Optimizing Operation at 5 GHz

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A White Paper from Laird Technologies

As the traditional 2.4 GHz operating band for IEEE 802.11-compliant Wi-Fi wireless local area networking becomes more crowded, network administrators increasingly look to the less crowded 5 GHz operating band to improve or maintain network performance and reliability. This is especially necessary in industrial Wi-Fi deployments which present greater operational challenges and more stringent requirements than residential and commercial Wi-Fi networks.

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Executive Summary

This document contrasts the key physical, regulatory, and interference considerations between the 2.4 GHz and 5 GHz band and how they impact critical Wi-Fi operational parameters like performance and reliability. This document focuses on 5 GHz Wi-Fi operation in challenging industrial environments and provides recommendations for optimal dual band deployments.

Industrial Networks

Deploying a reliable wireless network in an industrial environment such as a factory, warehouse, distribution center, or even an airport or hospital is much more challenging than deploying a wireless network in an office, home, or school for reasons that include:

- Need for persistence – Office Wi-Fi devices tend to be laptops and other general computing devices that use Wi-Fi for email, Web browsing, and other applications that do not require a persistent network connection. Wi-Fi devices in an industrial environment tend to be specialized, rugged devices that run business-critical applications that are sensitive to any disruptions in network connectivity. *Industrial Wi-Fi connections must be far more reliable than those found in more forgiving applications.*
- Mobility – In an office, few devices are used while in motion. In an industrial environment, devices are used while on the move, including while being driven on forklifts in both vertical and horizontal directions. While moving, devices may roam from one network infrastructure endpoint to another, and that roam must be seamless to the application. *Industrial Wi-Fi devices scan and roam far more frequently than more static devices found in non-industrial applications.*
- Building materials – Offices are built mostly of wood, stone, and drywall which moderately absorb and attenuate RF signals. An industrial workplace can be filled with metal shelving, stainless steel coolers, rooms encased with copper or lead, and inventory that can include large amounts of liquid. Metal reflects RF signals; water and lead absorb RF signals. *Industrial facilities present far greater connectivity challenges than residential and commercial environments.*

THE 5 GHZ AND 2.4 GHZ OPERATING BANDS

The IEEE 802.11 wireless LAN standards include service on two frequency bands, 2.4 GHz and 5 GHz. Both 802.11b and 802.11g operate exclusively in the 2.4 GHz band. 802.11a is generally less common and operates only in the 5 GHz band. 802.11n, which operates both in the 2.4 and 5 GHz band, is increasingly popular and promises to popularize dual band operation on both the 2.4 GHz and 5 GHz bands.

Physical Characteristics of the 2.4 GHz and 5 GHz Bands

Generally speaking, there is an inverse relationship between frequency and signal propagation; the higher the frequency, the shorter the distance a signal travels. The frequencies used by Wi-Fi devices operating in the 5 GHz band are approximately twice as high as frequencies used by Wi-Fi devices operating in the 2.4 GHz band (shown in Figure 1).

