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An Overview of Opportunities and Challenges of New LEO Satellite Constellationsfor ProvidingGlobal High Speed Internet Service to Underserved Areas

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Abstract:*The new Low Earth Orbit(LEO) satellites constellations will play a necessary role in the global connectivity ecosystem, connecting rural and remote populations, providing backhaul connectivity to mobile cellular networks, establishing communication in emergency and disaster response scenarios as well as aerial and maritime mobile users. Compared to their predecessors, the main differences of these systems are: increased performance that results from the use of digital communication payloads (such as on board processing and Intersatellite link), advanced modulation and coding schemes, multi-beam antennas, and more sophisticated frequency reuse schemes, as well as the cost reductions from modern technology and advanced manufacturing processes and reduced launch costs.*

This Paper focuses on the new LEO constellations, such as those being deployed by Starlink by SpaceX, Project Kuiper by Amazon, OneWeb, LeoSat, Lightspeed by Telesat, among others, may prove to connectingcountries by high speed broadbandinternet based on their global coverage and their suitability for areas not served by fiber optic cable networks.

This paper discussesthe opportunities and the challenges faced the expansion of internet connectivity, particularly for underserved geographies areas and countries with limited international internet bandwidth, such as landlocked developing countries, remote areas and small island developing states. With their global reach and coverage, LEO constellations are expected to significantly expand the availability of high-speed internet access with levels of service that competitor fiber optic cables in terms of speed,latency and at obviously reduced price levels compared to traditional Geostationary Earth Orbit (GEO) satellites.

Key Words:*LEOSatellites Constellation; GEO; Challenges and Opportunities;High Speed Internet.*

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I. INTRODUCTION

These Emerging Innovationsof LEO satellite constellations are intended to provide readers with a background understanding of the role of satellite communications in global internet connectivity and an exploration of the potential impact of the next generation of LEO constellation systems.

Satellites have used LEO since the beginning of space exploration; however, private investment in LEO constellations, consisting of hundreds or thousands of satellites, has been limited because significant up-front capital expenditure is required. While it remains to be seen how the next generation of LEO satellite constellations will evolve, LEOs are predicted to obviously increase the available internet bandwidth in remote and rural geographies not currently served by fiber optic cables.This increased bandwidth could be effectiveto increase economic and social development opportunities for individuals, organizations, businesses, and different government facilities located in these areas.

Internet connectivity has become a necessary component of every country's critical infrastructure given the dependency of all aspects of economic activity, governance, and social development on internet communications.The coronavirus disease (COVID-19) pandemic dramatically increased the importance of internetcommunications infrastructure. Trade, learning, employment, transportation, leisure, and communications quickly shifted into the digital field and countries with robust internet infrastructure and high adoption rates of internet-enabled devices were better able to adapt to the shift to digital activity. The United Nations (UNs) estimates that 1.6 billion learners were affected by school closures in 2020, affecting 94% of the world's student population [1].

Internet access continues to grow, increased competition, and allocation of shared resources, such as spectrum auctions and assignment. Despite these efforts, large access gaps remain especially in the most remote area difficult to reach, or sparsely populated districts remain disconnected, leaving about50% of the population around the world without access to the internet. This lack of digital infrastructure represents a big problem to accelerate economic and social development.

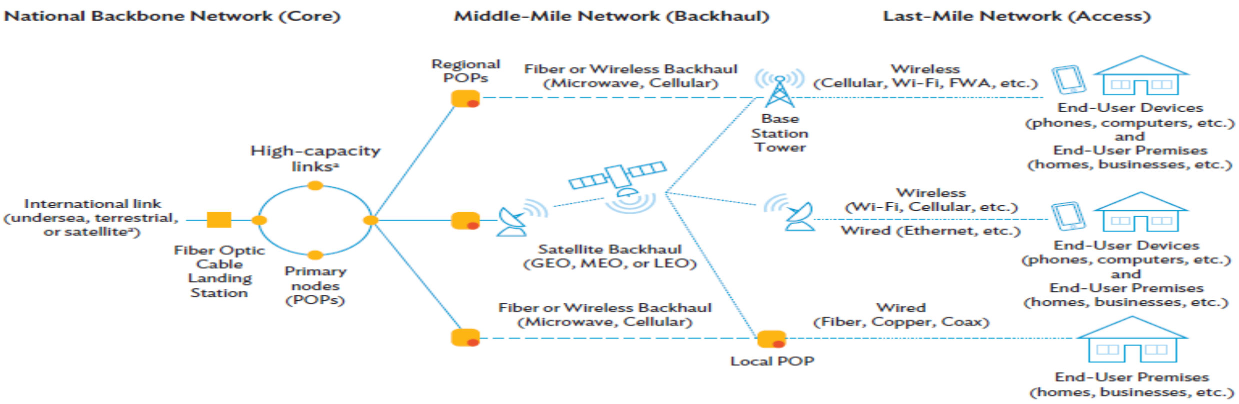
Despite the rapid expansion of internet connectivity infrastructure across the world, significant gaps remain in internet adoption and access to telecommunication infrastructure. This highlights the importance of satellite communications that can bridge gaps, swiftly expand network coverage, and enhance existing telecommunication infrastructure.

The latest estimates from the International Telecommunication Union (ITU) show that 3.7 billion

people around the world are still not participating online and 63% of rural households are without internet access [2].In addition, 1.5 billion people reside in areas without high-speed mobile data coverage (4G), while 607 million people reside in areas with no mobile data coverage at all (at least 4G or 3G coverage) and 220 million people reside in areas with no cellular coverage. The ITU estimates that nearly $428 billion is required to achieve universal access to broadband globally [3].The majority of the world's population, over 5 billion people, live more than 10 km away from any fiber optic cable infrastructure [4]. Other issues, such as affordability, digital literacy, and the lack of relevant or local language content.

Satellite connectivity is mainly used for backhaul connectivity for remote cellularbase stations and as a last-mile connection for individual subscribers and enterprises.Because of the higher relative cost of bandwidth transmitted via satellite versus terrestrial technologies, satellite is currently primarily used in situations where fiber optic cables and other high-capacity technologies are not financially viable due to low population densities and large distances between high-capacity networks and last-mile networks [5]. However, in a few cases, satellite connectivity is relied upon for international internet gateway traffic or as part of a country's core network.

