Low Earth Orbit (LEO) satellite telecommunications platforms: Feasibility and applications in the electric utility

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***Abstract* — This study explores the feasibility and applications of Low Earth Orbit (LEO) satellite telecommunications platforms, particularly Starlink and OneWeb, in the electric utility sector. The integration of these high-speed internet constellations promises to enhance global connectivity, particularly in remote areas. The project assesses the potential benefits for Iberdrola, Spain's largest electricity company, by evaluating the technical capabilities and economic feasibility of these technologies. The study delves into the evolution of satellite telecommunications, categorizing commercial solutions based on orbit, service type, frequency, antenna type, and cost. Through detailed use case analyses, including renewable generation parks, remote substations, and corporate office communications, the study identifies viable applications for LEO technologies. The performance of Starlink is tested for parameters such as speed, latency, and packet loss, revealing potential as a backup technology or for corporate services. The conclusions emphasize the need for further technological advancements and market competition to fully integrate these solutions into utility telecommunications infrastructures.**

***Index Terms*-- Smart Grid, Satellite, Telecommunication, Utilities, Commercial solutions, LEO (Low Earth Orbit), Digitalization, Mbps, Jitter, Latency, Packet loss, Availability.**

I. *Introduction*

The integration of LEO (Low Earth Orbit) high-speed internet constellations, such as Starlink and OneWeb, represents one of the most promising technologies for improving global connectivity in a safe and environmentally sustainable way. Without geographical barriers, with global, fast, competitive coverage and enhancement of economic and social development, these constellations are pioneers in the democratization of internet access.

Thanks to advances in reusable rocket technology, such as those from SpaceX, and improvements in satellite manufacturing, which are now smaller and cheaper, the cost of launch has been drastically reduced by being able to launch multiple satellites simultaneously. This has significantly lowered the barriers to entry into the telecommunications space segment creating a new environment. It is here where these constellations have emerged, opening up competition and allowing the participation of numerous agents in the sector, who continuously propose new solutions.

The advanced capabilities offered by LEO constellations have great potential to be integrated into the *utilities* sector, improving the digitalization of the network and facilitating communication in remote areas. The ability to provide high-speed connectivity in rural and hard-to-reach areas is critical for the efficient monitoring and management of energy infrastructure, as well as for the implementation of smart technologies on the grid. This interest is reflected in this project by Iberdrola, Spain's largest electricity company with an international presence, which seeks to assess whether it can take advantage of these new technologies across its many and dispersed assets.

Satellites, since their debut in 1957 with Sputnik I, have undergone tremendous evolution. Initially, their applications were primarily scientific and military. However, over the decades, their role has expanded to cover a much broader spectrum. Today, satellites serve various functions including private communication, meteorology, global positioning systems (GPS), as well as maintaining their crucial roles in military and scientific domains.

In this study, considering the scope and context, the focus will be specifically on satellites dedicated to commercial telecommunications.

II. *Comercial telecommunication satellite solutions*

Commercial satellites are the ones operated by private companies to provide telecommunications, internet, and other services to the public both individual customers and businesses. However, they are specialized towards different types of communication services with different advantages and constraints. Thus it is necessary to carry out an analysis to evaluate which aligns with Iberdrola's needs

In order to facilitate the evaluation of the technologies, a segmentation needs to be carried out based on their orbit, service, cost and type of antenna used.

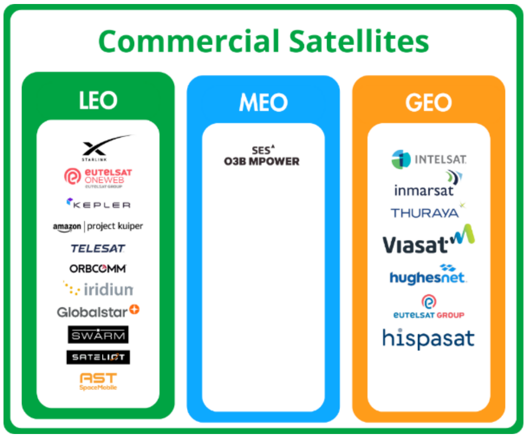

Figure 1: Categorization by Orbit

There are three categories of orbit based on their altitude; Geostationary Earth Orbit (GEO), Medium Earth Orbit (MEO), or Low Earth Orbit (LEO). And it is orbit which determines the latency and relative position relative to the observer on Earth. GEO (35,786 km) satellites have latencies of approximately 600 ms and remain static relative to the observer, while LEO satellites (500km–1500km) have much lower latencies, between 30 ms and 75 ms, and move relative to the observer[1], [2], [3]. This movement forces the antennas to dynamically follow the satellites to maintain the connection, as well as requiring jumps between satellites when they leave the field of view. The altitude of the LEO orbit influences how long satellites remain in the field of view, although this is usually less than an hour. Satellites in MEO orbits also suffer from this, but their viewing times are longer. Dynamic positioning complicates constellation operation and antenna orientation, although the new digitally oriented phased array antennas have mitigated this challenge considerably.

