October 19, 2023

# SiGNALS Flash!

*Dispatches from the frontier of wireless research*

# WE'VE GOT YOU COVERED (TO VARYING DEGREES)

## INSIGHT INTO 5G COVERAGE – ALL BANDS, ALL OPERATORS, ONE REPRESENTATIVE MARKET

SiGNALS Research Group
www.signalsresearch.com

# EXECUTIVE SUMMARY

Signals Research Group (SRG) collected scanner log data for all 5G bands and LTE CBRS in the greater Minneapolis-Saint Paul market to determine how well the four operators (AT&T, DISH Wireless, T-Mobile, and Verizon) have deployed 5G across their spectrum assets – from 600 MHz (n71) to 3.7 GHz (n77). We also looked at LTE CBRS coverage and who is using the spectrum, but we'll save that data for a rainy day, or more likely a snowy day later in the year when we are under the gun to get out some published research.

Since we did this report pro bono and strictly for our own marketing purposes, the analysis isn't as exhaustive as what we would normally do for a *Signals Ahead* report, which is a subscription-based/revenue-generating publication. Additionally, although we covered a lot of territory during our drive tests, we are by no means suggesting it is adequate for regulators or consumers searching for the "best" 5G coverage. The information, however, is very useful, completely independent, and likely representative of what we would obtain with a more thorough study of 5G coverage in the Twin Cities market. This effort, augmented by network performance data (downlink/uplink throughput, etc.) could easily be extended to other markets for those organizations that are interested. A subtle hint.

Key Highlights and Observations

- **Thanks.** A special thanks once again to Rohde & Schwarz (R&S) for the use of their TSMA6 scanner to capture all the data, along with Spirent Communications (Umetrix Data) for two sidebar studies we include in this report. We also use these solutions in our forthcoming Signals Ahead study of the DISH Wireless network performance in Las Vegas.
- **Signal Strength.** Coverage, based on signal strength (RSRP), generally favored the lower frequency bands for all four operators. Verizon (100% probability) and AT&T (100% probability) took top honors for their Band n5 coverage, followed by DISH Wireless (94%) and T-Mobile (93%) with their Band n71 networks. Ironically, the T-Mobile Band n41 coverage was very similar to its Band n71 coverage, despite the differences in propagation.
- **Signal Quality.** Coverage, based on signal quality (SINR), favored the mid-band TDD networks. We believe the SINR metric is more useful than RSRP since SINR also influences network performance, while RSRP is largely relegated to handovers and defining cell boundaries. T-Mobile Band n41 (93%) took top honors.
- **DISH Wireless.** DISH Wireless is doing reasonably fine in our area with its network buildout, albeit based entirely on scanner data. Its n70 and n66 coverage (both 59%), based on SINR, wasn't far off from Verizon n77 (67%) and AT&T n77 (63%). While we firmly believe the network wasn't commercial when we first started this endeavor (we explain), all signs indicate the entire network now supports commercial traffic with an out-of-the-box Motorola edge+ smartphone.
- **DSS and LTE-M.** Both Verizon (n5) and AT&T (2 @ n66) have 5G and LTE deployed in the same frequency. Specifically, they are both using LTE-M (1.4 MHz channel bandwidth) in the same channel where they have deployed 5G. Understanding the scheduling behavior could be an interesting study (stay tuned). Band n66 usage on AT&T will increase with 5G SA – our S22 never used it, instead opting for two n77 channels and LTE for the anchor band.


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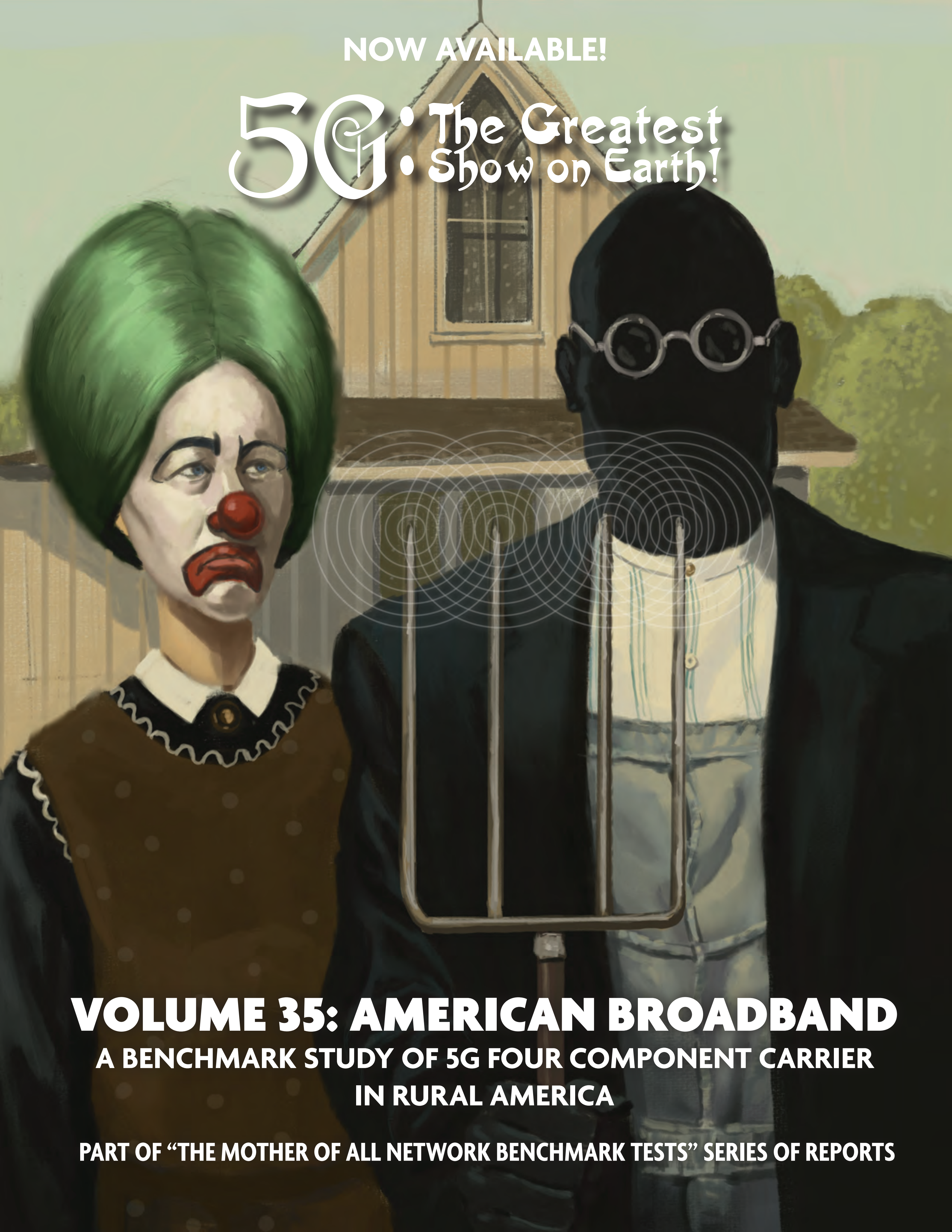
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## 5G COVERAGE STATISTICAL ANALYSIS

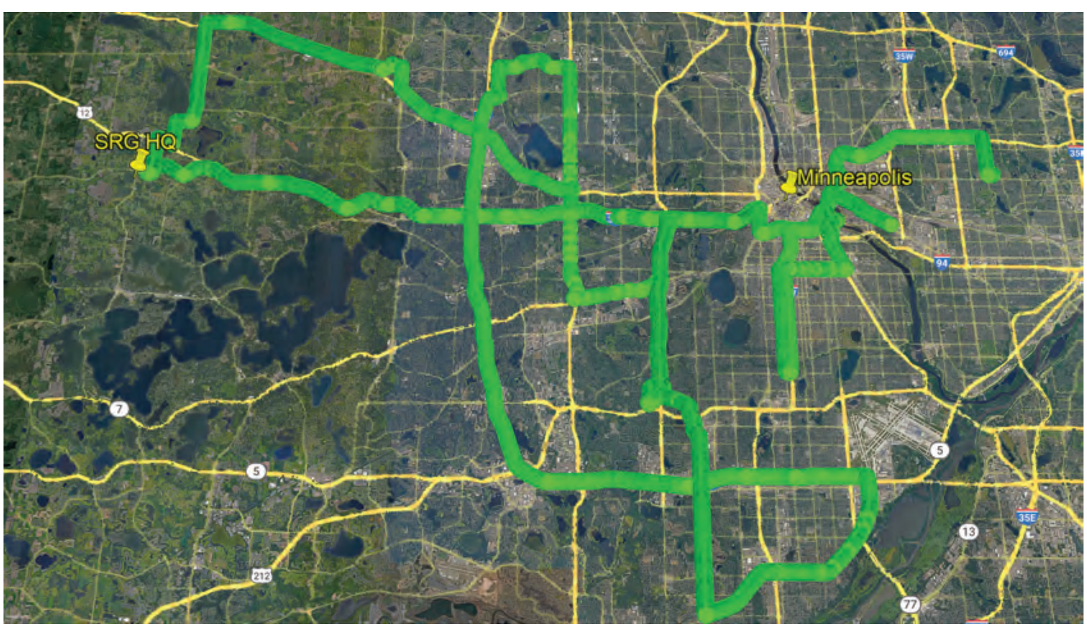
*Later next week, or perhaps early in the following week, we will be publishing an updated benchmark study of the DISH Wireless 5G network in Las Vegas, NV. The study will look at downlink and uplink performance by frequency band, the implications of using different data transfer protocols (e.g., HTTP or UDP), how the throughput was achieved (RB allocations, MCS, MIMO, etc.) and influenced by network conditions (RSRP and SINR), and VoNR with a particular emphasis on voice quality while stationary and mobile. This report will only be available to our* Signals Ahead *subscribers.*

We leveraged weekend chauffeuring responsibilities to navigate around the greater Twin Cities area with the R&S TSMA6 scanner in the back seat. For this testing, we left the omni-directional antenna within the vehicle – placing the antenna on the roof would have increased the signal strength (RSRP) by approximately 6 dB, based on our comparative testing.

Figure 1 shows where we drove while collecting scanner logs. To put things into perspective, it is approximately 40 kilometers from our furthest west location (SRG HQ) to the furthest east location. We inadvertently corrupted one scanner log, hence there are some gaps in the displayed route – the missing log impacted all bands and had no consequence on the relative results shown in this report.