Fig.1: Internet Infrastructure Network



For landlocked developing countries that are dependent on terrestrial fiber connectivity, in some cases, satellite connectivity serves as a substitute to multilateral negotiations to extend costly fiber connectivity to their country.Figure.1 provides an overview of the internet infrastructure network components, from international connectivity to the last mile.

The rest of this paper is organized as follows. Section2 discusses global coverage of satellite with trade-offs between capacity and affordability. Section3 defines the main difference between LEO and GEO systems. Section4 discusses the significantdifferences between LEO constellations configuration. Section5, focusing on the main opportunity and challenges to leveragingLEO satellites. Section6provides recommendations. Finally, section7 states major conclusions.

II. GLOBAL COVERAGE OF SATELLITE WITH TRADE-OFFS IN CAPACITY AND AFFORDABILITY

Satellite communications coverage is already global, composed of GEO satellites, medium Earth orbit (MEO), and LEO constellations. There are currently at least 775 active satellites in orbit that serve primary communications functions (excluding the new LEO constellations) [6]. However, the total satellite sellable capacity in 2020 of approximately 3terabits per second (Tbps) is relatively small compared by the roughly 2,000 Tbps of utilized fiber capacity. As of early 2020, there were at least 406 submarine cables in service and 99% of totalinternational internet data traffic is transmitted via fiber optic cables [7]. Wholesale prices also differdramatically with international internet transit (IP transit) pricing as low as $1–$3 per Mbps/month on major cross-country routes against wholesale prices for dedicated satellitecapacity approaching $200–$400 Mbps/month. Therefore, satellite connectivity is only costcompetitivefor remote and dispersed populations where fiber deployments are challenging. The newgeneration of LEO and high-throughput GEO satellites are expected to lower the cost structure andmake satellite connectivity more competitive(as shown in figure.2) particularly in situations where a high degree of data throughput is required per site, such as satellite backhaul for broadband cellular networks. The data volumes as well as the distance to the nearest backbone node play a significant role in cost comparisons between satellite connectivity versus terrestrial network deployments [8].

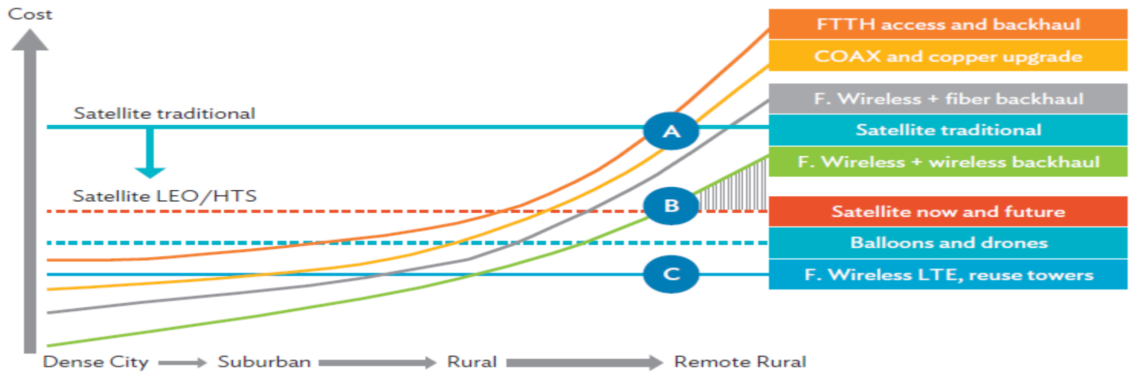


Fig. 2: Technologies Compared by Costs and Population Density

Satellite connectivity is the only option available for geographies without direct access to fiber optic cable infrastructure or at great distances from high capacity bandwidth capacity. Even where terrestrial network infrastructure that could be used for backhaul connectivity is available, satellite deployments may still be preferred because satellite terminals require only electrical power and a clear line of sight to the sky.However, an expansion of terrestrial infrastructure usually requires huge civil works (for example; underground fiber ducts, pole attachments, or tower construction for cellular base stations), which comes with challenges such as permits, securing the rights-of-way and having to pay the related fees.

As information and communication technologies play an increasingly important role in commerce,government services, health care, education, smart transportation, and other sectors, satellite connectivity allows communities to be connected rapidly, bypassing the infrastructure deployment challenges that come with terrestrial infrastructure deployments. Satellite technology may also be complementary with traditional wired and mobile broadband, which are better suited for densely populated areas. Satellite connectivity is already being used for network redundancy at national levels for international internet capacity, as well as for backup in core and backhaul networks and in emergency telecommunications.

III. MAIN DIFFERENCES BETWEEN LEO AND GEO CONFIGURATIONS

GEO satellites are positioned at an altitude of 35,786 km and, as a result, each satellite has a very wide coverage area. This allows them to focus their bandwidth capacity on their coverage area and reduces the requirement for achieving global coverage to as few as three satellites. However, because of their distance from the Earth's surface, their minimum latency thresholds are high roughly at least 0.477seconds for round trip latency.The latest generation of GEO satellites, known as high-throughput satellites (HTSs), have a significantly increased capacity (at least 10 times the throughput) than previous generations of GEO satellites, while the high latency remains the same.

In comparison, LEO constellations require a network of satellites to provide internet service because each LEO satellite is traversing the Earth's surface, orbiting the planet every 88–127 minutes (depending on their altitude, between 160–2,000 km). Their closer distance to the Earth's surface enables them to provide low-latency and high-speed internet. MEO satellites are positioned between LEO and GEO orbits, circling the planet by 2,000–35,786 km. These satellites handle high-speed, low-latency data traffic particularly cellular backhaul[9]. All of these features are given in figure.3 and table1.

