Overview of Commercial Small Satellite Systems in the "New Space" Age

Timothy J. Logue and Joseph N. Pelton

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Abstract

"New Space" or "Space 2.0" initiatives are changing the space industry and not in modest or one-dimensional ways. We are today experiencing change in profound ways that permeate the entire space enterprise. Thus smallsats and "New Space-related" changes now impact almost every aspect of the space industry.

T. J. Logue (✉)
Thales Alenia Space, Arlington, VA, USA

Arthur C. Clarke Foundation Board, Washington, DC, USA

Pacific Telecommunications Council Board, Honolulu, Hawaii, USA
e-mail: logue.tim@gmail.com

J. N. Pelton
Executive Board, International Association for the Advancement of Space Safety, Arlington, VA, USA

International Space University (ISU), Strasbourg, France
e-mail: joepelton@verizon.net

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These should not be seen as mere disparate or unrelated parts, but as key pieces of a whole revolution in the space industry. There are many changes that are occurring in the world of commercial space, which taken together should be seen as enabling forces. These “parts” are coalescing together to allow significant changes to occur throughout every dimension of the space industry.

In short, all of these various “disruptive” changes are a part of an overall gestalt. It is driven by what might be called a new way of thinking and analysis born of a way of thinking associated with Silicon Valley – namely, an approach that questions old ways of doing things. It asks not how can things be improved but how can new ways of thinking make significant changes that revolutionize how things are done. There is a constant search for major strides that are sweeping – rather than baby steps.

Out of “New Space” thinking has come new technologies, new market entrants, new launcher systems, new ways of financing space ventures, new satellite architectures, efficient new small satellite designs, new types of ground antenna systems with electronic tracking, and market shifts toward networked services. Over-the-Top (OTT) data streaming of entertainment and gaming services and demand for networking access in rural and remote areas of the world are just a few examples. These forces of change and new ways of thinking are converging together to create an integrated nexus of change in the space industry that has produced among other things the great spurt of activity related to commercial small satellite constellations and an effort to bring broadband digital services to the entire world.

Many of the companies in the global aerospace world that have built satellites, launch vehicles, ground antenna systems, provided satellite services, and insured and financed space enterprises for many years have been caught off guard by the swiftness of the change and are now struggling to find their footing in the swirling eddies of transforming markets, spacecraft, ground system, and launcher technologies, and even the regulatory framework that controls these industries.

This chapter explains that this dramatic change in the design, manufacturer, launch operations, architecture of satellite constellations, and business models of those operating small satellite constellations can only be understood in the context of all the forces of change that are coming from perhaps a dozen different basic shifts in the space industry. Those who think one-dimensionally or narrowly about shifts in technology, market forces, capitalization, and global operations will miss the overall scope of this change. This overview of commercial small satellites is actually designed to capture this larger picture. This chapter focuses on what might be called synoptic change in space industry. It is now an industry that is completely beset by new and “disruptive” ways of thinking about every aspect of commercial space industries – the various markets, the changing modes of financing new systems, the diverse technological components of its products and services, and all of the associated regulatory processes.

Keywords

Airbus · Angel investors · Blue Origin · Boeing · Crowd Funding · CubeSat · Electronic pointing phase array ground system · Kickstarter · LauncherOne · Microsats · Minisats · "New Space" · OneWeb · Reusable launch vehicles · Rocket Lab · Rounds of financing · Small satellite launch vehicles · Sierra Nevada · Space 2.0 · Surrey Space Technology Ltd (SSTL) · SpaceX · Thales Alenia Space Vector

1 Introduction

There are many commercial technology-based enterprises that started off with just one or two persons tinkering with a new idea in a garage or basement trying to see if they could turn a concept into a meaningful product or service. On the other hand, the earliest satellites launched into orbit may have been small, but they were essentially all governmental projects backed by serious resources and teams of scientists and engineers.

When volunteer scientists and engineers put together the OSCAR 1 amateur radio satellite, launched in 1961, it helped to begin thinking about how to design and build low-cost satellites. This spark eventually spawned a whole school of thought about how to design, build, launch, and operate satellites that percolated through many academic institutions. Many colleges and universities were intrigued by the idea of the cubesat which was a standardized approach to small satellites developed by California Polytechnic State University (Cal Poly) and Stanford University in 1999. For nearly 15 years, the cubesat phenomena remained largely an academic enterprise with the majority of these small satellite projects coming from colleges and universities. The idea was largely to provide an avenue for students to test concepts as to how to design and build satellites more effectively and to carry out in-orbit experiments, when "rides to orbit" could be found, which was not always easy.

But, by 2013 the majority of cubesat launches were, for the first time, commercial or amateur projects that were not just academic undertakings but a serious new type of entrepreneurial space venture. Books written on this sweeping miasma of change have documented how the space business, as driven by small satellites and new types of launcher systems, are transforming the space enterprises in significant ways. Examinations of this dramatic shift, such as *Space 2.0: Revolutionary Advances in the Space Industry* and just published in 2019, seem all but ready for a second edition in 2020 given the rapidity of change in this fast-moving world of innovation and industrial transformation (Pelton 2018).

