

High Performance Scheduling Unlocks Wi-Fi 6 Potential

A technology brief highlighting Qualcomm Technologies' competitive advantage

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1. Executive Summary

For over a decade, each new generation of Wi-Fi had taken aim primarily at increased data rates, employing improved coding techniques and/or offering operation in wider bandwidths, in some instances enhanced through the allocation of new spectrum. Wi-Fi 6 represents a departure from this singular pursuit, recognizing a more comprehensive performance approach to address both today and tomorrow's demand and use cases. Wi-Fi networks that support voice calls, video chat, real-time video sharing, gaming, and content sharing across devices must now deliver, in addition to high speed connections, low latency, massive capacity, and simultaneous management capabilities.

Wi-Fi 6 brings a collection of advanced technological tools to deliver both the low latency performance some applications require, as well as the high throughput demanded by others. But ensuring the right tool is applied to the right requirement and optimizing the combination of capabilities at any given moment has elevated the role of the network scheduler to one of singular importance.

The performance of the Wi-Fi 6 network scheduler is the best predictor of overall Wi-Fi 6 performance in a modern network. Qualcomm Technologies, Inc. wields a decade of scheduling optimization expertise, leveraging not only its vast networking pedigree but also tapping into advanced mobile scheduling capabilities. For manufacturers or designers of network infrastructure, this paper articulates the significant performance advantages Qualcomm Technologies has achieved through a highly optimized network scheduler.

2. Introduction and Objectives

Prior to Wi-Fi 6, previous generations of Wi-Fi have employed various techniques to regulate channel access between Wi-Fi access points and their connected devices. In many instances, networks leverage algorithms to schedule wireless traffic in randomly spaced transmissions or retransmissions. Similarly, and often in tandem, techniques such as CSMA/CA are employed to avoid mid-air data packet collisions. As a notable example, Enhanced Distributed Channel Access (EDCA) offers a degree of Quality of Service (QoS) differentiation by leveraging different channel access categories among traffic types, each with a distinct configuration to drive random back-off. Each of these techniques, however, is inherently based on a model of probability where the access point has no dynamic control of channel access to serve its connected devices. As a result, high QoS to connected devices is constrained in circumstances where probability-based scheduling is less relevant, as it increasingly is across today's complex and congested network landscapes.

Before discussing how a powerful scheduler drives Wi-Fi 6 performance, it is important to review how Wi-Fi 6 introduced new tools and techniques to improve baseline Wi-Fi network efficiency. Wi-Fi 6 focuses on effectively supporting applications with defined QoS requirements and offers a more dynamic approach to regulating channel access. Most importantly and for the first time, Wi-Fi 6 allows access points to schedule channel access among connected devices through triggered access. Triggered access reduces collisions and allows an access point to make scheduling decisions across connected devices as well as between downlink and uplink traffic paths.

The most important and well-known tools introduced or evolved with Wi-Fi 6 are OFDMA and MU-MIMO. Orthogonal frequency-division multiple access (OFDMA) is a new technology implementation for standards-based Wi-Fi, and splits bandwidth across several clients within a single channel access, bringing finer granularity to scheduling decisions in a dense network. MIMO (Multi-Input, Multi-Output), of course, has been core to Wi-Fi since Wi-Fi 4. Multi-User MIMO (MU-MIMO) uses spatial diversity to simultaneously deliver full bandwidth frames to multiple devices and was first introduced with Wi-Fi 5. Wi-Fi 6 adds bi-directional MU-MIMO capabilities, adding uplink operation where only downlink was offered previously.

These critical evolutions and implementations that define Wi-Fi 6 are neither new to Qualcomm Technologies nor to the wireless industry. Cellular technologies employ similar techniques to deliver highly scalable and high-quality services, with RAN (Radio Access Networks) delivering managed, high-quality service through intelligent decision making in the network.

The analyses that follow demonstrate how a powerfully designed, implemented, and optimized network scheduler, such as those deployed across Qualcomm Technologies' Wi-Fi 6 and 6E Wi-Fi networking platform portfolios, leverages these techniques in varied usage scenarios to deliver clear and differentiated performance advantages. Increasingly, the performance of the Wi-Fi 6 network scheduler will separate the higher performing platforms from competitors. This paper lays the analytical foundation for Qualcomm Technologies design decisions. The value of each network scheduling tool is explored, and the value of Qualcomm Technologies' Wi-Fi 6 network scheduler is quantified in metrics, including high throughput and low latency in mixed traffic environments.