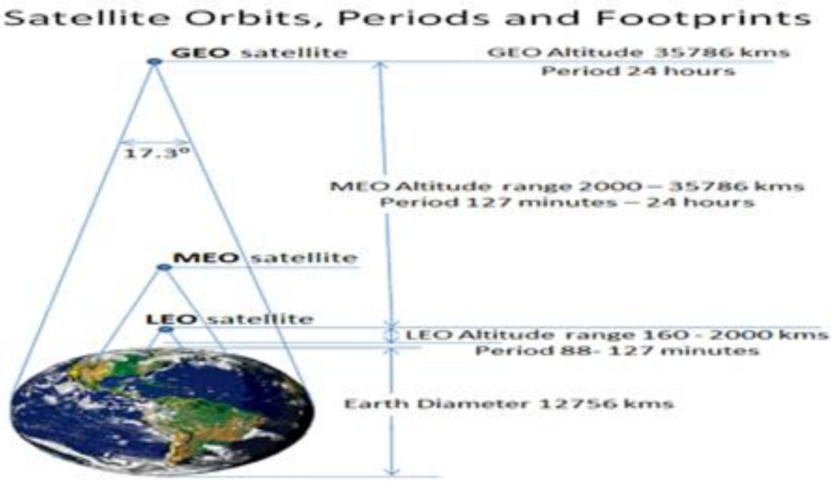


Fig.3: Comparison between main Characteristics: LEO, MEO and GEO

Table.1: Comparison between main Characteristics: GEO, MEO and LEO

Orbit	Altitude(km)	Orbital Period	Latency (roundtrip)	No. ofSatellites toSpan Globe	Cost/Satellite ($)	Lifetime of Satellite
LEO	160–2,000	88–127min	~2–27 ms.	100s or 1000s(depending on altitude)	~ 0.5–45 million	5–10 years
MEO	2,000–35,786	127min- 24h	~27–477 ms.	5–30(depending on altitude)	~80–100 million	10–15 years
GEO	35,786	24 hours	~477 ms.	3	~100–400 million	15–20 years

3.1. Comparison between capacity of LEO constellation and GEO satellites

Individual GEO satellites provide bandwidth capacity of 1–10 gigabits per second (Gbps), while the first-generation HTS range is 10–50Gbps, and third-generation (HTS-3) provides capacity of 150–350Gbps due to spot beams technology and using Ka band.With the next generation LEO constellations consisting of hundreds, if not thousands, of satellites each able to transmit tens (10s) of Gbps, the total capacity of new constellations is forecast to be in single digit to 10s of Tbps, dramatically surpassing existing sellable capacity of GEO as shown in figure.4. Satellites broadband capacity are forecasted to increase from an estimated 2 Tbps at the end of 2020, to 20Tbps by end of 2021 and 60 Tbps by the end of the decade [10].

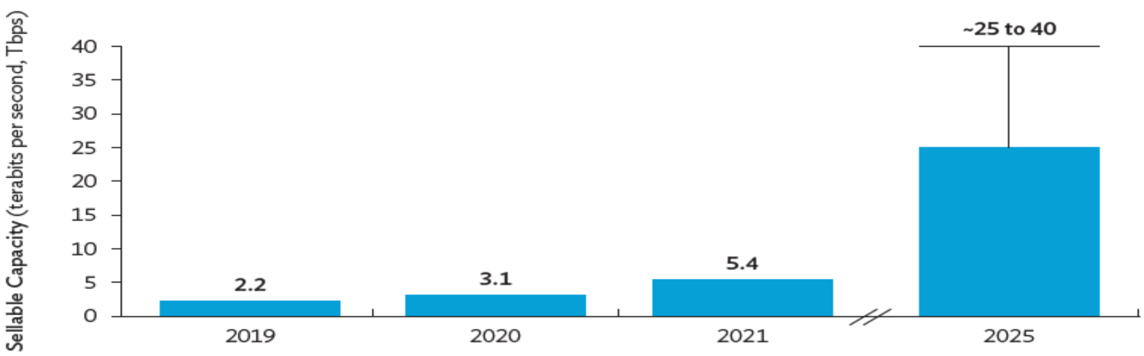


Fig.4: Total Sellable Satellite Bandwidth Capacity, 2019–2025

Satellite broadband is a growing and dominant segment of the overall satellite sector. Overall, the sector's revenues have been growing almost 4% per year and have increased by $38 billion over the last 5 years. The space market is expected to reach between $1.1 trillion to $2.7 trillion in the next 30 years, with the provision of internet access via satellite predicted to account for 50%-70% as the primary driver of growth [11]. Figure.5 forecasts that LEO and MEO satellites will capture 50% of the market for high-throughput satellite communications by 2027.

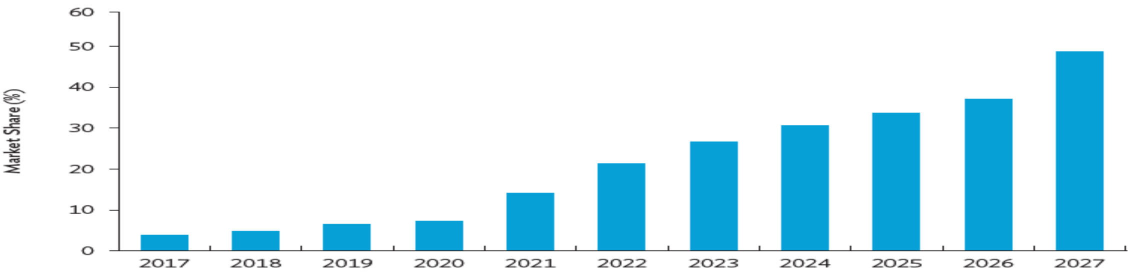


Fig. 5: Overall Shares of the HTS Satellites Market Supplied by MEO and LEO Satellites

3.2. LEO versus GEO: differences in subscriber data pricing for commercial service

The advent of HTS has led to a divergence in cost for satellite services, with rates for broadband connectivity falling faster than that for broadcast and distribution. For HTS GEO service offerings, the average bandwidth cost is between $250and $400 per Mbps/month [12]. Over the coming decade, wholesale rates are expected to fall below$100 per Mbps/ month, with one notable event in 2019 when it fell below $50 per Mbps/month in a unique circumstance.

As LEO and MEO satellites become ubiquitous, these technologies are expected to provide a cost advantage compared to GEO satellites. Since LEO constellations are expected to provide identical coverage for the service area under the constellation's footprint, they could potentially offer a uniformpricing model anywhere in the world. Combined with the high capacity, shorter-term contracts, LEOs could rapidly decrease satellite bandwidth costsglobally. There will also be significant opportunity for regional pricing because the up-frontinvestment in the constellation is the primary cost, and individual satellites are only able to serve the areaunder their current location.

