# Why Location is Now a Thing in Wi-Fi:

## Operational Considerations for Standard Power 6 GHz Wi-Fi

A Technical Paper prepared for SCTE by

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# 1. Introduction

The 6 GHz band has historically been licensed for point-to-point microwave communications as well as limited radio astronomy sites. In 2020, the Federal Communications Commission (FCC or "the Commission") enabled unlicensed use of the band allowing transmissions by Low Power Indoor-only (LPI) devices and indoor/outdoor Standard Power (SP) devices. Standard Power devices were given access to two portions of the band – 500 MHz in the Unlicensed National Information Infrastructure band Five (U-NII-5) and 350 MHz in the U-NII-7 band. Since licensed devices continue to operate in the band, the FCC requires that SP devices must operate under the control of an Automated Frequency Coordination (AFC) system to minimize interference with incumbents.

Given the relentless proliferation of Wi-Fi enabled devices as well as the steadily increasing demands on both Wi-Fi bandwidth and quality of service, access to this new spectrum is not only welcome but has the potential to be game changing. However, unlocking this new Wi-Fi resource places new requirements on providers of Wi-Fi services. This document provides details regarding the process of utilizing an AFC such that the benefits of Standard Power operations can be unlocked for US consumers. In addition, it provides guidance for how best to handle new requirements placed on the communications service provider. In particular, this paper addresses how to accurately determine the geolocation of installed SP devices and efficiently deliver this information to an AFC.

# 2. Performance of Standard Power Wi-Fi

As a starting point, it is important to reiterate the performance delivered by Standard Power over vs LPI within in the context of a typical single-family residence Wi-Fi deployment. Offering SP does add cost and new deployment requirements so these must be justified.

## 2.1. Single-family Dwelling

To demonstrate the substantial benefits of SP operation, a prior study was conducted in a typical, single-family dwelling.[1] An available 6E-compliant smartphone was tested against a multi-band 4x4 AP to evaluate rate/reach throughout the Wi-Fi house. In this study, the wireless router was placed in the central living room on the main floor. The mobile smartphone client with 2x2 antenna configuration was then moved room-to-room to measure data exchange rates and paint a coverage map for the house. The study was first undertaken with a low power indoor (LPI) effective isotropic radiating power (EIRP) spec access point (5 dBm/MHz power spectral density (PSD)) and the repeated with a Standard Power (SP) access point permitting up to 36dBm EIRP (23 dBm/MHz PSD). Per housing floor, the TCP bitrates were tabulated, and heat maps created. The results for the main floor for both LPI and SP are shown be :

[1] *Why 6 GHz Standard Power Wi-Fi is the Game Changer for Residential Use in the US*: Flesch, 2021

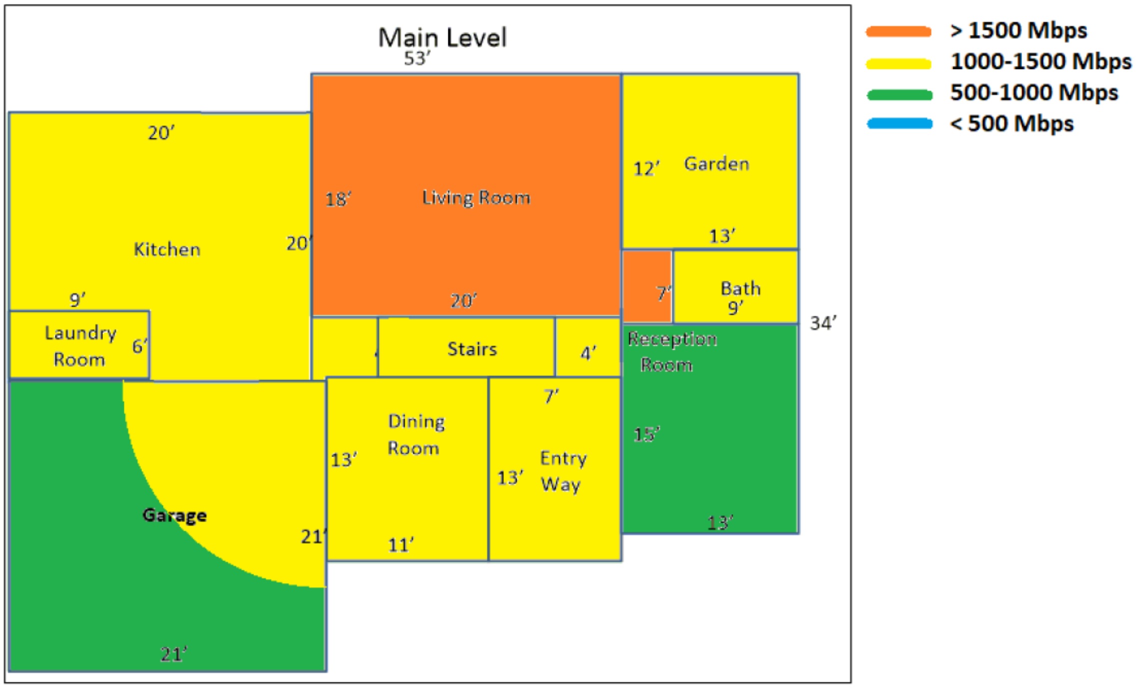


**Figure 1 – Main Level Home Service Coverage with LPI AP**

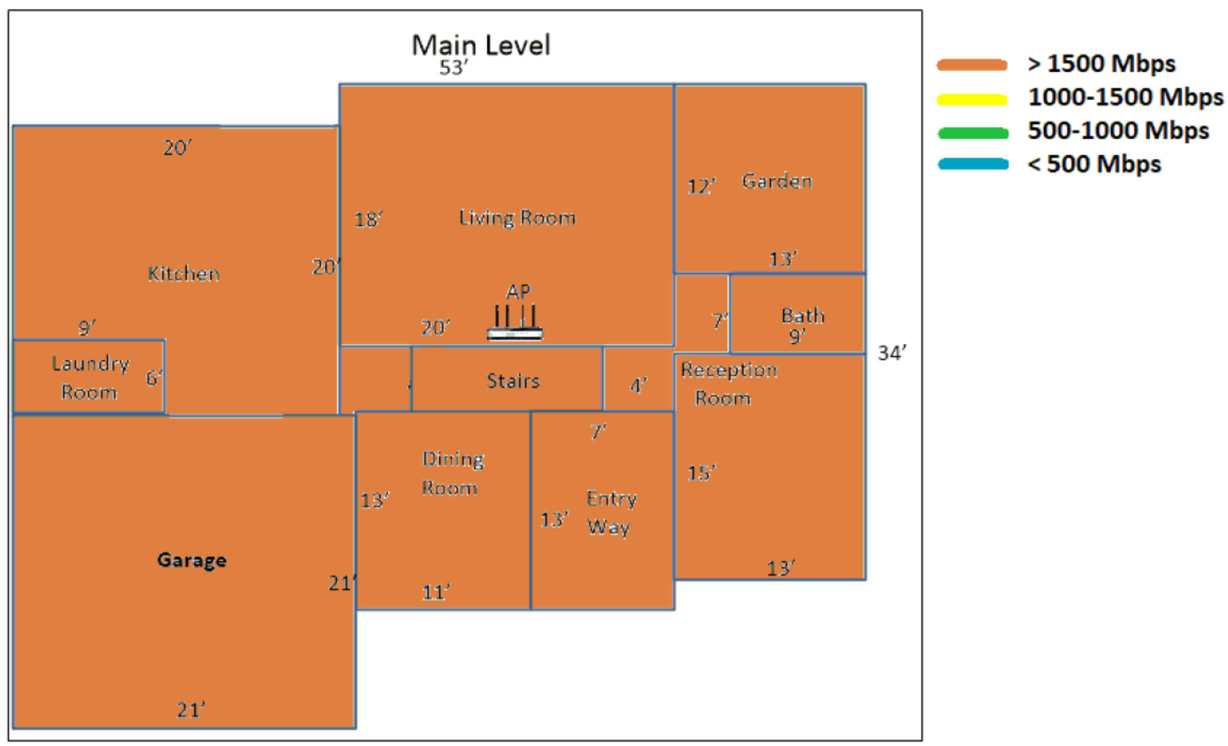


**Figure 2 – Main Level Home Service Coverage with SP AP**

As shown in the above figures, increasing to the higher output power (EIRP) of a single, centrally located AP significantly increased the downlink bit rate to clients. As such, when operating in standard power, a single AP can provide more than 1 Gbps everywhere, even in a larger home regardless of placement. This potentially reduces per home deployment costs by eliminating the need for multiple extender APs and allowing for a single installation point effectively anywhere within the home. In addition to increased raw bandwidth, standard power, 6 GHz client connections offer improved latency vs. what is possible in the lower Wi-Fi bands such as 5GHz. Leveraging standard power, "it should be possible to link large client populations throughout a spacious multi-story floorplan and still meet < 2 msec latency for all client links."[2]

