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# Defining the Synergies between LEO Satellite Constellations and Submarine Cables

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## Introduction

Low Earth Orbit (LEO) satellite constellations have introduced a new dimension to the global telecoms landscape. These advanced satellites can provide ubiquitous connectivity services, especially within remote geographies where telecom infrastructure is absent or lacking.

LEO constellations also offer capacity in the terabit range. This raises the question of how well LEO constellations compete or complement different terrestrial services such as fixed wireless access and wholesale services.

This paper is the result of joint analysis by Xona Partners (who have been actively advising on LEO satellite technologies and market opportunities), and Angola Cables a leading submarine service provider connecting African with Europe and the Americas and beyond.

We present the summary of our analysis of the competitive dynamics between LEO constellations and submarine fiber services. Within this context, we show that LEO constellations do not compete with submarine services, but rather highlight the evidence that the two technologies are complementary as a result of performance and cost comparative analysis. We illustrate the synergies through two case studies in Africa where the intersect of LEO satellites and submarine cables combines to improve the connectivity services and contribute to future revenues of both ecosystems.

## Overview of Submarine Fiber Cables

Currently, more than 400 subsea cables, covering a distance over 1.2 million kilometres, carry power and data between continents and geographies across the world [1]. These vital information highways carry more than 98% of the entire global internet traffic and form the backbone for cloud computing.

It is estimated that by 2022, IP traffic will reach around 4.8 zettabytes of data. By 2025, the demand for data is anticipated to skyrocket to 175 zettabytes per year to fuel the expanding global digital economy [2]. This is an enormous amount of data.

The capacity of the submarine cable is in the order of tens of Terabits with a lifespan of around 25 years. Cables installed in recent years with 100G technology have around 10 Tbps capacity per fiber pair, but technology evolution is already at 500G which allows a potential capacity of around 25Tbps within in a single fiber pair. Technology evolution will not stop their capacity grow, allowing future cable systems to have much more available capacity per fiber pair. Current systems installed in the last decade have between 6 to 8 fiber pairs and the new cable technology can have up to 16 fiber pairs. Cables of the future could grow to a potential of 50 fiber pairs. One could just imagine the potential capacity of future cable systems with all that extra boost capacity per fiber pair and the extra number of fiber pairs per cable.

Although the capacity of satellite pales considerably when compared to that of an undersea cable, the potential combined use of subsea cable infrastructure and low-orbit satellite could shift this paradigm in the years to come. The demand for broadband access is expected to double every two years. Deploying satellites with an interface to submarine cables could bring digital access to the many parts of the world, especially within Africa, where many do not have the benefit of being part of the digital economy.

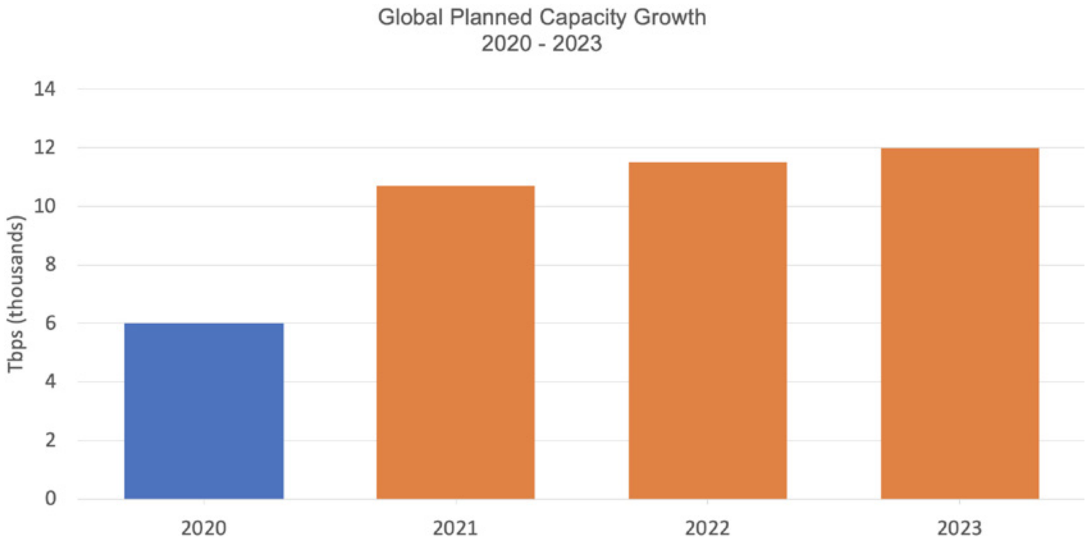

Figure 1: Transatlantic submarine cable capacity growth projection fueled by new routes across the South and Mid-Atlantic.

