Qualcomm

Unlocking 6GHz Wi-Fi's Full Potential

Qualcomm® Automated Frequency Coordination (AFC) Suite

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1 Executive Summary

With 19.5 billion Wi-Fi devices in use today[1] and more than 20 years of standards development, Wi-Fi is one of technology's greatest success stories. Constantly evolving to support new use cases and devices, it has permeated all aspects of our lives to become an essential connectivity means at home, at work and in public across the globe.

Qualcomm Technologies was amongst a group of technology leaders recognizing the importance of license-exempt spectrum to fuel continued growth for Wi-Fi and championing the ultimate U.S. Federal Communications Commission (FCC) decision[2] in April 2020 to open up the 6 gigahertz (6GHz) band with 1200 megahertz (1200MHz) of spectrum for license-exempt uses.

In the years since this milestone ruling, regulators and policy makers around the world have followed quickly in opening up 6GHz spectrum for license-exempt use. Today, 6GHz spectrum allocation decisions stand to benefit over 2.3 billion citizens in countries representing 70% of global gross domestic product[3] and a rapidly growing and diverse ecosystem of Wi-Fi 6E and now Wi-Fi 7 devices gaining quick traction in the marketplace.

While many countries have allowed low-power operation with the Low Power Indoor (LPI) and Very Low Power (VLP) operating classes, some countries have enabled a higher-performance, longer-range version of 6GHz operation with the Standard Power (SP) operating class. This operating class unlocks new use cases and provides significant benefits for consumer and enterprise deployments. With up to sixty-three times stronger signal, residential end-users benefit from a higher-power, longer-range version of 6GHz Wi-Fi indoors for high-performance whole home coverage.

6GHz SP Wi-Fi operation makes outdoors, weatherized enclosures and connectorized antennas possible, opening the door for many use cases such as wireless internet service provider (WISP), campus, and outdoor event venue coverage as well as 6GHz Wi-Fi use in manufacturing and industrial settings.

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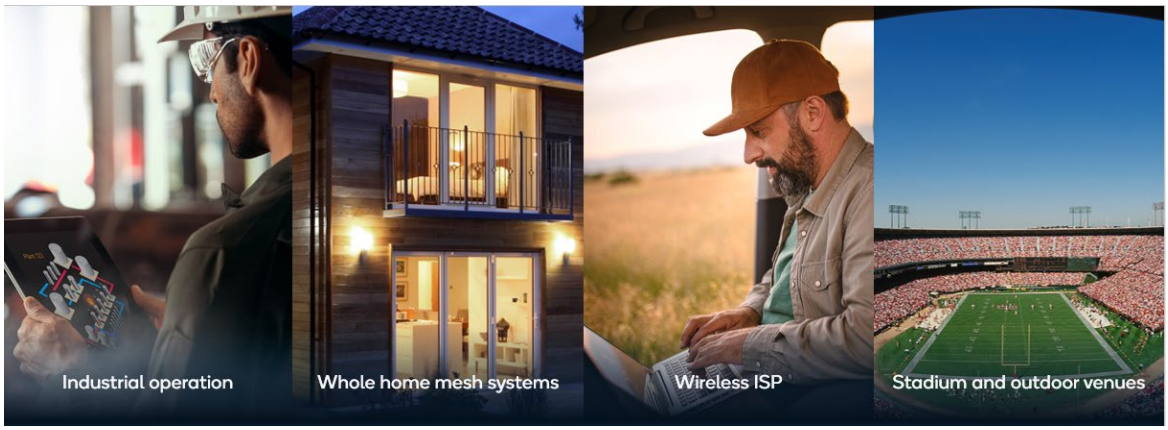
[1] IDC Worldwide Wi-Fi Technology Forecast, 2023-2027, #USS0019923, March 2023
[2] https://www.fcc.gov/document/fcc-opens-6-ghz-band-wi-fi-and-other-unlicensed-uses-0
[3] Population & GDP based on data from The World Bank, Indicators | Data (worldbank.org)

To ensure coexistence with incumbent users in the 6GHz spectrum, such as fixed microwave links operated by mobile operators, utilities, or public safety agencies, regulators have established rules governing operation of license-exempt devices in the spectrum. While these rules for operation vary country-by-country, Automated Frequency Coordination (AFC) is an important spectrum sharing mechanism designed to manage coexistence with incumbents by controlling operation of Standard Power devices.

SP Wi-Fi Access Points (APs) under control of an AFC system require a complete end-to-end solution encompassing an AP embedded AFC agent, automatic geolocation capabilities, and a cloud-based AFC system to determine frequency and power availability. Today, Qualcomm Technologies, Inc. has developed all the components that comprise the full end-to-end AFC solution.

The Qualcomm® Automated Frequency Coordination (AFC) Suite is a comprehensive, ready-to-deploy AFC offering that contains all the building blocks needed to simplify and accelerate the deployment of SP operation. Unique in its scope and level of pre-integration, the Qualcomm AFC Suite positions networking equipment vendors and service providers to maximize the value of their 6GHz Wi-Fi devices by integrating SP operation in their designs and by upgrading Wi-Fi 6E and Wi-Fi 7 devices already deployed in the field.

With a cloud-based geolocation service designed to fulfill regulatory geolocation requirements without additional hardware such as a Global Navigation Satellite System (GNSS) receiver or manual intervention such as a professional installation, the Qualcomm AFC Suite can enable faster time-to-market and more cost-efficient SP devices, enabling equipment vendors and service providers to commercialize a complete 6GHz solution faster, while driving the business and staying ahead of the competition.



2 Introduction

2.1 Regulatory Context

Starting with the United States' FCC decision in April 2020 to allocate the 6GHz band (5925 – 7125 MHz) for license-exempt use, a rapidly expanding set of countries has been making similar decisions as it relates to the 6GHz band. There are variations in the amount of spectrum made available and the radio regulatory rules covering license-exempt use, but from an overall perspective, three different regulatory operating classes governing the use can be identified:

- Low Power Indoor (LPI): fixed indoor operation, with maximum transmit powers of around 24 dBm.
- Very Low Power (VLP): supporting mobile indoor and outdoor operation, typically around 14 dBm maximum power levels.
- Standard Power (SP): supporting fixed outdoor and indoor operation, typically capped at 36 dBm.

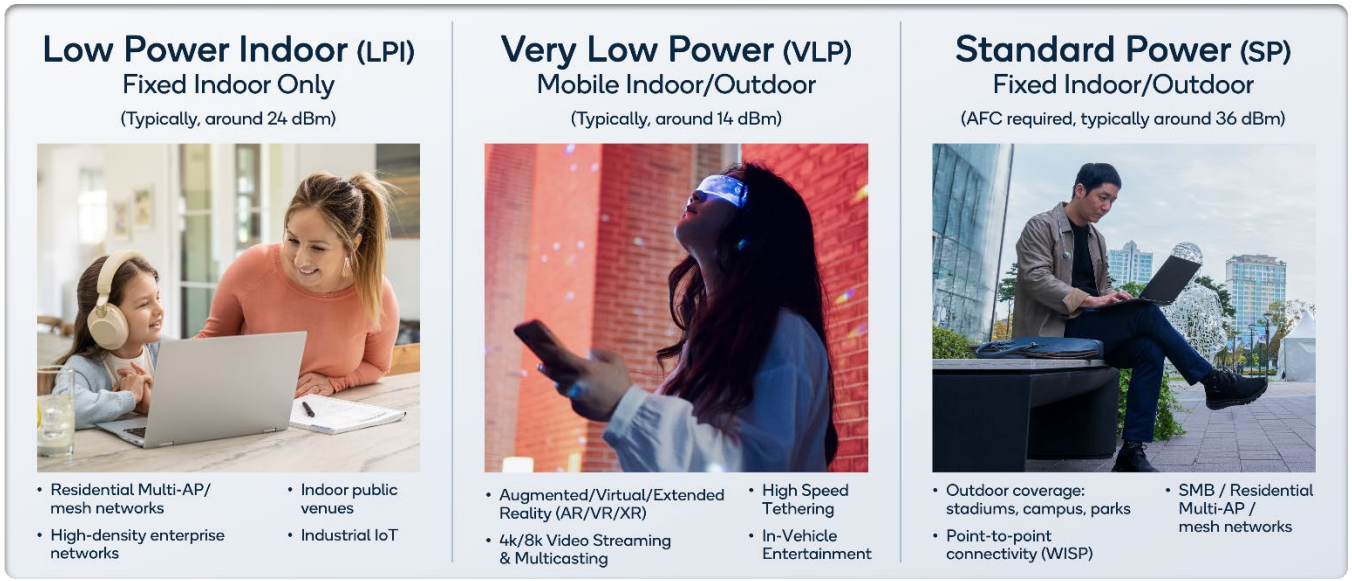


Figure 1: Typical regulatory operating classes for 6GHz band license-exempt operation

The FCC in the United States and Innovation, Science and Economic Development (ISED) in Canada have regulations in place for LPI, VLP, and SP classes. Figure 2 shows equipment classes available for certification in the U.S. and relationships between each.