3. How Wi-Fi Traffic is Scheduled

A modern Wi-Fi network must support a diverse combination of services with varying QoS requirements and traffic characteristics. An optimized and powerful Wi-Fi 6 network scheduler must also leverage multiple techniques to ensure the traffic flow for each user is optimized to deliver the experience required for the services in use.

User Prioritization

A Wi-Fi access point, when properly scheduling traffic, must prioritize which client is serviced in each scheduled channel access based on the QoS requirements of the services. For example, if a VoIP call and a video stream are concurrent the video stream must be served with sufficient capacity, while the VoIP call must obtain low latency. In this instance, an effective network scheduler should give priority as appropriate to meet the needs of each client. For traffic sessions that are not latency sensitive, an effective network scheduler provides basic fairness in air resource allocation among clients to distribute the available capacity as equitably as possible.

MU-MIMO and OFDMA

MU-MIMO is designed to provide higher throughput capacity by utilizing all of an access point's antennas to simultaneously transmit separate spatial streams to multiple users. MU-MIMO lowers latency when capacity is limited, such as when clients have heavy traffic loads. To realize increased network throughput with MU-MIMO, a sophisticated MU-MIMO scheduler (a.k.a. MU-MIMO spatial stream allocator) is critical. Figure 3.1 below expresses the average multi-user capacity gain realized by two client devices with uplink connections as compared to legacy single user techniques—a more than 70% overall average gain. Wi-Fi 6 added MU-MIMO to uplink for the first time, a critical tool given the growth in uplink traffic with real-time video conferencing and video sharing. Not all Wi-Fi 6 devices support this feature, but there will be a significant performance advantage for those that do.

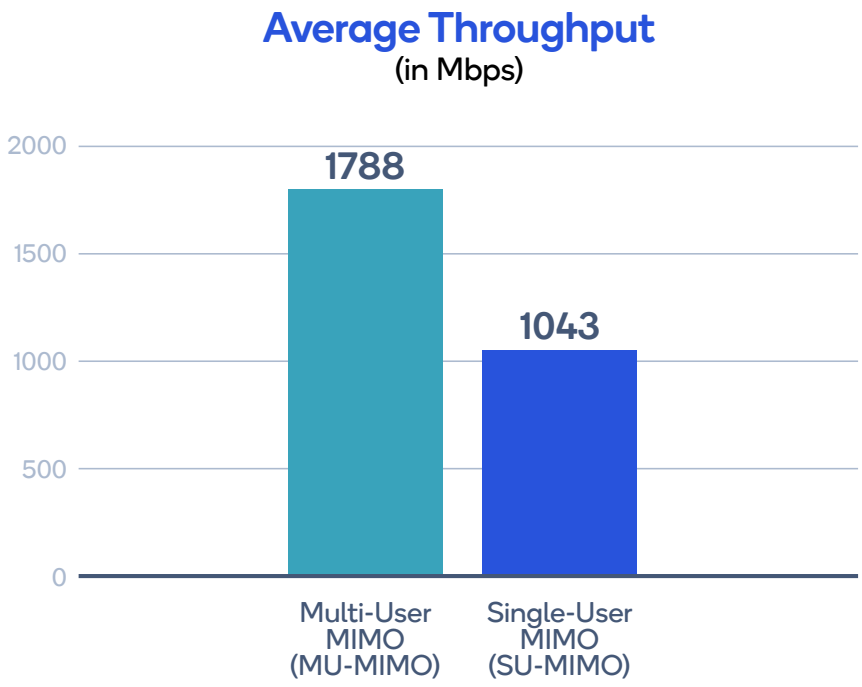


Figure 3.1 Average aggregate throughput gain in MU-MIMO vs. SU-MIMO modes in a 360-degree orientation test for two Wi-Fi 6 client devices.

OFDMA is a new technique being applied to Wi-Fi, joining MU-MIMO as a core multi-user feature that defines Wi-Fi 6. OFDMA simultaneously serves multiple users during one transmission by splitting the available bandwidth into multiple groups of subcarriers called resource units (RU). OFDMA also supports up to 36 users per data frame, making for lower latency when channel access latency is of paramount importance. A previously published whitepaper from Qualcomm Technologies, titled *The Benefits of OFDMA for Wi-Fi 6,* shows myriad analyses demonstrating OFDMA's benefits, including Figure 3.2 which highlights the latency benefit over legacy single user (SU) mode in a busy home environment.

