Distributed Internet-Optimized Services via Satellite Constellations

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Abstract

One of the most significant recent developments in satellite communications has been the sudden resurgence of large-scale constellation satellite programs to provide broadband services. This has occurred some 20 years after the several unsuccessful attempts to deploy such huge constellations like Teledesic in the USA and Skybridge in Europe. These were never deployed for several reasons

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that included financing and the bursting of the Internet bubble at the end of last millennium.

Of course, other telecommunication constellation programs have been deployed since that time (Globalstar 1st and 2nd generation and the Iridium and soon Iridium Next for instance). These systems, however, were designed to address narrower band services in low band frequencies (L and S-band) for mobile telephony and low-medium rate data.

These new types of constellations that are currently either recently operational or under design and development are intended to mainly provide broadband Internet-optimized services with the ability to offer low latency performances compared to geostationary satellite alternatives. These new systems, and in particular the O3b and OneWeb networks, both headquartered in the tax haven Jersey Island, UK, as well as the Leosat initiative, from a Delaware registered company, have been described as "disruptive," "game-changing," and "innovative" in their architecture (P. de Selding, "Never Mind the Unconnected Masses: Leosats Broadband Constellation is Strictly Business", Space News, Nov. 20, http://spacenews.com/nevermind-the-unconnected-masses-leosats-broadband-constellation-is-strictly-business/, 2015).

One remarkable aspect is that each one represents very different and specific approaches to addressing broadband applications by satellite. Some are in Low Earth Orbits (LEO) at about 1000–1500 km altitude while O3b is flying much higher in Medium Earth Orbits (MEO) at about 8000 km altitude. O3b is an equatorial MEO system of 12 full-sized satellites. Others are intended to represent a network of some 100 satellites of 700–1300 kg mass while yet others are requiring several hundred spacecraft of 175–200 kg mass. Some are envisioned to provide "local" services connecting a gateway with users in visibility of a sole spacecraft scale (Proposed Leo Sat Constellation, Space News, March, 2015 http://spacenews.com/proposed-leosat-constellation-aimed-at-top-3000/Last. Accessed 9 Dec 2015).

Other systems are designed with a more interconnected architecture for connecting users to a gateway or another user that can be located far away in an another continent thanks to inter-satellite links.

However, each concept in its own way is raising a number of regulatory and technical challenges.

This trend to deploy new broadband constellations for fixed and mobile satellite services started with the deployment of the medium earth orbit O3b constellation in 2013 and 2014, and now OneWeb has selected in mid-2015 Airbus Defence and Space as a joint venture partner to invest and manufacture some 900 small satellites (i.e., operational plus spares) to be deployed starting in 2018. There may be other companies that follow suit to deploy similar so-called mega-constellation systems, but currently OneWeb is the only such LEO constellation system under a development contract to manufacture and launch such a large-scale network. Another possible system has started design and engineering phases such as Arlington, Virginia-based LeoSat (although officially headquartered in Delaware). This system is exploring an 80 satellite that might be expanded to about a 110 satellite constellation. This project involves Thales Alenia Space. Then there is the announced effort whereby Singapore Space Intelligent IoTS Pte. Ltd. (SSII) is partnering with German satellite maker OHB System to develop the world's first Asia-based low Earth orbit Internet constellation (Singapore Space Intelligent IoTS Pte. Ltd. http://www.ssii.sg/Last. Accessed 8 Mar 2016).

Finally, there have been reports of a Space-X backed system that might deploy as many as 4000 satellites in a massive mega-LEO system.

These systems are, however, not yet contracted to manufacturing and thus are not addressed here in details. The Space X system would presumably like OneWeb involve quite a huge number of small satellites and be aimed at underserved developing countries' markets among other more mature markets. The LeoSat system in contrast would involve much larger and capable satellites with more than 2 kW of power and would be aimed at meeting the special needs of the largest corporations in the world (Propose LeoSat).

The implications of such large-scale constellations of small satellite are manifold. These new type satellite networks would seem to revolutionizing the cost of manufacturing and launching spacecraft, concerns about radio frequency allotments and protection from interference, orbital debris build-up and removal, collision avoidance, management of liability concerns, and more. What is clear is that the deployment of those satellite constellations in low earth orbits will provide a satellite network that is quite different in many ways when compared to GEO satellites. The LEO satellites would typically be some 30 times closer to the Earth's surface than GEO satellites with about 60 times less transmission delay for a round trip. Clearly such a network can accommodate latency-sensitive applications in Internet data transmissions (i.e., TCP/IP protocols) with greater efficiency and support voice conversation services with greater facility. On the other hand, their closer vicinity with the earth's surface restricts their coverage reach, and this requires many more satellites for a continuous earth coverage.

This new trend to deploy satellite constellations for broadband satellite services is occurring in close parallel with the development and deployment of very high throughput satellites (VHTS) in geostationary orbit that provide much greater capacities at lower costs. Clearly these parallel and potential "disruptive" trends to deploy even more capacitive HTS and low earth orbit constellations could serve to drive down costs and make available new digital services to consumers around the world at much lesser costs. We can even expect in a midterm the integration of both complementary solutions, the very high capacitive geostationary HTS systems providing a much higher data rate per user together with mega-constellation services offering low latency data flow and a world coverage including the poles. The involvement of well-known international satellite operators of geostationary fleet such as Intelsat that is involved in the OneWeb project or SES in the O3B is probably a revealing clue.

This chapter describes the various systems that have been implemented or now in production to be deployed in the coming years – especially O3b and OneWeb. This chapter provides some of the basic technical and operational characteristics of these new systems. It also addresses the various types of new services that are being offered or planned by these types of networks.