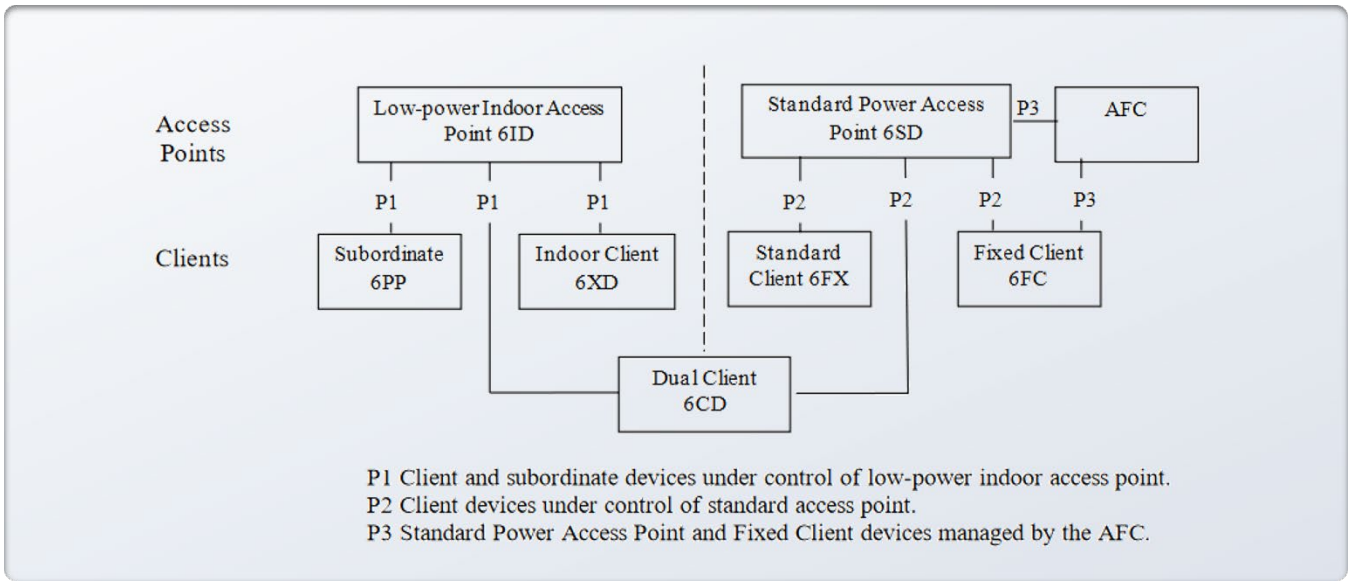


Figure 2: 6GHz device classes from FCC's KDB 987594

2.2 Standard Power and Low Power Indoor Operating Bands

LPI operations are allowed across all bands comprising the 6GHz spectrum in the U.S. and Canada. SP operation is allowed only in UNII-5 and UNII-7 bands in the U.S., resulting in 850 MHz of available spectrum, while in Canada, rules allow SP operation in U-NII 5, U-NII 6, and U-NII 7, resulting in 950 MHz of available spectrum. Refer to Figure 3 and Figure 4 below for both SP and LPI operating bands and channels in the U.S. and in Canada.

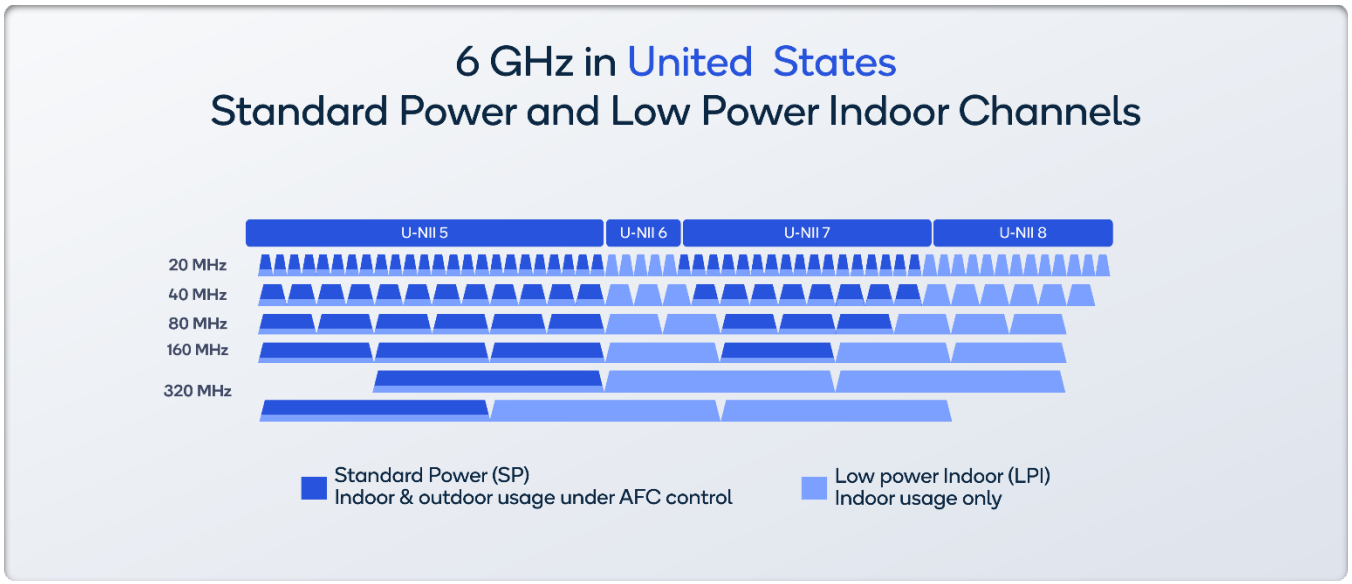


Figure 3: SP and LPI operating bands and channels in the U.S.

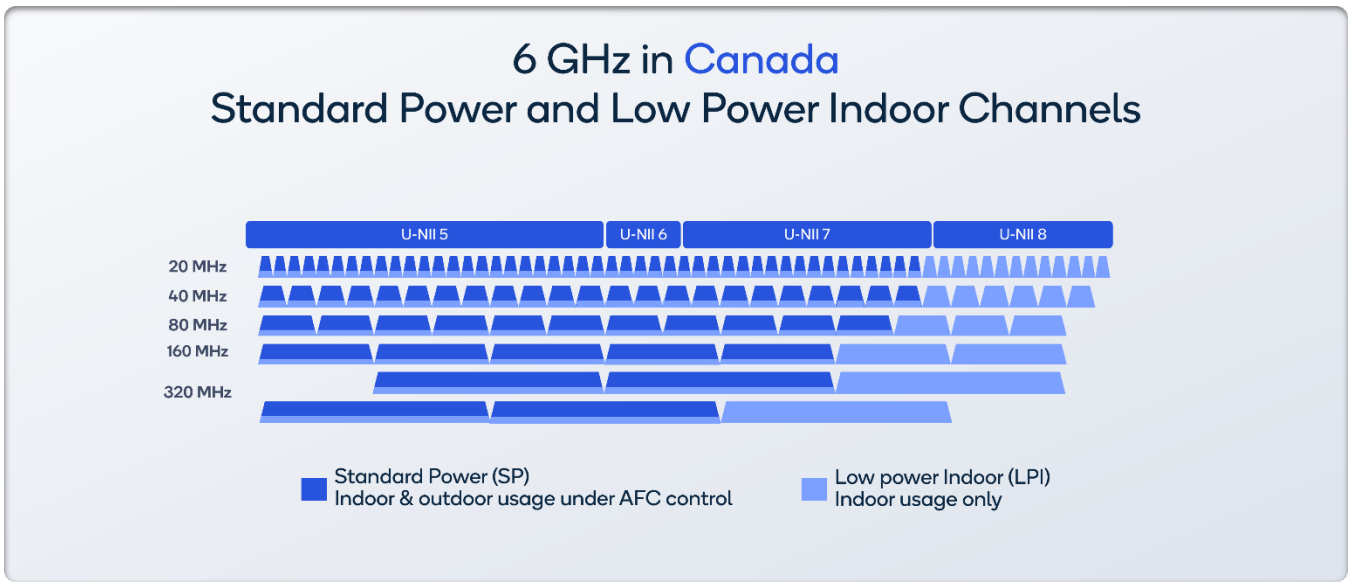


Figure 4: SP and LPI operating bands and channels in Canada

2.3 Benefits of 6GHz Standard Power Operation

The ability for a Wi-Fi AP to transmit at higher power increases the range of the wireless signal and therefore the size of its coverage area, while also increasing the throughputs at a given range. LPI

levels of transmit power can be sufficient in many settings; however, SP levels of transmit power have the potential to create a better user experience in more challenging settings such as large homes and attenuation from building material such as concrete walls.

