An Introduction to the 5G Frequency Spectrum

Fifth Generation (5G) communication systems are being planned to enable a hundred-fold increase in user data-rates – and with this increase comes a need for significant increases in bandwidth over what is currently available. At Knowles Precision Devices, the DLI filter technology team has explored some of the mechanisms behind this increase in bandwidth.

Shannon Hartley

Why does bandwidth follow when we ask for an increase in data-rates? In 1948 Claude Shannon and Ralph Hartley, both researchers at Bell Labs, developed what has become known as the Shannon-Hartley Theorem. It tells us the maximum amount of error-free digital data that can be transmitted over a channel of a given bandwidth in the presence of noise:

$$C = M * B * log_2\left(1 + \frac{S}{N}\right)$$

Where:

C= Channel Capacity in bits/second
M = Number of channels (e.g. the MIMO order)
B = Bandwidth in hertz
S = transmit power, in Watts
N = noise on channel, in Watts
S/N = Signal to noise ratio

To increase Channel Capacity (data rates) we can Increase Bandwidth, Increase the number of channels, Increase transmit power (S) and Decrease the noise on the channel (N).

In order to achieve the data rates targeted by 5G systems, innovation is taking place on all of these fronts, but the factor in the equation we will discuss in this article is B, the Channel Bandwidth.

Questions of Bandwidth come naturally to looking at *available spectrum* – both because of questions of how much bandwidth is available in a given part of the spectrum, and because as frequency increases a given percent bandwidth gives us a greater share of spectrum.

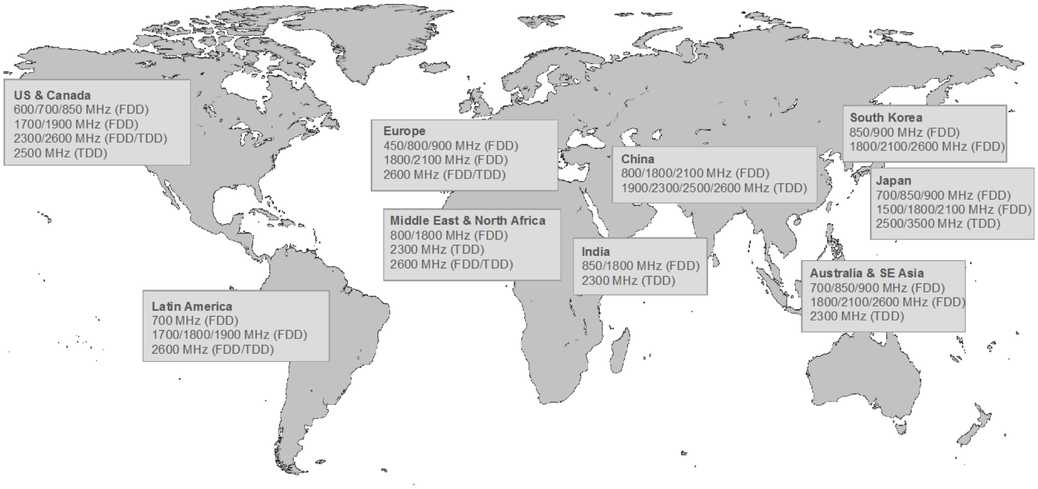

Table 1. LTE Bands in the US

Band	AT&T	Verizon Wireless	T-Mobile	Sprint
Band 2, FDD UL, 1850 – 1910MHz	●	●	●	
Band 2, FDD DL, 1930 – 1990MHz	●	●	●	
Band 4, FDD UL, 1710 – 1755MHz	●	●	●	
Band 4, FDD DL, 2110 – 2155MHz	●	●	●	
Band 5, FDD UL, 824 – 849MHz	●			
Band 5, FDD DL, 869 – 894MHz	●			
Band 12, FDD UL, 699 – 716MHz	●		●	
Band 12, FDD DL, 729 – 746MHz	●		●	
Band 13, FDD DL, 746 – 756MHz		●		
Band 13, FDD UL, 777 – 787MHz		●		
Band 17, FDD UL, 704 – 716MHz	●			
Band 17, FDD DL, 734 – 746MHz	●			
Band 25, FDD UL, 1850 – 1915MHz				●
Band 25, FDD DL, 1930 – 1995MHz				●
Band 26, FDD UL, 814 – 849MHz				●
Band 26, FDD DL, 859 – 894MHz				●
Band 41, TDD, 2496 – 2690MHz				●
Band 66, FDD UL, 1710 – 1780MHz			●	
Band 66, FDD DL, 2110 – 2200MHz			●	
Band 71, FDD DL, 617 – 652MHz			●	
Band 71, FDD UL, 663 – 698MHz			●	

