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THE COMPLEMENTARY ROLES OF 802.11ac AND 802.11ad WITH A WIRELESS DOCKING STATION IN AN OFFICE ENVIRONMENT

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Prepared by
Signals Research Group



www.signalsresearch.com

Paper developed for Qualcomm

On behalf of Qualcomm, Signals Research Group conducted third-party testing of 802.11ad and 802.11ac. The comparative tests focused on the user experience involving applications that are commonly used with a wireless docking station in an office environment.

As the sole authors of this study, we stand fully behind the results and analysis that we provide 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 STUDY

- While 802.11ac data speeds are more than sufficient for most applications, the higher data rates offered by 802.11ad greatly enhance the user experience when dealing with applications that require the transferring of large amounts of data
- The beamforming capabilities of 802.11ad support a much higher concentration of access points (APs) and end user devices or stations (STAs), with larger bandwidth requirements, including the transmission of video content
- Low latency is absolutely critical for many usage scenarios, including those applications involving virtual reality (VR) or augmented reality (AR); in that regard, the latency of 802.11ad is approximately one-tenth that of 802.11ac
- Although 802.11ad is not as resilient and robust as 802.11ac, 802.11ad delivers fairly consistent data speeds when the STA is moving around the AP; forthcoming commercial products with larger antenna arrays, combined with fast session transfer (FST) between 802.11ad and 802.11ac, will further increase the reliability.

Although 802.11ac and 802.11ad are only separated by a single letter of the alphabet from the perspective of their naming conventions, the two wireless protocols have vastly different performance characteristics. These differences position 802.11ac and 802.11ad as providing complementary roles when it comes to supporting various use cases in an office environment.

As part of our ongoing series of benchmark studies on wireless local area network technologies, Signals Research Group (SRG) conducted third-party analysis of how 802.11ac and 802.11ad perform for a range of use cases. For our first study of 802.11ad, we focused on use cases targeting the office environment since many of the initial 802.11ad commercial products target this market opportunity. Specifically, for these tests we used a 802.11ac/802.11ad wireless docking station for the 802.11ac/802.11ad access point (AP) and notebook computers or computer peripherals for the end user device, or mobile station (STA). Likewise, our initial suite of tests focused on scenarios that are likely to occur in this type of environment.

By using commercial products that could be easily configured to use 802.11ac or 802.11ad, we were able to easily quantify the differences between the two wireless technologies, while at the same time dispel some of the misconceptions of the 802.11ad protocol.

As discussed in the subsequent sections of this whitepaper, we found that 802.11ac is more than adequate for many use cases. We refer readers to the whitepaper on MU-MIMO that we published earlier in the year.¹ But there is a crossover point where the higher bandwidth and beamforming functionality supported by 802.11ad are essential for supporting a dense concentration of APs and STAs generating large amounts of data, including high-bandwidth video. We also found that the use of beamforming makes 802.11ad relatively robust and capable of supporting mobile STAs that move in and around the serving AP. The introduction of commercial products which are optimized for this use case and which contain larger antenna arrays than

¹ MU-MIMO and the User Experience: Quantifying the Benefits of More Advanced 802.11ac Features, February 2016 (available at www.signalsresearch.com)

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the initial products that we tested will further enhance this feature. Beamforming also allows the user to project onto an adjacent monitor, thereby significantly increasing the battery life of a portable tablet or notebook computer.

Our test results also reveal that 802.11ad offers dramatically lower latency compared with 802.11ac. With approximately one-tenth the latency of 802.11ac, 802.11ad is necessary for low latency applications, from the very basic (wireless mouse) to the more advanced applications, including those applications which leverage virtual reality (VR) and augmented reality (AR).

Lastly, 802.11ad will play a critical role in the future evolution of the wireline network and the Internet. In many regions of the world, Gigabit-per-second data rates to the home or office do not exist so 802.11ac more than suffices as the wireless extension. However, as the Internet evolves and fiber becomes more ubiquitous, 802.11ad will be essential in order to prevent a bottleneck from occurring after the fiber reaches its final termination point in the home or office. It is also worth mentioning that 802.11ad represents the first commercial implementation of millimeter wave frequencies for consumer-oriented applications. Therefore, it represents an early look at the potential of 5G/New Radio, which also leverages similar frequency bands.

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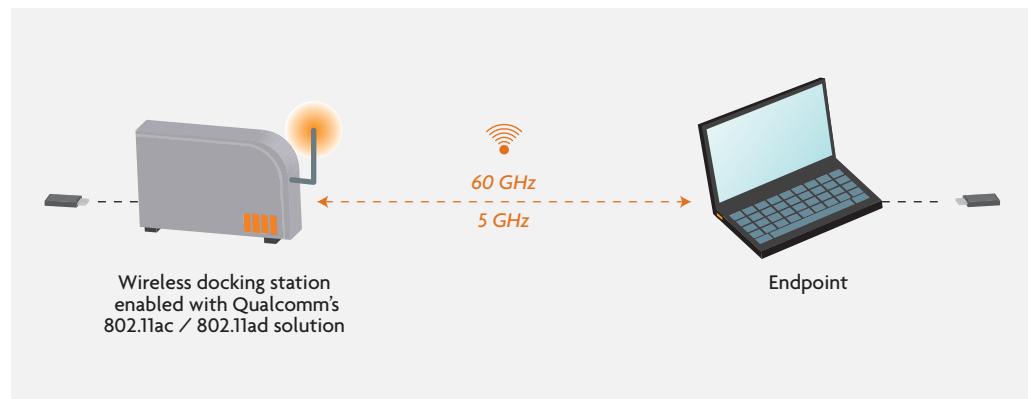
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High bandwidth applications, such as transferring large files, benefit from higher data rates that 802.11ad delivers

For many applications, 802.11ac provides more than adequate bandwidth. It's great for synching email, even with large attachments, delivering streaming video from the Internet, not to mention interacting with online storage services, such as Dropbox and Google Drive. However, there are certain applications and use cases where the amount of potential bandwidth isn't sufficient, or at least the available bandwidth detrimentally impacts the user experience.

To demonstrate this point, we conducted a series of tests involving the transfer of large data files between two local memory storage devices. For purposes of these tests, we used the USB 3.0 protocol to read/write data from a hard drive to a USB flash drive. As an organization that does a lot of benchmark testing and is accustomed to dealing with Gigabyte-sized log files, we frequently find ourselves moving data from one storage facility to another storage facility in order to free up memory or to preserve critical data for future use. Transferring pictures from the memory card of a digital camera to a separate storage unit is another example of a use case that we know from experience involves a lot of data. Therefore, we believe this usage scenario is pretty realistic, and speaking from personal experience, we know that it can be pretty time consuming if the transfer rate is slow.

Figure 1. Test Configuration



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802.11ad achieved data rate of 382 Mbps was fairly close to the hard-wired connection speed and 243% faster than the 802.11ac data speed of 111.5 Mbps.

Figure 2 shows the average transfer speeds that we recorded during a four minute transfer. The local transfer speed of 411.6 Mbps represents the speed that we recorded when the USB drive on the docking station was connected via cable directly to the main storage unit. In other words, this transfer speed is the highest possible for the hardware configuration that we used and it serves as the benchmark when comparing the data rates obtained with 802.11ad and 802.11ac. The comparison between 802.11ac and 802.11ad is more telling. In the case of 802.11ad, the achieved data rate of 382 Mbps was fairly close to the hard-wired connection speed and 243% faster than the 802.11ac data speed of 111.5 Mbps. This data speed is noticeably lower than what 802.11ac can support. One likely explanation for the lower-than-expected speed is that the USB 3.0 protocol is highly susceptible to packet delay (i.e., latency). As discussed in another section of this whitepaper, we found that 802.11ad latency was approximately one-tenth the latency of 802.11ac.

Figure 2. Measured File Transfer Speeds

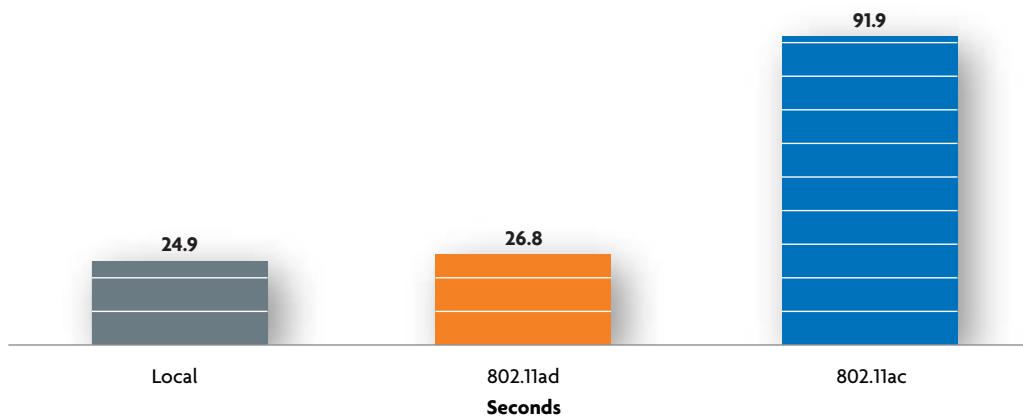


Source: Signals Research Group

It would take about 4x the time to transfer 10 GB of data with 802.11ac versus 802.11ad.

Faster data speeds not only sound impressive, but they have a real world impact on the user experience – namely, they result in less time spent transferring files from one storage location to another storage location. In Figure 3, we illustrate how the measured data rates shown in Figure 1 translate into longer time waiting for a transfer to finish. Time that could have been spent doing other things. For a 10 GB file or a folder containing 10 GB of data (i.e., a memory card for a DSLR camera), it would take about 4x the time, or an additional 65 seconds to complete the file transfer with 802.11ac versus 802.11ad.

Figure 3. The Impact of File Transfer Speeds on the User Experience



Source: Signals Research Group

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802.11ac may suffice today for most [not all] wireline Internet networks, but there will be a tipping point in the not-too-distant future when 802.11ac will not be sufficient.

For purposes of this study, the file transfer was localized and didn't extend to the Internet. In many regions of the world, the Internet is frequently the chokepoint today when dealing with either 802.11ad or 802.11ac. However, just as wireless networks are becoming faster today with the introduction of 802.11ad and the pending introduction of 5G in the macro network before the end of the decade, wireline infrastructure, not to mention the Internet as a whole, will become much faster than it is today and with even lower latency.

