RTT TECHNOLOGY TOPIC
September 2018

Massive Multiplexing

In last month's technology topic, From Silk Worms to Smart Phones, we reviewed the contribution that SAW and FBAR filters have made to modern smart phone radio frequency (RF) front ends.

The design challenge for RF front end designers over the past ten to fifteen years has been defined by the need to support increasing numbers of bands and technologies and more recently, operator, country and region specific multi band aggregation options. This has required new approaches to front end design including multiple hexaplexer switch paths..

The difficulty has been producing RF front ends that perform well across **all** supported bands. While it is possible to optimise RF performance across two or three core bands, there is generally an associated cost in terms of performance in other bands which means that the user experience can be variable both in terms of throughput and range.

While this may not be immediately noticeable to a user, there will be an operator coverage and capacity cost which will have an indirect but measurable impact on spectral realised value - the rule of thumb that a dB loss of RF performance is equivalent to a ten percent increase in network density still applies.

This relationship between user and IOT device performance and network opex and capex cost is also likely to be a determining factor in 5G delivery economics, the subject of this month's technology topic.

Read on

5G spectrum is closely coupled to the 3GPP 'new radio' (NR) standards process. The relevant work group is RAN4, with 5G new radio defined from Release 15 onwards in two frequency ranges (FR), FR 1 from 450 MHz to 6000 MHz with bands numbered from 1 to 255 commonly referred to as sub 6 GHz and FR 2 from 24250 MHz to 52600 MHz (24.252 GHz to 52.6 GHz) with bands numbered from 257 to 511.

The channels within the bands are a maximum of 100 MHz for sub 6 GHz scaling from Bands 41, 42 and 43 upwards and 400 MHz for mmWave.

The 27 RAN4# 83 defined bands for FR1 are listed in the table

Band number	Uplink (MHz)	Downlink (MHz)	Duplex Mode
N1	1920-1980	2210-2710	FDD
N2	1850-1910	1930-1990	FDD
N3	1710-1785	1805-1880	FDD
N5	824-849	864-894	FDD
N7	2500-2570	2620-2690	FDD
N8	880-915	925-960	FDD
N20	832-862	791-821	FDD reverse duplex
N28	703-748	758-803	FDD
N38	2570-2620	2570-2620	TDD
N41	2496-2690	2496-2690	TDD
N50	1432-1517	1432-1517	TDD

N51	1427-1432	1427-1432	TDD
N66	1710-1780	2210-2200	FDD
N70	1695-1710	1995-2020	FDD
N71	663-698	617-652	FDD reverse duplex
N74	1427-1470	1475-1518	FDD
N75		1432-1517	SDL
N76		1427-1432	SDL
N77	3300-4200	3300-4200	TDD
N78	3300-3800	3300-3800	TDD
N79	4500-5000	4500-5000	TDD
N80	1710-1785		SUL
N81	880-915		SUL
N82	832-862		SUL
N83	703-748		SUL
N84	1920-1980		SUL
N85	2496-2690		SUL

The supplementary uplink (SUL) is a new operational mode supporting a choice of lower band uplinks that can be paired with a 3.5 GHz downlink either using dual connectivity or aggregated.

Five of the defined sub 6 GHz bands are described as pioneering bands intended for early deployment (by 2020) including N77 in C band. This has been proposed in Japan as an 800 MHz pass band from 3.4-4.2 GHz implying a bandwidth ratio of over 20 % which implies challenging and costly front end filter specifications and or high out of band emissions. N78 would be more closely harmonised in different regions including Europe.

The other pioneer bands are N79 proposed by regulators in Japan, Russia and China and N28, formerly Band 28 also known as the APT 700 MHz (Asia Pacific) band which would be substituted by Band 20 where 28 is not available, for example in Europe.

Theoretical calculations support a claim that a 3.5 GHz downlink with massive MIMO gain would have similar range to a 700 MHz uplink from a handset but this would be significantly dependent on the real life efficiency of the 700 MHz antenna in the user or IOT device and base station antenna implementation.

There are also awkward second order and third order relationships between the sub GHz bands and Band 1 and the 3.5 GHz bands which will potentially degrade receive sensitivity.

