GIGABIT LTE AND THE USER EXPERIENCE

QUANTIFYING THE BENEFITS OF A GIGABIT LTE (CAT 16) SMARTPHONE USING REAL-WORLD APPLICATIONS AND COMMERCIAL LTE NETWORKS

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Paper developed for Qualcomm

SRG conducted a third-party benchmark study that analyzed the incremental benefits of a Category 16 smartphone versus a Category 12 smartphone. For this study, we used popular user applications and accessed commercial LTE networks in the United States. We previously used many of the test locations and the overall methodology when conducting a similar study for our subscription-based *Signals Ahead* research product.

As the sole authors of this paper, we stand fully behind the opinions that we present in this paper. In addition to providing consulting services on wireless-related topics, including performance benchmark studies, Signals Research Group is the publisher of the *Signals Ahead* research newsletter (www.signalsresearch.com).

Executive Summary

KEY HIGHLIGHTS FROM THIS WHITEPAPER

A Category 16 (Cat 16) Gigabit LTE smartphone delivers a meaningfully better user experience while requiring substantially fewer network resources than a Cat 12 LTE smartphone.

User benefits include faster downloads (up to 40% faster), and a better video streaming experience with far fewer freezes and frame impairments (low triple digits on a percentage basis). Operator benefits include network efficiency gains of up to 75%, depending on network conditions.

The benefits occur with all data applications and with all network conditions, including in LTE networks that only support a single LTE radio channel.

With excellent radio conditions, the Cat 16 smartphone performance gains are due primarily to 4x4 MIMO, or the ability to receive up to four unique data streams. For comparison purposes, a Cat 12 smartphone only supports up to two unique data streams (2x2 MIMO).

With more challenging network conditions, the Cat 16 smartphone leverages its four receive antennas to improve the strength and quality of the received data transmissions, thereby allowing the network to transmit at a higher data rate than what it transmits to the Cat 12 smartphone, even if multiple data streams are not possible.

Results are based on testing video performance and various Google applications (Play, Drive, Music, and YouTube) with excellent and poor network conditions, as well as full buffer data transfers during lengthy drive tests to measure network efficiency gains over all network conditions. For completeness, we also include a comparison between Cat 16 Gigabit LTE and Wi-Fi, as well as highlight the benefits of LAA.

The performance benefits of a Cat 16 smartphone exist with all mobile data applications, all LTE networks, and with all possible radio conditions.

For this benchmark study, Signals Research Group (SRG) compared the performance of a Category 16 (Cat 16) Gigabit LTE smartphone and a Cat 12 smartphone, analyzing the results from both a user's and a mobile operator's perspective. To make the analysis more meaningful to a worldwide readership, we conducted the study using very common mobile data applications with the testing occurring in LTE-Advanced networks that didn't necessarily support Gigabit LTE speeds – in some tests, the network only supported a single 20 MHz LTE FDD radio channel. The upshot of this approach is we demonstrate the performance benefits of a Cat 16 smartphone transcend Gigabit LTE with the advantages applicable to all mobile data applications, to all LTE networks, and with all possible radio conditions.

For user applications, we included video streaming with low and modest bit rates, and popular Google applications, such as Google Play, Google Music, Google Drive, and YouTube. User experience testing occurred in areas of the network with excellent conditions (high signal strength and low interference) as well as areas in the network with poor conditions, defined by low signal strength and high interference. For completeness sake, we also included suburban and rural drive tests so that we could quantify typical performance across all possible network conditions.

We found a Cat 16 smartphone delivers a much better user experience while requiring fewer network resources than a Cat 12 smartphone, with all data applications and with all possible network conditions. With excellent radio conditions, the Cat 16 smartphone leveraged 4x4 MIMO to receive up to four unique data streams from the serving cell site. The Cat 12 smartphone was limited to only two unique data streams since it only supported 2x2 MIMO. With more challenging radio conditions, the Cat 16 smartphone took advantage of its four antenna receivers to increase the strength and quality of the data transmission, which allowed the serving cell site to send the data at a higher bit rate than what it could transmit to the Cat 12 smartphone.

The Cat 12 smartphone had nearly 130% more video frame impairments than the Cat 16 smartphone

The higher bit rate resulted in faster downloads of applications, music, and stored video files from Google Play, Google Drive, and/or Google Music. We observed the Cat 12 smartphone required at least 17% to nearly 40% more time to complete the same download. Additionally, the higher bit rate meant a better video streaming experience with fewer video freezes and frame impairments. We show the Cat 12 smartphone had nearly 70% more video freezes and nearly 130% more frame impairments compared with the Cat 16 smartphone while streaming the same video from a dedicated server.

A Cat 16 smartphone requires up to 75% fewer network resources than a Cat 12 smartphone to complete the downlink data transfer.

From a mobile operator's perspective, the Cat 16 smartphone's ability to use more unique data streams and/or receive higher bit rate transmissions results in the use of fewer network resources. We documented a range of 30% to 75% fewer network resources with the Cat 16 smartphone than with the Cat 12 smartphone, with the most gain achieved with the poorer network conditions where 4x4 MIMO isn't used. In other words, an operator doesn't need to deploy 4x4 MIMO functionality in its network infrastructure to benefit from Cat 16 functionality. By using fewer network resources, the Cat 16 smartphone frees up capacity that can be used by other users/smartphones in the network, regardless of their capabilities.

With LAA, the Cat 16 smartphone achieved more than twice the data rate of the Cat 12 smartphone, with up to 80% of the bandwidth delivered over unlicensed spectrum.

Although a Cat 16 smartphone isn't required to support LAA (License Assisted Access), the Cat 16 smartphone we used for this study had the capability, so we conducted a performance assessment of LAA, using a commercial LAA deployment. We found that in addition to achieving more than twice the downlink data speeds with LAA versus a Cat 12 smartphone using only licensed spectrum, LAA freed up capacity from the operator's licensed spectrum assets by delivering up to 80% of the bandwidth over the unlicensed spectrum. We also compared Gigabit LTE and public Wi-Fi, by testing in multiple coffee shops which had both LTE and Wi-Fi connectivity. Thanks to limited backhaul with public Wi-Fi, the user experience using Gigabit LTE was substantially better with downloads that were more than 10x faster over the LTE network. In our case, the mobile data consumption was also free, thanks to unlimited cellular data plans, which we had already exceeded by a factor of two before doing the Wi-Fi tests.

Eventually, operators will need to fully maximize their LTE networks, so the networks can provide a seamless user experience when initial 5G networks, with limited coverage, are deployed. This requirement means leveraging carrier aggregation to the greatest extent possible – be it two carriers (2CCA) or five carriers (5CCA) in the downlink and 2CCA in the uplink. Additionally, Gigabit LTE will mean deploying features which increase spectral efficiency, including 256-QAM, uplink 64-QAM, and 4x4 MIMO, potentially even massive MIMO.

Consumers and mobile operators can greatly benefit from the capabilities of a Cat 16 smartphone before the Gigabit LTE network upgrades have taken place.

In the interim, consumers and mobile operators can greatly benefit from the capabilities of a Cat 16 smartphone before the Gigabit LTE network upgrades have taken place. Consumers benefit from an improved user experience while mobile operators maximize their deployed network resources by leveraging the increased spectral efficiency offered by the Cat 16 smartphones. It goes without saying (but we'll say it anyway), that handset manufacturers can help differentiate their product portfolio by offering smartphones which consumers want and mobile operators demand.

Table of Contents

Index of Figures

A Bit of Background Information

While there is a lot of interest in 5G and the capabilities it will one day deliver, the reality is that LTE/LTE-Advanced will remain the "bread and butter" technology for years to come. Mobile operators are just starting to deploy some of the more advanced features, which have already been standardized, while other new features are still making their way through the standardization process or the vendor product roadmaps.

Gigabit LTE bundles a number of compelling LTE-Advanced features into a single moniker, and while the term may sound futuristic, the reality is that it is here today. It will also play a critical role with the introduction of 5G since there needs to be a secondary network that is capable of delivering a seamless user experience where 5G network coverage does not exist.

The Cat 16 smartphone used a Qualcomm Snapdragon 835 mobile platform with an integrated X16 LTE modem.

To quantify the performance benefits of Gigabit LTE, we benchmarked a Cat 16 and a Cat 12 smartphone by conducting a host of tests in parallel on the two smartphones while measuring performance characteristics that matter to consumers and to mobile operators. Both smartphones used the Qualcomm Snapdragon 835 mobile platform with an integrated X16 LTE modem, but only one smartphone supported Cat 16 features. The second smartphone was limited to Cat 12 capabilities. The Cat 16 smartphone also supported LAA, although this feature isn't a requirement for a Cat 16 device. By definition, a Cat 16 smartphone supports a maximum data speed of nearly 1,000 Mbps (1 Gbps), while a Cat 12 smartphone is limited to "only" 600 Mbps.

From a technical perspective, the higher data rates offered by the Cat 16 smartphone are achieved with 4x4 MIMO. With 4x4 MIMO, the serving cell site transmits up to four unique data streams to the mobile device, essentially quadrupling the theoretical maximum data rate versus a single data stream. All other LTE device categories, including Cat 12 devices, are limited to no more than two unique data streams, or 2x2 MIMO. The 3GPP standards body included 4x4 MIMO in the initial LTE specifications, but it wasn't until recently that mobile operators became interested in the feature and the vendor community incorporated it into their product roadmaps. By default, while most LTE smartphones only support two receive antennas, the Cat 16 smartphone supports four receive antennas, which are necessary to support 4x4 MIMO. The two additional antennas increase the signal strength and signal quality of the LTE transmissions from the serving cell site, thus allowing the network to send more data bits with the same amount of radio network resources.

The Physical Resource Block (PRB) is the fundamental unit which helps defines used/available capacity in an LTE network.

The Physical Resource Block (PRB) is the fundamental unit which helps define used/available capacity in an LTE network. All things being equal, the more PRBs the network allocates to a mobile device, the higher its data rate. Unfortunately, the number of PRBs is finite – the exact number is determined by the LTE channel bandwidth. This limitation means that as more smartphones attach to the LTE network, the number of PRBs allocated to each smartphone decreases. This phenomenon helps explain why LTE networks perform much better in the middle of the night than during the evening rush hour.

4x4 MIMO and 256-QAM can increase a smartphone's data rate without needing additional PRBs.

The beauty of features, like 4x4 MIMO and 256-QAM, is that these features can increase a smartphone's data rate without needing additional PRBs. Conversely, these features also mean the same data rate can be achieved with fewer PRBs. For example, switching from 2x2 MIMO and two data streams (MIMO Rank = 2) to 4x4 MIMO and four data streams (MIMO Rank = 4) can double the data rate without using more PRBs. Similarly, if a Cat 16 uses 4 receive antennas to improve the signal quality, the network can send the data faster, even with only one or two data streams. If the LTE network can get the smartphones off the network sooner by transferring data faster, then the network can allocate its resources (PRBs) to other mobile devices in the network, thereby improving their data speeds and benefiting other users in the network, regardless of the device category.

For this study, we conducted the tests in multiple locations and repeated them several times at each location. The results we include in this paper represent typical results that we obtained from a much larger set of test results. We also include results from lengthy drive tests to help quantify the benefits of a Cat 16 smartphone over a wide range of radio conditions.

We'd like to thank Accuver Americas, Spirent Communications, and WirelessMETRIX for the use of their test solutions to conduct this study.

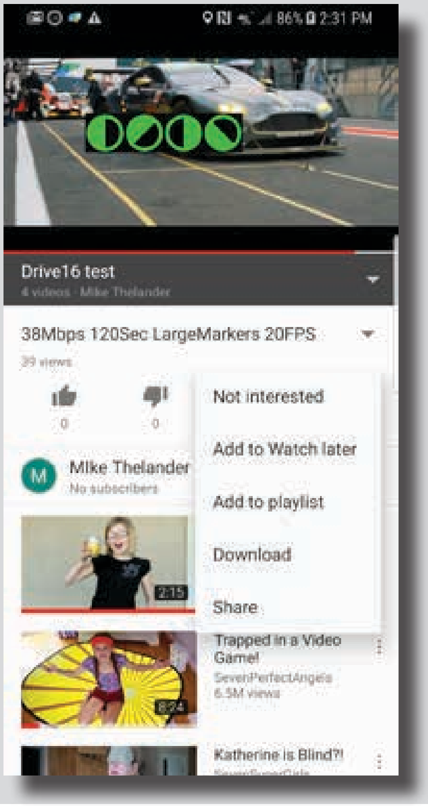
Finally, we'd like to thank Accuver Americas for the use of its XCAL-Solo drive test solution and XCAP post-processing software. We used this suite of drive test tools to conduct most of the studies provided in this paper. For the video testing, we used Chromatic from Spirent Communications and Link Master Logging/Link Master Analysis (LML/LMA) from WirelessMETRIX to quantify the video playback characteristics and the impact on the LTE network from streaming the videos. We explain these solutions and our overall test methodology in a dedicated section within this paper.

A Cat 16 Gigabit LTE Smartphone and Video Streaming

Video streaming is the most popular data application, accounting for an estimated 63% of all global mobile data traffic in 2016.[1] Further, YouTube, which is one of the most popular video portals, has at least 50% of its views occurring from a mobile device.[2] We used a combination of YouTube and a dedicated video server to conduct our video tests, comparing the relative benefits of a Cat 16 and a Cat 12 smartphone.

To summarize, the results from these tests show that in all cases the Cat 16 smartphone consumed less network bandwidth while viewing the videos. Since YouTube is a very efficient application that uses memory caching and relatively low bit rate encoding, we didn't observe differences in the video viewing experience for the tests we conducted. However, with a higher bit rate 15 Mbps video, which is about half the bit rate of a 4K video, we documented meaningful performance differences with far more frequent video freezes and frame impairments with the Cat 12 smartphone.

Figure 1. YouTube Video



Source: Smartphone Screen Shot

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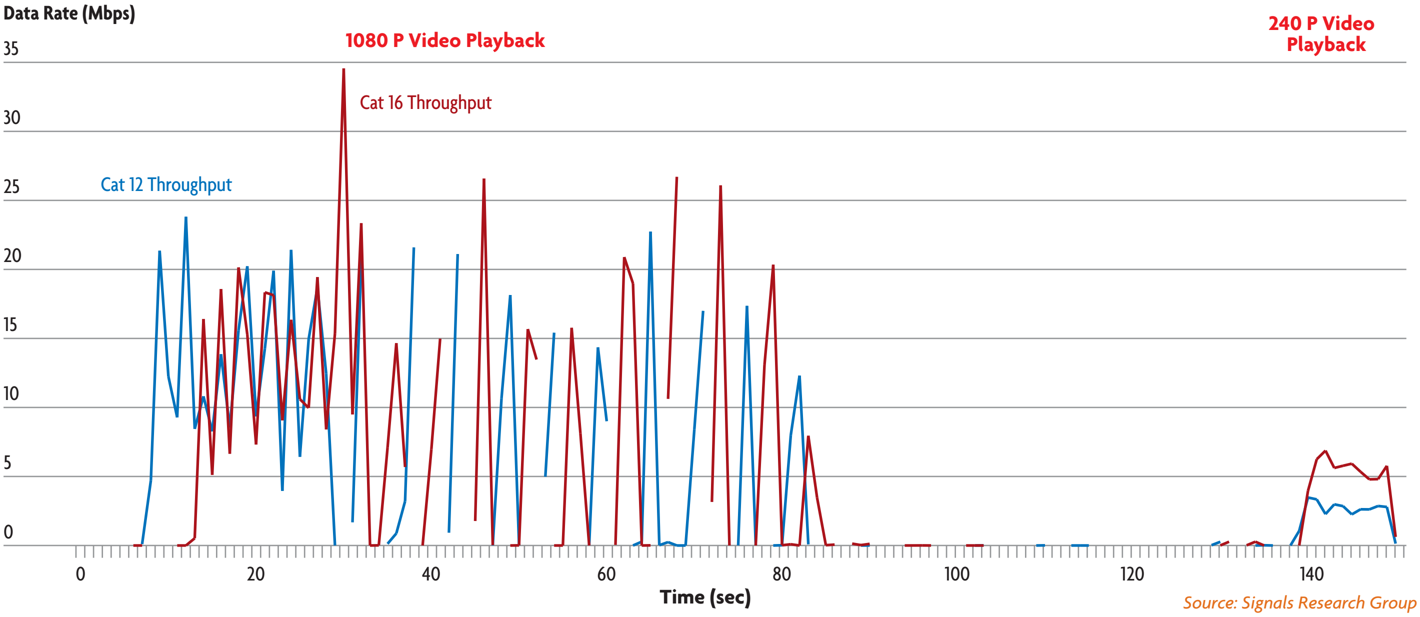
[1] Cisco VNI, 2017

[2] Tubular Insights (www.tubularinsights.com), 2014

We conducted a YouTube video test with poor network conditions, meaning low signal strength and relatively poor signal quality.[3] For our YouTube tests we used a high-resolution video, originally encoded with a bit rate of nearly 38 Mbps. However, since YouTube applies its own encoding algorithms, when playing the video, the bit rate was substantially lower. After clearing the memory buffer on the two smartphones, we streamed the video concurrently on both smartphones, using a 1080p format. The 3-minute video completely downloaded within the first 80 seconds of the playback with the remainder of video playback occurring from the phones' memory. For these reasons, we didn't identify performance differences in the video playback. Figure 2 shows the physical layer data speeds for the two smartphones during the test. The figure shows the videos completely downloaded by the 90 second mark, or about 80 seconds after hitting the play button. Although it isn't evident in the figure, the videos continued to play until about the 130 second mark, at which point the next video in the queue automatically started to play, albeit with a lower resolution.

