RTT TECHNOLOGY TOPIC
April 2021

Smart Fibre From Space

G-WON (Global Wireless Optical Networks) as a routing option

In this month's technology topic we cover one of the topics we will be addressing in depth on our 5 day workshop on LEO, MEO and GSO system and service integration being held on 14-18th June presented in association with the Continuing Education Institute.

To view the agenda and book a place on the workshop, follow the link
https://www.cei.se/course-820-leo-meo-and-gso-system-and-service-integration-group.html

In February this year, Google and their engineering contractor SUBCOM commissioned the Dunant subsea cable connecting Virginia Beach in the US to St Hilair de Riez on the French Atlantic coast.

Named after the founder of the Red Cross, the 6600 kilometres of cable carries 12 fibre pairs and is claimed to be the first long distance cable to use space division multiplexing (SDM). Each fibre pair supports a data rate of 25 Tbps yielding a cable capacity of 250 Tbps. The use of SDM rather than frequency multiplexing allows the pump lasers and related optical components to be shared across all fibre pairs and opens up the opportunity to realise higher pair counts, up to 24 pairs is regarded as practical in the near future. Next generation long distance subsea cables will therefore be capable of 500 Tbps of throughput.

In this month's Technology Topic/post we look at how photonic networks in space combined with optical uplinks and downlinks complement subsea and terrestrial fibre and existing and future RF based space and terrestrial networks.

Most of the Big LEO constellations are now either implementing or considering inter satellite (and in some cases inter constellation) optical switching in optical C band. Adding optical uplinks and downlinks creates a global wireless optical network which side steps the RF bandwidth/capacity cost limitations of existing networks.

Optical C band is used for fibre as it is in a transmission window with low hydroxide ion absorption. This is also means that it is a good choice for uplinks and downlinks both to minimise atmospheric effects but also to make the coupling between fibre systems and free space more efficient.

Theoretically optical links in space could be at almost any frequency (there are few hydroxide ions to worry about up there) but using the same band means that space photonic systems can use active and passive components developed for terrestrial fibre. It also makes it easier to couple the space links to optical uplinks and downlinks and then into fibre. In terms of available bandwidth, an ultra-dense wavelength division multiplex (DWDM) of 100 channels with 25 GHz channel spacing could be supported within the 4 THz optical C band pass band (191-195 THz).

Atmospheric distortions including cloud and rain effect Ku and Ka band and optical wavelengths. However it doesn't rain everywhere all of the time so as long as there are enough ground stations accessible from the space network there will always be clear optical routes to space. Adaptive optics are also now widely used to mitigate weather and atmospheric effects.

Inter space links do not suffer from chromatic dispersion so the distance limitations of terrestrial fibre DWDM do not apply. Power efficient high bandwidth optical links are already commonly used in space so this is something available now rather than in the laboratory.

This means that the rate of adoption is determined not by physical constraints or device availability but by the relative economics of terrestrial and space delivery including the relative system cost of DWDM in space and SDM in terrestrial long distance subsea and terrestrial fibre and the noise and interference floors of radio links.

Subsea cables are designed to have an operational life span of 25 years though may be decommissioned earlier or later depending on opex costs and replacement costs, route capacity requirements and fibre quality improvements. A fibre link in 1970 had a loss of 20 dB per kilometre. Today this has reduced to 0.2 dB per kilometre or less and further improvements are possible.

We have been laying cables under the sea for 160 years. The latest cable laying ships can cover 150 kilometres a day but a long distance undersea link takes years to plan and even when it is commissioned can be deliberately cut or damaged by ship anchors, trawling or undersea earthquakes.

Since the 1920's, **long distance wireless** has provided an alternative with Mr Marconi as the early pioneer. **100 years on, Mr Musk has a similar ambition to move the internet into space.**

The Telegeography team at the **Sub Optic Association** make a persuasive case as to why this will not happen. Their starting point is a beautiful map of the world's long distance cable networks, documenting approximately 400 cables spanning 1.2 million kilometres.
Submarine Cable Map

Subsea cables carry 97% of global internet traffic connecting hundreds of data centres via hundreds of landing stations. It is a triumph of engineering energised by investment from Google, Facebook and Microsoft and fellow travellers to deliver low cost reliable intercontinental fibre connectivity.

