



Satellite Internet Explained

How It Works & Why It Matters

Ashwin Prasad

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Satellite megaconstellations mark a new age in space-based internet. They comprise of hundreds or thousands of satellites working together to deliver internet services with a global coverage. This technology has wide-ranging applications across various civilian and military domains, making it a critical infrastructure with significant geopolitical and economic implications.

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Executive Summary

Internet connectivity is critical to communications, national security and economic stability, making internet infrastructure a key pillar of a nation's critical systems.

Satellite internet has emerged as an important part of this information infrastructure. It addresses the fundamental limitations of ground-based networks by providing resilient, global internet coverage that functions regardless of terrain, population density or infrastructure development. This technology represents not just a backup system but a transformative approach to internet provision.

Satellite megaconstellations mark a new age in space-based internet. They involve hundreds or even thousands of satellites orbiting a few hundred kilometres above Earth. Together, they form a network that beams internet services directly from space. This 'internet in the sky' has democratised satellite internet access.

Satellite internet has applications across many domains – military operations, disaster response, healthcare services, agricultural productivity, transportation, and public services. The inherently dual-use nature of satellite

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Author

Ashwin Prasad is a Research Analyst with the High-Tech Geopolitics Programme at the Takshashila Institution. He can be reached at ashwin@takshashila.org.in

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internet technology—serving both civilian and military purposes—creates complex security dynamics.

The potential and risks of satellite internet highlight the need for strategic investments. It is also important to integrate their use in disaster response protocols and leverage their potential to bridge the digital divide. Finally, it is necessary to establish regulation to tackle security concerns and engage in international forums to shape the technology's future.

This document represents the first in a planned series examining satellite internet. It focuses solely on the technological fundamentals of satellite internet systems, explaining their infrastructure, functioning, and applications. Regulatory aspects, policy frameworks, and governance challenges will be addressed comprehensively in future documents in this series.

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I. Abbreviations

GEO	Geostationary Earth Orbit
MEO	Medium Earth Orbit
LEO	Low Earth Orbit
IoT	Internet of Things
GNSS	Global Navigation Satellite Systems
AIS	Automatic Identification System
IoE	Internet of Everything
RV	Recreational Vehicle
GX	Global Xpress
GPS	Global Positioning System
UA	Ukrainian Army
O3b	(Satellite Constellation Name)
USD	United States Dollar

II. Introduction

Internet connectivity in a country is often likened to neuron connectivity in a human body.¹ It enables the transmission of information in real-time across the various discrete systems and actors. It is a fundamental technology that holds enormous integrative abilities across technologies in the civilian and military domains. Internet infrastructure equips this connectivity and consequently becomes central to national strategic information infrastructure.²

Internet connectivity can be provisioned by infrastructure on the ground, from space, or, a combination of the two. Ground-based networks for internet connectivity are the most prevalent. They use land-based infrastructure, such as cables, antennas, and towers. Highly populated urban centres present the easiest opportunity for these ground-based internet infrastructure investments. Despite the high initial capital expense, ground-based networks can cater to a large customer base in a densely populated region and therefore are able to offer internet services at low costs. With increasing digitisation and higher smartphone penetration, ground-based networks have also expanded to non-urban population centres.

Despite the cost advantage, ground-based networks suffer many limitations. Their need for local physical infrastructure makes ground-based networks economically unviable in sparsely populated areas. Also, natural disasters like floods and earthquakes can disrupt ground-based internet when communication is critical and downtime is not an option. Even when networks remain functional, disasters and emergencies are accompanied by a sharp surge in usage, resulting in network congestion and tower overruns.³ Additionally, the demand for ready internet availability on-the-go in remote locations or for operations in temporary sites cannot be fulfilled by ground-based systems.

These gaps can be addressed by space-based internet networks, also popularly known as satellite internet. Satellite internet functions atop a global infrastructure, offering extensive coverage, even in sparsely populated areas. It is resilient to natural calamities, thus able to aid in disaster relief and emergency communication, and can be rapidly deployed to meet sudden surges in demand. Satellite internet can operate virtually anywhere, providing connectivity on-the-go, even to planes flying in the stratosphere and in remote locations like mountainsides and offshore oil rigs.

Satellite internet offers far more than just backup capabilities for ground-based networks. With its inherent global coverage and penetrative capability, satellite internet holds immense potential to reshape the digital economy,

civilian infrastructure and military strategy. However, these benefits come with unique challenges. The following contemporary examples highlight the potential of this technology.

The rapid deployment of satellite internet during Hurricane Harvey underscores its role in disaster recovery when terrestrial infrastructure fails. Hurricane Harvey struck the Texas coast in 2017. The ensuing storm knocked out around 70% of cell towers in the affected regions. More than 2,00,000 homes were left with no internet and telephone services.⁴ With emergency response networks including emergency dispatch centres getting affected, satellite internet became the lifeline. Relief efforts relied on Viasat's satellite internet services for coordination of rescue operations and resource allocation.

