WHITEPAPER

# A Guide to Wi-Fi 6E

## Wi-Fi 6 in the 6 GHz Band

LITEPOINT

## Contents

## 1. Introduction

On April 23, 2020 the FCC voted unanimously to make 1,200 megahertz of spectrum available for unlicensed use in the 5.925-7.125 GHz (6 GHz) band. This historic event was the culmination of several years of work by Wi-Fi advocates underscoring the FCC's commitment to promote unlicensed standards as the indispensable engine for wireless connectivity for American consumers.

The extension of Wi-Fi in the 6 GHz band, named Wi-Fi 6E by the Wi-Fi Alliance [1], has been strongly advocated for by many in the Wi-Fi industry. From chipset and equipment manufacturers to service providers and end users, everyone agrees that more than doubling the available spectrum will revolutionize the Wi-Fi user experience. Chipset manufacturers [2] [3] have already announced new products capable of supporting the 6 GHz band and consumer equipment could become available as early as the end of the 2020.

To understand the importance of this event, deemed by many as the biggest revolution in Wi-Fi, this paper will review what makes the 6 GHz band compelling for unlicensed use and why additional spectrum is so badly needed to sustain Wi-Fi growth. The paper will also explore how the 6 GHz band will fit into Wi-Fi 6 deployments and analyze the challenges associated with bringing Wi-Fi 6E devices to market.

## 2. Why do we need more spectrum and why the 6 GHz band?

### Wi-Fi's Successes

As the most prevalent connectivity technology, Wi-Fi has proven to be a success story beyond the highest expectations. It is estimated that Wi-Fi contributes more than $2 trillion to the global economy each year [4] and now, more than ever Wi-Fi has become an essential part of how businesses, healthcare, retail, hospitality and education operate.

The availability of unlicensed spectrum in the 2.4 GHz and 5 GHz bands has been the driver of Wi-Fi's successes, as it lowered the barrier of entry for new comers and enabled new and innovative use cases to emerge. In the past 20 years, Wi-Fi evolved to become the ubiquitous local network connectivity technology that it is today.

The "little engine that could" of the wireless world, Wi-Fi carries more internet traffic than any other wireless technology. Yet, this was accomplished despite having less than 300 MHz of unrestricted spectrum available.

- **80 MHz** in the 2.4 GHz band (channels 1 to 13) (U.S. only allows channels 1 to 11, Japan allows channel 14 for 802.11b only)
- **180 MHz unrestricted** in the 5 GHz band or **500 MHz requiring** Dynamic Frequency Selection (DFS) spectrum sharing channels

DFS channels require a spectrum sharing mechanism to ensure that they do not interfere on frequencies used by nearby weather or military radar stations. The Wi-Fi AP must continuously monitor for the presence of radar signals to avoid interference. Due to the complexity and delay incurred by this implementation, the DFS channels are often not supported in consumer equipment or not used by network administrators.

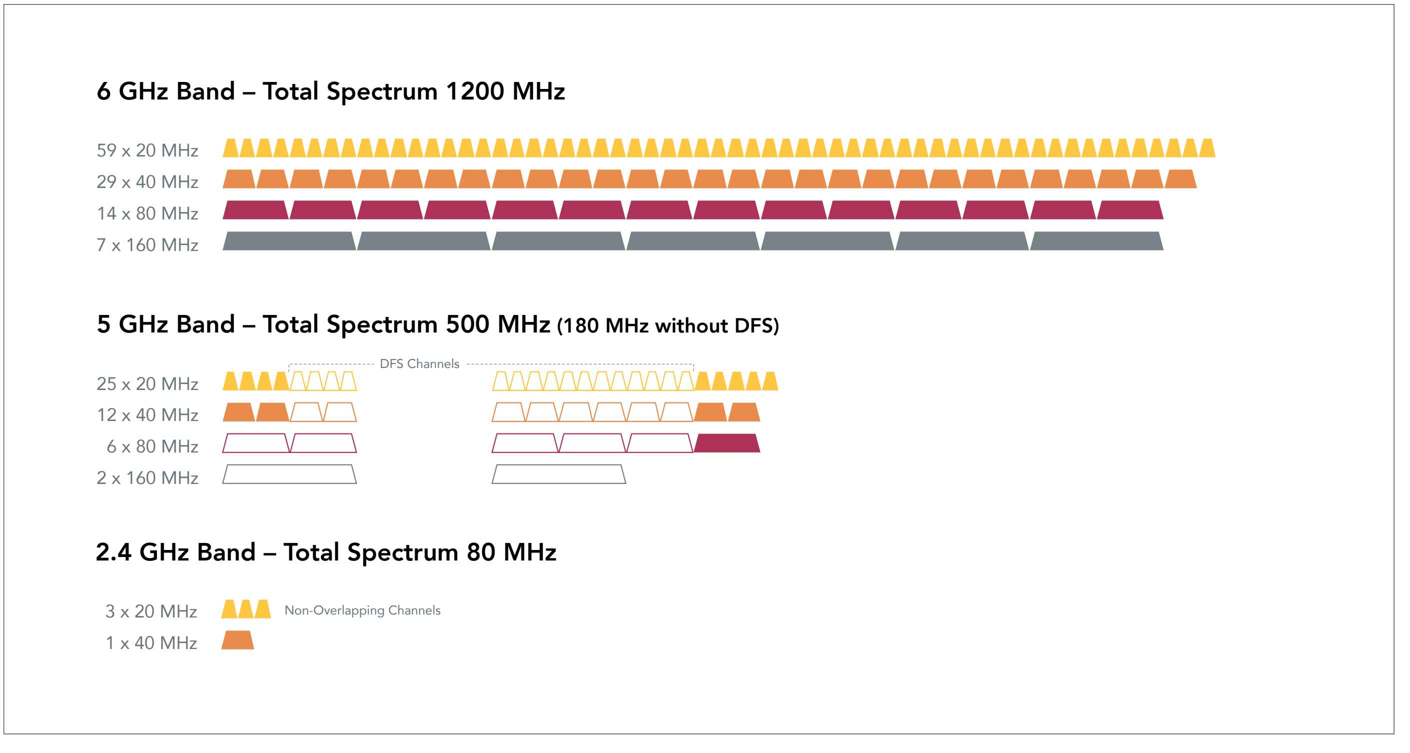



Figure 1: Wi-Fi spectrum comparison

## Wi-Fi's Challenges

Additional unlicensed spectrum is needed to address the main challenges facing Wi-Fi users as outlined below:

**Congestion –** The low number of Wi-Fi channels available today forces users to share available bandwidth and creates congestion. As each client station waits its turn to transmit (or receive) data, congestion is caused by devices, AP and Stations, sharing the same channel.

**Restricted 80-MHz and 160-MHz channel availability –** Today, the limited amount of contiguous spectrum makes it difficult to enable 80 MHz or 160 MHz channels, thereby limiting higher throughput which can only be achieved with wide channel bandwidth. In dense environments such as stadiums or airports or in large enterprises, it's hard to find an 80 MHz or 160 MHz channel free from interference caused by devices on overlapping channels. In response, network administrators often choose to disable these capabilities, thereby restricting the data speeds available on their network.

**Legacy devices –** IEEE 802.11 standards have always ensured that newer standards were backward compatible with previous standards. Older and newer devices can all interoperate, however overall data throughput is limited by the slowest devices. Legacy devices such as 802.11b/g/n require more air time to transmit data, therefore increasing latency and reducing throughput for all users.

To sustain Wi-Fi's projected growth and unlock new applications, a study [5] commissioned by the Wi-Fi Alliance predicted a shortfall of 800 MHz of spectrum to handle busy hour traffic by 2020 and a shortfall of 1.12 GHz by 2025. The study stressed the importance of making available continuous spectrum in order to enable 160 MHz (or future 320 MHz) wide channels. The 6 GHz band and its 1200 MHz of contiguous spectrum make an ideal candidate to fulfill the growth requirements and this is why it has been chosen for unlicensed use.

## Benefits of Wi-Fi 6E

Wi-Fi 6E devices operating in the 6 GHz band will be immediately able to take advantage of the benefits provided by this greenfield spectrum.

**High Capacity –** With 59 new 20 MHz channels available in the 6 GHz band, congestion issues will be immediately relieved. Wi-Fi 6E APs will not need to compete for spectrum and will be able to operate on congestion-free channels.

**Higher Speed –** 1200 MHz of contiguous spectrum enables 7 new 160 MHz channels and 14 new 80 MHz channels. Network administrators will be able to enable widespread use of wider channels without the risk of interference from overlapping channels and sufficient spatial reuse. Wider channels deployments will unlock multi-Gigabit Wi-Fi speeds for end users.

