
WHITE PAPER



TECHNICAL GUIDE TO WI-FI 6E AND THE 6 GHZ BAND



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ABOUT THIS PAPER

This white paper is designed for network architects to better understand the implications of Wi-Fi 6E in their environments. It begins with an overview of the regulations and then dives into the specifics of Wi-Fi 6E, including device classes and AP discovery. In the last section, this paper addresses how to design a network with Wi-Fi 6E and explores the implications for new and existing Wi-Fi footprints.

THE NEED FOR THE 6 GHZ BAND

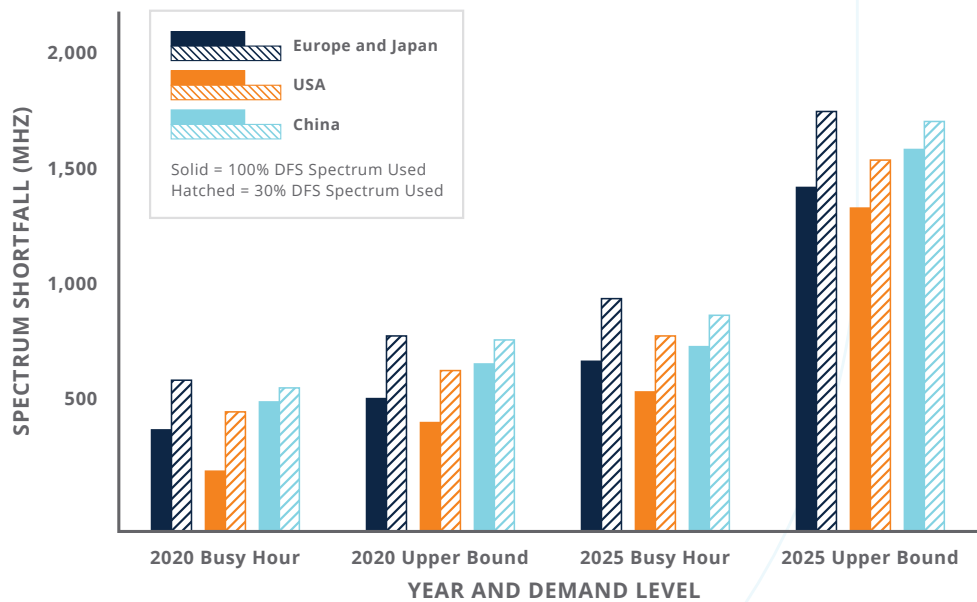
Wi-Fi’s success has been building for many years, but recently, the restrictions of limited spectrum were beginning to bite. Recent studies have shown that pinch-points exist in city centers and dense housing, where the 2.4 GHz band has been shown to be highly congested, and even the 5 GHz band has suffered poor performance due to the large number of Wi-Fi radios operating in a small space on limited channels.

A study by the Wi-Fi Alliance in 2017 showed that in order to maintain desired levels of performance, 1.5 GHz of new spectrum would be needed by 2025. This realization of the Wi-Fi industry fueled a search for suitable spectrum for Wi-Fi to expand and resulted in a focus on the ‘6 GHz band’ from 5.925 to 7.125 GHz.

Following advocacy by the Wi-Fi industry, and much study and consultation with industry participants, the US FCC issued a Report & Order (R&O) in 2020 that laid out rules for opening the new 6 GHz band for unlicensed use while protecting incumbent users. Subsequent to the R&O, the industry, operating through the Wi-Fi Alliance, developed specifications that adapt the existing Wi-Fi standards to the new 6 GHz band.

Because the 6 GHz band has no prior Wi-Fi activity and backwards-compatibility is not required, it can be treated as a greenfield band, allowing protocols to be simplified and optimized. The latest standard, Wi-Fi 6, is taken as a baseline, with its headline features allowing high spectral efficiency, strong QoS, simultaneous transmissions and low latency, and supplemented by a limited number of new features that improve performance both within the band and for tri-band APs. Baseline security is the latest WPA3 revision.

The new 6 GHz band almost triples the spectrum available for Wi-Fi, with minimal modification to standards, allowing fast rollout of new APs and devices. The new equipment will be labeled ‘Wi-Fi 6E’ and will benefit from greater capacity and better performance, enabling new services with higher data rates and low delay, along with strong quality of service and security.



Source: Quotient Associates for the Wi-Fi Alliance, 2017

Figure 1. Predicted Wi-Fi spectrum shortfall



While the FCC was the first national regulator to authorize unlicensed use of the 6 GHz band, many other countries have followed and more are expected to follow with at least part of the band, subject to national considerations. It is clear that at least 480 MHz of the 6 GHz band will become a global, harmonized band for Wi-Fi, allowing users to travel internationally without modifying client devices, as they do today.

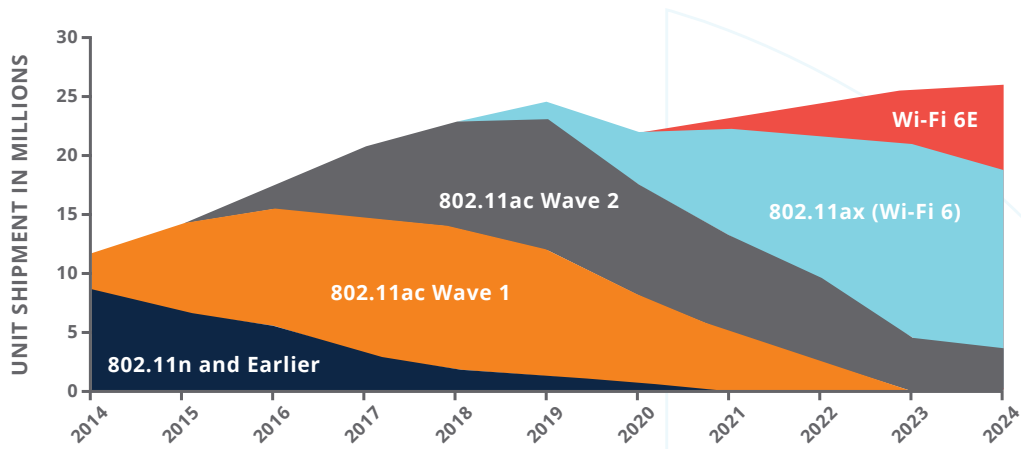


Figure 2. Shipments by standard with the introduction of Wi-Fi 6E

Shipments of Wi-Fi 6E are expected to rise quickly, as illustrated in the chart above. The 6 GHz band will require new hardware, and new Wi-Fi 6E equipment is expected to become tri-band or tri-band capable. For APs, this means supporting 2.4 GHz, 5 GHz, and 6 GHz simultaneously with three radios, while client devices will be able to flexibly switch their radio between the three bands.

THE NEW 6 GHZ BAND: REGULATIONS

Spectrum allocation is a regulatory function, and rules can differ at the national level. This section covers regulations in the US and European theaters; most countries will follow one or the other of these models, potentially with minor national variations.

Channels

The new grant in 6 GHz is 1200 MHz of spectrum, compared to 83.8 MHz in the 2.4 GHz band and 570 MHz in sections of 5 GHz (US figures). After a 20 MHz guard band at the low end, usable spectrum starts at 5.945 GHz and continues up to 7.125 MHz.

