A new paradigm for space

Enabling the emergence of mega-constellations

Edison themes

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Constellations of hundreds of small, interconnected satellites are increasingly being deployed by defence bodies to provide real-time threat detection with global coverage, and by commercial entities to provide internet connectivity to remote and rural areas, environmental monitoring services and asset tracking. This report, which is the third in our sequence of three on mega-constellations, explores how the space industry is adapting to this challenge by adopting nimble, lower-cost design and manufacturing methodologies and reducing the cost of launching satellites into space. It also discusses why mega-constellations such as SpaceX's Starlink are deploying optical communications links between satellites.

Proliferation of satellites

The shift from using a handful of complex satellites to constellations of hundreds of small, much less expensive satellites is driving a rapid increase in the number of satellites being launched each year. Until SpaceX started to launch its Starlink satellites into low Earth orbit (LEO) in 2019, the highest number of satellites launched in a single year was 143 in 1967. However, nearly 1,200 satellites were launched in 2020, with 1,778 satellites and spacecraft in 2021. This accelerated rate of satellite launches is expected to continue over the next decade. For this to happen, the cost of building and launching satellite platforms and their payloads needs to be substantially reduced so providing services via mega-constellations of LEO satellites is economically viable.

Interconnecting satellites with lasers

Constellations including SpaceX's Starlink, Telesat's Lightspeed and the US Space Defense Agency's (SDA's) system are deploying optical communications to connect satellites. These links enable data to pass between satellites at speeds comparable to fibre broadband connections and substantially improve the versatility and resilience of constellations. The report explores why intersatellite links are useful, the advantages of optical links over microwave ones and why the SDA is developing a standard to ensure interoperability between optical communications terminals from different vendors.

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Enabling the space industry's new paradigm

Acceleration in the number of satellites launched

As discussed in the first and second notes in this series, demand for connectivity and remote monitoring services over satellite for both government and commercial purposes is driving a rapid increase in the number of satellites being launched each year. According to Statista, between 1957 and 2019 the highest number of satellites launched in a single year was 143, which was achieved in 1967. There was a step-change in 2020, when nearly 1,200 satellites were launched (source: Satellite Industry Association), primarily attributable to SpaceX ramping up activity on its Starlink constellation. This was followed by the launch of 1,778 satellites and spacecraft in 2021 (source: CosmoQuest). The accelerated rate of satellite launches is expected to continue over the next decade. According to a report published by Euroconsult in December 2021, there will be an average of 1,700 new satellites launched each year by 2030.

Reduction in launch costs

We believe the step-change in launch activity that took place in 2020 was partly attributable to the substantial reduction in launch costs enabled by the use of reusable launch platforms. According to a study by the US Center for Strategic and International Studies, NASA's space shuttles cost an average of $1.6bn per flight, equivalent to nearly $30,000 per pound of payload (in 2021 US dollars) to reach LEO. Russia's Soyuz rockets cost from $53m to $225m per launch, equivalent to over $8,000 per pound of payload. In contrast SpaceX, which deploys reusable launch platforms, has recently put up its prices for its small satellite rideshare programme to start at $1.1m for a payload weighing 200kg (equivalent to c $2,500 per pound of payload).

Exhibit 1: Video showing SpaceX landing reusable rocket

Source: SpaceX

Reduction in manufacturing costs

If commercial mega-constellations are to be viable, they need to offer internet packages at rates comparable to those that can be achieved by fixed and mobile networks. This means the cost of manufacturing satellites also needs to come down. In 2016 satellite communication company Talia estimated that fewer than 100 high-throughput communications satellites would collectively cost over $17bn. In contrast, according to Teslarati the cost of manufacturing one of SpaceX's Starlink satellites was well below US$0.5m in 2019. The transition from deploying a few highly complex, expensive communications satellites to constellations of many smaller, relatively inexpensive satellites substantially reduces the initial capital costs for network operators and enables them to start collecting revenue more quickly because the network can be rolled-out in phases.

