

IEEE 802.11ax: The Sixth Generation of Wi-Fi

1 Executive summary

Wireless is evolving, driven by more devices, more connections, and more bandwidth-hungry applications. Future networks will need more wireless capacity and reliability. That's where the sixth generation of Wi-Fi comes in.

The emerging IEEE 802.11ax standard is the latest step in a journey of nonstop innovation. It builds on the strengths of 802.11ac, while adding flexibility and scalability that lets new and existing networks power next-generation applications. IEEE 802.11ax couples the freedom and high speed of gigabit wireless with the predictability we find in licensed radio (LTE).

IEEE 802.11ax allows enterprises and service providers to support new and emerging applications on the same Wireless LAN (WLAN) infrastructure, while delivering a higher grade of service to older applications. This scenario sets the stage for new business models and increased Wi-Fi adoption.

IEEE 802.11ax lets access points support more clients in dense environments and provide a better experience for typical wireless LAN networks. It also powers more predictable performance for advanced applications such as 4K video, Ultra HD, wireless office, and Internet of Things (IoT). Flexible wake-up time scheduling lets client devices sleep much longer than with 802.11ac, and wake up to less contention, extending the battery life of smart phones, IoT, and other devices.

IEEE 802.11ax achieves these benefits by pushing on three different dimensions:

- Denser modulation using 1024 Quadrature Amplitude Modulation (QAM), enabling a more-than-35-percent speed burst
- Orthogonal Frequency Division Multiple Access (OFDMA)-based scheduling to reduce overhead and latency
- Robust high-efficiency signaling for better operation at a significantly lower Received Signal Strength Indication (RSSI)

IEEE 802.11ax OFDMA technology lets even first-wave 802.11ax access points support eight spatial streams and deliver up to 4800 Mbps at the physical layer, depending on vendor implementation. All clients will achieve higher effective throughput at the MAC layer, for a better overall user experience.

Unlike 802.11ac, 802.11ax is a dual-band 2.4- and 5-GHz technology, so 2.4-GHz-only clients can take advantage of its benefits right away. Most importantly, 802.11ax 2.4-GHz support significantly increases the range of Wi-Fi, adding standards-based sounding and beamforming, and enabling new use cases and business models for indoor and outdoor coverage.

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6 Summary

IEEE 802.11ax will enhance existing 802.11a/g/11n/11ac deployments even if they are not fully upgraded to 802.11ax immediately. Its OFDMA-based channel access is fully backward-compatible with traditional EDCA/CSMA, and Cisco® access points will use each scheme optimally. Secondly, 802.11a/g/11n/11ac monitoring and wireless intrusion protection systems (Wireless Intrusion Protection Switching [WIPS]) can continue to decode most management frames such as beacon and probe request/response frames, even when sent in the new 802.11ax packet format.

IEEE 802.11ax was designed for maximum compatibility, coexisting efficiently with 802.11a/n/ac devices. Its new preamble (HE-SIG-A/B) follows the traditional 802.11a/g/n/ac preamble and extensions to request-to-send/clear-to-send (RTS/CTS) procedures for multiuser to help avoid collisions with older single-user mode users.

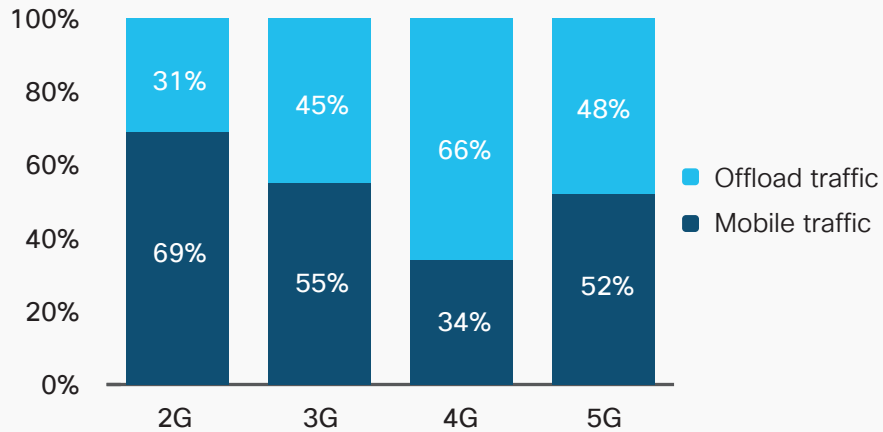
The emerging 802.11ax standard is a dramatic step forward in wireless technology, unlocking real benefits for enterprise and service provider organizations as time moves forward.

2 Market dynamics

Examination of the previous 802.11-based networks shows that each generation delivered increasing throughput and coverage to users to support the expansion and densification of enterprise networks. However, considering future wireless networks indicates that the next generation needs not only to support this ongoing expansion but also to offer a greater level of service to existing networks. In particular, there is a growing need to support 4K/8K video; augmented and virtual reality (AR/VR); and IoT for our enterprise customers, in addition to a reliable extension of mobile core capabilities such as voice for our service provider customers—all of which require a higher degree of deterministic behavior than achieved in previous generations of Wi-Fi.

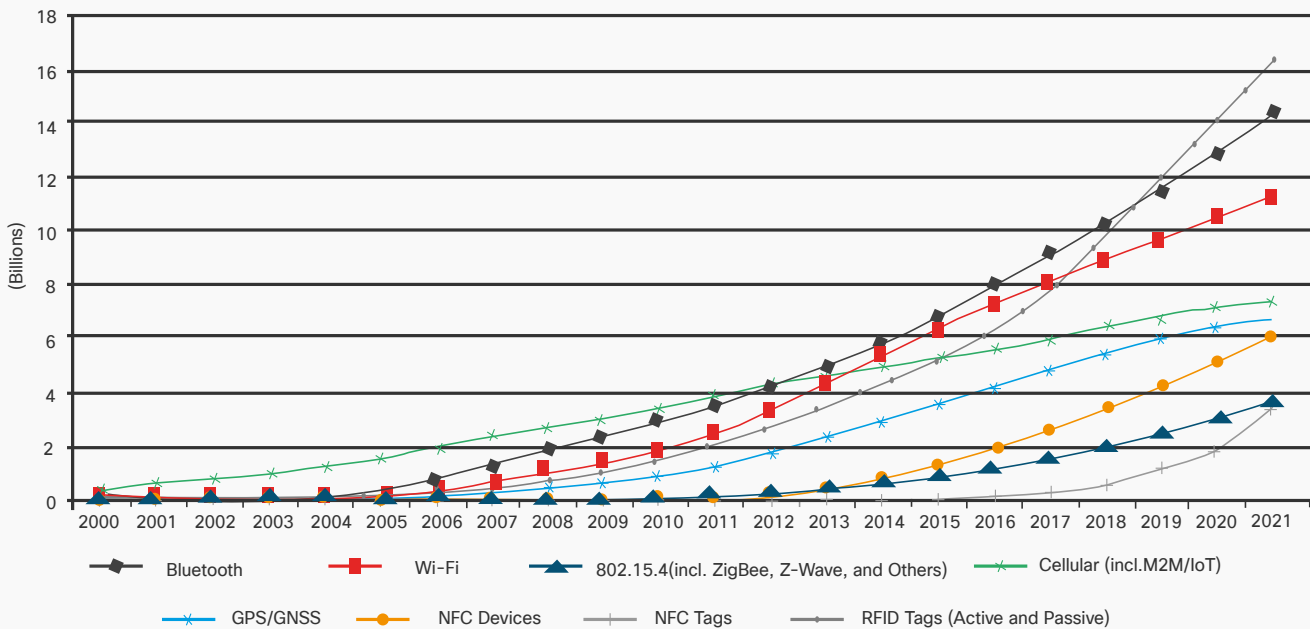
Historically, each generation of cellular (2G, 3G, and 4G) has offloaded more and more traffic onto Wi-Fi, including enterprise because of its superior speeds and economics. For the future (2020+ it is clear that even the newest cellular technology (5G) will require significant Wi-Fi capacity supportive of carrier-grade voice and video services that are best delivered with 802.11ax and its cellular-like scheduling capability (Figure 1).

