IS the BROADBAND LOW EARTH ORBIT (LEO) SATELLITE STAR RISING?
…a brief overview of what's happening, why, the challenges and the chances of success.

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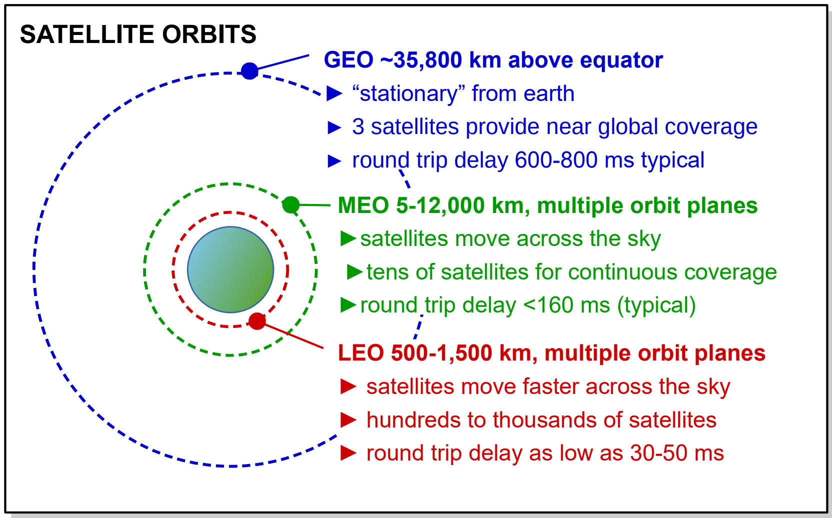
Communications satellites have been delivering a range of telephone, television and data services since the 1960s. The big benefit is "distance insensitivity" as the satellite can "see" and therefore communicate with large parts of the earth from space. Until recently nearly all communication satellites were in geostationary earth orbit (GEO). This orbit is above the equator and has an orbital period of 24 hours. Therefore, from earth a GEO satellite appears to be stationary in the sky. Non-GEO orbits are also of interest. As shown on the satellite orbit summary diagram, satellites can be categorized by the distance to orbit from the surface of the earth.



Low earth orbit (LEO) and mid earth orbit (MEO) satellites have an orbital period that is less than 24 hours. This means, from a fixed spot on the earth, the satellites move across the sky. For continuous coverage and communication session continuity, multiple satellites in multiple orbits are needed (often called a "constellation"). User terminals on earth track the satellites and hand-off between the satellites as they pass overhead.

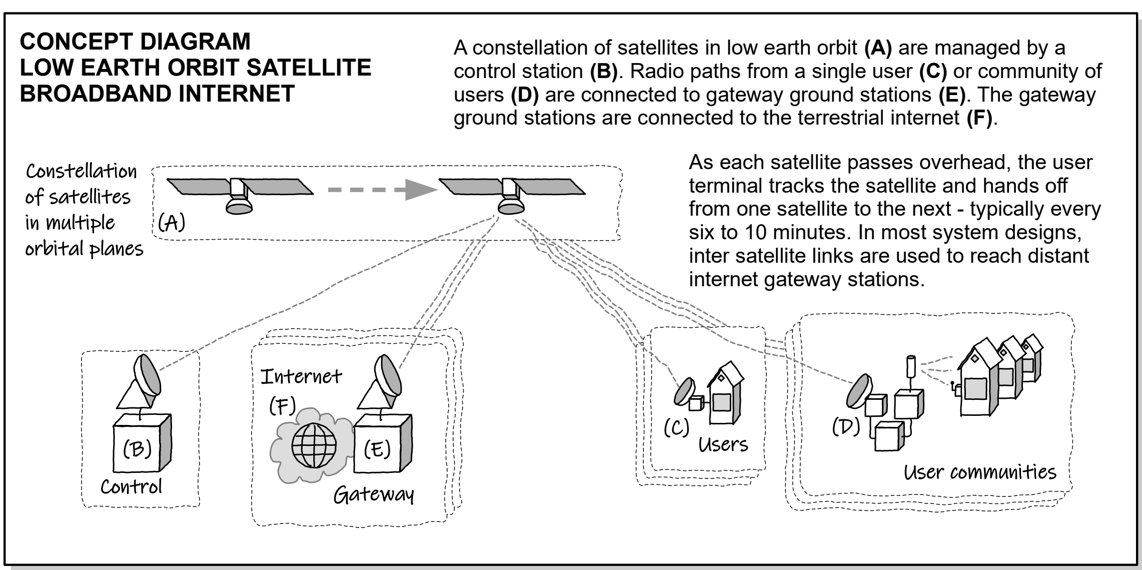
The main benefit of non-GEO satellites is lower delay. Communications delay is critical (as any internet gamer are will testify). Real time voice and video calls with delay over about 150 to 200 milli-seconds (ms) becomes conversationally inconvenient (as people tend to try to talk over one another). The round trip photon flight time for GEO communication is over 500 ms. LEO delay on the order of 50 ms is significantly better. Systems can be roughly divided into high capacity and low-capacity. Our interest in this article is broadband with consistent user throughput of tens to hundreds of Mbps; therefore, only high capacity are covered here. Today O3b, a MEO constellation operated by SES, is the only high capacity non-GEO system in commercial service.