Achieving this level of cost reduction has been a challenge for the space industry, which historically has manufactured one-off, highly complex and expensive satellites that have taken several years to design and build. The new approach needed is exemplified by companies such as AAC Clyde Space (AAC:SS; see our research on the company), which has been supplying the small satellite market since 2005. Among other services for the small satellite market, the group designs, builds, integrates and tests complete microsatellite platforms weighing up to c 50kg, including nanosatellites (satellites weighing less than 10kg). The use of standardised subsystems and platforms is fundamental to the group's approach, enabling it to supply multiple identical satellites for deployment in constellations. AAC also builds, owns and operates nanosatellites to service customer requirements and will launch networks of LEO microsatellites over the remainder of this decade to enhance its space data as a service (SDaaS) offering.

It is notable that SpaceX, which by April 2022 had launched more than 2,300 Starlink satellites, decided to design and manufacture these satellites in-house, rather than outsource them to a long-established aerospace contractor. By March 2022, SpaceX was manufacturing 'close to eight satellites a day' at its facility in Redmond, Washington. Both Planet Labs (PL:US), which has over 200 Earth observation satellites in orbit, and Satellogic (SATL:US), which has 22 Earth observation satellites in orbit, also build and manufacture their satellites in-house. Satellogic is building a factory in the Netherlands that it intends will be able to output 25 satellites per quarter by Q323. Bringing manufacturing in-house has the additional advantage of enabling these two Earth observation companies to update each new batch of satellites with up-to-date technology. (Please see our second note in this series, Internet in the sky, for details of these and other commercial mega-constellations.)

Achieving cost reductions is also a challenge for traditional defence contractors supplying satellite payloads. In December 2021 CACI International (CACI:US), a large defence contractor that had previously manufactured advanced laser communications systems for NASA and US intelligence agencies, acquired SA Photonics for US$275m to pursue military and commercial markets for small, lower-cost optical terminals. As well as changing their manufacturing methodology to meet customers' target prices, traditional contractors need to expand their manufacturing capacity. For example, CACI is expanding its manufacturing facilities in Florida so it can produce several hundred optical terminals per year. Tesat is preparing for a production rate of 160 optical communication terminals per month, equivalent to 1,920 terminals/year. General Atomics is expanding production facilities in California and Mississippi. Mynaric, which is a relatively new market entrant so does not need to unlearn traditional manufacturing methodologies, opened a new production hall at its facility in Germany in June 2021 to meet expected demand. The company has an ultimate annual production target of 2,000 terminals.

Reduction in design times

Historically, government satellite programmes have been more concerned about functionality, rather than cost. However, SDA is developing a mega-constellation of nearly 1,000 LEO satellites and intends to launch hundreds of satellites into space every two years until at least 2030. The agency has stated that to keep the pace needed to design, build, procure and launch so many satellites, it is relying heavily on industrial partners. Importantly, the SDA wants these industrial partners to change their mindset. The SDA notes its motto 'Semper citius', which translates as 'always faster', recognises that good enough capabilities in the hands of the joint war fighter sooner may be better than delivering the perfect solution too late. It wants its industrial partners to adapt their process methods from ones that were suitable for delivering small numbers of complex, individually designed satellites to methodologies suitable for delivery of hundreds of smaller, less expensive satellites. It is also asking suppliers to meet short timeframes. Historically, it has taken two to three years to develop and launch a larger commercial satellite. In contrast, a small satellite for deployment in a LEO mega-constellation can be developed and launched in less than a year.