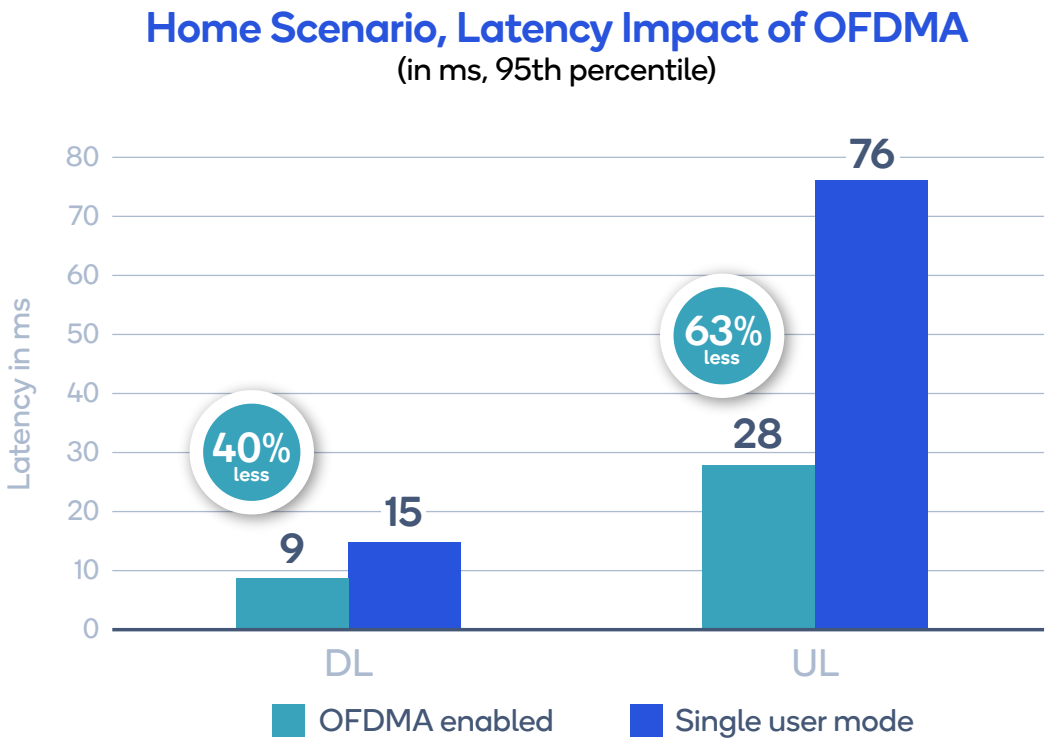


Figure 3.2 Impact of OFDMA on network latency in the home networking scenario, Qualcomm Technologies' AP scheduler

At the heart of powerful network scheduler performance is the dynamic use of both OFDMA and MU-MIMO to manage network traffic. The scheduler's ability to provide the best performance outcomes is predicated on the use of advanced intelligence to recognize which mode (either OFDMA or MU-MIMO) is best applied to real-time traffic flows. Figure 3.3 visualizes the conceptual breakdown of when and why each mode might be applied. When an application has very low latency requirements and low to moderate throughput requirements, it is ideally served with OFDMA. When an application has moderate latency requirements and higher throughput, MU-MIMO is the more appropriate choice. And a full range of application scenarios fall between. For each one, the network scheduler must dynamically identify and assign the ideal mode to ensure optimal network performance.

In many instances, when the total number of devices on a network (or overlapping network interference) creates airwave congestion, the mixed demands also require adaptation as to which mode is applied to which traffic. For example, OFDMA is most often the ideal channel access mode when latency gain is the priority in a high-interference environment. This intelligent and dynamic analysis and mode selection, at its most fundamental description, is the crucial role of today's network scheduler.

