# 2

# How Satellite Communications Systems Are Changing

## Introduction

The field of satellite communications is highly competitive and rapidly growing. Today, this sector of the global space industry market, including defense and commercial satellite communications, represents annual revenues of nearly $200 billion out of total revenues of over $350 billion [1].

For a half century there has been a predominant pattern of technological development in the satellite communications field. We have been designing, building and launching larger, more massive, higher-gain satellites that can operate with smaller and less expensive ground systems. Today there are literally millions of ground satellite user terminals and antennae. These units that are sometimes as small as hand-held transceivers are accessing and using communications satellites in some 200 countries and territories around the world.

This pattern of development has existed for a half century, but it is now suddenly changing. Indeed there are a number of important new innovations running in several different directions. The final outcome with regard to these various conflicting innovations is far from clear. A recap of the rise of satellite communications and an analysis of the many new directions are addressed in this key chapter, as the reinvention of the satellite communications industry is explored and key trends analyzed.

## The Rise of Conventional Communications Satellites from the 1960s to the 1990s

This is a condensed history of the development of satellites. A more complete history can be found in the author's much larger work, *Handbook of Satellite Applications* (Springer, Second Edition, 2017). We are at a point of diverging into new competitive streams of technology and potentially new global markets. This is a high stakes gamble not only for satellite communications but other NewSpace applications that

J. N. Pelton, *Space 2.0*, Astronautical Engineering,
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depend on supportive financial markets to fuel new innovation and the rise of new space systems.

In the 1960s, two major technical conclusions were reached about how to offer viable satellite communications services. Firstly, the big balloon experimental satellite ECHO, launched in 1960, confirmed that using a passive reflective surface as a satellite to bounce electronic signals off of was much too inefficient to be economically viable for commercial service. Secondly, Syncom 2 and 3 in 1963 confirmed that one could successfully place a satellite in geosynchronous (GEO) orbit and operate from this special type of very high orbit almost a tenth of the way out to the Moon. This unique orbit allowed a fixed Earth station on the ground to not require expensive and rapid tracking mechanisms.

The first satellite launched for commercial satellite communications was Early Bird (or Intelsat I). This was a so-called GEO satellite that was an expanded version of the Syncom satellites built by Hughes Aircraft Company – now morphed into the Boeing Corporation. This small beach ball-sized satellite was able to provide only 240 telephone circuits or one low-quality black and white television channel. As the first commercial communication satellite it was power limited, had a low gain squinted beam antenna, lacked the ability to point precisely back to Earth, and was limited to a single use of the C-band spectrum. These many limitations in satellite power and performance required these giant ground stations to be tremendously expensive multi-million- dollar facilities. In addition, these Earth stations had very large aperture antennas equipped with very high performance low noise amplifiers. They also required an extensive round the clock staff of 40 to 60 people.

In the years that followed the satellites grew in size and capability. They became more complex, more capable, and were equipped with higher power. These increasingly large satellites developed the ability to reuse frequencies not only in the C-band but in other higher frequency bands as well. Over time, commercial satellites moved upward in frequencies to include the Ku-band, the Ka-band and most recently in the Q/V bands as well. These communications satellites were for the most part deployed in the geosynchronous orbit in order to allow ground antenna systems to stay pointed to the satellite above rather than requiring constant tracking of the satellite as it moved over the horizon.

All of these innovations in satellite design that have occurred over a period of decades allowed the satellites to become a thousand times more capable and send thousands of times more telephone circuits, data and television channels. The main gains were:

- Much higher power on board the satellites (e.g., large solar arrays and bigger batteries).
- Larger high-gain aperture antennas on board the satellites that could be constantly pointed toward Earth and also were equipped for precise antenna beam pointing.
- Polarization techniques that allowed reuse of the available spectrum.
- Complex feed systems that allow many beams to be generated from high-gain reflectors. This allowed even more reuse of frequencies and focusing of tightly formed spot beams to limit beam power spreading and thus allow concentrated power to specific locations.

- Access to broader bands of spectrum in available higher frequencies – and much more.

All of this effort concentrated on making the satellites more powerful, having access to more and more RF spectrum, and also adding to the complexity of signals through the encoding of digital communications signals. These digital complexity techniques paid off in the efficiency of information transmission via the available spectra. All of these many gains also meant cost reductions, downsizing and simplification of the ground antennas for users.

Over the decades we saw more and more powerful satellites and more usable spectra both through more intensive frequency reuse and use of more spectrum bands. When these gains were combined there was the equivalent of hundreds of times more radio frequency spectrum that could be used for satellite communications around the globe.

The greatest gain in efficiency of satellite operations came via complex digital encoding that allowed much more information to be sent through the available spectrum. Virtually all of these efficiency gains in satellite operations and design allowed the ground antennas to become smaller and lower in cost and then even fully automated in their operation. There was no longer a need to staff Earth stations. The advent of digital satellite communications brought the greatest efficiency gains through the use of encoding to send more information or data per Hertz of bandwidth. The biggest barrier to satellite communications efficiency gains throughout this period was the lack of cost reductions for satellite launches that remained stubbornly resistant to new cost efficiencies.

