TECH BRIEF

802.11ax

High Efficiency Wireless Networking

AEROHIVE® NETWORKS

802.11ax

by ***David Coleman****,* ***Perry Correll****, and* ***Alexandra Gates***

Wi-Fi: In Review

Wi-Fi's enormous success is also proving to be its greatest challenge: the expected ubiquitous nature. Wi-Fi today is used across all markets and industries, from the home to the international space station (ISS) to large enterprise-grade deployments, and as a result the number of devices connected and their bandwidth requirements have continued to explode, placing higher and higher demands on the wireless network.

Wi-Fi started out 21 years ago as a concept and then a niche solution to enable mobility, originally only providing about 11 Mbps (802.11b). This was a good first step and within a few years (2003) demand justified increasing the speeds to 54 Mbps (802.11a/g). As demand increased, so did the speed and the next major improvement came with 802.11n (2009). This was really when Wi-Fi took its place as a peer with Ethernet. With data rates from 150-450 Mbps, Wi-Fi was now able to support identical services as the wired network. The 802.11ac revision of the standard (2013) brought with it the possibility of even higher link speeds, up to 866 Mbps on a single spatial stream. When taking into consideration added multiple streams, wider channels (160 MHz) and higher modulation rates (256-QAM), we saw potential data rates of up to 7 Gbps. However, it was soon realized that just making faster and faster chipsets was not solving the problem as we still saw a continuous increase in contention for airtime. It became obvious that higher data rates would not solve the growing challenges of more devices, higher bandwidth demands, growing uplink traffic (like social media) and more stringent QoS demands of applications. A solution to deliver a superior user experience was required, and 802.11ax is engineered to deliver just that.

IEEE 802.11ax High Efficiency Wi-Fi Introduction

The 802.11ax IEEE standard is engineered from the bottom up to solve the challenges previously mentioned by implementing multiple technologies to increase overall capacity by up to 4X, but more importantly significantly improves spectral efficiency to benefit both 2.4 GHz and 5 GHz bands in all environments.

Before diving straight into 802.11ax let's first look at why this new standard was developed. The issues facing next generation Wi-Fi systems involve degradation to system efficiency due to not just increasing density of clients but also the preponderance of small data frames (e.g. Voice-over-Wi-Fi). As a reminder, RF is a half-duplex medium, which means that only one radio can transmit on a frequency or channel at any given time. Today everybody must take turns communicating because if multiple devices "talk" at the same time, the data streams are corrupted and no data communication will get through; the result is retransmissions and resulting degradation of the overall network performance.

Additionally, in many ways Wi-Fi is a very inefficient protocol; 802.11 frame headers add a lot of overhead to each frame, taking away from the available bandwidth. Medium contention, the process used for a device to access the network (CSMA/CA), consumes a lot of bandwidth, and is referred to as "contention overhead". These inefficiencies and a few other factors contribute to the fact that average TCP throughput in a legacy a/b/g network is roughly 40%-50% of advertised data rates. And even with recent improvements, TCP throughput of an 802.11n/ac network is only up to 60%-70% of data rate. And both percentages only exist with pristine RF conditions.

Considering the excess overhead, increased congestion, more contention and the resulting increases in traffic collisions, it is no wonder wireless performance continues to suffer even though recent technology improvements have offered higher potential data rates. The current condition is further exacerbated by the fact that the bulk of data frames in a network are small, under 256 bytes, and this along with the emergence of IoT, will add increasing strain on Wi-Fi networks.

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Technical Overview

As mentioned, 802.11ax was challenged with improving the average throughput per user by a factor of at least 4X. Improved processors delivered greater raw link speeds than what was available in 802.11ac, however 802.11ax implemented many innovative technologies to provide not just higher performance but also to increase reliability and improve the user experience. Having the time, you could read the complete IEEE 802.11ax specification (all 600+ pages) and realize over 190 new features are defined in those pages, but this document will focus on the seven most interesting and impactful improvements.

