Commercial Small Satellites for Business Constellations Including Microsatellites and Minisatellites

Joseph N. Pelton and Rene Laufer

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Abstract

The smaller version of “smallsats” known as “femtosats,” “picosats,” and “nanosats” or “cubesats” was discussed in the preceding chapter. These very small spacecraft, plus small hosted payloads, or tiny space experiments that are carried out in the Nanoracks experimental platform on board the International Space Station provide a gateway into space that can allow students to conduct experiments without huge multimillion dollar investments.

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

R. Laufer
University of Cape Town, Cape Town, South Africa

Baylor University, Waco, TX, USA
e-mail: rene.laufer@me.com

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The commercial uses of “smallsats” for 1-unit cubesats and below are extremely rare. Increasingly, there are commercial systems, however, that are using 3U cubesats particularly for automatic identification services (AIS) and for messaging, machine to machine (M2M), and Internet of Things (IoT) connectivity. The other prime commercial applications by 3U and above cubesats are for remote sensing with lower resolution in cases where rapid updates of information and data analytics are the prime purpose of a small satellite constellation.

Thus small space units such as cubesats and even smaller pocketubes are typically used for student or scientific experiments or used for proof of concept for a much larger follow-on activity. This means that most commercial networks are using the larger class of microsats and minisats for their constellation designs. Thus this chapter is focused on the burgeoning growth of “smallsats” for commercial networks and the “NewSpace” or “Space 2.0” constellations that employ larger spacecraft. These satellites are still far smaller than the typical commercial and space agency research spacecraft that has grown to the size that ranges from 1000 Kg on up many thousands of Kgs.

There is now a huge and rapidly growing new commercial market for what are called “microsats” (e.g., 10–100 kg or 22–220 pounds) and “minisats” (e.g., 100–500 kg or 220–1100 pounds). Others, however, define minisats as being from 100 kg up to 1000 kg (or 220–2200 pounds). These types of “smallsats” unlike those discussed in the preceding chapter are typically being deployed for commercial missions and applications and most often for large constellations to create a global service. Space agencies, military agencies, and established research organizations are finding that these smaller but highly capable satellites can be used for scientific exploration in orbit and in deep space and for proof of concept for larger missions.

These microsatellites and minisats are most often launched in low Earth orbit (LEO) but not exclusively so. GEO-orbiting spacecraft and deep space missions can also use this type of “smallsat” that are performing ever more complex and difficult missions. Even radarsats that require substantial power levels because they require “active sensing” have been deployed as constellations using this type of smallsat such as Canada’s most recent Radarsat Constellation.

This chapter provides the background of the earlier “smallsat” constellations that failed financially, the resurgence in the technologies, financial support, markets for these new “smallsat” systems, and the regulatory and other challenges still to be faced in this highly dynamic market that is still in what might be considered a second shakeout phase of development.

**Keywords**

Commercial smallsat constellations · Electronic beam forming · Globalstar · HawkEye 360 satellite constellation · Iridium · Metamaterials · Microsatellites · Minisatellites · “NewSpace,” Off-the-shelf components · Orbcomm · Phased array antennas · Planet · Remote sensing constellations · SpaceX · Starlink
1 Introduction

The demand for “smallsats” is currently projected to increase and rise to a high level as demand for geosynchronous satellites for telecommunications and remote sensing appears to be falling.

The estimates as shown in Fig. 1 indicate that based on historic growth patterns as many as 2600 nanosats and microsats might be launched from the period 2020 through 2024. These estimates as developed by SpaceWorks suggest that the rate of these microsat launches might rise to a high of nearly 700 launches per year by 2022 if current market forecasts for full deployment continue for smallsats in the range of 1–50 kg. (Neiderstrasser 2019).

Yet, as high as these estimates are for microsats, the estimates for minisats (in the range of 50–500 kg) may conceivably be as high at 20,000. Although most estimates discount the full deployment of all licensed microsats and proposed for launch to a much reduced number, even the discounted figures are tremendously high.

The projections by Northern Sky Research in their studies indicate a wide range of possible launches for microsatellite in the range up to 500 kg for large-scale constellations that include networks for OneWeb, LeoSat, Telesat, two systems for SpaceX, Boeing, Constellation, Theia, and a number of other currently proposed constellations. Even in the case of these constellations, there continue to be filings to add to the size of these networks that are now working their way through licensing processes at the national or international level.

