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BHUTAN INFOCOMM AND MEDIA AUTHORITY

ROYAL GOVERNMENT OF BHUTAN

Broadband internet services from Low Earth Orbit (LEO) satellite

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1. Introduction

The Internet broadband has become a key ICT enabler in this 21st century for the global economic development and social growth. The internet broadband technology has also created an ecosystem for global digital connectivity, fostering technological and service innovation, changing global business models and providing societal and consumer welfare.

Broadband is frequently used to indicate an internet connection at 256 kbit/s in one or both directions. The Organization of Economic Cooperation and Development (OECD) has defined broadband as 256 kbit/s in at least one direction and this bit rate is the most common baseline that is marketed as "broadband". For the purposes of this document, the entry level broadband refers to a minimum download speed of 256 kilobits per second (kbps).

In the late 20th century, the introduction of internet technology or packet switching technology has paved the way for the development of broadband technology. With the advancement of internet technology, the conventional circuit switched voice signal now can be converted to data packets whereby converged voice, video and data signals can be transported over the same network with the use of IP technology. Satellite and terrestrial networks have been major transmission tools for worldwide broadband connectivity and for the growth of broadband technology. The satellite network has the advantage of mass geographical coverage over other networks, therefore, the satellite network has huge potential for global broadband connectivity and its growth.

2. Overview of satellite systems

2.1 Overview of Satellite Orbit System

The option to have a type of satellite system and satellite orbit for various communication services depends on the requirement of geographical coverage, type of services, availability of orbit resource, cost of satellite network and designed life span of satellite systems.

A geostationary satellite (GEO) is a geosynchronous satellite where it circles Earth above the equator from west to east following Earth’s rotation – taking 23 hours 56 minutes and 4 seconds – by traveling at exactly the same rate as Earth[1]. A geosynchronous satellite remains approximately fixed relative to the Earth and a geostationary satellite at a height of about 36 000 km (actually 35 786 km) above the Earth. Tracking of the satellite by small ground stations is therefore not necessary. Also, only a few satellites can provide global coverage making this option most

[1] https://www.esa.int/Enabling_Support/Space_Transportation/Types_of_orbits

economical and least complicated in most cases in terms of high speed switching and tracking. The latency of geostationary satellites is poor with an average latency of 250 ms.

A medium earth orbit satellite (MEO) system has an altitude ranging from 2000-35786km above the Earth and requires a larger number of spacecraft. In practice, the MEO satellite orbit has an altitude range of 5000-20,000 Km above the earth surface and typically MEO satellite requires a constellation of about 10 to 15 satellites to maintain constant coverage of the earth[2]. Reduced latency and improved look angles to ground stations at higher altitudes is an advantage over GEOs. Typically, MEOs have a shorter in-orbit lifetime than GEOs and require more expensive and complex ground station antennas for tracking the satellites.

A low Earth orbit (LEO) is, as the name suggests, an orbit that is relatively close to Earth's surface. It is normally at an altitude of less than 2000 km but could be as low as 160 km above Earth – which is low compared to other orbits, but still very far above Earth's surface[2]. With lowest latency, better frequency reuse, lower free space path loss and with better look angle even at higher altitudes, LEOs are easier to operate using low gain ground antennas. Nevertheless, LEO constellations need larger numbers of satellites to provide constant Earth coverage. They are more difficult to track and operate, have shorter in-orbit lifetimes due to orbit degradation and commonly result in higher expenditures to build, deploy and operate[2].

Table 1: Features of LEO, MEO and GEO satellite.

Orbit	Altitude	Orbital Period	Latency (round trip)	No. of Satellite to Span globe	Cost per satellite ($)	Effective lifetime of Satellite
GEO	35 786 km	~ 24 hours	~477 ms	3	Approximately 100-400 million	15-20 years
MEO	2000-35786 Km	127 Min-24 hours	~27ms-~477ms	5-30 (depending upon altitude)	Approximately 80-100 million	10-15 years
LEO	160- 2000 Km	88-127 min	~2-~27ms	hundreds or thousands (depending on altitude)	Approximately 0.5-45 million	5- 10 years

- GEO = Geostationary Orbit, Km= Kilometer, MEO= Medium Earth Orbit, LEO = Low Earth Orbit, Min= Minute, ms=millisecond.