Interest in LEO satellite constellations for broadband internet is running high. Although many initiatives have been announced over recent years, we identify projects in Sidebar-1 below that appear to have the best chance of entering service. These projects have approval for spectrum in their target markets, some level of funding assurance, and at least a prototype satellite in orbit. That is not to say that all will enter service, but only that their current status shows varying degrees of promise.

Market drivers: The urgency to extend low-cost high-quality broadband internet to under-served markets of the planet is identified as the principle market driver behind the current crop of broadband internet LEO initiatives. GEO satellite based internet service is widely available today in remote areas, providing a basic proof of concept. However, compared to terrestrial service, GEO satellite internet service suffers from high usage costs, long transmission delay and, during periods of congestion, slow user speeds. Can LEO remedy these shortfalls?

Key enablers: Several factors are underpinning expectations for LEO, including: (i) lower launch costs (particularly to reach LEO) are emerging from reusable launch vehicles (SpaceX Falcon) and more private sector launch competition (Blue Origin); (ii) advances in radio and network technology that lower costs, weight and power consumption are making small high performance satellites feasible; (iii) the expectation that volume production of hundreds to thousands of small satellites will hit economies of scale; and (iv) economy of scale expectations for hundreds of thousands to millions of user terminals.

It is very likely that the SpaceX StarLink network will see at least some level of commercial service within the next year. OneWeb, an early front runner, is currently emerging from bankruptcy. Telesat's LEO project has the benefit of 50 years of satellite experience and has taken a pragmatic and measured approach. Project Kuiper by Amazon has been quietly developing without much media attention. Amazon's deep pockets lend credibility to this Project. The Hongyun project in China is one of two competing state sponsored initiatives. For brief descriptions of these projects and initiatives, see Sidebar-1 below.



CHALLENGES: Although market and technology forces appear to be aligning, there are significant challenges. Even if regulatory hurdles for spectrum and licensing have been cleared for the desired market areas and the organization has capacity to build the network within the time frame allowed, technical, market and business challenges remain.

Technical challenges include: (i) building complex user terminals with low-cost tracking antennas; (ii) mitigating radio frequency interference from frequency reuse (including by other satellite systems); (iii) inter satellite links should be used to reduce the number of gateway ground stations required (i.e., satellite gateway stations connect the satellite network to the internet) and these links require high-speed tracking antennas and network protocols to efficiently route traffic; (iv) weather (rain and snow) is an issue particularly at the frequencies of interest; and (v) managing orbital congestion, particularly if multiple mega constellations launch (see Sidebar-3 below on Orbital Congestion and Space Debris).

Market challenges include competition from terrestrial networks and high altitude platforms (HAPs). Terrestrial services will continue to expand and include fiber to the premises networks and cellular mobile wireless networks. Although fiber optic networks have high initial costs, their high capacity and long useful life (some 20 to 30 years and more) makes high performance low cost service possible. Cellular mobile networks have a much shorter useful life (on the order of 10 years maximum) but massive global volumes and competition make unit costs very low (over a billion smart phones are sold each year). HAPs include a range of initiatives to use various unmanned aircraft and balloons as base stations or radio repeaters in the atmosphere. Although Project Loon is the only HAP currently in commercial service, there continues to be a stream of ideas and contenders. Project Loon started as a Google "moonshot project" in the 2011-2013 time-frame and commercial service started in Kenya in July 2020 with a fleet of 35 balloons providing internet over an area of 50,000 square kilometers.