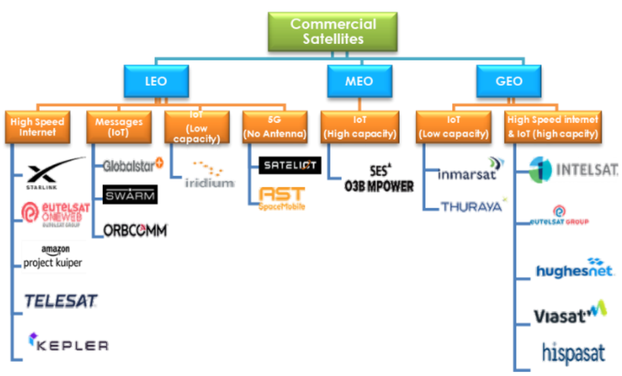

Figure 2: Service Categorization

Regardless of the orbit, three types of service have been identified: **IoT messages, low-capacity IoT, and high-speed internet.** There are other services such as 5G, which are not yet available. An additional comment should be made on IoT message technologies. As these are not really a data transmission technology, they cannot be considered in the study, as they do not fit Iberdrola's needs.

The study identifies the key characteristics that differentiate technologies according to their capacity. Depending on the service, higher or lower frequency bands are used. High frequencies provide greater bandwidth and, therefore, more transmission capacity, but they are more susceptible to environmental factors, such as heavy rain, which causes the phenomenon known as "rain fade"[4], and can cause a total loss of communication. Therefore, **a higher frequency implies greater capacity but with more vulnerable communications, and vice versa.**

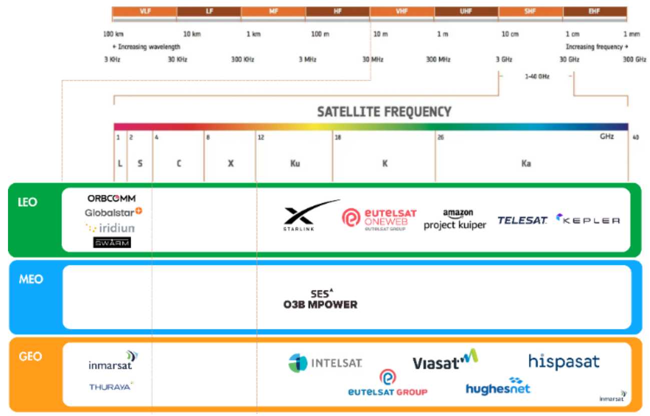

Figure 3: Categorization by frequency

The frequency used also affects the type of antenna required. Robust low-frequency, low-capacity telecommunications services require small antennas (patch), while high-frequency telecommunications services require larger antennas, such as VSATs (Very Small Aperture Terminals) or phase antennas. However, the market for phased antennas, is focused on the development of more powerful and smaller antennas.

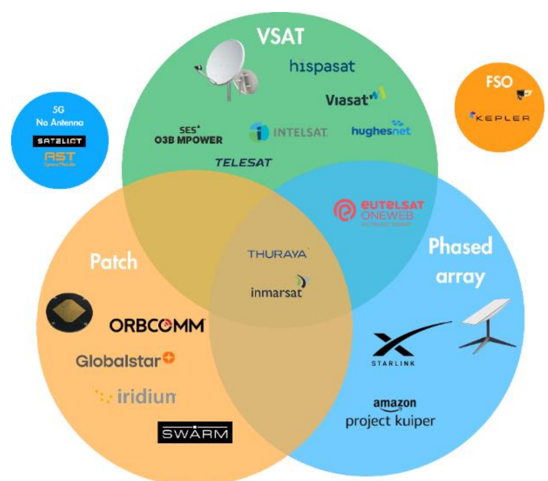

Figure 4: Categorization by antenna type

Finally, a categorization of the cost of traffic has been made. The costs have been estimated based on the tariffs of the main distributors. Given the difficulty of making direct cost comparisons, it has been approximated using the cost per MB. This calculation is complex because low-capacity technologies offer a base price for an initial range of data traffic and then charge higher additional fees for overage usage. In contrast, high-capacity technologies typically have a minimum supply that far exceeds the traffic needs of the telecommunications system. Therefore, the classification presented should be considered as a rough guide.