[2]https://www.adb.org/sites/default/files/publication/696521/sdwp-076-digital-connectivity-low-earth-orbit-satellite.pdf

2.2 Satellite system for broadband services

The use of Satellite communication systems for mobile telephony and data services has increased in recent years around the world. The Spectrum resources play a pivotal role in development and deployment of satellite systems for such services. The scarcity of spectrum resources for satellite services has somehow hindered the development and deployment of satellite communication services. However, with the advancement in communication technology and identification of new spectrum allocation to satellite services, a great stride has been made towards development of satellite systems for broadband services.

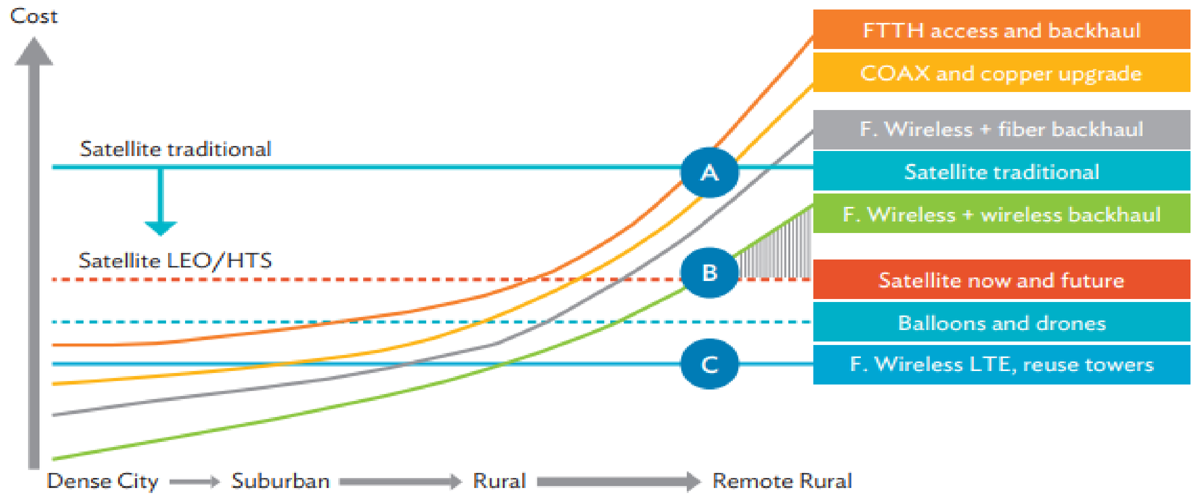
Satellite broadband services are offered in following technology categories:

- C band (4/6 GHz) FSS (Fixed Satellite Services)
- Ku band (11/14 GHz) FSS (Fixed Satellite Services)
- Ka band (20/30 GHz) bent pipe (with no on board processing in satellite)
- Ka band(20/30 GHz) with satellite on board processing
- L band (1.5/1.6 GHz) MSS (Mobile Satellite Services)

3. Conventional satellite communication for broadband services

Satellite connectivity is predominantly used for backhaul connectivity for remote cellular base 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. However, in a few cases, satellite connectivity is relied upon for international internet gateway traffic or as part of a country's core network. For landlocked developing countries that are dependent on terrestrial fiber connectivity, in some cases, satellite connectivity serves as a substitute to complex bilateral and multilateral negotiations to extend costly fiber connectivity to their country.

Although the conventional satellite communication has the advantage of global coverage, limited capacity and high cost (especially the operation cost) has hindered the development and deployment of satellite communication for broadband services.



COAX = coaxial cable, FTTH = fiber to the home, HTS = high-throughput satellite, LEO = lower Earth orbit, LTE = long term evolution.

Figure 1: communication technologies compared by costs and population density

Source: Adapted from World Bank. 2019. Innovative Business Models for Expanding Fiber-Optic Networks and Closing the Access Gaps.

