Mitigation of Anti-Competitive Behaviour in Telecommunication Satellite Orbits and Management of Natural Monopolies

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Abstract

Previous activities in developing satellite networks for telecommunications such as the TelStar, Relay and Syncom satellite networks of the early 1960s through to the Iridium, Globalstar and ORBCOMM constellations of the 1990s were reserved to geostationary orbits and low orbits with less than 100 satellites comprising their network. These satellite networks distinguished themselves by being business-to-government and business-to-business facing by contracting with government and domestic carriage and media providers for the supply of services. Customers for these services did not constitute either small to medium sized businesses, or individuals in the general public.

With the advent of what has been dubbed 'NewSpace', however, new entrants into the market are developing constellation satellite networks that operate in Low Earth Orbit (**LEO**). Unlike the legacy satellite telecommunication networks of the 1960s-1990s, these constellation satellite networks are focused on, amongst other things, Internet of Things (**IOT**) devices, asset management and tracking, Wi-Fi hot-spotting, backhaul networking and contracting with small businesses and the general public.

Regional examples of these new telecommunication heavyweights include Fleet Space Technologies (**Fleet**) - an Australian company undertaking to launch 100 satellites into LEO, Sky and Space Global (SAS) - an Australian-British-Israeli consortium that intends to provide a constellation of 200 small satellites, OneWeb's planned fleet of 650 satellites that may be expanded to 2,000 satellites, and, SpaceX's planned StarLink network of 12,000 satellites. In addition, companies such as Spire and PlanetLabs intend to provide geospatial information through their own constellation networks to government and educational institutions alongside the private sector.

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Although propertisation of space and celestial bodies is prohibited under the *Outer Space Treaty 1967* (UN), near-Earth orbits still remain rivalrous and commercially lucrative. By operating in a LEO environment, these satellite constellation networks have the potential to exclude competing services by new entrants to market. For example, where one constellation network has an orbital plane or orbital shell, another constellation may not be able to have the same orbital plane or orbital shell.
Presently, the literature to date focuses on the allocation of spectrum bandwidth, and space traffic management with a focus on orbital debris mitigation. This paper addresses these concerns and offers recommendations on how the risk of 'natural' monopolies forming for specific constellation satellite networks in LEO may be mitigated under instruments available to both UNOOSA and the ITU.

Keywords: anti-competitive conduct, constellation satellites, monopoly

Acronyms/Abbreviations

EO	Earth Observation
GEO	Geosynchronous Earth Orbit
ITU	International Telecommunication Union
LEO	Low Earth Orbit
OST	Outer Space Treaty
SSO	Sun Synchronous Orbit
UN	United Nations
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
UNOOSA	United Nations Office of Outer Space Affairs

1. Introduction

Space is vast beyond measure, but those volumes of it that are economically useful to humanity are not. Certain orbital shells become useful due to the orbital period of satellites inserted into those orbits (such as Geosynchronous Earth Orbit (**GEO**); the proximity for Earth to Earth observation (**EO**) satellites in LEO; and a combination of the previous two merits for satellites inserted in Sun synchronous orbits (**SSO**) for EO and satellite ground track coverage [1].
Since property rights are traditionally derived from national laws, and the Outer Space Treaty (OST) prohibits "*national appropriation by claim of sovereignty, by means of use or occupation, or by any other means*" [2], the regulation of orbital activities has fallen to various United Nations (**UN**) offices. The International Telecommunication Union (**ITU**) and the UN Committee on the Peaceful Uses of Outer Space (**UNCOPUOS**) have the regulation of space activities undertaken by UN member states included as part of their remit, including actions to ease and regulate the use of LEO domains [3]. This paper will discuss the effective monopolisation of certain orbits by individual consortia via the operation of satellite mega-constellations, and the anti-competitive nature of the behaviour that can

result when there is little incentive to ensure the openness of a given orbit shell.

The hazards of orbital debris are well described in the literature, from Kessler and Cour-Palais [4, 2637–2646] to more recent modelling by White and Lewis [5]. This paper explores the preexisting literature on orbital debris as well as existing treaties and legislative instruments and proposes recommendations to accommodate satellite constellations while mitigating the risk of monopolies and anti-competitive conduct from arising.