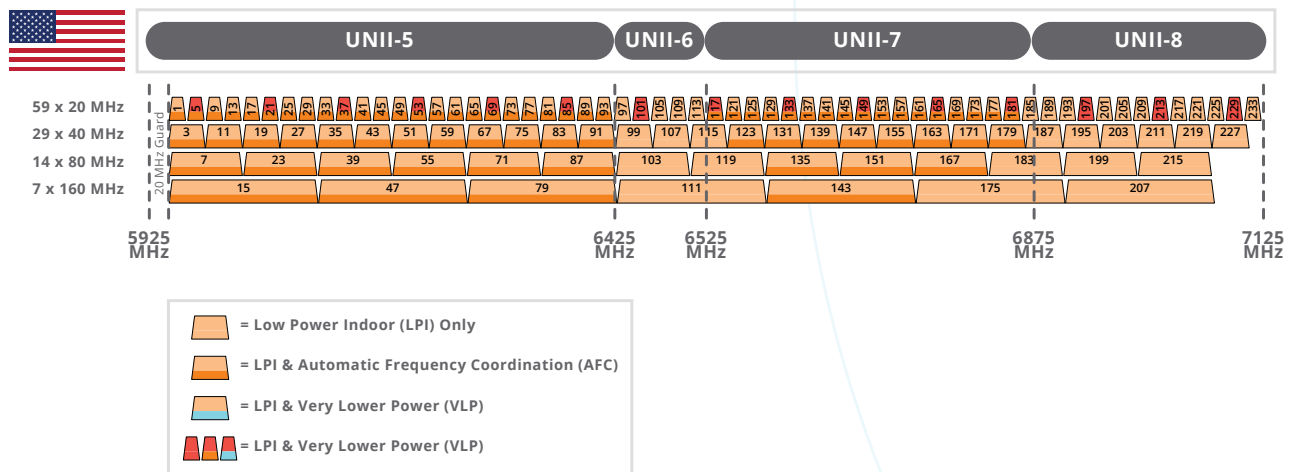


Figure 3. US channel distribution for 6 GHz



This allows for 59 20 MHz channels; 29 at 40 MHz; 14 at 80 MHz, or 7 at 160 MHz. The number of wide channels is especially significant, as gaps in allocated spectrum in the 5 GHz band limit 80 MHz channels to 7 and 160 MHz channels to 3, and wide channels are necessary for the highest data rates.

The US designates four sub-bands across the 1200 MHz: U-NII-5, 6, 7, and 8. These sub-bands are significant because they contain different incumbent types (see below), so while indoor APs will have uniform power limits across the entire 1200 MHz, there are differing restrictions for high-power and outdoor use across the sub-bands.

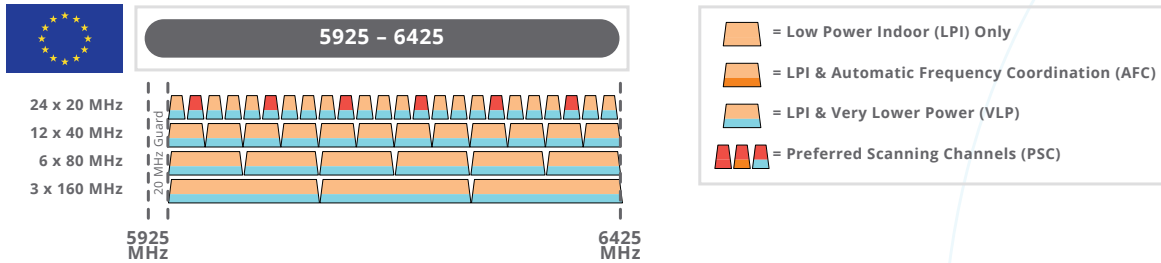


Figure 4. EU channel distribution for the lower half of the 6 GHz band

The European regulators’ rules are not the same as for the US. They have taken a more cautious approach, allowing operation in just the lower 500 MHz of the band (480 MHz after the 20 MHz guard band), equivalent to U-NII-5 in the US. This is primarily due to caution over spectrum-sharing approaches like the FCC’s Automated Frequency Coordination (AFC. See below.) which is necessary to protect incumbents from interference from 6 GHz unlicensed transmitters.

A consequence of this caution is that European countries will restrict 6 GHz operation to indoor WLANs for the near-term. Decisions on extending into the upper part of the 6 GHz band and allowing outdoor and higher-power operation have been deferred, for now.

Many other countries worldwide are in the process of adopting the 6 GHz band for unlicensed use; most of them are expected to follow either the US or European approaches, with minor deviations possible for national regulation.

Incumbents

While the 6 GHz band is continuous and channelized across the entire 1200 MHz, existing users are active in all sub-bands. To allow new equipment into the bands without disrupting the operation of incumbents, spectrum-sharing models are required; new users can be allowed to transmit only when they will not cause interference to incumbents.

However, there is no requirement in the 6 GHz band for special in-band sensing of incumbent transmissions, similar to the Dynamic Frequency Selection (DFS) mechanism used in parts of the 5 GHz band for radar avoidance. Instead, the 6 GHz band uses two spectrum-sharing techniques. Where it is possible to identify incumbent users in the vicinity of an unlicensed transmitter, its power and frequency options are circumscribed to stay clear of the incumbent. Alternatively, where specific knowledge of nearby incumbents is unavailable, power levels must be kept low enough to ensure they will never cause interference, even in the worst case.

For U-NII-5 running from 5.925 to 6.425 GHz and U-NII-7 from 6.525 to 6.875 MHz, the most important incumbents are point-to-point, licensed radio links used by service providers and private communications for utility companies and others. These links are licensed by the FCC and included in a database known as the Universal Licensing System (ULS). As they are point-to-point, they have narrow-beam antennas, often on tall masts, and can reach for tens of kilometers. The ULS database contains tens of thousands of these links, along with their location (transmitter and receiver, giving direction), frequency, and other characteristics. The FCC allows two spectrum sharing models for these sub-bands. At a low power threshold, and indoors only, unlicensed radios can transmit anywhere. Meanwhile, outdoor locations and higher-power transmitters are allowed where a calculation based on the ULS database shows they will not interfere with incumbents.



The spectrum sharing protocol for high-powered or outdoor unlicensed transmitters requires them to contact a central AFC server, which uses their location and transmit power to calculate whether any of the licensed incumbents in the ULS database might be affected and identifies safe power and frequency parameters.

In other sub-bands, U-NII-6 and U-NII-8, the incumbents are more difficult to coordinate, as they include mobile transmitters, and also temporary links used by local TV stations for outside broadcasts. These bands are less suited for spectrum sharing because the usage patterns are more dynamic, so outdoor, high-power transmitters are not allowed.

The protection of incumbents, and differing views of how to deal with it, shapes national regulators' approach to opening the 6 GHz band to unlicensed transmitters. Some national regulators are following the FCC approach and introducing spectrum-sharing mechanisms to ensure new unlicensed services can use this spectrum without causing interference, while others are shelving the question for now by addressing only the lower part of the 6 GHz band, without more complex spectrum sharing arrangements like the FCC's AFC.

Equipment Classes for 6 GHz Unlicensed Operation

The FCC wants to allow 6E networks to have the best possible performance while ensuring that licensed incumbents are not adversely affected. It achieves this goal by defining four separate operating classes for Wi-Fi 6E equipment: Low Power Indoor, Standard Power, Client Devices, and Very Low Power.

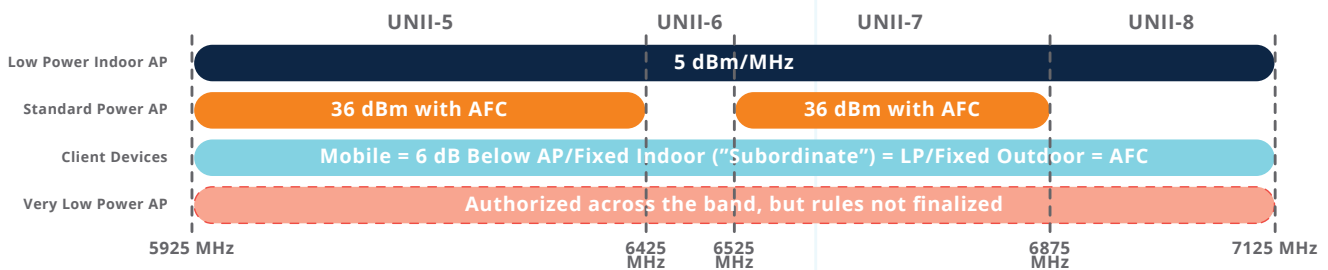


Figure 5. Equipment Classes for 6 GHz

Low Power Indoor

The most common class for Wi-Fi 6E access points (APs) will be Low Power Indoor (LPI). These will be the familiar home or enterprise APs. By definition, these APs are shielded by buildings to some extent so the power that leaks outside will be attenuated, which allows safe operation across the band at a power level similar to today's indoor Wi-Fi APs.