The Russia-Ukraine war has been another demonstration of the strategic advantages of satellite internet. SpaceX's Starlink rapidly deployed satellite internet services over Ukraine. The defence forces of Ukraine have relied on these services for coordinating troop movements, medical evacuations, and drone operations.⁵ Ukrainians even fitted Starlink devices on attack drones to bypass Russian jamming systems. There are also reports of the Russian troops getting access to Starlink devices through capture or illicit procurement, enabling them to monitor Ukrainian communications and counter operations.⁶



Figure 1: A Ukrainian soldier installing a Starlink user terminal⁷

Satellite internet plays a key role in boosting operational readiness in geographically isolated conflict zones. The Indian Army uses satellite internet on the Siachen Glacier at an altitude of 19,000 feet, enabling real-time coordination and medical support.⁸ Yet its fundamentally borderless nature also facilitates illicit use and complicates regulatory oversight. In Manipur and Andaman Islands, Indian security forces confiscated Starlink devices from insurgency groups and drug rackets.⁹ These devices were presumably smuggled from across the border, to illegally access satellite internet in India.

Nations are increasingly recognising that control over satellite internet infrastructure represents a new dimension of national power and influence in the international system. Given the latent economic and strategic benefits and risks of the satellite internet technology, policymakers, industry leaders and other stakeholders need a clear understanding of this technology and its functioning. This document explains how satellite internet works. It examines and analyses the infrastructure components and operational mechanisms of this technology that has made global internet coverage a reality.

This document is the first in a series on satellite internet and focuses exclusively on the technological aspects—the components, operational mechanisms, and applications. It aims to provide stakeholders with a clear understanding of how satellite internet works as a foundation for informed

decision-making. Subsequent documents in this series will address the complex regulatory challenges associated with satellite internet, including orbital congestion, spectrum allocation, cybersecurity standards, cross-border operations, and international governance frameworks.

This document is divided into three sections. The first offers a broad overview of the different approaches to satellite internet. The second section explores the Lower Earth Orbit (LEO) satellite megaconstellations in detail. The last section provides a thorough list of the present and potential applications of satellite internet.

III. Understanding Satellite Internet

A satellite internet network can act as a network that provides direct internet access to users and as a part of the internet backbone itself, by connecting remote areas to the main network. A satellite internet network broadly consists of a space segment and a ground segment. These components work together to provide internet connectivity to the users.

Satellites are the most capital-intensive part of the satellite internet infrastructure. They carry communication payloads equipped with antennas for transmitting and receiving data. The service life of these typically ranges from 5 to 20 years, depending on their orbit and design. To endure the harsh conditions of space for their entire service life, satellites must be built with resilience in mind. Due to the difficulty in repairing or updating satellite payloads after launch, a thorough deployment plan is essential. There are important considerations like the satellite's orbital altitude and trajectory, which in turn influence the type of the antennas onboard. The next section explains these considerations in detail.

Internet Backbone consists of the primary data routes between large networks that form the foundation of the internet.

Ground Segment includes all the equipment on Earth's surface that communicate with satellites.

Space Segment refers to the satellites in orbit.

Payloads are tools and instruments that a satellite carries. Payloads usually define the purpose of the satellite.

Service Life is the operational duration of a satellite before it needs to be replaced.

A. Satellite Deployment Options

All satellites are deployed in fixed orbital altitudes which vary a lot. They can be as high as 35,786 km above the Earth's surface or as close as 550 km. These altitudes are divided into designated orbits, namely the Geostationary Orbit (GEO), Medium Earth Orbit (MEO) and Low Earth Orbit (LEO).