When needed for very large or challenging home footprints, another important benefit of providing standard power indoors is to utilize that power to support wireless backhaul links to additional Wi-Fi Access Points (Aps). It should be noted that client devices operating in the 6 GHz band are required by FCC regulations to reduce their EIRP from that of the AP to which they are connected. This reduction is not insignificant (6dB) and must be applied regardless of whether the AP is operating using LPI or SP. The result is that coverage for a particular client in a home will be dictated more by the ability of a given AP to receive client transmissions vs. its ability to project downlink coverage to the same client.

Standard power 6 GHz can provide very high-speed connections between "mesh nodes". Adding one or more extenders will significantly impact coverage for client devices. Newer 6 GHz client devices supporting Wi-Fi 7 will not only take advantage of the raw increase in MCS/link speed. They will also

[2] *Why 6 GHz Standard Power Wi-Fi is the Game Changer for Residential Use in the US*: Flesch, 2021

 

benefit from full use of the range of Quality of Experience features available in the latest Wi-Fi standard including Multiple Resource Unit(s) (MRU).

Use of standard power in a home, while requiring the cost of AFC services and possibly requiring some added costs for SP hardware, can ultimately reduce the overall cost of deployment. Given the increased backhaul radius and higher downlink transmit power, it will cost less overall and create a more robust, less complicated network.

### 2.2. Multi-Dwelling Units

Unlike single-family homes, dense, multi-dwelling units (MDUs) may not benefit substantially from SP vs LPI operation. This may be somewhat expected given the typical MDU premise size and co-location of many access points in a single building. The US average apartment footprint is less than 1000 sq ft. Given this, offering standard power in these environments is not likely to substantially improve the customer Wi-Fi experience either in terms of delivered bitrate or latency vs. LPI operation.

In addition to providing minimal subscriber benefit, operation of SP within an MDU may have adverse consequences. For example, "use of 6 GHz could very well serve as a multi-dwelling source of OBSS energy which would tend to deny potential 6 GHz spectrum to very nearby alternate users. An additional aggravation would be that were standard power masks to be sought by several co-located users, the odds would be very high that any restrictive access to 6 GHz spectrum would be a shared restriction and so tend to funnel use into identical pieces of spectrum, compounding the interference potential."[3]

The exception to this blanket view lies in managed dwelling (enterprise) applications, where a single (or some very few connected) standard power Aps are used in concert with directional antenna coverage to supply stout trunk links to interior-placed extenders (each of the latter covering a single premises at LPI). The resultant subtended meshes are arranged for spatial and frequency division which provide the necessary keep outs to avoid the accidental interference (described above) which would otherwise occur. As far as the separate users in the MDU are concerned, each has his/her own AP – but it is actually a managed extender in a larger mesh network.

## 3. Automated Frequency Coordination

All kinds of wireless networks—those used by wireless operators, fixed wireless networks, enterprises and the ever-growing Internet of Things, for example—need access to high-capacity spectrum. Dynamic spectrum management methods such as the Automated Frequency Coordination (AFC) system unlock spectrum access by allowing these new users to share spectrum with incumbent licensees. 6 GHz AFC enables unlicensed access to the 6 GHz band by coordinating shared spectrum between Standard Power Access Points (SP) and incumbent point-to-point microwave.

Having established the benefits of operating using Standard Power, it is important to explore the core components of Automated Frequency Coordination. To access and utilize SP within the 6 GHz spectrum, an SP device must establish a connection with an approved AFC system and request what spectrum is available for use in a specified geographic location. The AFC uses FCC reference data on incumbent

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[3] *Why 6 GHz Standard Power Wi-Fi is the Game Changer for Residential Use in the US*: Flesch, 2021. "Standard power masks" here referring to allowed channels (spectrum) as well as maximum output power per channel.

systems, which may be combined with proprietary data to model the environment in the specified region and provide data on available spectrum.

Core functions of the AFC include:

- Allow unlicensed devices to securely register with the AFC individually or via a proxy
- Determine the available frequencies at a given geographic location or area and communicate this to devices
- Determine the maximum permissible radiated transmission power level for devices for given frequencies
- Enforce FCC Exclusion and Protection Zones
- Ensure that incumbent users of the 6 GHz band are protected from interference consistent with the FCC rules
- Collect incumbent data from the FCC Universal Licensing System (ULS) database and process it for use by the AFC
- Support interference identification and mitigation as needed identification

The figure below depicts the general functional architecture of the AFC managed 6 GHz system.

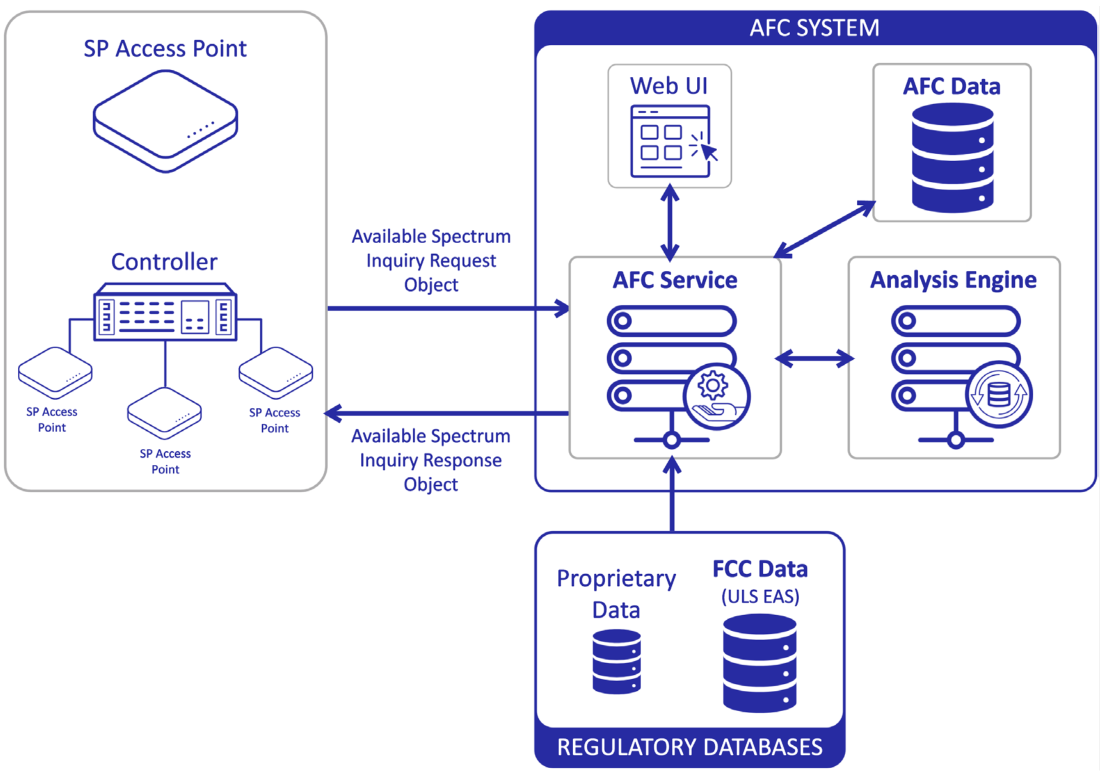


**Figure 3 – AFC System Architecture**

It is incumbent upon an AFC vendor to reliably provide a list of available frequencies and associated maximum transmit powers for standard power devices, so they don't interfere with incumbent microwave systems. Optimum performance of this task requires that the AFC maximize spectrum availability while thoroughly protecting incumbent microwave operations.