Thus Northern Sky Research has indicated that there is an opportunity of anywhere from 10,000 to 20,000 microsatellites to be launched over the next 6–7 years. This assessment, however, was made before the Covid-19 corona virus impacted the global economy. In contrast to these historically high number of satellites, there has been a large dip with regard to GEO satellites, especially for telecommunications. In this case there have only been nine large-scale GEO satellites ordered in the past couple of years. Part of this change, of course, is that the new high-throughput satellites are so highly efficient. These huge high-throughput satellites (HTS), at up to 150 gigabits/second, represent the throughput capabilities of 20–30 conventional GEO satellites of the past. Just as there is now a smallsat revolution seemingly underway involving low Earth orbit constellations, there is another revolution underway with regard to the superefficient and very cost-effective high-throughput satellites in GEO (Russell 2018).

There are clearly reasons why the number of possible launches of minisats varies so very widely. If one takes just the case of the SpaceX Starlink systems, one sees that these two currently filed and licensed smallsat systems together would constitute, when fully deployed, some 12,500 new smallsats in low Earth orbit (LEO) – this is far more than all communications satellites currently operating and all comsats ever launched into orbit. This system that would cost over $10 billion if fully deployed involves some 4500 operating in Ku-band and Ka-band frequencies and around 7000 operating in the extremely high-frequency V-band between 40 and 75 GHz.
And this is not some abstract concept; serious deployment of this network to challenge the OneWeb constellation has now also begun in earnest. Early on May 24, 2019, a reusable Falcon 9 satellite deployed 60 of the Starlink satellites in low Earth orbit in what seems to be the start of deploying a vast array of small satellites into low Earth orbit (LEO). And these satellites are not tiny cubesats but 500 pound (227 kg) spacecraft, many times the size and mass of the Intelsat I (Early Bird) satellite that started the age of global satellite communications in 1965 54 years earlier (Thompson 2019).

The truly vast size of these “megasatellite” systems and the large amount of capital that must be raised to pay for the manufacture and launch of these new systems—some of these constellations containing thousands of satellites—contribute to the uncertainty in the projected number of microsat launches. Thus there is today uncertainty of market forecasts as to the number of smallsats to be manufactured, the number to be launched, and the revenues that will be derived from smallsat constellations designed to provide telecommunications and networking services around the world (Torrieri 2018). There was significant uncertainty in smallsat forecasts even before the Corona virus impacted the global economy. Thus today most projections see a downturn in volume and even more bankruptcies such as has been the case with One Web, Leosat, Vector, Firefly, etc.—with more to follow.

This has set off a large number of “smallsat” launch vehicle development efforts. According to a study conducted by Northrup Grumman in 2018, there are over ten countries seeking to develop new “smallsat” launch capabilities. This is led by some 20 such commercial developments in the United States alone (Op. cit, Carlos Neiderstrasser).

Other developments are widely distributed around the world, i.e., China (six projects), Spain (three projects), the United Kingdom (three projects plus a joint project...
Table 1  Potential and actual developers of new “smallsat” launch vehicles

| Organization                              | Vehicle name               | Country       | Date         |
|-------------------------------------------|----------------------------|---------------|--------------|
| ABL Space Systems                         | RS1                        | USA           | Q3 2020      |
| Aphelion Orbitals                         | Helios                     | USA           | 2021         |
| Bagaveev Corporation                      | Bagaveev                   | USA           | 2019         |
| bspace                                    | Volant                     | USA           | 2018         |
| Celestia Aerospace                        | Sagittarius Space Arrow CM| Spain         | 2016         |
| Cloud IX                                  | Unknown                    | USA           | N.A.         |
| CONAE                                     | Tronador II                | Argentina     | 2020         |
| CubeCab                                   | Cab-3A                     | USA           | 2021         |
| Departamento de Ciencia e Tecnologia       | VLM-1                      | Brazil        | 2019         |
| Aerospacial                               |                            |               |              |
| ESA                                       | Space Rider                | Europe        | 2020         |
| Firefly Aerospace                         | Firefly Alpha              | USA           | Q3 2019      |
| Gilmour Space Technologies                | Eris                       | Australia/Singapore | Q4 2020      |
| Interorbital Systems                      | NEPTUNE N1                 | USA           | N.A.         |
| ISRO                                      | PSLV Light                 | India         | Q1 2019      |
| LandSpace                                 | LandSpace-1                | China         | H2 2018      |
| Launcher                                  | Rocket-1                   | USA           | 2025         |
| LEO Launcher                              | Chariot                    | USA           | Q4 2018      |
| Linkspace Aerospace Technology Group      | NewLine-1                  | China         | 2020         |
| One Space Technology                      | OS-M1                      | China         | 2018         |
| Orbex                                     | Orbex                      | United Kingdom| N.A.         |
| Orbital Access                            | Orbital 500R               | United Kingdom| 2020         |
| PLD Space                                 | Arion 2                    | Spain         | 3Q 2021      |
| Rocketeers                                | Intrepid-1                 | USA           | Q1 2019      |
| RocketStar                                | Star-Lord                  | USA           | 2018         |
| Skyrora                                   | Skyrora XL                 | UK/Ukraine    | N.A.         |
| Space Ops                                 | Rocky 1                    | Australia     | 2019         |
| SpaceLS                                   | Prometheus-1               | United Kingdom| Q4 2017      |
| SpinLaunch                                | Unknown                    | USA           | N.A.         |
| Stofiel Aerospace                         | Boreas-Hermes              | USA           | 2019         |
| Stratolaunch                              | Pegasus (Strato)           | USA           | N.A.         |

