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THE SUPERHET NET

Our thanks to John Haine from the University of Bristol and David Lister of Vodafone Australia for pointing out some mistakes in the first draft of this technology topic- here is a version duly amended!

The space sector has supported HETNET radio systems for many years. The Near Earth Network has been operational since the early 1990's combining LEO, GSO, HEO and lunar orbiting satellites into an integrated communications system across multiple frequency bands. Its predecessor, NASA's Spacecraft Tracking and Data Acquisition Network, was established by Robert Goddard in 1961.
https://www.nasa.gov/directorates/heo/scan/services/networks/nen

In this month's technology topic, we add to our evolving analysis of the emerging role of LEO, MEO and GSO satellites for 5G urban, rural and maritime mobile and fixed access wireless connectivity and the related positive impact on the sustainability of the 5G business model, we call this the SUPERHET NET, a combination of a terrestrial HETNET (horizontal HETNET) and space based HETNET (vertical HETNET).

The 5G business model is predicated on a number of assumptions. The underlying assumption put forward by the vendor supply chain is that data traffic between the network and user and IOT devices will grow by several orders of magnitude over the next ten to 15 years and that the revenues and margin realized from this volume growth will be sufficient to cover the additional capex and opex costs associated with the additional required capacity.

Higher data rates and lower latencies are also assumed as the basis for delivering higher added value services to and from user and IOT end points. These added value services require an improved link budget achieved from a combination of higher flux density on the transmit path and improved sensitivity on the receive path.

The challenge with these objectives is that they are mutually exclusive. As data rates increase, data reach reduces due to the lower Eb/No (energy per bit over the noise floor).

Therefore any increase of data rate and data throughput will involve additional capex and opex expenditure which includes new spectrum investment and the hardware and real estate assets needed to support that spectrum.

The vendor argument is that new spectrum combined with the spatial multiplexing gain from beam forming (measured as spectral efficiency in bits per Hz) will deliver cost efficient capacity and that the isotropic gain available from beam forming (improving the signal to noise and carrier to interference ratio) will deliver cost efficient coverage and capacity.

For example a 10X to 20X capacity gain is assumed from 5G deployed below 6 GHz. A 100 MHz pass band at 3.5 GHz coupled to a 2X to 4X efficiency gain is assumed to realise a spectral efficiency of 4-8 bps/Hz. A 20 MHz 4G pass band at 1.9 GHz is assumed to realize a spectral efficiency of 2 bps/Hz.

When compared to 1.9 GHz, the 3.5 GHz channel will typically have 6 dB of additional path loss outdoors and 3.5 dB for outdoor to indoor coverage which will be offset by 6-9 dB of beam forming gain. There will be an associated processing overhead both at the BTS and in the end point device which will have an energy cost in the BTS and a battery life cost in the end point device.

However there is also an assumption that more closely controlled latency can open up new high value applications including vertical markets such as automotive connectivity and critical machine type communication in manufacturing, the energy and utility sector and health care.

The evolving vendor view is that it will be easier and more cost efficient to deliver lower latencies from spectrum above 6 GHz. As stated in our September 2018 Technology Topic (Massive Multiplexing https://www.rttonline.com/tt/TT2018_009.pdf) the 3GPP new radio specifications divide 5G spectrum into two ranges, frequency Range 1 (FR1) below 6 GHz and Frequency Range 2 (FR2) over 6 GHz.

FR1 is also described as Low Band and Mid Band 1 with FR2 sub divided into Mid Band 2 and high band. The assumed performance bounds are described in the table below

FR1	Frequency range	Max cell size and performance
Low Band	Sub 1 GHz	30 km radius cells
		10 MHz channels
		10 ms latency
Mid Band 1	1 - 2.6 GHz	15 km radius cells
		20 MHz channels
		< 10 ms latency
FR2		
Mid Band 2	3.5- 6 GHz	8 km radius cells
		50 MHZ channels
		<5 ms latency
High Band	24 - 40 GHz	1 km radius cells
		100 MHz channels
		1 ms latency

Radio waves do not travel faster at higher frequencies so the reason to move to higher frequencies is to ensure sufficient capacity is available for latency critical applications. Moving anywhere close to a capacity limit is incompatible with a latency critical service and intrinsically implies a need to over provision bandwidth. Although latency is not impacted by time of flight in a cellular cell, the lowest latencies will only be achieved with small packet sizes, no retransmissions and higher modulation coding schemes so useful range will be less than mobile broadband.