These core features will be segmented into five sections: *Spectral Efficiency*, *Spatial Reuse*, *Power Management*, *Link Efficiency,* and *Frame Format changes.*

Spectral Efficiency

Spectral efficiency relates to using the Wi-Fi bandwidth more effectively. With previous Wi-Fi advancements, only one client could transmit at a time, so the focus was on making traffic go faster. 11ax's primary value is allowing multi-user *(MU)* access, where available bandwidth can be simultaneously shared between clients. With 802.11ac, multi-user was just MIMO technology, however, 802.11ax supports two different multi-user technologies; OFDMA and MIMO both support simultaneous transmissions between an AP and multiple clients. MU-MIMO allows for multiple-user access by using different spatial streams. OFDMA, on the other hand, subdivides the communication bandwidth into multiple sub-channels, more on this to follow. The 802.11ax standard also allows for the combined use of MU-MIMO and OFDMA technologies.

Orthogonal Frequency Division Multiple Access (OFDMA)

OFDMA is arguably the most important new feature in 802.11ax. To understand OFDMA you first need a basic appreciation of how Wi-Fi has always worked; this was called Orthogonal Frequency Division Multiplexing *(OFDM)*, see **Figure 1**. In OFDM, the total channel bandwidth contains sub-carriers. Presently when using OFDM, any one frame transmission to one client consumes all the subcarriers of the channel bandwidth. No matter how much data each client needs to send (whether big or small) all the subcarriers are assigned to a single client.

Orthogonal Frequency Division Multiple Access *(OFDMA)* takes advantage of this architecture and uses a mechanism that enables simultaneous communication to multiple clients by grouping and isolating subcarriers into separate communication paths called resource units *(RUs)*.

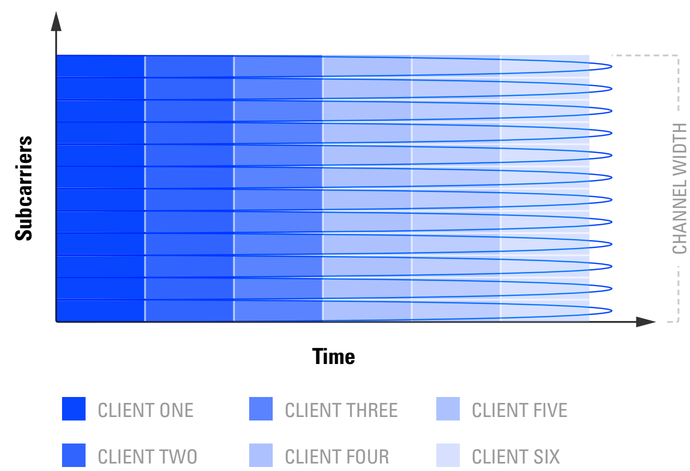

Figure 1: *OFDM. Only 1 client can use the channel bandwidth at a time.*

Resource Units

Just like with earlier advancements, 802.11ax supports 20, 40, 80 and 160 MHz wide channels. For discussion about resource units we will focus on 20 MHz wide channels. An 802.11ax 20 MHz channel contains 256 subcarriers and the AP can then subdivide them into groups containing 26, 52, 106, or 242 subcarriers— these are the **resource units** *(RUs)* and these groupings roughly equate to 2 MHz, 4 MHz, 8 MHz, and 20 MHz channels. Each resource unit can be used as a separate clients' communication path. An 802.11ax AP will determine how many RUs are used within a 20 MHz channel based on the number of clients and their respective bandwidth requirements.

For example, a traditional 20 MHz channel might be partitioned into as many as 9 smaller channels (See **Figure 2**). Using OFDMA's resource units an AP can simultaneously transmit traffic to nine 802.11ax clients, making far more efficient use of the medium.

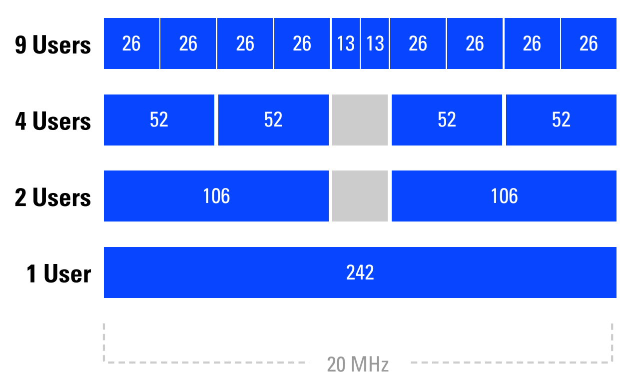

Figure 2: *20 MHz channel broken into resource units (RUs).*

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As can be seen in **Figure 3**, a combination of different resource unit sizes can be used to optimize communication across multiple clients. This ability for simultaneous transmission cuts down on excessive overhead at the MAC sublayer as well as medium contention overhead. Subcarriers can be allocated to transmission in blocks as small as 2 MHz and theoretically serve between 1 and 74 clients at a time.