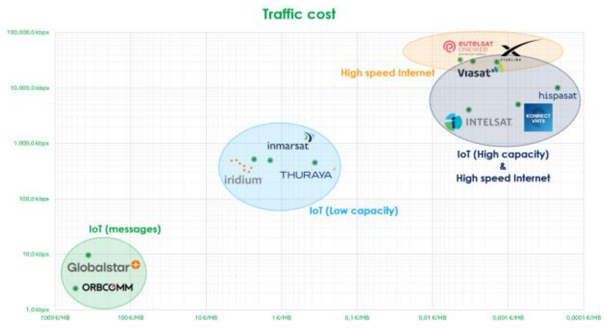

Figure 5: Categorization by Cost

III. Use Cases

Satellite technologies are the last technology to be considered when designing any telecommunication system. They are preceded firstly by optic fiber networks and then by wireless networks. These networks are preferred due to their technical characteristics; higher speed, higher transmission capacity, lower latency, and lower transmission costs. Thus, satellite communications are present in few circumstances, only employed where terrestrial networks are either not feasible or inaccessible, which is the case of rural and remote areas, at sea or during natural disasters, when the communications infrastructure is damaged.

Nevertheless, there are scenarios where satellite technologies could be considered within Iberdrola's owned assets. But first an analysis must be conducted on the feasibility of providing secure communications, and covering their crucial necessities, specific for each use case. Three use cases have been identified as potential options; Renewable generation parks and substations, Remote secondary substations (transformer stations, CTs) and remote reclosers (OCRs), and Corporate Office Communications

A. Renewable generation parks and substations

The different needs and constraints, common to this type of installation, are added up and summarized in the following table.

Large-scale electrical power plants & substations

Traffic	8 GB/month
Capacity	25 kbps
Latency	< 1s
Packet loss	Critical
Availability	> 99%
Reference feasibility cost	100 €/month/station
Antenna size	Not critical

Table 1: Large-scale electrical power plants & substations use case parameters

Narrowing down the commercial technologies identified by currently available, with over 95% of availability over the Spanish territory, and eliminating messages IoT. The last because messaging technologies are not really true data communication and do not fit with any of the scenarios or the telecommunications architecture of Iberdrola. The remaining potentially suitable technologies (for the three scenarios) are:

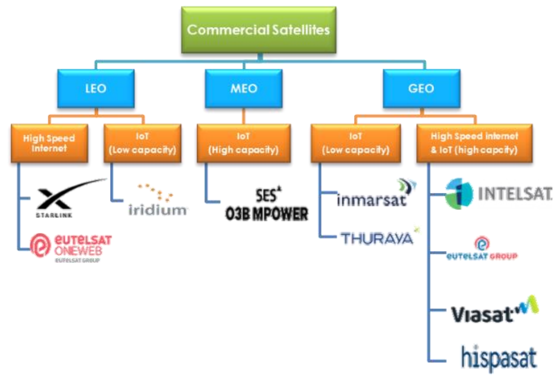

Figure 1: Suitable technologies

In this use case, the size of the antennas does not represent a constraint. The only restrictions are transmission capacities and costs. As mentioned, the capacity requirement is around 25 kbps symmetrical, which can be supplied by all of the suitable technologies. At this final stage, the analysis needs to filter through their cost feasibility. The threshold is 100€ for 8GB per month (0.0125€/MB).

Figure 2: Commercial technologies cost feasibility (Large-scale electrical plant use case)

In terms of cost feasibility, Low Capacity IoT technologies are clearly not feasible, their cost is 2 orders of magnitude higher than the threshold. This only leaves High Speed Internet solutions, both GEO and LEO.

Currently, Iberdrola has the GEO VSAT High Speed Internet technologies in use. They have sufficient capabilities to cover all telecom requitements, including the need of dedicated private channels to ensure the telecommunications, highly important in real-time systems such as monitoring, that requires determinism.

LEO high speed internet technologies offering meet all the capabilities requirements. Nonetheless, this have to be tested to ensure the network characteristics. This tests have been carried out and are described in section V. Then, based on the results, the viability and possibilities for integration will be evaluated. This evaluation will be carried out in the conclusions of the study.