(continued)
with Ukraine), as well as single projects in Argentina, Australia, Australia/Singapore, Brazil, pan-European (ESA), India, and New Zealand (Ibid.) (See Table 1).

The extent to which there are many challenges unknown in the future development, manufacture, launch, and operation of large-scale constellations using smallsats cannot at this stage be overstated.

### 2 Historical Background

There is not an exact time when the use of commercial smallsats in constellations first came to the fore, but it is convenient to start with the smallsat constellations for land mobile satellite communication which were first planned and launched beginning in the 1990s.

It was in the mid-1990s that the Iridium and Globalstar satellite networks were designed as smallsat constellations. These smallsat constellations numbered in the range of 50–70 satellites were in many ways the pioneers. The smaller Orbcomm network was also started in this time frame. Two other proposed networks that were proposed, started, but ended in bankruptcy before launch, namely, ICO and Teledesic, are also part of the early days of the smallsat revolution that began in the 1990s, seemed to pause in the early years of the twenty-first century, and then have come roaring back in the 2010s.

The Iridium and Globalstar smallsat constellations were constituted with the minimum number of spacecraft sufficient to provide continuous coverage for mobile communications services at the LEO selected for these systems. Constellations in LEO-based polar orbits designed to provide Earth observation, meteorological coverage, and remote sensing services had even been deployed with smaller-sized constellations since continuity of service was not required in these cases.

In the late 1980s and early 1990s, the ideas began to percolate. There were various proposals for large-scale constellations with hundreds or even thousands of smaller-scaled satellites deployed in LEO networks. This new type of satellite architecture was premised on a number of innovative ideas.
These ideas included the following rationale with regard to the use of “smallsat” constellations: (i) Smaller satellites in low Earth orbit (LEO) would be able to provide more power with greater efficiency because of lower path loss. The argument was that since they could be up to 40 times closer to the Earth’s surface, they would be able to deliver the equivalent of 1600 times greater intensity of power distribution based on “path loss” formulas.

(ii) These satellites would operate with much less transmission delay (or latency) due to being much closer to Earth.

(iii) These new smaller but much more numerous satellites could be mass-produced and be more efficiently tested for performance because of their much larger production runs.

(iv) The design of these “smallsats” might be able to use more off-the-shelf and lower-cost components because of the larger production runs and sparing philosophy that would simply replace any defective satellite with another “smallsat.”

(v) Although there were many more satellites to be launched, the launch of low orbiting spacecraft is easier to achieve and easier to operate than spacecraft launch all the way out to geosynchronous orbit – almost a tenth of the way to the Moon.

Despite these perceived advantages, there were several significant disadvantages. These were:

(i) The satellites, in low Earth orbit, would have much shorter lifetimes, typically of about 5–8 years, in that their orbit would decay and deorbit over time.

(ii) The GEO-orbiting spacecraft did not require ground stations or user terminals to track them since the GEO sats always appeared to hover over one fixed spot in the sky and thus did not require constant tracking of the satellite as it moved across the sky.

(iii) The signals coming to and being emitted from the satellite would have to be rapidly switched from beam to beam (about once a minute) and from satellite to satellite (about every eight minutes) in the most rudimentary constellations.

This constituted a particular challenge for telecommunications satellites in terms of potentially dropped calls since a typical telephone call lasts over 5 min and this would have required precision switching of beams four or five times for each call. In an environment with millions of calls on line in a global network, this would require an enormous precision of electronic switching accuracy that certainly challenged the state-of-the-art capabilities of the time when these first systems were proposed and the low orbits envisioned for the spacecraft.

For a variety of financial, marketing, operational, and technical problems, the initial systems that deployed LEO satellite constellations, or proposed to do so, all had financial and operational difficulties and ultimately experience bankruptcies. These included the Orbcomm data message relay satellite network, the Iridium, Globalstar, and ICO land mobile communications systems and the Teledesic megaLEO broadband system.
This last system, backed by Bill Gates and Craig McCaw, was to have been a Ka-band high data rate communications satellite network to support both fixed and mobile communications of all types. This highly innovative satellite systems design that would have deployed a host of new technologies initially envisioned the use of nearly a thousand satellites, including 80 spare satellites.