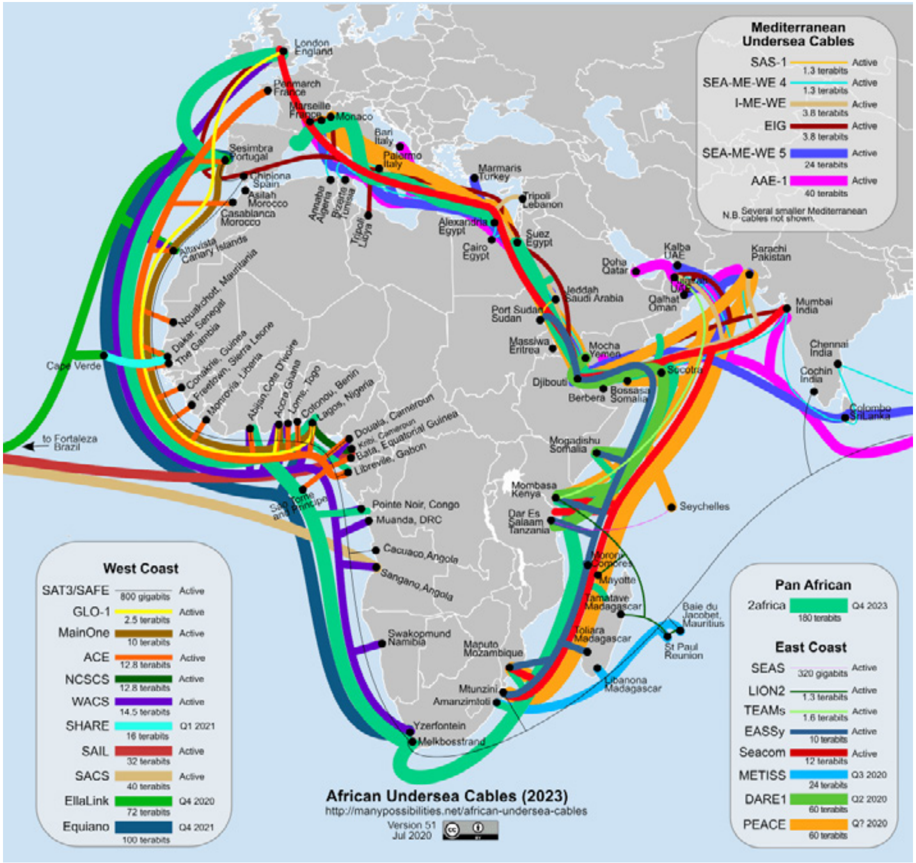

Figure 2: Subsea cables serving Africa.

Table 1: Key statistics on the global submarine cable industry

| | |
|---|---|
| Current estimated value of the subsea cable market: The market is expected to grow by 7.3% CAGR to 2027 | US$21.3 Billion |
| Total number of subsea cables in operation | 406 |
| Number of systems currently being planned | 54 |
| Fiber design capacity on major routes have increased at a CAGR | >25% |
| Bandwidth demand on subsea intercontinental cables in 2019 | 50 Tbps |
| Estimated bandwidth demand on subsea intercontinental routes in 2020 | >100 Tbps |
| Level of investment into submarine cables since 1990 | US$50 Billion |

Figure 3: Angola Cable service footprint.

## Overview of LEO Satellite Constellations

LEO satellites orbit the earth at altitudes of between 500 and 2,000 km, traveling at a speed between 7 and 9 kilometers per second (15,600 – 20,000 mph). A point on earth would be served by successive satellites flying overhead between every 5 to 15 minutes. The phased array antenna on a satellite provides coverage through multiple beams creating a re-use scheme similar to that of terrestrial mobile networks.