It was thought in the 1990s, a mega-LEO satellite system for broadband fixed satellite services similar to OneWeb might deployed. This network, which was named Teledesic and financially backed by Bill Gates, Greg McCaw, and venture capitalist Ed Tuck, was proposed along with about 15 other Ka-band satellite networks. The Teledesic system and the other proposed Ka-band systems were never deployed – except for the Wild Blue Geo satellite network (renamed the Ka-band satellite system) and which was delayed over a decade in its actual launch and deployment. Today, some 20 years later, the viability of such large-scale lower earth orbit satellite systems now seem to be economically feasible again.

Thus, the first generation of O3b has been designed, manufactured, and successfully deployed, and rapid progress is being made to design, manufacture, and launch OneWeb in a not so distant future. The advent of 3D printing, advanced manufacturing techniques taking benefits of more automated processes for large-scale production and testing, more extensive use of commercial off-the-shelf (COTS) components, and new commercial systems to launch small satellites at low cost have combined in a positive fashion to greatly reduce the cost of building and launching such satellites.

New satellite networks, born out of Silicon Valley, such as the Skybox constellation for remote sensing, now acquired by Google, have served to unveil a whole new pattern of commercial satellite business. "Disruptive" technologies and new satellite system architectures are thus the hot trend of the day driven by so-called New Space commercial ventures.

Keywords

Airbus Defence and Space • Disruptive technologies • Google • High throughput satellites (HTS) • Hughes Network Systems • Ka-band satellites • Ku-band satellites • Leosat • Liberty Media • Mega-LEO Constellations • O3B constellation • OneWeb • Qualcomm • SES Global • Silicon Valley • SpaceX • Thales Alenia Space • Via Satellite Virgin Galactic's Launcher One • Greg Wyler

Introduction

The field of commercial satellite communications has evolved in a continuous but sometimes "jerky" manner since its start in 1965 for a half century. The past 5 years has been one of those "jerky" periods, where there have been a number of disruptive technologies introduced. This is, in part, in response to expanded global networking needs and the greatly expanded capabilities of broadband fiber optic cable systems that can operate at terabit/s speeds and very little transmission delay. These changes are currently having a significant and explosive impact on the communications satellite industry and network design. These new technical capabilities and new market needs have helped create new patterns of competitive technologies and given rise to new competitive systems and new players on the global scene.

First of all perhaps the biggest change is that there are now high throughput satellites in GEO orbit that have 10–25 times the capacity of previous satellites, thanks to multibeams frequency reuse technologies and solutions, and are sharply competitive with more “conventional” satellite networks. These new networks are having a huge impact on the cost of service, a shift from transponder pricing to channel pricing, and competitive markets on a global scale. The race for more capacity seems to be accelerating since the beginning of 2016 with a new generation of Terabit satellites announced for a start of operation in 2020 and new concepts such as satellite optical rings being seriously considered. In close conjunction with the new more cost-competitive networks, there is new and increasing demand for broadband data services worldwide (even at high attitudes and over the pole) for mobile services to support commercial aircraft and new northern maritime routes, some of them being particularly sensitive to transmission delays associated with satellites in GEO orbit. In addition, there are also new techniques associated with the design, manufacture, acceptance testing, and low-cost launching of small satellites that have and will create new economic efficiencies with regard to the deployment of larger scale constellations of satellites in medium or low earth orbit.

Finally, there are new designs under development for ground systems. These new “smart” ground antennas will be able to track using electronically-formed beams rather than mechanically formed beams. This is expected to lead to relatively low cost and efficient tracking of LEO/MEO satellites. Those efficient and low cost terminals are key enablers for the good overall economic figures of these evolving mega-LEO constellations businesses. All of these factors have come together to create new opportunities – as well as challenges – for medium and low earth orbit constellations that are designed to meet previously unserved networking needs. Some of these systems are particularly optimized to meet market demands related to the developing countries of the world and their unmet needs. These new constellations as now designed and engineered can meet the needs of many developed economies as well. This chapter addresses the evolution of these new constellations for telecommunications and networking purposes and provides an overview of the space segment and ground segment system design, the markets to be served, and the issues that these new systems engender.

The first system of this kind is the O3b medium earth orbit that was deployed in 2013 and 2014. The OneWeb constellation, now under contract for manufacture and launch, that is planned for low earth orbit is the second. This constellation is planned to contain nearly 800–900 small satellites plus many spares and is scheduled for deployment in 2017 and 2018. This LEO-based system represents an even more ambitious initiative in terms of a large-scale constellation. This project and its technical design in many ways recalls the Teledesic or Skybridge satellite networks that was envisioned in the 1990s but ultimately both went bankrupt. Other aerospace entities have indicated less specific plans to build and deploy such large-scale constellations, perhaps on an even larger scale.

These new type constellations could give rise to new opportunities and lower costs for broadband data services around the world, but they give rise to concerns with regard to frequency interference to GEO satellites, a possible significant increase in orbital debris in the event of a collision in the orbital regions where these satellites are to be deployed or after satellite end of service period in their postmission disposal orbits, and the extent to which deployment of such large scale systems could preclude other countries or entrepreneur from being able to launch similar systems in the future.

This chapter provides information about the precursor satellite systems that have set the stage for the 03b and OneWeb networks and others that may follow. It then describes the two systems that have been or will be deployed and the markets they intend to serve. It then concludes with a consideration of the various technical, regulatory, market, frequency coordination, and orbital debris related issues that these new satellite constellations could give rise to and the various processes now underway to address such concerns.

History and Background to Medium and Low Earth Constellations for Communications

In the 1990s, a team of engineers were exploring new satellite architectures that might allow the successful deployment of satellite systems using the previously unutilized Ka-band frequencies. These designers were seeking a satellite system design that was optimized to provide Internet-based broadband services and also overcome the problem that rain attenuation posed, in particular, at that time for these very high frequencies (since, dedicated mechanisms has been elaborated within the waveform to manage the coding and the data rate during attenuation events).