In the design process, the initial network that would have been built by the Boeing Corporation was reduced to 280 smallsats in low Earth Orbit. This system that would have provided broadband services, rather than thin stream communications for mobile voice communications, was the most ambitious of the earlier “smallsat” constellation. Its bankruptcy, along with Iridium, Globalstar, Orbcomm, ICO, and other proposed LEO constellations, ended the first round of enthusiasms for such types of satellite networks (See Fig. 2).

Today, the early failures and bankruptcies of the early commercial smallsat constellations are considered to be, or at least hoped to be, behind us some 30 years later. There are certainly key advances in communications satellite technology, higher performance switching systems, more experience with high-volume manufacturing, additive and 3D manufacturing and automotive testing techniques, improved experience with inter-satellite links, new developments in ground systems that can provide electronic tracking of LEO satellites, and AI-controlled satellite management systems for large-scale constellations. All of these advances have contributed in a renaissance in the what, where, when, and how of LEO satellite constellation design and operation.

New innovations in network control systems artificial intelligence applied to constellations operations to avoid satellite conjunctions and interference to GEO satellites, ground and satellite antenna design, pointing and operation, and efficient manufacturing
and testing techniques are all important. All of these advances, plus new and expanded demand for various space-based services, have led to many new proposals for new commercial small satellite constellations to be deployed in the next decade.

The 2020s seem to be the time for deployment of a large number of small satellites. These range in size from 3-unit cubesats (around 5 kgs in mass) such as for the planet remote sensing network (now with over 400 Dovesats in orbit) up to 250–500 kg small satellites to support networks for worldwide networking services such as for Orbcomm, Linksat, the Telesat constellation, and over a dozen other constellations.

3 The Case Study of the OneWeb Smallsat Constellation

One of the reasons that the Teledesic satellite system went into bankruptcy was that the estimated costs for manufacturing of the satellites were underestimated. In the case of the OneWeb Satellite Constellation, the costs of production of the satellites are reportedly significantly underestimated. It seems that the prudent step has recently been taken to reduce the constellation size from around 900 to 600 satellites. This should prove to be a key way to control cost since this will not only reduce the cost of the manufacture and testing of the satellites but will also directly serve to reduce initial launching costs as well. The speculation is that this reduction was driven by the need to raise over a billion dollars in capital that was not readily available (Todd 2018).

If it were not for OneWeb’s bankruptcy this system would have been perhaps the first to market, and if possible support from the U.K. government materializes this could still possibly be the case. Greg Wyler, who first conceived to this type of system to serve underserved portions of the world, cleverly tested the idea by organizing the O3b medium Earth orbit (MEO) satellite network. This O3b network, with its name standing for the “Other Three Billion,” was designed to provide service to the equatorial regions of the world where some three billion people live with low incomes, inadequate health care and education, poor housing, limited access to potable water and food, and limited access to electricity, lighting, and telecommunications and networking capabilities. This network was started in partnership with the SES satellite network and other partners and is now wholly owned and operated by the SES company, headquartered in Luxembourg, and is one of the world’s largest satellite operators.

The experiment with the O3b satellite constellation in MEO orbits led to the much more ambitious further step that has been championed by Wyler. This was a move to provide a network that would allow even smaller ground stations less latency or network delay. This was the OneWeb network that Wyler hoped to deploy in 2021-22 before bankruptcy (Fig. 3).

This network is challenging on many different scales starting with the big three listed below:

1. There is a need to build and quality-test the satellites at sufficiently low cost to be financially viable.
2. There is the challenge of launching the network in an efficient and timely manner so that the very large number of satellites makes it into orbit in sufficient numbers within a narrow time constraint sufficient to provide the global service requirements and not break the budget.

3. There is the difficulty of ongoing viable operations that include avoiding collision of a huge number of satellites; not interfering with other satellites, especially in the GEO arc; and installing a large number of ground systems to interface with users.

With regard to challenge 1, OneWeb has reduced the number of satellites in the original constellation, presumably in part, because of cost overruns in producing the satellites and because of the need for raising more capital.

With regard to challenge 2 of a speedy and massive launch deployment campaign, one can look to the experience of the Iridium Next constellation. Here there was the problem of heavy dependence on a single launcher system. A launch failure when there is only one system does shut down launch operations when the failure analysis occurs. The deployment of the Iridium Next Satellite network was, for instance, seriously delayed by the SpaceX Falcon 9 launch vehicle failure. The following risk assessment was reported in 2016 by TeleAstra concerning the Iridium Next system where only some 70 satellites – not many hundreds – were being deployed. This launch risk assessment was provided in this case several years ago.