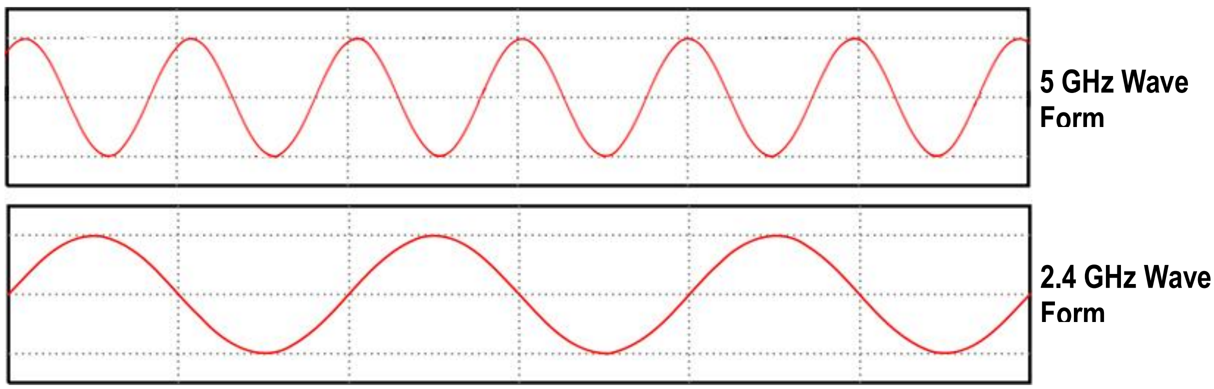

Figure 1: 2.4 and 5 GHz Wave Forms

Attenuation is the degree to which a signal is absorbed by physical objects. Higher frequency waves generally penetrate solid objects less than lower frequency waves. The 5 GHz wave form is attenuated by common building materials to a greater degree than the 2.4 GHz wave form. On the other hand, the 2.4 GHz wave form is optimally absorbed by water.

Note: This explains why a microwave oven operates at 2.4 GHz—the water in the food absorbs the microwave energy creating heat. This also explains why devices operating at 2.4 GHz in rooms crowded with people are attenuated to a greater degree than 5 GHz devices—people, like food, are mostly water.

Multipath propagation is the phenomenon of waves bouncing off an object, multiplying, and arriving at their destination out of sequence. (With sound waves, this is an echo.) Because higher frequency waves do not penetrate solid objects as well as lower frequency waves, multipath propagation occurs more significantly in the 5 GHz band. Traditionally, multipath propagation had a negative impact on Wi-Fi operation. Spatial Multiplexing, a technique incorporated into the 802.11n standard, takes advantage of multipath propagation.

For more information on multipath propagation, read the Summit Data Communication white paper on 802.11n by visiting http://www.summitdatacom.com/whitepapers.htm.

Regulations Applied to the 2.4 GHz and 5 GHz Bands

Both the 2.4 GHz and the 5 GHz bands are available around the world for unlicensed operation although regulatory agencies or collections of agencies (regulatory domains) allocate these bands in different ways.

The 2.4 GHz Band

The allocation of the 2.4 GHz band predates the development of the IEEE 802.11 Wi-Fi standards and was originally reserved for general industrial, scientific, and medical purposes. This band is approximately 80 MHz in width allowing for no more than three non-overlapping channels which limits Wi-Fi network capacity and scalability. Today, many communications devices use this band including Wi-Fi radios, Bluetooth radios, baby monitors, cordless phones, and radio controlled equipment or toys. With much activity comes much interference. Many people already consider the band overloaded and the problem will continue to worsen, adversely affecting device performance.

The 5 GHz Band

The 5 GHz band was allocated specifically with IEEE 802.11a in mind. Depending on regulatory domain, the 5 GHz band provides between two and seven times the number of channels and resulting network capacity as the 2.4 GHz band. In the United States and other countries that adhere to FCC policy, the band is divided into four sub-bands referred to as Unlicensed National Information Infrastructure (UNII) bands.

In the ETSI regulatory domain that covers Europe, Africa, portions of the Middle East, and other countries and in the FCC regulatory domain that covers the Americas and other countries, portions of the 5 GHz are also used by weather and military radar systems which have priority over Wi-Fi devices. In order to coexist with these critical systems, Wi-Fi radios must comply with two features that are part of the 802.11h specification: Transmit Power Control (TPC) and Dynamic Frequency Selection (DFS).

Note: TPC only applies to devices with very high transmit power and antenna gain. It is rarely an issue for Wi-Fi systems.

DFS compliance is required for both infrastructure (APs and controllers) and client devices operating on any of these shared bands. Infrastructure devices play a larger role in managing DFS; they essentially manage coexistence on behalf of all associated client devices.

Prior to transmitting on a DFS channel, an infrastructure device must first listen for the presence of a radar system. If radar is detected, the channel must be vacated and flagged as unavailable. The Wi-Fi infrastructure must continue to monitor the environment for the presence of radar during operation and, if radar is detected, must move to an unoccupied channel and instruct all associated client devices to do the same. Client devices may not transmit on a DFS channel unless instructed by an infrastructure device that the channel is free from radar. Due to these limitations, DFS compliance can impact Wi-Fi performance and reliability—particularly for highly mobile devices.