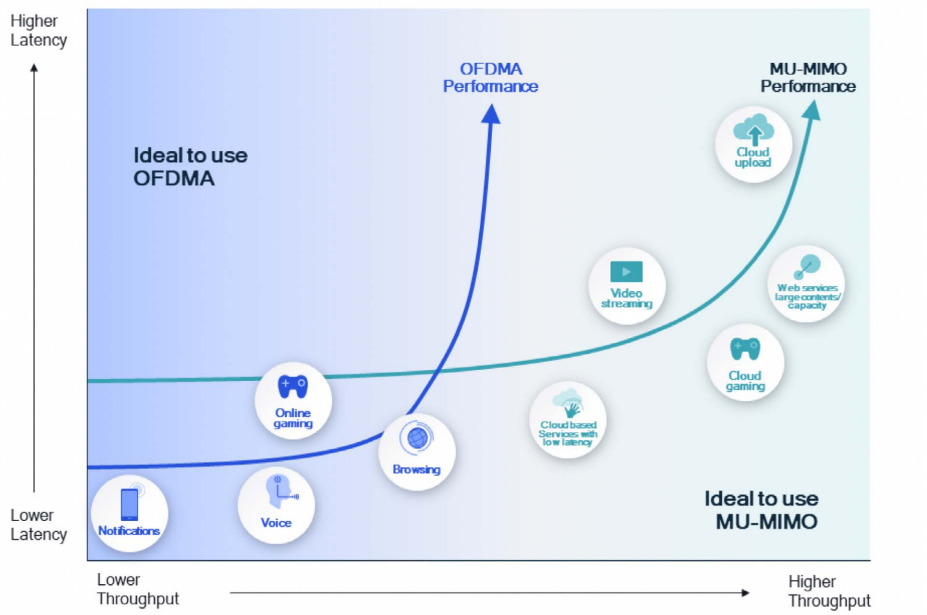


Figure 3.3 Illustrative of OFDMA and MU-MIMO technological assignment to common device applications

Channel Access Control

Triggered access is a powerful new tool for Wi-Fi 6 networks to manage the channel access and scheduling of downlink and uplink traffic. With triggered access, access points are better able to make decisions on timing and duration of access for multiple clients without unnecessarily consuming channel access or air resource for padding triggered uplink transmissions. This is critical for preserving overall network capacity while ensure low latency performance.

Triggered access is especially relevant for traffic with a deterministic packet arrival pattern. Triggered access offers opportunistic scheduling, for traffic with variable packet inter-arrival time, using a mixture of buffer status report-based triggered uplink channel access and clients' own uplink channel access. This opportunistic scheduling helps reduce air resource typically consumed by excessive trigger access with minimal impact on the end-to-end latency of uplink traffic.

A Wi-Fi 6 access point needs to manage triggered access for its Wi-Fi 6 clients in the presence of legacy clients, which will contend for the channel using their regular EDCA.

A Wi-Fi access point needs to intelligently use MU EDCA (Multi-User EDCA) to control how aggressive its Wi-Fi 6 clients may access the channel. MU EDCA should adjust dynamically based on the traffic demand and population of Wi-Fi 6 clients and legacy clients respectively, so that Wi-Fi 6 clients can contend for the channel aggressively against legacy clients.

4. Network Scheduler Differentiation Analysis

To make clear the specific value a powerfully designed, implemented, and optimized network scheduler can provide, Qualcomm Technologies has performed several case-specific analyses. Each reflects a distinct and necessary performance outcome aligned to the specific traffic need, as well as areas of differentiation for Qualcomm Technologies' networking platforms.

Smart Uplink Scheduling for Airtime Fairness in the Presence of Legacy Client Traffic

The analysis below illustrates the impact of effective scheduling in delivering airtime fairness in a mixed client environment with both Wi-Fi 6 and Wi-Fi 5 clients. In one instance, a group of clients were tested using only forced OFDMA, while the same set of clients were then testing using Qualcomm Technologies' powerful scheduling capabilities. The traffic scenarios of each are shown below in Figure 4.1.

The test environment consisted of:

- 36x Wi-Fi 6 clients, all with full uplink buffer UDP traffic
- 2x Wi-Fi 5 clients, all with full uplink buffer UDP traffic