This leads to the issue of market fragmentation, as a host of incompatible satellite technologies (and perhaps HAPs) potentially emerge. Standards are often needed to establish a "virtuous circle" ecosystem where continually growing volumes lead to continually falling prices. For example, specifications and certification testing to ensure multi-vendor compatibility by the Wi-Fi Alliance and the 3rd Generation Partnership Project (3GPP) enabled the global success of wireless local area networks and cellular mobile networks, respectively. There have been initiatives to incorporate satellite into 3GPP's 5G (Fifth Generation) cellular specifications. This has promise, but the timing and success of this concept is uncertain.

Business challenges: The primary business challenge is the ability to deliver unlimited usage high-quality broadband internet service at a price point that will attract millions of customers. Where is this price point? Arguably in developed economies, $80 per month per broadband customer might work. Customer premises equipment for consumers will need to be under $500 to allow service providers to offer one time costs on the order of $100-200 plus a $10-20 per month rental fee (part of the monthly costs). These are reasonable market price points for a developed economy. They are likely too rich for many less developed economies. Less developed economies may only be able to afford a quarter of these values; for example, on the order of $20 per month (and resale of unlimited plans will be a potentially tricky issue).

Can these price points be reached? The cost to launch a LEO service is estimated to lie in the $5-10 billion range plus $1-2 billion per year to sustain operations. If we take the low range numbers and assume this leads to a revenue requirement of $2 billion per year for capital recovery and ongoing operations and assume two million customers, then the revenue requirement per average customer is $1000 per year or close to $80 per month. How big is the market; specifically, are there millions of potential customers? The FCC has estimated there are 20 million Americans without internet service. For argument's sake, assume four people per household and 50% take-up of satellite service and assume the US is 10% of the global market: then the global market could be on the order of 50 million customers. This should be a low estimate because globally some 4 billion people are believed to be offline with affordability and lack of available connectivity major reasons. Although over 90% of the world's population has cellular mobile coverage, over 500 million people cannot connect because they live in rural areas without mobile broadband coverage. In short: if the price points can be hit, there may be a viable business case.

Investment sources: Where will the capital come from to launch broadband LEO satellite service? The current LEO initiatives appear to be generally attracting sufficient capital to keep their projects moving, with only some glitches and failures. Governments have been stepping up to accelerate broadband expansion, particularly in the wake of COVID-19 induced shelter-in-place orders. The UK government is considering $500 million to help OneWeb emerge from bankruptcy. The Canadian government has committed CA$85 million in capital and CA$600 million over 10 years to support the Telesat LEO project. The US federal government has committed $20 billion over 10 years to expand broadband internet to rural areas. If satellite is even a part of the solution, then expect SpaceX and perhaps others to line up at the federal trough. It is also noted that many rich technology companies have the resources to enter the LEO mega constellation game. For example, Amazon and Facebook each have over $50 billion in cash reserves and Apple has over $100 billion. These firms are all internet based success stories with a deep interest in the success of the internet. They may find compelling reasons to enter the game either on their own or as investors in one or more other initiatives.

What does all of this mean? Hitting the price performance point has the potential to disrupt the global broadband internet market in rural areas. Over the next year and out to about 2024, we should see if anyone can hit that point and get market traction. We can also expect to see some of the initiatives delay or combine, and some will probably fail. In any event, SpaceX is the prospect to watch. SpaceX is the front runner with StarLink positioned to gain first mover market advantage. Stay tuned and watch this space. We will be monitoring events closely to see when and how to begin factoring LEO service into broadband network planning and design work.