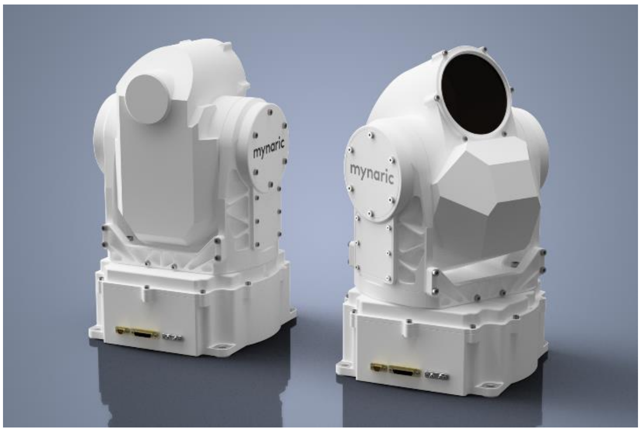
Interlinking satellites

Cross-links critical for difficult terrain

Until the advent of constellations with dozens of satellites such as Iridium, satellites typically operated on a 'bent-pipe' model. Satellites would receive signals transmitted from the Earth's surface and retransmit them to other points within the same footprint. This was fine for applications deploying satellites in geostationary orbit (GEO) because they are so far from the Earth that a single satellite can cover almost one-third of the Earth's surface. Since LEO satellites are closer to the Earth's surface, the footprint covered by each individual satellite is much smaller, typically a radius of about 1,000km. The 'bent-pipe' model is still viable for LEO observation satellites, but only if the data are not time critical and it is acceptable to wait for a satellite to pass over the North Pole and collect temperature data (for example), store those data until the satellite is above a ground station, such as in Alaska, transmit the data to the ground station then to a terrestrial network. It is only practical for an internet user if both they and a ground station are simultaneously in the same satellite footprint. It would not work for a military application if the US government wanted to receive data immediately from a satellite above, say Russia, because the nearby Earth stations would be under the control of another nation. The solution to these problems is to add cross-links to satellites so they can communicate with neighbouring satellites in the network. If there is not a suitable ground station underneath to transmit to, signals can be transferred from one satellite to the next until they reach one where there is a suitable ground station within its footprint.

Optical cross-links versus microwave crosslinks

Exhibit 2: CONDOR terminal for intersatellite links



Source: Mynaric

Exhibit 3: Testing optical communications links in a cleanroom environment

Source: Mynaric

One of the first satellite constellations to deploy intersatellite crosslinks was Iridium. It uses microwave (radio frequency) links operating at 23.2–23.4 GHz, which is the Ka frequency band. More recent constellations including SpaceX's Starlink, Telesat's Lightspeed and the SDA's system are deploying optical communications to connect between satellites. These operate at a much higher frequency than microwave links, for example Mynaric's (M0Y.DE, MYNA.US; see our research on Mynaric) optical terminals use near infrared light waves, operating at around 200THz (1THz = 1,000GHz). Optical technology supports transmission rates similar to what is achieved through optical cables in terrestrial applications. Experiments have demonstrated rates up to 320 times faster than the transmission rates achievable using advanced microwave links between satellites and the Earth and for intersatellite links. This speed is clearly advantageous for internet-in-the-sky applications. It is also beneficial for downlinks from Earth observation satellites, because microwave links do not have the bandwidth to transmit all the data the satellites actually collect. In April 2022 optical links were used to transmit and receive more than 200 gigabits of data between the two Mandrake 2 satellites deployed under US Defense Advanced Research Projects Agency's (DARPA's) Blackjack programme. (See the second report in this series for more about the Blackjack programme.) The two satellites were about 100 kilometres apart. This test was a key step in demonstrating the viability of establishing optical links between two fast-moving satellites. Future links are expected to achieve much faster transmission rates (see Exhibit 4).

Exhibit 4: Evolution of optical communication links

Programme	Estimated/actual timescale	Target/actual speed
Mandrake 2	April 2022	Estimated at 0.04Gbps*
Blackjack	H222	1.25Gbps
SDA Tranche 0 Transport Layer	H222/H123	< 2.5Gbps
SDA Tranche 1 Transport Layer	2024	Not known
Telesat Lightspeed	2025	10Gbps
Space-BACN	2025–26	100Gbps

Source: Edison Investment Research. Note: *Assuming bi-directional link operated continuously throughout the test period.

Wireless laser beams spread out orders of magnitude less than microwave links, so they are much more difficult to intercept illegally and therefore much more secure. The narrowness of the laser beam also means that wireless laser links from one network are less likely to interfere with wireless laser links in another network, so it is not necessary to obtain an operating licence from the International Telecommunication Union, for a wireless laser network. Obtaining a licence can take a year or two, significantly holding up constellation deployment. The interference issue is particularly important when considering constellations of many hundreds of LEO satellites and their impact on transmissions from existing GEO satellites. Additionally, laser links are significantly more power efficient, which is an important advantage when transmitting from a solar-powered satellite.

