The Benefits of OFDMA for Wi-Fi 6

A technology brief highlighting Qualcomm Technologies' competitive advantage

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1. Executive Summary

One of the defining features of today's first generation Wi-Fi 6 certification program is support for OFDMA (Orthogonal Frequency Division Multiple Access). OFDMA is offered as part of the Wi-Fi 6 standard and requires highly effective scheduling techniques to be delivered in highly congested and complex network deployments. As manufacturers and the industry at large embrace Wi-Fi 6, the potential value of successful OFDMA implementation, along with the ability to quantify that value, requires analysis and documentation.

As a vocal proponent of the full range of these multi-user technologies and scheduling techniques, Qualcomm Technologies has successfully delivered highly differentiated OFDMA implementations, as well as conducted analysis to clearly illuminate the benefits of using OFDMA.

These analyses were performed across a set of real-life, intense-usage network deployments spanning home, enterprise, and classroom scenarios. Across all scenarios, the primary user-level benefit delivered by OFDMA is an overall reduction of latency, with downlink latencies reduced by 40–90%, and uplink latencies reduced by 23–99% (depending on the scenario and compared to legacy single user (SU) mode).

Building on this analysis, Qualcomm Technologies further analyzed the combined benefits to system throughput and latency under additional intense-use application scenarios for voice, gaming, and uplink video. In these comparisons, two access points were used; the first featuring Qualcomm Technologies' commercially available scheduling technology, the second using the chipset and OFDMA scheduling technology of a leading chipset competitor. This analysis highlights the significant latency-based competitive advantage for multiple application and network loading scenarios delivered by the Qualcomm Technologies-based system, with up to 80–200 milliseconds (ms) of lower latencies for users in networking environments.

2. Introduction and Objectives

Prior to 2014, the primary focus of each generation of Wi-Fi technology was increasing peak throughputs. Starting in 2014, as dense deployment scenarios became the new normal, the Wi-Fi industry focused on creating new technologies and standards to increase the efficiency of Wi-Fi networking. The standard for high efficiency networking was developed in the IEEE 802.11ax Taskgroup. Key technologies adopted in the 802.11ax standard intended to increase the efficiency of networking, including: OFDMA (Orthogonal Frequency Division Multiple Access) and MU-MIMO (Multi-User Multiple Input and Multiple Output).

The Wi-Fi Alliance branded the generational technologies based on the 802.11ax standard as 'Wi-Fi 6,' and launched its interoperability certification program for Wi-Fi 6 in September 2019. With downlink MU-MIMO available as part of Wi-Fi 5 (in limited fashion compared to Wi-Fi 6), the most impactful new feature for first generation Wi-Fi 6 is OFDMA. Today, the industry and marketplace are starting to experience the potential of this powerful technology, along with some challenges in implementing and measuring the value therein.

As a leader in wireless technologies, Qualcomm Technologies is focused on ensuring that its Wi-Fi 6 implementations take full advantage of all OFDMA has to offer. Achieving the high efficiency benefits of Wi-Fi 6 is highly correlated to the effectiveness of the traffic scheduling technology used by the Wi-Fi access point.

The purpose of this whitepaper is to:

- Provide perspective and explanation around what OFDMA can and should deliver in the context of a Wi-Fi 6 network
- Highlight the benefits of effectively implemented OFDMA in real-life examples, as demonstrated by Qualcomm Technologies
- Illustrate the pivotal role sophisticated network scheduling technology plays in realizing the actual value of OFDMA in Wi-Fi 6 networks

3. Wi-Fi 6, High Density Networking and OFDMA

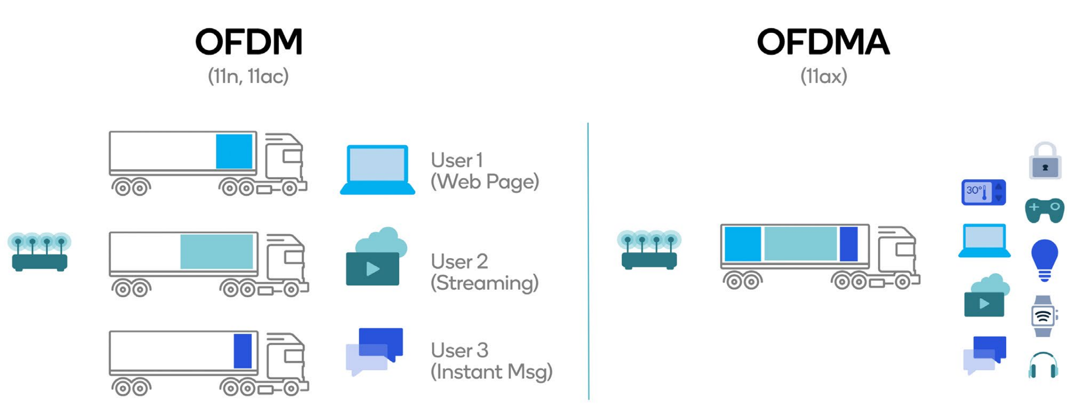
OFDMA (Orthogonal Frequency Division Multiple Access) is one of the key technologies used in Wi-Fi 6 to significantly increase the efficiency of Wi-Fi networks in today's increasingly dense deployments. In practice, this means OFDMA delivers higher aggregate throughputs and lower latencies in Wi-Fi networks with high client counts per access point, compared to single user operations.

