RTT TECHNOLOGY TOPIC
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Wavelength – reframing the 5G debate

In the past month, studies have been published by Ofcom and METIS on 5G spectrum.

http://stakeholders.ofcom.org.uk/binaries/consultations/above-6ghz/5G_CFI_Update_and_Next_Steps.pdf

https://www.metis2020.com/

This is a complex debate with a wide range of possible options, band combinations and competing industry interests.

This month's technology topic discusses how this debate could be framed using wavelength rather than frequency as a basis for defining and describing 5 G technology and spectrum options and their relative risk and return. This includes 5G systems proposed for deployment into the centimetre and millimetre bands.

We flatter ourselves by talking about the challenge of responding to 'unprecedented technology change' including the difficulties of delivering cost economic high bandwidth high frequency radio.

To put this into historical perspective it is useful to remember that by the 1890's there was a developed practical understanding of radio waves up to and including what we now call the UHF band, L band and the centimetre and millimetre bands. In 1888 Hertz used a sheet zinc parabolic cylinder reflector antenna to generate 66 cm radio waves (454 MHz). Marconi used a similar deep parabolic cylinder for 25 cm experiments (1200 MHz). By the early/ mid 1890's WC Bose was demonstrating radio waves at 5mm (60 GHz) and 6 mm (50 GHz).

https://www.cv.nrao.edu/~demerson/bose/bose.html

The mechanics of high frequency radio, parabolic reflectors, microwave absorbers, cavity radiators and round, square and rectangular waveguides were mastered several years before the theory. (Rayleigh - On the passage of electric waves through tubes, or the vibrations of dielectric cylinders Phil. Mag.43, 125-132, 1897).

Physics hasn't changed in the last 120 years and our ability to use the centimetre and millimetre bands for efficient high capacity local and wide area coverage remains dependent on antenna and wave guide design. For this reason there are persuasive arguments to going back to using wavelength to describe and define system, product, service and spectral requirements and investment risk and return for 5 G radio systems.

Read on

Early wide area/long range radio systems were described and are still described today as long wave, medium wave or short wave. The term microwave came into common usage after the Second World War as a way to describe wavelengths between 100 cm (300 MHz) and 0.1 cm (300 GHz).

Wavelength was used as a descriptor simply because wavelength is easier to measure. The Marconi wave meter is an early example of a wavelength measurement device.

https://www.mhs.ox.ac.uk/marconi/collection/glossary.php

Accurate measurement of frequency required highly stable quartz crystal oscillators. As these became more readily available through the 1930's there was a shift to describing radio in terms of frequency – VHF or UHF or other arbitrary naming systems, C, X and K bands for radar for example.

Forty years on frequency counters remained expensive, clumsy to use (range switching and cable changing) and only accurate when measuring relatively high power levels. The HP5340 introduced in 1973 solved many of these performance issues and worked from 10 Hz to 18 GHz but cost over $5000 dollars.

http://historycenter.agilent.com/exhibit1

The introduction of cellular radio from 1980 onwards marked a shift to describing systems with a specific frequency description, the 800 MHz AMPS networks (subsequently called Band 5), the 900 MHz TACS/ETACS networks (subsequently called Band 8) the 1800 MHz networks (subsequently called Band 3) and so on until we arrive thirty years later with 44 LTE bands implemented or proposed, all described by frequency and ranging from Band 31 in Brazil at 450 MHz (0.666metres) to Band 43 at 3800 MHz (0.111 metres).

LTE band plans are becoming incredibly complicated with the complexity compounded by carrier aggregation. Adding in C band, the K bands and V and W band (with the E band sub bands) for 5G makes a hard to understand landscape increasingly incomprehensible to anyone other than a subject specialist, and we don't want them to be responsible for 5G system design or economic modelling.

The answer is to think about wavelength rather than frequency.

We all know that wavelength and frequency are directly related. Radio wavelength is calculated as the speed of light (300 million meters per second) divided by frequency.

300 MHz is therefore conveniently one meter.
www.unit**conversion**.org/unit_**converter**/**frequency**-**wavelength**.html

The optimum theoretic length for an antenna is one quarter or one half of the wavelength to be received or transmitted. It is therefore wavelength that defines RF product form factor and RF product functionality not frequency.