Table 1 displays the 5 GHz band detailing the available DFS and non-DFS channels by regulatory domain.

Table 1: DFS Channels in the 5 GHz Band
✓ – Available channel and DFS is required; x – Available channel but DFS is not required

	ETSI (EMEA)	FCC (Americas)	KCC (Korea)	MIC (Japan)
UNII-1 (5150-5250)				
36	x	x	X	x
40	x	x	X	x
44	x	x	X	x
48	x	x	X	x
UNII-2 (5250-5350)				
52	✓	✓	-	✓
56	✓	✓	-	✓
60	✓	✓	-	✓
64	✓	✓	-	✓
Intermediate (5450-5725)				
100	✓	✓	-	-
104	✓	✓	-	-
108	✓	✓	-	-
112	✓	✓	-	-
116	✓	✓	-	-
120	✓	✓	-	-
124	✓	✓	-	-
128	✓	✓	-	-
132	✓	✓	-	-
136	✓	✓	-	-
140	✓	✓	-	-
UNII-3 (5725-5825)				
149	-	x	✓	-
153	-	x	✓	-
157	-	x	✓	-
161	-	x	✓	-

Interference in the 2.4 GHz and 5 GHz bands

The 2.4 GHz band, historically the more popular band, has become overloaded.

The 5 GHz band has more available spectrum and generally less traffic, so it has much less RF interference than the 2.4 GHz band. Less interference means better performance. The following diagrams illustrate RF interference in an industrial environment.

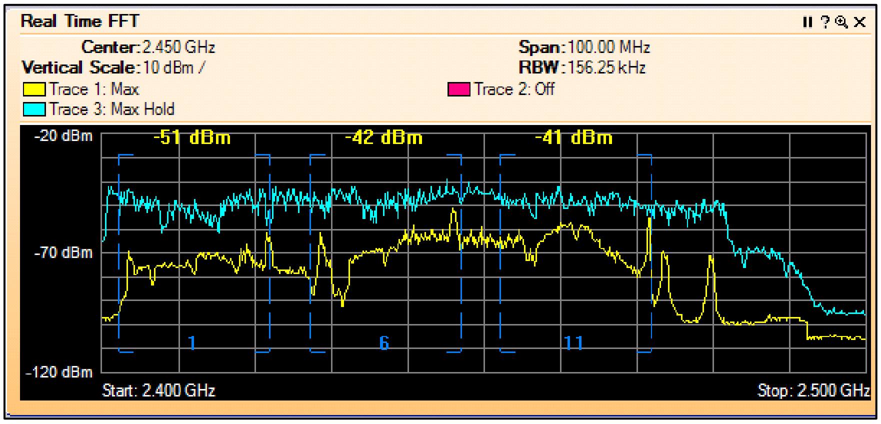

Figure 2: Real Time FFT (2.4 GHz)

Note: The RF interference diagrams were generated by Cisco Spectrum Expert (http://cisco.com/en/US/products/ps9393/index.html).

The first diagram (**Error! Reference source not found.**) indicates the strength of RF signals on the Y-axis and their relation to a 2.4 GHz channel scheme (1, 6, and 11) on the X-axis. The two graph lines indicate real-time traffic (the lower, yellow line) and maximum traffic over a duration of 10 minutes (the upper, light blue line). Note that all channels at some point are affected by signals as strong as -40dBm.