How does OFDMA work?

A Wi-Fi Alliance whitepaper succinctly describes the OFDMA feature <*source: 'Wi-Fi CERTIFIED 6: A new era in Wireless Connectivity,' September 2019'*>.

OFDMA brings an improvement over prior versions of Wi-Fi that use orthogonal frequency division multiplexing (OFDM). It subdivides the Wi-Fi channel into smaller frequency allocations called resource units. By partitioning the channel, parallel transmissions of smaller frames to multiple users occur simultaneously. For example, a traditional 20 MHz channel might be partitioned into as many as nine smaller channels. Using OFDMA, a Wi-Fi 6 AP could simultaneously transmit smaller frames to nine Wi-Fi 6 clients.

Figure 3.1 OFDM vs OFDMA Technology



The Wi-Fi Alliance Whitepaper further explains the difference between uplink and downlink OFDMA.

Uplink OFDMA is one of the key features introduced by Wi-Fi 6 and is among the most significant differences relative to 802.11ac. Uplink OFDMA allows data frames to be transmitted simultaneously by multiple stations. This amortizes preamble overhead and medium contention overhead, which leads to high aggregated network throughput. Uplink OFDMA can provide additional gains by permitting greater transmit power level per device, subject to regulatory requirements, and thus signal coverage on the uplink, since the transmit power of each client device can be concentrated on smaller allocated resource units.

Downlink OFDMA allows multiple data frames to be transmitted in a single data unit to multiple stations, thus amortizing preamble overhead and medium contention overhead, leading to higher aggregated network throughput. Downlink OFDMA can further optimize aggregate throughput by balancing the allocation of power between users at high versus low signal-to-noise ratios, subject to total power constraints and regulatory requirements.

Need for High Quality Scheduling

In dense networking environments, a Wi-Fi access point (AP) attempting to schedule OFDMA transmissions will typically encounter clients with varied applications, traffic patterns, distances from the AP, and Wi-Fi capabilities (e.g., the number of antennas and spatial streams supported). In a dense deployment environment, the role of the AP scheduler is critical and must be optimized for high speed decision making determining which data frames from which clients to combine into one transmission (either downlink or uplink). For scheduling downlink and uplink OFDMA transmissions, the AP may have as little as 20 microseconds (0.000002 second) to decide which resource units (packets) to include in the joint transmission*.

Successful, high-performance OFDMA scheduling requires a high degree of processing power and hardware support to enable multiple traffic queues. High performance, high-quality scheduler development is typically achieved through the application of deep networking expertise, and a discipline to continue year-over-year scheduler improvement.

**Note: The scheduler will typically have the LBT random backoff time to prepare the transmission, which is between 20–170 microseconds.*

4. Latency in Wi-Fi Networking

Latency refers to the time it takes for a packet to go from one network node to another. Several convergent market drivers today, like multiplayer gaming, VoIP, AR/VR, and real or perceived latency advantages of 5G cellular, are creating powerful incentive for reduced latencies in Wi-Fi networks.

One of the key benefits of OFDMA is the potential for reduced latencies in dense deployment scenarios. Since latency is an important factor in wireless networking, it seems worthwhile to provide some context.

One way in which consumers may become aware of latency is through a network speed test application (e.g., Ookla), which lists the ping latency. However, this latency number covers the entire set of network segments from the user's device to the ping server, such as the Wi-Fi connection between the client and AP, the access network (e.g., cable, DSL, fiber), the fiber optic backbone, and the access network for the ping servers in the cloud. These tests typically yield latency numbers somewhere between 10–30 ms (0.01–0.03 seconds), but physical distance to the ping server in the cloud plays a key role. For example, the ping latency for a Wi-Fi client in San Francisco is 10 ms to a ping server based in San Francisco and around 150 ms for a ping server based in Amsterdam.

In the context of Wi-Fi networking, overall Wi-Fi network latency is comprised of the combination of the downlink latency (AP to client) and uplink latency (client to AP). The latency achieved in practice is highly dependent on the traffic load, the density of the deployment, and interference (e.g., from overlapping Wi-Fi networks).

For example, testing conducted by Qualcomm Technologies has shown a roundtrip ping latency of around 2–3 ms in the case of one AP, one client, and no interference, and <4 ms for bi-directional VoIP. Testing in a two-hop multi-AP network setting has shown bi-directional ping latencies of 4–5 ms.

Another important concept determining networking performance is 'jitter,' (i.e., the variation in latencies experienced between two network nodes). In our analysis, we show the results of our latency measurements at the 95th percentile, which implies that actual latencies are lower in 95% of the cases relative to the number reported. Reporting latency measurements in this manner incorporates the concept of jitter, as a high-quality experience for real-time applications can only be retained if only a very small percentage of packets arrive later than a specific deadline.