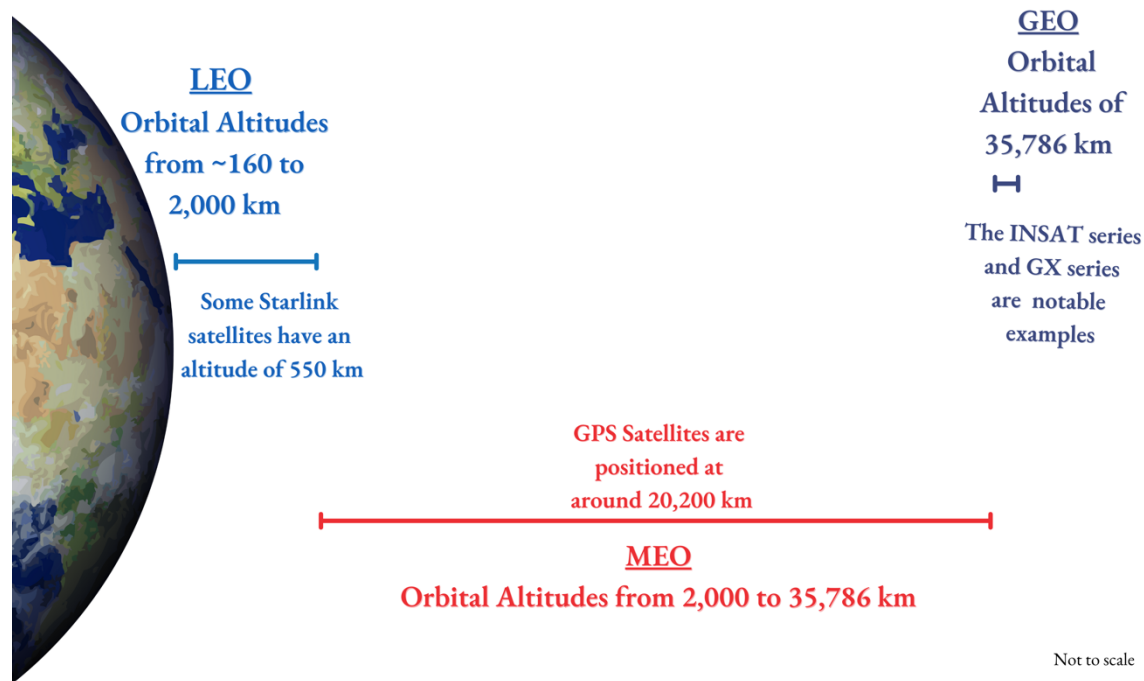


Figure 2: The three orbits (Author's Visualisation)

1. GEO Satellites

The GEO is a circular orbit at an altitude of 35,786 km above the equator. A satellite in this orbit takes about 23 hours and 56 minutes to finish one revolution around the Earth, matching Earth's rotation period. In other words, these satellites maintain a fixed position relative to a point on the ground, appearing stationary in the sky to an observer on Earth.

The main advantage of GEO satellites is their coverage area. Given their high altitude, a single GEO satellite can cover nearly one-third of the Earth's surface. However, their coverage does not extend to the extreme polar regions.¹⁰

A notable example is the Viasat-owned Global Xpress (GX) satellite system, which includes a fleet of GEO satellites capable of global internet coverage.¹¹ The following image shows the individual coverage areas of the first three satellites of the GX series. Two additional GX satellites were launched recently over elliptical orbits to extend the GX coverage to the Arctic.¹²

Coverage Area is the geographical region where a satellite can provide service.

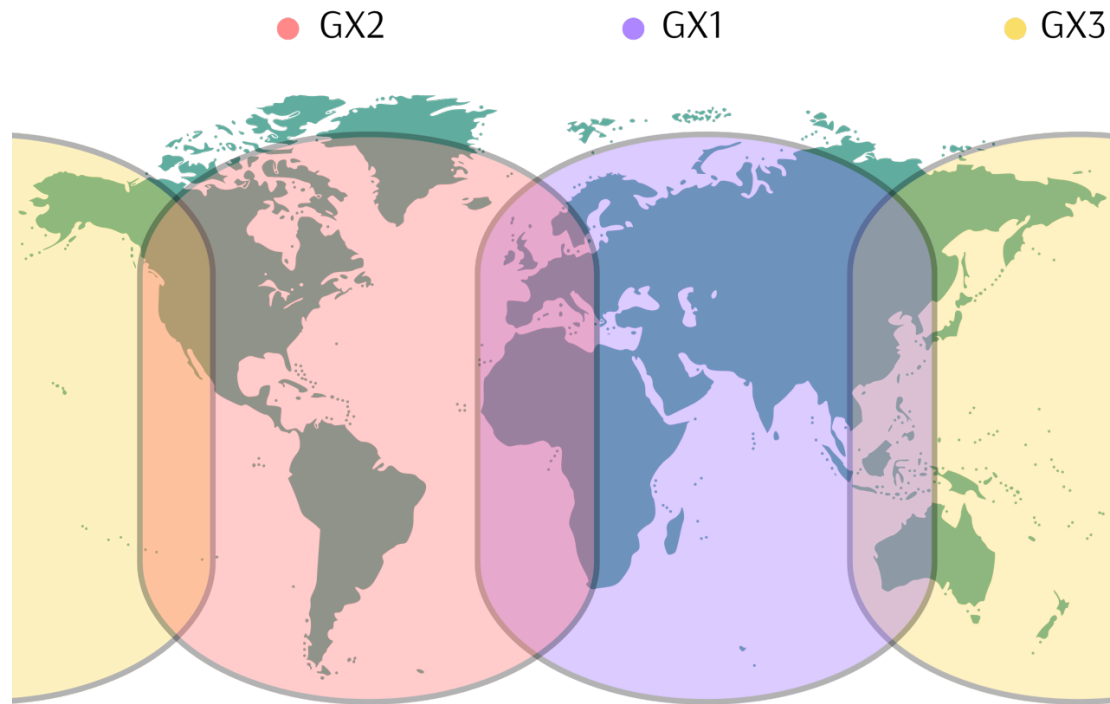


Figure 3: Footprints of three satellites of the GX series ¹³

While transmitting, GEO satellites typically act as relays or *bent-pipes*. They receive a signal, amplify it and re-transmit it without modifying or processing the data.¹⁴ Consequently, all of the signal processing tasks are handled by the ground stations. For that reason, the satellite has low-complexity equipment and most of the core components are deployed on the ground.

