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RF & Wireless

The Ultimate Wi-Fi Access Point: Which Wi-Fi 6 Features Define the New Premium Tier?

RF & Wireless Components (RFWC)RF & Wireless Components (RFWC)

Report Snapshot

Strategy Analytics examined features in premium tier, high-performance Wi-Fi 6 access points through discussions with testing labs, OEMs, carriers, and chipset providers. Although marketing messages have typically promoted OFDMA as the main feature of Wi-Fi 6, we found that 8 x 8 MU-MIMO provides the biggest benefit to total system throughput and capacity.

Components

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Exhibits

1. Executive Summary

Wi-Fi 6 significantly enhances wireless performance across multiple vectors, providing a new and improved user experience as compared to earlier versions of Wi-Fi. To accomplish this, Wi-Fi 6 uses wholly new technologies and methods, some from the cellular world, to efficiently deliver more capacity to more devices. This increased capacity and efficiency reduces congestion for a faster, more robust, and higher quality user experience in dense deployments.

Wi-Fi 6 comes with a host of new features, and here we'll focus on those of highest significance in defining the premium experience. While Wi-Fi 6 is expected to ramp very quickly across many market segments and tiers, this report particularly focuses on understanding how the most advanced implementations will be defined. **Among the features discussed, 8 x 8 MU-MIMO stands out as providing the most significant benefits to total system performance aligned with the promises of Wi-Fi 6.**

2. Analysis

2.1.1 Goals

This analysis of Wi-Fi 6 features in premium access points should serve to guide the expectations of consumers and manufacturers alike.

Wi-Fi 6, the Wi-Fi Alliance designation for the next-generation standard 802.11ax, will follow 802.11ac, leading to higher-performance Wi-Fi and a better user experience. Wi-Fi 6, as with any other major wireless technology transition, is expected to broadly deploy across nearly every application where Wi-Fi is found today, and in new applications as well. This report seeks to define the **premium tier feature set for network infrastructure applications**, where the highest possible performance expectations will require the fullest and most robust implementation of Wi-Fi 6.

To best understand which features define this highest performance tier, the author sought out insights from a representative sample of industry sources as indicators in preparing this report:

- **Testing labs,** which have early access and deep insights to silicon provider's chips to develop test equipment, as well as access to OEM's devices for testing. Testing labs can help to confirm actual device performance vs. theoretical. Testing labs the author contacted included Airgain, Cetacom, Deka, dot11labs, NTS, UNH, OctoScope (testbeds), and Spirent.

- **OEMs of residential access points** (APs), who tune performance criteria to consumer purchasing decisions.

- **OEMs of enterprise APs**, who look for much more extreme configurations than residential OEMs, with client counts in the hundreds, and with advanced software and hardware requirements. Enterprise IT departments value robust APs with enhanced link budgets, adaptability to interference, analytics for access control, application policy & network security, and multi-site management capabilities.

- **Carriers** (internet service providers or ISPs) that offer Wi-Fi Gateways to customers. Requirements may more closely resemble either residential or enterprise OEMs depending on the needs of the infrastructure installation. For example, in more complex installations, carriers can benefit from management functions similar to those used in enterprise Wi-Fi when these functions can reduce installation or troubleshooting time and improve consumer satisfaction.

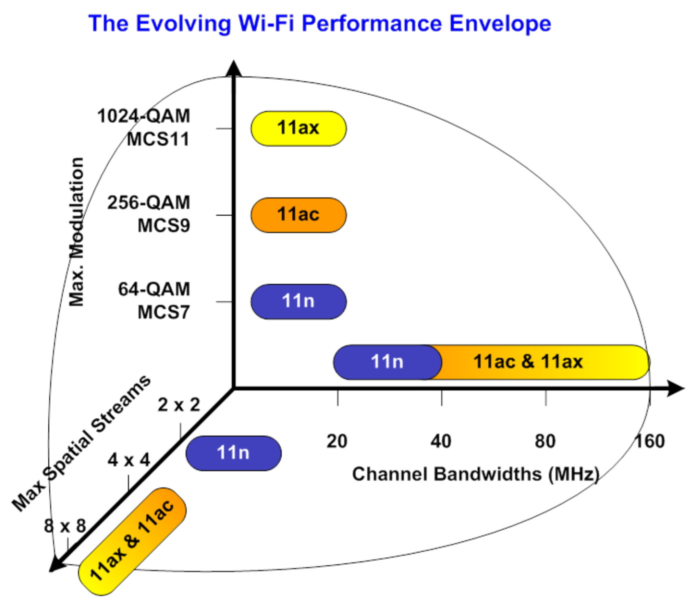
Strategy Analytics also conducted informal discussions with Wi-Fi chipset providers to gain their perspectives on necessary features and planning for Wi-F 6 APs.

The author anticipated that the "highest possible performance" features would apply to premium tier APs, potentially from enterprise OEMs, and that mid- and low-tier APs might have a different mix or emphasis on features. All participants in discussions were given anonymity unless requesting otherwise.

2.1.2 Wi-Fi 6 Background

Wi-Fi 6 addresses wireless performance across several vectors. Whereas Wi-Fi evolution has historically centered on the pursuit of higher peak data rates for a user (see Exhibit 1), Wi-Fi 6 achieves this through a completely different focus; Wi-Fi 6 was developed to **increase both overall efficiency and capacity**. This shift in priority from speed to capacity and efficiency aligns with the larger macro trends toward ever higher average data rates per device while networks contend with more devices and higher density deployments.

Exhibit 1 The Wi-Fi Performance Envelope



Source: Liang Jin, Spirent

Wi-Fi 6 is perhaps the most auspicious feature update to Wi-Fi ever undertaken by the Wi-Fi Alliance and industry. With scores of features in draft, below are considered some of the most essential to achieving higher efficiency and capacity under Wi-Fi 6:

- **Eight spatial streams in the 5 GHz band**, in conjunction with **four spatial streams in the 2.4 GHz band**, yields up to **12 streams** of Wi-Fi 6 connectivity, significantly boosting overall spectrum use.
- **MU-MIMO** uses spatial multiplexing to increase the number of simultaneous users of the same frequency resources, increasing capacity (i.e. system throughput), time efficiency and spectral efficiency. With 12 spatial streams available for MU-MIMO instead of four, this is a big upgrade for Wi-Fi 6 over Wi-Fi 5.
- **OFDMA** reduces overhead and contention, reduces packet-to-packet latency, and increases efficiency in congested conditions. OFDMA splits the total available spectrum among client devices.
- **Triggering.** A Wi-Fi 6 access point uses triggers to inform client devices how to make use of time and frequency resources, modulation, coding and spatial streams to minimize contention and improve capacity. Wi-Fi 6 can split bandwidth among low data rate clients, it can use spatial diversity with MU-MIMO to increase overall bandwidth, and it can do both in combination, a defining attribute of Wi-Fi 6.
- **Other important features:**
  - 1024-QAM is a higher-order modulation that delivers increased throughput.
  - Spatial reuse enhances Wi-Fi coexistence with other, nearby Wi-Fi networks.
  - Target Wake Time (TWT) reduces power consumption.
  - '20-MHz-only channels' allows IoT sensors to use spectrum more efficiently.
  - Wi-Fi 6 extends the new features to the congested 2.4 GHz band.