B. *Remote secondary substations (transformer stations, CTs) and remote reclosers (OCRs)*

This use case share multiple similarities with the large-scale energy sites use case. In the end, it is simply a downscale. Large-scale energy sites have a large number of assets to control, while this use case represents only a small part of those assets separately. The downscale of traffic requirements is not paired with the number of elements. If it were, the requirements would be much lower. This transmission speed capacity is also influenced by the telecommunications protocol. Thus, the downscale is not proportional to the reduction of communicating devices.

Remote reclosers and remote secondary substations have a critical downside, reduced available space. They are small assets, typically located on posts or in small buildings. Thus, technologies that utilize big antennas are not feasible. In all the other aspects, they mirror big energy sites but in a smaller scale referring to data traffic and capacity rates. As they only require to transmit the data from SCADAs and AMIs, as well as being capable of receiving control orders. An estimate of Iberdrola's needs for this kind of assets is the following:

Remote Reclosers and Secondary Substations

Traffic	300 MB/month
Capacity	1 kbps
Latency	< 1 s
Packet loss	Critical
Availability	> 99%
Reference feasibility cost	10 €/month
Antenna size	Critical

Table 2: Remote reclosers and Transformers substations use case parameters

Filtering the technologies that require large antennas is complex. Numerous satellite operators leave the task of developing antennas to third actors that have different incentives. Nevertheless, as it is the market the one that fixes those incentives, they can be somehow classified and superficially characterized. The first classification is made in the type of antennas the technologies typically use.

Firstly, all VSAT technologies are discarded because its size. Only Low Capacity IoT and LEO High Speed Internet are suitable for this assets at this stage of the analysis.

Costs is the final restraining aspect. Because of the fact that this assets are small and numerous, and costs has to be more competitive than the actual system (an operator that reads the meters). Costs filter Low Capacity IoT devices, their price surpass the threshold of 0,033€/MB (300 MB/month; 10€/month). The Intelsat marketers offer 45€ for 50MB/month, Iridium 240€ for 100MB/month and Thuraya 350€ for 1GB/month. Extrapolating the prices to the needs of each device while keeping the cost €/MB, they are all much higher than the €10 budget.

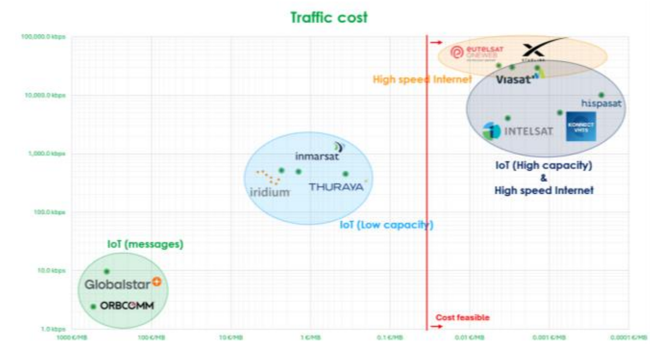

Figure 3: Commercial solutions traffic cost (Reclosers and SS use case)

Then, the remaining technology under study is the new LEO High Speed Internet. This however, could also be discarded for several reasons. First, the current antennas are a bit larger than desired. It is known that manufacturers are working on smaller antennas, but these are not expected for a few years, at least 2026, with the arrival of Kuiper. Kuiper announces that it will bring a 7cm x 7cm antenna to market, and the competition (Starlink and OneWeb) will probably be force to come up with similar options.

On the other hand, due to the residential focus, the minimum offer is 40GB. Excessive for the needs of this use case. Even if the cost (€/MB) is much lower than required, the cost exceeds the budget due to the distant minimum service contract. Finally, the cost of antennas cannot be afforded for this type of device. Currently, due to the new technology of phased array antennas, the prices are extremely high, reaching more than 15.000 €/antenna. For the other cases, the amortization can be studied, but for this case it is intuitive that it is extreme and does not even require a study. Therefore, **there is no current feasible commercial satellite technology option.**

C. *Corporate Office Communications*

There are cases where substations and generation plants have integrated offices rather than dedicated buildings in nearby towns, especially in remote locations. These need to meet the requirements of office telecommunications services for a small number of employees, while not being covered by the common technologies (fiber optic, backed up via cellular networks).

Corporate telecommunications can be reduced to video calls, internet access and a few activities more. Offices have high traffic sites, and require small latency for telecommunications as services are real-time and QoS might be affected.