Bent-pipe is a simple satellite design that receives signals, amplifies them, and sends them back down without processing the data.

Ground Stations are facilities on Earth with antennas that communicate with satellites.

The two main constraints that relegate GEO satellites to *bent-pipes* are also the two limitations of GEO satellites in general—**size** and **latency**. Given their distance from the surface and large coverage areas, GEO satellites must house larger equipment to carry out their transmission duties effectively. At roughly the size of a school bus, they are bigger and heavier than satellites in the lower orbits.¹⁵ This is why on-board signal processing is generally not added to the mix, as that will only add to the already large size and weight. Assembling and launching these massive satellites to such a far distance from Earth comes with high initial costs.¹⁶

The second and most significant disadvantage of GEO satellites is their propagation latency. Since the signal must travel nearly 36,000 km from the satellite to the Earth's surface and vice-versa, this delay makes them unsuitable for time-sensitive tasks that need a steady and sustained bandwidth, such as, emergency response, video conferencing, live streaming, remote control, real-time financial transactions and navigation systems.¹⁷ On-board signal processing on the satellites will only add to this delay. With the ultra-low latency of terrestrial networks now serving as the standard benchmark, GEO systems often fall short.

Propagation **latency** is delay from the time it takes for signals to travel between Earth and satellites.

On-board Processing is a satellite's ability to process and modify data instead of just relaying it.

2. MEO Satellites

MEO satellites represent a compromise between GEO and LEO systems. They operate at altitudes between 2,000 km and 35,786 km, positioning them below the GEO and above LEO. Consequently, they have smaller coverage areas than their GEO counterparts and therefore require a higher number of satellites in the constellation to provide global coverage. For instance, O3b, an MEO satellite internet constellation, consisting of 20 satellites, provides semi-global coverage that does not include the polar regions.¹⁸

While the propagation latency of MEO satellites is lower than that of GEO satellites, it is barely sufficient for time-sensitive tasks.¹⁹ These car-sized satellites remain considerably heavy and require costly launches.²⁰

3. LEO Satellites

LEO satellites fly at orbital altitudes of less than 2000 km. Being closer to the surface, they have very low latency and require only smaller, table-sized satellites. This also makes them suitable to carry out on-board signal processing. Due to their small size, they can be rapidly deployed with lower launch costs.²¹

The only relative disadvantage compared to their GEO and MEO counterparts is their smaller coverage. A geostationary Earth orbit (GEO)

satellite can cast footprints spanning entire continents, whereas a typical LEO Starlink satellite's coverage area is comparable to the geographic extent of an Indian metropolitan city.

A LEO satellite internet constellation deals with this issue by becoming megaconstellations. Hundreds, or in some cases, thousands of LEO satellites are deployed in orbit to achieve global coverage.

The Starlink megaconstellation has over 7,000 satellites in orbit presently and plans to eventually deploy 42,000 satellites.²² OneWeb is another notable example of an operational LEO satellite internet megaconstellation. Several others are planned, such as Amazon's Project Kuiper and Telesat's Lightspeed.

LEO satellite internet systems are the most relevant and the fastest-growing networks in recent times. They are attracting strong interest from industry and governments, with many organisations in the process of building their own megaconstellations. Given their growing potential and relevance and scope, the following sections of this document will focus only on LEO satellite internet constellations. However, most of these concepts are also applicable to satellite internet from MEO and GEO.

Megaconstellations are a network of hundreds or thousands of satellites working together.

IV. LEO Satellite Constellations

Satellite internet megaconstellations in the LEO consist of hundreds, if not thousands of small satellites working together to provide global internet coverage. They transform what would typically be limitation of individual LEO satellites into collective strengths. The small coverage area enables each satellite to house on-board signal processing.

On-board processing unlocks new advantages and possibilities. Firstly, on-board processing makes the data transmission to and from the satellites a lot more efficient. It can improve signal quality, reduce degradation, enable compression, reduce power usage, allow reconfiguration, improve flexibility and extend the satellite's lifespan and efficiency.²³

Additionally, with the processing happening on the satellite, the ground segment is relatively unburdened. This simplifies the terminals on the ground that a user needs to access satellite internet. The user terminal for satellite internet from the LEO are smaller, cheaper and more accessible even to individual households in a way that satellite internet from MEO and GEO never was.