This new type satellite network that was first called the Calling Satellite System and then renamed Teledesic represented a radical departure from the geosynchronous – or Clarke orbit – satellite networks that had dominated satellite communications architecture up to that time. The new system would deploy a massive amount of satellites in low earth orbit. The total network plus spares would have involved the launching of some 920 satellites (i.e., 840 plus 80 spares). The key elements of the design involved several new ideas: (i) the satellites would be designed and qualified so that they could be manufactured and quality tested like VCRs on a largely automated production line so that their unit cost would be much less than a typical satellite; (ii) the Teledesic satellites, by being deployed some 30 times closer to the ground than a GEO satellite (that orbited at 35,870 Km from the Earth's surface), would thus have 60 times less latency roundtrip (and thus better conversation continuity and data quality); and (iii) further, as a special bonus for the Ka-band satellites, there would also result in 900 times (i.e., proportional to $1/30^2$) less transmission power loss or what engineers called free-space path loss (Pelton 2013, Satellite Communications).

(The reason why that advantage would be "30 squared" was because the spreading out of transmitted power from the circular-shaped parabolic antenna required a calculation of the area of the expanding circle of the transmission. This is based on the formula $1/\pi r^2$.)

The Ka-band satellites because of their high frequencies are more sensitive to signal attenuations when there is heavy rain. Possible use of even higher frequencies in the Q/V spectrum bands in the future will represent an even greater challenge. The frequencies that are involved are of a wavelength similar to a drop of rain, which means the rain can, in effect, “bend” the path of the transmission. Such tiny radio wavelength is much more sensitive to rain attenuation and other forms of precipitation than the C-band or Ku-band. The heavy precipitation serves to distort the signal and make it harder to receive and thus power loss (or path loss) compounds the problem. This major power advantage obtained by having the satellites in low earth orbit, plus relative high masking angles (i.e., high elevation look angles to the satellites) were seen as key to this type of Ka-band satellite constellation being able to function during a rain or snow storm. This historical background is provided, because the envisioned OneWeb satellite network, although planned for the Ku-band, intends to utilize a technical design similar to that of the Teledesic system.

There was of course a down side to their innovative design – either for OneWeb or Teledesic. First the various beams on the satellite would have to be acquired, tracked, and handed off among many different beams as the satellite traveled overhead. This would be very hard to do because with so many satellites in the constellation, each with several beams, there would be very frequent handovers to successfully achieve continuity of service. These handovers would, for instance, be measured in seconds rather than minutes. Second, the design of the satellite and it’s especially designed antenna system would “paint” a coverage on the ground as the satellite moved over head. This meant that the satellite antenna design and computer processing capabilities would need to be more complex so that the ground antennas could be simpler. This, of course, adds complexity and possibly costs to the satellites. Third, there would be yet another driver of complexity in the satellite design which is needed to avoid interference with GEO satellites when the lower orbiting satellites were transmitting in the orbital arc. In the case of OneWeb, the satellite earth pointing axis moves as needed to steer away transmissions that would illuminate and interfere with GEO satellites.

The added cost of the rapidly tracking and steerable antennas on the satellite, the design elements to avoid interference with GEO satellites, the added cost of building and launching quite so many satellites, and the difficulty of switching quickly between and among many beams certainly were a tall order for the technology of the 1990s. The bottom line was that these economic and technical issues proved fatal to the Teledesic system and the system was never placed under contract and built.

Although this Teledesic system was formally filed and licensed by the FCC in the USA and then filings made with the International Telecommunication Union (ITU), the cost of the system when put out to bid was judged to be too high (estimated about 9 billion USD at that time). The project was ultimately canceled despite quite a few millions of dollars having been spent on this very ambitious satellite program. Despite the fact that more than a dozen other Ka-band satellite systems were filed with the FCC in the USA in the 1990s, none of these systems – whether LEO constellations or GEO orbit satellites – were built and deployed until years later. Only about 15 years later were Ka-band GEO satellites such as "Wild Blue," renamed the "Ka-band Satellite," actually deployed and operated by Viasat together with the Viasat-1 satellite to offer a continuous CONUS broadband coverage.

Today, there are a number of GEO-HTS based Ka-band satellites operating – most notably ViaSat 1 and Echostar/Jupiter-1 over North America, Ka-Sat from Eutelsat and Hylas-2 from Avanti over Europe, Yahsat 1B from Yahsat and Badr-7 from Arabsat over Middle East, the Thaicom IPstar over Asia, and the three Inmarsat 5 satellites for a worldwide coverage. Others systems are to be deployed or entering operation soon with Viasat-2 (2017 launch), the Intelsat EPIC (29e and 33e later in 2016), and Echostar Jupiter-2 (later in 2016) over North America. The need for Ka-band satellites with its broader spectrum range and the saturation of the lower C-bands and growing congestion in the Ku-bands has made the transition to Ka-band more and more desirable as far as retro-compatibility with legacy system is not a must for telecommunications companies, TelCo. But all of the Ka-band systems to date have been GEO satellite networks. None had been deployed in the low earth orbits as constellations to be used for the end-user broadband connection to satellite.

Today, only the O3b satellite constellation using Ka-band frequencies for fixed satellite services (FSS) has been deployed in a lower orbit (and this deployment is in medium earth orbit within the equatorial plan.) The mega-LEO OneWeb constellation that is planned for deployment in 2017 and 2018 has opted to use Ku-band frequencies for its satellite links but Ka-band spectrum for gateway links. This choice was driven by regulatory reasons (frequency filing in Ku-band for users). This has become a key enabler to implement such a system. The technical and economic challenges posed by the Teledesic design still have to be faced in the design and deployment of the O3b. This is even more so for the case of the OneWeb systems. Both of these systems were envisioned and championed by a man named Greg Wyler, who would set to bring new broadband capabilities to the developing world. His role in the creation of these systems will be discussed below.

