# The Economic Benefits of Updating Regulations that Unnecessarily Limit Non-Geostationary Satellite Orbit Systems

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## Executive Summary

Low-Earth Orbit (LEO) satellite systems, a form of non-geostationary satellite orbit (NGSO) systems, are one of the most promising recent advances in Internet access. These NGSO systems today provide valuable and cost-effective services to people around the world, particularly in remote areas and in areas where existing broadband services are inadequate or uncompetitively priced.[2] In this paper, I make the following points:

**LEO-satellite systems provide valuable services.** LEO-satellite systems provide valuable services to individual consumers, households, governmental customers, non-profit customers, enterprise customers, and network customers. These include the following services: direct-to-user connectivity; middle-mile connectivity; low-latency services; hybrid network connectivity; redundant connectivity; little or no incremental network cost for incremental customers; and price discipline on other broadband services.

**Current epfd rules are out of date and deprive consumers of more LEO-satellite system services at lower prices.** The International Telecommunication Union (ITU) equivalent power flux-density (epfd) rules crafted 25 years ago limit the capacity and effectiveness of NGSO fixed-satellite service (FSS) systems, reducing the availability and increasing the cost of services provided by NGSO FSS systems. Satellite technology has advanced considerably in the past 25 years. As a result of advances in antenna technology, spot-beam utilization, and frequency re-

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[2] "With their global reach and coverage, LEO constellations are expected to dramatically expand the availability of high-speed broadband Internet access with levels of service that rival fiber optic cables in terms of speed and latency, and at significantly reduced price levels compared to traditional geostationary satellites." J. Garrity and A. Husar, "Digital Connectivity and Low Earth Orbit Satellite Constellations" Asian Development Bank. Working Paper No. 76, April 2021, Executive Summary, available at Digital Connectivity and Low Earth Orbit Satellite Constellations: Opportunities for Asia and the Pacific (SDWP No. 76) (adb.org).

use, today's satellite systems are able to make more efficient use of the radio frequency spectrum, but current epfd rules prohibit those more efficient uses.

**Updating 25-year-old epfd rules would provide tens of billions of dollars of benefits to customers around the world, particularly to the 2 billion people not yet connected to the Internet.** Such updated rules would enable more broadband services at lower costs and prices around the world. Consumers, particularly those not connected to the Internet, would correspondingly benefit substantially. Updating the epfd rules would benefit customers both by increasing capacity and reducing prices.

A recent engineering study provides two case studies for updating epfd rules: one in the 17.8 – 18.6 GHz band and one in the 19.7 - 20.2 GHz band.[3] In the first case study, broadband capacity increases by 74 percent; in the second case study, capacity increases by 180 percent.

Based on the engineering study, I examine a range of expanded capacity of between 25 percent and 250 percent, and a range of price reductions per unit of capacity of between 10 and 50 percent. Under a range of reasonable assumptions, updated epfd rules would result in in welfare benefits to all customers ranging from $10 billion to $100 billion. The greatest benefit would likely accrue to many of the 2 billion people who are not connected to the Internet. These estimates of consumer welfare benefits may understate actual improvements for a variety of reasons, as reviewed in more detail in this paper.

**Estimated increase in net present value in consumer welfare in $billions from updating the epfd rules**

| Percentage Decrease in Price per Unit of Capacity | Percentage Increase in Capacity: 25 | 50 | 100 | 150 | 200 | 250 |
|---|---|---|---|---|---|---|
| 10 | $10.06 | $11.18 | $13.41 | $15.65 | $17.88 | $20.12 |
| 20 | $20.12 | $22.35 | $26.82 | $31.29 | $35.77 | $40.24 |
| 30 | $30.18 | $33.53 | $40.24 | $46.94 | $53.65 | $60.35 |
| 40 | $40.24 | $44.71 | $53.65 | $62.59 | $71.53 | $80.47 |
| 50 | $50.29 | $55.88 | $67.06 | $78.24 | $89.41 | $100.59 |

**New entrant LEO-satellite systems should particularly benefit from updating the epfd rules.** With updated epfd rules, new LEO-satellite systems would need smaller constellations and still have greater capacity to reach more customers. That result reflects a substantial reduction in launch costs, satellite costs, and costs of a new LEO constellation. Those lower costs should encourage new entry as well as lower prices for customers.

**The 2023 World Radiocommunication Conference (WRC-23 or Conference) should adopt a resolution to study regulatory changes to improve spectral efficiency in NGSO satellite**

[3] See Appendix A. David Kaufman, Alex Epshteyn, and Philippe Secher, "Technical Basis for improved NGSO FSS capability with an EPFD rule change," August 2023.

**systems.** WRC-23 in Dubai should adopt a resolution to study regulatory changes to improve spectral efficiency in operations by NGSO FSS systems while protecting geostationary satellite orbit (GSO) networks in the same frequency bands.[4] People around the world, including those in remote areas and in marginalized communities, would benefit substantially from greater availability of NGSO services, more competition and lower prices, and higher quality of those services. This paper explains in more detail the economic benefits that would result from updating the 25-year-old rules that limit NGSO FSS systems.

**The WRC-23 should consider principles to accommodate new beneficial technologies such as NGSO FSS systems.** The substantial consumer welfare benefits from updating the epfd rules developed over 25 years ago reflect a recurring problem in regulating rapidly changing technologies. I propose several principles that WRC-23 might consider in regulating such technologies. In particular, Conferences should deliberately review and update rules pertaining to rapidly changing technologies such as NGSO FSS systems.

I organize the remainder of the paper as follows: (A) LEO-satellite systems offer dramatic new ways of organizing broadband networks; (B) The ITU regulates outdated and inefficient epfd rules for NGSO FSS systems; (C) The current outdated epfd rules harm consumers in several ways; updating the rules would benefit consumers; and (D) WRC-23 should consider principles to accommodate new beneficial technologies such as NGSO FSS systems.

[4] *See, e.g.,* Tables 22-1A, 22-1B, 22-1C and 22-1D of Article 22 of the International Telecommunication Union Radio Regulations.

## A. LEO-satellite systems offer dramatic new ways of organizing broadband networks

Until a few years ago, global broadband networks were organized primarily around fiber backbones connecting major urban centers with clusters of fiber and wireless networks connecting to the fiber backbones. These fiber-backbone networks were and remain efficient at enabling broadband services in and near urban areas. But vast areas of the world including where billions of people live as well as oceans and remote terrestrial areas have little or no access to the broadband services available through fiber backbone networks.[5] Even remote areas that have infrequent new fiber investments cannot keep pace with advances in fiber technology, which improves every year. Populations with limited or no connectivity to the fiber backbone networks fall further behind major urban areas in broadband capabilities each year. Even for many people with Internet access, affordability and quality of service are constant challenges. For these areas of the world, other technological solutions are necessary.

The most promising new technologies for the distribution of broadband services are satellite-based networks, particularly LEO-satellite systems. These networks can provide broadband services anywhere in the world, including where fiber-backbone networks are too costly to build. Even without updating the ITU epfd rules, these LEO-satellite systems can be, and are being, used in different ways:

- *Direct-to-user connectivity* -- Whether on a ship at sea or in a remote area on land, a user can connect directly to a broadband service offered through a LEO-satellite system. These individual users will receive signals directly from, and transmit signals directly to, a LEO satellite.

- *Middle-mile connectivity* – Fiber and wireless networks can provide broadband connectivity within a village or town. But to interconnect the town or village with the global Internet requires a link to an Internet Exchange Point. That link is often called *middle mile*. LEO-satellite systems can provide middle-mile broadband connectivity to a distribution point in a village or town both for individual users and for enterprise users, such as schools, hospitals, and businesses.[6] Individual broadband users may pay for local access to the Internet or may receive broadband access free of charge through Wi-Fi. In remote towns and villages, middle-mile connectivity is often the missing link to the Internet; LEO-satellite systems can fill that missing link. LEO-satellite systems are being used today to provide middle-mile connectivity to remote and often impoverished villages that otherwise would have no broadband connectivity.