One of the new LEO constellations in deployment is SpaceX' s Starlink service, which is the mostadvanced LEO constellation in deployment in terms of number of satellites and current stage of internetservice offered. Starlink began a public beta trial program in October 2020 for subscribers in the northernUnited States and Canada between the latitudes of 45° and 52° focusing on rural locations. The service pricing offered during the public beta is $99/month forspeeds between 50–150 Mbps, plus a one-time equipment fee of$499[13]. Based on this data, a per Mbps price comparison wouldsee Starlink at $0.50–$1.50/Mbps compared to a range of pricing from HTS GEO services. It is important to note that this comparison should be revised when commercial pricing of LEObecomes available.Even as prices have fallen over the years, satellite broadband remains expensive compared to connectivityfrom terrestrial technologies at the same speeds.

IV. SIGNIFICANT DIFFERENCES BETWEEN LEO CONSTELLATION CONFIGURATIONS

The four constellations with current deployments (Starlink, OneWeb, Telesat and Amazon project Kuiper) havesignificantdifferences in configuration and satellites. Starlink satellites are configured to have lower orbit altitudethan its competitors, its latest configuration at up to 550 km from the ground. This will provide lowerlatencies for satellite-to-earth and earth-to-satellite communication. It originally planned to includeoptical inter-satellite links (OISL) which would reduce latency even further over long distances andprovide communications that could theoretically even be faster than fiber optic cable. However, ISL have not yet been fully deployed, and only a few of thesatellites launched to date include OISL technology [14].

In Telesat's constellation, each satellite will be an internet protocol node, with each satellite functioningas a router making decisions on where to send traffic. Telesat's more complex design helps to optimizenetwork architecture and efficiency as its satellites orbit at a higher altitude and will be equipped withOISL.

Unlike Telesat's model, OneWeb will employ a traditional "bent-pipe" architecture. Signals coming up from the ground will be "repeated" to another beam going down, with no routing taking place, simplifying the networking component of satellite design and engineering, but without the potential benefit of overall network redundancies and efficiency in data packet routing.

Along with Starlink, Project Kuiper, an Amazon subsidiary, is widely perceived to be among the most promising US companies. Currently, Project Kuiper plans to build a constellation of around 3,236 satellites. As with Starlink, the plans of the Amazon subsidiary build on the premise that the stationing costs for Internet satellites will drop in the future. Project Kuiper only received its authorisation for operating a satellite constellation over the United States in July 2020. At that time, Amazon announced its intention to invest at least US$10 billion in the project[15].

One advantage for Project Kuiper compared to Starlink is that it can draw on the experience of Amazon Web Services, which is one of the largest cloud providers worldwide and has a correspondingly extensive network of data centres. This subsidiary of the online mail order company runs data centres and data connections.

The Chinese government has created a company dedicated to creating and operating a 13,000-satellite broadband constellation in LEO. Spectrum allocation filings submitted to the ITU by China in Sep.2020 revealed plans to construct two similarly named “GW” LEO constellations totalling 12,992 satellites. The filings indicate plans for LEO constellations ranging from 500-1,145 km in altitude with inclinations between 30° to 85°,and they would operate across a range of frequency bands.Estimates by the Massachusetts Institute of Technology (MIT) in 2018 on total capacity of three of the LEO constellations in current deployment suggested that while each of the constellations will have significant capacity (each over 1Tbps), Starlink would have the largest throughput at 23.7Tbps based on 123 ground stations and a total of 4,425 satellites, compared to Telesat with 2.66Tbps with 40 ground stations and 117 satellites[16], and OneWeb with 1.56Tbps based on 71 ground stations and 720 satellites[17].

More recent updates from the LEO providers note that commercial service will begin for Starlink with 1,440 satellites, OneWeb with 648 satellites, and Telesat with 298satellites [15].In 2020, Starlink announced plans to construct a constellation with a final size of 42,000 satellites, and OneWeb has announced plans for 48,000. The differences in orbits and coverage are demonstrated in Table.2, including differences in average and maximum data rates per satellite.

Table.2: Differences between LEO constellations in Deployments, Constellations, and Satellites

Characteristics	SpaceX Starlink	OneWeb	Telesat Lightspeed	LeoSat	Amazon Project Kuiper
Constellation to initiate service	1,440	648	298	unknown	578
Total future constellation size	42,000	48000	1,671	78-108	3,236
Max. data rate per satellite	20.12 Gbps	8.8 Gbps	35.65 Gbps	5.2Gbps	50.8Gbps
Initial total capacity	Up to 30Tbps	Up to 5Tbps	15 Tbps	1.2-2 Tbps	Up to 9Tbps
Frequency	Ku&Ka-band	Ku-band	Ka& V band	Ka-band	Ka-band
Orbit	560 km	1,200 km	1,000 km	1400 km	590–630 km
Satellite mass	227–260 kg	150 kg	700 kg	unknown	unknown
Satellite life	5–7 years	~5 years	10–12 years	10years	unknown
Latency	<50 ms.	<50 ms.	<50 ms.	<50 ms.	<50 ms.
CAPEX	$10 billion	$2.4 billion	$5 billion	unknown	$10 billion
Cost per satellite	< $500,000	$2.5mil.	unknown	$30-45mil.	unknown
Vertical markets publicly targeted	Consumer broadband, cellular backhaul	Backhaul, government, mobility, broadband	Government mobility, carrier-grade requirements	Backhaul, Energy, Maritime, Trunking Enterprise.	Broadband, backhaul

It is important to note these were estimates from 2 years ago at the initial phase, it was clear that the capacity and coverage of each constellation is highly dependent on assumptions of satellite fleet size, satellite efficiency, and the number of ground stations demonstrating that Starlink, in particular, would require significant resources for its ground infrastructure with hundreds of ground stations and thousands of gateway antennas.

In all cases, most of the technological capacity of new LEO constellations systems are focused in orbits with an inclination between 40° and 55°, which coincides with the most densely populated areas on Earth. The objective of the systems is to achieve maximum coverage with maximum minimum elevation angle, as a lower-than-necessary angle only worsens the communication link. The reduction in minimum elevation angle allows offering better coverage, increasing satellite utilization and increasing the total system throughput. The dual gateway communication system increases the maximum effective capacity of their satellites and throughputs of the constellations systems.Finally, all architectures benefit from the usage of ISL, achieving great improvements when using 20 Gbps or 30Gbpsconnections.