Interoperability is key

Having cost-effective, interoperable, low-weight, low-power optical terminals is considered such a vital part of the SDA's system that DARPA has a dedicated programme, Space-Based Adaptive Communications Node (Space-BACN), to develop one. The companies participating in Space-BACN that manufacture terminals are Mynaric and SA Photonics, which was acquired by CACI International in November 2021 for US$275m. We have previously inferred that Mynaric, SA Photonics and Airbus's (AIR:PA) subsidiary Tesat are supplying terminals for the initial phase (Tranche 0) of the SDA's system. Since Northrup Grumman Space Systems has been awarded a contract worth US$692m to supply 42 satellites for the next tranche (Tranche 1) of the system and in March 2022 Mynaric announced that it had 'entered into a definitive agreement with Northrop Grumman for delivery of optical communication terminals in the framework of a US government space program led by the Space Development Agency', it is reasonable to assume that Mynaric will be supplying terminals for the next phase of constellation roll-out as well.

Interoperability between terminals from different manufacturers is key because this removes the risk associated with having a single supplier of such a critical component. It also means different constellations can communicate with each other, so a government body would not need a dedicated constellation with complete global coverage, but could achieve that by complementing its own coverage with that from commercial constellations.

In May 2021, Mynaric became the first manufacturer to demonstrate compliance with the SDA's optical intersatellite link standard. In May 2022 Mynaric announced it had signed a contract with Airbus U.S. Space & Defense to host a Mynaric terminal on the International Space Station's functional testbed, Bartolomeo. The location will give the terminal a clear view of Earth and space, allowing Mynaric to test and demonstrate a range of laser communication use cases for its customers, including compliance with the SDA's interoperability standard. The terminal involved should be shipped out as part of the International Space Station Fall 2022 resupply mission.

Market growth predictions

In February 2022, Northern Sky Research published the fourth edition of its Optical Satellite Communications report. This projects a US$2bn market for optical satellite communication equipment over the next decade, driven primarily by upcoming LEO constellations. The report predicts market growth of 47% CAGR over the next decade to reach projected cumulative demand of around 6,000 terminals between 2022 and 2031, with a maximum demand of just under 900 terminals in 2031. The level of manufacturing capacity being installed by CACI, Mynaric and others noted above suggests this prediction is highly conservative, provided of course that the potential capacity is relatively well-utilised. Indeed, SpaceX could account for this number of terminals on its own if it launches a substantial proportion of the 12,000 LEO satellites that it was given approval for by the Federal Communications Commission (FCC) in March 2018 and each of these is equipped with two or more optical communications links.

Optical links to provide navigation capability

Lasers can also be used to measure distance, for example the LiDAR currently used in iPhones for face recognition or in collision avoidance systems in vehicles. The lasers forming communications links between satellites can also be used to measure distance. The SDA also intends to use optical communication terminals and optical space to ground links to create a GPS-independent navigation capability for the National Defense Space Architecture constellation. The laser-based system will carry out situational awareness monitoring, providing information about the availability and possible corruption of GPS signals in both the terrestrial and space domains. If there is an issue with the GPS service, the system will then provide warfighters with an alternative source of positioning.

Other notes in this series

All seeing eye in the sky: a review of how governments are increasingly investing in constellations of many interconnected small satellites to provide timely information about military threats on a global basis, to support humanitarian rescue efforts, to monitor climate change and to prevent smuggling. **Published 9 May 2022**

Internet in the sky: a review of how constellations of hundreds of small, interconnected satellites are increasingly being deployed to provide internet connectivity to remote and rural areas, environmental monitoring services and asset tracking. The report also profiles several existing and proposed constellations, including those being rolled out by companies that have recently listed in the United States via the special purpose acquisition company route. **Published 23 May 2022**

While not part of this series of reports, the importance of adopting higher volume manufacturing methodologies to supply satellites at the price point, volume and timescales required for mega-constellations is discussed in our recent webinar The industrialisation of space and an associated interview with Mynaric.

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