September 28, 2022

SiGNALS Flash!

Dispatches from the frontier of wireless

STOP THE PRESSES: MU-MIMO

SiGNALS Research Group
www.signalsresearch.com

EXECUTIVE SUMMARY

Signals Research Group (SRG) captured a few log files in the Verizon Band n77 5G network near Minneapolis, MN. One log file was from testing at a cell site 12 miles due west of downtown Minneapolis (Wayzata) and another test occurred at a cell site another 12 miles further west, and in the vicinity of SRG HQ.

We're publishing some snippets of data from these two tests in a *Signals Flash!* report because they both demonstrate the presence of MU-MIMO in the Verizon network (Ericsson infrastructure). Later this year we intend to conduct a full-blown benchmark study of MU-MIMO that does the new 5G feature justice, and which is more reflective of a SRG benchmark study, but for now we can at least share that the feature is on the potential roadmap of at least some operators. Unlike this complimentary *Signals Flash!* report, our full-blown MU-MIMO study will only be available to *Signals Ahead* subscribers.

Key Highlights and Observations

- A special thanks once again to Accuver Americas (XCAL-M, XCAP, and XCAL-Solo) and Spirent Communications (Umetrix Data) for the user of their respective test equipment and test platforms. We will most certainly leverage their support when we do MU-MIMO testing at a later date.
- MU-MIMO can be a game changer for mobile operators since it can significantly increase total network capacity if the same network resources can be shared simultaneously across multiple phones within the same cell sector.
- Our view is that MU-MIMO can significantly increase the business case for fixed wireless access with mid-band 5G spectrum, plus the feature should perform at its best when the target devices are stationary.
- MU-MIMO is a relatively simple software upgrade to the cell site, as reflected in its presence at multiple cell sites (likely across all the metro area), including cell sites that can't possibly need that much additional capacity (unless used for FWA…).
- All signs look promising for the potential of MU-MIMO since we consistently observed twice the number of network resources (PDSCH RBs) used within the same sector with our two mobile devices (plus the additional contributions from other devices in the commercial network, which we could not capture).
- Due to limited backhaul at the two sites where we tested, we weren't able to observe the actual impact of MU-MIMO on sector throughput, but we'll tackle this logistical challenge when we do a "real study" of the feature later this year.

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BACKGROUND

A funny thing happened on the way to publishing our next *Signals Ahead* report. Let us digress. We are in the process of doing a multi-chipset (Qualcomm, MediaTek, Samsung) + multi-device 5G benchmark study that looks at 5G performance in both FR1 (sub 6 GHz) and FR2 (mmWave). This report is still in the works, and it will be available through our *Signals Ahead* research publication. The results of the study will be interesting but in the process of doing the study we came across something that we momentarily couldn't explain.

We were trying to understand some performance differences between two smartphones when testing the Verizon Band n77 network. In our analysis, we looked at PDSCH resource block (RB) allocations for the two smartphones and we discovered that both smartphones were simultaneously using the maximum number of RBs that are possible in a 60 MHz Band n77 channel. We reconfirmed both smartphones were using the same cell site (PCI) and, of course, Band n77. Upon further examination, we also discovered other anomalies that we do not typically observe in our testing in which the activity of one smartphone uncharacteristically influenced certain parameters for another smartphone.

And then it hit us – this phenomenon is a characteristic of multi-user MIMO (MU-MIMO), whereby the same network resources (RBs) are reused multiple times within the sector. In the immortal [paraphrased] words of Mr. Cheech Marin and Mr. Tommy Chong, *"…looks like MU-MIMO,… feels like MU-MIMO,… smells like MU-MIMO,… tastes like MU-MIMO,… then it must be MU-MIMO."*

The phenomenon we observed in the Verizon Band n77 network is a characteristic of MU-MIMO, whereby the same network resources (RBs)

As a quick refresher we've tested MU-MIMO in the past – once with LTE (SA 11/29/18, "The Matrix") and more recently with 5G. For the 5G MU-MIMO study, which we did as a sponsored research study for an undisclosed client, we leveraged a test network on the Ericsson campus in Plano, Texas (SF 09/08/20, "Sweet 16") to evaluate the potential for 5G MU-MIMO, based on a precommercial implementation. As suggested by the title of that report, the precommercial implementation supported up to 16 data layers that could be shared by up to eight mobile devices, resulting in a peak sector throughput of 5.45 Gbps in a 100 MHz TDD channel. MU-MIMO differs from SU-MIMO (single user MIMO) in that with MU-MIMO the layers are distributed across mobile devices in the sector while with SU-MIMO all the layers go to a single mobile device. Today's networks are limited to four layers (4x4 SU-MIMO) although 8x8 SU-MIMO is in the works. The net effect is that MU-MIMO can have a material impact on spectral efficiency/total sector throughput, but it doesn't increase the peak data speeds that can be observed by a single mobile device.

We reached out to Verizon and confirmed we were witnessing MU-MIMO with the operator noting that *"we are currently testing MU-MIMO and we have not deployed yet"* and that *"the feature is still under evaluation."* We don't know the extent of the MU-MIMO trial and when, or even if, they will commercially deploy it. We believe it is inevitable and likely imminent, but


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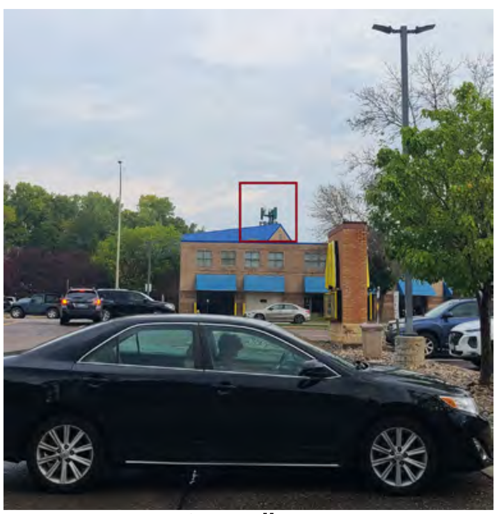
that is a personal opinion. However, we did take the liberty to capture a few logs and we'd like to share some of that information with our Signals Flash! readers. We stress that this effort does not represent a meaningful benchmark study of MU-MIMO since a real study would involve multiple mobile devices (at least 8) and a cell site with sufficient backhaul and the absence of commercial traffic since the latter would make it difficult to conduct a valid analysis.

