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## **Successful Wi-Fi 6 Deployment to Customer Homes**

### **A Service Provider's Guide to Intelligently Controlling And Optimizing the Wi-Fi 6 Home Network.**

A Technical Paper prepared for SCTE by

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## 1. Introduction

Hailed as a new era for Wi-Fi connectivity, 802.11ax—known better as Wi-Fi 6—has created much excitement and anticipation. Capable of more than doubling the speeds of its predecessor, 802.11ac (or Wi-Fi 5), Wi-Fi 6 promises to transform the home network.

As well as boosting throughputs, this new technology improves overall system capacity, security, and even power consumption and battery life. And the timing couldn't be better. Not only are consumers relying on home Wi-Fi more than ever, but the smart home is also evolving to include more connected devices, immersive experiences, and bandwidth-hungry applications.

The Wi-Fi Alliance anticipates nearly 2 billion Wi-Fi 6 devices to be shipped in 2021 to consumers and organizations.1 Wi-Fi 6 products entering the market will spark renewed consumer interest in Wi-Fi upgrades, including deployments of Wi-Fi 6 home networks. It's an exciting opportunity for Communications Service Providers (CSPs) to elevate their offerings to subscribers.

There's no doubt that the new capabilities of Wi-Fi 6 will improve the user experience in all connected spaces. But maximizing its full potential means optimizing Wi-Fi networks in ways that are both more critical and more complex.

Wi-Fi 6 connectivity in any space is only as good as the system controlling it. To deliver on the promise of this new technology for their customers, CSPs must understand the limitations of Wi-Fi 6 home deployments and the requirements for intelligently managing the networks.

## 2. The State Of The Wi-Fi 6 Industry And The Market

Wi-Fi has become as ubiquitous as the internet itself. Considering that Wi-Fi 6 brings the first major improvement to 2.4 GHz band in a decade, the buzz surrounding it is understandable.

And a lot has changed in that decade. The home network is much more complicated and customers are increasingly relying on that Wi-Fi connectivity for work, school, and entertainment:

- The average US household served by Plume has 14.5 connected devices.
- 28% of consumers use smart home devices such as cameras and thermostats. (Deloitte)
- The number of global shipments of smart devices is expected to grow 71% between 2019 and 2023 (from 814.8 million to 1.4 billion). (eMarketer)

The excitement about Wi-Fi 6 can be best summarized in the words of Federal Communication Commission (FCC) Chairman Ajit Pai, who said, "The American consumer's wireless experience is about to be transformed for the better."

The Wi-Fi 6 market is just emerging. But the technology's potential to transform the home network is tremendous, especially as the smart home and work-from-home (WFH) trends gain momentum. Research firm Strategy Analytics sees the wireless home becoming "one of the leading technology trends of the early 21st century."

Here's just a glimpse of what the industry forecasts:

- 17 billion home devices will be in use by 2030 globally, with Wi-Fi 6 accounting for a third of device sales by 2023. (ABI Research)

- Wi-Fi 6 will become the predominant Wi-Fi standard both for consumers and enterprises by 2023. (Cisco)
- On the public Wi-Fi front, Wi-Fi 6 hotspots will grow 13-fold between 2020 and 2023, comprising 11% of public Wi-Fi hotspots by 2023. (Wi-Fi Alliance)
- 2 billion Wi-Fi 6 devices will be shipped in 2021 to consumers, enterprises, and public agencies. (Data aggregated from the [Wi-Fi Alliance Product Finder](#), last accessed February 2, 2021.)

## 2.1. Market Developments

Rapid growth of the Wi-Fi 6 market began when the Wi-Fi Alliance launched its Wi-Fi CERTIFIED 6™ certification program, based on the IEEE 802.11ax standards, in September 2019. Even before that, some industry players—including networking vendors—began building the next-generation Wi-Fi infrastructure.

By February 2021, the Wi-Fi Alliance had certified nearly 1,400 different Wi-Fi 6 products. More than a third of those were in the router category, including home gateways. While the smart home category included only a few certified devices initially, some smart TVs, tablets, and even a couple of gaming systems were already available. It's only a matter of time before the consumer market explodes.

Momentum was also built in 2020 for Wi-Fi 6E (the E stands for Extended). Wi-Fi 6E is simply Wi-Fi 6 operating in the 6 GHz frequency band. The 6 GHz band has recently been allocated for Wi-Fi in the US, EU, and other geos. While this band promises more spectrum, better availability of 160 MHz wide channels, and lower interference levels, it requires more sophisticated management.

Notable Wi-Fi 6E events include:

- Broadcom announced a portfolio of residential and enterprise access point (AP) solutions for 6 GHz WLAN in January 2020, followed by a February announcement of a Wi-Fi 6E chipset.
- In April 2020, the United States became the first country to open the 6 GHz spectrum, and some have called the decision by the FCC historic and monumental.
- In December 2020, FCC authorized the first Wi-Fi 6E device, a Broadcom low-power indoor transmitter. In his statement, FCC Chairman Ajit Pai said this was "an exciting glimpse of America's Wi-Fi future."
- In early January 2021, the Wi-Fi Alliance introduced Wi-Fi 6E certifications, which will use enhanced, WPA3 security. The Alliance has certified more than a dozen products, including routers, from vendors such as Intel, Qualcomm, and Samsung, as of February.