- *Low latency services* – The time lag between when a signal is sent and when it is received is called *latency*. Many broadband applications depend on low latency. Latency depends

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[5] An estimated 63 percent of the world's population in 2023 has access to the Internet. That leaves more than 2 billion people with no Internet access. See Daniel Ruby, Internet User Statistics in 2023 (Global Data and Demographics), Demandsage, available at [Internet User Statistics In 2023 — (Global Data & Demographics) (demandsage.com)](). This estimate is consistent with a 2021 ITU publication that 37 percent of the world's population had never used the Internet. See ITU, "Facts and Figures 2021: 2.9 billion people still offline, available at [Facts and Figures 2021: 2.9 billion people still offline - ITU Hub]()

[6] See, e.g., [5 trends in satellite communications on the horizon - ITU Hub]().

on factors such as the distance a signal must travel as well as the number of intermediate connections. LEO-satellite systems have latency that is often an order-of-magnitude less than GSO networks and often even less than terrestrial fiber networks. LEO-satellite systems are thus the preferred network, or part of the preferred network, for latency-sensitive applications. For example, certain telehealth applications and financial service applications may choose to rely on LEO-satellite systems even where fiber and other networks are available.

- *Hybrid network connectivity* – LEO-satellite systems can be part of a hybrid network in combination with other technologies to provide broadband networks and services. LEO-satellite systems can be used in combination with terrestrial networks for last-mile distribution or for backhaul services. GSO networks and terrestrial networks can also employ LEO-satellite systems in a hybrid fashion for latency-sensitive applications.

- *Redundant connectivity* – Robust broadband networks are built for high reliability. But even the best broadband networks sometimes fail, either from human error or malicious hacking. In addition, natural disasters such as storms and earthquakes can disrupt terrestrial networks and submarine cables. LEO-satellite systems provide redundancy to ensure continued broadband connectivity when other networks fail. Furthermore, LEO-satellite systems are inherently resilient. Since more than one satellite is visible from a given location at a given time, a LEO-satellite system has built-in redundancy.

- *Little or no incremental network cost for incremental customers* – Most communications networks have substantial incremental costs to add new customers. New lines must be introduced to the network. But satellite networks such as LEO-satellite systems have little or no incremental cost to add new customers.

- *Price discipline on other broadband services* – Services from LEO-satellite systems provide competitive pressure on broadband services from all other communications networks: fiber, mobile and fixed wireless, and GSO. If those other communications networks were to attempt to raise prices above competitive levels, some customers would switch to LEO-satellite systems. The competitive pressure from services of LEO-satellite systems is particularly strong where other broadband services are either: poorly provided; lacking some of the characteristics of full broadband capability including capacity, speed, or low latency; or lacking competitive discipline where there is only one or a small number of non-competitive providers.

For each of these uses, LEO-satellites are used because they are lower cost and more efficient than alternatives. LEO satellite services enable lower-cost broadband access in all parts of the world including developing countries. Education, health care, and other social services can be and are efficiently provided entirely or in part by LEO-satellite-based networks.

### B. ITU regulates outdated and inefficient epfd rules for NGSO satellites

Satellites operate high above the surface of the Earth. GSO satellites at a fixed location are approximately 36,000 km above the equator. NGSO satellites can be at any altitude, but those in low-earth orbit are typically 400 km – 2,000 km above the earth.[7] Thousands of satellites orbit the earth today, and many more systems are likely to be launched in coming years. Satellites, both GSO and NGSO, often share the same bands of spectrum for communications, both with other satellites and with Earth-based stations. If there were no regulation of space, different countries and companies might launch satellites and constellations of satellites that would interfere with the communications of other satellites. Improving the use of the radio frequency spectrum, coordinating efforts to avoid harmful interference, and extending the benefits of new telecommunication technologies to all the world's inhabitants are among the fundamental purposes of the ITU.[8]

One of the ITU rules regulates the epfd of NGSO FSS systems.[9] Adopted provisionally in 1997 and finally in 2000,[10] the efpd limits were developed to quantify the level of protection from unacceptable interference for GSO networks under No. 22.2 of the Radio Regulations. These limits serve to ensure the protection of GSO networks from unacceptable interference from NGSO FSS transmissions.

The existing WRC epfd limits use conservative assumptions based on technology available in 1997 to define interference limits to protect GSO networks. The 1997 epfd limits are outdated because they fail to account for technological changes that reduce the likelihood of interference including the following: smaller, steerable spot beams for NGSO FSS systems;[11] improved NGSO constellation geometry and design;[12] adaptive coding and modulation technologies for GSO networks to maintain their links against naturally occurring degradation;[13] and improved earth station equipment for both GSO networks and NGSO FSS systems.

If they did not affect the design, operation, and cost of NGSO FSS systems, outdated epfd rules would not matter. But the epfd rules limit the efficient communications to and from an NGSO satellite.

In Appendix A, I attach an engineering study that I will refer to as the Technical Inputs Study.[14] It explains the engineering benefits of updating the epfd rules. It provides examples of how updating the epfd rules would improve the capacity and the efficiency of LEO-satellite systems while protecting GSO networks from unacceptable interference. The current epfd rules lead to unnecessarily large exclusion zones. To serve the same geographic area and the same population

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[7] See Non-geostationary satellite systems (itu.int).
[8] See, e.g., Our vision (itu.int)
[9] *See generally* Article 22 of the ITU Radio Regulations; see also ITU World Radiocommunication Seminar 2018: Equivalent power flux density limits (EPFD).
[10] See Final Acts WRC-27, Article S22; Final Acts WRC-2000, Article S22; and Resolution 58 (WRC-2000).
[11] See, e.g., Telesat Technical Information Supplement to Schedule S, FCC, November 4, 2021, 13337277.pdf (fcc.report); OneWeb Technical Information Supplement to Schedule S, FCC, 2379706.pdf (fcc.report); SpaceX, Technical Information Supplement to Schedule S, FCC, November 15, 2016, 1158350.pdf (fcc.report); Technical Appendix to the Application of Kuiper Systems LLC for Authority to Launch and Operate a Non-Geostationary Satellite Orbit System in the Ka-band Frequencies, Technical Appendix (arstechnica.net), July 4, 2019.
[12] Ibid.
[13] Ibid.
[14] See Appendix A. David Kaufman, Alex Epshteyn, and Philippe Secher, "Technical Basis for improved NGSO FSS capability with an EPFD rule change," August 2023.

of users, current epfd rules lead to a requirement of more NGSO satellites than would be needed with updated epfd rules. Further inefficiencies result from the current epfd rules including limitations on the number of customers that a LEO satellite can service in a geographic area.

The current epfd rules also unnecessarily limit transmissions that previously were thought to create co-channel interference under more primitive technologies than currently available, further reducing the service area of an NGSO satellite. Altogether, the epfd rules are obsolete in 2023; they impede the full and efficient development of an important technology that can better serve consumers and businesses.

## C. Updating the epfd rules would benefit consumers

As explained above, the outdated epfd rules harm consumers (including households, government entities, non-profit organizations, enterprise customers, and network customers) by making LEO-satellite systems less efficient and more costly than they need to be. More capacity with updated epfd rules means that a LEO-satellite system can serve more customers with more broadband without raising costs or prices. In Appendix A, I review several different types of consumer benefits from updating the epfd rules.