**As one might expect, the low-band frequencies had the highest average RSRP.**

***Figure 1. Drive Route***



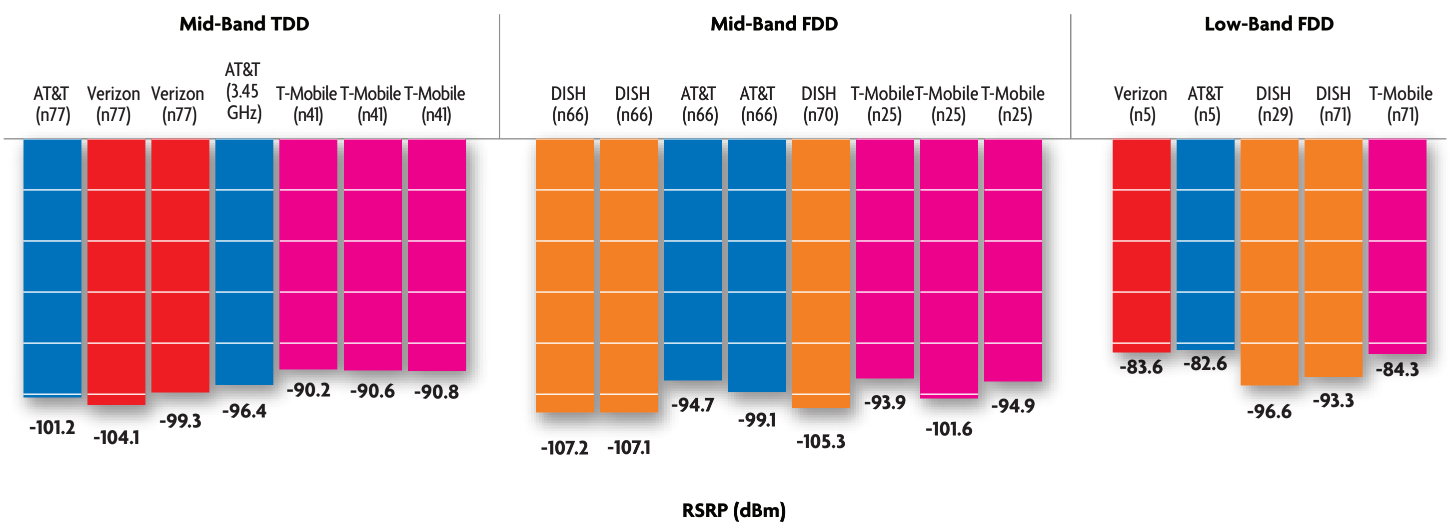

Source: Signals Research Group

For each 5G frequency band (NR-ARFCN) we looked at two primary metrics – the signal strength (RSRP) and the signal quality (SINR). We binned the data into uniform grid areas and then for each binned area (roughly 10x10 m), used the maximum RSRP and SINR values for each NR-ARFCN. This approach could overstate the actual coverage, but since we did it for all measured bands the published results are accurate on a relative basis. Figure 2 provides the average RSRP and Figure 3 shows the average SINR from all drive test results. As one might expect, the low-band frequencies had the highest average RSRP, compared with the mid-band FDD (1900-2200 MHz) and mid-band TDD (>2.5 GHz) frequencies.

Consistent with earlier scanner-related studies that we have done, the mid-band TDD frequencies delivered some of the highest SINR, led by T-Mobile Band n41 with SINR = 12 dB. One each of T-Mobile's Band n41 and Band n25 channels stand out for results that trend in the other direction. This situation occurred because the operator infrequently used this spectrum across the Twin Cities market – instead it used other n41 and n25 assets – but since the scanner was able to detect these signals from a great distance, the strongest signals from these 5G channels could still be relatively weak. Readers should focus on the best results for each operator + band combination and discount these anomalies. Likewise, we think the DISH Wireless Band n71 results take precedence over its n29 performance.

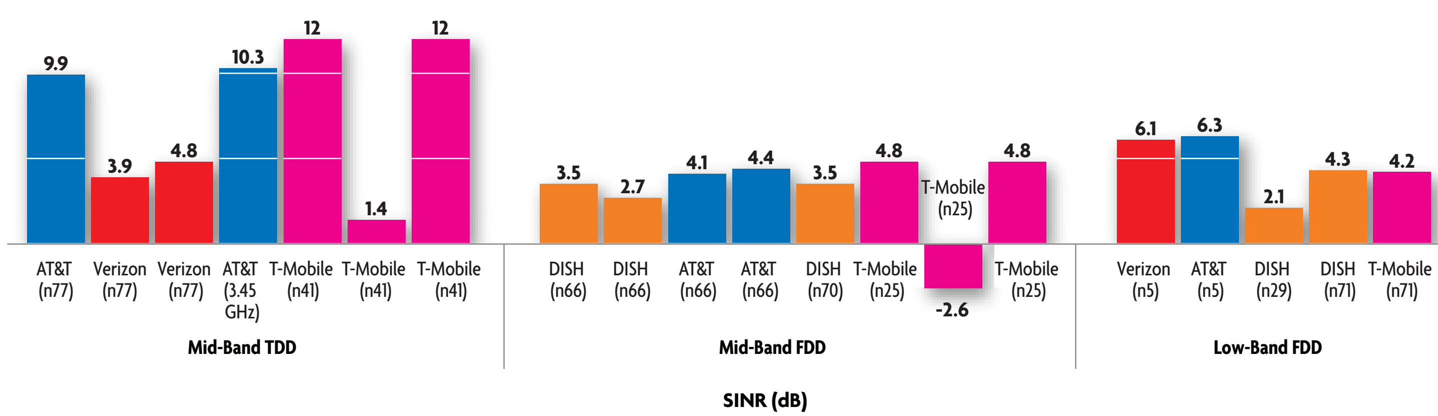
**The mid-band TDD frequencies delivered some of the highest SINR.**

*Figure 2. Average Signal Strength*




Source: Signals Research Group

*Figure 3. Average Signal Quality*



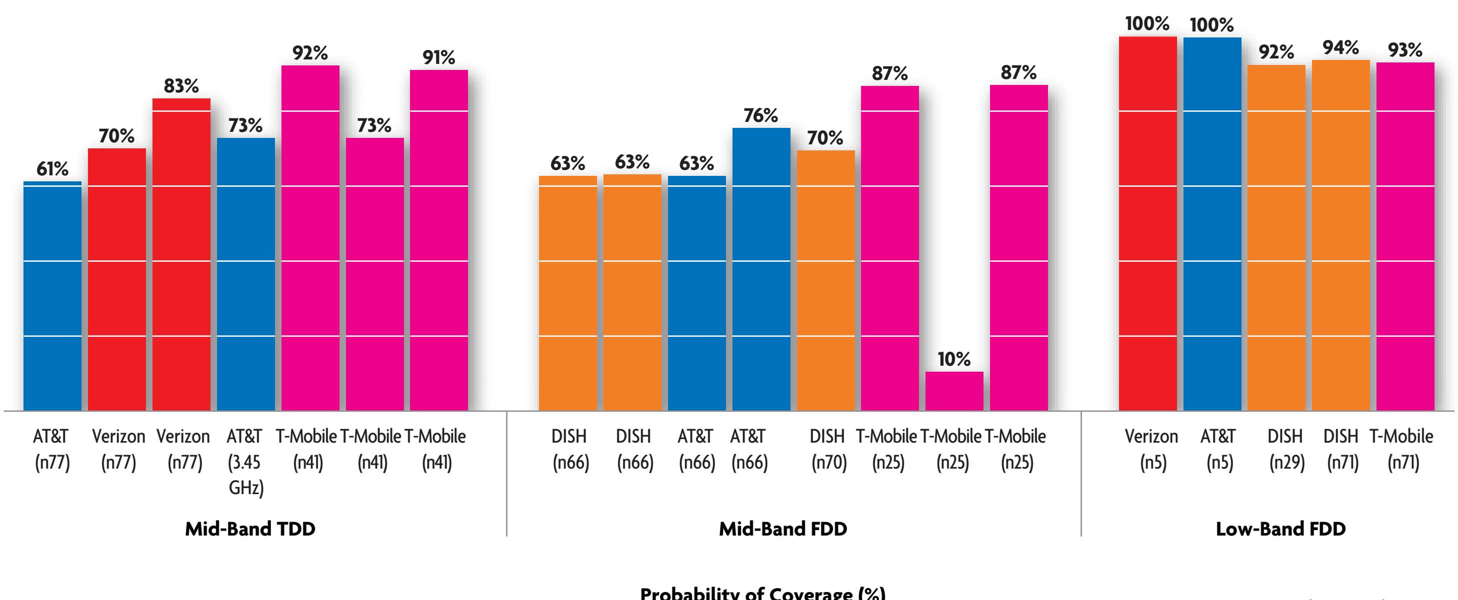

Source: Signals Research Group

We used the forthcoming distribution plots to show the estimated coverage for each operator + 5G band combination. We assumed an area was covered from a signal strength perspective if the RSRP was at least -115 dBm (a bit generous in our view). From a signal quality perspective, we required the SINR to be at least 0 dB to conclude there was 5G coverage at the location. Generally speaking, if the RSRP was -115 dBm and the SINR was 0 dB, it would be a pretty poor user experience with low data speeds, but it would be 5G coverage, nonetheless. There are also no guarantees a smartphone would connect and remain attached to a 5G signal with these conditions. We place greater faith in the SINR-based coverage results since in poor coverage areas there could be multiple sites delivering a low signal to the mobile device, resulting in multiple RRC connection attempts and ping ponging between multiple sites not to mention the RRC disconnect state.

**We required a minimum of RSRP = -115 dBm and a minimum of SINR = 0 dB to conclude there was 5G coverage available.**

Worth noting, we didn't take into consideration the dependencies of the 5G NSA networks on the coverage provided by the LTE anchor when determining 5G coverage. This point means that there may have been 5G coverage available on the AT&T and Verizon network, but due to the limitations of LTE, a phone wouldn't be able to attach to the network. This situation is most likely to occur with a combination of a low-band 5G channel (Band n5) and a mid-band LTE anchor (e.g., Band 2, Band 66, Band 30).