### 2.1.1. Wi-Fi 6 Vs. 6E Devices

Wi-Fi 6E devices will be backward compatible with Wi-Fi 6 and previous Wi-Fi standards. But to take advantage of those new 6 GHz channels in Wi-Fi 6E, you'll need to be using devices that support it. In other words, you'll only be using Wi-Fi 6E once you pair a 6E-enabled client device (like a laptop or smartphone) and a 6E-enabled access point. Wi-Fi 6 devices paired with a 6E-enabled router will still be using the typical 5 GHz or 2.4 GHz channels.

### 3. Key Wi-Fi 6 Features And Benefits

In the home environment, the network is becoming more congested as a larger number of devices connect to Wi-Fi and customers run more bandwidth-heavy applications such as 4K video streaming, virtual reality (VR) gaming, and video conferencing. Wi-Fi 6 brings key changes to several areas, including:

- 2x higher throughput in low-congested environments
- Improved power efficiency
- 2x more devices that can be supported efficiently (to 8)

The new features are designed to better handle different types of traffic simultaneously from multiple users, as well as improve coverage for overlapping networks and dense environments. In practice, however, many of the new capabilities have limitations and drawbacks. Mitigating the issues will require advanced tools that manage and optimize the home networks.

## THE POTENTIAL OF WIFI 6

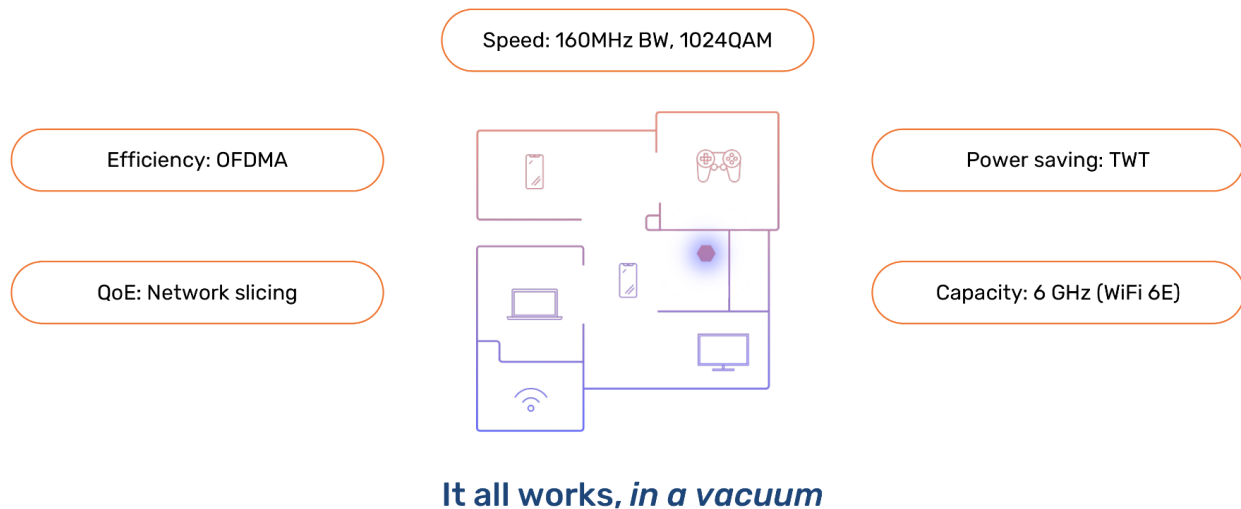


Figure 1 - The Main Advantages of Wi-Fi 6

#### 3.1. An Overview Of New Wi-Fi 6 Features

##### 3.1.1. 160 MHz Channel Bandwidth

The wider the channel used, the higher the data rate. While the Wi-Fi 5 technology officially supported 160 MHz capabilities, few devices actually offered channel bandwidths greater than 80 MHz. Although this is technically not a new feature, the expectation is for most Wi-Fi 6 devices coming to the market to support 160 MHz channel bandwidths.

### **3.1.2. 1024-QAM**

Wi-Fi 6 goes from 256 quadrature amplitude modulation (256-QAM) to 1024-QAM, increasing the physical layer data rate by 25% at short range. Essentially, this modulation brings a more dense packing of bits into the signal, thereby boosting the network speed by increasing the data rate for the channel.

### **3.1.3. OFDMA**

Uplink and downlink orthogonal frequency-division multiple access, or OFDMA, is a marquee feature of Wi-Fi 6, which allows for a single transmission to communicate with a large number of devices. It greatly improves efficiency and capacity by subdividing the channel into smaller frequency allocations (resource units) that are transmitted from one AP in parallel.

### **3.1.4. Resource Unit Reservations**

The resource units, or smaller frequency slices, that OFDMA operates with can get allocated to particular clients. This allocation changes dynamically over time, which is what allows a single, wide, efficient transmission to serve multiple clients at once. Reserving resource units for particular clients or data flows provides guaranteed Quality of Service (QoS) to those clients or flows because a fixed amount of bandwidth within the network is allocated specifically for that traffic.