Daily demand on the network is of the order of 2 Petabits per second (2000 terabits per second) and this demand is doubling every two years. The ability of the subsea industry to scale hundreds of long distance cables each delivering 500 Tbps suggests there will be plenty of bandwidth capacity available for the foreseeable future to meet this future demand.

Moving internet traffic into space therefore has to be justified on the basis of economics. It has to be cheaper, faster and more secure and ideally more environmentally friendly.

This seems a tall order. Two years ago, The Sub Optic Association asked MIT to calculate the total bandwidth available from three of the LEO mega constellations, OneWeb, Telesat and Starlink, based on their FCC submissions at the time which assumed 720 satellites for One Web, 117 satellites for Telesat and 4425 satellites for Starlink.

The maximum bandwidth per system came out as 1.56 Tbps for OneWeb, 2.66 Tbps for Telesat and 23.7 Tbps for Space X which in the context of a single subsea cable carrying 250 Tbps looks unimpressive.

However two years is a long time in the world of space telecommunications so it is worth revisiting these numbers. The estimates for how many LEOS will be sent into space between now and 2030 vary from ten thousand to over 100,000, the number of satellite submissions filed with the FCC. Starlink are presently planning a constellation of 4,400 satellites with a Ku downlink to user terminals between 10.7 GHz and 12.7 GHz and an uplink between 14 GHz and 14.5 GHz. The down links to ground stations are at 17.8 GHz-19.3 GHz with the uplinks at 27.5 to 30 GHz. At time of writing they have over 1000 satellites in space.

Telesat Light Speed will use the same RF bands. Historically these were the frequencies that were going to be used by Teledesic. One Web has a downlink at 10.7 GHz and an uplink at 12.75 to 14.5 GHz with Ka band links to ground stations. The FCC filing is for 48,000 satellites. Historically this was spectrum that was going to be used by Skybridge, like Teledesic, another first generation high count LEO constellation that never made it.

The Telesat Light Speed constellation is now stated as 298 satellites at an altitude of 1000 to 1325 kilometres. The space network has 10 Gbps optical intersatellite links with the capability to link to 17 Telesat GSO satellites.

Inter constellation switching has been used for many years in NASA's Tracking and Data relay Satellite System. The Hubble Telescope and the International Space Station talk to earth from their low earth orbits via NASA's GSO satellites. The data rate to ground in S band is 600 M/bit/s and 800 M/bit/s in Ku and Ka band but NASA now also has a large number of optical ground stations so an all optical link is available as an option.

The European Data Relay System commissioned in 2016 has a similar architecture but uses optical links in space. Free space optical technologies have taken a while to arrive but are now at a point where they deliver cost and performance benefits over RF links. The ability to 'complete the circuit' with optical uplinks and downlinks substantially changes the bandwidth cost equation.

Pointing loss in space can be an issue but spreading loss is minimal. Multi gigabit LEO to GSO optical links can now be supported over link lengths of 45,000 kilometres using coherent modulation (BPSK and QPSK). A 10 gbps link over 6000 kilometres can be provided by a laser terminal with a mass of 15 kg and a power consumption of 80 watts. Tiny optical transceivers weighing less than 400 hundred grams are being used in Cube Sats.

Taking the 10 Gbps interconnect rate of Telesat as a start point (10 Gbps on a single wavelength system) the next step logically are dual band systems at 1064 nm and 1550 nm with 1550 nm used for shorter range applications (6000 kilometres or less). Ultra dense WDM in C band would bring these numbers intriguingly close to terrestrial fibre particularly when the routing flexibility of tens of thousands of LEOs interconnecting with hundreds of MEOS and GSO's is added into the economic calculation.

Subsea cables have a sunk cost and OPEX costs that are determined by damage and deterioration and power consumption. Landing costs are also significant.
An optical network in space has launch costs which have to be amortized over anything between 5 and 25 years. The first generation of Iridium satellites had a life expectation of seven years but were still operational twenty five years later. It is of course always possible to write off sunk cost through a Chapter 11 filing. Global Crossing and Iridium both followed this route.

As with subsea cables, through life damage can happen. Over a 25 year period, one Iridium satellite was lost after a collision with a rogue Russian satellite but the other 66 satellites were fine. Collision risk and related insurance cost could be expected to increase as constellation count increases. Destroying satellites using high powered lasers is also possible. Solar panels suffer from particle abrasion and space hardware can be damaged by radiation.