4. Innovation and development in LEO satellite communication

The low earth orbit (LEO) satellites have been used for satellite placement since the start of earth exploration. Before the 1990s, Low earth orbits were mostly used for earth observation, spy, remote sensing and other military and scientific missions but now LEO satellites have been focusing on commercial deployments especially for global broadband internet connectivity. Most commercial LEO satellites use Ku band (11/14 GHz) and Ka band (20/30 GHz) for satellite communications.

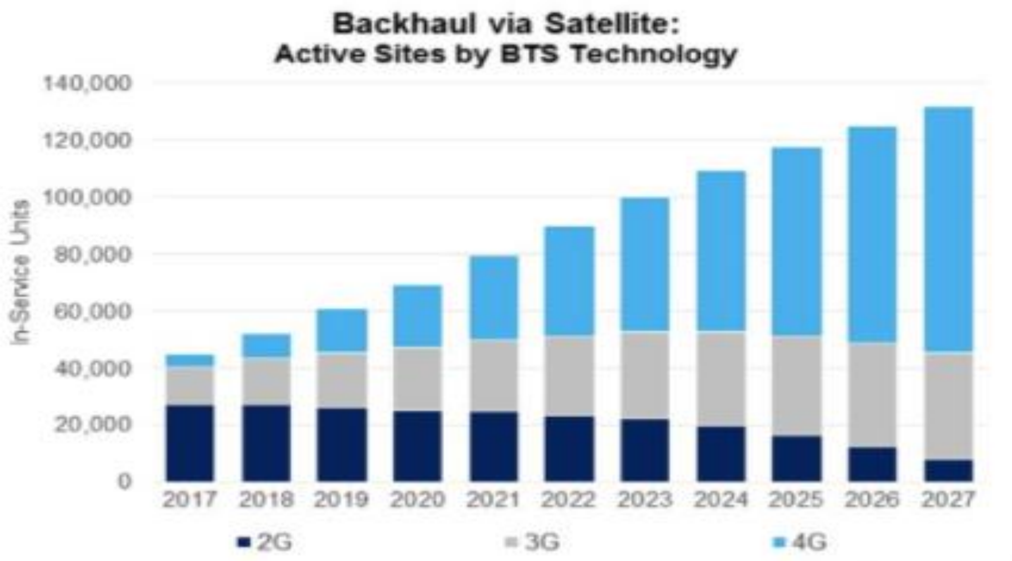
4.1 Capacity enhancement of satellite broadband services

Low Earth orbit constellations provide fundamentally different value propositions compared to geostationary orbit. GEO satellites are normally located at an altitude of 35,786 km and with such positioning of satellite, each satellite has a very wide coverage area where GEO satellites can have global coverage with 3 satellites. However, because of their distance from the Earth's surface, their minimum latency thresholds are high (roughly at least 0.477 seconds for round trip latency). Therefore, both bandwidth capacity and latency of conventional GEO satellites have been constrained due to its position and technology.

The latest generation of GEO satellites, known as high-throughput satellites (HTSs), have significantly increased capacity (at least 10 times the throughput) than previous generations of GEO satellites, while the high latency (which is a function of distance and the speed of light) remains the same. One of the high-throughput satellites (HTSs) in the Asia pacific region is Kacific. Kacific is a next-generation broadband satellite operator and they are committed to providing universal, fast, high-quality broadband access at an affordable cost using robust technologies and an agile business model. Kacific1 is a next-generation geostationary satellite operating in the Ka-band frequency spectrum. The satellite, which launched in December 2019, streams low-cost, high-speed, reliable, and stable broadband via 56 powerful spot beams. Wide reaching coverage extends over 25 countries in Asia Pacific (including Bhutan) with populations spread across their many islands, mountainous and rural regions. Kacific1 uses Ka-band technology and spectrum. Kacific1 satellites has 56 high throughput spot beam which is capable of delivering upto 60 Gbps of broadband capacity and it has latency of 550 to 600 ms.[3]

On the other hand, 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 range of 160–2,000 km). Their closer distance to the Earth's surface enables them to provide high-speed with low-latency internet services. The increase in capacity of satellite services for backhaul services is shown in figure 2.