The vertical integration in both Amazon’s and Starlink’s production and launch will give them deployment advantages and cost efficiencies. Disclosures by SpaceX suggest each satellite’s capital expenditure cost is below $500,000. It is worth noting that each Starlink satellite can transmit roughly 20 Gbps of capacity per satellite, while an HTS GEO has a capital expenditure range between $200 million for 10 Gbps on the low end, to $700 million for 1,000Gbps on the high end, including launch costs [14]. This makes LEO significantly cheaper on a per Gbps basis, but each geographic service area requires many LEOs in orbit versus only one GEO. One should note that LEO satellites are designed for shorter life spans compared to GEO satellites.

V. OPPORTUNITIES AND CHALLENGES TO LEVERAGING LEO SATELLITES

With the emergence of a new generation of LEO, satellites close to the Earth's surface, many opportunities and challenges have emerged, which we will review in the following points.

5.1. Challenges

Space is largely unregulated and satellites do not obey national borders. There are many challenges and difficulties facing the spread of services provided bynew LEO satellites constellations, the most prominent of them could be reviewed in the following set of points.

5.1.1. Global networks require various regulatory approvals across countries

In the space segment, US-based entities such as Starlink and Project Kuiper require regulatory approval from the FCC as well the ITU. The ITU at WRC 2019put into place new rules for non-geostationary orbit (NGSO) constellations to retain spectrum rights. As the ITU has noted: "Under the newly adopted regulatory approach these systems will be required to deploy 10% of their constellations within 2 years from the end of the current period for bringing into use, 50% within 5 years, and complete the deployment within 7 years[18]. In the ground segment, Earth stations or gateways will require technical and business licensing, and service provision to customers will require regulatory approval in every country of operation. How expeditious this process will be depending on the ease of doing business between countries, and the resistance that LEO companies may encounter as they try to enter markets dominated by incumbent operators.

Moreover, differences in licensing burdens between countries will affect LEO companies' ability to go to market with a uniform approach. The rules and requirements for internet service providers can be very different from those applying to supply backhaul to local internet service providers, potentially causing a delayed market entry or even a decision to not cover certain countries.

5.1.2. High Initial Investments

The high initial investments, however, are consider one of the economic challenges to be overcome if the plans for new LEO constellations are to be implemented. Urban centres, for example, are attractive markets with manyaffordable customers-but there is also already a lot of severe competition in these markets. Moreover, substantial additional investments would be required to be able to provide reliable Internet connections by satellite for large numbers of people concentrated in relatively small areas. Another challenge is the low purchasing power of end users in developing countries. Billions of people there still have no access to the Internet. One major reason for this is that it has so far not seemed profitable to telecommunications companies to provide access. If the operators of the mega constellations want to offer their services especially in developing countries, they should be faced low purchasing power of potential customers.

5.1.3. Interference in space

Interference issues will also have to be addressed if NGSOs interfere with the radio frequency propagation of GEOs. ITU rules are in place to limit power management of radio signals to prevent interference between transmission to and from satellites, as well as other adjustments such as changing frequency bands and reporting beams to avoid interference with GEO beams. The burden lies on NGSOs to ensure they are not interfering; otherwise, they will have to shut down problematic assets[19].

Moreover, interference with astronomical observation has been mentioned as a concern with regard to LEO satellites. For example, after initial launches of Starlink satellites in June 2019, the altitude and design of the first satellites resulted in the satellite being visible from Earth with the naked eye. As a result, Starlink adjusted the design in subsequent launches. These are known as "DarkSats" with a darkening coating to make the satellites less visible to stargazers and ground-based observatories. However, issues remain for wide-field sky surveys, particularly at twilight or sunset (with reflection from the sun). For example, 30%–40% of exposures made at some ground observatories around twilight and dawn could be impacted[20]. Further design and operational adjustments are in progress.

5.1.4. Space Debris and Debris Cost

Other concerns have been raised regarding the increase in man-made space objects (space debris), particularly in LEO, which could potentially result in cascading collisions. The large number of satellites employed by satellite providers create long-term danger of space debris resulting from placing thousands of satellites in orbit. LEO has the highest collision probability of all orbital regions, at least three orders of magnitude greater than in any other region. This is due to the higher density of debris and higher orbital speeds. Satellites have an orbital speed of about 3 km/s in GEO and 7-8 km/s in LEO resulting in collisions with significantly greater impact velocities in LEO.

Above 650 km, the collision probability among space debris is greater than the one involving operational spacecraft. Collision with larger debris will result in the loss of spacecraft capabilities, and in the worst case, the loss of the entire spacecraft.

For satellites in GEO, the OECD reveals that such a damage could amount to an estimated 5-10% of the total mission costs, which could be hundreds of millions of dollars. In LEO, the relative costs per mission could be even higher than 5-10%.The risk of collisions between objects in space is very real, and major collisions have

already occurred. Even one collision can produce a dangerous debris field that can disrupt a range of critical capabilities upon which people depend on it, such as global communications and navigation, and endanger the astronauts stationed in the International Space Station (ISS). In addition, the financial consequences could be tremendous.
European Space Agency estimates the total number of space objects in Earth orbit around 29,000 for sizes larger than 10 cm, 670,000 for sizes larger than 1 cm and more than 170 million for sizes larger than 1 mm.
Any of these objects can cause damage to an operational spacecraft. For example, a collision with a 10-cm object would entail a catastrophic fragmentation of a typical satellite, a 1-cm object would most likely disable a spacecraft and penetrate the ISS shields, and a 1-mm object could destroy sub-systems on board a spacecraft [21].

5.1.5. Satellite,Ground-Segment and User Equipment Cost

Large LEO-constellation providers release demand by making their prices competitive with terrestrial solutions. This can be achieved by reducing costs, from manufacturing to launch of satellite to user equipment. Companies planning for large LEO satellite internet constellations still need to reduce a range of costs significantly to ensure long-term viability. Lowering launch costs is one part of the equation, but it will be equally or more critical to reduce the cost of manufacturing spacecraft, ground equipment, and user equipment. If suppliers and constellation providers can achieve these reductions, they could release enough demand for large LEO constellations. Of course, there are other obstacles, but cost is the greatest challenge to profitability and long-term viability.