### **3.1.5. Target Wake Time**

First developed for 802.11 ah (900 MHz Wi-Fi, branded "Wi-Fi HaLow" by the Wi-Fi Alliance), target wake time (TWT) is expected to be deployed widely with Wi-Fi 6. This mechanism improves battery life for devices that are transmitting only occasionally or at a low-duty cycle. The AP creates a schedule with specific times for each client to be awake and reserves that time so no other devices can transmit during that window, giving the waking devices clear airwaves to quickly communicate and return to sleep.

### **3.1.6. UL-MU-MIMO**

The Uplink Multi-User Multiple Input Multiple Output (UL-MU-MIMO) is the companion to Downlink (DL) MU-MIMO that was standardized and implemented in Wi-Fi 5. UL-MU-MIMO allows multiple devices to be transmitting at the same time to the same AP, improving efficiency and uplink capacity. With OFDMA, the different devices transmitting at the same time use different parts of the frequency spectrum. In the MU-MIMO case, the devices involved rely on multiple antennas to separate the traffic by spatial means, so the AP can independently receive signals coming from clients in different directions.

### **3.1.7. BSS Color**

Basic Service Set (BSS) color added with Wi-Fi 6 allows more efficient airtime usage between overlapping networks that are on the same frequency channel. This technique marks (or "color-codes") shared frequencies at the very beginning of the packet to indicate which network the packet belongs to and enables devices to make a very quick assessment if they are safe to transmit or must defer to traffic coming from a network with a different color.

### **3.1.8. 6 GHz Frequency**

Wi-Fi 6E extends Wi-Fi 6 capabilities to the 6 GHz spectrum, previously only available to licensed users. This is considered a big step, as the need has become more urgent to prevent congestion on existing frequencies. The industry has been advocating for some time for the allocation of more bandwidth for

unlicensed use. The new spectrum makes available up to seven superwide 160 MHz channels that can support high-bandwidth applications such as unified communications and industrial IoT. For home networks, use cases that can benefit from the low-latency, higher-speed Wi-Fi include augmented reality and virtual reality.

## 4. Wi-Fi 6 Network Optimization And Controls

As highlighted earlier, the new or enhanced Wi-Fi 6 capabilities are not without issues. To ensure these features work to their full potential and truly benefit customers, CSPs need to implement sophisticated controls and optimize the network. These controls are especially critical in today's congested home Wi-Fi environments and in dense areas where issues such as interference arise.

### 4.1. 160 MHz Channel Bandwidth

Doubling the channel width from 80 MHz to 160 MHz should double throughput. So, in theory, customers would see twice-as-fast downloads, double resolution, and so forth, with the double data rate. The problem is that, in most countries, only two independent 160 MHz channels are available. In a dense environment, such as an apartment complex or even suburban homes on small lots, two different customers are likely to use an overlapping channel, leading to significant interference.

This issue can be mitigated with proper network configuration, which requires three factors:

- Intelligent sensing and prediction of the interference on 80 MHz subchannels of the 160 MHz transmissions.
- Intelligent channel allocation and bandwidth selection.
- Consideration of the complete interference picture in an environment, optimizing channel allocation across entire apartment complexes or neighboring homes.

Simple, locally managed networks can't achieve these factors. CSPs will need to handle them centrally through the cloud. For example, cloud-based interference analysis factors, loads, and device types. When considering what channel bandwidth to assign to each AP, the platform knows the history and current set of clients and loads that are present in the network at each access point. The system can then apply 160 MHz bandwidth channels where they are most needed and avoid them where they are not. Central cloud management also allows the optimal selection of channel bandwidths and frequency channels across an entire apartment building. Frequency channels can be "tiled" across the apartments, minimizing the conflicts between neighboring apartments. In cases where re-use of the same channel is unavoidable, the cloud-based optimization system can select apartments that are most able to share frequency channels based on their historical activity.

### 4.2. OFDMA

This signature Wi-Fi 6 feature stemmed from observing the poor efficiency of the small packets typically emanating from Internet of Things (IoT) and other low-data-rate devices. Each 802.11 packet has significant overhead, and to avoid collision with other transmitters, each transmitter must listen first to the medium for some time. Even if each transmission sends a modest amount of data, the overhead consumes a lot of airtime.

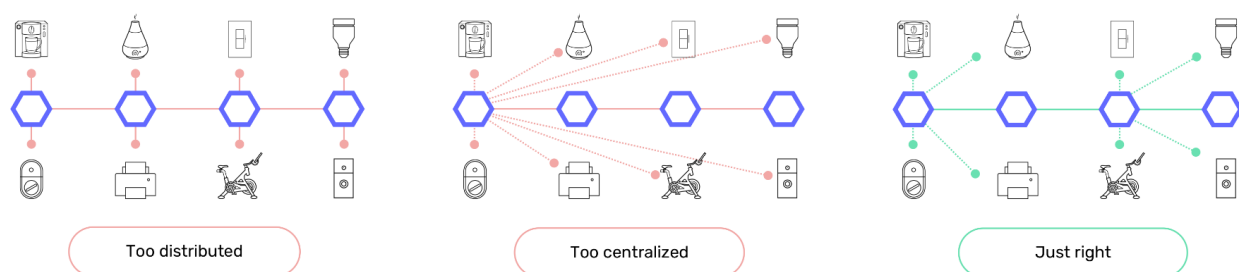
OFDMA allows transmission to multiple users simultaneously in one packet, eliminating overhead and wasted time. This capability only improves efficiency when a significant number of IoT devices are on



the same AP, each device sending or receiving a modest amount of data. But, modern Wi-Fi networks in smart homes will not always end up with a significant number of IoT devices on the same AP.