***Figure 4. Coverage Based on Signal Strength***




Source: Signals Research Group

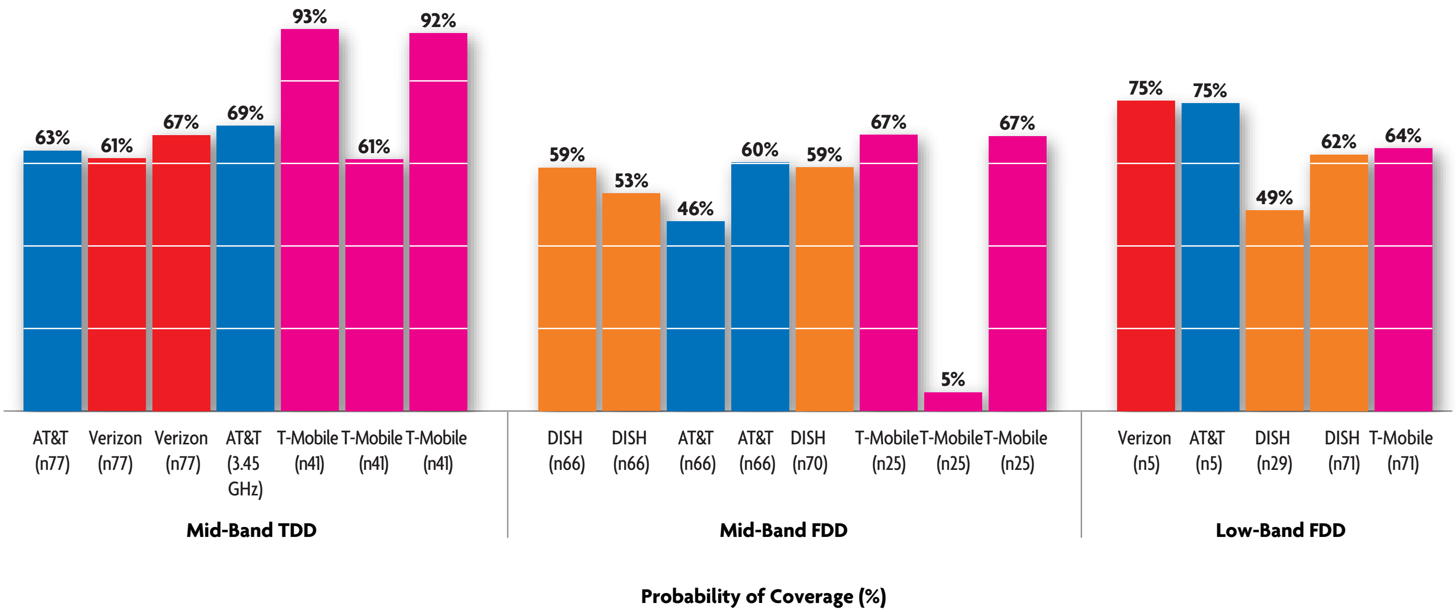
Based purely on RSRP, the low-band frequencies delivered the best 5G network coverage, led by the Verizon and AT&T Band n5 networks. Surprisingly, the T-Mobile Band n41 coverage wasn't too far off from the n5 coverage, and the n41 coverage nearly matched T-Mobile's n71 coverage.

There is a lot of interest in the DISH Wireless network coverage, and based on our results, the network held its own, although largely due to n71 and n29 – the latter band didn't fair well with respect to signal quality, suggesting the cells were "stretched" for the initial buildout. Band n70 is the workhorse band for DISH Wireless and its coverage was "OK" – on par with AT&T n77/3.5 GHz, although generally lagging behind the other two operators' mid-band TDD coverage profiles.

Signal quality (SINR), in our view, is the true definer of good 5G coverage. For all operators, the SINR-based coverage improved with the higher frequencies and suffered with the lower frequencies. A signal that travels "forever" isn't always desirable, especially in a relatively dense cell grid where the extended propagation characteristics are unnecessary, except for deep in-building coverage. Even Verizon and AT&T had much lower SINR-based coverage in n5 than they had RSRP-based coverage in the same band. T-Mobile also took top honors in the mid-band FDD spectrum with its Band n25 network. AT&T, DISH Wireless and T-Mobile all have at least two unique 5G channels in this frequency range. We're not sure how extensively smartphones use AT&T's Band n66 network since the phones will gravitate to the two n77 channels, along with LTE for an anchor band. More advanced phones with increased carrier aggregation capabilities can help increase usage of Band n66, but the biggest swing factor will be the transition to 5G SA, thereby allowing phones to rely exclusively on the 5G spectrum.

**Signal quality (SINR), in our view, is the true definer of good 5G coverage.**

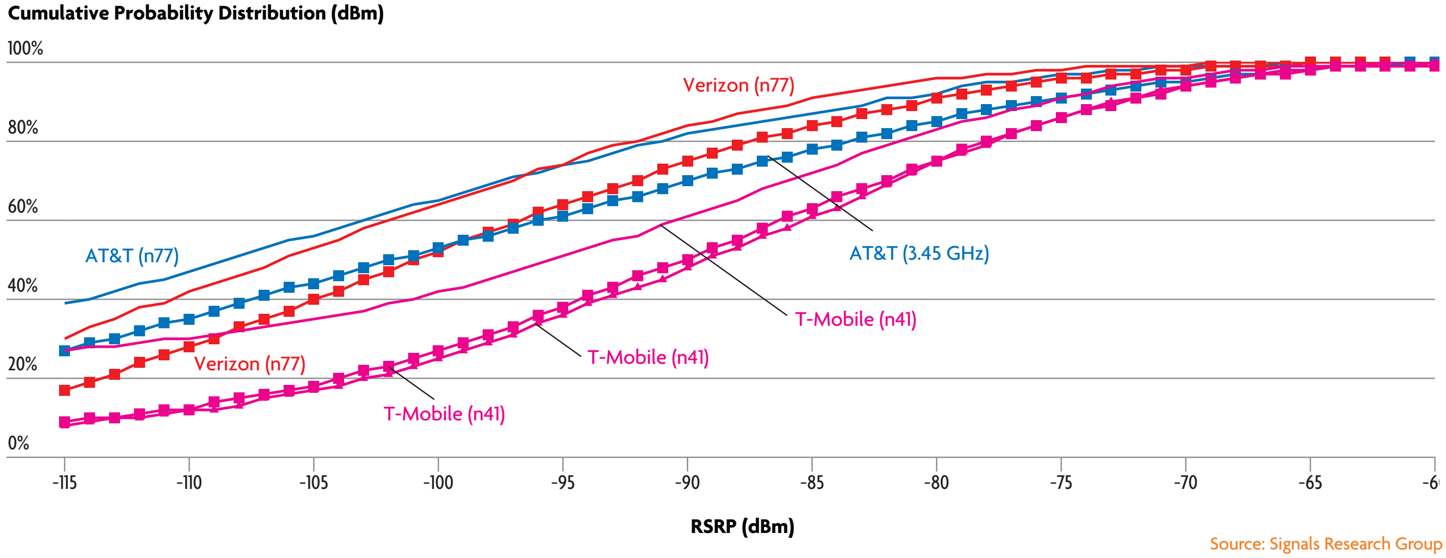
***Figure 5. Coverage Based on Signal Quality***




Source: Signals Research Group

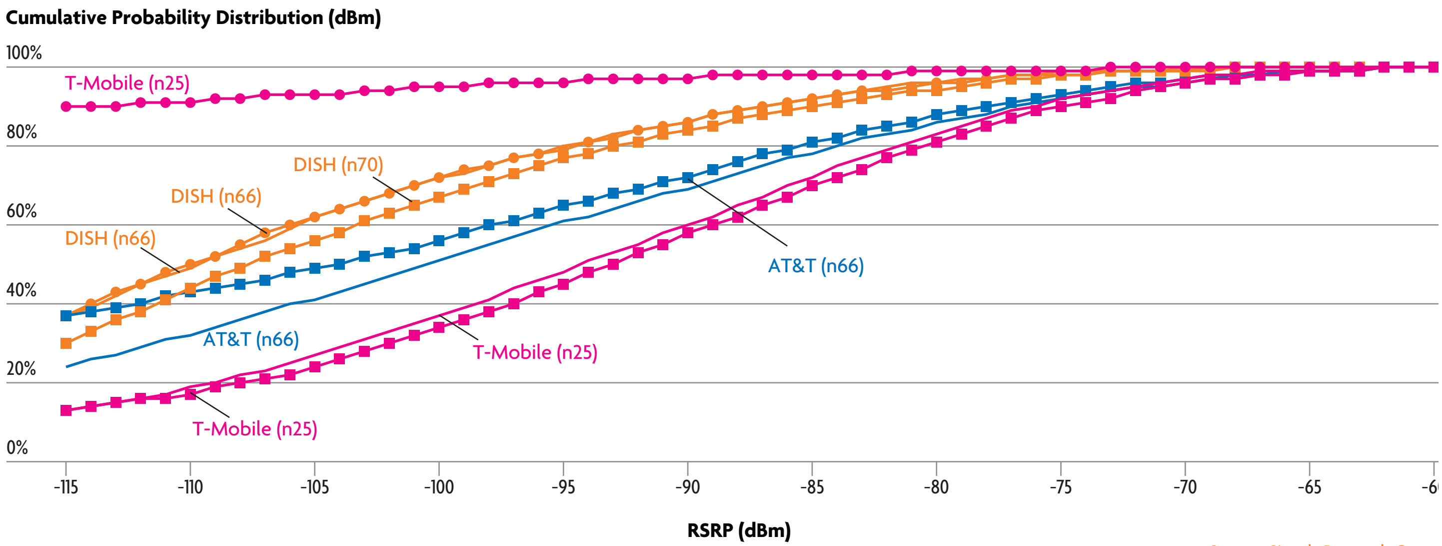
The next three figures (Figure 6 through Figure 8) show the cumulative distribution for the 5G coverage, based on the measured RSRP. In all three figures, the lines furthest to the right at any selected RSRP value indicate the "best coverage." Some of the lines for a given operator fall virtually on top of each other, suggesting collocated sites for all detected 5G radios in the two bands. In other cases, such as for AT&T and Verizon mid-band TDD, the lines are clearly separated, indicating the operators have deployed one of the 5G bands more aggressively than the other band. This situation is consistent with what the operators are doing as they gain more access and use of their mid-band spectrum assets. Case in point, Verizon was originally limited to 60 MHz of Band n77 but now it is deploying an additional 100 MHz of Band n77 in this market.

