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IT@Intel: Wi-Fi 6–The Advantages Are Real

Intel IT tests Wi-Fi 6 in an actual office environment during COVID lockdown, proving enhanced performance under challenging, real-world scenarios and delivering important insights for successful deployments

Authors

Omri Barkay
Principal Engineer, Intel IT

David Birnbaum
Principal Engineer, Client Computing

Liran Klein
Network Engineer, Intel IT

Yaki Lanciano
Wireless Validation Architect, Client Computing

Ifat Peczenik
Network Engineer, Intel IT

Ehud Reshef
Principal Engineer, Client Computing

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Executive Summary

Wi-Fi 6 may be the ideal gateway toward realization of an enterprise-wide wireless infrastructure. With many of our office spaces temporarily vacated due to the COVID pandemic, we had the unique opportunity to test this latest Wi-Fi standard in a real office environment using laptops equipped with Intel® Wi-Fi 6E (AX210) network cards.

We partnered with Intel's Client Computing Group to conduct a series of tests within these spaces. The team systematically stressed the network with scenarios relevant to today's working environments, including an increased number of connected devices and real-time collaboration applications. We varied user counts, roaming settings, channel configurations and more to benchmark the performance of each configuration.

Our test results demonstrated that a Wi-Fi 6 upgrade can provide the following advantages for a dense enterprise wireless local area network (WLAN):

- The ability to increase the number of users and devices per access point (AP), reducing deployment costs
- Enhanced support for an increasing number of devices with existing deployment densities
- Improved high-density performance with less interference, fewer dropped connections and more efficient packet transmission
- Faster data throughput
- Consistent service and improved reliability

We hope that sharing our insights into the advantages of Wi-Fi 6 can help the IT industry achieve successful Wi-Fi 6 deployment.

Background

Intel IT has been working toward enterprise-wide standardization of in-office WLAN Wi-Fi access for the last few years. Today, about 75 percent of Intel's workforce uses the WLAN as their main method of connectivity. But real-time services can be challenging given the limitations of Wi-Fi 5's stability, latency and channel usage. These limitations manifest in ways that are highly inconvenient to today's business operations (for example, lost connections or poor video service), creating frustration and productivity challenges for employees.

Previous Intel IT laboratory testing has shown some performance benefits to Wi-Fi 6.[1] However, we wanted to explore how the latest enhancements offered by Wi-Fi 6E impact performance in dense enterprise networks, and how it might improve our deployment strategy.

Currently, Intel IT designs wireless network deployments based on the following assumptions:

- Access points (APs) should be placed 13.7 m./45 ft. apart.
- Maximum users per AP should not exceed 15.
- Channel bandwidth is 40 MHz only in the cases where there are at least 6x 40 MHz non-overlapping channels. A channel width of 20 MHz is used where the above criteria is not met.

We wanted to test these lab-based assumptions in a real-world environment.

Pilot Study

Typically, real-world testing in a working Intel office environment would not be practical due to the presence of workers. However, the COVID pandemic presented a unique opportunity. With the majority of Intel's office staff working from home, we were able to use these empty offices to test our assumptions outside the lab.

We deployed the latest Wi-Fi 6-enabled APs throughout an Intel enterprise floor and connected to them using laptops running with a Windows operating system and equipped with Intel's Wi-Fi 6E (AX210) network card. With the floor vacated of workers, we were able to mix and match configurations and Wi-Fi operational modes without worrying about negatively affecting employee productivity. In four separate tests, we evaluated AP utilization, client throughput and the occurrence rate of resulting negative issues such as long jitter and round-trip time or packet loss.

Test 1: Maximum User Capacity per AP

This test used a single AP configured with a dedicated SSID to control the clients' AP connection. Clients were deployed in the cubicles around the AP. The test cycle was repeated for 5 users, 10, 15 and finally 25 users. Figure 1 shows the results of the following operating modes:

- Wi-Fi 5 (802.11ac)
- Wi-Fi 6 (802.11ax) with Multi-User, Multiple-Input, Multiple-Output (MU-MIMO) and Orthogonal Frequency Division Multiple Access (OFDMA) disabled
- Wi-Fi 6 (802.11ax) with MU-MIMO and OFDMA enabled

When the AP was configured to operate in Wi-Fi 5 (802.11ac) mode, client performance degraded significantly past 15 users. At 20 users the test failed completely, and we couldn't even reach our 25 users per AP goal.