We also tested the Verizon Band n77 network when they first launched it earlier this year (SA 02/08/22, "Happy Ending…or just the Beginning"). In that study, we looked in some detail at the use of SRS-based beamforming, which we assume is the underpinning of the recent MU-MIMO precommercial deployment. We found SRS-based beamforming significantly improved performance with low mobility or stationary mobile devices. Combining these two facets, along with the push of fixed wireless access (FWA) services and the need for ample capacity to support the high data use case, we believe MU-MIMO will be a key enabler of the burgeoning business opportunity.

Figure 1 shows a picture of the cell site where we tested in Wayzata from the exact location where we first observed MU-MIMO pairing between two adjacent smartphones. Although we were relatively close to the serving cell tower – the same cell site where we first started testing Dynamic Spectrum Sharing (DSS) many moons ago, the two smartphones, which successfully paired resource blocks were a mere 12 inches apart. Not only were they 12 inches apart but they were located directionally inline with each other and the 5G radio, meaning from the perspective of the 5G radio the two smartphones were figuratively and literally placed on top of each other.

Figure 1. Verizon MU-MIMO Cell Site and Phone Placements



Verizon Cell Tower

Phone Placement

Source: Signals Research Group

SAMPLE RESULTS AND ANALYSIS

We later returned to the area where we first detected the presence of MU-MIMO to do some additional data collection. For this testing we placed one smartphone (Galaxy S22) in our vehicle and used XCAL-M to log the chipset data. We used XCAL-Solo, which is a data collection tool designed to support walk testing, to collect chipset data from the second smartphone (Galaxy S22). Since MU-MIMO is a downlink feature we used Umetrix Data to generate high bandwidth data streams to the two smartphones, starting with the stationary smartphone located in the test vehicle and then to the second smartphone, starting 30 seconds later. We used a data stream to a single smartphone at the start of the test and at the end of the test to observe the total throughput in the absence of the second smartphone.

In our real-time analysis of the downlink throughput (transferred via LTE 3-carrier carrier aggregation plus 60 MHz of Band n77) we observed indications that the cell site was backhaul limited (~1 Gbps) and we subsequently confirmed this view when we later analyzed the data with the XCAP post-processing tool. Since our interest was on 5G MU-MIMO we then intentionally disabled three bands of LTE (Band 2, Band 5, and Band 13) on the two smartphones so that all the transferred data went over 5G Band n77 and LTE Band 66. We needed Band 66 for the LTE anchor. Even with a single LTE band, the total data throughput still hit 1 Gbps, thus reconfirming our backhaul limitation theory and making it virtually impossible to quantify the true benefits of MU-MIMO. We'd also need at least 8 mobile devices with logging capabilities and a cell site without any other 5G traffic to do a proper MU-MIMO analysis.

Figure 2 shows the walk test we used around the area. For this test, we moved the stationary location slightly from the original location where we detected MU-MIIMO. We also limited the area where we walked, in part because of the terrain, but also because we didn't want to leave our computer and phones for long in an unattended vehicle. The figure shows a couple of instances when we momentarily walked into an adjacent cell (the one instance isn't obvious) as well as a couple of occasions when we placed the smartphone into airplane mode (once again the one instance isn't obvious).

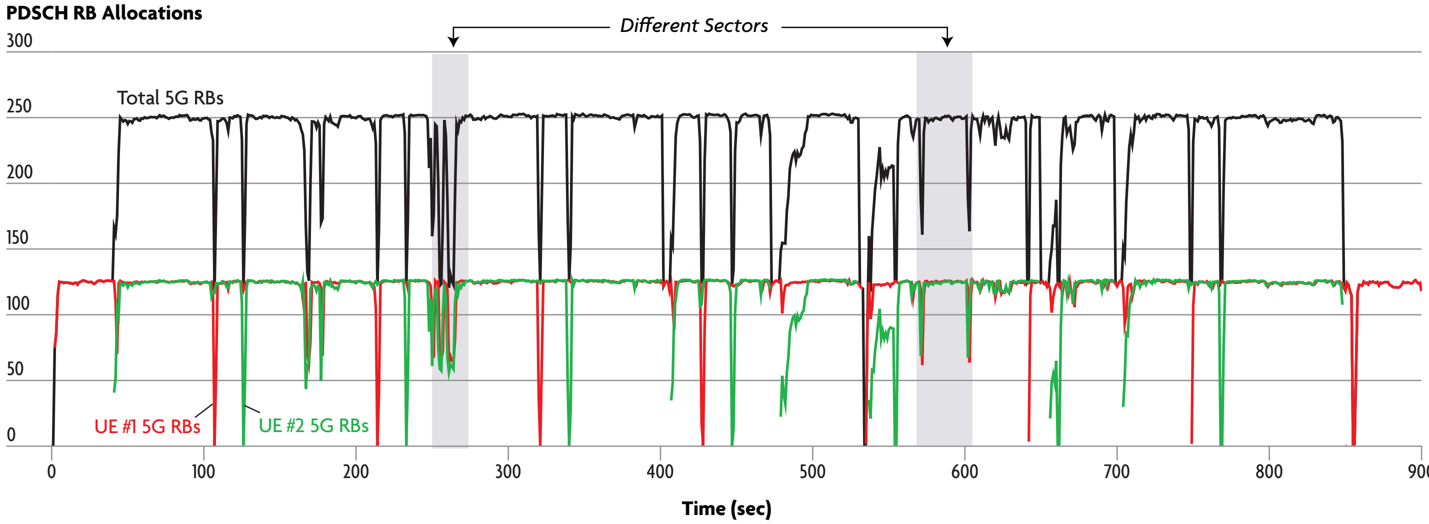
Figure 2. Wayzata Walk Test

Source: Signals Research Group

Figure 3 provides a time series plot of the 5G PDSCH RB allocations for the two smartphones, as well as the sum of the RB allocations for these two phones. We strongly suspect additional RBs were being assigned to other mobile devices in the area, but we cannot possibly capture this information. Figure 4 provides comparable LTE RB allocation information for the two smartphones. Both figures, as well as subsequent figures from this test, highlight two instances when we momentarily walked out of the test sector. Figure 3 also shows the two instances when we placed the smartphone used for the walk test into and out of airplane mode. We point out the periodic dips in the RB allocations reflect the start/stop of the 2-minute Umetrix full buffer data transfer sessions. In the case of the 5G PDSCH RB allocations it is evident that when UE #2 (the smartphone used for the walk test) started receiving the data transfer, the total 5G RB allocations doubled and that the total RB allocations dropped in half at the end of the test exactly when we stopped the data transfer going to UE #2. This phenomenon reflects MU-MIMO. Conversely, with LTE the total RB allocations remain unchanged when UE #2 started receiving data while the RBs being allocated to UE #2 dropped by approximately half their original numbers. The spike in LTE