Here's why: Home networks have migrated to multi-AP topologies using mesh networks, repeaters, or multiple gateways. If the IoT devices in the home were to simply connect to the nearest AP, each AP would have few devices appropriate for grouping into OFDMA transmissions. On the other hand, forcing devices to connect to an AP that is too distant will force the data rates of these connections to drop, compromising efficiency in a different way.

## STEERING MANAGEMENT



### OFDMA-aware steering

**Figure 2 - OFDMA-Aware Steering**

Consequently, OFDMA operation requires OFDMA-aware client steering. To make complex decisions, a centralized, intelligent network controller would need:

- Knowledge of which APs and clients are Wi-Fi 6 capable.
- Historical observation and forward prediction of the data needs of each device in the home.
- The ability to make intelligent, optimized choices about which of the multiple APs each device in the home should connect to considering the capabilities, traffic load, signal strength, and data rate each device can achieve.
- The ability to steer and hold devices on the correct AP.

For all the APs and clients to work efficiently, the best arrangement must be created through rigorous optimization. This should include the ability to steer clients to APs and hold them there, even if those aren't the closest APs. The steering mechanism must be specific to each type of device because different devices behave differently to various steering mechanisms.

### 4.3. Target Wake Time

Oftentimes, the home network has several APs operating on the same frequency channel. This creates potential overlap when multiple APs try to schedule the TWT for different devices. To avoid conflict, a central scheduler can ensure that TWT periods at the co-channel APs do not overlap.

The scheduler must know:

- The transmission requirements of all the TWT clients
- The shared channels among APs
- The clients connecting to each AP
- The signal strength between the APs and clients in the home

With this data, the system can create an optimized arrangement of TWTs at each AP, covering all clients across the home network.

In a multi-dwelling unit (MDU), the optimizer could go a step further, looking across overlapping networks that it controls in the MDU and plan TWT assignments and groups across the entire building. The system would factor the cloud-based controller's knowledge of which apartments interfere with one another, and the client capabilities and load requirements in each apartment.

#### **4.4. Network Slicing**

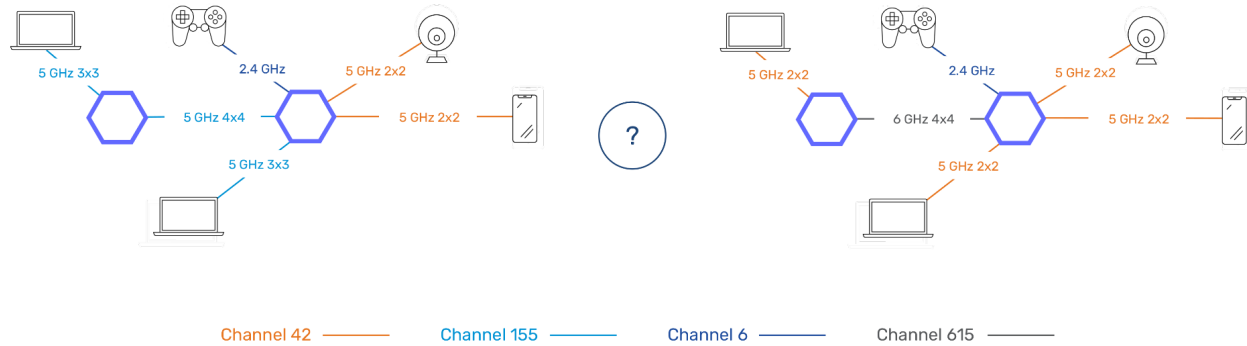
A QoS mechanism, network slicing is another way of allocating frequencies and time among different clients. This is essentially a time-division, multiple access (TDMA) method (where transmissions occur at reserved times) but has the added overlay of a divided frequency spectrum. In a home with multiple APs or in an MDU, network slicing can lead to high collision rates when both networks schedule the same time periods. The result is poor QoS, defeating the point of the time/frequency reservations. Centralized, intelligent controls can mitigate this issue by coordinating among the multiple APs.

#### **4.5. 6 GHz Frequency Band**

To protect point-to-point microwave systems that operate on the same 6 GHz spectrum, Wi-Fi 6E devices must use one of two modes:

- A low power (18dBm/63mW) that uses the low-power spectrum rules: This mode can't transmit as far or at as high a data rate because the signal is not very strong.
- Under the command of an AP that has an automated frequency control (AFC) system (30dBm/1 Watt allowed): In the US, for example, the AFC systems must check the data in an FCC database to ensure there are no microwave systems in the vicinity of the AP. There are currently around 100,000 microwave links in the US used by mobile carriers, industrial and business entities, and public safety agencies. By avoiding a frequency channel used by nearby microwave systems, the AP and its clients can operate at the high-power level, enjoying full range and data rates.