*Figure 6. Cumulative Distribution of Mid-Band 5G TDD Coverage*



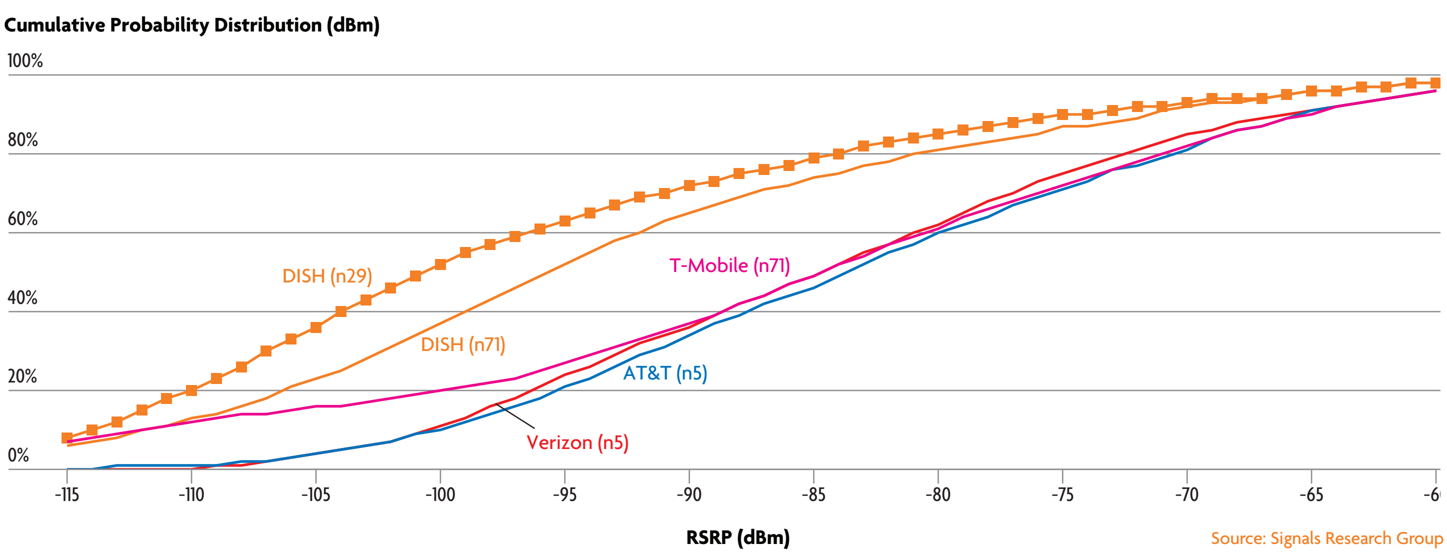

Source: Signals Research Group

*Figure 7. Cumulative Distribution of Mid-Band 5G FDD Coverage*




Source: Signals Research Group

*Figure 8. Cumulative Distribution of Low-Band 5G FDD Coverage*

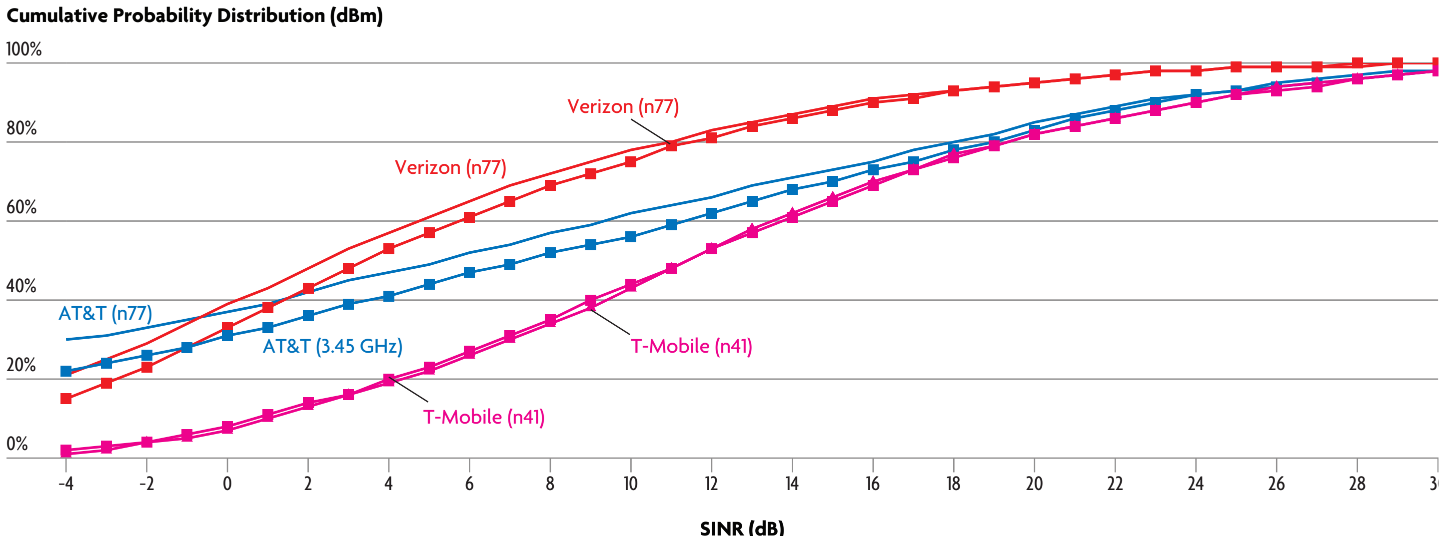



Source: Signals Research Group

Figure 9 through Figure 11 show the cumulative distribution of SINR for the same three groupings of frequencies. T-Mobile Band n41 had the most favorable SINR distribution in the mid-band TDD spectrum while in the mid-band FDD spectrum, there was some general consistency across AT&T, DISH Wireless, and T-Mobile if you only consider each operator's best performing band. The one T-Mobile n25 line is a bit of an anomaly since its seemingly poor SINR was inherently due to the limited use of this radio channel in this market. To be fair, the Y axis scale goes from 0 to 100%, thereby somewhat masking high single-digit differences in SINR. With the lower SINR values, where a slight difference in SINR can have the biggest impact on the user experience, these differences really matter.

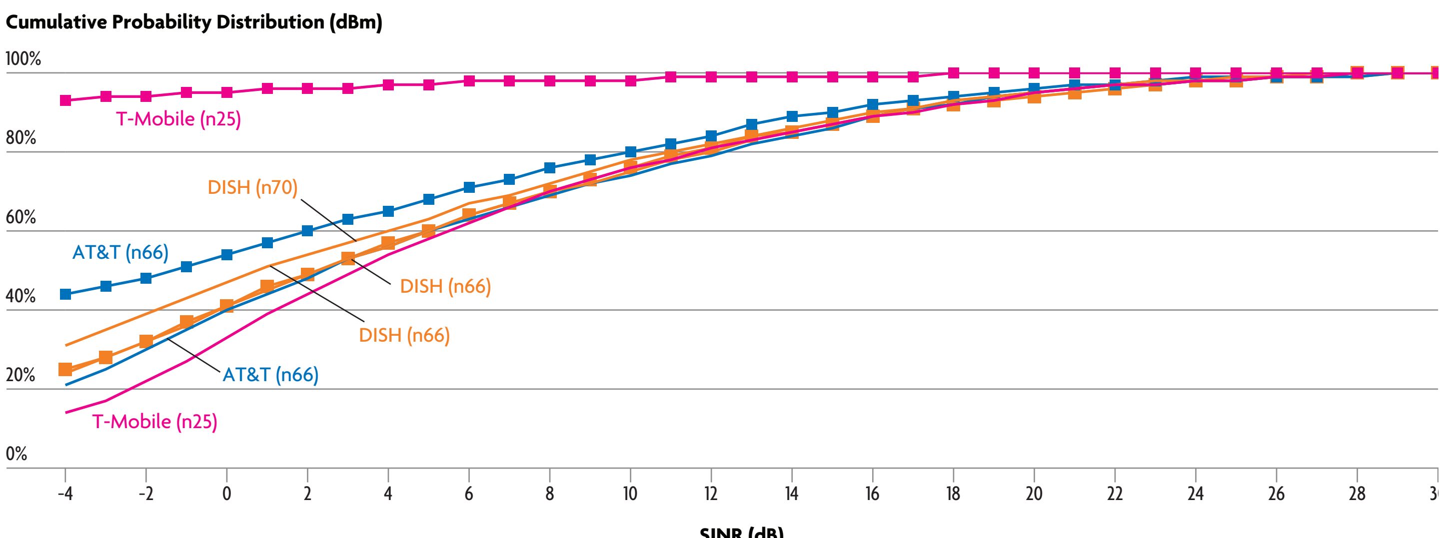
**With the lower SINR values, where a slight difference in SINR can have the biggest impact on the user experience, slight differences in SINR really matter.**

*Figure 9. Cumulative Distribution of Mid-Band 5G TDD Signal Quality*




Source: Signals Research Group

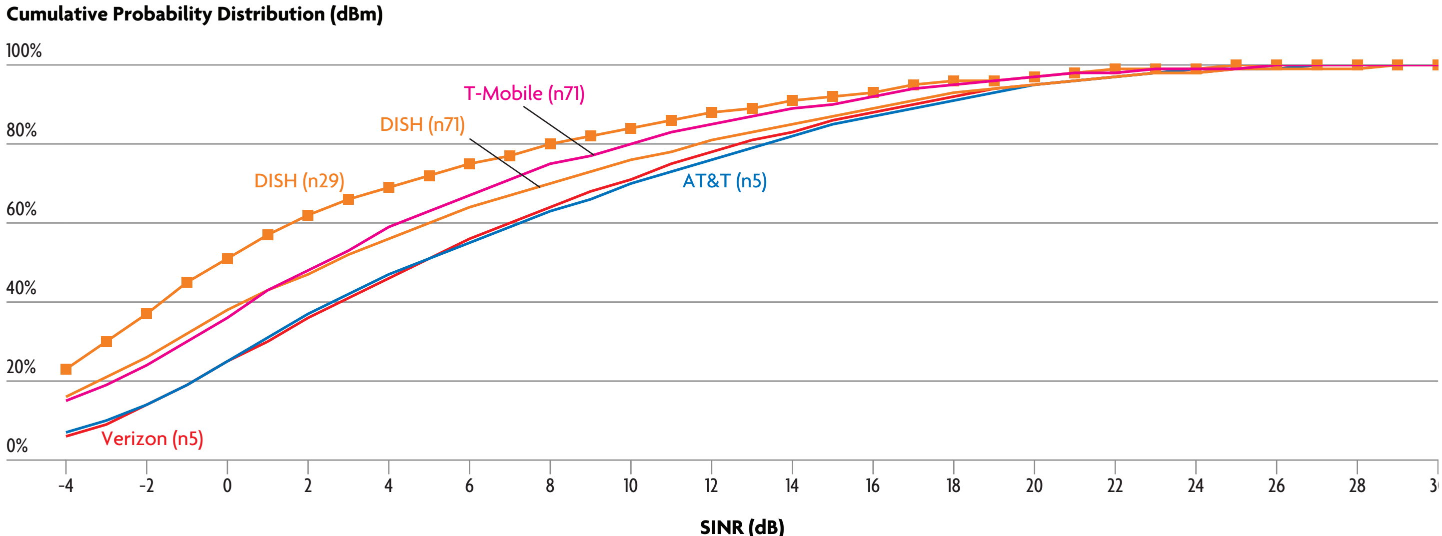
*Figure 10. Cumulative Distribution of Mid-Band 5G FDD Signal Quality*




Source: Signals Research Group

Turning to the low-band spectrum, AT&T and Verizon came out on top, as indicated earlier in this report. T-Mobile (n71) and DISH Wireless (n71) followed with DISH Wireless (n29) taking up the rear.