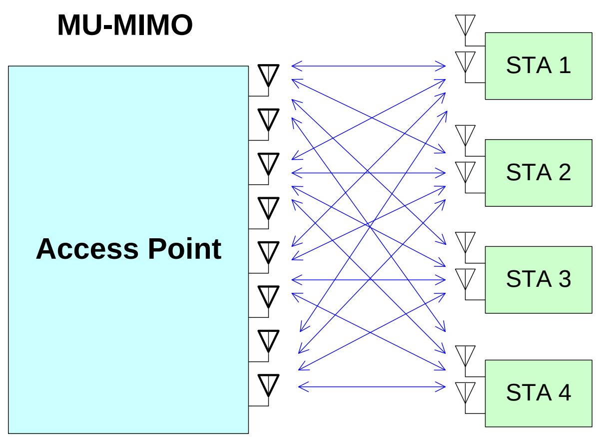
Most Wi-Fi 6 marketing activity has concentrated on OFDMA, but this report will look at another feature first, **multi-user MIMO**.

Introduced to Wi-Fi in 802.11ac, Wi-Fi 6 further extends MU-MIMO, increasing the number of simultaneous users for higher system capacity, time and spectral efficiencies:

- In Wi-Fi 6, MU-MIMO can make use **all 12 spatial streams in both the uplink (UL) and downlink (DL) directions.**
- Wi-Fi 5 (802.11ac) can use MU-MIMO only in the 5 GHz band, with MU-MIMO in the DL direction only.

In Wi-Fi 6, an access point can exploit as many as **eight spatial streams in the 5 GHz band** using eight antennas to simultaneously address eight 1 x 1 client devices or four 2 x 2 client devices. See Exhibit 2 (not all spatial paths shown for clarity).

Exhibit 2 MU-MIMO Clients and Stations



Multiple clients use same time-frequency resources simultaneously.

With **MU-MIMO** one can add client devices to the network without reducing the data rates for the other clients. As shown in Exhibit 3:

- One 2 x 2 client device, running MCS 11 with 80 MHz channel bandwidth, can in theory experience a data rate of 1,200 Mbps. Adding more client devices dilutes the data rate, which is shared among clients.
- With 4 x 4 MU-MIMO in the AP, two client devices can share the same frequency and time resources, at least under ideal conditions, each experiencing 1,200 Mbps data rates. Here the total aggregate data rate for the AP doubles to 2,400 Mbps.
- With an 8 x 8 MU-MIMO AP, four client devices can run at the same time, and the total aggregate data rate for the AP is 4,800 Mbps.

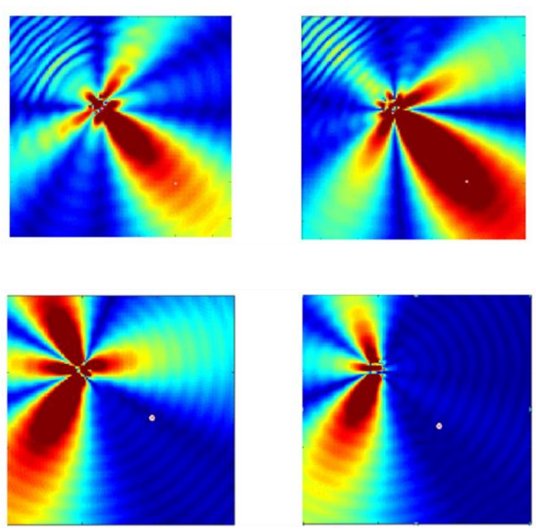
MU-MIMO exploits differences in the spatial paths of the signals to different client devices; the actual benefits of MU-MIMO depend on the path differences, and the example in Exhibit 3 is an ideal case.

Exhibit 3 Theoretical System Data Rate vs. Number of Clients with MU-MIMO

	Clients (STAs)	AP -- Aggregate System Data Rate (PHY) for the Network
OFDMA or SU-MIMO	One 2 x 2 device. Additional devices share frequency-time resources.	1,200 Mbps
4 x 4 MU-MIMO	Two 2 x 2 devices at the same time.	2,400 Mbps (1200 Mbps per device)
8 x 8 MU-MIMO	Four 2 x 2 devices at the same time.	4,800 Mbps (1200 Mbps per device)

1200 Mbps is the theoretical PHY rate with MCS11, 1024-QAM, 80 MHz channels, 800 ns GI. MAC rates around 80% of PHY are expected in this case. *Source: Ruckus Wireless.*

Exhibit 4 Beamforming



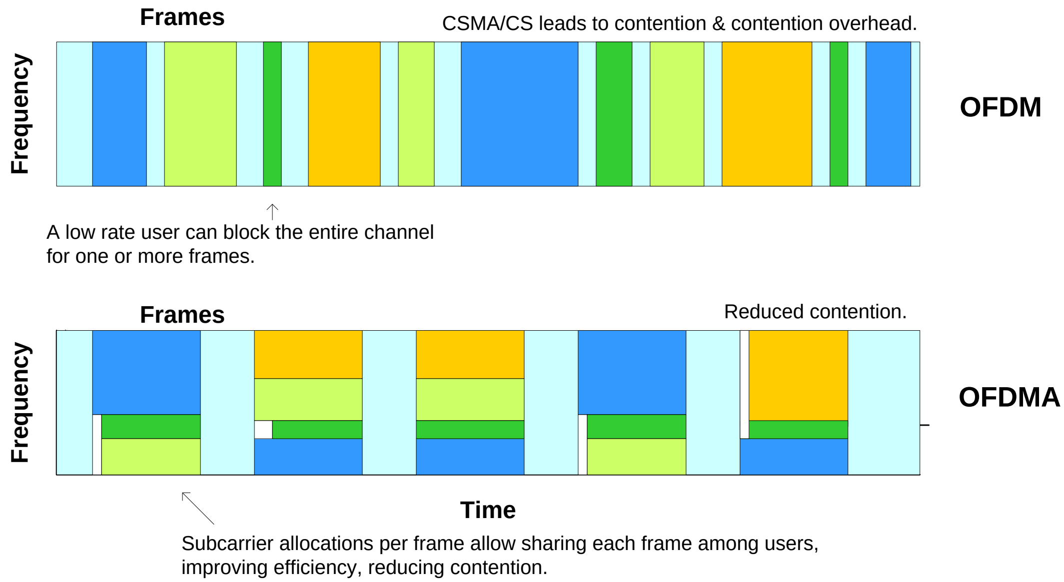
Higher gain possible (~3 dB) with eight antennas.