As seen in Figure 5 and Figure 6 Rate over Range plots (using 80 MHz and 160 MHz channel widths), SP provides longer-range operation for a given data rate compared to LPI in the 6GHz band.

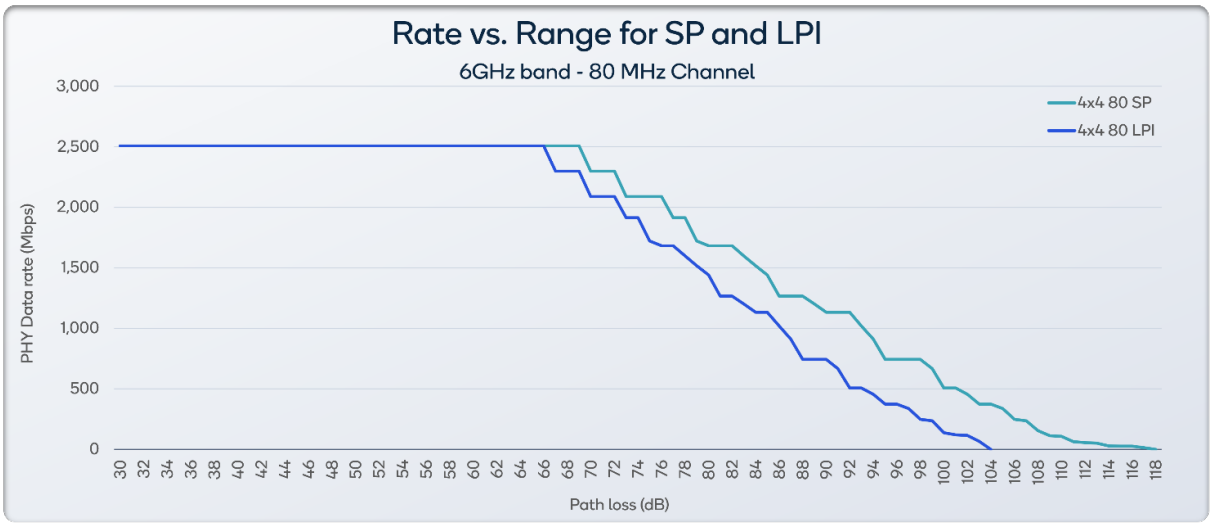


Figure 5: Rate over Range plot, 6GHz Wi-Fi LPI vs. SP operation (80 MHz)

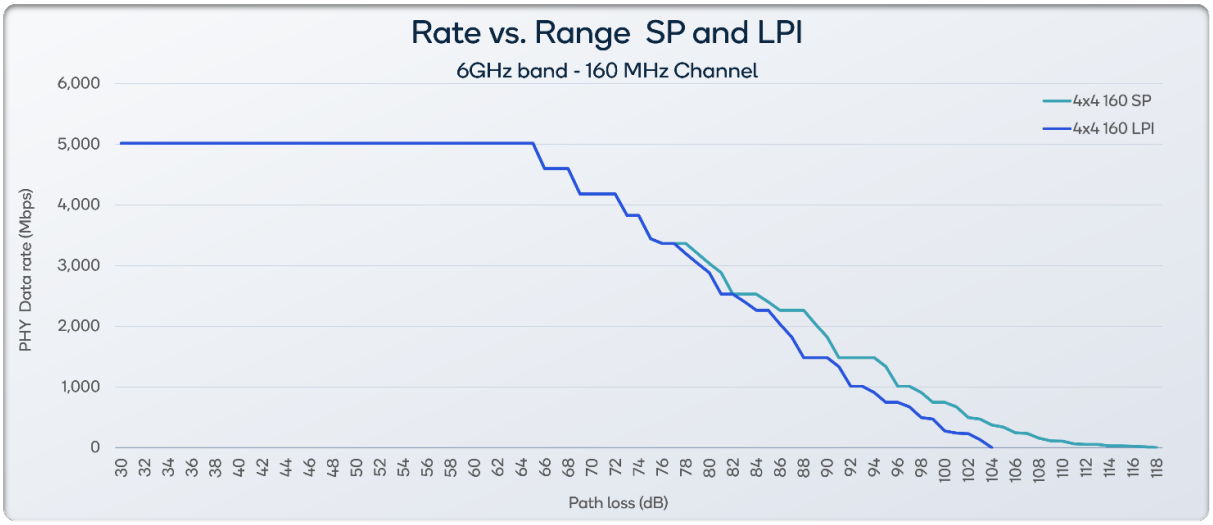


Figure 6: Rate over Range plot, 6GHz Wi-Fi LPI vs. SP operation (160 MHz)

In residential environments SP operation translates to high-performance connectivity in a wider area of the home, making it an important factor in ensuring high throughput to 6GHz clients or mesh nodes (for mesh backhaul) located throughout the home. Figure 7 and Figure 8 represent an AP/mesh (4x4) in a fixed location and the resulting PHY data rate connection for a client device (2x2) placed at various locations indoor and outdoor.

This example assumes free space path loss within rooms and attenuation from common building materials ranging from indoor drywalls to higher attenuation masonry walls (chimney, staircase, etc.) and external walls. This model demonstrates the importance of SP to realize wall-to-wall high-throughput coverage and outdoor connectivity in environments, typical of residential deployments, where LPI fails to provide the same level of performance.

