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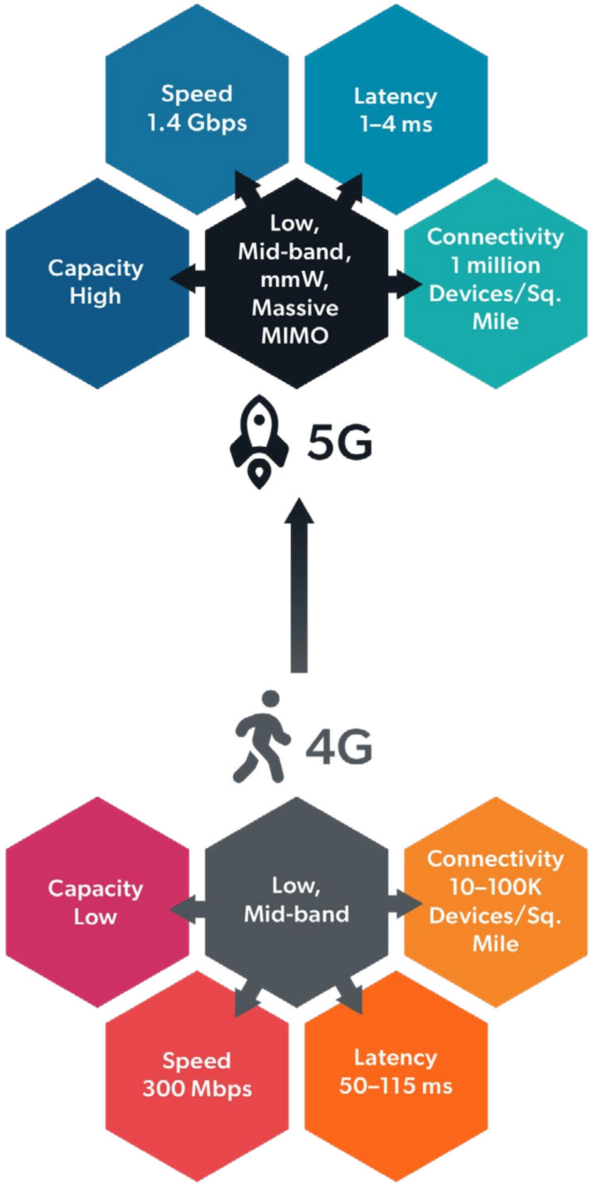
Evolving Spectrum Value Drivers in a 5G Millimeter Wave World

5G and the Internet of Things (IoT) are transformative technologies with wide-ranging effects.[1] In addition to ultra-quick data transfer speeds, a 5G network is envisioned to have other key capabilities, including increased density of throughput (as high as 10 megabits per second (Mbps) per square meter) and connection density (as high as one million devices per square kilometer).[2]



5G and the use of millimeter wave (mmW) spectrum upends many assumptions about the wireless industry. The commercial value of spectrum is based on the value created from deploying and using the spectrum. So, it is the present value of future expected cash flows that can be earned from the spectrum.

Traditional spectrum valuation relationships will change. Two broad groups of factors affect the value of spectrum:

1. Factors driving overall band value: macro factors, spectrum band propagation characteristics, the relative supply and demand of the spectrum, various impairments, cost of relocating incumbents, and the timing and uncertainty regarding availability.
2. Geographical factors that influence the relative value of spectrum.

Although these factors are still relevant to determining the value of a spectrum band, the conventional wisdom about how these factors relate to spectrum value requires updating to a 5G world.

The new 5G architecture is built on seamlessly integrating spectrum from different bands, as appropriate, depending on frequency advantages, network characteristics, demand profiles, and other relevant factors.

OVERALL BAND VALUE IN A PRE-5G WORLD

To understand the value drivers, Brattle used auction data to estimate an empirical model that relates the values realized in the auction with the observable value drivers – the frequency of the band, the license size, the supply of spectrum in the auction, and an estimate of the overall spectrum deficit. We used four pre-5G auctions in our dataset: AWS-1 (Auction 66), 700 MHz (Auction 73), AWS-3 (Auction 97), and the 600 MHz auction (Auction 1002). Our results showed four key takeaways:

> *The effect of license size is non-linear, with the value increasing with a larger license size, but declining after a threshold.*

Typically, LTE requires larger license sizes. One 10 megahertz (MHz) license is more efficient than two 5 MHz licenses and a 20 MHz license is more efficient than two 10 MHz licenses.

Overall spectrum band value for low- and mid-band spectrum is driven by license size, propagation characteristics, and spectrum supply in the auction. These explain 80% of value variation.

However, as the license size gets larger, it may also reduce competition for the license as smaller players are shut out of the market. This may decrease the value of larger licenses.