LOW POWER INDOOR (LPI) AP

- Fixed indoor only
- EIRP 5 dBm/MHz
- No antenna connectors
- No weatherproofing
- Wired power

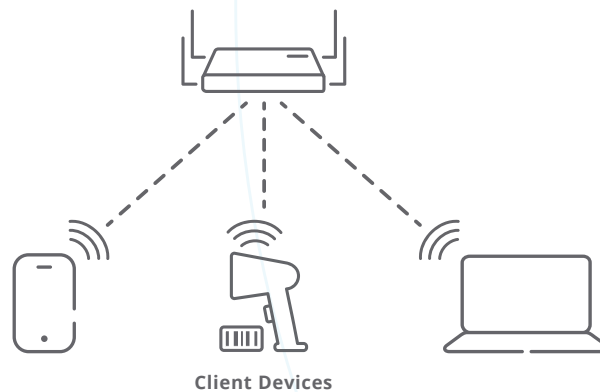


Figure 6. Lower Power Indoor (LPI) AP characteristics



The actual power level (EIRP) for LPI APs is not defined in absolute dBm, as for the lower bands, but at 5 dBm/MHz, adding 3 dB for every doubling of channel bandwidth, which gives 18 dBm EIRP for a 20 MHz channel, and up to 27 dBm for a 160 MHz channel. The FCC can apply this rule because incumbent links are generally narrow band compared to Wi-Fi channels. It is advantageous to the Wi-Fi network because background noise increases proportionally with bandwidth, so the SNR for a Wi-Fi receiver will be constant for different channel widths, given maximum transmit power levels.

LPI APs can operate across the whole band, as their transmit power is considered safe for all incumbents after building exit loss is subtracted. To ensure that these indoor-only units are not used outdoors, or with external high-gain antennas (which has the potential to cause interference), the FCC provides a list of physical requirements for certifying an LPI AP:

- No connectors for external antennas
- No battery-powered operation
- Not weatherized

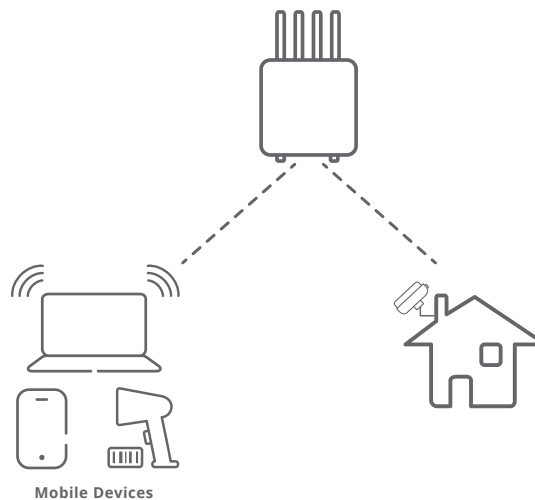
The current European regulators' rules allow only LPI APs; outdoor mounting is not allowed and transmit power (EIRP) is limited to 23 dBm. (Some countries may deviate from this value, but only by one or two dBm.)

Standard Power

APs mounted outdoors, or indoors operating at higher power than LPI, are subject to 'Standard Power' (SP) rules. This is because they may interfere with incumbents and, because they would not otherwise be aware of the risk of interference, they must check periodically with the AFC for channel availability.

STANDARD POWER (SP) AP

- Fixed indoor/outdoor
- EIRP 36 dBm max
- Controlled by AFC database
- Automated geolocation
- Pointing angle restriction



Fixed Outdoor Devices

- Same rules as SP AP, PLUS:
- Attached to structure

Figure 7. Standard Power (SP) AP characteristics

The AFC query protocol is defined by the Wi-Fi Alliance and consists of an inquiry message from the AP and a response from the AFC server. The most important information in the inquiry is the AP's geolocation. There is no list of approved methods for this; it is assumed that GPS or some other robust, hard to circumvent method is used. In exchange for its latitude, longitude, antenna height (above ground level) and some other information in an inquiry message, the AP receives a response containing the set of channels or frequency ranges and the maximum power levels that will not cause interference (more on AFCs later).

The transmit power of a Standard Power AP can be as high as 36 dBm EIRP. Because of the increased risk of interference, Standard Power APs are only allowed in the U-NII-5 and U-NII-7 bands for 41 20 MHz channels; 20 at 40 MHz; 9 at 80 MHz or 4 at 160 MHz.

There is not yet an equivalent to the Standard Power AP in European regulations.



Client Devices

As with the lower sub-bands, client devices are expected to be limited in geography by APs. If there is no AP signal, devices cannot connect and will not transmit. Therefore, it is assumed that the AP is transmitting in an authorized manner, and the client can adjust its transmit power and channel with reference to the AP.

MOBILE CLIENT

- Indoor/outdoor
- 6 dBm lower power than the connected access point



Client Devices

Figure 8. Client device characteristics for indoor/outdoor

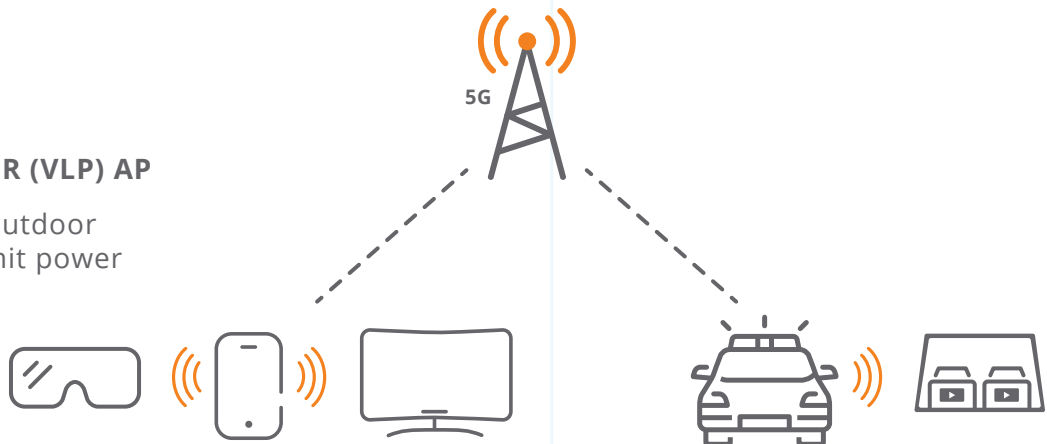
Across the whole band, fixed devices that are clients of LPI or SP APs can transmit up to the level of the AP, while mobile clients must stay 6 dB below that level. For example, an LPI AP at 80 MHz could transmit at 24 dBm EIRP, with its mobile clients up to 18 dBm. But if the AP were to transmit at 20 dBm, its mobile clients would be limited to 14 dBm. The AP advertises its current power to allow the client to adjust.

Very Low Power

The Very Low Power (VLP) category will allow for wearable or mobile APs, like hotspots on cellphones, at a low enough power level that they will not cause interference.

VERY LOW POWER (VLP) AP

- Mobile indoor/outdoor
- ~14 dBm transmit power



VLP Examples

Figure 9. Very Low Power (VLP) AP class type characteristics

The FCC is still deliberating on the exact power level allowed for VLP devices, but they will be able to operate across the whole band without AFC control, indoor and outdoor. This allows mobile APs, mounted in vehicles or hotspots on smartphones, to operate across the 6 GHz band.



WI-FI FEATURES FOR 6 GHZ EQUIPMENT

One attractive feature of the 6 GHz band is that there are no older Wi-Fi devices that need to be accommodated. Wi-Fi has done a remarkable job with backwards-compatibility over the years, but these efforts come at a cost of carrying legacy protocols and reduce bandwidth efficiency. The initial Wi-Fi 6E release sets a high bar with the new baseline of Wi-Fi 6 (802.11ax).

Equipment for the band must use Wi-Fi 6 standards, must conform to WPA3 security, and cannot offer older security options like WPA2 and Open modes. For WPA3-Enterprise, the differences are slight and exclude some combinations of WPA2-Enterprise security protocols that could expose vulnerabilities, but these combinations were never configurable on most enterprise class APs. The pre-shared key options for WPA2 are significantly changed and improved with WPA3-Personal, and a new 'Enhanced Open' standard replaces Open mode to ensure that over-the-air transmissions are encrypted even without authentication of the client device or the network. These mandates are in line with the Wi-Fi 6 standard, without allowance for backwards-compatibility for older client devices.