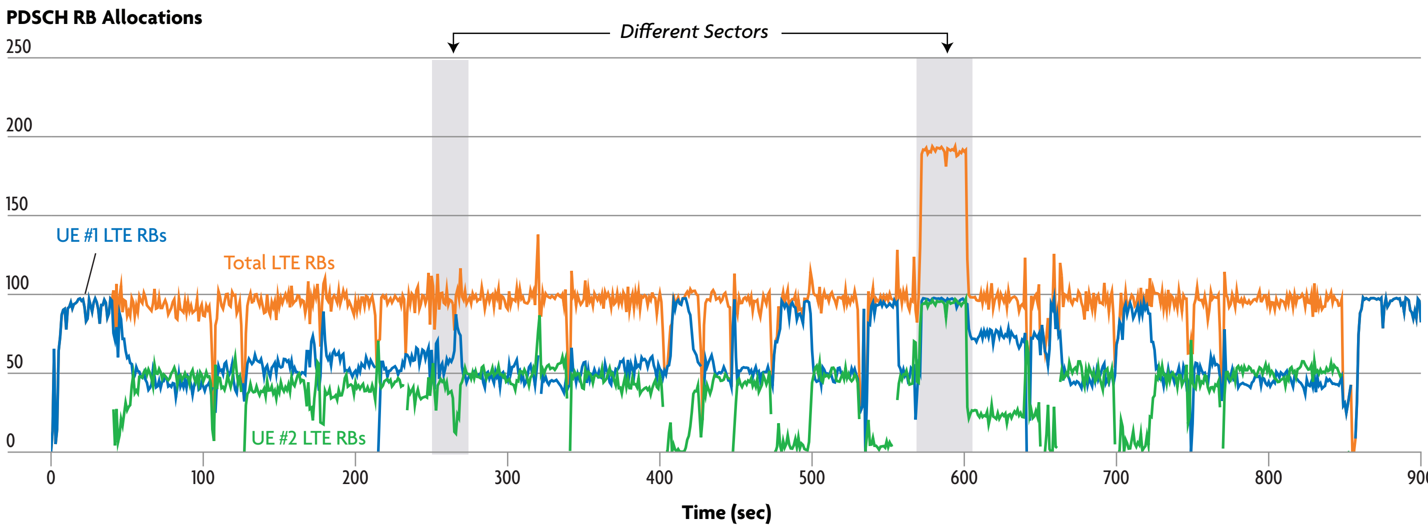
When UE #2 started receiving the data transfer, the total 5G RB allocations doubled – this phenomenon reflects MU-MIMO.

Figure 3. 5G PDSCH RB Allocations



Source: Signals Research Group

Figure 4. LTE PDSCH RB Allocations



Source: Signals Research Group

IN CASE YOU MISSED IT:
SIGNALS AHEAD BACK ISSUES

➤ **8/31/22 "5G: The Greatest Show on Earth! Vol 27: Behind the VoNR Curtain, Part 7"** SRG just completed its 27th 5G NR benchmark study. For this endeavor we collaborated with Accuver Americas and Spirent Communications to conduct an independent benchmark study of Voice over New Radio (VoNR) and how it compares with VoLTE, based on testing we did in T-Mobile's network.

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 Voice and Umetrix Data). SRG is responsible for the data collection and all analysis and commentary provided in this report.

Our Methodology. Testing took place over a two-day period in early July. We had access to a T-Mobile 17-site test cluster that is part of its commercial network. Using 2 Galaxy S21 with pre-release software that supported VoNR and SA we did comparative drive and stationary testing with two Galaxy S20 smartphones that supported VoLTE. We tested VoNR in both Band n71 (600 MHz) and Band n41 (2500 MHz), including with background data transfers taking place during the call.

Four Areas of Focus. We looked at voice quality (MOS), network resource utilization, background data transfers, and current consumption. We did this comparative testing while stationary and/or via extensive drive testing throughout the cluster where the smartphones were exposed to a wide range of RF conditions.

Its Nuanced. VoLTE offered a huge advantage over circuit switched 3G voice in terms of superior voice quality, not to mention the elimination of CSFB (circuit switched fallback). VoNR and VoLTE both use the same EVS codec so the benefits of VoNR over VoLTE are less obvious.

"Staying Alive" on 5G. Without question, the biggest advantage of VoNR is that it allows the smartphone to remain on 5G, which proves beneficial when background data transfers occur. Longer term, moving all traffic to 5G SA helps with technology migration while SA offers certain performance benefits over NSA that are unrelated to voice.

Balancing Act. 5G networks are not as mature as LTE so RF conditions are not always as favorable. 5G current consumption is a consideration, especially when VoNR occurs in Band n41. Lastly, 5G network resource utilization can be better optimized for low bit rate voice calls."

➤ **8/1/22 "5G: The Greatest Show on Earth! Vol 26: Three's Company"** SRG just completed its 26th 5G NR benchmark study. For this endeavor we collaborated with Accuver Americas and Spirent Communications to conduct an independent benchmark study of 5G 3CC, including Band n71 (FDD – 15 MHz), Band n41 (100 MHz – TDD) and Band n41 (40 MHz – TDD).

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 Voice and Umetrix Data). SRG is responsible for the data collection and all analysis and commentary provided in this report.

Our Methodology. Testing took place over a three-day period in early July. We had access to a T-Mobile 17-site test cluster that is part of its commercial network. Using a Galaxy S22 with pre-release software that supported 3CC and SA we did comparative drive testing with a Galaxy S21 smartphone that was limited to 2CC. We also forced this phone to operate in NSA mode.

Four Areas of Focus. We looked at 3CC peak performance in an "empty network", mapped SINR and RSRP to the distance to the serving cell(s) for both n71 and n41, documented the incremental benefits of using Band n71 FDD as the anchor carrier with Band n41 serving as the secondary cells, and evaluated the performance attributes of the Galaxy S22 and Galaxy S21 smartphones.