With eight antennas, more accurate beam steering to avoid interfering devices.

Source: Precoding for Eight Antenna MIMO Systems, *Dr. Sigurd Schelstaete, Quantenna.*

MU-MIMO draws on the ability to combine signals from separate antennas as well as spatial path differences. In **beamforming mode**, it is possible for an access point to direct signals to the desired clients and aim the effective receive signal power away from other devices. Here, eight antennas provide sharper beam steering than four. See Exhibit 4.

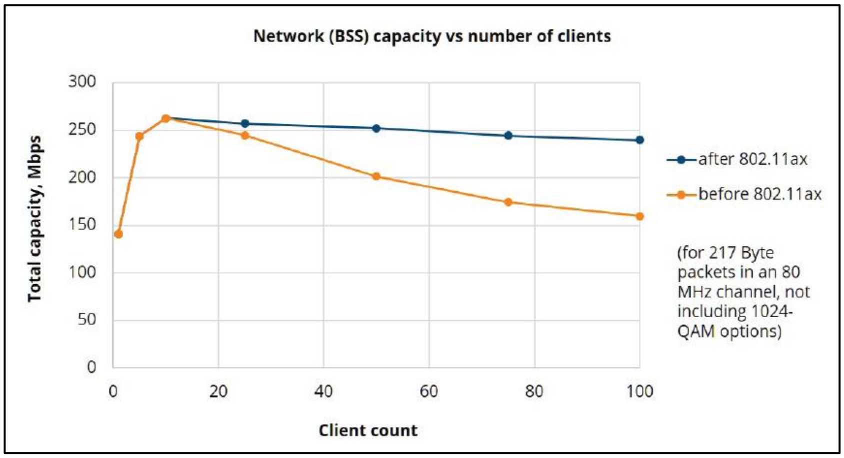
Exhibit 5 OFDMA Compared to OFDM



Now let's turn to **OFDMA**. In earlier generations of Wi-Fi using OFDM, a single low-data rate user could take an inordinate amount of airtime, affecting all users.

With OFDMA, Wi-Fi 6 spectrum is broken up into groups of subcarriers (Resource Units or RUs), and different users can be assigned RUs within the same frame. This reduces contention and improves efficiency. See Exhibit 5. As a result of the improvements in efficiency, aggregate throughput for the network does not drop off with more client devices as rapidly with OFDMA as it does with single-user, full bandwidth OFDM, as shown in Exhibit 6.

Exhibit 6 Network Capacity vs. Number of Clients, OFDMA vs. OFDM



Source: Aruba, White Paper 802.11ax.

2.1.3 Project Statistics

Discussions with companies producing and developing APs turned up a strong preference for 8 x 8 MU-MIMO (in the 5 GHz band) for the premium tier. Given the understanding of the value of expanded MU-MIMO capabilities across 8 x 8 configurations, this was not surprising:

- The project turned up, through May 15, 2019, 22 APs shipping or in development using 8 x 8 MU-MIMO, as shown in Exhibit 7.
  - Carriers and enterprise OEMs alike seem particularly interested in 8 x 8 MU-MIMO.
  - If one considers tri-band 4 x 4 as premium tier, APs with 8 x 8 MU-MIMO in the 5 GHz band actually outnumber tri-band designs. This count does not include dual-band 4 x 4 APs, of which many have been announced.
- Although Strategy Analytics did not receive confirmation from every OEM and carrier contacted, our analysis, largely informed from chipset suppliers, indicates that many more OEMs have 8 x 8 MU-MIMO APs in development.
- Aruba, Cisco, Engenius, Extreme Networks, Meraki, and Ruckus (a Commscope company) are among the companies that have announced Wi-Fi 6 APs for enterprise.
- NETGEAR and ASUS have launched APs for home markets.

Exhibit 7 Premium-tier APs Announced and In Development

Target Market	APs with 8x8 MU-MIMO @ 5 GHz
Residential	4
Enterprise & venue	6
Carrier (ISP)	15
Total 8 x 8	22
Total Premium (Incl. 4 x 4 tri-band)	33

Includes some early "AX compatible" devices that may not be Wi-Fi 6 certifiable.

See the Appendix (Exhibits 14 and 15) for a list of publicly announced APs as of the preparation of this report in May, 2019.

- On the device side, **four laptop PCs** and **more than nine smartphones** now support **Wi-Fi 6**. All except the Samsung Galaxy S10 (which may add Wi-Fi 6 features at a later date via firmware update) support 8 x 8 sounding feedback, and are therefore ready to take full advantage of the key premium Wi-Fi 6 feature 8 x 8 MU-MIMO. To date, all 5G-enabled smartphones support Wi-Fi 6 features.

2.1.4 Attractive Wi-Fi 6 Features in the Premium Tier

Carriers in particular appreciate the rate-over-range gain derived from the 3 dB improvement that is possible with 8 x 8 beamforming gain, which can improve coverage and reduce customer churn:

- Many Carriers want to provide a premium Wi-Fi 6 experience as part of a strong value proposition for their converged service strategy.
- The carriers typically want to provide customers with APs with **dual-band 4 x 4 for apartment flats**, **8 x 8 for houses**, and **8 x 8 plus 4 x 4 extenders** (with either wired or wireless backhaul) for **large houses**.
- This kind of portfolio can also make sense for top Wi-Fi performance in consumer retail and enterprise APs.

