IEEE 802.11ax Timeline

**IEEE 802.11ax**
Passed Draft 3 – Target standard release Q4 2019

**Wi-Fi Alliance 802.11ax**
Conducting Interoperability ‘plugfests’
Marketing Launch Oct 3rd
Wi-Fi CERTIFIED 6™ - Target Q3 2019

**Products**
Wi-Fi 2018

The Most Transformative Year For Wi-Fi Since Its Inception

The past decade has witnessed the transition of Wi-Fi from a key network access medium to a critical business resource.

Data rates have gone from a couple of megabits to multiple gigabits and this enabled the enormous growth in wireless usage.

That was just the beginning – as with the introduction of 802.11ax, WPA3 and IoT, ... 2018 will be the transformative year for Wi-Fi, as it fundamentally changes the way Wi-Fi operates.
First 20 years was all about speed, now it’s **efficiency**
## 802.11n vs. 802.11ac vs. 802.11ax

<table>
<thead>
<tr>
<th></th>
<th>802.11n</th>
<th>802.11ac</th>
<th>802.11ax</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Channel Size (MHz)</strong></td>
<td>20, 40</td>
<td>20, 40, 80, 80 + 80 and 160</td>
<td>20, 40, 80, 80 + 80 and 160</td>
</tr>
<tr>
<td><strong>Subcarrier (KHz)</strong></td>
<td>312.5</td>
<td>312.5</td>
<td>78.125</td>
</tr>
<tr>
<td><strong>Symbol time (µs)</strong></td>
<td>3.2</td>
<td>3.2</td>
<td>12.8</td>
</tr>
<tr>
<td><strong>Frequency multiplexing</strong></td>
<td>OFDM</td>
<td>OFDM</td>
<td>OFDM &amp; OFDMA</td>
</tr>
<tr>
<td><strong>Modulation</strong></td>
<td>BPSK, QPSK, 16-QAM, 64-QAM</td>
<td>BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM</td>
<td>BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM, 1024-QAM</td>
</tr>
<tr>
<td><strong>Multi User Operation</strong></td>
<td>N/A</td>
<td>Downlink MU-MIMO</td>
<td>OFDMA UL/DL, MU-MIMO UL/DL</td>
</tr>
<tr>
<td><strong>Spectrum Bands</strong></td>
<td>2.4GHz &amp; 5GHZ</td>
<td>5GHZ</td>
<td>2.4GHz &amp; 5GHZ</td>
</tr>
</tbody>
</table>
IEEE 802.11a/g

Mesh Link
IEEE 802.11n

Mesh Link
IEEE 802.11ac
But this is the problem:
THE GOAL OF IEEE 802.11ax
IEEE 802.11ax OFDMA

Mesh Link
IEEE 802.11ax Key Features

**OFDMA – Orthogonal Frequency Division Multiple Access**

- Multi-user version of OFDM enabling concurrent AP communication (Up/Downlink) with multiple clients by assigning subsets of subcarriers, called Resource Units (RUs), to the individual clients. Based on client traffic needs, the AP can allocate the whole channel to only one user or may partition it to serve multiple users simultaneously.

**MU-MIMO – Multi-User Multiple Input Multiple Output**

- Introduced in 11ax, MU-MIMO technology allows simultaneous transmission of multiple frames to different receivers at the same time on the same channel using multiple RF streams to provide greater efficiency. 11ax adds 8x8 and Up/Downlink MU-MIMO services to provide significantly higher data throughput.

**OBSS – Overlapping Basic Service Set**

- To improve spatial reuse efficiency and performance, 11ax adjusts the carrier sense operation based on the 'color' of the BSS. Depending on the BSS the traffic is generated from, the station can use different sensitivity thresholds to transmit or defer. This results in higher overall performance.

**QAM – 256 to 1024**

- Modulation techniques are used to optimize throughput and range. The number of points in the modulation constellation determines the number of bits conveyed with each symbol. 802.11ac uses 256 QAM which transfers 8 bits/symbol. 802.11ax supports 1024 QAM, using 10 bits/symbol for a 25% increase in throughput.

**TWT – Target Wake Time**

- TWT allows the AP to schedule a series of times for a station to ‘wakeup’ at scheduled intervals to exchange data frames. This allows the station to ‘sleep’ longer and reduce energy consumption. Key capability for IoT devices.

**Preamble Updates**

- Modified frame formats provide High Efficiency (HE) and Legacy information to support new advanced capabilities as well as information required to support legacy stations and backward compatibility.
2.4Ghz in BACK!