Figure 2. Real Time Throughput Analysis of YouTube Video Streaming with Poor Network Conditions



Source: Signals Research Group

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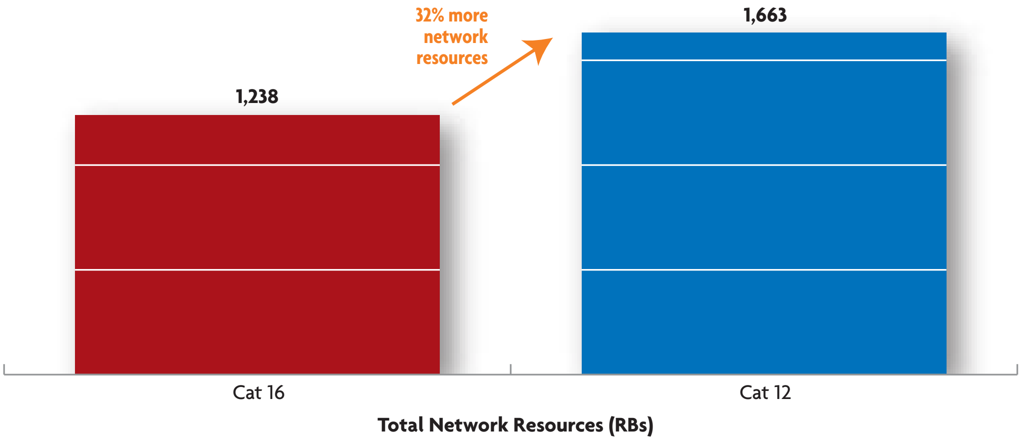
[3] RSRP = -111 dBm; SINR = 12.2 dB

Despite the modest network requirements, we still documented a meaningful difference in performance with the Cat 12 smartphone requiring 32% more network resources (Physical Resource Blocks) to stream the videos. In this case, the Cat 16 smartphone leveraged its four receive antennas to boost the signal quality and strength, thus allowing the network to transmit the video more efficiently than it could to the Cat 12 smartphone.

Figure 3. Total Network Resource Requirements with Poor Network Conditions



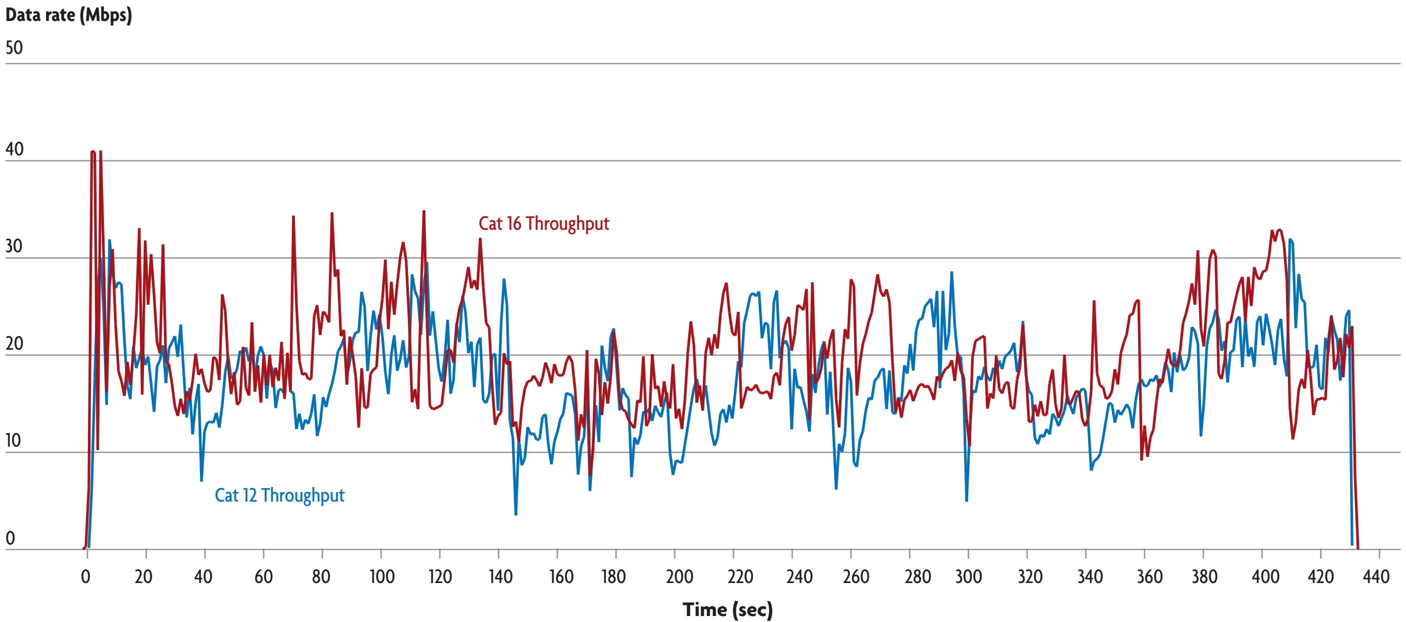
Source: Signals Research Group

We also streamed a video which was encoded with a bit rate of 15 Mbps and streamed from a dedicated server. To put things in perspective, a 4K video requires 20 to 30 Mbps, depending on the compression algorithm. This video (Figure 4) also included special visual and audio markers, which allowed the Chromatic video test platform to identify and quantify deficiencies in the video viewing experience. These deficiencies include video freezes and impaired frames, as well as synchronization problems between the audio and video markers.

Figure 4. Chromatic Video with Special Visual and Audio Markers

Source:: Spirent and SRG

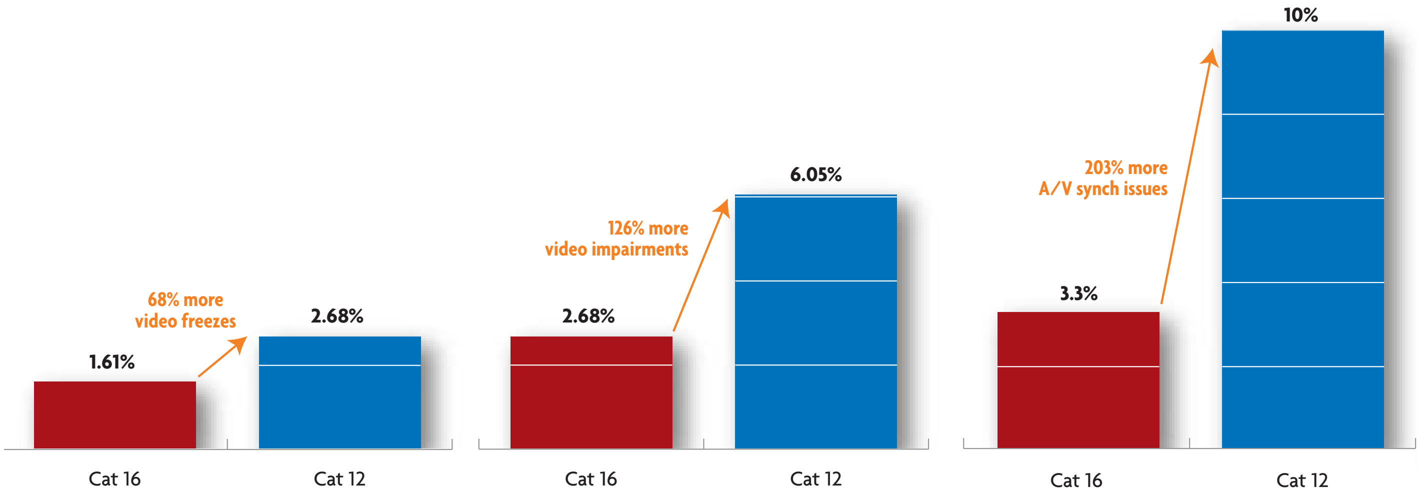
Figure 5. Real Time Throughput Analysis of Video Streaming with Poor Radio Conditions



Source: Signals Research Group

For this test, we observed 68% more video freezes with the Cat 12 smartphone, 126% more frame impairments, and 203% more A/V synchronization problems, as shown in Figure 6.

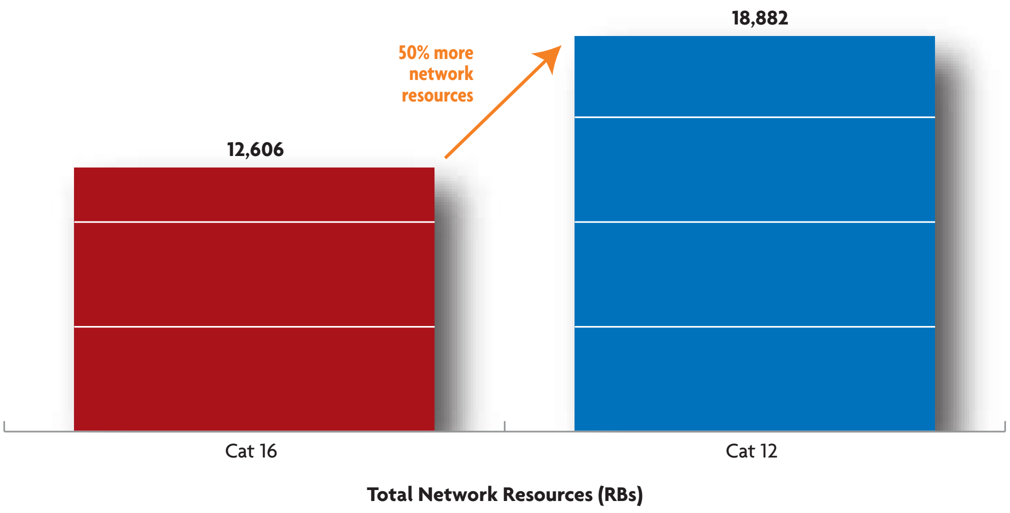
Figure 6. Video Performance Analysis with Poor Radio Conditions



Source: Signals Research Group

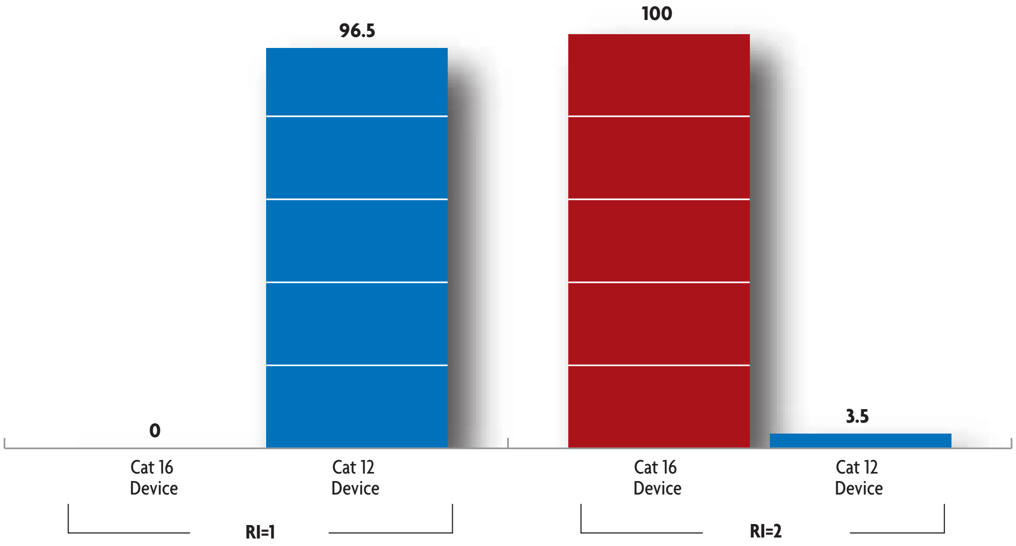
Clearly, the consumer benefits with the obvious differences in the video viewing experience – we played a portion of the poor performing video when we presented at Qualcomm's 4G/5G Summit in October. However, the benefits also extended to the mobile operator since the Cat 16 smartphone also required fewer network resources to stream the video. Specifically, the Cat 12 smartphone required 50% more network resources to stream the video (Figure 7). The reduced impact on network resources was due entirely to the Cat 16 smartphone using two data streams (MIMO Rank 2) for the entire test while the Cat 12 smartphone only used a single data stream (MIMO Rank 1) for almost the entire video, as shown in Figure 8.

Figure 7. Total Network Resources with Poor Radio Conditions



Source: Signals Research Group

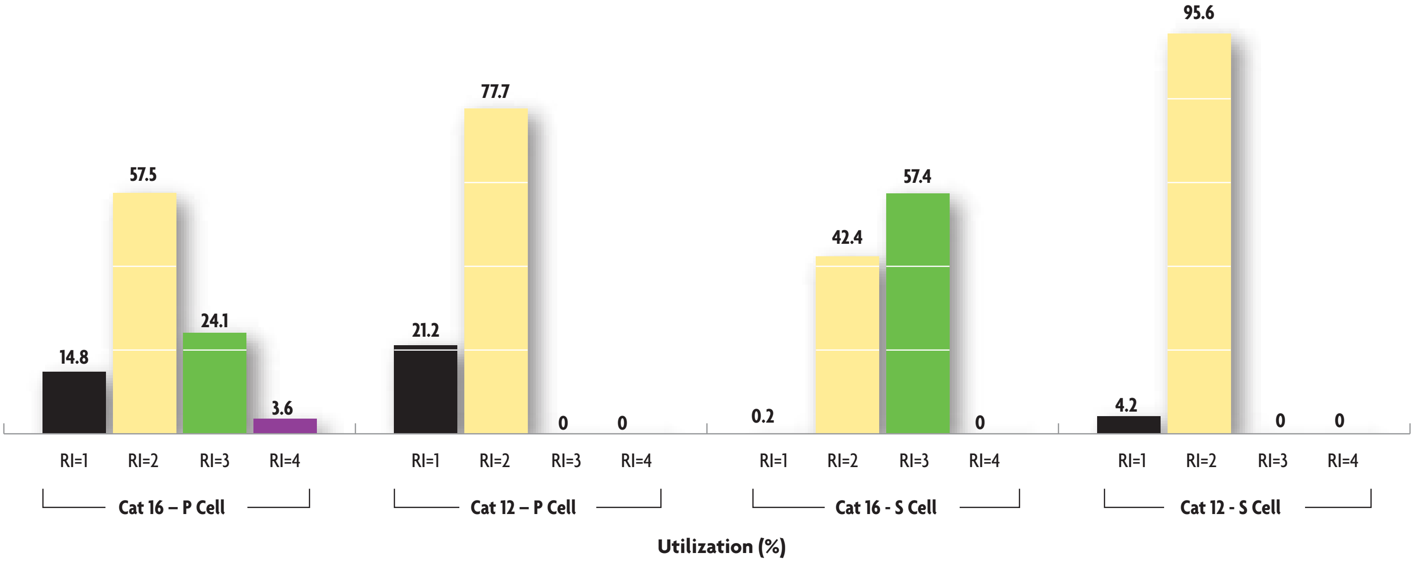
Figure 8. MIMO Utilization Rates with Poor Radio Conditions



Source: Signals Research Group

We repeated the same test in an area that supported carrier aggregation (2CCA) with excellent radio conditions. In this test, the video performance metrics were comparable since the LTE network was capable of streaming the two videos without interruption. We suspect, however, that with increased network loading, we would have observed performance differences, which would have favored the Cat 16 smartphone. Nonetheless, we still documented material differences in how the two video streaming sessions impacted the network. In this case, the Cat 16 smartphone benefited from a mix of three and four data streams while the Cat 12 smartphone could only use up to two data streams. Figure 9 shows the mix of MIMO rank for both smartphones. Since both smartphones used carrier aggregation, we include the MIMO Rank utilization rates for both the primary (P) and the secondary (S) carriers.

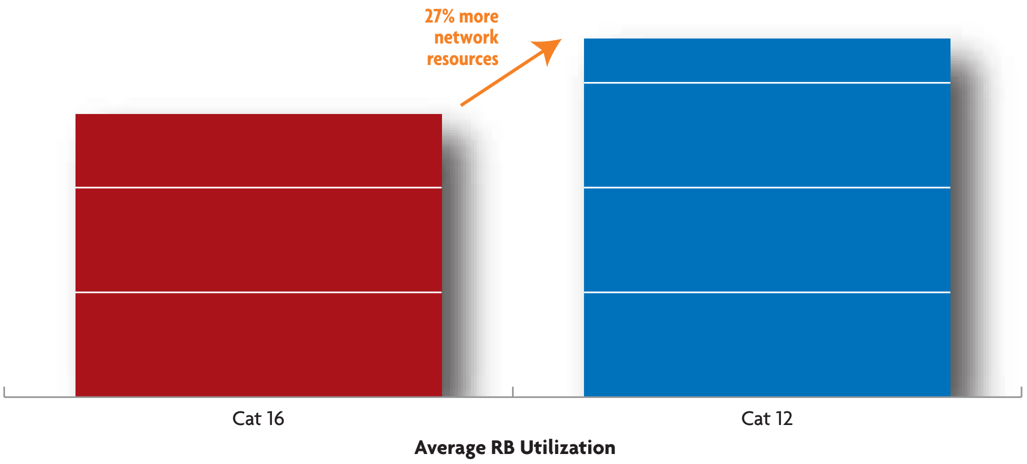
Figure 9. MIMO Utilization Rates with Excellent Radio Conditions – primary and secondary carriers



Source: Signals Research Group

Figure 10 shows the total network resource requirements for the two smartphones. The values reflect the summation of both radio channels. As indicated in the figure, the Cat 12 smartphone required 27% more network resources to stream the same video.