The Wi-Fi Alliance has introduced a limited number of new features in Wi-Fi 6E, many previously optional features are now mandatory, with two goals:

- Improved airtime efficiency. In crowded areas, much of the available airtime is taken up with AP discovery frames

such as beacons, probe requests, and probe responses. This detracts from airtime efficiency, so several features allow client devices to discover target APs and channels with fewer frames on the air.

- Faster AP discovery. Although the large number of new channels is a significant advance, it would take a long time for a client device to step through each channel, transmitting probe requests and awaiting replies to find a suitable AP. Therefore, new features aim to improve the speed and efficiency of AP discovery.

The features are classified as 'in-band' and 'out of band', meaning the client device discovers APs on the 6 GHz channel where they transmit, or on another channel in a lower band, 2.4 GHz or 5 GHz.

IN-BAND AP DISCOVERY FEATURES

The traditional way for a client device to discover a suitable AP for connection is to tune its radio to a 20 MHz channel, transmit a number of probe requests, wait on-channel for ~20 msec for probe responses from APs operating on that channel, then tune to the next channel and repeat. This takes time, may result in jitter or data loss as the device is away from its serving AP, and reduces battery life through extra frame transmissions. In addition, the probe requests and responses on the air reduce throughput for other user traffic.

TABLE 1. IN-BAND DISCOVERY FEATURES

Technique	Airtime Efficiency	Faster AP Discovery	Notes
Preferred Scanning Channels		Y	1 in 4 20 MHz channel designated for beacons and discovery
Beacon Changes	Y		Remove information elements for older generations: add some parameters to Wi-Fi 6 operations and configuration information elements
Multi-BSSID Beacon	Y		For multiple virtual APs on a single radio, transmit one beacon with elements for VAP deltas, rather than multiple beacons
Rules for Probing	Y		No probing in non-PSC channels unless a beacon is received. Restricted probing in PSC channels.
Unsolicited Probe Responses		Y	Short AP announcement every 20 msec (vs 102 msec for a beacon)
FILS Announcements		Y	Short AP announcement every 20 msec (vs 102 msec for a beacon)



For some time, the industry has been working towards passive scanning where devices learn about other APs and their serving channels through Neighbor Reports. This allows the device to switch to the new channel, reducing time off-channel and frames on the air, but can require up to 102 msec off-channel waiting for the next beacon transmission. This last issue is mitigated in the Neighbor Report by a beacon offset time value, allowing efficient passive scanning, but only in cases where an AP provides comprehensive Neighbor Reports in the beacon or probe response.

As a new, greenfield band, 6 GHz offers an opportunity to mandate features that reduce acquisition time, improve battery life, and avoid excess frames on the air. Several existing and new features improve 6 GHz AP discovery in all these areas.

Preferred Scanning Channels

Every fourth 20 MHz channel is designated for scanning, and APs should align their transmitting channels with Preferred Scanning Channels (PSCs). For wider channels, the ‘primary’ 20 MHz channel where the beacon is transmitted should align with a PSC. This achieves two goals. First, it means client devices searching for a suitable AP need to scan at most 15 channels to find a beacon or other advertisement.

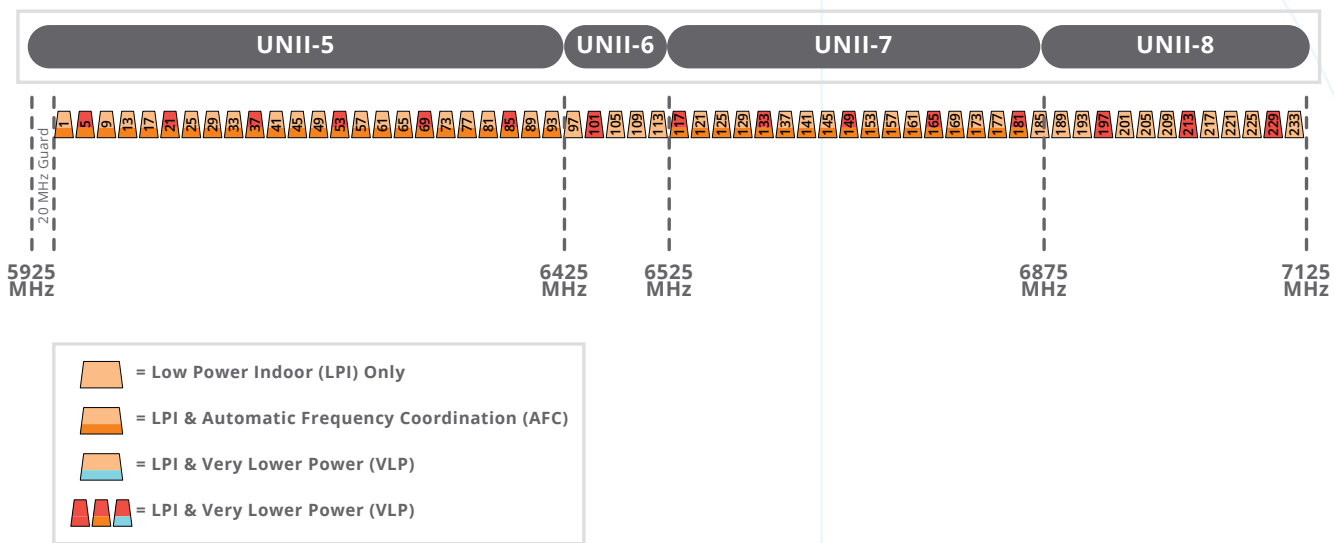


Figure 10. Preferred scanning channels

Second, it ensures that non-PSC channels are not burdened by beacons, probe requests or responses, and thus can transfer the maximum possible user data. To enforce good behavior, several rules are in place to reduce excessive probing and encourage device designers to optimize their probing algorithms.

TABLE 2. PROBE REQUEST RULES				
Type of Probe Request			Condition to Send Probe Request	Purpose
Destination Address	BSSID	SSID		
Broadcast	Wildcard	Wildcard	Not Allowed	Ban indiscriminate probe responses from all BSSs from all ESSs.
Broadcast	Wildcard	SSID	Not more than 1 per 20 ms.	Probe ESS but with reduced frequency.
Broadcast	BSSID/Non-transmitted BSSID		Not more than 3 per 20 ms.	Probe specific BSS with reduced frequency.

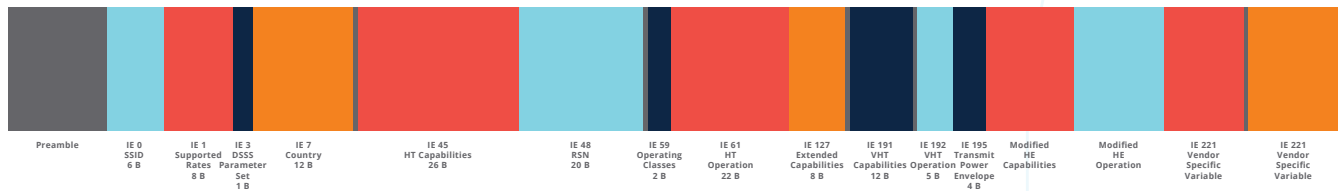


For example, a client device may not transmit (e.g. probe requests) in a non-PSC channel unless it has learned that an AP is present, through one of the mechanisms explained here. (A 'non-transmitted' BSSID is contained in the multi-BSSID beacon, which we'll explain later.) Even in PSC channels, wildcard probe requests are restricted, and the rate at which probes can be sent is limited.

Beacon Changes

The beacon itself can be shortened in time and complexity because there are no existing Wi-Fi devices operating in the 6 GHz band. 6 GHz takes advantage of opportunities for housecleaning, forgoing transmissions that would only be of interest to older equipment. An example is the backwards-compatibility in the form of 'capabilities' and 'operation' information elements. Because, for example, a Wi-Fi 4 device is not programmed to understand Wi-Fi 5 parameters, beacons in the 5 GHz band must include the older Information Elements (IEs) in addition to newer ones added for subsequent generations.