At present, there are multiple LEO constellations in the planning and deployment stages from companies in the US, Russia, China and other countries.  Some companies, like Elon Musk's, SpaceX is targeting the consumer segment for Internet connectivity services. Operators like Telesat and OneWeb are focusing on the business and enterprise market segment where throughput and reliability requirements are higher than that of the consumer segment. Others, like Kepler and Lacuna, are targeting IoT connectivity applications. Application of LEO satellites also include integration with 5G networks. The client base includes individual consumers, SMEs and large enterprises, MNOs and ISPs, among others. The point here is that not all LEO constellations are the same. Each constellation has different operating and performance parameters that make it suitable for its desired function and target market.

Table 2: Comparative characteristics of submarine cable and LEO satellite networks

| | Submarine Cables | LEO Satellites |
|---|---|---|
| Capacity | 10s – 100s Tbps | 10s – 100s Gbps |
| Latency[1] | ~50 msec | ~40 msec |
| Lifespan | 25 years | 5-10 years |
| Investment | $100-$500 Million | $5-$10+ Billion |

## Performance Comparison

To address the competitive dynamics between LEO and submarine cables, we have outlined a few critical performance characteristics of LEO satellites.

We chose the SpaceX Starlink constellation as an illustrative example as it targets primarily consumer access services. This is because SpaceX is leading other constellations with over 900 satellites in orbit as part of an initial plan to for a constellation of 1,440 satellites. While there are other constellations designed for transport services, we don't see our conclusions changing.

We focus the comparative assessment on capacity and latency. Reliability is another critical aspect. Many factors impact the reliability of satellite services, especially those operating in frequency bands such as the Ku and Ka bands which are susceptible to environmental and atmospheric losses. These technical aspects are beyond the scope of this paper.

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*1 Propagation latency over 10,000 km, excluding any routing, repeaters or other intermediary nodes between origination and destination points.*

## Capacity Comparison

Each Starlink satellite employs three user downlink beams with 2,000 MHz bandwidth in the 10.7 – 12.7 GHz range. The user uplink employs four beams in the 12.750 – 13.250 GHz range and three beams within 14.0 – 14.5 GHz for a combined bandwidth of 1,000 MHz.

SpaceX aggregate user downlink capacity is between 17 – 23 Gbps per satellite with an average of 20 Gbps [3]. This results in average spectral efficiency of 3.3 b/s/Hz, which is well within the performance of the DVB-2SX modem used in modern satellite communications. If we apply the same spectral efficiency to the uplink, we arrive at capacity ceiling of 11.6 Gbps per satellite and 1.6 Gbps per uplink beam. In practice, the uplink capacity would likely be lower.

The asymmetric bandwidth of SpaceX is suitable for access applications. However, transport services often require symmetric bandwidth which is not possible because of uplink limits. [The gateway uplink in the case of SpaceX is limiting, but for simplicity we focus on the user link here.]

## Latency Comparison

Traffic latency increases according to distance - and the number of satellites connecting the points of origin and destination. A constellation orbiting the earth at low altitude benefits from close proximity to earth, but it could require a larger number of intermediary satellites to connect two nodes.

To reduce the distance between origin and destination, LEO satellites benefit from inter-satellite links (ISL) to reduce the number of ground stations. These links could bridge two far-away points on earth as they route data packets among satellites from the point of origin to destination. The satellites employ a routing algorithm that accounts for the motion and optimizes packet routing along the shortest path to optimize latency.

Inter-satellite links have a throughput of 10 Gbps, although some constellations could feature higher speeds. ISLs are a differentiating feature that's not common to all satellite constellations. For instance, the first generations of SpaceX satellites do not support ISLs – a feature that is planned for 2022 at the earliest.

We compare the latency possible between low and high-orbit LEO constellations using the parameters of SpaceX in Table 2. We also note that the speed of propagation in fiber optical cable is two-thirds of s that in free space. Optical signals in fiber inherently have higher latency than RF signals in free space. For instance, the latency for 10,000 km of fiber is 50 msec in comparison with 33.3 msec in free space. The latency over LEO satellites for relatively short distances is close to that of fiber. Recently for instance, SpaceX reported that median latency is 30 msec and 95th percentile latency is below 42 msec as measured to Starlink Internet PoP [4].