The Wi-Fi 6 configuration, along with all features enabled, demonstrated far less degradation, even up to 25 users (see Figure 1). Using five users as a baseline, we observed the following as we increased the number of users:

- At 80 MHz, the full-featured Wi-Fi 6 could support 25 users with only a 20 percent overall degradation in throughput. In contrast, the Wi-Fi 5 system (left-side graph) showed an 80 percent overall degradation at just 15 users.
- Latency increased by a factor of 3.5 overall using Wi-Fi 6 but increased by a factor of 14 using Wi-Fi 5.
- Packet loss was negligible using Wi-Fi 6, while it was almost 100x worse with Wi-Fi 5.

[1] For details, read the white paper, "IT@Intel: Building a Faster, More Secure Enterprise Network with Wi-Fi 6."

Wi-Fi 5 vs. Wi-Fi 6 Throughput and Latency Comparison

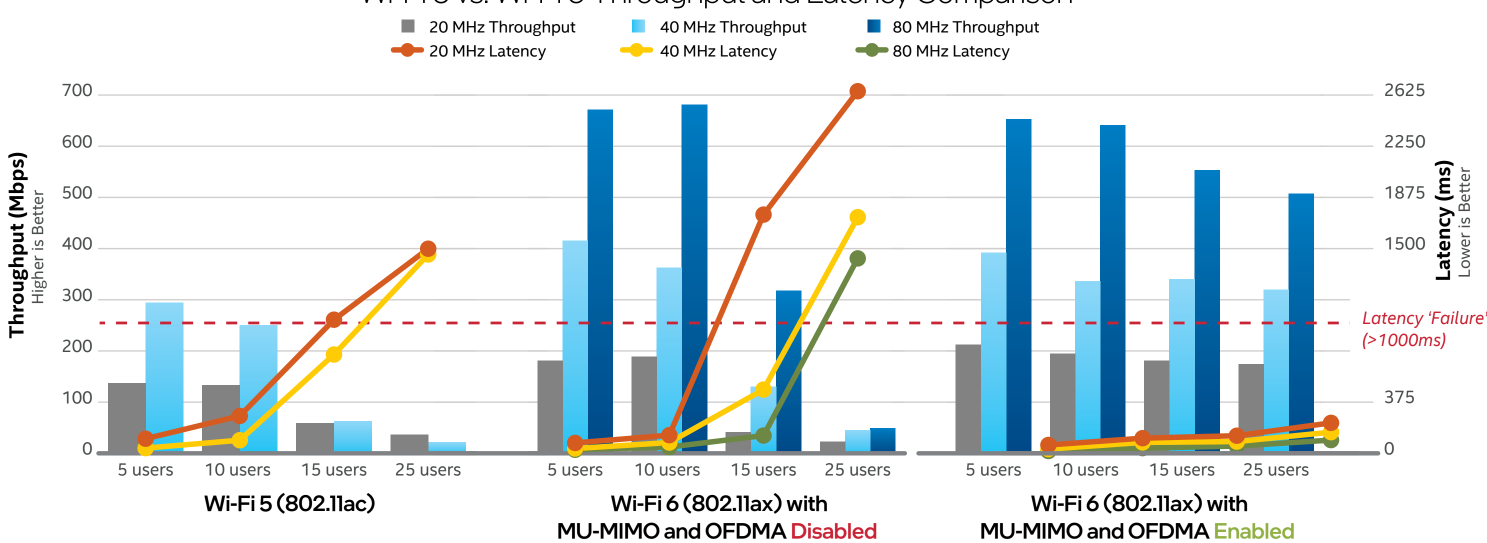


Figure 1. Wi-Fi 6 was able to support more users with less latency and packet loss. A marked drop in latency occurred using Wi-Fi 6 (802.11ax) with MU-MIMO and OFDMA enabled.

Test 2: Client Roaming and Advanced Roaming Features

This test focused on validating the AP spacing assumption. The testing environment was set up with three APs spaced at 13.7 m./45 ft., all broadcasting the same SSID. We changed the client roaming threshold while keeping the AP power level static at the medium setting. The client roaming distance from the AP was captured and the advanced WLAN logging was analyzed to identify the roaming cause.

Proper client roaming is critical to the user experience. It must occur in a timely and secure manner, otherwise latency-sensitive services such as voice and video may degrade. Excessive or inappropriate roaming can occur for a number of reasons, such as a when a client's signal level happens to be lower than the threshold configured within the roaming aggressiveness setting. A change in radio frequency can prompt roaming even if the client is stationary. APs must be deployed with the right spacing to avoid roaming that is either too frequent or too late.

