SATELLITE INTERNET AND LASER LINKS: ARE UNIVERSAL FSO STANDARDS NEEDED?

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Satellite Internet constellations ("SICs") promise to connect the world, finally delivering on the promise of global connectivity. This Note explains why SICs will only achieve their maximum potential with the adoption of free space optical ("FSO") communication technologies, which provide massive bandwidth and interference benefits over radio. FSO will yield the greatest possible benefits with standardization through a formal standard development organization. Standardized, with the ability to communicate, collaborate, and consolidate, SICs will provide the greatest coverage and fastest speeds to their consumers. While SIC consolidation will proffer many benefits, it will also bear risks, as large players exert outsized market influence and reduce innovation. Geopolitical competition will make universal standards unlikely, necessitating national and international collaboration.

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Introduction

Satellite Internet is poised to expand rapidly in this decade,[1] growing the influence of the private space industry. Satellite Internet constellations ("SICs") promise to connect the entire world to the Internet with minimal ground infrastructure. Many companies have announced intentions to provide worldwide Internet service using satellite constellations. A satellite constellation is "a number of similar satellites, of a similar type and function, designed to be in similar, complementary, orbits for a shared purpose, under shared control."[2] To provide Internet service, adjacent satellites within a constellation need to be able to communicate with each other effectively. Due to the great bandwidth requirements of satellite Internet service providers ("SISPs"),[3] intra-constellation communication is increasingly done using free space optical communications ("FSO"). FSO is a relatively new laser-based communication technology which can send an order more data than radio using far less power. But because it is so young,

1. James P. Dingley, Modelling the Satellite Internet Market using Agent-Based Computational Economics 22 (May 12, 2023) (unpublished manuscript) (on file with the MIT System Architecture Group), http://systemarchitect.mit.edu/docs/dingley23a.pdf [https://perma.cc/67MR-WM7X] (projecting 6x revenue growth from 2020 to 2030).

2. Lloyd Wood, *Satellite Constellation Networks*, *in* Internetworking and Computing Over Satellite Networks 13, 13 (Youngguang Zhang ed., 2003).

3. Constellations ("SICs") are the hardware that enables service providers ("SISPs"). The two terms are not interchangeable, as an SIC operator could theoretically not directly provide end-users service and SISPs could lease bandwidth from a constellation without operating their own. At the time of writing, all SICs are SISPs and no SISPs exist without operating their own constellation. However, this will not necessarily be true in the future. The two terms are used here precisely to ensure accuracy regardless of future developments.

FSO is largely unregulated[4] and minimally standardized. While radios may sometimes be made backwards compatible using software, satellites which use FSO must be made interoperable before launch.

Interoperability at scale would only be possible through strong standardization of FSO technologies across SICs. One such standard has been published by a powerful group of standard development organizations ("SDOs"): the Consultative Committee for Space Data Systems ("CCSDS"), the International Telecommunications Union ("ITU"), and the International Organization for Standardization ("ISO"). However, this standard has not achieved universal adoption, leaving the door open for other standard setting organizations ("SSOs"), such as single-promoters and industry consortia, to create competing standards.

It is important that one standard prevails to maximize benefits to the SISP industry and SISP consumers. Standardization would allow consumers to switch networks and introduce possibilities for emergency collaboration. Most notably, it would also increase incentives towards market consolidation. Two SIC/SISP mergers have already occurred,[5] and more are likely to follow. Intra-constellation communication standardization would make such mergers simpler and more profitable. While this would keep launch and space infrastructure costs low in the short term and decrease the congestion of satellites in orbit, it could also lead to increased costs to consumers in the long term as monopolistic entities amass price-setting power. The more widely SISPs are chosen over terrestrial ISPs, the more they will be able to increase prices. Each country could regulate prices of a global constellation domestically, but the regulatory landscape is already labyrinthian, and every new regulation makes it more so.

SISPs operating worldwide must comply with the laws of each country they hope to provide service in, presenting both a legally and technically complex problem. If relying on intra-constellation communication, SISPs may find it impossible to comply with all countries' regulations. This makes it likely that countries, or at least

4. *Cf.* Mahulena Hofmann, *Optical Communications in a Legal Vacuum?*, 55 PROC. INT'L INST. SPACE L. 688, 691 (2012) (explaining that FSO does not exist in a "law-free zone," even though it is not yet regulated in practice).

5. Peter Wood, *Satellite Mergers, Acquisitions, and Market Consolidation*, TELEGEOGRAPHY (June 22, 2023), https://blog.telegeography.com/satellite-mergers-acquisitions-and-market-consolidation [https://perma.cc/2YFF-NVPH]; Press Release, Eutelsat Grp., Eutelsat and OneWeb Combination Heralds New Era in Space Connectivity as World's First GEO-LEO Operator (Sept. 28, 2023, 11:31 AM), https://www.eutelsat.com/en/news/press.html#/pressreleases/eutelsat-and-oneweb-combination-heralds-new-era-in-space-connectivity-as-worlds-first-geo-leo-operator-3276261 [https://perma.cc/NCN4-J4NX].

blocs, will fund their own SICs as they did with global navigation satellite systems ("GNSSs"). This would reduce the total benefits gained by international standardization but could be minimized with international cooperation of the SICs themselves. Military space agencies are likely to have strong reactions to SICs and SISPs, although their interests are difficult to predict. Space agencies may follow, influence, or control the development of their state's SICs. The chosen approach, and its consequences, will vary greatly between states. The proposed US regulatory body based out of the departments of commerce and transportation should consider the issues presented above with haste. With several US-based SISPs providing global service, this regulator will have significant power to steer the industry internationally.

This Note is organized in the order so far presented. Section I provides a primer on FSO technology and adoption to date. Section II lists current standardization efforts and explores how future efforts might emerge. It also explores why this problem is unique to FSO technologies, and why it was not as significant for radio. Section III discusses the implications standardization or a lack thereof would have on various stakeholders, starting with commercial and scientific efforts and concluding with an eye towards international tensions. Each section presents forthcoming problems, followed by a discussion of possible solutions.

By providing a technical primer and industry analysis, this Note aims to be a starting point for future FSO scholarship. Minimal legal research has been done in this area, but the technology is poised to impact society greatly. Much has been written about the SIC Starlink, but the whole industry must be considered to avoid promoting a largely unregulated monopoly. We must begin this conversation now to promote competition as the market develops.

I. FSO Background

FSO is a communication technique which uses an optical laser beam to transfer data through an atmospheric channel.[6] The laser beam is considered "optical" because the wavelengths used are either in the human-visible or infrared spectra.[7] This means that objects or atmospheric disturbances can interrupt beams.[8] Light from the sun is dimmer on a cloudy day; since light from an FSO transmitter behaves similarly, a receiver on the ground would have a harder time seeing

6. A. Arockia Bazil Raj, Free Space Optical Communication 1 (2016).
7. *Id.*
8. *See id.* at 1–2.

an FSO-transmitting satellite on a cloudy day.[9] This can be especially problematic as beams for optical communication are unidirectional and tightly-focused, usually aimed at a receiving telescope around 30 cm large.[10] Because the target is so small, devices sending FSO transmissions must precisely point themselves at the receiver.

Optical communication is already widespread, though in a different medium: glass fiber. Fiber optic cables today comprise the backbone of global communications. FSO is also widespread in limited environments, such as in the infrared used by television remotes. This Note focuses exclusively on space-Earth[11] and space-to-space FSO, which became commercially viable recently, thanks to breakthroughs managing the atmospheric interference and pointing problems.[12]

A. Comparison to Radio

FSO's advantages and disadvantages emerge when compared to the currently dominant electromagnetic spectrum used for wireless communication: radio. Radio wavelengths are much longer – from millimeters to kilometers – compared to FSO's micrometers. This means that radio waves can be transmitted through walls, people, and weather. An FM radio channel is as clear on a rainy day, inside a listener's home, as it is on a sunny day at the park. Radio transmissions are generally omnidirectional – a station doesn't need to know how many listeners it has or where its listeners are to serve them effectively. Both characteristics have made radio incredibly popular for terrestrial applications, and it is now used for a wide variety of applications, from basic aural communication to Wi-Fi and 5G. However, both characteristics have tradeoffs when used in satellite applications.

Radio's long wavelength means that ground stations can still receive satellite transmissions on cloudy days, but it also caps the maximum amount of data that satellites are able to transmit. To simplify greatly, each wave can only convey so much information to the transmitter. Since electromagnetic waves travel at a fixed speed,[13] shortening the wave*length* means that more waves, carrying similar amounts of data, can be transmitted in the same amount of time. Light has a much

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9. *See id.*
10. ARUN K. MAJUMDAR, LASER COMMUNICATION WITH CONSTELLATION SATELLITES, UAVS, HAPS AND BALLOONS 6 (2022).
11. This term, as used in this Note, encompasses both space-to-Earth and Earth-to-space communications.
12. *See* RAJ, *supra* note 6, at 1–3; MAJUMDAR, *supra* note 10, at 6 (compiling sources on the technical breakthroughs that mitigated problems in atmospheric interference and pointing).
13. The speed of light, or its speed within the relevant atmospheric channel.

shorter wavelength than radio, so FSO takes advantage of that physical restriction. The downside is that FSO cannot occur between Earth and space if the weather is too inclement.

Radio's omnidirectionality makes music radio and Wi-Fi much easier to provide (as one station can transmit to many receivers without needing to know where they are) but is more problematic in space. A lot of power must be supplied to the transmitter, while most of the waves will go off in unused directions. Worse, they can be easily picked up by unwanted listeners and interfere with the transmissions of nearby satellites. FSO's tight focus lowers power requirements and makes snooping very difficult – interference is impossible without deliberate targeting of a station's receiver. However, transmitters must be pointed precisely, or no communication link can be established. This can be difficult and costly in space, as satellites are effectively in free-fall.

Ultimately, the increased bandwidth enabled by FSO is a key advantage for many projects deciding between the two technologies. As sensing and imaging technologies improve, it can be prohibitively time consuming for scientific projects to send their results through radio. And as satellite Internet becomes an increasingly critical service, bandwidth demands will only increase. FSO is particularly advantageous for satellite constellations providing Internet. With no atmospheric interference in space, satellites can reliably communicate with each other using FSO. Intra-constellation communication can be used to overcome the weather restriction on FSO as well. If an operator has many ground stations distributed across the world, constellations can route all their space-Earth communications through the satellites over ground stations with clear weather. This form of routing is not currently in use, but it is theoretically straightforward to implement, even with current technology.[14]

Due to these advantages and maturing research, FSO is rapidly expanding in use. Its capabilities were demonstrated in several prototyping missions[15] and it is now used by at least one SIC, Starlink.[16]

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14. MAJUMDAR, *supra* note 10, at 171–74.

