White Paper

Anritsu Advancing beyond

What is behind the drive towards Terahertz technology of 6G

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1 Introduction.

Discussion of Beyond 5G and 6G topics has started in the academic and research communities, and several research projects are now starting to address the future technology requirements. One part of this is the push to higher frequencies and the talk of "Terahertz Technology". What is behind this drive towards millimetre wave and now Terahertz technology for beyond 5G, and even 6G mobile networks? In this article, we will turn to our trusted colleague Claude Shannon and consider his work on channel capacity and error coding to see how future cellular technologies will address the fundamental limitations that his work has defined.

The driver behind this technology trend is the ever-increasing need for more capacity and higher data rates in wireless networks. As there are more and more downloads, uploads, streaming services, and inter-active AR/VR type services delivered on mobile networks, then more capacity and higher data rate is needed to handle this ever-increasing number of services (and always increasing the high resolution and high-definition nature of video). So, one of the main drivers for the future 6G technology is to provide more capacity into the networks.

Coverage is usually the other key parameter for wireless network technology. Increase in coverage is generally not seen as a fundamental technology challenge, but more a cost of deployment challenge. Sub 1 GHz networks give good coverage, and now 5G is adding satellite communications (Non-Terrestrial Networks) to provide more cost-effective coverage of hard-to-reach areas. But certainly, the interest in millimetre wave and terahertz technology for 6G is not driven by coverage requirements (quite the opposite really).

2 Defining channel capacity.

The fundamental definition of "Channel Capacity" is laid out in Shannon's equation, based on the ground breaking paper published in 1948 by Claude Shannon on the principles of information theory and error coding. This defines the theoretical maximum data capacity over a communications medium (a communications channel) in the presence of noise.

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

Where:
C = Channel Capacity.
B = Channel Bandwidth.
S/N = Signal to Noise Ratio of the received signal.

Clearly then the Channel Capacity is a function of the Channel Bandwidth and of the received Signal to Noise Ratio (SNR). But the important point to note in this equation is that the capacity is a linear function of the bandwidth, but a Logarithmic term of the SNR. We can see that a 10x increase in bandwidth will increase the capacity by 10x, but a 10x increase in SNR will only increase the capacity by 2x. This effect can be seen in figure 1 where we plot capacity versus the linear BW term and the logarithmic SNR term.

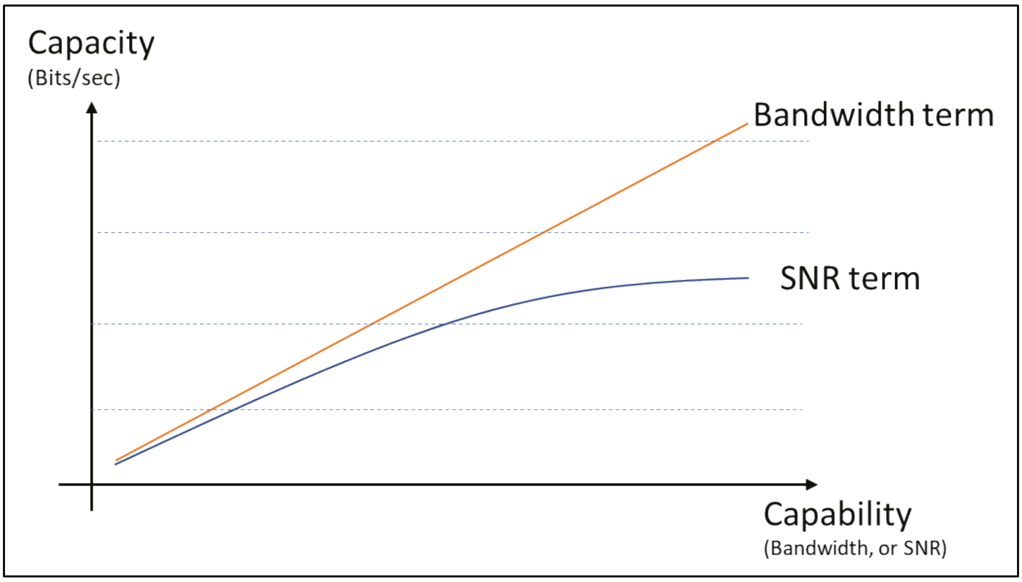

Figure 1

From this we can quickly see that there appear to be more gains in channel capacity from using more bandwidth, rather than trying to improve SNR. However, there is still considerable interest in optimising the SNR term, so we can maximise the available channel capacity for any given bandwidth that is available for use.

This effect is seen clearly in the development and evolution of 5G networks, and even 4G networks. Much focus has been put into 'Carrier Aggregation' as this technique directly increases the channel bandwidth. Especially for the downlink, this requires relatively little increase in the UE performance (generally more processing is needed). There has been only small interest in using higher order modulation schemes such as 256 QAM or 1024 QAM, as the capacity gains are less and the required implementation into the UE is more expensive (higher performance transmitter and receiver is required).