***Figure 11. Cumulative Distribution of Low-Band 5G FDD Signal Quality***



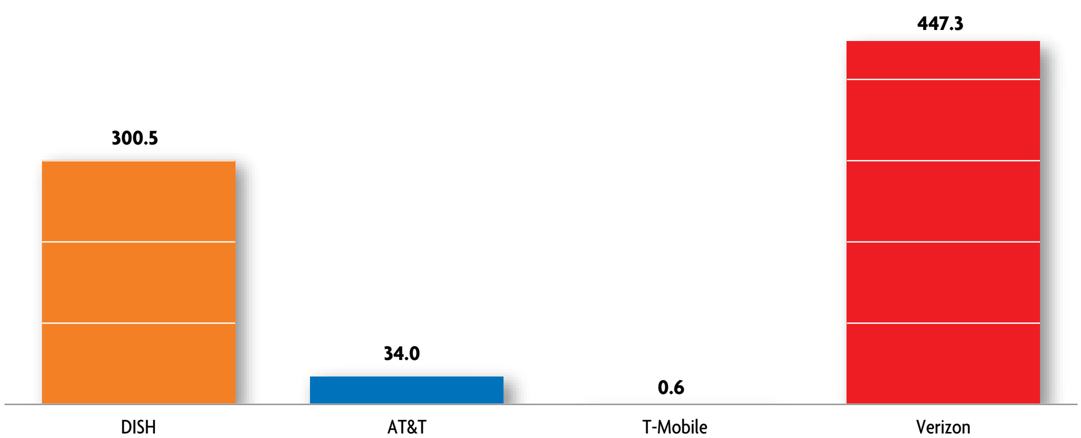

Source: Signals Research Group

## SRG HQ PERFORMANCE AND DSS IN THE WILD

We didn't include smartphone performance data in this quick study, but we did capture some simple results from our home office. Figure 12 shows the application layer throughput from each 5G network, based on a simple Umetrix 1 minute test that we ran with each network and an unlocked S22 smartphone. For the DISH Wireless network, we used the Motorola edge+ smartphone. It was possible to log chipset data with the S22 smartphone, so the shown throughput only reflects the contribution on the application layer from the 5G physical layer – all three networks were NSA. For DISH Wireless, since the network was SA, we knew all the physical layer throughput occurred over 5G so we could simply attribute 5G to all the application layer throughput.

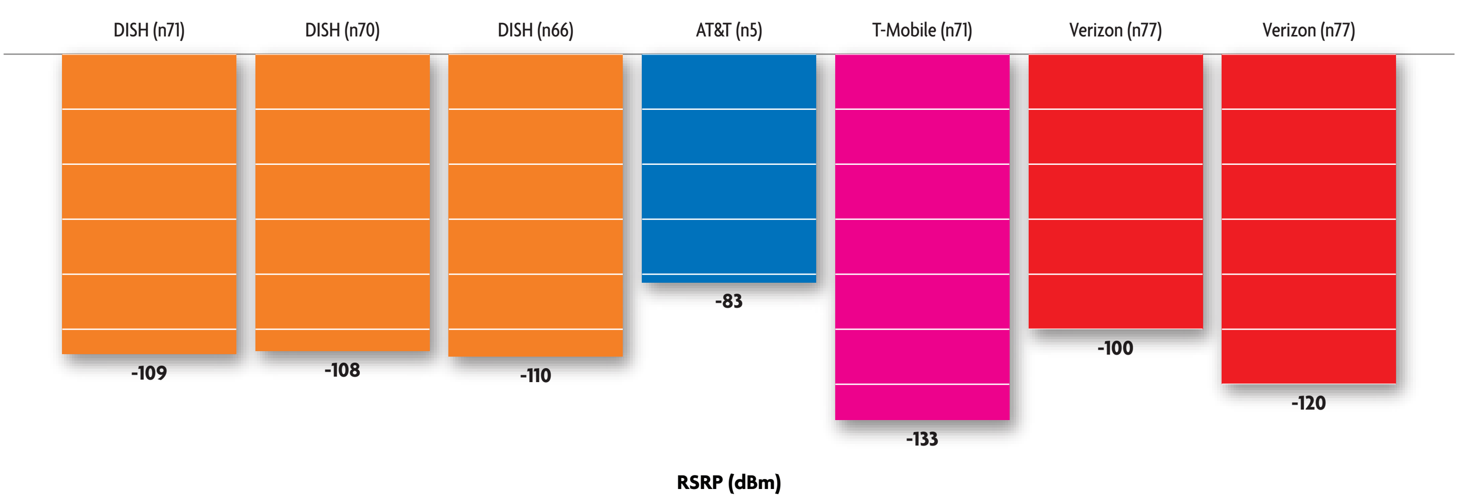
Figure 13 augments this information by showing the signal quality and strength for the bands used by the smartphone, based on scanner measurements – the scanner antenna was adjacent to the phone. We don't know for certain which bands the Motorola edge+ smartphone used but since the phone supports 3CC and since there were only 3 DISH Wireless bands with usable signal, we naturally assumed the phone used the three bands shown in the figure. Surprisingly, DISH Wireless

***Figure 12. 5G Application Layer Throughput from SRG HQ***



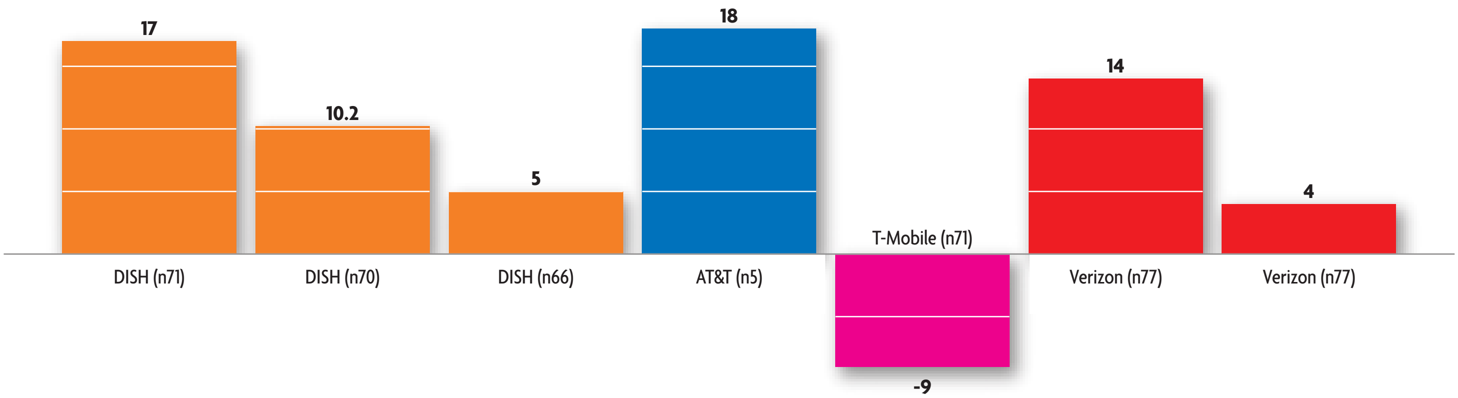

Source: Signals Research Group

***Figure 13. 5G Coverage from SRG HQ***




Source: Signals Research Group

***Figure 14. 5G Signal Quality from SRG HQ***

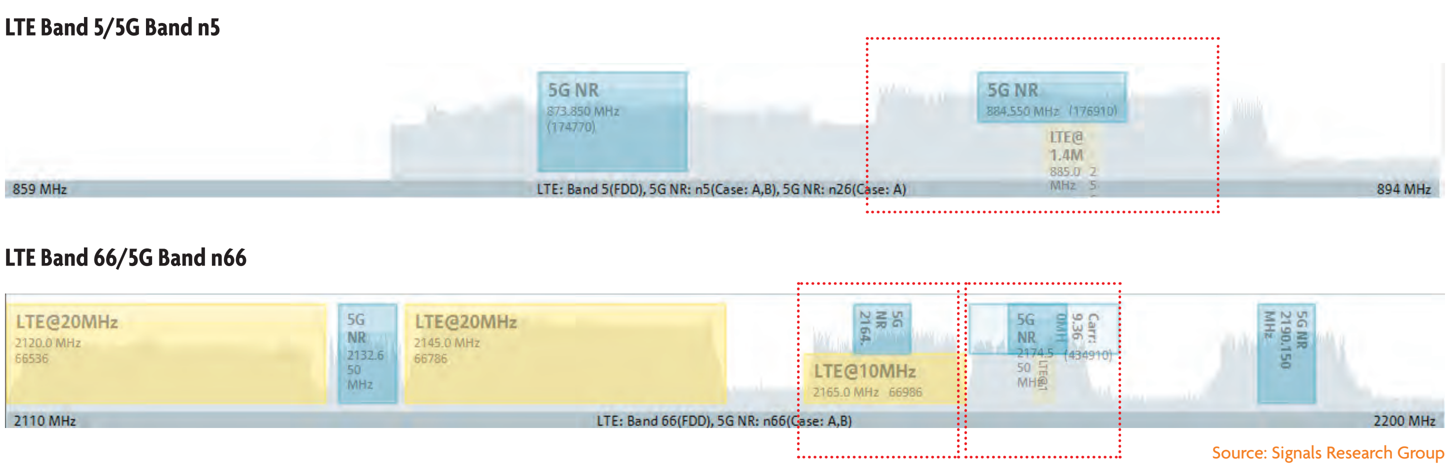



Source: Signals Research Group

offers the best coverage to SRG HQ and almost the best performance. DISH Wireless, AT&T and Verizon share two nearby towers while the T-Mobile tower is further away from our location. For T-Mobile, the S22 rarely remained attached to the 5G network so the average throughput includes multiple data points with 0 Mbps – when it was connected the 5G Band n41 speeds were between 1-2 Mbps.

We didn't specifically set out to include DSS, but the scanner did detect its presence, as evident by LTE and 5G bands overlapping. Specifically, Figure 15 shows Verizon using LTE-M in its Band n5 spectrum and AT&T is using LTE-M in its Band n66 spectrum. When Verizon first launched DSS, the entire channel was shared by both technologies while now there is just LTE in a 1.4 MHz channel.

***Figure 15. DSS and 5G***




Source: Signals Research Group

Although we had a Galaxy S22 on the AT&T network, it never used Band n66 when we tested briefly with it. Instead, the phone used 3.7 GHz and 3.5 GHz along with an LTE anchor band. This outcome isn't surprising since we assume the network pushes traffic to the higher bands. Further, with the LTE anchor requirement and the capabilities of the S22, we do not believe the smartphone can support three 5G channels and an LTE anchor. Once the operator moves to 5G SA we believe Band n66 will observe a lot more data traffic than presently.