15. *E.g.*, Christopher McFadden, *DARPA launches first, and now only, 'Blackjack' satellites*, INTERESTING ENG'G (June 14, 2023, 7:10 AM), https://interestingengineering.com/innovation/darpa-launches-first-blackjack-satellites [https://perma.cc/7B58-HPEU] (describing a recently launched Department of Defense FSO test); T. Tolker-Nielsen & J-C. Guillen, *SILEX: The First European Optical Communication Terminal in Orbit*, 1998 ESA BULL., no. 96, at 1 (describing an early European FSO test).

16. *How Starlink Works*, STARLINK, https://www.starlink.com/technology [https://perma.cc/4S6Q-JKYX] (last visited Apr. 8, 2024).

The National Aeronautics and Space Administration ("NASA") also recently launched a flight test of a deep space FSO system.[17]

B. Regulation

Proponents of FSO often claim that it is entirely "unregulated,"[18] but this is misleading. Unlike radio, the wavelengths of light used by FSO are very minimally regulated by the ITU or its American administrating agency, the Federal Communications Commission ("FCC").[19] But several legal obligations still apply to satellite operators using FSO. For example, SISPs have the same obligations as their terrestrial counterparts to combat copyright infringement online.[20] More significantly, SICs are subject to few but important obligations imposed by the UN space treaties.[21] Under these treaties, SICs must operate peacefully, register their satellites' orbits, and follow settled claims procedures in the wake of collisions.[22]

A satellite launched from the United States that only communicated with FSO could avoid a significant amount of regulation because of the FCC's prominence in satellite regulation. The FCC interprets its directive to regulate radio communication facilities[23] broadly, so it considers a satellite operator's plans for reentry, environmental impact, collision avoidance, and more when granting applications for satellite radio wavelength use.[24] To avoid duplicate applications, no other US agency considers these essential mission characteristics. Following the ITU, the FCC does not regulate FSO because bandwidth use does not need to be limited to avoid interference.[25] So, an FSO-only satellite with no remote sensing[26] and no need to file the FCC application would only

17. Abbey A. Donaldson, *NASA's Psyche Spacecraft, Optical Comms Demo En Route to Asteroid*, NAT'L AERONAUTICS & SPACE ADMIN. (Oct. 12, 2023), https://www.nasa.gov/news-release/nasas-psyche-spacecraft-optical-comms-demo-en-route-to-asteroid [https://perma.cc/LAK9-Q7AH].

18. *See, e.g.*, MAJUMDAR, *supra* note 10, at 67.

19. Hofmann, *supra* note 4, at 690–91; RAJ, *supra* note 6, at 7.

20. 17 U.S.C. § 512 (g) (2010) (establishing copyright infringement notice requirements for ISPs under the Digital Millennium Copyright Act).

21. Hofmann, *supra* note 4, at 691–92.

22. *Id.* at 692.

23. 47 U.S.C. § 151 (1996) (establishing the FCC and stating its purpose).

24. *Small Satellite and Small Spacecraft Licensing Process*, FED. COMMC'NS COMM'N, https://www.fcc.gov/space/small-satellite-and-small-spacecraft-licensing-process [https://perma.cc/7FMB-RB8E] (last visited Apr. 9, 2024).

25. *See* Hofmann, *supra* note 4, at 690–91; *cf.* RAJ, *supra* note 6, at 7 (stating that the FCC does not license or allocate frequencies for FSO).

26. A satellite with remote sensing capabilities must file an additional application through NOAA. *About the Licensing of Private Remote Sensing Space Systems*, NAT'L ENV'T SATELLITE, DATA, & INFO. SERV., NAT'L OCEANIC & ATMOSPHERIC ADMIN.,

have to register its launch with the Federal Aviation Administration[27] and its resulting orbit with the Space Defense Squadron.[28] There would be no other review by the federal government of the satellite's function or safety.

However, the federal government has the opportunity to address this problem before it becomes pressing. Due to weather interference, FSO-only satellites are likely several years from reality. FSO-only satellites could communicate directly with SICs, but this is also years away and very difficult without standardization. A recent proposal from the Biden administration would increase the regulatory powers of the Departments of Transporation and Commerce, covering up existing gaps.[29] Such regulatory movement is required to stop FSO-only satellites from skirting necessary oversight.

II. Space-Based FSO Standardization Efforts

FSO standardization is strong in limited contexts. IrDA, a seemingly defunct infrared industry coalition,[30] standardized infrared wireless communication for TV remotes and other household devices in the 1990s.[31] The Institute of Electrical and Electronics Engineers ("IEEE")[32] and ITU[33] recently published standards for Li-Fi, an indoor FSO replacement for Wi-Fi. Historically, in space communication, there were two predominant standard development organizations ("SDOs"): Consultative Committee for Space Data Systems ("CCSDS") and the International Telecommunication Union ("ITU"). Driven by the need to collaborate internationally to create the International Space Station,

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Dep't of Com., https://www.nesdis.noaa.gov/commercial-space/regulatory-affairs/licensing [https://perma.cc/H6AU-RBJQ] (last visited Apr. 9, 2024).

27. 14 C.F.R. § 450.43 (2021); *Payload Reviews*, Fed. Aviation Admin., https://www.faa.gov/space/licenses/payload_reviews [https://perma.cc/Q7QW-5R33] (last visited Apr. 9, 2024).

28. *18th Space Defense Squadron*, Joint Task Force-Space Def. (May 2, 2022), https://www.petersonschriever.spaceforce.mil/About-Us/Fact-Sheets/Display/Article/2817624/joint-task-force-space-defense/ [https://perma.cc/YQR5-GUHF].

29. Joey Roulette, *White House proposes transportation, commerce agencies handle new space regulations*, Reuters (Nov. 15, 2023, 12:14 PM), https://www.reuters.com/technology/space/white-house-proposes-transportation-commerce-agencies-handle-new-space-2023-11-15 [https://perma.cc/5FKC-9BQL].

30. *Compare* IrDA, https://web.archive.org/web/20120315130134/http://www.irda.org/displaycommon.cfm?an=1 [https://perma.cc/QS6U-U972] (last visited Apr. 9, 2024) (preserving archived version of IrDA website) *with* IrDA, https://www.irda.org/ [https://perma.cc/2GZ2-6TRL] (posting clickbait, most recently about crystals).

31. Rich Fisco, *Infrared: Facing the Firing Squad?*, PC Mag., Apr. 3, 2001, at 56.

32. Inst. of Elec. & Elecs. Eng'rs, IEEE 802.11bb-2023 (June 5, 2023).

33. Int'l Telecomm. Union, G.9991: High-speed indoor visible light communication transceiver - System architecture, physical layer and data link layer specification (Aug. 8, 2019).

CCSDS, ITU, and a third major SDO, the International Organization for Standardization ("ISO"), harmonized their space standards beginning in the 1990s.[34] Industry-driven standard setters may begin to compete in this space, but they will be impeded by extensive patent licensing negotiations. If no international standard becomes dominant, satellite operators will miss out on the potential benefits discussed in Section IV, including lowered operating costs, reduced orbital crowding, and emergency collaboration.

It is important to note that SIC communication standardization has two parts: space-to-space, and space-Earth. FSO is primarily used for space-to-space communication, while radio is still used for space-Earth communication because of the atmospheric interference issues discussed in Section II.A. SICs and scientists around the world are working to make space-Earth FSO reliable, but at the time of writing, radio is still used to avoid interference during inclement weather. So, it is highly possible that SICs standardize space-to-space FSO without agreeing on a solution for space-Earth communication, depriving consumers of some benefits discussed in Section IV. While software can be used to make some radio stations compatible retroactively, such an approach generally requires technical knowledge[35] and would violate[36] most SIC/SISP terms of service.[37]

A. Existing standards: CCSDS, backed by ISO and ITU

CCSDS is the predominant space standards organization, supported by 39 space agencies and about 145 companies.[38] It was founded in 1982 to solve space data system problems common to the major space

34. *See ISO TC20/SC13 Subcommittee Contents*, Consultative Comm. for Space Data Sys., https://public.ccsds.org/about/ISO_TC20-SC13_contents.aspx [https://perma.cc/M3DB-HGM7] (last visited Apr. 8, 2024) (providing a history of the CCSDS/ISO collaboration, beginning in 1990); *World Standards Cooperation*, Int'l Telecomm. Union, https://www.itu.int/en/ITU-T/extcoop/Pages/wsc.aspx [https://perma.cc/67QF-BJCY] (last visited Oct. 29, 2023) (providing a history of the ITU/ISO/IEC collaboration, beginning in 2001).

35. *See, e.g.*, Tech Minds, *Hacking Iridium Satellites With Iridium Toolkit*, YouTube (Aug. 31, 2019), https://youtu.be/usCJtuvXfPg [https://perma.cc/PR5H-4LY7] (demonstrating unauthorized communication with a satellite communications network using a software-defined radio).

36. *E.g.*, *Starlink Terms of Service*, Starlink § 3, https://www.starlink.com/legal/documents/DOC-1020-91087-64?regionCode=US [https://perma.cc/K7GB-YXF2] (last visited Apr. 8, 2024) (prohibiting use of unauthorized "kits," referring to ground hardware).

37. Unless otherwise specified, in this Note, "FSO standardization" refers to space-to-space standardization.

38. Nestor Mario Peccia, *A brief Story of a success: The CCSDS*, Am. Inst. of Aeronautics and Astronautics 1, 1 (May 5, 2014), https://arc.aiaa.org/doi/pdf/10.2514/6.2014-1827 [https://perma.cc/YL8G-4J8G].

agencies.[39] As of 1990, it functions as the ISO standards committee on space data and information transfer systems.[40] ISO coordinates 169 national standards bodies in many industries and sectors.[41] As of 2001, it harmonizes standards with ITU,[42] a similar organization focused exclusively on telecommunications. ITU is also the UN agency which coordinates matters of international law related to telecommunications.[43] ITU has the most direct members, with 193 member countries and hundreds of private-sector entities.[44] Unsurprisingly, standards harmonized between CCSDS, ISO, and ITU carry weight, and their radio standards are widely adopted.[45] However, as the space industry begins to compete more aggressively in telecommunications, it enters a landscape which is less dominated by formal SDOs.[46]

CCSDS published two comprehensive FSO standards in August 2019 (CCSDS 141, on the physical characteristics of FSO beams, and 142, on the coding and synchronization allowing a receiver and transmitter to communicate),[47] but they appear to be in limited use at the time of writing.[48] ITU published one report and two recommendations on subtopics of FSO which do not conflict with CCSDS 141 and 142. While the CCSDS standards are focused on communications

39. *Id.*

40. *Id.*; *ISO/TC 20/SC 13*, *supra* note 34.

41. *About ISO*, INT'L ORG. FOR STANDARDIZATION, https://www.iso.org/about-us.html [https://perma.cc/JPK3-Z59V] (last visited Apr. 8, 2024).

42. *World Standards Cooperation*, *supra* note 34.

43. *Overview of ITU's History*, INT'L TELECOMM. UNION, https://www.itu.int/en/history/Pages/ITUsHistory.aspx [https://perma.cc/2TPW-CBXP] (last visited Apr. 8, 2024).