2. The Rise of NewSpace

On 5 of May 1997 the first five of 66 Iridium LLC satellites were launched on a Delta II from Vandenberg Air Force Base [6]. The Iridium network of satellites promised to provide global mobile phone coverage to its subscribers – an exciting proposition for 1990s mobile phone customers when mass-market mobile telephony was still relatively new. The company intended to market its handsets to a disparate class of users including jet-setting executives who did not want to be burdened with changing mobile phone providers in new countries, offshore fishermen [7], as well as foreign aid workers operating in regional and remote areas of developing countries [8, p.251].

The first batch of five satellites marked an important step in the eventual deployment of all Iridium satellites throughout the early 2000s. The plan: for the first five satellites to enter a polar orbit to test command and control capabilities with satellite downlink ground control stations, and to confirm hardware and software capabilities [6].

Motorola served as the primary contractor for the manufacture of the Iridium Satellites and Chris Galvin - heir to telecommunications heavyweight Motorola - noted that '[t]*he successful launch of the first IRIDIUM satellites represents another step in the dawning of a new age of communications. Motorola is proud to help IRIDIUM bring personal global communications to the world*.'[6].

Iridium was not alone in looking to enter the lucrative market of consumer facing space-based communications infrastructure throughout the early days of 1990s cellular and internet networks. In the lead-up to the new millennium, Teledesic intended to launch 840 satellites in 21 orbital planes - not only in LEO, but also Medium Earth Orbit (**MEO**) and GEO [8, pp.194-195]. Globalstar, a joint venture between the Loral Corporation and Qualcomm, aimed for a more conservative 48 satellites that would integrate into terrestrial landlines for coverage [9, p.52].

Unlike their cold war satellite network predecessors such as Relay, Syncom and TelStar, that were limited to less than five satellites per constellation and focused on government, defence and business facing customers [10], the 1990s heralded a new period of mass-produced satellites aimed at providing communications infrastructure to the general public [9, 51]. Not all these constellations would be successful of course. Globalstar experienced significant delays in the launch of its satellite network, only fully deploying the network after the new millennium [11].

Iridium, meanwhile, faced significant liquidity issues throughout the latter part of the 1990s. In its 1998 annual report to investors, the board described financial position of the company:

> "*Iridium is in the process of revising its revenue and subscriber estimates in light of its initial marketing and distribution difficulties and intends to seek an amendment to the secured bank facility. These actions are likely to adversely affect Iridium's estimate of its future sources of funds, and Iridium expects that it may need additional financing*." [12, p.37]

This situation for Iridium would not improve in the lead-up to the new millennium. On 13 August 1999, Iridium filed for bankruptcy [13].

The more ambitious 840-satellite constellation proposed by Teledesic was abandoned in its entirety in the face of overwhelming costs for manufacture and launch [8, pp.194-195]. More practical concerns stymied the Teledesic satellite constellation coming to fruition. Writing on the period of 1990s commercial satellite growth, journalist John Bloom noted that 'that there weren't enough rockets in the world' to service the 840 satellite contract for Teledesic even if it had been successful [8, pp.194-195].

Despite failures and near-misses of consumer facing telecommunications satellite constellations of the 1990s, refinement of satellite manufacturing and software design continued throughout the 2000s, accommodating the rise of small satellites. During this time also, cube satellites - similar in outward appearance to the boxy Australis-OSCAR 5 designed by University of Melbourne students in 1970 [14] - began to present themselves as novel delivery rigs by the dawn of the new millennium [15, pp.46-47].

Alongside the software start-ups of California receiving funding from venture capitalists and angel investors, came new investment in commercial space activities, dubbed 'NewSpace'. One of the early pioneers of the new era of NewSpace was PlanetLabs (originally founded as 'Cosmogia'), whose first satellites entered orbit in 2013 promising organisations access to telemetry on demand through its *Flock* constellation of 100 cube satellites [16]. PlanetLabs was not alone in applying newly-designed small and cube satellites to form large scale constellations.

The latter part of the 2010s is seeing the burgeoning NewSpace sector begin to accommodate new satellite constellations in LEO that offer telecommunications services to the general public and small to medium sized businesses, such as OneWeb's constellation of 720 operational satellites in LEO [17], that will begin launching in 2019 and which may be expanded to 1980 satellites [18].