Finally, a greater number of satellites being in the line-of-sight of one another and having on-board processing, enables optical inter-satellite links. These

User Terminal is the device that allows users to connect to the satellite network.

links are communication pathways for satellites to exchange data directly without needing to send the information back to ground stations. In the absence of these links, satellites have to rely on ground stations heavily. Data must be transmitted from a satellite to a ground station and then back up to another satellite or user. This increases latency and reduces efficiency.

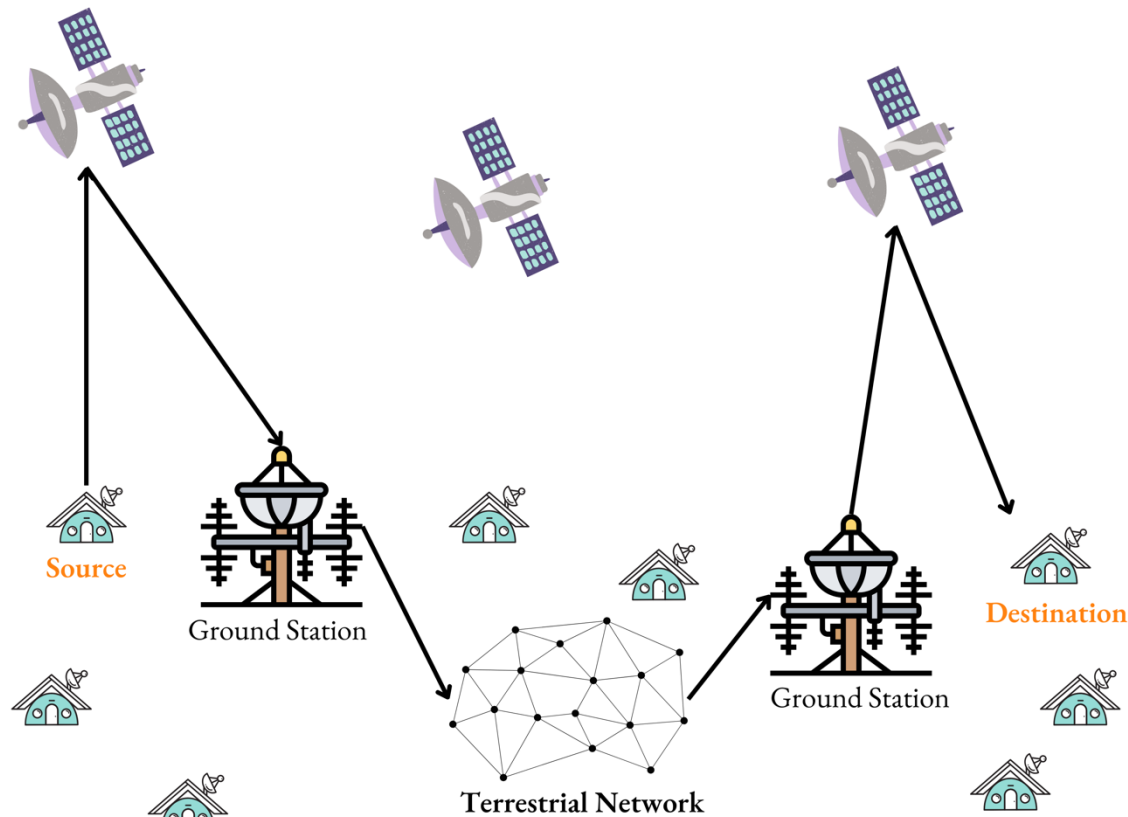


Figure 5: With terrestrial networks and without inter-satellite links (Author's Visualisation)

In a remote location devoid of any ground-based networks, data is transmitted from a satellite to a ground station and back up to another satellite and so on. The process repeats until a satellite can reach the user. The same is illustrated in the following image.

