Low Earth Orbit Satellite Systems

Comparisons with Geostationary and Other Satellite Systems, and their Significant Advantages

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Abstract: Satellites have been around for many decades, yet the low Earth orbit (LEO) was avoided as the cost exceeded the demand until recently. This paper is based on a live presentation to the Australian Telecommunications Association (TelSoc) by Ruth Pritchard-Kelly, Senior Advisor on Regulatory Affairs for OneWeb, and was chaired by TelSoc Broadband Futures Group member, John Costa. This paper describes the new generation of LEO satellites, how they substantially differ from earlier satellites, and the factors now making them not only viable but increasingly indispensable as part of a global communication ecosystem. The paper then introduces OneWeb's specific LEO plans, including details about deployment in Australia.

Keywords: Geostationary Satellite, Non-Geostationary Satellite, Low Earth Orbit, Medium Earth Orbit, Intersatellite Link

Introduction

This paper is based on a Forum about Low Earth Orbit satellites (LEOs) held in August 2021, the eighth in a series by the TelSoc Broadband Futures Group. LEOs are attracting global attention for provision of high-speed broadband in rural, remote, mobile, aeronautical, and maritime areas, particularly underserved or completely unconnected areas not adequately served by other infrastructures or prior satellite technology.

The Broadband Futures Group is currently focusing on broadband inclusion, affordability, and accessibility, particularly in regional, rural, and remote areas. The presentation and this subsequent paper consider factors leading to growing interest in LEOs. Differences between geostationary satellites (GSOs or GEOs) and non-geostationary satellites (NGSOs), specifically LEOs, are discussed, as well as differences among the proposed LEO providers. The paper then

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gives a brief introduction to OneWeb's initial LEO plans with highlights of the deployment in Australia, planned for late 2022. The paper concludes with a wide-ranging selection of questions and answers from the live forum. A postscript completed by the presenter seven months after the Forum, provides a brief update on OneWeb's Australian plans.

New satellite technology is dynamic and evolving and will effect rapid social and economic change in response to growing user demand and governmental inclusion pressures, and will support critical national and global communication and security needs.

Forum Presentation

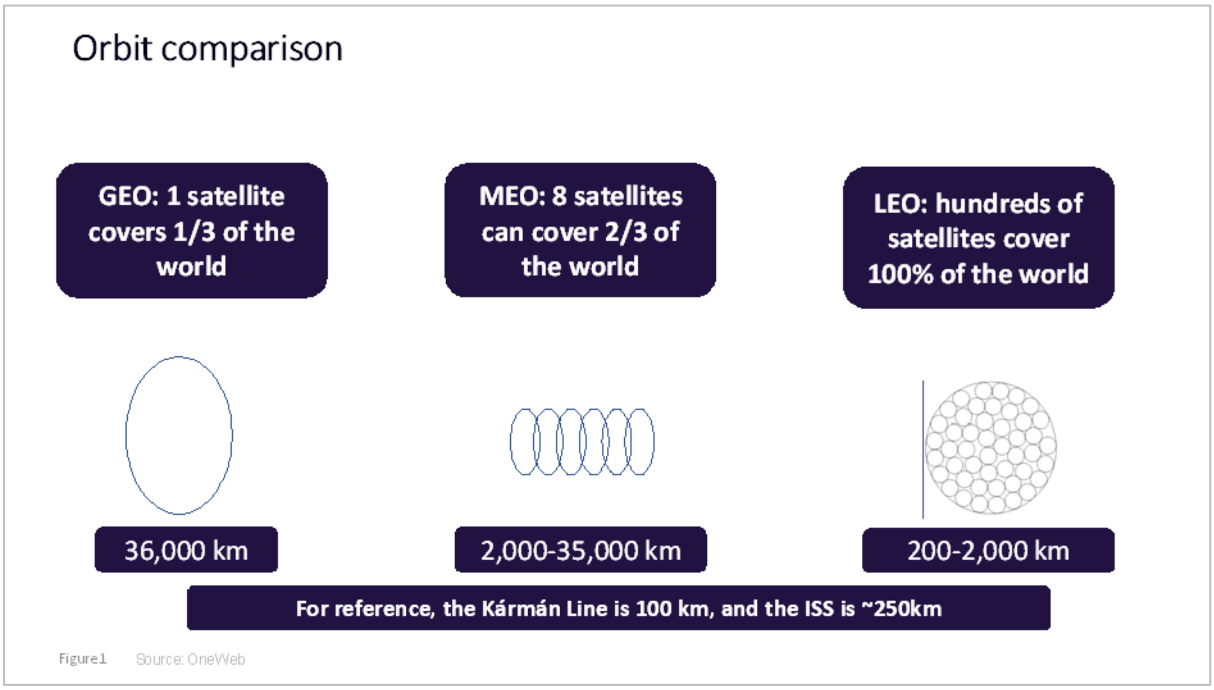

Figure 1. Orbit comparison

Orbital comparisons

Geostationary satellites cover massive areas of the world where a single GEO can cover a third of the world (Figure 1). Sixty years ago, engineers already understood the difference between geostationary satellites and LEOs. They knew that satellites closer to the earth would provide better communications and phone connections, but at that time were very unaffordable. The brilliance of Arthur C. Clarke (1945), the science-fiction writer who first proposed the concept of "radio stations in outer space" in 1945, is that he realized one could put merely three transceivers in a geostationary orbit and that would be all it would take to cover the entire globe. So that is what has been done for decades. Then, about 10 years ago, satellite company O3b (so-named for the "Other 3 Billion" people in the world without an Internet connection) realised that technology and demand had developed to the point where it could develop a cost-effective communication business plan by splitting the difference between GEO and LEO, planning a constellation in a medium Earth orbit (MEO) at roughly 8,100 km, which would only need 8–10 satellites to cover 80% of the world's population. More about the development of modern-day NGSOs is provided below.

Current satellite services and end-user experiences

Earlier satellite technology mostly provided limited end-user experiences that often came at high cost and with high latency, which became problematic for serving the growing demand for two-way, high-speed, low-latency Internet services. O3b's MEO could not quite cover the poles, but, beyond that, achieved the key target of population coverage and, due to the much shorter distance from the Earth, provided very low latency. On the heels of O3b's success, there are now four or five serious LEO competitors, all of whom are in the process of launching truly low Earth orbit satellites with around 50 ms round-trip latency. A couple of factors have contributed to that. In the past, people became frustrated with the performance limits of geostationary services, which were also very expensive. Technically speaking, reliability issues can arise within any part of the link to the user, be it the satellite, fixed wireless connectivity or Wi-Fi. However, the key issue was that, with the rapid growth of the Internet, demand for higher speed two-way connectivity for applications of data became key. Users would often time out mid-session if relying on geostationary satellites.