Boeing is also committed to entering the field of satellite constellation as part of the NewSpace race into LEO with its Boeing Satellite - the successor to Hughes Satellite - announcing its own satellite constellation of nearly 1,396 satellites prior to withdrawing its application for licensing on 31 July 2018 [19]. Thales Alenia is also intending to launch its own constellation of 108 satellites called LeoSat into LEO by 2022 [20, p.10].

Newer entrants into the space sector are also making their presence felt in the field of satellite constellations in LEO, such as SpaceX's StarLink planned constellation of 12,000 satellites [21] and Korean-based electronics manufacturer Samsung plans to launch 4,600 satellites into LEO by the end of the 2020s [22, p.3]. Both SpaceX and Samsung intend to offer their satellite constellations to business and consumer facing IoT devices, providing global coverage for internet use [22, pp.1-2, 23].

The field of LEO dominance for telecommunication services is not reserved to established entities. Smaller operators such as Australian-based Fleet is proposing 100 cube satellites for IoT services for infrastructure management [24]; Spire Global meanwhile has proposed launching up to 150 satellites for maritime services [25]; and the British-Israeli-Australian consortium Sky and Space Global (SAS) intends to provide low cost telecommunication services to countries in the equatorial region with their proposed fleet of 200 satellites [26].

Beyond their respective obstacles of design and launch, other challenges are posed by the large-scale deployment of multiple satellite constellations which distinguish NewSpace from previous generations of space activities. The LEO environment is not homogenous, nor infinite. Some orbital planes are more favourable for communications than others. The entities that commence operations first may have the advantage of preventing their competitors from also providing similar services, by monopolising the orbits of interest.

The universe is vast, but those volumes of it that are economically useful to humanity are not. Certain orbits are useful due to their orbital period (such as GEO); the proximity for Earth for Earth observation (EO) satellites in LEO; and a combination of the previous two points for satellites in Sun synchronous orbits (SSO) [27]. Spacecraft in highly inclined orbits can pass over every part of the Earth during the course of several revolutions; while the trajectory of the spacecraft remains fixed in an Earth-centred reference frame, the Earth rotates below it, presenting a different ground track to the satellite each revolution. After a sufficient number of revolutions, most if not all of the Earth's surface would have passed below the spacecraft, allowing it to observe any feature or communicate with any ground station on the Earth. If the number of revolutions required is a whole number, this is termed an SSO, and these orbits are particularly useful for communication and EO missions.

A constellation of satellites in circular polar/SSOs with the same altitude and inclination but orbiting in planes with differing longitudes of the ascending node and with spacecraft having different true anomalies along each plane's trajectory permits real-time coverage of the entire Earth's surface given a sufficient number of satellites [1]. We term such a collection of orbits an 'orbit shell' as per ITU recommendations discussing ground stations and EO applications [28].

As one constellation populates its orbit shell with spacecraft, that shell becomes more problematic to operate in due to space traffic management concerns. Over time, orbital perturbations will disrupt the orderliness of the constellation's initial condition, making collisions more likely. If another constellation begins operating in the same orbit shell, even if the satellites orbit in different planes from that of the first constellation, the collision risk at points where the planes intersect increases. After a collision, the debris generated would spread out through a broader shell, with debris orbiting at different inclinations, eccentricities and semi-major axes, which increases the difficulty of conjunction prediction and the rate of collisions. Once a threshold debris density is reached, the collisional cascade becomes self-sustaining and is termed the Kessler Syndrome [4, 2637–2646]. More recent modelling suggests that certain orbit shells are at, or are approaching, their relevant threshold debris density, and that without prompt action to begin a process of active debris removal, an orbital Tragedy of the Commons is likely to occur [5].

3. Regulatory Overview

Presently, a variety of international treaties, guidelines and both domestic and foreign legislative instruments govern the use of space, and property rights related to space. These include the *Outer Space Treaty 1967* (UN), the *Liability Convention 1972* (UN) and the *Debris Mitigation Guidelines 2007* (UN), alongside domestic legislation such as the *Space Activities Act 1998* (Australia); the *Outer Space and High-altitude Activities Act 2017* (NZ) and 51 U.S.C.A. *Space Resource Exploration and Utilization Act 2015* (USA).

The treaty-based regulation of space activities, and much of the national and domestic legislation regulating space activities, has focused on activities carried on by nation states (or their military forces) at an international and national level. This is because in the first few decades of the Space Age, space activities were largely dominated by space activities at nation state or governmental level. The advent of NewSpace has made space activities accessible to a range of smaller non-government (and non-military) commercial entrants.