**Low Latency –** IEEE's decision to reserve access of the 6 GHz band to 802.11ax devices will reduce the latency and enable < 1 ms latency for 6E devices [6]. First by removing all legacy slower devices and also by allowing only 802.11ax (OFDMA, MU-MIMO, 1024 QAM) capable devices, that can take full advantage of the capacity and latency improvement features provided by this technology.

| Channel Width | 2.4 GHz Band | 5 GHz Band | 6 GHz Band |
|---|---|---|---|
| # of available 20 MHz channels | 3 (non-overlapping) | 25 (9 without without DFS) | 59 |
| # of available 40 MHz channel | 1 | 12 (4 without without DFS) | 29 |
| # of available 80 MHz channels | 0 | 6 (2 without without DFS) | 14 |
| # of available 160 MHz channels | 0 | 2 (0 without without DFS) | 7 |
| # of available 320 MHz channels (future capability 802.11be) | 0 | 0 | 3 |

Table 1: Channel availability in 2.4, 5 and 6 GHz bands

## 3. Wi-Fi 5, Wi-Fi 6 and Wi-Fi 6E, how do they differ?

To understand the benefits that Wi-Fi 6E will bring, let's compare the evolution of the most recent Wi-Fi standards.

### New Naming Scheme

In order to make it easier for the general public to identify device generations without remembering the complex IEEE alphabet soup, the Wi-Fi Alliance has created a naming scheme using a number to identify the generation. Using this new consumer-friendly scheme, the 802.11ac generation devices have been renamed Wi-Fi 5, while devices based on the IEEE 802.11ax standard have been named Wi-Fi 6. Although the 802.11ax standard includes the 2.4 GHz, 5 GHz and 6 GHz bands, the Wi-Fi Alliance has introduced the denomination of Wi-Fi 6E to identify 802.11ax devices operating in the 6 GHz band.

| Wi-Fi Alliance Naming Scheme | IEEE Equivalent Standard |
|---|---|
| Wi-Fi 5 | 802.11ac |
| Wi-Fi 6 | 802.11ax |
| Wi-Fi 6E | 802.11ax |

Table 2: Wi-Fi generations naming

### Technology Evolution

Some of the key technology features of the Wi-Fi standards are highlighted below. As shown in Table 3, Wi-Fi 6 and Wi-Fi 6E devices are similar in all aspects except for the operation in the 6 GHz band.

| | Wi-Fi 5 | Wi-Fi 6 | Wi-Fi 6E |
|---|---|---|---|
| Operating bands | 5 GHz | 2.4 GHz, 5 GHz | 6 GHz |
| Modulation scheme | OFDM | OFDMA | OFDMA |
| Channel width | 20 MHz, 40 MHz, 80 MHz, 160 MHz | 20 MHz, 40 MHz, 80 MHz, 160 MHz | 20 MHz, 40 MHz, 80 MHz, 160 MHz |
| Highest modulation | 256-QAM | 1024-QAM | 1024-QAM |
| MIMO streams | Up to 8x8 | Up to 8x8 | Up to 8x8 |
| MU-MIMO | Downlink MU-MIMO | Downlink and Uplink-MU-MIMO | Downlink and Uplink-MU-MIMO |
| Target Wake Time (TWT) | No | Yes | Yes |
| BSS Coloring | No | Yes | Yes |
| Extended Range Improvements | No | Yes | Yes |

Table 3: Wi-Fi technology evolution

## 4. Who are the incumbents in the 6 GHz band?

While it is clear that the 6 GHz band provides great benefits to Wi-Fi, it is important to understand who its current incumbents are and appreciate the efforts that have been made to make this band available for unlicensed use.

The 6 GHz band (5.925 – 7.125 GHz) is host to incumbent services operating on a primary basis. These services include fixed point-to-point, fixed satellite service (FSS), broadcast auxiliary service (BAC), and cable television relay service (CARS).

Figure 2 below from the FCC NPRM FCC 18-147, shows the density of assignments per megahertz in the FCC databases for the terrestrial services (excluding FSS) and shows 47,695 unique uses between 5.925 and 7.125 GHz.

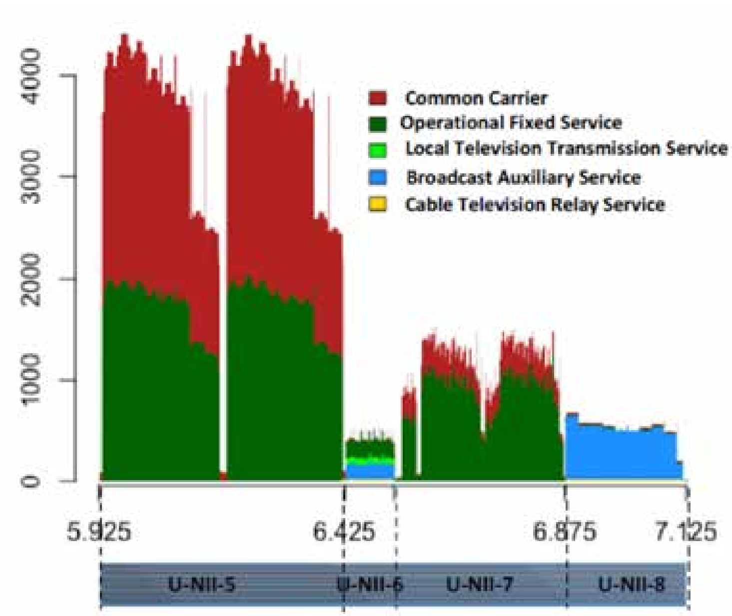



Figure 2: Licensed 6 GHz band users

Each of the 6 GHz's four U-NII Unlicensed - National Information Infrastructure (U-NII) sub-bands has a different set of incumbent services and operators. The table below shows the main users for each band:

| U-NII Band | Frequency Range (GHz) | Usage | Incumbent Services |
|---|---|---|---|
| U-NII 5 | 5.925-6.425 | Fixed | Fixed Satellite Services (earth to space)<br>Fixed Microwave |
| U-NII 6 | 6.425-6.525 | Mobile | Fixed Satellite Services (earth to space)<br>Broadcast Auxiliary Service Cable Television Relay Service |
| U-NII 7 | 6.525-6.875 | Fixed | Fixed Microwave<br>Fixed Satellite Services (earth to space) |
| U-NII 8 | 6.875-7.125 | Fixed and Mobile | Broadcast Auxiliary Service<br>Fixed Microwave<br>Cable Television Relay Service<br>Fixed Satellite Services (earth to space and space to earth) |

Table 4: Incumbent users of 6 GHz frequency bands

**Fixed Satellite Services –** Used for earth-to-space and space-to-earth communication to geostationary satellites, the incumbents in the band use the 6 GHz band mostly for content distribution to television and radio broadcast. The 7.025 to 7.075 GHz section (lower U-NII 8) is used for satellite digital audio radio service (SDARS), i.e. Sirius XM.

**Fixed Microwave Services –** Fixed microwave services are used for point-to-point microwave links. Users include commercial service providers such as AT&T or Verizon that carry traffic for wireless backhaul between base stations and wireline network. There are also industrial and business operators, carrying traffic for utilities, including power grid or natural gas and oil operation. Fixed microwave services are also deployed to carry critical traffic from public safety and emergency services like backhaul for police and fire vehicle dispatch.

**Broadcast Auxiliary Services (BAS) –** These include mobile television pickups and remote pickup stations which relay signals from a remote location back to the television studio for special events or remote locations.

**Cable Television Relay Service (CARS) –** These links are used by cable carriers to transmit video and audio back to the receivers.

Most of these incumbents have expressed valid concerns about coexistence with unlicensed technologies and potential harmful interference from unlicensed devices operating in the band. Fixed microwave services expressed concerns about harmful interference on their operation. These links, providing essential services for infrastructure or safety, are designed to achieve 99.999% reliability and operators argue that even rare interference from unlicensed devices can degrade their reliability. Operators have noted that hundreds of millions of access points will be deployed and this means that a significant number of microwave links will receive interference.

**UWB –** UWB (Ultra Wide Band) is a technology based on IEEE 802.15.4 providing secure and high precision ranging localization. It employs short pulses with ultra-low power ( 41 dBm/MHz) and large bandwidth (> 500 MHz) for communication and ranging [7]. UWB can operate from 3.1 GHz to 10.6 GHz. Although this technology is not an incumbent as they operate under Part 15 (unlicensed), they have nevertheless expressed concerns about the possible interference from Wi-Fi equipment operating in the same band.

Incumbents, as well as those in support of unlicensed use, have provided extensive studies and simulations in order to equip the FCC with the most relevant information to decide on operating rules for Wi-Fi devices across the multiple U-NII bands.

## 5. What are the rules of operation in the 6 GHz band?

The FCC's objective is to ensure that unlicensed devices operating under the Part 15 rules do not have a significant potential for causing harmful interference to the incumbent primary users that operate in the 6 GHz band. The Report and Order [8] adopted by the commission defines a set of operating rules designed to ensure coexistence of unlicensed devices in the spectrum.