“The real issue is that SpaceX has a launch manifest with 26 other launches prior to Iridium NEXT. Once the Falcon 9 launches begin it has taken about one month between launches. This means that the replacement constellation cannot begin to
provide new service until early 2018. In the mean time the old satellites are aging, wearing out, or running out of fuel” (TeleAstra assessment of iridium next launch deployment risks. Part 10, 2017 report.). In this case the first-generation satellites continued to operate many years beyond their expected lifetime, and the Iridium Next system is fully deployed, but the point is well taken.

Challenge 3. Even if challenges 1 and 2 can be surmounted, there are still an ongoing series of issues to be addressed. It is an exacting effort to create “fail safe” artificial intelligent control systems that are fully tested to ensure that there are no collisions within the large-scale constellation, that the satellites are pointed away from GEO satellites as they cross the equatorial arc, and that conjunctions with spurious debris are avoided. There are deployment and operational issues of getting thousands, tens of thousands, or perhaps even a million new ground systems installed and operating.

4 The Enormous Challenges of Deploying the SpaceX Starlink System and Achieving Financial Viability

If the OneWeb System faces challenges to be technically, operationally, and financially successful, then the challenges associated with the SpaceX Starlink Systems are much, much greater. This is because the number of satellites, the capital investment, and business model challenges are all much larger.

The challenge of manufacturing, qualifying, and testing of some 12,500 smallsats is an unprecedented set of tasks in the history of commercial satellite undertakings. At $10 billion this would be the most expensive satellite system, and some 7500 satellites would be operating in the V-band spectrum which has never been used operationally for telecommunications and networking services. To some this is a risk comparable to betting on the 3 race exacta at a horse race with long odds on all the horses, but then Elon Musk has already accomplished many long odds challenges with PayPal, Tesla, and SpaceX.

And not all of the risks to the megaLEO satellite network are out in space. In one of the recent actions by SpaceX, it has submitted a petition to the US Federal Communications Commission for a huge investment on the ground as well. In this petition permission is being sought to deploy on the order of one million ground systems to connect to these microsatellites in order to link to users in the underserved locations around the world so that the Starlink satellite network can serve the underserved or unserved populace of the world.

This petition sought approval to receive blanket approval for up to a million Earth stations that would be used by customers of the Starlink satellite for internet networking service. The petition that was filed on behalf of a sister company called SpaceX Services sought that these Earth stations could be considered for “type approval” rather than individual licensing and approval. The design for these Earth stations is now identified as being exclusively based on a flat-panel, phased array system that would be able to transmit and receive signals operating in the Ku-band to
and from the Starlink constellation. Presumably a similar approach will be taken for the V-band system that SpaceX has also proposed (Boyle 2019) (See Fig. 4).

The other aspect of the Starlink constellation is that it is being designed not only to provide access to rural and remote areas of the world that have limited broadband Internet service capabilities, but it is also conceived as a broadband network that would provide very high trunking throughput connections that could compete with fiber-optic networks. Some believe that only if this huge network can serve the developed and the developing world can it achieve sufficient revenues to support the large capital investment that it requires to succeed financially.

In the latest SpaceX filings with the FCC, it is proposed that the Starlink network would be deployed, at least partially in a much lower orbit than first proposed. This new deployment plan is explained on the basis of seeking to minimize the problems associated with orbital space debris and also with the desire for minimal transmission delay. Low latency, or in effect, very fast end to end connectivity is needed to be competitive with fiber links. In particular the latest proposal from SpaceX is that 1584 of the 4400 plus satellites in the Starlink constellations would be deployed to an altitude of 550 km (342 miles) as opposed to the 1150-km (715-mile) orbit described in SpaceX’s initial round of filings with the FCC (Boyle 2018). This filing was made after SpaceX had unexpectedly launched two experimental prototype “TinTinA and TinTinB” satellites into lower orbits than their previous filings had indicated (Grush 2018) (See Fig. 5).

The SpaceX filing has said in support of its lower orbit proposal: “This move will help simplify the spacecraft design and enhance the considerable space safety attributes of SpaceX’s constellation by ensuring that any orbital debris will undergo rapid

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**Fig. 4** The megaLEO constellation of smallsats know as the Starlink constellation. (Graphic courtesy of Thales Alenia)
atmospheric re-entry and demise, even in the unlikely event that a spacecraft fails in orbit.” It will also remove a small number of satellites from the constellation design.

The SpaceX filings have indicated that there is also a close focus on the latency issue. It was indicated that the latency experienced with the TinTin experimental satellites is currently 25 ms, but with the network deployed as proposed, it should only experience 15 ms delays. Or as Elon Musk has expressed it, this would support interactive computer game participation. Skeptics thus have indicated that it was latency performance and not concern with regard to orbital debris that has moved the network altitude to a lower level.