## BAND MANAGEMENT



### Band planning for tri-band 4x4, 2x2, 2x2 AP

**Figure 3 - Planning Band Management**

These operating modes will require different types of controls:

- For the low-power transmission, more complicated, multi-AP configurations will be required for an optimization system to select the appropriate network topologies, frequency assignments, and client-steering options.
- For the AFC systems, the AP will need to communicate with a smart controller that can look up the FCC database, factor in the geodata, calculate interference levels, then deliver instructions back to the AP.

For either mode, the control system needs to take into account the client types, loads, and capabilities to decide how to allocate the network's radio resources. Depending on the capabilities of the clients in the network, it is not always optimal to put one of the AP's radios in the 6 GHz band. For example, using a 6 GHz channel for the backhaul connection may help the backhaul, but it may take away the high-performance radio in the AP from the 5 GHz band. High-performance clients that do not have a 6 GHz capability may therefore connect at lower speeds, actually degrading the experience in the home.

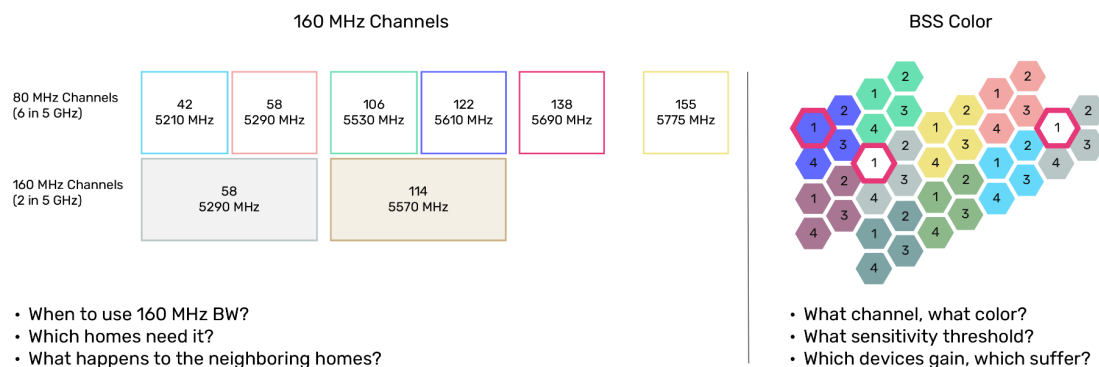
## 5. Intelligent Management Imperative For CSPs

Wi-Fi 6 brings long-anticipated improvements to a technology that's now 20 years old. The new features will solve many challenges created by the ever-expanding, increasingly more congested home network. It's undisputed that this technology takes the home network to a new level. However, Wi-Fi 6 brings additional complexities, such that simple controls can no longer satisfy the requirements of this evolved ecosystem.

To maintain the Quality of Experience (QoE) for their customers, CSPs will need to adopt an intelligent management approach. With centralized controls, ideally based in the cloud, CSPs can ensure that they're achieving the performance potential of Wi-Fi 6. More sophisticated controls, coordination, and

optimization will become especially critical as smart home adoption picks up the pace, putting further pressure on connectivity and performance.

## CHANNEL MANAGEMENT



**Need rigorous optimization across multiple homes**

**Figure 4 - Planning Channel Management**

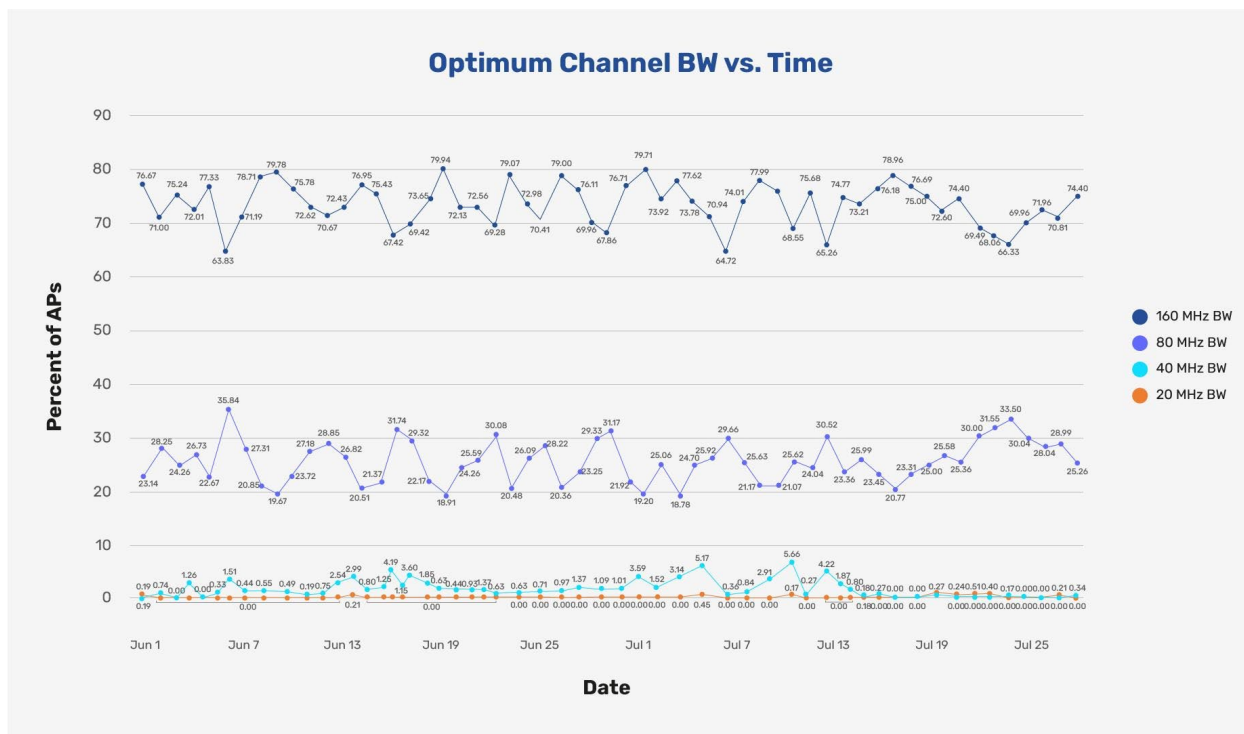
CSPs should harness the power of the cloud and artificial intelligence (AI) to make sure their subscriber's home networks are ready to support the exciting capabilities of Wi-Fi 6. The cloud offers practically infinite memory and computing power, supporting AI-driven innovation.