Non-geostationary constellations offer lower latency

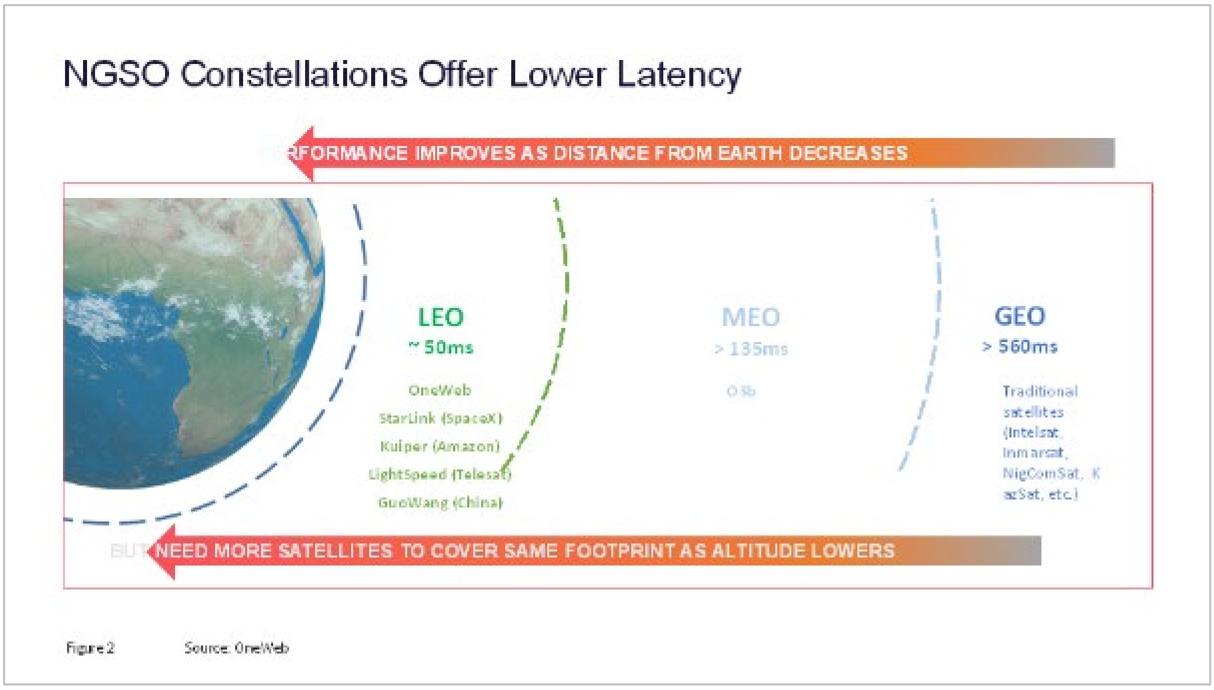

Figure 2. NGSO constellations offer lower latency

Now that the supply is less costly and the demand is higher, lower Earth orbit non-geostationary satellites is where recent constellations are all headed. Of these, OneWeb currently operates at the highest altitude of about 1,200 km, while Starlink, Kuiper and Guo Wang operate at around 500 km (Kulu, 2022). LightSpeed appears to be cutting the difference at about 800 km. O3b operates at roughly 8,100 km. The only drawback of O3b at the slightly higher MEO altitude is that its equatorial orbit does not cover north or south of 45 degrees. At the farthest extreme GEOs have greater individual coverage. That might appear favourable, except that they are designed as point-to-multipoint technology, and achieve that outstandingly. However, two-way, real-time connectivity is not their specialty. Latency (the delay between sending and receiving a signal) on GEO satellites at around 560 ms as a result of the much greater distance involved, compared to around 50 ms for LEOs (Figure 2).

Transformative satellite production

Substantial development has occurred in relation to throughput, launch costs, and therefore time to market. Very quickly a new generation of LEO satellites has drastically reduced costs for launches and assembly-line manufacturing of satellites (Figure 3). Some may recall the clean room of traditional satellite manufacturers, where it used to take a year, sometimes up to two, for hand-made construction. Now there are assembly lines in factories, not just for OneWeb, but also SpaceX and most likely Amazon are also looking to such an approach. This now means a satellite can be very quickly produced in under a day. Apart from cost savings, this translates to an ability to manufacture and start operating a new satellite generation in a matter of weeks, no longer a decade.

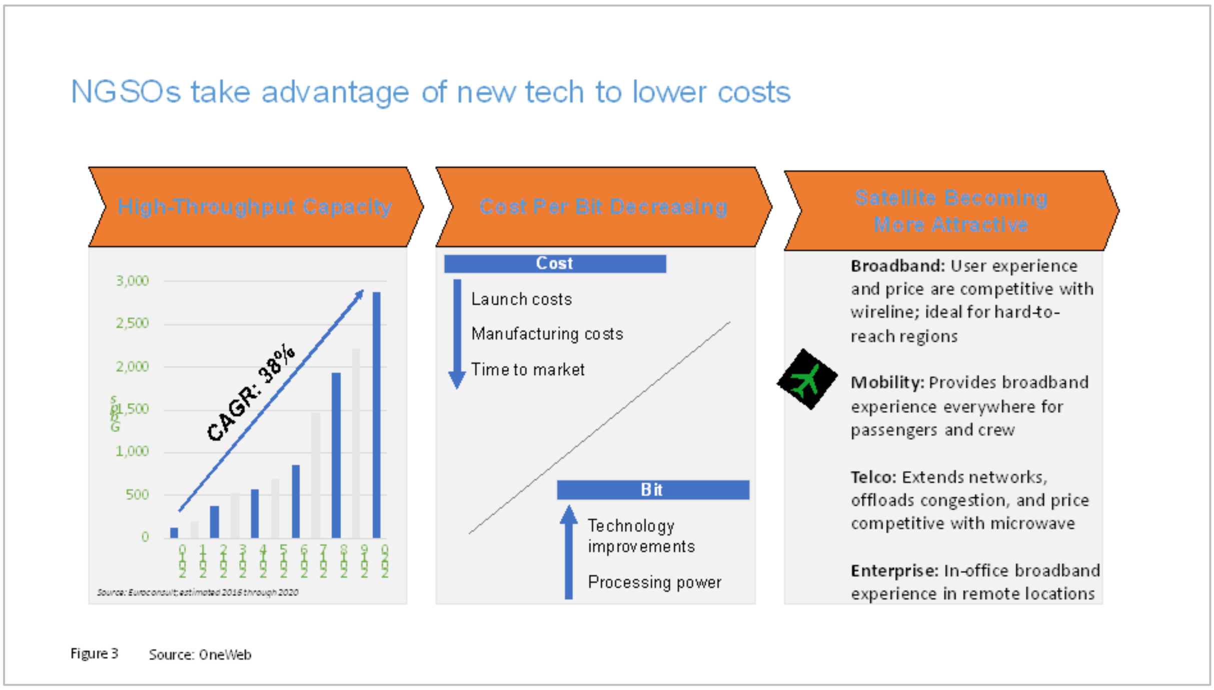

Figure 3. NGSOs take advantage of new technology to lower costs

Consequently, demand has skyrocketed, both because of the increased demand for high-speed Internet and also because of increased use of personal mobility devices. Those two things have changed the world from 20 years ago, when a whole group of LEOs in the 1990s tried to implement this concept but were not successful, resulting in some spectacular bankruptcies. Many in today's satellite industry worked in the 1990s for Iridium and will remember that it went into and out of bankruptcy but survived because of one major customer (the US Department of Defense), which allowed Iridium to survive long enough to benefit from the rise of the Internet and the explosion in demand for connectivity while mobile that followed. As an early starter, Teledesic failed despite being operationally ahead of its time. The concept was exceptional, but the demand simply was not there.

The OneWeb satellite manufacturing plant in Florida, USA, features a streamlined, rapid, and meticulous production process. The plant is a joint venture between OneWeb and Airbus, which was very excited to get into the new form of satellite manufacturing. When fully staffed, this plant can produce three satellites a day.

Development of NGSOs since the 1990s

Figure 4. Development of NGSOs since the 1990s

As shown in Figure 4, Teledesic excited the whole world about changing spectrum allocations at the International Telecommunication Union (ITU), making sure that non-geostationary satellites were a new part of communication thinking, which had not previously been the case; nor previously was the software available for the ITU to assess a non-geostationary satellite spectrum filing. This was previously all done basically by hand, not quite with slide rules, but Teledesic very significantly raised the awareness within the ITU of NGSOs. A very good book on this is *Eccentric Orbits* about Iridium (Bloom, 2016). It is the thrilling story of how Iridium stumbled and fell but then survived.

It is almost unbelievable how close Iridium came to de-orbiting a fully-functioning asset in outer space, but thankfully that did not happen. No fully-functioning asset in outer space has ever been deorbited, even ICO, Inmarsat's original attempt at a non-geostationary constellation. They only got one satellite up, although they needed 20 for the full constellation. The company went bankrupt; and after a year or so, the United Kingdom cancelled the associated filing with the ITU, but another operator bought that single satellite and made a new filing at the ITU and used that same satellite for a different purpose for many more years. So, simply getting an asset into outer space can be a very useful thing.