Employee internet consumption breakdown

Email Communication	100 MB/day
Internet Browsing	400 MB/day
Video Conferencing	2500 MB/day
File Downloads/Uploads	500 MB/day
Cloud Services	500 MB/day
Total	**4 GB/day**

Table 3: Data traffic consumption breakdown

Typically, the quality of these services are not affected until the latency surpasses the threshold of 150 ms. At this point, videoconferences and calls may start to lag and the communication will be affected. Other requirements that corporate communications have are included in the following table.

Office

Traffic	1 TB/month
Capacity	10 Mbps
Latency	150 ms
Packet loss	Non critical
Availability	> 99%
Reference feasibility cost	1000 €/month
Antenna size	Non critical

Table 4: Office use case parameters

For the monthly traffic requirement, an average of 10-11 employees has been assumed. With each consuming 4GB/day, and considering that a month has 22 working days, it results in a consumption need of about 1 TB/month.

The first filter to consider is the latency, technologies that have delays over 150 ms cannot be considered. This excludes all GEO solutions which have latencies of around 600 ms, due to their distant altitude. Furthermore, due to the high traffic speeds IoT(low capacity) technologies are also discarded. Furthermore, due to their lack of price disclosure, SES technology has also been discarded.

Only the new LEO high speed internet technologies meet the specified requirements. Finally, for economic feasibility, the cost of service should not exceed the threshold of 1000€/month. Their prices will be covered in depth in the following chapter. However, to show the feasibility, it can be anticipated that, for instance, Starlink has a 1TB/month plan for 180€/month. Almost an order of magnitude under the threshold.

Once again, this technologies are suitable in theory, based on the offering. However, for an unbiased assessment, they will be tested and evaluated based on the results obtained.

IV. LEO PLATFORMS STUDY

The study on LEO constellations (technology, business orientation, equipment, rates, operating model, etc.) was deepened, with the main characteristics presented in Table 5. Firstly, although OneWeb's technology is better aligned with Iberdrola's needs due to its ability to dedicate telecommunications segments and offer availability guarantees with SLAs[5], it has been found to be unfeasible due to the high cost of its equipment, specifically the antenna. The market price of this antenna is around €20,000, far from the budget of around €1,000 per installation.

	Starlink	OneWeb	VSAT
Orbit	LEO	LEO	GEO
Altitude	500 km	1200 km	36570 km
Latency	30 ms	70 ms	600 ms
Uplink Speed	~ 22 Mbps	~ 32 Mbps	~ 10 Mbps
Downlink Speed	~ 190 Mbps	~ 190 Mbps	~ 200 Mbps
Phased array antennas	Yes	Yes	No (some options)
Size	57cm x 51cm	56cm x 45cm	100cm x 100 cm
Price	2.000 €	20.000 €	2.000 € + 1.000€ (installation)
Installation	Easy	Easy	Difficult
SLA (Guaranteed channel)	No	Yes	Yes
Availability	95%	99%	99%

Table 5: Technology Comparison

Starlink on the other hand, though it is customer oriented (B2C), still can theoretically be a viable option to include to Iberdrola's telecommunications architecture[6]. However, it is important to check that the technology is aligned with the offered characteristics.

The service evaluation has been conducted through two different test. **Firstly**, to measure **traffic speed**, the Cloudflare speed measurement tool was used. This tool not only provides a detailed summary of a specific test but also allows data logging. The instant speed test is useful and provides the user with interesting graphs. However, this study requires a long-term view to truly evaluate Starlink's capabilities. It is necessary to determine whether the results of instant speed tests are stable or sporadic. Therefore, this software was chosen, as the Cloudflare Speedtest allows the generation of a ping log in CSV format. For the test, measurements of 20 pings were taken every minute for half an hour in three sessions at different times of the day over several days.

To determine the download speed, both 10 MB and 25 MB messages have been evaluated, while for the upload speed, the data from 10 MB messages have been assessed.