Figure 1. Mobile offload traffic trend (Cisco Virtual Networking Index [VNI])



An important trend, Internet of Things (IoT) presents a significant challenge to enterprises: how to securely and easily connect hundreds or thousands of electronic devices to the corporate IT network congruent with their operational and engineering needs. In contrast with user devices such as laptops, IoT devices have either a need for deterministic wireless service (for example, poll me every 5 ms or I will shut down) or low-power service (that is, I don't talk unless I really need to). Traditionally, these needs have been met with proprietary, niche, or service provider-specific technology, but enterprise Wi-Fi has been increasingly chosen as the indoor IoT platform because of its significant economies of scale and ease of management by IT. To address these IoT operational needs, 802.11ax and its IoT capabilities such as low power and determinism are expected to accelerate this adoption (refer to Figure 2).

Figure 2. IoT trends (Cisco VNI)



In the future, we can also envision an enterprise where users are virtually connected to colleagues, partners, and customers through Augmented Reality (AR), Virtual Reality (VR) or Mixed Reality (MR) technology. The benefits of this form of collaboration are being discovered every day as researchers, engineers, and IT develop enterprise solutions such as telemedicine, remote field support, retail visualizers, virtual training, and collaboration. What is clear is that significant throughput (for example, 1 Gbps+) and low latency (for example, <10 ms) are required for these applications and thus 802.11ax is well positioned with its advanced Multiple Input, Multiple Output (MIMO) (8 x 8) and scheduling capabilities (Figure 3).

Figure 3. All the realities: Augmented, mixed, and virtual



- ▶ These realities pose new demands on network quality and performance.
- ▶ Satisfying bandwidth and latency requirements is **critical** for high QoE.
- ▶ AR Traffic will grow 7-fold during 2016-2021: from 3 to 20 Petabytes/month.
- ▶ VR Traffic will grow 11-fold during 2016-2021: from 13 to 140 Petabytes/month.

3 What is 802.11ax?

First, 802.11ax is an evolution of 802.11ac. If you want to learn more about 802.11ac, visit: <https://www.cisco.com/c/dam/en/us/products/collateral/wireless/aironet-3600-series/white-paper-c11-713103.pdf>. If you are already familiar with the downlink (DL) multiuser (MU) MIMO, 256 QAM, and 160-MHz wide channels introduced by 802.11ac and you don't need a refresher, then proceed.

3.1 Drivers for 802.11ax

IEEE 802.11ax is an evolutionary improvement to 802.11ac. One of the goals of 802.11ax, also known as high-efficiency wireless (HE), is to deliver higher levels of efficiency in existing Wi-Fi networks:

- Deliver high data rates more consistently in typical Wi-Fi environments
- Focus on Key Performance Indicators (KPI) that improve Quality of Experience (QoE)

In the traditional enterprise space, the challenges include:

- Ultra-High-Density (UHD) environments with scores of users each carrying or wearing three or four 802.11 clients, all consuming network resources concurrently
- The increased adoption of real-time applications such as 4K video and augmented or virtual reality (AR/VR) placing new demands on already pressured environments

In the adjacent IoT space, a convergence of traditionally purpose-built operational networks onto the IT networks is accelerating the need to support:

- Low-complexity and low-power devices such as HVAC, asset tags, and healthcare sensors
- Ultra-Reliable Low-Latency Communications (URLLC) such as medical (imaging/control) and manufacturing (warehouse logistics, robotics) that require tight KPI control

3.2 How does 802.11ax go so fast?

Peak wireless speed is the product of four factors: channel bandwidth, constellation density, number of spatial streams, and per-symbol overhead. IEEE 802.11ax pushes on constellation density by adding 1024 QAM but more significantly improves the per-symbol overhead with flexible PHY timing parameters.

First, going from 256 QAM to 1024 QAM increases peak rates by $10/8 = 1.25$ times. Being closer together, the constellation points are more sensitive to noise, so 1024 QAM helps most at shorter range. 256 QAM is more reliable, but 1024 QAM does not require any more spectrum or more antennas than 256 QAM. It can be implemented easily with existing physical systems.

Second, going from a fixed symbol duration (T_s) of 3.2 microseconds (μs) and only two Guard Intervals (GI) of 400 or 800 ns to a longer T_s (12.8 μs) and three guard-interval options (0.8, 1.6, or 3.2 μs) allows both higher speed and, when needed, more reliability. Mathematically, the T_s -to (GI + T_s) ratio determines the peak time-domain efficiency, which for 11ac was up to $3.2 \mu s / (3.2 \mu s + 400 \text{ ns})$ or 88.9 percent, whereas with 802.11ax we can achieve up to $12.8 / (12.8 + 0.8) = 94$ -percent efficiency for a peak throughput gain of 5.9 percent, and yet with much greater multipath robustness. In addition, the 802.11ax tone plan is denser with 980 data tones (OFDMA sub-carriers) per 13.6 μs (T_s + minimum GI) over 80 MHz, whereas 802.11ac has 234 data tones (OFDM sub-carriers) per 3.6 μs in the same 80 MHz. This increased tone density results in an additional peak throughput gain of 10 percent with respect to 802.11ac in the same spectrum (since $(980/13.6) / (234/3.6) = 1.1$).

Then the speed is directly proportional to the number of spatial streams. More spatial streams require more antennas, RF connectors, and RF chains at transmitter and receiver. The antennas should be spaced $1/3$ wavelength ($3/4$ inch at 5.25 GHz) or more apart, and the additional RF chains consume additional power. The physical separation requirement in particular drives a vast majority of mobile devices to limit the number of antennas to one, or two. This trend is expected to remain unchanged for upcoming 802.11ax-capable mobile devices. However, for access points, these physical resource constraints are not as strict, so we expect first-wave 802.11ax access points to support up to 8 spatial streams, which is twice the maximum number provided in 802.11ac products today.

Collectively, these three accelerations are shown in Table 1.

Table 1. Calculating the speed of 802.11ac and 802.11ax

PHY	Bandwidth (as number of data subcarriers)	Data bits per subcarrier	Time per OFDM symbol (800ns GI)	1 SS	3 SS	4 SS	8 SS
802.11ac	234 (80 MHz)	$5/6 \times \log_2(256)$ ≈ 6.67	4 μs	390 Mbps	1.17 Gbps	1.56 Gbps	-
	2×234 (160 MHz) X	/	=	780 Mbps	-	3.12 Gbps	-
802.11ax	980 (80 MHz)	$5/6 \times \log_2(1024)$ ≈ 8.33	13.6 μs	600 Mbps	1.8 Gbps	2.4 Gbps	4.8 Gbps
	2×980 (160 MHz)			1.2 Gbps	3.6 Gbps	4.8 Gbps	-

3.3 IEEE 802.11ax and determinism

Providing gigabit data rates within a single spatial stream using 1024 QAM offers a peak theoretical throughput that is achieved regularly in low-density enterprise environments. However, when the client density (and resulting access-point density) increases, the likelihood of achieving these throughputs diminishes as channel contention or air-time usage increases from client usage either in the same Basic Service Set (BSS) (access point) or from clients and access points in a neighboring or overlapping BSS (OBSS). We often refer to this latter degradation as Co-Channel Interference (CCI), which is particularly problematic in open-space venues such as conference rooms and public hotspots where RF propagation is close to ideal or Line-Of-Sight (LOS).