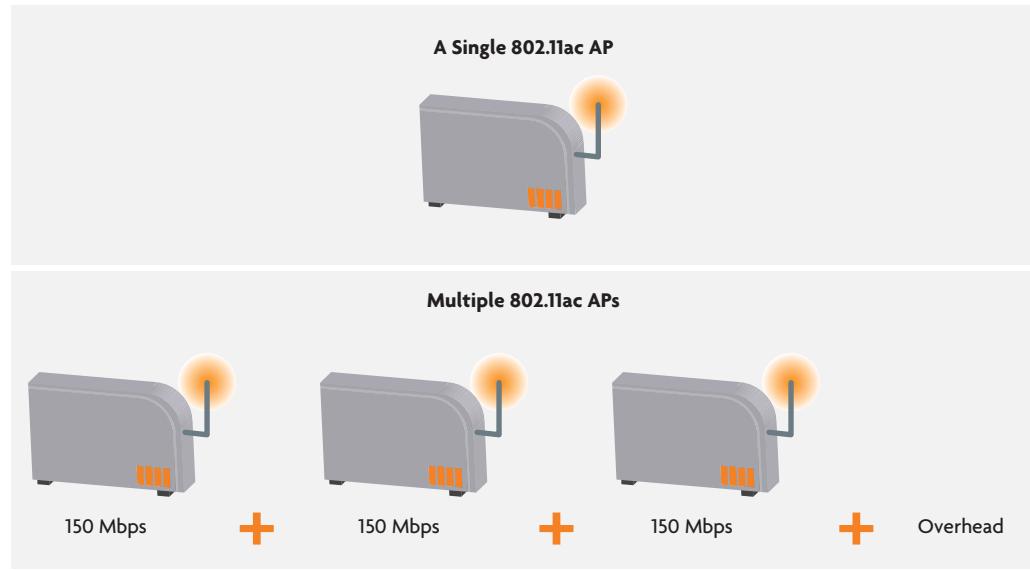
As service providers evolve their networks to support Gigabit-per-second fiber, they will need the wireless technologies, which connect to their wireline networks, to continue their evolutionary path toward higher data rates and lower latency. 802.11ac may suffice today for most [not all] wireline Internet networks (e.g., DSL and cable), but there will be a tipping point in the not-too-distant future when 802.11ac, or for that matter any wireless technology in the 5 GHz band, will not be sufficient. 802.11ad provides the necessary performance characteristics that these operators and their subscribers will require to capture the full benefits of a vastly improved Internet infrastructure.

802.11ad is ideal for high-bandwidth applications operating in a dense environment of access points and consumers

One compelling nuance associated with the beamforming capabilities of 802.11ad is that the highly directional nature of the transmissions are ideal for supporting multiple high-bandwidth applications. The benefits are even more significant when there is a high concentration of access points with a large number of consumers/STAs connected to the APs. 802.11ac can also deliver high bandwidth, and the use of MU-MIMO (multi-user MIMO) can increase capacity even further since the 802.11ac AP can reuse spectrum resources and transmit to multiple STAs simultaneously. Generally, with today's implementation of 802.11ac, the AP is limited to no more than three simultaneous transmissions.

There is, however, a limit to the total throughput that 802.11ac can support and the proximity of APs and STAs that are using the same 5 GHz radio channel. For example, let's assume a nominal 802.11ac peak speed of 500 Mbps, which factors in real-world conditions versus theoretical speeds that can only be achieved in a wired environment and with a channel bandwidth that is seldom used or supported. If the AP and the attached STAs support MU-MIMO then the AP can come reasonably close to supporting the 500 Mbps speed per transmission link to two or three STAs.

Figure 4. Dividing Spectrum between Multiple 802.11ac Access Points



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However, now let's consider an environment with multiple APs, each serving one or more STAs, and all APs and STAs using the same radio channel. Even if all of the APs and STAs support MU-MIMO – far from a guarantee, the maximum speeds achieved in each transmission link would be reduced by a factor corresponding to the number of APs. For example, with three APs, the peak speed achieved by a single AP would be one-third (166 Mbps) and this speed is only achieved with the best possible sharing mechanism. Based on testing we've done in the past, there is at least 10% overhead and typically 25% or more overhead when two or more APs share the same channel during which time none of the APs are using the shared radio channel. This overhead reduces the peak link speed to only 150 Mbps or more likely less than 125 Mbps. Not bad, but well below the capabilities of the technology in the absence of multiple APs and STAs. Further, we're making assumptions and using numbers that are pretty optimistic – a point that we will demonstrate with the results we show in a bit.

For this series of tests, we used three APs, each connected to a single STA, with the APs and STAs configured to support either 802.11ac or 802.11ad, depending on the test. We placed the three APs and the three STAs in the same large room of a house with their exact location in the room defined by the three network layouts summarized in the following bullets.

- **Network Layout #1:** The three 802.11ac/ad APs were located within a few feet of each other with the 3 attached APs placed such that each STA was within a few feet of its AP and with large angles of separation between the three individual transmission links.
- **Network Layout #2:** Identical to the above configuration with the exception that the three STAs were positioned further away from the APs.
- **Network Layout #3:** Identical to the first configuration (APs and STAs all in close proximity to each other) with the exception being that the three APs were also positioned such that there were narrow angles of separation between each transmission link.

We used two of the APs and the iPerf application to transfer large amounts of data to their attached STAs. These APs/STAs served as a source of interference for the “real test,” which involved the remaining AP/STA. We used the third AP to stream high bandwidth video to a secondary monitor. The usage scenario is very comparable to the functionality of Miracast or someone streaming a high definition video from their computer/smartphone to a display monitor.

We defined three performance criteria for these tests.

1. How was the video transmission impacted by the two interfering sources?
2. How much total throughput did the two “interfering” APs generate?
3. What was the quality of the video being displayed on the monitor?

We used the Chromatic test platform from Spirent Communications to quantify the impact [if any] of the two interfering sources on the transmitted video. The Test Methodology section explains in more detail how Chromatic works and it explains some of the KPIs in more detail that we used. Figure 5 shows the results from the tests involving 802.11ac and 802.11ad without any interfering sources. We used this test as the benchmark when gauging the impact of the two additional APs/STAs transmitting in the same radio channel. The results from this test show that 802.11ac and 802.11ad achieved similar video delivery scores that were near perfection with only minimal freezes in the absence of the interfering sources. For these tests, the docking station was transmitting the raw video bits from the video card at 30 fps and with a resolution of 1920x1080 with a bit depth of 16 or 32 bits.

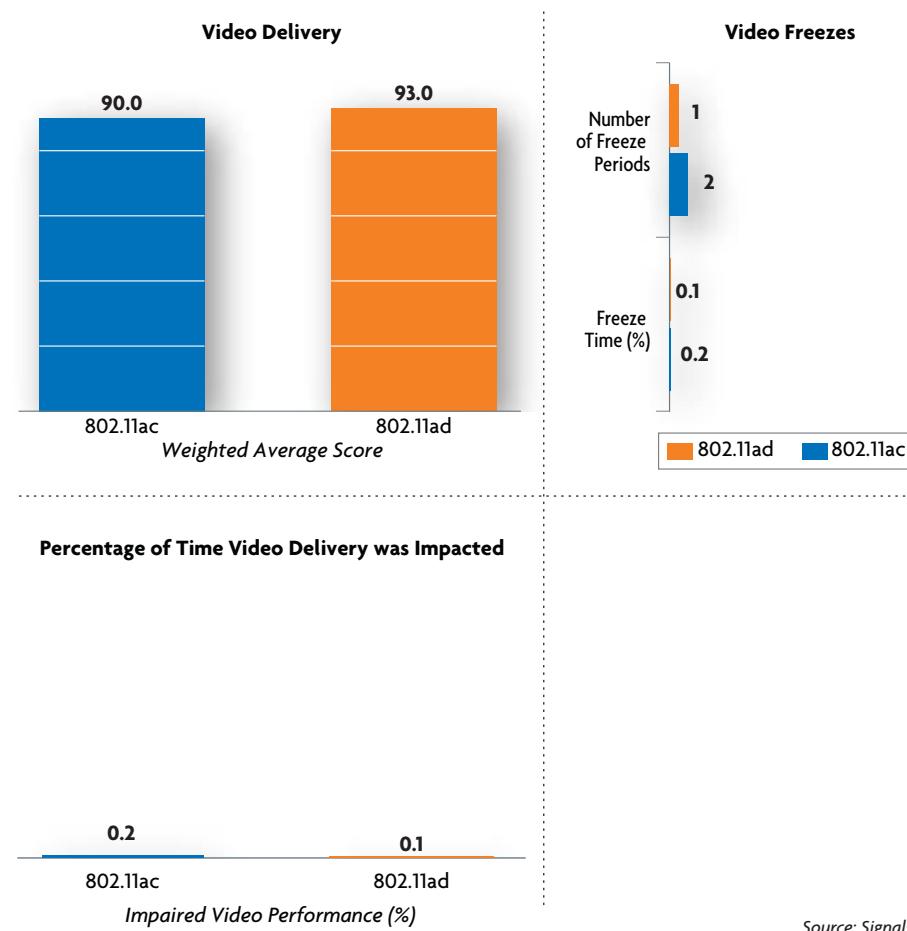
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We noticed through the Windows Task Manager, that the video transmission speed was about 400 Mbps with 802.11ac, but over 600 Mbps with 802.11ad. The codec repackages the video signal based upon the available bandwidth, which was obviously much higher with 802.11ad. By using a higher bit rate/less compression, the displayed video was clearer and more distinct to the human eye. Although this observation is subjective – Chromatic focuses on video delivery and not video quality – it is important to include in the overall assessment.

Although this information isn't depicted in the figure, we noticed through the Windows Task Manager, that the video transmission speed was about 400 Mbps with 802.11ac, but over 600 Mbps with 802.11ad. The codec repackages the video signal based upon the available bandwidth, which was obviously much higher with 802.11ad. By using a higher bit rate/less compression, the displayed video was clearer and more distinct to the human eye. Although this observation is subjective – Chromatic focuses on video delivery and not video quality – it is important to include in the overall assessment.