It comes as no surprise that the legislative framework has not kept pace with developments in NewSpace and is largely ill-equipped to regulate the fast developments in the commercial applications and uses of space for Earth-based services.

To the extent that international treaties, together with domestic and foreign legislative instruments, focus on proprietary rights in space at all, they focus on collision and related events, as well as obligations and undertakings related to space activities and debris mitigation.
Largely, the legal framework is yet to regulate ordered access to orbits shells.

3.1 Outer Space Treaty 1967 (UN)

Articles I and II of the *Outer Space Treaty 1967* (UN) provide access to space by all countries and prohibit the appropriation or propertisation of space and celestial bodies by use, occupation or other means. No definition is provided as to what does and does not constitute outer space or celestial bodies, however, *prima facie*, these terms refer to areas above the Karman Line as constituting outer space (see for example s8 of the *Space Activities Act 1998* (Australia)), as well as any naturally forming corporeal objects above the Karman Line as constituting a celestial body.
Although clearly setting out the rules of space activities for nation states for scientific purposes, as well as placing prohibitions on the propertisation of space, or militarisation of space by nation states, the *Outer Space Treaty 1967* (UN) remains silent on the use of space by commercial entities, as well as the use of space for non-scientific and non-military purposes, such as for providing telecommunication services to the general public from space. Commercial entities are, however, bound by domestic legislative instruments enacted by their countries that have ratified the *Outer Space Treaty 1967* (UN) (having the effect of passing international law into domestic law) and would be entitled to any rights and obligations under the *Outer Space Treaty 1967* (UN) through their national undertakings.
However, the application of this treaty is primarily related to the advancement of scientific purposes, as well as prevention of military applications, and does not govern the use of space for commercial undertakings or for activities that are primarily commercial in nature - such as providing telecommunication services to the general public. Furthermore, the treaty provides no express guidance on the use of LEO orbital planes for commercial activities.

3.2 Liability Convention 1972 (UN)

The *Liability Convention 1972* (UN), like its counterpart the *Outer Space Treaty 1967*, also touches on property rights in outer space and for artificial orbital objects. However, unlike the *Outer Space Treaty 1967* (UN) which is focused on the open access to space for scientific purposes, and prohibiting the propertisation of outer space and celestial bodies as well as ensuring the non-proliferation of weapons and military activities in outer space, the *Liability Convention 1972* (UN) recognizes some property rights and establishes a liability regime for personal and property damage, either in outer space or on the Earth’s surface.

The *Liability Convention 1972* (UN) also recognises property rights for non-nation state private entities under Article I(a) where the definition of 'damage' is sufficiently broad enough to include damage to property belonging to natural or artificial persons. Articles II and III of the *Liability Convention 1972* (UN) establish rights for compensation if property is damaged by a space object - either on the Earth's surface through uncontrolled re-entry; or, in outer space by collision. The operative clauses of the Treaty focus on compensation claims being brought where damage occurs from a space object, such as Article IV that allows for damages to be awarded where several states are involved in contributory negligence; Article VIII(2) that allows for an independent state to introduce claims on behalf of one of its nationals who has suffered personal or property damage; Article X that sets out the limitation period for a claim for damages to be lodged and Article XIV that allows for a Claims Commission to be established where an agreement for the awarding of damages cannot be reached by the parties.
However, notwithstanding the broader application of property rights in space to also accommodate individuals and to entitle parties to compensation in the event of damage by a space object, the *Liability Convention 1972* (UN) provides no express powers for the regulation of orbital planes. Where a space object collides with another space object and causes damage, remedies may exist but only 'after the event', but there are no rights in the existing orbital planes that may be commercially lucrative for commercial purposes.