Satellite Manufacturing

Satellites have long life-span requirements and this explains why a typical large communications satellite costs from $50,000 to $60,000/kg [22]. If costs remain at this level, large LEO constellations would be completely unaffordable. Although some recent GEO communications satellites reportedly are less expensive. If large LEO constellations are to be financially viable, their manufacturing costs must fall by more than an order of magnitude from those of traditional satellites. That would probably be at least 75% lower than the costs any company has currently claimed it can achieve. To cut costs in this way, manufacturers must strength every possible tool, from economies of scale to automation to reduced component costs across the value chain.

The reduction in satellite component cost could open the door to specialty providers in a number of areas, including solar arrays, power and thermal management systems, satellite guidance, navigation and control, on-board processing and antennas. Suppliers that can reduce component costs could be rewarded with contracts for thousands of spacecraft.

Launch Services

Many experts believe that launch costs should be the main target for cost reductions in large LEO constellations, and owners will certainly want to cut them. Launch providers will have to pull every cost reduction lever available. In addition to reducing the cost of materials and manufacturing, they should lower their operating costs—for instance, by maximizing savings from reusability of the launcher. A single large LEO constellation will requireanywhere from few to tens launches a year and this depending on both the size of the constellation androcket type.
For constellation operators these launch costs willbe significant. To ensure a viable business, launchproviders will probably need to reduce the cost toorbit below $2,000/kg.

Ground Equipment

Large LEO constellations will require many ground stations and thousands of gateways to maximize throughput, even with high-capacity ISLs. By one estimate, the 4,400-satellite version of Starlink will require 123 ground-station locations and about 3,500 gateway antennas to achieve maximum throughput. The gateway antennas must be larger and will require significantly more power than user terminals do.Current gateways for GEO satellite communications are quite expensivetypically from $1 million to $2 million each [23]. They are not directly comparable to LEO gateways, which have lower power requirements, but the numbers do suggest that gateway costs must be much lower than those of current approaches to make ground-segment costs manageable. Modular antenna designs could help, since they would enable equally critical cost reductions in user-equipment antennas, but owners of large LEO constellations will also look for other efficiencies.

User Equipment

LEO user terminal pricing will be an area of intense competition on price and innovation. Very small aperture terminals (VSATs) for HTS GEO service range around $1,000 each. The current $499 price for the Starlink terminal is a significant price reduction. However, it is not clear if this price level will be sustained during commercial service and even if so, the up-front cost may derive some subscribers out of the market, unless some form of amortized financing is offered.

The level of subsidy that SpaceX may be absorbing per unit is not known, but industry reports suggest that phased array flat panel antennas cost above $1,000 per unit. OneWeb's most affordable user terminal offering is priced at $1,200 per unit before freight, taxes, and other costs. However, Starlink should be able to achieve economies of scale with millions of terminals eventually required for its global customer base.

To be most effective, user equipment for a large LEO internet network must incorporate advanced electronically scanned apertures (ESAs). These devices currently cost several thousand dollars, though manufacturing costs may be substantially lower; some analysts suggest that they are in the range of $300 to $500[22]. At current levels, ESA prices would be too high for residential customerswho now pay about $100 to $200 to purchase customer-premise equipment (CPE) or pay monthly rental fees of $10 to $20.Even if constellation providers made their satellite access and bandwidth fees comparable to those of terrestrial solutions, the high cost of CPE would severely limit their success in the consumer market.

To open the consumer market, the cost of ESA antennas must drop by an order of magnitude or more. Companies that do createless expensive ESA concepts will need toprovide high data rates, reliable beam steering,smooth satellite handoff, and other features thatensure a good customer experience.

5.1.6. Security Challenges

One of the biggest challenges faced by these mega constellations is 'Cyber Security'. Satellite Communications has been serving the world for different services for more than half a century.

Traditional GEO Satellite Communication Networks have remained secure so far due to limited integration with the ground networks. These networks rely on not easily available specialized communication equipment, specific frequencies, and some additional technical skills to establish a successful connection. The sophistication of the equipment, technical parameters, skills altogether with costs involved have made commissioning of even a legal link a disturbing task, making it even more difficult for illegal connections or eavesdropping.

Moreover, traditional satellite communications links were only receive-amplify-transmitting kind of connections working only on the physical layer of the OSI, TCP/IP, UDP architectures. Except for MSS services, Customer networks are not usually directly connected to the satellite but through specialized interfaces of satellite communication equipment. Customers network interface with the public ground networks, PSTN/Cloud/Cellular/Fiber, are more vulnerable to intrusion as compared to their satellite communication interface. This uniqueness along with global coverage made satellite communication primary choice of important organizations.

However, the arrival of the new generation of NGSO mega constellations will change the outlook of the satellite communication horizons. With focus on provision of low latency, high throughput, global footprint broadband services, end user will be directly connected to the satellites. With easy to deploy and use terminals customers and their personal network of devices (IoT) will be able to enjoy the prosperitymatching with at least 4G LTE and will assist their purpose to complement the future terrestrial networks like 5G.

Potential Threats

Change in the dynamics of the communication technologies will result in increase of potential possibilities of network, cyber a data security related risk. With end user direct connectivity withthe satellites with lower cost easy to use and deploy terminals, no requirement of additional technical skillset, and satellites having on board processing to accommodate software-basednetworking technologies like SDN, SDR, NFV etc. can result in security breaches for the end-users, organizations, the network and even the satellites. It can be understanding that the wholeecosystem of these mega constellations; customers, network, data traffic, communication interfaces, satellites, as all the layers of the OSI, TCP/IP or UDP models will be exposed, can atleast expect similar threat level of any given terrestrial communication network. It can do the comparative and predictive analysis of the terrestrial network related security issues to map on the upcoming networks of the mega constellations.

In this era where internet is the focal backend technology being used by the latest technological deployments and upcoming solutions in the form of IoT where the modern devices are connected with each other and communicate through the pool of wireless communications, with the help of embedded sensors which makes them smart enough to collect and analyze data and transmit over the internet. This data needs to be protected and secured.