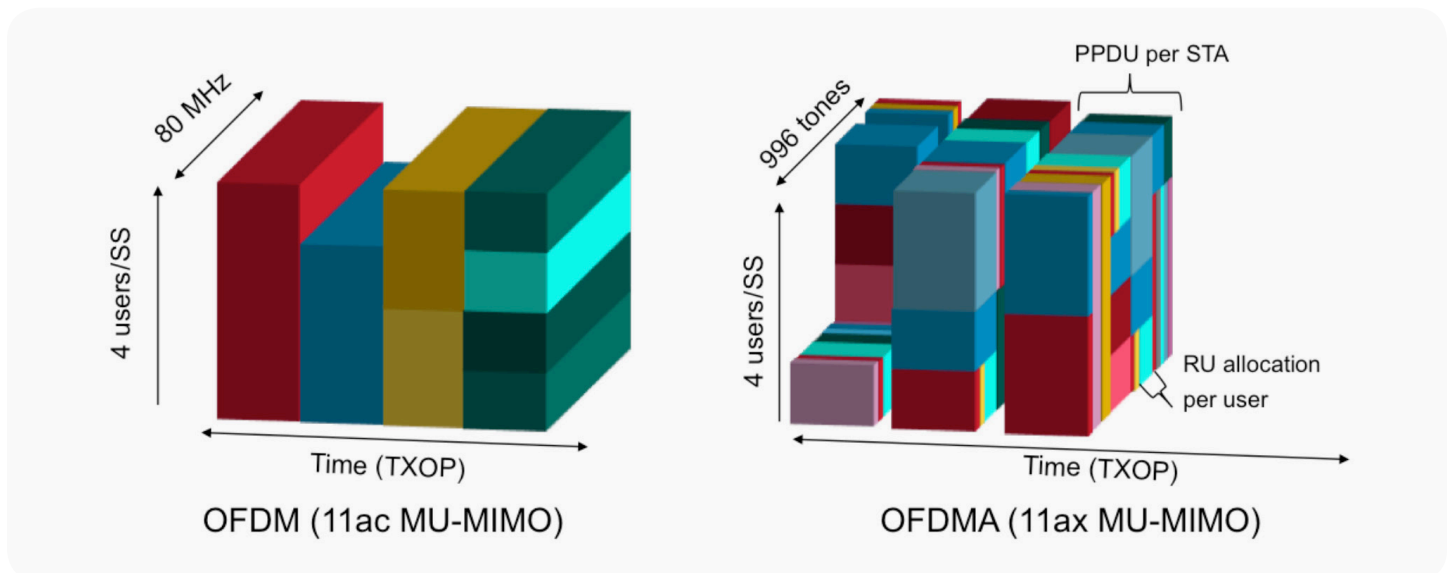
To combat these well-known phenomenon, 802.11ax introduces OFDMA, which is a new channel access mechanism similar to but distinct from cellular/LTE radio networks, because it maintains the robustness of Wi-Fi in unlicensed spectrum. First, OFDMA assures contention-free transmission to multiple clients in both the downlink (DL) and uplink (UL) within a respective single transmit opportunity (TXOP). Second, the addition of multiuser Enhanced Distributed Channel Access (EDCA) to UL-OFDMA allows the access point to affect the relative channel access priorities of clients, even between 11ax and 802.11ac clients. Both schemes are not only more efficient and less prone to packet loss and jitter due to contention, but because they allow the access point to have precise control of both uplink and downlink transmissions, they also allow for greater determinism.

3.3.1 Three dimensions of resource allocation

In 802.11ac, multiple users are separated by space and time. In the time domain, transmission opportunities are allocated to clients and access points alike in a distributed fashion using EDCA. In the spatial domain, downlink\ multiuser Multiple-Input-Multiple-Output (MIMO) techniques are used for isolation and simulcast capabilities limited by the number of transmit antennas (typically up to 4). Both techniques are applied on a per Multiuser Physical layer Protocol Data Unit (MU-PPDU) basis.

In 802.11ax, we inherit the same space and time separation as 802.11ac but we add a third multiuser dimension: frequency division. With 802.11ac, the Wi-Fi channel (20, 40, 80, or 160 MHz) was broken down into a collection of smaller OFDM sub-channels to mitigate interference. At any given point in time, a single user is allocated all of those sub-carriers in each PPDU. However, with OFDMA (802.11ax), individual groups of subcarriers are individually allocated to clients as a resource units on a per-PPDU basis (Figure 4).

Figure 4. OFDM vs. OFDMA



This third dimension (OFDMA) has many advantages, as discussed previously, such as determinism and increased efficiency through reduction of collisions and contention. But it also revolutionizes the way in which you can deliver Quality of Service (QoS). Previously, with 802.11ac, if an access point wished to deliver a certain throughput to one client but more throughput to another, the best it could do was schedule the correct number of downlink PPDU in the time domain (for example, with queuing and shaping techniques) and “hope” the client would be able to allocate a sufficient number of TXOPs for UL-PPDUs. This inefficiency and unpredictability makes it difficult to provide any assurance around throughput and other KPIs such as delay and jitter.

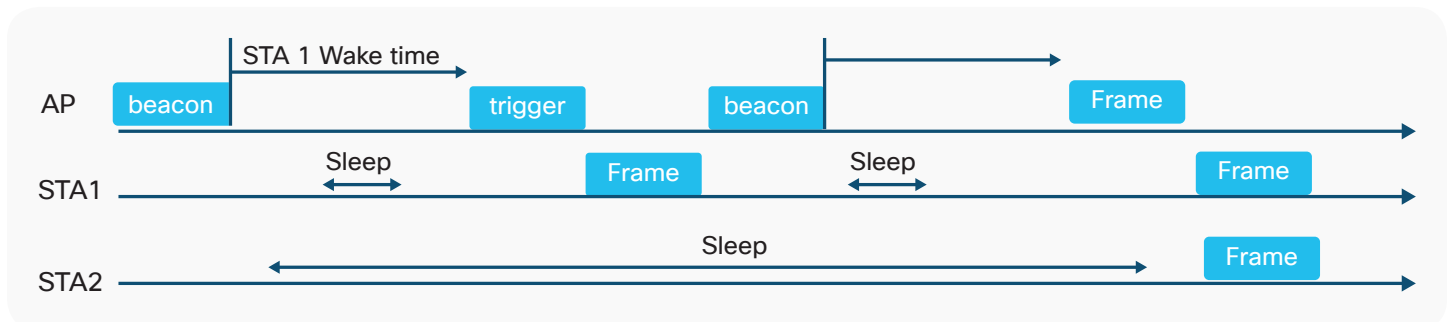
With OFDMA we now have both a more granular downlink resource unit of time + frequency and also for the first time a way of explicitly allocating resource units in the uplink. This bidirectional resource-unit allocation ability is akin to the LTE Resource Block (RB) and allows the formation of a virtual resource or “slice” in 5G terminology. As can be imagined, this 802.11ax slice could have various attributes such as bandwidth, delay, and jitter, allowing finer-grained QoS than previously available with 802.11ac.