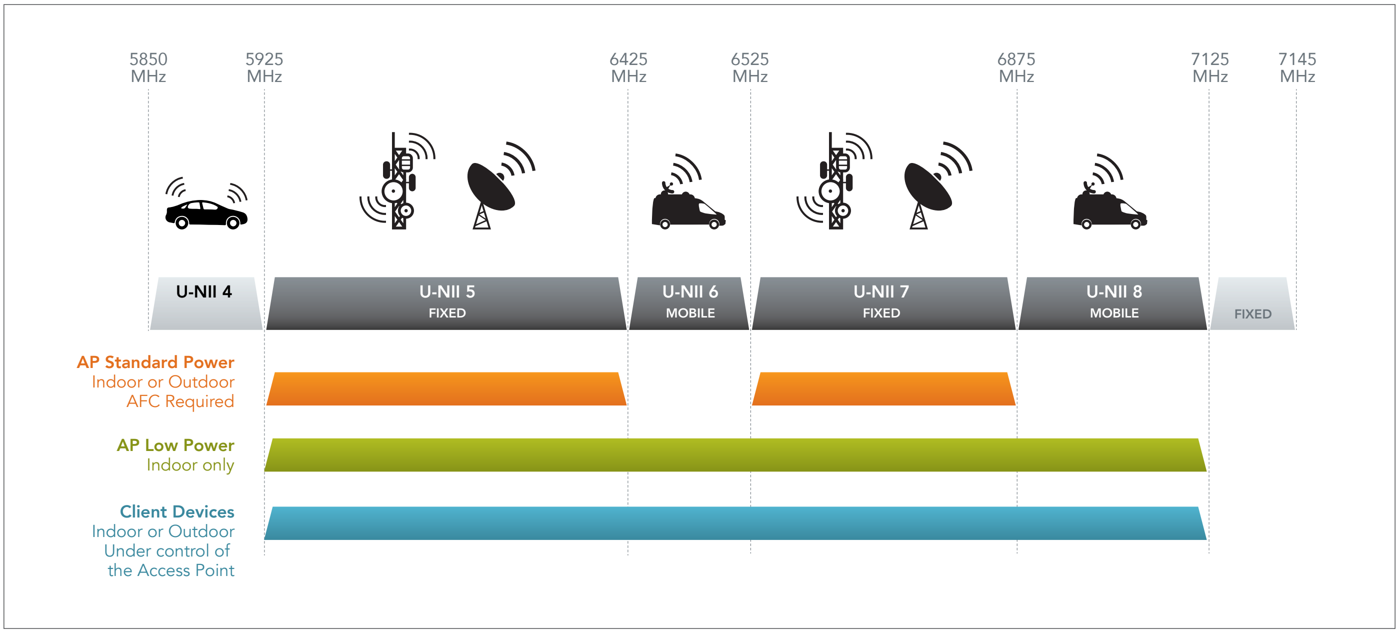



Figure 3: Rules of operation in 6 GHz unlicensed band

The rules define two classes of access point devices with their own set of operating rules: Standard Power Access Points and Low Power Access Points. Client devices cannot operate in standalone mode and must obey the operating rules of the AP that they connect to.

Table 5 below gives a summary of the radiated power requirements and operating frequencies:

| Device Class | Maximum EIRP (up to 320 MHz channel) | Maximum EIRP Power Spectrum Density | Operating Band |
|---|---|---|---|
| Standard Power AP | 36 dBm | 23 dBm/MHz | U-NII 5<br>U-NII 7 |
| Client connected to Standard Power AP | 30 dBm | 17 dBm/MHz | U-NII 5<br>U-NII 7 |
| Low Power AP | 30 dBm | 5 dBm/MHz | U-NII 5<br>U-NII 6<br>U-NII 7<br>U-NII 8 |
| Client connected to Low Power AP | 24 dBm | -1 dBm/MHz | U-NII 5<br>U-NII 6<br>U-NII 7<br>U-NII 8 |

Table 5: AP Power classes

### Standard Power Access Point

**Power –** Power requirements for the Standard Power AP class are consistent with those existing in the 5 GHz band (U-NII 1 and U-NII 3), with a maximum EIRP of 36 dBm and 23 dBm/MHz Power Spectral Density (PSD). This power class is defined, such that the maximum power fixed by the highest spectral density occurs for 20 MHz channels, while all other channel widths operate with a lower PSD in order to meet the maximum EIRP requirements.

| Channel Width | Standard Power AP Maximum EIRP PSD | Client (Connected to Standard Power AP) Maximum EIRP PSD |
|---|---|---|
| 20 MHz | 23 dBm/MHz | 17 dBm/MHz |
| 40 MHz | 20 dBm/MHz | 14 dBm/MHz |
| 80 MHz | 17 dBm/MHz | 11 dBm/MHz |
| 160 MHz | 14 dBm/MHz | 8 dBm/MHz |
| 320 MHz | 11 dBm/MHz | 5 dBm/MHz |

Table 6: Per channel PSD for Standard Power AP class

**Operating bands –** Standard Power APs can operate indoor or outdoor but only in the U-NII 5 and U-NII 7 bands. The decision to disallow operation in the U-NII 6 and U-NII 8 bands was made to protect incumbent mobile services (Broadcast Auxiliary Service and Cable Television Relay Service) operating in these bands.

**AFC –** In order to protect incumbent fixed microwave services in U-NII 5 and U-NII 7, the Standard Power APs can only operate under the control of an Automated Frequency Coordination (AFC) system. The AFC system is responsible for providing a list of frequencies where the AP can operate safely without interfering with incumbent fixed microwave receivers. This would be done by having APs connect to a cloud based AFC database to report their position, in turn the AFC database would determine the risks of interference with incumbent and assign a specific channel to the AP [9].

**Client devices –** Clients connected to a Standard Power AP need to operate at a maximum 30 dBm EIRP and 17 dBm/MHz EIRP maximum PSD, the power asymmetry between the AP and Client (6 dB) is designed to prevent clients from operating too far from the access point. These clients do not need to connect to an AFC system, however they can only operate on the frequencies communicated by the AP. Clients will not be allowed to transmit probe requests until they have received a transmission from an AP, and can only send a probe request on that same frequency.

**Channel width –** Although the current 802.11ax standard supports only channels up to 160 MHz, the rules allow Standard Power APs to operate up to 320 MHz setting the stage for the next generation Wi-Fi, the 802.11be standard.

Following these rules, Standard Power APs and connected clients are able to enjoy up to four 160 MHz channels on the allocated bands.

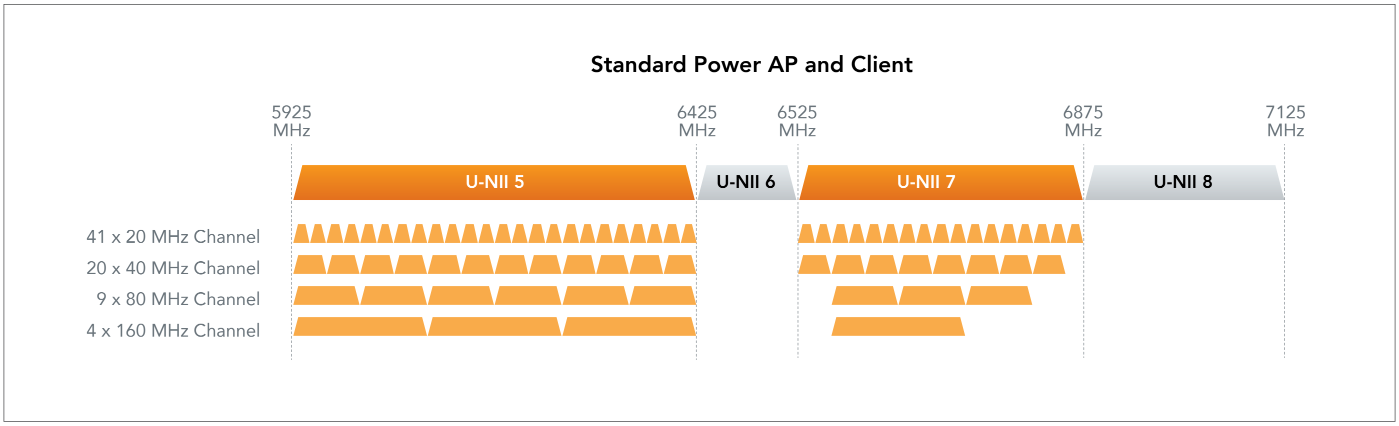



Figure 4: Channel allocation for Standard Power AP and Clients

### Low Power Indoor Access Point

Thankfully for the Wi-Fi community, the entire 6 GHz band (U-NII 5, 6, 7, 8) is opened for unlicensed indoor operation without the need for AFC controlled access. This decision is sure to greatly accelerate the deployment of Wi-Fi 6E devices for indoor operation.

In order to prevent interference to fixed or mobile incumbent services operating in these bands, the FCC has chosen to put the following restrictions on the systems: the devices can only operate at low power, indoors and must implement a contention based protocol.