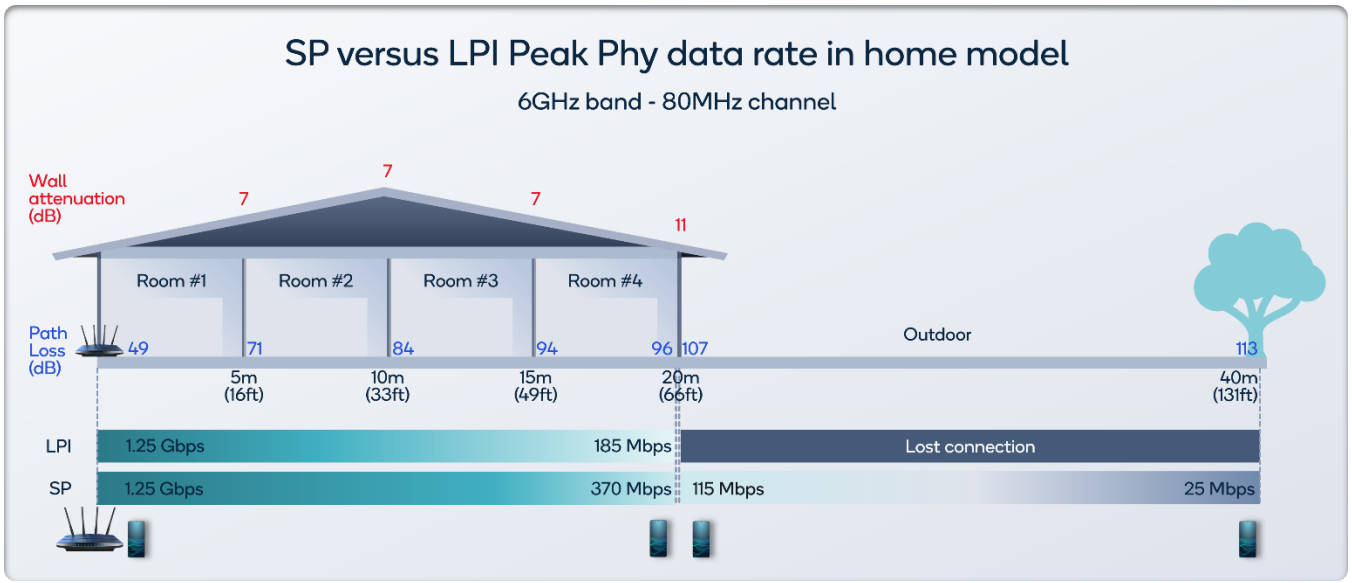


Figure 7: SP vs. LPI Peak PHY data rate in home for 80MHz channel

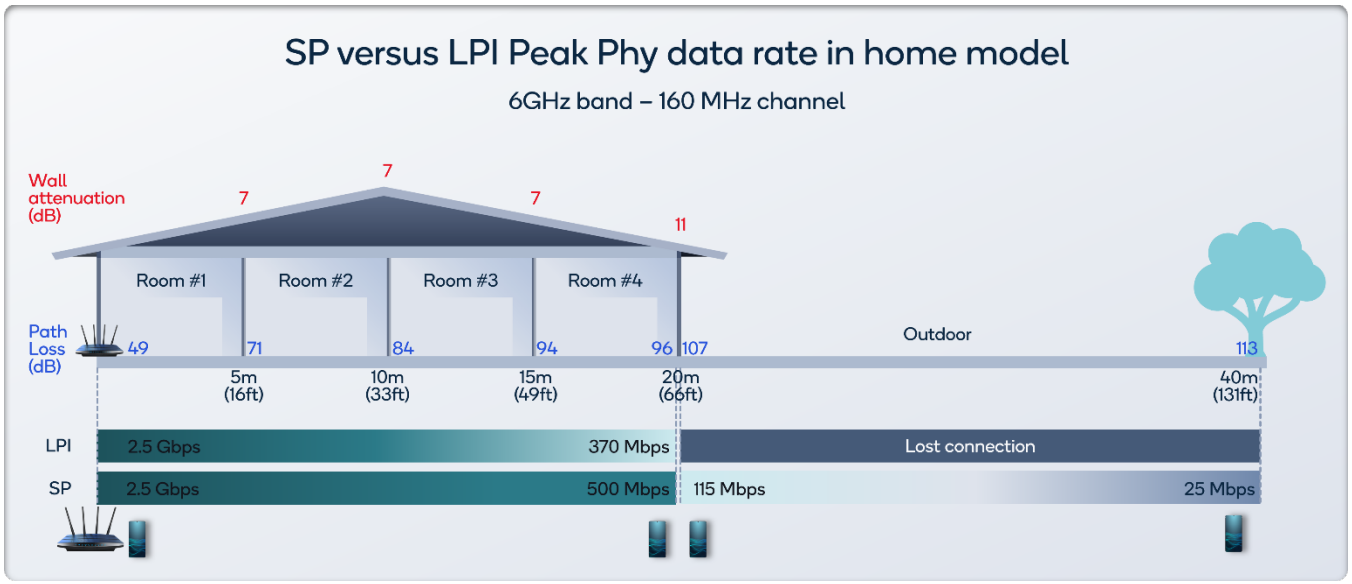


Figure 8: SP vs LPI Peak PHY data rate in home for 160 MHz channel

In addition to the benefits highlighted above, SP APs are allowed to operate outdoors, with weatherized enclosure and connectorized antennas. For enterprise applications, this opens a broad range of use cases and deployment options that were previously unavailable for 6GHz devices. Table 1 below provides examples of deployments benefitting from SP operation.

Table 1: Standard Power (SP) operation use cases

	Use Case Examples benefitting from Standard Power Operation
Outdoor	• Wireless ISP/ Broadband Access • Campus deployments • Municipal networks • Stadium and outdoor event venues
Enterprise Indoor	• Warehouses • Hallways • Manufacturing floors • Cruise ship • Hospitality

2.4 AFC for Spectrum Sharing

One of the key regulatory considerations governing the license-exempt use of the 6GHz band for geographies like the U.S. and Canada is ensuring coexistence with incumbent users, in particular fixed microwave services. These incumbent fixed links are operated, for example, by mobile operators for backhaul to cellular base stations, by utilities, or by public safety agencies. To protect these services, the U.S. and Canada require SP devices to consult with an AFC system before they can operate at high power levels based on location and frequency.

The AFC system is used to protect the receivers of incumbent fixed link systems as well as Radio Astronomy observatories from harmful interference by license-exempt devices.

2.5 AFC System Operation

An AFC system uses publicly available information about incumbent systems to determine frequency availability in a specific location. For example, in the U.S., all licensed services are included in the FCC's Universal Licensing Service database[4] (ULS). The AFC system models signal propagation based on parameters such as distance between license-exempt device and incumbent system, terrain, incumbent antenna direction/model, and climate data; and applies a set of interference protection criteria to calculate the permissible operating frequencies and power levels for the location of the requesting SP devices.

[4] https://www.fcc.gov/wireless/universal-licensing-system

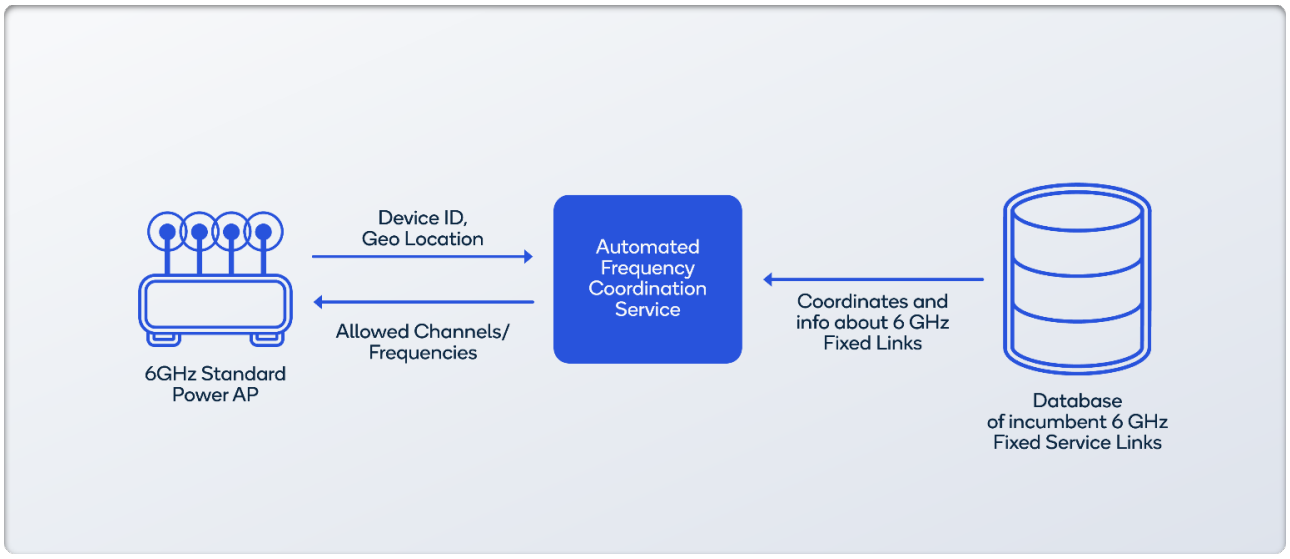


Figure 9: Basic operation of an AFC System

SP devices are required to repeat the AFC inquiry process at least once per day. This ensures protection of newly licensed incumbents.

2.6 SP Client Devices

While 6GHz SP APs are required to consult with an AFC system before they can operate at standard power levels, client devices are able to operate at SP client levels (at 6dB below the AP's authorized power level) when associated with a SP AP without completing an AFC inquiry. However, as shown in Figure 2, client devices certified as Dual Client can operate under control of either a LPI AP or a SP AP.

2.7 AFC Service Operators

In the U.S. and Canada, the respective national regulatory agencies FCC and ISED have created the opportunity for multiple parties to become AFC system operators and provide AFC service to users such as enterprises, small and medium businesses, government entities, or consumers. Additionally, parties such as broadband service providers or Wi-Fi AP network equipment vendors may also procure the AFC service on behalf of their end users. Several other countries and regulatory agencies have also issued consultations for AFC-like systems, including Brazil, CEPT, Australia, Korea, among others.

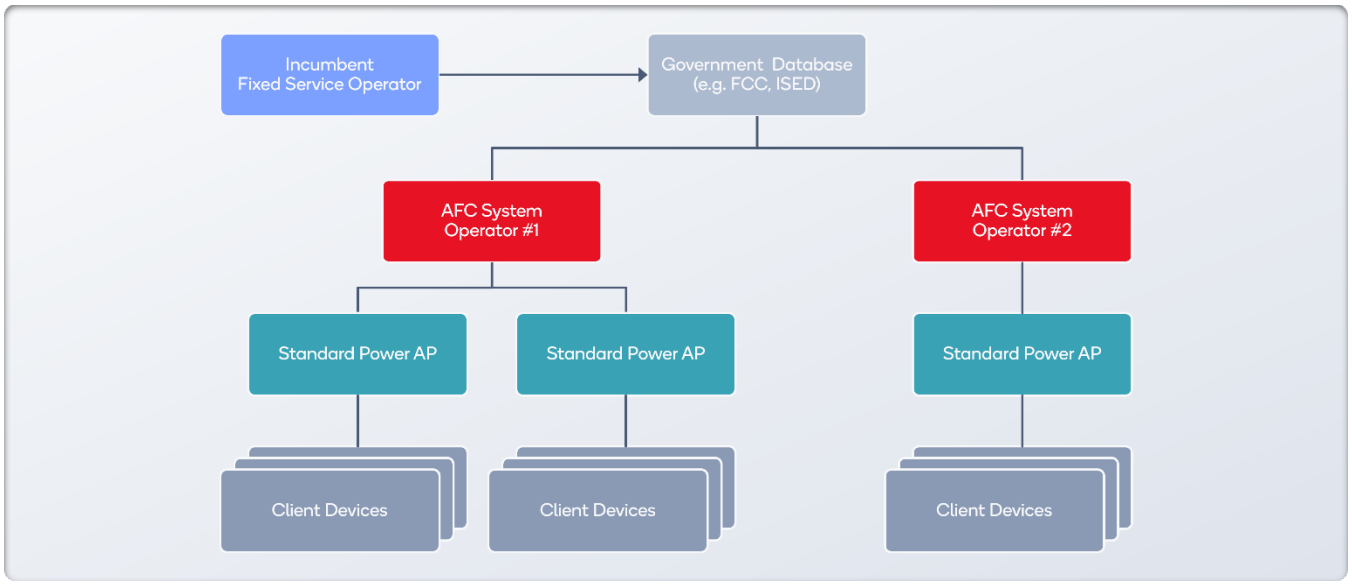


Figure 10: AFC Service Provider / Operator model

The Qualcomm AFC Service is approved to operate in the U.S. and in Canada, by the FCC and ISED respectively.