44. *Id.*

45. Peccia, *supra* note 38 (describing successful collaboration efforts between the three organizations across several standardization efforts, including radio).

46. C. Bradford Biddle, *No Standard for Standards: Understanding the ICT Standards-Development Ecosystem*, *in* THE CAMBRIDGE HANDBOOK OF TECHNICAL STANDARDIZATION LAW 17, 22 (Jorge L. Contreras ed., 2017).

47. CONSULTATIVE COMM. FOR SPACE DATA SERVS., CCSDS 141.0-B-1: OPTICAL COMMUNICATIONS PHYSICAL LAYER RECOMMENDED STANDARD (Aug. 2019); CONSULTATIVE COMM. FOR SPACE DATA SERVS., CCSDS 142.0-B-1: OPTICAL COMMUNICATIONS CODING AND SYNCHRONIZATION (Aug. 2019).

48. For one of few commercial implementations, see *KSAT + Sony CLS Successfully Demo SOLISS Optical Link Downlinks To Commercial Optical Ground Station*, SATNEWS (Oct. 10, 2021), https://news.satnews.com/2021/10/10/ksat-sony-cls-successfully-demo-soliss-optical-link-downlinks-to-commercial-optical-ground-station [https://perma.cc/2ZMK-JJBP]. The author was able to find only one implementation in a scientific experiment. Sachiko Hirota, *Japan-Germany international joint experiment on space optical communication*, EUREKALERT! (Mar. 26, 2021), https://www.eurekalert.org/news-releases/820477 [https://perma.cc/4DXV-3FLC]. And just one other SDO has adopted the standards. INTERAGENCY OPERATIONS ADVISORY GRP., THE FUTURE MARS COMMUNICATIONS ARCHITECTURE 56–65 (Feb. 22, 2022), https://www.ioag.org/Public%20Documents/MBC%20architecture%20report%20final%20version%20PDF.pdf [https://perma.cc/LZ2S-BEAS].

system architecture, coding, and synchronization,[49] the ITU report and recommendations focus on identifying areas for future research,[50] predicting distortion of FSO transmissions in weather,[51] and co-locating FSO systems to avoid interference.[52] Notably, CCSDS 141 claims to be free from conflicting patents.[53] CCSDS 142 notes that adjacent patents exist, but states that none apply exactly to the standard as written.[54]

Twenty patents related to FSO using the kind of encoding described by CCSDS 142 are currently valid and active.[55] These patents could harm adoption if organizations decide implementation of the standard would risk infringement.

Most concerningly for adoption of these standards, the network specification for NASA's massive Artemis program,[56] LunaNet, has not yet adopted an FSO standard either in the current version or the most recent draft version.[57] On the other hand, LunaNet has adopted relevant CCSDS standards for radio spectrums.[58] One possible source of these gaps is that NASA is taking a corporate-first approach to the Artemis

49. CONSULTATIVE COMM. FOR SPACE DATA SERVS., CCSDS 141.0-B-1, *supra* note 47; CONSULTATIVE COMM. FOR SPACE DATA SERVS., CCSDS 142.0-B-1, *supra* note 47.

50. *See* INT'L TELECOMM. UNION, ITU-R REPORT F.2106-1: FIXED SERVICE APPLICATIONS USING FREE-SPACE OPTICAL LINKS 1 (Nov. 2010) (describing the need for experimentation and analysis of free-space optical links to expand applications of the technology).

51. *See* INT'L TELECOMM. UNION, ITU-R RECOMMENDATION P.1817-1: PROPAGATION DATA REQUIRED FOR THE DESIGN OF TERRESTRIAL FREE-SPACE OPTICAL LINKS annex 1 (Feb. 2012).

52. INT'L TELECOMM. UNION, ITU-T RECOMMENDATION G.640: CO-LOCATION LONGITUDINALLY COMPATIBLE INTERFACES FOR FREE SPACE OPTICAL SYSTEMS (Mar. 2006).

53. CONSULTATIVE COMM. FOR SPACE DATA SERVS., CCSDS 141.0-B-1, *supra* note 47, at annex B-1.

54. CONSULTATIVE COMM. FOR SPACE DATA SERVS., CCSDS 142.0-B-1, *supra* note 47, at annex C-2.

55. PATENT GURU, https://www.patentguru.com/search?q=(abs%3D(LDPC))+AND+(CPC%3D(H04B10))&area=US [https://perma.cc/R4SP-WJDF] (last visited Apr. 8, 2024) (searching for patents in the FSO group with LDPC, the encoding used by CCSDS 142, in the abstract).

56. The Artemis program is NASA's effort to get humans back on the lunar surface and establish a long-term presence there. NASA is projected to spend $93 billion on the Artemis program by 2025. Alisa Harvey & Adam Mann, *NASA's Artemis program: Everything you need to know*, SPACE.COM (last updated Dec. 12, 2022), https://www.space.com/artemis-program.html.

57. NAT'L AERONAUTICS & SPACE ADMIN., LUNANET INTEROPERABILITY SPECIFICATION DOCUMENT VERSION 4, at 6 (2022) [hereinafter LUNANET INTEROPERABILITY SPECIFICATION DOCUMENT VERSION 4]; NAT'L AERONAUTICS & SPACE ADMIN., LUNANET INTEROPERABILITY SPECIFICATION DOCUMENT DRAFT VERSION 5, at 8 (2022) ("Standards for optical link interfaces are TBD.").

58. LUNANET INTEROPERABILITY SPECIFICATION DOCUMENT VERSION 4, *supra* note 57, at 36–40.

program, and many of NASA's corporate partners for Artemis and other recent missions are not CCSDS associates.[59] NASA's corporate collaborators could try to prevent LunaNet from using CCSDS 141 and 142. Another possible barrier to American support for CCSDS is that Space Development Agency ("SDA"), under the Department of Defense, also published a standard that utilizes a portion of the CCSDS optical standards but is not in complete harmony.[60] SDA could hamper NASA's adoption of CCSDS 141 and 142, but, due to its military ties, it is less likely to capture market participation outside of the United States.

B. Future Possible Space-Focused Standard Setters

Although CCSDS is an incumbent standard setter, satellite telecommunications providers are becoming increasingly economically powerful[61] and may start to exert their own influence on space industry trends. As the space industry separates from national space agencies, companies will have opportunities to drive their own standards. In this capacity, they would form standards as single-promoters or consortia.[62]

It is important to note that, as satellites are launched without adopting standards, the likelihood that any standards could become prevalent decreases. The high costs and historically slow development of satellites make mid-constellation adoption of standards extremely difficult compared to, say, infrared television remotes. Thus, the earlier a standard setter is to publish, the more likely it is that their standard will be widely adopted. Indeed, after it is adopted once by a satellite developer, path dependence makes it very likely that the developer will

59. *Compare* Nat'l Aeronautics & Space Admin., Artemis Plan: NASA's Lunar Exploration Program Overview 21 (2020), https://www.nasa.gov/wp-content/uploads/2020/12/artemis_plan-20200921.pdf. (naming Blue Origin, Dynetics, and SpaceX as Artemis lander developers) *and* Kendall Murphy, *CubeSat Set to Demonstrate NASA's Fastest Laser Link from Space* (May 24, 2022), https://www.nasa.gov/directorates/somd/cubesat-set-to-demonstrate-nasas-fastest-laser-link-from-space/ [https://perma.cc/55C6-DBAH] (naming Terran Orbital as a partner on a recent FSO mission), *with* Consultative. Comm. for Space Data Sys., Associates, https://public.ccsds.org/participation/associates.aspx [https://perma.cc/FR5H-LZEM] (listing CCSDS associates, which includes none of the four previous companies).

60. Space Dev. Agency, Optical Communications Terminal (OCT) Standard Version 3.0, at 2 (2021), https://www.sda.mil/wp-content/uploads/2022/04/SDA-OCT-Standard-v3.0.pdf (requiring compliance with the CCSDS coding standard, but overlapping the physical layer standard).

61. *See* Dingley, *supra* note 1, at 22.

62. Biddle, *supra* note 46, at 19–21 (describing the creation of consortia and single-promoters by for-profit entities, as opposed to governmentally recognized SDOs).

continue to use that standard. As such, CCSDS holds additional sway as the incumbent, and challengers will need to act quickly.

1. Single-promoters

Another possible outcome for FSO standardization would be corporate dominance by a single promoter. The spread of the charging port used by Tesla, NACS, provides a terrestrial example of a triumphant single-promoter standard. Tesla developed the port in-house and created an exclusive network of charging stations to service their vehicles. The quick construction of such stations became a major selling point for Tesla's cars. In April 2022, Tesla's quarterly growth started slowing.[63] By November 2022, the company announced that the port would be made public,[64] and in June 2023, SAE, a major automotive SDO, announced their propagation of NACS.[65] While Tesla holds several patents enabling NACS,[66] they issued a letter of assurance that any entity wishing to implement SAE's standard would be granted royalty-free, non-exclusive licenses to their use.[67] Since then, all major car manufacturers have announced that their forthcoming cars will use NACS ports.[68]

Tesla indirectly benefits from each adoption of NACS. Charging stations constructed by third parties will be more likely to include NACS chargers, making it easier for Tesla drivers to travel without planning their routes around charging locations. Additionally, customers who install home chargers for lower-end NACS cars may be more likely to later upgrade to Teslas if they could do so without having to modify their home's electric infrastructure further. And although providing competitors with a standard lowers their research and development costs, it gives Tesla a level of control over the standard-setting process,

63. *Tesla Revenue 2010-2023 | TSLA*, MACROTRENDS, https://www.macrotrends.net/stocks/charts/TSLA/tesla/revenue [https://perma.cc/6QZ5-336Z].

64. The Tesla Team, *Opening the North American Charging Standard*, TESLA (Nov. 11, 2022), https://www.tesla.com/blog/opening-north-american-charging-standard [https://perma.cc/9KYX-DSBN].

65. *SAE International Announces Standard for NACS Connector, Charging PKI and Infrastructure Reliability*, SAE INT'L (June 27, 2023), https://www.sae.org/news/press-room/2023/06/sae-international-announces-standard-for-nacs-connector [https://perma.cc/A9FR-UXAQ].

66. *See, e.g.*, U.S. Patent No. D694,188; U.S. Patent No. D724,031.

67. Letter from Drew Baglino, Senior Vice President, Tesla, Inc., to Christian Thiele, Dir. of Global Ground Vehicle Standards, SAE Int'l (June 27, 2023), https://standardsworks.sae.org/standards-committees/hybrid-ev-j3400-nacs-electric-vehicle-coupler-task-force.