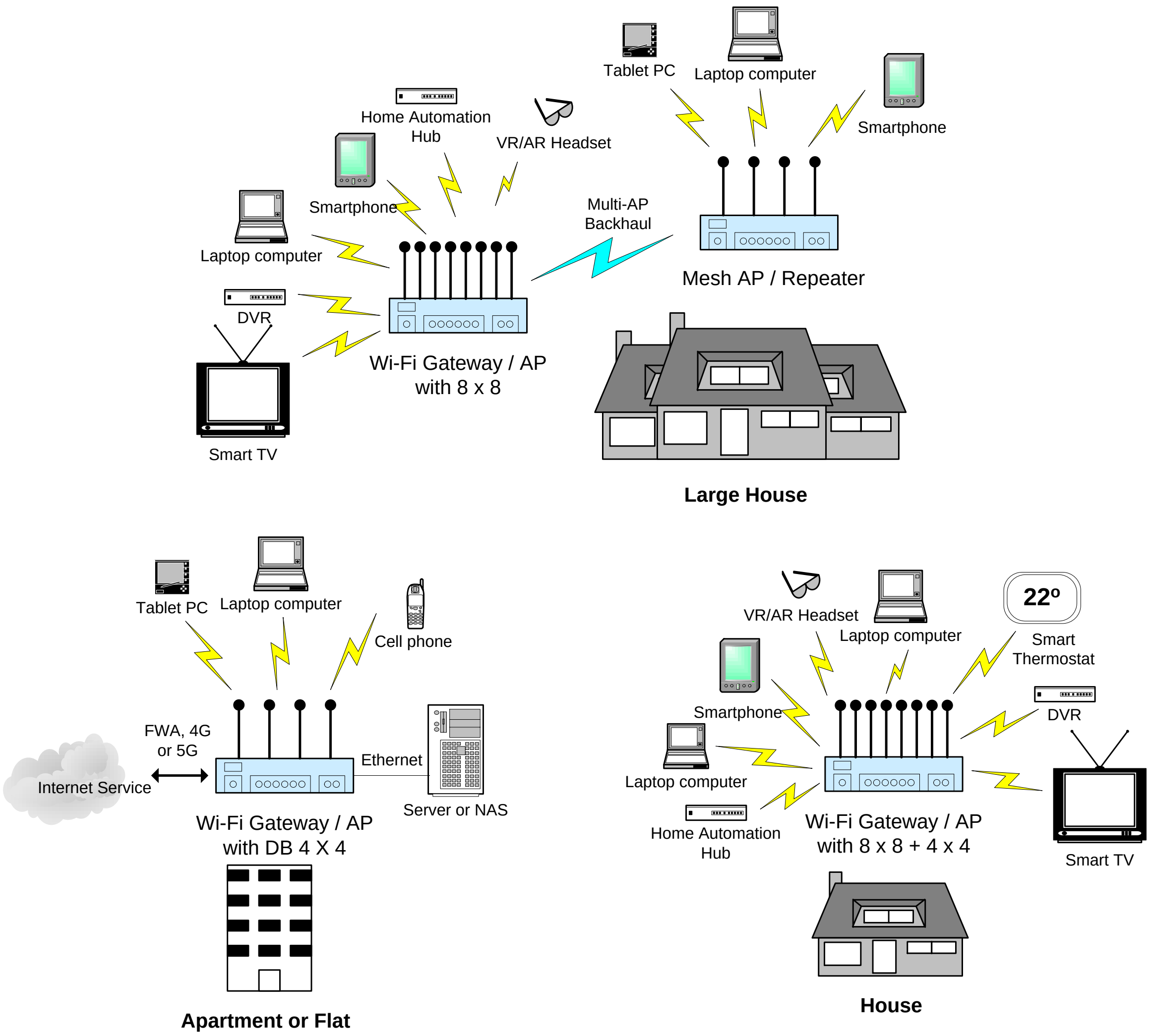
Based on our discussions, Exhibit 8 shows the typical product strategy for a carrier offering Wi-Fi 6 APs. Carriers seem to favor this product strategy for Wi-Fi 6, followed by enterprise OEMs and retail AP suppliers.

Most companies today that configure their APs for wireless Wi-Fi backhaul in conjunction with an AP as a hub use a proprietary backhaul technique. In the future, the Multi-AP standard could allow APs from different OEMs and service providers to operate with each other in backhaul / range extender configurations more smoothly, for example appearing to the user as a single network instead of multiple 2.4 GHz and 5 GHz networks.

Other Wi-Fi 6 benefits seen by companies that the author interviewed include:

- **8 x 8 MU-MIMO network capacity improvement** in terms of number of simultaneous stations (STAs. i.e. client devices). The companies have seen total network capacity improvements up to 3X to 3.5X with 2 x 2 stations and 8 x 8 MU-MIMO. Other attractive aspects of 8 x 8 MU-MIMO include:
    - **Works with 4 x 4 feedback from clients:** Wi-Fi 6 works best with 8 x 8 CSI (channel state information) feedback, but software in the chipset can improve network performance significantly even without 8 x 8 feedback. So far, most Wi-Fi 6 client devices support 8 x 8 feedback.
    - **Works with clients in motion:** AP capacity improves with MU-MIMO even with client devices in motion (see next section).
    - **Flexibility:** 8 x 8 can also operate as tri-band 4 x 4 depending on chipset & RF architecture. A second set of 5 GHz 4 x 4 antennas can backhaul a range extender or be assigned exclusively to legacy devices.
- **1024-QAM** adds up to 25 percent to peak data rate vs. 256-QAM as expected; however, the main benefit occurs at short range, within the same room as the AP.
- **Benefits at 2.4 GHz:** Carriers reported strong interest in the benefits of Wi-Fi 6 in the 2.4 GHz band for managing low-rate IoT sensor devices and providing managed services such as home automation and security.

Exhibit 8 Typical Wi-Fi 6 AP Product Portfolio

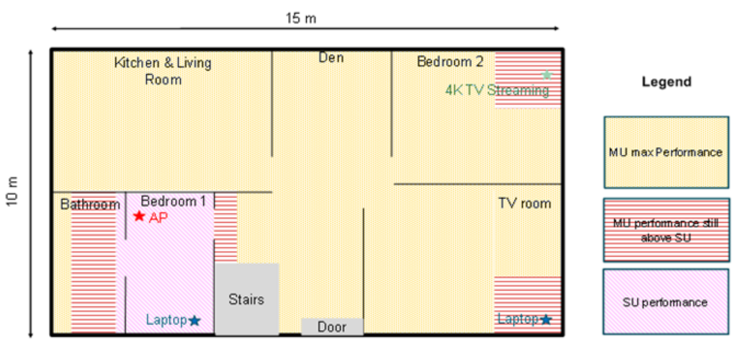


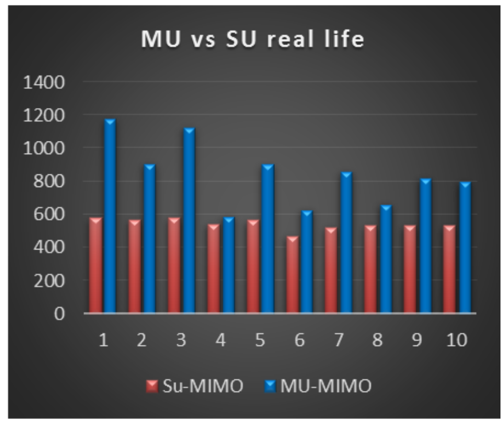
One criticism sometimes leveled at MU-MIMO is that it fails to deliver with **moving clients**, for example handheld mobile phones. To address this concern, Quantenna ran a series of tests summarized in Exhibit 9:

- Quantenna used an 802.11ax AP (8 x 8 MU-MIMO capable in the 5 GHz band).
- They installed the AP in a 250 square meter flat (nearly 2,700 square feet).
- The client devices consisted of a mix of flagship smartphones (2 x 2) and legacy devices.
- In all cases, MU-MIMO outperformed SU-MIMO and OFDMA modes, with an average throughput improvement of 55 percent. This includes cases during which the mobile phones were in motion within the dwelling, and clients were located both near and far from the AP. See Section 2.1.7 for a summary of Wi-Fi 6 modes.