Table 1 summarizes the roaming behaviors we experienced during our tests.

Table 1. Effect of Roaming Setting on Roaming Behavior

Roaming Setting	Roaming Distance Threshold (distance from AP)
High Aggressiveness	11 m./36 ft.
Medium Aggressiveness	16.5 m./54 ft.
Low Aggressiveness	21 m./70 ft.

These results align with the Received Signal Strength Indicator (RSSI) values. At approximately 9 m./30 ft. the client RSSI was -61 dBm and at 18-21 m./60-70 ft. it was approximately -85 dBm.[2] Note that -50 dBm to -60 dBm is a reasonable RSSI value for enterprises to optimize performance; -85 dBm is generally considered to be the effective edge of the AP coverage.

We concluded that a medium roaming aggressiveness setting in a similarly dense environment might cause a client to connect to an AP with a slightly lower RSSI. In a few instances, the client skipped the middle AP and connected to the next AP in line. Enabling 802.11k (Neighbor Reports) and 802.11v (BSS Transition Management Frames) did not appear to impact the client roaming decision in this dense environment.

[2] dBm indicates the signal power in log scale relative to 1 milliwatt (mW); 0dBm = 1mW; -30dBm = 1uW; -60dBm = 1nW, and so on.

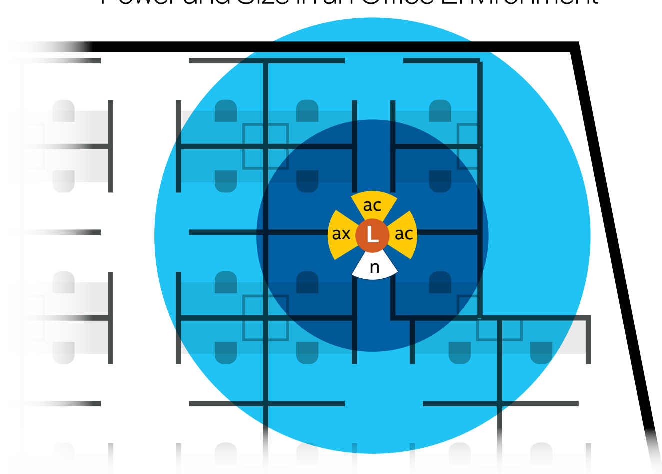
Test 3: Dual Radios on the Same Band

Test 3 explored deployments using dual radios per band. This architecture allows us to configure an AP with 2x 5 GHz radios to have one radio set as a wide-diameter cell using a higher power level and one radio set as a small-diameter cell with the lowest possible radio power level. Theoretically, this design may allow better client distribution and increased spacing up to 27 m./90 ft. between APs. It may also provide an improved signal to users. Specifically, users with a better signal can be concentrated on a single radio, while users with a poor signal due to distance or capabilities would use the macro cell, thus reducing negative impact on other users.

The testing concluded with two APs spaced at approximately 21 m./70 ft. and both 5 GHz radios enabled for client service. One radio was set at a very low power and the other at standard power. With both 802.11v and 802.11k *disabled* on the AP, the client association and roaming changed very little. At any given point, the client recognized and connected to the wider cell and experienced a more acceptable RSSI.

The most significant finding of this test involved clients positioned at the edge of the smaller cell. Here we began to see a misalignment between the AP load-balancing process and client roaming decision. The AP would move the user to the smaller cell and the client would subsequently roam back to the wider cell, creating an endless roaming scenario (see Figure 2). Ideally, when a client roams to a smaller cell, the RSSI should not be lower than the roaming threshold prior to the initial roaming. This should be configurable to meet different deployments.

Example of a Wi-Fi Device
Power and Size in an Office Environment



AP Coverage
- Channel with Lower Tx
- Channel with Higher Tx

Figure 2. Example of a Wi-Fi cell power and size in an office environment.

Test 4: Wider Channels and Co-channel Interference

It is generally accepted that when operating in a consumer environment with only a small number of APs and limited co-channel interference, the wider the channel bandwidth, the better. By increasing channel bandwidth, users in these environments usually experience better throughput, reduced jitter and lower latency.