Latency limits are also a function of end to end distance and need to avoid long round trip delays to servers hundreds or thousands of miles away. This in turn has focused the vendors on developing ‘edge based’ storage where web sites are cached in the local BTS. The additional cost of this storage is to be partially offset by moving some of the radio processing from the edge towards the network core. The effectiveness of localised cached storage is a function of how often the cache requires updating. The assumption is that in most environments, the local downloading and uploading behaviour will be relatively stable and predictable though this model has yet to be tested in telecoms networks.

However it can be seen that edge based storage implies a network with more investment at the network edge. This is potentially compounded by a need for more cells to accommodate 5G and user and IOT devices that have lost some RF efficiency due to the need to support multiple bands and technologies and hand capacitance issues at higher frequencies. At network level, surface scatter and absorption from signals delivered from street level or roof level 5G access points in the millimetre bands will compromise the link budget. At lower frequencies it will be harder to realise beam forming gain due to BTS and user device space constraints and at all frequencies, beam forming will introduce delay and delay variability.

Adding these factors together, it is hard to ignore the reality that the cost of delivering 5G services including latency sensitive connectivity is going to be higher than 4G which implies a belief that 5G will realise sufficient additional value to cover this additional cost.

Presently it seems to be assumed that much of this added value will come from enhanced urban connectivity but street level or roof top base stations are costly to acquire and run. While there are ongoing regulatory efforts to make access to street furniture easier, for example in the US, most countries still have structures such as street lights owned by multiple agencies which makes real estate acquisition and ongoing administration complex and impossible to scale. Roof level is no easier.

The outside to indoor 5G models is also questionable because it fails to take into account the ever improving economics and performance of in building Wi-Fi.

Other specialist indoor environments such as factories can also potentially be better served by Wi-Fi with equivalent performance to 5G and lower costs.

This suggests that 5G connectivity in outer urban and rural environments needs to be factored into operator business models but coverage from street level or roof level nodes is going to be variable and costly. Just as one example, the latency requirements and continuity requirements for automotive connectivity imply an increase in existing 4G link budgets of anything between 15 and 30 dB which would be an eye watering financial risk for mobile operators, particularly if better more reliable lower cost connectivity is available from non-terrestrial platforms.

Which is where we arrive at our ongoing narrative that a combination of high count nearly always nearly overhead LEO constellations combined with MEO and GSO connectivity is going to be an essential part of the 5G mobile and fixed access and (in band) back haul business model for urban, outer urban, deep rural and maritime connectivity (5G At Sea). This is based on the premise that the cost of delivering connectivity from terrestrial networks is increasing whereas the cost of delivering access from satellites is decreasing.

It is also useful to consider how the dividing line between urban connectivity value and rural connectivity value is likely to change over the next thirty years. The United Nations is projecting that by 2050 nearly 70% of the world's population will be urbanised.

https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html

However this does not mean that 70% of global connectivity added value will be city based. Just at a basic level, all these people will need to be fed and watered so rural and maritime environments will need to be monitored and managed.

The bottom line is that most terrestrial wireless connectivity business models are presently based on demographic coverage with city hot spots considered as potential 5G honey pots.

We predict that this assumption will come to a sticky end and that geographic rather than demographic coverage will be the 5G economic sweet spot with satellite as the key enabler.

Conversely supporting highly dense individually cached distributed base stations in cities will be hugely expensive over terrestrial fibre so satellites will score there as well with in band up haul as a cost effective alternative to terrestrial back haul/front haul and cross haul.

Either way it is hard to escape the conclusion that a significant part of the 5G future is most definitely upwards.

New Book - 5G and Satellite Spectrum, Standards and Scale

Our new book, **5G and satellite spectrum, standards and scale** is available from Artech House. You can order a copy on line using the code VAR25 to give you a 25% discount.

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

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