Figure 10. Total Network Resource Requirements with Excellent Radio Conditions

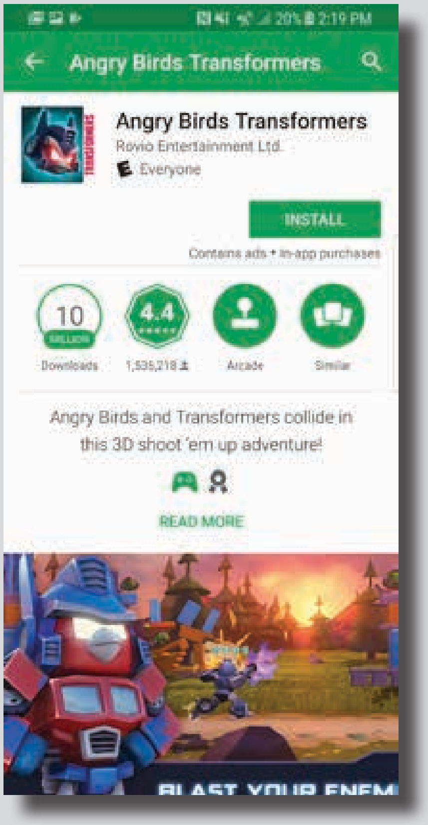


Source: Signals Research Group

A Cat 16 Gigabit LTE Smartphone and Google Play

According to Wikipedia, there were over 82 billion applications downloaded from Google Play through 2016, up from "only" 50 billion downloads in July 2013. The size of an application can range from a few MBs to nearly 4 GB, and while we don't know the average application size, it is fair to say the application size is increasing. For purposes of this study, we selected "Angry Birds Transformers," a 348 MB game that has been downloaded more than 10 million times since it was first introduced.

Figure 11. Angry Birds Transformers

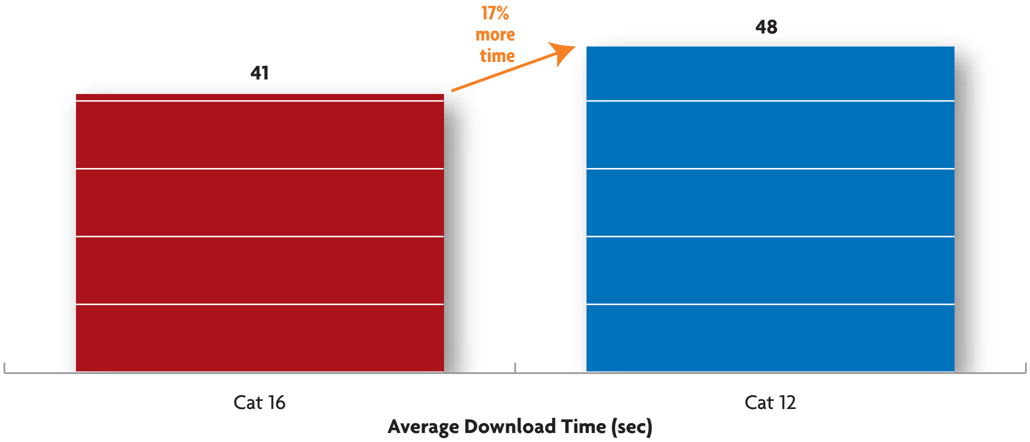


Angry Birds and Transformers collide in this 3D shoot 'em up adventure!

Source: Smartphone Screen Shot

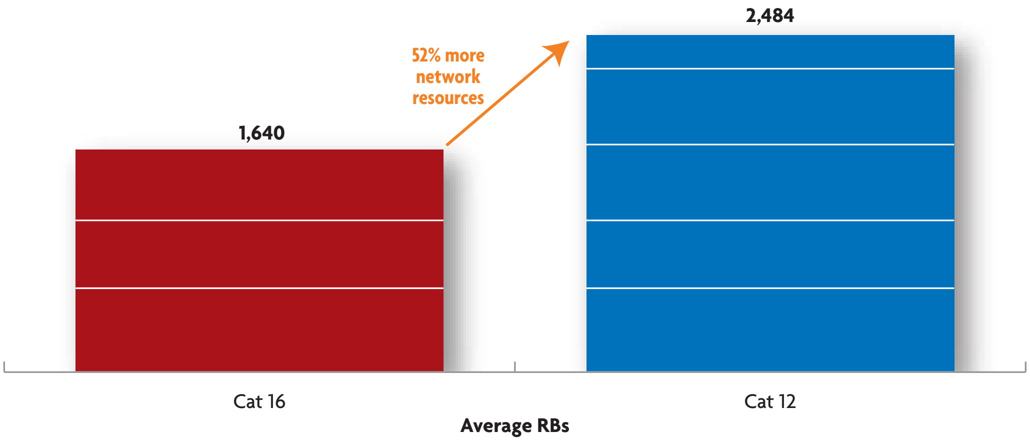
For our tests, we downloaded the application concurrently on both smartphones, repeating the download three times for each test to achieve a more statistically meaningful result. We did the tests with excellent conditions – strong signal strength and high signal quality – as well as with poor conditions – weak signal strength and poor signal quality.[4] With both extreme network conditions, we found the Cat 16 smartphone delivered a meaningful benefit to the user experience while requiring fewer network resources, thereby benefiting the mobile operator as well as other users in the network. As shown in Figure 12, it took 17% more time on average to download the application with the Cat 12 smartphone than with the Cat 16 smartphone. Equally important, downloading the application with the Cat 16 smartphone required fewer network resources than the Cat 12 smartphone – the latter required an average of 52% more network resources (Resource Blocks) to download the same application.

Figure 12. Average Angry Birds Download Time with Excellent Radio Conditions



Source: Signals Research Group

Figure 13. Average Network Resource Requirements with Excellent Radio Conditions



Source: Signals Research Group

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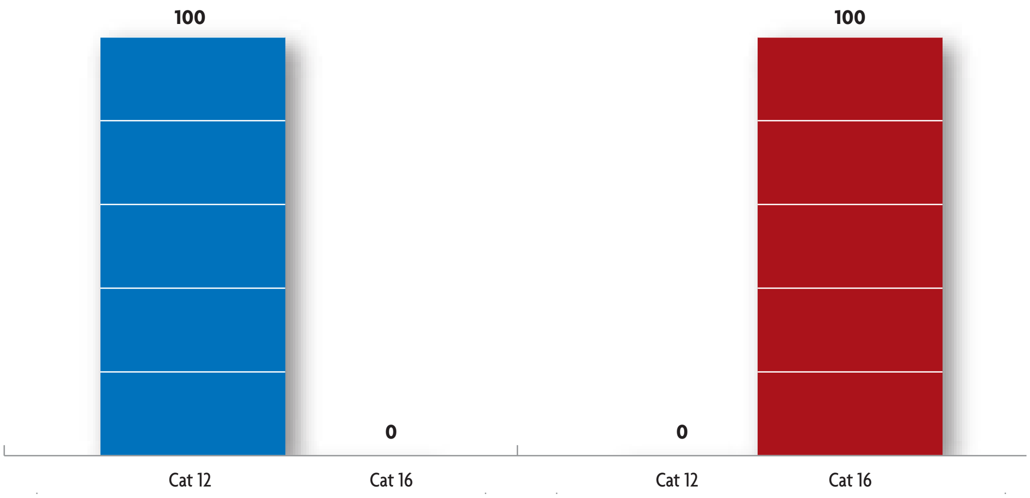
[4] Excellent conditions were RSRP = -75 dBm and SINR = 24 dB; Poor conditions were RSRP = -111 dBm and SINR = 12.2 dB.

The Cat 12 smartphone only supports 2x2 MIMO (Rank 2), meaning a maximum of two data streams while the Cat 16 smartphone supports up to 4x4 MIMO (Rank Indicator 4). For these downloads, the Cat 16 smartphone leveraged MIMO Rank 3 for almost the entire download (Figure 14), meaning 3 unique data streams between the serving cell site and the smartphone. Increasing the number of data streams is almost like getting a free lunch that no one has to pay. The extra data stream increases the downlink data rate and since it doesn't require additional network resources, the unused bandwidth is available for other mobile devices, thereby improving the user experience for a wider set of consumers, including those consumers that don't have a Cat 16 smartphone.

A Cat 16 smartphone can benefit consumers and operators, even with LTE networks that don't support carrier aggregation.

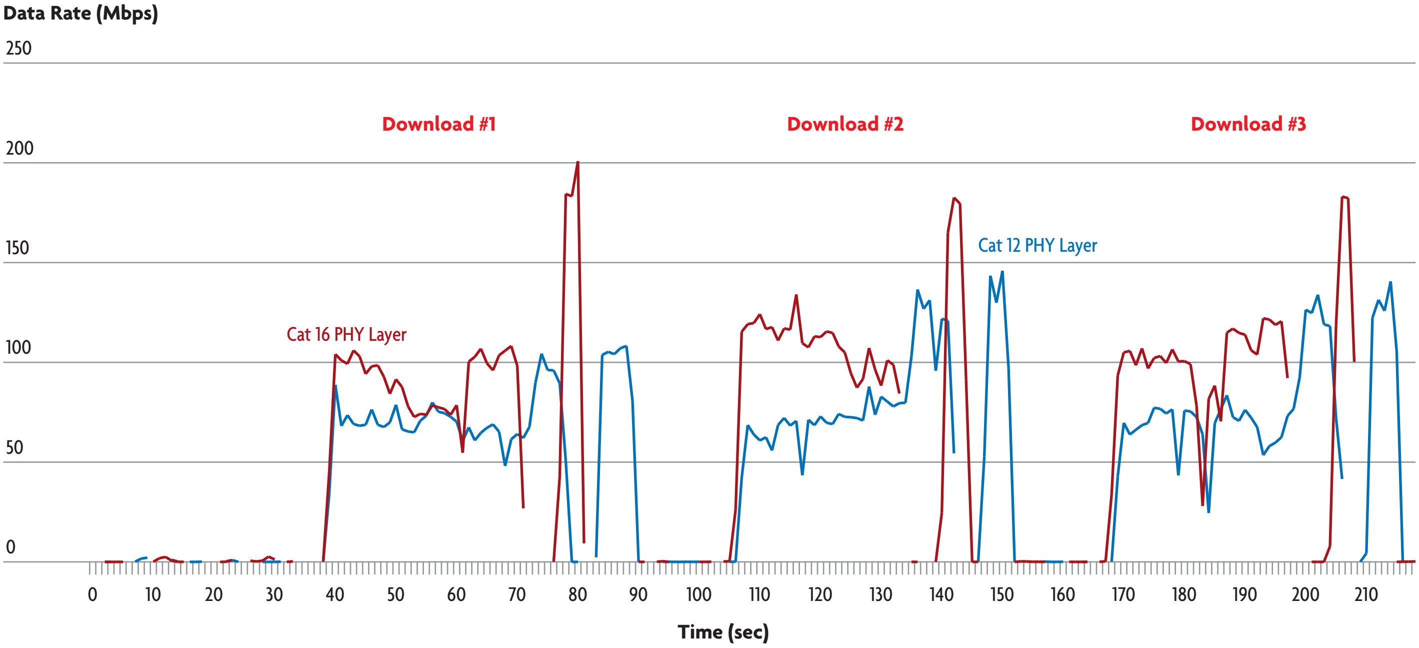
Figure 15 provides some additional clarity into the test. The figure provides a real-time plot of the data speeds for the two smartphones during the downloads. Readers should observe the Cat 16 data rates were higher and the downloads didn't take as long for each of the three tests. It is also important to note these tests occurred at a location where the LTE network only supported a single radio channel, in other words carrier aggregation wasn't available. This important observation helps prove that a Cat 16 smartphone can benefit consumers and operators, even with LTE networks that don't support carrier aggregation.

Figure 14. MIMO Utilization Rates with Excellent Radio Conditions



Source: Signals Research Group

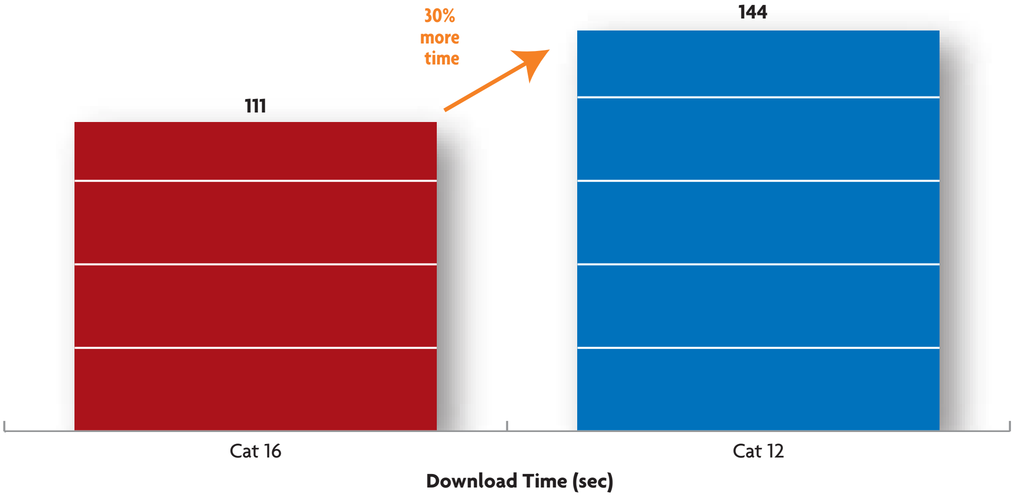
Figure 15. Real Time Throughput Analysis of Angry Bird Downloads with Excellent Radio Conditions



Source: Signals Research Group

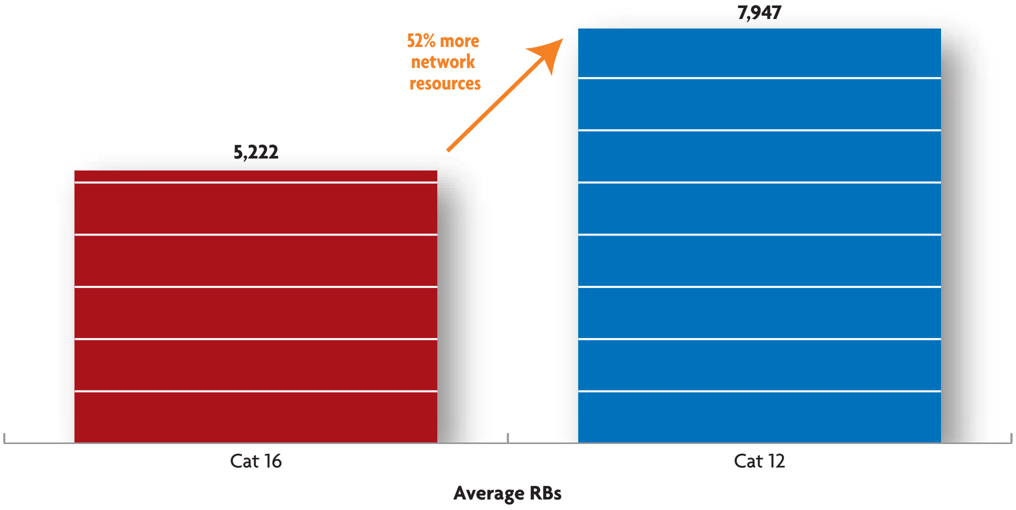
We repeated the Google Play download tests in an area with relatively poor conditions. The results were directionally consistent with the earlier tests done in excellent conditions, although the underlying explanation for the stronger Cat 16 smartphone is slightly different. With poor conditions, the Angry Birds download took 30% more time with the Cat 12 smartphone (Figure 16). Further, the Cat 12 smartphone also required 52% more network resources to complete the downloads (Figure 17).

Figure 16. Total Angry Birds Download Time with Poor Radio Conditions



Source: Signals Research Group

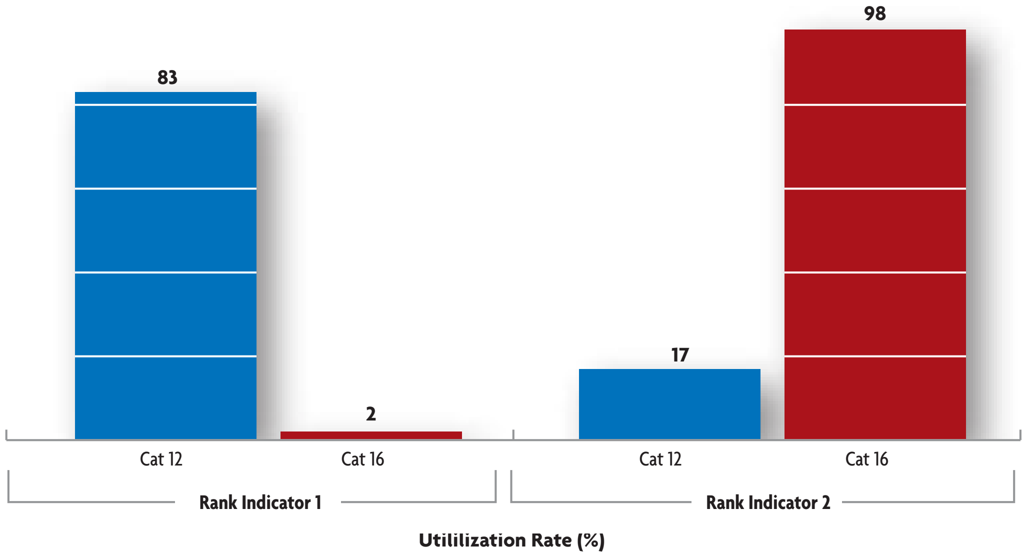
Figure 17. Average Network Resource Requirements with Poor Radio Conditions



Source: Signals Research Group

With poor network conditions, the Cat 16 smartphone couldn't use the higher MIMO rank, although the serving cell site did support 4x4 MIMO. Instead, the Cat 16 smartphone leveraged its four receive antennas to improve the quality of the signal. By using 4-way receive diversity, the Cat 16 smartphone could use two data streams (MIMO Rank = 2) while the Cat 12 smartphone only used a single data stream (MIMO Rank = 1) for most of the test, as shown in Figure 18.