The bottom line is that the SpaceX Starlink constellations will face the same types of challenges that OneWeb will face plus a few more. The cost of manufacturing and launching 12,500 satellites and have them operational by 2025 and keeping the costs down to 10 billion dollars is a huge challenge. To this amount must be added the cost of the ground segment that is using the new electronic beam forming technology. Further there can also be issues related to tariffs that might be imposed on ground systems as well as issues within various countries that are not members of the World Trade Organization (WTO) as to local landing rights and other trade or tariffs issues involving local telecommunications and networking companies.

There are also important technical issues involved with the operation of very large and complex megaLEO networks in order to avoid collisions or conjunction with orbital space debris. The ability to provide the high-speed switching from one beam to another at very short intervals and to operate inter-satellite links in very short order that link between multiple satellites to complete a transoceanic link are new challenges to the world of satellite operation. It is remarkable how similar the technical, operational, financial, and ground system implementation challenges that SpaceX with the world’s largest satellite constellation will face in the next five years, that the Teledesic System faced two decades ago. The latest challenge has come from astronomers who are now complaining of visual pollution of the heavens.
The Many Other Microsat and Minisat Constellations and the Challenges that They Face

The preceding analysis of the OneWeb and SpaceX Starlink was chosen to be highlighted since these two constellations represent on one hand the first of the megaLEO systems to be deployed and on the other hand the largest system that is planned to be deployed. These two systems are useful case studies for analyses but are still not completely representative of the many smallsat constellations now planned and the wide diversity of services that they might offer in the next few years. The technical, operational, and financial plans for these two systems nevertheless serve to help identify some of the basic issues and challenges that all of these various smallsat constellations will face. There are an ever-growing number of smallsat constellations that are still being envisioned, and the size of these smallsats ranges from the low end of microsats or the high end of nanosats (such as 3-unit cubesats) with a mass of only a few kilogram up to the high end of microsats with a mass up to 500 kg. The diversity is still very great in proposed small satellite constellations. HawkEye 360 only has 3 of 18 smallsats deployed and it is providing new RF Geolocation services. Karousel is to have 12 elliptical orbit satellites and it is designed for video programming services. At the other extreme is the SpaceX Starlink and V-band networks with a proposed network of over 12,500 smallsats. This exceedingly wide range of planned and proposed networks is shown in Table 2. This diversity is too great to make many generalized statements about smallsat constellations. Thus each proposed commercial smallsat constellation deploying microsat or minisat networks must be considered and assessed on its individual merits (See Table 2).

Various sources of inspiration and backing have led to the proliferation of various new smallsat constellations. In Canada, the Canadian government has backed programs to design and build small satellites. It created a $100 million Innovation Fund for rural communications and small satellites. It also created a streamlined regulatory process to encourage small system. This effort seemed to pay off and to spur innovation in this field (Pugliese 2019).

Indeed at this time there are 13 identified initiatives to create small satellite constellations that represent a total of over 300 new satellites with at least 3 new systems yet to be publicly announced (Boucher 2018) (See Table 3).

There have been additional promotional efforts to encourage smallsat experimentation and new commercial developments. In the United States, there have been numerous conferences, funder conferences, and NewSpace- and incubator-related activities in Silicon Valley, Utah State University, in cooperation with the AIAA, the New York Space Alliance, and more.

In China there has been strong governmental support for new small launcher industries and new small satellite ventures. This has led to a number of new Chinese ventures. These small satellite and launch vehicle startups include the following smallsat constellations Commsat, Hongyan, Lucky Start, and Xinwei. In New Zealand, the government has not only included strong support for the Rocket Lab’s small satellite launcher program. New Zealand has now started a global recruitment drive to bring space entrepreneurs to New Zealand as immigrants. All of these efforts are aimed at creating new high-tech jobs and encouraging enterprises to support the
growth of NewSpace economic enterprises for the twenty-first century. And the examples provided above with regard to the United States, China, and New Zealand are illustrative of efforts elsewhere. The large number of new efforts shown in Appendix C on small satellite constellations and in Appendix D with regard to new launch vehicle industries shows how these new enterprises are spreading worldwide.