These decades-long advances to develop more efficient and cost-effective satellites also enabled the reduced cost and size of ground systems. This trend became known as "technological inversion." This meant more and more complex and powerful satellites in the sky with more access to new radio frequencies and more spectrum via frequency reuse allowed smaller and lower cost ground antenna systems. In short, the satellites were bigger, more powerful and more costly, but this enabled smaller and less costly units on the ground. (See Fig. 2.1a and b to see

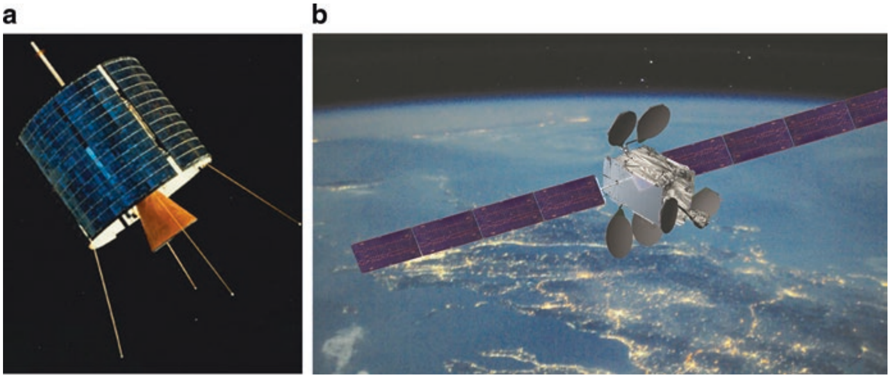

**Fig. 2.1** **a.** Tiny Early Bird (Intelsat 1) and **b.** Gigantic Intelsat Epic satellite in 2018. (Graphics courtesy of Intelsat.)

enormously increased satellite power, antenna gain, and throughput capabilities.)

Ground systems have shrunk in size but enormously increased in numbers from one giant Earth station per country to millions of small satellite ground systems spread over the globe. The satellites grew in cost by ten times and then even a hundred times more in order to build and launch. Yet this allowed dramatic decreases in the cost of the user terminals and the spread of low-cost antennas all around the world. The overall system costs remained in balance between the cost of the space-based systems and the systems on the ground.

These ground systems indeed shrank to very small aperture antennas. Instead of costing millions of dollars, the costs of ground systems shrank to only thousands or then even hundreds of dollars for receive-only television terminals. The ultimate shrinkage has now led to hand-held units used for mobile communications and the very smallest receive-only satellite television dishes that in some cases are as small as cereal bowls. These small dishes are nevertheless capable of receiving multiple television channels from the highest powered direct broadcast satellites. The predominant trend of technology inversion from 1965 through the 1990s is shown in Fig. 2.2.

This trend that allowed the ground stations to shrink from 30-meter-high gain antennas down to VSATs and now even hand-held units is shown in Figs. 2.3a, 2.3b and 2.3c.

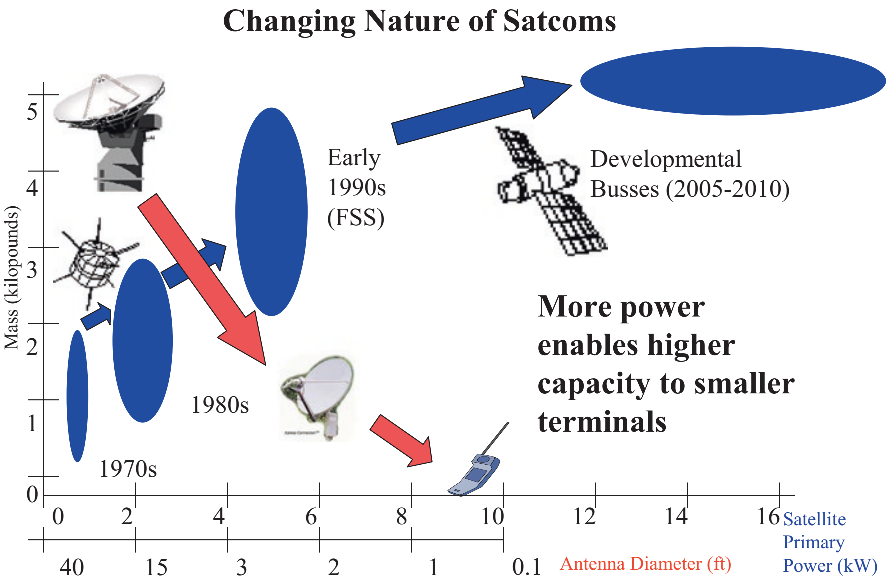

**Fig. 2.2** Early 1960s small satellites in GEO orbit have grown to powerful satellites with large multi-beam antennas allowing ground antennas to shrink in cost and size. (Graphic provided by the author.)