## DISH NETWORK COMMERCIAL STATUS

When we first started preparing for our Vegas testing of the DISH Wireless network, we purchased a Motorola edge+ smartphone since the Project Genesis website indicated our home address was under its coverage. However, when we received the phone, we determined the phone was always using the AT&T network. We drove into Minneapolis and experienced the same outcome the whole way, despite putting the phone into and out of airplane mode to force the phone to reacquire the network. To make a long story short, we figured out how to force the phone into 5G SA mode, at which point the phone quickly attached to the DISH Wireless network. Based on this occurrence, along with a few other data points, we are pretty convinced that in late August the DISH Wireless 5G network in our area was not accepting commercial data traffic. By forcing the phone into SA mode, we inadvertently bypassed the restriction, and we gained access to the network. At a minimum, we weren't able to connect to the operator's 5G network with two different Motorola edge+ smartphones.

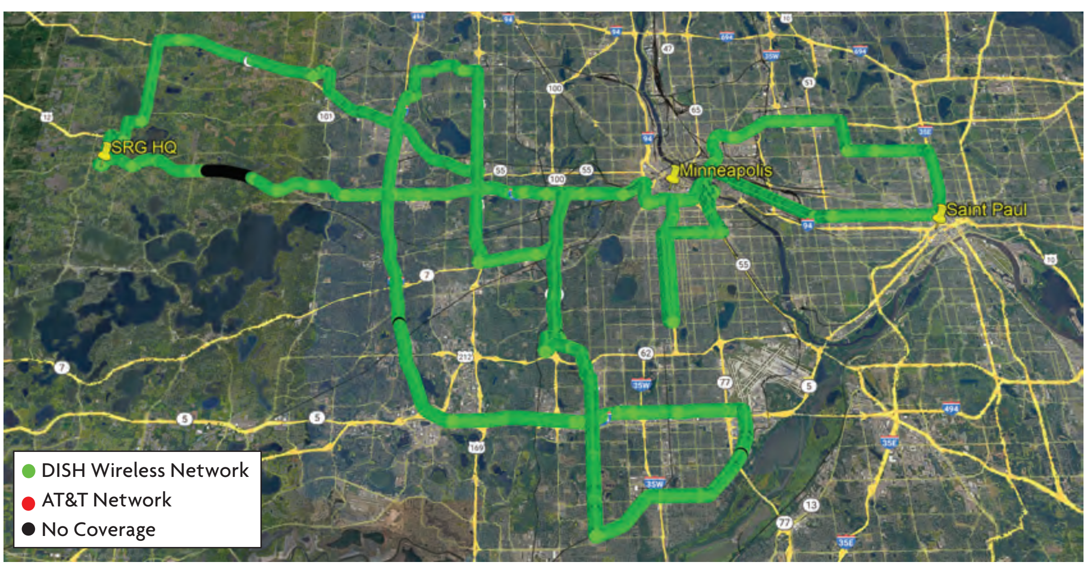
**In late August our Motorola edge+ smartphone wouldn't connect to the DISH Wireless network until after we locked the phone to SA mode.**

This point is a bit moot since the original Motorola edge+ smartphone and another phone that we subsequently purchased now attach to the DISH network, even with the standard implementation that allows both NSA and SA configurations. The results in the next two figures are, therefore, less interesting than they might have been if we had collected the data back in late August. For this study we locked one Motorola smartphone to 5G SA only and we allowed the other phone to use either 5G NSA or 5G SA. We then used a repetitive Umetrix Data test which involved a 10 second downlink data transfer (500 kbps) followed by 30 seconds of idle mode. We designed the test to determine if a DISH Wireless site was commercial without introducing loading onto the network.

As shown in Figure 16 and Figure 17, the behavior of the two phones was almost identical, indicating the DISH Wireless sites were commercial and that our phones were using them. Figure 17 shows a brief stretch where the unlocked phone used AT&T, but given the DISH wireless coverage in this area, we assume the phone switched to AT&T due to poor coverage on the DISH Wireless network. The SA locked phone was able to stay on the DISH Wireless network since it had no choice.

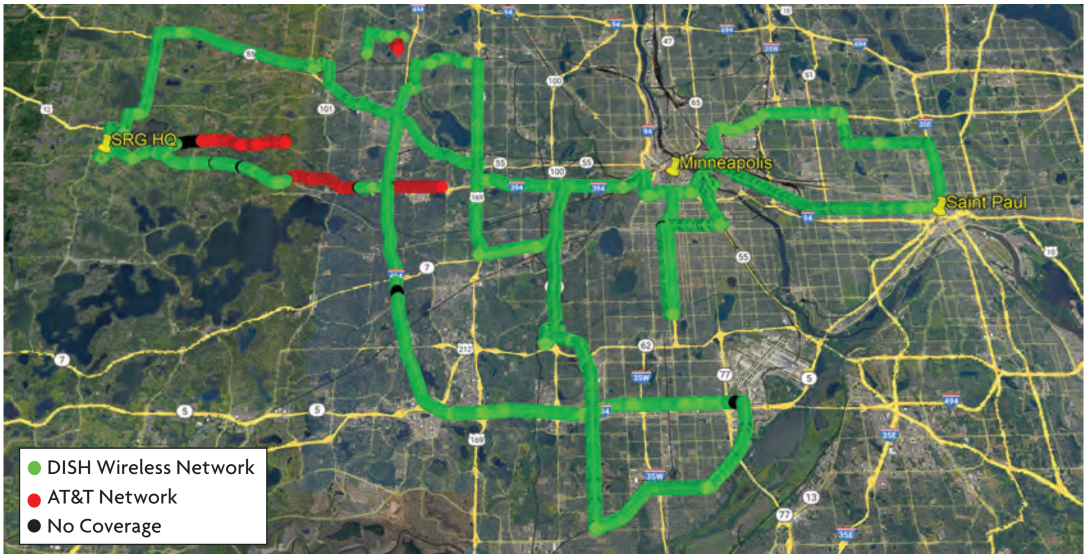
**Our test results show the Motorola edge+ smartphone remained on the DISH Wireless network, rarely dropping back to the AT&T network.**