"New Space" enthusiasts were suddenly converting small satellite projects into real commercial ventures or at least test launches of prototypes for full-fledged commercial smallsat projects (CubeSat).

NASA, ESA, and other space agencies that had started programs to stimulate cubesat student experiments expanded their smallsat programs to spur corporate innovation, spur new small satellite ventures, assist with launches, and initiate their own smallsat experimental projects (NASA Venture Class Procurement Could Nurture Ride 2015).

Today Cal Poly has a structured partnership with 40 other academic institutions to provide the latest version of the cubesat specification (9th version), and there are now specifications for pocketqubes that are one eighth the size of a cubesat and even femtosats that are in the 10–100 g mass range. This supportive environment for the design, building, and launch of small satellites of the cube satellite class or below has grown in the last 25 years, and this trend will likely continue.

Today, according to the UN Office of Outer Space Affairs, some 9,000 satellites have now been launched into Earth orbit and to date less than 10% are associated with commercial satellite constellations. However, based on filings and licensing by national governments, this balance is set to change and change dramatically. Over 20,000 commercial satellites are now proposed to be launched in the next 5 years or so, and most of these are associated with small satellite constellations. The OneWeb and SpaceX Starlink constellations represent the majority of these launches. Amazon has also announced plans to launch its own constellation of thousands of satellites, which it calls Kuiper. This dramatic shift in the number of satellites to be launched and the rise of so-called MegaLEO smallsat constellations gives rise to concern about orbital collisions and even the possibility that deorbiting satellites from large constellations could strike an aircraft or a vulnerable point on the ground. The following

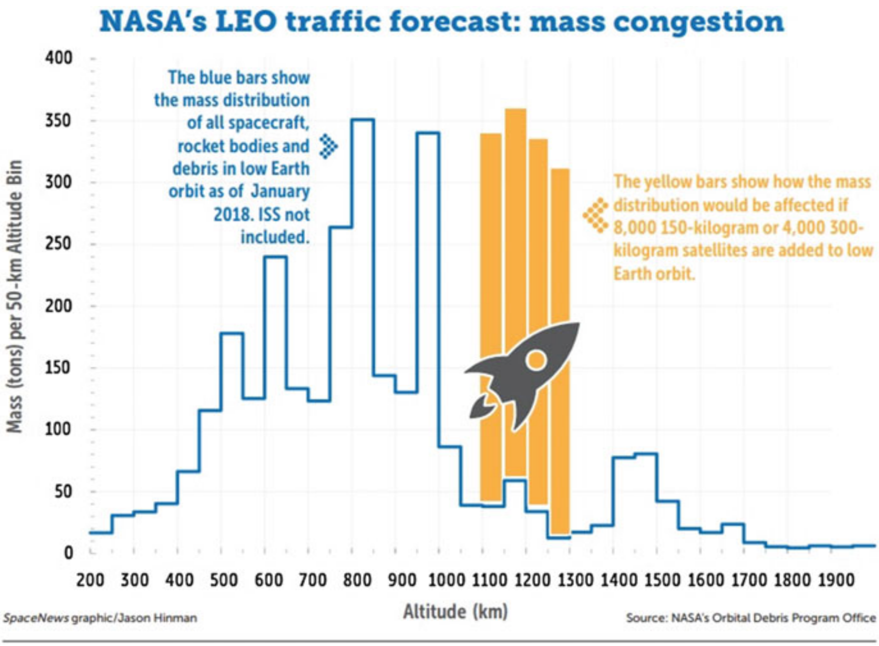

Fig. 1 NASA projected traffic congestion forecast in specific LEO orbit altitudes. (Graphic courtesy of NASA)

graphic shows how deployment of new MegaLEO constellations would create new levels of mass congestion as they are deployed at specific altitudes (see Fig. 1).

The world of small satellite constellations is thus moving rapidly forward. There are new technologies that are enabling constellations to be designed, built, launched, and operated more efficiently. There are new types of digital markets, particularly in the digital streaming and networking services arena, that are quickly developing. There are also new mechanisms to fund these various new ventures and new players in the space application field that are disrupting normal patterns of investment. Finally, there are new concerns with regard to orbital space debris, space situational awareness, space traffic management, and regulatory and liability provisions that all may require change to accommodate this new space environment and almost chaotic pattern of change in the space industry. Each of these new patterns related to commercial small satellite systems will be analyzed in the following pages.

2 Small Satellite Constellations and the New Technologies that Enable These New Systems

The rather steady and deliberate evolution of space technologies and systems and launch operations has been disrupted. It is really not productive to seek to determine which is the “chicken” and which is the “egg” in this rapid period of change. The overall trend is that many innovators in the aerospace industry have embarked on developing new technologies and new modes of operation across all sectors of the aerospace industry (Madry et al. 2018).