Then, just a little more than 10 years ago, an engineer named Greg Wyler was struggling to set up a mobile phone network in Rwanda and he was irritated that he could not receive signals outside the city. Wyler went to a group of engineers he knew in Boulder, Colorado (USA) and asked them how he could address this challenge. Their response was to create a space-based solution, realizing that satellite is the only economical way to get geographic coverage across the world. SES, the Luxembourg-based satellite behemoth, quickly recognized that non-GEO satellite technology was the future and invested further by fully purchasing O3b. It is now reportedly considering inclined orbits for O3b, knowing the drawback of having only an equatorial orbit. OneWeb, along with three or four other very likely competitors, are now committed to lower Earth orbits. These LEOs want to provide 5G where possible and are already looking ahead to 6G, which is currently being explored.

Today's NGSOs build on past experience

Today's NGSOs build on that experience

Now, with the internet and personal mobility, the demand has skyrocketed at the same time the technology has developed and lowered in cost

	OneWeb	SES O3b mPOWER	SpaceX Starlink	Telesat Lightspeed	amazon project kuiper	Guo Wang 国网
Constellation Size	588 (Gen1) (254 launched)	11	4,409 (Gen1) (1,740 launched)	298	3,236	6080 Gen1 12,992 Gen2
Frequency Bands	Ka gateways Ku users	Ka	Ka gateways Ku users	Ka	Ka	Ka (maybe also V, Q)
Orbit	1,200 km	8,062 km	550 km	1000 km	600 km	590-600 km 1145 km
Capacity	~5 Tbps (~7.5 Gbps/sat)	~2.7 Tbps (~200-315 Gbps/sat)	~75 Tbps (~17 Gbps/sat)	~12 Tbps (20-50 Gbps/sat)	~30-32 Tbps	Unk.
Target Markets	Wholesale, B2B, backhaul, enterprise, government, mobility	Backhaul, trunking, energy, cruise, aero, government	Residential broadband, government	Backhaul, mobility, enterprise, government	Residential broadband, enterprise, backhaul, mobility	Belt & Road diplomacy

Figure 5 Source: OneWeb

Figure 5. Today's NGSOs build on past experience

Figure 5 highlights differences between the current six main LEO competitors. None of them is fully operational yet but close to becoming so. It is effectively a race. What is particularly interesting is that each one of these constellations has a different architecture and each employs the most outstanding systems engineers. There are various ways to be *not* geostationary, and these can all work differently. Some of the competitive factors at play here include who gets financing and who gets built, because each one of these constellations costs $5 billion to $10 billion to put up, as you cannot simply put up just a single LEO, or even just one plane of LEOs. A full constellation is required and that is a lot of satellites and a great deal of money. Overall, it is effectively a matter of who attracts the funding.

The next key issue is who is going to get the customers? Many will remember fights between hardware and software, where the winner was not necessarily the one which engineers considered the best. Rather, it could be a matter of who has better marketing, or who has best bundled its software and hardware. As an example, Microsoft bundled the "Word" word-processing software with its computers for free, so most of the world starting using that software, as opposed to WordPerfect, which was arguably a better software. Similarly, others may remember Beta versus VHS back in the video cassette day. Most engineers considered Beta a better product but, for various market-driven reasons, VHS became the success story. So, unfortunately, the best engineering does not always win the day. There are other factors. All these LEO constellations include excellent engineering, but all are based on different architectures.

Importantly, it is to be pointed out that the one thing all these satellite systems do have in common is the Ka spectrum band. Every single one of these LEOs is dependent on the Ka band. For at least four of these systems, it is both the gateway's main band as well as the band for user links. Some of these satellite systems use other bands for user links, but the Ka band being used, the 28 GHz band, is vital. And so, the incursion by terrestrial use into this band is a unifying enemy for the LEO world. It is a real threat, and the satellite industry strongly prefers that the terrestrial industry moves into the 26 GHz band, where there are not as many satellite users.

Note, too, that the competing LEOs use different orbits, and they are all claiming to offer different capacity. In reality, capacity is scalable, depending on how many satellites are put up. And then, with second and third generation constellations (often shortened as "Gen2" and "Gen3"), everyone will design more powerful satellites. So even though you will have still only 200 satellites, they will have 10 times the capacity because each one will be larger or more powerful. Finally, these constellations are basically all going for the same target markets. Anything terrestrial in such situations does not do so well.

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These LEOs work exceptionally well in particular situations. Some LEO providers are starting out more in the wholesale direction. For example, OneWeb will not be selling directly to consumers. The likes of Telstra and Optus and local mobile phone companies will be OneWeb's customers. They will use the OneWeb infrastructure as their backbone to provide their universal service and/or their coverage to all of mainland, islands, waters, and skies of Australia. SpaceX currently is using a different business model. While obviously they can offer wholesale to a mobile network operator, they are aiming to go direct to consumers right away as in their current beta trials. They are starting with residential broadband as their main focus. It should also be pointed out that Guo Wang, the Chinese satellite company, actually has three or four systems under contemplation and may now be known as ChinaSatNet. It can be anticipated that one of these might get built more for political and diplomatic than for commercial reasons.

However, there are always challenging issues; for example, the USA and China have had disagreements over Huawei. It would likely be very hard for political reasons for the Chinese government to allow its people to use Amazon or SpaceX. And so, use of a satellite constellation may relate to what its home country is, and who are that country's allies. The Russians have talked about a system, but perhaps the Russians will join with a Chinese or other system. Then, there are further political issues. You might want to use a Chinese launch vehicle, but might not be allowed by your government to do so. And so, such complex issues get thrown into the mix as well.

The early days of OneWeb

Some will remember that, at the same time the world effectively went into lockdown for a pandemic, OneWeb went into bankruptcy, and these events are not unrelated. SoftBank, OneWeb's main investor at that time, lost $40 billion in a week. When they pulled their financing, OneWeb was not yet fully funded and it was a real shock. OneWeb fired 95% of its staff, retained only core employees and fleet engineers to keep the satellites safely flying, and — through the United States Court bankruptcy process — started to find new ownership.

What emerged was that Bharti Airtel, a multi-national mobile network operator based in India and offering service in many nations in Africa as well, and who had been an early investor in OneWeb, effectively stepped back in and was able to convince the UK government that — since these satellites were authorized by the UK and listed in the UN as UK objects and the ITU spectrum filing was also through the UK — this constellation was a national asset, and that the UK had every reason to keep it going, and to make it better. It turned out to be a successful argument, and Bharti and the UK jointly put in a billion dollars and brought OneWeb out of bankruptcy. That was in the summer of 2020. This is broadly outlined in Figure 6.

