.
**Fig. 2** Terrestrial infrastructure can struggle to withstand the forces of nature. (Graphic courtesy of Hughes Network Systems)

**Fig. 3** Satellite connectivity at the airfield of San Juan Airport. (Graphic courtesy of Hughes Network Systems)
Portable and scalable transportable case includes battery, 2-4 foldable solar panels (125W) Direct AC (110 or 220VAC) and DC (12VDC) outlets Recharged via solar panels, vehicle DC or AC; can operate for 2 days: typical load (Antenna+Ctrl+mode +IPphone+laptop)

Fig. 4 Example of transportable self-pointing parabolic antenna. (Courtesy of C-COM Satellite Systems)
Whether operating over GEOs, MEOs, or LEOs, and whether for airborne, maritime, or train services, such configurations are bulky and relatively expensive, on the order of 100 thousand or more US dollars, and as a result have been limited to low volume commercial and military markets.

Figure 6 shows an example of an airborne, mechanically steerable Ku/Ka dual-band antenna designed for commercial aircraft. Besides the high cost of retrofit, the relatively large radomes to house such antennas increase flight drag and add to fuel costs. Despite these barriers, the market demand is unabated, and Euroconsult estimates that more than 23,000 commercial aircraft will offer connectivity to passengers by 2027 (up from 7,400 aircraft in 2017).

A discussion of electronically steerable phased arrays as a game-changing alternative to the mechanically steerable parabolic follows in chapter ▶ “Electronic Beam-Scanning Technology for Small Satellite Communication Systems and Their Future Development,” highlighting its advantages in reducing size, weight and power requirements and with lower cost. This is especially important for airborne applications through reduced radome sizes and hence corresponding drag, not to mention opening up the potential for personal vehicle applications.

4 Emerging Hybrid Architecture: From GEOs, MEOs, to LEOs, SmallSats, and 5G Wireless

Today, with over 7 billion wireless and over 4 billion Internet subscribers, we are on the brink of creating a truly interconnected global society with unprecedented opportunities to advance social and economic development in all nations. But to
realize this dream, the most pressing question now is how can we create the best delivery ecosystem on a planet-wide scale to realize the greatest promise of the Internet itself: To be always available, easy to use, affordable, and transparent to users? The answer lies in marrying new generations of satellite with both terrestrial fixed and wireless technologies such as 5G. This is already happening in the marketplace – and rapidly advancing beyond GEOs to include MEOs, LEOs, and an emerging plethora of SmallSat constellations. Figure 7 summarizes Euroconsults’ forecast of total satellites of all types to be built and launched by 2026, approaching 3000 and representing approximately $300B of investment. The latest filings and

| Receive frequency [GHz] | 10.7–12.75 | 17.8–18.8, 18.3–19.3, 19.7–20.2 |
|-------------------------|------------|---------------------------------|
| Transmit frequency [GHz]| 13.75–14.5 | 29.25–30                         |
| Polarization RX/TX      | Linear VP/HP| Circular LHCP/RHCP              |
| Selectable via A791 AMIP|            |                                 |
| Receive G/T (at 30° elevation)* | 11.6 dB/K @ 12.75 GHz (cruise level) | 15.4 dB/K @ 20.2 GHz (cruise level) |
| Transmit EIRP [dBW]*    | 43 dBW @ 14.5 GHz | 48 dBW @ 30GHz                 |
| Transmit antenna patterns | FCC 25.209 | FCC 25.209                        |
| EIRP spectral density   | FCC part 25.222 and 25.227 ETSI EN 302 186 | FCC Part 25.138, ETSI EN 303 978 |
| IF input (TX)           | 950–1700 MHz |                                  |
| IF input (RX)           | 950–2150 MHz |                                  |
| Antenna to Modman interface for configuration, control, and monitoring | ARINC A791 AMIP | FCC Part 25.138, ETSI EN 303 978 |
| Antenna to inertial reference unit (IRU) | Supporting ARINC A429 |       |
| Power consumption (antenna only) | 240W (average) |                                      |

**Fig. 6** Dual-band Ku/Ka airborne antenna. (Courtesy Hughes Network Systems and Gilat)
launch schedules may actually change substantially due to new small satellite constellation launches on the plus side or Covid-19 virus impacts on the negative side. According to Researchandmarkets.com, the overall global supply of satellite capacity – including GEO, MEO, and LEO constellations – will grow from 1.3 Tbps in 2017 to almost 10 Tbps by 2022, an eightfold increase in just 5 years.