68. Andrew J. Hawkins, *Stellantis Becomes the Last Major Automaker to Adopt Tesla's Charging Plug*, THE VERGE (Feb. 12, 2024, 11:56 AM), https://www.theverge.com/2024/2/12/24070654/stellantis-tesla-ev-charging-plus-nacs-adapter[https://perma.cc/7RC9-GJM4].

with benefits which may be hard to quantify. Controlling a standard gives a single-promoter the ability to condition the market in their favor, lowers the research and development costs they would have to expend regardless, and increases their ability to displace incumbent competitors.[69] In terrestrial telecommunications, optical connector manufacturer Tyco increased its profits by $50–100 million during the first ten years after it shifted the industry standard towards its intellectual property.[70] These profits were earned through licensing, but also through increasing market share and margins.[71]

Similar dynamics may exist in the satellite Internet industry, which Tesla and SpaceX/Starlink CEO Elon Musk could play to his advantage. SISPs can make a stronger value proposition to their customers if provider switching is cheap. This capability reduces the risk of signing up for satellite Internet – if a customer's provider goes out of business, loses a satellite, or raises prices, customers can go to other providers. While competition would drive prices down, SISPs could still increase their profits though increased demand. Starlink is later to the general SISP market than Tesla, but it is the first flexible, low-latency SISP to provide service to worldwide end-consumers. By largely ignoring industrial customers and developing the end-consumer market, Starlink has rapidly increased its market share in a manner that has garnered attention from its competitors. It also holds no patents relevant to FSO.[72] If it were to publicize its FSO design, even if established competitors did not adopt it, newcomers which did would benefit from lower research and development costs, while Starlink would benefit from increased demand. Starlink would also cultivate the ability to acquire constellations already in orbit, which will be discussed further in subsequent sections.

Starlink's extraterrestrial ambitions provide even greater incentives to promote standardization. Unlike its major commercial competitors, which are primarily focused on Earth-facing solutions, Starlink has a stated intention to provide outward Internet service as far as Mars. A strong standard would help Starlink provide Internet to other satellites

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69. Andrew Updegrove, *Value Propositions, Roles and Strategies: Participating in a SSO*, ConsortiumInfo.org (2007), https://www.consortiuminfo.org/guide/participating-in-a-sso/value-propositions-roles-and-strategies [https://perma.cc/EM53-J27Q].

70. Tim Büthe & Walter Mattli, The New Global Rulers: The Privatization of Regulation in the World Economy 31 n.41 (2011).

71. *Id.*

72. Patent Guru, https://www.patentguru.com/search?q=(asn%3D(Space+Exploration+Technologies))+AND+(CPC%3D(H04B10)) [https://perma.cc/SD3V-NRKE] (searching for patents registered to SpaceX in the FSO category; no results are returned).

and missions beyond Earth's orbit. This would also help drive demand for SpaceX's deep space launch services, providing a great advantage to SpaceX as a whole. Even if Starlink were to lose market share to competitors using a hypothetical open standard, SpaceX could benefit. With several incentives to do so and minimal downsides, Starlink would be prudent to promote an FSO standard.

2. *Industry Consortia*

Consortia are industry groups which coordinate to propagate a standard.[73] Like single-promoter standards, consortia standards are driven by industry rather than governments or international organizations. However, national space industries may prefer consortia to single-promoters as the latter do not leave sole control over a standard in the hands of one company. At the time of writing, there do not appear to be entities likely to form a significant space-use FSO consortium. But consortia are not new to the space industry, and a few adjacent consortia do exist. Space Enterprise Consortium, SpEC, is recognized by at least the United States Space Force and Department of Defense.[74] They claim to develop and share prototypes across several areas, including optical payloads.[75] No further information about SpEC is available. Another consortium, the Digital Intermediate Frequency Interoperability Consortium ("DIFI") was originally formed to standardize intermediate frequency communication.[76] Its members now include at least one manufacturer of FSO equipment,[77] indicating that it may look towards FSO standards next.

These consortia claim to share prototypes, so constituent companies could rapidly adopt any standards the consortia publish. Member companies would presumably be less hesitant to adopt consortium standards than single-promoter standards, as they can be involved in the development process. However, the funding provided by national space agencies is core to many, if not most, space industry

73. Biddle, *supra* note 46, at 19–20.

74. Lisa Sodders, *Space Enterprise Consortium Membership Meeting to Bring Government, Space Industry Together*, U.S. SPACE FORCE SPACE SYS. COMMAND (Oct. 5, 2023), https://www.ssc.spaceforce.mil/Newsroom/Article-Display/Article/3549023/space-enterprise-consortium-membership-meeting-to-bring-government-space-indust [https://perma.cc/H2BR-QJZB].

75. *Technology Areas*, SPACE ENTERPRISE CONSORTIUM, https://space-enterprise.org/the-space-enterprise-program/technology-areas [https://perma.cc/NPH9-SDY3].

76. *About*, DIFI CONSORTIUM, https://dificonsortium.org/about [https://perma.cc/SGW6-WWJL].

77. Press Release, WORK Microwave, WORK Microwave Joins Digital IF Interoperability Consortium (Feb. 28, 2022), https://work-microwave.com/work-microwave-joins-digital-if-interoperability-consortium [https://perma.cc/9RET-LZQ4].

companies. This dynamic may limit the ability of consortia to deviate from SDO-created standards. Additionally, patents are most problematic for consortia. Holders of patents relevant to a standard may block adoption by disputing terms at length, known as "patent holdup," or by accumulating rights in a "patent thicket."[78] Patents are dense in the defense and semiconductor sectors,[79] and FSO is no exception. At the time of writing, 256 valid patents related to FSO are held by Boeing and Raytheon alone.[80] With so many relevant patents, negotiating a consortium with fair and reasonable licensing terms is likely to be very time intensive. FSO consortia are worth watching but are unlikely to publish standards conflicting with CCSDS.

III. Standardization Implications

FSO standardization would have implications across all aspects of satellite Internet service. From consolidation, to improved service, to international conflicts, the consequences would be far-reaching, with a mixture of benefits and risks. This section is organized by sector, in order of the ease of predicting consequences. It is most straightforward to predict changes brought by standardization to the commercial and science sectors, followed by cross-sector consequences. International relations are the most difficult to predict but the most significant, as space continues to grow in economic and strategic importance. Across each area, the risks created by standardization are less than the benefits if given sufficient attention by regulators.

A. Commercial

Standardization of FSO would likely lead to consolidation of SICs, bringing short-term benefits to consumers with possible long-term downsides. Consolidation would lower costs for consumers, as merged SICs would not need to launch as many satellites for complete global coverage. It would also improve coverage as SICs gain satellites in multiple orbits. However, over a longer period, monopolistic power could lead to abuses of the market. National space agencies with trusted

78. Pierre Larouche & Geertrui van Overwalle, *Interoperability Standards, Patents and Competition Policy*, *in* The Law, Economics, and Politics of International Standardisation 379–85 (Panagiotis Delimatsis ed., 2015).

79. *See* Peter Drahos, *TRIPS Through a Military Looking Glass*, *in* 30 MPI Stud. on Intell. Prop. & Competition L. 657, 677 (Christine Godt & Matthias Lamping eds., 2023).

80. Patent Guru, https://www.patentguru.com/search?q=(asn%3D(Boeing)+OR+asn%3D(Raytheon))+AND+(CPC%3D(H04B10))&area=US [https://perma.cc/YLN4-D6J4] (last visited Apr. 8, 2024) (searching for FSO patents assigned to Boeing or Raytheon).

SICs would benefit from significant cost and complexity reductions, and their presence in the market may be a helpful regulating power. But they may inadvertently encourage the formation of monopolies through their coordination efforts. Some amount of consolidation is already visible, with one collaboration between SES and Starlink and a merger of two constellations, as I will discuss below.

1. SES and Starlink Collaboration Hints at Future Trends

A recent deal between Starlink and another SISP, called SES, illustrates how beneficial network effects can be and how technological standardization could further benefit consumers and certain companies. In September 2023, SES announced that it would provide a joint service with Starlink to cruise ship companies.[81] Cruise ships are uniquely capable of installing the hardware necessary to receive service from both providers; while Starlink's receivers are only a few feet on each side, SES's receivers are yards long and require industrial installation. This is necessary because their satellites are in a higher orbit—medium Earth orbit ("MEO"), at an altitude of about 8,000 km[82] —while Starlink's are in low Earth orbit ("LEO"), at an altitude of about 550 km.[83] Limited by the size of their terminals, SES primarily targets industrial customers, such as telecommunications providers and cruise ship operators.[84]

The combination of service from MEO and LEO SICs is powerful, as the constellations have different advantages. MEO constellations have slightly higher latency in exchange for greater coverage of the Earth per satellite.[85] This means that terminals can spend longer connected to the same satellite—around one hour, rather than ten minutes—reducing handover costs.[86] So, an LEO constellation is ideal for low-latency applications such as videocalls and gaming, while MEO constellations can handle most of the remainder of Internet communication.

However, the 2023 SES-Starlink deal does not leverage the constellation's comparative advantages as effectively as possible. Combined service requires cruise ships to install both SES and Starlink

81. Jason Rainbow, *Starlink and SES Join Forces for Multi-Orbit Cruise Connectivity*, SpaceNews (Sept. 13, 2023), https://spacenews.com/starlink-and-ses-join-forces-for-multi-orbit-cruise-connectivity [https://perma.cc/8FZA-RX8S].

82. *The Power of MEO*, SES, https://www.ses.com/o3b-mpower/power-meo [https://perma.cc/8RES-SJMS].

83. *How Starlink Works*, *supra* note 16.

84. *The Power of MEO*, *supra* note 82.

85. *Id.*

86. *See generally* Yitao Li et al., *Forecast Based Handover in an Extensible Multi-Layer LEO Mobile Satellite System*, 8 IEEE Access 42768 (Mar. 2, 2020) (explaining the cost of handovers and proposing one method to reduce them).

terminals; there are no plans to create a combined terminal.[87] This means that connection balancing happens based on which service is available, rather than which service is ideal for a given application. Essentially, customers of the SES-Starlink service receive a simpler billing scheme and no additional benefits compared to subscribing to both services independently. If the constellations were able to communicate with each other, they would be able to route traffic to the appropriate satellite depending on its bandwidth and speed, which would only be possible if the satellites used standardized communications technology. Demand for this kind of mixed service is increasing rapidly, and economic research suggests a Starlink-SES merger would greatly increase overall value in the satellite Internet market.[88] With such clear economic advantages, SICs are likely weighing the adoption of international standards.

2. *One Technology, Low Barriers to Network Switching*

The greatest benefit end-consumers would reap through standardization would be the ability to switch networks seamlessly. Standardization that enabled network switching was an essential feature of the post-AT&T monopoly American telecommunications market. With many networks to choose from, consumers were able to shop around, unsurprisingly often choosing their provider based on the price of service.[89] Thanks to standardization, customers were often able to switch networks while keeping the same expensive phones. Competition is easily identified as a factor that kept consumer costs low. Now, in the wake of numerous mergers, telecommunications company executives are signaling that increased profits can be made at the expense of consumers.[90] Having networks that customers can switch between is also helpful for emergencies and fault tolerance. For example, if an iPhone user is not connected to their telecommunications provider's network, they are still able to make emergency calls using available infrastructure.[91] This allows users to connect to emergency services using any available cell towers if a natural disaster or physical- or cyber-attack has damaged some but not all infrastructure in an area.