3 Qualcomm AFC Suite

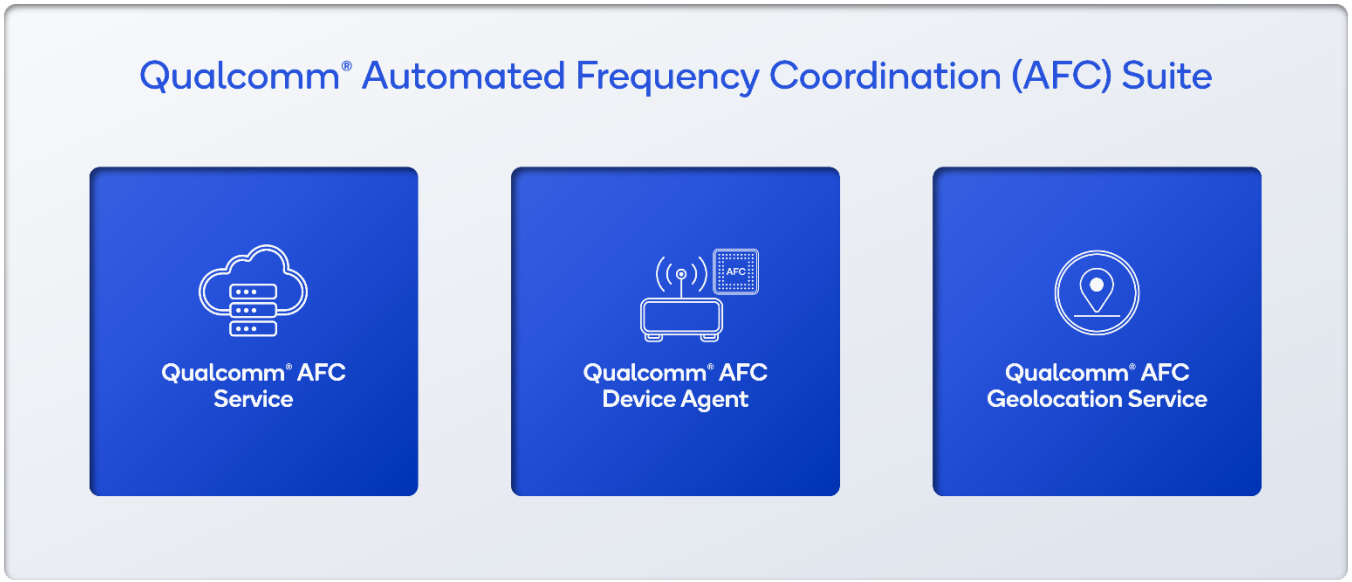


Figure 11: Qualcomm Technologies' end-to-end AFC solution

Three main components are necessary for a Wi-Fi AP to operate at SP levels (either outdoor or indoor) in the U.S. and Canada. These components are:

- An embedded AFC agent capable of securely communicating with an AFC system to receive channel availability information via standard-defined APIs and adjusting its operating channel and power level.
- Geolocation functionality designed to enable the AP to automatically determine geographic coordinates and elevation along with associated uncertainties.
- An AFC System using a database of incumbent systems to determine the frequency and power availability at the specific location provided by the APs.

Qualcomm Technologies has developed all the components that comprise a full end-to-end AFC suite. Available for customer device integration, this turnkey silicon-to-cloud offering is designed to meet regulatory and certification requirements. Qualcomm AFC Suite ensures a simple customer deployment model, is secure, robust, and scalable to support millions of devices.

The Qualcomm AFC Suite is architected in a modular fashion, with all three components operating independently and communicating via standard-defined interfaces. Significant

synergies are achieved by combining multiple elements of the full solution. For example, using Qualcomm® AFC Geolocation Service in conjunction with Qualcomm® AFC Service enables solutions that do not require dedicated geolocation hardware, such as GPS and barometer sensor, in the APs. Furthermore, the use of Qualcomm Technologies' pre-integrated Qualcomm® AFC Device Agent, an AFC AP agent software, significantly streamlines OEM software development and accelerates time-to-market.

In the following sections of this paper, the Qualcomm AFC Suite is described from a single stand-alone AP perspective. The Qualcomm AFC Suite also supports large scale enterprise implementations, whereby Network Controllers can serve as proxies for one or multiple APs, and the AFC service processes batch AFC requests from multiple devices in the network.

3.1 Qualcomm AFC Service

Qualcomm AFC Service uses a high-performance and secure cloud-based AFC System. At the heart of Qualcomm AFC System lies the calculation engine, which determines channel and power availability based on the current 6GHz licensed incumbent information. When a Standard Power Access Point sends a query for spectrum availability, the calculation engine evaluates frequency availability and calculates the maximum power that the Standard Power Access Point can transmit on a given channel.

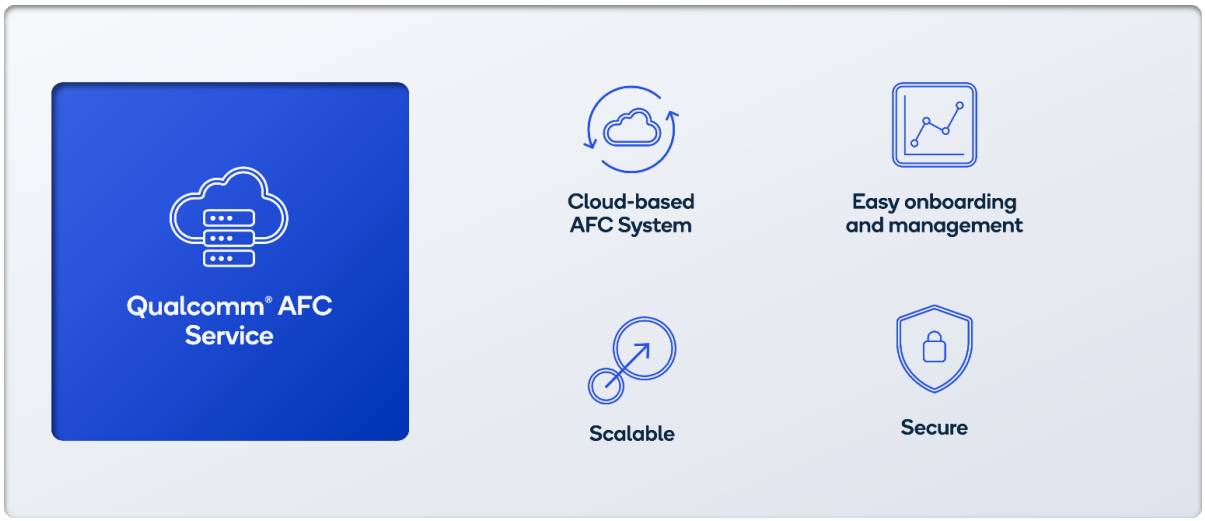


Figure 12 Qualcomm AFC Service

The determination is based on calculations of a protection zone (accounting for both in-channel and adjacent channel interference) around the 6GHz licensed incumbent's receiver. Inputs from the incumbent systems database, the requestor Standard Power x's location and propagation models considering parameters such as terrain and climate data, are used in calculations.