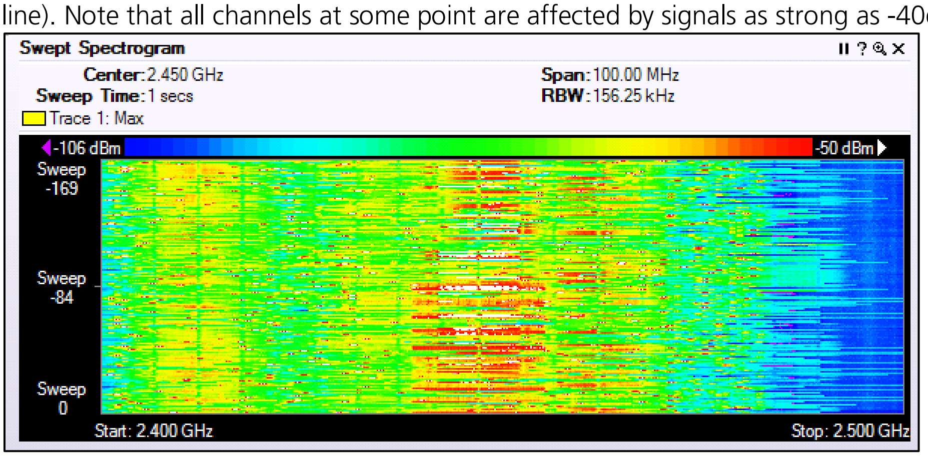

Figure 3: Swept Spectrogram (2.4 GHz)

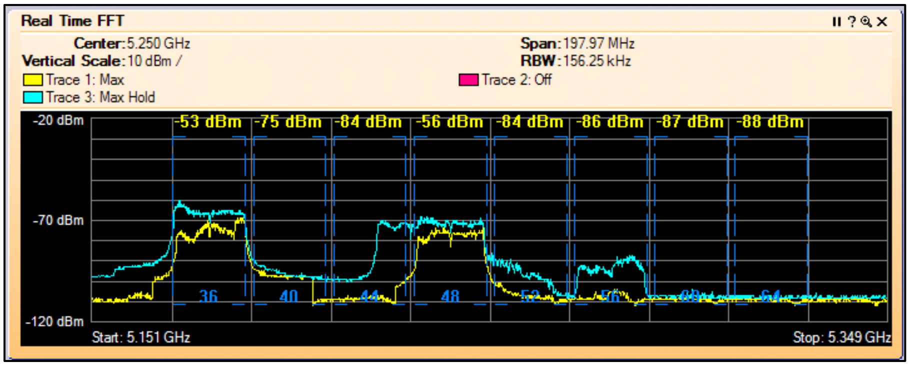

Figure 4: Real Time FFT (5 GHz)

The same channel layout (1, 6, and 11) applies to the second diagram called "Swept Spectrogram". Signal strength is indicated by color, ranging from weak traffic (blue) to strong traffic (red). Relatively strong traffic is indicated in the non-overlapping channels of 1, 6, and 11. Also note that the "speckled" distribution indicates the strong presence of Frequency Hopping (FH) RF interference which is caused by common devices like Bluetooth radios and cordless phones.

The next two diagrams (**Error! Reference source not found.** and **Error! Reference source not found.**) indicate portions of the 5 GHz band in the same environment. The overall RF environment is less busy, transmitting devices are using less power, and there is a complete absence of FH devices.

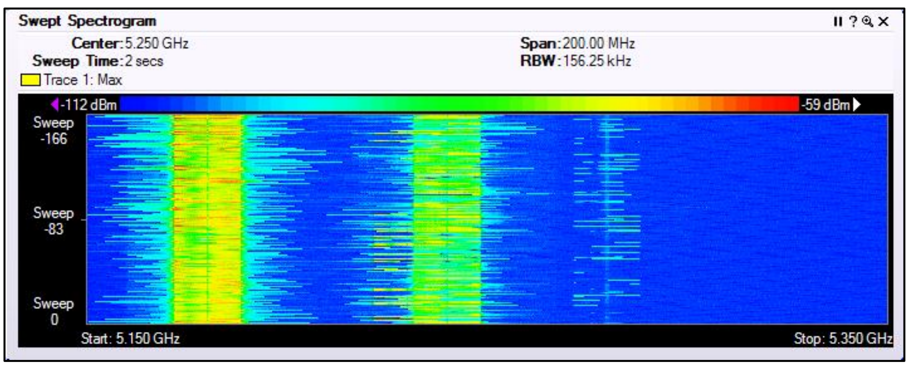

Figure 5: Swept Spectrogram (5 GHz)