- 11ac focused only on 5GHz
- They forgot there are useable channels available in 2.4 GHz!
- IoT devices will likely have significant usage of the 2.4 GHz band
- 11ax operates in both bands
PHY headers provide backward compatibility with 802.11a/b/g/n/a
The increase in the number of subcarriers (tones) also increases in the OFDM symbol duration (from the maximum of 4 μs used in IEEE 802.11ac to the maximum of 16 μs used in 802.11ax) and additional guard interval (GI) durations (legacy 0.8 μs and new 1.6 μs and 3.2 μs) are supported.

The use of longer OFDM symbols allows for larger coverage areas as the system becomes more robust to propagation delays, and longer GIs decrease inter-symbol interference. Guard interval longer than delay spread
Much like 256-QAM, we anticipate that very high SNR thresholds (~ 35 dB) will be needed in order for 802.11ax radios to use 1024-QAM modulation.
Target Wake Time – Scheduling Mechanism

- **Target Wake Time (TWT)** is a power saving mechanism negotiated between a STA and its AP, which allows the STA to sleep for periods of time, and wake up in pre-scheduled (target) times to exchange information with its AP.

- Allows the station to ‘sleep’ longer and reduce energy consumption.

- Key feature for **IoT** type sensors.
Co-Channel Interference (CCI)

- Does RF just stop?
- Almost impossible to prevent CCI at 2.4 GHz
BSS Color

BSS Color with Spatial Reuse potentially solves the CCI problem.

BSS color information is communicated at both the PHY layer and the MAC sublayer.

Channel access behavior will be dependent on the color detected.

AP radios and client radios will be able to apply adaptive CCA thresholds via Spatial Reuse.
BSS Color

- 802.11ax solution to deal with overlapping basic service sets (OBSS):

- The BSS color is a numerical identifier (color) of the BSS

- 802.11ax radios are able to differentiate between BSSs using BSS color identifier when other radios transmit on the same channel
Adaptive CCA implementation could raise the Signal Detect threshold for inter-BSS frames, while maintaining a lower threshold for intra-BSS traffic.
Dual NAV Timers