## 4. FCC Requirements for Use of Standard Power in 6 GHz

The FCC order regarding 6 GHz operation encompasses several spectral bands and different classes of products. Rather than reproduce the available FCC documents here, the following section focuses on critical requirements for a 6 GHz capable access point to operate in Standard Power. FCC product classes cover both Standard Power and LPI access points and clients.[4] Rather than reproduce the available FCC documents here, the following section and this paper more general will focus on critical requirements for a 6 GHz capable, non-fixed access point to operate in Standard Power. In the parlance of the FCC, this device is referred to as a Standard Power Access Point (6SD) and includes products like broadband Wi-Fi gateways and extenders.

Devices in this class operate in the 5.925-6.425 GHz (U-NII 5) and 6.525-6.875 GHz (U-NII 7) bands.

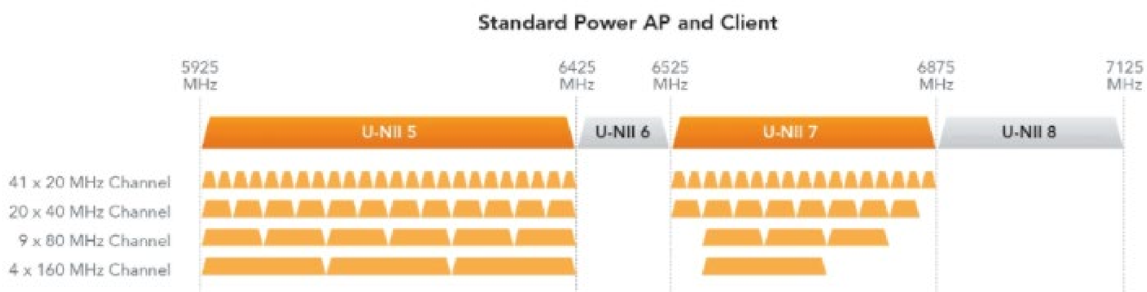


**Figure 4 – FCC 6 GHz Band Allocations**

Maximum power spectral density must not exceed 23 dBm EIRP in any 1-megahertz band. In addition, the maximum EIRP over the frequency band of operation must not exceed 36 dBm. For outdoor devices, the maximum EIRP at any elevation angle above 30 degrees as measured from the horizon must not exceed 125 mW (21 dBm).

SP access points are required to provide information to their connected clients such that those clients can adjust their EIRP to comply with the regulations. As noted in the prior section, even standard power clients associated with an SP must adjust their EIRP to no more than 6 dB lower than what is authorized by the AFC for the standard-power access point.

These devices must include specific labeling requirements and may operate as a bridge, peer-to-peer connection, connector between the wired and wireless segments of the network, or a relay between wireless network segments.

Importantly, devices in this class must access an AFC system to determine the available frequencies and the maximum permissible power in each frequency range at the device's geographic coordinates prior to

[4] Per the FCC, a client is a U–NII device whose transmissions are generally under the control of an access point and is not capable of initiating a network.

transmitting and may transmit only on frequencies and at power levels that an AFC system indicates as available.

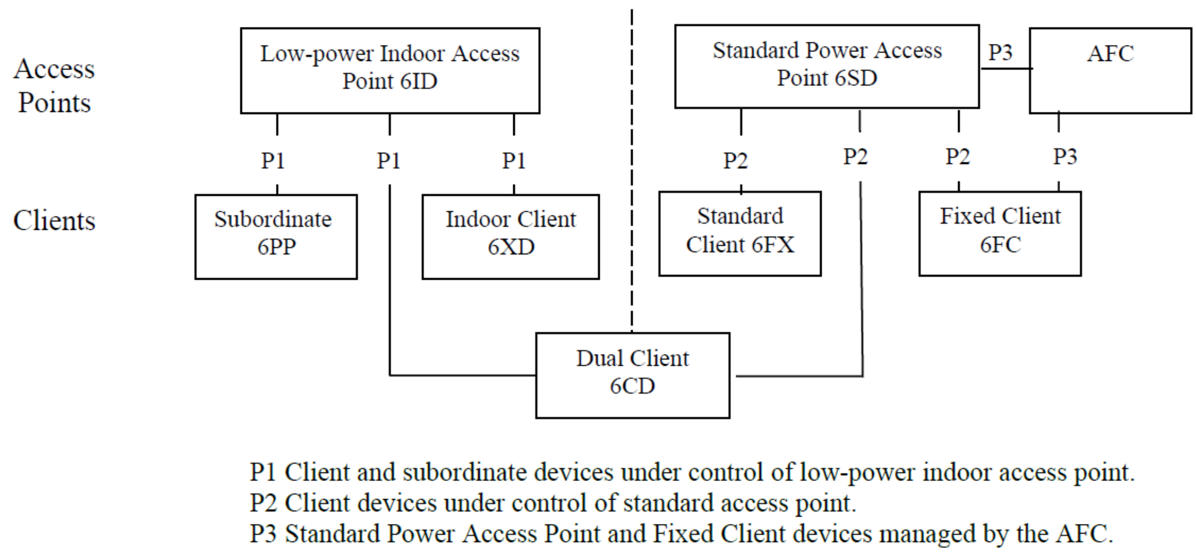


**Figure 5 – FCC Part 15 Equipment Classes[5]**

To determine the appropriate channel masks, devices in this class must provide geolocation data to the AFC. To achieve this, the device must include either an internal geolocation capability or an integrated capability to securely connect to an external geolocation device or service to automatically determine the access point's geographic coordinates. The location uncertainty must be provided (in meters), with a confidence level of 95%. The device must report coordinates and location uncertainty to an AFC system at the time of activation from a power-off condition. Reporting of the device's height can be determined either automatically or by the device's installer/consumer and must include an associated height uncertainty. Additional details regarding this facet of SP operation are discussed at some length later in this document.

Registration of any SP device must be with, and operation be authorized, by an AFC system prior to initial service transmission. After a change in location, devices must obtain a list of available frequencies and the maximum permissible power in each frequency range at the device's location. Device's register with the AFC system by providing geographic coordinates (latitude and longitude referenced to North American Datum 1983 (NAD 83)), antenna height above ground level or sea level, FCC identification number, and unique manufacturer's serial number. If any of these parameters change, the device must provide updated parameters to the AFC system. All information provided by the device to the AFC system must be true, complete, correct, and made in good faith.

Consequently, all AP devices operating in standard power must contact an AFC system by rule at least once per day to obtain the latest list of available frequencies and the maximum permissible power the device may operate with on each frequency at the device's location. If the device fails to successfully contact the AFC system during any given day, the device may continue to operate until 11:59 p.m. of the

[5] FCC Knowledge Database 987594 D02 U-NII 6GHz General Requirements v0r02, August 22, 2023

following day at which time it must cease operations until it re-establishes contact with the AFC system and re-verifies its list of available frequencies and associated power levels.

Lastly, the device software must incorporate adequate security measures to prevent it from accessing AFC systems not approved by the FCC and to ensure that unauthorized parties cannot modify the device to operate in a manner inconsistent with the rules and protection criteria. Security mechanisms must also be in place to ensure that communications between devices and AFC systems are secure to prevent corruption or unauthorized interception of data. Additionally, the AFC system must incorporate security measures to protect against unauthorized data input or alteration of stored data, including establishing communications authentication procedures between client devices and standard power access points.

# 5. Device-to-AFC Messaging

In its ruling, the FCC refers to a document published by the Wi-Fi Alliance as the industry specification of the protocol between the AFC and a device.[6] It offers a technical specification that defines the messaging protocol and transport for the interface between an AFC System and an AFC Device. It includes the architecture, protocols, and functionality for entities that support the AFC System to AFC Device Interface.

## 5.1. AFC Connection and Security

The AP connects to the AFC via an HTTP POST method using HTTP version number 1.1 or later. In most cases, TLS is performed for AFC authentication by the SP device prior to any communication. This establishes an encrypted connection with the AFC system.