Overall, the marginal effect of license size on value is positive.

> *Also, as expected, the higher the frequency, the lower the value of the spectrum. However, the relationship is quadratic up to a threshold.*

In general, since higher frequency bands have lower coverage radii, their value should be lower, as indicated by the negative coefficient on the level term.

> *Interestingly, for the low- and mid-band spectrum, the quadratic term was positive, implying that there was an inflection point after which the value of capacity dominates over coverage.*

The positive quadratic term shows this effect is moderated for frequencies beyond a certain range, which likely indicates that, when capacity is more important than coverage, the impact of frequency on value moderates.

> *The spectrum deficit term – defined as the gap between expected demand and supply of spectrum – shows that as the deficit increases, spectrum value increases.*

The results above align with our expectations on the value drivers of spectrum for the traditional lower and mid-band spectrum in a pre-5G world.

HAVE THE OVERALL BAND VALUE DRIVERS CHANGED IN A 5G MMW WORLD?

Three factors are at play with 5G that change the equilibrium values historically seen in spectrum markets.

1. The architecture of 5G networks will require spectrum in a variety of different bands.
   - Low-band spectrum will provide coverage for wide-area and long-range communications.
   - Mid-band spectrum will support applications that would benefit from a combination of coverage and capacity support.
   - MmW spectrum will provide capacity for short-range communications that require fast data rates and low latency.[3]
2. 5G encompasses more efficient technologies that increase the capacity of spectrum.
3. 5G will reset consumer expectations for spectrum-based services, creating a substantial increase in demand for those services. This higher demand will extend beyond the urban cores, where mmW frequencies will be first deployed, and increase demand for spectrum-based services everywhere.

We estimated the pre-5G spectrum value model for the 5G era mmW auctions – Auction 101 (850 MHz of the 28 GHz band), Auction 102 (700 MHz of the 24 GHz band), and Auction 103 (3400 MHz in the Upper 37 GHz, 39 GHz, and 47 GHz spectrum bands) – to explore how the relationship with the value drivers has changed.[4]

> *In this model, as the frequency band increases, so does spectrum value. This cannot be a coverage story. Rather, this result can be interpreted as a capacity story.*

With the lower and mid-bands as coverage bands, the coverage radii decreased as the frequency increased. Hence, the value decreased, leading to a negative relationship between spectrum value and frequency.

MmW spectrum value is driven by capacity and not coverage.

Propagation characteristics entirely explain the value of the bands.

Higher frequencies of mmW spectrum have larger capacities that are ideally suited for 5G and IoT applications. Therefore, the relationship between value and frequency is positive.

However, the quadratic term is negative, implying that after a certain threshold, the value starts decreasing.

This may be due to the drastic reduction in coverage radii, which may limit the usability of very high band mmW.

GEOGRAPHIC BAND VALUE IN A NON-5G WORLD

The relative values of rural and urban markets are driven by a complex interplay of factors. These are determined by inherent economic differences between areas that drive demand and geographic and demographic characteristics that drive cost.