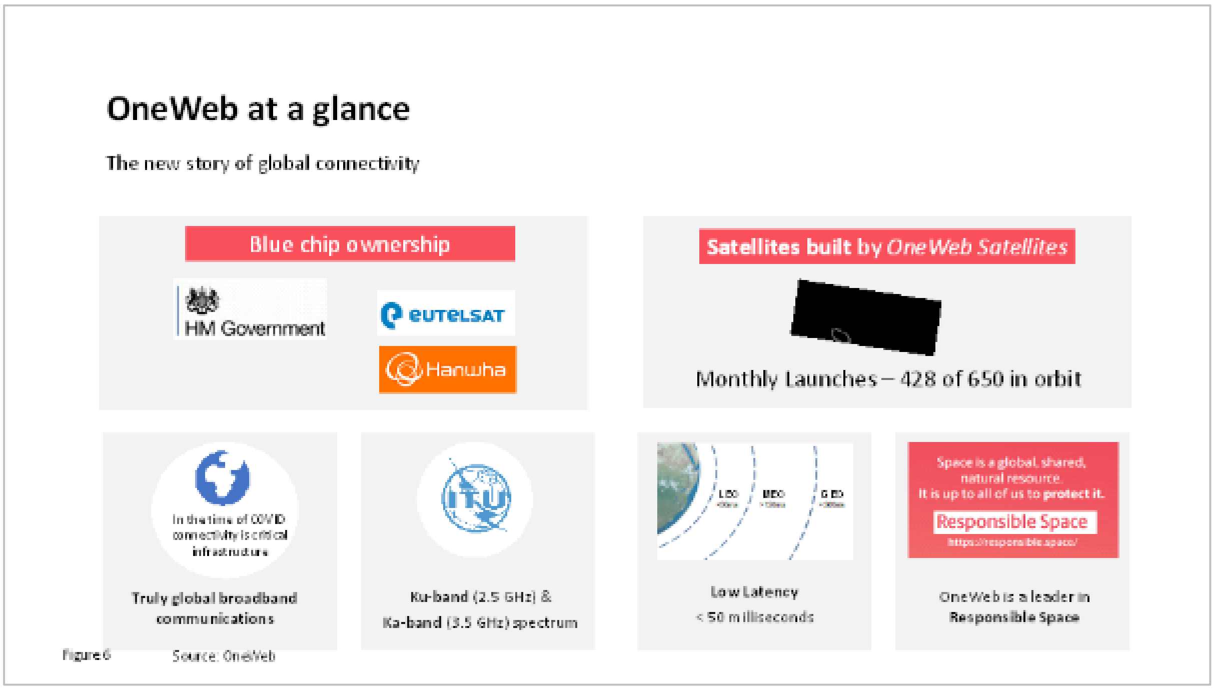

Figure 6. OneWeb at a glance

By the end of 2020, Eutelsat had come in with a significant investment and Bharti put in a further half billion as a way to confirm its commitment and prevent dilution of its share. In 2022, Eutelsat increased its investment, and Hanwha of South Korea also invested. OneWeb are now fully funded for their first-generation satellites and well into the design of the second generation. At the time of writing, OneWeb has over two-thirds of its constellation in orbit. Already OneWeb can provide service above 50 degrees north. As it is a polar orbiting satellite system, one can picture lines of longitude around the globe to sense the layout of the architecture.

Although OneWeb could theoretically also provide service below 50 degrees south, as that area is also already fully covered by satellites, the gateways and service providers are not in place for that part of the globe as yet. The whole rest of the globe should be covered by satellites by the end of 2022, and services will start as soon as gateways and service providers are set up in regions. By the end of 2022, OneWeb expects to have all of the first generation of satellites in orbit and able to provide coverage anywhere in the world, including the oceans and the skies. As shown at the lower left of Figure 6, and as is now widely recognised, the pandemic strongly reaffirmed the need for remote connectivity.

Of particular interest are the events that made OneWeb's business plan make sense to the financial world. The first was when Amazon entered the field a couple of years ago, which was after SpaceX and OneWeb and several other companies had applied to the US Federal Communications Commission (FCC) and obtained their licenses, and crucially after these companies had already filed for spectrum at the ITU. Amazon came in after all the others, which said to the world that Amazon thought they could compete and win, despite those hurdles. Suddenly that made financial analysts look at OneWeb differently. Then, intriguingly, the pandemic led to demand for universal remote wireless connections, and staff in Wall Street itself and the City of London also needed remote connectivity, which led them to truly understand the global need for remote connectivity.

Then, the last thing on Figure 6 is to point out that sustainability of outer space has become *the* discussion. All users of outer space, not just the satellite operators, now recognise that space objects are coming under great scrutiny as people begin to recognise and understand that space includes garbage, left intentionally or unintentionally, that could cause collisions, disrupting communications for people on earth. So work is underway on that important discussion.

OneWeb is acutely aware of and engaged in work avoiding physical traces of unneeded space objects. They are also now discussing with the astronomers the unexpected issue of light pollution, and the great concern to the astronomers of the world that all of these constellations are creating. It is a problem for them, so OneWeb are strongly focused on responsible space use and appropriate measures.

OneWeb's constellation

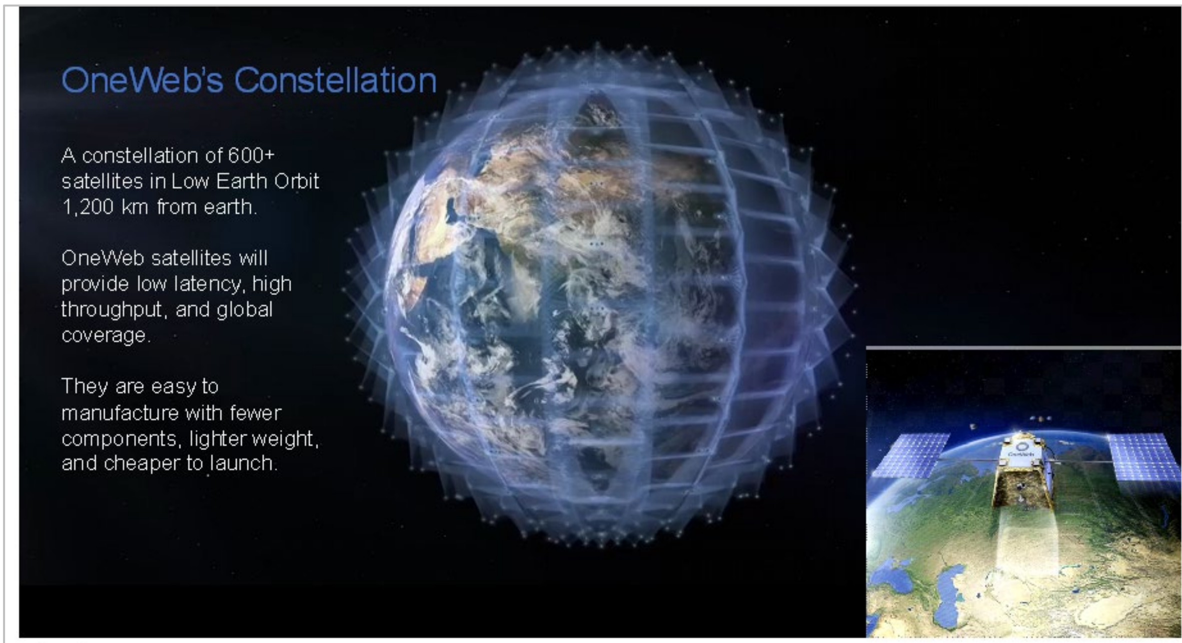

Figure 7 Source: OneWeb

Figure 7. OneWeb's constellation

OneWeb's architecture will have 12 planes in polar orbit (Figure 7). As already indicated, the first generation will comprise about 650 satellites. Some of those will be spares, so it is anticipated there will be 588 active satellites with approximately 50 satellites in each plane.

Depending on how the demand grows, the design is flexible and does not require overbuild. OneWeb has already begun discussions on what the Gen2 satellite system might look like, and its capacity. Some customers are interested in 'hosted payloads' taking advantage of having a constellation up there that could also support other services, such as positioning, timing or remote sensing.

A visual overview of the OneWeb solution is shown in Figure 8. The Ka band is used with OneWeb's large gateway earth stations that are called "satellite network portals" or SNPs, each of which is a group of antennas.