5. Impacts of OFDMA in real life scenarios

Wi-Fi 6 technologies were specifically developed to improve network performance in environments where there are large numbers of devices per access point and intensive (high-bandwidth/low-latency) application usage. In addition to handling the needs of many simultaneously operating devices all connected to a single access point, these networks often exist in overlapping networks environments like densely populated apartment buildings or downtown offices. Overlapping Wi-Fi networks typically operate on the same frequency band. Because they are in such close proximity to one another, the Wi-Fi 'Listen Before Talk' sharing protocol causes the networks to defer to each other. This effectively splits the time each network can be involved in a transmission.

To highlight the benefits of using OFDMA in such dense deployment scenarios, Qualcomm Technologies conducted a set of throughput and latency measurements for three different 'real-life' networking scenarios defined as; home, office, and classroom.

This section discusses each scenario and the results of associated analysis, highlighting the impact of using OFDMA compared to traditional single user transmissions.



5.1. Home Scenario

During the year 2020, due to the COVID-19 pandemic, home networks have been exercised intensively, with multiple people in a household conducting work, schooling, gaming, and entertaining, all using the home Wi-Fi network. To showcase the latency benefits of OFDMA, a test setup was used with a similarly intense use case scenario. A further example of this type of home scenario might be where three family members are engaged in multiplayer gaming, while also being engaged in video communication with the other players.

The busy home scenario we modeled covers:

- 4x High-quality video calls (3 Mbps each)
- 4x Multiplayer gaming sessions, each with a 1.5 Mbps downlink video session
- 5x Security cameras (3 Mbps)
- 3x People browsing the Internet, with interactive content

In addition, the scenario included the following background traffic:

- 2x File synchronization (6 Mbps UL) (e.g., uploading files)
- 1x Email send/receive
- 4x OBSS traffic (50 Mbps) (overlapping networks using the same frequency channel)

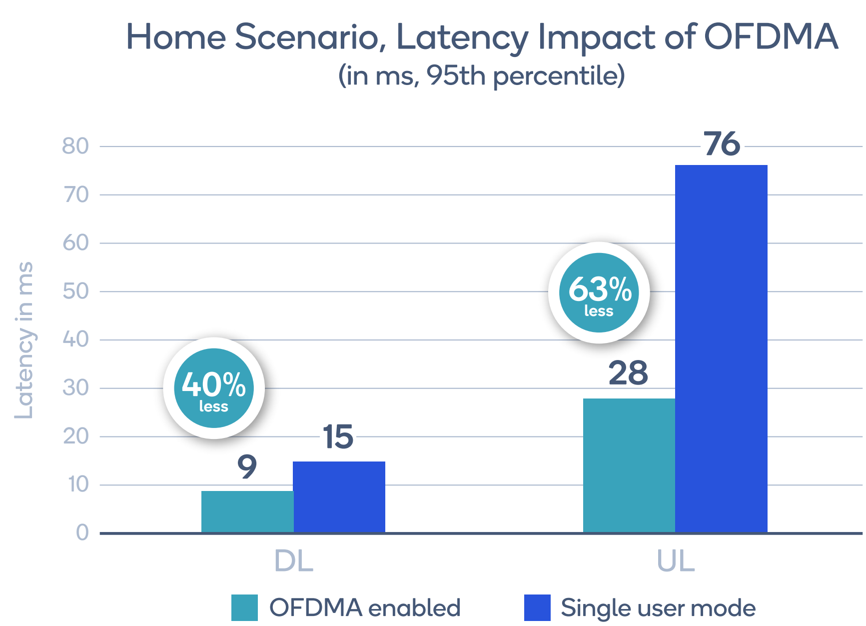


Figure 5.1 Impact of OFDMA on network latency in the home networking scenario, Qualcomm Technologies' AP scheduler

In this scenario, the data clearly show that use of the OFDMA feature set delivers a downlink latency reduction of up to 40% and an uplink latency reduction of up to 63%.

5.2 Office Scenario

The office scenario consisted of 20 users with a diverse mix of application usages. The office activity is captured in table 5.2.

Table 5.2 Users, applications and traffic patterns in the Office Network

Profile	Primary (P)	Secondary (S)	Avg data rates (P+S)	# of users
Latency DUT	P2P audio call Screen sharing Cloud productivity	Web browsing Mail send/receive File sync Syncplicity/One driver	DL/UL = 2.5/2	8
Light	Mail send/receive	Web browsing	DL/UL = 3.5/0.2	3
Analytic	Web browsing Mail send/receive	File downloading/uploading File sync Syncplicity/One driver	DL/UL = 10/3.3	5
Educational	Watching video: YouTube	Web browsing Mail send/receive File sync Syncplicity/One driver	DL/UL = 2.4/2.6	4

The OFDMA latency reductions in this scenario are captured in Figure 5.2.