3.3.2 Flexible low-power device scheduling

In prior generations of 802.11, low-power devices such as mobile phones were accommodated with Unscheduled Automatic Power Save Delivery (U-APSD) or Wi-Fi Multi Media Power-Save (WMM-PS). A client in this mode can have the access point buffer transmissions to it instead of sending it immediately. Instead, the access point signaled availability of data in periodic beacons through a Traffic Indication Message (TIM), which allows the client to keep its radio receiver off (saving power) and waking-up only periodically to receive beacons (generally a multiple of every 102.4 ms). However, this strict adherence to beacons limits the potential energy-saving potential for IoT devices that don't require regular channel access like a mobile phone yet must always be ready to receive a phone call.

With 802.11ax and the new OFDMA scheduling capability of 802.11ax, we can devise a new power-savings mode called Target-Wakeup Time (TWT). With TWT, there is no longer a tight relationship between access-point beacons and the sleep time of the device. Generally, the station can request a schedule to wake up at any time in the future. The result is significant power savings for battery-powered devices, particularly those in the IoT space (Figure 5).

Figure 5. Target Wakeup Time (TWT) operation



A related but significant benefit of TWT is that it can also be used as an uplink scheduling method akin to UL-OFDMA. That is, because TWT effectively puts clients to sleep with a predetermined wake-up time (based on their request), deterministic transmission times and hence uplink scheduling is possible. The access point can use this ability to both reduce contention (more distributed channel usage) and address delay sensitivity of applications.

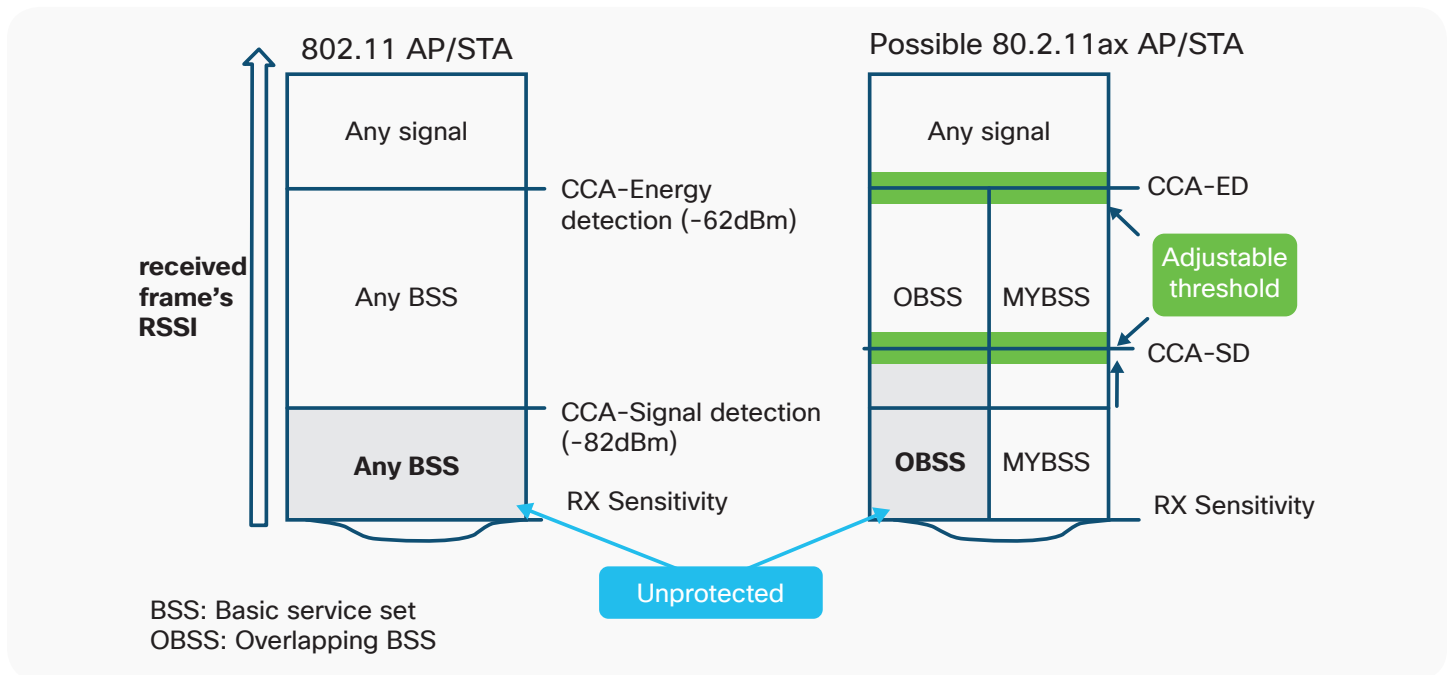
3.3.3 Improving capacity while reducing scheduling uncertainty

It is well known that CCI management is critical in unlicensed spectrum because it markedly reduces total system capacity, but it also interferes with access-point scheduling duties because neighboring access points (for example, from other networks) are not generally coordinated. IEEE 802.11ax offers an elegant mechanism to manage CCI based on the principle of distinguishing transmission of my own cell (BSS) from that of another cell or BSS or OBSS.

In particular, 802.11ax supports dynamic OBSS Packet Detection (OBSS-PD), which allows clients/access points in one BSS to ignore frames from other BSSs, which are typically some distance away. This setup is achieved by dynamically selecting appropriate Clear-Channel-Assessment (CCA) thresholds and minimum transmit power (TXP) levels to receive from and reach members of their own BSS.

This scheme is illustrated in Figure 6.

Figure 6. OBSS & BSS Color operation



The benefits include system capacity gain, but also more critically a significant reduction in latency variation because the serving access point or client is much less likely to have its TXOP delayed by a friendly (or rogue) neighbor.

3.4 How did the IEEE make 802.11ax more robust?

One of challenges of 802.11 is balancing the coverage needs of clients with the overall performance needs of the system. With 802.11ac, we needed to keep the minimum data rates of clients high in order to maximize the use of the spectrum because only one device could access the air at a time. Thus, we sacrifice coverage for overall performance. However, with OFDMA, this is no longer the case because multiple users access the medium at the same time and the impact of each is limited to a smaller portion of the channel. Given this truth, the designers of 802.11ax were able to extend coverage by:

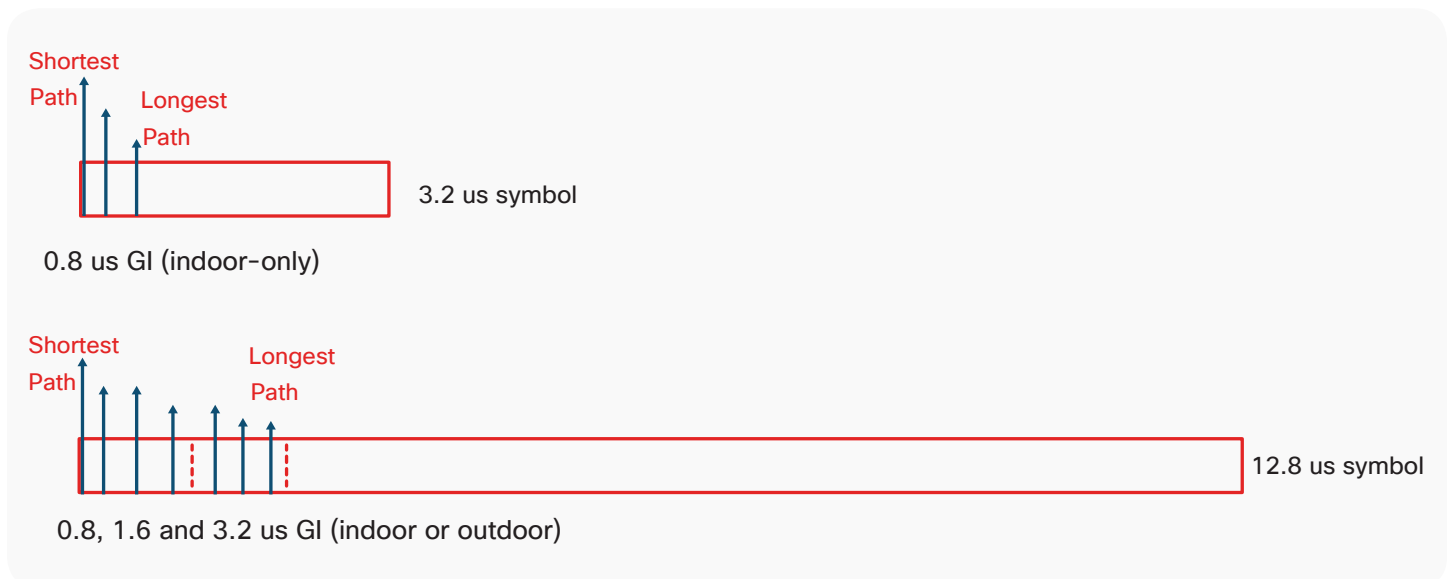
- Introducing low-rate and low-power modes
- Using flexible PHY timing

Very low data rates address the problem of decoding signals at long range or in noisy environments because smaller resource units (that is, reduced number of OFDMA sub-carriers) require a lower total energy and still achieve the same Signal-to-Noise Ratio (SNR). Although the smallest channel in 802.11ac was 20 MHz, the smallest resource unit in 802.11ax is 2MHz, resulting in a very significant 8-dB reduction in the noise power, and accordingly allowing the required signal power to be 8 dB lower too. This situation allows 802.11ax to tolerate 8 dB more noise and achieve a much larger coverage area for low-bit-rate clients (such as IoT telemetry data).

The flexible PHY timing, including Guard Interval (GI), addresses the problem of multipath fading (for example, outdoor) whereby “echo” energy from one OFDM symbol leaks into the next OFDM symbol, causing Inter-Symbol-Interference (ISI). It can be shown that this more robust guard interval results in up to twice the throughput in outdoor environments such as those currently served by cellular/LTE technology. These two capabilities combined allows Wi-Fi operators to offer compelling cost-efficient Wi-Fi-based solutions competitive with 4G LTE and 5G-NR for the lower-speed IoT space.

As shown in Figure 7, when the RF channel is spatially compact (for example, indoor small cells), the Delay Spread (DS) or difference between the shortest and longest path is small (for example, 300 ft) and thus exhibits low delay spread (for example, 300 ns). However, when the RF channel is spatially large (for example, outdoor large cells), then the delay spread is high; for example, one signal component might be LOS but the next may bounce off a far-off building, resulting in a path difference of approximately 1 km (3200 ft) and thus exhibit very high delay spread (3.2 μ s) [1]. In all OFDMA systems such as 802.11ax and LTE, the OFDMA guard interval must be longer than the delay spread in order to avoid significant decoding errors caused by ISI or the time overlap of one version of a signal upon itself. Thus, to support outdoor (for example, metropolitan) or partially outdoor (for example, stadium or hotspot) channels, the guard interval in 802.11ax is extendable from the original 0.8- μ s specification of 802.11ac to 1.6 μ s or as high as 3.2 μ s, depending on the channel type.

Figure 7. PHY timing options

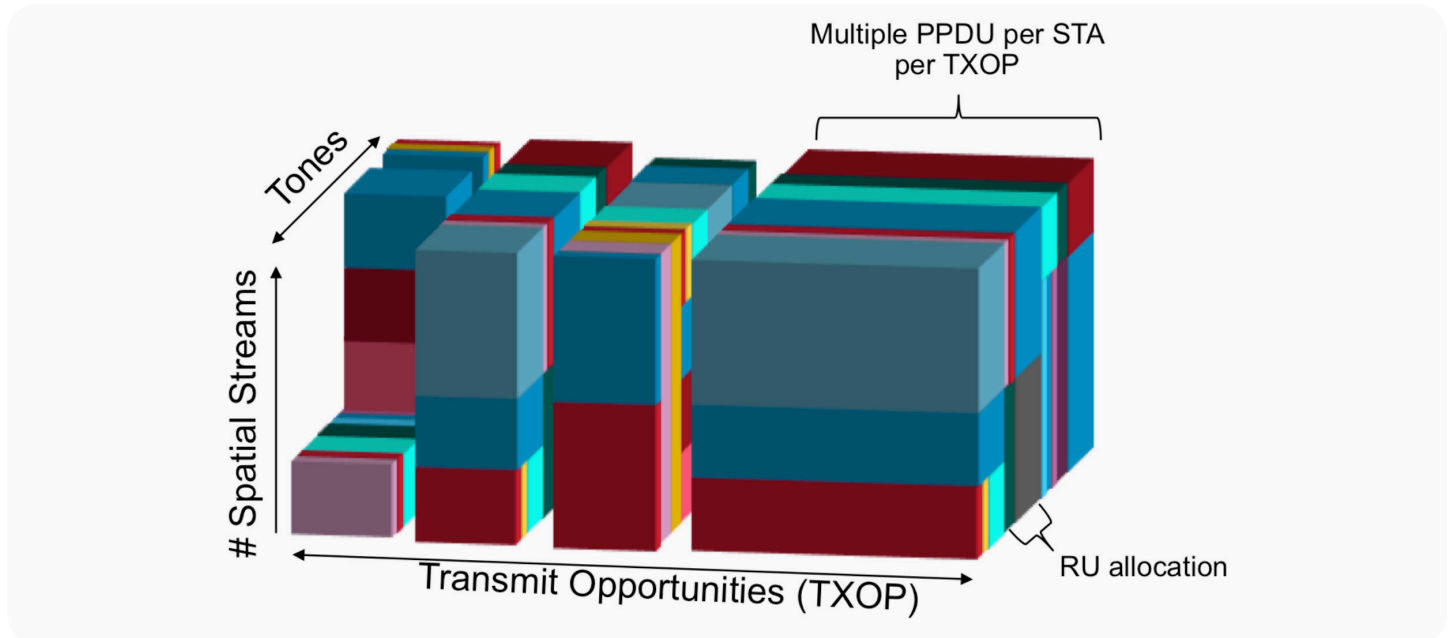


3.5 Technology overview

3.5.1 OFDMA and resource unit allocation

The ability to allocate a resource unit, a set of contiguous OFDMA sub-carriers (“tones”), to each client or station (STA) in the same PPDU is unique to 802.11ax within the 802.11 family. With the smallest resource unit being 26 tones (2 MHz) and the largest being 2 x 996 tones (160 MHz), there is a large degree of flexibility to balance aggregate (average) performance and peak throughput. At the same time, 802.11ax supports multiuser MIMO and can allocate 1 to 8 Spatial Streams (SS) to each STA (refer to Figure 8).