Launch Services: The new technology in the launch services industry is blossoming everywhere. There are a number of start-up launch services companies that are seeking to develop launch systems that operate with reusable first stage rocket components such as Blue Origin and SpaceX.

Others such as Virgin Galactic, Sierra Nevada, and now failed Swiss Space Systems have sought to extend the reusability associated with spaceplane development to provide small satellite launch capability.

Vulcan Inc. with its Stratolaunch Systems has sought to eliminate the need for expensive launch sites as well as provide new launch efficiency with regard to large mass air-launched rocket systems that represent an extension of approaches first developed by Orbital Sciences and Burt Rutan.

Yet others such as Vector in the USA, Rocket Lab in New Zealand, and many other start-ups in China, Europe, Israel, etc. have focused on developing highly efficient and quite small launchers for small satellites in particular (see Fig. 2).

India with its Polar Satellite Launch Vehicle (PSLV) and China with its Long March family of launch vehicles have simply focused on creating a conventional launcher that could be manufactured at lower cost and high reliability.

These various and diverse launch service initiatives have fed off of one another. These varied and more efficient launcher systems have served to drive down launch costs significantly in the past 5 years. For many decades launcher systems grew bigger in their capabilities, but the cost per kilogram of mass launched remained

Fig. 2 Efficient Electron launch vehicle offers new options for small satellites. (Graphic courtesy of Rocket Lab)

quite high. Today the cost of launching small satellites either on dedicated small launchers or packaged together on larger rocket systems is rapidly declining.

All of this innovation and these new launch systems that offer lower cost ways to orbit have forced the conventional providers of launch services such as Arianespace, Boeing, Lockheed Martin, United Launch Alliance, and Russian launch manufacturers and services providers to develop new and lower cost launch capabilities to compete with these new providers of launch services. The Ariane 6 vehicle will only have a modest increase in lift capability over the Ariane 5, but its cost per kilogram is expected to be cut in half. The United Launch Alliance's effort to cut costs is focused on the Vulcan launcher. More than a dozen lower-cost launch systems from start-ups in China, Israel, the USA, and Europe are aimed at capturing the small satellite launcher market and to compete with Vector, Rocket Lab, and LauncherOne for this sizable new market.

In several cases the approach to lowering cost is focused on reducing the high cost of operating launch sites. Options such as Stratolaunch and the carrier vehicle for LauncherOne represent one approach. Another concept is to develop simple, truck-mounted launch operations such as that developed for the Vector launcher.

Piggyback launches from larger launch vehicles such as the Polar Satellite Launch Vehicle that launched a record number of 104 cubesats remain extremely cost efficient. The same is true for the dispenser system on the International Space Station that now offers two options for smaller cubesats and more recently for nearly 1-m^2 satellites after the smallsats have been delivered along with other cargo to the station. The various launch options for small satellites continue to grow rapidly. The bottom line is that lower launch costs help to fuel the small satellite revolution in a significant way by lowering the cost to orbit and providing more rapid access to space.

New Ground Systems with Electronic Tracking of Satellites: The next key technology that enables the deployment of small satellite constellations for communications and networking is the new ground systems with electronic tracking capabilities. There is a mad scramble for the manufacturers of user terminals for satellite communications to bring new flat panel antennas with electronic tracking capabilities to market. Flat panel antennas are seen as a needed breakthrough permitting the rapid installation of ground equipment in new or usually restricted places, such as aircraft, smaller ships and yachts, and in rural and remote areas, opening up or expanding markets beyond what can typically be done with traditional parabolic ground terminals especially for MegaLEO constellation services. At the Satellite 2019 Conference and Exposition in Washington, DC, Gilat, SatixFy, Kymeta, Isotropic Systems, ThinKom, Alcan Systems, C-Com, Wafer, EM Solutions, Hughes Network Systems and Phasor were in various ways seeking to respond to this rapidly changing Earth station market in new and innovative ways. The suppliers of these new flat panel antennas include established suppliers, entirely new start-ups, and start-ups with big name backers. Perhaps most notable in this regard is the Kymeta flat panel antennas that feature the use of meta-materials. This innovative product is backed by Microsoft founder Bill Gates, among others (see Fig. 3).