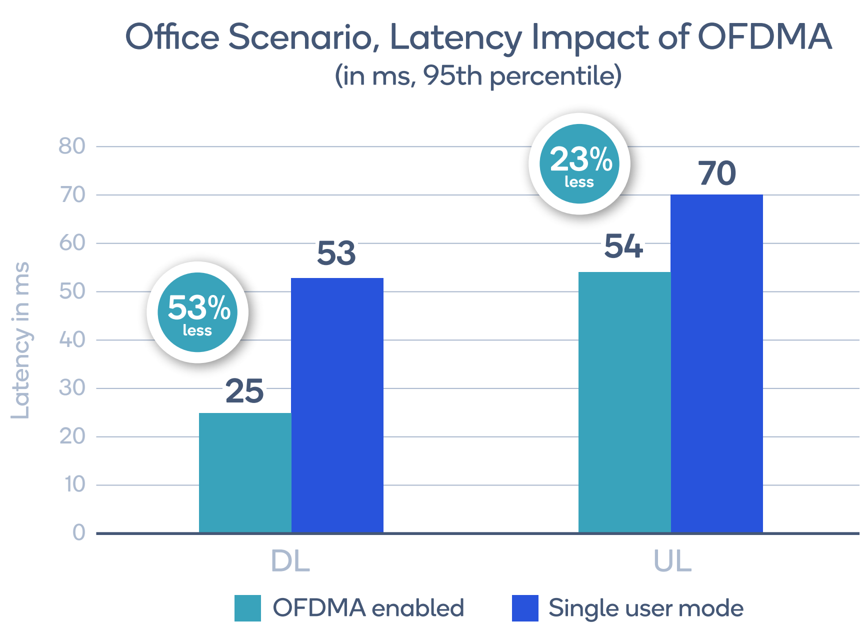


Figure 5.2 Impact of OFDMA on network latency in the office networking scenario, Qualcomm Technologies' AP scheduler

5.3 Classroom Scenario

In the modern 20-person classroom scenario, it becomes quickly clear that a single AP network would prove ineffective without the use of OFDMA. For this scenario, the analysis included a setup with 19 students and one professor, in addition to background traffic generated by overlapping networks (e.g., from other classrooms). The setup consisted of the following set of users, applications, and traffic patterns:

- 20x High definition video conferencing (3Mbps BiDi) AC_VI
- 4x Online document editing (cloud productivity) AC_BE

For back ground traffic we assume:

- 4x Email traffic
- 4x Web browsing
- 4x Messaging
- 2x Overlapping networks with 50Mbps of traffic each

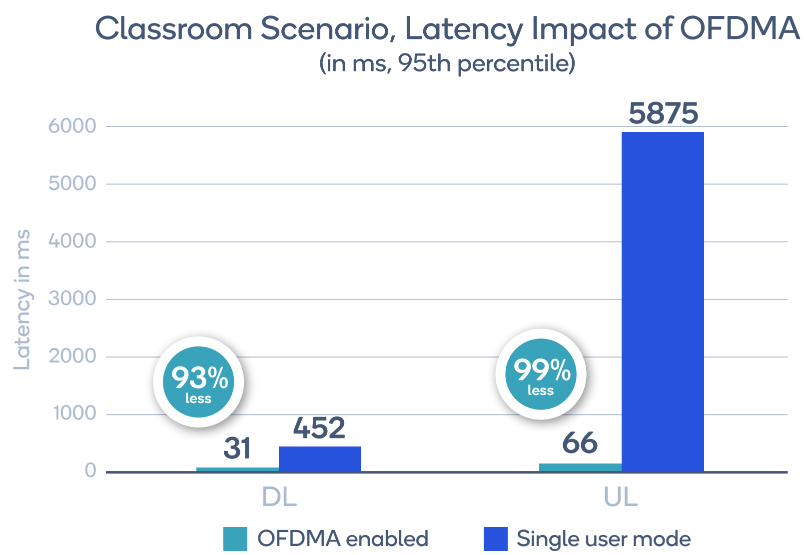


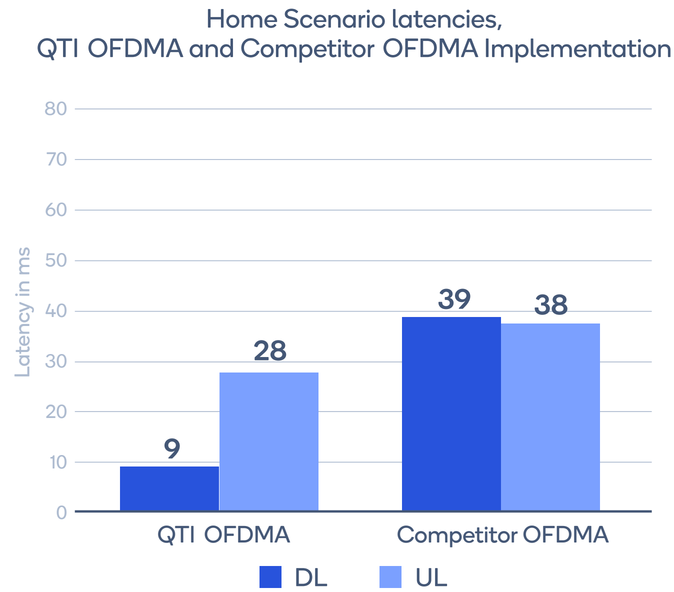
Figure 5.3 Impact of OFDMA on network latency in the modern classroom scenario, Qualcomm Technologies' AP scheduler