3.3 Debris Mitigation Guidelines 2007 (UN)

In 1994 the Committee on the Peaceful Uses of Outer Space ('the committee') began considering the risks posed by space debris collision with artificial satellites [29, p.ii-iii]. In 2001, the committee agreed to develop voluntary debris mitigation guidelines for international adoption during 2002-2005. In resolution 62/217 of 22 December 2007, the General Assembly endorsed the committee's guidelines and aimed for the voluntary adoption of guidelines to mitigate space debris.
The guidelines provide a broad category of recommendations to General Assembly members regarding the minimisation of space debris in the launch of new satellites, and suggestions on reduction of debris for satellites that are planned for destruction. In consideration of the application of the guidelines, the United Nations General Assembly stated:

> "*Member States and international organisations should voluntarily take measures, through national mechanisms or through their own applicable mechanisms, to ensure that these guidelines are implemented, to the greatest extent feasible, through space debris mitigation practices and procedures.*
> *These guidelines are applicable to mission planning and the operation of newly designed spacecraft and orbital stages and, if possible, to existing ones. They are not legally binding under international law.*" [29, p.6]

Of particular note for space objects traversing LEO is Guideline no. 6 that states:

> "*Spacecraft and launch vehicle orbital stages that have terminated their operational phases in orbits that pass through the LEO region should be removed from orbit in a controlled fashion. …*
> *When making determinations regarding potential solutions for removing objects from LEO, due consideration should be given to ensuring that debris that survives to reach the surface of the Earth does not pose an undue risk to people or property, including through environmental pollution caused by hazardous substances.*" [29, pp.3-4]

Although there is no legal basis for the observance of the recommendations by member states, it should be noted that emphasis is placed on determining methods for objects entering Earth's atmosphere from LEO orbit, which must take into account that there is no resulting injury, damage to property, or ecological issues.

Presently, those guidelines are voluntary, and therefore non-binding and unenforceable. Furthermore, the guidelines focus solely on the de-orbiting of space objects during their end of life cycle, but remain silent on space traffic management for orbital planes in LEO during the operational life of space objects. Additionally, proprietary rights in space objects focus solely on the obligations of a safe controlled de-orbit and are not sufficiently broad to deal with right to access for orbital planes for commercial purposes.

4. Domestic Legislation

A number of countries have introduced legislative provisions for the use of outer space for commercial undertakings. These include (in Australia) the *Space Activities Act 1998*) and its amending legislation the *Space Activities Amendment (Launches and Returns) Act 2018* (Cth); the *Outer Space and High-altitude Activities Act 2017* (NZ) and 51 U.S.C.A. *Space Resource Exploration and Utilization Act 2015* (USA).

These legislative instruments focus particularly on the licensing scheme for commercial launch operations as well as the mitigation of risk and indemnity in the event of collisions or similar accidents occurring - such as s 9(1)(c) of the *Outer Space and High-altitude Activities Act 2017* (NZ) or Division 3 of the *Space Activities Amendment (Launches and Returns) Act 2018* (Cth).

Presently, these legislative instruments do not focus on orbital planes in LEO in which a country may operate space activities. One potential avenue has been 51 U.S.C.A. *Space Resource Exploration and Utilization Act 2015* (USA) that entitles US citizens to commercialise a 'Space Resource'. § 51301 (2)(A) of the *Space Resource Exploration and Utilization Act 2015* (USA) defines a 'Space Resource' as being any resource that comprises an 'abiotic resource in situ in outer space'. § 51301 (2)(B) of the *Space Resource*

Exploration and Utilization Act 2015 (USA) goes further in defining a space resources as including water and minerals. Although a 'Space Resource' is presently unrestricted in its definition beyond those parameters expressed in § 51301 (2)(B) of the *Space Resource Exploration and Utilization Act 2015* (USA), the focus on an abiotic resource pursuant to § 51301 (2)(A) would exclude an orbital plane from constituting a resource for the purposes of the Act given that such as a resource is non-corporeal in nature.

5. Potential Remedies & Discussion: The International Telecommunications Union

Administration and regulation of radiofrequency communications, including terrestrial, surface-to-orbit and inter-spacecraft, falls under the jurisdiction of the International Telecommunications Union's Radio-communication Sector (**ITU-R**). Being part of a UN specialist agency, the ITU-R is the organisation responsible for allocating both radio spectrum bandwidth for communications and GEO orbital "slots" for communications satellites, among its other activities. Historically, some ITU-R decisions, alongside their domestic counterparts [ex. 30] have been contentious, but they have also achieved decades of peaceful and productive operations in the GEO communications market, while disallowing any monopolisation of communications spectrum by any operator or class of spacecraft.