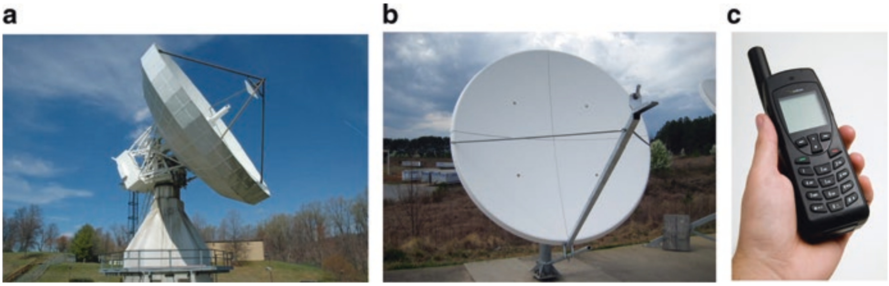

**Fig. 2.3** **a.** A 1960s giant Earth station. (Illustration courtesy of Comara.) **b.** VSAT small terminal from the 1990s (Illustration courtesy of Hughes). **c.** Sat phone of today. (Picture courtesy of Iridium.)

## The Rise of New Space Communications Systems from the 1990s to the Present

In the 1990s, however, several things began to change to allow a new pattern of development for satellite communications. This new pattern perhaps first began when some satellite designers began to question the mainline concepts of putting virtually all of the communications satellites in the geosynchronous (or Clarke) orbit that is 35,850 kilometers (22,230 miles) out in space. As already noted, this is the special orbit where ground stations do not have to actively track what is essentially seen as a satellite hovering above in the sky.

The problem was that this orbit is way out in space, almost a tenth of the way out to the Moon, and this very high altitude orbit comes with penalties. Communications satellite engineers, who were looking for a new approach, explained that while it was useful not to constantly track the satellite, this very long transmission path results in what is called by satellite communications experts “path loss.” Further there is also a time delay or latency that represents a problem for voice and data networking services. The further the satellite transmission has to travel, the greater the delay. Even at the speed of light, there is a quarter-second delay from the ground to the satellite and back down. With the return link for someone talking at the other end, this can mean a half-second delay and is a problem with normal telephone conversation. Even a quarter-second delay is a problem in computer networking.

Engineers noted that if the satellites were 40 times closer, the effective power advantage, due to less path loss or reduced beam spreading was 1,600 times greater. This is because antenna transmission spreads out in the form of a circle (i.e., the area of a circle is $A = \pi r^2$). This meant that the loss in signal strength was equivalent to the square of the distance represented by the satellite orbiting above Earth. They also noted that if you wanted to provide mobile communications to ground systems they would need to be moving in any event to receive the satellite signal. Thus these satellite engineers argued in favor of a network of low Earth orbit satellites. They conceded that because the satellites would be much closer to Earth there would need to be constellations of at least 50 or so to blanket the globe effectively at an altitude as low as perhaps 500 to 800 km (or about 310 to 500 miles) above Earth's surface.

This led to the development of several new satellite communications systems that could provide mobile communications satellite services. These new systems departed from the usual practice of using the predominant geosynchronous orbit. Innovators came up with the idea of using a constellation of satellites in low Earth orbit to provide global mobile services. Those systems that were actually deployed in the late 1990s included the Iridium Satellite System and the Global Star Satellite System.

Another system known as ICO, that was a spin-off of the INMARSAT system for maritime communications, was never deployed but followed Iridium and Globalstar into bankruptcy. These systems were designed for voice land mobile communications and engineered to connect to hand-held units. In addition, there was the OrbComm satellite system, which was designed to provide store and forward data communications or machine-to-machine (M2M0) service. Another system named GEOstar that used different frequencies and only allowed short messaging was also deployed in a low Earth orbit constellation during this time of innovation.

All of these innovative systems, for several reasons, initially failed and the companies went into bankruptcy.

In the case of Globalstar and Iridium, there were several factors. These included the high cost of the voice-based land mobile satellites services. The cost of the satellites, ground systems and user terminals, the regulatory constraints created by national tariffing policies on landing rights and user terminals ultimately ended up being more expensive than had been first estimated. Charges ended up being quite steep, i.e., between a $1 a minute to even $10 a minute. Most significant was the fact that terrestrial cellular services had greatly advanced in coverage and power margins during the time that Globalstar and Iridium systems were being designed, manufactured and launched. And also the satellite hand-held units were large in comparison to the cell-phones that were being manufactured some seven or eight years later.

The satellite phones were sometimes called "bricks." Perhaps the important fact was that these LEO mobile satellite systems did not have enough power margin, so that they typically did not operate within houses or buildings, and even in cars they did not operate with a sufficient degree of reliability. These factors all contributed to a lack of significant growth of the market for the satellite phone service. The millions of users that market analysts had projected did not develop. The customer base was instead in the thousands. The result was a series of consequent bankruptcies for Iridium, Globalstar and ICO.

Likewise there was also a lack of market penetration by the store-and-forward data services using M2M messaging. Thus these other satellite systems also failed. Orbcomm went to the bankruptcy court as a financial loss and Geostar did not survive as a service provider. Eventually the Globalstar, Iridium, and Orbcomm systems were reorganized and under new management and ownership did re-emerge and are now still providing service through second-generation spacecraft, but the initial damage to in terms of market support had been done. The markets were skeptical of new satellite communication constellations in low Earth orbit.