Exhibit 9 Wi-Fi 6 8 x 8 MU-MIMO Motions Tests

# Test Case	Brief Description	SU-MIMO (Mbps)	MU-MIMO (Mbps)	% Improvement
1	Same room no motion	580	1180	103%
2	Same room motion inside room	567	910	60%
3	Same room motion outside room	580	1129	95%
4	Stress test full motion	544	590	8%
5	Stress test "TV time"	567	906	60%
6	Stress test “moving phone"	470	632	34%
7	STAs spread no motion	522	861	65%
8	STAs spread full motion	534	663	24%
9	STAs spread motion outside living room	532	821	54%
10	STAs spread motion inside living room (slow motion).	532	800	50%





2.1.5 Myths Surrounding MU-MIMO

In our discussions, we encountered some objections to 8 x 8 MU-MIMO mainly from competitors to the companies that offer 8 x 8 MU-MIMO chipsets.

Client devices do not support 8 x 8 sounding. This is **not true.** Most client devices shipping so far support 8 x 8 feedback, and 8 x 8 in the AP has advantages even without 8 x 8 sounding feedback from all clients.

MU-MIMO was a failure under 802.11ac. Why should it succeed today? Many hundreds of millions of phones have shipped with it 802.11ac Wave 2 / MU-MIMO. On the retail-consumer AP side, 8 x 8 MU-MIMO did not take off quite as hoped, probably a failure to market the benefits of Wave 2 clearly on the box. Today, the support for 8 x 8 sounding by makers of Wi-Fi 6 client chipsets shows an acknowledgement of the importance of 8 x 8 MU-MIMO as a key part of the Wi-Fi 6 standard.

No UL MU-MIMO is available today! This will very likely change with Wi-Fi 6 Rel. 2, and could be available in shipping chipsets as early as next year. Also, UL MU-MIMO operates independently of DL MU-MIMO, so consumers can today enjoy the full benefits of Wi-Fi 6 even without UL MU-MIMO.

OFMDA is more important than MU-MIMO. OFDMA is important especially for small packet size data and very congested conditions, reducing contention, but MU-MIMO can dramatically increase total system throughput. **Both are key features of Wi-Fi 6.**

MU-MIMO does not work with motion. MU-MIMO is best for stationary clients, but tests show it provides worthwhile benefits even with mobile devices. See Exhibit 15.

8 x 8 MU-MIMO is too power hungry. According to the system OEMs we spoke with, power consumption is manageable, with 802.3bt Type 3 (4PPoE) adequate to supply power (50 – 60 W).

Simultaneous OFDMA and MU-MIMO will be too complex to manage. OFDMA and MU-MIMO complement each other, with the AP determining the best mix of techniques given the mix of client devices and traffic demands. For example, an AP might use DL MU-MIMO along with UL OFDMA in some situations. With modern FinFET SoCs, and especially with some of the computation offloaded to the on-board network processor(s), this level of management and optimization is quite practical.

8 x 8 MU-MIMO is too expensive. There are benefits to MU-MIMO, as proven by the level of interest in it for Wi-Fi 6 and by the use of MU-MIMO by the cellular industry. The best implementation of a Wi-Fi 6 AP depends on the cost-benefit trade-offs for the application. Dual-band 4 x 4, tri-band 4 x 4, and 8 x 8 + 4 x 4 all have their places, but 8 x 8 + 4 x 4 provides the best system capacity.

2.1.6 The Industry View of Wi-Fi 6 Product Positioning

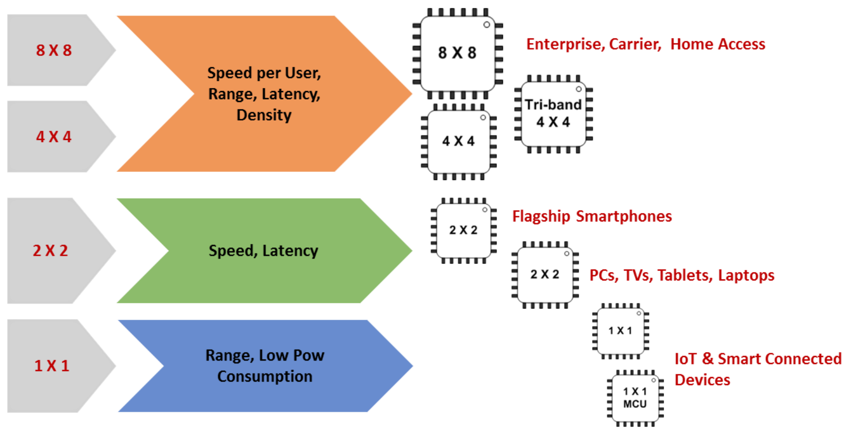
Wi-Fi 6 devices have started to ship. Infrastructure networking devices in enterprise, carrier, and residential / consumer retail segments have started to ship, joined by client devices such as smartphones and PCs with Wi-Fi 6 features. There is a diverse range of Wi-Fi 6 features supported across these devices. This diversity translates, it seems, to distinct performance profiles largely driven by technology and feature implementation decisions at the chipset level.

- Access points have been introduced in configurations ranging from:
  - 8 x 8 MU-MIMO @ 5 GHz + 4 x 4 MU-MIMO @ 2.4 GHz (12 streams across two bands).
  - Tri-band 4 x 4 MU-MIMO with two 4 x 4 radios at 5 GHz (also yielding 12 streams, but with the 5 GHz band split into two, each with a 4 x 4 radio).
  - Dual-band 4 x 4 MU-MIMO (eight streams).
  - Dual-band 2 x 2 MU-MIMO (four streams) at the entry or budget level.
- Most client devices use 2 x 2 antenna configurations. This includes smartphones and laptop PCs.
- IoT “Smart Devices” around the home and office do not all require high data rates, and many will take advantage of Wi-Fi 6 features now available in the 2.4 GHz band with a 1 x 1 antenna configuration. Examples will likely

include Wi-Fi 6 wall switches, light bulbs and sensors. Other home IoT devices such as cameras, set-top boxes and streaming dongles will benefit from higher data rates and higher performance Wi-Fi 6 configurations.