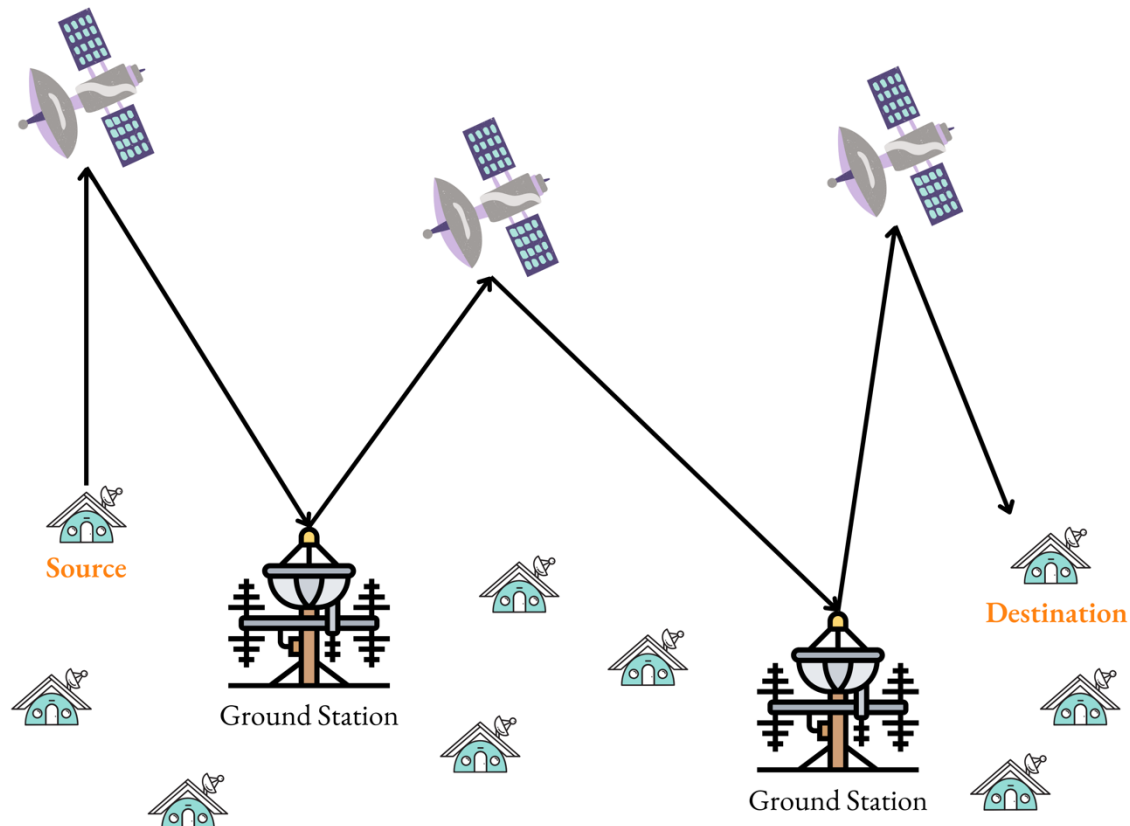


Figure 6: Without inter-satellite links (Author's Visualisation)

When inter-satellite links are available, satellites can exchange data directly with each other without needing to go through ground stations, as shown in the following image.

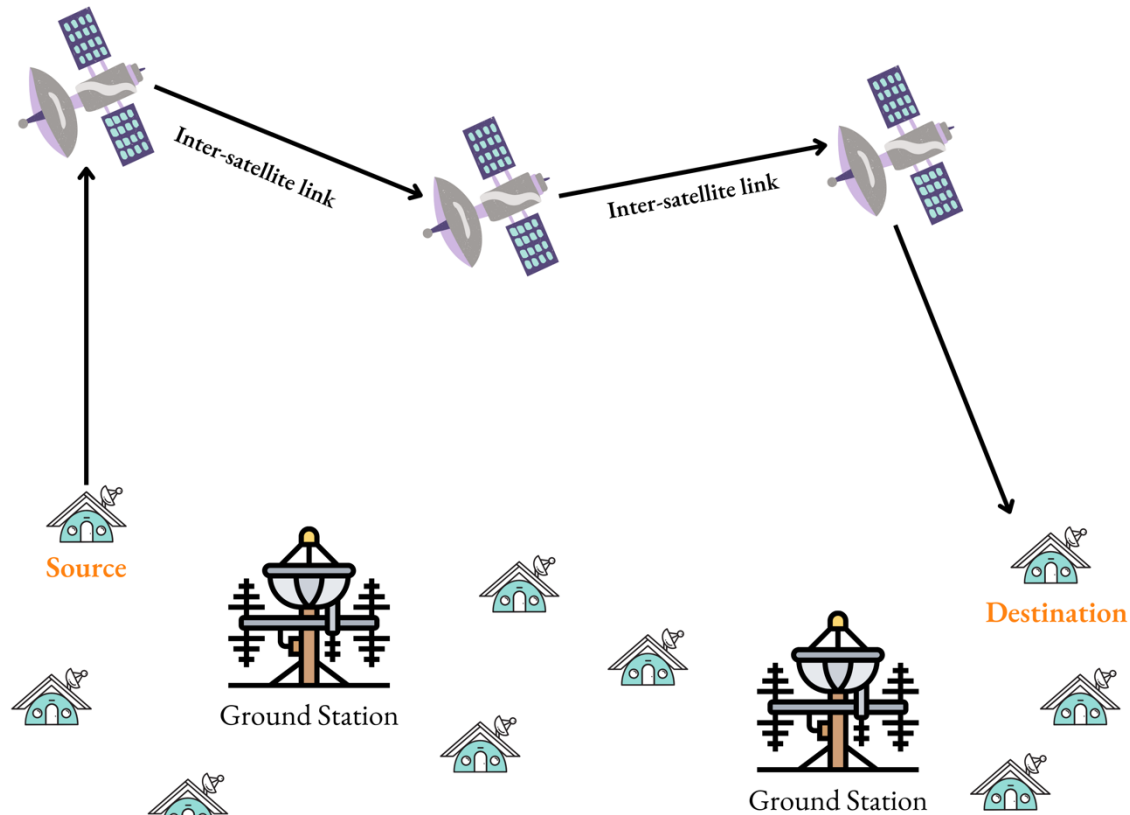


Figure 6: Without inter-satellite links (Author's Visualisation)

