RTT TECHNOLOGY TOPIC
August 2020

Polar Bears Dividends

The gravity defying economics of polar constellations.

In this month's technology topic/posting we look at how satellites in polar and near polar low earth orbits add value and review present cost and performance trends.

The story starts 60 years ago with the launch of the first Transit satellite navigation system satellite into a 600 nautical mile polar orbit. Working at 150 MHz and 400 MHz and operated by the US Navy, the satellites were used to provide positioning for Polaris submarines. The system was retired in 1996. Similar systems exist today including Orbcomm using a 1 MHz +1 MHz pass band in the 137-150 MHz VHF band to provide enhanced maritime positioning (and IOT data). As referenced in last month's posting, part of the rationale for the UK government's investment in OneWeb is to have access to a positioning and location system which is more accurate than GPS and harder to jam. Iridium already offers this as a service. Mr Musk must be tempted to put a Starlink terminal into every Tesla car particularly as this is the only way in which cars can ever be safely autonomous.

Polar constellations are deployed from VHF to V band with channel bandwidths that vary from a few KHz to 1 GHz, for example V band constellations are proposed that operate with 1 GHz channel bandwidths within a 5 GHz pass band. Starlink, Project Kuiper and One Web are deploying into Ku and Ka bands, typically on a 250 MHz channel raster sitting within a 750 MHz pass band (Ku band) or 3.5 GHz pass band (Ka band), similar in many ways to FR2 5G. There are ongoing intensive and ill-tempered discussions about inter satellite and intra satellite system beam to beam interference. Adding 5G into the mix should theoretically be good news but in practice adds fuel to the bonfire of a bandwidth battle that will cost billions of dollars of lost revenue and market opportunity but that's a subject for another day.

LEO Satellites also scale in weight and size from a few kilograms (CubeSats) to thousands of kilograms, the ISS being presently the largest man made object in space. Orbits can be anything from 100 kilometres (the Karman line) to 1200 kilometres. There are also some highly elliptical orbits but let's ignore those for the moment. Lower orbits reduce payload cost as it is a shorter journey into space though the terminal speed of the satellite needs to be higher. This in turn produces a stronger Doppler signal but the satellites will have a shorter service life and will require more station keeping though this is less of an issue than it used to be.

The choice of orbit height and trajectory are almost infinite. Project Kuiper is being planned on the basis of three orbit heights at 367 miles 379 miles and 391 miles with an inclination off set that maximises coverage south of 56 degrees north and north of 56 degrees south, the logic being that polar bears in the Arctic and penguins in the Antarctic and sheep in the Outer Hebrides don't use or need satellite phones so capacity is better concentrated elsewhere.

Starlink are initially deploying at 340 miles but with other options in mind. OneWeb is deploying a yet to be finally confirmed number of satellites (anything between 648 and 42,000) into 18 orbit planes at 750 miles (1200 kilometres). Iridium has 66 satellites deployed at an orbit height of 483 miles at an orbital speed of just under 17,000 miles per hour (27,000 kilometres per hour) which translates to a complete orbit of the earth every 100 minutes. Half the satellites go north to south and half the satellites go south to north, a neat trick which minimises inter satellite switching latency and doubles the relative Doppler shift. However, two satellites running into each other at a combined approach speed of 34,000 miles an hour creates embarrassing and expensive space debris. This has only happened once in thirty years and a rogue Russian satellite was to blame.

However the risk of collision is increasing partly due to the number of commercial LEO satellites proposed, close to 100,000 if all the present FCC submissions are added together and partly due to the introduction of configurable constellations. These are satellite systems being deployed by defence agencies though could be deployed commercially. A present example is the Hypergiant CubeSat constellation which can be reconfigured to respond to changing defence requirements. The 'satellite swarms' use a combination of ground control and autonomous station keeping to maintain orbit discipline but imply a need for constellation coordination which does not exist on a global scale. As a consequence it is hard to quantify collision risk but potential costs need to be fully factored into business plans.

Compared to constellation coordination, spectrum coordination should be simple but in practice is a problem that is getting worse not better over time. Iridium has the relative luxury of tidy L band spectrum with no coexistence or adjacent band issues and cleanly designated K band for the inter satellite links. By contrast in Ku and Ka band, the wider bandwidth and almost infinite choice of orbital planes combined with a wide range of possible power budgets and beam configurations makes interference modelling unimaginably complex, hence the ongoing arguments over protection ratios both between high count LEOS in the same or adjacent bands but also between LEOS and MEOS and GSO satellites and, in the future, millimeter wave (FR2) terrestrial 5G.

The lack of a global air interface standard for satellites compounds this problem which will only be solved as and when and if a super operator combines a high count LEO constellation with an integrated MEO and GSO and terrestrial service offer. To date, only SES has made any progress in this direction with some commercial coupling between their GSO assets and their O3b MEO acquisition.

This is a pity because space has many added value opportunities any or all of which potentially transform the economics of space based delivery. The starting point is to remind ourselves that LEO constellations offer the commercial and military Holy Trinity of positioning, imaging and communication. This equates to multiple ways to earn money from the same satellite. Sun Synchronous polar orbits are particularly good for imaging, passing over the same spot at the same time each day usually close to dawn or dusk but any orbit is potentially useful.