### *1. Expanding capacity for a LEO-satellite system*

Current epfd rules unnecessarily limit LEO-satellite system broadband capacity. Appendix A examines case studies of how much satellite system capacity for a LEO-satellite system could be expanded with updated epfd rules, and how much the efficient use of spectrum could be improved. The engineering study provides two case studies for updating epfd rules: one in the 17.8 – 18.6 GHz band and one in the 19.7 - 20.2 GHz band. In the first case study, broadband capacity increases by 74 percent; in the second case study, capacity increases by 180 percent. The spectral efficiency improvement in the first example is 75 percent; in the second example, the spectral efficiency improvement is 181 percent.[15] The corresponding decrease in spectral efficiency for a GSO networks is substantially less at around 2 percent.[16]

The case studies in the engineering report do not represent either the largest or smallest likely changes in capacity or spectral efficiency from changing the epfd rules. Specific changes in capacity and efficiency depend on a variety of factors including the number of satellites in a constellation, the orbit angles, and spectrum band for communications. All of these factors vary by LEO-satellite system. But the case studies illustrate that the changes in capacity and efficiency can easily exceed 100 percent.

Based on the results in Appendix A, I prepared Appendix B to examine the consumer welfare benefits of expanding LEO-satellite system capacity. Appendix B presents scenarios with capacity increases ranging from 25 percent to 250 percent. In a competitive market—and satellite services typically offer services in competitive markets, improved technologies will be passed along to consumers in the form of higher quality services.

[15] Appendix A, Table 1.
[16] Ibid.

2. *Lowering costs, and prices, for LEO satellite services*

Current epfd rules unnecessarily increase the cost of LEO-satellite system broadband capacity. Appendix B examines how much satellite system costs for a LEO-satellite system could be reduced with updated epfd rules. In one specific example, updating the epfd rules would reduce average costs by 43 percent; in another example, average costs are reduced by 64 percent. Appendix B presents scenarios with price decreases ranging from 10 percent to 50 percent. In a competitive market reduced costs will be passed along to consumers in the form of lower prices.

3. *Expanding unnecessarily limited opportunities for new-entrant LEO constellation networks*

Current epfd rules harm new LEO-satellite systems entrants in at least two ways. First, a new entrant will need more satellites under current epfd rules than under updated rules. Requiring more satellites is equivalent to raising the cost of service, a barrier to entry for new entrants. Also, requiring more satellites leads to more manufacturing of satellites, more launches and more costs of operations for the satellite system operator, and possibly more ground infrastructure to support space infrastructure. In the extreme case, artificially high government-imposed costs of providing a service can lead to a single provider of the service. Removing the obsolete rules would benefit consumers not just by the direct reduction in costs to a satellite operator, and the related price reduction discussed above but also by enabling additional competition. Consumers are the biggest beneficiary of competitive new service providers. Competition leads to lower costs and lower prices, better quality services, and new innovative ideas.

Second, current epfd rules specifically harm small constellations and new entrants. As shown in the Technical Inputs Study, a constellation that would require 462 LEO satellites under existing epfd rules to have a certain coverage could obtain the same coverage with updated epfd rules with only 360 satellites.[17] That result reflects a substantial reduction in launch costs, satellite costs, and costs of a new LEO-satellite system. Those lower costs should encourage new entry as well as lower prices for customers.

[17] Appendix A, Table 2.

4. *Increasing consumer welfare for services that consumers purchase*

As shown in Appendix B, consumers would benefit substantially from updating the epfd rules from directly paying customers. In Exhibit 1, I assume that new epfd rules are put in place in 2028, and I present the NPV in 2023 of the rule changes with a 10 percent discount rate. The NPV of the change in consumer welfare ranges from $10.06 billion annually for a 10 percent reduction in price and a 25 percent increase in capacity to a $100.6 billion annually for a 50 percent reduction in price and a 250 percent increase in capacity. The results in Exhibit 1 illustrate that, under a wide range of assumptions, the NPV of changing epfd rules are in the tens of billions of dollars.

The calculations in Exhibit 1 are based on conservative assumptions such as the global baseline subscribership is 10 million. If the base case global subscribership is greater than 10 million, the NPV calculations in Exhibit B.3 could be correspondingly higher. Also, many governmental agencies use a lower discount rate than 10 percent. Lower discount rates would increase the value today of consumer benefits in later years; for the purpose of these analyses, lower discount rates would increase the value the NPV of consumer welfare from updating the epfd rules.

**Exhibit 1**

**Estimated increase in net present value in consumer welfare in $billions from updating the epfd rules**

| Percentage Decrease in Price per Unit of Capacity | Percentage Increase in Capacity: 25 | 50 | 100 | 150 | 200 | 250 |
|---|---|---|---|---|---|---|
| 10 | $10.06 | $11.18 | $13.41 | $15.65 | $17.88 | $20.12 |
| 20 | $20.12 | $22.35 | $26.82 | $31.29 | $35.77 | $40.24 |
| 30 | $30.18 | $33.53 | $40.24 | $46.94 | $53.65 | $60.35 |
| 40 | $40.24 | $44.71 | $53.65 | $62.59 | $71.53 | $80.47 |
| 50 | $50.29 | $55.88 | $67.06 | $78.24 | $89.41 | $100.59 |

These estimates of improvements in consumer welfare understate the total value to consumers of updating the epfd rules for two reasons: First, many consumers, including low-income consumers, do not pay for local network connectivity. These consumers may connect to local networks with Wi-Fi or other free access methods. These local networks in turn may be connected to the Internet in whole or in part by LEO-satellite systems providing middle-mile connectivity. Second, part of the consumer value of services from LEO-satellite systems is enhancing network reliability through network redundancy. LEO-satellite systems help provide redundant connectivity that is particularly valuable when networks based on other technologies are overloaded or fail, or when the capacity or quality of service of other systems is inadequate.

*5. Reducing costs for businesses and public sector*

Consumers are not the only ones to benefit from lower prices for Internet access with improved epfd rules. Businesses enterprises and governmental entities such as schools and hospitals that do not have access to dedicated private broadband lines benefit from the competitive availability of services from LEO-satellite systems. The lower prices for Internet access would reduce the cost structure for these businesses and enable them with better opportunities to compete with firms in regions with more competitive—and lower cost—Internet access. Also, LEO-satellite systems with low latency capabilities increase the opportunity to enterprises and businesses to remain where they are, rather than having to relocate due to network connectivity requirements.

*6. Increasing the quality of services for terrestrial services*

Although services from LEO-satellite systems can be, and are, offered on a retail basis directly to individual consumers, many of the most innovative applications of satellite services are in used in combination with terrestrial networks, particularly terrestrial wireless networks. Terrestrially-based operators, such as mobile network operators, can operate in coordination with LEO-satellite systems that can provide services in areas that are too costly for the mobile network operator to reach. Thus, in many areas of the world satellite services, and LEO-satellite systems in particular, are instrumental in the provision of vital services such as educational services, health care services, financial services, and other social services.[18] By raising the costs and reducing the quality of NGSO FSS systems, current epfd rules also limit the quality of these and other terrestrially based services that depend on satellite services.

*7. Removing harm to marginalized communities from obsolete epfd rules*

It is easy to imagine technological advancements such as LEO-satellite systems creating new products and services that benefit a wealthy population. But recent technological advancements related to the Internet have likely had a much greater positive effect on the poor. In 1990, nearly 40 percent of the world's population lived in what the World Bank characterizes as extreme poverty, a bare subsistence existence.[19] For the past few years, fewer than 10 percent of the world's population was at the same subsistence level.[20] Most of the world's population still live in poverty on a few dollars a day,[21] but these income levels are still advances on a generation ago. For impoverished populations, the past generation has likely seen the greatest economic advancement in human history. Much of this improvement in the past generation can be

[18] See, e.g., Low-Earth Orbit Satellites in Healthcare - Clarus LEO; How LEO satellite technology can connect the unconnected | World Economic Forum (weforum.org); Perspectives on LEO Satellites - Using Low Earth Orbit Satellites for Internet Access (Internetsociety.org); Five ways low earth orbit satellites will impact Asia and the Pacific | Asian Development Bank (adb.org); January/February 2022 - The State and Future of LEO Satellite Internet Connectivity in Africa | Via Satellite (satellitetoday.com); Internet Connectivity with Low Earth Orbit (LEO) Satellites | TE Connectivity.