OFDMA is not just employed for downlink communication *(AP to client)*, as MIMO currently is. OFDMA operates in both directions and is normally identified as **DL-OFDMA** *(Downlink)* and **UL-OFDMA** *(Uplink)*. The process for downlink OFDMA is as follows: When the AP has traffic for one or more clients it will go through the standard Wi-Fi contention process to access the channel. By using the standard contention process legacy stations are also able to participate. Once the AP has 'grabbed' the channel it will announce to one or more clients that the AP has information for them, after stations acknowledge this, the AP will transmit the data. The process then repeats as long as the AP has data for its clients. Also note that each transmission resets the resource unit assignments and sizes based on clients and traffic loads.

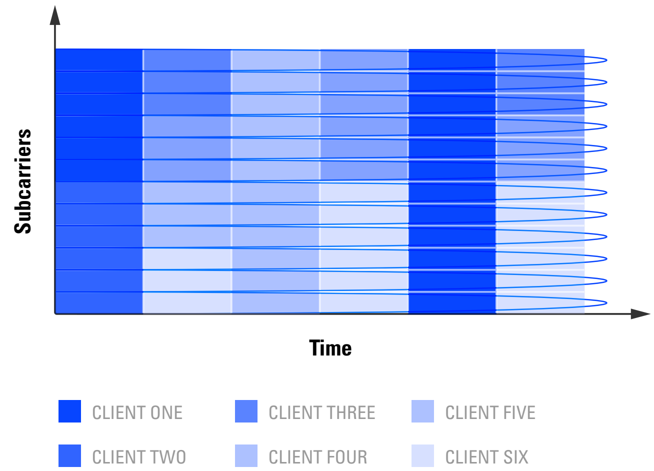

Figure 3: *OFDMA technology across several different clients.*

UL-OFDMA *(uplink)* supports traffic transmissions from the clients to the AP. The uplink process is slightly more intricate as the AP first needs to determine which stations have data to transmit. There are multiple ways to accomplish this, but the easiest method is by the AP using what is called a Buffer Status Report Request (BSRR). As the name implies, the AP polls the clients to determine transmission needs; clients will reply with uplink requirements including amount of buffered traffic and the QoS requirements of traffic. Based on this information the AP will build a resource unit allocation schedule identifying priority of clients, type of traffic, bandwidth, power levels, needs, etc. The AP then maps the client needs to resource units and sends another form of trigger frame to the clients selected for next transmit opportunity.

Here is a simple way to look at it: OFDMA allows multiple users with varying bandwidth needs to be served simultaneously. If you think of today's Wi-Fi as a delivery van which delivers one package for every trip, in comparison, OFDMA divides up the spectrum and allocates it to different users, akin to a delivery truck which carries packages from different senders on a single trip – which is clearly more efficient from the outset.

To summarize, in OFDMA the AP controls the medium both downlink and uplink frame by frame. OFDMA is ideal for low bandwidth applications and results in better frequency reuse, reduced latency, and increased efficiency. The main benefit of OFDMA is that it allows an AP to allocate the whole channel to a single user at a time or it may partition a channel to serve multiple users simultaneously.

MU-MIMO

Another form of multi-user communication, **multi-user multiple-input multiple-output** *(MU-MIMO)*, was first introduced in the 802.11ac Wave 2 standard. This technology also allows the simultaneous transmitting of traffic to different receivers on the same channel. But instead of subdividing the Wi-Fi channel as OFDMA does, it uses multiple RF *'spatial'* streams to provide this functionality (see **Figure 4**). The 802.11ac standard supported up to 4 separate streams while 11ax adds support for up to 8. Additionally, 11ac only supported MU-MIMO in the downlink direction *(AP to client)* while 802.11ax supports multi-user MIMO communication in both directions. The actual date of availability of uplink MU-MIMO is currently in discussion and its support and certification may be delayed until 802.11ax Phase 2.