Imaging and positioning can subsidise communication. The extension of Amazon Web Services (AWS) into the ground station business suggests this is happening faster than most people thought it would (see our October 2019 posting 5G for Free and more recent Press Announcements.)

But the economics of space delivery are also determined by the relative cost and performance of the many thousands of components used in space hardware and user and IOT devices. This includes solar panel arrays, batteries, processors and active RF devices such as power amplifiers, low noise amplifiers and related radio functions such as mixers and combiners, splitters, filters and matching components. Space networks are not short of spectrum but they are short of power.

While it would be nice to use low cost silicon, the efficiency loss at higher frequencies is unsupportable hence the use of more expensive (rarer) materials that deliver system efficiency gain. Gallium nitride solid state amplifiers for example have now largely replaced travelling wave tube amplifiers. This has helped reduce launch weights and in orbit reliability across large temperature gradients, a mean time to failure of over 100 years being not untypical. Gallium nitride is also usually used for adaptive phased array antennas. Given that each element in the array needs its own RF amplifier and LNA this is generally going to be too expensive for consumer terminals.

Adaptive phased array antennas are needed so that user and IOT devices including earth stations in motion (ESIM) and fixed devices can track a satellite as it moves from horizon to horizon, a journey that takes typically between 8 and 15 minutes. Phase array antennas are however inefficient at lower elevation angles due to path length and rain fade and blocking from buildings, vegetation and hills.

As we have said in previous postings, as satellite counts approach 20,000 or so, there will nearly always be a satellite nearly always overhead so a low cost fixed narrow beam, for example a simple microwave dish looking directly upwards, becomes feasible albeit with an additional switching overhead. The advantage apart from cost and line of sight and beam width gain is that these devices work equally well across multiple constellations including LEO and GSO together.

Simpler options that look directly upwards are therefore technically and commercially more attractive. If the target market includes consumer broadband, low orbit satellite systems need somewhere between 20 and 30 dB of additional gain to be technically and commercially competitive with terrestrial networks. This implies a line of sight link across the shortest available path which is always going to be straight upwards. In some cases such as non-line of sight terrestrial FR2 5G, the link budget from a satellite can be more favourable.

This highlights the need for the satellite industry to contrive a way in which constellations can be shared by multiple operators. Why launch 100,000 satellites to achieve nearly always nearly overhead coverage when 20,000 LEOS plus a smattering of MEO and GSO will achieve the same result? If more capacity is needed, the size of the satellites rather than the number of satellites can be increased. Collision risk will also be decreased.

It also highlights the need for global standards combined with spectrum sharing and coexistence agreements which remain as the cornerstone for achieving consumer scale. The commercial failure of Iridium in the late 1990's can be attributed to the rapid cost reduction of GSM networks and user devices. This only happened because the terrestrial cellular industry sorted out global spectrum and standards issues quickly and effectively. While the satellite industry has made some progress in this area it remains significantly short of where it needs to be if ambitions to build consumer price friendly networks and products are to be realised. Repeated use of Chapter 11 as a survival strategy is never going to make you popular with the investment community even if late entry investors benefit. Internal industry arguments about spectrum don't help either.

So will investors in the new LEO constellations be enjoying dividends at some point in the not too distant future? Well this all depends. Narrow band lower frequency constellations such as the Myriota CubeSat constellation seem to be well targeted at markets such as deep rural IOT where the value proposition is clear and compelling. These networks could also be helpful in tracking polar bears and penguins and sheep and other animals that move quite slowly. Similarly adding imaging and positioning to LEO communication payloads is a neat way of sharing costs across multiple revenue streams from commercial and military markets.

For low cost consumer broadband service offers it ultimately comes down to cash and customers where companies with emerging space interests such as Amazon and Facebook have an inherent commercial advantage.

To take our animal analogy to its inevitable end point down a deep burrow, the share values of legacy satellite operators have been in the dog house for too long. It is time to take the bull by the horns and turn a bear market into a growth stock that recognises the infinite and ever expanding value opportunities that can be unlocked by the risky but rewarding space and satellite sector.

Foot Note – Star Dust and Satellites - The Romance of Space Engineering

Science and engineering does not need to be dull but can it be romantic?

In the context of space radio engineering the use of exotic and relatively rare elements such as Gallium is an essential part of the economic eco system. Gallium occurs in microscopic quantities in the earth's crust. It is usually produced as a by-product of aluminium and zinc production as direct extraction would be prohibitively expensive. As such it is one of many rare earth materials, elements and minerals that are essential to modern electronics.

Gallium combined with nitride is used in many space components where power efficiency is more important than cost. It is one of the rare earth materials that enable us to explore space, make money out of space and use space for military defence. Rare earth elements are a product of the big bang, an event that produced a large quantity of soot and a small quantity of magic dust, material that 13.8 billion years later helps us to build rockets run by computers that launch and control satellites that can do useful things in Near Space like delivering TV and broadband, imaging and positioning and wonderful things in Deep Space. Voyager 1 and 2, launched in 1977 have both now left the solar system and we can still talk to them with radio systems powered by radio isotopes, also a by-product of the big bang. Radio isotopes will also be powering the latest US Mars mission.

Satellites and space exploration powered by Stardust - what could be more romantic?

Ends

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