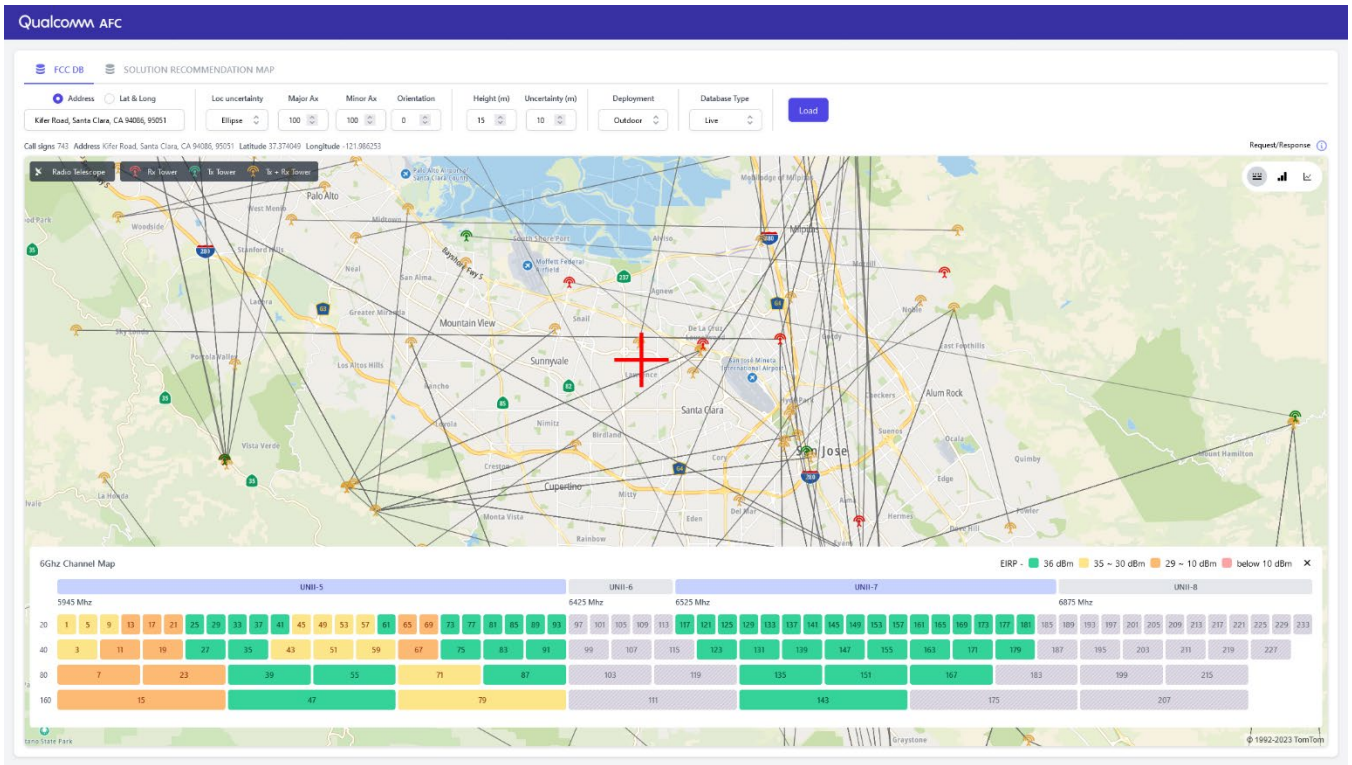


Figure 13: Qualcomm AFC System user interface

This turnkey AFC system makes it easy for network equipment manufacturers to integrate and onboard new devices with dashboards for device management and proxy mode for batch request processing. The cloud-based system has been designed for scalable operations to support millions of devices and secured using the latest industry standards. To facilitate integration, interoperability and certification, Qualcomm AFC System has been developed in accordance with Wi-Fi Alliance's 'AFC System to AFC Device Interface Specification'. The Wi-Fi Alliance's specification defines an open API for Standard Power capable 6GHz Access Points to communicate with an AFC system.

Our AFC System implementation allows for rapid response to changes in regulatory requirements and in location-specific information and enables AFC customers to expand to additional geographies when allowed by regulators. While initial users of AFC services will be Wi-Fi 6E and

Wi-Fi 7 Standard Power systems, Qualcomm Technologies' AFC implementation could be extended to enable alternative non-Wi-Fi technologies in a similar fashion, such as 5G NR-U.

The Qualcomm AFC Service is approved to operate in the U.S. and in Canada, by the FCC and ISED respectively.

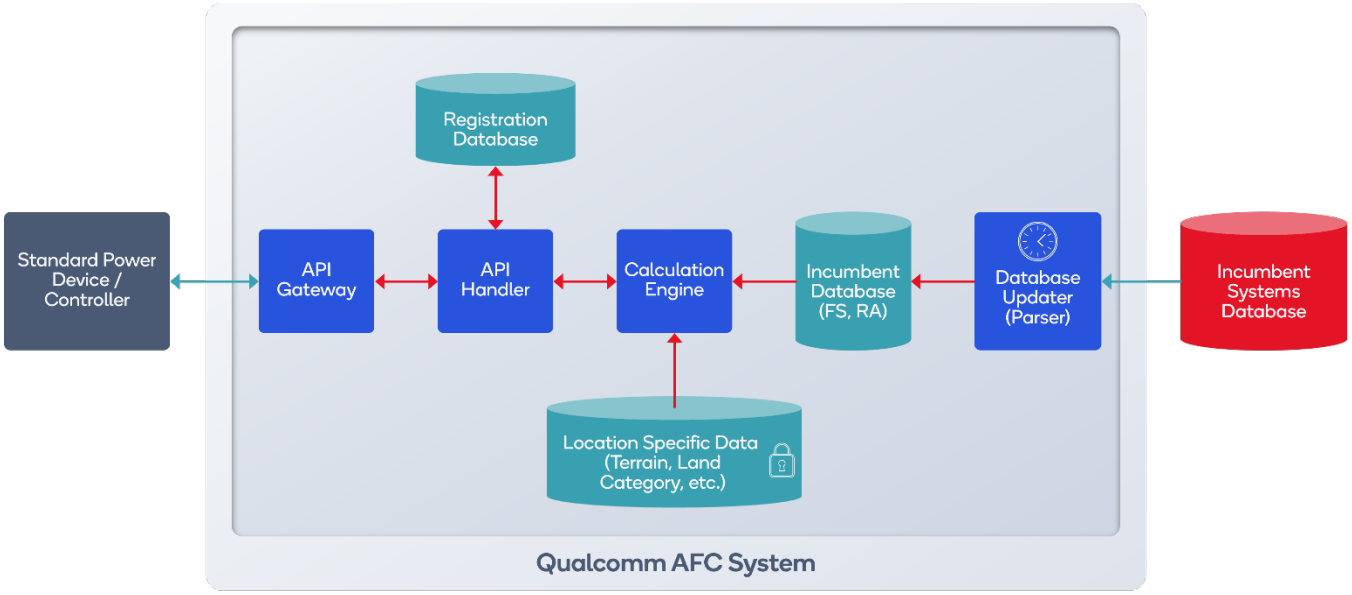


Figure 14: Qualcomm AFC System overview

3.2 Qualcomm AFC Device Agent

Figure 15: Qualcomm AFC Device Agent for platform portfolio

A Standard Power capable Wi-Fi Access Point implementation requires an embedded AFC device agent capable of securely communicating its geolocation with an AFC system, receive channel availability information via standard-defined APIs and adjust its operating channel and power level.

The Qualcomm AFC Device Agent enables seamless device integration across Qualcomm Technologies' full portfolio of Wi-Fi 6E and Wi-Fi 7 networking platforms, ensuring streamlined deployment and fast time-to-market with minimal software integration.

Qualcomm Technologies' advanced Wi-Fi 6E, and 7 networking platforms support solutions ranging from home mesh systems to high performance broadband gateways, to massive capacity Access Points for enterprise and public venues.

- Qualcomm® Networking Pro Series Platforms combine superior connectivity, computing power, and intelligence. These high-performance enterprise solutions keep users connected, with platform options that can peak at a system capacity of 33 Gbps designed to deliver high bandwidth connectivity in businesses, schools, and venues with hundreds or thousands of simultaneous users.
- Qualcomm® Immersive Home Platforms enable compact, power-efficient, and cost-effective designs with a modular and scalable architecture to deliver a premium Wi-Fi user experience for virtually every size home – powerful enough to support highly demanding networks with innovative mesh Wi-Fi capabilities and Wi-Fi 6E and 7 connectivity.
- The Qualcomm® 10G Fiber Gateway Platform integrates high performance Wi-Fi 7 with 10G-PON broadband access. This highly scalable carrier gateway platform enables broadband service providers to deliver home gateways combining high-performance connectivity, open software architecture with application optimized Wi-Fi 7 for a superior subscriber's quality of experience.

3.3 Qualcomm AFC Geolocation Solutions

3.3.1 Geolocation Requirements

Under the U.S. regulatory rules[5], SP devices must be able to automatically determine their geographic coordinates (X, Y axes) and height (Z axis) along with associated uncertainties in meters at a 95% confidence level.