LTE Spectrum

The 3GPP document TS 36.101 defines the LTE FDD and TDD bands. Version 14.5 defines 52 bands for 4G LTE spectrum, ranging in frequency from 450MHz (Band 31) to 5900MHz (Band 47).

The spectrum outlined in the standard is intended to support six channel bandwidths: 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, and 20 MHz. To reach higher bandwidths (and thus higher data rates) a technique called Channel Aggregation (CA) is used to stitch together non-contiguous bands. TS 36.101 defines the bands available for CA.

Globally there are over 1000 band combinations supported. An overview of common frequency ranges in operation today can be seen in the map above.

In the US the major carriers have centered their activity around 11 bands (see table 1)

Contiguous bandwidth of 100MHz is hard to find in the LTE spectrum landscape. Given that the peak data rate goal for 5G is 20Gbps (and the goal for LTE was 1Gbps) that 20x increase in channel capacity has to come from somewhere. Now as we mentioned above innovation is happening to address all of the variables in the Shannon Hartley model to get us there. A key innovation at the heart of 5G is utilizing new spectrum where increases in bandwidth are easier to come by.

5G spectrum

3GPP has been working on 5G for some time, and a major differentiator is the maximum bandwidths allocated to each channel. Where in 4G we had 20MHz maximum (and CA to stitch together more), in 5G we will have caps of 100MHz below 6GHz and 400MHz above 6GHz. Below 6GHz 400MHz will be achieved through CA (e.g. 4x 100MHz). In moving from 20MHz to 400MHz max, 3GPP have built the potential for a 20x increase in channel capacity right into the spectrum planning.

Table 2. 5G Candidate Bands

Region	F_{low}	F_{high}	Band
Korea	3400 MHz	3700 MHz	
	26.5 GHz	29.5 GHz	
EU	2570 MHz	2620 MHz	38
	3400 MHz	3800 MHz	42+43
	24.25 GHz	27.35 GHz	
	31.8 GHz	33.4 GHz	
	40.5 GHz	43.5 GHz	
Japan	2496	2690	41
	3400	3600	42
	3600	4200	
	4400	4900	
	27.5 GHz	29.5 GHz	
US	2496	2690	41
	3550	3700	48
	27.5 GHz	28.35 GHz	
	37 GHz	38.6 GHz	
	38.6 GHz	40 GHz	
	64 GHz	71 GHz	
China	2300	2400	40
	2555	2655	41B
	3300	3600	
	3400	3600	42
	4400	4500	
	4800	4990	

Table 2 lists some of the 5G candidate bands. With these new bands come groups of use-cases based on frequency. We can look at use cases that fall into frequencies below 1GHz, between 1GHz and 6GHz and those at the cm-wave and mm-wave frequencies.

Frequencies below 1GHz in the UHF perform well in applications that require long range and high data rates – these are the frequencies we are used to seeing in Macro base station applications. Moving forward to 5G they will be leveraged for lower data rate and narrow band applications (such as already used in 4G IoT applications) and are looked at for the ‘massive Machine to Machine Type Communications’ (mMTC).

From 1GHz to 6GHz we encounter the familiar LTE bands. This region is being looked at for use cases that need of the order of 100MHz of bandwidth, with the 2.5GHz Band 41 and 3.5GHz (42+43) regarded as candidates for 5G enhanced Mobile Broadband (eMBB) applications.

Starting at 28GHz we find the cm-wave and mmWave frequencies that are being utilized in Fixed Wireless Access (FWA) applications. It is these frequencies that are being deployed first, with demonstrations already having happened at the Winter Olympics in Korea this year.

The high end of the spectrum offers the most dramatic increase in available bandwidths, allowing designers to push Shannon-Hartley to incredible speeds.