RTT TECHNOLOGY TOPIC
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Satellite Spectrum and Standards

In April 2016, AT&T and EchoStar announced a potential sharing framework for the 28 GHz band with Hughes Network Systems and Alta Wireless as possible partners. In parallel, Verizon and Viasat agreed to undertake coexistence, co sharing and cooperation studies.

This followed the AT&T filing with the FCC in January for an experimental license to conduct fixed and mobile testing with *various types of new wireless equipment* between 27.5 GHz and 28.5 GHz.

The CTIA suggested these studies should be broadened to include Upper Microwave Flexible Use (UMFU) shared access agreements in the 37 to 40 GHz band. Last month (July 2016) the FCC responded by approving its Spectrum Frontiers proceeding releasing UMFU designations for 27-28.35 GHz, 37-38.6 GHz and 38.6-40 GHz and a new unlicensed band at 64 to 71 GHz.

The interest by US and other potential 5G terrestrial mobile operators in the 28 GHz and 38-40 GHz bands is easy to explain.

The satellite industry has access to FDD spectrum which is ideally suited to terrestrial 5G implementation. Additionally the satellite industry has successfully implemented fractional beam width antenna technology which meets many and potentially all of the 5G wide area high data rate link budget requirements.

Additional scale economy benefits are also realisable from 28 GHz and 38 GHz terrestrial fixed link hardware.

In this month’s technology topic, we study the band plans used by Ka band high throughput (HTS) satellites, how technical and commercial innovation in the satellite sector is transforming the economics of the satellite industry and the implications for 5G spectrum and standards making.

We compare the 28 GHz and 40 GHz bands with other options including Ku band spectrum at 12 GHz and V band millimetre wavelength spectrum between 40 and 75 GHz and review the issues arising from the present mismatch between US and ITU 5G and satellite spectrum and competition policy.

Read on

Sixty years of satellites

On October 4th 1957, the 40th anniversary of the Bolshevik revolution, the USSR launched Sputnik 1, the first artificial satellite in space. The size of a beach ball and weighing 83.6 kg, Sputnik had transmitters at 20.005 MHz (15 metre wavelength) and 40.002 MHz (7.5 metre wavelength).

Satellites today include Pico satellites weighing less than 1 kg, Nano satellites weighing less than 10 kg, Micro satellites weighing between 10 and 500 kg and Macro satellites (>500 kg)

Inmarsat I-5 Ka band satellites for example are (big) macro satellites with a launch mass of 6100 kg, the body height of a double decker bus, a solar array wing span of 33.8 metres generating 15 kilowatts of power and a xenon ion propulsion system for in orbit manoeuvring.

The economics of delivering large and small satellites into space are being transformed by launch innovation, for example reusable rockets from Space X, Europeanized Soyuz rockets and electric satellites (launched into interim orbits before floating up to their final orbit). Satellites are lasting longer and can be refuelled and repaired in space.

Sixty years ago, Sputnik spurred the formation of NASA. The Cuban missile crisis of 1962 highlighted the strategic importance of space. The 1962 Satellite Communications Act *'allowed the US Government to supervise fair access for commercial satellites'* and coincided with the launch of Telstar 1, the world's first communications satellite, followed in 1963 by the first geosynchronous satellite.

The Satellite Communications Act created Comsat which in 1964 became Intelsat with a membership of 17 nations. In April 1965, the first Intelsat satellite, Early Bird was launched into geostationary orbit to deliver *'TV and telephone and telegraph and high speed data*'– the world's first quad play platform.

The Intelsat regulatory model was adopted in other regions. Eutelsat was formed in 1977 to operate the first European satellite (launched in 1983). Arabsat was founded in 1976 by the 21 member states of the Arab league.

Inmarsat (the **In**ternational **Mar**itime **Sat**ellite Organisation) had a different starting point, set up as an International Service Operator in 1976 to oversee safety of life at sea (SOLAS).

In 1982 Inmarsat started to provide mobile satellite communication services extending to land mobile in 1989 and aeronautical services in 1990. It was the first of the International Satellite Operators to deregulate (in 1999) as a response to the ITU 'open skies policy'. They were followed by Intelsat and Eutelsat in 2001.