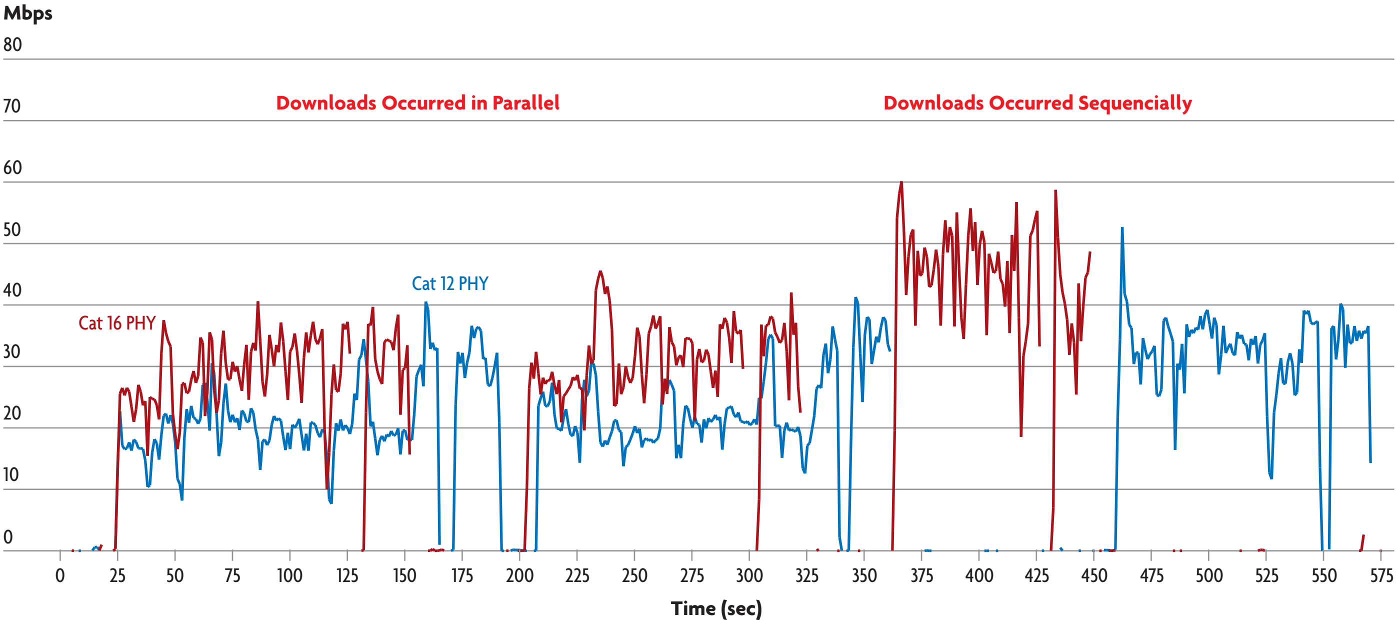
Figure 18. MIMO Utilization Rates with Poor Radio Conditions



Source: Signals Research Group

For these tests, we downloaded the Angry Birds application concurrently with both smartphones for the first two downloads. For the final download, we first downloaded the application with the Cat 16 smartphone. Once finished, we downloaded the application with the Cat 12 smartphone. Figure 19 shows the observed data speeds during these tests. Both smartphones exhibited higher data speeds for the final download since the other smartphone wasn't downloading the application, however, for both concurrent downloads and serial downloads, the Cat 16 data speeds were higher, and the download times were shorter. We elected to use serial downloads for the final download to capture the performance of each smartphone by itself. For this reason, we are showing the total download time in Figure 16 versus the average download time.

Figure 19. Real Time Throughput Analysis of Angry Bird Downloads with Poor Radio Conditions

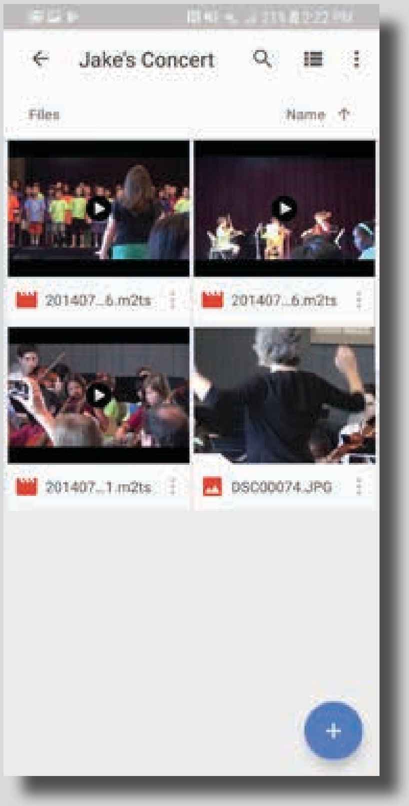


Source: Signals Research Group

A Cat 16 Gigabit LTE Smartphone and Google Drive

We use Google Drive to back up our work files and we use it to offload pictures and videos from our smartphones so that we can make room for even more pictures and videos. Proud parents frequently take 2 to 3-minute videos of their children or grandchildren, offload them to the cloud, and then download and view them at a later date. This test scenario replicates this behavior, using video clips that we took a few years ago. Each of the 3 video clips that we used for this test were just under 200 MB in size. To make things interesting, we also included a 2 GB log file from a drive test that we conducted in Telstra's Gigabit LTE network – we're serious when we write that we back up all our work in the cloud.

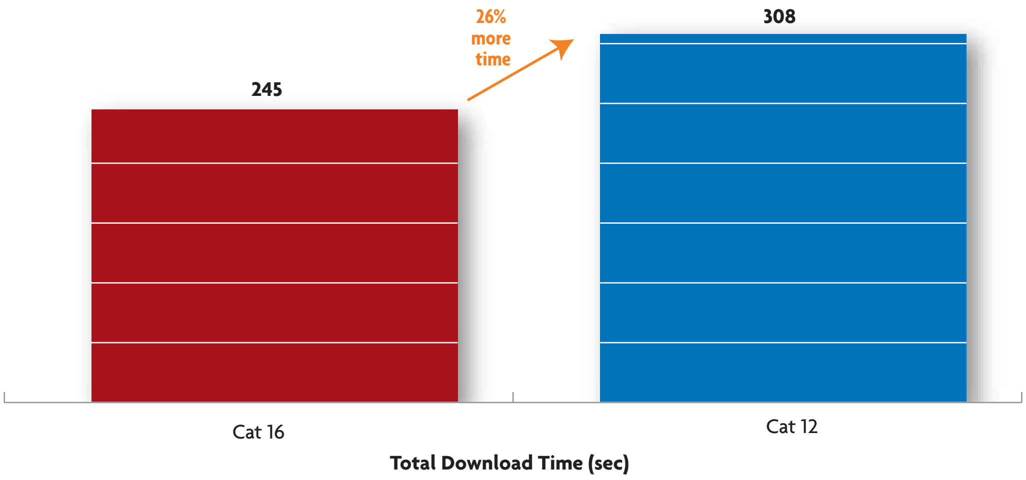
Figure 20. Google Drive Files



Source: Smartphone Screen Shot

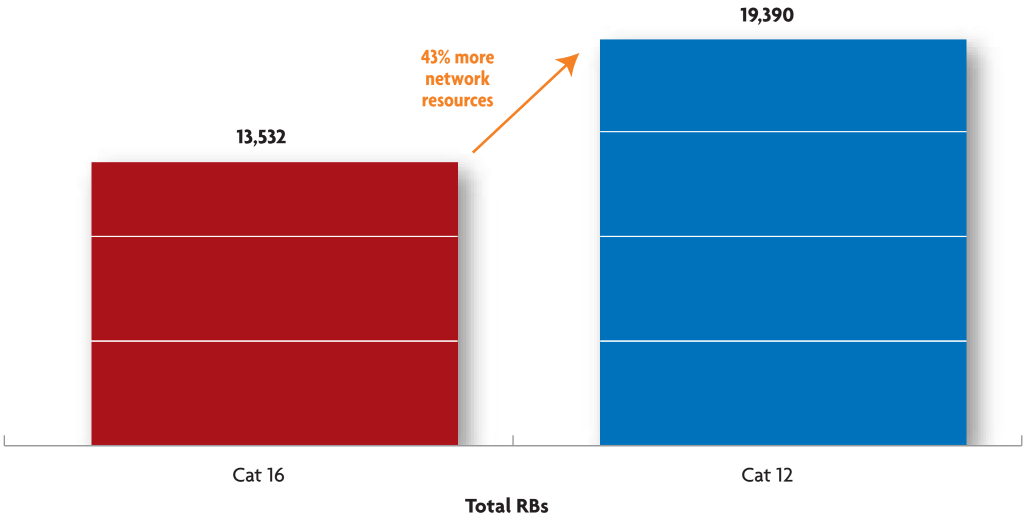
We used the same test locations that we used for the Google Play tests. The results with a different Google application are very similar to the results we presented in the previous section. With excellent radio conditions, the Cat 12 smartphone required took 26% more time to download the three videos and the log file (Figure 21). Additionally, the Cat 12 smartphone required 43% more network resources to download the same files (Figure 22). The ability of the Cat 16 smartphone to leverage MIMO Rank 3 or MIMO Rank 4 explains the faster download times and the reduced impact on the network. In this test, the Cat 16 smartphone used at least three data streams for all downloads, while the Cat 12 smartphone resorted to only two data streams for virtually the entire data transfer, as shown in Figure 23.

Figure 21. Total Google Drive Download Times with Excellent Radio Conditions



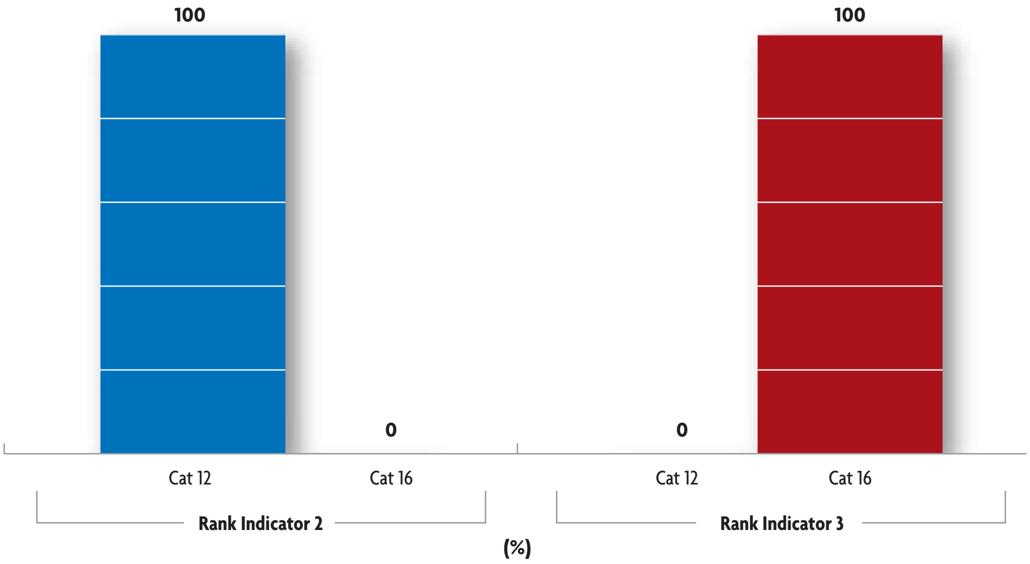
Source: Signals Research Group

Figure 22. Total Network Resource Requirements with Excellent Radio Conditions



Source: Signals Research Group

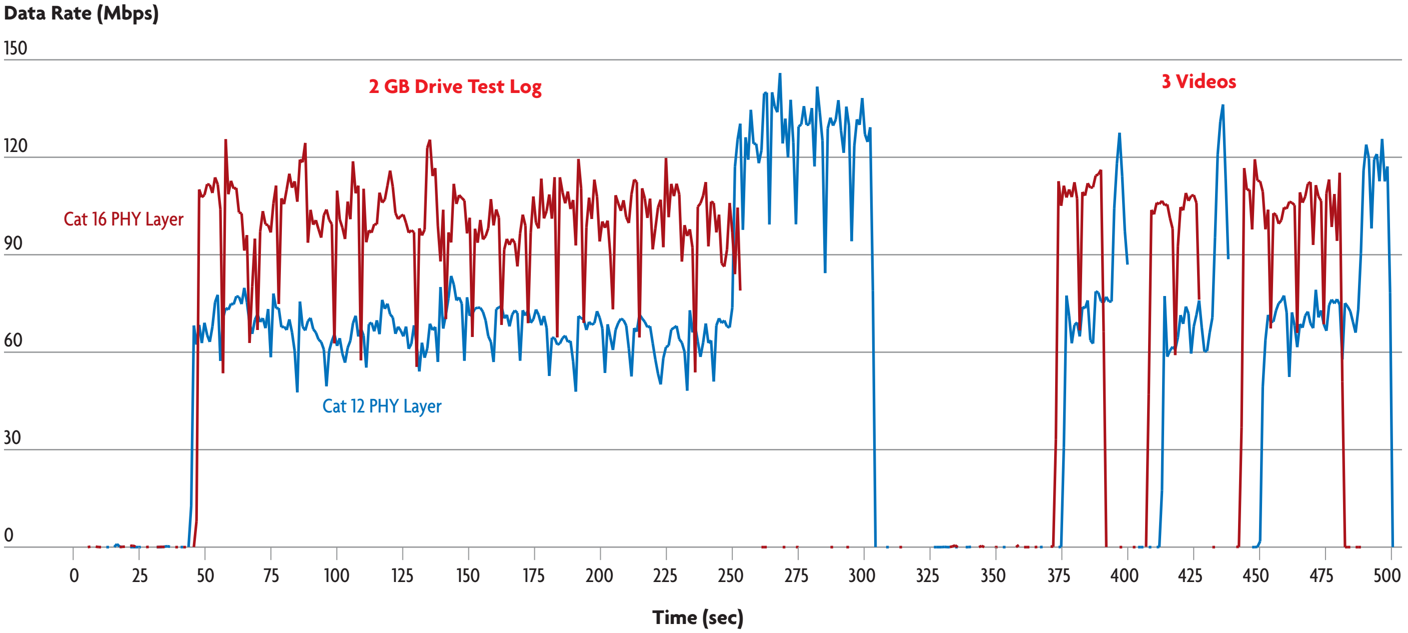
Figure 23. MIMO Utilization Rates with Excellent Radio Conditions



Source: Signals Research Group

Figure 24 shows the actual data rates as a function of time for both devices while downloading the 2 GB log file and the three videos. The Cat 16 smartphone achieves higher data speeds than the Cat 12 smartphone, so it finishes the downloads first. Once the Cat 16 smartphone completes a download, additional network resources are available to the Cat 12 smartphone, hence its data rate increases for the remainder of the download.

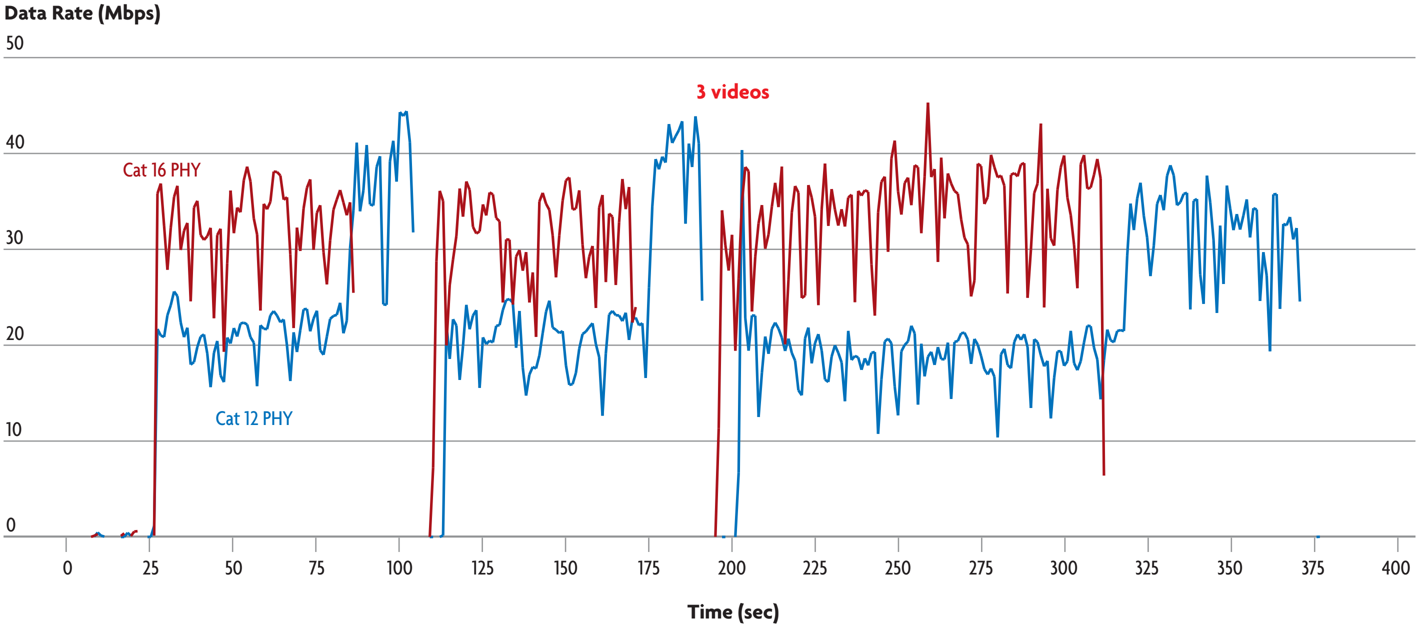
Figure 24. Real Time Throughput Analysis with Excellent Radio Conditions



Source: Signals Research Group

With poor radio conditions, the results are directionally similar with the Cat 16 smartphone downloading the files faster, while requiring fewer network resources. For this test, we only downloaded the three videos, as implied in Figure 25.