No visionary could predict these advances, not even Arthur C. Clarke, who in 1945 had postulated that geostationary orbiting platforms could provide all types of services to mankind everywhere, with receiving parabolic antennas of about 1 foot in diameter! Indeed, the communications satellite is a machine that has changed the world for the better – one of the major engineering achievements of the twentieth century.

### 4.1 The Affordability Challenge

In countries and regions where individual subscriptions to satellite service are too expensive for the average resident, hybrid solutions of wireless and satellite technologies are emerging to power community Wi-Fi hotspots and shared VSAT services that make access affordable. The main advantage of these solutions is that
people can use their own devices, usually handheld mobile phones, a category today that accounts for 48% of web page views worldwide (https://www.statista.com/topics/779/mobile-internet/). This simple example of marrying cellular and satellite technologies has helped bring connectivity to numerous “mobile first” markets in Asia and Africa, providing cellular operators a cost-effective path to expand their addressable markets beyond higher density urban areas. It’s estimated that by 2022 nearly 12% of global mobile traffic will be via the emerging 5G wireless technologies (https://www.nsr.com/geo-vs-non-geo-who-wins-the-90-billion-consumer-broadband-opportunity/?utm_source=NSR+Email+List&utm_campaign=509a5de80e-VBSM18.BL1&utm_medium=email&utm_term=0_524993cda3-509a5de80e-259555657), which in ex-urban and rural regions with limited or no terrestrial services will undoubtedly include combined sat/cell hybrid approaches.

At the satellite systems level, the industry has advanced from single CONUS-coverage Ku-band GEO satellites with a few Gigabits of capacity, to multi-spot beam GEO architectures with from tens to 100s of Gigabits of capacity – so-called high-throughput satellites (HTS) – and on the near horizon, numerous constellations of MEOs, LEOs, and the newest category of SmallSats or Microsats. Table 1 summarizes the key variables of GEO/MEO and LEO satellites extracted from Reference (Architectures for Next Generation High-Throughput Satellite Systems 2014), which is an excellent treatise on the subject of satellite architectures.

This architectural evolution has led to new designs for systems, gateways, and a plethora of high-speed user terminals which are beyond the scope of this handbook. The reader may reference any number of manufacturer’s websites to learn about their respective system and service offerings, including advancements such as wideband channels with DVB-S2x modulation, high-density gateways with lights-out operation, web acceleration/caching, advanced compression, and hardware security – which all taken together result in more efficient management of satellite bandwidth and, hence, low OPEX/CAPEX for operators, greater flexibility in creating competitive service plans, and a media-rich customer experience.

4.2 The Internet of Things (IoT) Explosion

On the immediate horizon is the Internet of Things (IoT) and its associated cellular/wireless 5G technology, arguably one of the most exciting and revolutionary technological developments of the Internet age. IoT is a network of cyber-physical devices comprising embedded electronics, sensors/actuators, software, and connectivity, enabling such devices to collect and exchange data over the Internet. These devices interact with physical environments, whether in homes/offices or externally on land, sea, or airborne, and their data collected by sensors are processed intelligently in order to derive useful inferences and enable controlling them. For example, an actuator is a device that is used to effect a change in the environment, such as adjusting the temperature controller of an air conditioner, which could be on an airplane, in cruise ship, or in an apartment.
### Table 1  Satellite system parameters

|                      | LEO | MEO | GEO |
|----------------------|-----|-----|-----|
|                      | Up to 20 deg elevation & Over 400 km wide nadir cell | Up to 20 deg elevation & Over 400 km wide nadir cell | Up to 20 deg elevation & Over 400 km wide nadir cell |
| User elevation β     | β   | β   | β   |
| Beta β RAD           | 0.35| 0.35| 0.35|
| Orbit height H Km   | 840 | 20,200 | 35,786 |
| Earth radius Rₐ Km  | 6378.00 | 6378.00 | 6378.00 |
| Orbit radius Rₒ Km  | 7218.00 | 7218.00 | 26578.00 |
| Path distance d Km   | 1840.93 | 866.52 | 23712.03 |
| SAT centric angle θ | 0.98 | 0.23 | 0.23 |
| Earth centric angle ϕ | 0.24 | 0.30 | 0.99 |
| Total angle Deg      | 90.00 | 0.01 | 0.32 |
| Radius in satellite UV plane rₜₜₜ | 0.14 | 1.08 | 8.14 |
| Number of cells Nₙₙₙ | 1.00 | 1.00 | 1.00 |
| Nadir cell diameter Dₑ Km | 3087.23 | 12682.95 | 13765.04 |
| Coverage area Asat Km² | 7449137.889 | 125653.4071 | 125653.4093 |
| Area normalized to GEO coverage | 0.06 | 0.86 | 1 |
IoT applications are essentially unlimited, spanning industrial processes, logistics, eco-sustainability, energy efficiency, remote assistance, and environmental monitoring, with estimates of as many as 50 billion devices by 2025. As for any networks, performance indicators, such as scalability, reliability, data throughput, latency, and energy consumption are important system design considerations. In particular for IoT – representing networks of networks – the range of metric values is especially wide, given there will be literally billions of devices which can each be served timely with very low data rates, while aggregations can require substantial capacity.