**Power –** In order to find a compromise that both protects incumbent services from harmful interference and provide sufficient power to Wi-Fi devices, the Low Power APs will be allowed to 30 dB maximum EIRP and 5 dBm/MHz PSD. Unlike the Standard Power AP class, the power rules for the Low Power AP are defined to incentivize wider channel deployments, as the maximum EIRP meeting maximum PSD criteria, is reached for 320 MHz channel.

| Channel Width | Low Power AP Maximum EIRP | Client (Connected to Low Power AP) Maximum EIRP |
|---|---|---|
| 20 MHz | 18 dBm | 12 dBm |
| 40 MHz | 21 dBm | 15 dBm |
| 80 MHz | 24 dBm | 18 dBm |
| 160 MHz | 27 dBm | 21 dBm |
| 320 MHz | 30 dBm | 24 dBm |

Table 7: Per channel radiated power for Low Power AP class and clients

**Indoor operation –** In order to ensure that Indoor Low Power APs remain indoors and prevent users to install them outdoors, the following precautions will be required.  These devices will not have a weather resistant enclosure, they will not be able to operate solely on battery power and they will have integrated antennas, preventing the installation of external antennas.

**Contention based protocol –** For fair network air-time sharing, the FCC requires the implementation of a contention based mechanism. The IEEE 802.11 CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) mechanism provides a medium access fairness, by only allowing transmission when the channel is idle. Indoor Low Power AP's and their associated client, will be required to use this mechanism.

**Client devices –** Clients connected to Indoor Low Power APs are limited to a 24 dBm EIRP maximum with a max PSD at -1 dBm/MHz. The power asymmetry between the AP and Client (6 dB) is designed to prevent clients from operating too far from the access point.

**Mesh and Extenders –** These devices will be allowed to operate at the same power level as Low Power Access Point since they are intended to work in conjunction. They have to follow the same requirements in term of power, indoor operation and contention.

**Channel width –** Although the current 802.11ax standard supports only channels width up to 160 MHz, the rules allow Low Power Indoor APs to operate up to 320 MHz setting the stage for the next generation Wi-Fi the 802.11be standard.

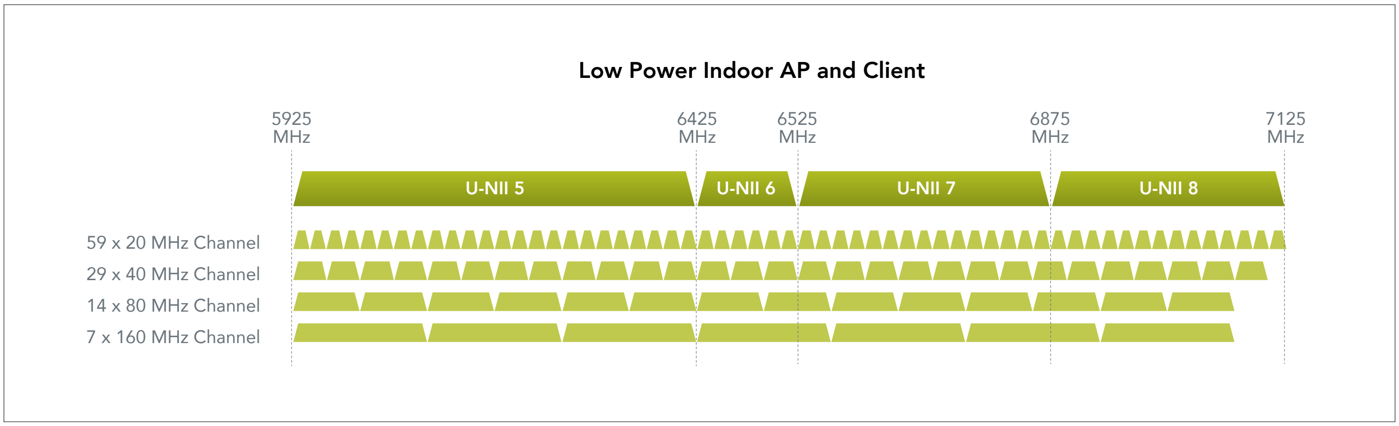



Figure 5: Channel allocation for Low Power AP and Clients

## Emissions Masks

In order to prevent emissions from unlicensed devices to interfere outside of their allocated spectrum, the FCC has mandated emission masks for in-band and out-of-band emissions.

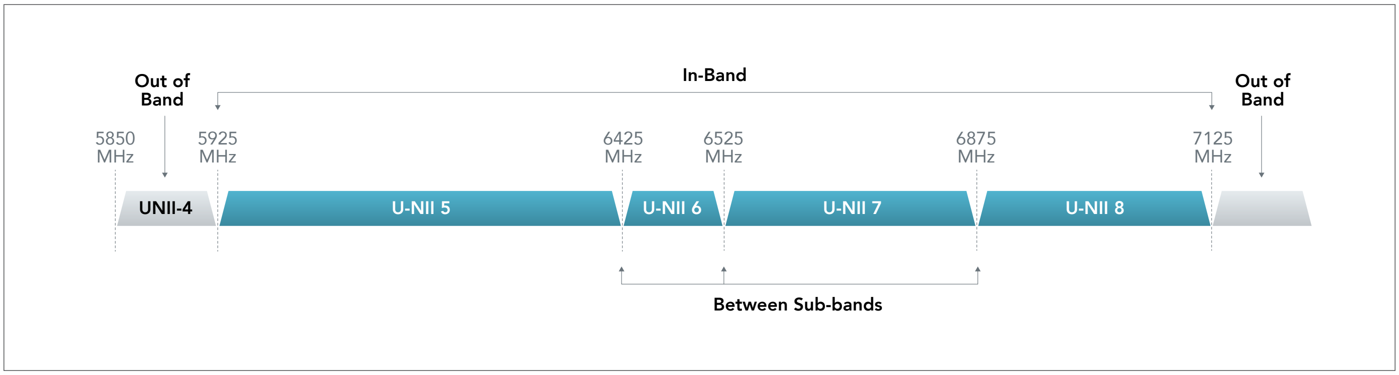
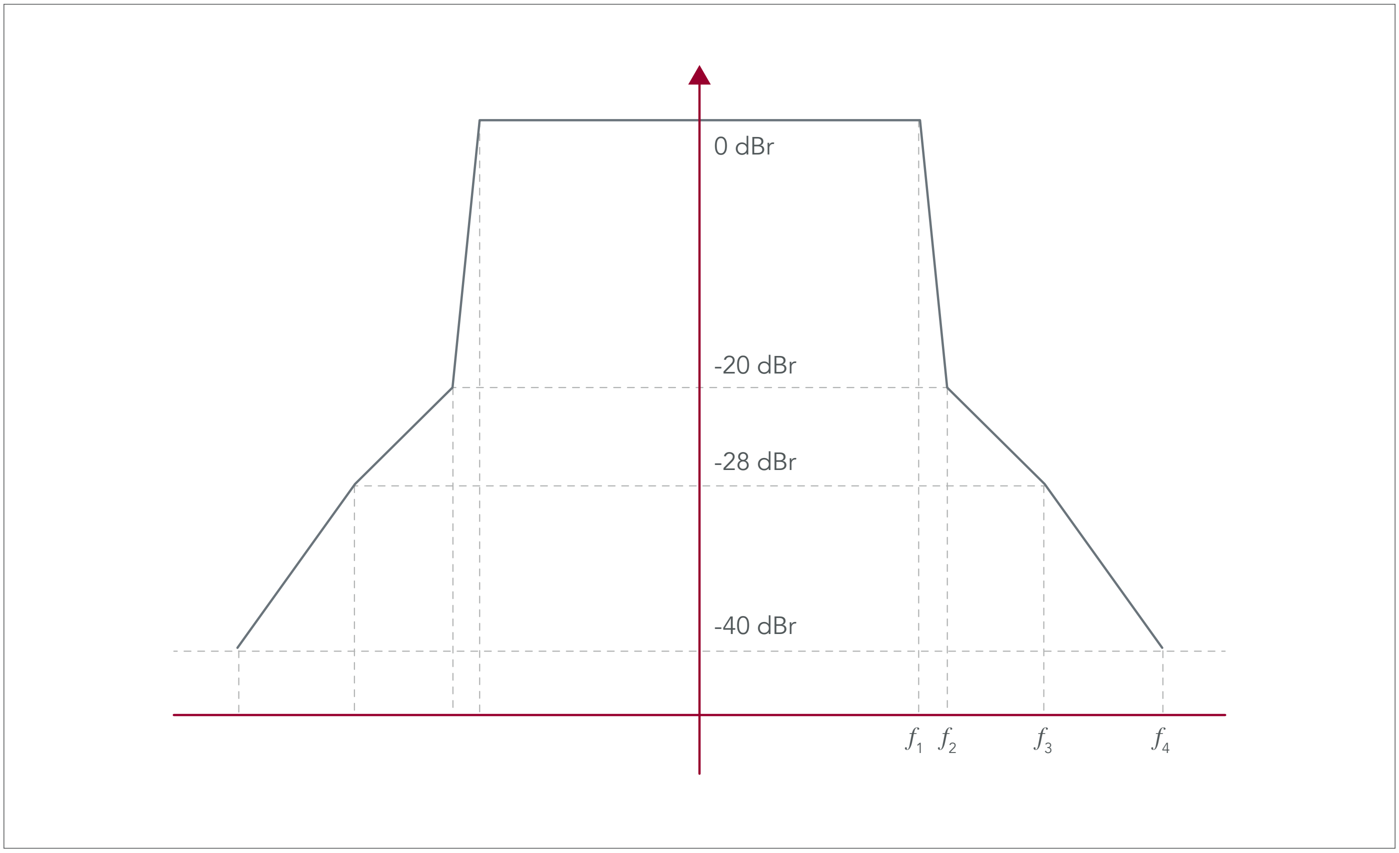



