Why network optimization is critical to Wi-Fi 6

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Wi-Fi 6 (also referred to as 802.11ax) is the next generation of Wi-Fi Media Access Control (MAC) and Physical Layer (PHY) technology. It has been greatly anticipated in recent years as the next big step in Wi-Fi technology. “Pre-certification” products are just launching, and certification by the Wi-Fi Alliance™ as Wi-Fi 6 is planned to begin in late 2019.

It is anticipated that Wi-Fi 6 will generate a wave of new products, and renewed consumer interest in Wi-Fi upgrades. Wi-Fi 6 is claimed to improve throughputs, overall system capacity, even power consumption and battery life.

While there are many unknowns about the adoption and effect of Wi-Fi 6, one thing is certain: *Wi-Fi 6 will make the optimization of Wi-Fi networks more critical, and more complex*.

This paper describes the new features of Wi-Fi 6, and addresses how the new features impact the need for network optimization and management.

Wi-Fi 6 Features

Wi-Fi 6, like the major revisions to the 802.11 standard that preceded it including 802.11ac, 802.11n, and 802.11g, consists of a collection of features. Like the previous standards, these features will not all be implemented in the first products, nor will they be tested and certified as interoperable in the first wave of Wi-Fi certification. Rather, Wi-Fi 6 will be a roadmap that will take several years to play out completely. The following table summarizes the new features of Wi-Fi 6, the basic benefit of that feature, and which "wave" of Wi-Fi 6 products are likely to support those features.

Feature	Primary Benefit	"Wave"
160 MHz Channel BW	2x higher throughput (in environments with low 5 GHz Wi-Fi congestion)	"Pre-Certification" Products
1024 QAM	25% higher peak throughputs	
8x8 MIMO	Up to 2x higher throughput for large scale (e.g. 8 antenna) devices	
4x Symbol Length	Significantly longer range (at lower data rates) in outdoor environments	
DL-OFDMA	Higher efficiency/capacity for networks with large numbers of small (IoT) Wi-Fi 6 devices (for downlink traffic)	
Resource Unit Reservations	Ability to strictly allocate bandwidth between traffic flows and clients	
UL-OFDMA	Higher efficiency/capacity for networks with large numbers of small scale (IoT) Wi-Fi 6 devices (for uplink traffic)	Wave 1 Wi-Fi 6 Certification

TWT	Lower average power consumption (longer battery life)	
UL-MU-MIMO	Higher uplink efficiency/capacity for medium scale devices	Wave 2 Wi-Fi 6 Certification
BSS Color	Better efficiency/capacity when there are overlapping networks	

There are some key differences in this feature list compared to previous generations of Wi-Fi enhancements. Previous major enhancements tended to focus on one particular frequency band (11g: 2.4 GHz, 11ac: 5 GHz), but Wi-Fi 6 will have many features that apply in both the 2.4 GHz and 5 GHz bands. Another key difference is that many of the features in Wi-Fi 6 require a high degree of coordination between clients, and between APs (access points), for them to work successfully. It is this requirement for coordination that makes Wi-Fi network optimization and management critical for Wi-Fi 6.

Wi-Fi 6 and Network Optimization

All of these new features will certainly improve the performance of Wi-Fi, but they may also inspire a false confidence. Some have proposed that the current need for Wi-Fi network optimization and management will go away with Wi-Fi 6. In practice, eight of the nine major new features in Wi-Fi 6 require better and more specialized optimization and management capabilities than previous generations of Wi-Fi. This can be understood by looking in more detail at the various features, and considering what is required to make them work in the real world. In some cases, this white paper groups features when the added optimization/management required is similar for both features.

160 MHz Channel BW

While 160 MHz channel bandwidths were officially supported in 802.11ac devices, very few 11ac devices actually supported greater than 80 MHz channel bandwidth. Wi-Fi 6 devices coming to market generally do support 160 MHz channel bandwidth. While not officially a new Wi-Fi 6 feature, in practice Wi-Fi 6 certified devices will be the first to enable 160 MHz channels in a significant way.

The wider the channel width used, the higher the data rate. Doubling the channel width from 80 MHz (common in 11ac devices) to 160 MHz (common in Wi-Fi 6 devices) should double throughputs. However, many regulatory regions supported up to eight independent 80MHz channels. In most areas of the world, there are only two independent 160 MHz channels. Considering an apartment complex, or even a suburban environment, most Wi-Fi networks see more than a single neighboring network. Using the 160 MHz channels invites significant interference if intelligent management is not applied. Proper network configuration requires three factors not well handled by simple locally self-managed networks:

1) Intelligent sensing and *prediction* of the interference on 80MHz sub-channels of the 160MHz transmissions.