Among the conditions for operating a spacecraft in GEO is the disposal requirement; that a certain portion of spacecraft propellant be reserved so that the spacecraft can be moved safely away from the operational GEO and into a "graveyard" orbit as per Recommendation ITU-R S.1003 [31]. This requirement is part of any GEO satellite owner/operator's application to its relevant national authority for the allocation of a GEO slot, and as such is subject to relevant laws in accordance with the ITU treaty. The disposal requirement has kept GEO space largely free of debris while ensuring that new satellites can be moved into slots vacated by ageing satellites. Something similar could be suggested for LEO constellations.

A similar scheme to that for GEO disposal and allocation of orbital "slots" may foreseeably reduce the potential for established NewSpace operators to prevent new entrants to market from providing services to the general public. Underpinning such a scheme, orbital planes could conceivably be administered by the ITU-R in order to prevent monopolies from forming within LEO orbital planes. A licensing scheme may also be advantageous in such a scheme, as it may incentivise organisations that are operating satellite constellations with minimal subscribers, or on a sub-economic basis, to deorbit their constellations to 'make way' for new entrants to market. However, such a licensing scheme, if implemented, would require careful administrative oversight to ensure that new entrants to market are not 'priced out' by existing competitors.

6. Conclusion

Presently, legislative frameworks remain focused on the non-militarisation of space, the promotion of scientific endeavours and the mitigation of orbital debris. However, these legislative frameworks do not anticipate the use of orbital planes in LEO for non-government (and non-military) commercial operators; or, the management of orbital shells for LEO. Further investigation will be required to ensure that the use of these orbital shells remains optimal for ongoing space activities, and to enable access for a range of new entrants into a burgeoning market for the provision of space-based commercial services on Earth.

References

[1] Wertz, James R. 'Orbit and Constellation Design' in Larson, Wiley J., & Wertz, James R. *Space Mission Analysis and Design* (Micrososim Press, 3rd ed, 1999).

[2] Article II, *Outer Space Treaty 1967* (UN).

[3] 'Inter-Agency Space Debris Coordination Committee Report of the IADC Activities on Space Debris Mitigation Measures' UN COPUS S&T Subcommittee, 41st sess, (February, 2004) <https://www.iadc-online.org/Documents/IADC-UNCOPUOS-final.pdf>.

[4] Kessler, DJ & Cour-Palais, Burton G., 'Collision frequency of artificial satellites: The creation of a debris belt' (1978) 83.A6 *Journal of Geophysical Research*.

[5] White, Adam E. & Lewis, Hugh, 'An adaptive strategy for active debts removal' (2014) 58.3 *Advances in Space Research*.

[6] Windolph, John M., 'IRIDIUM™, LLC announces launch of the first five IRIDIUM™ satellites' (Media Release, 5 May 1997) <https://web.archive.org/web/20040513025433/www.motorola.com/General/Press/PR970506.html>.

[7] 'Iridium Beefs Up Asia Pacific Push' *Space Daily* (online), 27 June 2001 <http://www.spacedaily.com/news/iridium-01e.html>.

[8] Bloom, John, *Eccentric Orbits* (Grove Press, 2016).

[9] Lim, JaeJoo, et al., 'Good Technology, Bad Management: A Case Study of the Satellite Phone Industry' (2005) 16.2 *Journal of Information Technology Management* <http://jitm.ubalt.edu/XVI-2/article5.pdf?cmpid=newscred>.

[10] Martin, Donald H., *Communication Satellites* (The Aerospace Press, 4th ed, 2000) <https://books.google.com.au/books?id=_azf94TByF8C&printsec=frontcover#v=onepage&q&f=false>.

[11] Ray, Justin, 'Globalstar constellation completed with Delta Launch', *Spaceflight* Now (online), 8 February 2000 <https://spaceflightnow.com/delta/d276/000208launch.html>.

[12] 'Iridium World Communications Ltd. 1998 Annual Report', Iridium World Communications Ltd. (1999) <http://ourthing.altervista.org/files/vario/1998AnnualReport.pdf>.

[13] 'Iridium files Chapter 11' *CNN Money* (online) 13 August 1999 <https://money.cnn.com/1999/08/13/companies/iridium/>.

[14] Bennet, Holly, 'The Students Who Built Australia's First Satellite', *University of Melbourne* (online) 19 September 2017 <https://pursuit.unimelb.edu.au/articles/the-students-who-built-australia-s-first-satellite>.

[15] Carrasco-Casado, Alberto, et al. 'Optical Communication on CubeSats Enabling the Next Era in Space Science' (2017) *IEEE International Conference on Space Optical Systems and Applications (ICSOS)*, <http://www.kiss.caltech.edu/final_reports/OptComm_final_report.pdf>.