[3] https://kacific.com/technology#kacific1-satellite



(source:NSR)

Figure 2: Increase in global satellite backhaul capacity demand.

4.2 Cost of satellite broadband service

With the widespread deployment of LEO satellites and its technology, 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 uniform pricing model anywhere in the world. LEO constellation satellites have a combined advantage of high-capacity and shorter-term (and, therefore, more competitive) contracts which could rapidly decrease satellite bandwidth costs globally. There will also be significant opportunity for regional pricing due to the fact that the up-front investment in the constellation is the primary cost, and individual satellites are only able to serve the area under their current location.

One of the recent LEO constellations is SpaceX's Starlink service, which is the most advanced LEO constellation in terms of deployment of the number of satellites. Currently, SpaceX charges $499 for the Starlink hardware and $99 a month for broadband service, plus shipping and handling and taxes.[4]

The price of star link LEO constellation satellite broadband is much cheaper compared to the pricing of GEO and HTS GEO services shown in figure 3.

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[4] https://crsreports.congress.gov/product/pdf/R/R46896

Satellite Provider	Country of Service Offering	Local Service Provider	Download Speed	Upload Speed	Data Cap	Price per month ($)	Price per Mbps per month (download; $)
SES	Philippines	iGSat Satellite Broadband/ Delco Telecoms	Up to 5 Mbps	Up to 1 Mbps	40 GB	276.65	55.33
Thaicom/ IPStar	Philippines	We are IT Phils. Inc.	Up to 4 Mbps	Up to 1 Mbps	Unlimited	79.27	19.82
Hughes (JUPITER)	Indonesia	Telkomsat/ Mangoesky	Up to 6 Mbps	n/a	10 GB	52.02	8.67
Hughes	United States	HughesNet	Up to 25 Mbps	Up to 3 Mbps	50 GB	149.99	6.00
ViaSat	United States	Viasat/Exede	Up to 25 Mbps	Up to 3 Mbps	60 GB soft cap	100	4.00
MEASAT	Malaysia	CONNECTme	Up to 25 Mbps	Up to 1 Mbps	60 GB	47.83	1.91
Sky Muster	Australia	ipstar/nbn	Up to 25 Mbps	Up to 5 Mbps	50 GB peak + 50 GB offpeak	47.47	1.90
Eutelsat	France	Orange/Nordnet	Up to 100 Mbps	Up to 5 Mbps	150 GB prioritized/soft cap	79.85	0.80

GB = gigabyte, Kbps = kilobits per second, Mbps = megabits per second.

Sources: Author's analysis and survey; service packages, and foreign exchange rate as of 3 April 2021.

Figure 3: Sample Retail Satellite Service Offerings of GEO satellite in Asia and pacific region.

5. Status of deployment and development of LEO satellite for broadband services

Four main companies are taking the spotlight in terms of next-generation LEO constellation deployment for broadband communications. These four are Starlink by SpaceX, OneWeb, Lightspeed by Telesat, and Project Kuiper by Amazon. These companies are at various stages in development, testing, and deployment:

- Starlink is by far the most advanced in its satellite deployments. As of March 8, 2022, SpaceX has delivered 2,234 Starlink satellites to orbit on Falcon 9 rockets.[5] Starlink internet works by sending information through the vacuum of space, where it travels much faster than in fiber-optic cable and can reach far more people and places. Because Starlink satellites are in a low orbit, the round-trip data time between the user and the satellite – also known as latency – is much lower than with satellites in geostationary orbit. This enables Starlink to deliver services like online gaming that are usually not possible on other

[5]https://spaceflightnow.com/2022/03/08/spacex-to-continue-starlink-deployment-with-another-falcon-9-launch/

satellite broadband systems.[6] SpaceX has launched more than 1,730 Starlink satellites, with plans to launch 42,000. [7]

- Amazon is yet to launch any satellites as part of its planned 3,236 system-strong Project Kuiper constellation. However, as a condition of its FCC authorization, Amazon is required to deploy at least 1,600 satellites by 2026.[8]