Wi-Fi 6 (802.11ax HE) beacon in 5 GHz showing with information elements (example)



Wi-Fi 6 (802.11ax HE) beacon in 6 GHz showing information elements (example)

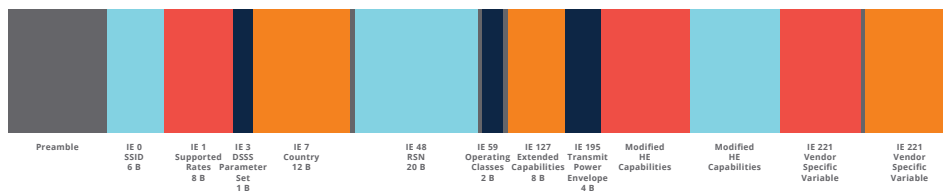


Figure 11. Beacons in 6 GHz

The greenfield nature of 6 GHz allows these older elements to be dropped, saving time on the air and improving bandwidth efficiency. The example above shows that the HT and VHT operations and capabilities IEs are removed, and those values that are not superseded are added to the equivalent HE (Wi-Fi 6) IEs.

TABLE 3. IEEE STANDARDS AND NAMING CONVENTIONS			
IEEE Amendment		IEEE Name	Wi-Fi Alliance Name
802.11a, g	Non-HT	Non-High Throughput	None
802.11n	HT	High Throughput	Wi-Fi 4
802.11ac	VHT	Very High Throughput	Wi-Fi 5
802.11ax	HE	High Efficiency	Wi-Fi 6
802.11ax in 6 GHz	HE	High Efficiency	Wi-Fi 6E
802.11be (Future)	EHT	Very High Efficiency	Wi-Fi 7?

The 'operations' IEs are announcements from the AP about the channel it is transmitting on and are part of the beacon, probe response, association response, and re-association response frames.



The ‘capabilities’ IEs list the options that APs and devices can use, and are transmitted in the information elements listed above and also the equivalent requests from client devices. Other modifications to the beacon include the rate at which the elements are transmitted: no pre-Wi-Fi 6 rates are allowed, forcing higher rates, shorter durations, and better bandwidth efficiency.

Multiple BSSIDs in One Beacon

This feature was introduced some time ago in 802.11v but was optional and has not been implemented in client devices or APs. For 6 GHz, it is mandatory for client devices to be able to support the multiple BSSID feature.

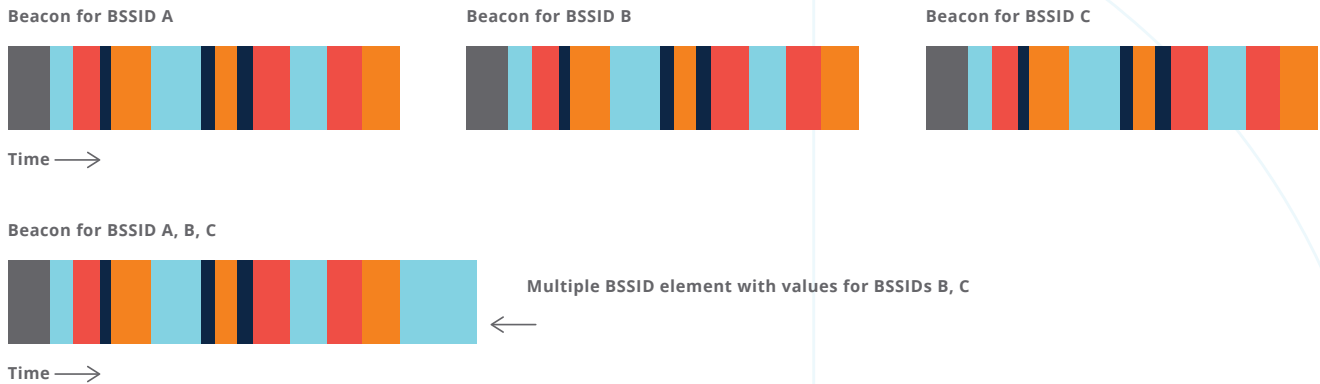


Figure 12. Multiple BSSIDs in one beacon

Where many SSID/BSSIDs are advertised on the same radio, as is commonplace in residential and enterprise WLANs, previously, each BSSID or virtual AP had to transmit its beacon separately. If an enterprise wanted to transmit four SSIDs, four separate beacons were transmitted in each 102.4 msec beacon interval, and many IEs were duplicated across beacons. With the multiple BSSID feature, the common elements are transmitted once, and a separate information element is appended with the values unique to each virtual AP, now termed a ‘non-transmitted’ BSSID. The new beacon is considerably shorter, improving WLAN bandwidth efficiency. However, this method may not be universally applied. For example, a limit on the beacon size may restrict the number of multiple BSSIDs to a maximum of 4, so when more than 5 SSIDs are used, multiple beacons may still be necessary to support the multiple BSSID feature.

Unsolicited Probe Responses

Unsolicited probe responses act as mini beacons. While the usual beacon interval is 102.4 msec, unsolicited probe responses can be transmitted every 20 msec, allowing a client device to decide whether the AP is suitable for a connection through passive scanning rather than active probing, and also to discover neighbor APs through the reduced neighbor report. The unsolicited probe response is a significant advance because a client, rather than tuning to a channel and transmitting some probe requests and waiting ~20 msec for responses, can listen passively for just 20 msec and be sure that it has heard all BSSIDs on that channel. Unsolicited probe responses can contain the same information elements as a ‘normal’ probe response, but they are transmitted to the broadcast address. Because they are transmitted by the AP without a frame exchange, there is very little contention loss to get this information to a client device.



FILS Announcements

Fast Initial Link Setup (FILS) is a complete protocol for AP discovery, authentication, and handover that was introduced in 802.11ai and the Wi-Fi Alliance Optimized Connectivity certification. It was aimed particularly at public networks but has not yet been widely adopted. FILS announcements act as mini beacons, transmitted every 20 msec. Each announcement frame contains the information necessary for a client device to decide whether the AP is suitable for connection.

FILS Discovery Information Field



Order	Information	Notes
1	Category	None
2	Public Action	Action Frame
3	FILS Discovery Information Field	See Below
4	Reduced Neighbor Report Element	Optional – Identifies Neighbor BSSIDs
5	FILS Indication Element	Optional
6	Roaming Consortium Element	From Passpoint, Indicates Authentication Options

Figure 13. FILS announcements

FILS announcements can also incorporate reduced neighbor reports to advertise the channels of other APs of the same network. The ‘short SSID’ can optionally be substituted for the SSID in the FILS announcement. This value is a hash of the full SSID.

FILS announcements and unsolicited probe responses serve the same purpose, and only one would normally be required. At the time of writing, it seems FILS announcements will be the default advertisement for 6 GHz channels.

‘OUT-OF-BAND’ AP DISCOVERY

The techniques above allow a client to scan the 6 GHz band to discover APs there. But most 6 GHz APs will be multi-band, where their other radios can be coordinated, so a client associated to a 5 GHz AP can learn about a 6 GHz AP on the same physical unit without tuning its radio to 6 GHz.

TABLE 4. OUT-OF-BAND DISCOVERY			
Technique	Airtime Efficiency	Faster AP Discovery	Notes
Reduced Neighbor Report	Y	Y	Included in beacons and probe responses, identifies neighbor BSSIDs normally with same SSID, in same or other bands
ANQP Access Network Query Protocol	Y	Y	Pre-association frame exchange that allows an access point to provide information on neighbor BSSIDs



Reduced Neighbor Report

The Reduced Neighbor Report (RNR) was developed for use with the FILS discovery protocol, but its use is expanded for 6 GHz operation. When associated at 5 GHz, the client can request a RNR and discover the channels where 6 GHz neighbor APs in the same physical unit or separate units are transmitting. This allows them to move directly to the target 6 GHz channel.