802.11ax AP-1

STA 1

802.11ax AP-2

STA 2

neighbor BSS #2

BSS #1

Duration = 200 µs

Intra-BSS NAV = 200 µs

Basic NAV = 125 µs

802.11ax AP-1

STA 2

neighbor BSS #2

802.11ax AP-2

Duration = 125 µs

Duration = 200 µs

Intra-BSS NAV = 200 µs

Basic NAV = 125 µs

802.11ax AP-1

STA 2

neighbor BSS #2

802.11ax AP-2

Duration = 125 µs

Duration = 200 µs

Intra-BSS NAV = 200 µs

Basic NAV = 125 µs

802.11ax AP-1

STA 2

neighbor BSS #2

802.11ax AP-2

Duration = 125 µs

Duration = 200 µs

Intra-BSS NAV = 200 µs

Basic NAV = 125 µs

802.11ax AP-1

STA 2

neighbor BSS #2

802.11ax AP-2

Duration = 125 µs

Duration = 200 µs

Intra-BSS NAV = 200 µs

Basic NAV = 125 µs

802.11ax AP-1

STA 2

neighbor BSS #2

802.11ax AP-2

Duration = 125 µs

Duration = 200 µs

Intra-BSS NAV = 200 µs

Basic NAV = 125 µs

802.11ax AP-1

STA 2

neighbor BSS #2

802.11ax AP-2

Duration = 125 µs

Duration = 200 µs

Intra-BSS NAV = 200 µs

Basic NAV = 125 µs

802.11ax AP-1

STA 2

neighbor BSS #2

802.11ax AP-2

Duration = 125 µs

Duration = 200 µs

Intra-BSS NAV = 200 µs

Basic NAV = 125 µs

802.11ax AP-1

STA 2

neighbor BSS #2

802.11ax AP-2

Duration = 125 µs

Duration = 200 µs

Intra-BSS NAV = 200 µs

Basic NAV = 125 µs

802.11ax AP-1

STA 2

neighbor BSS #2

802.11ax AP-2

Duration = 125 µs

Duration = 200 µs

Intra-BSS NAV = 200 µs

Basic NAV = 125 µs

802.11ax AP-1

STA 2

neighbor BSS #2

802.11ax AP-2

Duration = 125 µs

Duration = 200 µs

Intra-BSS NAV = 200 µs

Basic NAV = 125 µs

802.11ax AP-1

STA 2

neighbor BSS #2

802.11ax AP-2

Duration = 125 µs

Duration = 200 µs

Intra-BSS NAV = 200 µs

Basic NAV = 125 µs

802.11ax AP-1

STA 2

neighbor BSS #2

802.11ax AP-2

Duration = 125 µs

Duration = 200 µs

Intra-BSS NAV = 200 µs

Basic NAV = 125 µs

802.11ax AP-1

STA 2

neighbor BSS #2

802.11ax AP-2

Duration = 125 µs

Duration = 200 µs

Intra-BSS NAV = 200 µs

Basic NAV = 125 µs

802.11ax AP-1

STA 2

neighbor BSS #2

802.11ax AP-2

Duration = 125 µs

Duration = 200 µs

Intra-BSS NAV = 200 µs

Basic NAV = 125 µs

802.11ax AP-1

STA 2

neighbor BSS #2

802.11ax AP-2

Duration = 125 µs

Duration = 200 µs

Intra-BSS NAV = 200 µs

Basic NAV = 125 µs

802.11ax AP-1

STA 2

neighbor BSS #2

802.11ax AP-2

Duration = 125 µs

Duration = 200 µs

Intra-BSS NAV = 200 µs

Basic NAV = 125 µs

802.11ax AP-1

STA 2

neighbor BSS #2

802.11ax AP-2
AP use DL MU-MIMO to serve multiple clients requires spatially diverse position.

AP can specify multiple STA to simultaneously send uplink frames via trigger frames.
Multi-TID AMPDU

Frame Aggregation: A-MPDU is comprised of multiple MPDUs, prepended with a PHY header

Prior to 802.11ax, the individual MPDUs must all be of the same 802.11e QoS access category

Voice MPDUs cannot be mixed with Best Effort or Video within the same aggregated frame.

11ax introduces multi-traffic identifier aggregated MAC protocol data unit (Multi-TID AMPDU) which allows the aggregation of frames from multiple traffic identifiers (TIDs), from the same or different QoS access categories = Reduced overhead, increased throughput = efficiency
20 MHz only clients

- **20 MHz-only** operational mode for 802.11ax clients
- The 20 MHz-only operational mode is ideal for IoT clients that could take advantage of the 802.11ax power-saving capabilities but not necessarily need the full capabilities that 802.11ax has to offer
- This will allow client manufacturers to design less complex chipsets at a lower cost which is ideal for IoT devices.
OFDM
ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING
Orthogonal Frequency-Division Multiplexing (OFDM)

OFDM is a digital modulation technology that encodes data across multiple carrier frequencies (subcarriers). OFDM systems allocate the entire spectrum, all subcarriers for an amount of time to a single user. Subsequent users then get all the subcarriers for TXOP.

- From Wikipedia
OFDM Subcarriers

20 MHz
OFDM subcarriers (20 MHz)

OFDM divides bandwidth into subcarriers

- **Data subcarriers** – Carry modulated data
- **Management Subcarriers** – Don’t carry data, they are used for synch and interference protection purposes

64 subcarriers (312.5 kHz)

56 subcarriers (4 pilot and 52 data)

20 MHz Channel
OFDM – 802.11a/g/n/ac

- Subcarriers
- Time
- Channel width

Client 1
Client 2
Client 3
Client 4
Client 5
Client 6
OFDMA
ORTHOGONAL FREQUENCY-DIVISION MULTIPLE ACCESS
OFDMA - Orthogonal Frequency-Division Multiple Access

- Multi-user channel access technology of the popular orthogonal frequency-division multiplexing (OFDM) digital modulation scheme

- Multiple access is achieved in OFDMA by assigning subsets of subcarriers to individual clients

- This allows *simultaneous* low data rate transmission to/from multiple users.
### 802.11a/n/ac vs. 802.11ax subcarriers

- 256 subcarriers (tones) in 20 MHz, (40MHz/512, 80MHz/1024, 160MHz/2048)
  - Data subcarriers: 234 / 468 / 980 / 1960
  - Pilot subcarriers: 8 / 16 / 16 / 32
  - Unused subcarriers: 11 / 23 / 23

802.11a/n/ac subcarrier spacing: 312.5 kHz

802.11ax subcarrier spacing: 78.125 kHz
Frequency allocations for both uplink and downlink OFMDA define resource units (RU) with 26, 52, 106, 242, 484 or 996 subcarriers (tones)

The subcarriers (tones) are in fixed locations of each 20, 40 or 80 MHz channel & 2x 80Mhz
Based on multi-user traffic needs, the AP decides how to allocate the channel. Whole channel to one user or partition it to serve multiple users simultaneously.
Resource Units: Locations (20MHz)

pilot tone index
-116
-90
-48
-22
-10
10
22
36
48
62
6
102
52
13
26
26
26
26
26
1
5 Edge
6 Edge
6 Edge
6 Edge
5 Edge
5 Edge
5 Edge
242 + 3 DC
102+4 pilots
102+4 pilots