Our initial test, which included a single AP with two users connected to it, supports this common assumption. As we increased the channel bandwidth from 20 MHz to 40 MHz to 80 MHz, the AP air utilization dropped from over 90 percent to 75 percent to about 50 percent, without any changes to user count or traffic load (see Figure 3). At the same time, we saw a decrease in jitter and network latency (see Figure 4) as the bandwidth widened.

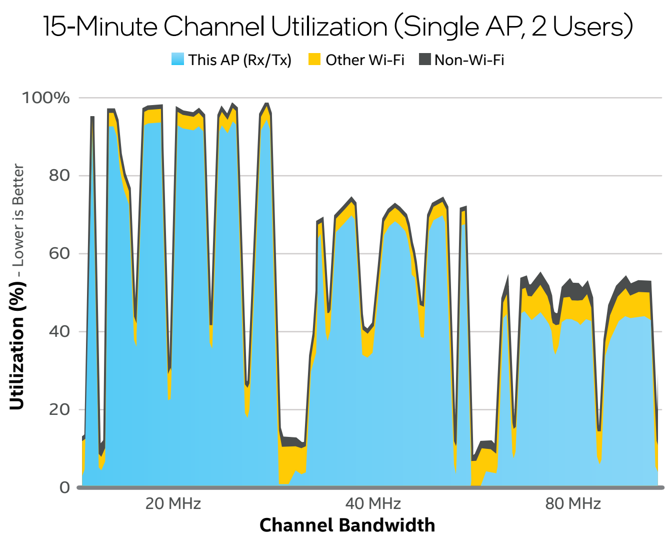


Figure 3. Wi-Fi 6 testing with two users per AP showed that we could increase bandwidth and decrease air utilization without penalty.

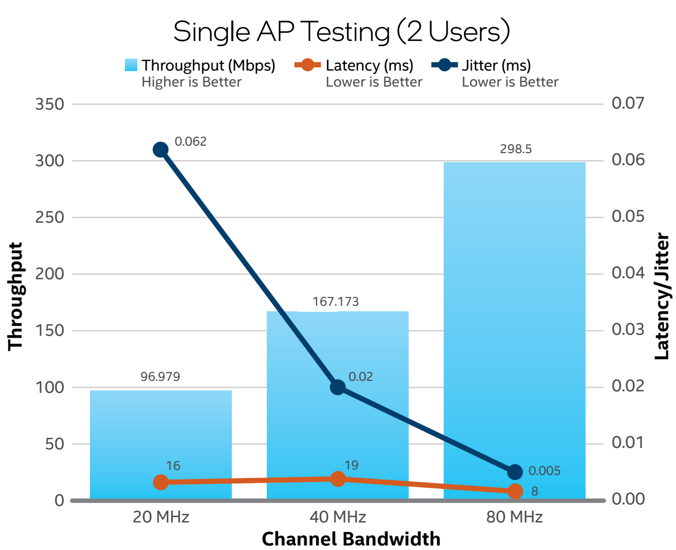


Figure 4. Wi-Fi 6 testing with two users per AP shows that jitter and network latency decreased as bandwidth is widened.

However, the complexity of enterprise environments makes dense AP deployment much more challenging—channel bandwidth is not the only factor to consider.

With APs typically spaced at 14-18 m./45-60 ft., co-channel interference increases dramatically. Here, our testing demonstrated that the number of non-overlapping channels plays a critical role. When using a single channel across all the APs, the nearest AP on the same channel will be 13.7 m./45 ft. away. Using two non-overlapping channels with the same deployment plan, the distance is increased to 19 m./62 ft. from the nearest AP on the same channel. Using four non-overlapping channels, the distance to the nearest AP is 27 m./90 ft. When using six non-overlapping channels, the distance is 41 m./135 ft. to the nearest AP on the same channel.

Our test showed that with two APs operating on the same channel and spacing them at 13.7 m./45 ft., only one AP has users connected and streaming data. Both have the same utilization, but the contributing factor on the AP with the users is Transmit/Receive (Tx/Rx) traffic, while on the other AP it is "Other Wi-Fi" and not Rx/Tx traffic (see Figure 5).