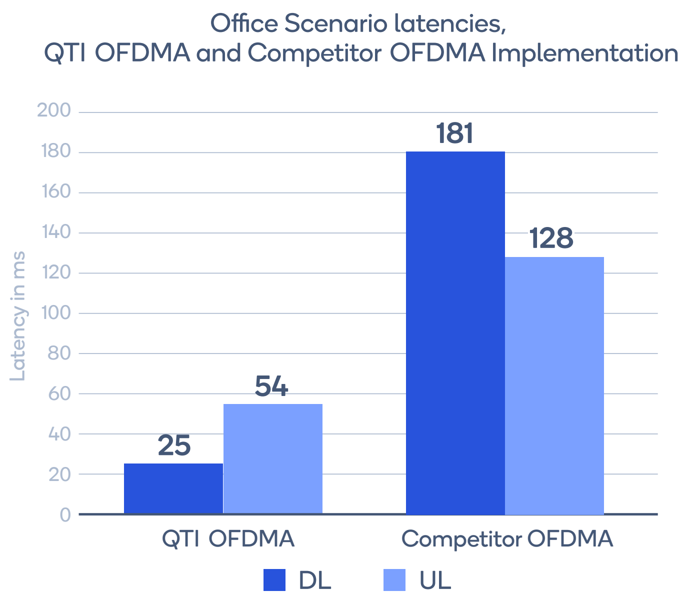
6. Importance of a world-class OFDMA scheduler

Due to the complexity involved, developing a high-quality scheduler for OFDMA requires a high degree of wireless networking expertise, as well as the determination to commit resources for continual scheduler performance improvement.

Given that the scheduler operation is critically tied to the Wi-Fi AP chipset hardware and firmware, Wi-Fi silicon vendors play a central role in developing OFDM scheduling capabilities. The OFDMA scheduler needs to balance, in real time, between using OFDMA to benefit multiple users with relatively small payloads or using single user mode for users with large payloads. Another high-value requirement for scheduler implementation is providing network equipment original equipment manufacturers (OEMs) with the proper set of interfaces to which their own scheduler extensions might be added.

To highlight the importance of a high-performance OFDMA scheduler, this analysis compared the performance of a Qualcomm Technologies' access point scheduler against the performance of an access point using a Wi-Fi 6 generation chipset from a leading competitor. The tests were conducted with the latest commercial grade software available from the competitor-based design during the second half of 2020.