October 17-19 2018
Wi-Fi Trek | San Diego, CA
Resource Units: Locations (80MHz)
Resource Units: Spectrum Analyzer View

![Spectrum Analyzer View Graph]
### RU Allocation MAC Layer: User Information Field

<table>
<thead>
<tr>
<th></th>
<th>26 tone RU</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RU-1</td>
<td>RU-2</td>
<td>RU-3</td>
<td>RU-4</td>
<td>RU-5</td>
<td>RU-6</td>
<td>RU-7</td>
<td>RU-8</td>
</tr>
<tr>
<td>RU allocation bits</td>
<td>0000000</td>
<td>0000001</td>
<td>0000010</td>
<td>0000011</td>
<td>0000100</td>
<td>0000101</td>
<td>0000110</td>
<td>0000111</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>52 tone RU</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>RU-1</td>
<td></td>
<td>RU-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subcarrier range</td>
<td>-121:70</td>
<td>-68:17</td>
<td></td>
<td>17:68</td>
<td>70:121</td>
<td></td>
</tr>
<tr>
<td>RU allocation bits</td>
<td>0100101</td>
<td>0100110</td>
<td></td>
<td>0100111</td>
<td>0101000</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>106 tone RU</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>RU-1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>RU-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subcarrier range</td>
<td>-122:17</td>
<td></td>
<td></td>
<td>17:122</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RU allocation bits</td>
<td>0110101</td>
<td></td>
<td></td>
<td>0110110</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>242 tone RU</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>RU-1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subcarrier range</td>
<td>-122:2, 2:122</td>
<td></td>
</tr>
<tr>
<td>RU allocation bits</td>
<td>0111101</td>
<td></td>
</tr>
</tbody>
</table>
DL MU OFDMA
DOWNLINK EXCHANGE
OFDM vs OFDMA
DOWNLINK MU-OFDMA OVERVIEW

- AP controls the medium during TXOP
- AP contends and ‘Gets Air’
- OFDMA Process Overview:
  - **MU-RTS** (Trigger frame from AP to sync upstream CTS client response)
    - Sent across whole 20 MHz so legacy clients understand.
    - Identified clients to receive traffic
    - TXOP is for entire exchange,
  - **CTS** responses from the clients in parallel (Resource Units)
  - DL MU-PPDU data transmissions from the AP to the OFDMA clients
    - AP transmit power can be adjusted per resource unit (RU)
  - **Block ACK** - Auto BlockACK or BAR/BA
DOWNLINK MU-OFDMA

802.11ax AP

Trigger

MU-RTS

Multi-user DL-PPDU

STA 4 RU 4 : 52 tones
STA 3 RU 3 : 52 tones
STA 2 RU 2 : 52 tones
STA 1 RU 1 : 52 tones

802.11ax clients

STAs

Block ACK

STA 1

Block ACK

STA 2

Block ACK

STA 3

Block ACK

STA 4
DOWNLINK MU-OFDMA

802.11ax AP

802.11ax clients

STA 1

STA 2

STA 3

STA 4

Mult-user DL-PPDU

STA 4 RU 4 : 52 tones
STA 3 RU 3 : 52 tones
STA 2 RU 2 : 52 tones
STA 1 RU 1 : 52 tones

MU-RTS

SIFS

AIFS

MU-RTS

SIFS

SIFS

SIFS

SIFS

SIFS

Trigger

CTS

Block ACK

CTS

Block ACK

CTS

Block ACK

CTS

Block ACK

MU-RTS

SIFS

SIFS

SIFS

SIFS
802.11ax OFDMA Operation

<table>
<thead>
<tr>
<th>Subcarriers</th>
<th>Time</th>
<th>Channel width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource Unit (RU)</td>
<td>Client 1</td>
<td>Client 2</td>
</tr>
</tbody>
</table>
IEEE 802.11ax OFDMA

Mesh Link
UL MU OFDMA
UPLINK EXCHANGE
BUFFERS STATUS REPORTS

APs require specifics on client buffer states to perform appropriate RU scheduling, two approaches available:

- Clients deliver Buffer Status Reports (BSRs) to assist the AP in allocating UL MU resources.
  - Clients can implicitly deliver BSRs in the QoS Control field or BSR Control field of any frame transmitted to the AP (unsolicited BSR).
  - Clients can explicitly deliver BSRs to the AP in response to a BSRP trigger frame (solicited BSR).
- In either case AP will determine client transmit requirements.
UPLINK MU-OFDMA OVERVIEW