There was in the late 1990s yet another proposed system to be deployed in low Earth orbit that was described as a mega-LEO system. This was a satellite system proposed to provide a broadband Internet in the sky. It envisioned the provision of broadband services for fixed satellite services that would have been in competition with organizations such as Intelsat, Eutelsat and other such service providers. In this case the proposal was for launching nearly 1,000 satellites plus spares in a giant LEO constellation. This system design was highly innovative and was envisioned as being able to provide high data rate services using Ka-band (30 GHz/20GHz) spectrum. The concept was to design, manufacture and launch these satellites on a mass-produced and highly efficient basis. The plan was to benefit from economies of scale in production and qualification testing, unlike the limited production levels that had generally been used for GEO orbital satellite networks in the past. This system, known as Teledesic, had the additional feature of being backed by entrepreneur Bill Gates. This planned system went into bankruptcy before any of its 980-plus spare satellites were deployed. But then a decade passed.

Over time, Iridium, Globalstar and Orbcomm all came back out of bankruptcy and thus the feasibility of the use of low Earth orbit constellations did begin to be taken seriously again in financial and business markets. Further groups, such as the Surrey Space Centre Ltd., was producing small satellites, known as "Surrey sats." at quite low costs. Others such as Skybox and Planet Labs were producing small sats using off the shelf materials and deploying new systems at very low cost for remote sensing. (This is a subject that will be addressed in the next chapter.)

On top of everything, additive manufacturing or 3D printing was starting to show how key components of satellites could be manufactured at very low costs. Collectively all of these factors combined to produce new interest in the idea of how low Earth orbit constellations might be designed to create new satellite systems to provide telecommunications and networking services to underserved parts of the world.

However, it was during this period beginning around 2010 that many different innovations sprang up at once and created new synergies.

## Space 2.0 Comes to Satellite Communications

The world of satellite communications since 2010 has been turned upside down and some would say almost reinvented. Satellite engineers have now designed, built and launched high throughput satellites (HTS) that are able to operate at truly prodigious speeds for space systems. Throughput speeds of 140 gigabits per second have been achieved with Viasat 1 and 2, with Intelsat Epic satellites and Hughes Network Systems Jupiter satellites not far behind. These high throughput satellites (HTS) have ten to fifty times higher throughput rates than conventional satellites of only a few years ago and have continued the conventional trend lines of finding more ways to reuse RF spectrum, adding more power and exploiting the capabilities provided by the latest in digital encoding technology. These satellites with their greater power can link to even lower cost ground stations.

Other satellite designers, however, are moving in the direction of small sat constellations flying in low Earth orbit that would deploy a very large number of satellites.

These new ventures are finding ways to design and build small satellites for large-scale constellations that can be built on assembly lines at high speeds and use additive manufacturing to build key components at lower cost and with higher reliability and exactness. They are not as small as cube satellites, because antenna diameters have to be larger to achieve needed gain, and there is also a need for higher power. Yet these small satellites with a mass typically ranging from 200 to 400 kilograms (440 to 880 lbs.) are ten to fifty times smaller than giant high throughput satellites (HTS) that Viasat, Intelsat, Inmarsat, SES or Echostar/Hughes Network Systems are now placing into service. There are of course many more satellites in these constellations than in GEO-based systems, but it is much easier to launch smaller satellites, especially to low Earth orbit.

In mass production these small satellites are much lower in cost than their big brothers, even after taking their relative mass into account. Perhaps their biggest advantage in terms of performance is due to the fact that they are much closer to Earth. This gives the advantage of much lower path loss and perhaps even more importantly up to 40 times less latency to support more effectively either voice or networking services.

This new approach of deploying satellites in non-geosynchronous orbits started with the O3b system (standing for Other Three Billion people in the underserved world). The O3b network deployed 12 satellites in medium Earth orbit (MEO) initially and then added 6 more, and in the latest filings dozens more are planned for launch. Gregg Wyler, the entrepreneur who started O3b, has been focused on finding new ways to provide communications and networking services to the developing world for a couple of decades and has moved on to an even more ambitious venture. He has now sold out his interest in O3b to SES of Luxembourg, and has moved on to acquire a new group of partners and raised the capital to launch the very ambitious OneWeb satellite constellation in low Earth orbit (LEO).

This system is currently just starting to be launched, and in the next few years through 2020 or 2021 will deploy about 800 satellites, including spares to provide networking services in new ways throughout the developing world. Thus OneWeb is particularly designed to provide coverage and Internet-optimized services in areas such as Africa, Asia, the Middle East, South and Central America and the Caribbean plus the South Pacific islands. But all is not smooth sailing; the cost per satellites for the OneWeb system have increased, and the overall system has not been financed. Further the cost of flat-panel ground systems that can electronically track the fast-moving LEO satellites are currently around $30,000 apiece from suppliers such as Kymeta. In short the cost of the satellites and ground antennas for LEO constellation systems for communications and networking services are higher than were first estimated. Further it is not clear that the manufacturers of the new flat-panel antennas could possibly meet the huge expected demand.