This was not good timing. The dot com bubble had burst in 2000 and the telecom industry followed two years later. The dot com boom had produced a feverish investment in transatlantic fibre and over supply. All that unlit dark fibre meant that per bit long distance delivery prices reduced to almost zero.

In parallel, the satellite operators needed to maintain existing terrestrial and space hardware and put together plausible investment plans for new Ku band and Ka band constellations.

The result was that the satellite sector started to run uncomfortably high debt ratios. The debt servicing cost of Intelsat is presently equivalent to buying three satellites a year.

Fortuitously income from TV including income from fully amortized C band satellites and military payloads have helped to save the day but it is a tribute to the satellite industry and their patient shareholders that they survived their first 15 years in the private sector and remain in a position to justify new R and D and hardware and software investment.

Satellite Technology Innovation- Fractional Beam Width Antennas

The proof of this can be observed by considering present Ku and Ka band satellite technology innovation.

This includes fractional beam width antennas with a 3dB beam width between 0.5 and 1.5 degrees implemented as 12 to 100 spot beam arrays.

At this point it is worth highlighting the difference between fractional beam width antennas and MIMO systems. Both approaches require highly linear transmit and receive paths to support phase shifting, both require adequate wavelength spacing between antennas but everything else is different.

MIMO systems are configured to produce multiple paths with each path separately modulated and channel coded (and amplified) to support high per user data rates with adequate multiplexing efficiency over short distances. Fractional beam width antennas are configured to deliver link budget gain from single narrow beam paths between a base station and user/IOT device.

MIMO systems exploit multi path. Fractional beam width antennas minimize multi path (and the associated delay spread). A well designed fractional beam width antenna can produce more than 40 dBi of isotropic gain – the primary objective is to support moderately high data rates over long distances rather than super high data rates over short distances. Fractional beam width antennas are the single most important technology enabler for present generation of high throughput (HTS) satellites. They are used to focus 'on demand' RF energy on small geographic areas.

Fractional beam width antennas can also be used in terrestrial networks to focus 'on demand' RF energy on individual users or IOT devices. This makes them the single most important technology enabler for cost economic power efficient wide area high data rate high mobility 5G networks.

FDD dual use dual band spectrum with fractional beam width antennas

The other important difference between MIMO and fractional beam width antennas is that MIMO is more efficient when implemented in TDD spectrum as the uplink and downlink are reciprocal.

However TDD systems do not deliver the same sensitivity as FDD systems and get less sensitive and less efficient with distance. In other words TDD systems do not scale efficiently in wide area networks and only work adequately well if all operators are co sited which given present competition policy is largely impractical. The same applies in the satellite sector.

A typical Ka band satellite FDD band plan at 28 GHz has four 250 MHz uplink channels between 28.35 GHz and 30 GHz paired with a downlink between 17.7 and 21.2 GHz. This is matched to a military band uplink at 30 to 31 GHz and a military down link at 20.2 to 21.2 GHz

The Ka band payload of an Inmarsat Global Express satellite can be switched between military and commercial frequencies with the military bands supporting a range of high added value applications including unmanned aerial vehicle (UAV) connectivity and control.

Present Launch Plans – Intelsat and Eutelsat

In 2009, Intelsat announced a $3.5 billion fleet investment and a hosted payload agreement with the Australian defence force followed in 2012 by plans for a new generation (known as the EPIC generation) of high throughout (HTS) satellites.

Two of these 6500 kg satellites, built by Boeing, are capable of being launched from a single Ariane 5 rocket. The satellites are initially planned to have Ku band transponders with services being targeted to aeronautical and maritime markets, treading on Inmarsat's traditional stamping ground.

Eutelsat have a 44 transponder Ku band electric satellite (Eutelsat 7C) planned for launch in the third quarter of 2018 optimised to provide service to sub Saharan Africa and a Ka band satellite built in Israel called AMOS (Affordable Module Optimized Satellite but also a Jewish prophet) to be launched on a Space X rocket from Cape Canaveral.

Facebook have announced an agreement with Eutelsat to use this satellite to provide low cost internet access to Africa using six of the AMOS Ka band spot beams. The satellite GSO orbit at 4 degrees west will also provide coverage for the Middle East, Western, Central and Eastern Europe though some country specific landing rights issues will need to be resolved.