Figure 6: 6 GHz In-band vs. Out-of-band

**In-Band Emissions Mask –** The in-band spectrum emission mask defines the limits required within the 6 GHz band and applies to channels within U-NII 5 to U-NII 8. This mask is designed to protect incumbent services operating in a channel adjacent to the Wi-Fi device. It is defined as the allowed power distribution on the channel as well as the required attenuation from its peak amplitude at frequency offsets from the channel's center frequency, as described in Figure 7  below:




| Channel size | $f_1$ | $f_2$ | $f_3$ | $f_4$ |
|---|---|---|---|---|
| 20 MHz | 9 MHz | 11 MHz | 20 MHz | 30 MHz |
| 40 MHz | 19 MHz | 21 MHz | 40 MHz | 60 MHz |
| 80 MHz | 39 MHz | 41 MHz | 80 MHz | 120 MHz |
| 160 MHz | 79 MHz | 81 MHz | 160 MHz | 240 MHz |

Figure 7: In-band emissions mask

**Out-of-Band Emissions Limit –** Below U-NII 5 (U-NII 4 frequencies below 5.925 GHz) and above U-NII 8 (frequencies above 7.125 GHz) operate other services that also need protection from unlicensed devices operating in the 6 GHz band. To prevent harmful interference to these out of band services, the FCC is mandating Wi-Fi devices to a limit of -27 dBm/MHz PSD of emissions at the edge of the 6 GHz band.

**U-NII 5 to U-NII 8 Sub-bands –** The FCC is fortunately not mandating the strict out-of-band emission limits (below U-NII 5 and above U-NII 8) within the 6 GHz band between the U-NII sub-bands. Between U-NII 5 and U-NII 8 sub-bands only the in-band emission mask applies. This is an important decision, because it enables Wi-Fi devices to operate on channels that cross U-NII boundaries, as long as the power class and other criteria are in place. And crucially, this opens the door to future operations of wider 320 MHz channels.

## 6. How does the IEEE define operations in the 6 GHz band?

With 20 years of experience in standards development and pristine new spectrum, the IEEE 802.11 Working Group has a golden opportunity to define operations in the 6 GHz that promote speed and efficiency without the constraint of legacy devices. The standard under development, IEEE 802.11ax High Efficiency WLAN defines operation in the 2.4 GHz, 5 GHz and 6 GHz frequency bands. At the time of this writing the IEEE 802.11ax standard is not finalized and the information listed below is based on Draft 6.0 and subject to change.

### Rules of Operation

AP and Stations require HE (High Efficiency) only operation in the 6 GHz band. Arguably one of the most important decisions taken by the IEEE's disallows operation of devices of older generation in the 6 GHz band. A device operating in the 6 GHz band is not allowed to transmit HT (i.e. 802.11n), VHT (i.e. 802.11ac), DSSS, HR/DSSS (i.e. 802.11b) or ERP-OFDM (i.e. 802.11g) PPDU. Therefore, only HE capabilities are allowed in the 6 GHz band.

Devices operating in the 6 GHz band must therefore be capable of transmitting and receiving PPDUs that are compliant with the mandatory requirements and may support the optional features defined for High Efficiency. These features include:

- Mandatory support for Downlink and Uplink OFDMA
- Mandatory support for Downlink MU-MIMO
- Optional support for Uplink MU-MIMO
- Optional support for MCS 10 and MCS 11 (1024 QAM)
- Optional preamble puncturing

### HE PHY in the 6 GHz band

HE PHY operations for the 6 GHz band are the same as defined in the 5 GHz band. Transmitter spectral mask, spectral flatness, clock frequency tolerance, modulation accuracy, EVM as well as Receiver input sensitivity and channel rejection follow the specifications set for the 5 GHz band.

### Scanning and Probing in the 6 GHz band

Making full use of the greenfield status of the 6 GHz band the scanning, beaconing and probing mechanisms are being defined with 2 goals in mind. Optimize the stations scanning mechanism to cover 1200 MHz of spectrum and 59 new channels in an efficient manner and reduce wasteful management frame traffic. There is however a fine balance to achieve between maintaining efficient roaming while streamlining the discovery process to reduce overhead airtime utilization.

**Passive Scanning –** With 1200 MHz to cover and 59 channels to scan, a station with a dwell time of 100 ms per channel would require almost 6 seconds to complete a passive scan of the entire band. This excessive latency would result in slow roaming or even loss of connectivity for the end user as well as excessive power consumption for the device. New mechanisms are being put in place for mitigation.

**Out of band discovery –** Dual-band or tri-band APs operating in the 6 GHz band as well as in a lower band (2.4 GHz or 5 GHz) will be discoverable by scanning the lower bands. In the lower band, APs will include information about the 6 GHz BSS via a reduced neighbor report in beacons and probe response frames. The station will therefore have enough information to determine where and how it can associate with the 6 GHz AP.

**Fast Passive Scanning –** For 6 GHz-only APs, clients are not able to learn of their existence using the previously described out of band method. Instead, they will use a fast passive scanning method focusing on a reduced set of channels (25% of all 20 MHz channels) designated as Preferred Scanning Channels (PSC). PSCs are a set of fifteen 20 MHz channel spaced every four channels (80 MHz apart), all PSCs may not be available based on the regulatory restrictions. Passive scanning of these fifteen PSCs reduces the total scan time to the more manageable 1.5 seconds (assuming a 100 ms dwell time). The spacing of PSCs has been optimized so that APs deployed with 80 MHz channels or more will overlap with a PSC. A 6 GHz-only AP should set up the BSS with a primary 20 MHz channel that coincides with a preferred scanning channel (PSC) to assist Stations that are scanning the band. Otherwise the AP might temporarily set its primary channel on a PSC and then switch to a non-PSC channel after it has been successfully discovered.


Figure 8: Primary Scanning Channels

**Probing –** Probe requests are an effective tool to speed up the discovery process. Without having to passively wait on a channel for a beacon, a station can initiate a broadcast probe request and wait for responses. This behavior however impacts the performance of stations and APs operating on the same channel since the broadcast probe requests, especially using wildcard BSSID, create a large number of responses and therefore higher traffic utilization and increased collisions. When a high number of stations resort to this behavior, it creates a probe storm. This is greatly detrimental to the overall system capacity and reduces useful throughput for everyone. To avoid this behavior, the IEEE has set forth a new set of rules for probing operation in the 6 GHz band.

A station operating in the 6 GHz band cannot transmit a probe request to the broadcast destination address using wildcard BSSID and wildcard SSID i.e. a station's "who's there" blind probing behavior is not allowed.

Stations may however transmit a directed probe request frame to an AP that is has discovered out of band or from which it has already knowledge.

If the station is scanning a Preferred Scanning Channel (PSC), and has no knowledge of an AP there, it has to wait for at least the duration of the minimum probe delay interval (approx. 20 ms) before sending a broadcast probe request.

If the station is scanning a non-Preferred Scanning Channel, then it can only send a probe request if it has knowledge of an AP operating there.

In any case, local regulatory rules take precedence over the operating behavior defined by the IEEE. In the U.S., as we discussed in section 5, client devices are not allowed to send probe requests until they have detected a transmission from the AP and can only send them on the same frequency as the AP's transmission.

## Channelization

The 802.11ax standard defines channel allocations for the 6 GHz band. This allocation determines the center frequencies for 20 MHz, 40 MHz, 80 MHz and 160 MHz channels over the entire 6 GHz band. However, regulatory domains specifications take precedence over the IEEE specification and channels that are falling on frequencies or overlapping on frequencies that are not supported in a regulatory domain cannot be used.

As of draft 6.0 the channel center frequencies are defined at every integer multiple of 5 MHz above 5940 MHz, however there is a proposal to switch the start frequency to 5950 MHz in order to provide a wider guard band interval between the low U-NII 5 channels and the U-NII 4 band (5 GHz band). This change is likely to be included in further revisions of the IEEE standard, therefore the figures below show channel allocations for both configurations.