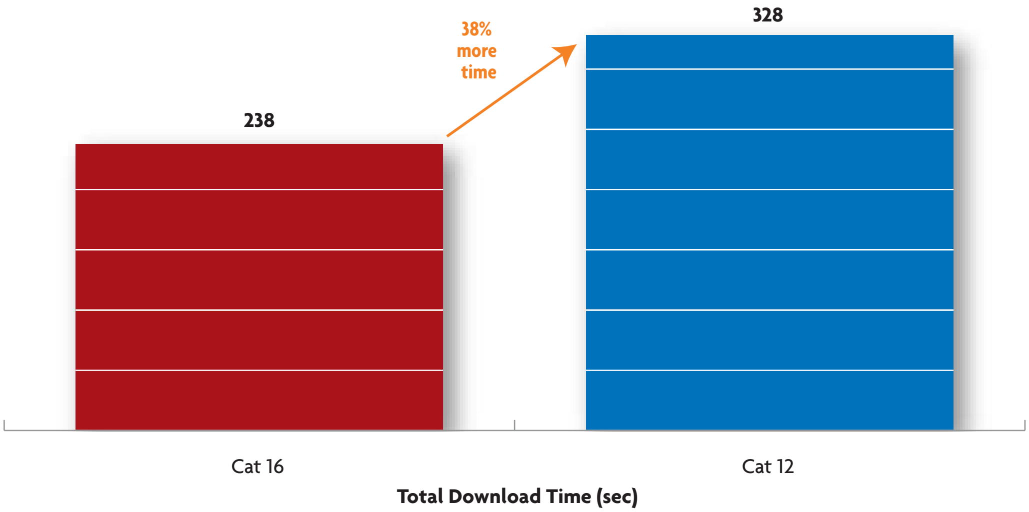
Figure 25. Real Time Throughput Analysis with Poor Radio Conditions



Source: Signals Research Group

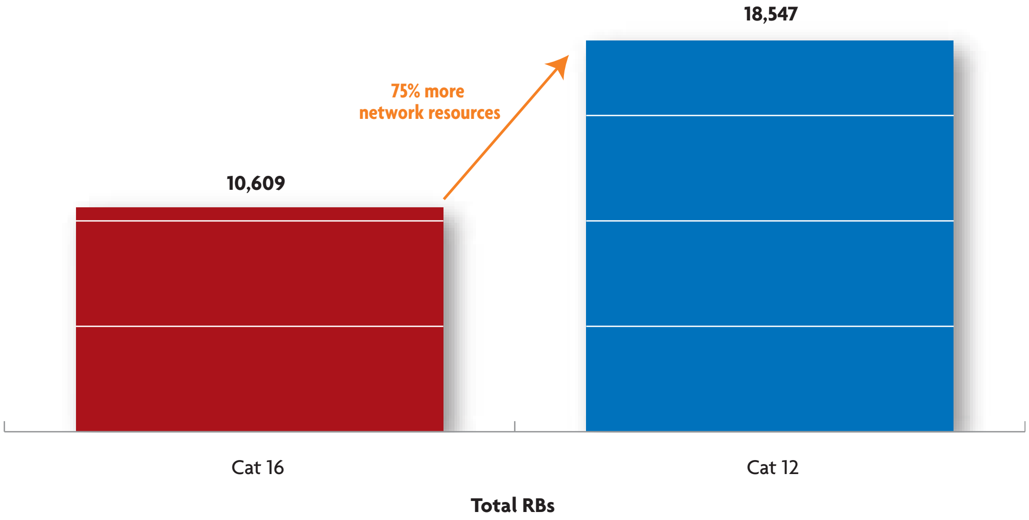
With more challenging conditions, the Cat 12 smartphone required 38% more time to download the three videos (Figure 26) while consuming 75% more network resources (Figure 27). The lower MIMO rank, as shown in primarily explains the increase in network resources (Figure 28).

Figure 26. Total Download Time with Poor Radio Conditions



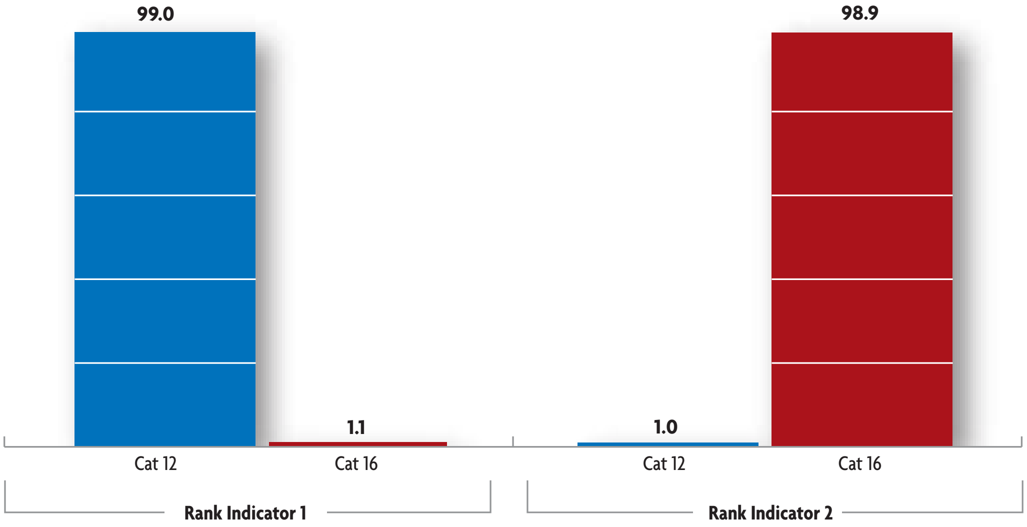
Source: Signals Research Group

Figure 27. Total Network Resource Requirements with Poor Radio Conditions



Source: Signals Research Group

Figure 28. MIMO Utilization with Poor Radio Conditions



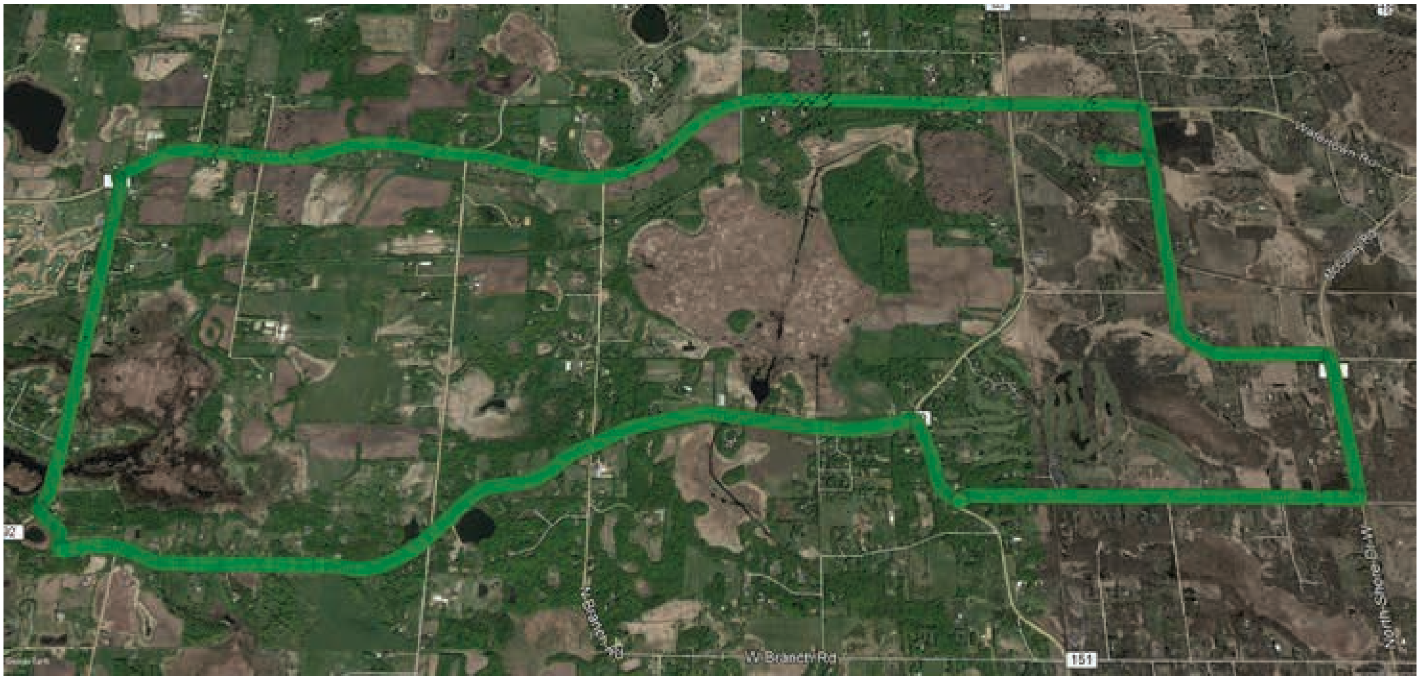
Source: Signals Research Group

Cat 16 Performance Across all Network Conditions

Until now, the results in this paper have focused on excellent and poor conditions. While these results cover the full range of radio conditions, it is useful to get an overall perspective. The best way to accomplish this task is a drive test. For this study, we selected two different locations – a suburban location close to the local international airport and a rural drive route about 20 miles west of downtown Minneapolis.

We repeated the rural drive route (Figure 29) twice while using a dedicated UDP server to sustain high bit rate transfers for extended periods of time. During the analysis phase, we filtered out all data points when the two smartphones were not connected to the same cell site. In addition to calculating the median data rates observed by the two smartphones, we also calculated the RB-normalized data rates. An RB-normalized data rate is the calculated data rate the smartphone would have likely achieved if the network allocated it all network resources (RBs). For example, if a smartphone achieved 25 Mbps with 50 RBs out of a possible 100 RBs, then its RB-normalized data rate would be 50 Mbps. In essence, the RB-normalized data rate provides insight into the implied spectral efficiency for a particular smartphone by compensating the observed data rates for network loading.

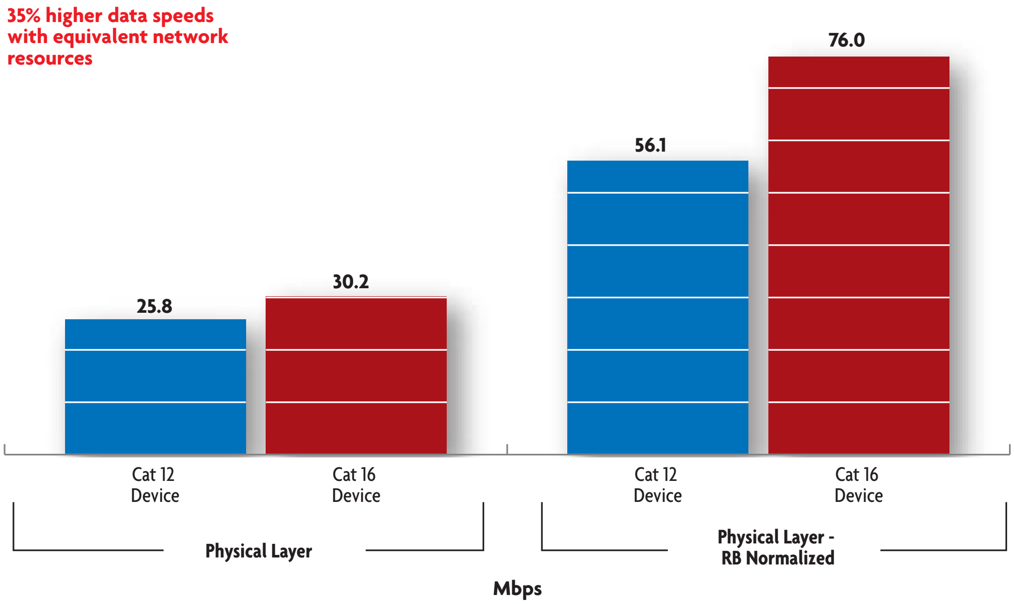
Figure 29. Rural Drive Route



Source: Signals Research Group

Figure 30 shows the Cat 16 smartphone achieved a higher median data rate than the Cat 12 smartphone (30.2 Mbps versus 25.8 Mbps). Once we normalize these values for the number of resource blocks required to achieve these speeds, we find the Cat 16 smartphone could have achieved 76 Mbps with all 100 RBs while the Cat 12 smartphone would have only hit 56.1 Mbps. Note both smartphones were sharing the same radio channel along with other smartphones, hence their speeds were limited during these tests compared with an "empty network." We don't know now many devices were using the network during this test, but we do know how many RBs the network assigned each smartphone, so the RB-normalized data speeds are relatively easy to calculate.

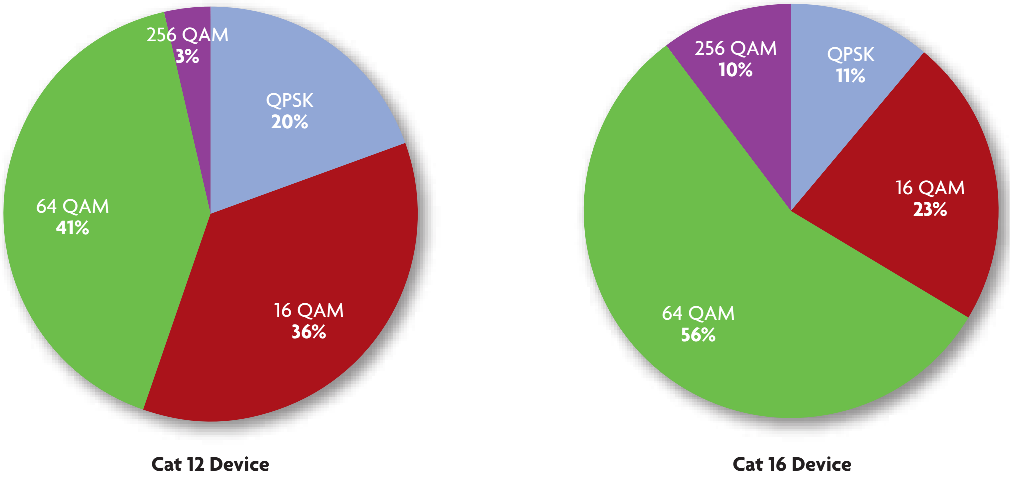
Figure 30. Physical Layer and RB-Normalized Physical Layer Data Speeds – Rural Drive Route



Source: Signals Research Group

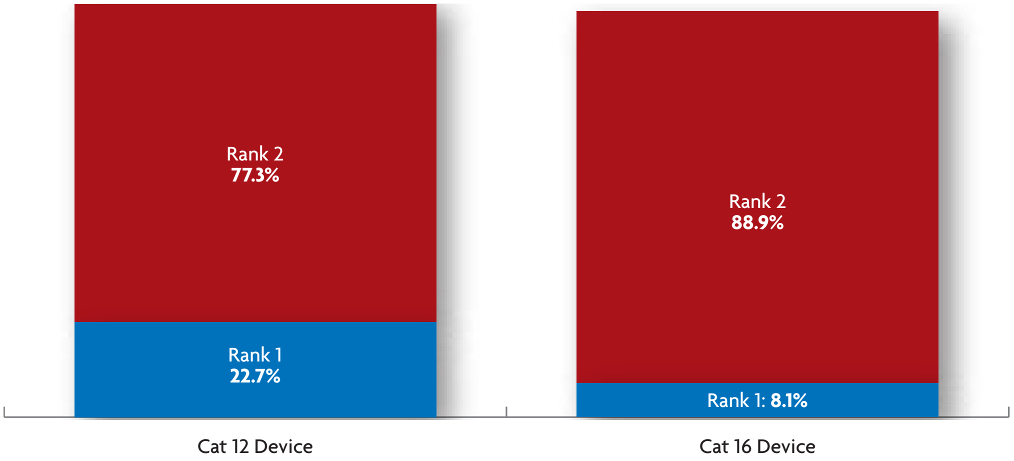
Figure 31 and Figure 32 provide additional insight into two important underlying metrics which help explain the observed and RB-normalized data speeds. Both smartphones were limited to MIMO Rank 2, but the Cat 16 smartphone used two data streams more frequently than the Cat 12 smartphone (88.9% versus 77.3%). Additionally, as shown in Figure 31, the Cat 16 smartphone had a more favorable distribution of modulation schemes (e.g., higher usage of 256-QAM, 64-QAM, etc.) Given the challenging conditions with low signal strength (the RSRP never exceeded -85 dBm), the Cat 16 smartphone didn't take advantage of highest MIMO rank, however, it could leverage the four receive antennas to increase the usage of MIMO Rank 2 and 256-QAM while minimizing the use of QPSK, which is the lowest/least efficient modulation scheme.