- The OneWeb confirms successful launch and contact with all 36 satellites, bringing the total in-orbit constellation to 394 satellites (as of December27, 2021). [9] OneWeb plans to launch and operate 1,000 satellites by August 2026, plus an additional 926 by August 2029.[10]
- Telesat's constellation is composed of 298 LEO satellites and may scale to 512 LEO satellites.[11]

Differences in Per-Satellite average and Maximum Data rates

Per Satellite	OneWeb	Starlink	Telesat
Average data rate	8.80 Gbps	20.12 Gbps	35.65 Gbps
Maximum data rate	9.97 Gbps	21.36 Gbps	38.68 Gbps

Gbps = gigabits per second.

Source: I. del Portillo et al. 2018. A Technical Comparison of Three Low Earth Orbit Satellite Constellation Systems to Provide Global Broadband. MIT presentation delivered at the 69th International Astronautical Congress. Bremen. 1 October.
The difference in deployment, constellation among four LEO constellation giants is shown in figure given below:

[6] https://www.starlink.com/satellites
[7] https://www.space.com/spacex-starlink-satellites.html.

[8] https://www.datacenterdynamics.com/en/news/amazon-to-launch-two-test-kuiper-satellites-next-year/
[9]https://oneweb.net/resources/oneweb-confirms-successful-launch-36-satellites-after-rapid-year-progress
[10]https://www.satellitetoday.com/broadband/2020/08/26/fcc-grants-oneweb-market-access-for-2000-satelliteconstellation/.

[11] https://spacenews.com/telesat-says-ideal-leo-constellation-is-292-satellites-but-could-be-512/.

Information and current status of the largest LEO constellations

Specification or company	**SPACE X**	**One Web**	**TELESAT**	**AMAZON**
System	**Starlink**	**OneWeb**	**Lightspeed**	**Kuiper**
Country of origin	United States of America	United Kingdom	Canada	United States of America
No. of SATs- Initial Phase(IP)	1584-2814 (total 4408)	648	298	576 upto 1600
Planned constellation size	12000-30000	7000	1671	3236
Beginning of service	2020	2021	2023	2026
Connectivity coverage	N. America, N Europe , Pacific	Northern Latitudes above 50 degree	N/A	N/A
Throughput -Full deployment	27 Tbps	25 Tbps	16-24 Tbps	53 Tbps
User Links(Band)	ku	ku	ka	ka
Operational orbit	540-570 km	1200 km	1015 and 1325 km	590, 610 and 630 km
Satellite mass	260 kg	150 kg	750 kg	N/A
Satellite lifespan	6 years	5 years	10 years	7 years
Satellite Manufacturer	SpaceX	Airbus(Arrow platform)	Thales Alenia Space	N/A
Target Markets	Consumer broadband	Enterprise, Mobility, government	mobility, backhaul, government	Consumer, business , government

Source:orbofleet https://spacewatch.global/2021/07/orbofleets-take-on-mega-constellations-and-leo-satellite-market/

Figure 4: difference in deployment, constellation among four LEO constellation giants.

6. Status of Starlink satellite deployment in our region (Asia and Pacific)

Starlink's 2234 satellites launched is by far the most advanced stage of deployment by any lower Earth orbit constellation.While Starlink's current public beta trial is serving customers in northern US and Canada between latitudes of 45º and 52º.

Commercial operations have already begun in Australia and New Zealand, focused on establishing earth stations. Coverage across Asia and the Pacific may not occur until mid- to late-2021 and into 2022.

7. Affordability of Starlink LEO constellations fixed broadband internet

The service pricing offered during the public beta is $99/month for speeds between 50–150 Mbps, latency between 20–40 milliseconds, plus a one-time equipment fee of $499. No data cap has yet been implemented. Based on this data, per Mbps price of Starlink would be at $0.50–$1.50/Mbps.

Our current fixed leased line rate is Nu. 1350/Mbps , which is approximately $17.76 (1USD exchange rate is taken at Nu.76). This means that the star link internet price would be approximately 12 to 36 times cheaper than current leased line price given at a current star link offer rate.