According to the last figures presented by Northern Sky Research there are now 25,000 constellation satellites filed for launch. There are thus several quite serious challenges here that could be a show stopper for many of these constellations. These problems are thus: (a) cost of manufacture of many of these commercial small satellites might be higher than first estimated; (b) the cost of flat-panel antennas capable of tracking LEO satellites may stay higher than is needed to support service in rural areas; (c) the supply of tracking ground systems may be greatly inadequate to meet the huge demand that will be needed to provide the connectivity for actual users; and (d) there may be inadequate launch capability for all of these satellites at least on the schedule that the many new small satellite system operators would hope to achieve. The good news is that many new LEO satellite constellations will be deployed and provide important new services. The bad news is that for the above four reasons a number of the filed systems will fail. And that is not all the problems to be solved. New regulations to control the proliferation of satellites, minimize radio frequency interference, cope with orbital space debris or limit pollution and particulates in the stratosphere could create new regulatory hurdles as well. What is clear is that the next ten years will be a time of great turbulence [2].

Table 2.1 provides a listing of the many of the filings that have been announced and registered with regulatory authorities. One can see from this chart the many diverse plans for proposed new entrants seeking to build and launch what are typically designed as

**Table 2.1** Listing of some of the proposed small sat constellations for communications. (Listings were prepared by the author.)

| State | Constellation | # of Sats | Radio Frequency Bands |
|---|---|---|---|
| **Canada** | **CANPOL-2** | **72** | **LEO and highly elliptical Earth orbit in VHF-, UHF-, X-, and Ka-bands** |
| **Canada** | **Telesat Constellation** | **117 satellites plus spares** | **LEO in Ka-band** |
| **Canada** | **COMSTELLATION** | **Nearly 800 Satellites** | **LEO in Ka-band** |
| **France** | **Thales Group's MCSat** | **between 800 and 4000** | **LEO, MEO, and highly elliptical Earth orbit in Ku- and Ka-bands** |
| **Liechtenstein** | **3ECOM- 1** | **264** | **Ku- and Ka-bands** |
| **Norway** | **ASK-1** | **10** | **Highly elliptical Earth orbit in X-, Ku-, and Ka-bands** |
| **U.K.** | **L5 (OneWeb)** | **750 plus spares** | **Ku- and Ka-bands** |
| **U. S.** | **Boeing** | **1396-2956** | **V-band in 1200 km orbit** |
| **U. S.** | **SpaceX** | **Up to 4000** | **Ku & Ka band** |
| **U. S.** | **SpaceX** | **7500 plus** | **V-band** |
| **U. S.** | **Leosat** | **About 80** | **Ka-band** |

small sat constellations to be deployed in low Earth orbit. These proposed systems, however, must be viewed with some skepticism, based on past history.

Back in the 1990s there were 17 filings to launch a number of new Ka-band satellite systems. These were all submitted to the U. S. Federal Communications Commission. Of those filings, which most notably started with the Teledesic system filing, only the Ka-band satellite system, originally known as Wild Blue, was ultimately fully deployed as filed. And this was a GEO orbit system and not a new-type LEO constellation.

Key to these newest small sat constellation projects going forward are two additional factors that extend beyond the idea of achieving low-cost mass production and new quality assurance testing of high volume production spacecraft. One important factor is that of much lower cost launch systems, including reusable launchers, and the other is a key new and almost revolutionary development in Earth station technology. Currently SpaceX and Blue Origin are leading in the development of new reusable launchers that promise to lower launch costs significantly. It appears that Stratolaunch, which is backed by Paul Allen and his Vulcan Inc, will likely soon provide yet another option to provide new lower cost launch options. For small sat launches, Launcher One by Virgin Galactic (Sir Richard Branson's company) and Vector One are yet other companies that are bringing new lower cost launch services to the market.

These various efforts to reinvent the satellite launching industry will be addressed in a later chapter. It is only important to note here the significant fact that if launch costs could be cut in half – or more – then these systems become much more affordable to place in service and resupply if there is a satellite failure.

Perhaps the biggest impetus for LEO constellations, however, comes from the new type of satellite Earth stations that use electronic beams that form as a result e of meta-materials in their design. This allows the design and manufacture of flat antenna systems that can electronically track a low Earth orbit satellite as to moves over the horizon in about 7 or 8 minutes of time.

This electronic tracking via a reasonably low cost Earth station is truly a game changer. It allows the ground segment part of these satellite constellations to become affordable and tracking systems to be more reliable. The Kymeta Earth station company that is now producing these new type ground systems represents a key part of this new revolution in the satellite communications business. Again the interesting angle is that Bill Gates, the co-founder of Microsoft, is a key investor in Kymeta [3]. Another company, known as Phasor Solutions, is also now coming to market with new satellite antennas that have electronic beam tracking systems that will seek to compete with Kymeta [4].

And the various listings of small sat constellations provided in Table 2.1 are far from a complete compilation. The number of additional filings for new small sat constellations or supplemental additions to systems already filed simply keeps growing. Below is a listing of additional filings received by the U. S. FCC for additional systems, including additions to the O3b MEO satellite constellation and a new MEO constellation by Viasat.