*Figure 16. 5G SA Locked*




Source: Signals Research Group

*Figure 17. 5G NSA/SA Enabled*

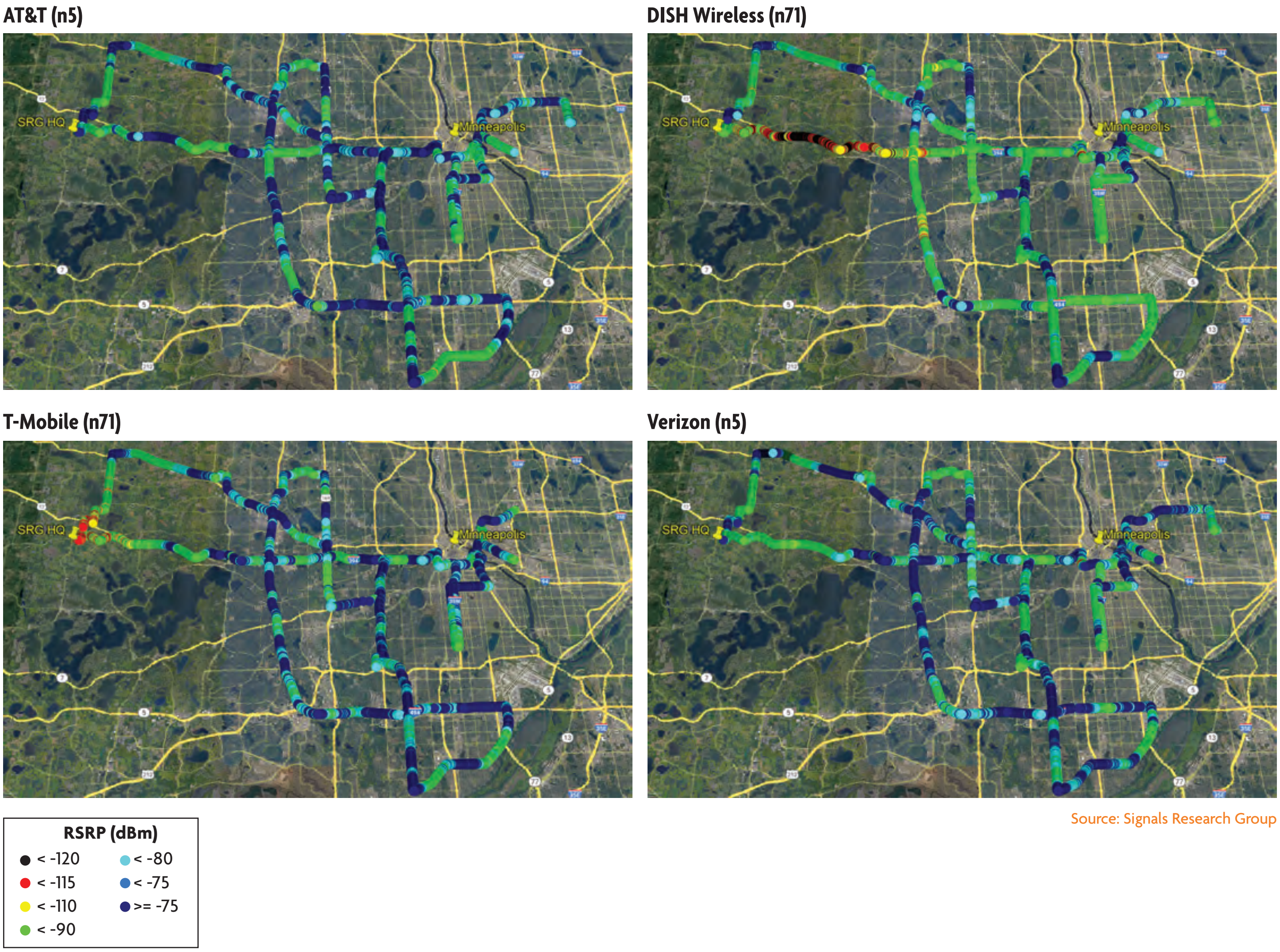



Source: Signals Research Group

# 5G COVERAGE MAPS

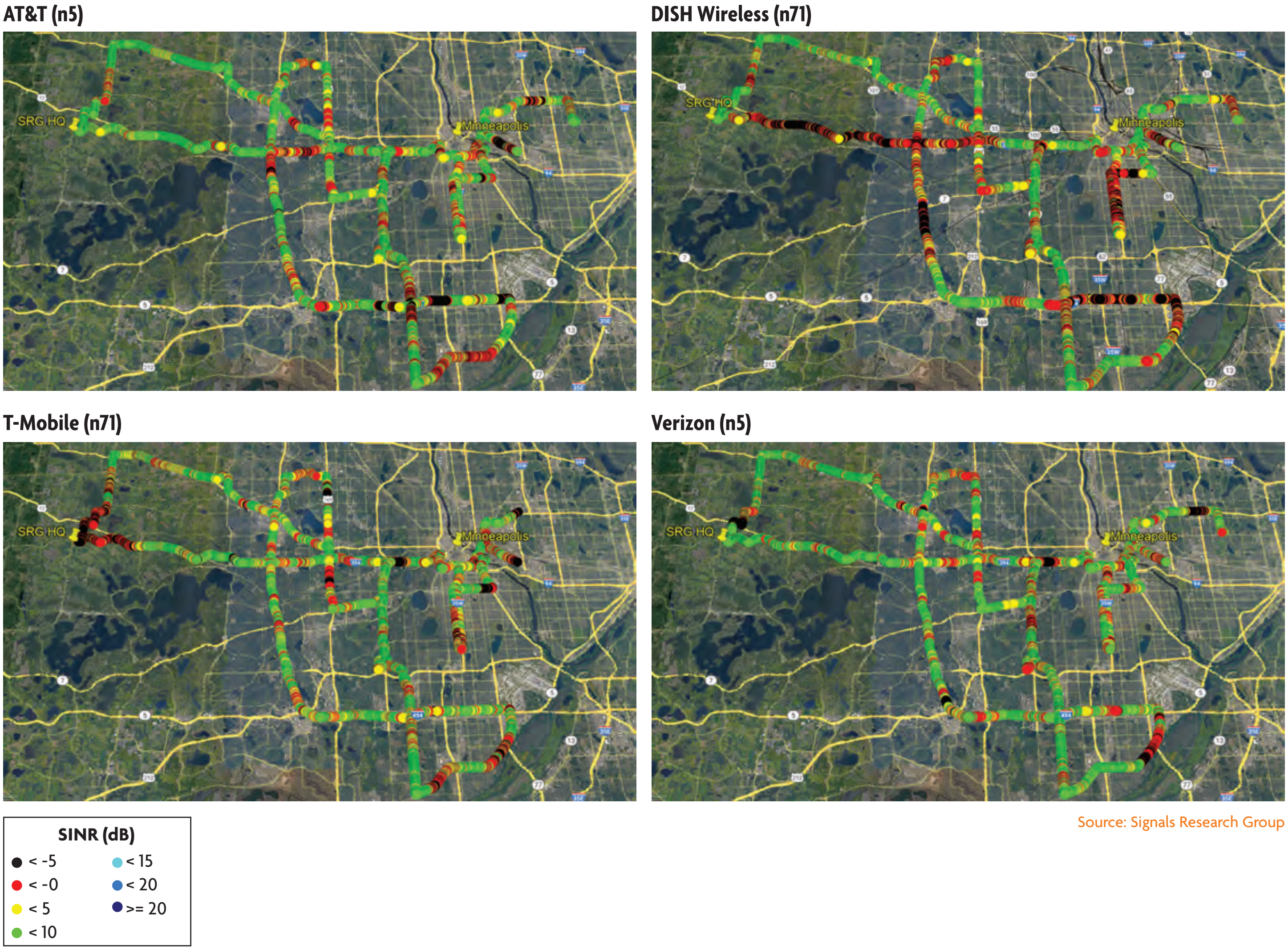
The remaining figures in this Signals Flash provide geo plots for several operator + 5G band combinations. The information in these figures serves as the basis for the statistical results provided on the previous pages. For those figures where there are missing colored circles it is likely an indication the scanner did not detect any 5G signals in that band.

*Figure 18. Low-band FDD 5G Coverage based on Signal Strength*



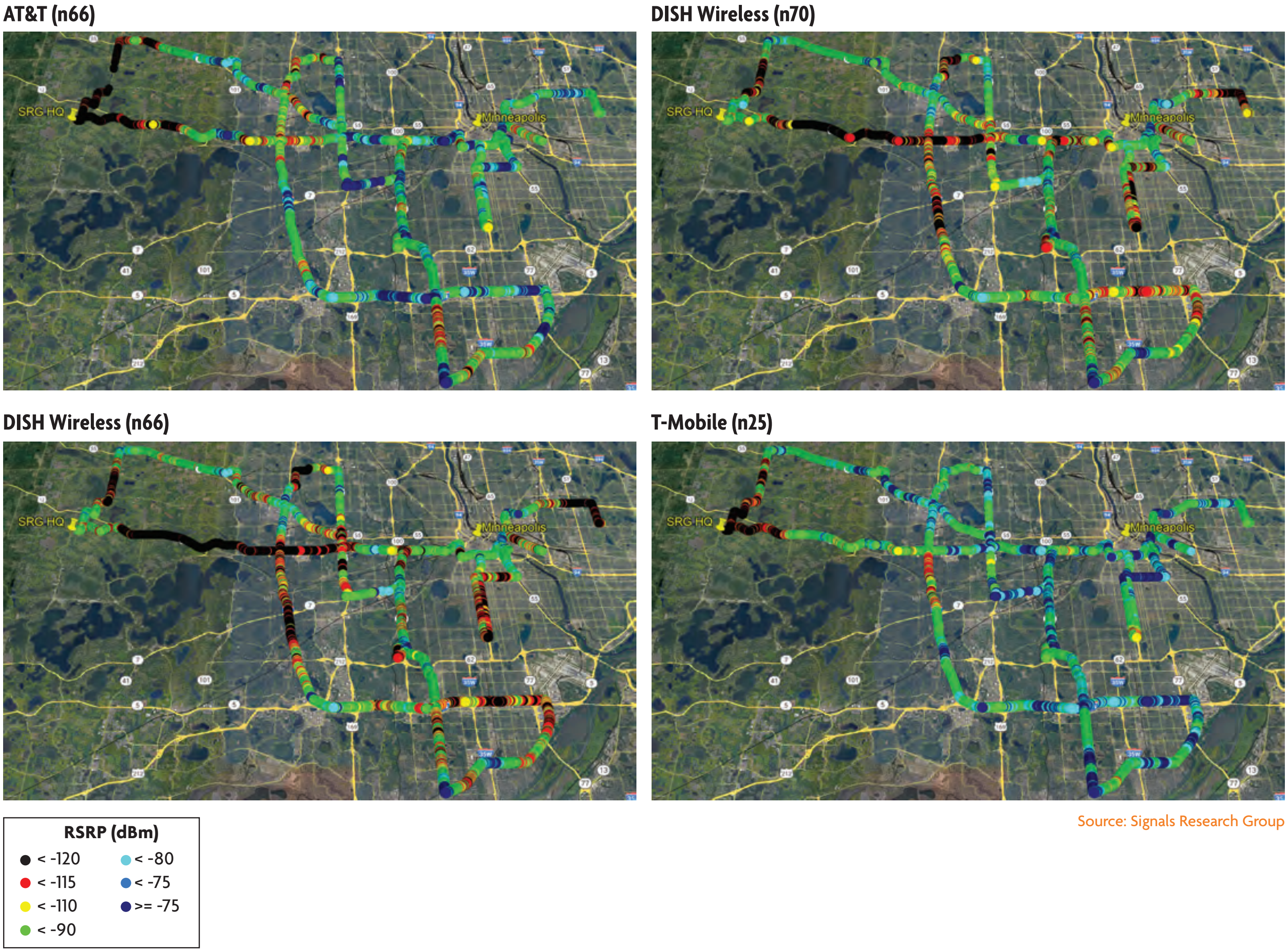

Source: Signals Research Group

*Figure 19. Low-band FDD 5G Coverage based on Signal Quality*




Source: Signals Research Group

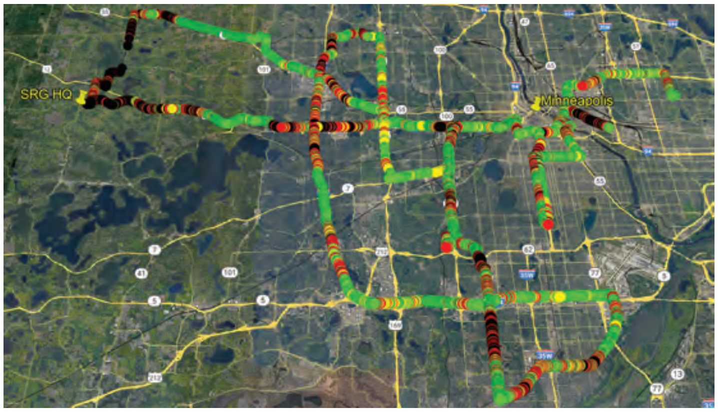
*Figure 20. Mid-band FDD 5G Coverage based on Signal Strength*




Source: Signals Research Group

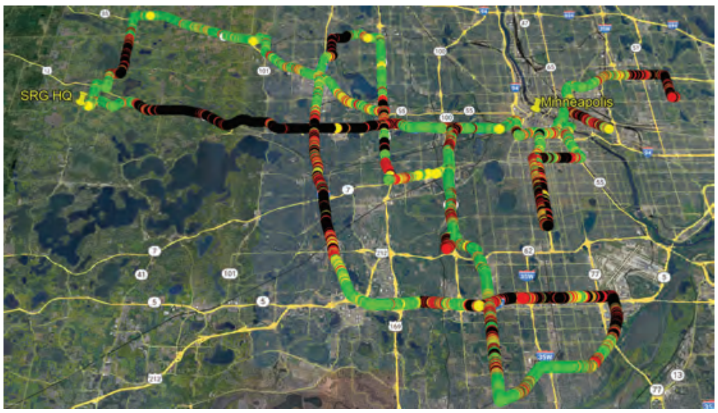
*Figure 21. Mid-band FDD 5G Coverage based on Signal Quality*