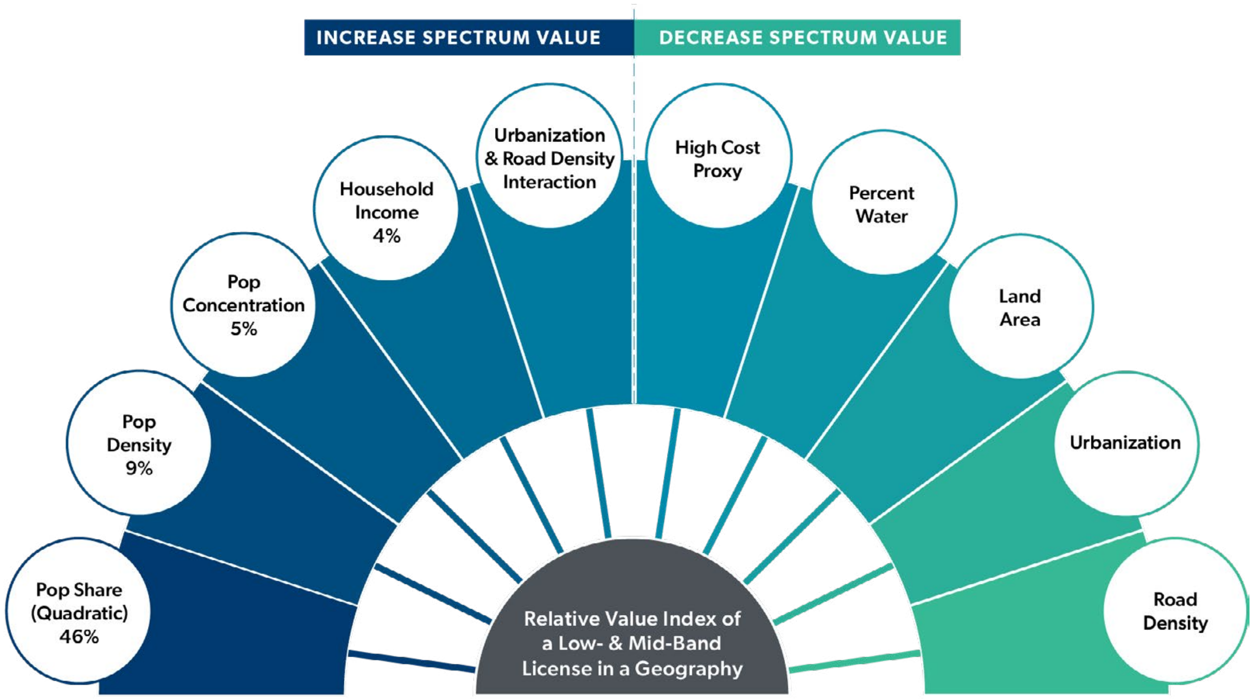


FIGURE 1: FACTORS AFFECTING GEOGRAPHIC SPECTRUM VALUE FOR LOW- AND MID-BAND SPECTRUM

Note: We used a color gradient to show the factors that decrease spectrum value in our econometric estimation. Those that positively influence value are shown in dark blue. All are statistically significant. The urbanization variable is negative in levels, but after accounting for the interaction with road density, it positively affects spectrum value.

To show this, we constructed a geographic relative value index (RVI), which is the gross dollar amount per MHz pop (the number of MHz of spectrum reaching a population (pop) in the coverage area) relative to the national average price for a spectrum block in an auction. **Figure 1** shows how each of the factors impact the spectrum's geographic value. All the variables are statistically significant, and the percentages show the amount of variation in value explained by the covariate. The variables without the percentages each explain less than 1% of the value variation.

> *In total, the population-based measures explain 61% of the variance and population share explains 46% of the variance.*

A higher pop potentially signals greater demand for spectrum-based services and, hence, increases spectrum value to a certain point.

A license area with a denser and/or more concentrated population has a higher value, as the cost of buildout will be lower in these places vis-à-vis covering the same pop in a larger or more uniformly distributed area.

> *Other demand factors increase spectrum value and cost proxies lower spectrum value.*

The median household income, a demand indicator, also has a positive impact on value.

Two cost proxies, the percentage of water and the proxy for high-cost areas, are negative and significant, which indicates – as expected – that spectrum value should be lower in harder-to-build areas.

The urbanization and road density variables are negative at the level term, but their interaction is positive. This implies that in a non-urban area with denser roads – such as rural state lines with higher road density, but fewer people – the spectrum value will be lower. However, in areas that are urban and have denser roads, the spectrum value will be greater.

ARE THE GEOGRAPHIC VALUE DRIVERS OF MMW DIFFERENT?

To observe whether the same factors also influence the relative geographic value of spectrum for mmW, we estimated the RVI model for mmW as we had for the low-