However, the nature of wireless media being shared and easily vulnerable to interceptions, makes it more exposed towards security threats. Let us have a look at the common security threats and the areas where the wireless communications are making its application a challenge to be implemented on most of the crucial industries. Key areas which can be under threat are: (i) critical information which is shared over the network; (ii) Nodes attached to the network; that can be servers or clients which have private information stored on them;

and(iii)most importantly the network itself.The elimination of threats to the information transmitted over the network is the major challenge in terrestrial communications systems. A few types of threats, which can cause major damage to the vital areas described above, are discussed briefly below:

Spoofing and Manipulation of Data

Spoofing is the action of camouflaging a message that can be in form of an email, text message, web links or a phone call, from a malicious sender and manipulated as being from an identified and reliable source.Spoofing can be done to an extent of masking the IP addresses to an allocated IP pool from the private network.

Manipulation of data can cause to change the original information into something, which is not the actual and authentic fact. Data alteration and access to the key resources is the most common risk when it comes to secure transmission and handling of critical information.

Most Authentication and Confidentiality protocols are implemented to mitigate the risk of security breaches in terrestrial communications but with the advancement in technology and shared network infrastructural approach in form of cloud networking, the risk and dangers are becoming very worse and a new challenge encountered by the industry.

Interception and Replay Attack

Interception is the major challenge in shared network communications Now days. Here the attacker intrudes the ongoing transmission through wiretapping or sniffing. This can cause the attacker to get access to authorized information and even credentials for the accounts transmitting the information. A replay attack is commonly known where the transmission packets are replayed with a delay to access certain information from the network.

5.1.7. Management of large constellations

The operator of a large LEO constellation must monitor and manage the status and functions of hundreds or thousands of satellites. Recent advances in analytics and technologies, integrated with improved computing power and artificial intelligence algorithms, can assist with these functions while reducing response times and operating costs. Likewise, ISL advances that increase throughput also reduce backhaul costs, reduce number of ground stations and its cost and improve satellite control and network latency. Combining these elements would promote the autonomous and semiautonomous control and management of spacecraft, and reducing staffing requirements.

5.2. Opportunities

The satellites industry is ready to become an engine of economic growth and innovation in the near future. Near-term future space industry growth will be driven largely by the massive demand for bandwidth, massive data that connected world requires, and rapidly decreasing costs.

Demand for bandwidth is annually growing exponentially, driven by an increasing number of global internet users and terrible increase in usage rates per individual. In addition to continuously growing demand for current internet use, future demand will also be driven by emerging technologies, including autonomous vehicles, industry revolution 4.0, the IOTs, and high bandwidth enhanced video and virtual reality technologies. While satellite-based internet is currently only a tiny percent of the satellite industry, satellite internet will surely be necessary to meet growing demand.

Over the next thirty years, provision of internet access via satellite is estimated to account for 50% to 70% of the space market and continue to be the primary driver of industry growth.

On the supply side, launch costs have fallen substantially as highly innovative, private launch companies have entered the market. Emerging technologies like reusable rockets have decreased costs from hundreds of millions of dollars per launch to tens of millions, and the declining cost trend is estimated to continue. New technologies are also pushing down the cost of satellites. Smaller satellites are less expensive to produce and to launch, and as demand grows for ever-greater numbers to be deployed, costs will decrease even further with the realization of economies of scale in mass production manufacturing.

The space industry will be a major contributor to future economic growth, and over time, a significant portion of the global economy will depend on some way upon space assets.

The challenge for advancing the future space economy is to create a robust policy framework domestically and globally that accommodates the reality of the private sector leading the way.

There are many advantages and promising opportunities in this field, the most important of which are presented in the following set of points.

(i). LEO satellites orbit at height of less than 2,000 km above the Earth's surface and for this reason; they circle the planet several times a day. As a result, each constellation requires hundreds or thousands of satellites, covering the entire globe, to provide continuous connectivity for any given area. By contrast, traditional satellites are mainly positioned in GEOs and provide concentrated connectivity service that covers a fixed

geographic area. LEO constellations are estimated to be able to increase satellite internet capacity more than 10 times in just a few years and will distribute their service more evenly across the world.
(ii). The low altitude of LEO satellites reduces the time it takes for data to travel between two points, known as latency, from approximately 480ms. inherent in GEO service to less than 26 ms.This means they can be used for real time and interactive applications that rely on very low latency, such as high-definition video conferencing or action-based gaming, processing of sensitive financial transactions, or remote operation of machines.Taking advantage of the improved quality of service (QoS)for data communications over LEO, Starlink has collaborated with Microsoft to connect its infrastructure directly to Microsoft's cloud and data center infrastructure. Amazon’s Project Kuiper is expected to offer cloud services as well. This would further enhance internet quality, particularly for cloud-hosted applications and services, enabling remote communities to access services such as online banking, e-learning, government services and to offer products and services online.
(iii). Due to the spectrum scarcity, satellite operators are moving from the conventional C-band and Ku-band to Ka-band, which offers much greater signal bandwidth than C and Ku-bands altogether. The large LEO concepts are mainly planning to use Ka-band and some propose V-band as well. Ka-band enables narrower beams and therefore higher satellite antenna gain, improved link budget and therefore higher throughputs for a given antenna dimension – this is important because antenna size can be constrained (by the size of the launch vehicle placing the satellite into orbit). For a given required end user antenna gain, Ka-band results in a smaller user terminal antenna or for a given end user antenna size, a larger gain and therefore better radio-frequency link budget. A better link budget allows the use of higher order modulation and coding schemes, resulting in a higher spectral efficiency, increased throughput and thus more cost-effective Mbit/s.
A better link budget offers the possibility to operate with a higher level of interference in system design. Ka-band enables more reuse of frequency and therefore more capacity, due to the typically smaller beams deployed. This also allows very tailored, optimized coverage to be delivered. Ka-band is more sensitive to severe atmospheric perturbations. However, these only occur during very limited time periods, and can be mitigated using Fade Mitigation Techniques (FMT).
To enhance the spectral efficiencyfor new broadband applications, satellite systems have moved from single-beam to multi-beam satellites with smaller beam spots. In essence, the multi-beam satellite payloads are designed to allocate a fixed bandwidth segment to each beam according to a regular frequency reuse scheme and constant equal power. Therefore,the maximum system capacity of current multi-beam satellites is limited by the fractional frequency reuse factor.
(iv). the expansion of global satellite capacity driven by LEO constellations is expected to help reduce costs where service is available. The ease of market entry for satellite service providers, and a drop in equipment costs as production is scaled up and competition should reduce broadband prices where LEO-based internet service is permitted.
(v). some countries around the world are particularly vulnerable to communications disruptions caused by natural disasters that damage terrestrial infrastructure, such as earthquakes, volcanic eruptions and typhoons. Satellite connectivity is already key to re-establishing communications and supporting disaster response.Landlocked developing countries and small island developing states may have limited direct international connectivity via terrestrial or undersea fiber optic cable. For these countries, the additional coverage and capacity introduced by LEOs would expand options for redundancy or backup connections and can improve network infrastructure flexibility for regions vulnerable to natural disasters.
(vi). Large LEO satellite constellations for broadband data communications have been tried before, particularly in the 1990s, and several high-profile initiatives failed. However,the growing demand for high-speed data communications, improvements in satellite technology and modern electronics have allowed far greater capabilities in a smaller satellite. This made a dramatic reduction in launch costs led by rocket re-use technologyeliminatedthe old picture.As the cost of launching satellites continues to come down, this can benefit Earth observation for measuring economic activity, providing data for predictive analytics in disaster management and support development countries.