What must be considered – amid all this new enthusiasm for space – is the possibility of oversupply of new small spacecraft offering a panoply of new networking bandwidth services, new remote sensing, automatic identification services

Table 2  Basic information on various planned small satellite constellations

| State            | Constellation         | # of sats | Radio-frequency bands                                                                 |
|------------------|-----------------------|-----------|--------------------------------------------------------------------------------------|
| Canada           | CANPOL-2              | 72        | LEO and highly elliptical Earth orbit in VHF-, UHF-, X-, and Ka-bands                 |
| Canada           | Telesat constellation| 117 satellites plus spares | LEO in Ka-band                                                                      |
| Canada           | COMSTELLATION         | Nearly 800 satellites | LEO in Ka-band                                                                      |
| Canada           | Kepler constellation  | 15 Gen-1 and eventually 140 | LEO in 1100 Km orbit using cellphone frequencies                                     |
| France           | Thales Group’s MCSat  | Between 800 and 4000 | LEO, MEO, and highly elliptical Earth orbit in Ku- and Ka-bands                     |
| Liechtenstein    | 3ECOM-1               | 264       | Ku- and Ka-bands                                                                     |
| Norway           | ASK-1                 | 10        | Highly elliptical Earth orbit in X-, Ku-, and Ka-bands                               |
| Norway           | STEAM                 | 4257      | Ku- and Ka-bands                                                                     |
| United Kingdom   | L5 (OneWeb)           | 650–750   | Ku- and Ka-bands                                                                     |
| USA              | Boeing                | 1396–2956 | V-band in 1200 km orbit                                                             |
| USA              | SpaceX                | Up to 4000 | Ku- and Ka-bands                                                                     |
| USA              | SpaceX                | 7500 plus | V-band                                                                               |
| USA              | LeoSat                | Initially about 80 | Ka-band                                                                 |
| USA and intern’l partners | Theia   | 112 constellations | Combined networking and remote sensing constellation                                 |
| USA              | Planet                | 400 to 500 3U cubesat and Terra Bella Sats | Remote sensing system that combines Skybox/Terra Bella satellites, Planet Lab “Dove” satellites, 6 SSTL “Eye” Satellites |
| USA              | Karousel LLC          | 12 Satellites | Elliptical Orbits to use Ku- and Ka-bands for TV video programming streaming         |
| USA              | HawkEye 360           | 3 Satellites | RF frequency use and AIS monitoring net                                              |

Note: This table is prepared by J. Pelton for lectures for the Spacelab program at the University of Cape Town, and all rights are reserved. This chart is licensed for this publication on a one-time use basis.
The competition that comes from this disruptive technology and disruptive business models could drive global markets to be priced below incremental costs. In the world of communications and networking satellites, this is not only a matter of new smallsat constellations competing against each other, but there are other dimensions here as well. At the same time there are new high-throughput satellite systems that are disrupting GEO satellite markets. There are also fiber nets connected to 5G systems that are being deployed around the world. Short disruptive technologies in the telecommunications and networking world are transforming global markets and making competition virtually explode in both the developed and developing world.

The listings in Table 2 of new smallsat constellations are not exhaustive, and new systems keep being filed, and even those that are already filed are changing orbits and adding satellites or design features. Today these systems are dominated by US-, Canadian-, and European-based networks, but systems from other parts of the world may still be filed in coming months and years. The appendices found at the end of the handbook are as current as possible, but it is wise to go to indicated

**Table 3** Canadian smallsat constellations pending deployment. (See [http://spaceq.ca/13-canadian-commercial-satellite-constellations-in-development/]())

| Organization                        | Name of sat constellation | Number of sats planned | Type of orbit | Service planned                                           |
|-------------------------------------|----------------------------|------------------------|---------------|----------------------------------------------------------|
| Aireon                              | Hosted payload on Iridium Next | 66 | LEO | Aircraft navigation and surveillance                      |
| exactEarth                          | AprizeSat                  | 75 | LEO | Automatic identification service (AIS)                    |
| CB2.0 Communications                | Clarke Belt 2.0            | 24 | HEO | Internet of Things, 5G mobile backhaul services and connectivity |
| GHGSat                              | GHGSat                     | 13 | LEO | Global emission monitoring                                |
| Govt. of Canada                     | Radarsat Constellation     | 3  | LEO | Remote sensing                                            |
| Helios Wire                         | Helios Wire                | 28 | LEO | Internet of Things, M2M data relay                       |
| Kepler Communications               | Kepler                     | 140| LEO | Internet of Things, M2M data relay                       |
| NorthStar Earth and Space Inc.      | Northstar                  | 40 | LEO | Remote sensing using optical, infrared, and hyperspectral sensing |
| UrtheCast                           | Optistar                   | 16 | LEO | Combined optical and synthetic aperture radar sensing     |
| Wyvern                              | Wyvern                     | 1  | LEO | Hyperspectral sensing                                     |
| At least 3 other small sat constellations pending public announcement | Pending publication | ? | ? | ? |
websites to get the latest and updated information. The Covid-19 related economic downturn, the rapid rate of technical innovation, and the uncertainty in financial markets and emerging bankruptcies, all suggest turbulent times ahead for new smallsat constellations.