## 6. Measured Results

The previous sections outline the need for centralized cloud management in a Wi-Fi system, particularly when Wi-Fi 6 capabilities are being exploited. This section presents measured results of what can be achieved when centralized management is applied to real-world networks.

### 6.1. Selection Of 80 Vs. 160 MHz Channels

As described earlier, Wi-Fi 6 devices include the option to operate in 160 MHz channels, but this may not result in optimum performance. The optimization system measures the interference in homes and chooses the optimum channel bandwidth to maximize the throughput in that home. The chart below shows the percentage of homes that the system configures into 160, 80, 40, or 20 MHz. This study was conducted across a sampling of households in the United States.



**Figure 5 - Channel Bandwidth: SuperPod\_AX to SuperPod\_AX links**

Several interesting observations can be made. First, roughly 25% of homes will achieve better throughput in 80MHz mode than in 160 MHz mode. Second, the exact distribution varies on a day-by-day basis due to variance in network usage and therefore neighbor interference. Finally, there are a small number of locations that achieve the best throughput in 40 MHz mode.

Clearly, a system that sets all networks into 160 MHz mode, or one which makes a one-time selection of 160 vs. 80 MHz will result in sub-optimal performance in a significant percentage of homes.

## 6.2. DFS Impact On 160MHz

Much of the 5 GHz frequency band is shared with radar systems. Wi-Fi networks must search for the presence of radar signals, and vacate the channel if they are observed. These radar events cause significant disruption to users as the entire network switches to different frequency channels to avoid the signal that looks like radar. Often these signals are not coming from a real radar system, but are generated by other types of devices operating in the 5 GHz band, or unusual signals generated by the collision of Wi-Fi packets from multiple networks. Therefore, these radar effects can be seen anywhere in the country, but are more common where radars are present, such as near airports.

Theoretically, doubling the channel bandwidth roughly doubles the odds that a radar event will happen within the channel, requiring the system to suspend operation and switch to a different channel. However, we have studied these radar events extensively and find that they are not at all evenly distributed by location, or by frequency channel at a given location. The table below shows the measured radar event rates reported by APs in a series of locations, some with multiple APs, some with a single AP. The rates are expressed as the number of radar events per hour of operation (0.04 = one radar event per day on average). The color-coding in the diagram highlights the location, AP, and frequency channel triplets that have high (orange), medium (yellow), and low (gray radar event frequency. Note that in this diagram each

numbered channel is 20 MHz wide. Therefore an 80 MHz channel will span 4 of these channels, while a 160 MHz would span 8.