Phasor, the developer of a modular design for antennas that can electronically track LEO satellite signals, is developing a flat antenna that would have increased

Fig. 3 Kymeta flat panel antenna with electronic tracking. (Graphic courtesy of Kymeta)

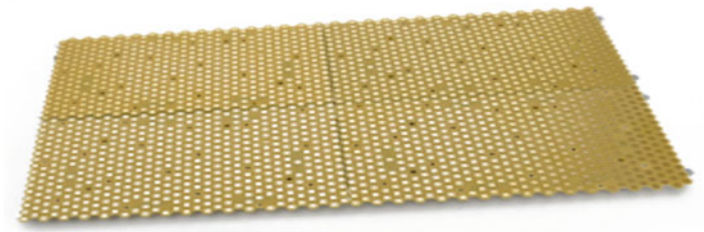

Fig. 4 Phasor modular flat antenna that can be shaped to conform to the sides of aircraft. (Graphic courtesy of Phasor)

sensitivity performance and could be adapted to conform to the side of an aircraft for mobile communications between airplanes and LEO constellations (see Fig. 4).

The principal advantage of GEO orbit satellites in Clarke orbit has always been that user antennas did not need to physically track the satellite's movement across the sky. These satellites seemed to remain fixed in place. LEO satellites, depending on their altitude, typically traverse across the sky in about 5–10 min and thus need ground terminals with rapid tracking capability. If the tracking is done using electronics rather than physical tracking of the satellite's path across the sky, then the Earth station's reliability is increased, and moving parts eliminated entirely. Currently, the cost of these flat panel, or conformal-shaped, antennas for aircraft is relatively expensive compared to classic fixed dishes, but the economies of scale of mass production are bringing these costs down rapidly.

There is clearly trade-offs in technical performance and cost efficiencies involved here. One must consider the relative gain in effective power performance of a LEO satellite which is perhaps 40 times closer to earth than a GEO satellite. This closer altitude provides a significant effective power increase in performance that is some (40×40) or 1600 times greater than from a geostationary satellite. Since the signal from a satellite spreads like a widening circle and the area of a circle is calculated as πr^2, the path loss or the effective strength of an electronic signal is represented by the square of the spreading circle.

In addition, there is another key gain in LEO systems. This is in the signal's latency, or path delay, which is 40 times less for a LEO satellite that is 40 times closer to Earth. In a world where digital networking is the prime mode of communications, this suggests that LEO networks, as well as MEO networks, will be better suited for digital networking and streaming services via the Internet. This is especially true for two-way communications links for either data or voice, where delays are most noticeable. The current betting is that these closer-to-Earth satellite constellations will be able to capture a larger market share over GEO satellites over time. A key market driver will thus be how rapidly do flat panel antenna costs come down and how good will their technical performance be at both providing service and avoiding interference to GEO satellites and injecting additional RF interference into adjacent radiofrequency bands used for radio astronomy, GNSS services, etc. The biggest concern of all is over-congestion of LEO orbits that results in collisions and the creation of orbital debris which could create major disruptions for all types of space-based services. This issue will be discussed further in this chapter and elsewhere in this handbook.

3 New Efficiencies in Small Satellite Manufacture

Yet another significant change that has come with the small satellite revolution is new and improved ways of designing, manufacturing, and testing small satellites in large production runs. Early New Space satellite developers used Silicon Valley-like approaches that saw every launch of a handful of satellites as a way to test new technologies and manufacturing techniques. Innovations were rapidly incorporated in the next batch and tested on-orbit like upgrades to software. However, to become commercially viable, these operators and manufacturers needed to shift to a different model that focused on an easily reproducible product designed for manufacturability. In the classic space industry, the production of a handful of GEO satellites in any 1 year by any one manufacturer did not allow for large production run efficiencies and cost-effective means of quality assurance testing. Each satellite was essentially handcrafted and painstakingly tested based on the not unrealistic view that it had to operate for 15 years or more and was largely out of reach after successfully reaching geostationary orbit. Only a few spacecraft, having suffered mishaps in the early stages of their deployments when the space shuttle was still operating, had any chance of being rescued and either sent on their way or brought back to earth for retrofit and relaunch. Today there are strides being made in on-orbit servicing. NASA and DARPA are funding relevant research, and there are some commercial initiatives in this field, but there is still a long way yet to go.

But the production of a large number of satellites with standardized component parts poses a challenge for any manufacturer, whether seasoned or New Space. Supply chains had to be streamlined and prepared for mass production and on-time delivery of parts with high reliability, low cost, and high quality had to be perfected. If the New Space constellation is to be based on "off-the-shelf" components, traditional space equipment suppliers may need to be trained not to go through the painstaking quality checks and testing usually demanded. Alternatively, nontraditional suppliers may have to be briefed on the unique demands of space manufacturing, even if the equipment to be supplied was said to be "off-the-shelf," usually denoting equipment repurposed from established commercial applications on Earth. The development of additive manufacturing added a new potentially cost-saving approach which could reduce costs and manufacturing times. Testing regimes were altered to focus on full testing of the first handful of satellites in a production run using high-quality acceptance standards. Thereafter, only rudimentary testing is to be used for full production runs. Some of these production and testing technique had been developed during the mid-1990s, when the first commercial constellations were developed and launched for Iridium, Globalstar, and Orbcomm, but the lessons learned then, if still remembered, had to be significantly adapted for constellations involving hundreds and thousands of satellites, using the latest production technologies and techniques. Moreover, the commercial success of these constellations maybe based at least partly on the speed and efficiency of production. Whereas it takes only three geostationary satellites to cover most of the earth, for New Space LEO constellations to achieve full market coverage, the satellites must be built quickly and launched in large batches or else operators' revenue will be severely constrained by incomplete coverage. The gap between first launch and full coverage cannot be understated, since many New Space satellites are being designed for relatively short lifetimes on-orbit, often under 6 or 7 years. Thus, while the first satellites launched in a constellation have only limited opportunities to generate revenue, they are already degrading in the harsh space environment. Thus, completion of the constellation quickly becomes critical. This is especially true for smallsat constellations providing telecommunications services, as well as Earth observation systems whose key selling point is rapid revisit of (almost) every point on the Earth.