6 The Future

The future of microsats and minisats is currently unclear. Today the world of satellite manufacturing and space launch systems is in a period of transition. The global trend that has existed for nearly 50 years has been toward bigger and more capable satellites with more power and larger aperture antennas for communications and larger remote sensing satellites.

This course has successfully been pursued by such global communications satellite providers such as Intelsat, SES, Telesat, Eurosat, EchoStar, and DirecTV to extend their markets and reduce cost. The same has been true for those providing space-based remote sensing for many decades such as Spot Image, WorldView, GeoEye, Digital Globe, QuickBird, and IKONOS. The world of space-based applications is clearly changing not only for telecommunications but also remote sensing and many new services such as for automatic identification services (AIS) and frequency monitoring. There are many innovations that continue to appear in the world of smallsat constellations. This is very much the case for commercial space services now being offered by 3-unit cubesats, microsats, and minisat constellations.

The graphic in Fig. 6 shows a new landscape in the world of remote sensing that is being driven by start-up constellations using a lot of smallsats, drones, or high-altitude platforms (HAPS), in lieu of a few large-scale satellites. This map of innovators in the remote sensing world shows just how pervasive the changes are becoming as 20 new startups are identified here (Ivanov 2017).

![Fig. 6](image-url) The exploring number of disruptive new ventures in remote sensing. (Graphic courtesy of AgFunder)
This changing world has yet to come into focus. Some of the new start-up constellations will fail, but others will succeed. In some cases first-generation constellations will fail at first try, but will reinvent themselves with new owners, new management, or creative mergers. The first satellite constellations for mobile services such as Iridium, Globalstar, and Orbcomm went through such transitions to emerge with new strength and improved business plans. The future will remain in a shakedown period through the mid 2020s. The outcomes for the success, failure, or perhaps reinvention of the dozens of smallsat constellations now being launched or proposed will remain unclear until the later part of the 2020.

7 Conclusion

The world of smallsat constellations is clearly swirling with change. There have been major technical changes that have also served to reduce cost. We have seen the miniaturization of various electronic sensing devices, of digital processing and memory systems, and of thrusters, stabilization systems, as well as other components onboard spacecraft. We have also seen the development of ground stations with the ability to electronically form beams to track spacecraft as they move across the horizon. In some instances, these new smallsats can be fabricated using off-the-shelf components. These factors combine to reduce the volume, mass, and cost of satellites to a striking degree. And this is not all. The smaller and lighter smallsats also serve to reduce launch costs—a lot. Further the launch into low Earth orbit with many of the smaller spacecraft being launched at the same time, rather than painstakingly being launched into a precise geosynchronous orbital slot, also serves to reduce cost as well, although this is offset by the fact that many more spacecraft must be launched to create a fully populated global coverage system.

The name of this revolutionary series of changes known as “NewSpace” or “Space 2.0” reveals a lot. The amount of disruption to the various space industries is significant. At the same time newly engineered GEO satellites, called high-throughput satellites, have likewise been disruptive in that these satellites can be ten times more cost-efficient or even more so. This has also served to disrupt markets.

Satellites in low Earth orbit have the power advantages that come from much less path loss or beam spreading that is associated with sending a signal all the way to or from the GEO orbit. Newly deployed commercial satellites in constellations deployed in low Earth with masses that might range from 5 to 500 kg are quite different from their GEO forebears which might have a mass of 5000–8000 kgs. Each one of these smallsat systems may have a different size, shape, configuration, mission, and orbit and a different means of launching. Yet these systems are still recognizable as different from the large spacecraft that have been dominating the commercial satellite industry up until just a few years ago.

There is still not a single rule that applies. Large GEO satellites are still highly cost-effective and still dominant for the most lucrative of all satellite services which is direct broadcast television services that can also provide direct digital
services such as software downloads and others to the edge services via DVB-RCS2, DOCSIS, and other such video broadcast standards. The innovations with miniaturization and satellite constellation design are certainly not yet complete. The further development of new interactive ground systems with electronic beam forming and employing meta-materials will be key to reducing costs and these additional innovations.

Perhaps the most interesting part of the unfolding saga with regard to the development of new smallsat constellation of microsats and minisats is not which of the new systems will succeed or fail. The most interesting question is what new applications and services will evolve. Already the new economics and thought process associated with the NewSpace revolution has seen new systems being planned and launched to provide such innovative and unexpected services. We have seen new networks designed to capture the automatic identification service (AIS) signals from ships and other vehicles (i.e., the Spire and HawkEye 360 systems). The HawkEye 360 system is also designed to provide global monitoring of frequency use that might be used to identify sources of frequency interference and assist with law enforcement in such areas as drug smuggling, illegal fishing, or even crimes against humanity.

8 Cross-References

- 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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