Figure 31. Distribution of Modulation Scheme – Rural Drive Route



Source: Signals Research Group

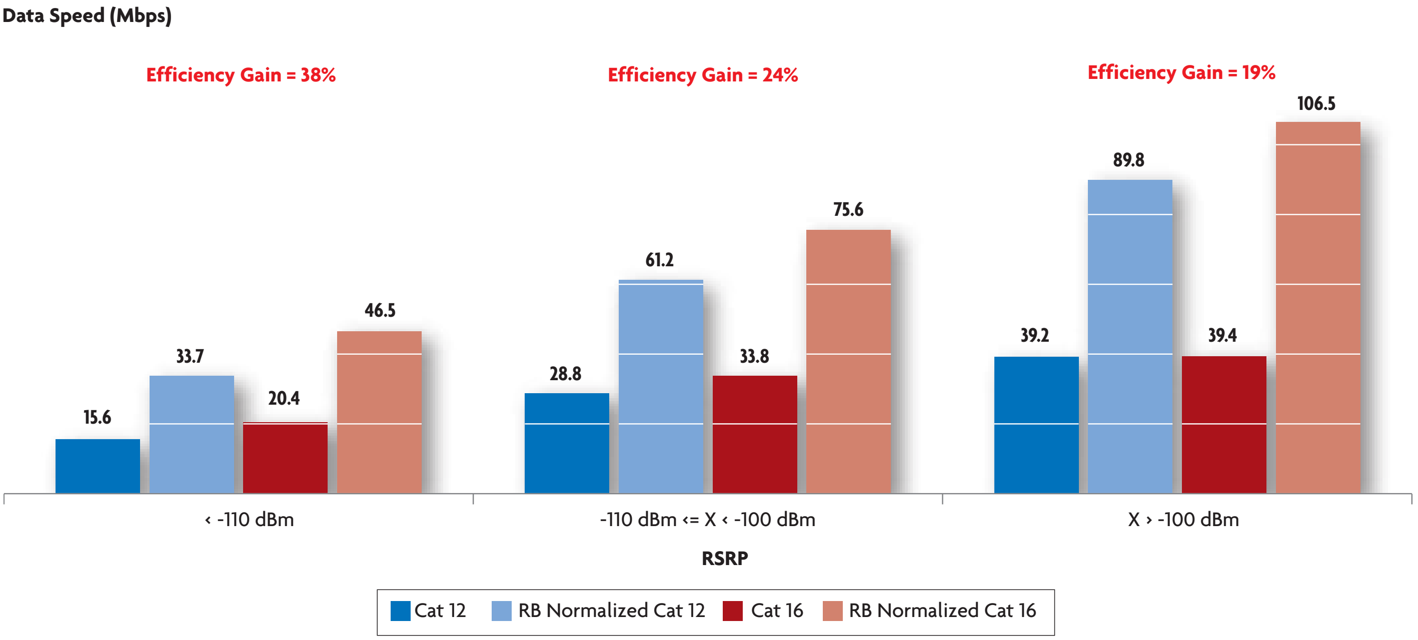
Figure 32. Distribution of MIMO Rank – Rural Drive Route



Source: Signals Research Group

To provide greater granularity into the benefits of a Cat 16 smartphone, we grouped the results into three buckets, representing different signal levels (i.e., RSRP), as illustrated in Figure 33. With the lowest signal levels (RSRP < -110 dBm), the Cat 16 smartphone was 38% more efficient than the Cat 12 smartphone, meaning the Cat 12 smartphone required 38% more RBs to achieve a data rate comparable to the Cat 16 smartphone. With the highest signal levels, which in this case was in the range of -85 dBm to -100 dBm, the Cat 16 smartphone was 19% more efficient than the Cat 12 smartphone.

Figure 33. Efficiency Gain versus Signal Strength – Rural Drive Route



Source: Signals Research Group

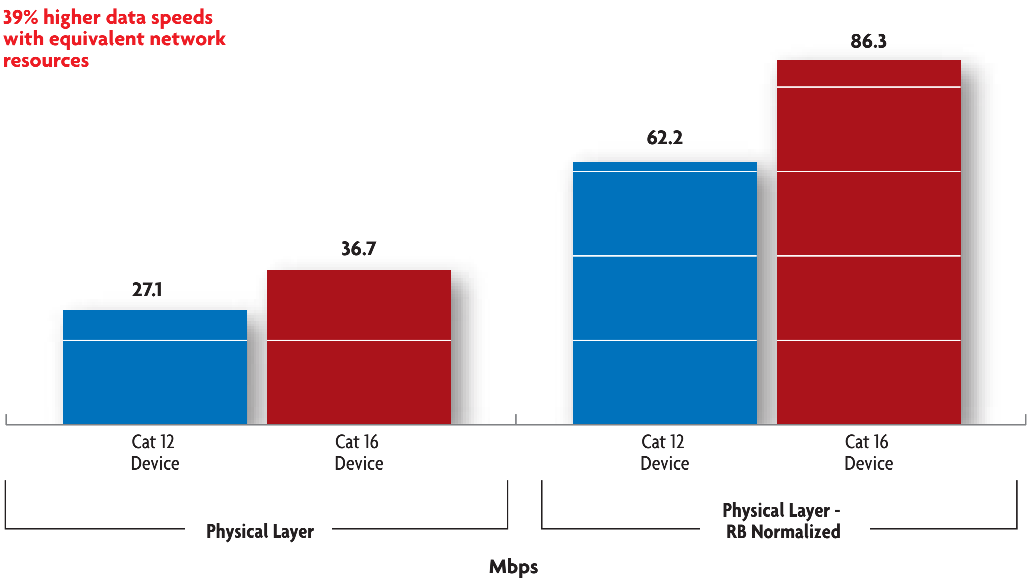
We used a similar data collection and analytical approach to analyze the data for a drive route located in the suburbs where most cell sites supported 4x4 MIMO. Most, but not all cell sites, only had a single 20 MHz LTE FDD channel in Band 4. This drive test, shown in Figure 34, resulted in 86 minutes of logged data.

Figure 34. Suburban Drive Route

Source: Signals Research Group

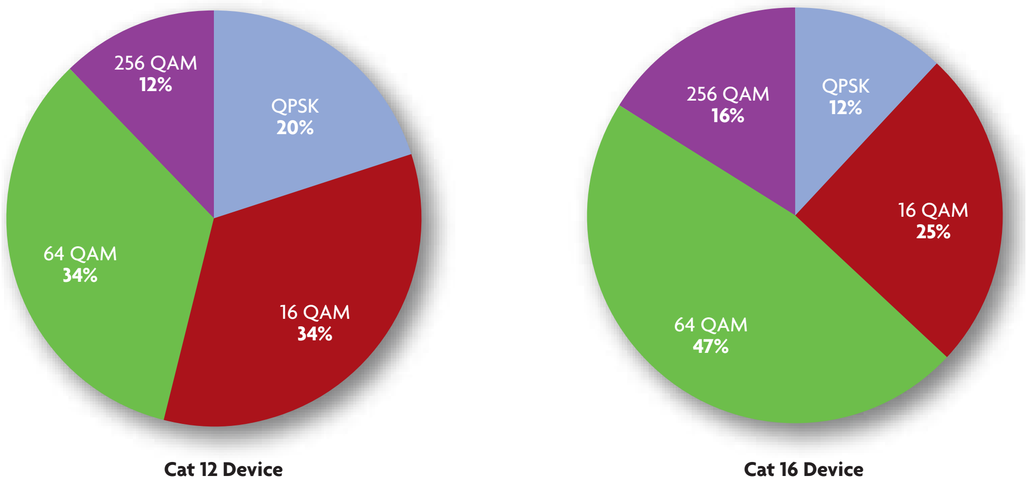
Figure 35 shows the observed and RB-normalized data rates for the two smartphones. During this test, the Cat 16 smartphone was 39% more efficient than the Cat 12 smartphone. The improved performance stems largely from a more favorable distribution of modulation scheme (Figure 36) and MIMO rank (Figure 37). With the more favorable conditions in the suburbs, the Cat 16 increased its MIMO rank, achieving MIMO Rank 3 for 15% of the time, as well as its use of 256-QAM. The Cat 16 smartphone used the highest modulation scheme for 16% of the time, compared with 12% of the time for the Cat 12 smartphone.

Figure 35. Physical Layer and RB-Normalized Physical Layer Data Speeds – Suburban Drive Route



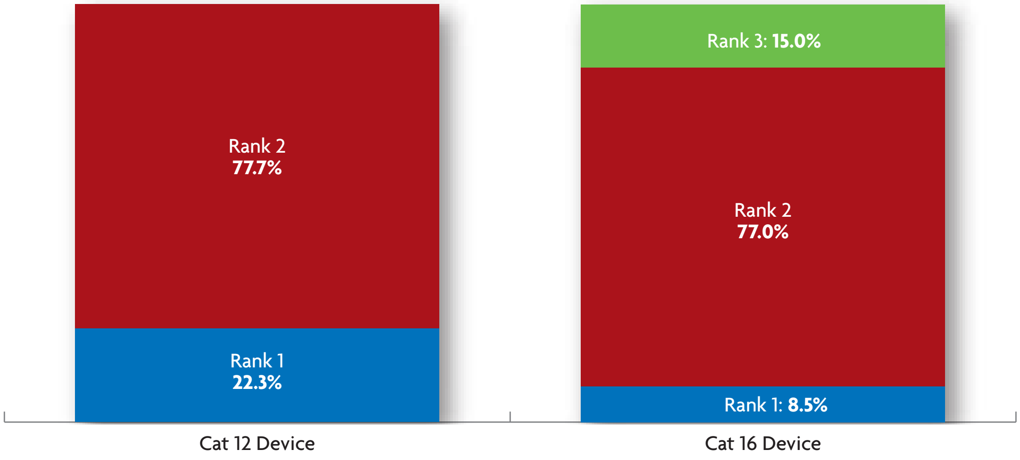
Source: Signals Research Group

Figure 36. Distribution of Modulation Scheme – Suburban Drive Route



Source: Signals Research Group

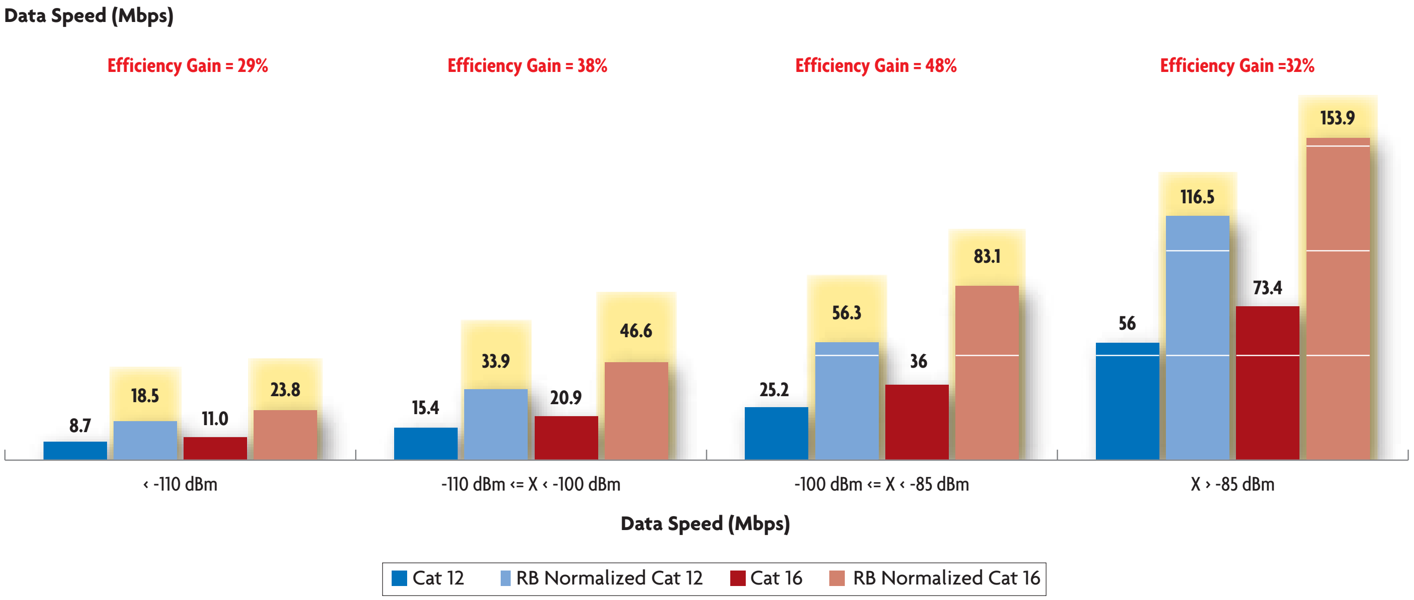
Figure 37. Distribution of MIMO Rank – Suburban Drive Route



Source: Signals Research Group

Looking at the efficiency gain as a function of signal strength (Figure 38), we found the Cat 16 smartphone was 29% more efficient with the weakest signals and 32% more efficient with the highest signals. With an RSRP range of -100 dBm to -85 dBm, the Cat 16 smartphone was 48% more efficient than the Cat 12 smartphone.

Figure 38. Efficiency Gain versus Signal Strength – Suburban Drive Route



Source: Signals Research Group

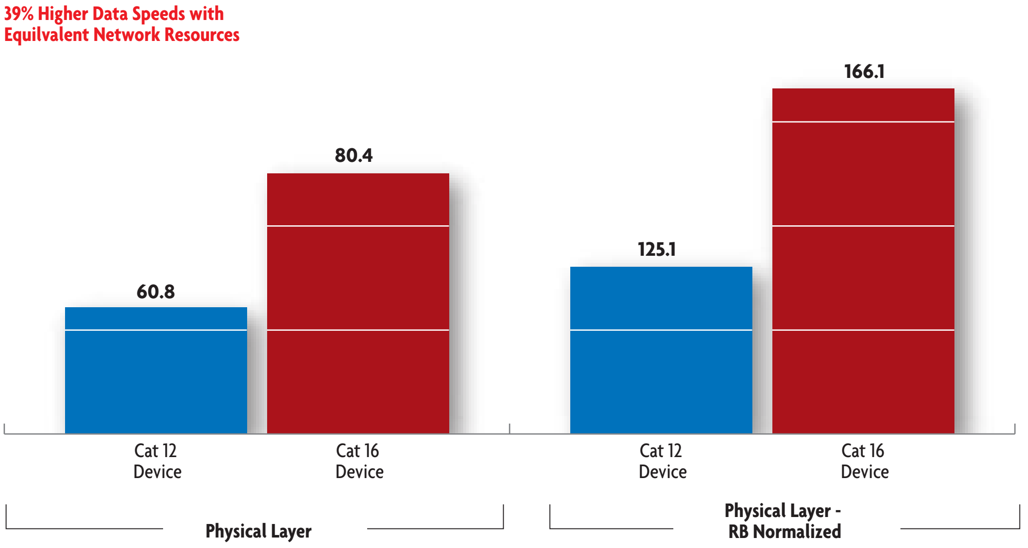
Within this drive route, we conducted a separate test in which we walked for several blocks in the vicinity of one of the cell sites. This cell site was located on the bell tower of a local elementary school. Figure 39 shows the path that we followed on this walk. The figure also shows the MIMO rank we observed on the Cat 16 smartphone. Most of the time, the MIMO rank was at least 3, if not 4, with the MIMO rank dropping to two data streams at the furthest locations from the cell site and when we were out of line-of-site with the tower. In the figure, we've highlighted two additional areas near the serving cell where the MIMO rank fell to 2. In these locations, we were transitioning between adjacent sectors of the 3-sector cell. Put another way, the edge of a cell can occur in close proximity to the serving cell, just as it can occur at a great distance from the serving cell when transitioning to a new serving cell that is located at another physical location.

Figure 39. Suburban Walk Route

Source: Signals Research Group

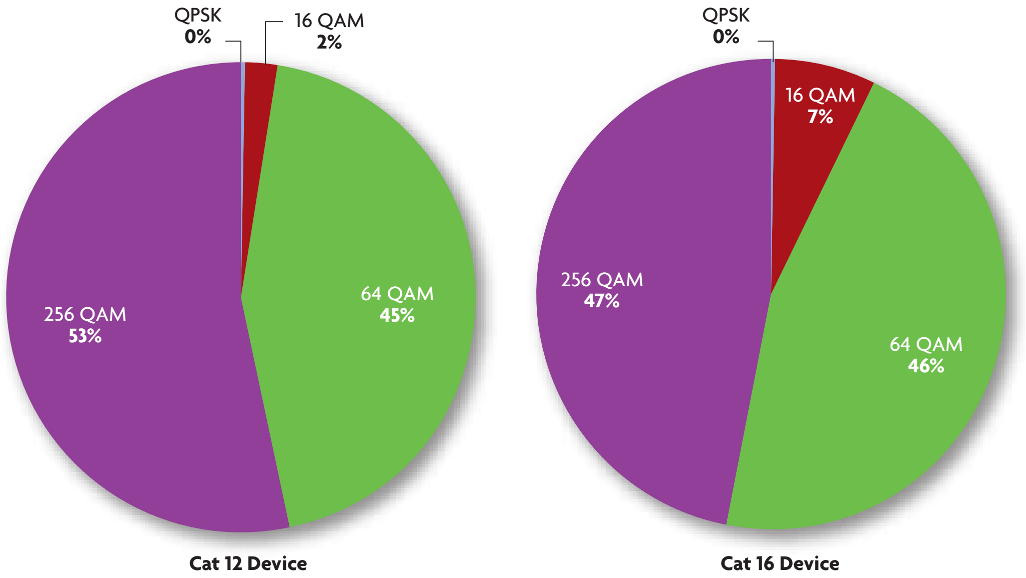
For this test, the observed data rates were meaningfully higher, thanks to the excellent radio conditions (reference Figure 40). However, the Cat 16 smartphone achieved higher data rates (80.4 Mbps versus 60.8 Mbps) and it was 39% more efficient.

Figure 40. Physical Layer and RB-Normalized Physical Layer Data Speeds – Suburban Walk Route



Source: Signals Research Group

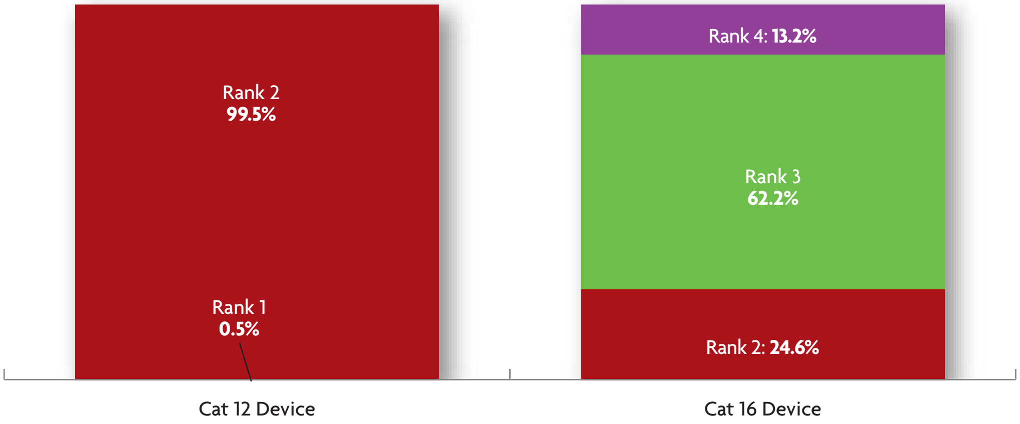
Figure 41. Distribution of Modulation Scheme – Suburban Walk Route



Source: Signals Research Group

The very favorable radio conditions resulted in very favorable MIMO rank and modulation distributions. The Cat 16 smartphone used at least three data streams for more than 75% of the time (Figure 42) while it used 256-QAM for 47% of the time (Figure 41). The Cat 12 smartphone could only support up to 2 data streams (MIMO Rank 2). The Cat 12 smartphone did use 256-QAM for 53% of the time, which is slightly higher than achieved with the Cat 16 smartphone. This result isn't surprising since we've observed in the past the use of higher MIMO rank can have some impact on the use of the higher modulation schemes. However, it is the overall increase in data speeds and spectral efficiency that matters, and in this regard, the Cat 16 smartphone performed meaningfully better than the Cat 12 smartphone.