2) Intelligent channel allocation and *bandwidth selection.*

3) Consideration of the complete interference picture in an environment, *optimizing channel allocation across entire apartment complexes*.

Plume's cloud-based optimization provides all three of these factors. By moving interference measurements to the cloud, interference can be analyzed over time. Sophisticated machine learning algorithms can be applied to predict the interference for the next time period. This is in contrast to simply reacting, or worse, measuring once and statically assigning channels and bandwidths as devices do today.

Plume's cloud-based interference analysis factors loads and device types. When considering what channel bandwidth to assign to each access point, Plume knows the history and current set of clients and loads that are present in the network at each access point. 160 MHz bandwidth channels can be applied where they are most needed, and avoided where they are not.

Finally, by performing its channel and bandwidth selection in the cloud, Plume can plan out the configurations for all APs that it controls in an entire multi-dwelling unit (MDU/apartment complex). To the extent that Plume controls the majority of APs throughout a complex, it can plan the best possible set of channel and bandwidth assignments, considering expected loads. It can deploy that optimum configuration stably, avoiding the oscillations inherent in a distributed control system in which each AP changes channels on its own timing.

With Wi-Fi 6, the small number of 160 MHz channels, together with ever more devices using the 5 GHz band, requires more sophisticated channel and bandwidth optimization.

1024 QAM and 8x8 MIMO

Both of these techniques increase the throughput between *some* devices. However, neither technique works with legacy devices. A Wi-Fi 6 8x8 MIMO, 1024 QAM, 160MHz device communicates at 40 times the data rate as a legacy 802.11n, 1x1 MIMO device using its maximum 40MHz transmission bandwidth. Both devices will be prevalent, and both operate in the same 5 GHz channels. Imagine the hazards of a highway with traffic moving at speeds with a ratio of 40:1. Carefully planning what devices should be in which frequency bands and channels, and which APs they should be connected to, is like laying out the right traffic rules and lanes for our "40:1" highway.

Plume's cloud-based optimization utilizes sophisticated device typing to know the capabilities of each AP and client in the network. In addition, it has a history of the patterns of usage of these devices. Based on this information, the optimizer plans the entire topology, including AP to AP connections, channel assignments, client steering, and band steering. This plan for the network and its clients is put together factoring individual client throughputs, joint load handling, and fairness between the clients. A rigorous optimization is required when capabilities span such a broad range. Even a single slow legacy client, placed in the wrong band or on the wrong AP, can throttle a multi-gigabit Wi-Fi 6 network.

UL-OFDMA and DL-OFDMA

Uplink (UL) and downlink (DL) orthogonal frequency-division multiple access (OFDMA) are the marquee features of Wi-Fi 6. They came about from observing the poor efficiency that Wi-Fi networks achieve with the small packets typically emanating from IoT and other low data rate devices. Each 802.11 packet has significant overhead. Before transmitting, the transmitter must listen to the medium for some time, to avoid colliding with other transmitters. Each packet has a pre-amble, on which the receiver locks on the transmission. Each packet has a header that contains addressing and other "administrative" information. Finally, each packet is followed by an acknowledgement that confirms successful reception. If a device is sending just a few bytes of information a lot of airtime is wasted on overhead.

OFDMA allows transmitting to a large number of devices simultaneously with a single transmission. For example, 32 different devices in the home, each of which need just a few bytes of information could be transmitted to at the same time, with a single packet exchange. The improvement in efficiency can be great. However, this can only happen if there are a large number of devices, each with a modest amount of traffic to send or receive, attached to the *same AP*. It is the same AP part that becomes a challenge in modern home Wi-Fi networks. Home networks have rapidly migrated to multi-AP topologies using mesh networks, repeaters, or multiple gateways. This will continue with Wi-Fi 6, since for in-home high data rate operation, Wi-Fi 6 has no features that extend the range/coverage of Wi-Fi. Given multiple APs in the home, 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.

It is this grouping of devices to maximize the potential for OFDMA gains that is critical to Wi-Fi 6 and requires centralized, intelligent control of the network. To do this effectively, the network controller needs all of the following:

- 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 multiple APs each device in the home should be connected, considering the capabilities, traffic load, and signal strength/data rate each device can achieve to each of the APs in the home
- The ability to steer and hold devices on the correct AP

The decisions required are complex. As clients are asked to connect to APs that are farther away from them, the data rates of those connections will drop. However, if devices connect to the nearest APs scattered throughout the home, the ability to form efficient Wi-Fi 6 OFDMA transmissions will be reduced. Only a rigorous optimization can come up with the best arrangement for all the APs and clients simultaneously. The Plume based cloud optimization system is ideally suited to making the correct decision about how the network should be arranged, and to which AP each client should connect.