The incremental costs of satellites on large production runs should decrease significantly. In the case of highly automated production systems, the cost of manufacturing small satellites in thousands of units largely becomes the cost of the materials in the spacecraft. If operators of LEO smallsat constellations can significantly reduce the cost of manufacturing, reduce the cost of quality acceptance and independent verification and validation testing, significantly reduce the cost of launch, and increasingly automate the operation of large constellations, then the total cost of a constellation can be reduced significantly, largely through economies of scale. On the other hand, if the failure rate of such highly automated small satellites continues to be high, such as the 5 small satellites out of the first 60 Starlink satellites launched mid-year 2019, the problem of derelict small satellites remaining in space becomes of prime concern. This issue is discussed further below and elsewhere in this handbook with regard to orbital space debris (O'Callaghan 2019).

It is further anticipated that new flat panel antenna systems with electronic tracking can follow a similar cost reduction curve. SpaceX has filed a petition with the Federal Communications Commission asking for type licensing of a million broadband user terminal transceivers to work with its Starlink satellite constellation. The planned deployment of one million of these future broadband units represents tangible evidence of efforts to achieve major future cost reductions associated with flat panel user antennas (Nyirady 2019).

4 New Markets Such as Over-the-Top Data Streaming Via Commercial Small Satellites

The commercial satellite market is a nearly $300 billion a year enterprise, and the largest sectors are satellite services that represent about $130 billion dollars in annual revenues – followed closely by ground systems sales of about $120 billion. The largest portion of that services market represents subscription sales for direct broadcast satellite services that are now offered as an alternative to cable television subscription services. These industries – both direct broadcast satellite television and subscription television services – are currently experiencing rapid change as many consumers around the world are shifting from watching video via cable TV or DBS subscription to data streaming and viewing videos on laptops or even cell phones, rather than conventional television sets. The advent of 5G cellular service will likely accelerate this trend.

Most analysts foresee the market shifting away from cable TV or DBS subscription-based services delivered from broadcasting satellites or in the case of cable television, fixed service satellites. This shift allows providers such as Amazon Prime, Netflix, Fubo, Hulu, Sling TV, Now TV, Sky Go, and dozens of Internet-based video streaming services to compete with cable TV subscription or direct broadcast satellite TV services. This shift is currently hitting subscription service providers such as HBO, Starz, Cinemax, etc. the hardest. Most of these OTT services offer video programming and broadband access at much lower rates that via cable TV subscription services or the offerings via satellite broadcast networks such as

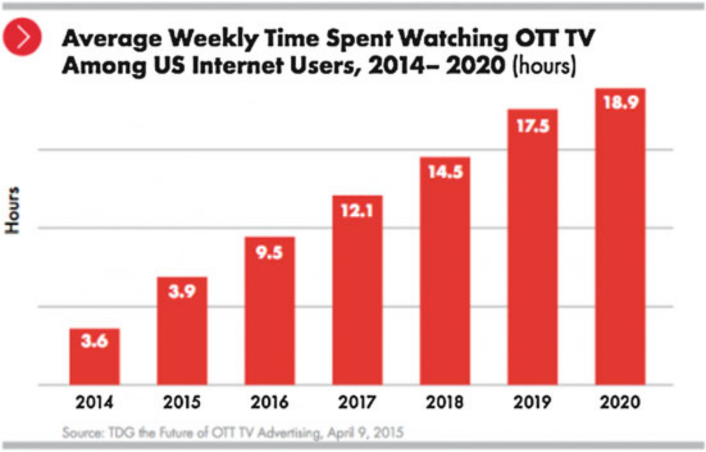

Fig. 5 The rapid rise of OTT television viewing. (Source courtesy for TDG)

DirecTV, Dish, SkyTV, or other DBS providers around the world (The New TV – The State of the New TV Industry).

One of the key questions is how will these video services be paid for in the future. Today video programming is paid for in various ways, often through a combination of subscription fees and paid advertising inserted along with the programming. In the OTT digital streaming model, the subscription fees are less, but advertising with OTT services is now largely absent. However, it is envisioned that ads will become an important part of the future revenue streams (see Fig. 5).