[19] See World Bank, *Correcting Course*, Poverty and Shared Prosperity 2022: Correcting Course (worldbank.org), Figure 1.1., p. 30, accessed June 28, 2023.

[20] Ibid., Figure 0.5.

[21] Ibid., Figure 1.6.

attributed to Internet access. The World Bank notes that marginalized groups were harmed during the Covid pandemic by less access to the Internet than higher income groups.[22]

Current epfd rules are an impediment to greater Internet access for populations, often marginalized, in rural and remote areas. Modernizing the obsolete epfd would particularly benefit these marginalized populations.

### D. WRC-23 should consider principles to accommodate new beneficial technologies such as NGSO FSS systems

Rapidly changing new technologies and regulation are often in tension with one another. It is difficult if not impossible for regulators to keep pace with rapidly changing new technologies, much less to anticipate the direction and results of technologies that have yet to be developed. This is a challenge that faces regulators around the world. This is precisely the situation that WRC-23 faces with respect to epfd rules for NGSO satellites. The Radio Regulations reasonably set out provisions to protect services provided by GSO networks, but WRC-23 must be careful not to impede the development of new technologies such as NGSO FSS systems with LEO satellites. ITU members should seek a balance between these two goals.

- One principle would have short-term rules with frequent reviews. In hindsight, it made little sense to have epfd rules adopted decades ago for emerging NGSO FSS technologies that would not be reviewed periodically. With the right regulatory structures in place, new technologies would become part of the spectrum sharing evaluations under the new epfd rules.

- Another principle would be to address why specific protection criteria are made. The current epfd rules were adopted to protect then-existing GSO networks with technology from more than 25 years ago in specific bands where NGSO FSS systems planned to operate. It is not obvious in that the considerations that led to the quantification of protection for GSO networks at the expense of NGSO systems in 1997 would hold today. Nor is it obvious that the limits adopted at the time were intended to impose undue constraints on the development of NGSO FSS systems and their services.

- Still another principle would be to consider technological changes in all sectors related to the epfd rules. Just as the technology and population of NGSO FSS systems has changed in the past 25 years, so too has the technology and population of GSO networks changed, although not as dramatically. Adaptive coding and modulation technologies for GSO networks are much improved as are earth station technologies.

- A final principle would be to consider the consumer welfare benefits of changing the epfd rules. As noted above, those benefits are easily in the tens of billions of dollars.

Regulations rarely are absolute rights that never change. By their nature, regulations are subject to review and to change. The ITU membership should review the epfd rules to enable far more

[22] Ibid., pp. 39-40.

spectrally efficient NGSO FSS systems while still providing essential protection to GSO networks. Consumers around the world, particularly in marginalized communities, would benefit from updated epfd rules.

## Appendix A

### Draft technical basis for improved NGSO FSS capability with an epfd rule change

**An engineering study presented by amazon**

**David Kaufman, Alex Epshteyn, and Philippe Secher**

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**Background**
Non-geostationary satellite orbit ("NGSO") fixed-satellite service ("FSS") systems are required to meet equivalent power flux-density ("epfd") limits in the Ku and Ka radiofrequency ("RF") bands to protect geostationary satellite orbit ("GSO") satellite networks from unacceptable interference.

NGSO FSS systems adopt a combination of the following operational constraints to ensure compliance with today's epfd limits:

a. NGSO FSS systems limit their RF power and effective isotropic radiated power ("EIRP").
b. NGSO FSS systems constrain where they steer their downlink and uplink satellite antenna beams to prevent in-line interference events with GSO satellites. This is called GSO arc avoidance.
c. NGSO FSS systems limit the number of satellites in their systems that may simultaneously transmit to any earth station.

These NGSO FSS system constraints have severe effects on NGSO FSS system performance and cost. Both NGSO and GSO technologies evolved and the current epfd limits, which were adopted more than two decades ago, contain an overwhelming margin. A new type of interference limits could enable greater NGSO FSS system performance while resulting in little impact to GSO satellite networks.

This document presents two analyses to demonstrate the impact of current epfd limits and the benefits of possible new interference limits based on the representative NGSO and GSO systems described in Annex A. The first is an analysis that compares the effects of the current epfd limits and possible new interference limits on NGSO FSS system performance. The NGSO FSS system EIRP constraint is examined to determine the additional capacity that an NGSO system could provide under alternative interference limits. The second analysis considers the impact in terms of number NGSO FSS satellite needed to avoid the GSO arc under the existing limits compared to the number of satellites needed to avoid the GSO arc under new limits. The effect is launching fewer satellites to maintain the same continuity of service to subscribers.

Interference from NGSO FSS systems into GSO networks occurs in two geometries:

- NGSO FSS satellite orbits can directly intersect with a GSO network's satellite-to-earth station link. In this situation, the angular separation between the GSO network's earth station receiver, GSO network's satellite transmitter, and NGSO FSS system transmitter is 0°, such that the GSO network's earth station receiver cannot discriminate between the wanted RF energy and the interfering RF energy. The probability and duration of such in-line events is low even for NGSO FSS systems that have many satellites. These kinds of interference events are often called "short-term" interference events.
- For most of the time, there will be large angular separation between the GSO network's satellite transmitter and the NGSO FSS system transmitter. In this circumstance, the interfering RF energy from the NGSO FSS system transmitter is received by the GSO network's earth station receive antenna's sidelobe. While the GSO network's receive earth station antenna can better discriminate between the wanted and interfering RF energy at these large angular separations, the

interference received from multiple NGSO satellites can still mildly degrade the GSO network's signal quality. Because this interference situation occurs frequently and for longer periods of time, it is often called "long-term" interference.

**NGSO FSS system capacity impacts due to EIRP constraints driven by current long-term epfd limits**

NGSO FSS system EIRP constraints are employed to prevent exceedance of the short-term and long-term epfd limits. For this analysis, we focus on the long-term epfd limits. As an alternative to long-term epfd limits, an interference-to-noise ratio ("I/N") into the GSO earth station receiver of -12.2 dB, which is equal to a 6% delta-T/T[23] was considered. The NGSO FSS system analyzed has nearly 500 satellites in the constellation, operating at 1000 kilometers in altitude. The average elevation angle to the earth station is assumed to be 40 degrees above the local horizon. In Annex A Table A-1, we show a static calculation of NGSO FSS downlink interference into a GSO network's downlink in the 17.8-18.6 GHz frequency band. In the "epfd Limited" column, the NGSO system EIRP is set to produce an epfd equal to the long-duration epfd limit.[24] In the "I/N Limited" column, the same computation is repeated, this time setting the NGSO FSS system EIRP to produce an I/N into the GSO earth station receiver of -12.2 dB. In the "I/N Limited" case, the allowable NGSO FSS system EIRP is 8.5 dB higher than in the "epfd Limited" case.

Annex A Table A-2 repeats the analysis for an NGSO FSS system and GSO network's earth station operating in the 19.7-20.2 GHz frequency band.[25] In this case, the allowable NGSO FSS system EIRP is 14.2 dB higher when limited by I/N rather than by today's epfd limits.[26]

The increased NGSO FSS system EIRP level achieved by using the rational I/N threshold has a direct impact on the NGSO FSS system's achievable carrier-to-noise ("C/N") ratios. This is demonstrated in Annex A Tables A-3 and A-4.[27] This improved NGSO FSS system operation translates to higher spectral efficiency on a bits-per-second-per-Hertz basis, thereby increasing the per-satellite and system-wide throughput potential of NGSO FSS systems.