Figure 5. Video Performance without Interfering Sources



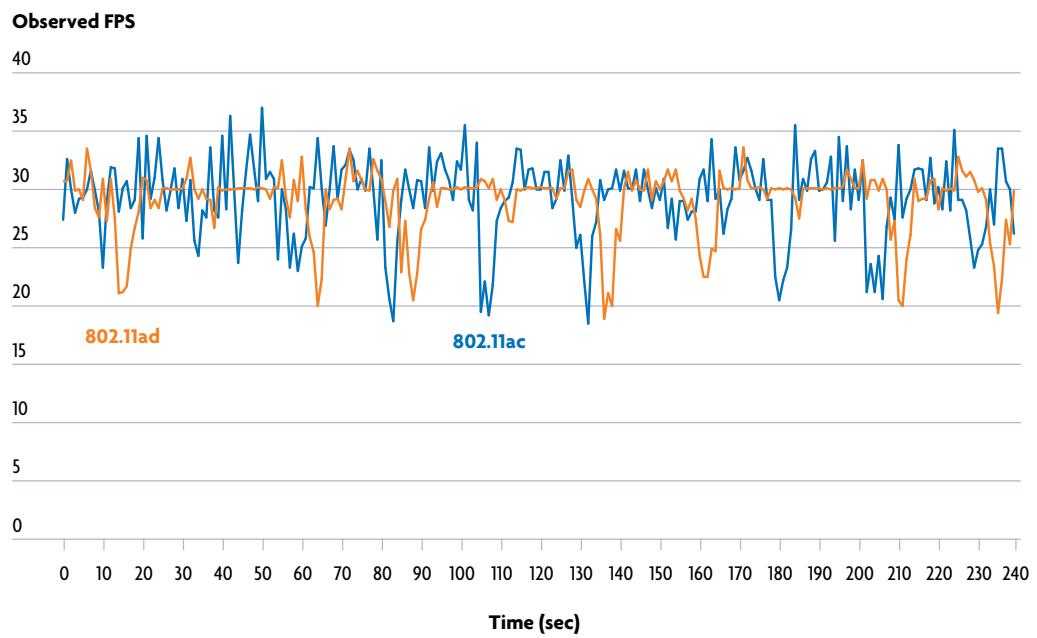
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Dips in the observed frame rate are a good indication that there were observable video freezes or impairments.

Figure 6 shows the observed frame rate, capture by the Chromatic test tool, for the two videos that we streamed with 802.11ac or 802.11ad. The figure illustrates that 802.11ac and 802.11ad transmitted the video with largely comparable variations in the frame rate. We emphasize that we used the same video source when testing both wireless technologies and that the observed frame rate doesn't provide any insight into the amount of bandwidth/use of compression, which we observed with the Windows Task Manager. However, dips in the observed frame rate, especially if they last for an extended period of time, are a good indication that there were observable video freezes or impairments evident when watching the video on the secondary monitor.

Figure 6. Observed Frame Rate without Interfering Sources



Source: Signals Research Group

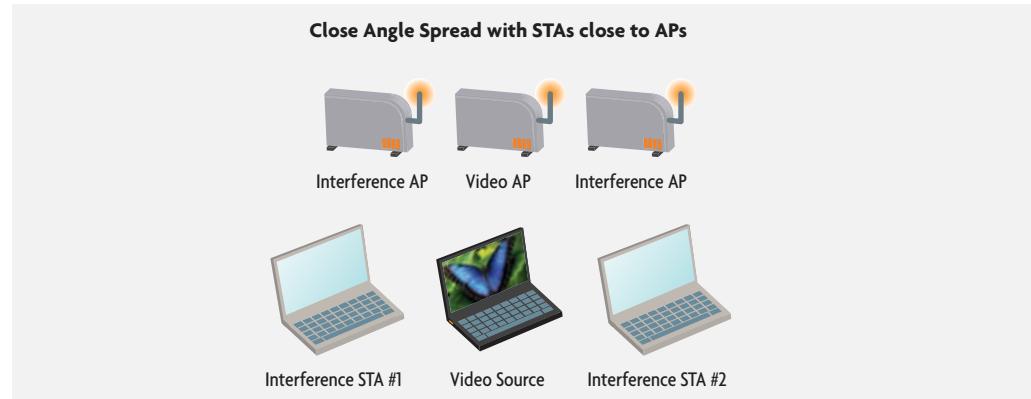
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When the APs and STAs were configured to support 802.11ad, there was not any observable impact on the transmitted video.

We now turn to showing the results from the tests involving the three network layouts. Since these tests included file transfers from the two additional pairs of APs/STAs, we also include the average speeds from these file transfers since they factor into the overall user experience for the office environment. Figure 7 shows the diagram for Network Layout #1.

Figure 7. Network Layout #1



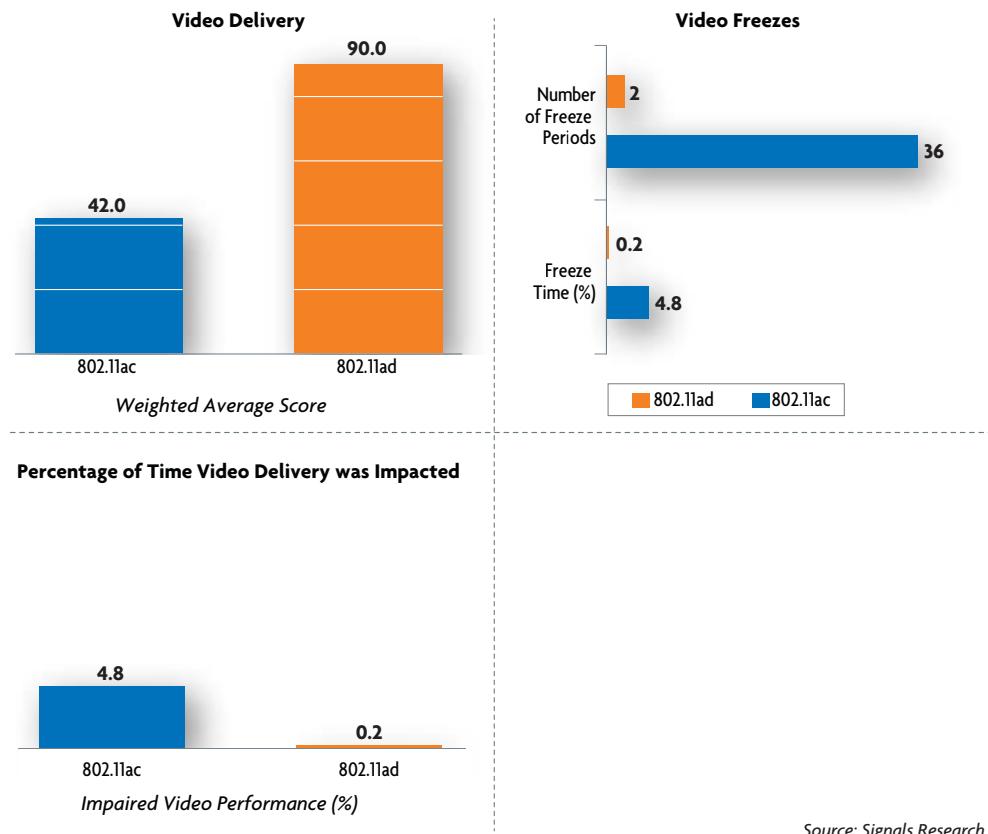
Source: Signals Research Group

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Figure 8 shows the video delivery KPIs for Network Layout #1 and Figure 9 highlights the observed frame rate for 802.11ac and 802.11ad in these two tests. Although the two additional 802.11ac transmissions had a dramatic impact on the video performance, when the APs and STAs were configured to support 802.11ad there was not any observable impact on the transmitted video.

Figure 8. Video Performance with Network Layout #1



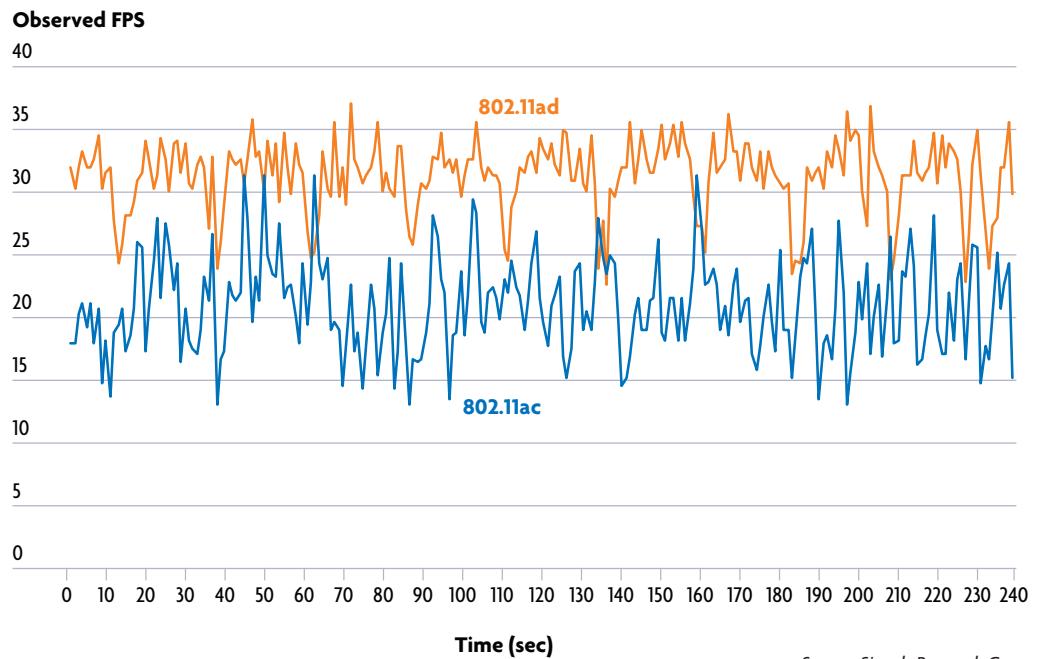
Source: Signals Research Group

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The information shown in Figure 9 is especially interesting when compared to the plotted lines that we showed in Figure 6. Without interfering sources, the two plotted lines, which reflect the observed frame rate, were largely comparable, as shown in Figure 6. However, with the introduction of the two interfering sources there was a noticeable drop in the observed frame rate for 802.11ac, but not for 802.11ad.