FDD-TDD Advantage. We once again observed the benefits of using FDD as the anchor band to help extend and improve Band n41 coverage and performance. For us, the challenge remains finding locations in the network where the feature is necessary.

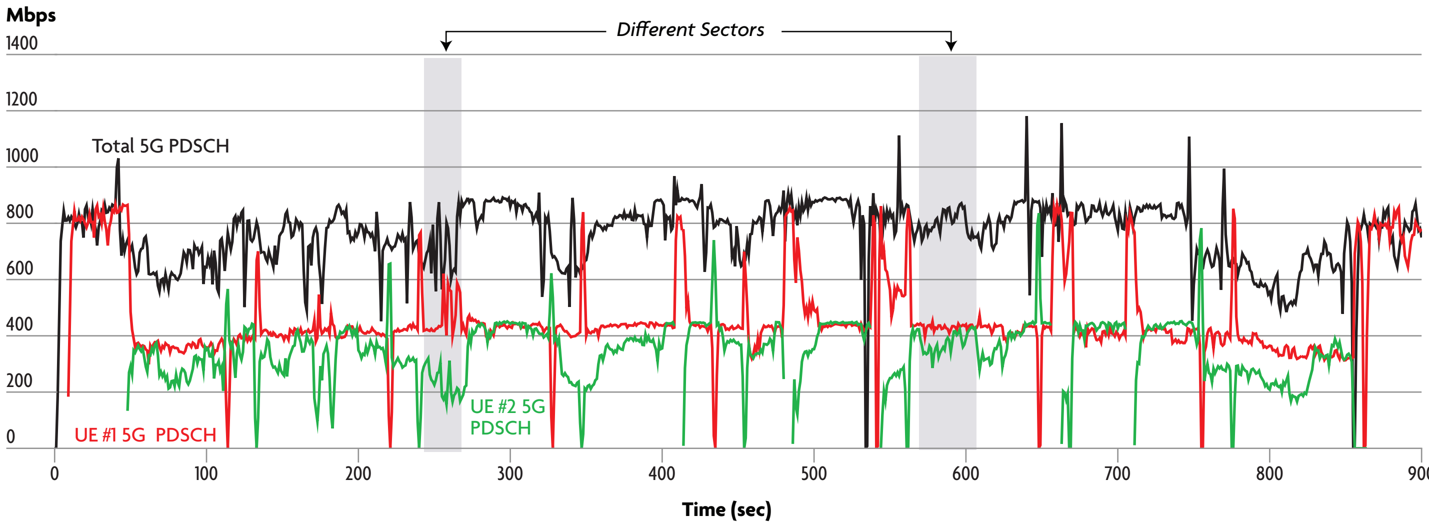
n71 Versus n41. By knowing the exact locations of the serving cell sites we were able to show the relationships between Band n41 and Band n71 RSRP and the distance to the serving cell. We show that in a network designed for capacity (not simply coverage) the penalty for using mid-band frequencies for 5G are overstated (although real). Further, we once again show that low frequencies may be great for coverage but the mid-band frequencies actually deliver overall better network quality.

S21 Versus S22. For us, this analysis proved to be the most interesting. Although the two phones performed largely the same over all network conditions, there were obvious differences in how they achieved their respective results. Further, one smartphone tended to perform much better with more favorable RF. We'll let you guess which one."

RB allocations right before 600 seconds is consistent with the smartphone moving into the adjacent sector. In the case of 5G, UE #2 was also using RBs from the adjacent sector but since it was already using the full allocation (as was UE #1) there wasn't an impact on the total allocated RBs.

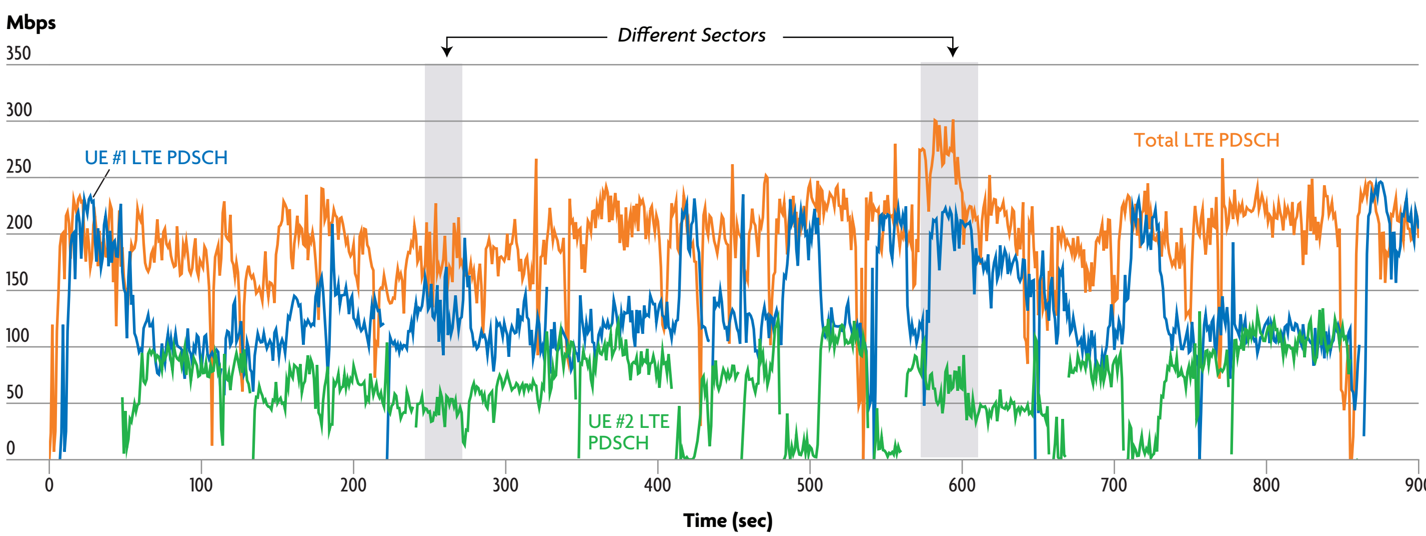
The next three figures show the PDSCH throughput. Figure 5 shows the 5G throughput for the two smartphones, as well as the total 5G throughput, Figure 6 provides similar information for the LTE throughput, and Figure 7 just shows the total 5G throughput and LTE throughput, as well as the combined 5G + LTE throughput. Although the LTE throughput increased when UE #2 moved into the adjacent sector, the total throughput remained unchanged. Without a backhaul limitation, we would have expected a much higher increase in the total throughput. With an efficient use of MU-MIMO, the UE #1 throughput would have remained unchanged when UE #2 started receiving data, meaning the total throughput would have been much higher than shown in the figure. In effect, the throughput would have looked like the RB allocation figure, albeit with a different Y axis.