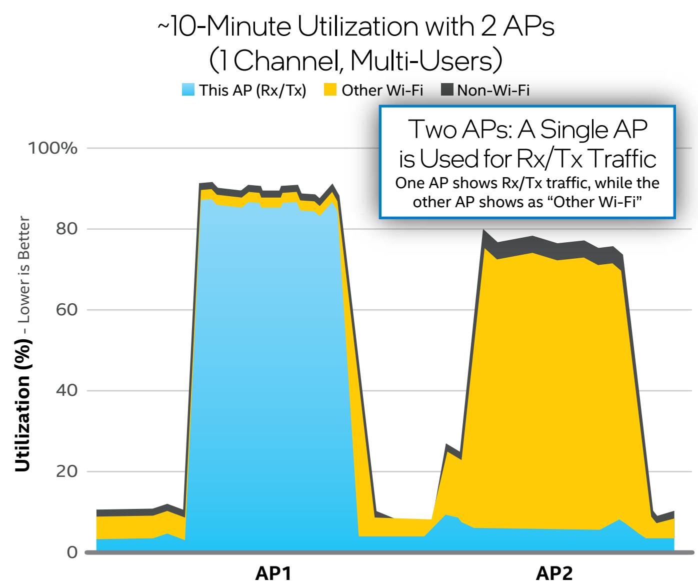


Figure 5. Two neighboring APs operating on the same channel have the same utilization; however, only one AP has users connected and is generating data.

Due to the nature of RF propagation in open space, we observed the impact of APs using the same channel in close proximity (co-channel interference). When AP spacing was between 14-27.5 m./45-90 ft., we did not observe any benefits in utilization. When two APs were on the same channel and one was loaded, the other AP also showed the same load, regardless of the spacing. There was no improvement in performance until we increased the distance between the APs experiencing co-channel interference. The further the distance, the better the performance became, with 41 m./135 ft. appearing to be the minimum distance required to maintain performance comparable to a baseline of six non-overlapping channels with 13.7 m./45 ft. between the APs (see Figure 6).[3]

[3] Note: Due to countries' regulatory variances, the total number of channels available will vary in different geographies.

The space limitations of our test location, as well as other properties, did not always allow us to support all the necessary conditions (wide spacing between 6 non-overlapping channels) to maintain performance. More testing is needed to optimize network configuration and achieve increased performances.

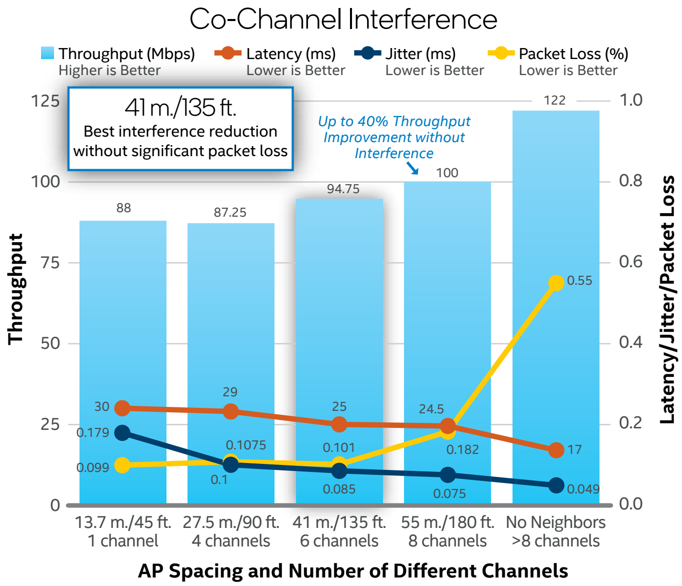


Figure 6. APs must be placed at least 41 m./135 ft. apart to avoid co-channel interference.

In some cases, due to regulatory limitations or other deployment limitations, we must utilize a small portion of the available bandwidth. We showed earlier that a wider channel is better than a narrow channel. Next, we added co-channel interference to see if the negative effect of the interference from another AP negates the benefit of a wider channel. In other words, we wanted to determine which option yielded the best overall performance: a wider co-channel with co-channel interference or a smaller channel bandwidth with less or no co-channel interference. Our test environment comprised four APs spaced at 13.7 m./45 ft. and eight evenly spaced users with two users per AP. The APs were configured as shown in Table 2.

As shown in Figure 7, although we saw some improvement in throughput with 40 MHz compared to 20 MHz, we saw a sharp increase in latency and jitter due to the co-channel interference. When we increased the bandwidth to 80 MHz serving all four APs, throughput got worse, and latency increased; jitter decreased but was still higher than normal. From this test, we concluded that generally a narrower channel with no interference is better than a wider but noisier channel. When we combine that conclusion with our previous observation that six non-overlapping channels is the minimum for our dense deployment (see Figure 6), we see that we could have achieved a 40 percent improvement in throughput without interference.