Figure 9. Observed Frame Rate with Network Layout #1



Source: Signals Research Group

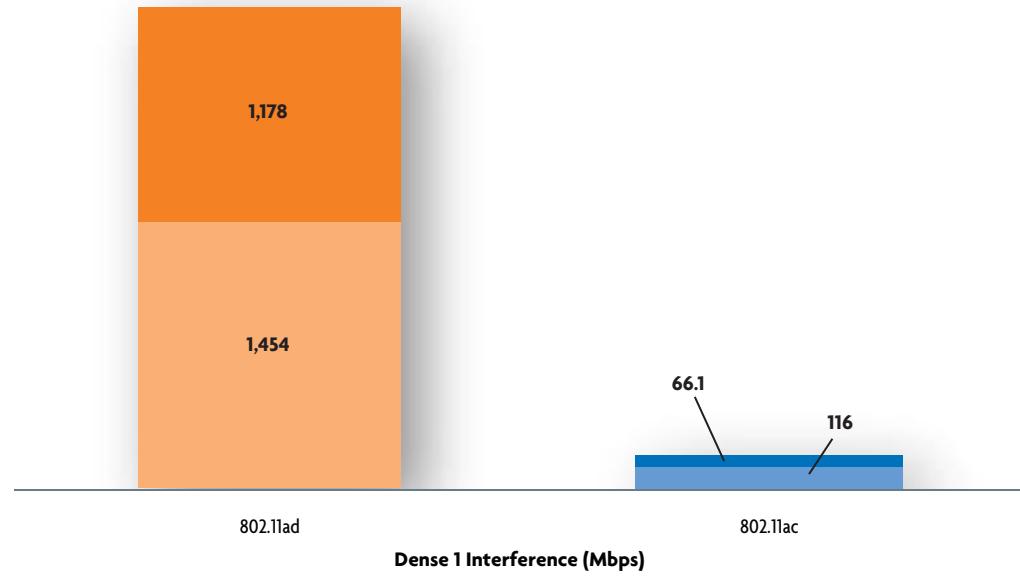
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With 802.11ac, someone would need to wait up to 18x longer for a file to transfer with 802.11ac instead of 802.11ad, or nearly 20 additional minutes for a 10 GB file(s).

It should be pretty obvious that in this scenario the user(s) watching the video definitely noticed the impact of switching from 802.11ad to 802.11ac – lower resolution/video quality and an increase in video freezes. Now we'll look at the file transfer rates from the two additional APs using either 802.11ac or 802.11ad and how the choice of technology could have impacted the user experience. As shown in Figure 10, by switching from 802.11ac to 802.11ad, the file transfer rate increased by a factor of 12.5x for one AP and by a factor of 17.8 for the second AP (net increase of 14.5x). Translating decreased speed into lost time and productivity is helpful since it means someone waiting for a file transfer to finish would need to wait up to 18x longer for a file to transfer with 802.11ac instead of 802.11ad, or in this cases nearly 20 additional minutes for a 10 GB file(s).

Figure 10. Average Throughput from Interfering Sources with Network Layout #1



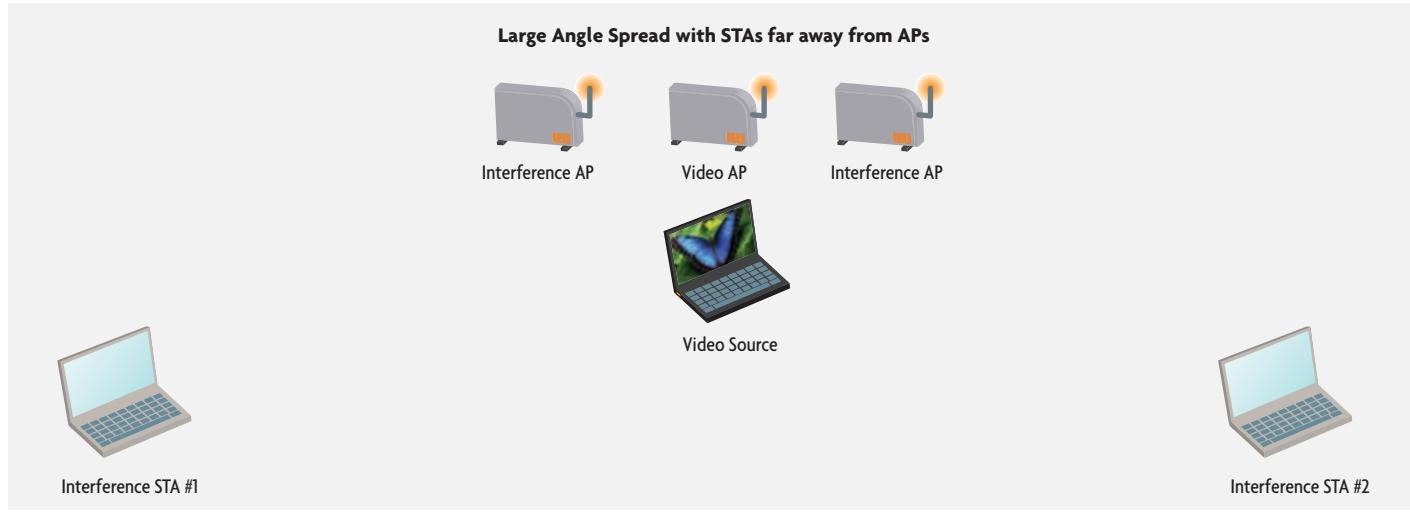
The remaining figures in this section of the whitepaper provide results for the other two network layouts described earlier in this section. The results are directionally comparable to the results for Network Layout #1 and are included for completeness sake.

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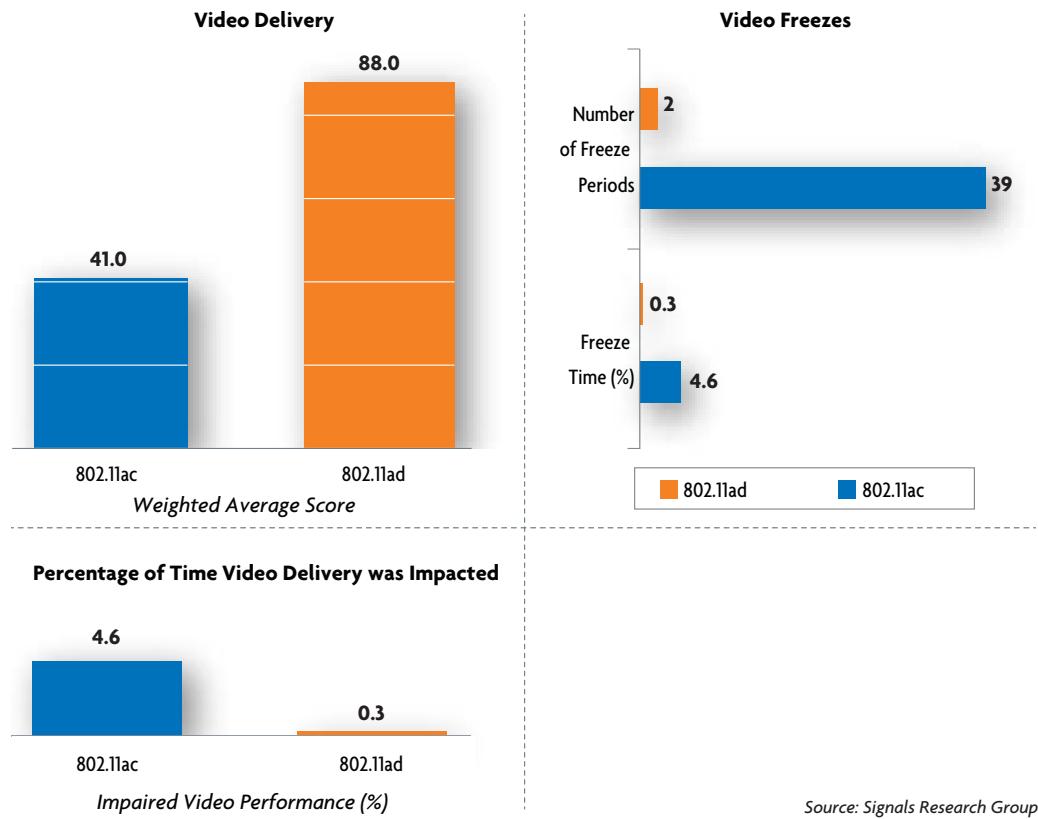
The results from Network Layout #2 and Network Layout #3 are directionally similar, despite the obvious differences in the file transfer rates from the two sets of tests. Specifically, in both sets of tests, 802.11ac would have required 11-17x more time to finish transferring a file, depending on the AP.