In addition, the following requirements are spelled out in the regulations:

- SP AP must report coordinates and location uncertainty automatically to an AFC system at the time of activation from a power-off condition, i.e., geolocation must be determined every time the device power cycles unless it has an approved method to verify its location has not changed after a power cycle.
- Manual entry of geolocation coordinates is not permitted.
- An external geolocation source can be used, which can be connected through either a secure wired or wireless connection.
- A single geolocation source may provide location information to multiple SP APs or fixed client devices[6].

[5] See 47 CFR 15.407(k)(9) for detailed rules available at https://www.ecfr.gov/current/title-47/chapter-I/subchapter-A/part-15#p-15.407(a)

[6] This requirement is relevant for installations like multi-AP mesh system installations in residential or enterprise environments and SMB multi-AP deployments.

- For Standard Power APs using an external geolocation capability, the uncertainty reported must account for the accuracy of the geolocation source plus the separation distance between the geolocation source and the SP AP.

The location uncertainty can be visualized as a 3-dimensional volume, with 95% certainty that the AP is located within this volume. The volume of the uncertainty zone is inversely proportional to the accuracy of the geolocation technology used by the AP. Therefore, a highly accurate locationing technology will yield a smaller volume than a less accurate one. As will be covered in section 3.4, the uncertainty zone derived from accumulated inaccuracies has a direct impact on the number of channels available to the SP AP, and a larger volume will reduce channel availability.

The impact of a SP AP's height on available spectrum is significant since locations higher up in buildings increase the likelihood for interference into the incumbent services which are typically installed at elevated locations.

3.3.2 Qualcomm AFC Geolocation Solution Portfolio

Figure 16: Qualcomm Geolocation Solutions

While the FCC and ISED require an automatic determination of the Standard Power AP's location, the technology used by network equipment manufacturers to source this geolocation is not mandated as long as the 95% confidence level requirements are met. Solutions providers are therefore able to select from multiple geolocation technologies to find a method that is best

suited for their specific deployment scenarios. Qualcomm Technologies has developed a comprehensive set of geolocation methods to span deployment scenarios and accuracy requirements from residential to large enterprise deployments, providing unmatched flexibility and scalability to network equipment manufacturers.

A. Qualcomm® GNSS Solutions

A GNSS receiver can be embedded in the SP AP to provide longitude, latitude, and height coordinates. Qualcomm Technologies provides chipsets, software, and reference design integration for GNSS/GPS, including Ephemeris data service for improved accuracy.

GPS implementations for outdoor SP APs can generally achieve horizontal accuracy below 5 meters at the 95% confidence level. For indoor implementations, accuracies can vary significantly. Qualcomm Technologies measurements of GPS performance in indoor installations showed horizontal accuracies of from +/- 5 meters to +/- 9 meters in a single-family home. For measurements in a high-rise office building, 95 percentile accuracies vary between +/- 10 meters to +/-45 meters, variation mostly driven by how near or far an AP is installed in relation to windows at the outer edge of the building.

B. Qualcomm® Terrestrial Positioning Service (TPS)

An alternative approach available in the Qualcomm AFC Suite, Qualcomm TPS is an easy-to-deploy cloud-based service that uses existing network infrastructure to resolve location, using large global database of billions of geolocated Wi-Fi APs. This innovative solution provides geolocation capabilities without any additional hardware requirement that come with alternative location systems such as a GNSS receiver. The Wi-Fi based geolocation service is well suited for feature-constrained devices along with those used indoors and underground where GPS signals are obstructed.

Using this service, the SP device will scan for Wi-Fi beacons and record each Wi-Fi AP's MAC Address and received signal strength indicators (RSSI). The recorded data is transmitted to the Qualcomm TPS cloud service, which in-turn determines the location of the SP device by correlating this information to our global database of geolocated Wi-Fi APs.

Based on measurements campaigns conducted by Qualcomm Technologies, this implementation can achieve average longitude and latitude accuracies of around 80 meters at 95% confidence levels. This cloud-based service provides unmatched flexibility as it enables network equipment manufacturers to rapidly adopt a geolocation solution in their existing AP designs without additional dedicated hardware. This capability can even be added to devices in the field as a simple software upgrade.

C. Barometric/Pressure Sensor Calibration Service for Elevation Determination

Elevation determination refers to estimation of height Above Mean Sea Level (AMSL) or above ground on which an object is placed. Using GNSS/GPS for elevation determination, a SP AP operating outdoors can typically achieve accuracies of +/- 6 meters at the 95% confidence level[7]. However, there are instances where GPS measurements cannot be used for elevation. Because elevation determination relies on satellites that are observed in the horizontal plane, signal blockage is quite common, especially for APs installed indoors, even in instances where signal from satellites above the GPS receiver can be used for horizontal (longitude, latitude) positioning.

Figure 17: AP Elevation determination

[7] https://www.nstb.tc.faa.gov/reports/2020_Q4_SPS_PAN_v2.0.pdf#page=38

Using barometric pressure to determine elevation provides a more consistent and reliable method. In this model, APs fitted with barometric pressure sensors provide pressure and temperature readings. The recorded data is transmitted to the Qualcomm AFC Geolocation Service. The cloud-based service in-turn determines the height of the AP and associated uncertainty using models integrating weather related variations in atmospheric barometric pressure.

Based on internal analysis conducted by Qualcomm Technologies, the implementation can achieve accuracies of +/- 18 m at the 95% confidence level with barometric pressure readings.

D. 3D Buildings Database-based Elevation Determination

For devices that are not fitted with barometric pressure sensors, an alternate method for elevation determination is the use of building databases. Provided with the horizontal location of the SP AP, the Qualcomm AFC Geolocation Service resolves the corresponding height and associated uncertainty based on the known building heights for that location. When the horizontal location uncertainty space reported by the SP AP includes a building, the service will report an Above Ground Level (AGL) elevation which covers the height of the building, including a fixed margin.

Considering that around 70% of housing in the US has two floors or less and around 90% of housing has three floors or less, very accurate height information can be obtained using this method without need for additional hardware deployed in the AP. This service enables network equipment manufacturers to rapidly adopt a height determination solution in their existing AP designs without additional dedicated hardware. This capability can even be added to devices in the field as a simple software upgrade.

E. Wi-Fi Ranging Based Locationing

Wi-Fi ranging technology uses time-of-flight measurements to estimate the distance between two Wi-Fi devices. Also called Fine Timing Measurement or FTM, this technology has been enabling application developers and other solutions implementers to provide a variety of services including indoor navigation, asset tracking, geofencing, access control (locking/unlocking), and device operation, all with increased accuracy and performance without sacrificing real estate or overall cost. Since their implementation in 2009,

Qualcomm® Wi-Fi ranging technologies have been shipping in devices globally with clear signs of accelerated adoption. Ranging capabilities have also continued to improve over multiple generations, with modern Wi-Fi ranging technology offering high levels of accuracy in real-world scenarios.

Used in the context of AFC, this technology is especially relevant for the enterprise segment. Using APs powered by Qualcomm Technologies' networking platforms supporting AP-to-AP time-of-flight distance measurement, it enables location determination for APs that are not capable of obtaining GPS location fixes themselves, for example, APs that are deep inside a building. Such APs can obtain their location from APs that have location information through GPS or other methods and be enabled for SP operation. Accuracies of AP-to-AP FTM distance measurements are typically well within 1 meter.

In summary, the Qualcomm AFC Geolocation Solutions portfolio provides a wide range of capabilities to adapt to network equipment vendors' and broadband service providers' unique needs and deployment models. Depending on the market segment served, the geolocation method can be scaled to serve all service tiers. For example, cost-effective consumer retail routers or mesh systems could use a cloud-based geolocation service provided by Qualcomm TPS and building elevation database, alleviating the need to equip devices with geolocation hardware, whereas enterprise systems may be fitted with GPS or barometer sensors. With a turnkey solution for each deployment model, Qualcomm AFC Geolocation Solutions enable fast deployment of new device offerings and a diverse product portfolio.

Figure 18: A full portfolio of geolocation solutions

3.4 Impact of Location and Height Accuracies on Channel Availability

In the previous sections we highlighted the different methods available as part of the Qualcomm AFC Geolocation Solution to determine horizontal and vertical location. Depending on the technology used, the size of the uncertainty volume in which an AP can be located for AFC purposes can vary. The volume of the uncertainty zone depends on the accuracy of the geolocation technology used by the AP. This means that different geolocation methods will yield a different number of channels available for Standard Power operations. Hence, it is worthwhile to analyze the impact of accuracies on the actual channels and power levels available to the end user.