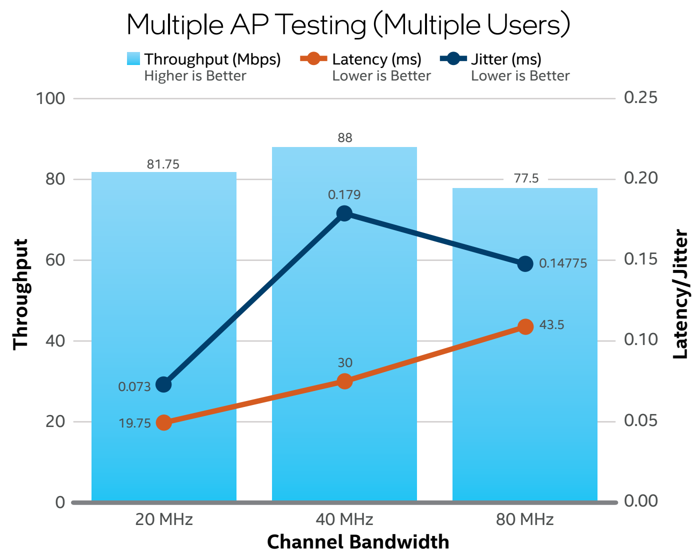


Figure 7. In an environment with multiple users per AP, increasing bandwidth from 20 MHz to 40 MHz resulted in significant performance issues.

Table 2. Channel Testing Setup

Test Scenario	AP Name	Channel Number	Channel Bandwidth	Number of Users
Each AP has its own dedicated but narrow channel (no co-channel interference)	AP1	36	20 MHz	2/AP
	AP2	44	20 MHz	2/AP
	AP3	52	20 MHz	2/AP
	AP4	64	20 MHz	2/AP
A pair of APs on each of two somewhat wider channels (some co-channel interference)	AP1	36-40	40 MHz	2/AP
	AP2			2/AP
	AP3	52-60	40 MHz	2/AP
	AP4			2/AP
All four APs on a single really wide channel (substantial co-channel interference)	AP1	36-48	80 MHz	2/AP
	AP2			2/AP
	AP3			2/AP
	AP4			2/AP

Wi-Fi 6 Best Practices

Based on all of the above testing, we feel confident that upgrading to Wi-Fi 6 would provide Intel employees with the advantages of a better overall wireless performance while reducing costs associated with hardwiring our facilities. We also learned valuable lessons that can be applied toward future deployments and serve other similar enterprise IT networks. The key takeaways from this study are as follows:

1. **AP capacity.** Future Wi-Fi 6 deployments will enable more user connections to individual APs without compromising end-user service levels. This aligns with the expected user growth associated with the introduction of new IoT devices across the enterprise and the migration to a "no wires" office.
2. **Performance.** Even at increased capacity per AP, we found that upgrading to the latest Wi-Fi 6 technology improved performance in terms of throughput and latency, especially when compared to Wi-Fi 5.
3. **Advanced roaming features.** 802.11k can be safely enabled, regardless of the setting. The advanced algorithm included with the latest Intel network interface card may actually mask some of the benefit associated with the advanced roaming features of Wi-Fi 6. Those who are not yet using this card will likely see a more pronounced benefit. Using multiple radios on the same AP resulted in excessive 802.11v forced roaming, raising the question of whether using two radios on the same band is desirable. Currently, a third radio is recommended for use in "monitoring only" mode until Wi-Fi 6E with 6 GHz is available.
4. **Co-channel interference.** We observed the impact of the co-channel interference when the non-overlapping channel list was around six channels. Fewer channels created a performance impact to our end customers. We concluded that the ideal environment should contain at least six non-overlapping channels for a dense WLAN enterprise deployment. The bandwidth will increase significantly with Wi-Fi 6E and the use of channel bonding, which is currently limited to 40 MHz.

Related Content

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- Building a Faster, More Secure Enterprise Network with Wi-Fi 6
- Building a Multi-Cloud-Ready Enterprise Network

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Acronyms

AP	access point
MU-MIMO	Multi-User, Multiple-Input, Multiple-Output
OFDMA	Orthogonal Frequency Division Multiple Access
RSSI	Received Signal Strength Indicator
WLAN	wireless local area network

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