Exhibit 10 shows product positioning in terms of number of antennas (and MIMO streams) and general characteristics of the products in terms of speed, range, latency, density and power consumption.

Exhibit 10 Industry View of Product Positioning



"8 x 8" means 8 x 8 @ 5 GHz + 4 x 4 @ 2.4 GHz. "Tri-band 4 x 4" means 4 x 4 @ upper 5 GHz + 4 x 4 @ lower 5 GHz + 4 x 4 @ 2.4 GHz. Others are usually dual-band, equal number of antennas in the 5 GHz and 2.4 GHz bands. IoT devices may be 2.4 GHz only. *Based on a slide presented by Marvell at Wi-Fi Now 2019.*

2.1.7 Why Upgrade to Wi-Fi 6 Now?

Wi-Fi 6 future-proofs your network with the latest hardware:

- **Even with legacy client devices, Wi-Fi 6 improves performance.** Wi-Fi 6 access points have the latest processors, memory and software to future-proof your network, preparing your installation for more Wi-Fi devices in the future.
- **Adding Wi-Fi 6 client devices to a Wi-Fi 6 network improves performance for all**, including legacy devices, by freeing up time-frequency and spatial domain resources.
- Most access points shipping in 2019 will comply with Wi-Fi 6 Release 1.0, expected to be approved in the second half of 2019. These access points will pass Wi-Fi 6 certification tests, and will earn the **Wi-Fi CERTIFIED 6** logo. The Wi-Fi Alliance will release the final Wi-Fi 6 Certification Rel. 1.0 guidelines in Q3 2019.
- Under Release 1.0, Wi-Fi 6 supports the key features of 802.11ax including OFDMA and MU-MIMO.

Wi-Fi 6 is shipping with the most important features NOW!

Under Wi-Fi 6 Release 1, an AP can operate in one of **three modes** at a time, **MU-MIMO mode**, **OFDMA mode**, or **SU-MIMO mode**. Each frame is sent using one of these modes, as decided by the AP. See Exhibit 11.

- The first release of Wi-Fi 6 requires MU-MIMO for downlink traffic, which uses **sounding feedback,** currently supported by most Wi-Fi 6 clients. Some chipset vendors are expected to support **UL MU-MIMO** even before formally required under future releases of Wi-Fi 6. UL MU-MIMO addresses the possibility of uplink bottlenecks for activities such as video chatting, real-time gaming, and workplace collaboration.
- Theoretical aggregate data rates for single user MIMO (SU-MIMO) are the same as OFDMA, but OFDMA adds efficiency, especially for small packet sizes. See Exhibit 11.
- OFDMA is not enabled in today's shipping 802.11ax client devices, although this should change within a few months with firmware updates and the release of certification guidelines.

Exhibit 11 Wi-Fi 6 Release 1.0 Modes

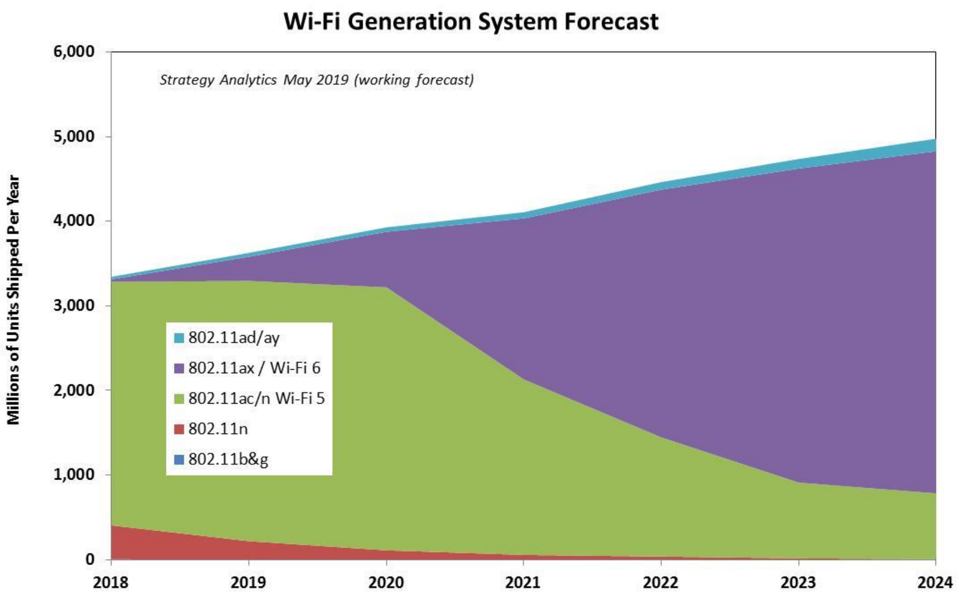
	Modes & Theoretical Aggregate PHY Rates (Mbps)*		
Client Devices	**MU-MIMO**	**OFDMA**	**SU-MIMO**
Two 2x2 clients	1,922	960	960
Three 2x2 clients	2,882	960	960

**Conditions: MCS9, 800 ns GI, 80 MHz channel. Source: RFWireless-world.*

2.1.8 Wi-Fi 6 Forecast

With many devices already shipping with Wi-Fi 6 as shown in Exhibit 12, demand for Wi-Fi 6 APs is growing. Based on expected phone, PC, and other device volumes, Strategy Analytics predicts that the inflection point for Wi-Fi 6 shipments will occur in 2020, as shown in Exhibit 12. Wi-Fi device shipments passed 3 billion units per year several years ago, and will pass the 4 billion unit mark soon, with Wi-Fi 6 units soon to make up more than half of shipping Wi-Fi devices.