And if O3b and OneWeb prove successful, then other lower earth orbit systems may well seek to follow even though frequency coordination issues and concerns about orbital debris may serve to lock additional systems. The high throughput LeoSat Constellation, with an initial network of nearly 80 satellites that can be increased based on demand, has indicated its intention to try to deploy its network as early as 2019 or 2020. It is seeking in its design to use powerful and capacitive intersatellite links to securely connect very distant users with very high data rates and will also see to utilize the benefits of new types of flat panel ground antennas currently under development that can generate beams electronically and thus address and track rapidly the various moving satellites in a more efficient and hopefully more cost-effective way.

The largest Leo constellation that has been actively considered by SpaceX has been conceived as having as many as 4000 satellites. The future of these types of constellations is both largely unknown and highly dependent on a wide range of quite different design considerations. These various known or pending constellation designs differ in terms of satellite size and power, constellation orbital configurations, satellite operating lifetime, nature of intersatellite links, launch arrangements, satellite antenna and ground antenna design, and technical arrangements to avoid interference with GEO satellites. One of the largest unknowns is the extent to which these communication satellite constellations can still avoid in-orbit collisions that would greatly increase the orbital debris problem and also successfully deorbit their satellites in a controlled manner at the end of life.

The First Communications Satellite Networks Were for Mobile Services

Design concepts for low and medium earth orbit constellations were conceived for the design of mobile satellite systems in the 1900s that were deployed or planned for deployment in the late 1990s and early 2000s. The Iridium Satellite System and the Globalstar Satellite System were designed as low earth orbit constellations. The ICO satellite system, which was a spin-off of INMARSAT, in contrast, was first envisioned a MEO constellation. Over time, when Iridium, Globalstar, and ICO declared bankruptcy, ICO was re-envisioned as a GEO satellite system design. The Iridium system of 66 satellites plus spares was deployed beginning in 1996–1997 and the Globalstar system was deployed very shortly after. The bottom line was that all three ventures – namely Iridium, Globalstar, and ICO all collapsed financially and went through bankruptcy proceedings. In the case of these three satellite networks, the main issue seemed to be a lack of market demand, but the technical performance and the high service price of the system perhaps partially contributed to the market failure. Certainly, the Iridium and Globalstar networks demonstrated that the overall control and network management of the satellites was difficult. During the first months of operation of the Iridium system so-called cockpit errors in terms of wrong commands to the constellation were a problem with just over 70 satellites in the network. This type of problem certainly raises questions about the difficulty of "cockpit management" of a network of over 800 operational satellites and spares of satellites in two grids.

The various mobile satellite communications systems, regardless of orbit, used much lower radio frequency bands (i.e., around 1.6/1.5 GHz rather than 30/20 GHz) and provided only narrow data/voice channels rather than broadband. In these mobile satellite systems design, it was recognized that the mobile user would have to have tracking or omnidirectional antennas in any event since the customer would be moving and not be at a fixed location. Iridium and Globalstar also envisioned using networks with far fewer satellites (i.e., 50–70 satellite plus spares rather than 840 satellites plus spares envisioned for the Teledesic system). The backers of the Iridium, Globalstar, and ICO systems also thought that many millions of people would pay a premium for this premium service. The customer base ultimately turned out to be quite small. This was due to the fact that during the time the Iridium and Globalstar satellite networks were being designed, manufactured, and launched, the terrestrial mobile cellular systems had been built out and upgraded in their performance throughout the 1990s and early 2000s. The ultimate result was that all three mobile satellite systems, namely Iridium, Globalstar, and ICO were forced to declare bankruptcy because the market that they had hoped to serve had been captured by terrestrial cellular systems that were now much more pervasive in urban areas and had been upgraded so they had a thousand to ten thousand times more power so that inside calling and calling within cars was now possible. The bankruptcies of Teledesic, Iridium, Globalstar, and ICO convinced the financial markets that LEO and MEO constellations were risky propositions. Meanwhile, the GEO satellite networks that were succeeding were seen as much better business investments.

But over time, new technology, manufacturing techniques, and innovations in launch services have helped to change perspectives. What failed 20 years ago is now being seen with new eyes today. The fact that the new systems have lower latency and are seen as better suited for Internet services and optimized for unserved or underserved developing economies has opened the door to new investment – especially by digitally oriented companies in Silicon Valley such as Google. As noted earlier, one of the key people that have restored interest in communications satellite constellations is a man named Greg Wyler. He is today considered the father of both the O3b (Other three billion people) satellite system and OneWeb. The history of how these two systems came to be is useful and instructive.

Wyler initially engaged in an effort to upgrade the rural communications of Rwanda to meet modern telecommunications needs. Every concept that he explored using terrestrial technology failed to come close to providing a viable business plan that could one day even break even. Slowly he came to realize that only a satellite network that provided integrated coverage to the entire equatorial region of the planet where three billion people lived that were ill-served communications networks that could provide Internet connections. Wyler grasped that it was only satellites that could provide the connectivity and the modern information and communication technology (ICT) for Africa, South America, the Caribbean, the Middle East, and Asia in any reasonable time period and that could possibly be economically viable.

It was from this realization that the idea for the O3b satellite network was born. Wyler was a dynamo that used his financial investment "smarts" to convince a range of technology and communications companies to invest in O3b. He was able to convince Google, Liberty Global, SES of Luxembourg, Satya Capital, North Bridge Venture Partners, Sofina, and Allen & Company, plus HBSC bank to invest as well as to retain HSBC also to arrange debt financing to fund his ambitious project. Altogether a total of $1.2 billion in financing was put together in a remarkably short period of time in order to build and launch a medium earth orbit constellation that would circle Earth's equatorial orbit. Wyler formed the O3b company in 2008 and the satellites in the initial constellation went up in 2013–2014.

Teledesic, Iridium, Globalstar, and ICO projects all essentially began as the result of "technology push" provided by service providers, equipment suppliers, and investment backers. All of these systems failed financially. The market that was envisioned unfortunately never materialized.