Figure 11. Network Layout #2



Source: Signals Research Group

Figure 12. Video Performance with Network Layout #2

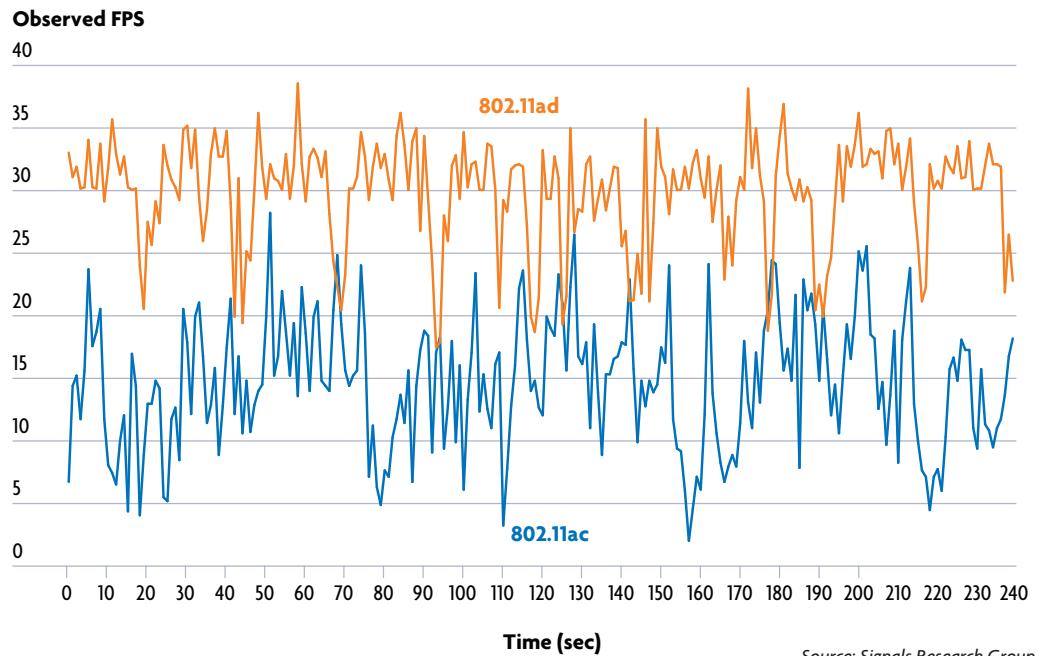


Source: Signals Research Group

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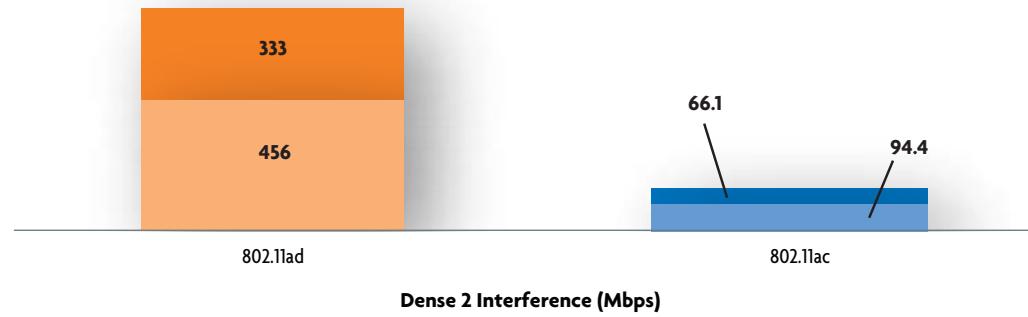
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Figure 13. Observed Frame Rate with Network Layout #2



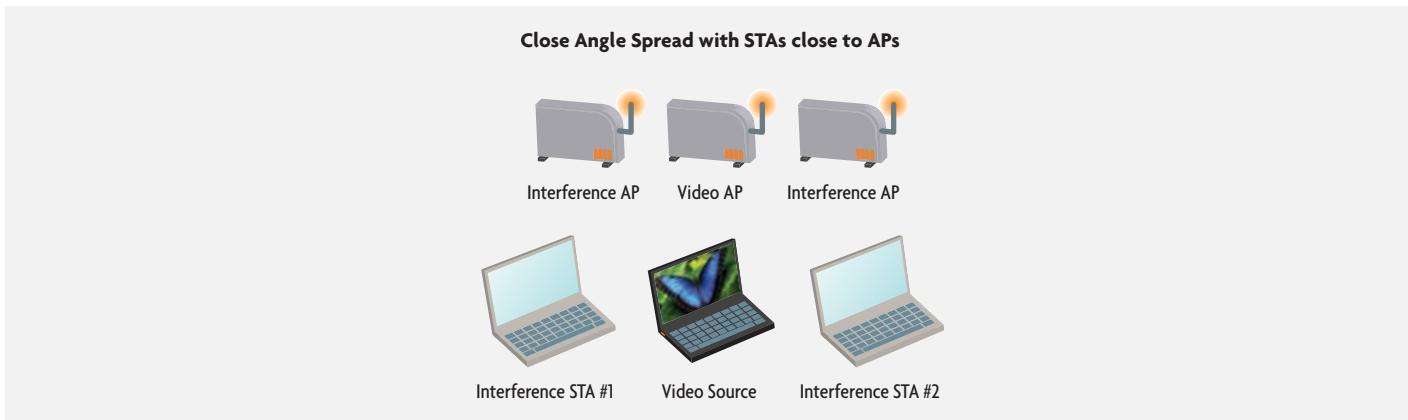
Source: Signals Research Group

Figure 14. Average Throughput from Interfering Sources with Network Layout #2



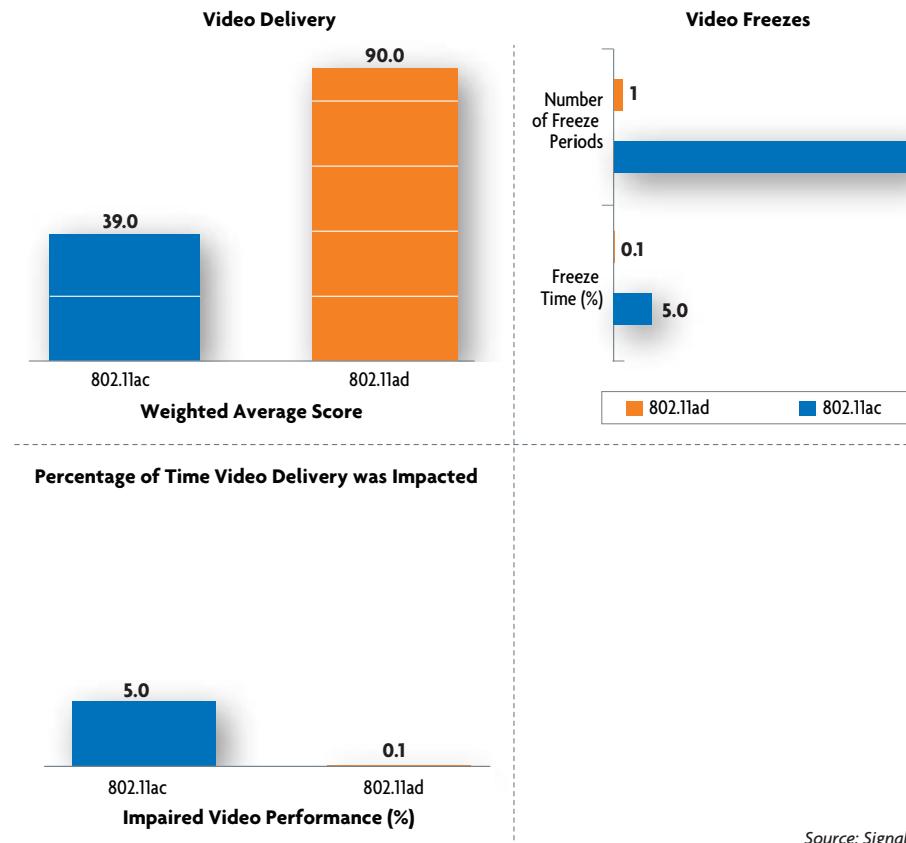
Source: Signals Research Group

Figure 15. Network Layout #3



Source: Signals Research Group

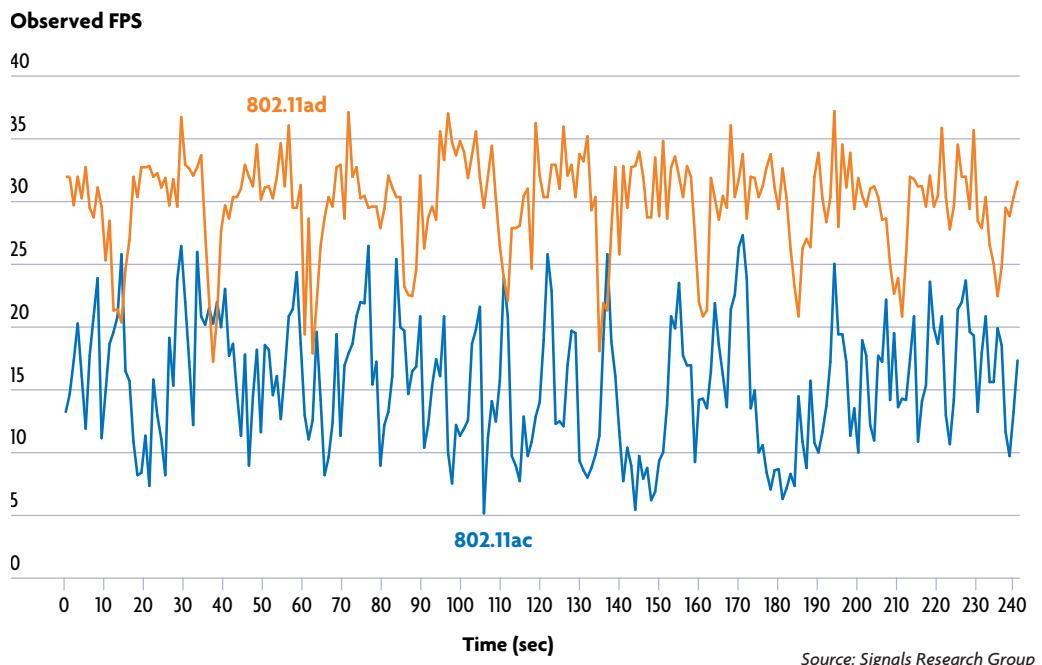
Figure 16. Video Performance with Network Layout #3



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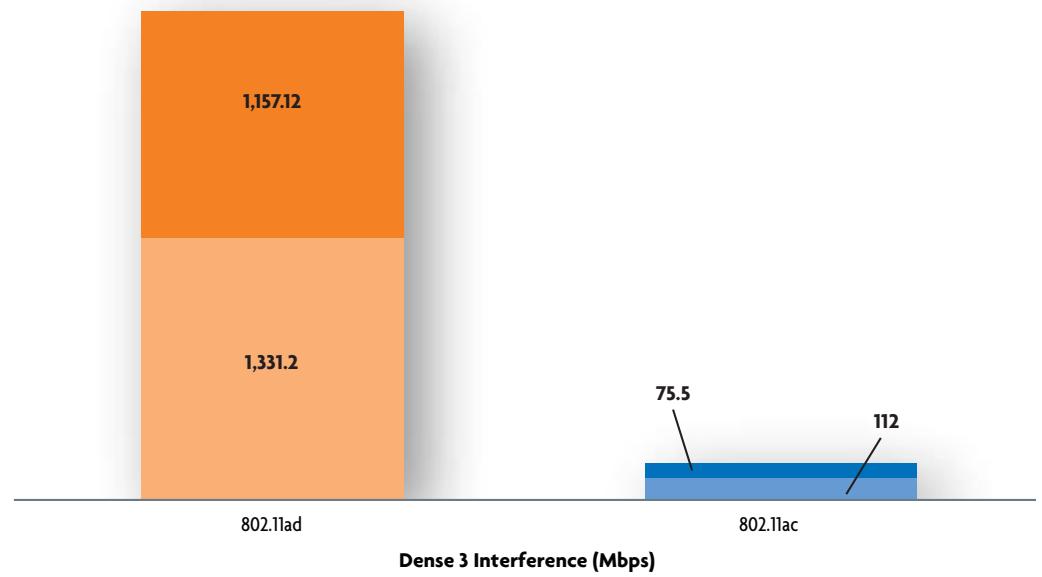
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Figure 17. Observed Frame Rate with Network Layout #3