The FR2 bands in Release 15 are shown in the table below

Band number	Uplink (GHz)	Downlink (GHz)	Duplex Mode
N257	26.5-29.5	26.5-29.5	TDD
N258	24.75-27.5	24.75-27.5	
N259	31.8-33.4	31.8-33.4	
N260	37-40	37-40	

The US, Korea and Japan are also planning to deploy in the 28 GHz band, coexisting with existing backhaul allocations and therefore supporting in band backhaul. Other regions are proposing other bands including 5.925-8.5 GHz, 10-10.6 GHz in Europe or 7.075-10.5 GHz and 15.35-17.3 GHz in Africa.

However there are also multiple band and technology combinations where LTE and 5G carriers are supported simultaneously either in band or intra-band. The options known as LTE and or 5G carrier combinations (CC) are listed in the table below

Carrier combination	Total number of combinations proposed
LTE_1CCNR_1CC	99
LTE_2CC_NR_1CC	101
LTE_3CC_NR_1CC	69
LTE_4CC_NR_1CC	24
LTE_5CC_NR_1CC	1
CA intra-band x DL/1UL	2
CA intra-band 2DL/1UL	13
LTE_1UL_NR_ULDL	4
LTE_1CC_NR_2CC	5
LTE_2CC-NR_2CC	6
LTE_3CC_NR2CC	4
LTE_4CC_NR_2CC	1
Total	329

This prompts some general comments.

In LTE, there are presently something approaching 50 band options and about 100 potential channel aggregation options.

In practice it is only economic in terms of dollar cost and performance cost to support a sub set of these bands in an LTE phone or IOT device, typically 12-14 bands with limited aggregation. Release 15 and subsequent Releases will expand these 50 bands to 500 bands with over 300 aggregation combinations.

This includes higher C band and Ku, K and Ka band where SAW and FBAR filters have to be replaced with ceramic filters. Ceramic filters become more manageable in terms of their real estate footprint in a phone at these higher frequencies but there is still a finite limit to how many filters can be included in a hand held user device or low cost compact power efficient IOT terminal.

Additionally a decision needs to be taken on how power amplification is realised. In a non-stand-alone network where an LTE connection anchors 5G, the user/IOT device would be required to maintain two uplink connections, one for LTE and one for 5G NR. Using one amplifier would split the available power across the two uplinks, limiting uplink range. Using multiple amplifiers would drain power and produce internal heat rise and frequency stability issues and introduce additional cost and weight.

While it could be argued that user to user /device to device interference could be managed to an extent by beam forming (spatial separation of wanted and unwanted signal energy) this does not solve internal interference issues which include unwanted reciprocal mixing and receive desensitisation.

Additionally, beam shaping and beam forming relies on accurate phase offsets being maintained across all antenna elements. This can be realised effectively across relatively narrow bandwidths either side of a single centre frequency but having to support many different bands, many with wide pass bands, will limit range gain. The range gain and throughput calculations for 5G assume either a 256 or 512 element antenna array on the base station and an 8,16 or 32 element array in the handset or IOT device. These arrays could be designed to be broad band, for example by switching in additional element lengths, but getting them to beam form efficiently as well will be challenging in terms of processing overhead, size and cost even for networks working at Ku band and above and very challenging for C band (3.5 GHZ for example).

This will mean that LTE-5G phones could potentially deliver high data rates in ideal signal to noise environments by exploiting multiplexing gain across multiple bands but MIMO gain would be marginal which would mean that the phones will perform poorly in rural and outer urban areas.

This would seem to suggest that adding satellite connectivity into phones would be particularly useful.

However the LTE-5G new radio standards are not satellite friendly.

The proposed extended FR1 C band and FR2 Ku, K and Ka band spectrum options are proposed as TDD deployed in bands that are either expected to coexist or be adjacent to satellite FDD uplinks and downlinks.

Apart from the timing and clocking issues of TDD, the 100-400 MHz channel raster allocations for 5G are expected to co-exist with the 250 MHz channel raster used in satellite uplinks and downlinks which then scale to 1 GHz and 2 GHz pass bands in V and W band and E band.

The channel throughput constraints in 5G are countered by the use of 1024 QAM (assuming high SNR) which could cause significant spectral splash into adjacent channels including satellite receive channels. Other modulation options with less envelope variation are supported including lower order QAM and BPSK though there is no support for the default PASK used in most satellite transponders. Note that PASK is used to deliver maximum RF Power amplifier efficiency and would be equally useful for terrestrial node B transceivers in applications where energy is scarce and expensive – rural Africa and Latin America being two examples.