According to the FCC 47 CFR 15.407(k)(8)(v) requirement, standard power devices (SPDs) must incorporate adequate security measures to prevent unauthorized access to AFC Systems not approved by the FCC. Additionally, the AFC System may establish communications authentication procedures between the AFC System and SP devices or their Proxies.

The first mandatory rule requires that all SP devices must present valid, FCC-issued FCC IDs and must be validated by the AFC system when querying spectrum availability information. This is typically governed by the secured AFC system database preloaded with the FCC approved SP devices. SP devices establish a service relationship with a specific AFC system through registration.

The second highly recommended requirement pertains to the authentication between the devices and the AFC systems. This recommendation is outlined in the Wireless Innovation Forum (WInnForum) technical report WINNF-TR-2012. For the AFC System authentication, TR-2012 recommends employing a TLS Server Certificate issued by a Trusted Certificate Authority (WInnForum AFC System CA). This CA is attested using a CA certificate issued by a trusted root CA (WInnForum Root CA).

Regarding authentication, TR-2012 proposes two possible approaches. The first approach involves employing a TLS Client Certificate, mirroring the AFC System authentication through the server certificate. This method accomplishes mutual authentication of both the AFC System and SP device

[6] AFC System to AFC Device Interface Specification," Wi-Fi Alliance.

 

during the phase of the TLS session establishment. In this approach, each device (or device Proxy) necessitates a distinct certificate. The SPD certificate may encompass information like the device's FCC ID and serial number, enabling the AFC System to conduct additional validation during SP device authentication. Similarly, the device client certificate might incorporate a manufacturer-provided unique identifier, facilitating additional validation during Proxy authentication by the AFC System. The second approach is to use Bearer Tokens issued to an SP device or Proxy by the AFC System. The AFC System will only generate tokens for trusted entities and thus they can be used to authenticate the holding entities. The Bearer Token is transmitted over an encrypted TLS session during communication. Bearer Tokens are part of OAuth 2.0, which is commonly used in industry.

The SP device/Proxy authentication based on a TLS Client Certificate offers a high level of security, constituting a robust authentication method albeit with relatively higher costs. In comparison, the Bearer Token approach is more cost-effective to implement and maintain, but it does not provide the same level of strength in security and authentication.

In summary, both the FCC and WInnForum stipulate that SP devices accessing AFC Systems must possess FCC-approved identities. The mutual authentications between AFC Systems and devices or their Proxies, while not mandated by the FCC, are recommended by WInnForum. It should be noted that diverse methods exist for implementing security and authentication within the AFC ecosystem and AFC operators have the flexibility to choose solutions that align with FCC Rules provided compliance can be substantiated. Nevertheless, it is likely that many operators will embrace WInnForum's recommendations to effectively address the growing concerns and demands for security. Adopting mutual authentication based on TLS certificates is a widely endorsed industry practice.

### 5.2. AFC Messaging

HTTP message payloads utilize JSON primitives. The AvailableSpectrumInquiryRequestMessage object is used by the SP device to request available spectrum from the AFC. The AFC responds with the AvailableSpectrumInquiryResponseMessage object. These two message objects represent the entirety of the AFC sequence flow.

The request object includes fields to describe SP operation including a device description, geographic location area for operation, a frequency range or list of channels associated with the request and optionally a minimum desired EIRP. The response object includes fields to describe the regulatory rules used by the AFC system to determine spectrum availability, the available frequency range(s) or channels including the maximum permissible EIRP for each, a time when the spectrum availability specified in the response expires, and information on the outcome of the inquiry. The following figures illustrate examples of AvailableSpectrumInquiryRequestMessage and AvailableSpectrumInquiryResponseMessage objects in JSON format.

```
{
  "version": "1.3",
  "availableSpectrumInquiryRequests": [
    {
      "requestId": "2_132",
      "deviceDescriptor": {
        "serialNumber": "test1234",
        "certificationId": [
          {
            "nra": "FCC",
            "id": "OPS6GHZ"
          }
        ],
        "rulesetIds": ["US_47_CFR_PART_15_SUBPART_E"]
      },
      "location": {
        "ellipse": {
          "center": {
            "latitude": 36.36106,
            "longitude": -119.047
          },
          "majorAxis": 0,
          "minorAxis": 0,
          "orientation": 0
        },
        "elevation": {
          "height": 7.62,
          "heightType": "AGL",
          "verticalUncertainty": 0
        },
        "indoorDeployment": 2
      },
      "inquiredChannels": [
        {
          "channelCfi": [

          ],
          "globalOperatingClass": 132
        }
      ],
      "minDesiredPower": 24
    }
  ]
}
```


**Figure 6 – Sample Spectrum Inquiry Request Message**

```json
{
  "version": "1.3",
  "availableSpectrumInquiryResponses": [
    {
      "requestId": "2_132",
      "rulesetIds":  "US_47_CFR_PART_15_SUBPART_E",
      "availableChannelInfo":
         {
            "globalOperatingClass": 132,
            "channelCfi": [7, 39, 55, 71, 135, 151, 167],
            "maxEirp": [27.8, 36, 36, 36, 36, 33.0, 36]

         },
       "availabilityExpireTime": "2023-07-08T14:35:05Z",
       "response":
         {
            "responseCode": 0,
            "shortDescription": "SUCCESS"
         }
    }
   ]
}
```

**Figure 7 – Sample Spectrum Inquiry Response Message**

## 6. Device Geolocation Acquisition

In support of Standard Power operation, a substantial new requirement is placed on the typical residential Wi-Fi device and by extension the service provider. This requirement is to accurately determine the installation coordinates and height of the device requesting SP operation. To determine the appropriate channel masks, devices in this class must provide geolocation data to the AFC. To achieve this, the device must include either an internal geolocation capability or an integrated capability to securely connect to an external geolocation device or service to automatically determine the access point's geographic coordinates. The location uncertainty must be provided (in meters), with a confidence level of 95%.

The device must report coordinates and location uncertainty to an AFC system at the time of activation from a power-off condition. Reporting of the device's height can be determined either automatically or by the device's installer/consumer and must include an associated height. In nearly all cases, the measured geolocation will be very similar (assuming the device is physically in the same location). It is likely that within the area of uncertainty, the geolocation coordinates will "match". Most AFC systems will, to improve efficiency, cache the previously calculated mask for that location/request. Masks will be flagged as invalid or removed from the system if new licensed 6 GHz operations are added to a specific locality in which case the spectral mask will be recalculated by the system.

## 6.1. Internal GPS Location Service

The most direct means to determine the location of a SP device is through the use of an embedded GPS radio. This allows the device to directly read its current location and include its current geolocation parameters in its daily request to the AFC.

Inclusion of the GPS system directly in the Standard Power AP does have some undesirable characteristics. One obvious consideration is cost. Each device is outfitted at the factory with a GPS device. Depending on the overall capabilities of the device (full gateway/router vs wireless AP only), this cost can be non-trivial. Also, if SP operation is only planned for a subset of the device population (for example, for customers in certain markets/regions or who purchase a specific type of service plan), the additional cost is unnecessarily invested for those customers or demands the use of multiple stocking units (SKUs), one for LPI and one for SP operation.

An additional consideration is that, without some type of visual indicator, it may be difficult for a technician or end user to determine if the correct geolocation is being presented. It is possible, especially in denser urban settings, that reflections in the GPS signal could occasionally result in incorrect coordinates being realized by the GPS system. To fully validate the location, these coordinates would need to be validated against another source such as the address of record where the device is installed. If the detected GPS location and address of record don't match, the device could be flagged, and manual intervention applied such as relocating the device slightly within the premise if possible. In the worst case, use of SP may have to be disabled if a valid reading cannot be obtained.

## 6.1. Smart phone-based Location Service

An alternative mechanism vs internal GPS is to use an external device to determine the geolocation of the SP capable device. The external GPS device by rule must be securely connected to the SP device. By using an external device, the SP device itself does not need to carry the burden of the GPS cost and, if the external device has a display, it can be used to visually confirm a proper location before submission to the AFC.