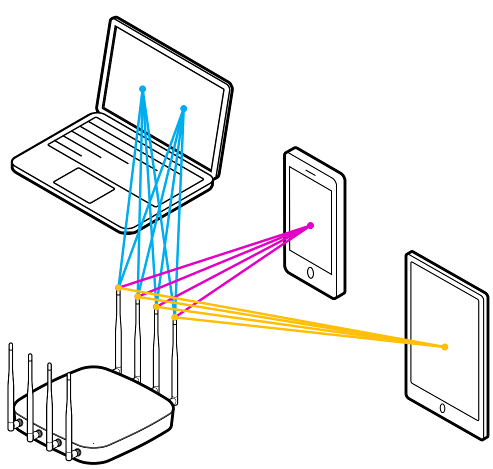

Figure 4: *Multiple RF 'spatial' streams, MU-MIMO.*

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Spatial Reuse

Spatial reuse is the ability to allow devices to transmit even when they detect other devices already transmitting. Traditional access rules restrict this form of spatial reuse to prevent traffic loss due to *'collisions'* and the potential for corrupted frames. However, allowing multiple devices to transmit at the same time and on the same channel under specific conditions could potentially increase overall system efficiency.

Due to the half-duplex nature of the RF medium, APs and clients that can 'hear' each other on the same channel will defer transmissions. This creates what is known as overlapping basic service sets (OBSS) which results in excessive medium contention overhead. Better spatial reuse has the potential to address this problem. Spatial reuse is also often referred to as **basic service set coloring** *(BSS Coloring)*.

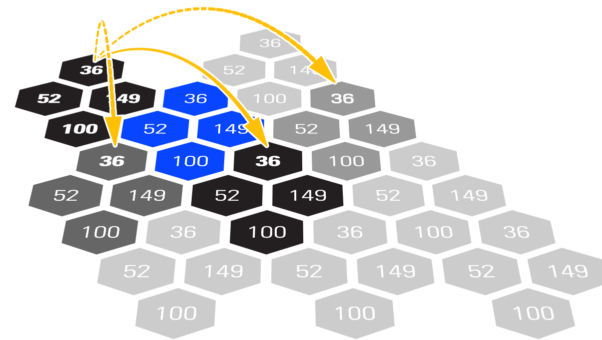

Figure 5: *BSS (Basic Service Set) Coloring*

The main goal of 802.11ax is to increase network efficiency and one method is to increase frequency reuse between BSS's. Existing medium access rules forced devices from one BSS to defer to another device on the same channel, no matter the BSS. Spatial reuse uses the concept of BSS Coloring, or adding a 'color' bit to the frame. This mechanism was introduced in 802.11ah to identify different BSSs by defining a "color bit" for each BSS— this allows APs and clients to identify the different BSS traffic. New, multiple channel access behavior rules are now implemented based on the 'color bit' detected. 802.11ax stations can adjust the carrier sense operation based on the "color" of the BSS (see **Figure 5**). Depending on the BSS the traffic is generated from, the station can use different sensitivity thresholds to transmit or defer.

Essentially stations are able to apply different network access rules depending on the BSS assignment *(color)* of the traffic they detect. The result is superior spatial reuse and network efficiency.

Power Management – Target Wake Time (TWT)

The **Target Wake Time** *(TWT)* feature allows APs to explicitly schedule the time clients exchange data *(i.e. are awake)*. Once again, 802.11ax has 'borrowed' this capability from another specification, 802.11ah, and allows client devices to negotiate with the AP when and how often they will wake up to send or receive data. Increasing a device's sleep time substantially improves battery life. In 802.11ax, the 802.11ah TWT mechanism has been modified to support triggered-based uplink transmission, meaning it can support stations that have not negotiated any implicit agreement with the AP. In addition to reducing power consumption by explicitly identifying the times when a STA should be awake, TWT's scheduled operation also reduces the overhead and inefficiency of the of the normal Wi-Fi contention process.

Link Efficiency – 1024 QAM

In **Figure 6**, you see 256 to 1024 **QAM** *(quadrature amplitude modulation)*. If you think back to 802.11ac, that standard introduced 256 QAM which equates to 8 bits per symbol. 802.11ax's 1024 QAM equates to 10 bits per symbol. The use of 1024 QAM can result in a 25% increase in physical data rate. How? This is achieved using more efficient packaging of data for the same spectrum.