In terms of spectral efficiency, the improvement for NGSO FSS systems is significant. With the current epfd limits, the spectral efficiency in the 17.8-18.6 GHz frequency band increases from 2.72 bits-per-second-per-Hertz to 4.75—an increase of 75%. For the 19.7-20.2 GHz frequency band, where the long-term epfd limits are more severe, the improved spectral efficiency increases from 1.77 bits-per-second-per-Hertz to 4.98—a 181% increase. These results are shown in Annex A Tables A-3 and A-4. In stark contrast to this significant increase for the NGSO FSS system, the GSO network experiences a decrease in spectral efficiency of only 1% in the 17.8-18.6 GHz frequency band under the possible new epfd framework. In the 19.7-20.2 GHz frequency band, the decrease in spectral efficiency is 2% which, in absolute terms, is a 0.06 bits per second per Hertz change. These results are shown in Annex A Tables A-1

[23] A 6% delta-T/T is the default GSO-to-GSO coordination trigger. *See also* Recommendation ITU-R S.1432-1, *Apportionment of the allowable error performance degradations to fixed-satellite service (FSS) hypothetical reference digital paths arising from time invariant interference for systems operating below 30 GHz*, adopted in April 2006.

[24] *See* Table 22-1B to Article 22 of Volume 1 to the Radio Regulations, 2020 Edition.

[25] *See* Table 22-1C to Article 22 of Volume 1 to the Radio Regulations, 2020 Edition.

[26] *See* Table 22-1C to Article 22 of Volume 1 to the Radio Regulations, 2020 Edition.

[27] This analysis only varies the NGSO FSS EIRP level. In practice, the suggested EIRP increases, which may be achieved using increased antenna gain or amplifier power, would require satellite system design changes and potentially higher power consumption. While satellite technology has advanced in recent years to enable higher EIRP levels, NGSO FSS operators may not rely solely on an increase to satellite EIRP to achieve greater capacity if the epfd limits were changed, and may instead consider a combination of design and operational improvements, such as increasing system bandwidth, the number of co-frequency beams each satellite may form, and the number of satellites simultaneously serving the same location on the same frequency.

and A-2 and summarized in Table 1 below. This comparison demonstrates how much more the finite spectrum resource can be utilized by NGSO FSS systems without reducing the quality of service for GSO networks.

**Table 1. Summary of potential spectral efficiency for NGSO and GSO systems under current and possible new epfd limits.**

| | Current epfd Limits | Possible New Limits | Change [%] |
|---|---|---|---|
| **17.8-18.6 GHz Band** | | | |
| NGSO Spectral Efficiency | 2.72 | 4.75 | 75% |
| GSO Spectral Efficiency | 4.74 | 4.68 | -1.3% |
| | | | |
| **19.7-20.2 GHz Band** | | | |
| NGSO Spectral Efficiency | 1.77 | 4.98 | 181% |
| GSO Spectral Efficiency | 3.96 | 3.90 | -1.6% |

Each unique NGSO FSS system has different potential system capacity, but the improved spectral efficiency summarized above will have a directly proportional increase to system capacity. In the generic NGSO FSS system modeled, we see a 75% increase in total throughput in the 17.8-18.6 GHz band and a 181% increase in the 19.7-20.2 GHz band, an overall increase in system capacity from 7.1 Tbps using today's epfd limits to more than 14.5 Tbps using the standard I/N threshold for inter-system interference avoidance. Considering a target capacity objective of 10 Mbps for each household served by this NGSO FSS system, the total households that could be addressed with the current rules is around 708,000 when considering both RF ranges (17.8-18.6 GHz and 19.7-20.2 GHz).[28] With new, flexible limits built in recognition of the standard I/N threshold in this analysis, the NGSO FSS system operating in both frequency bands could provide service to nearly 1.5 million households representing a more than 100% increase in addressable households by only changing the epfd limits.

**NGSO FSS system continuity of service impact driven by current short-term epfd limits**

As mentioned, there are two interference categories of NGSO FSS systems into GSO networks, short-term inline events, and long-term interference into GSO receiver side-lobes. For NGSO systems using GSO arc avoidance to meet the short-term inline interference criteria, it effects how many satellites they need to launch to both protect GSO networks and maintain continuity of service to their subscribers. In other words, the subscriber would never experience a service outage due to not having at least one eligible satellite in view. This section details a hypothetical NGSO FSS system design under the current epfd limits and a hypothetical design operating under new, more flexible limits necessary to maintain continuity of service to subscribers.

Consider an NGSO FSS system seeking to deploy into low-earth orbit ("LEO") at an altitude of 1000 km above the Earth's surface, with a polar inclination angle, and seeking to provide subscribers with internet or other connectivity services. A reasonable assumption for subscribers is to operate with a minimum elevation angle of 25 degrees which provides them with a large, line-of-sight view the sky while still pointing above nearby obstructions on the local horizon like buildings and trees.

[28] The number of households served at a throughput objective of 10 Mbps is a simplification for the purposes of this analysis. The operational reality will be much more complex. This NGSO FSS system will have a diverse set of customers ranging from individual households to large enterprise business customers to government users—each having unique and variable throughput and performance requirements. This 10 Mbps is the throughput averaged over 24 hours and accounts for demands that could exceed 200 Mbps for short periods of time. This is consistent with the FCC Chairwoman's objective to increase the national standard broadband speed to 100 Mbps (*see* DOC-395473A1.pdf (fcc.gov)).

To respect current epfd limits, NGSO FSS systems can require GSO arc avoidance angles ranging between six and 18 degrees depending on the number of satellites in their constellation and antenna gain performance of their satellite antennas. For this hypothetical NGSO FSS system, we assume eight degrees is sufficient to protect GSO networks from short-term interference under the current epfd limits. This is a reasonable assumption based on publicly available epfd demonstrations submitted to and evaluated by the ITU's Radiocommunication Bureau.[29] While more difficult to predict, we assume four degrees is sufficient to protect GSO networks from short-term interference under the new interference limits.[30]

With the above parameters fixed, the number of needed satellites can be iterated by varying the number of orbital planes and number of satellites per orbital plane. The goal is to launch the fewest number of satellites while still providing subscribers with 100 percent continuity of service assuming subscribers could be at any latitude between 80° South and 80° North. There are multiple solutions to achieve this goal and the one presented herein is one such solution.

The simulation started with 720 satellites in 24 orbital planes with 30 satellites per plane. At each iteration, inter-plane phase shift was calculated to maximize the distance between satellites. To test for 100 percent continuity of service, the NGSO FSS system was propagated over a 24-hour period in 1-second intervals. The simulation iterated downward by first reducing the number of satellites in the orbital planes (i.e., from 30 satellites to 29). If this reduction demonstrated the subscribers still maintained continuous continuity of service at all latitudes over the 24-hour simulation, the satellites per plane were reduced again. If this again demonstrated continuous service, an orbital plane was removed (i.e., from 24 orbital planes to 23). This iterative process was repeated until a discontinuity of service occurred at one of the tested latitudes. Under the existing epfd rules with an eight-degree GSO arc avoidance angle, the fewest number of satellites was 462 distributed across 22 orbital planes, with 21 satellites per plane. This means a new entrant seeking to deploy a LEO NGSO FSS system would need a 462-satellite constellation to both respect GSO arc avoidance requirements and provide subscribers with continuous connectivity.

The same analysis was repeated under the possible new interference limits assuming only a four-degree GSO arc avoidance angle would be necessary. Starting from the 462-satellite design, the simulation iterated downward, just like above, until a discontinuity occurred. In this case, the fewest number of satellites needed to provide continuous connectivity to subscribers was 360, distributed across 18 orbital planes and 20 satellite per plane.

In summary, under the possible new interference limits a NGSO system would hypothetically need 102 fewer satellites to achieve the same continuity with is subscribers. This is a 28% savings in capital expenditures on satellite vehicles to achieve continuous connectivity as shown in Table 2 below. Stated another way, NGSO operators today are paying a 28% premium to fly additional satellites needed to offer 100 percent continuity of service while also meeting the conservative short-term protection objectives prescribed in the current epfd limits. There will also be an increase in operating costs associated with the daily management of a larger NGSO system and the additional ground facilities, equipment, and staff supporting the operations of the additional satellites.