In addition, Plume has developed methods for steering clients to APs, and holding them there, even when it is not the closest AP. These steering mechanisms must be specific to each device type, as different devices behave differently to steering. Using the cloud, Plume is able to identify devices accurately, and learn across millions of networks and clients which steering techniques work, and which do not, for each detailed device type. This type of dynamic, deployment wide learning is unique to Plume’s cloud architecture.

Making appropriate use of OFDMA in a multi-AP home is a very complex problem. Without optimizing and managing the network centrally, the primary innovation of Wi-Fi 6 will be lost.

Resource Unit Reservations

OFDMA operates by dividing up a wide bandwidth transmission (e.g. 80 or 160 MHz) into smaller frequency slices that are then allocated to particular clients. This allocation is changed dynamically over time. The resulting checkerboard style grid of spectrum allocation over time is what allows a single wide, efficient transmission to be used to serve multiple clients at once.

This capability, necessary for making OFDMA work, can be used advantageously to provide “guaranteed” quality of service (QoS) to particular clients, or particular data flows. The spectral slices across a unit of time are commonly called resource units (RUs). By reserving RUs for a particular flow to a particular client, it is possible to reserve a fixed amount of bandwidth within the network to carry that traffic. For example, an intelligent system might recognize that an IPTV stream is being sent to a set top box. It could then observe the required data rate for that video stream. By reserving the appropriate number of RUs for that data flow, it can reserve the appropriate amount of bandwidth to ensure the video stream can be delivered uninterrupted.

The identification of streams and throughputs can be done using local intelligence. However, the appropriate allocation of RUs across an entire multi-AP network, or across an entire MDU, requires centralized control that can be aware of the conditions at each of the access points. Co-channel sharing within the home/MDU, traffic loads at each of the APs in the home, expected interference from neighbors, and packet error/retry rates at each AP must all be factored when balancing the allocation of RUs throughout an entire home/MDU. The required centralized control, and sophisticated allocation algorithms, can most conveniently be implemented in the cloud.

TWT

Target wake time (TWT) is a feature that was first developed for 802.11ah (900 MHz Wi-Fi) but will first see widespread deployment in Wi-Fi 6. It improves the battery life for devices that are transmitting only occasionally or at a low duty cycle. Using TWT, the AP provides the client with a customized schedule of when the client should wake up and transmit or receive. The AP reserves this time from use by other devices to ensure that when the TWT clients wake, the airwaves are clear, and the clients can immediately transmit or receive. In this way, TWT prevents energy from being wasted waiting for the airwaves to clear. Depending on the expected activity levels of the various clients, the AP may assign independent wake times, or may have a group of clients share a wake time schedule.

In a single AP network, optimizing the behavior of TWT involves planning which clients can share TWT schedules, and what those TWT schedules should be. While clients provide hints to the AP about their expected traffic loads, Plume's device typing, and history-based load prediction methods can greatly aid in understanding what different clients need.

Cloud based centralized control becomes even more important in homes with multiple APs. Often several APs in a home will be operating on the same frequency channel. In that case, to ensure that TWT periods at the co-channel APs do not overlap, a centralized scheduler is required. This centralized scheduler must know the transmission requirements of all the TWT clients in the home, which APs share channels, to which AP each client is connected, and the signal strength between the APs and clients in the home. Using this information, an optimized arrangement of TWT times and client groupings can be assigned across the entire network in the home.

Plume's cloud-based system has the potential to take this a step further, looking across overlapping networks that it controls in an MDU. Commensurate with the earlier discussion of selecting channel bandwidths, it is possible to plan the assignment of TWT periods and groups across an entire MDU, factoring the cloud controller's knowledge of which apartments interference with each other, and the client capabilities and load requirements in each apartment. This is far more sophisticated than any coordination that has been done for Wi-Fi in the past, and can only be accomplished with a cloud-based control system.

UL-MU-MIMO

Uplink multi-user multiple input multiple output (UL-MU-MIMO) is the companion to downlink (DL) MU-MIMO that was standardized and implemented in 802.11ac devices. UL-MU-MIMO allows multiple devices to be transmitting at the same time to the same AP. In the OFDMA case described earlier, the different devices transmitting at the same time are using different parts of the frequency spectrum. In the MU-MIMO case, the devices involved use multiple antennas to separate the traffic by spatial means. In other words, the AP can independently receive signals that are coming from clients in different directions.