To this end, Qualcomm Technologies conducted an analysis on a large sample set of 1,000 AP locations distributed in the San Francisco Bay area. For each AP location, our simulation determined the number of available Standard Power channels yielded by different geolocation methods. Modeling the uncertainty associated with the various geolocation methods available, the following scenarios are compared:

- GPS: This scenario assumes APs fitted with a GPS receiver. The geolocation is modeled using 10 meters horizontal and +/-10 meters vertical uncertainty.

- GPS & Weather station: This scenario assumes APs fitted with a GPS receiver, a barometer sensor, and access to private weather stations information for elevation determination. The geolocation is modeled using 10 meters horizontal uncertainty and a vertical uncertainty of +/-3 meters.
- Wi-Fi & Barometer: This scenario assumes APs fitted only with a barometer sensor using Qualcomm Technologies' calibration solution (for elevation determination) and using Qualcomm TPS (for horizontal determination). The geolocation is modeled using 80 meters horizontal uncertainty and a vertical uncertainty of +/-15 meters.
- Wi-Fi & Building: This scenario assumes that APs are not fitted with any additional hardware and only using Qualcomm TPS (for horizontal determination) and Qualcomm Technologies' building database (for elevation determination). The geolocation is modeled using 80 meters horizontal uncertainty. Vertical uncertainty of the APs is determined using locations of the APs and our building database solution.

The horizontal locations of devices in this analysis represent actual Wi-Fi APs locations obtained from Qualcomm Technologies' TPS database. Figure 15 and Figure 16 compares Standard Power channel availability yielded by the various geolocation methods for 20 MHz and 160 MHz channel sizes in indoor residential environments. While not presented in this paper for brevity, our analysis for enterprise and outdoor environments resulted in similar conclusions in terms of channel availability for different methods studied.

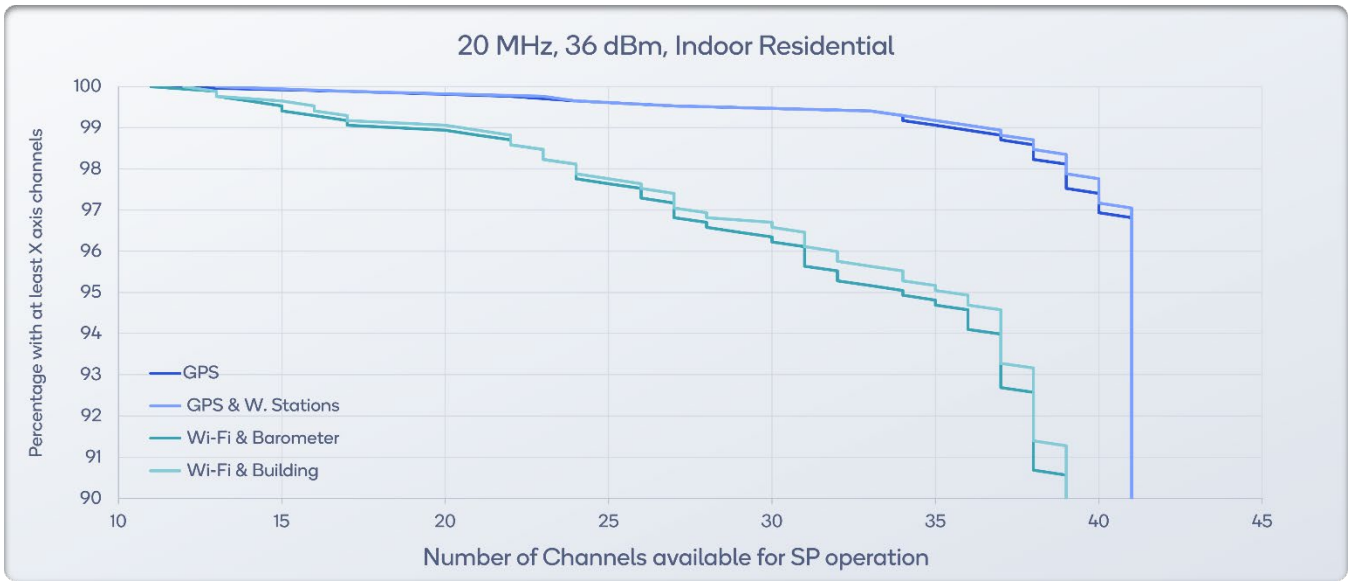


Figure 19: Analysis of Standard Power 20 MHz channel availability with different geolocation methods (San Francisco Bay Area, indoor residential deployment)

Figure 20: Analysis of Standard Power 160 MHz channel availability with different geolocation methods (San Francisco Bay Area, residential deployments)

While methods using APs fitted with dedicated hardware (GPS receiver and barometer sensor) have access to the highest number of channels, it should be noted that in all the scenarios considered, 90% of AP locations have access to over 90% of the 6GHz SP channels regardless of the geolocation method employed.

4 Accelerating the Future of SP 6GHz Wi-Fi

4.1 A Complete End-to-End AFC Solution

Figure 21: Qualcomm AFC Suite

With the Qualcomm AFC Suite, Qualcomm Technologies is accelerating the future of SP 6GHz Wi-Fi. The end-to-end, ready-to-deploy solution contains all the building blocks enabling equipment manufacturers and service providers to quickly and efficiently deploy new devices maximizing the 6GHz spectrum with AFC. Serving a broad set of customers across diverse verticals and with varying levels of in-house development capabilities, our AFC suite is designed to meet the needs and use cases of our customers across all market segments with:

- A standard based and interoperable solution approved for operation by regulatory bodies.
- A single-source solution for all elements comprising an end-to-end AFC deployment and addressing all aspects of software integration, hardware customization and service operation, reducing design risks.
- Streamlined software development with AFC agent device integration enabling manufacturers and developers with rapid time-to-market.
- Streamlined operations with onboarding and license management into AP designs to manage devices, services, and insights seamlessly through the cloud.
- A cost-effective geolocation solution with no incremental AP geolocation hardware requirements, driving bill-of-material savings.
- In-field upgradability, enabling activation of AFC services for SP APs already installed in the field.

Using the silicon-to-cloud Qualcomm AFC suite, our customers are uniquely positioned to quickly innovate and create competitive differentiation with their Standard Power devices offerings.

4.2 A Flexible AFC Solution

Figure 22: Qualcomm AFC Suite Flexibility

The Qualcomm AFC Suite was developed with the anticipation that different deployment models will be required to accommodate the wide variety of customer use cases and deployments. In addition to the complete end-to-end solution, the Qualcomm AFC Suite is designed for flexible support of equipment manufacturers and service providers using third-party Wi-Fi silicon, geolocation methods or AFC systems. Significant synergies are achieved by combining all elements of the Qualcomm Technologies' full AFC solution, but the solution is architected in a modular fashion, with all three components of the Qualcomm AFC Suite operating independently and communicating via standard-defined interfaces. Integration can be achieved for customers whose product offering includes a mix of Access Points using Qualcomm Technologies' and third-party Wi-Fi silicon, or customers who intend to use Qualcomm Technologies' Standard Power AP designs but use a third-party geolocation or AFC systems.

5 Conclusions

Standard Power 6GHz Wi-Fi operation unlocks new use cases and provides significant benefits for consumer and enterprise deployments. With up to sixty-three times stronger signal, residential end-users benefit from this higher-power, longer-range version of Wi-Fi 6E and Wi-Fi 7 indoors for mesh backhaul and large home coverage. Outdoors, 6GHz Wi-Fi operation makes weatherized enclosure and connectorized antennas possible, opening the door for many use cases such as Wireless ISP, campus, and outdoor event venue coverage as well as Wi-Fi use in manufacturing and industrial settings.

AFC is an important mechanism designed to control operation of SP devices to manage coexistence with incumbent users in the 6GHz spectrum. This innovative and efficient spectrum sharing mechanism ensures that incumbents are protected from harmful interference by license-exempt devices and is required in the U.S. and Canada for 6GHz Wi-Fi SP operation.

Enabling SP operation under control of an AFC system requires the use of a broad set of technologies and services:

- An embedded AFC agent capable of securely communicating with an AFC system to receive channel availability information via standard-defined APIs and adjust its operating channel and power level.
- Geolocation functionality designed to enable the AP to automatically determine geographic coordinates and elevation along with associated uncertainties.
- An AFC System using a database of incumbent systems to determine the frequency and power availability at the specific location provided by the APs.

Including all the components of a full end-to-end AFC solution, the Qualcomm AFC Suite is unique in its scope and level of pre-integration and enables manufacturers and developers to reduce design risks and time-to-market by addressing all aspects of software integration, hardware customization and service operation. With unique capabilities such as a cloud-based geolocation service, the Qualcomm AFC Suite contributes significantly to the overall cost effectiveness of the complete solution. With the silicon-to-cloud Qualcomm AFC Suite, our customers are uniquely positioned to quickly innovate and create competitive differentiation with their Standard Power devices offerings.

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