Source: Signals Research Group

Figure 18. Average Throughput from Interfering Sources with Network Layout #3



Source: Signals Research Group

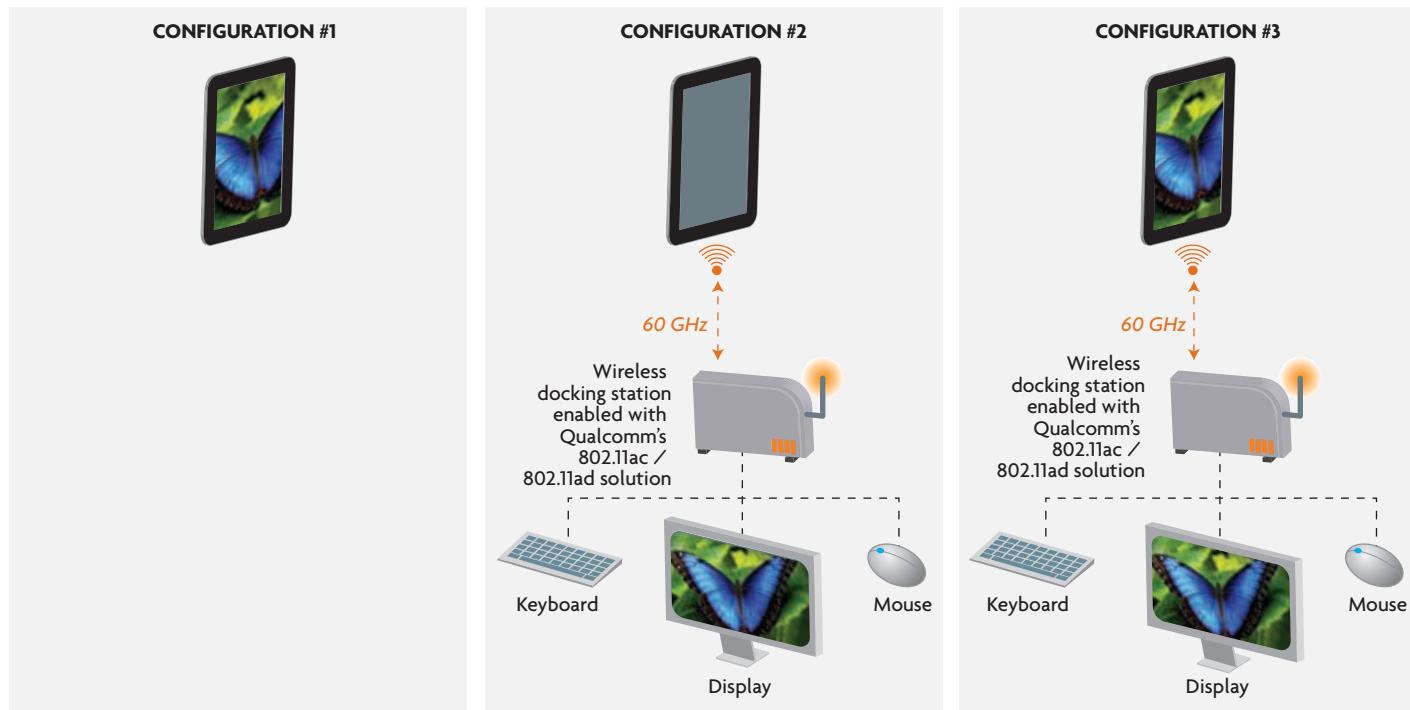
Using 802.11ad to project onto a nearby monitor can meaningfully increase the battery life of a portable tablet or notebook computer

Consumers and business customers who want to rely on a tablet or notebook computer for their personal and business needs generally want to remain completely untethered throughout the day. Thanks to cellular and wireless local area network communications it is possible to abandon cables and wires for basic communications purposes; however, there is still the matter of the battery life. Unless the tablet/notebook computer has enough battery life to last the entire day, the consumer or business customer needs to pack a charging cable. Besides increasing the size and weight of the contents that must be carried in a briefcase or computer bag, there is the additional inconvenience of needing to recharge the battery throughout the day.

The backlight of the display monitor accounts for majority of the power consumption so by keeping the backlight turned off it is possible to meaningfully extend the battery life. Unfortunately, if the backlight is turned off then the tablet/notebook computer doesn't provide any useful functionality. Using a wireless docking station and 802.11ad, it is possible to get the best of both worlds. To demonstrate this point, we conducted three separate tests involving a tablet running a number of applications, including web browsing, email, and displaying images (e.g., a PowerPoint presentation). We continuously rotated through these applications while using a third-party application (TabletMark V3 from Bapco) to measure the battery life.

- **Configuration #1** – Tablet not Docked (Screen ON)
- **Configuration #2** – Tablet Docked via 802.11ad to Wireless Docking Station (Screen OFF)
- **Configuration #3** – Tablet Docked via 802.11ad to Wireless Docking Station (Screen ON)

Figure 19. Tablet Battery Life Test Scenarios



Source: Signals Research Group

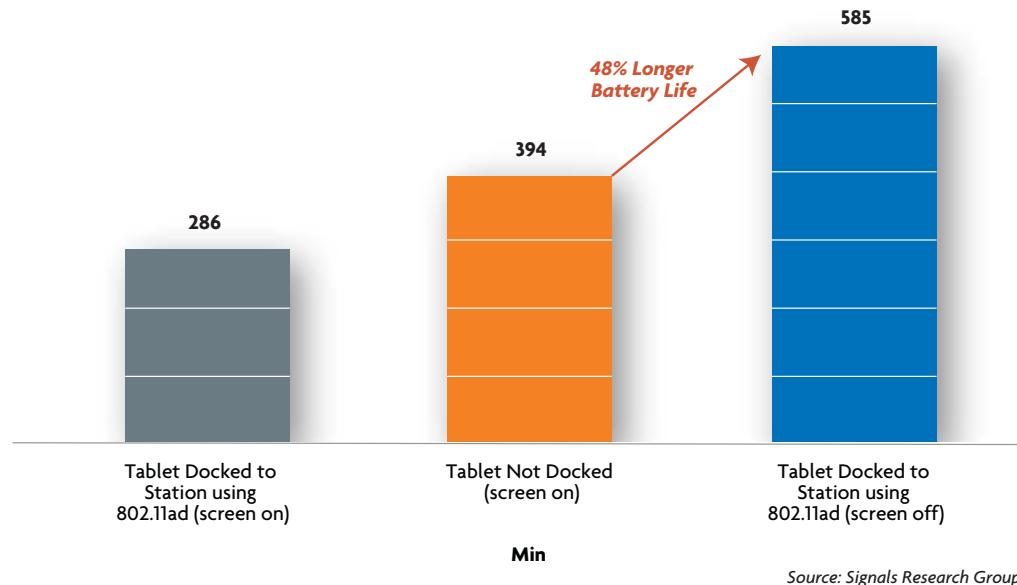
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Configuration #1 represents the traditional usage model that is most typically today. Configuration #2, which involves using 802.11ad to connect the tablet to a wireless docking station, provides the same degree of mobility throughout the room where the wireless docking station is located. However, because there is a secondary display monitor connected to the wireless docking station, the display on the tablet can be turned off. We also included Configuration #3 for comparison purposes. It differs from Configuration #2 in that the tablet display remains turned on.

The results from these tests show that by using 802.11ad, combined with a wireless docking station and a secondary display monitor, the battery life of the tablet increased by 48%. Furthermore, by providing nearly ten hours of battery life (585 minutes), it is possible to use the tablet for an entire business day while leaving the battery charger at home. Using the tablet by itself means the display needs to be left turned on in order to provide the necessary functionality. This requirement limited the battery life to only 6.5 hours (394 minutes), or well below what is possible with 802.11ad.

Figure 20. Tablet Battery Life with Different Configurations



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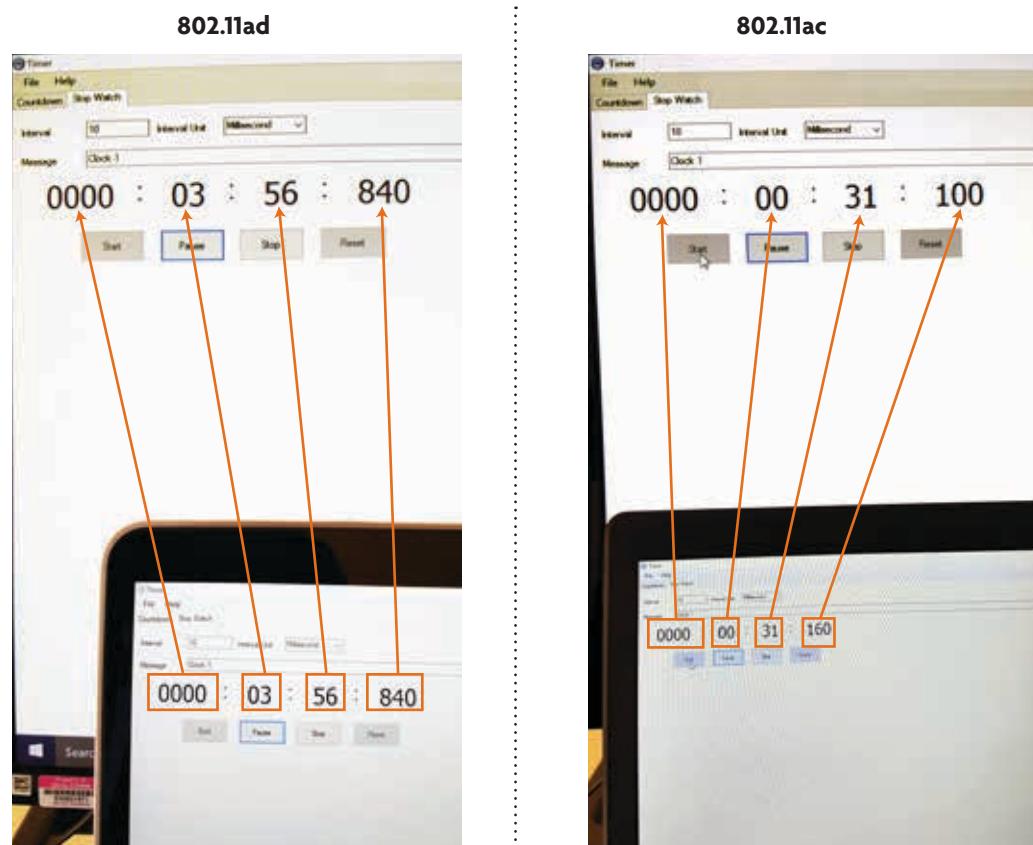
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In addition to delivering ultra-high bandwidth capabilities, 802.11ad supports very low latency applications

802.11ad is widely recognized for enabling high bandwidth applications; however, it also supports applications which require near-real-time responses, thanks to the ultra-low latency of the wireless protocol.