[29] *See* epfd data and epfd examination results, Radiocommunication Sector, ITU, https://www.itu.int/en/ITU-R/space/Pages/epfdData.aspx (last accessed July 31, 2023).

[30] This is a reasonable assumption considering GSO satellite networks routinely operate with other neighboring co-frequency GSO satellite networks that are separated by two and three degrees in geocentric angle. The FCC has default service rules for GSO satellite networks using conventional FSS spectrum that are detailed in CFR Title 47, Part 25, Section 140.

**Table 2. Number of satellites needed to provide 100% geographic coverage under current epfd limits and possible new limits.**

| | **Current epfd limits** | **Possible new limits** |
|---|---|---|
| Total number of satellites required for 100% coverage | 462 | 360 |
| Capital expenditure savings | | 28% |

**Conclusion**

This document presents two analyses to demonstrate the impact of current epfd limits against possible new interference limits, and shows that (1) NGSO FSS system capacity and spectral efficiency would be greatly increased under possible new interference limits, (2) NGSO FSS systems could achieve world-wide coverage with fewer satellites, and (3) GSO FSS systems would not experience significant increased interference or performance impacts under the possible new epfd rules considered.

**Annex A – Supporting Data and Computations**

Table A-1. Example Computation of Allowable NGSO System EIRP when limited by epfd limits and GSO System Interference-to-Noise (17.8-18.6 GHz Band)

| | | | epfd Limited | I/N Limited |
|---|---|---|---|---|
| | **Frequency** | **MHz** | 17800.00 | 17800.00 |
| | **Wavelength** | **m** | 0.0168 | 0.0168 |
| **GSO System** | **GSO Altitude** | **km** | 35786.00 | 35786.00 |
| | **GSO Elevation** | **deg** | 40.00 | 40.00 |
| | **GSO Slant Range** | **km** | 37778.34 | 37778.34 |
| | **GSO PFD** | **dB(W/m^2/MHz)** | -120.00 | -120.00 |
| | **GSO Spreading Loss** | **dB** | 162.54 | 162.54 |
| | **GSO Path Loss** | **dB** | 209.00 | 209.00 |
| | **GSO EIRP** | **dBW/MHz** | 42.54 | 42.54 |
| | **GSO Earth Station Size** | **m** | 1.00 | 1.00 |
| | **Diameter / Wavelength** | | 59.37 | 59.37 |
| | **GSO Earth Station Max Rx Gain** | **dBi** | 43.17 | 43.17 |
| | **GSO Earth Station Minimum Off-axis Gain** | **dBi** | -4.00 | -4.00 |
| | **GSO Earth Station Noise Temperature** | **K** | 290.00 | 290.00 |
| **NGSO System of 462 satellites** | **NGSO Altitude** | **km** | 1000.00 | 1000.00 |
| | **NGSO Elevation** | **deg** | 40.00 | 40.00 |
| | **NGSO Slant Range** | **km** | 1428.63 | 1428.63 |
| | **NGSO PFD** | **dB(W/m^2/MHz)** | -114.23 | -105.71 |
| | **NGSO Spreading Loss** | **dB** | 134.09 | 134.09 |
| | **NGSO Path Loss** | **dB** | 180.56 | 180.56 |
| | **NGSO EIRP** | **dBW/MHz** | 19.86 | 28.38 |
| | **NGSO Nco** | **#** | 1.00 | 1.00 |
| | **Total NGSO PFD into GSO Sidelobe** | **dB(W/m^2/MHz)** | -114.23 | -105.71 |
| **GSO Performance and Interference** | **C** | | -123.29 | -123.29 |
| | **N** | | -143.98 | -143.98 |
| | **I** | | -164.70 | -156.18 |
| | **C/N** | **dB** | 20.68 | 20.68 |
| | **epfd** | **dB(W/m^2/MHz)** | -161.40 | -152.88 |
| | **epfd Limit (Long Duration, 10% exceedance)** | **dB(W/m^2/MHz)** | -161.40 | -161.40 |
| | **epfd Margin** | **dB** | 0.00 | -8.52 |
| | **I/N** | **dB** | -20.72 | -12.20 |
| | **C/(I+N)** | **dB** | 20.65 | 20.43 |
| | **C/N Reduction** | **dB** | -0.04 | -0.25 |
| | **Spectral Efficiency (C/N)** | **bits/hz** | 4.75 | 4.75 |
| | **Spectral Efficiency (C/I+N)** | **bits/hz** | 4.74 | 4.68 |
| | **Throughput Reduction due to Interference** | **%** | 0.20% | 1% |

Table A-2. Example Computation of Allowable NGSO System EIRP when limited by epfd limits and GSO System Interference-to-Noise (19.7-20.2 GHz Band)

| | | | epfd Limited | I/N Limited |
|---|---|---|---|---|
| | **Frequency** | **MHz** | 19700.00 | 19700.00 |
| | **Wavelength** | **m** | 0.0152 | 0.0152 |
| **GSO System** | **GSO Altitude** | **km** | 35786.00 | 35786.00 |
| | **GSO Elevation** | **deg** | 40.00 | 40.00 |
| | **GSO Slant Range** | **km** | 37778.34 | 37778.34 |
| | **GSO PFD** | **dB(W/m^2/MHz)** | -120.00 | -120.00 |
| | **GSO Spreading Loss** | **dB** | 162.54 | 162.54 |
| | **GSO Path Loss** | **dB** | 209.88 | 209.88 |
| | **GSO EIRP** | **dBW/MHz** | 42.54 | 42.54 |
| | **GSO Earth Station Size** | **m** | 0.70 | 0.70 |
| | **Diameter / Wavelength** | | 46.00 | 46.00 |
| | **GSO Earth Station Max Rx Gain** | **dBi** | 40.95 | 40.95 |
| | **GSO Earth Station Minimum Off-axis Gain** | **dBi** | -4.00 | -4.00 |
| | **GSO Earth Station Noise Temperature** | **K** | 290.00 | 290.00 |
| **NGSO System of 462 satellites** | **NGSO Altitude** | **km** | 1000.00 | 1000.00 |
| | **NGSO Elevation** | **deg** | 40.00 | 40.00 |
| | **NGSO Slant Range** | **km** | 1428.63 | 1428.63 |
| | **NGSO PFD** | **dB(W/m^2/MHz)** | -119.05 | -104.83 |
| | **NGSO Spreading Loss** | **dB** | 134.09 | 134.09 |
| | **NGSO Path Loss** | **dB** | 181.44 | 181.44 |
| | **NGSO EIRP** | **dBW/MHz** | 15.04 | 29.26 |
| | **NGSO Nco** | **#** | 1.00 | 1.00 |
| | **Total NGSO PFD into GSO Sidelobe** | **dB(W/m^2/MHz)** | -119.05 | -104.83 |
| **GSO Performance and Interference** | **C** | | -126.39 | -126.39 |
| | **N** | | -143.98 | -143.98 |
| | **I** | | -170.40 | -156.18 |
| | **C/N** | **dB** | 17.58 | 17.58 |
| | **epfd** | **dB(W/m^2/MHz)** | -164.00 | -149.78 |
| | **epfd Limit (Long Duration, 10% exceedance)** | **dB(W/m^2/MHz)** | -164.00 | -164.00 |
| | **epfd Margin** | **dB** | 0.00 | -14.22 |
| | **I/N** | **dB** | -26.42 | -12.20 |
| | **C/(I+N)** | **dB** | 17.57 | 17.33 |
| | **C/N Reduction** | **dB** | -0.01 | -0.25 |
| | **Spectral Efficiency (C/N)** | **bits/hz** | 3.96 | 3.96 |
| | **Spectral Efficiency (C/I+N)** | **bits/hz** | 3.96 | 3.90 |
| | **Throughput Reduction due to Interference** | **%** | 0% | 2% |