For example it is possible to design compact 'electrically short' antennas for smart phones in the 450 MHz band or 700 MHz band but the wavelengths are .666 metres and .428 metres. These antennas when cramped into an artificially small space with an inefficiently small ground plane introduce a loss of the order of 6 or 7 dB. A 7 dB loss is equivalent to the theoretical propagation gain achieved in a 700 MHz cell when compared to an 1800 MHz cell.

Put another way you have just thrown away the additional coverage gain that you thought you might get from a 450 or 700 MHz network and the user experience will be more variable due to unwanted external coupling including hand capacitance effects. Some of this additional variability can be reduced by using adaptive tuning (variable capacitance using RF MEMS) but this adds cost and complexity. The counter side to this is that as wavelength decreases, antenna size decreases. This means that multiple antenna elements can be fitted in the space formerly occupied by a single longer wavelength antenna. This is the science underpinning 5G smart antenna design and provides the mechanism for delivering high capacity high data rate ultra-dense access or high data rate wide area access.

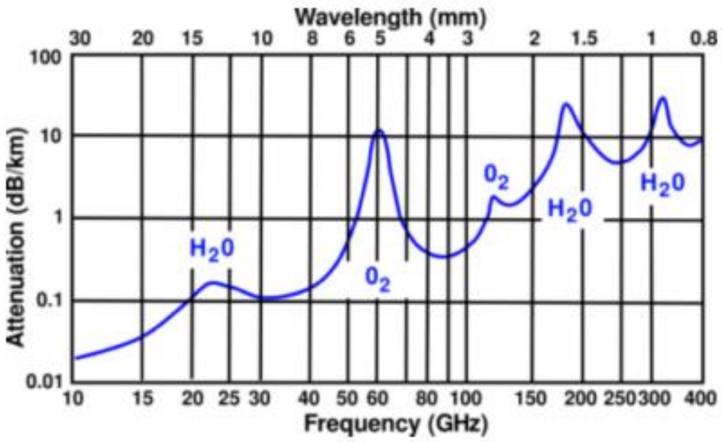
At a recent Cambridge Wireless technical conference, Moray Rumney of Keysight Technologies provided a link to a WiloCity YouTube video of a WiGig 5mm wavelength (60 GHz) dense network delivering 3 Gbps per square meter of data throughput using beam forming.

www.youtube.com/watch?v=4M4ngJsQF70
http://www.cambridgewireless.co.uk/cwtec/resources/

This is a demonstration of commercially available equipment compliant with IEEE 802.11ad, not a '5G' laboratory experiment.

The 5mm wavelength is at the peak of oxygen resonance and therefore provides high attenuation. In the WiloCity example this is used to provide user to user channel to channel separation and intensive spatial re-use. Beam forming can be used equally effectively to deliver range rather than high capacity per square metre but radio systems need to be implemented in the transmission windows between the resonance peaks.

The attenuation characteristics of millimetre radio links were studied at Rutherford Appleton Laboratory in the 1980's. The graphic below shows the 60 GHz oxygen peak and the three water vapour peaks.



The transmission windows for longer links (up to 60 km) include the 5 G-E band options at 72-77 GHz (4.16-3.89 mm), 81-86 GHz (3.7-3.48mm) and 92-95 GHz (3.25mm-3.15mm) presently used for lightly licensed fixed point to point backhaul and proposed for use for military communication based on rapidly deployable sub space systems to provide high data rate wide area coverage.

http://www.rttonline.com/tt/TT2015_001.pdf

Our 5G 'wavelengths of interest' can therefore be defined as spanning the metre, centimetre and millimetre bands.

Frequency	KHz 3-30	KHz 30-300	KHz 300-3000	MHz 3-30	MHZ 30-300	MHz 300-3 GHz	GHz 3-30	GHz 30-300
Wavelength	Kilometres	Kilometres	Metres	Metres	Metres	Metres	Centimetres	Millimetres
	100-10	10-1	1000-100	100-10	10-1	1-0.1	10-1	10-1
Name	100 kilometre band	10 kilometre band	Kilometre Band	100 metre band	10 metre Band	Metre Band	Centimetre Band	Millimetre Band
		Long Wave	Medium Wave	Short Wave		Microwave →		
						Terrestrial	Terrestrial?	Terrestrial?
							Satellite	Sub space
Atmospheric noise up to 20 MHz →								
				Galactic noise to 100 MHz				
					Circuit noise →			
					Aperture gain offsets propagation loss →			

Satellites are allocated the following wavelengths for mobile satellite services in the centimetre band.