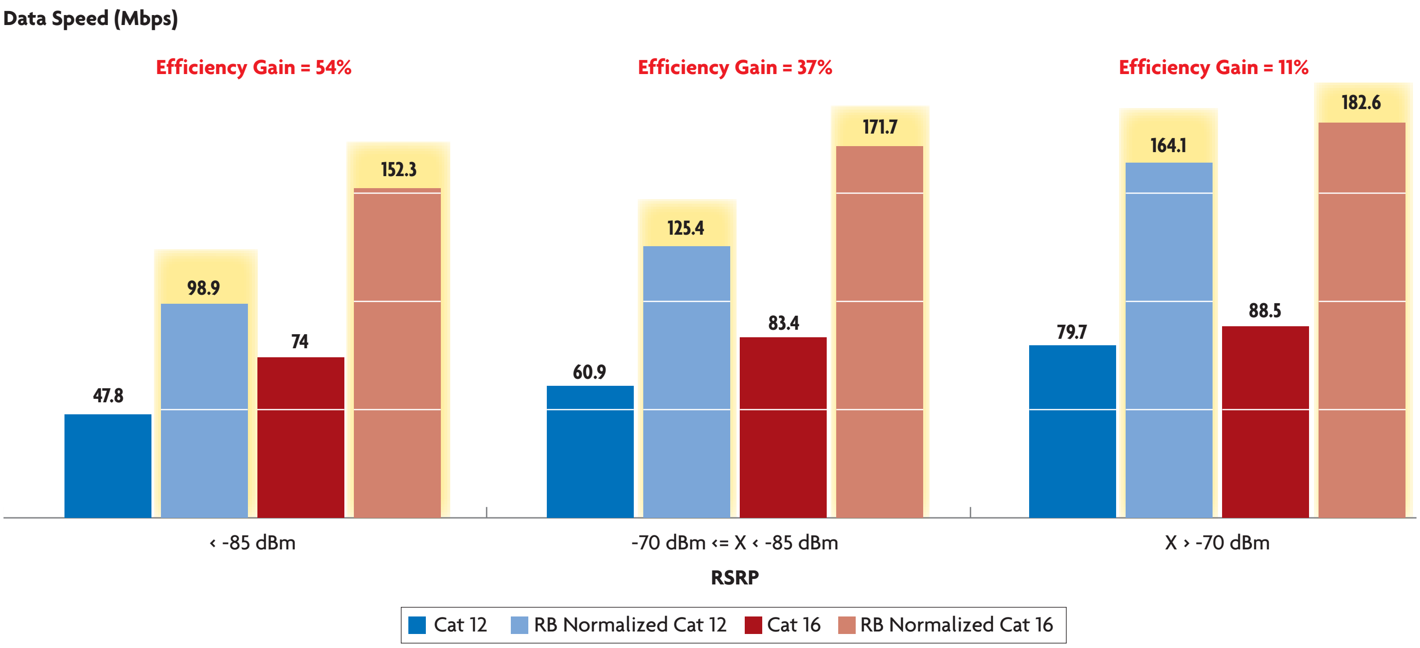
Figure 42. Distribution of MIMO Rank – Suburban Walk Route



Source: Signals Research Group

Figure 43 shows the efficiency gains of the Cat 16 smartphone as a function of the signal strength. In this walk test the RSRP was very favorable, and frequently higher than -70 dBm. The results indicate the Cat 16 smartphone was more efficient with each grouping of RSRP values, ranging from 11% with the highest RSRP to 54% with the lowest observed RSRP values.

Figure 43. Efficiency Gain versus Signal Strength – Suburban Walk Route



Source: Signals Research Group

A Cat 16 Device with LAA

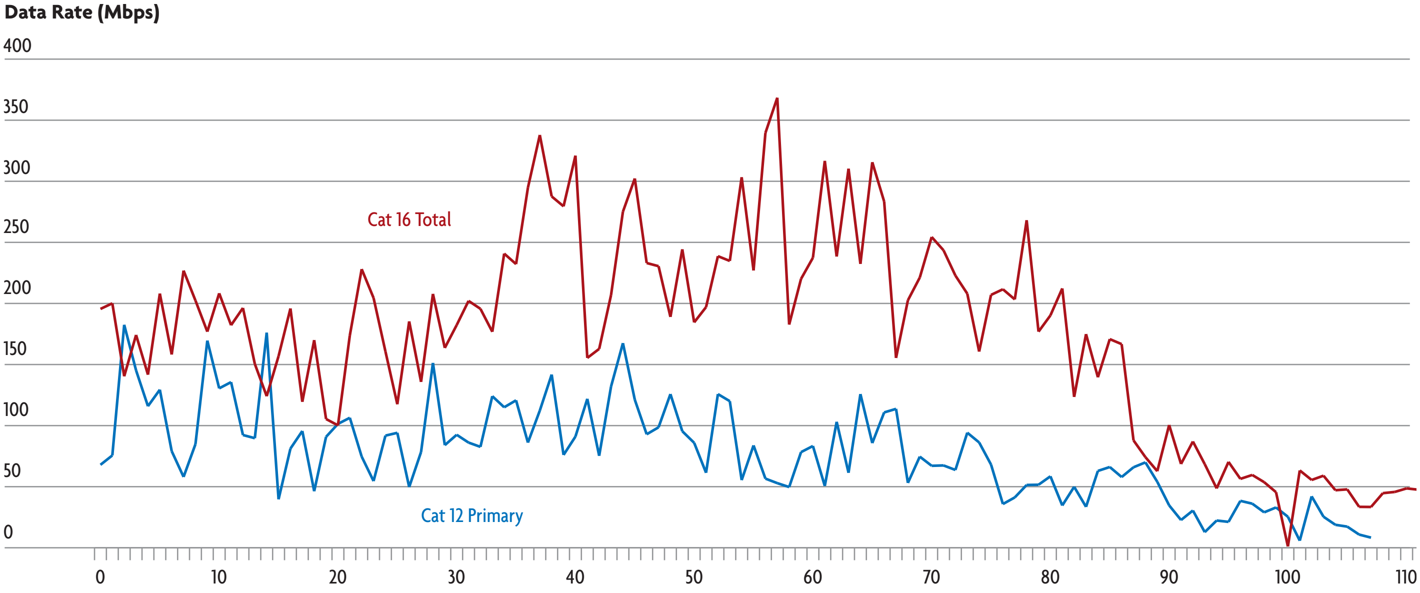
Although a Cat 16 smartphone isn't required to support LAA, the Cat 16 smartphone we used for this study supported LAA. Since we were in San Francisco where an operator has deployed LAA, we took the opportunity to evaluate the impact of LAA on the user experience and network efficiency. Figure 44 shows a picture of the small cell. From our analysis of the log files, this small cell supported Band 2 (20 MHz) and three LAA radio channels in the unlicensed spectrum.

Figure 44. An LAA Small Cell

Source: Signals Research Group

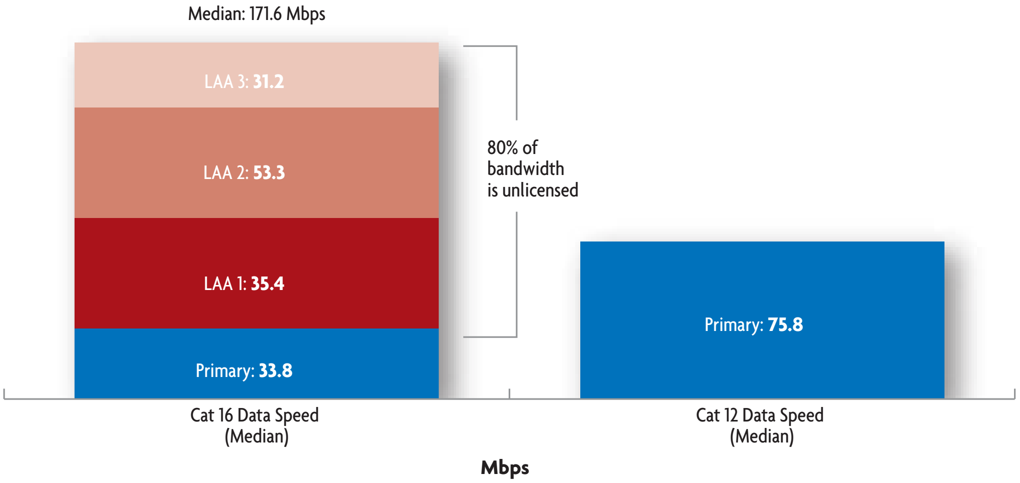
Before conducting some user experience tests, we conducted a walk test with the Cat 16 smartphone and the Cat 12 smartphone, which didn't support LAA. The walk test took us approximately one block in every direction from the LAA small cell, including up a perpendicular street that introduced non-line-of-site conditions. Figure 45 shows a time series plot of the observed data rates on the two smartphones during this test. Of note, the peak data speed observed during this test was 368 Mbps. Although it isn't evident in the figure, the unlicensed spectrum provided the majority of the bandwidth to the Cat 16 smartphone – 80% of the bandwidth/observed data rates came from the unlicensed spectrum, as shown in Figure 46. From a user's perspective, the higher data rates result in a better user experience, as we'll demonstrate in a bit. From a mobile operator's perspective, it is a win-win situation since it can deliver a better user experience without using its valuable spectrum resources.

Figure 45. Real Time Throughput Analysis with LAA



Source: Signals Research Group

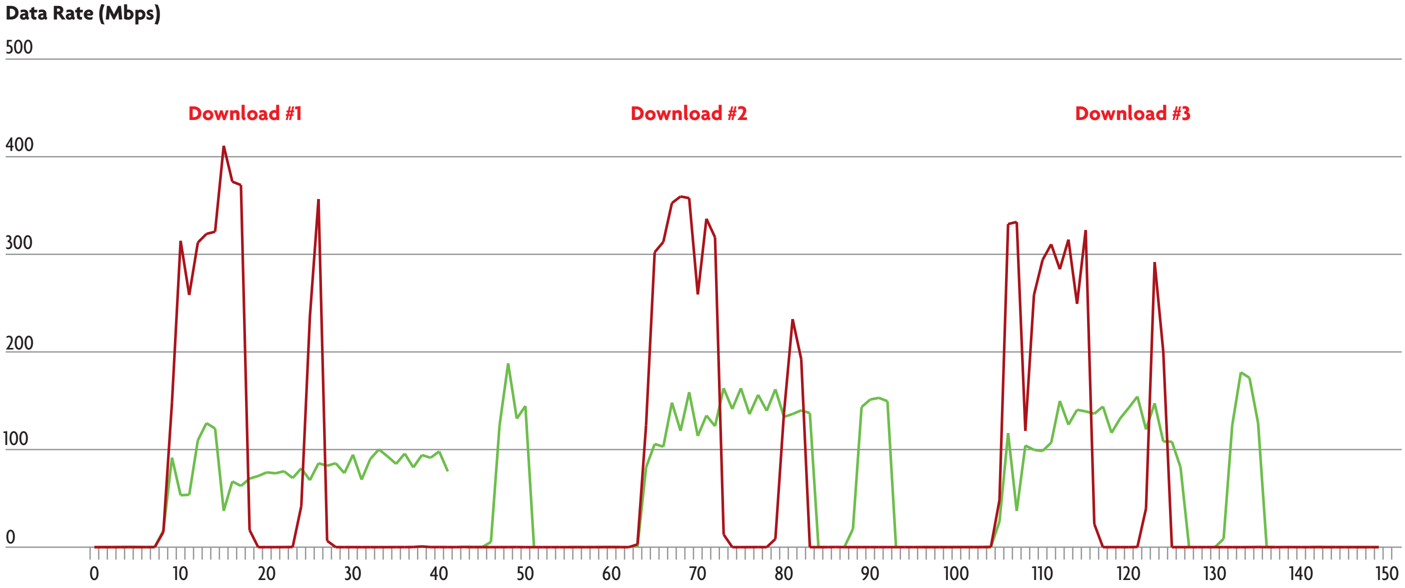
Figure 46. Total Throughput Distribution with LAA – by Component Carrier



Source: Signals Research Group

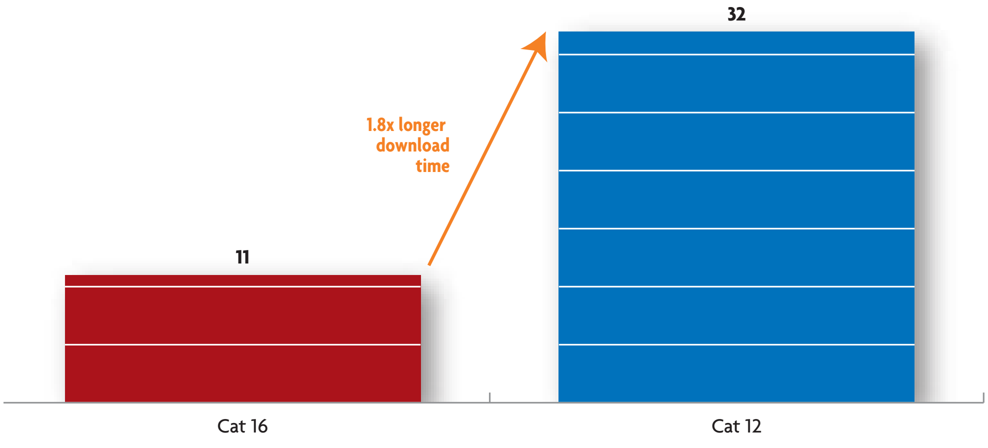
The results from our user experience tests should come as no surprise to readers given the earlier results. We are including the Google Play results for illustrative purposes. Figure 47 shows the observed data speeds on the two smartphones while downloading Angry Birds Transformers. The data rates are substantially higher with the Cat 16 smartphone, exceeding 400 Mbps during the first download, while the Cat 12 smartphone clearly took longer to download the application in each of the three tests. In fact, it took 1.8x more time, on average, with the Cat 12 smartphone than it did with the Cat 16 smartphone, as shown in Figure 48.

Figure 47. Real Time Throughput Analysis with LAA and Google Play



Source: Signals Research Group

Figure 48. Average Download Time with LAA and Google Play

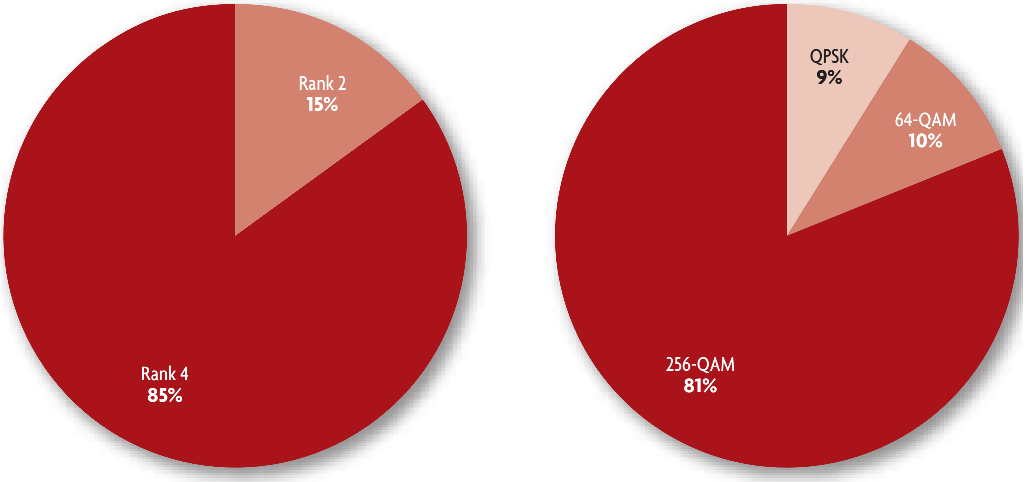


Source: Signals Research Group

The Cat 16 smartphone leveraged LAA for 76% of the total bandwidth to achieve the median download speed of 285 Mbps.

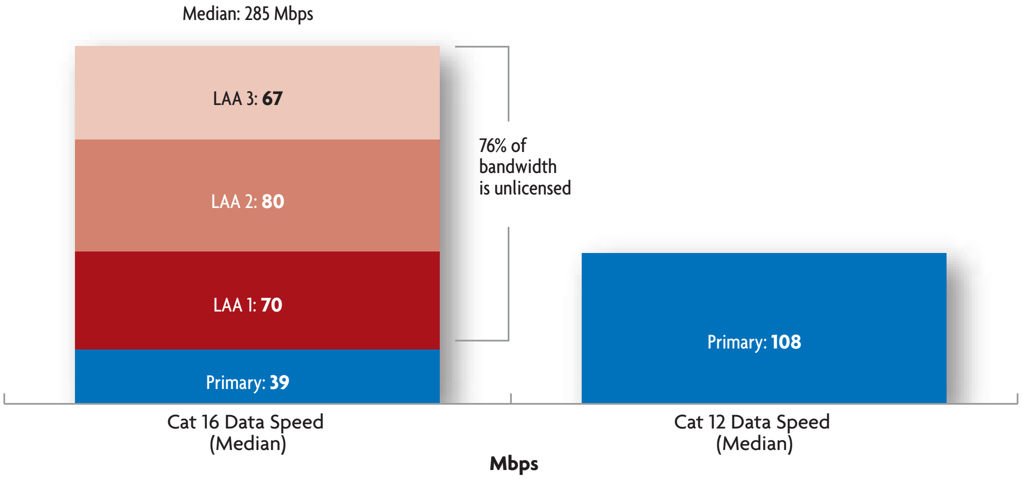
Given the favorable conditions from the adjacent small cell, the Cat 16 smartphone took full advantage of 4x4 MIMO and 256-QAM, as shown in Figure 49. These results are specific to Band 2. Likewise, the Cat 16 smartphone leveraged the three LAA carriers for 76% of the total bandwidth to achieve the median download speed of 285 Mbps during the three downloads.