Table A-3. Example Computation of NGSO System Throughput Potential (17.8-18.6 GHz Band)

| | | **epfd Limited** | **I/N Limited** |
|---|---|---|---|
| **Frequency** | **MHz** | 17800.00 | 17800.00 |
| **Wavelength** | **m** | 0.0168 | 0.0168 |
| **NGSO Altitude** | **km** | 1000.00 | 1000.00 |
| **NGSO Elevation** | **deg** | 40.00 | 40.00 |
| **NGSO Slant Range** | **km** | 1428.63 | 1428.63 |
| **NGSO PFD** | **dB(W/m^2/MHz)** | -114.23 | -105.71 |
| **NGSO Spreading Loss** | **dB** | 134.09 | 134.09 |
| **NGSO Path Loss** | **dB** | 180.56 | 180.56 |
| **NGSO EIRP** | **dBW/MHz** | 19.86 | 28.38 |
| **NGSO Nco** | **#** | 1.00 | 1.00 |
| **NGSO Earth Station Size** | **m** | 0.30 | 0.30 |
| **Diameter / Wavelength** | | 17.81 | 17.81 |
| **NGSO Earth Station Max Rx Gain** | **dBi** | 32.71 | 32.71 |
| **NGSO Earth Station Scan Loss** | **dB** | 3.84 | 3.84 |
| **NGSO Earth Station Noise Temperature** | **K** | 290.00 | 290.00 |
| **C** | | -131.82 | -123.30 |
| **N** | | -143.98 | -143.98 |
| **C/N** | **dB** | 12.16 | 20.68 |
| **Spectral Efficiency (C/N)** | **bits/second/Hz** | 2.72 | 4.75 |
| **Frequency Range** | **MHz** | 17800-18600 | 17800-18600 |
| **# Reuse Per Satellite, including Polarization** | **#** | 20.00 | 20.00 |
| **Bandwidth per Satellite** | **MHz** | 16000.00 | 16000.00 |
| **Capacity per Satellite** | **Mbps** | 43579.96 | 75928.91 |
| **# Satellites in System** | **#** | 462 | 462 |
| **Satellite Utilization** | **%** | 25% | 25% |
| **System Capacity** | **Mbps** | 5,033,485.62 | 8,769,789.17 |
| **System Capacity** | **Tbps** | 5.03 | 8.77 |
| **Capacity objective per household** | **Mbps** | 10 | 10 |
| **Total addressable households** | **#** | 503,349 | 876,979 |

Table A-4. Example Computation of NGSO System Throughput Potential (19.7-20.2 GHz Band)

| | | epfd Limited | I/N Limited |
|---|---|---|---|
| **Frequency** | **MHz** | 19700.00 | 19700.00 |
| **Wavelength** | **m** | 0.0152 | 0.0152 |
| **NGSO Altitude** | **km** | 1000.00 | 1000.00 |
| **NGSO Elevation** | **deg** | 40.00 | 40.00 |
| **NGSO Slant Range** | **km** | 1428.63 | 1428.63 |
| **NGSO PFD** | **dB(W/m^2/MHz)** | -119.05 | -104.83 |
| **NGSO Spreading Loss** | **dB** | 134.09 | 134.09 |
| **NGSO Path Loss** | **dB** | 181.44 | 181.44 |
| **NGSO EIRP** | **dBW/MHz** | 15.04 | 29.26 |
| **NGSO Nco** | **#** | 1.00 | 1.00 |
| **NGSO Earth Station Size** | **m** | 0.30 | 0.30 |
| **Diameter / Wavelength** | | 19.71 | 19.71 |
| **NGSO Earth Station Max Rx Gain** | **dBi** | 33.60 | 33.60 |
| **NGSO Earth Station Scan Loss** | **dB** | 3.84 | 3.84 |
| **NGSO Earth Station Noise Temperature** | **K** | 290.00 | 290.00 |
| **C** | | -136.64 | -122.42 |
| **N** | | -143.98 | -143.98 |
| **C/N** | **dB** | 7.34 | 21.56 |
| **Spectral Efficiency (C/N)** | **bits/second/Hz** | 1.77 | 4.98 |
| **Frequency Range** | **MHz** | 19700-20200 | 19700-20200 |
| **# Reuse Per Satellite, including Polarization** | **#** | 20.00 | 20.00 |
| **Bandwidth per Satellite** | **MHz** | 10000.00 | 10000.00 |
| **Capacity per Satellite** | **Mbps** | 17728.92 | 49794.40 |
| **# Satellites in System** | **#** | 462 | 462 |
| **Satellite Utilization** | **%** | 25% | 25% |
| **System Capacity** | **Mbps** | 2,047,690.67 | 5,751,253.22 |
| **System Capacity** | **Tbps** | 2.05 | 5.75 |
| **Capacity objective per subscriber** | **Mbps** | 10 | 10 |
| **Total addressable subscribers** | **#** | 204,769 | 575,125 |

## Appendix B

### Economic calculations of quantifiable consumer welfare benefits from updating epfd rules

In this appendix, I calculate the quantifiable consumer welfare benefits from updating the epfd rules. These calculations are based on changes in prices and quantities for services from LEO-satellite systems for customers—consumers, households, government entities, non-profit organizations, enterprise customers, and network customers—that actually purchase services from LEO-satellite systems.[31] These calculations are likely conservative underestimates of the total consumer welfare value of updating the ITU epfd rules for reasons explained in the main report and below. For example, many of the consumer welfare benefits are for consumers who do not directly pay for the services.

Any modernization of epfd rules could benefit consumers in the following measurable ways:

- *Increase capacity of NGSO FSS systems of a given size*. The "Technical Inputs Study" in Appendix A finds that under reasonable assumptions, for a constellation with a fixed number of satellites, modernizing epfd rules would increase capacity at 17.8 GHz – 18.6 GHz without increasing costs would increase by 74 percent.[32] System capacity at 19.7 GHz to 20.2 GHz without increasing costs would increase by 180 percent.[33] These capacity increases might be reflected in either: (a) an increase in the capacity for satellite users, without increasing the number of users; (b) increases in the number of satellite users; or (c) a combination of both (a) and (b). Presumably, various scenarios show an even wider range of capacity increases. In the analysis below, I consider increases in capacity in the range of 40 percent to 240 percent.
- *Reduce number of satellites necessary for an NGSO FSS system to provide a certain capacity of service to a certain geography or population* – Some NGSO FSS systems seek to serve a certain geography or population with a certain level of service. Updating the epfd rules would reduce the number of satellites necessary for the NGSO FSS system to meet its demand, thereby reducing the cost of the service to customers.
- *Facilitate entry and enhance competition for services from LEO-satellite systems*. By reducing the cost of providing services from a LEO-satellite system and by reducing the number of satellites necessary for the constellation, updating the epfd rules would facilitate entry and enhance competition.
- *Reduced prices for services from LEO-satellite systems.* Assuming that most costs for satellite services are fixed, the system capacity increases described above reflect a decline in average costs per unit of capacity of between 43 percent and 64 percent.[34] Actual price

[31] Consumer welfare for a service is usually measured as the area under the demand curve for the service but above the market price. For the purposes of this study, the demand curve is for all LEO satellite services.
[32] Appendix A, Table A-3, 74% = increase from 5.03 Tbps to 8.77 Tbps.
[33] Appendix A, Table A-4, 180% = increase from 2.05 Tbps to 5.75 Tbps.
[34] 43 percent = 1-1/1.74, and 64 percent = 1 – 1/2.80.

declines facing satellite broadband users, either individuals or enterprise customers, would depend on many factors including the cost structure of the satellite service provider and the elasticity of demand for the satellite broadband services. In the analyses below, I consider decreases in prices per unit of capacity between 10 percent and 50 percent.