O3b, in contrast, started from a market of "wannabe Internet users" that were seeking to be served in Africa, the Middle East, Asia, the Caribbean, and South

America. The question is still pending as to the extent to which OneWeb, in contrast to O3b, is indeed a response to market demand, or technology push, or perhaps a useful combination of both. What is clear is that the investors in OneWeb are indeed dominated by suppliers of the satellite system, ground equipment, and launch services.

What is known is that Wyler, after getting O3b underway, embarked on an even more ambitious project and for this project he developed essentially a whole new group of investors. After spending only a short stay at Google that was a major funder of O3b, he left and spun off his WorldVu company that began the even more ambitious OneWeb constellation. Many perceived this as moving from being a Google-sponsored project with O3b to become an Elon Musk and SpaceX sponsored enterprise.

By his concerted efforts Wyler has been able to raise most of the capital for the 12 satellite O3b network that costed about $1.2 billion. He has now raised $500 million from among his suppliers for the building and launching the OneWeb network of 648 satellites.

Wyler has been most adept in finding investors that would also be his equipment suppliers, his launch operators, as well as to find backing from the world's largest satellite service provider in Intelsat. In these arrangements, AirBus became the manufacturer of the satellites, SpaceX, Virgin Galactic's Launcher One, and Arianespace/Soyuz became the provider of launch services, while Echostar/Hughes Network Systems became the supplier of the innovative new ground systems for the OneWeb network. The danger that could arise in such an arrangement is that as the project shifts from one designed to meet market demand to one in which the suppliers push the products forward, the problems that manifested itself with Iridium and its bankruptcy could happen again. Intelsat's investment of a modest $25 million seems clearly an attempt to learn what the new market demand really is and whether this system is truly viable (de Selding 2015, One Web's Partners).

This project has moved ahead with remarkable speed from idea to firm contracts. It may represent a remarkable case of where the Arthur C. Clarke laws of prediction and his three stages of evolution of a project have been compressed in a remarkably short span of just a few years. Clarke's three stages of a project are whimsically set forth as:

> "**Stage 1**: It's impossible; **Stage 2**: It's possible but it's not worth doing; **Stage 3**: I said it was a good idea all along." (Pelton 2015, The Oracle. . .)

To date it seems O3b to have established itself as a new satellite system that has evolved at a time when market need for low latency data-oriented satellite networks and new technological and manufacturing capabilities have coincided in a positive way. The past history represented by Teledesic, Skybridge, Iridium, Globalstar, ICO, and even Orbcomm may have helped to overcome technological, economic, and market pitfalls that earlier networks have encountered. The future of new systems such as OneWeb, and others that may follow, clearly face stiff technical, economic, market, and other challenges. These challenges are numerous and include: orbital debris avoidance and removal, avoidance of interference with GEO satellite networks that enjoy protected status, coping with potential liability claims, avoidance of interference from terrestrial and high altitude platform system (HAPS) networks. In addition there is the business challenge of matching capital costs and operating expenses to revenue flows. The market demand and the technical, regulatory, and economic challenges remain to be clearly understood. Even so the current backers of the OneWeb system have an impressive array of technical competence and financial resources to address these challenges.

The Development of the O3b Satellite Network

The basic idea that the O3b network represents was proposed by Brazil's space agency (INPE) almost two decades ago. At this time, they proposed what was known as "the string of pearls" concept for an equatorial constellation of six to eight satellites in the equatorial band that would serve all nations near the equator. O3b began as an eight satellite equatorial constellation but has now been upgraded to a more intensive 12 satellites constellation. The O3b network can be further upgraded to an 18 satellite network in the future as demand might warrant. This upgradability based on market demand is one of the O3b constellation positive features – both from a business and a market-responsiveness perspective. As noted above, the Ka-band based Teledesic satellite constellation plus the design and operation of the Iridium and Globalstar constellations have also provided useful information with regard to the design and operation of the O3b satellite constellation as well as the OneWeb network.

One of the key design features of the O3b satellite is the many steerable antennas on each spacecraft. This allows the steerable antennas on-board each satellite to be continuously steered so that parabolic dish antennas on the ground can be continuously illuminated. This design feature is key to keeping the ground systems simple and lower in cost. The satellite's steerable beams can also be used to minimize interference to GEO satellites. To date, interference issues involving O3b satellite and GEO communications satellites have been avoided. The prime manufacturer of the satellites for O3b is Thales Alenia Space. The future concern, however, could be a failure in the steering mechanism for the antennas that could in time create a problem. In the future, the antenna beams might be electronically generated and steered by computer software, but again even electronically formed beams could malfunction (Fig. 1).

With the 12 satellite configuration, the O3b system actually covers a good deal of human populated Earth. The entire area from 45° North to 45° South can be effectively covered by this unconventional network. This means that the many billions of people that reside in this area including a very high percentage of those countries with developing economies are reachable via the O3b constellation. Many developed economies such as the USA, Japan, South Korea, and Australia are also within the coverage area as clearly shown in Fig. 2.

Fig. 1 The O3b satellite in systems test in the Thales Alenia production plant (Graphic courtesy of Thales Alenia)

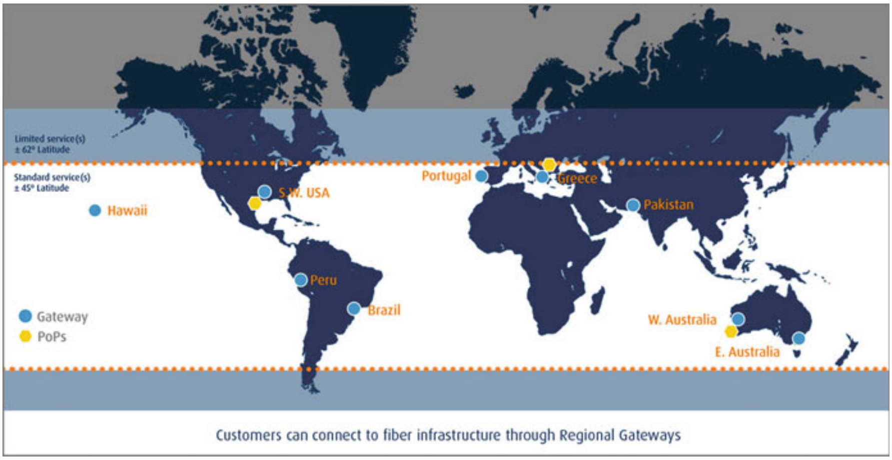

Fig. 2 The coverage of the O3b networks satellite constellation (Graphic courtesy of O3b)