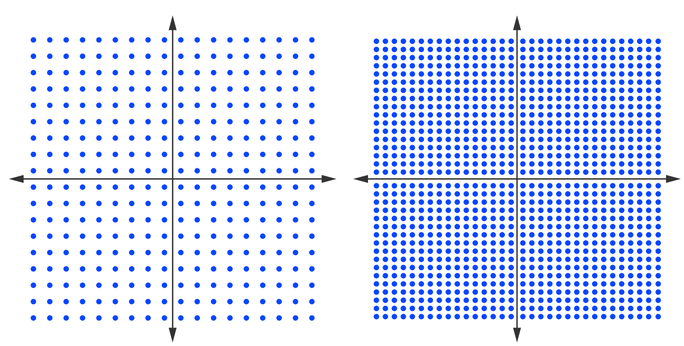

Figure 6: *256 (Left) to 1024 (Right) QAM.*

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Frame Format Changes

The 802.11ax amendment also modifies the **frame format** to maintain backwards compatibly with earlier 802.11 technologies. This is accomplished by the PHY layer header preamble. (See **Figure 7**, below). The preamble performs synchronization between transmitting and receiving radios and consists of two parts: the legacy and the High Efficiency *(HE)* parts. The legacy preamble is easily decodable by any legacy STAs *(802.11a/b/g/n/ac)* while the HE preamble provides 11ax specific information for those stations able to decode.

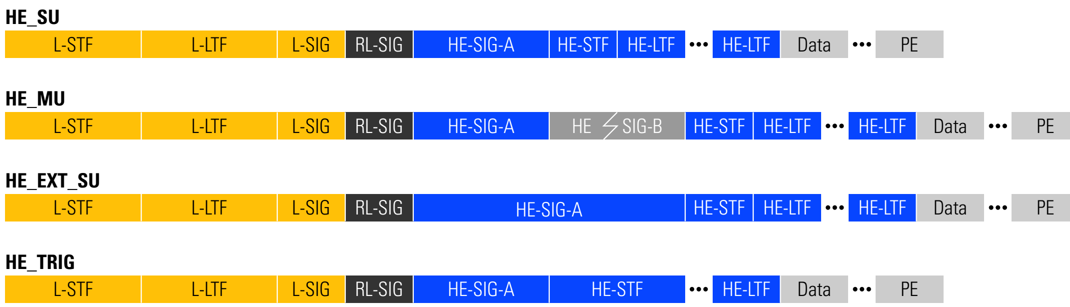

Figure 7: *Preamble Updates*

Business Benefits / Use Cases

So what does all this mean? What are the clear-cut business benefits and where will we see those benefits? These are just a few of the use cases for 802.11ax—anything relatively high density will see huge improvements in efficiency with this new standard.

- Education institutions (both K-12 & Higher Education)
- Wireless office, enterprise organizations
- Healthcare organizations/hospitals
- Airports and train stations
- Shopping malls
- Stadiums
- City-wide Wi-Fi
- Dense apartment building/multi-dwelling units
- Theme park rides with control and video streaming
- Dense suburban residential homes

802.11ax vs. 802.11ac; what are the benefits of upgrading?

- Increased aggregate network throughput
- Increased rate at range
- Peak link throughput increase
- Reduced overhead
- Increased efficiency
- Increased robustness outdoors
- Increased client battery life
- Optimized traffic management
- Increased processing power on AP hardware

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Technology Summary

Many of the features discussed are not really new, as some have been deployed for years in other wireless and even wired technologies. The 802.11ax Wi-Fi enhancement has just identified and grouped multiple technologies under a single IEEE standard and Wi-Fi Alliance certification program.

All the features and enhancements discussed in this whitepaper reflect items in the draft IEEE standard. This technology will take a bit more time to mature and through 2018 we will see which features become a reality. 802.11ax clients will be required to take full advantage of 802.11ax technology. As we see more 802.11ax clients mixed into the client population, the efficiency improvements gained by 802.11ax client devices will also free valuable airtime for legacy clients, therefore improving the overall efficiency of the system.

802.11ax will eventually become the new default standard, making networks smarter and more efficient.

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