This leads us to an important conclusion: LEO latency could only be meaningfully lower than submarine fiber over long distance routes and in constellations that are optimized for inter-satellite backhaul.

Table 3: Comparative parameters for SpaceX satellites in the low and high orbital altitudes.

| Distance between two points on earth | 10,000 km | |
|---|---|---|
| Reference constellation | SpaceX - Low orbit | SpaceX - High orbit |
| Orbit altitude (km) | 550 | 1,150 |
| Ground coverage per satellite (km) | 573.5 | 1,060 |
| Distance in space (km) | 10,863 | 11,805 |
| RF propagation delay (msec) | 40 | 47 |
| ISL maximum range (km) | 2,000 | 2,000 |
| Number of satellites required to bridge distance | 6 | 6 |
| Processing delay / satellite (msec) | 0.5 | 0.5 |
| Total latency (msec) | 42.9 | 50 |
| Latency on earth in fiber | 50 | 50 |
| Latency improvement in satellite over fiber | 14% | 0% |

## Market Synergies

The technical performance points to the complementary nature of submarine cables and LEO satellites. Here, we identify the following areas where the two industries could converge.

### Market Extension

LEO satellites help extend the presence of submarine cables into new markets beyond the landing station. There are different types of market extensions. For instance:

- Submarine cables can leverage LEO satellites to connect inland enterprises and/or ISPs beyond the reach of cable landing stations. This is of particular interest in regions of the world where inland connectivity is expensive or not available - as is the case in large parts of Africa, especially within rural and remote regions.
- LEO satellites provide land-locked countries with an alternative mode to connect to submarine cables. Hence, the relationship between LEO satellites and submarine cables could develop into a strategic partnership where nation-states look to diversify their connectivity options. For example, 16 of the 54 countries in Africa are land locked. Moreover, 37 of the 38 countries with seashore have only one submarine cable landing.
- LEO satellites could provide the ability to connect to various ingress of submarine cables, or directly into terrestrial transit points, possibly enabling competition across submarine cable operators.
- LEO satellites complement submarine cables to connect islands or areas where traffic density and economics of undersea fiber are not attractive.

### Submarine Cable Offload

In some instances, LEO satellites provide a superior latency advantage. This has great benefits for many enterprises dealing with time sensitive data. Take for example the financial industry where trades hinge on millisecond timings for execution, this sector would see high value in LEO satellites. This traffic could be off-loaded from submarine cables and onto satellites. The amount of traffic requiring such low latency is typically small, but it has high value.

Latency-sensitive traffic could be offloaded from submarine cables with virtually no loss to the submarine cable operator. The LEO satellite operator could carry such traffic with preferential QoS at a higher price than regular traffic. Hence, submarine and satellite operators could partner to identify and tag traffic at the source to route low-latency, high-value traffic over satellite infrastructure while keeping the rest of traffic on submarine cables.

### Submarine Redundancy

Similar in principle to submarine offload, submarine cable redundancy is specific to cases where the cable fails. In such a case, a small portion of the traffic can be redirected to the LEO constellation.

### A Stop-Gap Solution

This is an option where LEO satellites can connect locations where submarine cables are in planning or where they are not commercially available.

## The Cost Structure

We illustrate the cost structure case for the market extension scenario taking Africa as an example. Africa is well connected to the rest of the world by a number of submarine cables. These cables are typically filled to under 50% of capacity, leaving ample room for growth. The challenge in Africa has been connecting the various cities, towns and villages inland – especially those in land-locked countries. This is where the synergies between LEO satellites and submarine cable can combine to deliver a potential solution.

The cost of capacity for submarine is relatively low and currently stands at around $8-$33 per Gbps-months[2]. The price paid by customers is about $3 per Mbps – although this varies based on location, distance and other factors. As we explain further, both these values are a fraction of those for satellites.

The cost of LEO satellite capacity depends on a number of factors and varies depending on the scale of the constellation. LEO constellations are capex-heavy endeavors.