Exhibit 12 Wi-Fi Forecast by Standard



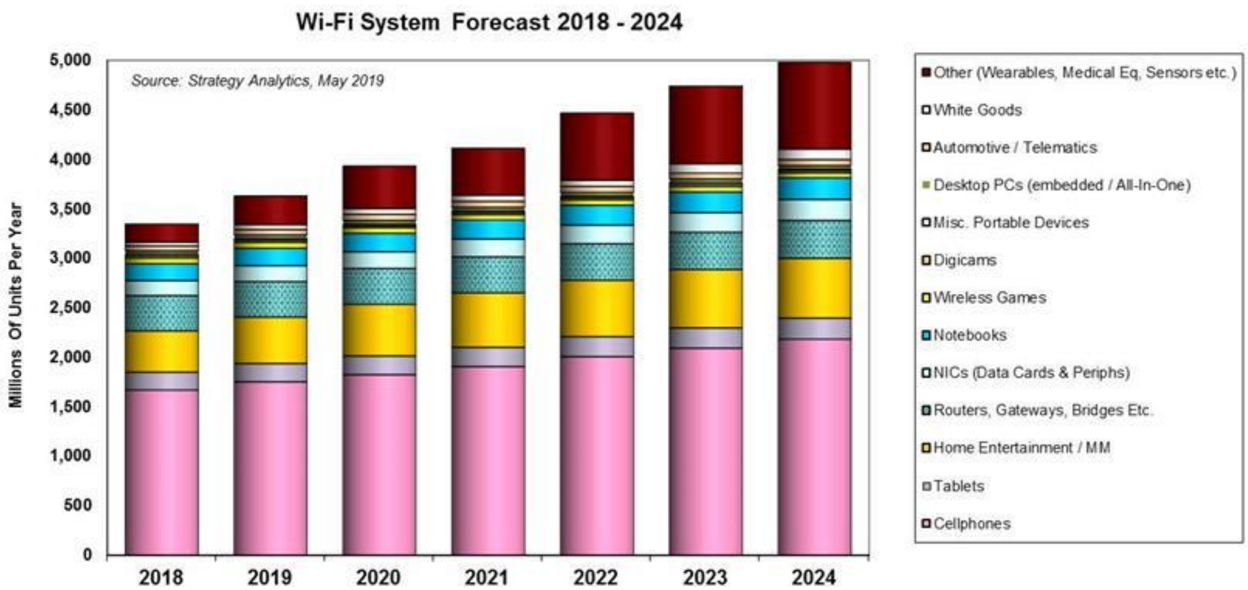
According to the Wi-Fi Alliance, Wi-Fi has an installed base of 9 billion units. Therefore, it could take Wi-Fi 6 four or five years to dominate the installed base, at which time there will be little or no incentive to *not* buy Wi-Fi 6 devices.

In terms of Wi-Fi applications, shipments of IoT Smart Wi-Fi devices will grow rapidly, and shipping devices will make the transition to Wi-Fi 6 over the next year or so. See Exhibit 13. Devices included in this category, according to the Strategy Analytics *Smart Home Strategies (SHS) service,* would include:

- Wall switches, sockets & smart plugs, programmable thermostats, gateways/hubs/panels, smoke detectors, water leak sensors, door/window sensors, motion detectors, eDoorlocks, smart bulbs, smart appliance controllers, irrigation controllers.
- eHealth monitors.
- Smart speakers.
- Wearables.

Wi-Fi 6 will provide benefits to wireless mesh networked devices that use Z-Wave, ZigBee, and Bluetooth Mesh via gateways that serve as concentrators. However, Cees Links of Qorvo has argued that with the capacity, coverage, efficiency, and reduced power consumption improvements provided by Wi-Fi 6, these dedicated low-rate wireless mesh networking standards could become obsolete, replaced by Wi-Fi. This will mean more Wi-Fi devices in the home, and benefits to consumers that adopt Wi-Fi 6 APs.

Exhibit 13 Wi-Fi Forecast by Application



3. Implications

8 x 8 MU-MIMO is the highest performance choice for Wi-Fi 6 APs today, and is clearly a defining feature for the premium tier. 8 x 8 MU-MIMO helps extend range and improve system throughput for a better user experience with more client devices. The main benefits to total system throughput and capacity come from Wi-Fi 6 with 8 x 8 MU-MIMO. APs with 8 x 8 DL MU-MIMO have a performance edge here over 4 x 4.

- Many 8 x 8 APs are shipping and in development today. We identified 22 such systems, and according to chipset companies, missed many more that have not yet been publicly announced.
- Most Wi-Fi 6 client devices shipping this year will fully support 8 x 8 sounding and work well with APs that support 8 x 8 MU-MIMO.
- We recommend that companies and consumers choose APs with support for 8 x 8 MU-MIMO for the best performance, to future-proof installations, and to ease the transition from legacy to Wi-Fi 6. Evaluate 8 x 8 carefully vs. tri-band and dual-band 4 x 4 for the target application and available budget, if possible.
- 8 x 8 MU-MIMO and OFMDA together will provide symbiotic benefits for users across applications, from high data rate users to high density venues and IoT Smart devices.

Systems that support Wi-Fi 6 Release 2 could eventually make up the next premium tier. These systems will include UL MU-MIMO, and will support flexible assignment of radio resources and antennas to potential new Wi-Fi bands as required. This will provide opportunities for chipset providers as well as RF PA-front-end module suppliers, and should extend Wi-Fi capacity to new heights.

4. Appendix

In this section, the author lists some basic information on publicly announced, commercial Wi-Fi 6 APs that use dual-band 4x4, tri-band 4x4 and 8x8 MU-MIMO configurations *as of May 2019*. The information reflects are interpretation of available information from the manufacturers at the time of the publication of this document.

Exhibit 14 Publicly Announced Wi-Fi 6 APs with 8 x 8 MU-MIMO at 5 GHz

Brand & Model	Type	Chipset	Announced*	Expected or Estimated Ship Date
ASUS GT-AX6000	Router. 8x8:8 @ 5 GHz + 4x4:4 @ 2.4 GHz.	Qualcomm: QCN5054 x 2, QCN5024; IPQ8074 processor, QCA8337 Ethernet switch.	January 2018	H2 2018
Calix GigaSpire Max GS2020E	Router. 8x8:8 @ 5 GHz + 4x4:4 @ 2.4 GHz, BT LE, ZigBee, Z-Wave for IoT.	Qualcomm: QCN5054 x 2, QCN5024; IPQ8074 processor.	November 2018	H1 2019
Calix GigaSpire Blast GS2026E	Router. 8x8:8 @ 5 GHz + 4x4:4 @ 2.4 GHz.	Qualcomm: QCN5054 x 2, QCN5024; IPQ8074 processor, QCA8075 Ethernet switch.	November 2018	H1 2019
Cisco C9117AXI-B	Router. 8x8:8 @ 5 GHz + 4x4:4 @ 2.4 GHz.	Qualcomm: QCN5054 x 2, QCN5024; IPQ8074 processor.	November 2018	H2 2019
Cisco Meraki MR55	Router. 8x8:8 @ 5 GHz + 4x4:4 @ 2.4 GHz, BT LE. Cloud managed.	Qualcomm: QCN5054 x 2, QCN5024; IPQ8074 processor.	January 2019	March 2019
Compex HK01	Embedded board. 8x8:8 @ 5 GHz + 4x4:4 @ 2.4 GHz.	Qualcomm: QCN5054 x 2, QCN5024; IPQ8074 processor.	July 2018	November 2018
Extreme Networks TBD	Enterprise AP: 8x8:8 @ 5 GHz + 4x4:4 @ 2.4 GHz.	Qualcomm	TBA (in development)	TBA
H3C WA6628	Router. 8x8:8 @ 5 GHz + 4x4:4 @ 2.4 GHz.	Qualcomm: QCN5154, QCN5124, IPQ8078 processor.	August 2018	September 2018
Huawei AP7060DN	AP. 8x8:8 @ 5 GHz + 4x4:4 @ 2.4 GHz.	Qualcomm: QCN5154, QCN5124, IPQ8074 processor.	September 2017	
Netgear RAX120	Router. 8x8:8 @ 5 GHz + 4x4:4 @ 2.4 GHz.	Qualcomm: QCN5054 x 2, QCN5024; IPQ8074 processor.	November 2018	May 2019