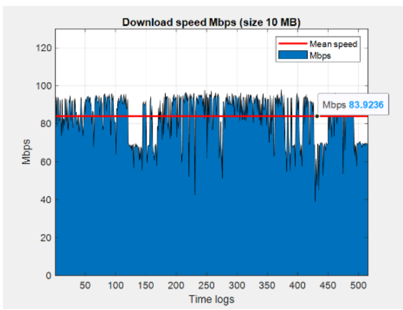

Figure 4: Download speed 10MB

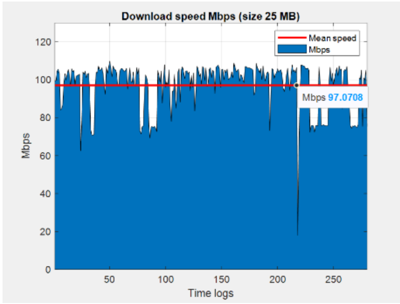

Figure 5: Download speed 25MB

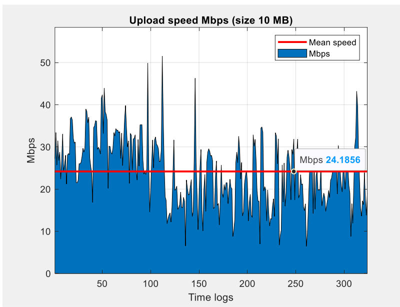

Figure 6: Upload speed 10MB

	Download		Upload
Message size	**10 MB**	**25 MB**	**10 MB**
Average	83.92 Mbps	97.07 Mbps	24.19 Mbps
Standard Deviation	12.01 Mbps	12.36 Mbps	7.96 Mbps
Minimum	38.75 Mbps	17.96 Mbps	6.47 Mbps
Maximum	97.91 Mbps	109.84 Mbps	51.50 Mbps
Median	90.12 Mbps	102.52 Mbps	24.49 Mbps

Table 6: Speed test results

In terms of download speed, the 25 MB messages have a higher average speed (97.07 Mbps) compared to the 10 MB messages (83.92 Mbps), suggesting that the network can efficiently handle larger downloads. The standard deviation is similar for both message sizes, around 12 Mbps, indicating **consistent variability** in download speeds. However, the minimum and maximum speeds vary significantly, with a lower minimum and a higher maximum for the 25 MB messages. This could be due to variations in network load or other external factors during the tests. When compared to the speeds advertised on Starlink's availability map on their website, which state that Spain should experience download speeds between 137 Mbps and 207 Mbps, the **recorded average speeds are noticeably lower**. The discrepancy between the advertised speeds and the measured speeds cannot be contested since Starlink does not offer a service level agreement (SLA) guaranteeing performance. This lack of guaranteed service levels is a critical consideration for utilities like Iberdrola.

Regarding upload speed, the 10 MB messages show an average of 24.19 Mbps, which falls within the range stated by Starlink for Spain (19 Mbps to 35 Mbps). The standard deviation of 7.96 Mbps, if normalized, would indicate even **greater variability than the download speeds.** Despite this, the minimum upload speed is still a relatively decent 6.47 Mbps.

Secondly, to measure parameters such as **latency and packet loss or availability**, a more precise tool called PingPlotter has been used. This tool allows pings to be sent at a maximum frequency of 2.5 seconds per ping to various IPs. For testing, a series of 11 IPs from different websites with databases in various countries were used. These included the DNS of Google (8.8.8.8) and Cloudflare (1.1.1.1), as well as the websites of Google, Iberdrola, Comillas, IEEE, Starlink, OneWeb, X (formerly Twitter), Amazon, and PingPlotter.

The tests conducted involved recording pings to the beforementioned 11 representative IPs every 2.5 seconds for approximately 4 hours, resulting in a total of around 5000 pings per IP. This large number of pings allows for more accurate data on the performance of the Starlink network.

The results of the tests indicate that the overall average latency across all tested IPs is **approximately 153.63 ms**, which is significantly higher than the 30-36 ms announced on their website. This discrepancy is likely due to the fact that the website's figures do not account for delays outside physical data transmission from the antenna to the gateway, such as server and other network-related delays. Starlink satellites have inter-satellite communication (ISL), meaning that the user communicates with one satellite, which can transmit the signal to the nearest gateway, or if that gateway is very congested, it can communicate with other satellites to route the signal to a different gateway less congested. This means that the destination **gateway for the transmitted message is not guaranteed**. It can be either inside or outside the national territory where the signal was emitted. These gateways, owned by Starlink, are where the signal exits to the internet.

The overall average packet loss percentage is approximately 2.69%, reflecting the reliability and stability of the network. Within the different IPs, packet loss ranges from 2.4% to 2.8%, indicating a relatively stable network with occasional packet loss.

The gray band visible in the graphs corresponds to the suspension of equipment during the lunch break. This pause however, did not affect the accuracy of the test results. Moreover, due to the similarity of all the graphs, it can be deduced that the performance does not vary significantly based on the website, the database it uses, or its location. Therefore, for a more in-depth analysis, it was decided that focusing on one website, Google DNS (8.8.8.8), would be sufficient.