- Audacy: 3 MEO relays to communicate with LEO spacecraft. (SATLOA2016111500117)

- Karousel: 12 IGSO satellites for video (SATLOA2016111500113)
- Kepler MULTUS: 2-140 LEO nanosats-M2M communication (SATLOI 2016111500114)
- O3b: Amendment to add another 40 satellites (SATAMD2016111500116)
- SpaceX: With its huge number of satellites has its own thread (SATLOA2016111500118) http://forum.nasaspaceflight.com/index.php?topic=41634.0
- Space Norway: 2 satellites in high-inclination 16-hour orbit (SATLOI 2016111500111)
- Boeing: 60 IGSO (This is separate from small sat system they previously filed) (SATLOA2016111500109)
- Theia: 112 for remote sensing (SATLOA2016111500121)
- Viasat: 24 in polar MEO (SATLOI 2016111500120)

As noted above the combined tally of communications and remote-sensing constellations now filed from countries around the world is around 25,000.

## The Promise, the Opportunities, and the Pitfalls

The satellite communications industry today is clearly at a crossroads. It seems likely that there will be a number of clear-cut winners and losers that will emerge over the next five years. The new high throughput satellites are five times or more cost efficient than many of the conventional satellites currently in operation. This is true for systems that provide either fixed satellite services (FSS) or broadcast satellite services (BSS).

The bottom line is that many satellite systems now in operation will potentially be priced out of existing markets. These higher throughput satellites put enormous economic pressure on the less cost-efficient satellites now in orbit and especially those which have not been fully amortized. Another danger is that some satellite systems have been loaded up with heavy debt and are subject to financial pressures to perform in a very highly competitive market.

There are even more questions about the extent to which high throughput satellites in GEO orbit will be in serious competition with many of the planned large-scale LEO constellations. Some argue that the new LEO constellations are largely seeking new markets in currently underserved areas. Thus they are targeted to provide Internet connection in areas where there are currently no telecommunications, data or Internet links in service. At one point Intelsat, the world's largest fixed satellite service provider, was going to become a major investor in the new OneWeb constellation in a deal that was to be financed by Softbank. The basis of the deal was that this merger with OneWeb would feed new businesses into Intelsat and the two systems were largely not in competition. This particular business arrangement that would have led to a $14 billion merger fell through, and thus this proposition was never tested [5].

What is clear is that of the various LEO constellations currently filed, only the LeoSat filing to launch some 80 highly capable satellites has advertised its offering as geared to business enterprise networks as opposed to those largely leveraged to provide new types of networking services to underserved portions of the world. The LeoSat website thus explains its alternative approach to its constellation's proposed services thusly:

> The LeoSat system is being developed in conjunction with Thales Alenia Space, a company with unmatched expertise in designing and manufacturing low Earth orbit constellations. The high-throughput satellites (HTS) will form a mesh network interconnected through laser links, creating an optical backbone in space which is about 1.5 times faster than terrestrial fiber backbones, thus creating a paradigm shift in the use of satellites for data connectivity – rather than a gap filler or last resort where no terrestrial alternative is available [6].

What does seem clear is that the very large number of constellations that have now been proposed seem to require a huge amount of new capital investment for what many market analysts see as largely virgin territory for totally new services. Thus most of the various small sat constellation filings are to put up satellites without an existing market or established revenue stream. Past experience, as shown by Teledesic and the original Iridium, Globalstar, ICO and Orbcomm systems, clearly raises some red flags. There are serious concerns as to whether all of the proposed systems can become financially viable. This seems to be a clear case of technology push driving most of these new satellite filings as opposed to any established or clear-cut market pull for all of these new communications satellite and networking constellations.

Even more to the point it should be noted that the structure of satellite communications revenues are strongly geared toward the direct provision of consumer services in the form of retail sales of direct broadcast entertainment services. The other parts of the industry revenue streams are much more modest. As can be seen in Table 2.2 there are revenues north of $100 billion for consumer services, and fixed and mobile satellite services bring total annual revenues to around $130 billion. In contrast, revenues from satellite manufacturing ($13.9B), launch services ($5.5B), and Earth station sales related to communications satellite services (around $40) totaled around $60 billion in 2016 [7]. These revenue figures do not include figures related to defense communications satellite networks.

