WHITE PAPER

Low Signal to Noise Ratios (SNRs)

More Bandwidth May Not Mean More Capacity

Be careful because the rate of increase in capacity rolls off at both very high and very low bandwidths.

Technology is opening up millimeter wave frequencies and everyone is looking for higher data throughputs, which can be achieved with wider bandwidths. So, is wide bandwidth millimeter wave going to be the answer? Well, maybe. The Shannon-Hartley Theorem directly links bandwidth and channel capacity, and millimeter frequencies are the most promising place to find that bandwidth.

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

However, the Shannon-Hartley formula also includes a signal/noise term, with important implications for RF power in real wireless systems. Specifically, if available transmitter power is a fixed quantity, extra bandwidth may not solve your problems.

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First, let’s plot how signal-to-noise ratio drops as you widen the bandwidth, if you have a fixed RF channel power level at the receiver (green line). Far over to the right hand side, the signal-to-noise drops quite dramatically at 10*log(bandwidth). For example, a bandwidth of 1 GHz at a fixed power level results in 10 dB lower SNR compared to a 100 MHz bandwidth.

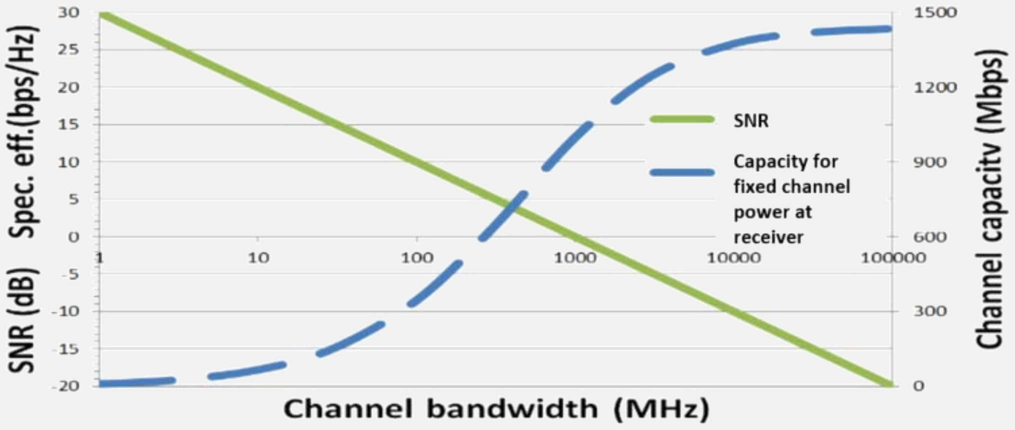

Figure 1 - The green line representing signal-to-noise ratio passes through 0 dB at ~1 GHz. You could reduce or increase the transmit power to vary that intersection, but this broadly represents what is utilized in many commercial radio transceivers. The blue dashed line represents channel capacity.

Next, let’s examine the tradeoffs that drive real-world designs, shown by the blue dashed line. Using the conventional Shannon-Hartley expression, we'll see there is a region in the center where channel capacity increases significantly as bandwidth increases. Note that far over to the right hand side, the blue line indicating channel capacity stops increasing at much wider bandwidths.

Keep in mind, however, that RF power is likely be limited, especially at millimeter frequencies, where power is more costly. You can see that that fixed RF power at the receiver results in diminishing increases in channel capacity as you move to wider bandwidths. If you want to achieve further increases in channel capacity, you would need to boost the power (within regulatory limits). To boost the power, you probably need more expensive components and will need to utilize more energy from your battery. This is an engineering trade-off that will depend on your application.

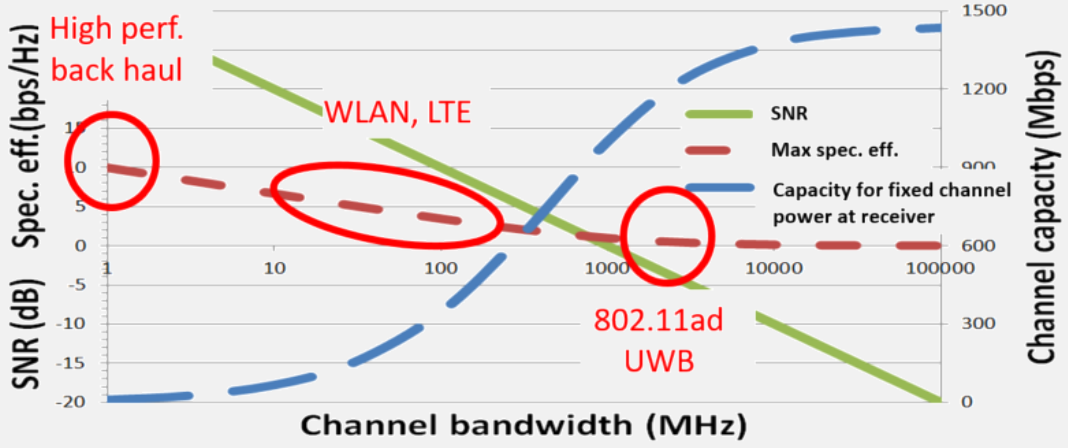

Figure 2- Low vs high vs broadband load models across a frequency range of 0-70 GHz.

Finally, let’s plot where different wireless systems operate. Some very high-performance back hauls are working with extremely high signal-to-noise ratios to ward off signal fade. Over quite a broad range in the center of both bandwidth and signal-to-noise ratio, we've got the WLAN and LTE technologies. Operating close to the 0 dB signal-to-noise ratio, or even sometimes below it, we have the existing 802.11ad and some of the previous instances of ultra wideband (UWB).

It’s also worth keeping in mind that wider bandwidths often mean more power for signal processing, more power-hungry ADCs, DACs and filtering, and other demands.

Conclusion

When all factors are considered, extremely wide bandwidths are a promising technology but not a panacea. As an engineer, you need to understand your power situation because limited RF power at the receiver has some constraints. In particular, extremely wide bandwidths require more RF power (which may not be available) to achieve the promising capacity gain.

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