The exported data recorded was treated with MATLAB for representation and better understanding. The following graphs are displayed. The first is a representation similar to the graph presented by PingPlotter, showing latency records over time with packet loss incidents marked. The second and third graphs delve deeper into **packet loss**. In these, the **samples are grouped into 5-minute intervals, meaning 120 samples per group (1sample/2,5s)** to provide the most accurate representation of the data. Finally, to better visualize the latency, a box plot and its frequency distribution are included to observe its variability.

Latency statistics:

Average	Median	Variance	Standard_Deviation	Minimum	Maximum
161.64	154.61	884.42	29.739	132.12	483.68

Packet loss (PL) percentage: 2.4106%

Table 7: Google DNS (8.8.8.8) communication statistics

The results are quite promising. The average latency is 161.64 ms, with a median of 154.61 ms, which indicates that most latency values are clustered around the median. The variance of 884.42 and the standard deviation of 29.739 ms show some variability in the latency, with a minimum latency of 132.12 ms and a maximum of 483.68 ms. The packet loss percentage is 2.4%, which is relatively low, indicating a reliable connection with minimal data loss.

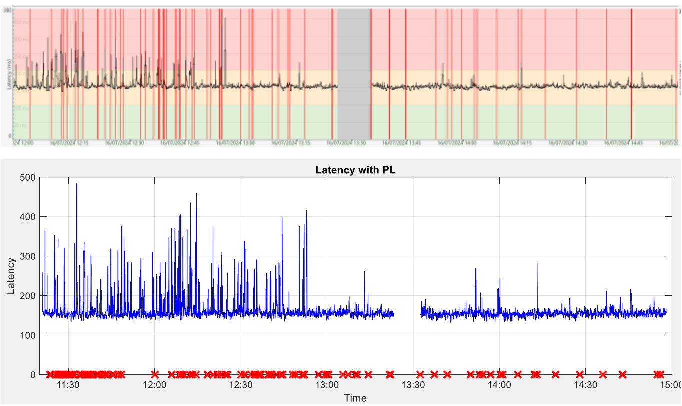

Figure 7: Latency over time, Google DNS (8.8.8.8) (Top: PingPlotter; Bottom: Matlab)

The graph shows that latency hovers around 160 ms for most of the time, with some notable spikes. These spikes are primarily observed in the first part of the test. Since the conditions remained constant throughout the testing period, these deviations can be attributed to the network itself, highlighting a lack of stability.

Regarding availability and packet loss, it is in the **initial phase of the test where most failures are observed**. Although the network **shows potential in its characteristics, especially towards the end**, it loses credibility due to its **variability**. Instances of packet loss reaching up to 10% completely rule out the network for certain utility applications, where consistent and stable performance is crucial.

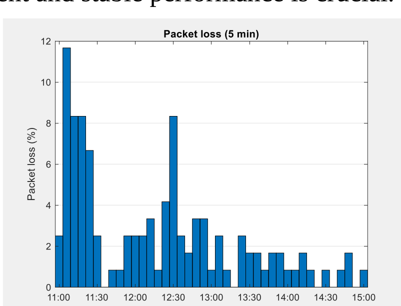

Figure 8: PL (%) over time, Google DNS (8.8.8.8)

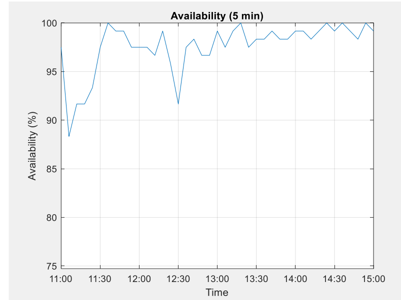

Figure 9: Availability (%) over time, Google DNS (8.8.8.8)

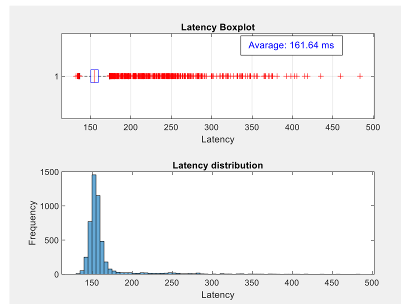

Figure 10: Google DNS (8.8.8.8), Top: latency boxplot; Bottom: latency frequency distribution

In summary, Starlink tests resulted in the following:

	Uplink Speed	Downlink Speed	Latency	Availability	Packet loss
Avarage	24,19 Mbps	97 Mbps	153,63 ms	97,31%	2,69%
Variability (Std.)	7,96 Mbps	12,3 Mbps	29,94 ms	2,64%	

Table 8: Starlink test results

The results of the tests that have been carried out place starlink with average telecommunication parameters comparable to the networks of 4G operators. But its high variability has a major drawback. In addition, this variability is aggravated by temporality. In the tests there have been periods of poor results and others of excellent results.