What is not clear about all of the new low Earth orbit satellite

**Table 2.2** Communications satellite services over a five-year period [7]. (Source is Information Satellite Industry Association, State of the Industry Report, 2017.)

| **Analysis of revenue streams for commercial communications satellite services** | | | | | |
|---|---|---|---|---|---|
| **Year** | **2012** | **2013** | **2014** | **2015** | **2016** |
| **Consumer services** | **$93.3** | **$98.1B** | **$100.9B** | **$104.2B** | **$104.7B** |
| Satellite TV | $88.4B | $92.6B | $95.0B | $97.8B | $97.7B |
| Sat Radio | $3.4B | $3.8B | $4.2B | $4.6B | $5.0B |
| Sat Broadband | $1.5B | $1.7B | $1.8B | $1.9B | $2.0B |
| **Fixed** | **$16.4B** | **$16.4B** | **$17.1B** | **$17.9B** | **$17.3B** |
| Transponders | $11.8B | $11.8B | $12.3B | $12.4B | $11.2B |
| Managed Service | $4.6B | $4.6B | $4.8B | $5.5B | $6.2B |
| **Mobile** | **$2.4B** | **$2.6B** | **$3.3B** | **$3.4B** | **$3.6B** |
| **TOTALS** | **$113.5B** | **$118.6B** | **$122.9B** | **$127.4B** | **$127.7B** |

communications is how they will operate on a country to country basis, especially when they seek to sell services to end-users and whether local telecommunications service providers will insist on a share of the revenues. It was this critical factor that created the problem for Iridium and Globalstar in obtaining landing licenses in countries around the world. The requirement to operate through local telecommunications providers greatly inflated the costs of these satellite service providers when they sought to operate on a retail basis as opposed to a wholesale basis, which is most common for fixed satellite service providers who typically sell transponders or managed satellite services to local telecommunications providers.

## Regulatory Oversight Concerns

And there are more than just market concerns related to all of these new LeoSat constellations. There are also serious concerns related to space traffic management and orbital space debris issues that are also worthy of serious policy analysis. Many now feel that new regulatory action is needed at the national and/or international level.

There are definitely increased policy concerns that come with the prospect of perhaps tens of thousands of new satellites being launched into low Earth orbit. How will these satellites be de-orbited at the end of life? What are the implications if a defunct satellite, like the defunct Russian satellite that crashed into the Iridium satellite in 2009, should recur? In such a case would it set off a cascade of collisions within these new satellite constellations? If all of the proposed satellites were actually launched this would increase the number of satellites in orbit by more than a factor of ten. All of the proposed systems have identified methods to control their own network and to de-orbit satellites and to avoid interference to the protected class of GEO communications satellites, but there is no defense against defunct, out of control satellites already in space and particularly concentrated in the polar regions where Sun-synchronous meteorological satellites are launched and where many defunct satellites now orbit.

Fig. 2.4 provides a graph that shows by type the growth of tracked satellites and orbital debris of significant size and the corresponding increases over time. This graph shows the two significant impulse increases in debris that occurred when the Chinese shot down one of their own defunct weather satellites in 2007 and then again in 2009 when a defunct Soviet weather satellite collided with a functioning Iridium satellite.

The current projection is that even without additional launches another collision that creates major new debris will occur on average every five to ten years. The European Space Agency using a computer-based simulation model has concluded that a collision will likely occur every five years, while NASA models project collisions somewhat less frequently. At the time these ESA estimates were first presented at an orbital debris conference in Frankfort, Germany, by Dr. Klinkrad, at the time Head of ESA's orbit space debris unit. He said: "The only way to keep this from happening is to go up there and remove them. The longer you wait, the more difficult and far more expensive it is going to be." [8].

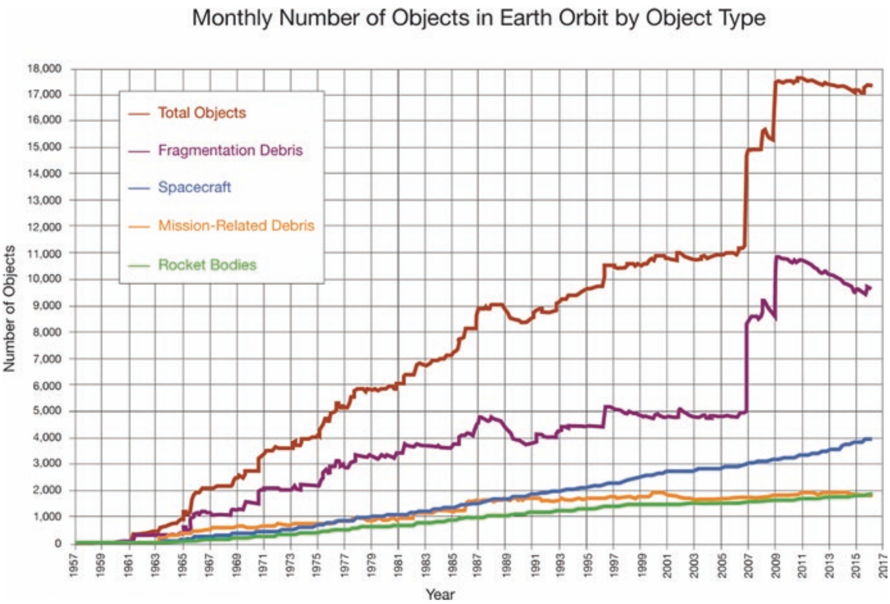

**Fig. 2.4** Objects larger than 10 cm in diameter being tracked in Earth orbit. (Chart courtesy of NASA.)

Orbital space debris and space traffic management are issues that the U. N. Committee on the Peaceful Uses of Outer Space, and especially its Working Group on the Long Term Sustainability of Outer Space Activities (LTSOSA) are addressing. The book *Global Space Governance: An International Study,* by this author, was published in 2017. It includes the result of a truly international study that was conducted between 2014 and 2017 on a number of key space issues and recommended actions focused on these issues and possible actions that might be taken. Chapters 13 and 14 particularly addressed the topics of space traffic management, including not only for Earth orbit but also for near space (called the protozone), orbital space debris and on-orbit services as well as active debris removal [9].