To demonstrate the latency of 802.11ac and 802.11ad we used a fairly simplistic, albeit highly reliable means of measuring the latency. We used either 802.11ac or 802.11ad to rebroadcast/mirror the contents of one computer monitor on a second monitor – comparable to the setup that we used for our video tests. We then used the Timer feature of Windows to start a stopwatch which tracked the time in millisecond increments. By placing one monitor behind the other monitor we could then use the camera/video functionality of our smartphone to take rapid-shot pictures or video of the two monitors. We let the stopwatch run for tens of seconds with each wireless technology in order to capture a meaningful amount of data (pictures or still frames from a video) and then analyzed each picture to determine the time differences displayed on the two monitors. Figure 21 shows two sample images out of the hundreds that we collected. With 802.11ac, there was 60 ms of latency while with 802.11ad there was no discernable amount of latency. In all likelihood the 802.11ad latency wasn't 0 ms, but it was at least low enough to not be evident with our test methodology.

Figure 21. Sample Images from Latency Test



Source: Signals Research Group

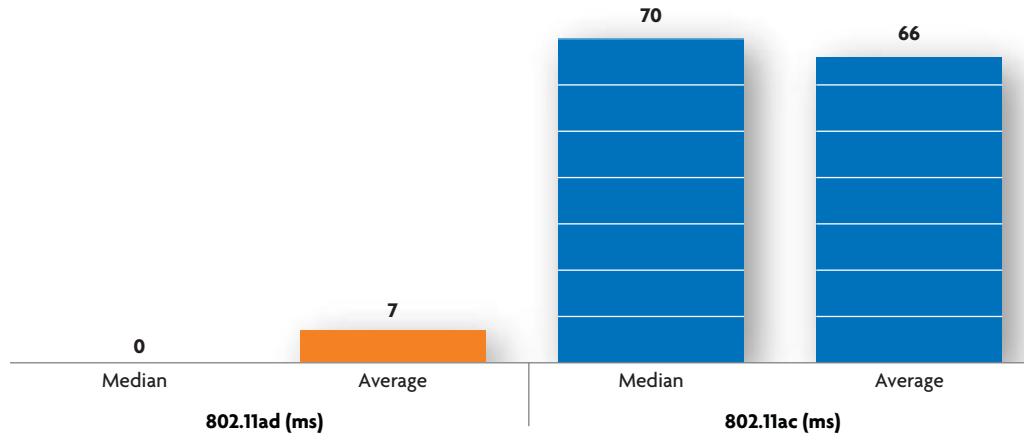
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The latency of 802.11ad is approximately one-tenth that of 802.11ac.

We subsequently used dozens and dozens of images, such as the ones shown in Figure 21 to calculate the average and median latency values for the two wireless protocols. Based on our analysis of the data (Figure 22) we conclude that the latency of 802.11ad is approximately one-tenth that of 802.11ac.

Figure 22. Latency Differences between 802.11ac and 802.11ad



Source: Signals Research Group

“High latency” in the air interface can turn what would have been a compelling VR/AR user experience into a big headache – both literally and figuratively.

Latency of only 60 ms isn’t bad and it more than suffices for many use cases, including video. However, when it comes to applications that leverage virtual/augmented reality or even more basic applications, such as a wireless mouse, “high latency” in the air interface, even if it is only tens of milliseconds can turn what would have been a compelling user experience into a big headache – both literally and figuratively. High latency can result in nausea or a form of motion sickness not to mention making it very difficult to complete the task being simulated by the VR/AR system.

Although we are by no means VR/AR experts or “gamers” we’ve read enough to know that the end-to-end latency needs to be in the range of 10-20 ms for most people to not be able to notice the time delay. With a sub-10 ms latency that 802.11ad supports, there should be sufficient room in the latency budget for other factors which contribute to latency, including computer processing and the delivery of the content from a remote server, such as the Internet.

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The complementary roles of 802.11ac and 802.11ad with a wireless docking in an office environment

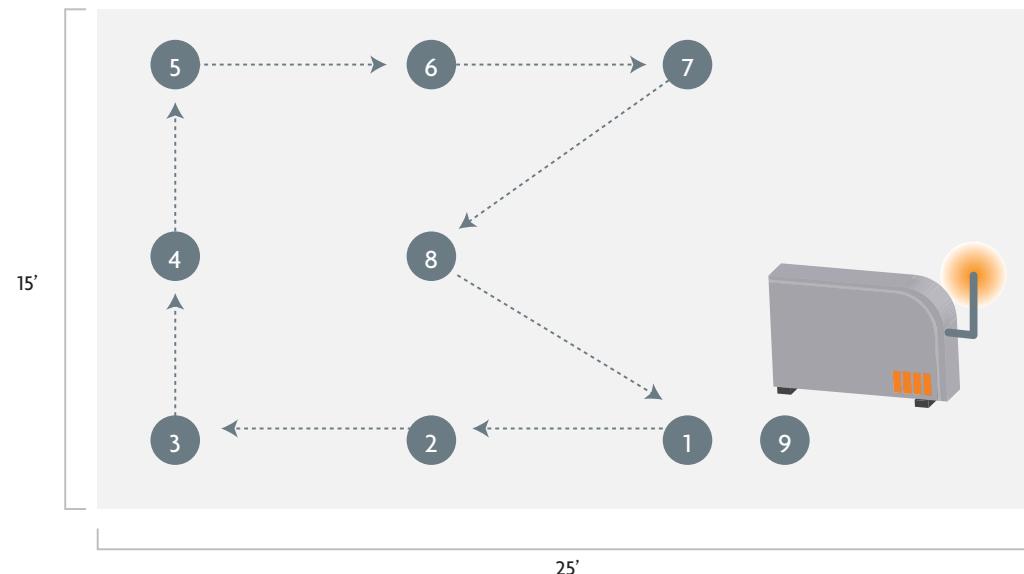
FST will allow the consumer to take full advantage of the capabilities of 802.11ad while benefiting from the coverage and robustness that 802.11ac offers.

802.11ad offers reliable coverage, even with solutions that are optimized for personal area applications and services

One perceived limitation of 802.11ad is that it is highly susceptible to movement and anything that gets in-between the AP and the STA. While it is true that 802.11ac is more reliable and resilient than 802.11ad, thanks largely to the use of 5 GHz versus 60 GHz, this statement shouldn't be extrapolated to suggest 802.11ad doesn't support a fair degree of robustness, even when the STA is moving around the room. Additionally, there is a forthcoming feature called FST (fast session transfer) which will enable seamless session handovers between the two air protocols for various applications. This feature will allow the consumer to take full advantage of the complementary nature of 802.11ad and 802.11ac.

For this study, we placed the 802.11ad AP at one end of the room and then walked around the room while transmitting data between the AP and the STA using iPerf. For this study, the 802.11ad antenna was mounted toward the top of the display of a commercial notebook computer. Figure 23 shows the path that we followed while carrying a laptop computer with 802.11ad functionality. Each circled number reflects a point along the route where we paused for several seconds before moving to the next measurement point. We spent about 4-5 seconds walking to each point and then stopped at each data point for 25-26 seconds (30 seconds total) before moving to the next measurement point.

Figure 23. Walking Path and Stationary Points



Source: Signals Research Group

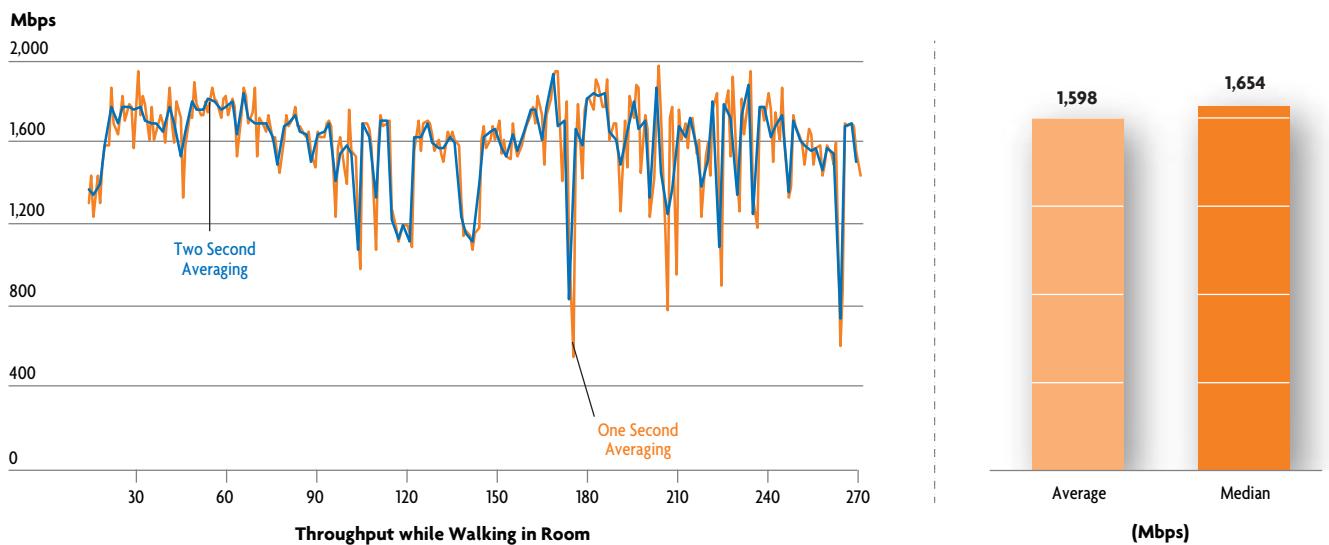
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The lowest data speed that we recorded during the 802.11ad test (545.8 Mbps) is arguably a high data rate for 802.11ac with normal operating conditions.