Reduced Neighbor Report Element Format

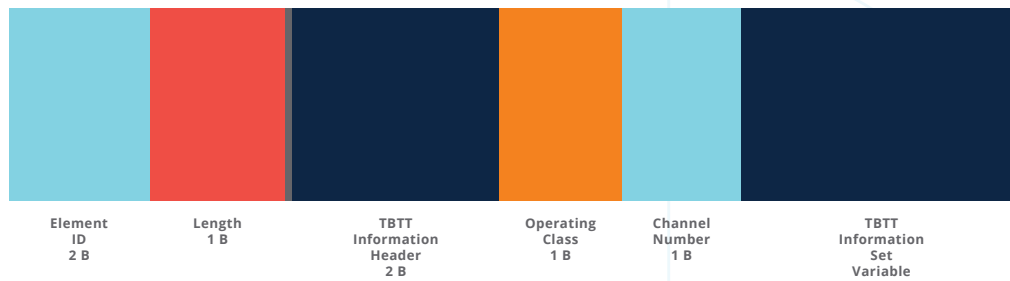


Figure 14. Reduced neighbor report

The reduced neighbor report IE is included in the beacon and probe response frames of the lower-band BSSID. The report includes fields for each neighbor BSS, transmitting the same SSID in the 6 GHz band, along with its channel and beacon offset.

The operating class and channel number refer to tables in IEEE 802.11 listing all possible channel widths and center frequencies. For 6 GHz, this guides the client device to the correct channel out of the 59 possible at 20 MHz, 29 at 40 MHz, etc. With this information, the client device interacting with a 2.4 or 5 GHz BSSID can go directly to the channel in the 6 GHz band where it will find an equivalent SSID/BSSID.

The Target Beacon Transmission Time (TBTT) information in the reduced neighbor report refers to the beacon offset in time. The TBTT is measured in Time Units of 1.024 msec, and allows the client device to schedule an accurate time to go off-channel from the current AP and passively scan the beacon of the 6 GHz BSSID, subsequently authenticating if desired.

The full neighbor report could be used in place of the RNR, as it contains a superset of the RNR information, but the standard promotes the latter because it is shorter and more efficient.

Access Network Query Protocol

Access Network Query Protocol (ANQP) is a pre-association exchange protocol initially added for Passpoint operation. It allows a client device to query an AP about capabilities such as Passpoint, information about the venue, and identity providers that can be reached for authentication. When used for 6 GHz WLANs, it is used to convey a full neighbor report for 6 GHz BSSIDs that may be in the same WLAN, whether using the same SSID or different SSIDs. Transmitting the neighbor report element over ANQP rather than directly in the beacon or probe responses is more efficient, as air time is not consumed unless the client device requests the Neighbor Report.

In a multi-band network, BSSIDs in the lower bands would advertise ANQP capability, and multi-band client devices would request neighbor reports via ANQP, allowing them to discover full SSID, BSSID, channel and beacon offset information without leaving the lower band to receive or transmit in the 6 GHz band.

DESIGNING AN ENTERPRISE WLAN WITH WI-FI 6E

All network designers face practical constraints on their planning, so a discussion of how to introduce Wi-Fi 6E into a network will depend on 'facts on the ground' like cabling and existing edge switches, as well as budget limits and other factors.



New Building Cable Plant

For those with a brand-new building or area to outfit, it is possible to offer some guidelines what on the ‘ideal’ Wi-Fi 6E network might look like. AP spacing for offices and densely populated areas has been contracting in recent years. The guidelines of around 3500 sq ft (325 sq meters) at the time of Wi-Fi 4 (802.11n) moved to around 2400 sq ft (220 sq meters) by the Wi-Fi 5 era, and now many enterprise WLAN customers are designing networks for new buildings with APs covering 1500 - 2000 sq ft (140 - 190 sq meters).

Customers and professional services firms have been driven by the realization that optimal performance results from every client being near an AP, with AP power and channel plans controlled automatically and, for power, well below the maximum of an AP’s capability. In many cases, it’s easier to overpopulate APs and have the software take care of reducing power than to rigorously survey an area and install minimum APs. So, for a brand new building, it is best to pull at least 2 Ethernet cables to locations with linear spacing of around 40 – 50 ft. It is so expensive to pull cable that the plant lifetime needs to span several new generations of APs after Wi-Fi 6E. Of course, there continue to be special situations where metal, concrete, or masonry building materials provide motivation for full radio frequency site surveys, and the 6 GHz band is no different in this regard.

As the traffic generated per AP continues to grow, and installation-labor costs comprise the bulk of cable plant costs, it often makes sense to install a high-spec cable, which today would be Cat 6 or 6A. While Cat 5e can support 802.3bz Smart Rate Ethernet at 2.5 Gbps and 5 Gbps, it has severe range restrictions at higher rates and will not be sufficient for 10GBaseT rates in the future.

Regarding edge switch equipment connecting to APs, the state of the art would be Smart Rate (2.4 and 5 Gbps) gigabit Ethernet ports with PoE++ (802.3bt type 3, up to

60W per port) power. Two ports per AP may be necessary if redundancy or power considerations dictate (i.e. a single switch port cannot supply the power needs of an AP).

Existing Building Upgrades

For the majority of Wi-Fi 6E network upgrades, cabling termination points are a fact on the ground, so the most likely location for a new AP is the same as the old one. Partial network upgrades, due to budget or other constraints, may present a question of which areas to prioritize. Because the performance improvements of Wi-Fi 6E will initially accrue to newer client devices, late-model laptop computers, and smartphones, it makes sense to identify where people with those devices (mobile-nomadic users) will pause to work, and require either large volumes of traffic (laptop file upload/downloads) or low-latency interactions (smartphone app and web interaction).

It will often be best to upgrade areas of the network rather than isolated APs. One reason is that an isolated Wi-Fi 6E AP surrounded by older APs may not benefit from all the out-of-band discovery methods tied to Wi-Fi 6E, although that is a software choice of the AP supplier. While it is possible to replace every 4th AP, for example, with a 6E tri-band model, providing an overlay of 6 GHz coverage over a wider area, this will not result in the best performance because of distance and propagation losses and is likely to be expensive in labor costs. Nevertheless, this model may be the best option for networks with specific requirements or circumstances.

Edge Switch Backhaul Considerations: Bit-rate

Enterprise-class Wi-Fi 6E APs are expected to include 2 Ethernet ports and able to fall back to a single link for redundancy. These Ethernet ports will be capable of 802.3bz (Smart Rate) operation at 1, 2.5 and perhaps 5 Gbps.

TABLE 5. THROUGHPUT PER CHANNEL AND AGGREGATE THROUGHPUT OF WI-FI 6E APs

Peak Throughput, Gbps	2x2 AP	4x4 AP
160 MHz channel @ 6 GHz	2.4	4.8
80 MHz channel @ 5 GHz	1.2	2.4
20 MHz channel @ 2.4 GHz	0.29	0.57
Total	3.9 Gbps	7.8 Gbps



All the way back to the introduction of Wi-Fi 5, it has been theoretically possible for a single AP to generate more than 1 Gbps of traffic from the wireless side. This would make a 1 Gbps Ethernet backhaul link the bottleneck under certain conditions, but as many have pointed out, these conditions were quite unlikely for most practical use cases. However, Wi-Fi 6E APs will have three radios, rather than 2 previously, and credible maximum traffic levels will exceed 2 Gbps. This makes it more likely that the Ethernet backhaul will become the bottleneck, and network managers should consider this when embarking on edge switch upgrade projects. For many networks, a study of AP backhaul rates and edge switching capabilities is warranted when planning a Wi-Fi 6E upgrade project.

Edge Switch Backhaul Considerations: Power

New enterprise-class Wi-Fi 6E APs will include 3 radios, increasing power requirements. Depending on the other features of the AP (primarily the number of antennas), the power demand for full operation will be right at the limit of PoE+ (802.3at class 4, nominally 25.5W), or into PoE++ (802.3bt class 5, 51W if all 4 pairs are used for power).

TABLE 6. POE CONSIDERATIONS BY TYPE AND CLASS

Standard	Type and Class of PoE							
802.11bt							Type 4	Type 4
802.11bt	Type 3	Type 3	Type 3	Type 3	Type 3	Type 3		
802.11at	Type 2	Type 2	Type 2	Type 2				
802.11af	Type 1	Type 1	Type 1					
Class	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
Wiring	2-pair	2-pair	2- or 4-pair	2- or 4-pair	4-pair	4-pair	4-pair	4-pair
Nominal Power at Switch	4W	7W	15.4W	30W	45W	60W	75W	90W
Max Power at Device	3.8W	6.4W	13W	25.5W	40W	51W	62W	71.3W

As has been the case for recent technology generations, Wi-Fi 6E APs that sense insufficient power availability will gracefully disable features in order to continue operation. Therefore, while PoE++ will be necessary for full operation, the marginal performance limitations may be insufficient to drive edge switch upgrades for power alone.