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87. Rainbow, *supra* note 81.
88. Dingley, *supra* note 1, at 152.
89. Melody Wang & Fiona Scott Morton, *The Real Dish on the T-Mobile/Sprint Merger: A Disastrous Deal from the Start*, ProMarket (Apr. 23, 2021), https://www.promarket.org/2021/04/23/dish-t-mobile-sprint-merger-disastrous-deal-lessons [https://perma.cc/W7SS-QP2E].
90. *Id.*
91. *If You See No Service, Searching, or SOS on Your iPhone or iPad*, Apple (Mar. 29, 2024), https://support.apple.com/en-ph/HT201415 [https://perma.cc/2FG2-2UQA].

Network switching depends on space-Earth standardization rather than space-to-space. If space-Earth FSO is not standardized, consumers could be required to acquire new hardware to switch networks. With space-to-space standardization only, SIC consumers would not benefit from the ability to easily switch networks, but they would benefit from a limited increase in network resiliency. For example, if one of SES's thirteen[92] MEO satellites were damaged or became inoperable, another SIC could be contracted to fill in the resulting gap in constellation communications. While their ground customers would be inaccessible under the missing satellite, space-only data flows could be sustained for the rest of the global network. This would result in service blackouts for just part of the network, rather than the entire network.

If space-Earth communication is standardized as well (whether using radio or FSO), customers will reap the benefits which were enjoyed by post-monopoly, pre-consolidation cellphone service consumers. They would be able to buy one ground station and switch between networks as beneficial based on price or availability. With the threat of consumers switching networks on a large scale, providers would have to keep their prices low. Consumers would also be able to boycott providers for enacting disagreeable policies related to aspects of service like net neutrality[93] or broader political actions, such as decisions made regarding provision of service in zones of conflict.[94] If, for example, LEO were to become less habitable due to debris or crowding, constellations in higher orbits would be able to connect to and service consumers in emergency situations. Such capability would be especially important if war in space becomes more common, as some analysts predict.[95] Enabling constellations to fill each other's gaps would make the SIC system far more resilient to many of the unpredictable interruptions which space could impose.

Intermediate consumers (such as cruise lines) would benefit in addition to individual consumers, needing fewer ground stations and

92. *The Power of MEO*, *supra* note 82.

93. *Cf. Starlink Fair Use Policy*, STARLINK, https://www.starlink.com/legal/documents/DOC-1469-65206-75?regionCode=US [https://perma.cc/7DHP-V5UJ] (promising traffic neutrality, a provision which, if reneged on, could generate significant consumer response).

94. *See, e.g.*, Tara Copp, *Elon Musk's Refusal to Have Starlink Support Ukraine Attack in Crimea Raises Questions for Pentagon*, AP NEWS (Sept. 11, 2023, 6:42 PM), https://apnews.com/article/spacex-ukraine-starlink-russia-air-force-fde93d9a69d7dbd1326022ecfdbc53c2 [https://perma.cc/GGG3-ULRT] (indicating unease within the Pentagon at reliance on Starlink, given Musk's unpredictability).

95. *Cf.* DANIEL DEUDNEY, DARK SKIES: SPACE EXPANSIONISM, PLANETARY GEOPOLITICS, AND THE ENDS OF HUMANITY 165–67 (2020) (narrating the anti-satellite arms race).

getting extra bandwidth and use from each station. Consider the SES-Starlink partnership. To benefit from the combined service, cruise lines must install several terminals from each provider. Space-Earth standardization would allow cruises to install fewer terminals while receiving the same benefits to service. Additionally, terminals could balance constellation traffic intelligently, rather than providing service based on whichever satellite is closest. They could route traffic that benefits from lower latency to lower satellites and route bulk data transfers to higher, more well-connected satellites. These features would lower costs and improve service for their end-consumers as well.

B. Science: Space Agencies and their Scientists Benefit from Easier and Cheaper Services

Another kind of customer would benefit greatly from widespread standardized FSO SICs: national space agencies. Scientific missions such as telescopes and landers would be even more useful with easily available and cheap high-bandwidth links. FSO, at a baseline, will provide bandwidth improvements, and NASA is already launching serious scientific missions that utilize the technology.[96] SICs could solve another major problem for deep-space communications: ground stations.

Scientific missions which take place far from Earth rely on solutions like the Deep Space Network ("DSN"), an international system of three massive radio dishes which can receive transmissions from "tens of billions of miles from Earth."[97] Networks like the DSN benefit from having several ground stations evenly distributed worldwide;[98] because of the motion of bodies through the solar system, a lander launched towards Mars trying to communicate with Earth will point at different parts of the Earth depending on the time of day and year. The DSN is primarily used by NASA and the European Space Agency ("ESA")[99] so state agencies without access to it must build (and have built)[100] their

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96. Donaldson, *supra* note 17.

97. Heather Monaghan, *What is the Deep Space Network?*, NAT'L AERONAUTICS & SPACE ADMIN. (Mar. 30, 2020), https://www.nasa.gov/directorates/somd/space-communications-navigation-program/what-is-the-deep-space-network [https://perma.cc/6KNY-NRR5].

98. *Id.*

99. *See ESA and NASA Extend Ties with Major New Cross-Support Agreement*, EUR. SPACE AGENCY (Apr. 2, 2007), https://www.esa.int/About_Us/ESOC/ESA_and_NASA_extend_ties_with_major_new_cross-support_agreement [https://perma.cc/V63K-ZWPL].

100. *See, e.g.*, I. Molotov, *Two-Year Program to Upgrade Bear Lakes RT-64 for EVN Membership*, 6 EUR. VLBI NETWORK SYMP. (June 25–28, 2002), https://web.archive.org/web/20040123144423/http://www.mpifr-bonn.mpg.de/div/vlbi/evn2002/

own expensive, technologically complex ground station networks in as many parts of the world as they have allies. Satellite constellations solve this problem by operating above and outside of national territories. Any single country with sufficient resources could launch a satellite network which would be capable of constantly receiving transmissions from outer (non-Earth) space. A satellite in the constellation wouldn't have to store transmissions; it could route them to satellites already in convenient positions. Deep space relay constellations already exist, but due to bandwidth constraints and limited intra-constellation communication, they do not enable continuous, or even *high*-latency, communication.[101] Missions utilizing FSO SICs will benefit from higher bandwidth and near-constant communication with Earth, which will enable scientific breakthroughs benefiting the whole world. However, because of the military nature of many space programs,[102] state agencies may not trust the commercial SICs launched by other states and international companies. It is likely that constellations will be launched by a plethora of states, like GNSSs. Further ramifications are discussed in Section IV.D.

C. Cross-Sector: Whichever Providers Win Will Win Bigger

Standardization is not solely beneficial—it would also enable consolidation of SICs in a manner that could harm consumers over time. Standardized constellations will be able to collaborate to provide emergency service, but they will also be able to provide cross-constellation service long-term. As discussed with regard to the joint Starlink-SES cruise ship offering, this will deliver reliability and speed benefits to consumers, increasing demand and benefiting SICs. However, not all businesses survive, especially not in an industry as

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book/IMolotov2.pdf (detailing the latest addition to the Russian deep space network); Cassandra Garrison, *China's Military-Run Space Station in Argentina is a 'Black Box,'* REUTERS (Jan. 31, 2019, 1:13 AM), https://www.reuters.com/article/us-space-argentina-china-insight-idUSKCN1PP0I2 [https://perma.cc/MM9D-242A] (discussing a Chinese deep space network station in Argentina); *Indian Deep Space Network (IDSN)*, INDIAN SPACE RSCH. ORG., https://web.archive.org/web/20141105203059/http://www.isro.org/Chandrayaan/htmls/ground_segment_spacenetwork.htm (last visited Apr. 13, 2024) (listing stations in India's deep space network).

101. *See* Paul Carter & E. Glenn Lightsey, *Deep Space Relay Architecture for Communication and Navigation* 1–2 n.4 (last visited June 19, 2024) (unpublished manuscript) (on file with the Space Systems Design Laboratory at Georgia Institute of Technology), https://ssdl.gatech.edu/sites/default/files/ssdl-files/papers/mastersProjects/CarterP-8900-V2.pdf (describing existing deep space relay system with up to two weeks of downtime).

102. *See generally* Asif A. Siddiqi, *Soviet Space Power during the Cold War*, *in* HARNESSING THE HEAVENS 135 (Paul G. Gillespie & Grant T. Weller eds., 2008) (summarizing the history and organizational evolution of the Soviet space program).

expensive as one that relies on satellite constellations. With astronomical launch costs and uncertain demand, it is likely that some SICs will go bankrupt after launching satellites.

In this scenario, the worst possible outcome would be for the satellites to remain in-orbit without active operation. In-orbit inactive satellites present a major debris risk, as they cannot be redirected when the possibility of a collision is detected.[103] With interoperability, remaining SICs would be able to integrate the satellites of bankrupt operators into their constellations. This would lower the operating costs of the surviving SIC, as it would not need to launch as many satellites and could improve service if a competitor in another orbit is acquired. In the short term, consumer costs would stay low, and they would be protected from service interruptions that could be introduced by the bankruptcy of failed SICs.

But in the long term, if consolidation is unrestricted, consumers of an essential infrastructure could end up at the mercy of a monopoly. Monopolies can impose on customers higher prices and other restrictions, introducing harm which a market would otherwise address. Even if multiple SICs continue to exist, standardization can be used by monopolies to entrench their power over certain aspects of a market.[104] As AT&T standardized local phone lines so they could remain the backbone of the national long-haul telephone network,[105] an SIC could standardize ground terminals and allow multiple manufactures to sell them while retaining control over the space-based infrastructure. A monopoly over digital infrastructure would be especially concerning, as many consumers would have no choice to opt out. For example, rural consumers could be forced to pay monopoly prices or be disconnected from the Internet entirely. Societies already struggle to reckon with software platform monopolies;[106] physical infrastructure monopolies would surely multiply those harms and introduce new, unpredictable ones.

From a regulatory perspective, a potential monopolist would face a complex landscape. As Starlink is currently finding out, each country has a unique regulatory scheme with which service providers must

103. *See* Ram S. Jakhu, *Iridium-Cosmos Collision and its Implications for Space Operations*, in YEARBOOK ON SPACE POLICY 2008/2009, at 254, 256 (Kai-Uwe Schrogl et al. eds., 2010).

104. Jorge L. Contreras, *A Tale of Two Layers: Patents, Standardization, and the Internet*, 93 DENVER U. L. REV. 853, 866 (2016).