Figure 8. OFDMA resource dimensions



The general downlink OFDMA operation is as follows:

1. The access point decides how many STAs and the size of each resource unit in this TXOP, and indicates it in a field in the preamble of the PPDU.
2. The access point transmits downlink data to multiple STAs in their allocated resource unit (MU-PPDU).
3. The access point requests block acknowledgement from all STAs (MU-BAR).
4. STAs send block ACKs back to access point (M-BA).

The general uplink OFDMA operation is as follows:

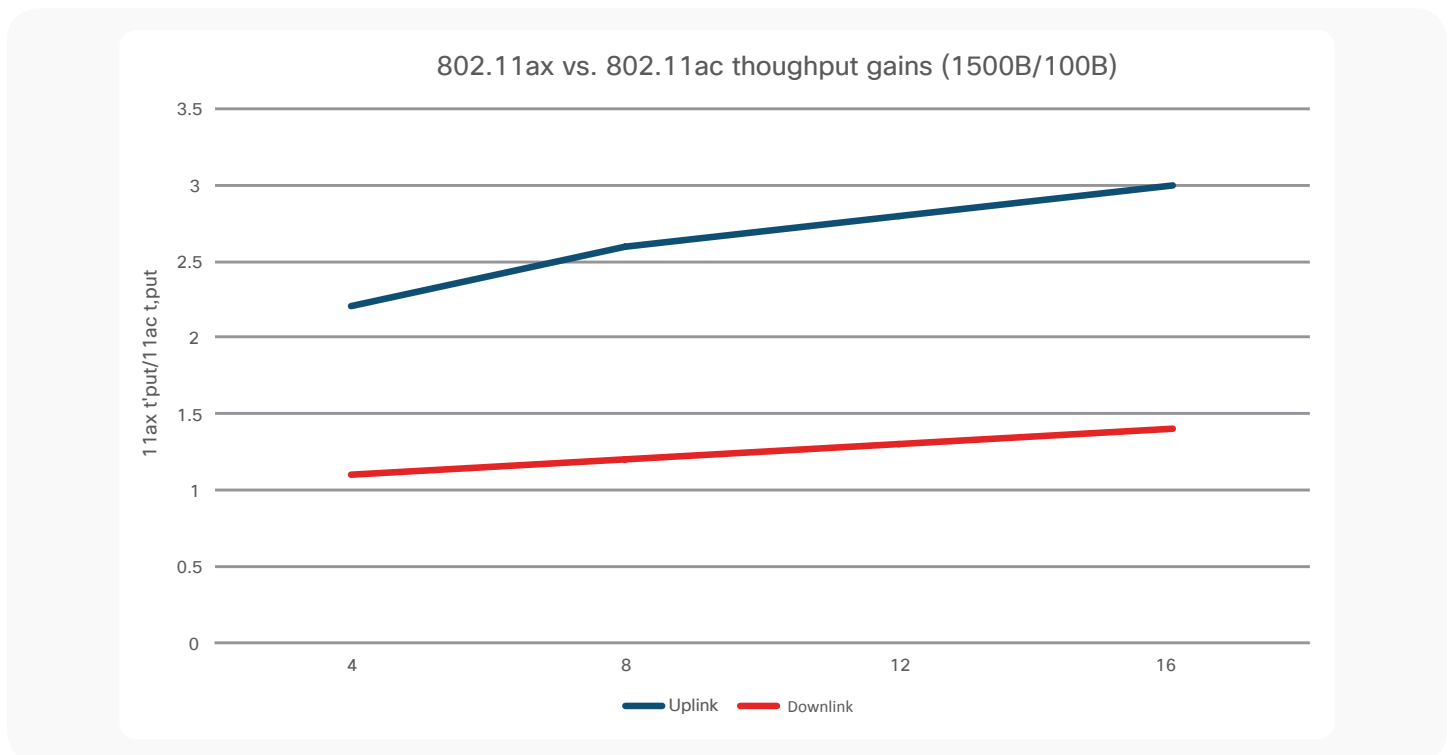
1. The access point decides which STAs need to be asked for data and how many resource units will be allocated to each
2. The access point requests or polls data from STA with a trigger (HE Trigger)
3. STAs respond with data (uplink MU-PPDU)
4. The access point responds with an ACK (M-BA).

Unlike 802.11ac, the 802.11ax access point is in control of the downlink and uplink resource-unit allocation on a per-PPDU basis, which can be seen as a form of access-point scheduling (in the frequency and spatial domains). Although 802.11ax does not formally specify time-based scheduling similar to licensed-spectrum LTE, one can imagine advanced queuing or QoS techniques being used to achieve similar results as cellular because the basic framework is already in place and a pure 802.11ax network would have excellent spectrum and interference management capabilities.

For mission-critical and latency-sensitive applications such as augmented and virtual reality and IoT, the access-point scheduling capability is critical to achieving the desired characteristics of higher effective throughput and determinism. Likewise, the STA must support the directives of the access point in order to achieve a good experience. This area is one that vendors are expected to differentiate and, in particular, where interoperability between access point and STA will play a key role in achieving the highest performance.

On throughput, the gain (over 802.11ac) is shown in Figure 9, where we see the downlink and uplink gains with respect to simultaneous clients (STA). For example, with only 4 STAs, the 802.11ax downlink throughput (with large 1500B packets) is only 10 percent higher than 802.11ac but the uplink throughput is 2.2 times that of 802.11ac (or 120-percent gain). In general, the more clients and access point serves in each TXOP or channel-access, the more efficiency over 802.11ac the access point achieves, especially with small packets such as from voice, video, or TCP ACKs.

Figure 9. Downlink and uplink gains with respect to STA



3.5.2 1024 QAM

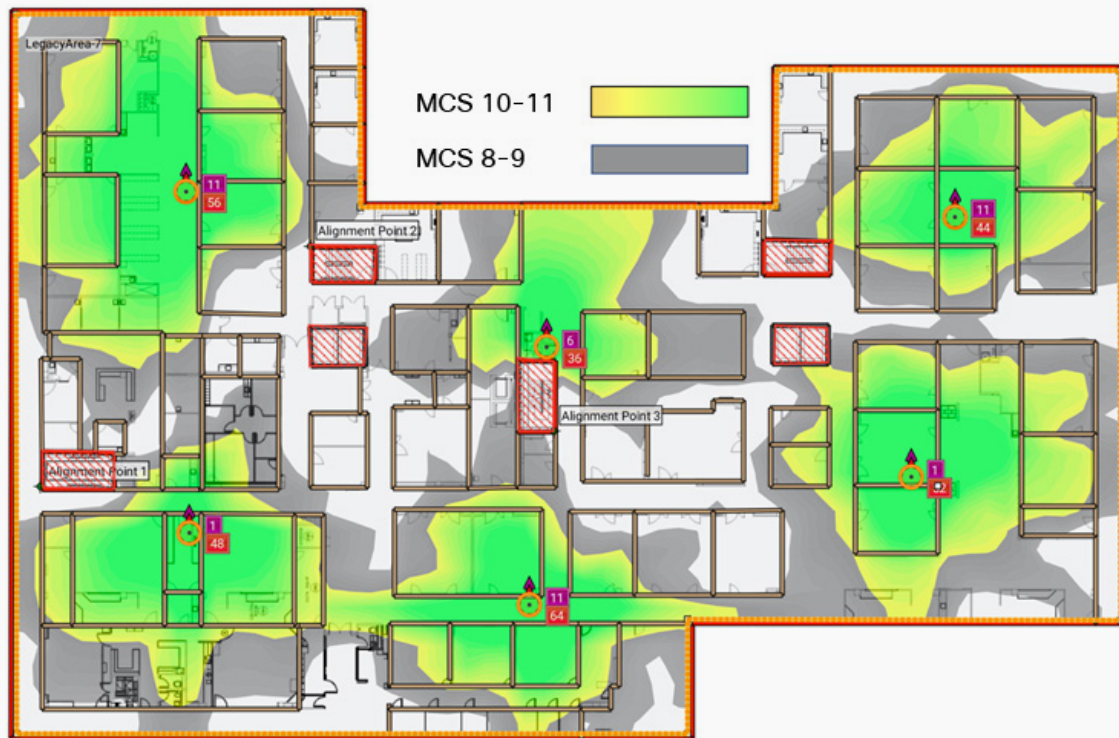
The introduction of 1024 QAM into 802.11ax was achieved by pairing it with 3/4 and 5/6 coding rates to create two new Modulation and Coding Schemes (MCS) 10 and 11. The raw speed gain over the 802.11ac 256 QAM is 10/8 or 25 percent, making 802.11ax the first commercial wireless technology capable of gigabit speeds with a single antenna.