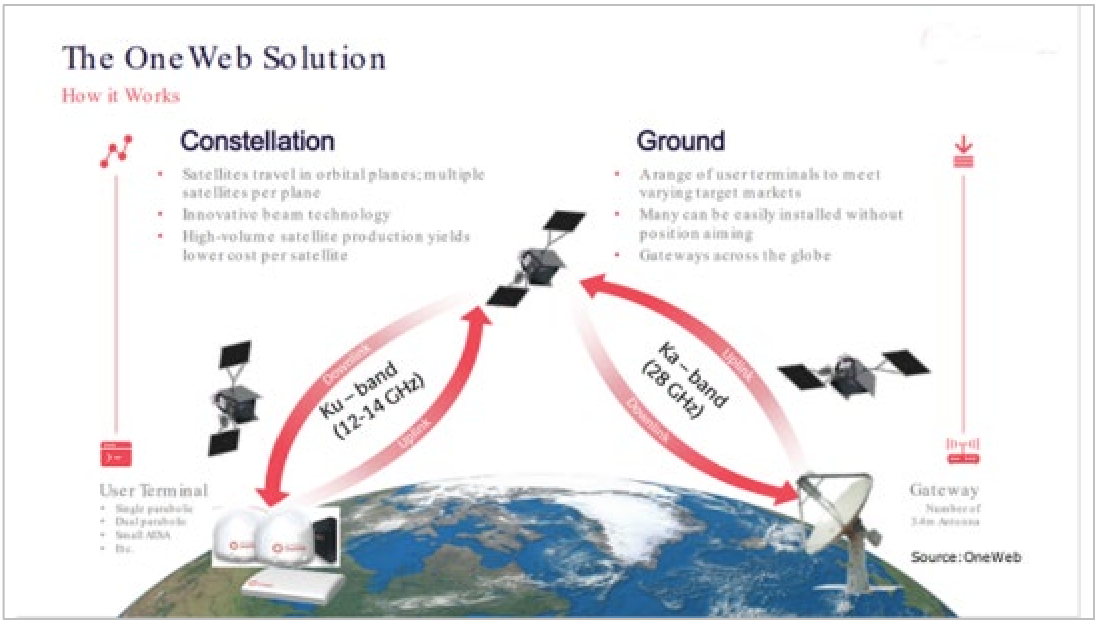

Figure 8. The OneWeb solution

Sometimes, a satellite operator will collocate its network control and its data protection at the gateway, but for OneWeb's operations the connection to the Internet (and therefore data security) happens at Points of Presence (PoPs). The PoP could be many miles away, even in another country. OneWeb does not need an antenna farm in every country of the world, hence it has changed the terminology somewhat to "SNPs". On the left of Figure 8, the downlink to the users is in the Ku band, very typical classic, fixed satellite service allocations, so nothing is new there. It is just the size of the satellites and the size of the antennas on the ground that are somewhat novel.

A simple operational sequence can be visualised as one SNP hands off a user connection to another SNP. The user beams on the satellites are slender rectangular beams, what OneWeb calls a 'Venetian blind pattern'. As any one satellite begins to distance itself from an SNP, a second gateway picks up the signal; and there is a very brief moment when the two SNPs both control the user signal before the first SNP hands off to the second. The LEOs all use some sort of handoff, so there are no dropped communications.

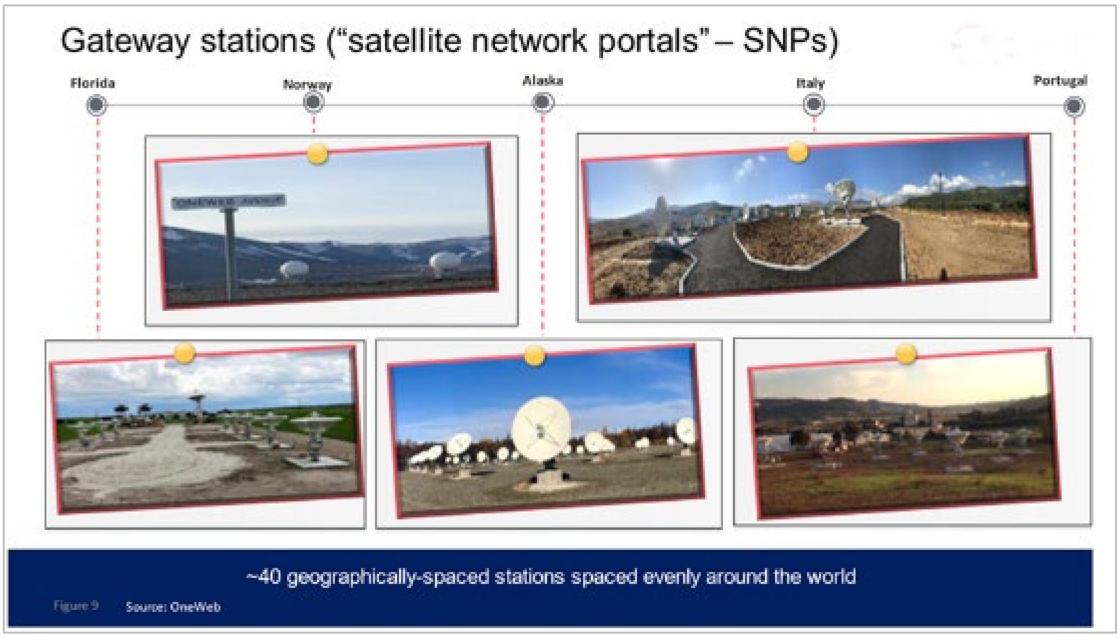

Figure 9. Gateway stations (Satellite Network Portals – SNPs)

Figure 9 show some OneWeb gateways. There are likely to be around 40 of these gateways geographically spaced around the globe. They use traditional parabolic 7.2 m satellite dishes. OneWeb’s SNPs need about 20 antennas to link to the full constellation. At the far north and far south of the globe, the SNPs use more antennas because of the convergence of the planes over the poles, where our stations are looking at hundreds of satellites at the same time. The antennas in the far north are covered by a dome, mostly for wind protection but partly also against the cold. SNPs at the equator are not linking to as many satellites at the same time, as the planes are more spaced out at the equator, so there OneWeb only needs about 15 antennas.

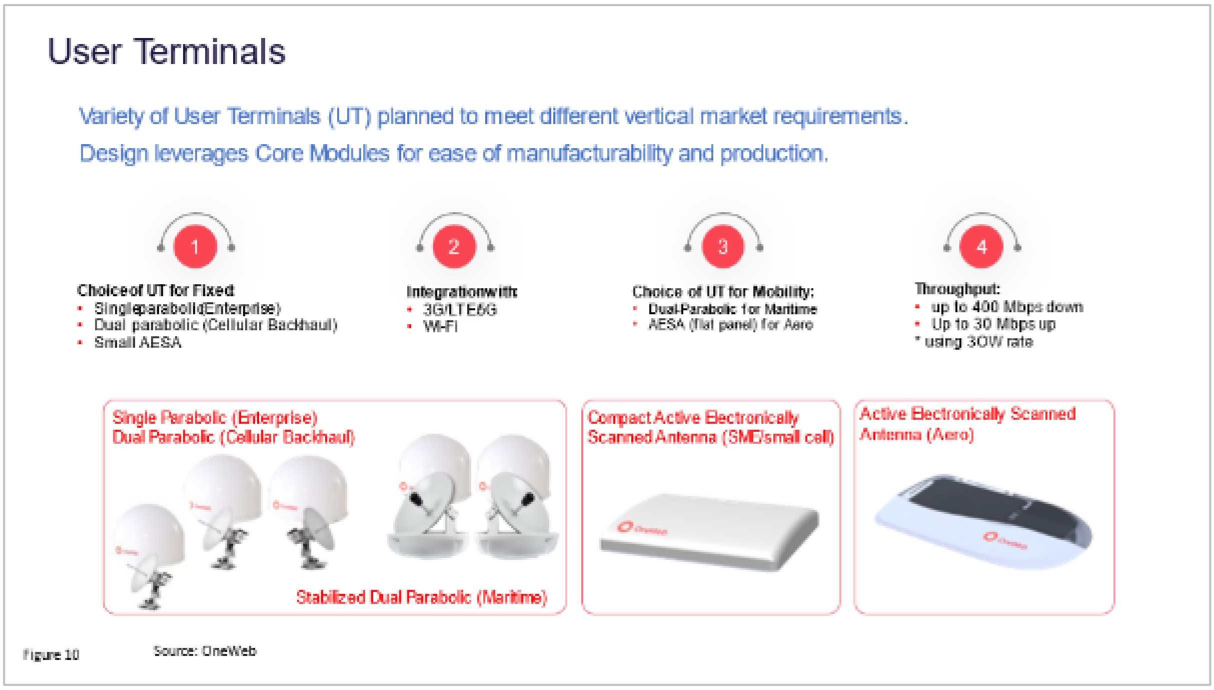

Figure 10. User terminals

Now to describe the generic User Terminal types. On the left of Figure 10, the traditional state-of-the-art is two small parabolic antennas, which track the satellites. The satellites do not appear geostationary: they appear to rise and set just like the sun. So, the antenna must track them as they rise and set. The second antenna receives a hand-off from the first, before the first antenna hops back to the start position to track the next satellite rising on the horizon. They are about a metre in diameter and, while that is too large for mobile applications, for a population in the middle of nowhere, they probably have a field where they would be perfectly happy to place two antennas.