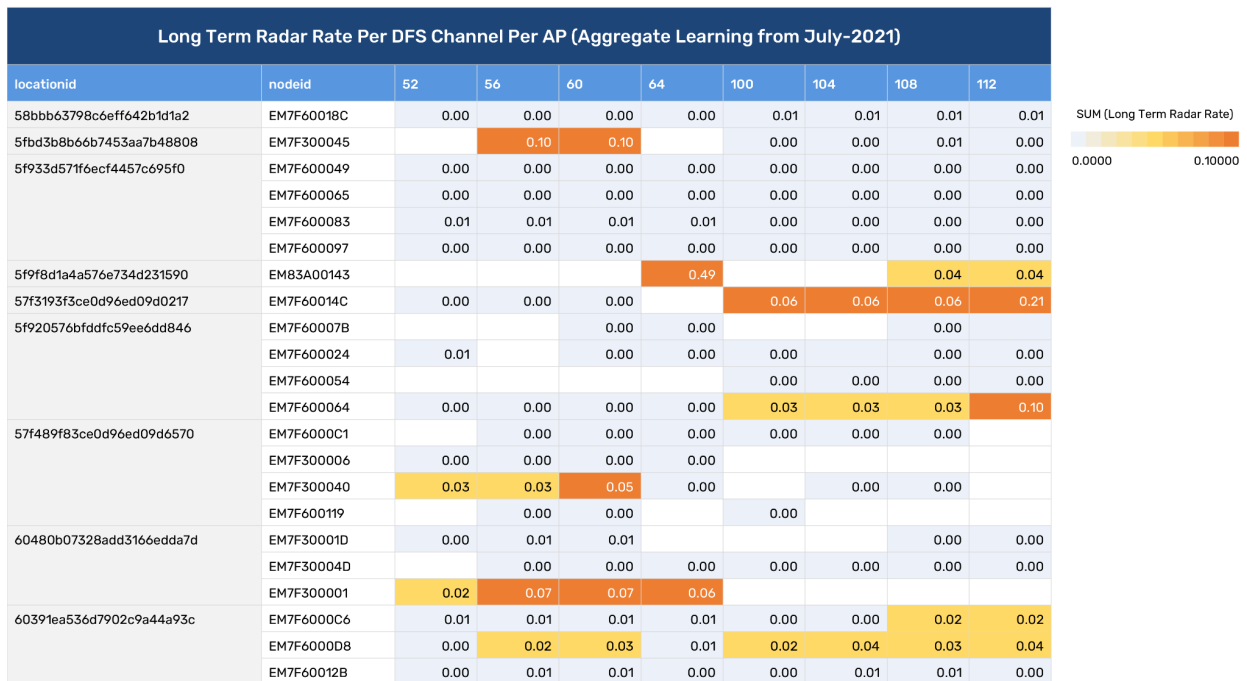


Figure 6 - Long Term Radar Rate For DFS Backoff

Looking at the chart, it is easy to see that some locations can use 160MHz channels without concern, while others would be hit by radars at a high rate, frustrating users with frequent channel changes. However, many of the homes that could not support a 160 MHz channel can support an 80 MHz channel if it is properly positioned.

To minimize service interruptions, the system should monitor and record the radar rates that occur at each individual AP, and use that to intelligently avoid channel usage that would result in frequent radar events.

### 6.3. Clustering

Interference can occur in any type of environment, degrading or eliminating the benefits of Wi-Fi 6. However, the most likely location for high interference is in apartment complexes, or MDUs. Interference in these types of environments can be minimized using optimizations that consider MDUs in a holistic way, optimizing across the entire MDU. Because it would be impossible to jointly optimize the entire planet, the first step is to identify the MDUs, or sets of locations that present strong interference to each other.

Unfortunately, there is no simple database for knowing which locations will interfere with other locations. While conceptually this would be aligned along MDUs, actual interference patterns are complicated by any number of factors. The necessary grouping is accomplished through a clustering step. Each AP reports the neighbors that it can see, including the neighbors that it can see on different frequency channels using off-channel scanning. This database is then used to group the locations into clusters that should be optimized together because the locations have a high degree of interaction.

Community network machine learning algorithms can be used to accomplish this task. The diagram below shows a conceptual picture of how this works. Tightly intertwined locations are grouped together (e.g. locations in the same apartment complex), while only mildly connected groups (e.g. neighboring apartment complexes) are segmented.



**Figure 7 - Tightly Intertwined Locations Are Grouped Together (Left) While Only Mildly Connected Groups Are Segmented**

The following table summarizes the results when clustering algorithms were applied to two large service providers’ customer bases. Keep in mind that the system clusters only the locations that have an AP that is managed by the cloud system. Because the cloud system cannot control neighbors that are not part of the system, there is no reason to cluster them together.

**Table 1 - Cluster Identification For Community Network Machine Learning Based On Two Large Service Providers**

Parameter	Service Provider A	Service Provider B
Number Of Plume-Managed Locations	12,527,567	5,017,865
Total Number Of Clusters	2,012,417	928,133
Size Of Largest Cluster	1,173	412
No. Of Clusters With >100	8,367	7,049
No. Of Clusters With 50-100 Locations	21,633	85,036
No. Of Clusters With 10-50 Locations	195,747	74,748
No. Of Clusters With 1-10 Locations	1,786,670	760,277

With the clusters identified, a joint optimization of all APs within the cluster can be performed, optimally assigning frequency channels and channel bandwidths across each of the clusters.