The fact that all of the satellites are precisely maintained in an orbit that is 8,062 km (i.e., 5000 miles) in altitude means that the transmission path even to the extremes of the coverage area is on the order of only 12,000 km (7500 miles). This is still three times less than the minimum transmission path of a GEO satellite and perhaps five times less than the maximum transmission path for a GEO satellite connecting to high latitude regions (O3b Networks Frequently Asked Questions).

The key to the success of the O3b network is in many ways dependent on its ground segment. If the ground network is efficient in allowing a significant level of throughput, then the system can support a significant amount of traffic to be supported by the satellite network. If the ground system is composed of all small, lower traffic volume earth stations, then the total system throughput is significantly reduced. The key design element of O3b is that the space segment can be increased and network throughput enhanced as demand for service grows. This type of constellation design that allows network growth as traffic volume grows is one of its attractive features that distinguishes it from OneWeb that requires a very large network which 648 satellites deployed in 20 planes to be deployed to activate the system.

The basic technical characteristics of the O3b Ka-band network are provided as follow below: (The O3b Non Geostationary Orbit).

- Non-geosynchronous orbit (NGSO), fixed satellite service (FSS), Ka-band satellite network
- Initial constellation of eight medium-earth orbit (MEO) satellites increased to 12 MEO satellites
- Complete constellation will be at least 18–20 satellites
- Spacecraft provided by Thales Alenia Space
- Orbital height = 8,062 km; Equatorial inclination: 0°
- Ground period = 360 min/Number of contacts = 4 per day
- 30° spacing with 12 satellites
- Initial Ka-band frequencies (TT&C and Data Gateways)
- Downlink: 17.8 GHz – 18.6 GHz and 18.8 GHz – 19.3 GHz
- Uplink: 27.6 GHz – 28.4 GHz and 28.6 GHz – 29.1 GHz
- Global coverage
- Optimal coverage between 45° N/S latitudes
- Ten beams per region (seven regions) with 105 remote beams with 12
- Satellite constellation
- ~1 Gbps per beam (600 Mbps × 2); 126 Gbps available per 12 satellite constellation
- Beam coverage: Beam diameter to 600 Km
- Transponder bandwidth: 216 MHz; 2 × 216 MHz Fwd/Return Pair

The network is thus envisioned as providing high speed gateway access but also providing an air interface capability for wireless services. Today O3b is providing services to a wide mix of customers such as remote oil and mining operations, cellular operators in Samoa, etc. The potential of O3b to meet unmet needs in developing economies has been widely praised.

Dr. Hamadoun Touré, Secretary-General of the International Telecommunication Union (ITU), the UN agency for Information and Communications Technologies (ICTs) has said back in 2013:

> I am delighted to welcome an innovative newcomer to the ICT market, especially one whose strategy offers the potential to extend connectivity to broadband networks to millions more people worldwide. O3b's plan adds an exciting new piece to the puzzle through a low-cost solution that could help quickly bridge the emerging broadband divide separating rich and poor nations. The company's plan to have services available by 2013 means this solution could also play a significant role in harnessing ICTs to help meet the UN Millennium Development Goals by the target date of 2015. (O3b Network raises)

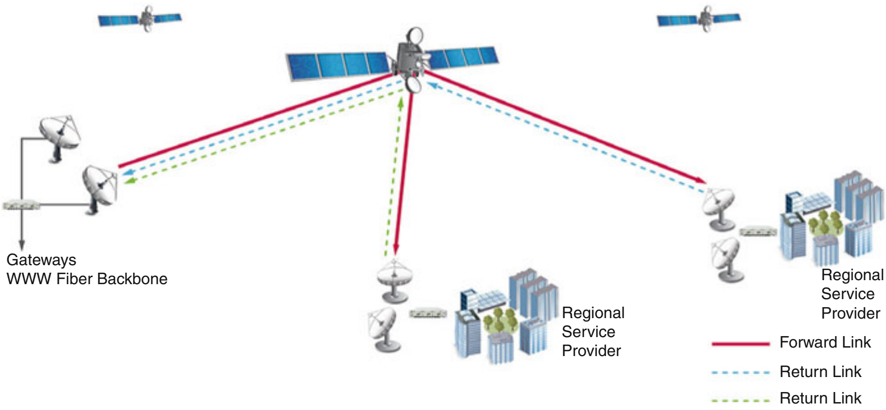

Fig. 3 Schematic showing MEOLINk ground antennas that can support data links up to 810 Mbps (Graphic courtesy of Qualcomm)

The Viasat-developed modems and encoding systems for the O3b system are highly efficient and the gateway stations that interconnect with fiber backbone are able to support data links at speeds up to 810 megabits/s. The network design is optimized for asymmetrical traffic so that thin-streams of traffic can be supported in the return link while very broadband services are supported for such throughput requirements as fiber interconnections (Fig. 3).

The OneWeb Network System

The OneWeb network has had evolved in its design in terms of its likely orbital configuration and number of satellites. At the current time, the network will involve some 648 satellites deployed in 20 different orbital planes some 18° apart and in a 1200 km (750 mile) orbit that will service the entire populated world. The design envisions a network that can provide very high speeds through gateways as well as air-interface standards that can support thin route services to villages and homes (Fig. 4) (OneWeb Taps Airbus To Build 900 Internet Smallsats 2015).