That is the type of user terminals the very first demonstrations and trials will involve and will subsequently always exist as an offering. However, what OneWeb and the other LEOs are designing now are the devices on the right, which are flat panel, electronically steered, phased array antennas, where mechanical tracking is no longer required. They are small and are referred to as being the size of a pizza box. They are also lightweight, which is especially important for aeroplanes, but also in a car. This is where the most inventive work is happening. Antenna manufacturers are actively striving to invent this next generation of user terminals.

Once these LEO constellations prove themselves, they will be in demand in the middle of 'nowhere'. This is not going to catch on in downtown Sydney but, if you need to drive from Sydney to Perth, or you live somewhere between, or you are in a boat or aeroplane, there is a need for reliable and consistent connectivity. And so, space-based wireless will be the solution, and the best antennas are required.

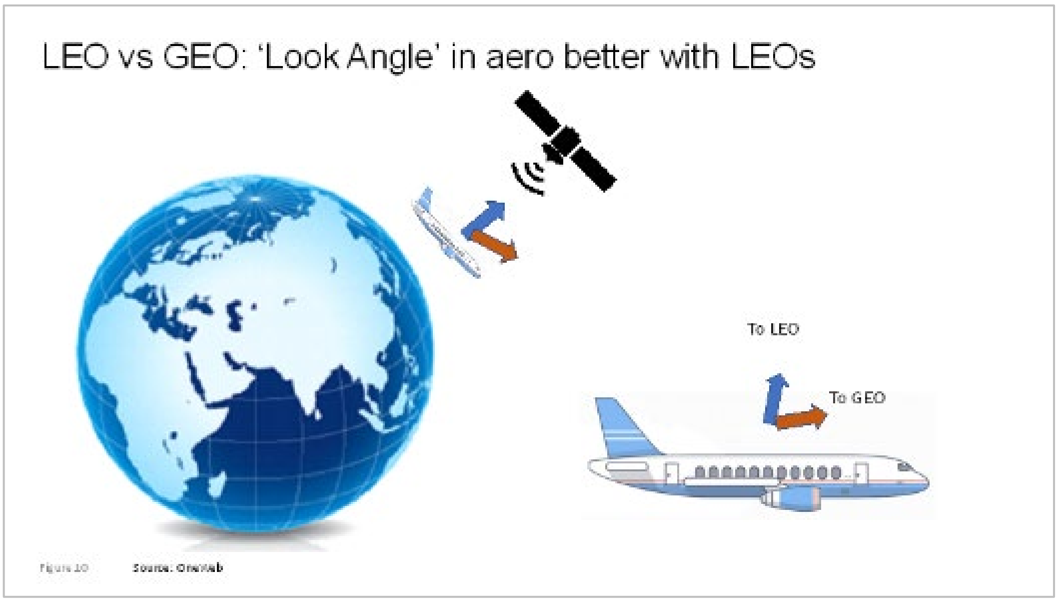

Figure 11. LEOs vs GEOs: 'Look angle' in aero services better with LEOs

Figure 11 illustrates satellite connections to airlines around the world. Until now, they have mostly been using an OCB (One Connect Box) to serve airlines or cruise lines. Their antennas are pointed towards the equator because that is where the geostationary satellites are which are the ones currently providing aero services, but that pointing direction is not great for many routes.

If, for example, you are flying the North Atlantic route from Paris or London to New York or Los Angeles using the old technology, there is quite a low 'look angle' to link to your satellite and that is a problem. However, if you use a LEO, given that these constellations cover the entire globe, there is always a satellite directly above you. Connection via LEO for aeroplanes will substantially improve communication service and quality, just as for shipping of any kind. The only problem area, true for all of the LEOs, will be a small patch of the South Pacific that is quite far from any landmass, and thus hard to land the link at a gateway or SNP.

Constellations are challenged by where best to locate gateways, as some parts of the oceans are too far from any land and so mobility customers in the sea or air would not be able to connect currently. The obvious solution is Intersatellite Links (ISLs), which can then deliver communication from anywhere to anywhere. ISLs allow satellites to talk directly to each other, without landing the signal on Earth. Although some countries have been nervous about intersatellite links, because of a fear this could be a way for one home ITU administration to control another country's communications, in fact ISLs are the very way that a nation can ensure that its air and maritime communications do not need to land in an unintended foreign territory.

The industry will likely have ISLs on most of the second-generation LEOs. And again, ISL — like the flat-panel antenna technology — is just not yet fully available for mass production but is expected to be in the next year or so.

Anywhere in the world in the middle of nowhere, a pole or tower can be erected, whether for a village or a mining community — or along the path of a highway, an antenna can simply be used that might also be a user terminal — and these can be connected to a community with Wi-Fi, fibre or whatever else might be required on the ground for wider local distribution. You can also be on any kind of moving vehicle or ship, large or small. The new LEOs hope that, with a smaller antenna, they can also compete with the existing maritime satellite operator for superior experience, lower latency, and higher broadband speeds.

The military and the UN have been using O3b from 2015 for various peacekeeping missions in areas such as central Africa. These have mobile requirements with wide locational needs. Again, space-based infrastructure is clearly the solution for many military theatres.

Finally, cities can be covered too; however, satellites are not likely to be used where terrestrially-based wired and wireless services already exist and are plentiful and affordable. Space-based solutions can also offer a kind of insurance in case of natural disasters. It is possible to drop in a new terminal via helicopter and have replacement communications

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within a few hours. Space-based communication is the only technology that literally covers the whole world at any time.

Given OneWeb's horizontal organisation structure, its overall market sectors broadly comprise Cellular backhaul, Government, Satellite Broadband and Mobility, visually summarised in Figure 12.

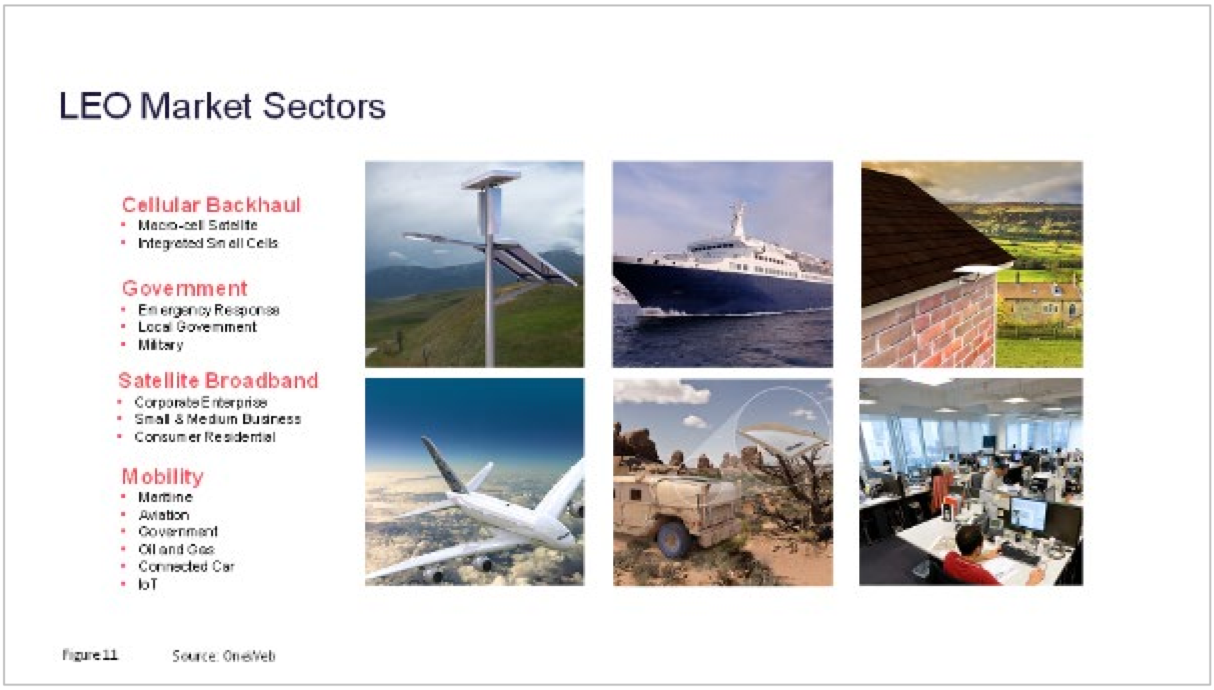

Figure 12. OneWeb's market sectors

In Australia, OneWeb has already started building three SNPs. Coverage of Australia should be complete by the end of 2022 and service can begin when local partners are ready. OneWeb has two POPs, near Sydney and Perth. There will be a customer demonstration site in Sydney. There will be both Ka- and Ku-band antennas on the roof of that demonstration site, and a package showing what user experience would be like. OneWeb will also support large customers ready to trial or demonstrate at their own premises.