Introduction of 5G wireless links will provide for high data rates with low end-to-end latency, which are particularly important properties for such time – critical applications as autonomous cars and intelligent transportation systems. Coverage of 5G networks will in the foreseeable future be limited to urban and higher density areas, due to cost constraints of terrestrial buildout. This presents the opportunity to marry satellite and 5G terrestrial wireless networks to create a unified framework for seamless IoT coverage as illustrated in Fig. 8.

Such an architecture is rapidly evolving and with the following advantages:

(i) **Global Coverage**: Constellations of GEO (Geo-stationary) satellites employing Ka-band spot beam technology are rapidly covering the globe and already delivering high speed, affordable Internet access to millions of subscribers either unserved or underserved by terrestrial broadband technologies,
whether fiber, DSL, cable, or wireless. Soon to be launched LEO (low-earth-orbiting) satellites such as by OneWeb, Telesat, and Amazon will augment capacity globally in the next few years, and orbiting at approx. 1000 km result in much lower latency than GEO’s at 40,000 km.

(ii) **High Reliability/Availability**: The high reliability of satellites is well proven, with service quality levels typically at or above 99.9% and with in-orbit operational lifetimes of 15 years as the norm, meaning IoT networks can be readily configured as a combination of terrestrial 5G and satellite with either providing primary or backup connectivity or as a hybrid simultaneous cellular-satellite solution.

(iii) **Longevity**: As already noted, satellite network operational lifecycles today are typically 15 years, and since all of these constellations are expected to be backward compatible, technology life cycles of 20+ years in future can be anticipated.

(iv) **Deployment Flexibility**: Besides ubiquity, satellite coverage can be targeted and dimensioned via spot beams much like terrestrial cell sites to deliver a specified capacity to serve a given collection of sensors. Furthermore, low power/low data rate sensors can be easily deployed and operate using solar power options in rural or remote areas. For higher-throughput control or aggregation applications, such as backhauling of cellular traffic, VSAT terminals with up to 1 Gbps can be rapidly deployed at a low cost that’s distance insensitive, unlike terrestrial options requiring middle and last mile physical infrastructure.

(v) **Isolation**: The fifth value proposition comes from a satellite IoT network generally being offered as a proprietary, closed system, enhancing reliability, and offering greater security.

(vi) **Multicasting**: The final benefit is multi-casting. This refers to broadcasting a message to a group or subgroup of subscribers as a single billable event. Multi-casting of a single broadcast to reach multiple units when combined with satellite’s flexible coverage and capacity dimensioned beam sizes yields the most cost-effective network designs, mitigating overall capital, and operating costs (CAPEX and OPEX).

Given the ubiquity and capacity of space-based communications, satellite technology will play a critical role in supporting the development of the IoT sector and realizing the full potential of interconnected devices, having created a broadband superhighway in space – easily handling the potential billions of forecasted IoT devices.

### 5 Conclusion

As the above examples show, incredible progress has been made by the satellite industry in just a few short decades, and yet we find ourselves in a sense “back to the future,” at the dawn of yet a larger and more profound era. And nobody, not even...
Arthur C. Clarke, could have predicted the significant scale of satellite markets growing and expanding as new satellite technology in space and on the ground is deployed. The one certainty is that there will be progress, fueled by the combined creativity and partnerships of people and businesses across the expanding spectrum of technologies – terrestrial and satellite alike – to make these advances happen.

In particular, the following article in “Electronic Beam-Scanning Technology for Small Satellite Communication Systems and Their Future Development” on phased arrays and related market opportunities describes the disruptive potential of these new generation antenna systems that are poised to displace parabolic, mechanically steerable technology as large-scale small satellite constellations become deployed in the 2020s.

6 Cross-References

▶ Economic and Market Trends for Ground Systems to Support New and Future Small Satellite Systems
▶ Electronic Beam-Scanning Technology for Small Satellite Communication Systems and Their Future Development
▶ Ground Systems to Connect Small-Satellite Constellations to Underserved Areas
▶ Small Satellites and Innovations in Terminal and Teleport Design, Deployment, and Operation

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