8. Opportunities in leveraging LEO satellites in developing countries

1. Satellite broadband has potential to be an important technology for addressing the growing digital divide.
2. LEO satellites can contribute to the growth of broadband connectivity in developing countries.
3. Starlink and other LEO constellations could serve as an alternative in supporting universal access objectives of national satellites. CAPEX cost of launching satellites by countries can be reduced.
4. Affordabile internet service through Community Wi-Fi deployments using the LEO satellite.

9. Opportunities in leveraging LEO satellites in Bhutan

1. Internet broadband connectivity through LEO satellites can address the issues of growing digital divide in the country;

   We have a dispersed population distribution that is divided by its geographic challenges such as high mountain passes, deep valleys and rugged geographical terrains. Therefore, the information communications technology (ICT) is seen as a powerful tool in assisting the already existing mechanisms to disseminate information and bring about efficiency, transparency and accountability in delivering services. Bhutan owing to its difficult geographical terrain, the internet connectivity through fiber network and terrestrial network has been challenging and few pockets of remote areas in Bhutan still do not have proper internet connectivity. The LEO satellite broadband has potential to provide internet connectivity in most places on earth due to mass coverage of satellite networks. Therefore, the LEO internet broadband connectivity can potentially address the growing digital divide between urban and rural areas due to its mass coverage and affordability by the general public of the country.

2. Affordable internet through Community Wi-Fi deployments using LEO satellites;

   Starlink and other LEO constellations could serve as an alternative in supporting universal access objectives of national satellites. At the current public beta pricing level, Starlink's $99 monthly plan will not be affordable for many developing countries like Bhutan. However, the variable pricing modality of broadband internet through LEO constellations network can help to achieve affordable internet services in developing countries. Similarly, community Wi-Fi models could be deployed in Bhutan, such as

   those being implemented by Hughes/Express Wi-Fi in Indonesia and Latin America where an individual subscription supports time- or data-bound service to potentially hundreds of users consuming small data bundles (in the megabytes) through a publicly accessible Wi-Fi access point.[12]

3. Redundancy for Government network and disaster communication networks;

   Most of the current LEO constellation satellite networks are targeted in providing the backhaul for government network or cellular communications. Therefore, the LEO constellation satellite network can provide a good redundant network for cellular communications, government networks and disaster communication networks.

4. Redundancy to backhaul networks of cellular and Internet services;

   LEO constellation networks can serve as redundancy for cellular communication and Internet communication networks. Our telecom operators and Internet Service providers

[12]https://www.adb.org/sites/default/files/publication/696521/sdwp-076-digital-connectivity-low-earth-orbit-satellite.pdf

(ISPs) can offer reliable voice, data and other value added service if the LEO constellation satellite network is used as redundancy for the cellular and internet networks.

10. Challenges of LEO satellites

1. Interference with astronomical observation has been cited as a concern with regard to LEO satellites.

2. Increase in man-made space objects (space debris), however, many of the LEO constellations in development include satellites designed for a useful life span of less than half of the 15+years of GEO satellites. Starlink's satellites, for example, are designed to be 100% demisable and burn up completely once they are put into deorbit at the end of their life span.

3. Revenue and Taxation of foreign satellite service providers ;
   While we look to harness the potential benefits of foreign LEO satellites, we must also look at the tax and revenue collection for the country. The taxation on foreign LEO satellites will be complex due to technical complexities in operation of LEO satellites. Currently the policy and regulation on the operation of foreign LEO satellites across the world is still not mature.

4. Monitoring of consumer protection, quality of service;
   If the foreign satellite is allowed to operate directly in the country, regulatory aspects like consumer protection, data protection, and enforcement of quality of service and tariff regulation will be challenging since the monitoring of quality of service, consumer protection and data protection will be dependent on foreign satellite service provider.

5. Impact on the domestic market of our telecom and internet service providers ;
   The current market of our local licensed telecom and internet service provider will be impacted if foreign satellite internet providers are directly allowed to operate in the country since they will have undue advantage over domestic internet service providers due to difference in business modality, technology maturity and market size.