Figure 5. 5G PDSCH Throughput



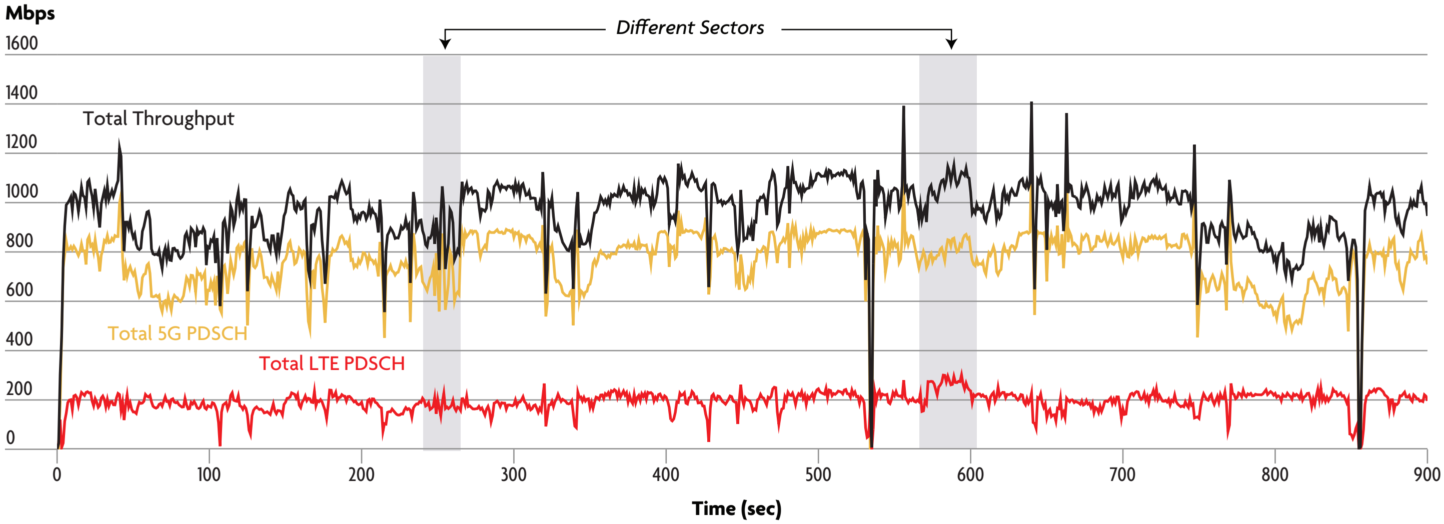
Source: Signals Research Group

Figure 6. LTE PDSCH Throughput



Source: Signals Research Group

Figure 7. Total 5G and LTE PDSCH Throughput

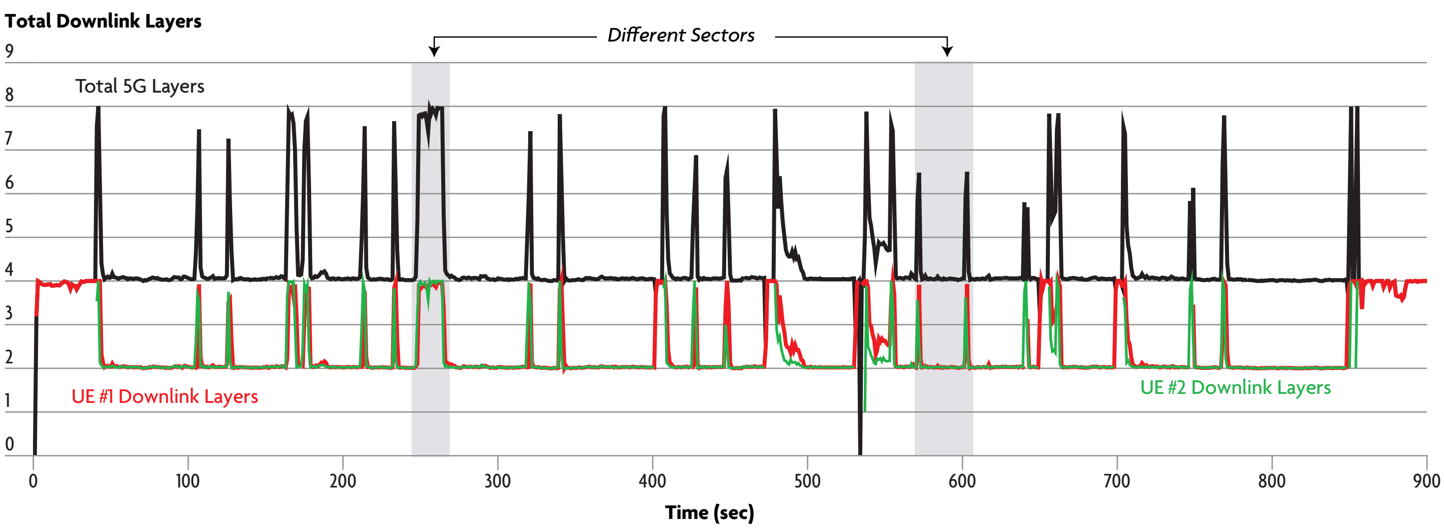


Source: Signals Research Group

Figure 8 shows the total number of MIMO layers as well as the contributions from the two smartphones. Excluding the periodic spikes to four total layers, the total number of layers remained at four layers. For example, the UE #1 MIMO rank went from Rank 4 to Rank 2 as soon as UE #2 started receiving data. Even more interestingly, if you compare the RB allocation figure (Figure 3) with this figure you will notice the total RB/total MIMO layer plots are a mirror of each other. When the total RB count dropped, the total MIMO layer count increased (and vice versa). These events occurred at the start/stop of each Umetrix data session when the data speeds started off very low and then ramped due to the HTTP protocol. We believe this is another indication of a backhaul limitation, meaning there could have been full RB allocations and eight MIMO layers for the two smartphones over much of the test, and a subsequent significant increase in the total sector throughput.