OneWeb's Australian presence at this stage comprises 3 SNPs in Perth (*West:* Gnangara, Perth, WA), Darwin (*North:* Tivendale, Darwin, NT), and Toowoomba (*East:* Charlton, Toowoomba, QLD); 2 PoPs in Sydney and Perth; and a planned Sales and Service demonstration Centre in Sydney.

Audience Questions and Answers below are from the August 2021 Forum, and are followed by a Postscript added in early March 2022.

Selected Questions & Answers from the Forum

What are the status and availability of the various user-terminal types?

For SpaceX, residential terminals appear to be their focus. They are organisationally vertically integrated so are building their own satellites and user terminals. Obviously, they are also launching their own satellites, but I am not sure about their gateway or stations. So, they control the whole system, and their focus is on a residential terminal first. In comparison, OneWeb is structured horizontally and has collaborative “distribution partners”. OneWeb is simply the operator of the satellites, so OneWeb hopes others will invent user equipment. Historically, it is a challenge to get enough devices built, so, when new products emerge, it is often the government who is the early mover.

The military is willing to try new technology at an early stage and is less concerned with cost. They want something small enough to fit in a backpack and are often prepared to pay a premium if it works. So that is typically the first adopter. Then there are other people for whom price is less important than connectivity. There will also be some people who absolutely must have new products. In a few years, perhaps 2025, pricing will be at truly wide-scale residential levels. Between now and 2030, many people will begin using a non-GEO for their communications. They will still have their terrestrial service, but it is likely that the GEOs will no longer be providing voice or Internet after that time, because there will be a better technology and GEOs will be used for something else other than two-way communications.

It is impossible to have low latency from much higher orbit GEOs, so what is their future?

Looking at six GEO providers, just three of those appear likely to survive. It does not mean GEOs will not still be used. But they will not be used anywhere near as much, and will not be used for two-way communication, except in an emergency, or where they need to provide temporary capacity, in which case they will be valuable, as ‘something’ in a crisis is better than nothing.

The Soviet era Molniya military satellite system used highly concentric elliptical orbits to achieve a long dwell time over high latitudes. Is that helpful?

The Molniya orbit was a brilliant idea for the Russian land mass, but it is not needed for a constellation with polar planes that wishes to serve the whole globe, not just the far-north land mass of Siberia. OneWeb’s planes cover Australia without the complications of a Molniya-type orbit. None of the LEOs currently planned are considering this orbit. That does not mean that Russia might not use it for their own purposes. They might not want a full constellation but do need to cover their far north. There are political reasons why they might not want to use other systems being planned.

Are mining companies likely to be significant users of LEO systems?

Absolutely. Mining companies in Australia and the rest of the world are bigger than many cities and have enormous business data demands, together with quality-of-life data for their workers. The same applies to oil and gas platforms in the middle of nowhere, where enormous volumes of data are needed for the industry, and also people wanting to Skype, manage their bank account, and watch television. It is two-way traffic, so large enterprises are very much a big part of the market for OneWeb.

Is NBN Co likely to be interested in using LEOs for satellite services?

In areas where they do not have or cannot provide good coverage yet, LEOs provide opportunities to cover everyone: for all the islands which are part of Australia, all of the waters, all of the airways, and as you drive across country, in the middle of nowhere.

Without pricing information, what can be said about LEOs and the Digital Divide? Will non-governmental organizations (NGOs) be able afford your services in remote areas?

All satellite companies need and want to make money. But they also need to offer competitive pricing or their services will not be bought. Whatever it would cost for you to get a fibre or an alternative connection in unserved remote locations or in the middle of nowhere, satellites will be less expensive in such locations. They will probably never be as cheap as getting 4G in the city because it is already there. However, there are so many ways to bring the price down where there is dense population. But, if there is any way right now for you to get satellite in the middle of nowhere, LEOs will all be cheaper. For digital-divide reasons, some satellite services might also be subsidised. OneWeb will work with governments to help ensure it is affordable.

OneWeb knows it needs to be cheaper than the competition and, for a lot of NGOs, the technology just has not been there to provide connection. O3b was the first satellite company that really met the promise to connect the unconnected. That has brought along other competitors. OneWeb knows it has to be affordable, or no-one will use it. There cannot be promises that the service is going to be cheap, but it will exist and be reasonable. If you are a farmer in the middle of nowhere, you are going to expect to pay more than the guy in the middle of a large city.

What is the risk of interference with many LEOs in a small area?

There are two kinds of interference of concern. One is spectrum interference, and the other is physical interference. And, obviously, OneWeb is paying attention to both. Most engineers here are well familiar with spectrum interference. You do all kinds of coordination, including with other satellite operators, and the way the system works is that the newer system has to take into account whatever is there already: the system designed five years ago could not envision that a new system would come along later with a potential new interference issue. Spectrum coordination is now a mature and largely self-regulating regime. However, it is still very effective because, if you ignore it and proceed to broadcast your signal, both parties suffer. The coordination process itself is straightforward.

Space is big and there is no one "sweet spot" for NGSOs. There is no one altitude that is much better than others. There is no reason why the people operating at 500 km, say, could not be at 600, 700 or 800 kms, with virtually no difference in latency. OneWeb and others develop an architecture and then approach the ITU via their administrative countries. If several countries all want to use the same altitude, the question is: who is going to move? However, in practice, currently working satellites are not the problem in outer space.

If you have two objects that can both manoeuvre, there is not going to be a collision. Nobody wants a collision: you lose money. The problem is where you might have two objects that do not or cannot manoeuvre, or where one of the objects is so small, it cannot be seen. The objects that are smaller than about 10 cm are often not trackable. And those are the ones we are worried about, tiny bits of debris which, if hit, can cause trouble. The problem is not that six LEO constellations are going to go up and going to hit each other. That is not going to happen. And the LEOs are not going to collide with their own satellites either. Even if one of them were suddenly to become non-operational, that is not going to happen. The problem is the small bits of debris from other earlier accidents, and that is what the industry needs to address. The world needs to figure out how to readily remove debris from space and industry needs to continue to engage on this.

How do you deal with the visual impact of satellites, in particular for astronomers?

This conversation is active between OneWeb and the astronomy community. OneWeb goes to all associated conferences and talks with astronomers in the UK, the US and elsewhere. OneWeb has started collecting data from the GAL Hassin observatory in Sicily. Nobody wants to interfere with the astronomers' work. There is no upside to a constellation blocking the skies for astronomy, so OneWeb is actively exploring solutions with them. How can OneWeb design Generation Two satellites so they are not reflective? What can OneWeb do via software for the telescopes to mask the reflectivity, based on knowledge of where our orbit is going to be?

Alternatively, is there a way to put telescopes on our satellites as a hosted payload, effectively raising the telescope above the height of OneWeb's orbit? OneWeb's satellites are not visible to the naked eye. The Starlink satellites are visible as they rise on orbit. They are visible to the naked eye, and this is what shocked the world when astronomers saw a 'string of pearls' across their photographs, and of course were understandably troubled.