3 Increasing the Channel Bandwidth term in 6G.

As shown in figure 1, the bandwidth term has a direct linear relationship to the channel capacity. So, network operators are wanting to use 'new' bandwidth to expand capacity of their networks. Of course, the radio spectrum is crowded and there is only a limited amount of bandwidth available to be used. This search for new bandwidth was seen in the move to 3G (2100 MHz band), and to 4G (800 MHz, 2600 MHz, and re-farming of old 2G/3G bands), and then in 5G there was the move to the millimetre wave bands (24-29 GHz, 37-43 GHz).

As we are considering the absolute bandwidth (Hz) for the channel capacity, if we search to find 100 MHz of free spectrum to use then at 1 GHz band this is very demanding (10% of the available spectrum) whereas at 100 GHz this is relatively easier (0.1% of the available spectrum). Hence, as we move to higher operating frequency then it becomes increasingly easier to find new bandwidth, as the amount of bandwidth that exists is far wider and the chances to find potentially available bandwidth becomes much higher. However, as we move to higher frequencies then the physics of propagation starts to work against us.

As shown in figure 2, the pathloss of radiation from an isotropic antenna is increased by the square of the frequency (f2). We can see that a 10x increase if the operating frequency leads to a 100x increase in losses (20 dB losses) for an isotropic radiation source if the other related parameter of distance is kept constant. This type of loss is usually overcome by having a physically 'large' Rx antenna, so by keeping the physical size of the Rx antenna to the same size when we move to higher frequencies, then this loss can be mostly overcome. By using 'large' antennas, we have additional antenna gain due to the narrow beam directivity of the antennas, and this helps to overcome the propagation loses. However, this directivity introduces the need for alignment of Tx and Rx beams to complete a radio link, and the consequent alignment error between Tx and Rx beam that must be controlled.

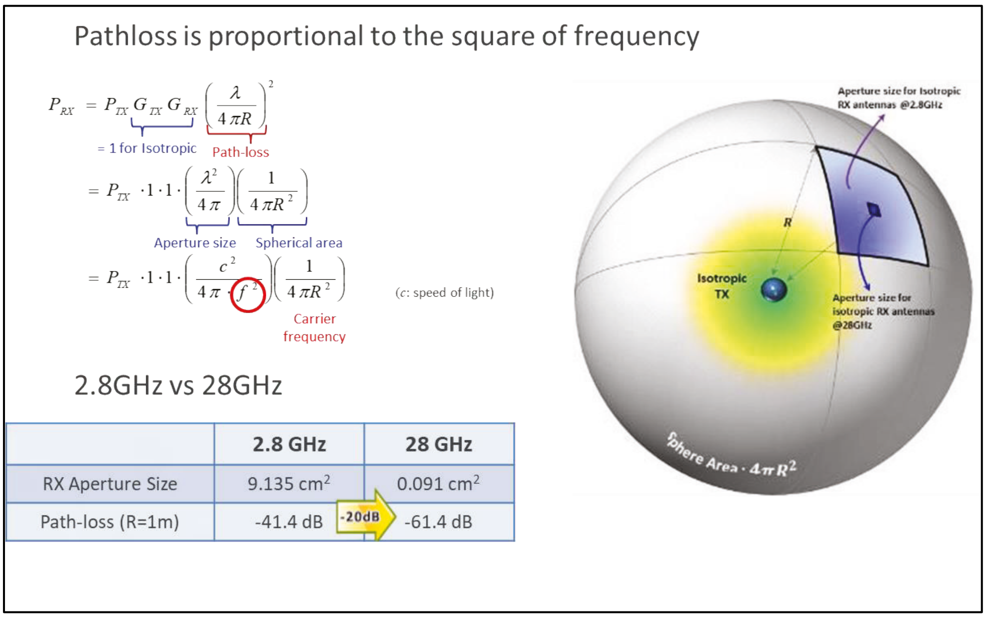

Figure 2

The second type of loss we incur as we move to higher frequencies is the atmospheric attenuation loss. This occurs due to particles in the atmosphere that absorb, reflect, or scatter the radiated energy from the transmitter and so reduce the amount of signal that arrives at the receiver. This type of loss has a strong link between the wavelength (frequency) of the signal and the physical size of the particles in the atmosphere. So as we move to wavelengths of 1mm or less then moisture content (rain, cloud, fog, mist etc) and dust particles (e.g sand) can significantly increase attenuation. In addition, certain molecular structures (e.g. H2O, CO2, O2) have a resonance at specific wavelengths and this causes sharp increases