Figure 9 below shows channelization starting at 5940 MHz. Channel numbers are shown as a continuation of the 5 GHz band channels:

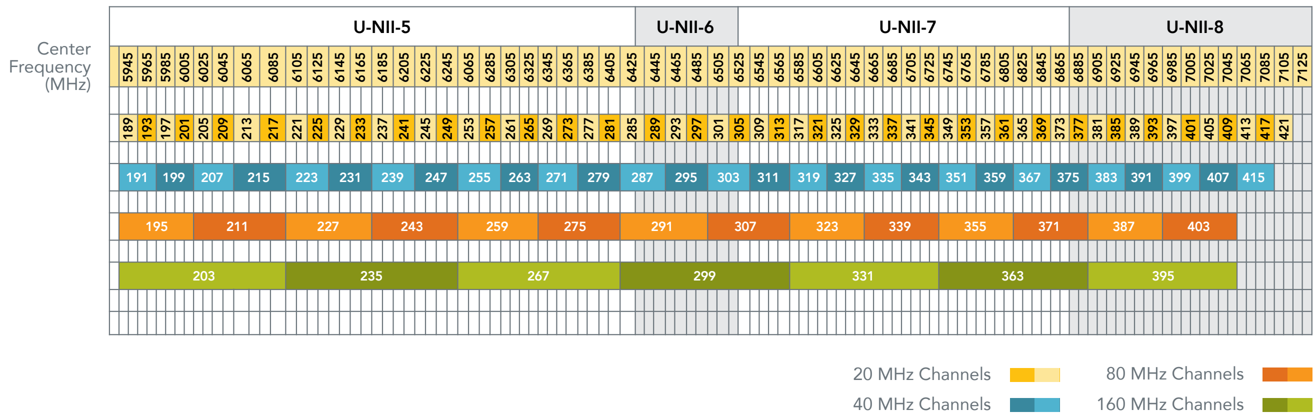



Figure 9: Channel allocation starting at 5940 MHz

Figure 10 below shows channelization starting at 5950 MHz. Channel numbers are shown as a continuation of the 5 GHz band channels:

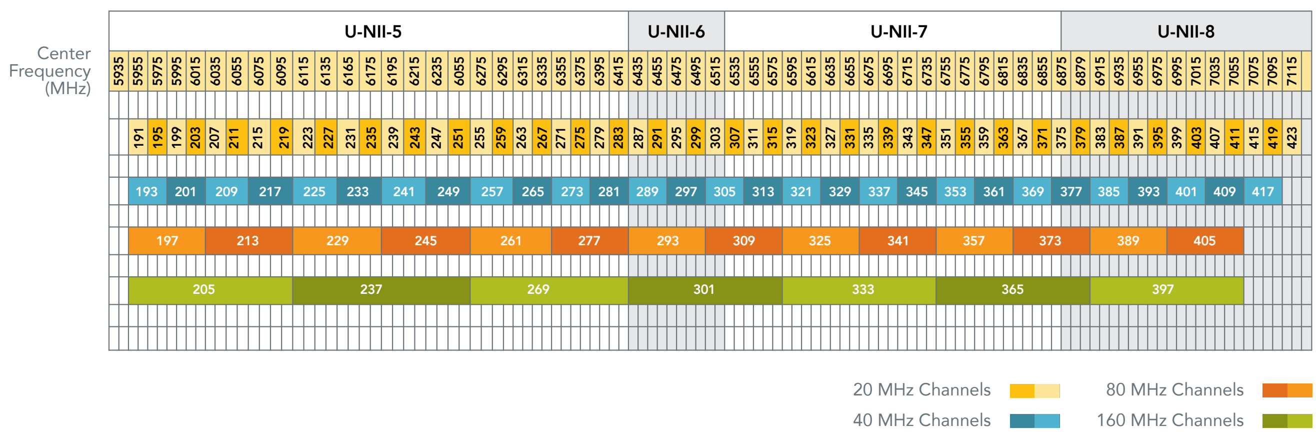



Figure 10: Channel allocation starting at 5950 MHz

Beyond the advantage of giving 20 MHz guard band with the lower band, making it easier to design equipment compliant with the out of band emission requirements. Providing starting frequencies at 5950 MHz provide a better alignment with the U-NII 6 demarcations. With this configuration, the U-NII 6 can fit a complete 80 MHz channel, two 40 MHz channels and five 20 MHz channels. This could provide a benefit in regulatory domains where the U-NII 6 operates under different rules.

## 7. Wi-Fi 6E Challenges

Earning more spectrum from regulatory bodies has been an arduous and momentous step on the road to delivering Wi-Fi 6E equipment in user's hands, but building the next generation of equipment capable of taking full advantage of 1200 MHz of new spectrum also bares its share of challenges. The following sections give an overview of some of the challenges presented by this new technology.

### The 6 GHz Barrier

Even though the 6 GHz band sits right above the 5 GHz band, crossing the 6 GHz barrier is a major shift for RF equipment. Up until now, consumer devices with commonplace connectivity technologies like Wi-Fi, Bluetooth and cellular only supported frequencies up to 5.9 GHz. Therefore, components and equipment used for design and manufacturing had historically been optimized for frequencies below 6 GHz. Retooling for support up to 7.125 GHz has a major impact to the full product lifecycle from product design and validation all the way to manufacturing.

### Consistent Performance across 1200 MHz

With 1200 MHz of additional spectrum, Wi-Fi 6E devices will need to be able to provide consistent performance over a frequency range double of the coverage needed for the 2.4 and 5 GHz bands. This challenges the designs especially of the RF front end as it needs to provide consistent performance across the entire spectrum from the lowest to highest channels and requires good linearity of the Power Amplifier/ Low Noise Amplifiers used to cover the 6 GHz range. Typically, performance will start to roll off at the upper frequency edges of the band and devices will need to be calibrated and tested up to the highest frequencies to ensure that they can generate the expected power levels.

### Dual Band or Tri Band Devices

Wi-Fi 6E devices will be most often deployed as dual band (5 GHz + 6 GHz), or (2.4 GHz + 5 GHz + 6 GHz) devices. Again this places a high demand on the RF front end in terms of integration, space, heat dissipation and power management for the multiple bands and MIMO streams to coexist. The filtering needs to ensure proper band isolation to avoid interference within the device. This increases the design complexity and the validation of the devices as more coexistence/desense tests need to be done, and multiple bands need to be tested simultaneously.

### Emissions

As discussed earlier, the FCC has approved the use of the 6 GHz band for Wi-Fi, but put in place a set of rules ensuring that it can coexist peacefully with the incumbents, both in band and out of band. For protection of incumbent mobile and fixed services, the FCC mandates 2 classes of devices (standard power and indoor low power). Devices operating outdoors will also need to ensure that they respect the right of way of incumbent services by implementing AFC (Automated Frequency Coordination).

Another level of protection is the emissions compliance to the spectral mask defined by the FCC. This spectral mask describes the distribution of the power across the channel and into the adjacent channels and ensures that RF energy that is being radiated on other channels will not produce harmful interference to incumbent services. The spectral mask analysis is usually done at the maximum output power, since this where the power amplifiers are being stressed the most and start exhibiting leakage. The tests are also done over the whole frequency range and channel width to ensure compliance over the entire frequency band.

### 80 MHz and 160 MHz Channels

Even though 80 MHz and 160 MHz channels were available in previous generations (802.11ac and 802.11ax in the 5 G band), they were not mandatory and were often not supported or deployed because of the lack of spectrum availability. The 6 GHz band opens up enough contiguous spectrum to make full use of these wide channels, and they will be part of most 6 GHz deployments to unlock the highest multi-Gbps throughput. 320 MHz channels are already being planned for the next generation IEEE 802.11be standard.

Wider channels width however present design challenges because more bandwidth also means more OFDMA data carriers being transmitted (and received) simultaneously. An 80 MHz channel has 996 sub-carriers, while 160 MHz channel has twice this amount. The SNR per carrier is reduced and therefore requires higher transmitter modulation performance for successful decoding. The spectral flatness, which is a measure of the distribution of the power variations for all the sub-carriers of the OFDMA signal, is also more challenging to achieve for wider channels. Distortions occur when the carriers at different frequencies are attenuated or amplified by different factors, the larger the range of frequencies the more they are likely to exhibit this type of distortions.