In order to improve bandwidth efficiency, 5G resource blocks are supported to the band edge, for example the whole 20 MHZ of a 20 MHz carrier compared to LTE where 100 resource blocks sit within an 18 MHz channel in a 20 MHz carrier. This trades in band efficiency against higher Out of Band (OOB) transmissions.

The 3GPP standards process is therefore producing the worst possible coexistence conditions, guaranteeing adversarial arguments over future 5G to satellite protection ratios. Vertical to horizontal power separation will solve some of these problems but not all of them.

This seems perverse given that the FCC has decreed that OneWeb has the regulatory authority to deploy a minimum of 720 satellites and a maximum of 1980 satellites into low earth orbit at 1200 kilometres using Ku band spectrum with full deployment by 2027. Space X has clearance to deploy 4425 satellites using Ku and Ka band again with a nine year deployment requirement with 50% deployment within six years. In telecoms time this is the equivalent of tomorrow and would produce two networks with complete global land and sea coverage where at least one satellite will be nearly always overhead nearly all the time.

Having regulatory clearance to do something is of course no guarantee that things will actually happen as planned or scheduled and there are many factors that may limit these roll out plans including resistance from incumbent GSO, MEO and LEO operators concerned about the rate of rate reduction implied by bringing so much space based bandwidth into the market in such a relatively short time scale.

To put this into perspective, there is minimal public domain information about Mr Musk's satellites and satellite constellation except that it will be inter satellite switched.

For fund raising reasons, (One Web is invested by Virgin, Softbank, Coca Cola, Bharti, Qualcomm and Airbus), Mr Wyler has needed to be more forthcoming with detail and the statistics are startling.

The OneWeb constellation will not be inter-satellite switched. The impact of this decision is debatable. The satellites are simpler and lower cost but dependent on expensive earth stations.

On the other hand the shift of satellite TV from satellite to fibre releases significant earth station uplink and downlink bandwidth. More compelling are the performance statistics.

The cost of getting to space is measured by weight. The OneWeb satellites being built by Airbus in Toulouse and Florida are, unusually, lighter than planned, weighing in at 145 kilogrammes. Each 14.5 kilogrammes yields 1 gbps of throughput.

With nearly 2000 satellites in orbit and ten gbps per satellite that suggests a 20 terabit per second network with Mr Musk probably thinking about something significantly larger with tighter more controllable latency than anything deliverable across future 5G terrestrial networks.

And no site costs, no electricity costs and the bandwidth where you need it when you need it with a higher flux density than 5G in many urban and rural environments.

There are many reasons to expect that the satellite industry will not live up to the present heightened expectations fuelling an investment frenzy in launch capacity courtesy of Mr Musk, Mr Bezos of Blue Origin/ Amazon, Mr Zuckerberg, (US President Elect 2030?), Mr Branson and Peter Beck (Hello New Zealand)) not to mention the regional investment of the Indian and Chinese and Indonesian and Brazilian and European (and British?) space industries.

On the other hand, the telecommunications industry has a history of springing surprises. The long distance latency gain that inter-satellite switched high count LEOS deliver over fibre might be the biggest of these.

Ends

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

Our new book, **5G and satellite spectrum, standards and scale** is now available from Artech House.

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

Geoff will be presenting a paper on 5G and satellite coexistence issues at a Cambridge WIreless Radio Technology event at the University of Bristol on Tuesday 18th September
https://www.cambridgewireless.co.uk/events/radio-technology-5g-making-it-work/

And co-hosting with other members of the Wireless Heritage SIG *Sixty Years of Satellites from Sputnik to Space X* at the Science Museum on Friday October 5th

https://www.cambridgewireless.co.uk/events/sixty-years-satellites-sputnik-space-x/

About RTT Technology Topics

RTT Technology Topics reflect areas of research that we are presently working on. We aim to introduce new terminology and new ideas to help inform present and future technology, engineering, market and business decisions.

The first technology topic (on GPRS design) was produced in August 1998. 20 years on there are over 220 technology topics **archived on the RTT web site.**

Do pass these Technology Topics and related links on to your colleagues, encourage them to join our **Subscriber List** and respond with comments.

Contact RTT

RTT, **Policy Tracker** and **The Mobile World** are presently working on research and forecasting projects in the mobile broadband, public safety radio, satellite and broadcasting industry and related copper, cable and fibre delivery options.

If you would like more information on this work then please contact **geoff@rttonline.com**
00 44 7710 020 040