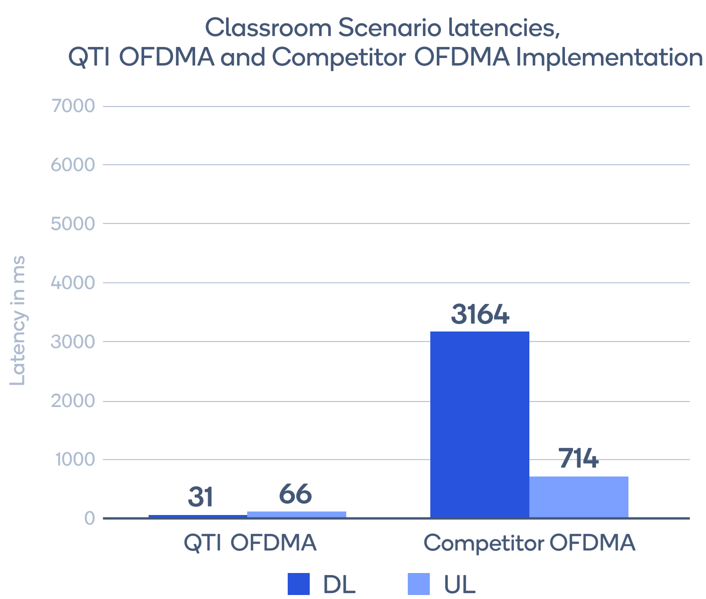


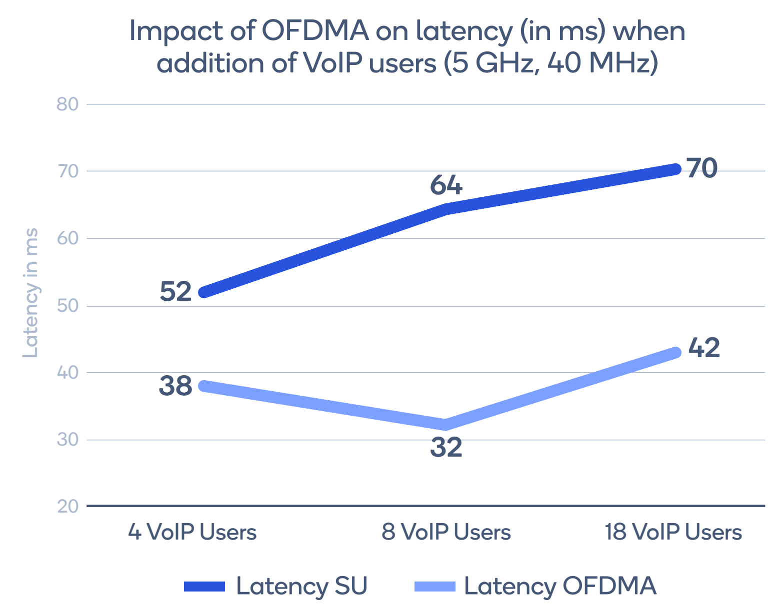
Figure 6.1 Latency comparison by scenario; Qualcomm Technologies' OFDMA, competitor OFDMA implementation, 95th percentile latency in milliseconds (ms)

This figure illustrates, in terms of latencies achieved, that Qualcomm Technologies' OFDMA scheduler significantly outperformed the competitor implementation. In the home scenario, the Qualcomm Technologies' combined downlink and uplink latency advantage was over 2x better versus the competitor. For the office scenario, the Qualcomm Technologies' advantage was nearly 4x. Additionally, the competitor implementation was able to support downlink latencies exceeding 3 seconds in the classroom scenario, rendering it functionally useless.

Loaded network comparisons

To analyze overall systems performance for both the latency and throughput dimensions, the system under analysis needs to be fully exercised by adding background traffic. Wi-Fi 6 generation systems possess ample throughput potential and therefore lightly loaded traffic scenarios will not highlight the throughput advantages of using OFDMA.

Figure 6.2 below shows the impact of using OFDMA on both latency and systems throughput for systems that are running will full buffer background traffic.



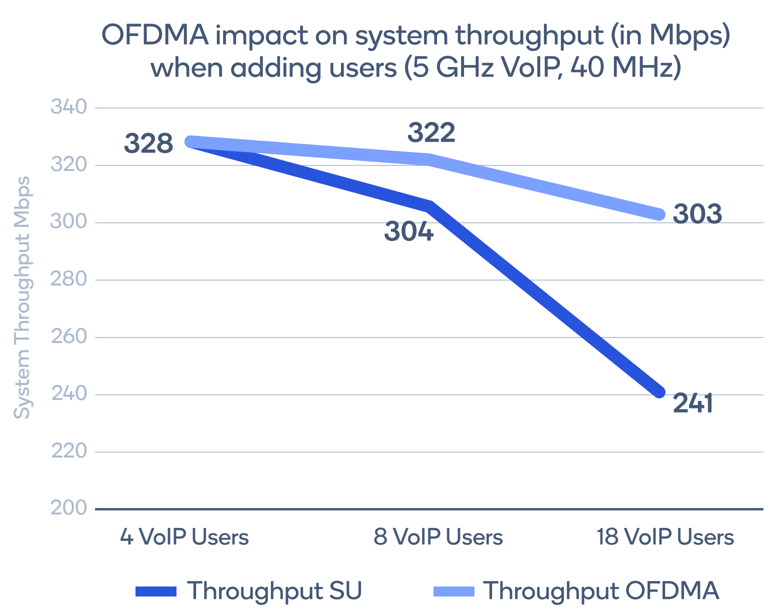
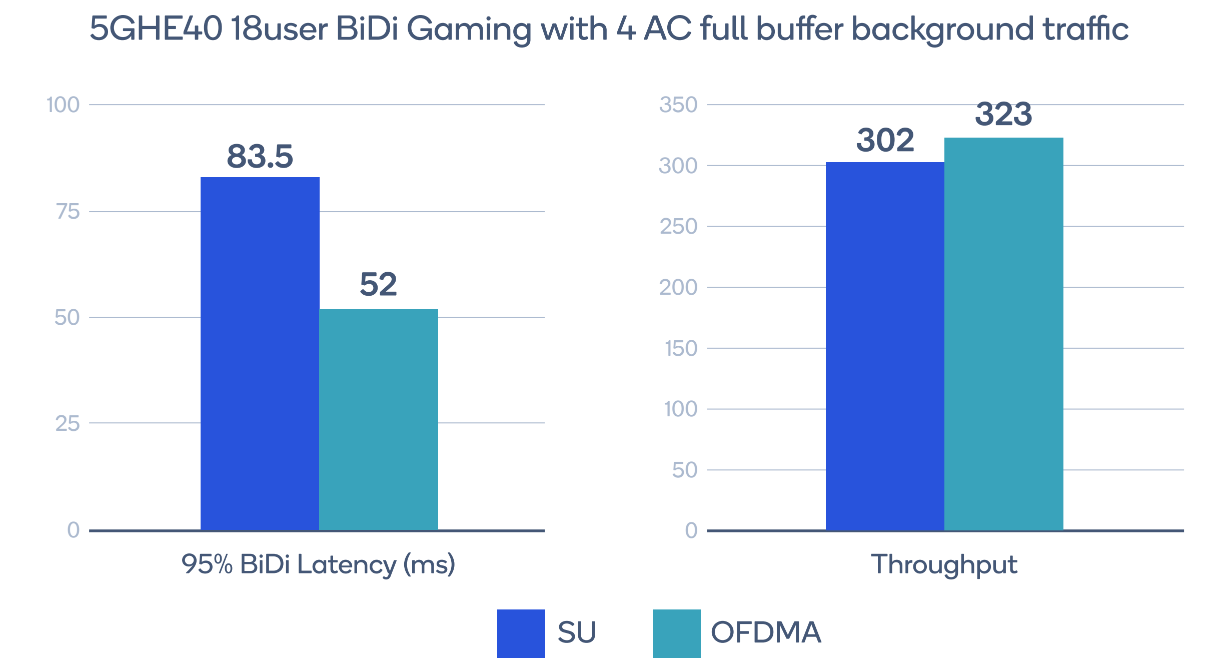