On the cost credit side, power comes for free in space and there are no landlord costs. On the income credit side, a subsea cable earns its money by moving photons around. A LEO satellite has multiple ways in which it earns money. It is a camera, a clock, a positioning and location device, a multi-function sensor and synthetic aperture radar. New space communication is a means to many ends.

It is also a defence asset. The Telesat constellation will be configured as a mesh network of satellites that can provide ultra-secure (quantum encrypted) ultra-resilient communication to troops

fighting on the ground integrated with terrestrial military LTE and 5G networks, military aircraft and unmanned aerial vehicles including high altitude platforms (HAPS) under the clouds and high altitude pseudo satellites (higher HAPS) above the clouds between 60,000 and 90,000 feet (18 to 27 kilometres). Voice communication can be blended with imaging data from space; ground based sensing and feeds from aerial and space assets. The construction contract was placed with Thales earlier this year.
For link lengths of 10,000 kilometres or more it is faster to go via LEO (photons in free space move at 300 million metres per second, photons in fibre move at 270 million metres per second). These attributes are of high value to defence customers but also have value for high frequency trading and global financial transactions.

The bandwidth gap and performance and cost gap between space and earth is therefore getting narrower over time. Space delivers additional profit and performance opportunities and costs in space are going down. At ground level optical transceivers could be installed in city centres on the top of high buildings or on the top of data centres to reduce landing station estate costs and to minimise latency.

Rockets are getting cheaper whereas the cost of laying a cable under the sea or under the ground remains largely constant. The next generation of Falcon heavy rockets are capable of carrying 100 tons of hardware into Low Earth Orbit. Lorries in the UK are limited to 44 tons so that is more than two lorry loads of base stations every launch.

It is also a truism that you do not have to make money to make money. The promotional buzz around Starlink has helped to increase Space X's share price and a successful IPO for Starlink as a separate business would provide access to significant amounts of low cost cash.

Starlink has a first mover advantage in terms of satellites launched. More satellites mean higher elevation which means a better RF and optical link budget. Blocking from buildings, hills and vegetation reduces as elevation increases. More satellites translate into trunking gain (capacity gain) and increased network value **(The Metcalfe effect).**

Other clearly differentiated constellation offers could also potentially raise substantial sums through an IPO. A Telesat Light Speed IPO for example could be financially persuasive.

As we have said in other posts, US carriers have spent $80 billion dollars on 100 MHz of RF C band spectrum. $8 billion dollars will buy you a high count LEO constellation with global reach, multiple income opportunities and lower opex costs. To date governments have not started to auction optical spectrum so that comes for free so the choice is 4 THz of free optical C band or a few tens of MHz of RF C band priced at billions of dollars or a few GHZ of congested and potentially expensive Ku and Ka band.

This does not mean that free space optical networks will replace subsea and terrestrial fibre or RF wireless networks.

Fibre networks work amazingly well and new sources of investment means the industry can invest in capacity and technologies which reduce cost per bit and match evolving customer expectations. RF will be still be used for space inter connect and uplinks and downlinks but the role of free space optical links must surely become greater over time.

The most likely outcome is a hybrid approach in which space and terrestrial assets are combined with a **G**lobal **W**ireless **O**ptical **N**etwork (G-WON), complementing rather than competing with subsea and terrestrial fibre, complementing rather than competing with existing RF networks, a World Wide WON supporting the World-Wide Wireless Web.

Ends

If like me, the science of space photonics is a bit of a mystery than the following links are highly recommended and illustrate 'the case for space' as an optical end to end bearer.
https://www.tesat.de/
Mynaric - Space Foundation
About | Archangel Lightworks
The Empower Space Alliance - BusinessCom Networks (bcsatellite.net)https://atlasground.com/optical/
New Ground Station Brings Laser Communications Closer To Reality | NASA
OneWeb's space lasers scheme to safeguard broadband | This is Money
SpaceDataHighway - Telecommunications - Airbus
And the team at the University of Western Australia
40 Tbps fibre based data transfer in a single optical C band (1550 nm) channel
Record-breaking laser link could help us test whether Einstein was right - ICRAR

On a historical note **The history of Cable and Wireless (the company) provides a 170 year summary of how cable and wireless are complementary rather than competitive.**

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http://uk.artechhouse.com/5G-and-Satellite-Spectrum-Standards-and-Scale-P1935.aspx

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00 44 7710 020 040