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[2] *Based on $100-500 million capex; 80-100 Tbps capacity; and 25 years of useful life with 50% utilization.*

SpaceX raised approximately $3.5 billion to date and plans 1,440 satellites for initial service launch. The estimated costs to build a denser constellation is around $10 billion[3] [5]. Using the former capex figure, the cost of capacity would be $5,000/Gbps-months in the case of an optimistic 25% capacity utilization[4]. The cost increases to $30,000/Gbps-months for a conservative 4% utilization of a larger, higher capex constellation. For comparison, GEO satellites operate at 75%-100% utilization. The actual price extended to customers will have account for the cost of the ground segment, operating costs, profit margins, cost of terminals and other costs. For reference, the price of satellite backhaul capacity is in the order of $250/Mbps and declining at a rate of between 5-10% per year.

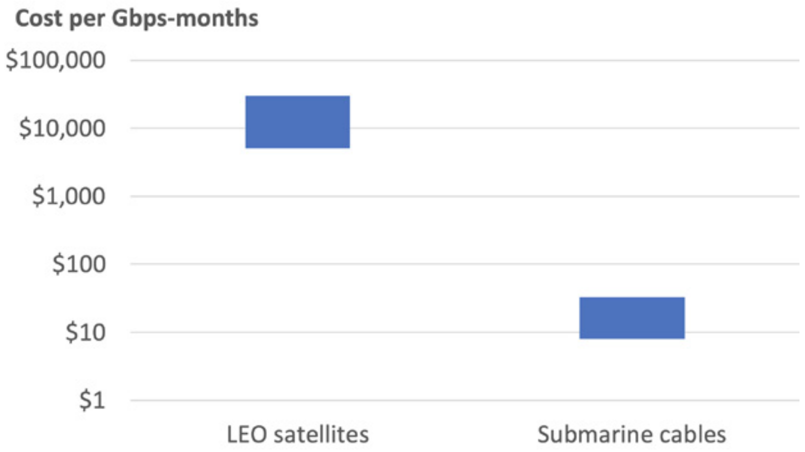

Figure 4: The cost structure between LEO satellites and submarine cable favors complementary services.

With the cost per Gbps-months for submarine being about 1,000x lower than that for LEO satellites, there is a strong business case and motivation for collaboration between the two ecosystems for long-haul traffic use. The net effect is filling the submarine pipes with more traffic while satellite players reduce their long-haul traffic costs.

Running the business case for LEO constellations sheds further light on the importance of designing the constellation to efficiently cater for transport services - if that is the target of the constellation. For instance, a satellite in a low orbit constellation will cover a smaller area of the earth's surface. This consequently limits the range of inland penetration before inter-satellite links are used to bridge the distance. A satellite in a higher orbit constellation will connect inland locations more cost effectively but will exhibit higher latency. This is one trade off among many that we mention here for illustration. Such tradeoffs differentiate the satellite constellations from one another - and could factor in determining financial viability of these constellations. Additional information on how LEO constellations differentiate is available in [6].

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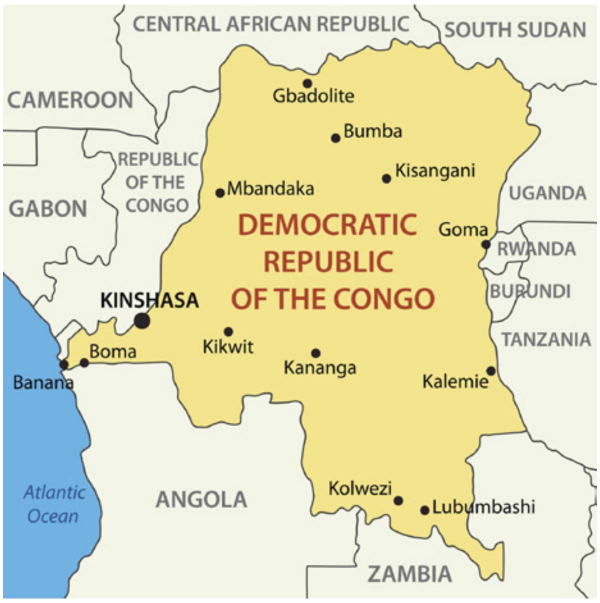
[3] *The statement of SpaceX executive followed FCC authorization for 4,425 satellites in the first rollout phase. See [5]*