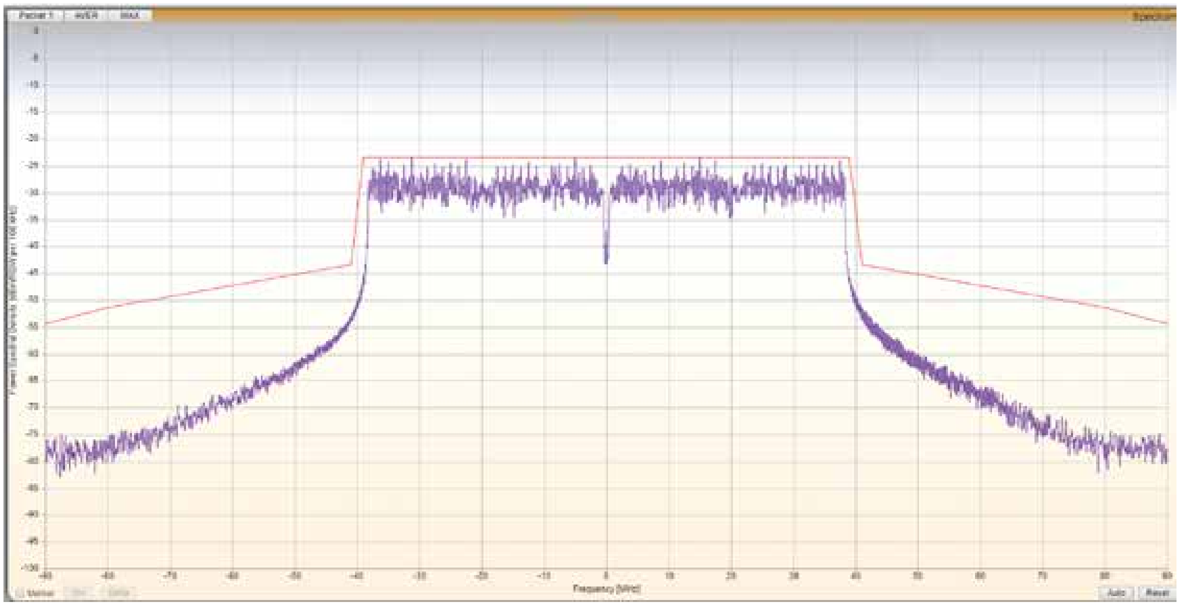


Figure 11: HE SU 80 MHz

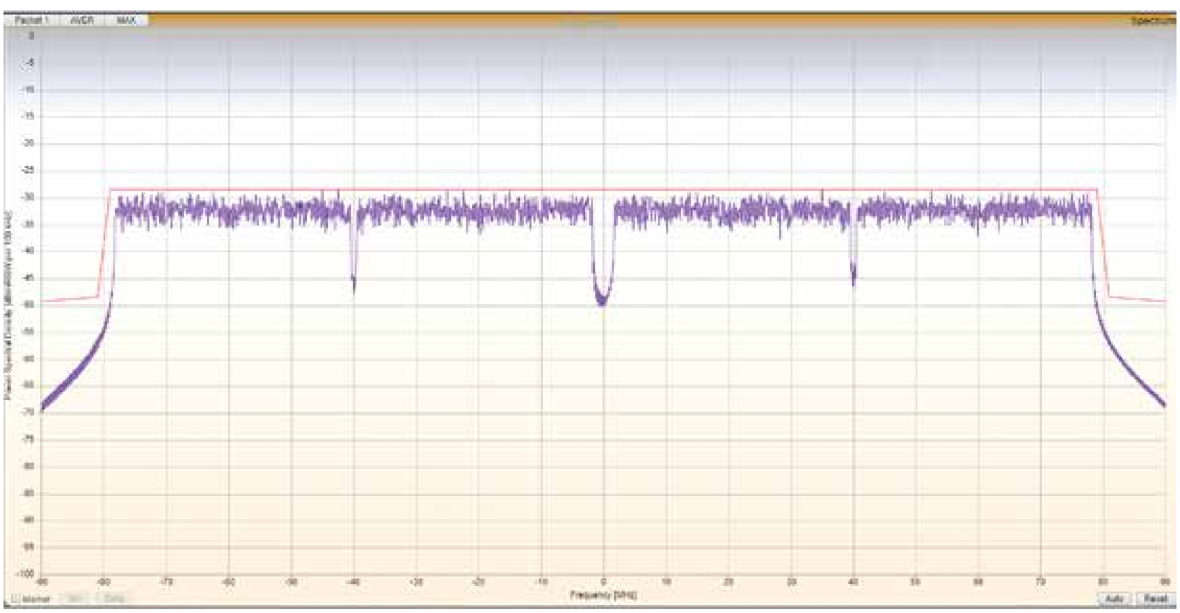


Figure 12: HE SU 160 MHz

## Higher Order Modulation: 1024-QAM

1024-QAM modulation is already part of Wi-Fi 6 in the 2.4 and 5 G bands, while the previous generation 802.11ac (Wi-Fi 5) only supported up to 256-QAM. With 10 bits of data encoded per sub-carrier vs 8 bits in 256-QAM, 1024-QAM improves the peak data rates by 25% and is defined in the two new MCS rate MCS 10 and MCS 11.

The 6 GHz band is going to enable more ubiquitous usage of the high data rates. First because, this band (per IEEE decision) is going to be reserved to 802.11ax/ 1024-QAM capable devices only, therefore all transmitters and receivers will be 1024-QAM capable, and second because the RF conditions are going to be more favorable to high data rate. With higher order QAM modulation, the constellation points are much closer together and devices become more sensitive to impairments. Systems require a higher SNR in order to be able to properly demodulate. The 6 GHz spectrum will provide a better/cleaner RF environment with less interference from other devices since it has enough spectrum to avoid adjacent channel or overlapping channel interference.

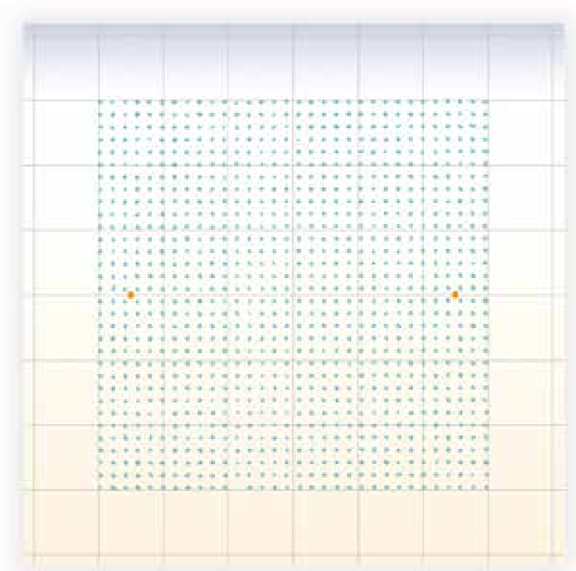


Figure 13: 1024-QAM constellation plot

Obtaining the highest level of modulation accuracy for 1024 QAM drives hardware of the chipset and RF front end to have excellent phase noise and linearity performance to meet the IEEE requirements. The accuracy is usually measured by a metric called the EVM (Error Vector Magnitude) that measures the deviation of the constellation points compared to their ideal location. The 802.11ax standard requires < −35 dB EVM for 1024QAM, compared to < −32 dB for 256 QAM. Since this metric is a really good indicator of the combined effects of all the possible defects on the transmitter chain, it is typically measured in manufacturing to ensure transmitter quality.

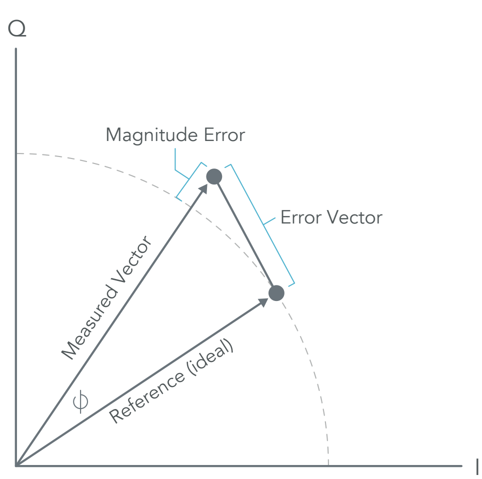



Figure 14: Error Vector Magnitude

## OFDMA

Older Wi-Fi generations were based on OFDM modulation, where but each channel (20, 40, 80 or 160 MHz wide) was fully reserved to a single user for each transmission.  In contrast, OFDMA introduced in 802.11ax divides the channel into sub-channels, also known as Resource Units (RU). For example, a 160 MHz channel can be divided into up to 74 separate RUs, where each RU can be assigned to a different client station (STA). This technology allows multiple users to communicate information simultaneously, rather than waiting for their turn.