V. CONCLUSIONS

Based on the results obtained, it is concluded that the possible uses of Starlink are mainly as **a backup technology, or specifically dedicated to corporate services**. Iberdrola uses SDN (Software Defined Networking) devices to seamlessly integrate two or more telecommunications infrastructures into a single installation. These devices allow total control of telecommunications, making it feasible to dedicate a specific service to a certain technology.

The first potential use case is renewable generation parks, currently served exclusively by VSAT with two antennas. Starlink could be integrated by replacing one of the technologies to create a GEO-LEO service. This would not only maintain redundancy with other technology, but also allow for improved corporate services by running them on the LEO segment.

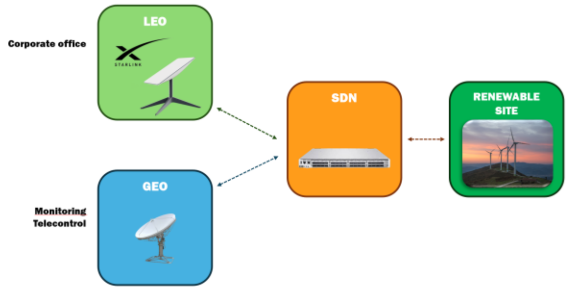

Figure 6: Architecture with Starlink integration (renewable generation park)

Another scenario where Starlink has potential utility is as a backup technology for infrastructures currently connected via optic fiber (O.F.) or radio (P2P or P2M) networks. Currently, Iberdrola uses operator networks as a backup to its own network (fibre optics, point-to-point radio (PP), point-to-multipoint radio (PMP)) in substations. While 4G can be used as a backup where there is coverage, in areas without coverage, VSAT GEO or LEO could be employed. The main advantage of Starlink as a backup would be its self-sufficiency with respect to electricity supply, since Starlink satellites do not depend on terrestrial electricity supplies, unlike traditional mobile and radio networks. This autonomy is particularly advantageous compared to 4G operator networks, as private networks are already designed independently of the electricity supply.

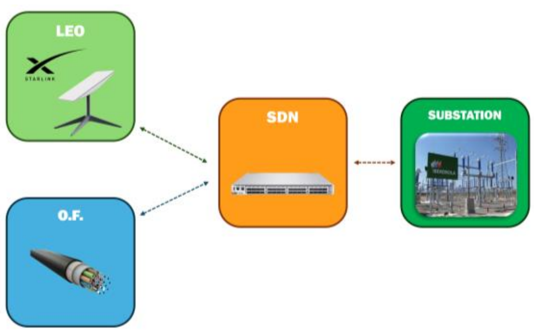

Figure 7: Architecture with Starlink integration (Substation, OF)

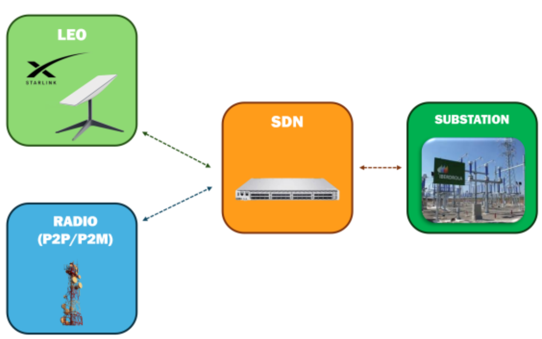

Figure 8: Architecture with Starlink integration (Substation, Radio)

In short, Starlink already has certain applications where it can be implemented effectively. In addition, as technologies evolve, the range of uses for Starlink will expand. In two years, the arrival of Amazon Kuiper, which promises to vastly surpass Starlink services with more powerful and smaller antennas, will bring real competition to the Starlink market. Additionally, as the cost of antennas decreases, OneWeb will become a very attractive technology. And finally, Starlink's business customers are known to be continuously requesting dedicated IP services. Who knows if they will respond to this demand and become a much more reliable service?

VI. REFRERENCES

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