One obvious choice for the external device is the use of the ubiquitous smart phone to provide the needed geolocation information. The device can be securely connected to the SP device over Wi-Fi. To ensure that the smart phone is not too far from the SP device, a signal strength limit can be enforced to ensure that the smart phone is within close proximity to the SP device for which it is measuring the location. Any device geolocation mobile application components can be integrated with a service provider's mobile application to provide a more unified customer experience, though it is obviously possible to use an AFC Geolocation in a standalone form.


**Figure 8 – Use of Smart Phone To Determine SP Device Location**

Use of standard smart phone GPS is expected to be at least as accurate as onboard GPS radios. The performance of the GPS radios themselves are similar but, in the case of the smart phone, the operating system can also enhance the accuracy of the smart phone location using other available data.

To get a sense of the practicality of using a smart phone for measuring the location of a SP device, CommScope devised a brief study wherein random study participants used a test mobile application to sample their location as provided by the smart phone. Participants in most cases provided data when in proximity to their current broadband Wi-Fi device.  The participant was then asked to pinpoint their actual location as closely as possible by touching the screen on a map overlay.

The data collected was quite positive in terms of reliably using the mobile phone to provide location services with the required 95% accuracy. As shown below in Figure 9 – Location Accuracy Reported by Mobile Phones, the vast majority of phones reported a GPS accuracy level within 20 meters and 96.9% reported accuracy within 50 meters.

 

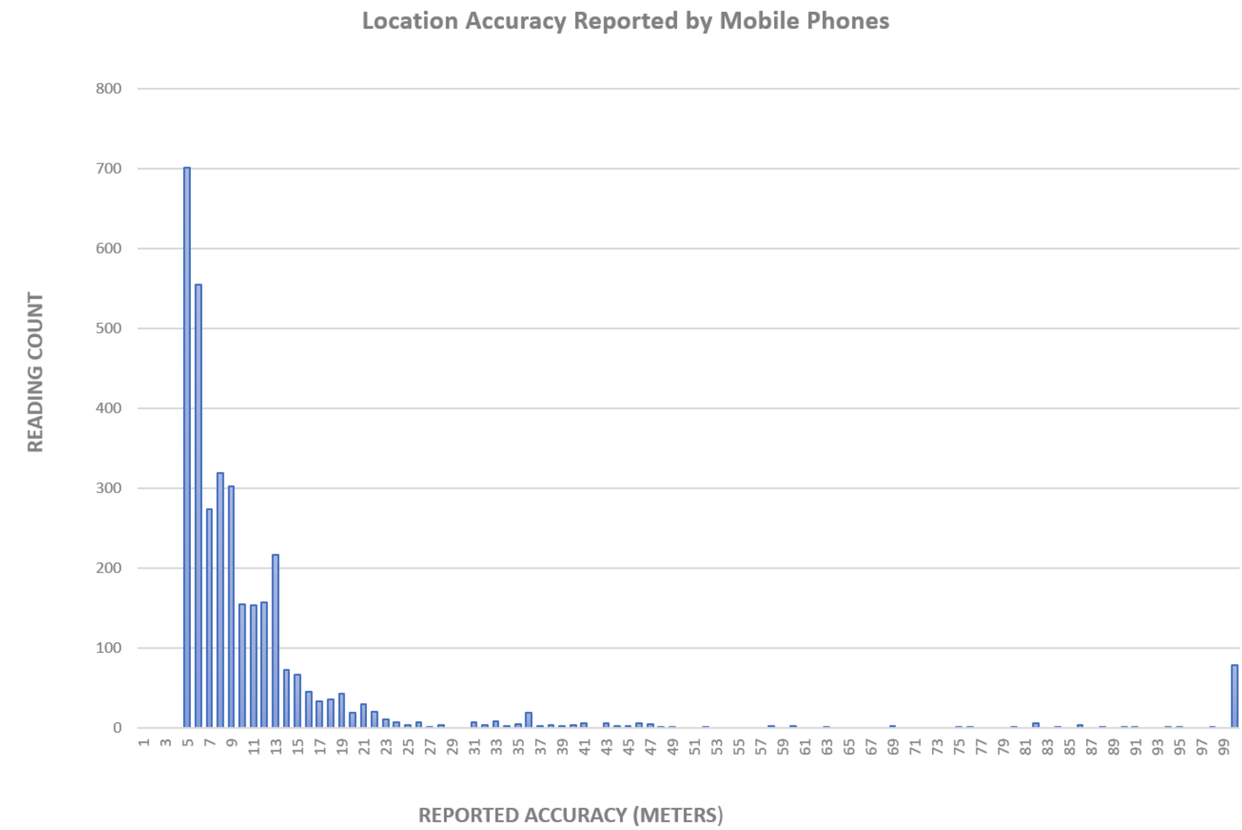


**Figure 9 – Location Accuracy Reported by Mobile Phones**

For the purposes of the test, users were instructed to indicate their actual location on the map overlay as precisely as possible by touch the screen. Doing this allows for further study as to how far the average center point of the GPS determined location was from the "correct" location as identified by the tester. Again, the results were promising. Of 32 recently completed tests with sufficient GPS reported accuracy, 32/32 (100%) were within a radius of 25.3m. 31/32 (96.9%) were within radius of 20.6m.

The normal distribution of these results are presented below. Note also that some error is introduced here by the resolution of a finger press on the screen. (The center pixel was used.) In a few cases, the underlying mapping software did not show a precise premise outline to help the tester more accurately touch their location.

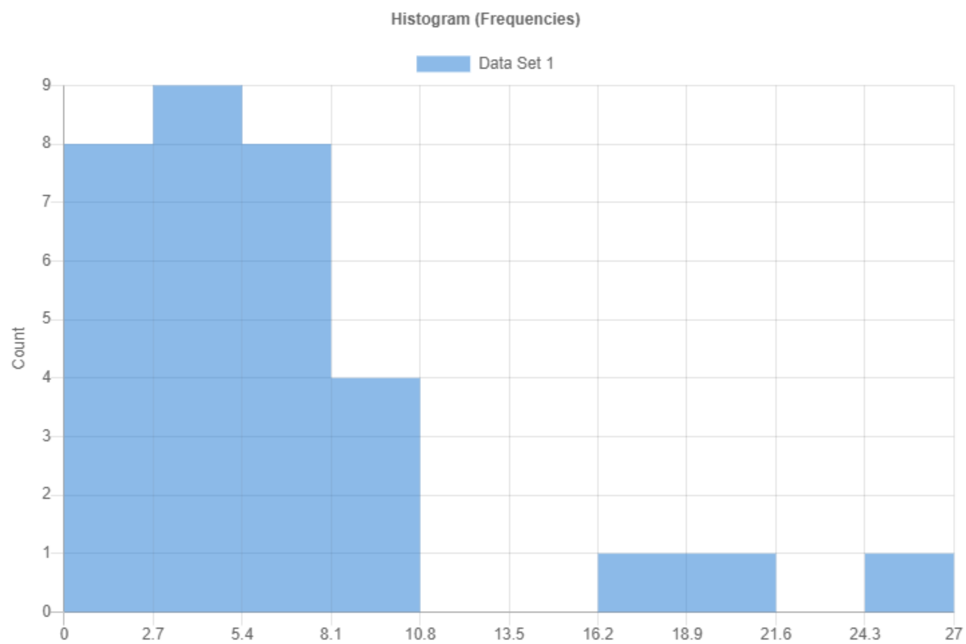


**Figure 10 – Histogram of Distance between Phone Reported Location and Tester indicated Location**

Using the same test application noted above, testers were shown dwelling structures and, based on the location of the indicated GPS coordinates, these structures were able to be automatically highlighted providing the precise outline of the premise in which the device was located. Using the boundaries of the premise as the area of uncertainty for AFC calculations offers a very precise means of determining the available spectrum mask and ensuring that the maximum number of channels and transmit power are made available.