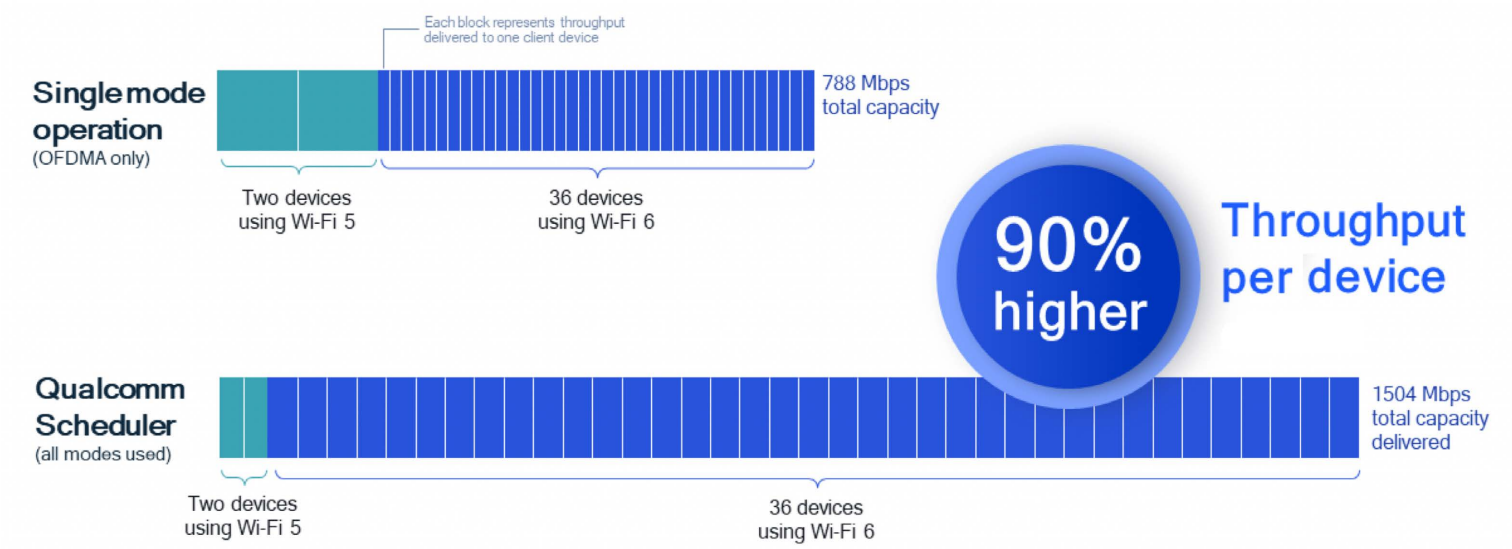


Figure 4.1 Impact of smart uplink scheduling on airtime fairness in the presence of legacy devices with Qualcomm's AP scheduler

In heavy traffic scenarios like the one outlined here, if the access point without Qualcomm Technologies' advanced scheduling capabilities uses only OFDMA to control and schedule its clients' traffic, it struggles to provide adequate air resource. This results in lower overall capacity delivered, as well as a significant imbalance of performance between Wi-Fi 6 and Wi-Fi 5 clients. The scheduler leveraging Qualcomm Technologies' capabilities, however, intelligently selects the ideal mode and adjusts to provide air resource fairness to both its Wi-Fi 6 and Wi-Fi 5 clients.

Smart Uplink Scheduling for VoIP Latency in a Congested Environment

To highlight the importance of deploying a high performance scheduler in order to provide timely and efficient triggered access for uplink traffic of clients, we tested the performance of Qualcomm's advanced scheduler compared with legacy SU mode. The results are shown in Figure 4.2. Traffic scenarios consisted of:

- 8x Wi-Fi 6 clients producing VoIP traffic in best-effort traffic prioritization (AC_BE)
- 4x Wi-Fi 5 clients serving as uplink interference traffic (full buffer) in the 5GHz band (HE20)