The advantage of GEO-based systems providing direct broadcast television services to fixed dishes is seemingly being lost to data networks that provide services via broadband digital streaming using OTT distribution processes. This is particularly true for users who are opting to have their service provided to smaller computer screens or cell phones rather that television sets. In many cases, such as services offered by Hulu, subscribers are able to control their viewing schedule and see programming when they want rather than when scheduled networking programmers dictate.

Currently direct broadcast satellite service sales, such as for DirecTV, Dish, and SkyTV, are seeing slowing growth rates or even modest declines in the range of 1–2% annually in revenues. This trend is expected to continue. When 5G cellular becomes more widely available and the new small satellite constellations are deployed globally to support 5G services, the revenues within the traditional satellite industry could shift in a way that sees a decline in cable television subscriptions, in subscriptions to direct broadcast satellite services, and in paid entertainment channels subscribed to via either cable or DBS systems.

If small satellite constellations are successfully deployed to provide global broadband Internet access, entertainment distributors, such as Netflix, Hulu, Sling TV, Now TV, Sky Go, and dozens of others now offering streaming entertainment, will be tempted to seek new customers through them. This, in turn, could greatly impact the structure of satellite networks and how these businesses are operated.

Fig. 6 Graphic showing many of the new applications that 5G could provide. (Graphic courtesy of NewTec)

In addition, broadband 5G will be much more than an enabler of more OTT video services. The concept of 5G is that it will open up a host of new applications from driverless cars, to finding a parking place more easily, to improvements in water systems, electrical grids, and more generally grouped under the concept of the Internet-of-Things (see Fig. 6) (What Next for Satellite in a 5G and OTT Era 2018).

The key question is whether 5G and interactive IoT services will be augmented by broadband satellite systems in GEO, MEO, or LEO orbits and whether low latency will be considered essential to many of these applications. Some applications related to IoT monitoring and feedback, such as utility operations, may have a high tolerance for GEO satellite delay and can also be well served by cubesat type LEO systems. But other 5G applications, such as sensors related to driverless cars, may have more exacting limits that require superfast interactive networking and can be only well served by very broadband LEO systems, likely complementing terrestrial wireless systems.

This projected near term future has been described in the following terms by iDirect market analysts. "Today, we are on the verge of seeing what a truly 'connected world' looks like. It's projected that soon there will be 6 billion people, 30 billion devices and 50 billion machines online. That's essentially everyone and everything connected, across every geography, supporting every application from consumer broadband, mobile gaming and connected cars to global business networks, ships, planes, soldiers, first responders and connected farms" (The 5G Future and the Role of Satellites).

It will be perhaps another decade before it will be sorted out clearly as to which type of satellite service will respond best to which aspect of these burgeoning new data networking markets. These markets may be different for different regions of the world and especially differentiated for applications in developing and highly developed economic markets. What is clear is that there will be an explosive growth in machine-to-machine communications, data networking, and various types of video services in the coming decade. This should sustain growth in terrestrial and satellite service markets and perhaps also engender growth in new areas such as high altitude platform systems. Satellite networks, because of their inherent global accessibility and global coverage, will be part of this mix. Reduced latency of connection as provided by LEO and MEO constellations is expected to drive this satellite growth, while high-throughput satellites in GEO orbit can also fulfill part of this new growth as well.

5 Small Satellites and Their New Backers

The communications satellite industry for five decades or more has been sustained by companies that grew out of the aerospace industries, as well as telecommunications, broadcasting and entertainment companies, or large enterprises associated with the so-called military-industrial complex. These backers and customers relied largely on geostationary satellites to connect far-flung corners of the world and distribute video and later broadband Internet-related services. This support and patronage allowed steady and sustained growth that spread the use of satellite communications across the globe. Satellite services were embraced by most countries of the world, and nearly all joined or used the Intelsat satellite system, which was originally established as an intergovernmental treaty organization until its privatization in 2001. Dedicated national satellite systems or leased capacity on global networks, such as Intelsat, SES, Eutelsat, Telesat, Iridium, Globalstar, Inmarsat, and other systems, extended satellite telecommunications and broadcasting services to virtually every country and territory in the world. Other applications such as remote sensing satellite systems, global navigational satellite services/precise navigation and timing systems, and meteorological satellite services widened further the extent and impact of global satellite services, though these specialized systems relied even more on the needs of government and government-related customers. While attempts were occasionally made to privatize these services and to attract private capital, especially to remote sensing and meteorological services, commercial markets were for many years too small to support such investments.