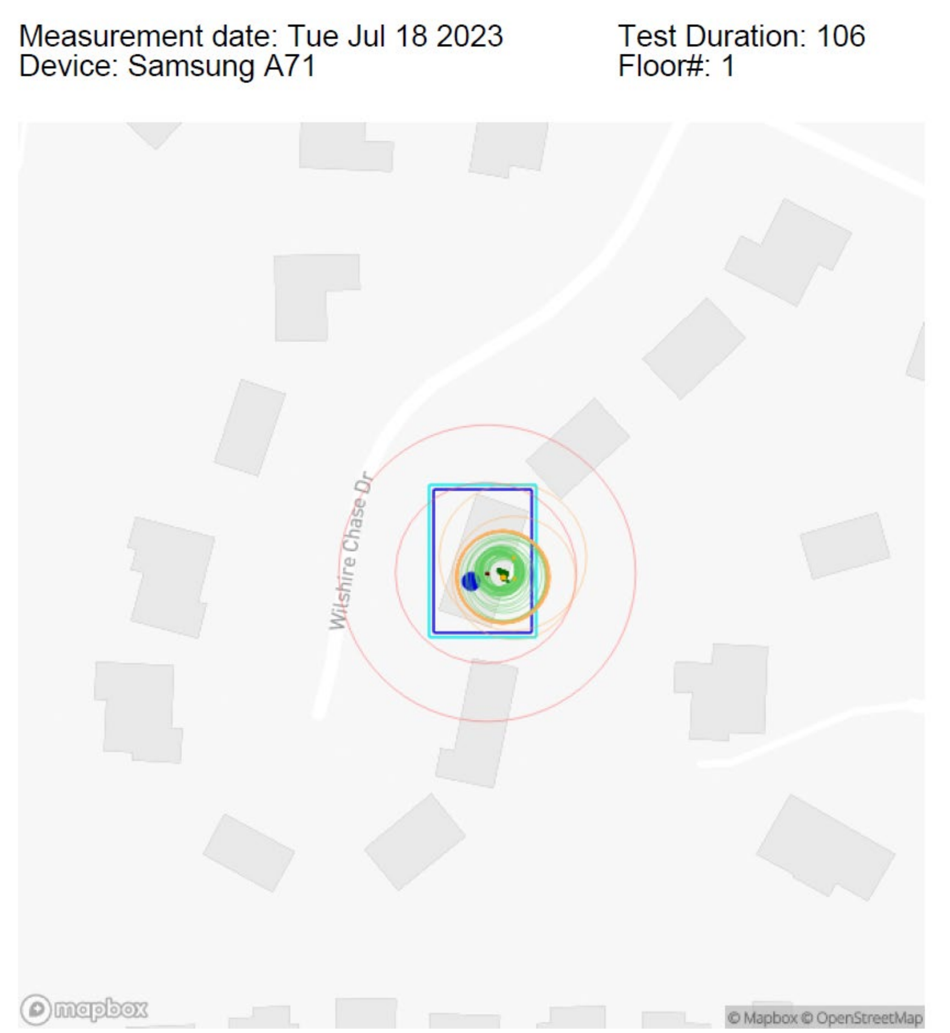


**Figure 11 – Test Application Sample Result with Automated Dwelling Boundary Determination**

An added benefit of the use of the smart phone for setting the geolocation of the SP is that mapping data, specifically structure related data can be used to further enhance location. This would allow the creation of a location and uncertainty that covered the entirety of the residence such that the channel mask would be valid anywhere inside the premise. In the consumer use case, the FCC is ultimately expected to allow for additional consideration for devices used inside of buildings. Thus "building loss" will be applied at the AFC when determining the proper spectral mask for the SP device given that the transmissions of the SP are attenuated by the external structure of the building itself. This is discussed in more detail in the section on" Indoor-Only Standard Power Devices" below.

### 6.2. Location Validation on Power Cycle Event

The current FCC specification does require the device to verify the device location after a reboot. If the device is in the same location/uncertainty area and the previously provided mask was obtained within the 24-hour window, no action is needed. If the location has changed, then the device must request a new set of mask information from the AFC. This requirement is straightforward in the case of integrated GPS, though given the infrequent nature and technical limitation of users relocating equipment from one premise to another, it again highlights that internal GPS may not be the most cost-effective means for SP geolocation determination.

In the case of an external location mechanism like a smart phone, it is possible to revert to Lower Power Indoor (LPI) operation after each reboot and then require revalidation of the location via the external device, using a smart phone notification as an example. However, this is impractical and would result in potentially extended periods of operation outside of SP. To avoid this, software-based validation mechanisms can be employed to determine if the SP device has changed location. These checks can be performed either with software running on the target platform or remotely using a cloud-based service which is remotely connected to the SP device.

As part of an SP device location and location error determination (initially or subsequently), baseline location “fingerprint” values can be determined for the SP device. The same fingerprint values can then be determined following SP device repowering and periodically (prior to an AFC Available Spectrum Inquiry Request) and compared with the baseline fingerprint values associated with its last location and location error determination.

If there is an adequately significant change in new and baseline fingerprint values such they there is a reasonable possibility the device has been relocated, its operation can be reverted to LPI operation and the smart phone or other external device/application is required to reconfirm the device location. Naturally, if there is no change or an insignificant change in new and baseline fingerprint values, the last measured location and associated error can be reused in a subsequent AFC Available Spectrum Inquiry Request.

Following are possible coarse “fingerprint” values to detect an inter-residence AP device move:

- Network access node (first-hop) address change detected from gateway
- Visible neighbor reporting (OBSS and signal strength)
  - Resulting from off or on-channel scans
  - Neighbors may add or remove devices which will change the BSSID information, however if there is a change, this can be ignored if other BSSIDs and beacon signal strength information remains unchanged (within threshold margin)
- WAN DHCP server response information
  - DHCP MAC address (presumably the access node MAC)
  - Router IP (option 6)
- Traceroute to given network server
  - Priority to the first few hops given that an PI route could be dynamically altered by the routing logic
- WLAN fixed client devices and their RSSI and/or PHY rate and gross number of known devices
  - Requires understanding of which client devices are fixed (e.g. video set-tops, printers, IOT devices, etc.)

- Above may be discovered based on device type via DPI or host name or other means such as RSSI variation over time
- "Known" devices would be those retained over a period of time (e.g. weeks) to avoid the scenario of guest devices (e.g. gaming console) being seen over a relatively short period of time

The fingerprint values noted may be considered relatively variable, even without an SP device move. Consequently, they should be accompanied with a threshold margin to determine if a "change" in new and baseline values is significant enough to consider a location change. Also, to avoid false positive location move indications, some combination the multiple fingerprint values should be used. Moreover, fingerprint values with potentially high variability (e.g. static clients that are moved temporarily) should be omitted unless they persist over several measurement periods.

The choice of fingerprint values may also include a mix of both course and granular measurements. However, logic can be applied to look at course fingerprint value(s) before granular fingerprint value(s), since an inter-residence move rules out the need for granular value comparison. Also, based on the type of AFC frequency / power mask that was received previously, granular fingerprint measurements may not even be needed in a comparison.

An AP device's last measured location and associated error, its baseline fingerprint values, and new fingerprint values may be retained in the AP or in a device proxy that issues the AFC Available Spectrum Inquiry Request for the AP device. Naturally if used at a device proxy, this information must be accessible by proxy device.

The following block diagram shows the high-level logic for determining when an AP's location has changed and when a new location determination is needed.