Propagation Loss and Transmit Power

Propagation losses in the 6 GHz band will necessarily be greater than for 5 GHz, but the difference is not significant. The path loss difference between the lowest frequency of the 5 GHz band (5.15 MHz) and the highest at 6 GHz (7.125 GHz) is 3dB, while the opposite ends of the band have no practical difference. Balanced against this, the noise floor at 6 GHz will, for some years at the least, be much lower than 5 GHz due to the scarcity of transmitters. So, the 'IN' in 'SINR' will make a lower denominator and better performance, all else being equal.

And the 'S' or numerator will be equivalent to 5 GHz APs, although arrived at from a slightly different direction. A typical 5 GHz Wi-Fi 6 AP is capped by regulation at around 27 dBm (18 dBm conducted power per chain x4 for 24 dBm, with a 3 dBi antenna gain). The equivalent figure for 6 GHz would be regulated on channel width at 27 dBm for a 160 MHz channel, or 24 dBm for 80 MHz. In any case, enterprise APs very seldom operate at full power levels.

Therefore, propagation and transmit power levels will be very similar to 5 GHz equipment, and network designers need not necessarily change their guidelines from Wi-Fi 6 to Wi-Fi 6E.



RF Plans

New enterprise APs are likely to be tri-band, with 2.4, 5 and 6 GHz radios. For densely populated areas, these may be configured for 20 MHz channels at 2.4 GHz, 40 or 80 MHz at 5 GHz and 80 or 160 MHz at 6 GHz, due to the way available spectrum scales in these bands. These figures will allow for Low Power Indoor AP WLANs, in the US, to support:

- 3x 20 MHz channels at 2.4 GHz
- 6x 80 MHz channels at 5 GHz, including DFS channels
- 7x 160 MHz channels at 6 GHz

For efficient operation, the primary 20 MHz sub-channel of a wider channel in the 6 GHz band should be aligned with a Preferred Scanning Channel (PSC) so beacons are transmitted in the PSC. Under normal conditions, WLAN software will automatically configure this.

When expanding into the new band, policy concepts may be useful in assigning or steering different traffic or devices.

One rationale for usage of the three available bands is below:

- Keep the 2.4 GHz band for those devices with only a 2.4 GHz radio, and/or for IoT devices. Older 5 GHz devices (Wi-Fi 4 or 802.11n) may fall into a 'legacy' category and be moved to this band to avoid dragging down performance of preferred clients in the 5 GHz band.
- The 6 GHz band can be used for the latest, highest-performance devices, almost by definition in the first few years of rollout. It benefits not only from the highest rates available, but also from the lack of legacy equipment and lower noise levels in the band.
- 5 GHz becomes the band for mainstream high-performance devices that are not 6 GHz capable, allowing non-preferred devices to be relegated to 2.4 GHz as above.

Adjacent Channel Allocation Across the 5 GHz and 6 GHz Bands

Most new 6 GHz enterprise APs are expected to be tri-radio, with separate radio units for the 2.4, 5, and 6 GHz bands that will operate concurrently. This brings a risk of interference between the 5 and 6 GHz radios.

If no special measures are taken, co-located radios operating in the top half of the 5 GHz band simultaneously with the lower half of the 6 GHz band will interfere with each other, as transmissions from one radio will overwhelm the receiver of the adjacent radio.

AP designers will need to add hardware or software features that mitigate this interference, whether by avoiding the worst combinations of channel allocation where feasible, or by shielding and filtering between the radios. Flexibility of channel allocation, and WLAN performance with neighboring channels, may become an area of differentiation between enterprise APs.

AUTOMATIC FREQUENCY COORDINATION

The 6 GHz bands contain incumbent users, and for high-power or outdoor operation with Standard Power APs, the FCC requires that these incumbents are protected from interference by unlicensed 6 GHz users, including Wi-Fi. Some areas of the band are not allowed, even with AFC control. The available channels are from 5945-6425 MHz and 6525-6875, the U-NII-5 and U-NII-7 bands.

Fortunately, the incumbent point-to-point fixed service users are known, as they are licensed and their details are listed in the ULS database, maintained and updated by the FCC.

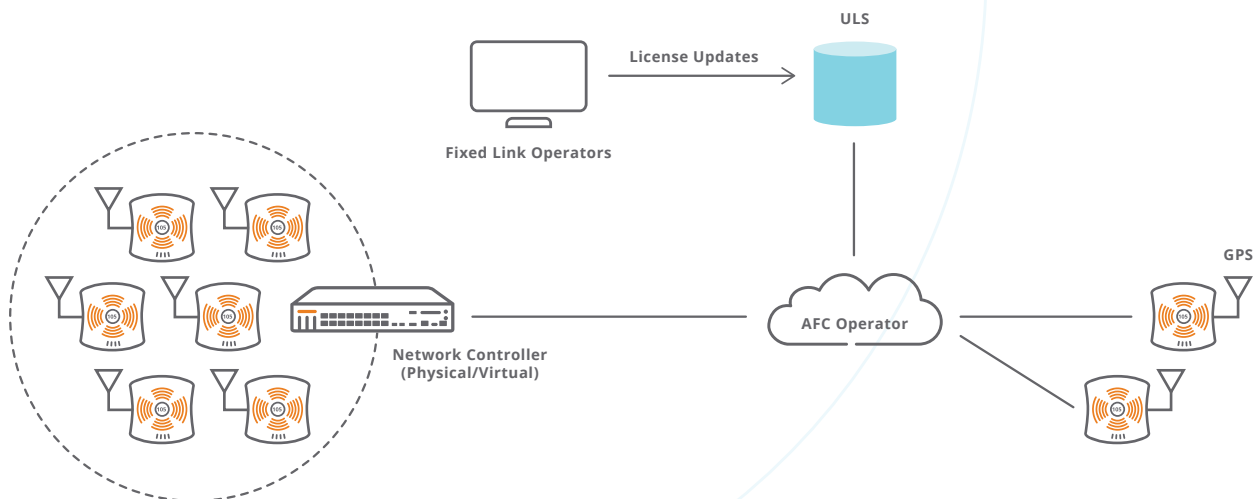


Figure 15. Automated Frequency Coordination (AFC) architecture



This general architecture centers on an AP, or group of managed APs, generating an inquiry message that includes its location, elevation above ground level, and indications of the desired transmit power levels, channels or frequencies for transmission. The AFC uses this information as input to its algorithms along with ULS data of licensed links and a terrain map of the United States. Some AFC operators may add building outlines to their terrain map to identify RF shadows. The AFC’s response to the AP inquiry will include a range of channels or frequencies that are available, and the AP, or its manager can pick from this list and transmit. The FCC will license a number of AFC service providers. APs must check with an AFC at least every 24 hours to receive fresh information.

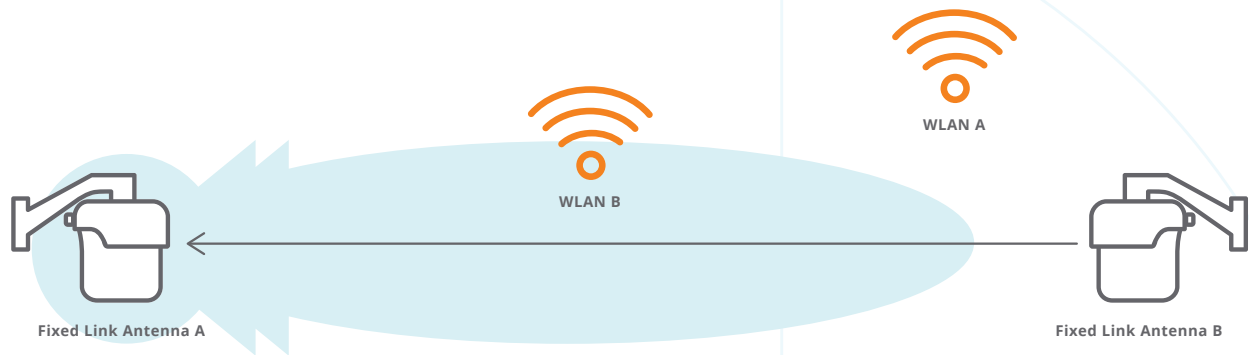


Figure 16. AFC calculations

The general concept of AFC calculations is as follows. Each licensed receiver’s location, antenna pattern, elevation above ground, and sensitivity are taken from the ULS database and used to plot contours defining zones of interference for given transmit power levels. The example above shows one contour calculated for interference to the antenna A; another plot would be generated for antenna B.