This study recommended that the U. N. Committee on the Peaceful Uses of Outer Space (COPUOS), and the U. N. International Civil Aviation Organization (ICAO) seek to devise a framework where international guidelines for implementing space traffic management for both Earth orbit and the protozone might be undertaken. Such consultative processes need to be undertaken, in cooperation with their member states and interested bodies and organizations such as the InterAgency Space Debris Committee (IADC), Secure World Foundation, the International Association for the Advancement of Space Safety (IAASS) and the International Telecommunication Union (ITU). The key missing step in this process is the lack of clear-cut international agreement as to how to proceed. Perhaps there needs to be a new international treaty, an amendment to the Chicago Convention of 1944 or some other agreement, perhaps reached within the U. N. General Assembly on the recommendation of COPUOS [10].

What is clear is the need to create a new globally agreed framework whereby space-faring nations might agree to cooperative arrangements for space traffic management (both for Earth orbit and for the protozone) and for active space debris removal to be undertaken. This might also require new interpretations of the provisions of the Liability Convention and other international agreements as to who (i.e., nation states, private commercial organizations under licensing by nation states, or designated international entities) might undertake these activities.

The plans to increase operational satellites from the current 1,500 or so spacecraft to as many as 15,000 and the ever-increasing risk of orbital collision as well as many new possible activities in the protozone region, makes action in this area of even greater importance. Ever expanding interest in the protozone also creates concerns as well. These national and commercial interests include operation of spaceplanes taking suborbital flights, positive hypersonic transportation flights, high altitude platforms for communications, networking and remote sensing, high altitude launch of rocket launchers and spaceplanes, robotic transport flights above commercial airspace, and possible dark sky research platforms with electronic propulsion flights to orbit.

It would be most unfortunate if international agreement and positive proactive action is not taken soon within the international space community and well before a catastrophic accident or runaway space debris cascades as predicted by the so-called Kessler syndrome becomes a reality.

## Conclusions

There is no area of space applications that is currently more dynamic, more churning with technological innovation, or larger in market size than that of satellite communications. Change is everywhere, but the outcome in both market direction and technological success is far from clear. There are innovations in Earth station design and new technologies and systems being rapidly developed to support large-scale constellations. There are new capabilities to launch telecommunications and networking satellites into orbit at lower cost. The advent of reusable rocket launchers is of particular note. There is great innovation that comes from additive manufacturing, 3D printing, large-scale manufacture and automated quality testing that is allowing the building of satellites, Earth stations and launchers faster, at lower cost, and hopefully with greater reliability.

What is clear is that there are new entries into all aspects of the space industry. Many of these new initiatives cluster around the space sector with the greatest revenues, potential profits, and perhaps greatest growth potential. Time will tell if the projected new markets to bring network connectivity to the underserved developing countries will pay off as many are anticipating.

The next five years will show whether the established satellite providers will adapt successfully and well to this new environment or whether the many new entrants will emerge as the new stars in the dynamic world of satellite communications applications.

## References

1. The space report. The Space Foundation. https://www.thespacereport.org/ (2017). Accessed June 2018
2. Northern Sky Research market briefing on new satellite constellation. 7th Annual Space and Satellite Consortium, ReedSmith, Washington, D.C., 18 October 2018
3. Kymeta electronically steered antennas. https://www.kymetacorp.com/. Accessed 25 August 2018
4. Henry, C.: Phasor sets 2018 release for electronically steered antennas. Space News. https://spacenews.com/phasor-sets-2018-release-for-electronically-steered-antenna/ (4 Aug 2017)
5. DiNapoli, J., Baker, L.B.: Exclusive: SoftBank to let OneWeb-Intelsat merger collapse. Reurters. https://www.reuters.com/article/us-intelsat-m-a-oneweb-exclusive-idUSKBN18S3LP (31 May 2017)
6. LeoSat: a new type of satellite constellation. http://leosat.com/technology/ (Accessed 9 June 2018)
7. Satellite Industry Association: State of the industry report for 2017. Bryce Space and Technology. https://www.sia.org/wp-content/uploads/2017/07/SIA-SSIR-2017.pdf (June 2017)
8. ESA: Time to clear space junk from Earth's orbit, Reuters. https://www.voanews.com/a/european-space-agency-esa-space-junk-removal-earth-orbit-gps/1648848.html (25 April 2013)
9. Jakhu, R., Pelton, J.N.: Global Space Governance: An International Study. Springer, Basel (2017). Chapters 13 and 14
10. Convention on International Civil Aviation, 7 December 1944, 15 UNTS 295, Can TS 1944 No. 36 ICAO DOC 7300/9 (Chicago Convention)