Optical inter-satellite links use laser, achieving even higher data speeds and being resistant to interference. While functioning in this interconnected manner, satellites can dynamically task each other to distribute the loads and

operate at greater efficiency. These features form a blanket of satellites, interconnected in space, capable of providing internet independent of ground stations. This creates a true internet in the sky that can provide as good a user experience as terrestrial networks in cities.²⁴

The challenges of continuous connectivity are another critical aspect of LEO systems. The satellites in a LEO megaconstellation are zooming past motionless users on the ground at great speeds. To maintain continuous internet services for a user, there should be at least one satellite of the constellation within the line-of-sight of the user. A satellite stays in range of a user for as little as four minutes before moving past. As a satellite connected to a user moves out of coverage, another satellite has to take over. The connection is handed-off from the first satellite to the second.

As a result, these satellites typically have multiple, independent steerable antennas, which can electronically steer their transmissions and therefore simultaneously communicate with multiple users and ground stations.²⁵ To visualise this dynamic tracking system, imagine a theatrical performance with moving stage lights. Multiple beams from these moving lights illuminate various performers on the stage. Just as these lights track and illuminate multiple performers simultaneously, LEO satellites can maintain connections with multiple users and ground stations concurrently, all the while moving

Line-of-sight is a direct, unobstructed path between a user and a satellite.

Hand-off happens when one satellite passes connection responsibility to another satellite as it moves out of range.

at speeds of nearly 27,000 km per hour, over 500 km from the surface. And when one satellite can no longer reach a user, another seamlessly takes over.

A. User Experience

The previous sections have covered the working of space-based internet from the perspective of the satellites in space. This section describes how it all appears for a user on the ground.

As highlighted in the previous sections, the advancements in technology with highly capable on-board processing systems on the satellites themselves reduce the cost of the ground segment hardware, also referred to as the user terminal. Any user who wishes to use satellite internet services will need a user terminal. These terminals are now cheaper and more accessible, even to individual users. Starlink user terminals are sold for around \$500 today.²⁶ Older satellite internet systems required heavy upfront costs, professional installation, and mostly only catered to enterprise connectivity, not households or individual users.

In contrast, user terminals of modern LEO satellite internet megaconstellations are a lot more compact, easier to set up and install without professional assistance, and can even be portable. This reduces friction and makes them a lot more accessible to the common user.

The user terminals are not just receivers of transmissions for downloads but also transmit themselves to the satellite for uploads. Despite the miniaturisation and relative reduction in costs, the terminals are still a costly investment for the user. While some service providers allow users to lease the terminal for a monthly fee, others require users to purchase it upfront for a few hundred dollars. The monthly costs of the service are also higher than terrestrial broadband, with the prevailing rates starting at around \$50.²⁷

While these costs are significantly higher than terrestrial internet services, for maritime and aeronautical businesses, people in rural areas, RV owners, digital nomads, and those in remote locations, this cost is justifiable. Given the benefits of the internet in today's world, the opportunity cost of not having internet is often higher than the cost of using satellite internet.

Some satellite internet providers like AST SpaceMobile and Starlink have already tested direct-to-smartphone satellite service. In these cases, a user's smartphone serves as the user terminal. This technology is slated for public launch before the end of 2025.²⁸ Such innovations could potentially eliminate the need for separate user terminals and significantly reduce the cost of satellite internet for the everyday users.

Direct-to-Smartphone service is a technology allowing regular smartphones to connect directly to satellites without special equipment.

As demand for global internet connectivity grows and satellite internet becomes more mainstream, consumer electronics manufacturers may

integrate specialised hardware into smartphones and laptops to enable seamless satellite connectivity, similar to how cell connectivity works today. These technological advancements, coupled with reduction in launch costs, could make satellite internet even more accessible and affordable worldwide.

V. Applications of Satellite Internet

Satellite internet technology has an enabling effect across numerous domains. It is an emerging medium of information exchange. It greatly improves the penetration of the internet and improves global digital equity. Its true value can be realised when it is integrated and adopted widely across industrial and governmental processes. This section lists many of the possible applications that satellite internet can provide across various sectors.²⁹

Sector	Application
Communication and Connectivity	• Network access for rural and remote areas • Internet of Everything • Networks for civil aircraft • Maritime communications • Remote Internet of Things (IoT) • Wearable devices • Drones • Smartphones
Navigation and Positioning	• Autonomous air-ground cooperative navigation • Seamless in-vehicle navigation

Internet of Everything is a concept of connecting people, processes, data and things to the internet.