When the total RB count dropped, the total MIMO layer count increased (and vice versa), strongly suggesting the benefits of MU-MIMO would have

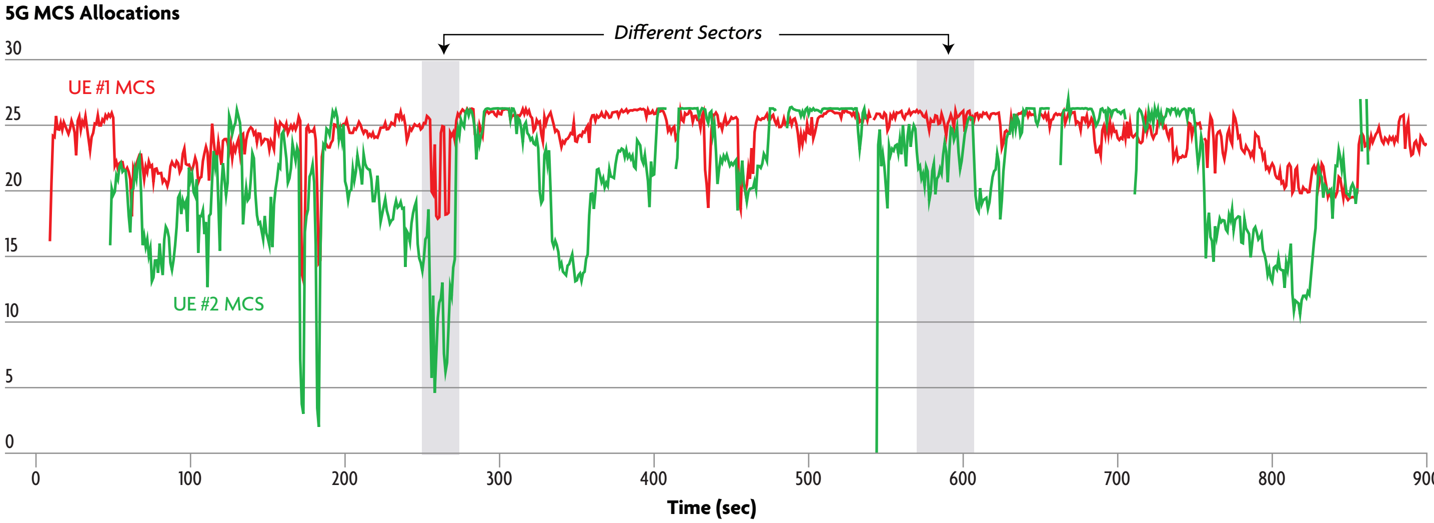
Figure 8. 5G MIMO Layer Count



Source: Signals Research Group

Figure 9 illustrates the modulation and coding scheme (MCS) values for the two smartphones. We would expect UE #2 to have much greater variability in its MCS values since this smartphone was moving throughout the sector with varying RF conditions. When the smartphone moved into the adjacent sector, it was an area with higher interference, hence the MCS values didn't improve.

Figure 9. 5G MCS Allocations

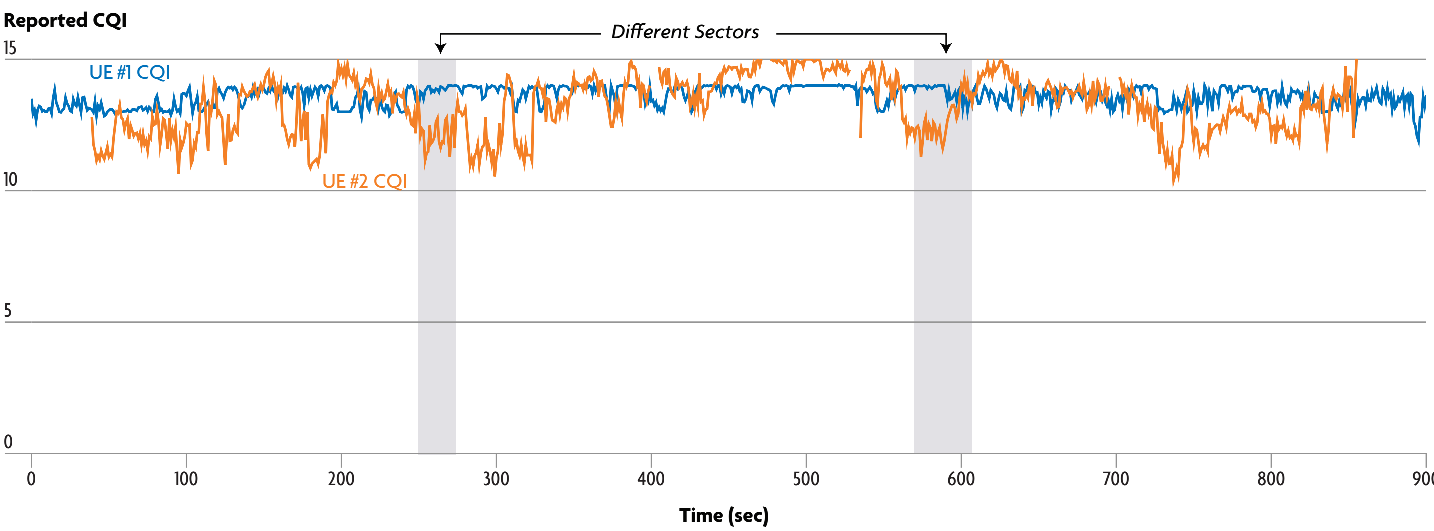


Source: Signals Research Group

Figure 10 shows the Channel Quality Indicator (CQI) measurement reports for the two smartphones. The CQI reports for UE #1 remained largely unchanged, even with the presence of UE #2, while there was greater variability in the CQI reports for UE #2, consistent with the varying RF conditions. Although we didn't include a corresponding figure, we confirmed the PDSCH block error rate (BLER) for the two smartphones was well within an acceptable range (generally sub 10%) during this test.

We confirmed the PDSCH BLER for the two smartphones was well within an acceptable range.