Only in the last 10 years have nontraditional financial and business backers expanded into the space sectors. The business world of aerospace and communication has been joined in a dynamic and disruptive way by the world of cyberspace, networking, data streaming, and OTT video services. In short, the world of Silicon Valley, Google, Facebook, and social media has joined the world of commercial satellite services. And as is the custom in this digital world of commerce, these new investors did not look for improvement or change in modest 5% incremental gains. They seek disruptive innovations that change business models and reinvent the way an industry operates in great leaps forward (Madry 2019).

Much of what is described as "New Space" or "Space 2.0" can be traced back to Silicon Valley and entrepreneurial thinking. Skybox and Planet Labs that have reinvented the world of remote sensing came from young people thinking outside the box. They found ways to undertake remote sensing in ways that were ten times less costly than the commercial enterprises highly reliant on government customers that preceded them. The small satellite revolution has now moved to the world of satellites and digital networking (Pelton 2018).

The technology that has led to new ways of designing and building satellites, of designing and manufacturing launch vehicles and ground antennas, and so on has been described earlier in this chapter. But, the driving force behind these various innovations is the entrepreneurial thinkers who envisioned new ways of designing these commercial space industries and seeking new sources of capital investment attuned to disruptive enterprises and new ways of doing business (Madry 2019).

This has not only led to major innovations in how every aspect of how commercial space enterprise is done today but also how such ventures are financed. The new enterprises are today not only being backed by companies like Google, Facebook, Qualcomm, and others from the world of computers and cyberspace but financial institutions that have been investing in these higher growth industries.

And the change in capital formation to support new smallsat initiatives does not end there. Angel investors, investment capital firms, venture capitalists, investment bankers, and others who are pursuing crowd-sourcing opportunities as means to invest in the next big growth industry are finding ways to invest as well. There are now many new start-up commercial satellites systems that have started with such innovative sources of funding. The Spire small satellite system got started with a Kickstarter funding initiative that led to a series of rounds of funding by angel investors.

In the case of Planet Labs and Spire, they have ensured their futures with long-term anchor client contracts to supply data for years to come. In the case of Planet Labs, now just Planet, they are supplying remote sensing data for years to come. In the case of Spire, they have a long-term data supply contract with the European Space Agency worth billions of dollars.

There are other potential investment groups such as sovereign wealth funds, technology investment corporations such as SoftBank of Japan, and other investors that have fueled the rapid growth of many new systems. OneWeb has used an interesting method of including many of its suppliers as investors in the new system. Thus Airbus Defence and Space, which is building the small satellite spacecraft; Virgin Galactic and Arianespace which are providing a significant part of the launch services for the network; Grupo Salinas of Mexico, a major mobile services supplier; and Qualcomm, a major equipment supplier, are all investors in OneWeb. At one point Intelsat and OneWeb were going to merge together with SoftBank financing the transaction costs, although this arrangement was never consummated. Instead, Intelsat remains an investor and close technical advisor and partner.

In OneWeb's latest round of investment, its 7th round, it raised $1.25 billion. These investors included the Japanese conglomerate SoftBank, Mexican conglomerate Grupo Salinas, Qualcomm, and the Rwandan government. There are now some 20 private investors that include aerospace corporations, launcher companies, high-tech computer and Internet companies such as Qualcomm and Google, media companies, as well as large conglomerate investment firms, investment banks, and sovereign funds (Sheetz 2019).

The world of space applications has thus changed dramatically with a new range of investors from the Internet and investment banking world that were not part of this type of business a decade ago. There is clearly a great deal of new technology evolving in the world of small satellites, but much of the change and entrepreneurial spirit that abounds in this field has come from many of the new players who are expecting new (and higher) types of profits from their investments and substantial new benefits from the new technology.

There are some from the financial and space communities who well remember the experience from the first wave of new non-geostationary systems of the 1990s, such as the Iridium, Globalstar, and Orbcomm mobile communications systems, and the broadband Teledesic system. Those ventures ended in bankruptcy, though some have emerged and continue as going businesses. Those with long memories, however, are concerned with the high level of enthusiasm and the massive numbers of filings that now exist in national licensing proceedings and international frequency coordination processes. Currently, there are over 20,000 small satellites proposed for launch in new constellations that suggest the possibility of some significant financial risks with at least some of the new systems. The OneWeb and Starlink systems are just the first of these systems. Additional systems proposed or under construction have yet to find anchor customers for their new systems. The potential for new traffic based on expanded Internet connectivity, 5G broadband cellular systems, Internet-of-Things (IoTs) traffic, automatic identification services, and more is clear, but converting that potential into signed contracts for services represents both a challenge and potential risk.

And, that risk is not just in terms of signed contracts from paying customers, there is also concern about the potential creation of massive amounts of orbital debris. Just managing the traffic in space so that satellites in these large constellations avoid colliding with other objects – possibly defunct spacecraft or rocket launcher stages that remain in orbit – is a major risk and potential long-term barrier to future space infrastructure.