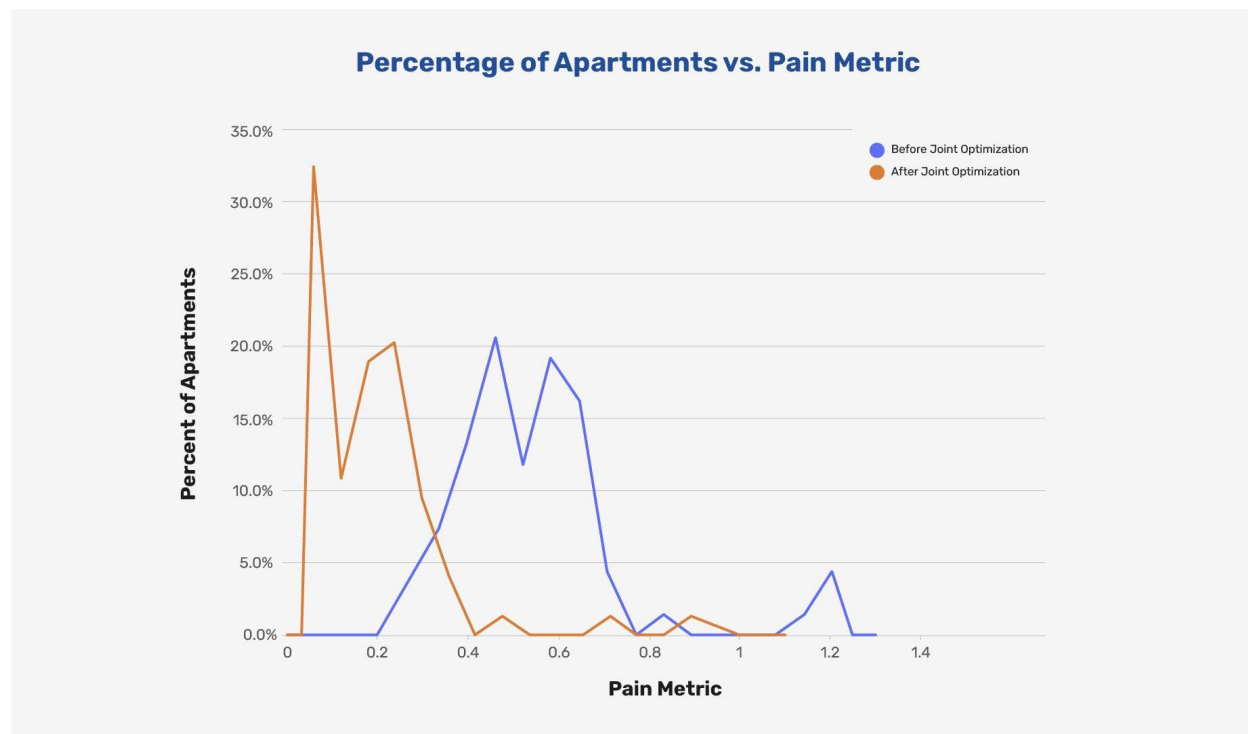
#### **6.4. Interference Improvement**

Studies of the improvement that can be achieved when optimization is applied across complete clusters as opposed to optimizing at each location individually were performed. These studies were done in a selection of individual MDUs, which were identified by our service provider partners.

The following diagram shows a histogram of the number of locations in the set of MDUs vs. the “pain” metric coming from interference. The pain metric is a function of the interference seen in a certain home times the load that devices in that home place on their own network. The pain metric does a better job of

estimating the true customer QoE than just the interference. For example, a home that is completely idle (no traffic flowing), is not impacted by a high level of interference from a neighbor. On the other hand, a home that has a very high load, consuming nearly 100% of the airtime, can be degraded with only minor interference from a neighbor. At a pain index of ~0.5 consumers experience occasional interruptions in real-time services such as voice and video.

In the diagram, the “Before” distribution represents the histogram of the homes in the MDUs prior to joint clustered optimization, and the “After” distribution represents the histogram of the same set of homes after joint clustered optimization.



**Figure 8 - No. Of Locations In The Set Of MDUs Vs. The Interference “Pain” Metric**

The histogram shows that the number of homes at high levels of pain (exceeding the threshold at which real-time services are impacted) can be significantly reduced by the clustered optimization process.

## 7. Conclusion

As with most new technologies, it will take a few years for Wi-Fi 6 to become ubiquitous. But the possibilities are thrilling once the technology is fully developed and implemented. The greatly enhanced speed and performance of Wi-Fi 6 will open new doors for emerging technologies such as IoT and AR/VR. It's not only a new era for consumers but also an opportunity for CSPs to take advantage of the technology to enhance and expand services.

Wi-Fi 6 is, indeed, powerful. But it doesn't eliminate the need to optimize the network—on the contrary, the complexity of this technology creates an even greater demand for intelligent management. CSPs should take advantage of the advanced management solutions that future-proof their customer deployments while meeting customer demand and maintaining QoE.



## Abbreviations

802.11ac	current generation of Wi-Fi (Wi-Fi 5)
802.11ax	next generation of Wi-Fi (Wi-Fi 6)
AFC	automated frequency control
AI	artificial intelligence
AP	access point
AR	augmented reality
BSS	basic service set
CSPs	communications service providers
dBm	decibel-milliwatts
DL	downlink
FCC	Federal Communications Commission
GHz	gigahertz
IEEE 208.X	Institute of Electrical & Electronics Engineers Local Area Network Standards
IoT	Internet of Things
MHz	megahertz
mW	milliwatt
OFDMA	orthogonal frequency-division multiple access
QAM	quadrature amplitude modulation
QoE	Quality of Experience
QoS	Quality of Service
SCTE	Society of Cable Telecommunications Engineers
TDMA	time-division, multiple access
TWT	target wake time
UL	uplink
MDU	multi-dwelling unit
MU-MIMO	multi-user multiple input multiple output
VR	virtual reality
Wi-Fi HaLow	wireless networking standard IEEE 802.11ah
WFH	work from home
WLAN	Wireless Local Area Network

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