While the effect of 1024 QAM on overall cell throughput is expected to be greater for smaller, denser cells (<2500 ft²) than for larger cells (>5000 ft²), the peak speeds of 4.8 Gbps will enable new capabilities such as immersive enterprise-grade virtual reality using wireless headsets (HMD), a very favorable outcome.

The cost of this high speed is 50-percent tighter constellation points, resulting in approximately a 6-dB higher SNR requirement. However, unlike 802.11ac, 802.11ax is designed to support 8 x Tx and 8 x Rx antennas, facilitating greater transmit beamforming and Maximal-Ratio-Combining (MRC) gains to offset this deficit. From a Wi-Fi deployment perspective, designers should consider these peak speeds in terms of the required network capacity.

As can be seen in the Ekahau heat map shown in Figure 10, in a typical enterprise office the coverage area of 1024 QAM (MCS 10-11) is, as expected, less than that of 256 QAM (MCS 8-9). However, the key areas under the access point are well covered and those users are still likely to achieve multigigabit speeds (depending on device capability).

Figure 10. Ekahau heat map



3.5.3 Spatial Reuse (SR) and OBSS operation

With any wireless system including 802.11 CSMA-based networks, sharing the same RF channel in the same physical space has always been a challenge. Although 802.11 does it more robustly and politely than the alternatives, the clients (STA) and access points still act independently to maximize their own Quality of Experience (QoE). For example, some clients might use too much power given the proximity to their associated access point, creating unnecessary interference, or they may use too little power given the interference, and be unable to reach their access point.

Critically, the signal level (RSSI) at which a STA determines the channel is “free to transmit” or what we call Carrier Sense (CS) has historically been conservative based on minimal performance expectations and in practice supplemented by individual vendors to improve performance. However, going forward, 802.11ax standardizes this behavior to ensure optimal performance improvements by formalizing four concepts:

1. Overlapping Basic Service Set (OBSS) is the overlap or interference between a BSS (that is, the access point and its associated STAs) that the STA is associated with and a neighboring BSS that the STA is not associated with.
2. BSS Color is a method to differentiate between BSSs (that is, access points and their clients) on the same RF channel.
3. OBSS Packet Detection (PD) is the ability to detect signals from other BSSs (OBSSs).
4. Clear Channel Assessment threshold control is the ability of a device to change its CCA sensitivity based on its associated access point and current transmission.

When we put these concepts together, we have a capability to effectively manage interference in managed networks such as those deployed by enterprises and service providers. Specifically, this capability allows the clients and access points to implicitly agree upon the required packet-detection or “busy” signal thresholds and transmit power (TX) levels.

Operation of BSS Color is as follows:

- Each BSS (access point) uses a different “color” (6 bits in the signal preamble or SIG).
- Each STA learns its own BSS upon association and thus other BSSs are OBSSs.
- Signals with the same BSS color use a low RSSI threshold for deferral, thereby reducing collisions in the same BSS.
- Signals with a different BSS color use a higher RSSI threshold for deferral, thereby allowing more simultaneous transmissions.

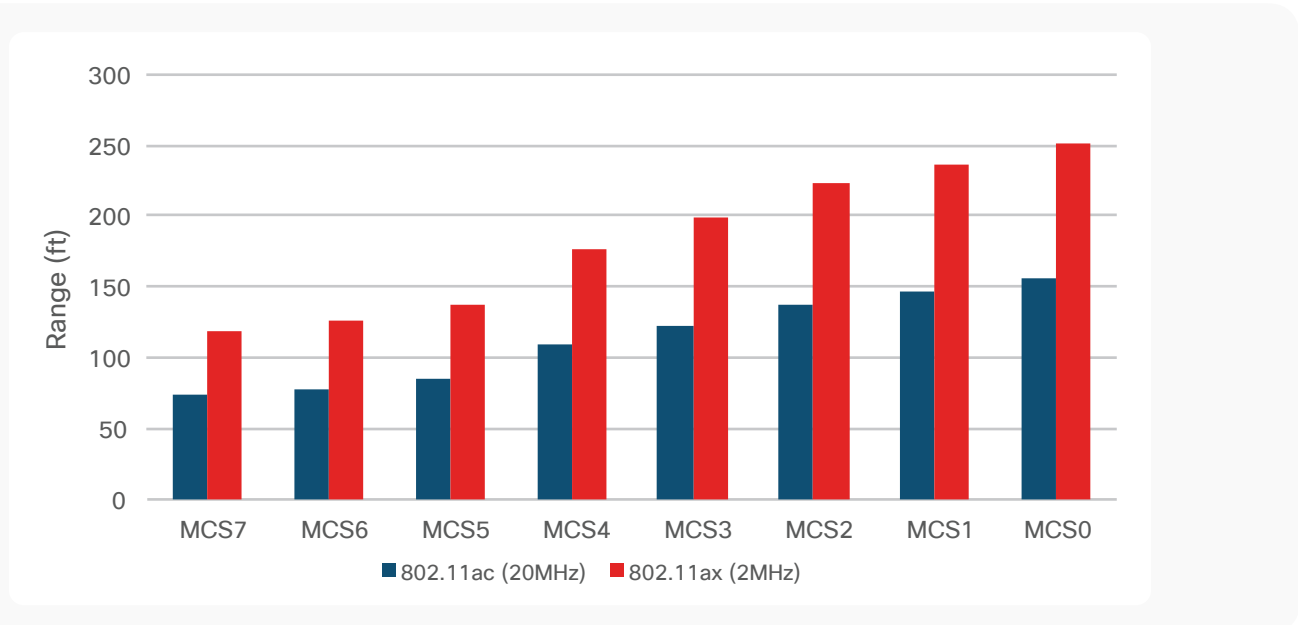
Fundamentally, this scheme trades some degree of ubiquitous fairness (that is, every STA has equal opportunity to contend for a TXOP) for higher per-access point capacity (that is, STAs within my BSS take precedence). In managed High-Density (HD) enterprise networks, this technique is effective, whereas in unmanaged environments, the impact of this capability may be less effective or even detrimental to client performance. Overall, although not the perfect solution for the RF design purist, if used responsibly, this capability does go a long way in improving conditions in a range of conditions where individual STA behavior causes cellwide degradation.