105. *Id.*

106. *See, e.g.*, Francis Fukuyama et al., *How to Save Democracy from Technology: Ending Big Tech's Information Monopoly*, 100 FOREIGN AFFS. 98, 102–03 (2021).

comply.[107] As states and provinces introduce new legislation, SICs will have to bring their already-launched infrastructure into compliance, presenting significant technical challenges.

But at a certain point, the monopolist becomes so entrenched that it takes on extrajudicial power. For example, imagine a state with rugged terrain which struggles to provide reliable internet to all its residents. The benefits of satellite Internet are obvious to its population, and over time a majority signs up with the monopolist SISP. When, a leak reveals that the SISP is violating the privacy of its customers a few years later, the state's legislature decides to require new personal data protections. For the SISP, a massive multinational corporation, the state's population is not large enough to take on a significant financial burden to come into compliance with the new regulation, and it announces that it will exit the state's market, leaving hundreds of thousands of people without access to the Internet. This scenario is not farfetched—a similar scenario played out with Google and Facebook News in Canada.[108] In response to Canada's Bill C-18, which required the platforms to negotiate revenue sharing deals with publishers, both Google[109] and Meta[110] withdrew their news-oriented services, leaving consumers with reduced access to news in the country. This is extremely damaging for a functioning democracy, and the ramifications could be even more serious for a state that caused its citizens to lose access to the Internet. The power amassed by an SISP monopolist would be a matter of grave international and domestic concern.

D. International Governance and Military

Whether captured by a monopolist or as a competitive market, SICs present a novel, diverse set of concerns for governments around the world.

107. *Cf. Why China Fears Starlink*, THE ECONOMIST (May 18, 2023), https://www.economist.com/china/2023/05/18/why-china-fears-starlink [https://perma.cc/6W3Z-TQGF] (exploring tension between Starlink and China over providing satellite Internet service to Taiwan).

108. *Facebook Owner Meta Carries Out Threat to Block News in Canada. Google Plans to Do the Same*, AP NEWS (Aug. 3, 2023, 3:38 PM), https://apnews.com/article/facebook-meta-canada-news-google-e23fae879596af2c5ac8075fa92f3689 [https://perma.cc/6686-BL3T].

109. Kent Walker, *An Update on Canada's Bill C-18 and Our Search and News Products*, GOOGLE CAN. BLOG (June 29, 2023), https://blog.google/intl/en-ca/company-news/outreach-initiatives/an-update-on-canadas-bill-c-18-and-our-search-and-news-products [https://perma.cc/V46B-WDPL].

110. *Meta Tests Blocking News Content on Instagram, Facebook for Some Canadians*, AP NEWS (June 2, 2023, 2:10 AM), https://apnews.com/article/meta-news-canada-facebook-instagram-d0afcc95469107a51d98e127c05f636d [https://perma.cc/3Z8G-QB3G].

Given the proliferation of GNSSs, it is safe to assume that unique SICs will be created to service political blocs. Each additional constellation increases the traffic in Earth orbits, raising the likelihood of collisions that could interrupt service and make future space travel hazardous. Unlike Earth-based infrastructure, a satellite constellation cannot be physically blocked from operating "within" a country. Instead, satellites within a constellation could be jammed over a country's airspace, with difficult-to-predict geopolitical consequences. The mere existence of this technology is likely to tempt corporations to evade traditional political processes altogether; so-called "sovereign barges," evoking the "sovereign citizen" movement,[111] present minimal governance concerns compared to on-orbit data centers. Given the military nature of many national space programs, the plethora of problems raised by SICs is particularly harrowing and difficult to predict.

1. Constellation Proliferation Is Likely, Making Standardization Even More Important

Positioning data is extremely sensitive, but data transmitted over the Internet can be even more revealing. Satellite Internet service can even be used to provide device positioning.[112] Just as countries launched their own GNSSs to avoid reliance on the American Global Positioning System ("GPS"), they will likely launch their own SICs. This is likely no matter how internationally agreed upon design standards become. From this lens, the problems are sovereignty and security, not standardization; the Russian military will not give an American-military-run constellation its positioning data no matter how ubiquitous and well-documented the American service is. Yet the more constellations are launched, the more orbital crowding will become a problem, endangering all SICs and the entire space industry.

The first GNSS, Transit, was launched by the United States Navy in 1960.[113] With accuracy within around 25 meters, it was groundbreakingly useful for navies. But due to low satellite coverage and long required

111. *See* Lorelei Laird, *'Sovereign Citizens' Plaster Courts with Bogus Legal Filings—And Some Turn to Violence*, ABA J. (May 1, 2014, 10:20 AM), https://web.archive.org/web/20141102010820/http://www.abajournal.com/magazine/article/sovereign_citizens_plaster_courts_with_bogus_legal_filings/ [https://perma.cc/HT9F-FDJU].

112. Mark Harris, *Starlink Signals Can Be Reverse-Engineered to Work Like GPS—Whether Spacex Likes It or Not*, MIT TECH. R. (Oct. 21, 2022), https://www.technologyreview.com/2022/10/21/1062001/spacex-starlink-signals-reverse-engineered-gps [https://perma.cc/HBS9-WKPP].

113. BASUDEB BHATTA, GLOBAL NAVIGATION SATELLITE SYSTEMS: NEW TECHNOLOGIES AND APPLICATIONS 12 (2021).

observation times, it was not ideal for civilian users.[114] By 1985, the US military's GNSS had gone through two revisions and become the GPS used today.[115] In the same time frame, the Soviet Union developed their own GNSS called GLONASS. The modern version became fully operational in 1995.[116] Neither version was initially intended for civilian use; GPS was fully opened to the public in 2000, and GLONASS in 2007.[117] Yet both systems remain under the operation and control of their respective nations, and neither ensures continuing signal to civilians.[118] This uncertainty led to the creation of Galileo, a GNSS intended for civilian use by the European Space Agency ("ESA"),[119] an intergovernmental organization.[120] China launched its own GNSS as well, with a first launch in 2000 and completion in 2020.[121] Countries augment GNSS with overlay systems as well. Such systems have been implemented in the US, Europe, Japan, and India.[122]

Many satellites were launched to create these eight constellations, but the number pales in comparison to those which would be required for eight SICs. GPS, for example, contains 24 operational satellites.[123] Starlink has already launched over 4,000 satellites, with plans for tens of thousands more.[124] Amazon's Project Kuiper plans to launch 3,236 satellites.[125] Smaller constellations, such as SES, may include fewer satellites than GPS,[126] but many SICs have been announced in the US alone: Starlink, Project Kuiper, SES's 03b MEO and O3b mPOWER, Viasat, and HughesNet. Predictably, competitors have been announced from developers in several other countries, including Telesat from

114. *Id.*
115. *Id.* at 13–14.
116. *Id.* at 14.
117. *Id.* at 15.
118. *Id.*
119. *Id.*
120. *ESA and the EU*, ESA, https://www.esa.int/About_Us/Corporate_news/ESA_and_the_EU [https://perma.cc/RW7H-SWXM].
121. Bhatta, *supra* note 113, at 15.
122. *Id.* at 15–16.
123. *Space Segment*, GPS.gov, https://www.gps.gov/systems/gps/space [https://perma.cc/BSD2-BMMQ].
124. Press Release, SpaceX, Second Generation Starlink Satellites (Feb. 26, 2023), https://api.starlink.com/public-files/Gen2StarlinkSatellites.pdf [https://perma.cc/Y2N6-6JYK]; Adam Satariano et al., *Elon Musk's Unmatched Power in the Stars*, N.Y. Times (July 28, 2023), https://www.nytimes.com/interactive/2023/07/28/business/starlink.html ("Mr. [Musk] plans to have as many as 42,000 satellites in orbit in the coming years").
125. *Project Kuiper*, Amazon https://www.aboutamazon.com/what-we-do/devices-services/project-kuiper [https://perma.cc/ZMQ7-B9FX]
126. *The Power of MEO*, *supra* note 82 (explaining the design of SES's newest constellation, which includes thirteen satellites).

Canada, Guo Wang from China, Eutelsat from France, OneWeb from the United Kingdom, and more. The European Commission has also announced an initiative to launch an SIC,[127] although companies are lobbying to implement it as an SISP using an existing SIC instead.[128, 129] These constellations vary in size as well, from 35 Eutelsat satellites[130] to a planned 13,000 from Guo Wang.[131] If all these constellations are launched with the planned number of satellites, there would be 100,000 satellites in orbit just to provide Internet service.

The Chinese government is unlikely to relinquish its control over the country's Internet infrastructure, and other countries may raise similar concerns. It is essential that remaining operators standardize so they can consolidate and rapidly reduce the number of satellites in orbit in cases of emergency and orbital debris, which is already a serious problem.[132] Several collisions have occurred in recent years,[133] increasing the presence of orbital debris, presenting threats to the safety of other satellites and, most importantly, of humans traveling to space.[134] The reactions to the most recent collisions suggest that debris could become an instigator of conflict.[135] With too many constellations, it will get even worse.

Constellations have the potential to be particularly dangerous producers of debris, as hundreds or even thousands of satellites in a

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127. *IRIS²: the new EU Secure Satellite Constellation*, EUR. COMM'N, https://defence-industry-space.ec.europa.eu/eu-space-policy/iris2_en [https://perma.cc/Q3ZP-HZG3].

128. This would be the first SISP without its own constellation.

129. Jason Rainbow, *UK Pushing to Combine Oneweb Gen 2 and European Sovereign Constellation Efforts*, SPACENEWS (Nov. 2, 2023), https://spacenews.com/uk-pushing-to-combine-oneweb-gen-2-and-european-sovereign-constellation-efforts [https://perma.cc/PYJ2-AV8F].

130. *Connectivity Solutions*, EUTELSAT GRP., https://www.eutelsat.com/en/satellite-communication-services/eutelsat-advance-satellite-connectivity.html [https://perma.cc/ZGG7-6ZD9].

131. Matt Williams, *China Has Begun Launching its Own Satellite Internet Network*, UNIVERSE TODAY (July 14, 2023), https://www.universetoday.com/162361/china-has-begun-launching-its-own-satellite-internet-network [https://perma.cc/3R8G-2ECH].

132. THOMAS J. COLVIN ET AL., NASA OFF. TECH., POL'Y, & STRATEGY, COST AND BENEFIT ANALYSIS OF ORBITAL DEBRIS REMEDIATION 1 (Mar. 20, 2023), https://www.nasa.gov/wp-content/uploads/2023/03/otps_-_cost_and_benefit_analysis_of_orbital_debris_remediation_-_final.pdf [https://perma.cc/9LKP-VP9X].

133. *See, e.g.*, Mike Wall, *Space Collision: Chinese Satellite Got Whacked by Hunk of Russian Rocket in March*, SPACE.COM (Aug. 17, 2021), https://www.space.com/space-junk-collision-chinese-satellite-yunhai-1-02 [https://perma.cc/5EH8-6WVV].