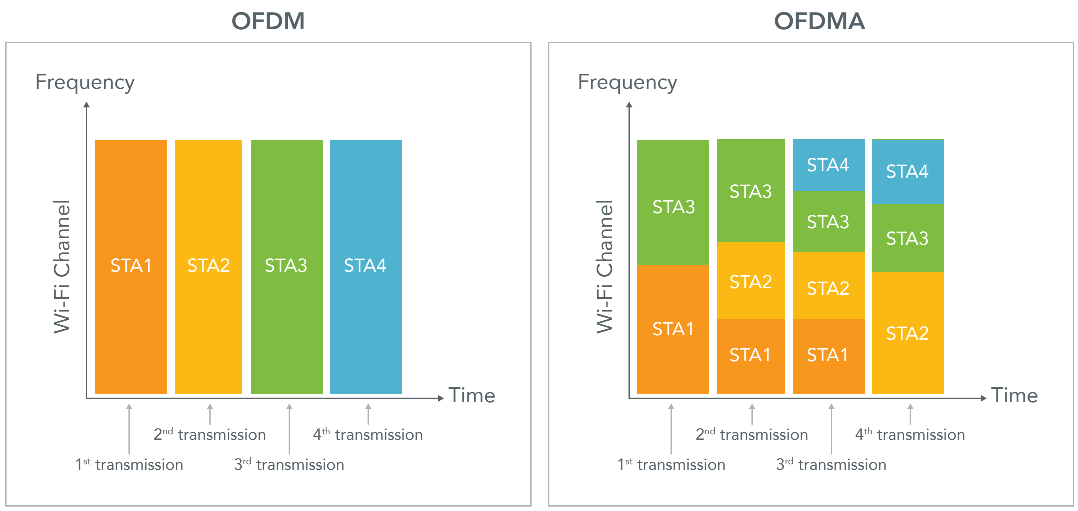



Figure 15: OFDM vs OFDMA with 4 client stations (STA)

A mandatory feature of the 11ax standard, OFDMA has been described as one of the key technology evolution to address network congestion. Its impact often gets compared to upgrading from a single-lane road (OFDM) to a multi-lane freeway (OFDMA) providing a nearly fourfold increase in user and system capacity over earlier generations. While it has great potential, OFDMA only becomes effective with widespread adoption of the technology in client devices and access points. Indeed, each time a legacy device (11ac, 11n or older) transmits in the network, the transmission reverts back to standard OFDM mode with a single transmission occupying the entire spectrum. Only 11ax devices are capable of participation in an OFDMA transmission but until most consumer devices deploy Wi-Fi 6, the promised capacity or latency reduction will not materialize rapidly.

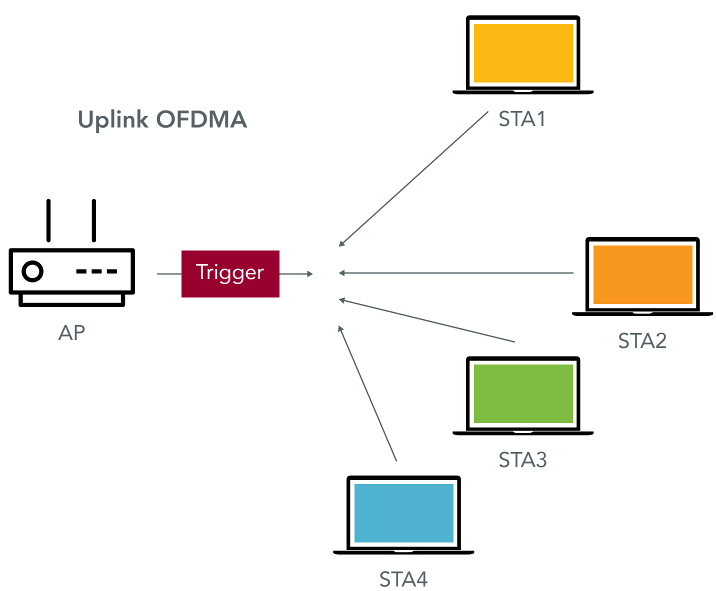



Figure 16: UL OFDMA Trigger based Transmission with 4 client stations (STA)

IEEE's decision to reserve access of the 6 GHz band to 802.11ax OFDMA-capable devices immediately unlocks this technology's potential for capacity improvement and latency reduction. With no legacy device present, Wi-Fi 6E clients and access points are able to immediately enjoy the benefits of OFDMA in green-field deployments.

While OFDMA has long been in use in 4G/LTE networks, it is the first time it is being applied to Wi-Fi. OFDMA is a powerful feature but it is also one of the most challenging aspects of the 11ax standard because it requires all devices participating in the transmission to be synchronized. The accuracy of time, frequency and power synchronization between AP and client stations determines the overall network capacity. When multiple users share the available spectrum, interference from a single bad actor can degrade network performance for all other users. Client stations participating in transmission must transmit at the same time within 400 ns of each other, with their frequency aligned (± 350 Hz), and with a transmit power accuracy within ±3 dB. These specifications require a level of accuracy that was never expected from Wi-Fi equipment in the past and require careful validation.

# 8. LitePoint's Solutions for Wi-Fi 6E

Founded in 2000, LitePoint started just as Wi-Fi was seeing the beginning of its wide market adoption. In these 20 years, we have helped manufacturers deliver over 10 billion Wi-Fi-enabled products to market. LitePoint's innovative approach delivers purpose-built wireless test equipment that combine high performance with ease-of-use and enables the most innovative wireless technology to transition from the lab to high volume manufacturing.

The capability and complexity of the technologies behind Wi-Fi continue to change at an extremely rapid pace, and we work with the leading chipset manufacturers and standard bodies to provide innovative test solutions for the latest wireless standards. LitePoint was the first to introduce a fully integrated tester for Wi-Fi 6 and Wi-Fi 6E in the 2.4 GHz, 5 GHz and 6 GHz band and already supports turnkey test and calibration software for Wi-Fi 6E Chips for access point and client devices.


### IQxel-MW 7G

LitePoint's IQxel-MW 7G is the first fully integrated tester for Wi-Fi 6 and Wi-Fi 6E in the 6 GHz Band. This fully integrated test solution, supports a continuous frequency range from 400 MHz to 7.3 GHz, thereby ensuring coverage for Wi-Fi 802.11 a/b/g/n/ac and 802.11ax testing in the 2.4 and 5 GHz and 6 GHz bands.

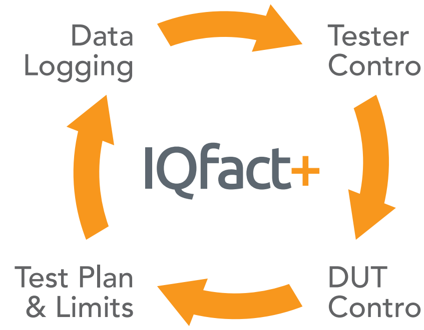
For R&D characterization or high volume production, the IQxel-MW 7G family is available in three configurations: 2 ports (2 VSA/VSG), 8 ports (2 VSA/VSG), and 16 ports (4 VSA/VSG). These support up 4x4 MIMO testing in a single tester (extensible to 8x8 MIMO), and high efficiency parallel testing for up to 16 devices.

Capabilities include:

- Frequency range from 400 MHz to 7300 MHz
- Native support for per-port 160 MHz and 80+80 MHz signal combination
- Exceptional residual EVM performance at 1024-QAM
- WiFi 6 testing capabilities: Single-user OFDMA, Trigger based multi-user OFDMA, Uplink and Downlink testing with easy-to-edit RU allocations
- Wi-Fi 6 Carrier Frequency Offset (CFO), power and timing control verification
- MIMO testing with 4x4 testing capability and expandable architecture supports up to 8x8 MIMO

## IQfact+

IQfact+ test programs are a result of LitePoint's partnership with the leading chipset manufacturers, and offer a quick, easy, and cost-effective way to develop and test chipset specific solutions. The software provides turnkey solutions for customized testing and calibration of leading chipsets, enabling thorough design verification and rapid volume manufacturing with minimal engineering effort.




To facilitate accurate test synchronization, IQfact+ controls both the LitePoint tester and the DUTs. In addition, each IQfact+ is tailored to provide the best test efficiency for a specific chipset and designed specifically for the LitePoint tester architecture, resulting in drastically reduced test time and engineering effort.

IQfact+ encompasses a growing library of over 350 chipsets and supports all key wireless connectivity technologies.

**Reference:**

[1] https://www.wi-fi.org/news-events/newsroom/wi-fi-alliance-brings-wi-fi-6-into-6-ghz

[2] https://www.qualcomm.com/news/releases/2020/02/25/qualcomm-highlights-technology-leadership-industry-readies-wi-fi-6e

[3] https://www.broadcom.com/company/news/product-releases/52926

[4] https://www.wi-fi.org/value-of-wi-fi

[5] https://www.wi-fi.org/downloads-registered-guest/Wi-Fi%2BSpectrum%2BNeeds%2BStudy_0.pdf/33364

[6] https://www.broadcom.com/info/wifi6e

[7] https://www.litepoint.com/uwb

[8] https://www.fcc.gov/document/fcc-opens-6-ghz-band-wi-fi-and-other-unlicensed-uses-0

[9] http://dynamicspectrumalliance.org/wp-content/uploads/2019/03/DSA-Event-Handout_Final.pdf

LITEPOINT





CONTACT INFORMATION
180 Rose Orchard Way
San Jose, CA 95134
United States of America

+1.866.363.1911
+1.408.456.5000

LITEPOINT TECHNICAL SUPPORT
www.litepoint.com/support

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