It is important to consider at this point how an enterprise or service provider solution might complement this basic capability. First, we need to understand that the STA responds to the RF conditions that it perceives, so it is key that the Wi-Fi or WLAN infrastructure have an accurate view of the network as seen by the client in order to deliver the best QoE. In fact, the more historical or analytical data the WLAN can glean about its clients the better given the diversity of clients in the ecosystem. Secondly, because access points cooperate in a group to provide contiguous service, it is key that the Radio-Resource-Management (RRM) function provide the right conditions (for example, at the cell edge) to the STA in order for it to derive the optimum CCA thresholds for both its own and other BSSs. In other words, RRM should be BSS_COLOR and OBSS_PD aware when making RF allocation decisions. In any case, BSS_COLOR and OBSS_PD are expected to significantly improve the QoE and capacity of both enterprise and service provider networks alike, enhancing existing HD use cases and perhaps enabling new business models for Wi-Fi operators.

3.5.4 Rate at range

In addition to offering higher speeds, 802.11ax also delivers greater range than 802.11a/g/n/ac. In particular, lower effective data rates through the minimal resource-unit allocation (26-tone, 2 MHz) can be used in order to provide a link budget boost of up to 8 dB with respect to 802.11ac. This gain is shown in Figure 11.

Figure 11. IEEE 802.11ax 2-MHz range boost (indoor 5-GHz NLOS)



4 When is 11ax happening?

IEEE 802.11ax-enabled products are the culmination of efforts at the IEEE and Wi-Fi Alliance pipelines. IEEE 802.11ax delivered an approved Draft 2.0 amendment in September 2017 and will deliver a refined Draft 3.0 in May 2018, with final ratification planned for the end of 2019. In parallel, the Wi-Fi Alliance is expected to take an early IEEE draft, such as Draft 2.0, and use that as the baseline for an interoperability certification for the first-wave products in mid-2019.

5 How does 11ax affect me?

5.1 Compatibility

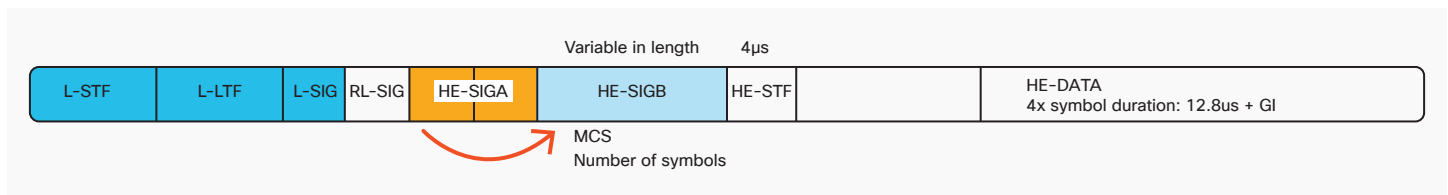
One effect not to worry about is compatibility.

IEEE 802.11ax is carefully designed to be maximally forward and backward compatible with 802.11a/g/n/ac devices. In fact, the 802.11ax compatibility design is even simpler and more thorough than 802.11n compatibility with 802.11a devices.

An 802.11ax device must support all the mandatory modes of 802.11a/g/n and 802.11ac. An 802.11ax access point can communicate with 802.11a/g/n and 802.11ac clients using 802.11a/g/n or 802.11ac formatted PPDU. For this purpose, it is as if the access point were an 802.11ac access point. Similarly, an 802.11ax client can communicate with an 802.11a/g/n or IEEE 802.11ac access point using 802.11a/g/n or 802.11ac PPDU. Therefore, the emergence of 802.11ax clients will not cause problems with existing infrastructure.

The preamble of the 802.11ax formatted packet (refer to Figure 12) is an extension of the established 802.11a/g formatted packet. This extension allows the existing CCA mechanisms already in use for 802.11a/g/n and 802.11ac devices to continue in an 802.11ax world. As soon as these devices see the 802.11ax preamble, they know the duration of the PPDU and can honor that time request. PPDU are typically followed by an Ack or Block Ack frame sent in an 802.11a/g format PPDU, so compatibility with existing devices is ensured and all can honor the time commitments established before continuing to contend and transmit as usual. In the worst case, a device hears the 802.11ax PPDU but is out of range of the station transmitting the Ack or Block Ack (hidden node). In this scenario, the observing station must still wait for an extended duration (called EIFS) and allow time for the expected Ack or Block Ack to be transmitted, thereby reducing the fear of collision.

Figure 12. 802.11ax signal format



Because of this preamble-level compatibility, there is no inherent need for 802.11ax devices to precede their 802.11ax transmissions by CTS-to-self or RTS/CTS, although devices may still choose to implement and send them to protect longer PPDU. However, 802.11ax adds the capability of multiuser RTS/CTS which allows the access point to reserve the channel (set the NAV) for multiple STAs simultaneously with a single MU-RTS PPDU that is then confirmed with simultaneous CTS PPDU from multiple STAs. This scenario overcomes the inherent inefficiency of single-user RTS/CTS still prevalent in 802.11ac networks while adding protection to 802.11ax transmissions.

5.2 When to upgrade to 802.11ax?

Enterprise and service provider customers alike are in the fortunate position to be able to pick between two great technologies:

- IEEE 802.11ac with MU-MIMO, beamforming, and speeds from 290 to 1300 Mbps within 80 MHz
- IEEE 802.11ax with up to 8 SS and 600 to 1800 Mbps for clients (with 1024 QAM) plus additional predictability for advanced applications

IEEE 802.11ac is available today and is robust for most current customer use cases.

IEEE 802.11ax is the future of wireless LANs, but Wi-Fi-certifiable 802.11ax access points will be available only in several months. Clients (smartphones, tablets, laptops, etc.) supporting 802.11ax are also expected to be available starting in 2019. IEEE 802.11ax will provide:

- 4K/8K video at range to multiple simultaneous users (a true relief to every parent of teenagers in a household for sure)
- Ultra-High-Density (UHD) clients
- Determinism for AR/VR applications and significant power savings, especially for IoT devices

Most enterprise customers deploy new access points at the same time that they fit out a building or retrofit a space. For these customers, we recommend installing 802.11ac wave 2 access points today, because of the sheer value of 802.11ac wave 2. Consider also the infrastructure (port speeds) of the LAN and WAN networks because 802.11ac can deliver higher than gigabit speeds today, and 802.11ax can certainly deliver it tomorrow, so your investment plans for the future make this evaluation relevant today.

Mission-critical applications increasingly require determinism and predictability. IoT scale continues to outpace projections. For these reasons consideration of 802.11ax is warranted. The incremental value of 802.11ax exceeds any reasonable price differential and protects your investment without compromising operational realities today.

6 Summary

IEEE 802.11ax is an exciting new step for wireless LANs.

This sixth generation of Wi-Fi will not only deliver higher effective speeds, but will enable new business models and use cases, including:

- Full service provider carrier offload
- IT/IoT convergence
- Real-time applications such as enterprise-grade 4K/8K video or augmented or virtual reality

As with every other recent Wi-Fi advances, 802.11ax is backward-compatible, building on existing technologies and making them more efficient. This scenario enables a graceful installed base transition with ever-increasing gains as the client base converges toward 802.11ax. 802.11ax is worth considering as soon as it's available, even if the client density for the technology is still evolving. In the meantime, enterprise and service provider customers looking at long-term investments in wireless LANs should strongly consider 802.11ac access points.