Qualcomm Research, the R&D division of Qualcomm Technologies, is designing many of the technology innovations required for the OneWeb network. The announced objective is to develop a new, high-performance wireless air interface for end-to-end satellite communications including system design of a new approach for wireless coding, modulation, and protocols. The specific objective is to allow OneWeb's architecture to provide layer 2 and layer 3 services that can be used by any ISP or telecommunication provider to extend any network using IP protocols. The plan is to develop and provide low-cost small cell terminals and a core network that is fully3GPP compatible with the 3rd Generation Partnership Project (3GPP) standards that seven standards organizations have joined together to develop. This in

Fig. 4 The mega-LEO constellation known as OneWeb

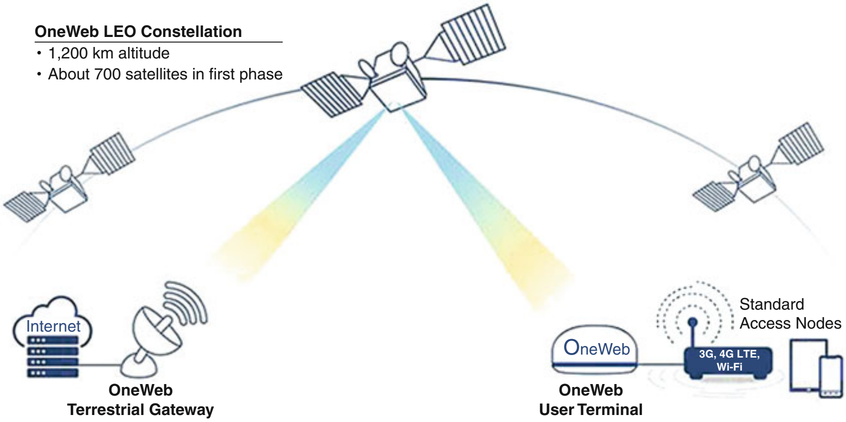

Fig. 5 Qualcomm engineering concepts for OneWeb broadband gateways and smaller user terminals (Graphics courtesy of Qualcomm)

theory will allow OneWeb to work together with providers in any regulatory environment, anywhere in the world.

To deliver reliable connectivity, the wireless air interface will enable intrasatellite, intersatellite, and intergateway handoffs. It will also be designed with advanced interference avoidance techniques to adhere to spectrum requirements. To help ensure the OneWeb system will be ready for commercialization, Qualcomm Research is also developing a modem hardware and software reference design for the OneWeb User Terminals – the terrestrial access nodes to enable connectivity to the satellite network (Connecting the Unconnected) (Fig. 5).

Table 1 Technical design aspects of the OneWeb satellites

Major design elements for the OneWeb satellites	
Orbital configuration	Initial configuration is 648 satellites deployed in 20 orbital planes at an altitude of 1200 km (750 miles). Note this is a change from earlier concepts of satellites at lower altitudes in two types of circular orbits at two different altitudes around 800 km
Satellite mass	Between 175 and 200 Kg
Satellite antenna characteristics	Phased array antenna measuring 36 by 16 cm (14.2 by 6.3 in)
Frequency band	Ku-band
Capacity of each small satellite	Theoretical throughput of 6 gigabits/s per satellite. Internet service speeds to ground antennas at 50 megabits/s
Approach to avoid interference to GEO sats	Patented “progressive pitch” system in which the satellites as they cross orbital arc are slightly turned to avoid interference with Ku-band satellites in geostationary orbit and then return to after crossing orbital arc
Construction schedule	The objective is to produce three satellites per day when into full production mode
Debris mitigation system	Details to be identified, but will meet minimum requirement of removal from Earth orbit within 25 years of end of life

The final design of the OneWeb Satellites are still in development and may during design reviews be modified to some extent. Nevertheless, the key technical specifications are largely now fairly clearly identified as shown in Table 1.

François Auque, Head of Space Systems at Airbus Defence and Space, at the first public announcement of the award stated that: “Teaming with OneWeb with a requirement to produce several small satellites each day has inspired us to develop innovative designs and processes that will dramatically lower the cost in large volumes for high performance space applications. . .. . .Without doubt, this program is challenging but we’re ready for it because we have leveraged resources and expertise across the entire Airbus Group.” Airbus officials have claimed that they will adapt manufacturing techniques developed in the manufacture of the A380 aircraft to the rapid production of the nearly thousand satellites they will produce for OneWeb (France’s President).

New LEO Constellations on the Horizon

To date the O3b satellite has been deployed in a 12 satellite MEO constellation and the OneWeb constellation is being manufactured at AirBus facilities and launch arrangements are in place. The Leosat constellation, in an initial constellation of 78 satellites, is likely to be the next LEO constellation to be deployed perhaps as early as 2019 or 2020. This network is different in that it would entail the launch of much larger and capable satellites with high capacity intersatellite links in order to support higher throughput requirements for large corporations and to support back-haul requirements for 4G LTE broadband cellular networks (LeoSat Constellation).

The Leosat constellation is also unique in its plan to use flat panel, metamaterial ground antennas that are able to track satellites as they transit in low earth orbit, rather than requiring satellite antennas that track ground stations mechanically. In the particular case of the Leosat constellation, there appears to be a close relationship between the Leosat constellation and the Kymeta Corporation that is one of the leaders in the new flat panel ground antennas that provide electronic (and computer controlled) beam formation and tracking. Kymeta is also working with Intelsat.

Kymeta's innovative antennas use metamaterials technology to electronically and dynamically adjust the antenna beam towards transiting satellites and does so with no moving parts. The technology enables flatter, smaller, and less expensive antennas compared to traditional parabolic dish satellite antenna technologies. Kymeta has already begun large-scale production of its antenna products for a variety of applications for terrestrial and space communications applications (CNBC Names Kymeta).