134. Rebecca Heilweil, *The Space Debris Problem is Getting Dangerous*, VOX (Nov. 16, 2021, 2:45 PM), https://www.vox.com/recode/2021/11/16/22785425/international-space-station-russia-missle-test-debris [https://perma.cc/77CT-PVT3].

135. *See id.*

constellation can cross a given point over the course of a day.[136] It would take a physical impact to just one satellite to create a massive debris cloud, as subsequent satellites passing through the original cloud would shatter as well. In the worst-case scenario, the Earth could suffer from "Kessler syndrome," a hypothetical condition which would render an orbit or part of an orbit impassable due to debris.[137] There is currently no technology that could end a Kessler syndrome scenario, so it is of the utmost importance that it does not occur. The best way to avoid Kessler syndrome is to minimize the number of objects in orbit.[138]

2. Standardization May Minimize Crowding

Standardization of FSO technology may be an effective way of encouraging mergers and keeping the number of satellites in orbit as low as possible. A constellation is defined as a single entity, rather than a collection of individual satellites.[139] Therefore, constellations with standardized hardware could be made to communicate through or with a single controller, forming one constellation, with a software update directing them to recognize each other. This will keep the number of satellites in orbit lower because constellations are generally designed with a fixed number of satellites in mind; if constellation A was designed to be complete with 1,000 satellites and has already launched 700, the acquisition of constellation B with 500 satellites in the same orbit would generally not boost A's coverage beyond its original plan.[140] The 200 surplus satellites could be kept in orbit as backups or deorbited. In either case, the acquisition would likely obviate the launch of the final 300 satellites originally planned by the operators of constellation A.

There is preliminary evidence that consolidation will happen, and standardization can play a role, in the form of Eutelsat's acquisition

136. *See* SATELLITEMAP.SPACE, https://satellitemap.space [https://perma.cc/9L6J-KQ5Z] (tracking Starlink and OneWeb satellite positions, displaying their overlapping positions over time, and forecasting numerous near misses (called "conjunctions") over the next 24-hour period).

137. COLVIN ET AL., *supra* note 132, at 6.

138. *Cf. id.* ("Note that *removal* of debris may not be the most effective method of remediating debris and reducing debris-on-debris collisions.") (implying the most effective method would be preventing creation of debris).

139. Wood, *supra* note 2, at 13.

140. *Cf.* Neel V. Patel, *Here's How Just Four Satellites Could Provide Worldwide Internet*, MIT TECH. R. (Jan. 16, 2020), https://www.technologyreview.com/2020/01/16/130832/heres-how-just-four-satellites-could-provide-worldwide-internet [https://perma.cc/8TL5-NSXY] (explaining how four satellites could provide worldwide Internet; in such a constellation, more satellites might increase bandwidth but would not increase coverage).

of OneWeb. Announced on September 28, 2023,[141] it is the first inter-orbit merger of active satellite Internet providers. Details are scant on the technical aspects of the merger, but the patchwork of updates to the two companies' websites suggests that the Eutelsat geosynchronous orbit (GEO, 35,000 km altitude and higher) network and OneWeb LEO constellation will continue to operate with some degree of independence.[142] This is likely to be common to the first wave of SIC mergers, like the SES-Starlink collaboration, because of the varied benefits provided by satellites in different orbits.[143] This kind of merger may result in a limited decrease in the number of satellites in orbit[144] and it protects the extremely large investments made in the struggling OneWeb.[145] But standardization-enabled mergers could decrease the number of satellites in orbit by an order of magnitude. OneWeb is currently in late deployment; with standardization, another operator in LEO could acquire struggling constellations like OneWeb, taking advantage of their existing satellites without needing to launch any more. If inter-orbit SICs become the norm, they will be able to acquire and integrate mid-deployment constellations in any orbit and provide better service.

This merger may also indicate one way to increase trust in SISPs: international cooperation during development. Trust is likely to be lowest for constellations developed unilaterally, especially those with direct unilateral oversight by an entity or individual seen as unpredictable.[146]

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141. Eutelsat Grp., *supra* note 5.

142. *See, e.g.*, *Connectivity Solutions*, *supra* note 130 (referring to the networks as "complementary" and linking to separate pages with information about their technologies and coverage).

143. *But see* the May 2023 Viasat-Inmarsat merger of two GEO constellations. Jason Rainbow, *Viasat Has Enough Throughput on Viasat-3 Americas to Avoid Replacement*, SPACENEWS (Oct. 12, 2023), https://spacenews.com/viasat-has-enough-throughput-on-viasat-3-americas-to-avoid-replacement. [https://perma.cc/57RX-2QTR]. This merger received considerably less press than the Eutelsat-OneWeb merger, likely due to the capacity restrictions inherent to Viasat and Inmarsat's high orbits. *See* Dingley, *supra* note 1, at 130 (deciding to analyze the markets for only the constellations with flexible capacities). GEO is far more expensive to reach, so in the medium-to-long term, satellite Internet constellations will need to have satellites in LEO and/or MEO to increase market share by flexibly scaling to meet customer demand.

144. *Eutelsat to Combine with OneWeb*, EUTELSAT.COM (Oct. 12, 2022), https://www.eutelsat.com/files/PDF/investors/2021-22/Eutelsat%20Strategic%20Update%20-%20vF2.pdf, at 12, 47 (explaining that fewer OneWeb satellites could be launched thanks to Eutelsat's existing coverage).

145. *See Britain's Government Bailed Out Oneweb in 2020. Now It's in Trouble*, ECONOMIST (Mar. 12, 2022), https://www.economist.com/britain/2022/03/12/britains-government-bailed-out-oneweb-in-2020-now-its-in-trouble [https://perma.cc/UAF6-YKVD].

146. Copp, *supra* note 94.

After it was bailed out in 2020, OneWeb was largely owned by the UK government.[147] With the sale to Eutelsat, the UK government signaled an implicit trust in the French Eutelsat. This is not surprising, as the UK and France are strong allies, but similar mergers or joint operation between less closely allied nations may be one way to increase trust in constellations in the future.

As discussed above, consolidation is not inherently positive for consumers. Regulators will need to allow consolidation to a point, paying careful attention to when an SIC becomes too big to acquire more competitors. The regulatory agencies which could address these concerns vary by country. In the United States, the Federal Trade Commission ("FTC") investigates mergers. The FCC could be involved as well; it approves radio licenses and could block licenses for a variety of reasons.[148] However, the FCC, following the lead of the ITU, does not regulate FSO, as the technology carries minimal bandwidth and interference concerns.[149] The ITU should take a more active stance, as debris due to massive SICs is likely to pose significant technological and political problems within a few years.[150]

3. Jamming and Interference may be Mitigated More Effectively with Standardization Technology

Since the first human-made satellite was launched, satellites have been a source of geopolitical tension.[151] As satellites in most orbits cover large swaths of the Earth, they are often seen as having the capacity to violate aspects of sovereignty.[152] Telecommunications satellites can be particularly problematic, as they provide an opportunity for a person to communicate beyond their country's borders and without oversight from their country's regulators.[153] In an age of increasing restrictions to an open Internet,[154] governments of countries such as China already

147. *Britain's Government Bailed Out Oneweb in 2020. Now It's in Trouble*, *supra* note 145.

148. *See supra* Section II.B.

149. Hofmann, *supra* note 4, at 690–91.

150. *See* Ruth Pritchard-Kelly, *WRC-23 on the Horizon: Large Satellite Constellations, ITU Issues, and Industry Perspective*, 48 Air & Space L. 179 (2023).

151. *See e.g.*, Thomas J. Hamilton, *President Bids Again for Action on Arms*, N.Y. Times, Aug. 2, 1959, at E3.

152. Bryan R. Early et al., *Spying from Space: Reconnaissance Satellites and Interstate Disputes*, 65 J. Conflict Resol. 1551, 1555–56 (2021).

153. *Why China Fears Starlink*, *supra* note 107.

154. Gabe Cherry, *'Extremely Aggressive' Internet Censorship Spreads in the World's Democracies*, Mich. News (Nov. 17, 2020), https://news.umich.edu/extremely-aggressive-internet-censorship-spreads-in-the-worlds-democracies [https://perma.cc/J6D5-8KPF].

see global SISPs as a threat.[155] With this in mind, it is possible that governments seeking total control over their citizens' Internet access will attempt to jam SIC satellites over their territory. China has demonstrated kinetic anti-satellite capabilities, as well as non-destructive techniques, including radio jamming.[156] The technology to jam FSO already exists as well;[157] it is a question of *when* and *how* it will be used rather than *if*. Such an action would be even more serious than it may seem on its face—a satellite on top of a border between two countries can service both countries, so jamming such a satellite could be seen as a territorial incursion. Standardization arguably makes jamming easier, as it reveals the operating wavelength of a constellation.[158] Standardization may reveal other aspects of operation, such as the signal encoding scheme,[159] which may enable interference that is subtle and difficult to detect.[160]

Yet, contrary to the standard wisdom of the US defense sector, security through obscurity is not useful in securing systems.[161] Indeed, FSO operates within a narrow enough band of wavelengths that guessing is not difficult.[162] An emerging belief that "sunlight is . . . the best of disinfectants"[163] strongly supports standardization of high-profile technologies such as FSO for satellite Internet.[164] Whether through espionage or simply repeated attempts at infiltration, malicious actors are likely to eventually find their way into an obscured system. "Sunlight" can "disinfect" by pooling the energies of security researchers.[165] An open, or at least accessible, standard allows good actors to analyze security measures and suggest improvements where necessary. By widening the net of experts who can weigh in on a

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155. Williams, *supra* note 131.
156. Ajey Lele, *Space Security Dilemma: India and China*, 17 ASTROPOLITICS 23, 31 (2019).
157. *See* Pratiti Paul et al., *Jamming in Free Space Optical Systems: Mitigation and Performance Evaluation*, 68 IEEE TRANSACTIONS ON COMMC'NS 1631, 1631 (2019) (evaluating mitigation efforts for known jamming techniques).
158. *Id.*
159. *See, e.g.*, CONSULTATIVE COMM. FOR SPACE DATA SERVS., CCSDS 142.0-B-1, *supra* note 47 (standardizing FSO coding).
160. Paul et al., *supra* note 157, at 1633.
161. *See* Andrew Moshirnia, *No Security Through Obscurity*, 83 BROOK. L. REV. 1279 (2018) (enumerating examples where security through obscurity failed to harden systems, tracing the origins of this trend through the two world wars).
162. Paul et al., *supra* note 157, at 1631.
163. Louis D. Brandeis, *What Publicity Can Do*, HARPER'S WEEKLY, Dec. 20, 1913, at 10, 10.
164. *See* Moshirnia, *supra* note 161, at 1318–28 (explaining the importance of security research on voting machines).
165. *Id.*; Brandeis, *supra* note 163, at 10.

system, a developer benefits from increased attention before a system is released and receiving heightened scrutiny. So, while standardization would not inherently eliminate the possibility of jamming, it would not necessarily aid jamming either, and it may lead to the development of systems which are more resilient.