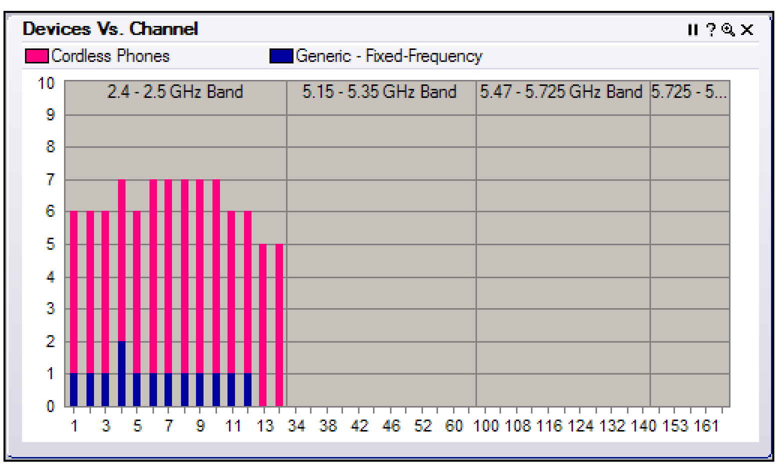

Figure 6: 2.4 GHz and 5 GHz Bands by Channel

A view of the active (non-802.11) devices per channel (**Error! Reference source not found.**) reveals a number of devices on all 2.4 GHz channels at any given time while the 5 GHz channels are clear.

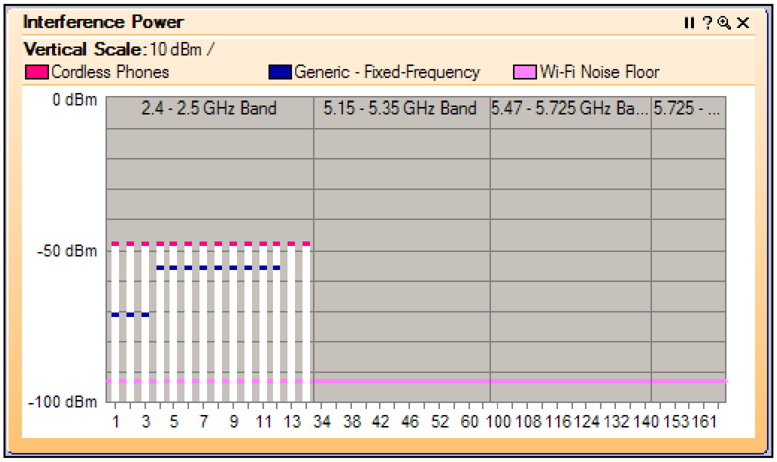

Figure 7:Interference Power by Band and Channel

A deeper look at the nature of the interferers (**Error! Reference source not found.**) shows a strong (disruptive) signal strength of -50dBm on each 2.4 GHz channel due primarily to a FH cordless telephone system.

RANGE

Due to the physical characteristics of the 2.4 GHz waveform, devices operating in this band typically provide greater range (the distance between Wi-Fi infrastructure and client devices) than those operating in the 5 GHz band. There are other factors that tend to result in greater range in the 2.4 GHz band than the 5 GHz band including:

- When operating in the 5 GHz band, Wi-Fi devices tend to have less transmit power than when operating in the 2.4 GHz band.
- The 802.11b standard, which operates only in the 2.4 GHz band, supports lower data rates than the 802.11a and 802.11n standards in the 5 GHz band. Lower data rates allow for operation at greater distances than higher data rates.
- Early 802.11a devices, the first Wi-Fi devices that operated in the 5 GHz band, were far less mature than contemporary 802.11b devices and provided relatively poor overall performance.

Due to a number of factors, however, the range gap between devices operating in the 2.4 GHz band and those operating in the 5 GHz band has narrowed significantly:

- The narrow 2.4 GHz band has become “a victim of its own success”… overcrowded with a variety of devices. This resulting interference increasingly raises the noise floor and reduces the signal to noise ratio (SNR, the difference between the transmitted signal and the surrounding interference). As the SNR decreases, so does range.
- The spatial multiplexing capabilities found in 802.11n devices leverage multipath propagation to improve signal range and predictability. Because the 5 GHz waveform is subject to greater multipath propagation than the 2.4 GHz waveform, its range and predictability benefit more from spatial multiplexing.
- The lower data rates provided by 802.11b (i.e., one and two megabits per second) are frequently insufficient for even the most modest performance requirements of today’s network applications. While these low data rates allow for greater range, connection at these ranges is often of no operational benefit.