[16] Reinhardt, Erika, 'Planet Labs Raises $52M In Series B Financing' (Media Release, 18 December 2013) <https://www.planet.com/pulse/series-b/>.

[17] Federal Communications Commission 'FCC Grants Oneweb Access To U.S. Market For Its Proposed New Broadband Satellite Constellation' (Media Release, 22 June 2017) <https://www.fcc.gov/document/fcc-grants-oneweb-us-access-broadband-satellite-constellation>.

[18] Henry, Caleb, 'OneWeb asks FCC to authorise 1,200 more satellites' *Space News* (online), 20 March 2018 <https://spacenews.com/oneweb-asks-fcc-to-authorize-1200-more-satellites/>.

[19] Federal Communication Commission, 'Schedule S Technical Report', *Federal Communication Commission Satellite Space Station Authorisations - Callsign S2966* (2018) <http://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/reports/swr031b.hts?q_set=V_SITE_ANTENNA_FREQ.file_numberC/File+Number/%3D/SATLOA2016062200058&prepare=&column=V_SITE_ANTENNA_FREQ.file_numberC/File+Number>.

[20] Federal Communications Commission, 'Attachment Technical Annex', *LEOSAT Non-Geostationary Satellite System Attachment A,* (2017) <https://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/attachment_menu.hts?id_app_num=110179&acct=325180&id_form_num=12&filing_key=-289821>.

[21] *Space Exploration Holdings, LLC, Application for Approval for Orbital Deployment and Operating Authority for the SpaceX NGSO Satellite System, IBFS File No. SAT-LOA-20161115-00118* (filed Nov. 15, 2016) (SpaceX Application) <https://transition.fcc.gov/Daily_Releases/Daily_Business/2018/db0329/FCC-18-38A1.pdf>.

[22] Khan, Farooq, 'Mobile Internet from the Heavens' (2015) *Samsung Electronics* <https://arxiv.org/ftp/arxiv/papers/1508/1508.02383.pdf>.

[23] Daniels, Patrick, 'SpaceX Starlink: Here's everything you need to know', *Digital Trends* (online), 5 August 2018 <https://www.digitaltrends.com/cool-tech/spacex-starlink-elon-musk-news/>.

[24] Russell, David, 'Fleet Space Technologies to build satellite mission control centre in Adelaide' (Media Release, 17 January 2018) <https://www.sasic.sa.gov.au/docs/default-source/default-document-library/media-releases-2018/fleet-space-technologies-to-build-satellite-mission-control-centre-in-adelaide.pdf?sfvrsn=a3e9cac1_2>.
[25] Werner, Debra, 'Spire Global is expanding cubesat constellation to offer persistent global view', *Space News* (online), 10 January 2018 <https://spacenews.com/spire-global-is-expanding-cubesat-constellation-to-offer-persistent-global-view/>.
[26] SAS, *Operations*, Sky and Space Global <https://www.skyandspace.global/operations-overview/>.
[27] Boden, Daryl G., 'Introduction to Astrodynamics' in Larson, Wiley J., & Wertz, James R. *Space Mission Analysis and Design* (Micrososim Press, 3rd ed, 1999).
[28] ITU, 'Methods of calculating low-orbit satellite visibility statistics', *ITU-R SA-1156* (1995) International Telecommunications Union <https://www.itu.int/rec/R-REC-SA.1156/en>.
[29] *Space Debris Mitigation Guidelines of the United Nations Committee on the Peaceful Uses of Outer Space,* GA Res 62/217, UN COPUS, 50th sess, A/62/20 (22 December 2007), paras 118 and 119 <http://www.unoosa.org/pdf/publications/st_space_49E.pdf>.
[30] Petition to Deny of Iridium, File Nos. SES-LIC-20170217-00183 and SES-AMD-20170414-00381, (filed 05/26/2017), "Petition to Deny" <http://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/reports/related_filing.hts?f_key=-292116&f_number=SESLIC2017021700183>.
[31] International Telecommunication Union, 'Recommendation ITU-R S.1003-2', *Environmental protection of the geostationary-satellite orbit,* (2010) <https://www.itu.int/dms_pubrec/itu-r/rec/s/R-REC-S.1003-2-201012-I!!PDF-E.pdf>.