Sidebar-1 BROADBAND LEO PROJECT SAMPLER The following is a sampler of broadband LEO hopefuls. Note that technical details, including the number of satellites and their orbital plans, are not cast in stone and the numbers have been changing as plans progress.
SpaceX StarLink (United States) Constellation when fully built out as 3 orbital shells: 340 km shell at 70° inclination with 7,500 satellites, 550 km shell at 53° with 1,600 satellites, and 1,150 km shell at 98° with 2,800 satellites. Each satellite weighs about 260 kg. The outer shells will enter service first using the Ka-band and Ku-band (radio frequency bands). The inner shell is expected to use the V-band. Market: Most broadband internet segments including consumers. Cost: Estimated total to achieve global coverage may be on the order of $10 billion. Status: By end of September 2020, over 700 StarLink satellites had been launched and 9 satellites de-orbited. As of September 2020, user beta testing is underway in the northern US. Tests to standard user terminals have apparently reached up to 100 Mbps download with round trip delay in the 40 to 50 ms range. SpaceX is is building up to 6 satellites per day launching 60 satellites per month. Commercial service in the band between 44° and 52° North latitude could start before the end of this year. Near global service may be achieved in 2022 with some 1,584 operational satellites.
Project Kuiper (Amazon) Constellation when fully built out as 3 orbital shells: 590 km shell with 789 satellites, 610 km shell with 1,296 satellites, 630 km shell with 1,156 satellites(for 3,236 total); at least some use of Ka-band. Market: Broadband internet and possibly a vertical integration play with Amazon business interests. Cost: More than $10 billion. Status: As of October 2020, a build team is being hired. Access to Amazon financial backing and Blue Origin launch capability provides credibility of project resources.

Telesat LEO (Canada)
Constellation: 117 satellites for global coverage using the Ka-band, but 200 to 300 numbers have also been floated, and the total number of satellites could reach 500 or up to 800 eventually to meet capacity demand.
Market: Broadband internet delivered to network operators, rural and remote communities, and businesses (not consumer).
Cost: Unknown but the satellite production contract alone has been estimated in the $3 billion range.
Status: A prototype has been in orbit since 2018. Initial plans call for 78 satellites in polar orbit to provide coverage of northern latitudes (up to the pole) as early as 2022. Additional launches to place satellites in inclined orbits to achieve global coverage could happen in 2023. Funding from the Government of Canada will be used to partially fund procurement of some of the initial satellites ($85 million) and also to subsidize operations ($600 million over 10 years) which will be used to lower prices for northern communities. Construction contract(s) for satellite production could be let this year (2020).

OneWeb (UK)
Constellation: 648 satellites (~150 kg) in 1,200 km polar orbits operating in the Ku-band for users and Ka-band for gateway communication. Satellite numbers up to 720 have been published with 600 possibly required initially.
Market: Broadband internet.
Cost: Unknown (but too much for the early investors that included Softbank, Qualcomm and Airbus).
Status: OneWeb filed for bankruptcy protection in March 2020. Of the 74 satellites launched, 68 are in orbit at 1,200 km and operational. In May 2020 and in spite of bankruptcy, OneWeb filed with the FCC to increase the constellation size to 48,000 satellites. In July 2020, a consortium that includes the UK government and Bharti Global won an auction to purchase OneWeb. This consortium is expected to invest $1 billion. Launches may restart in December 2020.

Hongyun Project (China)
Constellation: 865 satellites in inclined orbits at 1,174 km.
Market: Broadband internet, initially in China.
Cost: Unknown.
Status: A prototype test satellite is in orbit since 2018 at 1,067 km. The Chinese government has invested in two competing initiatives: Hongyun and Galaxy Space.

Sidebar-2 SATELLITE FREQUENCY BANDS

Satellite radio frequency bands are often referred to using electromagnetic spectrum terminology from the Institute of Electrical and Electronic Engineers (IEEE). The following bands are typically used for satellite (GHz means GigaHertz or billions of cycles per second):

- L-band: 1 to 2 GHz
- C-band: 4 to 8 GHz
- Ku-band: 12-18 GHz
- Ka-band: 27 to 40 GHz
- V-band: 40 to 75 GHz

Sidebar-3 ORBITAL CONGESTION and SPACE DEBRIS

Orbital congestion and space debris is getting more attention. There are already an estimated 5 thousand satellites in orbit (of which approximately 40% are operational) along with some 900 thousand bits of space debris over 1 cm in size and over 100 million smaller pieces over 1 mm in size. LEO satellite velocities are on the order of eight kilometers per second. At these speeds even a glancing blow by a pea size object can have catastrophic results and generate thousands of fragments. Some LEO satellite plans include autonomous active collision avoidance systems. Other counter measures to control LEO space debris include regulations mandating reliable de-orbit mechanisms that are enabled as satellites reach the end of their operational life.

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