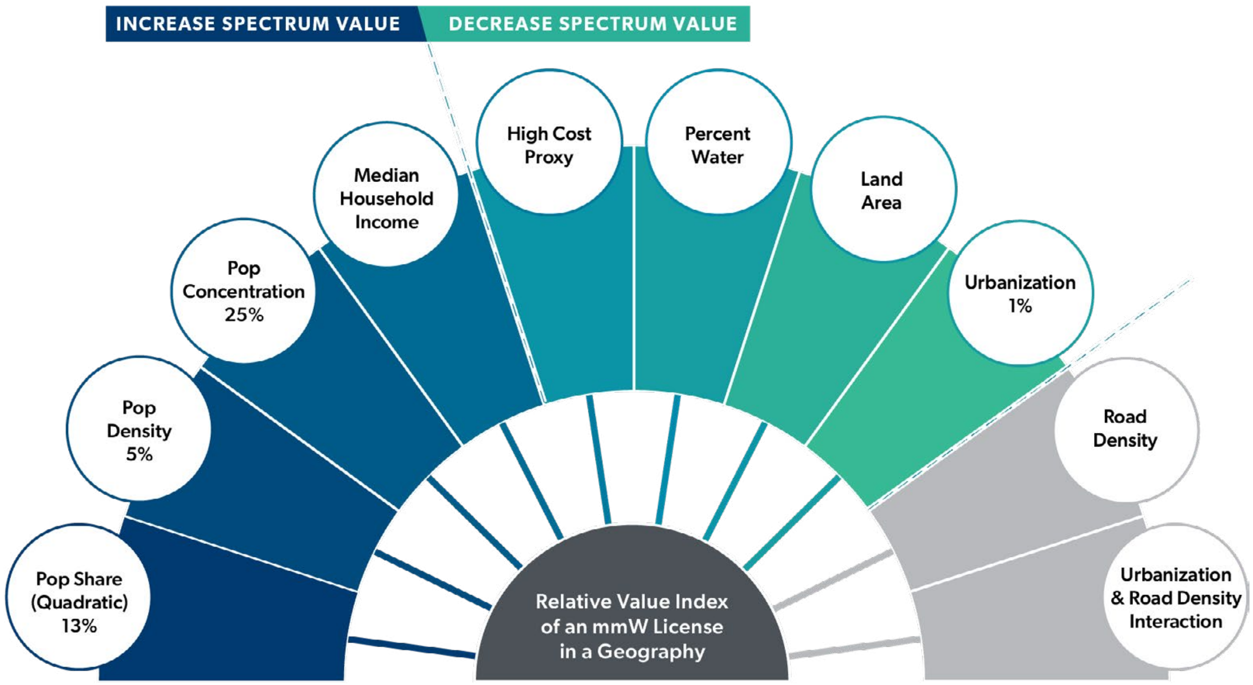


FIGURE 2: FACTORS AFFECTING GEOGRAPHIC SPECTRUM VALUE OF THE MMW BAND

Note: We used a green-to-teal color gradient to show the factors that decrease spectrum value in our econometric estimation. Those that positively influence value are shown with the dark blue gradient. The gray color is used when the coefficient is not statistically significant.

and mid-band spectrum. **Figure 2** shows how each of the factors impact the geographic value of mmW spectrum. As before, the percentages show the amount of variation in value explained by the covariate. The variables without the percentages each explain less than 1% of the value variation.

> *Our non-5G model of geographic relative value performs poorly in the mmW context. The covariates explain only 46% of the variance in license-level relative value compared to 65% in the low- and mid-band model. The significant difference is in the behavior of the population variables.*

In the low- and mid-band RVI model, the population share explained 46% of the variation in the relative value of the spectrum, compared to only 13% for mmW. This is a clear indicator that a larger share of the auction population is not as key a value driver as was shown in **Figure 1**.

Rather, population concentration is more important compared to the prior estimation. In the mmW spectrum, the population concentration measure explains a quarter of the variation in relative value, compared to slightly over 5% for the low- and mid-band spectrum.

This implies that, for mmW spectrum, areas with a highly concentrated population are much more valuable than areas with a higher population that is more evenly distributed.

WHERE DO WE GO FROM HERE?

This deficiency of our traditional model suggests that fundamentally different drivers of value are important for mmW spectrum. For instance, should only a portion of the population be counted (i.e., is population an important value driver only after a certain density threshold)? How important is the presence of fiber backhaul to 5G spectrum deployment? Do state and local regulations on the ease of deploying 5G infrastructure explain the differences in value? The jury is still out!

ENDNOTES

1 Qualcomm, "Qualcomm Network Simulation Shows Significant 5G User Experience Gains," February 24, 2018, accessed February 25, 2021, https://www.qualcomm.com/news/releases/2018/02/25/qualcomm-network-simulation-shows-significant-5g-user-experience-gains. See also, GSMA, "5G Spectrum," GSMA Public Policy Position, March 2020, p. 5, https://www.gsma.com/spectrum/wp-content/uploads/2020/03/5G-Spectrum-Positions.pdf.

2 The other three key 5G capabilities listed by the ITU are: increased spectrum efficiency, increasing mobility, and increased network energy efficiency. See ITU, "IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and Beyond," Figure 3, p. 14, September 2015, https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf. See also, Sacha Kavanagh,"5G vs 4G: No Contest," 5G.co.uk, March 9, 2020, https://5g.co.uk/guides/4g-versus-5g-what-will-the-next-generation-bring/.

3 Jon Gold, "How 5G Frequency Affects Range and Speed," Network World, July 23, 2020, https://www.networkworld.com/article/3568253/how-5g-frequency-affects-range-and-speed.html.

4 FCC, "Auction 101: Spectrum Frontiers – 28 GHz," Fact Sheet, https://www.fcc.gov/auction/101/factsheet. "Auction 102: Spectrum Frontiers – 24 GHz," Fact Sheet, https://www.fcc.gov/auction/102/factsheet. "Auction 103: Spectrum Frontiers – Upper 37 GHz, 39 GHz, and 47 GHz," Fact Sheet, https://www.fcc.gov/auction/103/factsheet.

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