	Centimetre Band			
	Ku Band		K band	KA Band
Frequency	12 GHz	14 GHz	18 -20 GHz	27-30 GHz
Wavelength	centimetres	centimetres	centimetres	centimetres
	2.49	2.14	1.66-1.49	1.1-0.99

These supplement existing mobile satellite services in the metre band at L band and proposed services in S band adjacent to LTE Band 1

http://www.inmarsat.com/news/inmarsat-to-deliver-in-flight-connectivity-over-new-european-aviation-network/

	Metre band Mobile satellite services				
	L band			S band	
Frequency	1518-1559	1616-1626	1626-1675	1980-2110	2170-2200
Wavelength	19.75-19.22	18.55-18.43	18.43-17.89	15.14-14.20	13.81-13.62

From the above it would seem obvious that terrestrial 5G networks for wide area coverage in the centimetre bands will need to integrate with existing and future satellite systems in the centimetre and metre bands. Terrestrial 5G networks for wide area coverage in the millimetre bands will need to integrate with millimetre sub space systems and point to point backhaul.

There is however minimal recognition of this within the present 5 G standards or spectrum discussion process.

Summary

By default we think of radio spectrum for cellular systems in terms of radio frequency.
The multiplicity of frequency band plan options for LTE is already complicated. The complexity is compounded by regionally specific performance characteristics - OOB emissions being one example, and multiple carrier aggregation options.

5G radio systems proposed for implementation in the K bands and V and W band add further complexity. The end result will be hundreds of potential bands and band combinations - at least three hundred options.

RF performance is defined by wavelength rather than frequency. Revisiting potential 5G radio spectrum in terms of wavelength reduces hundreds of band combinations to three wavelength options - the metre band, the centimetre band and the millimetre band.

Over the past thirty years, cellular radio has expanded from the original allocations at 800 MHz (0.37 metres) and 900 MHz (0.33 metres) and now spans 450 MHz (0.666 metres) to 2600 MHz (0.111metres).

LTE terrestrial networks are proposed for the lower end of the centimetre band at 3400 -3800 MHz (8.81 centimetres) to 3800 MHz (7.788 centimetres) and 5 G allocations are being discussed as being feasible up to and including the millimetre bands.

Scaling terrestrial cellular systems to the higher end of the metre band (2600 MHz and 3400-3800 MHz) has meant that coexistence with satellite and radar systems has had to be managed. This process has introduced or will introduce additional cost and complexity and performance loss in some markets.

Scaling terrestrial cellular systems to the lower end of the metre band (450-800 MHz) has meant that coexistence with terrestrial broadcasting has had to be managed. This process has introduced or will introduce additional cost and complexity and performance loss in some markets.

Extending this process into the higher end of the centimetre band and millimetre band for 5G terrestrial systems introduces similar coexistence challenges with mobile satellite and sub space service providers and potentially a similar cost and performance impact.

The most profitable parts of the metre band are 900 MHz (0.33 metre) and 1800 (0.166 metres). The technology economics of 5G in the centimetre and millimetre bands are at present far from obvious but would seem to imply a need to provide better capacity economics than present 802.11 ad systems at 60 GHz and better wide area range economics (data reach) than present and future satellite and sub space systems in the centimetre and millimetre transmission windows.

This seems unlikely but then thirty years ago who would have believed that the metre band would be supporting a terrestrial mobile broadband industry generating a trillion dollars of revenue per year.

Thirty years from now will the centimetre and millimetre bands be generating similar revenues? Which parts of these bands will be profitable and who will own the income?

To answer the question, don't think about frequency; think about wavelength. Don't think about 300 frequency bands but think about three wavelength bands, the metre band, the centimetre band and millimetre band as the way to work out 5G radio value and investment return.

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http://www.rttonline.com/tt/TT1998_008.pdf

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