Remote Internet of Things (IoT) is IoT devices operating in areas without traditional connectivity.

	• Global Navigation Satellite Systems (GNSS) performance enhancement in harsh environments • Global real-time precise point positioning • Self-driving car navigation • Smart cars
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Global Navigation Satellite Systems (GNSS) are systems like the GPS that provide positioning, navigation, and timing services.

Transportation	• Smart railways (disaster sensing, perimeter intrusion warning, infrastructure monitoring, remote decision-making) • Road maintenance • Ship Automatic Identification System (AIS) • Internet of Vehicles • Intelligent trajectory prediction of vessels • Cold-chain logistics for ocean catches
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Automatic Identification System (AIS) is a tracking system used by ships for identification and location sharing.

Internet of Vehicles is a network of vehicles and infrastructure that communicate with each other.

Cold-chain logistics is temperature-controlled supply chain for preserving products like food and medicine.

Public Administration	• Smart cities • Urban air governance • Data governance • Spatial data services • Public service accessibility
Disaster Management	• Disaster early warning • Post-disaster rescue • Maritime distress alarm management • Search and rescue command • Mine emergency response • Forest monitoring • Emergency imaging in earthquake-stricken areas
Healthcare	• Telemedicine • Medical assistance at sea • Remote consultation and care • Patient activity monitoring • Patient location awareness • Sustainable remote health services for rural areas

Agriculture	• Crop health detection • Intelligent soil quality analysis • Yield prediction • Smart agriculture • Precision agriculture
Environmental Monitoring	• Wetland remote sensing monitoring • Digital wildlife monitoring • Multi-species assessment • Earth resource data analysis • Earth scene/event analysis • Geospatial monitoring and planning • Environmental sustainability
Energy	• Oil and gas exploration in remote areas • Construction of offshore oil platforms • Offshore oil field signal coverage • Emergency communications for energy sites

Tourism and Recreation	• Cruise tourism • Scenic area business process reengineering • Intelligent operation and management of tourist sites • Tourist location awareness • Distress rescue for tourists
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Military and Defence	• Enhancement of military communication quality and redundancy • All-dimensional reconnaissance and surveillance • Improved positioning accuracy for military navigation • Anti-jamming capability • Monitoring of events in conflicts • Assessment of post-war losses
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Economic Impact	• Digital services for intelligent solutions • Reduction of information asymmetry • Enterprise access to knowledge
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	• Simulated environments for production modelling • Reducing the digital divide and promoting financial inclusion • Enhanced supply chain transparency • Market competition restructuring
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Table 1: Possible applications of Satellite internet

VI. Conclusion

Having examined the technological underpinnings of satellite internet, it is important to note that this document serves as the first instalment in a broader series. While this document focuses on the technical aspects, subsequent documents will explore the regulatory landscape, addressing critical questions of orbital and spectrum resource management, international governance, security considerations, and policy frameworks.

Satellite internet bridges the connectivity gaps in today's world. It addresses the fundamental limitations of ground-based networks by providing resilient, global coverage that functions regardless of terrain, population density or infrastructure development. This technology represents not just a backup system but a transformative approach to internet provision.

The emergence of LEO megaconstellations marks a new age in satellite internet capabilities. Through smaller, cheaper satellites, on-board processing, and inter-satellite links, these systems deliver performance that rivals terrestrial networks while maintaining global reach. This evolution from earlier GEO and MEO systems has democratised access to space-based connectivity.

The inherently dual-use nature of satellite internet technology—serving both civilian and military purposes—creates complex security dynamics. Satellite internet can simultaneously function as critical civilian infrastructure and as a strategic military asset. The Ukraine-Russia conflict has highlighted how satellite internet has become a geopolitical tool capable of shaping modern warfare and crisis response. Governments will increasingly recognise that control over satellite internet infrastructure represents a new dimension of national power and influence in the international system.

The satellite internet landscape will likely be transformed by:

- Integration of direct-to-smartphone capability eliminating the need for specialised terminals.
- Decreasing costs through technological advancement and increased competition.
- Hybrid networks combining terrestrial, stratospheric, and space-based connectivity.
- Increased integration with IoT devices, autonomous vehicles, and smart infrastructure.

The borderless nature of satellite internet creates unprecedented regulatory challenges requiring an up-to-date understanding of the workings of this technology.

For major powers seeking technological supremacy, satellite internet represents both an opportunity and a necessity. India should consider comprehensive strategies encompassing the following:

- Support for domestic satellite internet capabilities through policy and investment.
- Integration of satellite internet into national resilience and disaster response planning.
- Leveraging satellite internet to bridge digital divides and foster economic development.
- Participation in international governance forums shaping the future of this technology.

Time is of essence here. The global satellite internet landscape will evolve rapidly in the coming years. India must act swiftly to develop and implement these strategies, ensuring it does not fall behind in this critical technological race that will define the next era of global connectivity and strategic advantage.

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