- *Elasticity of demand* Measurements of increases in consumer welfare as LEO-satellite system capacity increases and prices fall depend not only changes in output and price but also on the elasticity of demand. The exact measure of the increase in consumer welfare is the increase in the area under the demand curve above the market price. I will approximate that area as follows:
    - Change in price x original quantity; plus
    - ½ change in price x change in quantity.

In Exhibit B.1, I present the percentage change in global consumer welfare from updating the epfd rules under the assumption that the baseline revenue for all services from a LEO-satellite system is $1 per year. I examine the change in consumer welfare based on parameters for reduction in price per unit of capacity[35] of between 10 percent and 50 percent and increases in capacity of between 25 percent and 250 percent. The percentage changes in consumer welfare range from:

- 11 percent increase in consumer welfare from a 10 percent reduction in price and a 25 percent increase in capacity; to
- 113 percent increase in consumer welfare from a 50 percent reduction in price and a 250 percent increase in capacity.

Exhibit B.1

Estimated change in consumer welfare on a percentage basis from updating the EPFD rules
Assuming baseline is capacity of all LEO satellites at $1 per year

| Percentage Decrease in Price per Unit of Capacity | Percentage Increase in Capacity: 25 | 50 | 100 | 150 | 200 | 250 |
|---|---|---|---|---|---|---|
| 10 | 11% | 13% | 15% | 18% | 20% | 23% |
| 20 | 23% | 25% | 30% | 35% | 40% | 45% |
| 30 | 34% | 38% | 45% | 53% | 60% | 68% |
| 40 | 45% | 50% | 60% | 70% | 80% | 90% |
| 50 | 56% | 63% | 75% | 88% | 100% | 113% |

Change in consumer welfare estimated as
Change in price x original quantity; plus
½ change in price x change in quantity

[35] These price decreases are measured per unit of capacity, not necessarily corresponding to price per subscription. For example, if capacity doubled but price stayed constant, the price per capacity would fall by 50 percent.

Of course, the revenue value of services from a LEO-satellite system is far more than $1 per year. These percentage changes in consumer welfare in Exhibit B.1 can be applied to projected values for the number of LEO satellite users in 2030 of more than 10 million users[36] at current monthly residential rates for Starlink of roughly $120/month.[37] The net result is a baseline industry revenue of $14.4 billion. I present the results in Exhibit B.2 from updating the epfd rules. The change in consumer welfare ranges from $1.62 billion annually for a 10 percent reduction in price and a 25 percent increase in capacity to a $16.2 billion annually for a 50 percent reduction in price and a 250 percent increase in capacity. Of course, to the extent the total baseline LEO satellite revenue is more (less) than $14.4 billion, the results in Exhibit B.2 are correspondingly understated (overstated).[38]

Exhibit B.2

Estimated annual increase in consumer welfare in $billions from updating the EPFD rules
Assuming baseline capacity of all LEO satellites is
10 million users in this example at $120/month
based on percentage changes in Exhbit B.1

| Percentage Decrease in Price per Unit of Capacity | Percentage Increase in Capacity: 25 | 50 | 100 | 150 | 200 | 250 |
|---|---|---|---|---|---|---|
| 10 | $ 1.62 | $ 1.80 | $ 2.16 | $ 2.52 | $ 2.88 | $ 3.24 |
| 20 | $ 3.24 | $ 3.60 | $ 4.32 | $ 5.04 | $ 5.76 | $ 6.48 |
| 30 | $ 4.86 | $ 5.40 | $ 6.48 | $ 7.56 | $ 8.64 | $ 9.72 |
| 40 | $ 6.48 | $ 7.20 | $ 8.64 | $ 10.08 | $ 11.52 | $ 12.96 |
| 50 | $ 8.10 | $ 9.00 | $ 10.80 | $ 12.60 | $ 14.40 | $ 16.20 |

Change in consumer welfare estimated as
Change in price x original quantity; plus
½ change in price x change in quantity

The information in Exhibit B.2 represents annual increases in consumer welfare from updating the epfd rules. These measures are based on the assumptions of $120 per month for service and of a base case of 10 million global LEO-satellite system customers. The assumption of $120 per month as a revenue base case may be high or low, depending in part on the development of demand from governmental users. Under reasonable assumptions, the baseline global subscribership in 2030 could be substantially more than 10 million. For example, the Technical

[36] Broadband satellite internet service | Deloitte Insights, November 30, 2022.
[37] How much do Starlink plans cost, and are they worth it? - Android Authority.
[38] The $14.4 billion estimate is close to the $11.29 billion estimate in LEO Satellite Market Information and Statistics Report 2023-2030 - MarketWatch.

Inputs Study finds that baseline capacity for a *single* NGSO FSS system operating in the 17 GHz and 20 GHz frequency bands with a target capacity objective of 10 Mbps for each subscriber, corresponding to FCC Chairwoman Rosenworcel's proposed broadband target of 100 Mbps down and 10 Mbps up, could serve just under 5 million subscribers.[39] With many different LEO constellations approved globally, the base case for the capacity for the number of global subscribers could easily be much more than 10 million.

Alternatively, assuming a target capacity objective of 2.5 Mbps,[40] corresponding to the current FCC broadband definition, a single LEO constellation could serve just under 20 million subscribers in the base case. With many different LEO-satellite systems approved globally, the base case for the capacity for the number of global subscribers could easily be many tens of millions.

The increases in consumer welfare presented in Exhibit B.2 are for a single year. Consumers would benefit from new epfd rules in all years after the rules were adopted. To capture the full value of improvements in consumer welfare, I calculate the net present value in 2023 of consumer welfare improvements in all years after the rules would be in place. New epfd rules cannot be considered until 2027 and presumably cannot be put in place until 2028.

In Exhibit B.3, I assume that new epfd rules are put in place in 2028, and I present the NPV in 2023 of the rule changes with a 10 percent discount rate. The NPV of the change in consumer welfare ranges from $10.06 billion annually for a 10 percent reduction in price and a 25 percent increase in capacity to a $100.6 billion annually for a 50 percent reduction in price and a 250 percent increase in capacity. The results in Exhibit B.3 illustrate that, under a wide range of assumptions, the NPV of changing epfd rules are in the tens of billions of dollars. If, as discussed above, the base case global subscribership is greater than 10 million, the NPV calculations in Exhibit B.3 could be correspondingly higher. Also, many governmental agencies use a lower discount rate than 10 percent. Lower discount rates would increase the value today of consumer benefits in later years; for the purpose of these analyses, lower discount rates would increase the value the NPV of consumer welfare from updating the epfd rules.

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[39] "Technical Inputs Study". The 10 Mbps is based on Chairwoman Rosenworcel's proposed new standard of 100 Mbps download with a loading factor of 10. See DOC-395473A1.pdf (fcc.gov), July 25, 2023.

[40] With a loading factor of 10, this would correspond to 25 Mbps per subscriber.

Exhibit B.3

Estimated NPV in consumer welfare in $billions from updating the EPFD rules
Assuming annual increase in consumer welfare as presented in Exhibit B.2
with updated EPFD rules available in 2028

| | | Percentage Increase in Capacity | | | | | |
|---|---|---|---|---|---|---|---|
| | | 25 | 50 | 100 | 150 | 200 | 250 |
| Percentage Decrease in Price per Unit of Capacity | 10 | $10.06 | $11.18 | $13.41 | $15.65 | $17.88 | $20.12 |
| | 20 | $20.12 | $22.35 | $26.82 | $31.29 | $35.77 | $40.24 |
| | 30 | $30.18 | $33.53 | $40.24 | $46.94 | $53.65 | $60.35 |
| | 40 | $40.24 | $44.71 | $53.65 | $62.59 | $71.53 | $80.47 |
| | 50 | $50.29 | $55.88 | $67.06 | $78.24 | $89.41 | $100.59 |

Change in consumer welfare estimated as
Change in price x original quantity; plus
½ change in price x change in quantity