Figure 6.2 Impacts on latency (95th percentile, in milliseconds) and systems throughput (in Mbps) of 4, 8, and 18 VoIP users, single user (SU) mode versus OFDMA with full buffer background traffic

This data illustrates that using OFDMA in this fully loaded network scenario provided significant latency advantages for VoIP traffic. It also shows that OFDMA retained overall systems throughput significantly better when additional VoIP users were added compared to latency SU.

Other examples of OFDMA benefits for fully loaded network settings across different traffic type scenarios are shown in Figure 6.3 below. Here, single user (SU) and OFDMA operation are compared for both a bi-directional (uplink and downlink) gaming and an uplink video scenario.



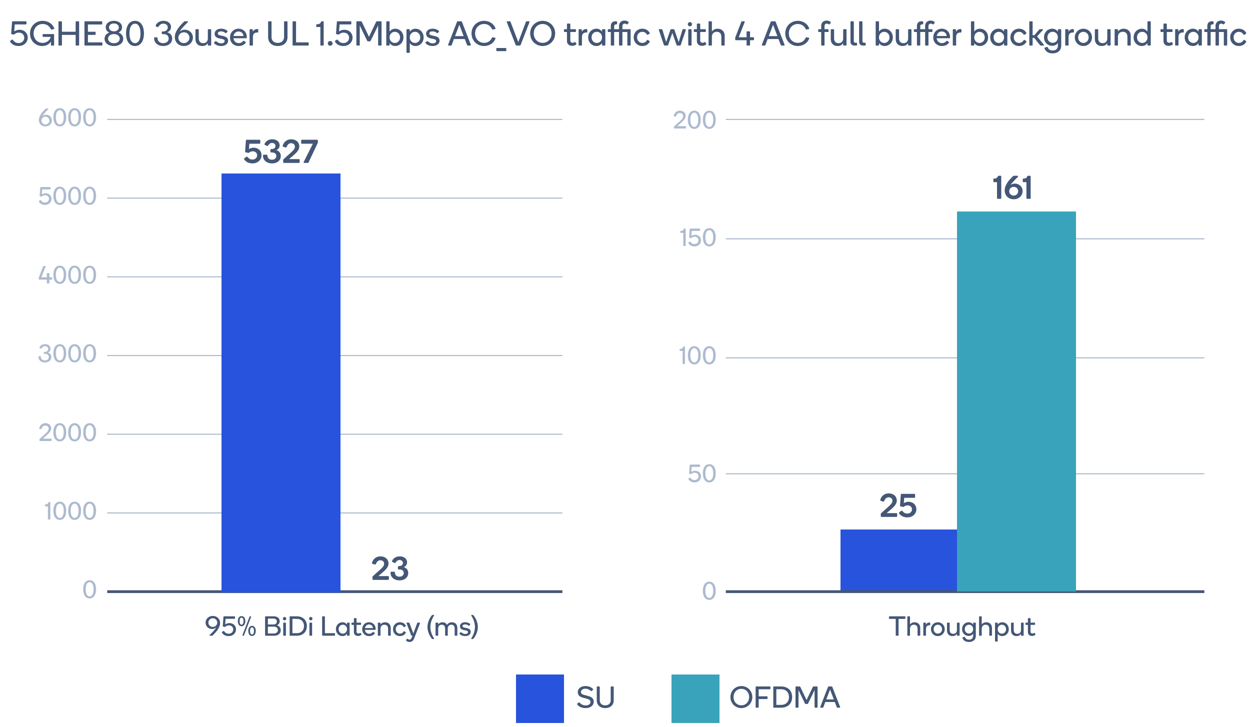


Figure 6.3 Impacts on latency (95th percentile, in milliseconds) and systems throughput (in Mbps) single user (SU) mode versus OFDMA with full buffer background traffic for a bi-directional gaming scenario and an uplink video scenario (AC_VO)

Loaded network performance comparison with competitor implementation

Finally, to ascertain a competitive advantage of Qualcomm Technologies' implementation of the OFDMA scheduler, additional analysis was conducted to demonstrate the differences in latency achieved for varied traffic type user scenarios (gaming, VoIP, and video). For each of these scenarios we tested with three different background traffic loads (30%, 75%, and 100%). As in previous instances, this analysis pitted Qualcomm Technologies' AP against a Wi-Fi 6 generation AP chipset from a leading competitor. The tests were conducted with the latest commercial grade software available on the competitor-based design during the second half of 2020.