Figure 10. 5G CQI Reports



Source: Signals Research Group

Since we captured MU-MIMO test data at another cell site, we are including some figures in this Signals Flash! without much additional commentary. Figure 11 shows the area where we conducted this test. Worth noting, there isn't much going on in this area and it is clearly a cell site that doesn't need a lot of bandwidth for mobile data. There are two golf courses in the area, but otherwise it is a rural area. Side note – we know from an earlier study that there are homes within coverage of this cell tower that do not have access to a fixed broadband service. It would also be an ideal location to conduct a MU-MIMO benchmark study if an operator was willing to increase the backhaul. Just sayin'.

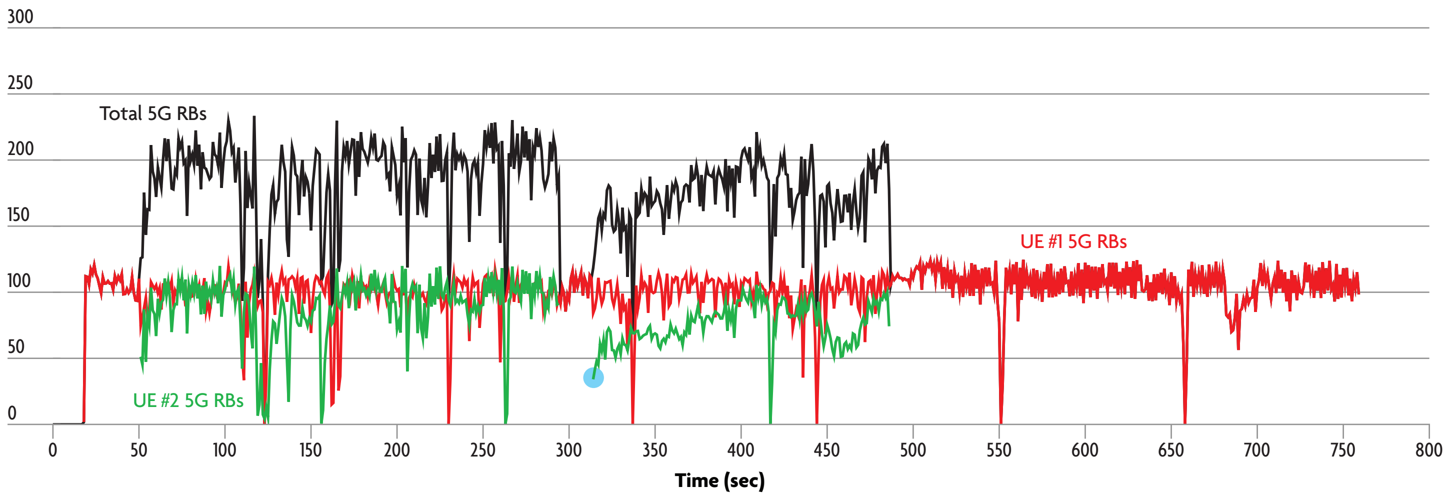
Figure 11. Windsong Farm Walk Test

Source: Signals Research Group

Interestingly, we observed more network loading from other devices at this test location than we observed at the other test location, despite the rural location. This observation is supported by the greater variability in the RB allocations, even with only a single smartphone attached to the network. We observed the same occurrence for an extended period of time while testing when we were not capturing a log file.

Figure 12. 5G PDSCH RB Allocations

PDSCH RB Allocations

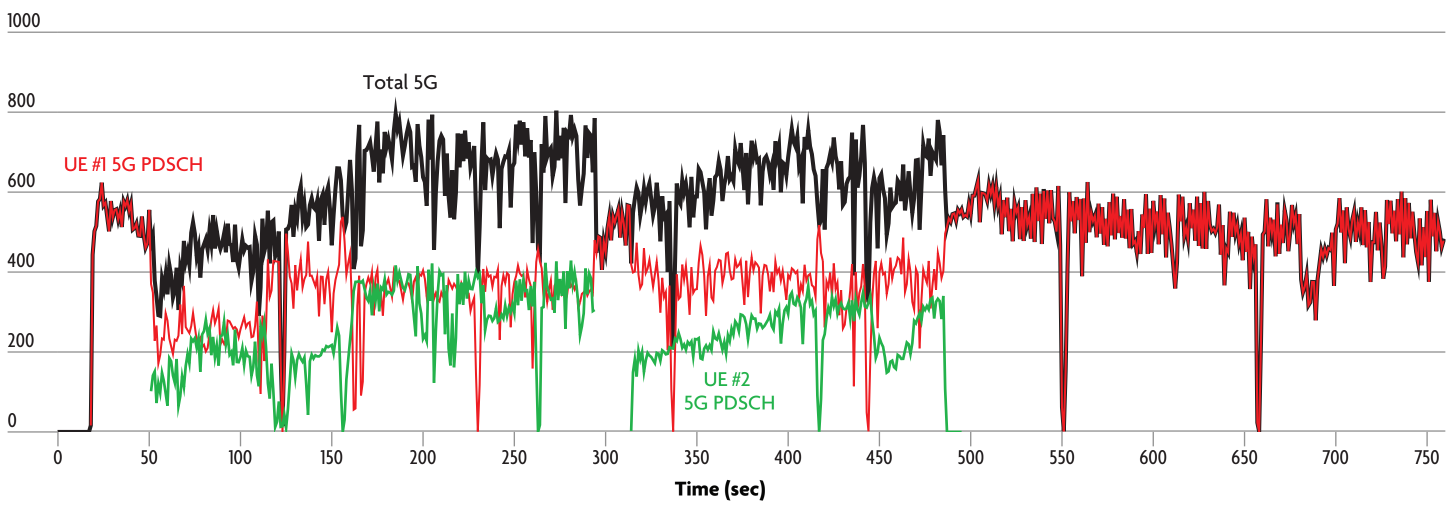


Source: Signals Research Group

Finally, Figure 13 and Figure 14 show information about the 5G LTE and total throughput. The dips reflect the start/stop of the Umetrix Data session with one instance when we placed one smartphone into and out of airplane mode.