People and politics in the satellite industry

This brings us to politics and the people behind the politics. On the 13 April 2016, Congressman Jim Bridenstein, a Congressman from Oklahoma, home of the Oklahoma Air and Space Port, introduced the American Space Renaissance Act.

The Act envisions a renaissance of the military, civil and commercial US space industry. Citing Mr Putin's investment in Glonass, Mr Bridenstein makes the American case for military investment in 'the ultimate military high ground', the need to invest in civil space missions including a Mars mission (27 NASA space missions have been cancelled over the past twenty years at a cost of $20 billion) and a favourable regulatory environment for Mr Musk at Space X and Mr Branson at Virgin Galactic.

A significant number of Republican congressmen and senators are also apparently planning to launch Mr Trump into deep space at the earliest opportunity.

The bill is supported by EchoStar owned by Charles Ergan who also owns Dish Networks and bought $1 billion par value Light Squared stock in 2013 at a deep discount following the Light Squared Chapter 11 filing in May 2012. As with the early years of the competitively regulated cellular industry, individuals can make a major market impact and a not inconsiderable fortune, Craig Mc Caw being a notable example.

Mr McCaw then went on to invest in the Teledesic satellite project, a planned constellation of low-Earth orbit (LEO) satellites operating in Ka-band (30GHz uplink/20 GHz downlink) with the mission to deliver low cost internet connectivity from initially 840 satellites (1993) and then 288 satellites (1997). Teledesic closed down in October 2002.

Light Squared by comparison has re-emerged as Ligado, the Spanish for connected, chaired by Ivan Seidenberg, the former Chairman and CEO of Verizon and Reed Hundt, former Chairman of the FCC. The name at least suggests a Latin American low cost inter connectivity business plan.

Third time lucky for hybrid satellite terrestrial networks?

The reappearance of Light Squared could be interpreted as a positive indication that hybrid terrestrial satellite networks could be on the agenda again. However Ligado is not being positioned as a hybrid network. There are existing examples of hybrid networks such as Thuraya (GSM+ satellite) which are technically and commercially successful but only in high ARPU countries with large amounts of desert. There are also VHF satellite systems such as Orbcomm providing IOT connectivity that could potentially be combined with terrestrial cellular networks.

Dish Networks has applied for a patent for reusing frequencies between satellite and terrestrial systems based on MIMO and beam forming. Dish is part of a coalition of ten companies that is lobbying the FCC to reallocate 500 MHz of presently unused Non Geostationary Orbit Fixed Service Spectrum (NGSO FSS) between 12.2 and 12.7 GHz (the lower end of Ku band) for '5G' Multi-Channel Video Distribution and Data Services (MVDSS).

This would reduce the NGSO allocation to 11.7 to 12.2 GHz though this is being contested by Space X, One Web LCC and Intelsat. One Web, based in the Channel Islands raised $500 million in June 2015 and partnered with Airbus to build 900 low earth orbit satellites to be launched on Soyuz rockets in 2018 and 2019 though an additional $2.5 billion (and an operating license) will be needed to make this viable. Space X has similar plans to build a constellation of 4000 Ku band satellites

Scale and standards issues

Compared to Ka band, Ku band has the advantage of a lower rain fade margin but there is a scale and standards issue.

Apart from satellite TV with DVB-S as a relatively widely adopted standard in Europe and Asia, the satellite industry is dominated by proprietary physical layers with minimal overlap with present terrestrial cellular radio standards. Within ETSI, efforts were made ten years ago to support UMTS/IMT-2000 interoperability with satellite systems at 2 GHz adjacent to terrestrial cellular Band 1 but little progress was made. Market presentations about LTE and satellite integration are statements of intention rather than imminent reality.

However we would argue that 5G needs the satellite industry. The satellite industry doesn't need 5G but that is not to say that 5G/satellite integration would not be mutually beneficial.

5G needs the satellite industry because economic wide area high data rate high mobility connectivity can only be achieved by using techniques such as adaptive fractional beam width antennas that are already deployed in the satellite sector.

Economic wide area high data rate high mobility connectivity can only be achieved by using spectrum already used by the satellite industry.

Channel bandwidths and pass bands – satellite and 5G band plan implications

This becomes obvious when channel bandwidth requirements are considered.

As per user data rates increase, wider channel bandwidths are required to maintain multiplexing gain. However wider channel bandwidths reduce RF efficiency particularly in space constrained user devices.