Exhibit 14 Publicly Announced Wi-Fi 6 APs with 8 x 8 MU-MIMO at 5 GHz *(continues)*

Brand & Model	Type	Chipset	Announced*	Expected or Estimated Ship Date
Ruckus R730	Indoor AP. 8x8:8 @ 5 GHz + 4x4:4 @ 2.4 GHz, BT & ZigBee. For stadiums, public venues, train stations, schools.	Qualcomm: QCN5154, QCN5124, IPQ8074 processor.	July 2018	Sept. 2018
Starry Beam	Router. 8x8:8 @ 5 GHz	Quantenna QSR10GU-AX	November 2018	H1 2019
Telefonica xHGU	Router. 8x8:8 @ 5 GHz + 4x4:4 @ 2.4 GHz.	Quantenna QSR10GU-AX	February 2019	Q3 2019
Telefonica xPORT	Repeater. 8x8:8 @ 5 GHz + 4x4:4 @ 2.4 GHz	Quantenna QSR10GU-AX	February 2019	Q3 2019

Note: All 8 x 8 @ 5 GHz APs in the table above use chipsets from Qualcomm or Quantenna. Celeno and Marvell have recently announced 802.11ax AP chipsets supporting 8 x 8 MU-MIMO at 5 GHz as well.

Exhibit 15 Publicly Announced Wi-Fi 6 APs with Dual-band and Tri-band 4 x 4

Brand & Model	Type	Announced*	Estimated Ship Date
Aerohive	In development, AP: Multiple radios @ 5 GHz + 2x2 or 4x4 @ 2.4 GHz for sectorization.	In development	TBD
ASUS GT-AX11000 (RT-AX95U)	Router. 4x4:4 + 4x4:4 @ 5 GHz + 4x4:4 @ 2.4 GHz [triband 4 x 4].	February 2018	November 2018
ASUS RT-AX88U	Router. 4x4:4 @ 5 GHz + 4x4:4 @ 2.4 GHz.	August 2017	End of 2018
ASUS RT-AX92U	Router. 4x4:4 + 2x2:2 @ 5 GHz + 2x2:2 @ 2.4 GHz.	June 2018	June 2018
Aerohive AP630	Router. 4x4:4 @ 5 GHz + 4x4:4 @ 2.4 GHz.	January 2018	Mid-2018
Aerohive AP650 & AP650X	Enterprise AP: 4x4:4 @ 5 GHz + 4x4:4 @ 2.4 GHz, BT LE. Dual 5 GHz radio capability in software.	January 2018	Mid-2018
Arris NVG578	Fiber Gateway / Router. 4x4:4 @ 5 GHz + 3x3:3 @ 2.4 GHz.	December 2017	Mid-2018
Arris SURFboard W31	Router: 4x4:4 @ 5 GHz + 4x4:4 @ 2.4 GHz, or 3x3:3 @ 5 GHz + 4x4:4 + 1-stream DL @ 2.4 GHz.	January 2019	H1 2019
Arris TG9442	Cable Modem / Router: 4x4:4 + 4x4:4	October 2018	Q3 2019
Aruba Networks AP-514 / AP-515	Enterprise AP: 4x4:4 @ 5 GHz + 2x2:2 @ 2.4 GHz, BT LE, ZigBee.	November 2018	November 2018
Cisco C9115AXI-B	Enterprise AP: 4x4:4 @ 5 GHz x 4x4:4 @ 2.4 GHz, BT LE.	May 2019	H2 2019
Cisco C9120AXI-series	Enterprise AP: 4x4:4 @ 5 GHz + 4x4:4 @ 2.4 GHz, BT LE / ZigBee.	May 2019	H2 2019
D-Link AX6000 DIR-X6060	Router: 4x4:4 @ 5 GHz + 4x4:4 @ 2.4 GHz	January 2018	Was due H2 2018. H2 2019?
D-Link DIR-X9000 AX11000 Ultra	Router: 4x4:4 @ 5 GHz + 4x4:4 @ 2.4 GHz; tri-band?	January 2018	Was due H2 2018. H2 2019?
Extreme Networks AP505i	Enterprise AP: 4x4:4 @ 5 GHz + 4x4:4 @ 2.4 GHz.	January 2019	April 2019

Exhibit 15 Publicly Announced Wi-Fi 6 APs with Dual-band and Tri-band 4 x 4 *(continues)*

Brand & Model	Type	Announced*	Estimated Ship Date
Extreme Networks AP510ie	Enterprise AP: 4x4:4 @ 5 GHz + 4x4:4 @ 2.4 GHz.	January 2019	April 2019
Netgear RAX200	Router:4x4:4 + 4x4:4 @ 5 GHz + 4x4:4 @ 2.4 GHz.	March 2019	May 2019
Netgear Orbi Wi-Fi 6	AP / Router: 4x4:4 + 4x4:4 @ 5 GHz + 4x4:4 @ 2.4 GHz.	February 2019	H2 2019
Netgear Nighthawk AX8 (RAX80)	Router:4x4:4 @ 5 GHz + 4x4:4 @ 2.4 GHz.	August 2018	January 2019
TP-Link Archer AX11000 Tri-Band Gaming Router	Router: 4x4:4 + 4x4:4 @ 5 GHz + 4x4:4 @ 2.4 GHz.	January 2018	April 2019
TP-Link Archer AX6000	Router: 4x4:4 @ 5 GHz + 4x4:4 @ 2.4 GHz.	January 2018	December 2018

**FCC filing date may precede announcement date in the US.*

5. How Can We Help You?

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