As the antennas for point-to-point links are usually very high-gain, these plots are shaped like a keyhole, with a short-distance circle around the back for sidelobe sensitivity and a long path down the antenna boresight.

The contour is significant because any Wi-Fi transmitter within the contour and above the power threshold for which the contour is calculated would cause interference at the fixed link’s receive antenna and should not be allowed at that location, frequency, and transmit level.

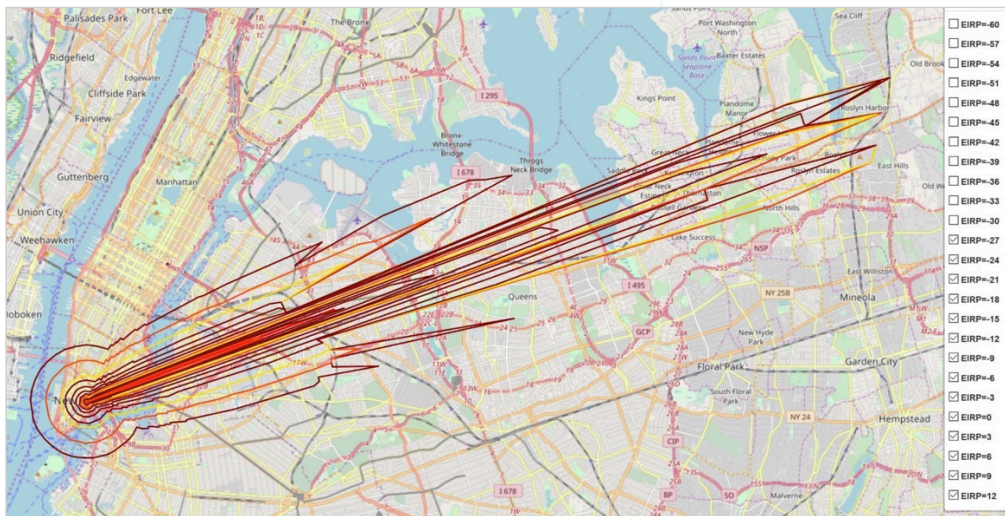


Figure 17. Contours for AFC calculation



Many plots or contours must be calculated and plotted depending on the power of the interfering signal, and terrain is taken into account to determine line-of-sight conditions or whether high ground obscures the path. AFCs may pre-calculate the contours to reduce response delays. The diagram above shows a set of contours from an AFC, calculated for different power levels for a single fixed link receiver.

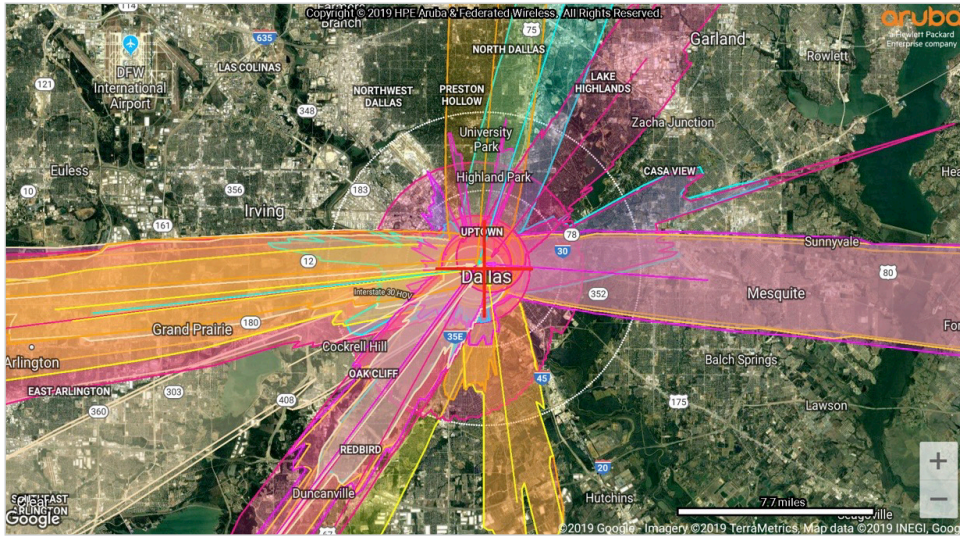


Figure 18. Terminations for fixed links: tall buildings and towers

As the diagram above shows, some tall buildings and towers are good sites for terminating many fixed links. The AFC must determine which links might be impacted from a given location. To complete the calculation, these contours are tested against the location, height, and transmit power level of the AP. An uncertainty estimate for location also allows for a multi-AP deployment, perhaps for a whole floor of a building if covered by a managed WLAN. A WLAN contour is drawn for the area where the AP(s) may transmit, and if the WLAN contour crosses an equivalent incumbent interference contour, the AP should not transmit at that frequency and power level.

In the example above, WLAN B's contour intersects with antenna A's receiver and may cause interference. Therefore, the AP will need to reduce power or find a different channel away from the fixed link's operating frequency. If the WLAN contour is not crossed by any interference contours (WLAN A in the example), the AP can transmit without causing interference and the AFC will indicate this.

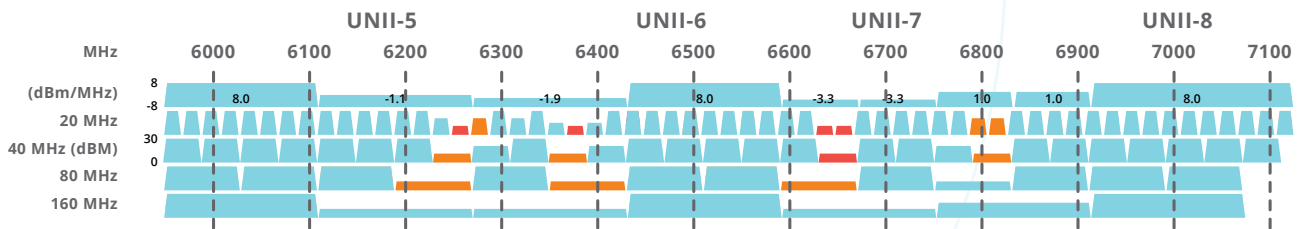


Figure 19. AFC client application display of available channels and ranges



The response from an AFC to an AP inquiry message may be either a list of available channels, or available frequency ranges, along with the maximum power levels available, or both. The graphical example above shows how such information might be displayed on an AFC client app. The top row is a frequency range response, giving power spectral density limits for the various ranges. The lower levels show channel availability by transmit power level (coloring is not part of the AFC response). It is clear that there are fixed links near the location, and that these effectively exclude a number of channels. The AP would choose only those channels allowing viable operation.

As AFC operation is not permitted in the U-NII-6 and U-NII-8 bands, the results shown in the diagram for those frequencies are invalid.

Note that the AFC does not grant a particular frequency to the AP; it just indicates those channels, frequencies, and power levels that will not cause interference. There is no attempt to allocate specific channels or coordinate different channels for neighboring APs or WLANs from the AFC itself.

NEXT STEPS

Organizations considering Wi-Fi 6E to meet greater demand for Wi-Fi should begin with a pilot to better understand the implications in their environments. Network designers will need to evaluate how to introduce Wi-Fi 6E into a network depending on their cabling and existing edge switches. The 6 GHz band presents a gift of unlicensed Wi-Fi spectrum that organizations will need to determine how best to take advantage of to provide more capacity, wider channels for low-latency, high bandwidth applications, and less interference.

Learn more about Aruba's Wi-Fi 6E solution and how to get started at arubanetworks.com/wifi6e.