[4] *Based on 2 GHz downlink spectrum with re-use 3 and 0.5 GHz uplink spectrum with re-use 7. The constellation includes 1,440 satellites with $3.5 billion capex; or for 4,425 satellites with $10 billion capex. Constellation lifetime is 5 years. User terminal and operating costs are not included.*

## Deployment Examples

Two examples characterize the potential market synergies between submarine cables and LEO satellites:

### Example 1:
### Expanding Digital Connectivity in the Democratic Republic of the Congo (DRC)



The DRC is the largest country in sub-Saharan Africa with a population of over 89 million people. As of January 2020, there were only 16.35 million people who were connected to the internet. This represents about 18% of the population which is significantly below the global Internet penetration of 56%. Mobile connections stand at around 35 million, or about 40% of the population.

The country has access to broadband internet via the West Africa Cable System (WACS) subsea cable mostly through the Congolese Post and Telecommunications Company (SCPT) which retains a monopoly on broadband access at present.

Given the expansive geography and the low levels of digital penetration, the country could benefit immeasurably from a subsea cable / Leo constellation network solution.

### Example 2: Boosting Broadband Access in Mali

Mali is the eighth-largest country in Africa, with large tracts of sparsely populated desert and hard to reach settlements. Of the 20 million population, only 4.8 million or 24% of its citizens have access to the Internet. Mobile broadband penetration stands at under than 1%.

Security issues have delayed the building a national backbone network. Underinvestment in fixed-line networks has also meant that the telecom infrastructure is barely adequate to serve consumer needs in most towns and is largely absent in most areas of the country.

A hybrid configuration of LEO satellites and subsea cable partnership could provide digital services to dispersed communities for applications in education, healthcare, agriculture and mining amongst other practical use cases.

## Conclusion

LEO satellites present a greenfield play that complements the role of submarine cables. Comparative performance and cost analysis of LEO satellites and submarine cables points to the many synergies between the two industries.

Submarine cables offer substantially higher capacity and roughly equivalent latency at a substantial discount in the estimated cost at 1,000x for a unit Gbps-month. While submarine cables form the backbone of Internet traffic, LEO satellites can act to extend the reach of submarine cables into markets that cannot be reached otherwise. Land-locked countries and inland markets far from the seashore are prime candidates for combined LEO satellites and submarine services network configurations.

In addition, LEO satellites complement sub cable infrastructure in various types of applications such as redundancy for high-value traffic and a stop-gap solution for fiber services which cannot reach every single point on earth in the same ease as that of LEO satellites. A market such as Africa, where many submarine cables land but have ample unutilized capacity, provides a sensible opportunity for LEO operators to reduce their cost structures by partnering with submarine cable operators.

## References

[1] Telegeography Almanac, 2020.

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[3] Application for Approval for Orbital Deployment and Operating Authority for the SpaceX NGSO Satellite System, November 15, 2016.

[4] SpaceX Starlink Update, https://bit.ly/3g3vfa2, October 13, 2020.

[5] SpaceX's Shotwell: Starlink internet will cost about $10 billion and 'change the world'. E. Kelly. https://bit.ly/37vV26P, 2018.

[6] Comparing LEO Satellite Constellations: How They Stack Up!. Frank Rayal, https://bit.ly/33P5Ax8, December 6, 2020.

Angola Cables is a multinational company operating in the ICT industry with tailored connectivity solutions for the wholesale and corporate segments. With a robust transport infrastructure and highly interconnected IP network, Angola Cables allows customers with greater access to the largest IXP´s, Tier 1 operators and global content providers. Through SACS, Monet and WACS submarine cable systems the company directly connects the Americas, Africa, and Europe and has established partnerships to reach Asia. We manage the Tier III Data Centre AngoNAP Fortaleza (Brazil) and the Data Centre AngoNAP Luanda (Angola) as well as PIX and Angonix - one of the largest Internet Exchange Points (IXPs) in Africa. Angola Cables also provides digital services for multiple industries with a customized cloud and gaming resources available to customers. For more information, visit: https://www.angolacables.co.ao/

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