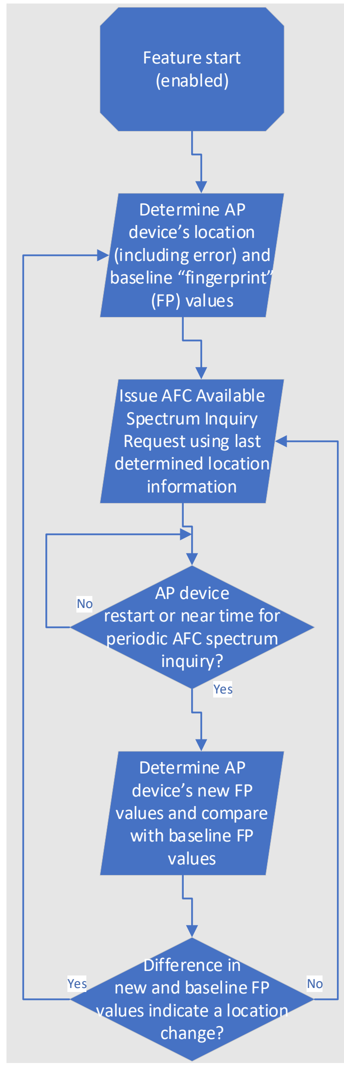


**Figure 12 – Logical Flow When Determining If An AP Location Has Changed**

## 6.3. Height Determination

To properly determine the channel mask for a given location, the AFC system must have SP height information in addition to the geolocation coordinates.  To support this, as with the internal GPS system, one option is to embed an altimeter in the SP device. However, as with the inclusion of the GPS radio, this is a cost burden to the product. Also, unlike the GPS, the accuracy of these solutions is affected by real-time atmospheric conditions at the site. There are third party companies which, given a geolocation, altimeter value and time can use this information to accurately define height above ground to a specific structure floor. However, the geographic coverage of the specialized calibration sensors needed to make adjustments is somewhat limited and is primarily intended for urban locations with a greater number of high-rise residential buildings. Use of these specialized systems which are more typically used for more mission critical applications like first responders will also add cost to the overall solution.

Correctly assessing height is further complicated by the practice of maintaining positive pressure in buildings, positive pressure meaning that the internal pressure inside the building is maintained slightly higher than the atmospheric pressure outside. Positive pressure is maintained for a number of reasons including lessening indoor humidity, preventing cold drafts in the winter and hot spots in the summer, and reducing energy costs due to untreated air entering the building. A positive pressure error would return a height lower than actual.

Given the above, it is likely that the height will be typical be manually provided by a technician or the Wi-Fi device owner. As before, use of a smart phone app to locate the SP can also be an effective tool for determining a reasonable height assessment. It is important to note that most residential structures in the United States are three stories or less. Therefore, a technician or end user can simply input the maximum number of stories of the structure. This value can be used to determine a maximum height using commercially available data for the specific geolocation and estimates of the typical height measurement of a single story plus a small amount of uncertainty. It should be noted that the FCC contemplated this in their order and, unlike geolocation, does allow for manual entry of the height assuming an appropriate uncertainty.

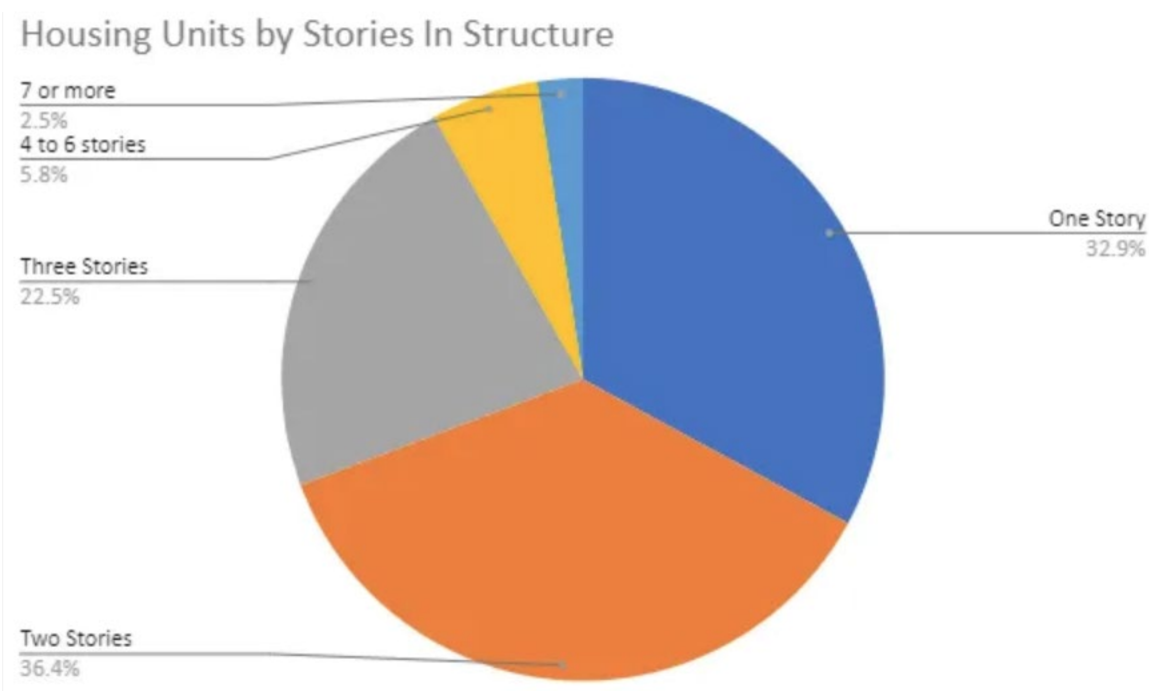


**Figure 13 – US Housing Unit Percentage by Stories**

For high rises, the entry level floor of the unit in which the SP device is installed can similarly be used to estimate the height. This value can be additionally validated by the height value provided by the mobile phone. Though not the primary focus of the above referenced smart phone study, height data captured does appear to provide an adequate level of accuracy to minimally validate manually entered data. This would be in addition to some entry-based validation (e.g. disallow negative or excessively large numbers). For example, if the customer indicates a low-floor or one-story residence but the smart phone app is reporting significant height above ground, the entry app would require re-confirmation or disallow the entered value.

## 7. AFC Proxy Solutions

Leveraging a proxy between the SP device and the AFC system is permitted by the FCC and can provide several benefits. Service providers can utilize their existing gateway management solution including its well understood security and network-to-device communication elements such as the User Services Platform (USP) and BBF data models to facilitate 6 GHz operation. In addition, an AFC proxy can be used to provide additional insights into the performance of the 6 GHz network such as compliance reporting based on the actual channels in use in the event of an incumbent interference complaint.

Using an AFC proxy provides a means to reduce hardware costs by supporting software-based approaches for setting geolocation data in the primary residential gateway at the customer premise. It may also be possible in the future to leverage the GPS data generated by the main SP device in a premise to provide AFC support to connected extenders as well via the AFC Proxy. The AFC Proxy solution can gather location data from GPS systems embedded within the CPE with data inserted into the BBF TR-181 object model or directly from an external phone application. Once this information is gathered, the AFC Proxy can request updated Channel Mask data for updates from AFC database systems.

Employing the AFC Proxy allows for additional insights and usage reports to be generated around 6 GHz channel utilization. For example, the AFC Proxy can report devices that that been provisioned with a Standard Power mask but are still in LPI mode which may be the result of a software bug. In the event of an incumbent reporting interference on a licensed link, an AFC Proxy can generate a report confirming that all devices within the relevant geographic area of the link under dispute are operating on channels as authorized by the AFC.  Generally, use of an AFC Proxy in conjunction with the AFC may reduce the likelihood of incumbent interference issues. Providing direct enforcement of the received channel mask, the proxy can force devices back into LPI or compliant channels when it is detected they are operating outside the prescribed channel mask.

Performance and compliance reports can be derived from the AFC Proxy database and audit updates done. Reports can be delivered direct to email based on an external utility which provides the reporting information.

## 8. Expected Enhancements to Standard Power Rules

As of the time of writing, there remain some outstanding topics which it is expected that the FCC will address. As is typically the case when the FCC makes substantial new rules, these tend to evolve over a period of time as new clarification requests and related public comments are considered. Below, we discuss some key subjects which have yet to be fully adjudicated but are important to the potential effectiveness of 6 GHz operation.

## 8.1. Indoor-Only Standard Power Devices

In February 2023, the Wi-Fi Alliance filed a Request for Waiver with the FCC. This limited waiver request was related to the application of building loss when calculating the available 6 GHz channel mask for a given SP AP located indoors. Application of Building Entry Loss (BEL) can have a significant effect on the available channels as this loss is expected to be applied at -20.5dBm.