Finally, there is the least defined project of all. This is the SpaceX constellation that is being considered by Elon Musk that would possibly contain as many as 4000 quite small satellites that would, as in the case of OneWeb, be manufactured rapidly in a production line at a small cost well below $1 million per unit. While OneWeb and the SpaceX constellations would involve small satellites and optimized for Internet-related traffic for developing countries, the Leosat constellation is presumably envisioned for the top 3000 corporations in the world. The common element among the OneWeb, Leosat, and SpaceX constellations would be the difficulty of launching and managing such large satellite networks and avoid the problem of satellite collisions and to minimize the difficulty of problem of orbital debris build-up issues at the stage of launch, network management, or deorbit at end of life.

Issues Posed by New FSS Satellite Constellations

The advent of fixed satellite service (FSS) systems that are non-geosynchronous orbit (NGSO) systems creates a number of issues. By far, the greatest number of communication satellite networks are indeed concentrated in GSO, but one MEO network like O3b adds 12 satellites to Earth orbit and OneWeb mega-LEO will add, just in the initial configuration, something like 700 satellites. The disproportionate number of satellites added by mega-LEO triggers a number of key issues.

Frequency Allocation and Number of Large-Scale Constellations that Can Be Deployed

Satellites networks registered and coordinated through International Telecommunication Union (ITU) procedures have a protected status against other systems. There is also an agreed model of acceptable interference between GEO systems and NGSO that was agreed at the last ITU World Radio Conferences. Once a network has met these agreed interference criteria, then it too becomes protected. The problem is that each new system that is planned to be deployed that it has greater and greater difficulties of being successfully coordinated. Thus once the O3b systems and the OneWeb systems are coordinated, and if other systems such as the LeoSat NGSO and the Space X NGSO systems also go forward, it may be practically impossible for other systems such as those that might be envisioned by European, Chinese, or other countries to be deployed and achieved successful coordination as well.

Frequency Interference

There is concern that the ITU procedures agreed at the International Telecommunication Union (ITU) World Radio Conference (WRC) 23 January–17 February 2012 that established model levels of "acceptable" interference between LEO constellations and GEO satellite networks may in time be increased so that meeting ITU standards may become much more difficult. Even with the existing levels set for interference will make it increasingly difficult for additional systems that may be filed with the ITU and launched in the future. In short, there are two major problems that new LEO constellations represent with regard to GEO networks and even to additional MEO and/or LEO networks. These are the problems of frequency interference between various satellite systems, and, as more LEO constellations are added, the problem of actual physical collision.

Orbital Debris Concerns

At the current time, the largest practical concern is that of orbital debris increase. Since the 1960s there has been a steady build-up of orbital debris. On January 22, 2007, the Chinese missile destruction of the defunct Fen yun (YC-1C) weather satellite created an impulse jump of well over 2000 new trackable debris elements. The collision of the Iridium 33 and Cosmos 2251 satellites on February 22, 2009 created well over 2000 new debris elements. The NASA scientist Donald Kessler who warned of orbital debris and the possible growing cascade effect of debris that might ultimately grow out of control has warned that even with the amount of debris that is currently in orbit – without adding thousands of new satellites – will likely result in a significant new collision once every 10 years. The addition of the nearly 1000 satellites represented by OneWeb constellation, the 100 + satellites of the Leosat Constellation, the potential 4000 satellites of the SpaceX constellation present significant challenges to the future management of the ever growing space debris problem.

And this concern with regard to space debris does not include the Iridium current and generation NEXT constellation, the Globalstar network, plus the remote sensing networks of Skybox (Google), Northstar (Norstar Space Data) as well as US Defense mobile satellite network, LEO meteorological satellites, etc. There are currently some 22,000 + orbital objects more than 10 cm in diameter being actively tracked. When the new S-band radar “space fence” ultimately comes on line around 2018, it is estimated that over 250,000 objects will be trackable and only a small percentage will represent active satellites with active deorbit capabilities. If there is one problem to highlight with these new systems that is of greatest concern then orbital space debris is clearly the number one issue.

Liability Provisions

There is an associated concern that relates to all of the above issues and this is who pays for liability claims if there is a future situation where physical or financial damage is engendered as a result of a satellite or satellite constellation creates a low to others either in space or on the ground. Although increasingly it is private companies that own and operate satellite networks or entire constellations, it is not they that are liable. The liability is that of space insurance companies or ultimately of the “launching state” as explicitly identified in the Outer Space Treaty and the so-called Liability Convention. If SpaceX, a US company, for instance, launches a LEO constellation of 4000 satellites and this deployment somehow triggers a run-away cascade of space debris with many space objects crashing into one another and creating a deadly shield of space debris encircling Earth and traveling at over 10,000 km/h, the USA could presumably be liable for trillions of dollars in damages. Vital networks such as for weather forecasting, communications, remote sensing, and navigation, positioning, and time, etc., could ultimately be lost since replacement satellites could not be safely launched.

For many years, the liability claims related to space have been minimal and issues have largely involved concerns related to the use of isotope fuels. Today it appears that a whole new era of concerns have arrived.

Conclusion

The concept of deploying constellations of satellites in low earth orbit or medium earth orbit is not a new idea. Even Arthur C. Clarke anticipated the use of low earth orbit satellite systems. The advantages that such LEO or MEO constellations can bring include low transmission latency (which is particularly useful for Internet-related services) and much less path loss for the RF signals transmitted to and from the satellite. New spacecraft and ground antenna technology and improved processing and coding techniques today make the commercial and operational feasibility of such systems much higher. There are still a number of challenges for these new systems and concerns about such issues as orbital debris. The success of the O3b system is a hopeful sign that broadband services can indeed be efficiently provided from non-geostationary satellite systems (NSGOs). The experience achieved with the various new systems discussed in this chapter will provide a much clearer pathway to the future of communications satellite services and the types of spacecraft that will be deployed in the decades ahead. These new systems will also greatly affect the design of ground systems as well.

Cross-References

► Broadband High-Throughput Satellites
► Satellite Orbits for Communications Satellites
► Trends and Future of Satellite Communications

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