VI. RECOMMENDATIONS

As the new LEO constellations begin offering commercial service in 2022, measures can be taken to ensure that low- and middle-income countries are well positioned to take advantage of potential cost savings and increased coverage. These include:

- **Licensing regimes and Regulatory developments:** Licensing regimes of internet service providers (ISPs) differs widely between countries and good practice licensing policy includes simple registration with administrative bodies, rather than complex and exhausting procedures that require legislative approvals. As well as, ensure flexible and streamlined licenses procedures for domestic ISPand satellite broadband providers.

If companies wish to operate in multiple markets, they must address landing rights—the ability to operate in a specific country. The potential for electromagnetic interference (and the resulting liability) is also an area where rules are not yet clear. Once regulators and providers have more clarity, there could be more operating restrictions or additional costs.

- **No requirement for domestic ground stations**: Allow for satellite provision of international internet capacity without a requirement for domestic ground stations to route traffic to and from satellite transponders.So-called data localization regulations, that require internet traffic within a country to pass through nationally mandated infrastructure points of presence, create barriers to deployment and increase cost and complexity.National requirements, which impose that satellite transponder data traffic must transit through a domestic ground station create burdensome infrastructure deployment requirements and this represent more cost for markets with small potential revenue opportunities.If future versions of LEO satellites are able to deploy OISLs, optical laser beams will directly transmit traffic between satellites in space. This will create further efficiencies in space network segments and could allow satellite constellations to reduce the number of ground stations needed.Regulations that require a domestic ground station would deny these efficiencies.In cases where the requirements to transmit data locally are driven by sovereignty and cybersecurity justifications, it may be possible to put in place policies that preserve sovereignty and cybersecurity principles without requiring data localization.
- **Regional integration**: Integration between countries and their neighbors could accelerate deployment timelines by easing the more difficult regulatory issues and shaping convergence of licensing issues.Engage in regional discussion and cooperation both in terms of regulatory convergence to improve the business for LEO satellite connectivity. Similarly, gathering of demand between markets could present more attractive deployment timeline prioritization and may also generate negotiating power for favorable terms of service.
- **Reduce cost of satellite user terminals**: Hardware, software, and licensing costs for user terminals contribute to the total cost of satellite internet service, and user terminals are already priced significantly above other broadband internet service hardware. Reducing the cost of producing satellite stations to the user requires mass manufacturing, economies of scale and working to reduce trade barriers between countries.To increase the affordability of user terminals for individual subscriptions, governments could work with consumer finance institutions to develop programs that amortize the cost of user terminals over a service period, reducing the up-front cost barrier to access LEO service.
- **Debris management and better constellation management**: Companies should adhere to plans to remove satellites at the end of their life spans; the amount of space debris could increase because of early failures and loss of control. Companies should investigate solutions for removing satellites that fail unexpectedly.LEO satellites should be designed to be 100% demisable and burn up completely once they are put into deorbit at the end of their life span. Furthermore, LEO constellations should build an Autonomous Collision Avoidance mechanism into each satellite to move the satellites out of collision paths[24].Companies that launch hundreds or thousands of satellites need exceptional control and monitoring systems. Even if cost were not a factor, they would still need to develop highly automated solutions to manage this large number of systems effectively.
- **Security Protocols:** LEO satellites constellations and their users will be exposed to many threats and will require continuously evolving mitigation techniques to combat the threats. The security concerns do not end up here, but the physical security is another challenge. The Space Warfare needs to be addressed as well, these satellites, although commercial entities should be considered as critical strategic assets.
- **Competition between LEO and GEO:**Existing satellitecommunications providers-GEO- with large capital costs already invested, could try to lower prices. They will certainly work to lock in business customers, such as Airlines and Maritimes, before the large LEOs can deploy. On the consumer side, cable and telecom internet service providers will no doubt not only offer lower prices and other incentives but also make an all-out marketing push to keep customers.The large LEO providers must therefore demonstrate that they have the ability to compete on service and reliability as well as price.

VII. CONCLUSION

The new LEO satellites constellations would add tens ofbillions of dollars of economic activity to satellitemanufacturing, operations, and launch and consumerequipment. Simultaneously, more consumers willhave access to internet connectivity. Together,these benefits should encourage providers ofsatellite components to struggle.

LEO networks add significant additional capacity with minimal latency as their orbits are below 1500km. The combination of constellations has the potential to extend coverage everywhere, while concentrating capacity where it has needed the most. In particular, lower latency LEO satellites will be more attractive for real-time interactive applications.The new LEO satellites constellations represent a major paradigm shift for broadband applications, particularly for underserved geographies areas and countries with limited international internet bandwidth, such as landlocked developing countries, remote areas and small island developing states.

Mostnew LEO satellites constellations could offer a total capacity around tens of Tbps. With this volume of data-rates, they would not be able to compete with the current Fibre optics cables, which move around thousands of Tbps, but could complement the coverage of the land infrastructure in regions where a cable connection is inappropriate, or unfeasible (e.g., rural areas, isolated coastal and remote areas, and aerial and maritime mobile users).

The path forward faces many obstacles besides costs, all of which need to be addressed in order to achieve the wide spread of broadband Internet as well as the desired goals and prosperity of all countries of the world. The COVID-19 pandemic dramatically increased the importance of high-speedinternet communications infrastructure via the next years.

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