Taking into account the building entry loss is a simple "acknowledgment that interior wall and flooring transitions will serve to attenuate and scatter 6 GHz Wi-Fi energy on its outbound journey. Further, depending upon exterior construction, building entry loss (BEL) anywhere from 6 to 30+ dB will constrain the radiation footprint on its inside-to-outside propagation."[7]

As noted in the waiver request, the rules for unlicensed operations in the 6 GHz band authorize two distinct device categories: standard-power and low-power indoor ("LPI") devices. LPI access points ("6ID") are referenced earlier in this paper. LPI devices do not require a connection to an AFC but must operate in a limited number of bands and must operate using a relatively low power ceiling. These devices are limited to indoor locations, have an integrated antenna, and cannot use a weatherized enclosure. Low-power indoor access points must be powered by a wired connection and not by battery power. Low-power indoor access points may use battery backup only during power outages. In addition, they must include labeling indicating that the devices are for indoor use only.

In their waiver, the WFA argues that devices that meet the LPI requirements but also have the capability to transmit in Standard Power, should be given special consideration when compared to the standard SP device type. Since these devices meet the indoor-only constraint, the AFC should be able to take BEL into consideration when applying predictive propagation models to determine available spectrum. The WFA argues that this will provide greater access to the 6 GHz band and by extension improved bandwidth and coverage to the public, an assertion is borne out by empirical testing as noted earlier in this paper.

The mechanics of this process are still being worked out at the FCC, but will entail some method related to specific information a device's record in the FCC Equipment Authorization Database that will be available to the AFC to indicate that the device is an indoor-only SP AP.

It is expected that the FCC will be addressing this issue in the near future. As noted by the WFA in the conclusion of its waiver request, "Waiver of the rule will promote the Commission's goals, consistent with the public interest, by allowing … devices greater access to available spectrum, allowing further use by the American public of the critical connectivity capacity provided by the 6 GHz band."[8]

## 8.2. Extenders as Standard Power Subordinates

The use of Standard Power Wi-Fi extenders presents a unique challenge to the AFC managed Wi-Fi ecosystem. Since the FCC has indicated that standard power Wi-Fi extenders are not yet allowed per se, it is worth discussing how that may be accommodated if and when they are allowed.

[7] *Why 6 GHz Standard Power Wi-Fi is the Game Changer for Residential Use in the US*: Flesch, 2021
[8] *Wi-Fi Alliance Waiver Request in the matter of Authorizing 6 GHz Band Automated Frequency Coordination Systems,* Federal Communications Commission. ET Docket No. 21-352

Registering Wi-Fi extenders will incur additional costs potentially in terms of including GPS systems in the extender as well as transactions against the AFC. An AFC system solution could address this by providing a mechanism in conjunction with an AFC Proxy offering to consider devices originating from the same household together, potentially reducing the overall deployment costs for households using extenders.

The fundamental issue to overcome here is that a co-located extender device in the same home mesh is permitted use of standard power (as is the main AP)-- but such should not produce an alternate operational spectrum mask if the same geolocation error footprint is used for both devices. The use of a proxy device to query the AFC system simply helps scale back the redundant query and calculation burdens of the AFC system in this regard and is easily achieved with a very slightly modified use of the original GPS location effort.

Recall that the main AP establishes its location and error footprint by leveraging either its internal GPS capability or that of a smartphone. In the smart phone case, proximity to the main AP is anchored via Wi-Fi RSSI value. In the extender case, geolocation registration can be performed but as an additional calculation step, this location and error can be compared with the main AP's and a virtual single device created with location midpoint of the two fixes and with a resultant error footprint the maximum of the two added together. This is supplied to the proxy which, on 24-hour mask lease renewal boundaries, requests a spectrum power mask on behalf of the virtual single device and then supplies this both to the main AP and its extender. Note that the above approach may preclude the use of extender-to-extender (multi-hop) mesh networks. Lack of multi-hop support (enforced by the devices themselves) is not a significant concern as noted earlier, a single SP access point can cover a large residential footprint allowing a "hub-and-spoke" only architecture with extenders to cover even the largest homes.

Note that this proposed methodology is not yet approved by the FCC but is intended shortly for PIA submission as the AFC mandate matures. Part of the FCC concern in this regard has to do with footprint growth which might permit obfuscation of the use of BEL (building entry loss). leading potentially to it being incorrectly used for an externally operating device (such resulting in an overly permissive mask being provided to an outdoor unit). But this can be quashed by the simple expedient of examining the FCC ID detail for the virtual device, which the proxy can validate based on its own copy of the FCC ID details for the actual devices installed. (Note that the proxy would have to supply a worst-case "outdoor" designation for the virtual device if ANY of the actual devices were anything but indoor units; it may be necessary to proxy the main AP details – so modified – in order for the AFC to acknowledge a known FCC ID).

## 9. Conclusion

Availability of the 6 GHz band is a welcome development, not only in the US and Canada but globally. Given the unrelenting growth of Wi-Fi connected devices and, in some cases, their need for much higher and reliable throughput, the availably of more spectrum, especially when combined with a new Wi-Fi generation (Wi-Fi 7), is an important development which is likely to have a substantive impact on both services providers and their customers. As noted in this paper, use of Standard Power can significantly extend high-bandwidth, downlink reach for US consumers vs LPI.

However, accessing this new spectrum using SP does require some added complexity. In particular, service providers must partner with an AFC system operator to coordinate spectrum with incumbent licensees. The AFC determines both the available frequencies for a provided geographic location or area and the maximum permissible radiated transmission power level for devices for given frequencies. Further, the Standard Power devices themselves must meet specific requirements, the most important being to provide the AFC an accurate location and height such that the AFC can properly determine the above referenced channel and power mask.

Understanding device location represents the most significant and novel change for operators. Several options are possible, each with their own benefits and challenges. Including GPS radios and altimeters in Standard Power devices represents the most straightforward means of determining device location and height. However, it does add fixed cost to every device regardless of whether it is used in Standard Power operation. Use of an external solution such as a smart phone app is more flexible, does not add fixed costs, and allows for more technician and customer interaction to help confirm the proper location and height. However, use of an external location solution requires additional software either in a cloud proxy or the device itself to assess whether a device has been relocated in the event of a power-cycle. Automatically determining height involves additional complications due to the impact of variability in the local atmospheric conditions and the practice of maintaining positive building pressure.

Finally, continued innovation and evolution is expected with regard to the authorization and implementation of 6 GHz Standard Power operation. AFC Proxy systems will come to market which will provide additional benefits and features such as allowing for reuse of already deployed security and network-to-device communication elements to facilitate 6 GHz SP operation. In addition, AFC proxies can provide valuable 6 GHz performance insights and reporting and potentially allow for more efficient management of 6 GHz devices (gateways and extenders) operating within a single household. On the regulatory front, ongoing rule making is expected to allow the use of an allowance for building entry loss which should improve 6 GHz spectrum availability in many cases.

# Abbreviations

| | |
|---|---|
| 6SD | FCC Standard Power AP Device Type |
| AFC | Automated Frequency Coordination |
| AP | Access Point |
| BBF | Broadband Forum |
| BEL | Building Entry Loss |
| CA | Certificate Authority |
| CFR | Code of Federal Regulations |
| dBm | Decibel-milliwatts |
| DHCP | Dynamic Host Configuration Protocol |
| DPI | Deep Packet Inspection |
| EIRP | Effective Isotropic Radiated Power |
| FCC | US Federal Communications Commission |
| GPS | Global Positioning System |
| HTTP | Hypertext Transfer Protocol |
| HTTPS | HTTP plus TLS |
| IoT | Internet of Things |
| IP | Internet Protocol address |
| JSON | JavaScript Object Notation |
| LPI | Low-Power Indoor |
| MAC | Media Access Control |
| MDU | Multi-Dwelling Unit |
| MRU | Multi Resource Unit |
| NAD 83 | North American Datum 1983 |
| OBSS | Overlapping Basic Service Set |
| PIA | Public Information Act |
| PSD | Power Spectral Density |
| SCTE | Society of Cable Telecommunications Engineers |
| SP | Standard Power |
| TLS | Transport Layer Security |
| ULS | Universal Licensing System |
| U-NII | Unlicensed National Information Infrastructure |
| URL | Uniform Resource Locator |
| USP | User Services Protocol |
| WAN | Wide Area Network |
| WFA | Wi-Fi Alliance |
| WInnForum | Wireless Innovation Forum |

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