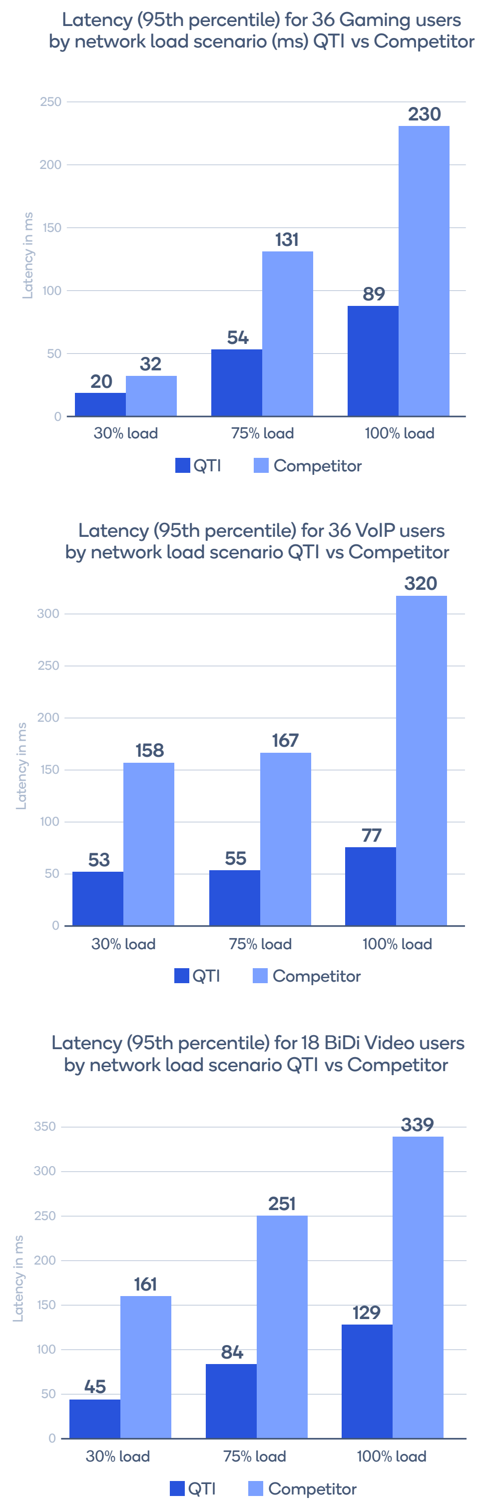


Figure 6.4 Latency (95th percentile, in milliseconds) for Qualcomm Technologies' OFDMA and competitor systems by traffic type scenario and background traffic load

The analysis shows that the Qualcomm Technologies' OFDMA implementation significantly outperformed the competitor system implementation. On average, there was nearly a 2x latency advantage for the gaming scenario, a 3.5x latency advantage for the VoIP traffic scenario and a 3x latency advantage for the bi-directional video scenario.

A fourth traffic scenario for high density video upload was analyzed but only the Qualcomm Technologies' implementation was able to perform effectively. This scenario consisted of 36 clients conducting uplink video traffic simultaneously (e.g., resembling a stadium/theater experience with social media uploads). In this scenario, the Qualcomm Technologies' OFDMA implementation was capable of latencies below 31 ms for all background traffic load scenarios. The competitor implementation dropped all relevant performance capabilities in this scenario with latencies well over 3 seconds (3000 ms), regardless of the background traffic load applied.

7. Conclusions

This technology brief introduced the key innovations to Wi-Fi networking delivered by OFDMA. Through the analysis of a real-world set of scenarios, we demonstrated the significant positive impact of using OFDMA on the network latency customer experience. Specifically, this impact is highly relevant for real-time applications such as gaming and voice/video calling. Moreover, in one scenario (classroom), it was demonstrated that a network could not operate effectively without the use of OFDMA. In a further series of analyses, we demonstrated the combined network capacity (aggregate throughput) and latency benefits of using OFDMA in Wi-Fi 6 networks.

Having demonstrated the significant positive impact OFDMA can deliver, this brief then set out to establish the critical enabler in delivering that impact, namely the network scheduler. Developing a world-class scheduler for OFDMA requires a high degree of wireless networking expertise, as well as the resources and stamina to continuously improve scheduler performance. Comparisons of the Qualcomm Technologies' OFDMA scheduler with the implementation that used the chipset of a leading competitor shows Qualcomm Technologies' significant performance advantages in terms of latency and network capacity.