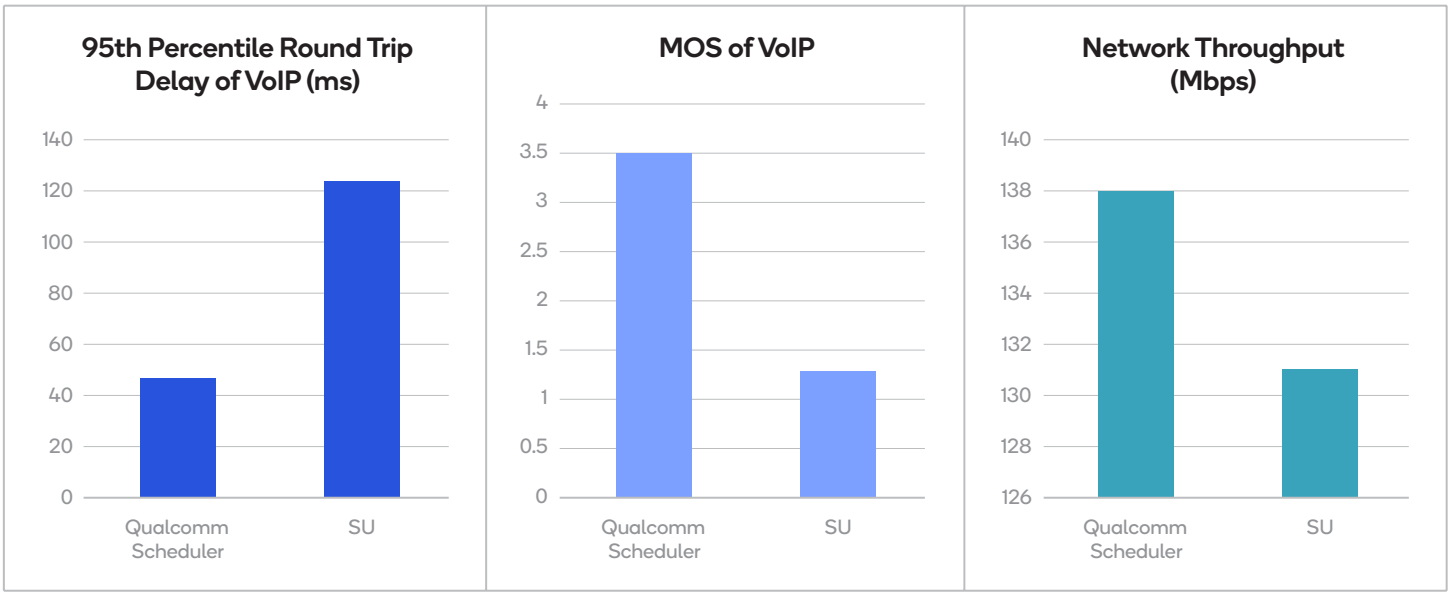


Figure 4.2 Impact of smart uplink scheduling on latency, MOS score, and throughput with Qualcomm's AP scheduler in comparison to SU mode

The test results show that Qualcomm Technologies' high performance network scheduler successfully reduces VoIP traffic latency (vs. legacy SU mode) by up to 60%. Furthermore, in human-judged voice quality measures (Mean Opinion Score, or MOS, where higher is better), Qualcomm Technologies scored more than 2.5X higher. Finally, these improvements were achieved while still delivering significant throughput advantages (or without sacrificing throughput performance).

5. Importance of a Highly Optimized Scheduler in Achieving High Throughput and Low Latency

As discussed, Wi-Fi 6 access points must intelligently apply the proper techniques, offered by Wi-Fi 6 and legacy Wi-Fi standards to each unique traffic scenario. A powerfully designed, implemented, and optimized scheduler, like those developed and offered by Qualcomm Technologies, must interpret the traffic needs of all users, assess the capabilities of those devices, and consider the interference environment.

To further illustrate the performance of a Qualcomm Technologies scheduler we constructed another analysis. In these scenarios, we compared the performance results between an access point based on the Qualcomm® Networking Pro Series Wi-Fi 6 platform and a competitor's Wi-Fi 6 access point. These scenarios ran latency-sensitive real-time traffic, side by side, with heavy uplink traffic across the same network. The traffic scenarios seen in Figure 5.1 consisted of the following set of users, applications, and traffic patterns:

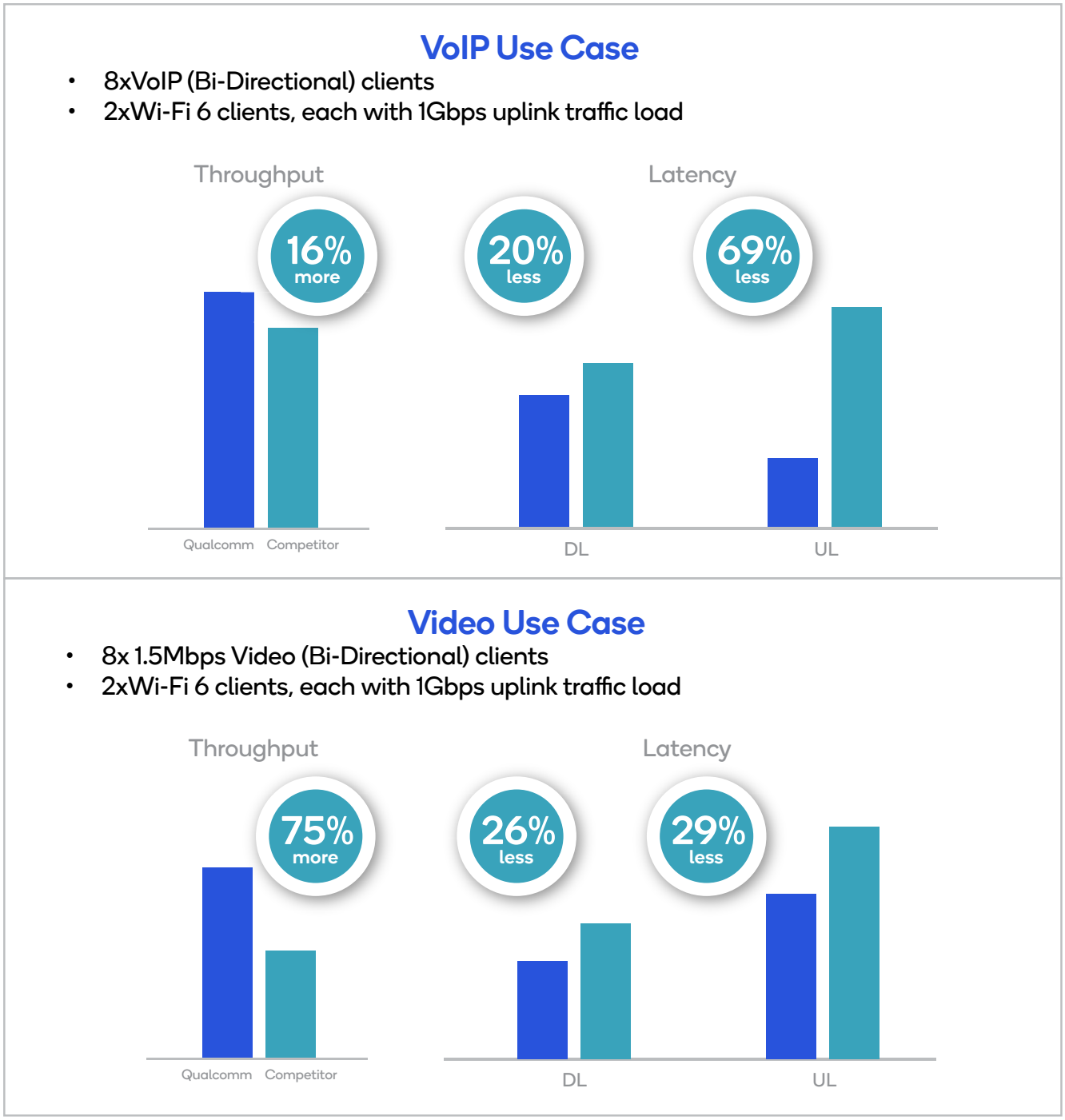


Figure 5.1 Throughput and latency comparison by scenario; Qualcomm Technologies' scheduler, competitor's scheduler implementation

In such traffic scenarios, a Wi-Fi access point needs to balance scheduling between users that have heavy traffic load and small payload while selecting the proper mode between OFDMA and MU-MIMO to serve their traffic.

The test results show that, compared to its competitor, the scheduler in the Qualcomm Networking Pro Series platforms achieves up to 70% higher throughput for the heavy-traffic clients in the presence of VoIP users or video users, while latency is up to 69% lower with 95th percentile round-trip delay for both the VoIP traffic sessions and the interactive video traffic sessions.

Qualcomm Networking Pro is a product of Qualcomm Technologies, Inc. and/or its subsidiaries.

6. Conclusions

Wi-Fi 6 has provided new tools and techniques needed for QoS differentiation in mixed traffic environments, significantly increasing performance over previous Wi-Fi standards.

In this white paper, we provided insight on the merits of these Wi-Fi 6 tools and what techniques are needed to increase the overall throughput for clients with heavy traffic load and reduce overall latency for clients with relatively smaller payload latency-sensitive traffic. We also demonstrated that properly scheduled triggered access in the presence of legacy client traffic can meet airtime fairness and latency objectives.

Wi-Fi 6 is an important milestone on Wi-Fi's evolution path to provide scalable, high-quality services. We should expect a large variance in access point performance based on the ability to make intelligent decisions on which tools to use and how to schedule delivery of different traffic types. To properly evaluate the difference between access points, they should be tested in more complex scenarios that are typical of real network usage and will better determine the quality of the scheduler.

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