**AT&T (n66)**




**DISH Wireless (n70)**


**DISH Wireless (n66)**



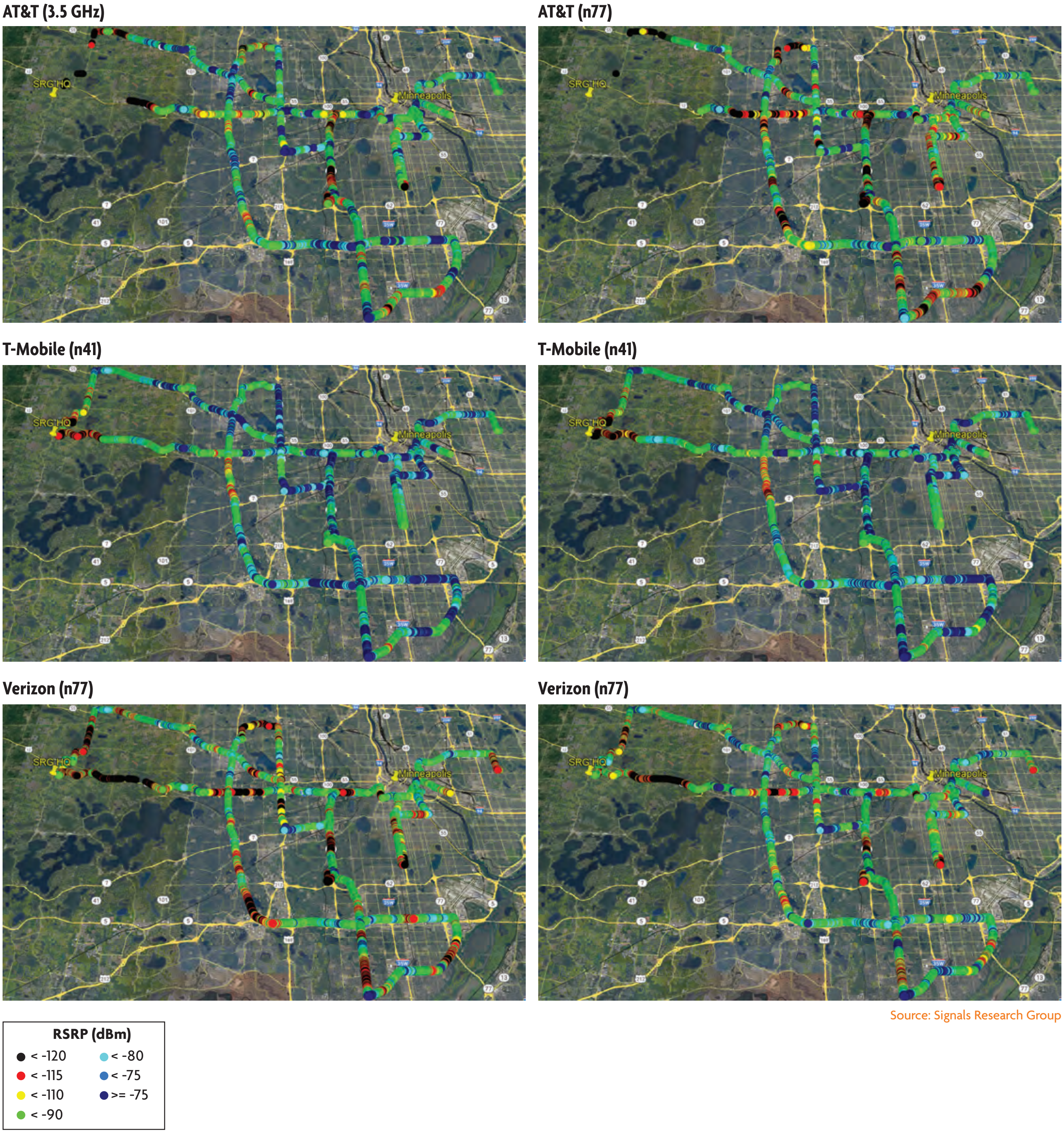

**T-Mobile (n25)**


**SINR (dB)**

- < -5
- < -0
- < 5
- < 10
- < 15
- < 20
- >= 20

Source: Signals Research Group

*Figure 22. Mid-band TDD 5G Coverage based on Signal Strength*




Source: Signals Research Group

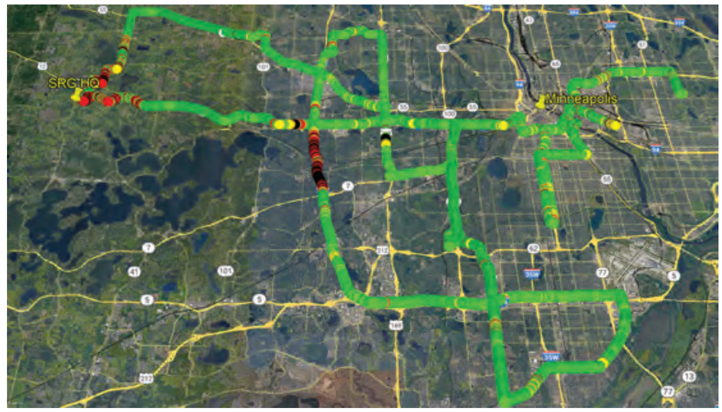
*Figure 23. Mid-band TDD 5G Coverage based on Signal Quality*

**AT&T (3.5 GHz)**

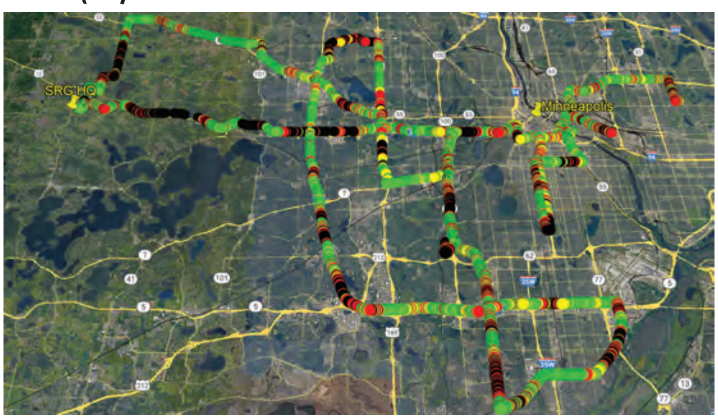

**AT&T (n77)**


**T-Mobile (n41)**

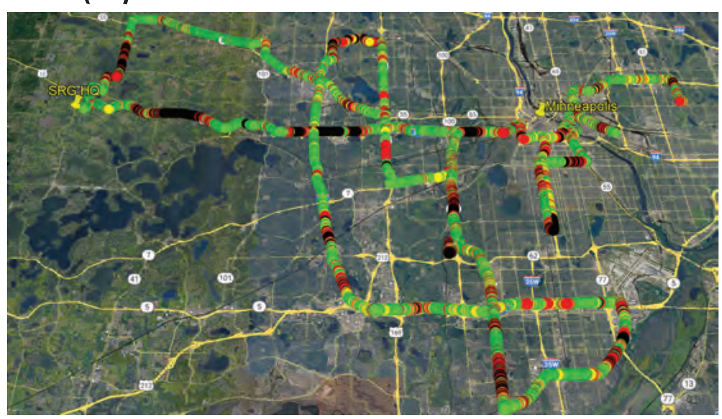

**T-Mobile (n41)**




**Verizon (n77)**




**Verizon (n77)**




**SINR (dB)**

| | |
|---|---|
| ● < -5 | ● < 15 |
| ● < -0 | ● < 20 |
| ● < 5 | ● >= 20 |
| ● < 10 | |

Source: Signals Research Group

# IN CASE YOU MISSED IT:
## SIGNALS AHEAD BACK ISSUES

➤ **9/22/23 "5G: The Greatest Show on Earth! Vol 35: American Broadband (a benchmark study of 5G four component carrier in rural America)"** SRG just completed its 35th 5G benchmark study. For this endeavor we collaborated with Accuver Americas and Spirent Communications to conduct an independent benchmark study of 5G 4CC using T-Mobile's commercial 5G network in rural South Carolina, where Ericsson the RAN infrastructure supplier.

***Highlights of the Report include the following:***

***Our Thanks.*** We did this study in collaboration with Accuver Americas (XCAL-M and XCAP) and Spirent Communications (Umetrix Data). SRG is responsible for the data collection and all analysis and commentary provided in this report.

***Our Methodology.*** We used a Galaxy S23 smartphone to test the downlink performance in a cluster of 10 Gbps cell sites that had 1x180 MHz of Band n41, 2x20 MHz of Band n25, and 2x20 MHz of Band n71. We primarily did drive tests along the rural roads as well as in the suburban neighborhoods, which were ideal for a fixed wireless access (FWA) service offering.

***FWA is for Real.*** It wasn't so much the "what" (1 Gbps average, 2.2 Gbps peak) or the "how" (5G 4CC), but the ""where"" that was impressive. Without question, there was far more 5G network capacity than the operator needed for mobile broadband, meaning the cell sites were recently upgraded to target FWA services to the surrounding homes and businesses. We discuss.

***FDD-TDD CA.*** In addition to looking at overall performance, we took the opportunity to look at the benefits of FDD-TDD CA, namely the use of a lower frequency 5G carrier as the primary cell to extend Band n41 coverage and improve throughput in poor coverage scenarios. We quantify the gains.

***SRS-based Beamforming.*** We revisit the benefits of SRS-based beamforming for improving end user data speeds and MU-MIMO in low mobility scenarios. We quantify the gains and the relationship between mobility and SRS accuracy.

➤ **8/7/23 "5G: The Greatest Show on Earth! Vol 34: UP (a benchmark study of 5G uplink carrier aggregation using n25 and n41)"** SRG just completed its 34th 5G benchmark study. For this endeavor we collaborated with Accuver Americas and Spirent Communications to conduct an independent benchmark study of 5G uplink carrier aggregation (CA), using T-Mobile's commercial 5G network in Seattle, WA, where Nokia is the RAN infrastructure supplier.

***Highlights of the Report include the following:***

***Our Thanks.*** We did this study in collaboration with Accuver Americas (XCAL-M and XCAP) and Spirent Communications (Umetrix Data). SRG is responsible for the data collection and all analysis and commentary provided in this report.

***Our Methodology.*** We used two MediaTek M80 test platforms (provided by T-Mobile) with the M80 5G modem to test the uplink feature, which T-Mobile enabled for our benefit on a few cells within its commercial network. We did stationary and drive tests while doing full buffer uplink data transfers. In addition to testing with a single test phone, we did additional testing in which we locked each phone to an individual band to determine the incremental benefits of uplink CA versus other device/network configurations.

***The Timeline.*** Uplink CA is most likely in 2024 at which point it will be limited to one layer per band. In 2025, there will be support for uplink CA plus 3 layers, including 2 layers in the mid-band channel (n41 in the case of Tmo). With our test methodology, we were able to show both the expected results for the 2024 CA functionality as well as what we can expect in 2025.

***The Results are In.*** Uplink CA with two layers (one per band) will always outperform a single component carrier without uplink MIMO and almost always outperform a single component carrier with uplink MIMO. Almost all 5G networks and most 5G smartphones do not support uplink MIMO, which we view as a critical mistep by the industry. With uplink CA and 3 layers the performance will always be better than uplink MIMO and substantially better than 1 component carrier with a single layer. We provide the hard numbers in the full report.

## ON THE HORIZON: POTENTIAL *SIGNALS AHEAD/SIGNALS FLASH!* TOPICS

We have identified a list of pending research topics that we are currently considering or presently working on completing. The topics at the top of the list are definitive with many of them already in the works. The topics toward the bottom of the page are a bit more speculative. Obviously, this list is subject to change based on various factors and market trends. As always, we welcome suggestions from our readers.

### Thematic Reports

- *Mobile Edge Computing and the impact of data caching at the cell edge*

### Benchmark Studies

- *Video performance in a congested 5G network*
- *UL-MU-MIMO*
- *Open RAN network performance benchmark study 1 – Dish Network Revisit*
- *Open RAN network performance benchmark study 3 – Scheduling Efficiency*
- *FR1 + FR2 NR-DC network performance benchmark study*
- *MU-MIMO benchmark study, part III (FR1)*
- *SRS-based beamforming benchmark study*
- *DSS Update benchmark study*

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