This is somewhat analogous to the early days of telephones and telegraphy and electricity, where ugly poles and aerial cables blocked or impaired the view, yet all needed electricity. So, the world put up with the visual pollution for a while until industry figured out how to address this, whether by burying cables or using wireless. There will be a similar compromise in this situation. The world will put up with some of the light pollution (because connectivity is a human right as well), while continuing the discussion of how the LEOs can decrease their impact on a dark sky. A huge amount of work is going on right now in this area of responsible space.

Will OneWeb be able to offer unlimited bandwidth services to individuals?

As I am unsure of what is meant by unlimited gigabytes, the answer must be no, because, even if the individual involved were our customer, there would need to be a contract for a specific amount of capacity. An individual customer could not have all of the, say, four terabytes available. However, if you are talking about a data plan for residential users, I am sure the answer is yes for the particular capacity offered with that plan. Again, OneWeb has terabytes of capacity over the world and expects to progressively scale up as demand expands. Remembering that the ISP is the customer, the answer will be what the ISP offers. OneWeb is not going directly to end-users. Over time, that overall capacity will increase.

Do you consider AST's satellite service connecting to standard mobile phones a direct competitor?

Direct links from a satellite to a personal mobile are the holy grail for the satellite industry. That is what the industry has to invent. The right batteries and the right power on the satellites are needed. AST is not planning to do that. They are going from their satellite to a cellular network, and then from the cellular network to your phone. As a competitor they are a few years behind OneWeb.

What can you say about OneWeb's innovation program and where it is heading?

The innovation program is really about hardware for the satellites and user terminals. Everyone is encouraged to get involved, and to reach out to OneWeb's Chief Technology Officer and explore what needs to be invented.

Other initiatives involve spectrum. The satellite industry has been working on NGSO issues since the 1990s. At the 2019 World Radiocommunications Conference, the industry suggested future agenda items that are being studied now to be addressed and resolved at the 2023 Conference. Retaining the 28 GHz band for satellites (the Ka band) is imperative.

Sharing between NGSO systems needs to be coordinated. The ITU rules are overwhelmingly designed for GEOs, and to protect the GEOs over other configurations (such as LEO). By 2027 there may be an agenda item to ease the restrictions imposed to protect the geostationary arc,

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as there will be fewer GEO satellites by then. There will be no need to protect the whole arc; systems can do a one-on-one coordination with whatever GEOs still exist.

The design and management software at the ITU also has to be improved to handle more NGSO coordination. Geostationary is comparatively easy. Once you are *not* geostationary, there are an infinite number of possible architectures for which their software was struggling to cope. So that is an issue for the ITU. NGSO sharing and protecting the Ka band are the big issues, as are the build-out milestones. There are six main systems that have been proposed. So, in 2019, the ITU's quadrennial World Radiocommunication Conference (WRC) agreed to the idea that you can bring a LEO system into use with one satellite, but then you have got to build it out within certain timeframes. If you do not build it out, you lose your right to that spectrum priority, which is only fair. There are a couple of planned satellite constellations that are not likely to make their build-out milestones, their first 10% milestone. So, the question will be — will their government go to the ITU, to the WRC, and say: please give us a waiver? They can argue that they are moving but it has taken longer than first thought, and that it has never been done before. It is likely that a government will go to bat for their LEO systems at least once to ask for a waiver.

Will OneWeb collaborate with non-satellite telcos to improve remote area service?

Absolutely yes. That is our ideal customer. We are pleased for a telco in a remote area to come to OneWeb and put an antenna wherever they need it to cover their entire population. It will be an overnight solution to universal access and coverage.

Can you share your retail service provider strategy?

OneWeb will be a wholesaler, business-to-business. Direct-to-consumer (or "retail") might come later but is not being discussed yet. OneWeb offers high throughput, 4G-quality broadband. OneWeb will also offer many 5G-quality connections, but the most latency-sensitive 5G and 6G applications are not going to use satellite: they will need small cells very close, with line of sight. However, those are only a few niche applications (financial, smart cars). Most applications will find the latency of LEOs to be as good as fibre. The commercial team does not discuss prices except directly to our distribution partners, and it is they who set the service prices in any country. Our partners know they must compete with mobile and fibre and will price accordingly.

What can you say about using LEOs as a terrestrial competitor?

One of the reasons that the UK government wanted to make sure its OneWeb asset in the sky continues is that the UK decided to leave the EU, thus depriving itself of access to the EU GPS competitor, the European system known as Galileo. Many countries now realise that being

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dependent on a single other country for vital information, such as positioning and location, is maybe not a good idea, especially when GPS was originally a US military product, although it is no longer military. So, Galileo came along, and then the UK, much to their surprise, were kicked out of Galileo when they decided they did not want to be part of the EU.

The UK were looking for a way to have a national positioning-navigation-timing (PNT) system and are talking to OneWeb about what it can offer. The current generation of OneWeb was clearly not designed to be a GPS-like satellite, but there are things OneWeb can do even with the current generation. Gen2 is wide open in this respect so, again right now, that is exactly the kind of thing being discussed.

Although a commercial question, will non-government organizations be able to afford your service in remote areas, and is it likely that you would have charging regimes that depend on the particular type of user?

Every government in the world wants its population covered. If that population or government does not have the money themselves, they often turn to the World Bank or the IMF or the UN for funding. There are many other nations like Australia that have an enormous universal service fund, but maybe the technology has not been there. So now, they have the technology.

You mentioned the polar orbits, which of course is very similar to Iridium. You also had, in some of your models, orbits about the Earth at an inclined angle at about 55 degrees and about 50 and also 45 degrees, and it looked like you almost had three different satellite skins going round in the later model. Noting that you had already asked for permission to go up to 48,000 satellites, what is the thought process behind that?

The answer is simply "options", as all the LEOs are still inventing their best architecture. OneWeb filed at the ITU back in 2015, and then did more filing in 2017 and 2019. And yet this system is not going to come to fruition until 2023, or later, so an ITU filing has a bit of brainstorming. What could the best architecture look like? What might be needed? Constellation architects may change their thinking as the system begins to actually operate, and the next generation of constellations may not need tens of thousands of satellites. At one point, SpaceX had filings of up to 42,000. In 2021, OneWeb thought briefly that it might need 48,000, but, honestly, it seems more likely that OneWeb will not need more than about 1,000, because the plan is for Gen2 to be more powerful, instead of needing more satellites.

Inclined orbits are a concept that would put more satellites directly over population centres. The downside of a polar orbit is that there is a huge capacity at the North and South Poles where there is very little demand. The idea with an inclined orbit, at say 50 degrees, is that the satellites will orbit right over many of the major cities of the world and all of the supply will be used.

Where will the ground stations be in South America?

The ground stations across the world are evenly spaced geographically. There are four in South America, two or three in Central America, and four or five in North America. Any country that is concerned about network security can have a PoP in their country, because the PoP is where the gateway connection to the Internet is, so every country does not actually need an SNP.

Postscript (written seven months after the Forum)

As of March 2022, OneWeb has successfully launched 428 satellites. Plans to launch the rest of this first generation (for a total of 648) are under discussion. The constellation will then cover the entire globe, and service could be provided in any country where there is a distribution partner to offer service. In Australia, OneWeb has announced three partners so far: Field Solutions Holdings Ltd. (FSG), Australia's leading rural and regional telecommunications carrier (OneWeb, 2022); Vocus, a carrier specializing in delivering reliable communications infrastructure to large enterprises in remote locations with limited or no connectivity, including resource-based projects, emergency responders, and infrastructure projects (OneWeb, 2021); and Telstra, which has signed a Memorandum of Understanding (MoU) to explore new solutions for improved digital connectivity across Australia and the Asia-Pacific region for Telstra customers. The SNPs outside Perth (Gnangara) and Toowoomba (Charlton) are ready to operate, and the SNP near Darwin is nearing completion.

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