- AP controls the medium during TXOP

Process Overview:
- AP sends a **Buffer Status Report Poll (BSRP)**
- Clients reply with synchronized **Buffer Status Report (BSR)** frames
  - Information about their AID, data length, type of data (QoS), etc.
- AP builds RU schedule with following information:
  - Start, Stop times / Client RU mapping / RUs per clients / MCS setting / Power levels per RU
- AP may send a trigger frame variant: **MU-RTS**
  - (An extended trigger frame from AP to sync upstream CTS client response)
- **CTS** responses from the clients in parallel (RU)
- AP sends a basic **Trigger frame** to allocate the RUs and time-sync
- Clients send **UL-DATA** via their assigned RUs
- Multi-User Block ACK from the AP
RU Allocation

802.11ax AP

802.11ax clients

STA 1: 52 tone – RU-1
Subcarriers: -121:-70
Bit index: 0100101

STA 2: 52 tone – RU-2
Subcarriers: -68:-17
Bit index: 0100110

STA 3: 106 tone - RU-2
Subcarriers: 17:122
Bit index: 0110110
Uplink MU-OFDMA

802.11ax AP

Multi-STA Block ACK

802.11ax clients
Uplink MU-OFDMA

802.11ax AP

<table>
<thead>
<tr>
<th>Trigger #1</th>
<th>Trigger #2</th>
<th>Trigger #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSR</td>
<td>CTS</td>
<td>UL-PPDU</td>
</tr>
<tr>
<td>SIFS</td>
<td>SIFS</td>
<td>SIFS</td>
</tr>
<tr>
<td>BSR</td>
<td>CTS</td>
<td>UL-PPDU</td>
</tr>
<tr>
<td>SIFS</td>
<td>SIFS</td>
<td>SIFS</td>
</tr>
<tr>
<td>BSR</td>
<td>CTS</td>
<td>UL-PPDU</td>
</tr>
<tr>
<td>SIFS</td>
<td>SIFS</td>
<td>SIFS</td>
</tr>
<tr>
<td>BSR</td>
<td>CTS</td>
<td>UL-PPDU</td>
</tr>
<tr>
<td>SIFS</td>
<td>SIFS</td>
<td>SIFS</td>
</tr>
</tbody>
</table>

802.11ax clients

- STA 1
- STA 2
- STA 3
- STA 4
Uplink MU-OFDMA

AP sends ‘Trigger’ to alert clients when to transmit

- Subcarriers
- Time
- Client 1
- Client 2
- Client 3
- Client 4
- Client 5
- Client 6
UORA – UPLINK OFDMA RANDOM ACCESS

In addition to the scheduled OFDMA channel access 802.11ax also provides an random OFDMA UL MU channel access. This is favorable for the case when the AP is unaware of UL traffic buffered at the STAs.

The process works as follows:

- AP sends random access trigger frame to allocates RUs for random access
- Clients wishing to transmit uses the OFDMA Back-off (OBO) procedure
  - Initially, the client chooses a random value, with each Trigger frame the client decrements the value by the number of RUs specified in the Trigger frame until it reaches zero.
  - After that, the STA randomly selects a RU and transmits its frame.

May allow ‘unassociated’ stations to get data to AP ????
OFDM - OFDMA – IEEE OFDMA Cascade Mode

With cascading

- DL Data (STA 1)
- DL Data (STA 2)
- Trigger (STA 4)
- DL Data (STA 3)

Preamble

- DL Data (STA 1)
- DL Data (STA 2)
- UL BA (STA 1)
- UL BA (STA 2)
- Trigger
- UL Data (STA 4)
- DL Data (STA 5)
- DL Data (STA 6)

SIFS

Contention

xIFS

Contention

xIFS

SIFS

SIFS

xIFS

SIFS

SIFS

SIFS

SIFS

SIFS

SIFS
OFDMA Summary – The AP is in charge!

- AP controls the medium during a TXOP for both **downlink** and **uplink**
- AP transmit power can be adjusted per resource unit (RU)
- Number of sub-channels and users can vary packet per packet
- The AP decides how the client transmits on the UPLINK
IEEE 802.11ax Timeline

IEEE 802.11ax
Passed Draft 3 – Target standard release Q4 2019

Wi-Fi Alliance 802.11ax
Conducting Interoperability ‘plugfests’
Marketing Launch Oct 3rd
Wi-Fi CERTIFIED 6™ - Target Q3 2019

Aerohive 802.11ax
Access points Available now!
Questions
THANK YOU