4. In-orbit Servers Raise Governance Questions Easily Answered by Vigilant Regulators

To this point, the discussed applications of telecommunications satellites are primarily improved connections for terrestrial endpoints. Only in rare cases have satellites enabled space-to-space communication[166] or space-Earth communications with no intention of relay.[167] However, the extremely high bandwidth enabled by FSO will create a new possibility, which SISPs may or may not choose to exploit: in-orbit data centers. Such a system could be implemented as a network of servers housed in each satellite within an SIC. Alternatively, companion server satellites could be placed in orbit physically nearby a communications satellite. Standardization would allow the satellites of various SICs to contact in-orbit servers regardless of provenance. This approach would be more costly, as launching more satellites is nearly always more costly even if their weights are equal,[168] but it would allow an SIC to create an interoperable in-orbit data center even after its communications network is launched.

The technical advantage of an in-orbit data center would be in placing servers as close to customers as possible. Companies such as Google and Facebook already do this on Earth; it's how they minimize the time it takes to use their services, thereby increasing engagement and advertising revenue.[169] Much of Internet traffic today is carried by

166. Deep space communication is one of the rare contexts in which relay satellites are used to enable space-to-space communication, discussed *supra* Section IV.B.

167. Communication with the International Space Station is one of the rare contexts in which relay satellites are used to enable space-Earth communication.

168. It is more expensive to launch more weight into orbit. Thomas G. Roberts, *Space Launch to Low Earth Orbit: How Much Does It Cost?*, AEROSPACE SEC., https://aerospace.csis.org/data/space-launch-to-low-earth-orbit-how-much-does-it-cost [https://perma.cc/777D-VHJ5] (last updated Sept. 1, 2022). It is more expensive to launch two satellites that each weigh 5kg than one satellite which weighs 10kg because each satellite requires support structures during launch. The two 5kg satellites could not be packed into a 10kg satellite slot, or they would damage each other during the significant vibrations of launch. Two would likely be heavier than one at a baseline because all satellites have redundancy built-in; two satellites would generally have double the redundancies of one.

169. Michael Waters, *Energy-hungry data centers are quietly moving into cities*, MIT TECH. R. (June 22, 2022), https://www.technologyreview.com/2022/06/22/1053889/city-server-farms-energy.

fiber-optic cables which are limited in speed only by the speed of light. Thus, the closer a server is to the user, the less distance their traffic travels and the faster it can be routed to and from the server.[170] Placing a server in an FSO satellite is the dream of the Googles and Facebooks, as instead of satellite Internet traffic being routed from Earth to the nearest satellite, through a series of satellites, back down to a server on Earth, and then back through the same path, the traffic would be routed directly from Earth to the nearest satellite and back. This would benefit consumers as well, as they would experience minimal latency during their Internet browsing.

The legal advantage of an in-orbit data center is, according to some, freedom from governmental oversight. In response to a recent United States Executive Order on artificial intelligence technology, a "company" called Del Complex announced the creation of a compute cluster on a barge, designed to evade government regulation.[171] As the company has not filed to do business in Delaware or any of the three states in which it claims to have offices (California, Nevada, and Texas),[172] it does seem to be a fake.[173] However, the sentiment it captured may be indicative of wider attitudes.[174]

Starlink, a company which certainly exists and is already providing services to customers, wrote a terms of service agreement which contains an unusual provision on governing law. Section 11 of the Starlink Terms of Service states that service provided on the Earth and Moon will be subject to the laws of California.[175] But it goes on to say that "the parties recognize Mars as a free planet and that no Earth-based government has

170. Andrew Blum & Carey Baraka, *Sea Change*, REST OF WORLD (May 10, 2022), https://restofworld.org/2022/google-meta-underwater-cables [https://perma.cc/FH7S-VSUW].

171. *BlueSea Frontier Computer Cluster: The Future of AI Innovation*, DEL COMPLEX https://www.delcomplex.com/blue-sea-frontier [https://perma.cc/XHP8-6WFK]. Company is in quotes because it may or may not exist—while one news organization took the announcement at face value, Francisco Pires, *Del Complex Proposes Floating AI Data Centers in the Ocean to Flout US Sanctions*, TOM'S HARDWARE (Nov. 1, 2023), https://www.tomshardware.com/desktops/servers/del-complex-proposes-floating-ai-data-centers-in-the-ocean-to-float-us-sanctions [https://perma.cc/G9H9-PS26], Vice claimed the company was fake later that day. Jordan Pearson, *Is a Rogue AI Company Training Powerful AI on a Barge to Avoid U.S. Regulations?*, VICE (Nov. 1, 2023, 4:44 PM), https://www.vice.com/en/article/88xk7b/del-complex-ai-training-barge [https://perma.cc/P64B-UR6A].

172. *Facilities*, DEL COMPLEX, https://www.delcomplex.com/facilities [https://perma.cc/WR9P-2P6S].

173. Research conducted by author.

174. *See, e.g.*, BALAJI SRINIVASAN, THE NETWORK STATE 9 (2022) (suggesting the creation of "network states," communities formed through the Internet with the ultimate intention of acquiring territory and recognition from traditional states).

175. *Starlink Terms of Service*, *supra* note 36, at § 11.

authority or sovereignty over Martian activities. Accordingly, Disputes will be settled through self-governing principles, established in good faith, at the time of Martian settlement."[176] This provision is, without a doubt, unenforceable under international law.[177] The Outer Space Treaty ("OST"), which binds the United States, and therefore Starlink, a corporation of the United States, clearly applies to the use of "outer space, including the moon and other celestial bodies."[178] The OST recognizes outer space as beyond the reaches of national sovereignty[179] but stipulates that all activities in outer space shall be supervised by national governments.[180] The United States government has entered a period of decreased deference to the Outer Space Treaty,[181] but Starlink's provision, if Musk attempted to act on it, would be one step too far, as a direct challenge to the sovereignty of the United States and the governments of the entire planet.

Walking back from the most extreme example, SISPs may attempt to use their constellations to avoid data governance regulations. The OST is less explicit on this point, but non-governmental entities operating in space are subject to the *entire* legal code of their supervising country, as they "require authorization and continuing supervision by the appropriate State Party to the Treaty."[182] At the very least, this would enable a state to withdraw previously granted operational authorization for a satellite operator's noncompliance with laws on the Earth.

Therefore, a European telecommunications provider cannot escape the General Data Protection Regulation just by moving their infrastructure to space. They would be subject to loss of their operating licenses if their noncompliance was detected. Space-based operations do give SICs a physical distance from regulators that could make it easier for them to avoid detection of unlawful activities. And their global coverage means that SISPs have numerous local regulations to

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176. *Id.*

177. Antonino Salmeri, *No, Mars is Not a Free Planet, No Matter What Spacex Says*, SPACE NEWS (Dec. 5, 2020), https://spacenews.com/op-ed-no-mars-is-not-a-free-planet-no-matter-what-spacex-says [https://perma.cc/54PK-L92Y]; Christian van Eijk, *Sorry, Elon: Mars is Not a Legal Vacuum – And It's Not Yours, Either*, VÖLKERRECHTSBLOG (May 11, 2020), https://voelkerrechtsblog.org/sorry-elon-mars-is-not-a-legal-vacuum-and-its-not-yours-either [https://perma.cc/UJ8Y-VSJH].

178. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, art. I, *opened for signature* Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205 [hereinafter Outer Space Treaty].

179. *Id.* at art. II.

180. *Id.* at art. VI.

181. DEUDNEY, supra note 95, at 22.

182. Outer Space Treaty, *supra* note 178, at art. VI.

comply with. However, until telecommunications employees live on space stations, they are the weak link. They can easily be compelled to testify in court, exposing any nefarious activities in the stars. And telecommunications companies are no strangers to complying with various local regulations.[183] As long as regulators remain vigilant, Earth orbit provides very limited opportunities to shield data governance circumventions.

Conclusion

Satellite Internet service providers have the potential to connect the entire world to the Internet, creating untold sums for the global economy and bringing the potential for rapid development in historically underserved rural areas. SISPs will only be able to provide low-latency, high-bandwidth communications if they utilize free space optics for intra-constellation communication. FSO is already powering the most sophisticated operational SISP, Starlink. It is also powering recent missions from NASA and other space agencies, enabling the transmission of far more scientific data than previously possible. FSO is set to rapidly expand in use in the coming years, benefiting SISPs, consumers, and scientists.

Standardizing FSO will unlock further benefits, from emergency in-orbit communication to mergers of SICs. The method of standardization matters, and space agencies like NASA and ESA should push their constituents to adopt the international standard promulgated by CCSDS, ISO, and ITU. If industry consortia or single-promoters like Starlink set standards without supervision from the international civil community, they will acquire market power in a sector already fraught with monopolistic pressures. Consolidation will benefit everyone in the short term but could lead to serious consumer harm in the medium-to-long term.

Constellations and service providers will enable true global connectivity at a medium cost. Even the world's poorest citizens will be able to connect to the Internet at terminals placed in population centers with funding from non-profits. Through the next decade, in-orbit servers will exist but be too expensive to create significant governance concerns. The sensitivity of the data carried over the Internet will lead to real sovereignty concerns, and many countries will launch SICs as they did with GNSS. Yet the astronomical costs associated with launch

183. *See, e.g.*, *Orange in the World*, ORANGE, https://www.orange.com/en/orange-world [https://perma.cc/85BA-66EB] (listing the 26 countries receiving service from telecommunications provider Orange S.A.).

and maintenance will result in consolidation, regardless of sovereignty concerns.

Consolidation should be expected throughout the 2020s. The first two SIC mergers were completed in 2023, and it is extremely likely that more will follow even without standardization. Standardization would help these consolidations provide more benefits to their consumers while reducing orbital crowding. If Starlink publishes its FSO design as a standard before Eutelsat/OneWeb and other low-latency competitors provide their services widely on the open market, it has a very strong chance at becoming the predominant standard. It has emerged as a dominant player in the SIC/SISP market because it has rapidly expanded service to end-customers, focusing less on industry. OneWeb, Project Kuiper, and many others are targeting the same market; Starlink's dominance would help it propagate a standard. If it chooses not to publish a standard, CCSDS/ISO/ITU are likely to hold their dominance. In any case, by the 2030s, it is reasonable to expect that the SIC market will be cornered by two to three global players servicing many SISPs, plus Guo Wang as the combined SIC and SISP providing connectivity in China.

Regulators will need to think very carefully about how to balance the benefits of consolidation with the possible harms. An international, heavily regulated oligopoly may be the best way to balance crowding with data centralization concerns. It is extremely likely that SICs, corporate entities with (at least in the United States) relatively minimal regulatory oversight, will cause incidents of international tension. Cascading collisions caused by SICs are all but guaranteed if even two or three constellations launch thousands of satellites. For all these reasons, it is extremely important that the international community, ideally led by the ITU, proactively address SICs through FSO standardization and market regulation.