So for example in an ideal world, antennas would work over a bandwidth of 10% of centre frequency and filters would work over 4% of centre frequency.

These ideal bandwidths are often exceeded. With antennas this is achieved by changing the electrical length of the antenna or increasing the physical length (for example a PIFI antenna) but in both cases there will be an efficiency loss. With RF filters, wider pass bands soften the filter edges and increase the amount of adjacent channel leakage and inter and intra system interference. This can be mitigated by introducing additional filters, roofing filters as one example, but these increase insertion loss and take power out of the mobile uplink link budget.

The get out clause is that it is not the channel bandwidth that is important but the channel bandwidth as a ratio of the centre frequency.

RF filters are the reason that pass bands in cellular FDD networks below 1GHz are typically not more than 40 MHz (4% bandwidth ratio) supporting some combination of 5 MHz and 10 MHz LTE channels.

The expectation within LTE Advanced is that pass bands of 100 MHz will be needed to deliver an adequate compromise between multiplexing gain and RF efficiency.

100 MHz at 3 GHz is an efficient (3.3%) bandwidth ratio.

There is some consensus that an initial 5G network deployment in five years' time (2020) will need a channel bandwidth of 250 MHz to deliver adequate multiplexing efficiency. If spectrum continues to be auctioned on the basis of four operators per band this implies a pass band of 1 GHz.

This means that the centre frequency will need to be somewhere close to 30 GHz. This coincides with the spectrum presently being used by Ka Band HTS satellites. Anything much below this would compromise RF efficiency.

By 2025 a channel bandwidth of 500 MHz implies a pass band of 2 GHZ increasing to 1 GHz by 2030 implying a pass band of 5 GHz. This bandwidth is only practical from an RF efficiency bandwidth ratio perspective using the millimetre band, with the spectrum either side of automotive radar being an obvious option.

Automotive radar is being implemented between 77 and 81 GHz leaving 5 GHz pass bands either side between 72 and 77 GHz (immediately adjacent to the newly designated US unlicensed band between 64 and 71 GHz) and 82 to 87 GHz. This assumes that in ten years' time, digital signal processors will be capable of handling 1GHZ channel bandwidths and 5 GHz pass bands power efficiently across a dynamic range of 100 dB. Given that the automotive industry has a similar problem to solve, it will probably happen.

Ku band is a possible alternative to Ka band and has the advantage of a lower fade margin but it is currently hard to see how these proposals could scale globally. The pass band of 500 MHz potentially available at 12 GHz is also arguably insufficient if a multi operator auction model is required. A 1 GHz pass band at 12 GHz, assuming it could be made available, would result in a loss of RF pass band efficiency.

By contrast, the 28 GHz band is conveniently allocated on a 250 MHz channel raster within a 1 GHz pass band with an efficient (2.5%) bandwidth ratio. The band has established scale in fixed link terrestrial hardware which could be translated into low cost 5G hardware. 28 GHz is therefore arguably an optimum technical and commercial start point for 5G deployment with 38 to 40 GHz as a second alternative.

Later deployments based on 500 MHz and 1 GHz channel bandwidths within a pass band of 4 or 5 GHz are going to be technically more efficient at millimetre wavelengths at 70 and 80 GHz.

Summary

It is difficult to see how 5G can be deployed cost efficiently and power efficiently without borrowing from present satellite technologies and without initially using satellite spectrum in the centimetre band (Ka band and possibly Ku band) and longer term in E band, V and W band (the millimetre band).

The AT@T announcements with EchoStar and Verizon and Viasat and Facebook and Eutelsat are an early sign of this emerging dependency and appear to be validated by a shift in US spectrum and competition policy.

This shift is not reflected in present ITU spectrum or standards policy and needs to be factored in to future competition policy. Satellite operators have by and large been gifted their spectrum and typically have access to at least 4 GHz of aggregated bandwidth (including L band and C band allocations).

It will however be a delicate balancing act to arbitrate what are likely to be complex coexistence, co-sharing cooperation and commercial challenges and opportunities between the 5G community and satellite industry. The complexity will likely be compounded by the US taking a significantly different approach to the rest of the world in terms of regulatory and competition policy. The 28 GHz band would appear to be particularly well suited to initial 5G deployment but will be politically challenging if global scale is to be achieved.

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