6 Rising Concerns About Orbital Space Debris and New Coping Mechanisms

The people most aware of the space debris problem and concerned about the potential of collision with space debris associated with their new LEO and MEO networks are the very operators of these systems. OneWeb, which is deploying its large-scale network, and SpaceX, which has also now started to deploy an even larger MegaLEO system, have noted their level of concern about this problem and called for responsible operations and effective government regulations, supporting new initiatives began by the US government (Maclay et al. 2019).

They have explained in some detail their own plans to deorbit their own satellites at the end of life of their spacecraft and to bring all of their defunct satellites into a "disposal orbit" that would serve to bring all of these end-of-life satellites back down within 1 year. SpaceX even announced that it would actively deorbit 2 of its first 60 Starlink satellites soon after launch in order to simulate end-of-life disposal. Three other satellites of the first 60, however, failed to activate and were being counted on to deorbit without control and pointing. These early setbacks highlight the potential challenges of deorbiting the hundreds and eventually thousands of additional satellites to be launched by SpaceX, OneWeb, and others (O'Callaghan 2019).

They have also indicated plans to maintain a clear picture of possible conjunctions (collisions) that might occur. The US Air Force, after sometimes equivocal support for providing such warnings, have stepped up their efforts and close cooperation with the private space industry in recent years, especially after an Iridium satellite collided with an old Russian rocket stage in 2009. Long term, the administration of Donald Trump has announced plans and introduced legislation in the US Congress to shift traffic management responsibilities to the US Commerce Department, which already licenses new remote sensing systems. There are detailed plans for carrying out improved space situational awareness that would alert operators of large networks when conjunctions might occur. Thus, those that plan to launch many satellites into low Earth orbit have joined forces with regulatory agencies such as the FCC and the Department of Commerce in the USA to address the need for better space situational awareness, some form of improved space traffic management, and much more strict guidelines for deorbiting of satellites at the end of their life (Brookin 2017).

OneWeb has proposed to launch its satellites into a lower orbit and test them for reliability and functionality before placing them into their operational orbits (Brookin 2017).

Yet, despite all of these efforts and stated goals to manage space debris and prevent satellite collisions that could create thousands of pieces of new debris, the current situation is still considered dangerous. As more satellites are launched, that concern will grow. Efforts by the UN Committee on the Peaceful Uses of Outer Space to develop new guidelines for space debris removal and address the very difficult issue of space traffic management have over the past 5 years made only modest gains.

Currently pending issues with regard to orbital space debris and space situational awareness and space traffic management include the following:

- Concerns about large numbers of deorbiting satellites possibly hitting an aircraft (based on the study by Aerospace Corporation and other analyses).
- Coordination and information sharing between private companies providing space situational awareness data and defence agency operations.
- Improved methods of providing possible conjunction information about potential in-orbit collisions so as not to overload alert systems so that warnings of real possible collisions are taken seriously and evasive actions are taken. These might include improved use of artificial intelligence algorithms to focus on most serious possible collisions.
- Adoption of new "best practices" guidelines to encourage debris removal down from 25 years from end of life to 1 year from end of life.

- National actions to focus on and adopt new regulatory processes related to commercial constellations and debris removal and conjunction avoidance (U.S. Space Policy Directive 3 being one such example) (U.S. Space Policy Directive 3 2018).

7 Conclusions

The development of space applications for many decades followed the trajectory of bigger and better (and more complex) satellites that were more and more cost-effective. These were launched on bigger and better launch vehicles. The small satellite revolution that accompanied the “New Space” revolution has suddenly transformed the paradigm of how to respond to growing demand for digital communications services and the best way to improve satellite applications. This chapter has provided an overview of how new small satellite constellations and the new low latency services that they can provide are a part of the new space industry revolution. The ability to design, build, and test small satellites more cost effectively and launch them at much lower cost into low orbit constellations is changing the entire space industry. It is creating new regulatory issues and concerns but opening doors to innovation and allowing new entrepreneurial ventures to enter these new markets. This chapter has provided an overview of many aspects that will be covered in more detail in later parts of this handbook of small satellites.

The many new commercial satellite constellations that are now being designed and manufactured would not be possible without the new and improved satellite technologies covered in Part 3, the new launcher capabilities described in Part 4, the new approaches to manufacturing discussed in Part 5, the new ground antenna systems discussed in Part 6, and the new uses of small satellites described in Parts 7 and 8. The quite small satellites known as cubesats in some ways pioneered the larger and more sophisticated microsats and minisats that are more typical of very large constellations that are being manufactured and launched today. But the innovations that came with these smallest of the small satellites blazed the trail for the current commercial systems that are staging the next phase of the small satellite revolution.

8 Cross-References

► Network Control Systems for Large-Scale Constellations
► Overview of Commercial Small Satellite Systems in the “New Space” Age
► Overview of Cubesat Technology
► The Smallest Classes of Small Satellites Including Femtosats, Picosats, Nanosats, and Cubesats

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