Figure 49. Modulation and MIMO Rank Distribution with LAA



Source: Signals Research Group

Figure 50. Total Throughput Distribution with LAA – by Component Carrier



Source: Signals Research Group

A Cat 16 Device and Public Wi-Fi

We compared Gigabit LTE and public Wi-Fi by testing in several coffee shops in Northern California and Minnesota. We are showing just a few test results from one of the locations, but these results are consistent with our overall observations. In general, the public Wi-Fi hot spots are limited by backhaul connectivity, meaning if the host providing the Wi-Fi service increased its backhaul capabilities then the results would be different. In the US and Europe, we don't see this scenario developing any time soon. In some Asian countries, the abundance of fiber means the public Wi-Fi hot spots can be materially faster than what exists in other markets. However, the LTE networks are also much faster in these Asian countries, so the gain is somewhat offset.

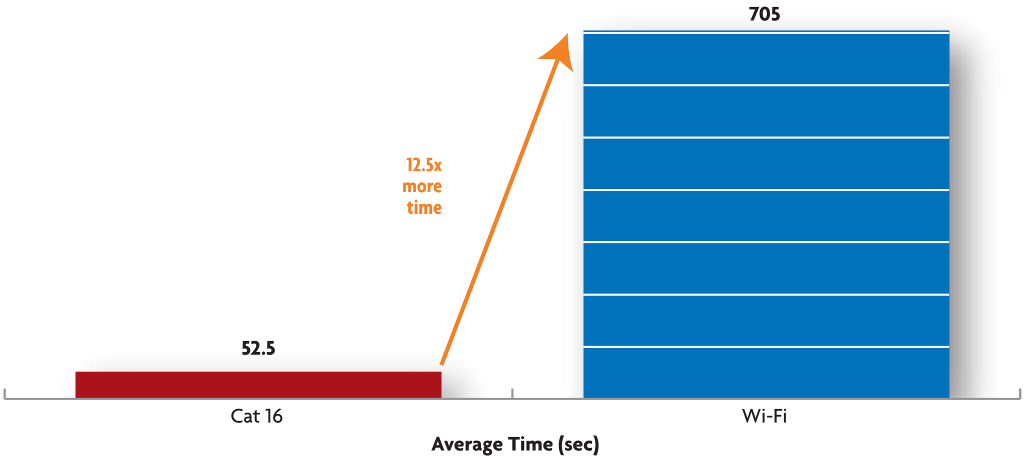
Some readers may question why someone would use LTE when the Wi-Fi was free, even if it was much slower. This view is fair, but we note US operators are offering unlimited data plans, frequently with some sort of data throttling that kicks in once the subscriber exceeds a certain threshold, which is as high as 50 GB per month at the moment.

With unlimited data plans and throttling policies that usually have little impact on the user experience, mobile data is becoming close to a free lunch.

For all our tests, we used commercial SIMs. To ensure we had meaningful results, we initially swapped SIMs when we hit the threshold. However, we've observed from other testing we've done in the past that the so-called throttling is very infrequent since it also requires meaningful network loading before the operator activates it. For the Wi-Fi tests and for all the drive tests, we used SIM cards with data usage well in excess of the operator's monthly data usage threshold. For the Wi-Fi tests, we had easily exceeded the monthly data usage threshold by a factor of two. In other words, our cellular data usage in the coffee shop was also free, and we didn't have to register before connecting to the network.

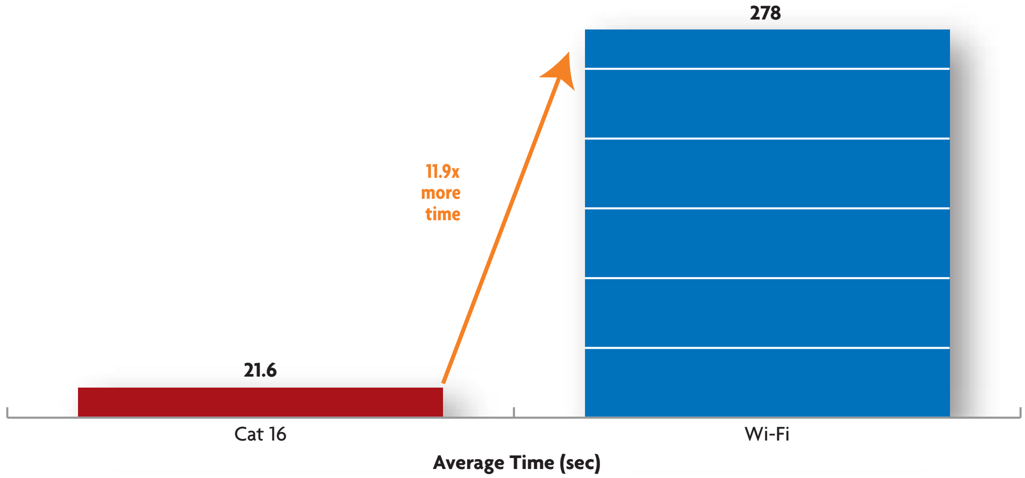
Since the two phones were using different networks, we weren't as concerned with the simultaneous nature of our testing. However, we did start the Google Play download tests at the same time on the two smartphones. Given the huge disparity in the download times – it took 12.5x more time over Wi-Fi, as shown in Figure 51, we moved on to the Google Music and Google Drive tests with our Cat 16 smartphone. In fact, we finished all the tests over the LTE network before completing the Google Play downloads over Wi-Fi. In the interest of time, we stopped testing over Wi-Fi at this location before completing the series of tests, so we didn't conduct the Google Drive tests. Figure 52 shows the results from the Google Music tests, which involved downloading all the tracks from one album as well as a separate music playlist. For this test, it took 11.9x more time over Wi-Fi than over the LTE network.

Figure 51. Average Download Time – Google Play



Source: Signals Research Group

Figure 52. Average Download Time – Google Music



Source: Signals Research Group

Test Methodology

SRG conducted these tests in Northern California and Minnesota in late September and early October. We conducted the tests at randomly selected locations, although we did seek certain network conditions when conducting the user experience tests. Given the wealth of test data, we elected to only include some of the results in this whitepaper. We included results that were representative of all test data. We also included lengthy drive test studies to show the incremental benefits of a Cat 16 smartphone over all possible network conditions.

For virtually all tests, we operated the Cat 16 and Cat 12 smartphones in parallel since their performance is influenced by network loading – a parameter that is constantly changing and virtually impossible to predict. When analyzing the data, we only included results when the two smartphones shared the same radio channel(s) and the same serving cell site. This approach helps ensure a meaningful comparison of the data.

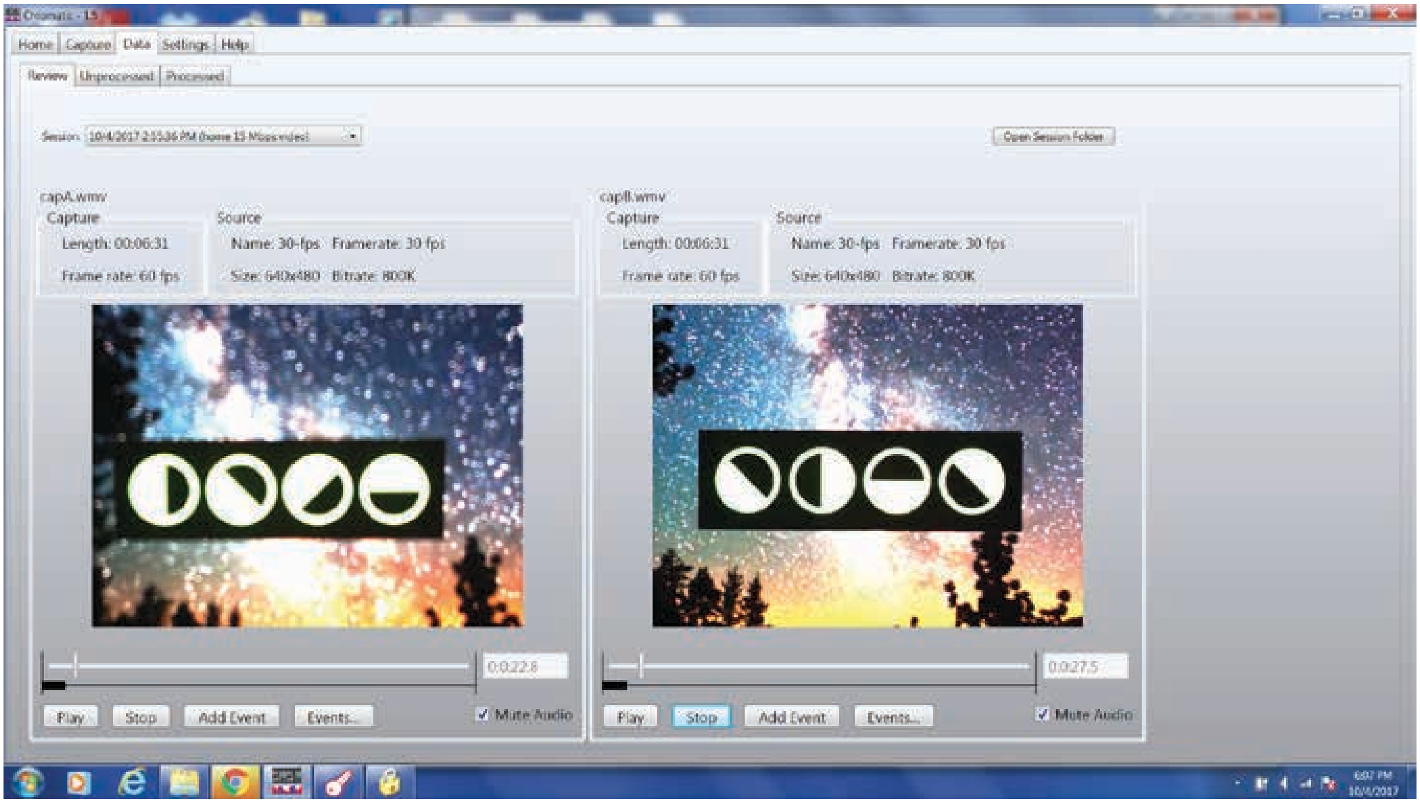
We leveraged test equipment from our partners to conduct these tests. For the drive tests and many of the user experience tests, we leveraged XCAL-Solo from Accuver Americas to capture the chipset diagnostic messages coming from the two smartphones. These messages include a wealth of information, including parameters we showed in this paper, such as RSRP, SINR, RB allocations, MIMO rank, and modulation scheme, not to mention essential information like frequency band and the serving cell PCI. We used the company's XCAP post-processing software to analyze the log files.

Figure 53. XCAL-Solo

Source: Signals Research Group

For the video performance tests, we used the Chromatic video test platform from Spirent Communications. Chromatic uses a vision-based capture mechanism to record the videos playing on the displays of the smartphones. Since the videos include special markers and audio tones, we can analyze the data to quantify video delivery performance, including frozen and impaired frames, as well as synchronization issues that exist between the audio and the video. We also used Link Master Logging and Link Master Analyzer (LML/LMA) from WirelessMETRIX for the video studies. This tool proved to be especially useful since it is integrated with the Chromatic test platform. This integration means we could easily trace video playback problems to network parameters and device performance, based on the chipset diagnostic messages captured by LML. We used LMA during the analysis process as well as the inherent capabilities of the Chromatic software.

Figure 54. Chromatic

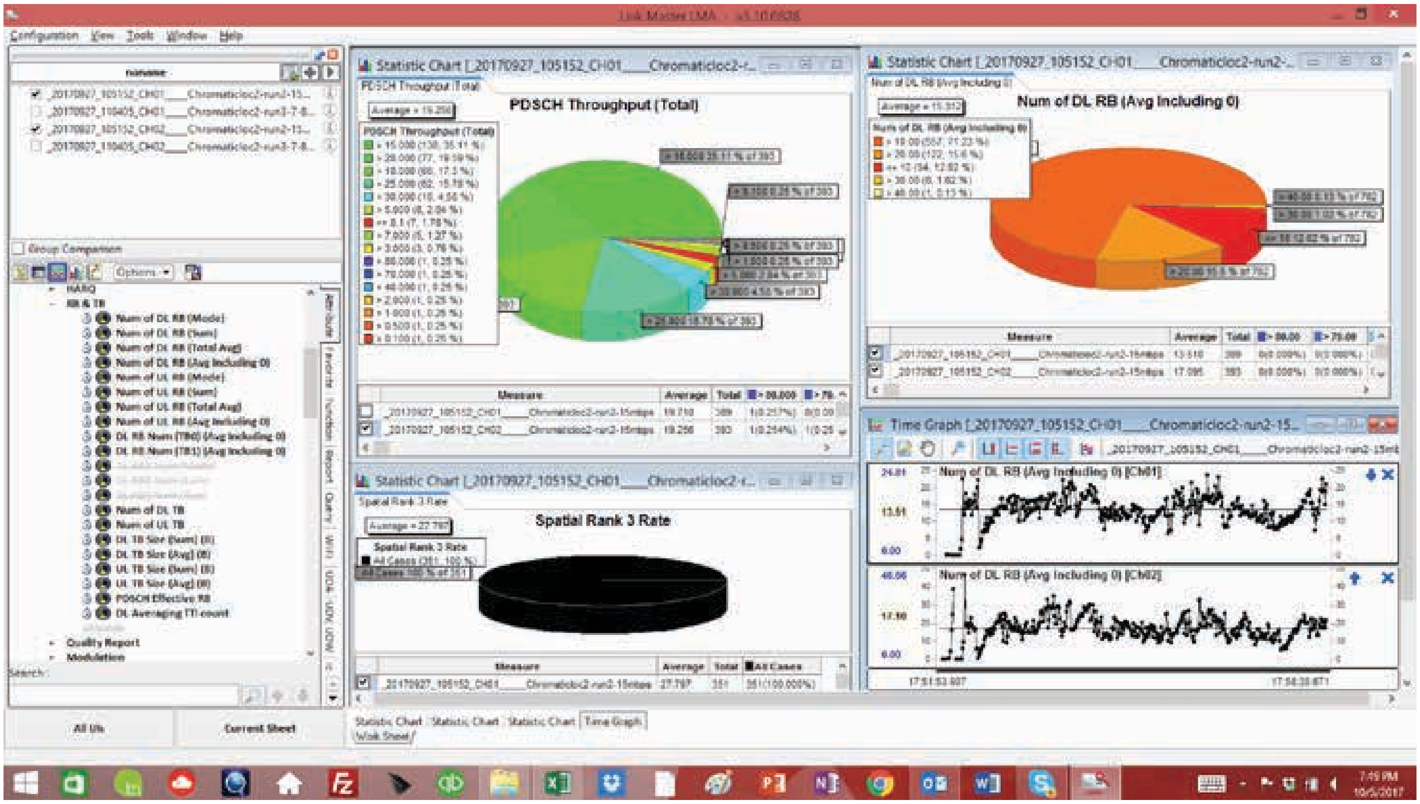


capA.wmv
Capture
Length: 00:06:31
Frame rate: 60 fps
Source
Name: 30-fps Framerate: 30 fps
Size: 640x480 Bitrate: 800K
0:0:22.8
☑ Mute Audio

capB.wmv
Capture
Length: 00:06:31
Frame rate: 60 fps
Source
Name: 30-fps Framerate: 30 fps
Size: 640x480 Bitrate: 800K
0:0:27.5
☑ Mute Audio

Source: Signals Research Group

Figure 55. Link Master Logging and Link Master Analysis



Source: Signals Research Group

Final Thoughts

Gigabit LTE is becoming a reality and it will be a necessity when mobile operators eventually upgrade their networks to 5G.

Gigabit LTE is becoming a reality and it will be a necessity when mobile operators eventually upgrade their networks to 5G. In addition to network upgrades, Gigabit LTE requires device compatibility with Cat 16 smartphones being the first devices capable of achieving the peak data speeds implied in the Gigabit LTE moniker.

It isn't, however, just the ability to achieve higher data rates that make the Cat 16 features compelling to consumers and mobile operators. As we've shown in this benchmark study, a Cat 16 smartphone outperforms a Cat 12 smartphone with all mobile data applications and with all network conditions – the performance advantage is almost always in the double digits, if not the triple digits on a percentage basis. With 4x4 MIMO, a Cat 16 smartphone can receive up to four data streams, which theoretically quadruples its potential data rate versus a single data stream and it doubles the potential data rate versus a Cat 12 smartphone, which is limited to 2x2 MIMO. With more challenging network conditions, a Cat 16 smartphone leverages its four receive antennas to boost the signal strength and signal quality of the transmitted signal from the serving cell site. By boosting the signal strength and quality, the serving cell site can transmit data with a faster bit rate for each data stream, even if it is only a single data stream. Consumers benefit from a better user experience and mobile operators benefit from increased network efficiency, not to mention happy subscribers.

Finally, the introduction of LAA and unlimited data plans, including throttling policies that usually have no impact on the consumer, means that user data consumption will continue to increase, and consumers will use bandwidth-heavy applications, such as streaming 4K video. For this study, we used ordinary applications, yet the Cat 16 smartphones proved beneficial. As bandwidth-heavy applications become more mainstream, Cat 16 functionality and Gigabit LTE networks will be critical to ensure a favorable user experience continues.

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