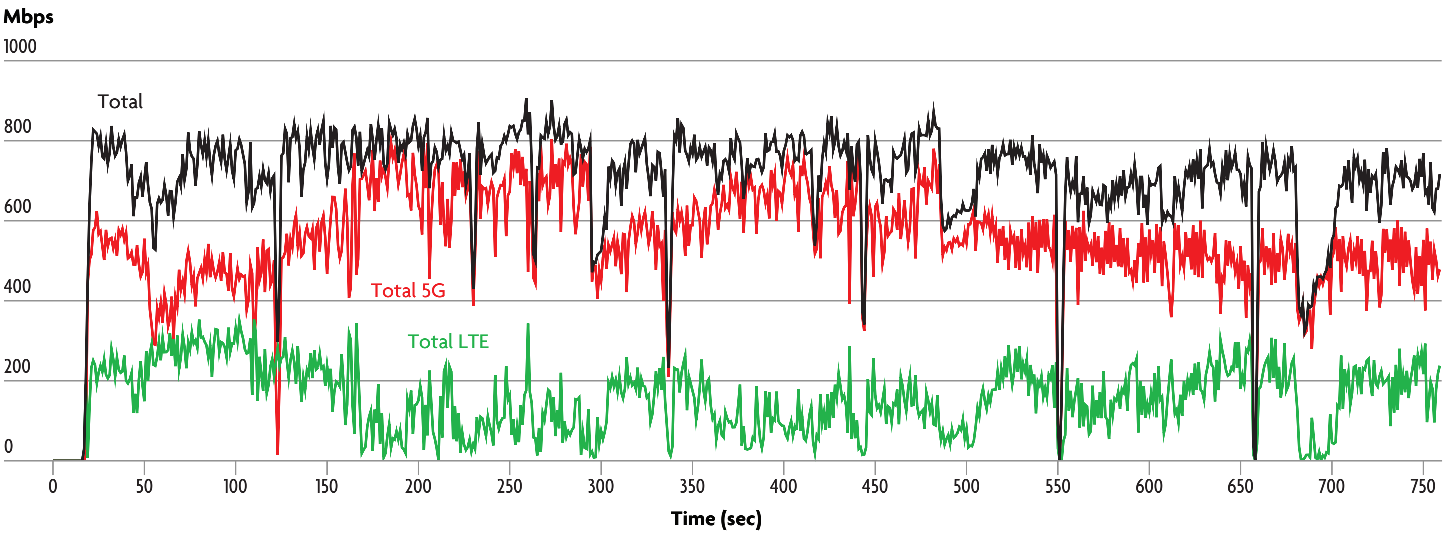
Figure 13. 5G PDSCH Throughput

Mbps



Source: Signals Research Group

Figure 14. Total PDSCH Throughput



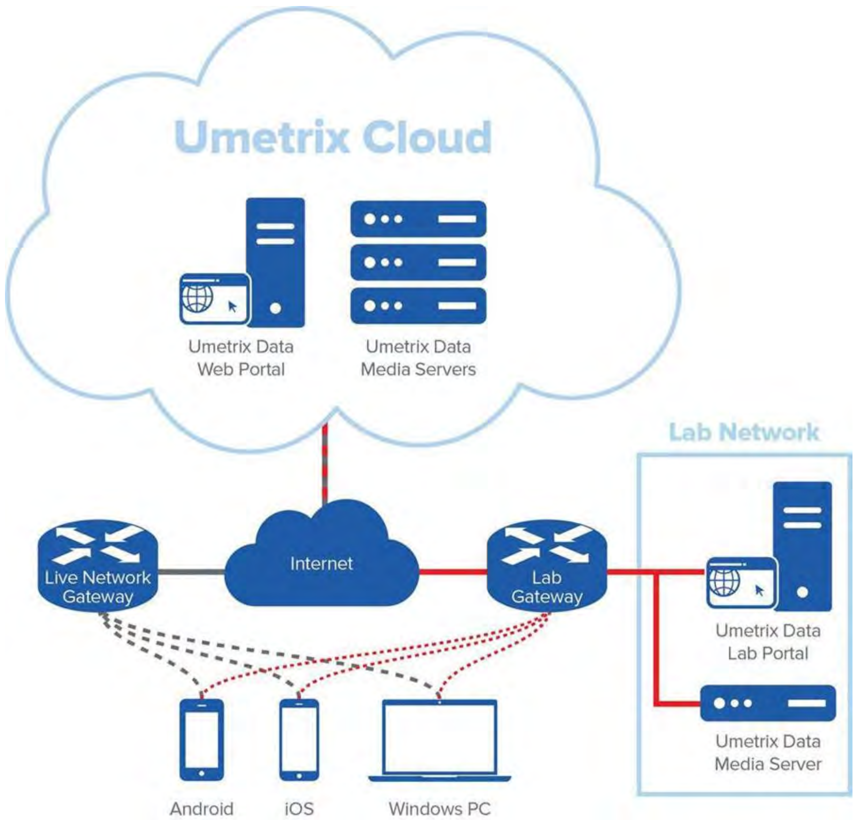
Source: Signals Research Group

Figure 15 shows a picture of the XCAL-Solo unit that we used during our walk tests. Figure 16 illustrates the Umetrix Data platform that we used to generate high bandwidth downlink data transfers to the two smartphones. A special shoutout and thanks to Accuver Americas and Spirent Communications for their continued support in our benchmark studies.

Figure 15. XCAL-Solo

Source: Accuver Americas

Figure 16. Umetrix Data Platform



Source: Spirent Communications

We'll be back sometime in October with our chipset/device benchmark study based on testing we are currently doing in the T-Mobile (Band n41) and Verizon (Band n77 and mmWave) networks. Until next time, be on the lookout for the next *Signals Ahead*....

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.

5G Standardization

- *5G from a 3GPP Perspective (ongoing series of reports – published quarterly or as warranted)*

Thematic Reports

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

Benchmark Studies

- *5G NR mmWave Fixed Wireless Access with IAB*
- *Over-the-Air 5G NR smartphone performance benchmark study (FR1)*
- *SRS versus codebook beamforming benchmark study*
- *Over-the-Air 5G NR smartphone performance benchmark study (FR2)*
- *Multi-operator benchmark study based on ETSI 103.559*
- *Mobile Edge Computing*
- *Open RAN network performance benchmark study 1 – RF performance*
- *Open RAN network performance benchmark study 2 – User Experience*
- *Open RAN network performance benchmark study 3 – Scheduling Efficiency*
- *FR1 + FR2 EN-DC network performance benchmark study*
- *MU-MIMO benchmark study (FR1)*
- *MU-MIMO benchmark study (FR2)*

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