Figure 24 shows the measured data speeds in one second time increments during the 270 second test. Additionally, the bar graph provides information regarding the average and median data speeds during the test. There are a few dips in the instantaneous data speeds that we observed but these dips were very brief before the data speed quickly returned to a much higher level. Further, it is worth noting that the lowest data speed that we recorded during the test (545.8 Mbps) is arguably a high data rate for 802.11ac with normal operating conditions.

Figure 24. Measured Data Speeds



Source: Signals Research Group

These tests also leveraged a docking station as the access point even though the configuration was not optimal for this type of usage scenario. We anticipate even stronger performance with 802.11ad access points that are designed to provide enhanced coverage versus the coverage necessary for a docking station. These products will also likely include larger antenna arrays, which will further magnify the performance of 802.11ad beamforming.

Test Methodology

SRG conducted the tests in large room of a residential home in Atherton, California. We used commercially-available products that could be configured to support 802.11ac or 802.11ad. The commercial products with 802.11ad are somewhat limited so we focused this initial study on use cases that are likely in an office environment. We note that we used a docking station with 802.11ac/802.11ad functionality as one of the primary APs in the study. SRG collected and analyzed all of the data, but we did receive some logistical support, such as reconfiguring the APs between the two wireless protocols, from Qualcomm engineers.

For the video tests, we used Spirent Communications' Chromatic test solution.

For these tests, we defined three primary groups of key performance indicators (KPIs): throughput, latency, and video performance. For throughput, we used iPerf to generate the data transfers and the log files which contained instantaneous data speeds in one second increments. For the latency measurements, we used the camera/video functionality of our smartphone to capture what was being displayed on two video monitors. For the video tests, we used Spirent Communications' Chromatic test solution. We have used Chromatic numerous times in the past when analyzing the video delivery capabilities of LTE, including IR.94. Chromatic is a vision-based measurement tool that leverages the video and audio feeds through an HDMI output on the Wi-Fi STA to capture and analyze the streaming video, which the smartphone is simultaneously playing on its screen. By using video with special markers and audio tones, it is possible to quantify how well the Wi-Fi system delivers the video and audio content to the mobile device (STA).

Analyzed video-related parameters include the following:

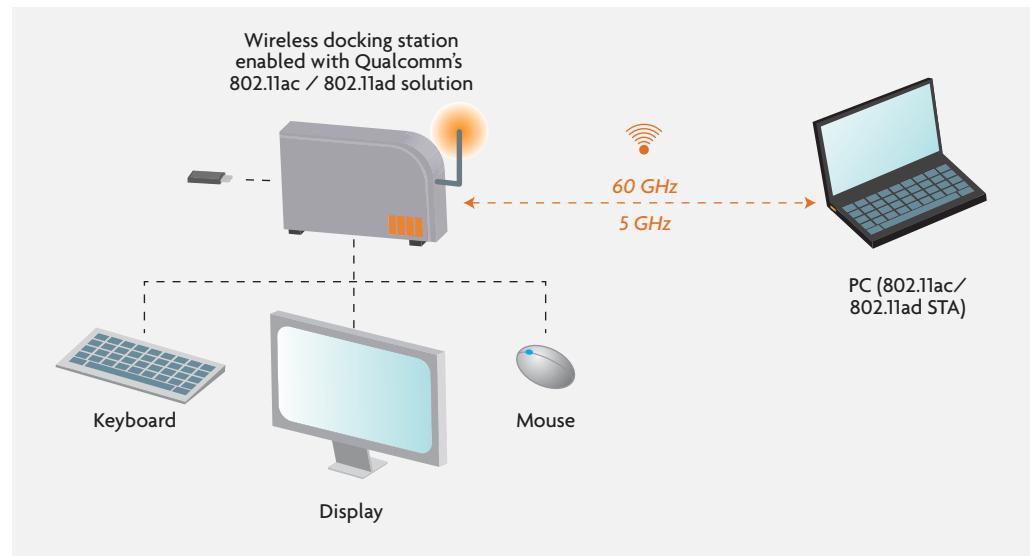
- **Video Freezes** – the percentage of time and the number of instances in which the video was frozen
- **Impaired Video Frames** – the percentage of time and the number of instances in which the delivered frame was impaired
- **Impaired Video Performance** – the percentage of time that the video was frozen OR impaired (the sum of the video freeze time and impaired video time)
- **Frames per Second** – time series plot of the observed frames per second (fps) – done in order to show variations in the observed fps during the test period
- **Weighted Average Video Score** – quantifies the overall video delivery experience using a combination of the video freezes and impairments, as well as variations in the fps

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The test setup was pretty straightforward and we discussed it earlier in this paper. However, we are including two diagrams which illustrate the configurations used for most of our tests. For the tests involving the docking station (Figure 25), we connected various peripherals to the wireless docking station, including a USB flash drive, a second display monitor, and a mouse/keyboard. The notebook computer subsequently connected to the docking station using either 802.11ac or 802.11ad.

Figure 25. Network Configuration – Wireless Docking



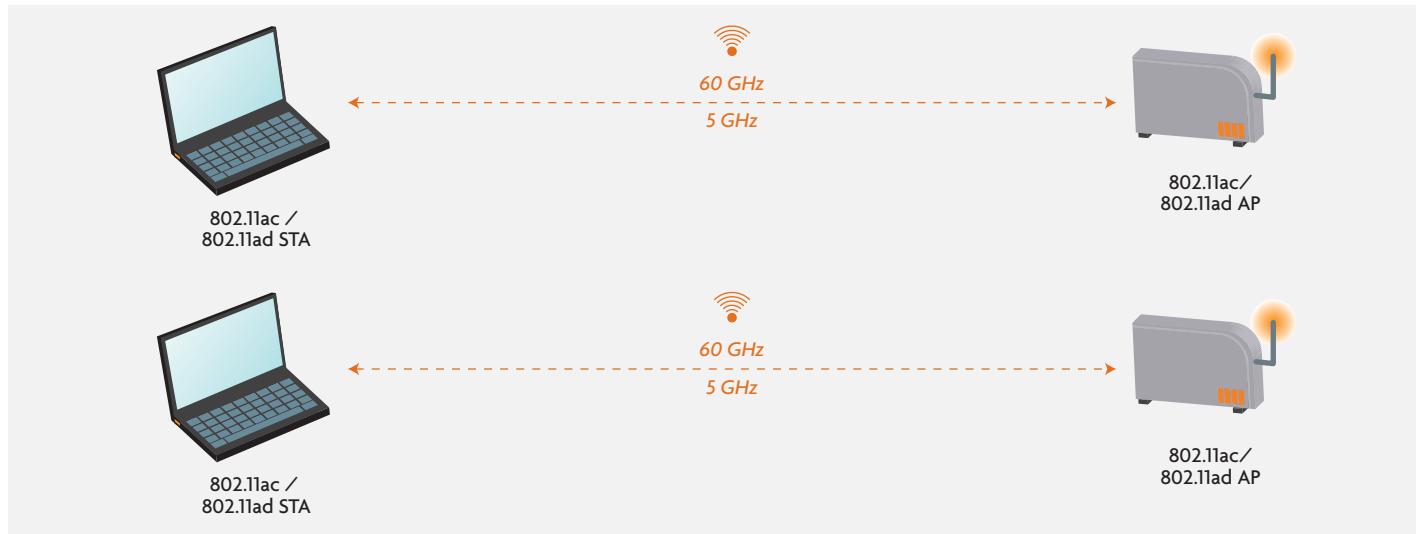
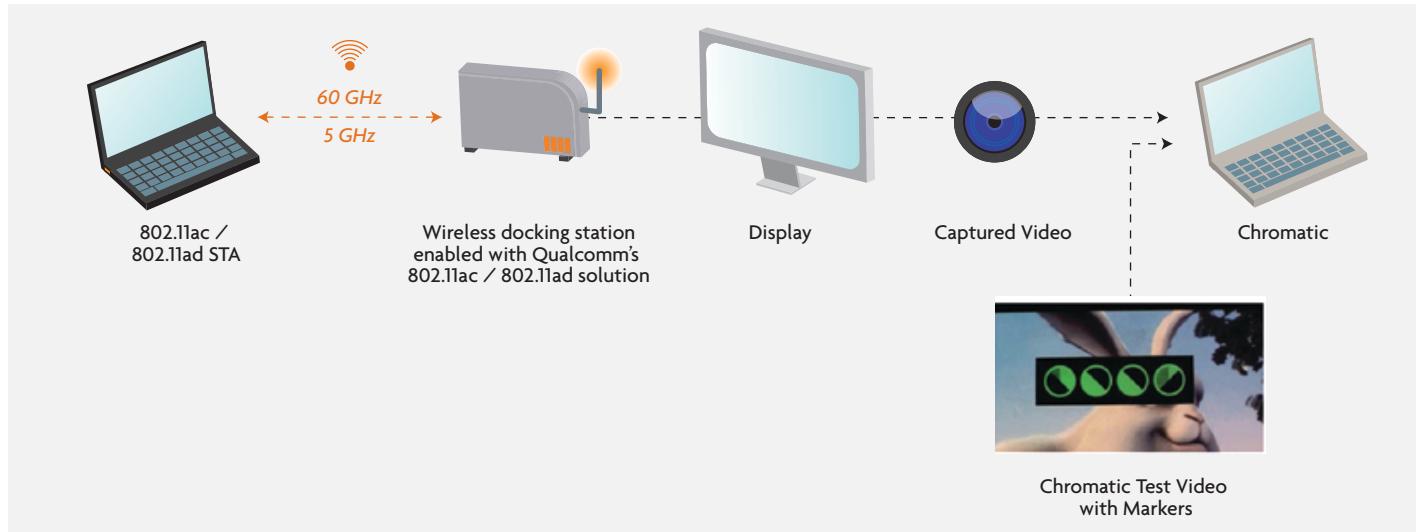
Source: Signals Research Group

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For the video tests, we connected a notebook computer to the AP via 802.11ac or 802.11ad with the AP connected to a second display using HDMI. We then played a video with the inserted video and audio markers on the computer, with the video also rebroadcast to a second monitor using one of the wireless protocols. In order to generate additional data traffic in the same radio channel, we used two additional APs/STAs. We provided the layout of the APs and STAs in earlier figures.

Figure 26. Network Configuration – Video Tests



Source: Signals Research Group