Much of the analysis regarding UL-OFDMA applies to UL-MU-MIMO as well. In order for multiple devices to transmit at the same time using MU-MIMO, the devices must be sufficiently spatially separated, they must be transmitting to the same AP, and must be at somewhat similar distances from that AP. These conditions are difficult to ensure in a home with multiple APs unless the APs and clients are centrally managed. Similar to the OFDMA case, there is a tradeoff in the MU-MIMO case between pushing clients to connect to the same AP for efficiency (UL-MU-MIMO simultaneous transmission), and having the client transmit farther to reach the AP, degrading the data rate that the client can use. As with the OFDMA case, MU-MIMO in a multi-AP environment is best managed by a controller that knows the device capabilities, required traffic loads, signal strengths, and spatial correlation properties of all the clients at each of the APs. The type of sophisticated information synthesis and optimization required is best done in the cloud.

BSS Color

Basic Service Set Color (BSS Color) is a technique added into Wi-Fi 6 to allow more efficient airtime usage between overlapping networks that are on the same frequency channel. 802.11 is based on a “listen before talk” protocol. Before transmitting, each device checks if the airwaves are clear, and transmits only if any signals that are present are below a single, quite low, threshold.

The thinking is that you don’t want to step on a transmission from somewhere else in your own network, colliding and destroying both transmissions as they arrive at the AP. However, there are times that it might make sense to go ahead and transmit even if a signal stronger than the threshold was observed. Consider the case of an overlapping neighbor network. If it were known that signals from the neighboring network were very weak when they arrive at your AP, you would feel that you could safely transmit even if the signal from the neighbor was above the threshold. Presumably your transmission would arrive at your AP with high signal strength, the signal from the neighbor would be very weak, and your signal would be receivable despite the weak interference.

The BSS Color feature makes this possible by putting a marker in the very beginning (preamble) of the packet indicating which network (BSS) a given packet belongs to. Devices can then make a very quick assessment if they are safe to transmit or must defer to traffic from their own network. While the BSS Color marking in the header is an important ingredient, the key to making this work is to set the correct thresholds for when it is safe (for you and for your neighbor’s sake) to step on your neighbor’s traffic.

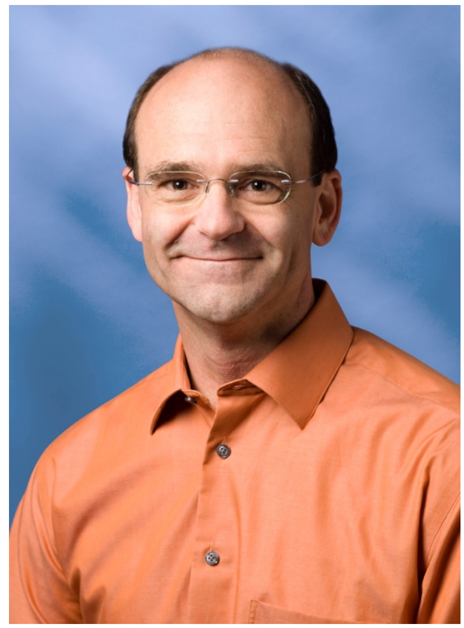
Once again, a Wi-Fi 6 feature requires more sophisticated optimization and control to gain benefit. The Plume cloud approach, in the same way that it can plan channels, bandwidths, and Target Wake Times across MDUs, can similarly set thresholds for the BSS Color operations. It can do this by knowing just how strongly each client in the entire MDU is seen at each AP in the MDU. Armed with this information, it can determine the thresholds that will minimize interference while maximizing transmission opportunities.

Conclusion

Wi-Fi 6 will bring significant improvements to Wi-Fi, but it will not decrease the need for sophisticated network optimization and management. In fact, eight of the nine major features that Wi-Fi 6 brings will require more sophisticated optimization than 11ac networks have required. This is particularly true in homes with multiple APs, and in buildings with multiple dwelling units. Only a cloud-based control system, utilizing sophisticated, rigorous optimization, will be able to take advantage of the new features enabled by Wi-Fi 6.

About the Author

Bill McFarland is the CTO of Plume. He previously was VP of Technology at Qualcomm, and the CTO of Atheros Communications. Bill holds over 70 patents and has authored over 35 technical papers. Bill received a BSEE from Stanford University, and an MSEE from U.C. Berkeley. Bill was elected fellow of the IEEE in 2014.



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