- 5 GHz Wi-Fi radio designs have been available for nearly ten years; today's 802.11a devices provide far greater performance than earlier versions. This 5 GHz radio design work, initially applied to 802.11a, is now applied to 802.11n-compliant devices. Although the 802.11n standard is fairly recent, 802.11n-compliant devices at the radio level have been available for a much longer period of time.

Today a 5 GHz wireless network can be created in a similar fashion to a 2.4 GHz wireless network. It is not typically necessary for network designers to place 5 GHz-only APs in addition to dual band 2.4 GHz and 5 GHz APs (as was common with early 802.11a-compliant devices). Due to the rate shifting capabilities of all 802.11 standards, client devices in the 5 GHz band may, at worst, operate at slightly lower data rates than in the 2.4 GHz band when at the same distance from the AP.

SCANNING

When a Wi-Fi client device initializes and as it roams through a wireless network, it must search for an AP to which it can associate. This searching process is referred to as scanning. There are two types of scanning:

- Active scanning – The client actively searches for an AP by transmitting probe requests on each channel it is configured to use and waiting to receive probe responses from APs. The client then determines the most ideal AP to which it can associate.
- Passive scanning – Instead of transmitting probe requests, the client listens only for beacon frames transmitted by at regular intervals by APs on each channel.

Active scanning is more efficient because it actively sends probes across all channels (channel by channel) to find an AP. The client remains on each channel for a set length of time (approximately 10 to 20 ms) while waiting for the probe response.

Passive scanning cycles through the channels more slowly than active scanning because, rather than sending active probes, it listens for beacons that are sent out by APs. The client must remain on each channel for a longer period of time.

Note: Summit software allows you to configure the dwell (listen) time when passively scanning on a DFS channel. When changing from the default time, corresponding changes in the infrastructure's beacon period are recommended. For optimal performance and reliability, Summit recommends a dwell time that is 1.5 times that of the beacon period.

Active scanning is far better suited to the highly mobile client operation that's typical in industrial networks. This is particularly the case when operating in the 5 GHz band which has far more channels than the 2.4 GHz band. While scanning, a client device is incapable of sending and receiving "payload" data. Because of this, long scans impact performance and reliability particularly for latency-sensitive applications such as real-time data base access and voice.

Although wireless infrastructure can detect the presence of radar, wireless clients cannot. Because of this, wireless clients must first passively scan DFS channels to detect whether or not beacons are heard on that particular channel. Once beacons are detected, the client is allowed to actively scan on that channel. If the access point detects radar, the client must move to an alternate channel designated by the access point.

Conclusion and Recommendations

Industrial networks present greater challenges to networking professionals than do residential and commercial networks. The 5 GHz operating band has traditionally presented greater challenges than the 2.4 GHz band particularly as they relate to range and performance.

Despite this, when properly designed as part of a dual band network, operation on the 5 GHz band can add substantially greater network capacity without sacrificing performance and reliability. The need to incorporate 5 GHz operation into industrial Wi-Fi networks will increase over time as the 2.4 GHz band becomes more overused by a variety of devices.

Summit Data Communications, a company dedicated specifically to industrial Wi-Fi, recommends the following when designing an industrial dual band network that incorporates the 5 GHz operating band:

- Because the 802.11a and 802.11n standards that operate in the 5 GHz band provide for data rates no lower than 6 Mbps, APs should be placed such that client devices maintain connectivity at data rates of 6 Mbps or greater. Given the mission critical nature of industrial Wi-Fi networks and given the ever-increasing and unpredictable application requirements for these networks, it is important that networking professional design their Wi-Fi networks for operation at data rates substantially above their current application requirements. These current, and certainly future, requirements are typically well in excess of 6 Mbps.
- When placing APs for operation at a given data rate, this spacing should be determined when operating on the 5 GHz band rather than the 2.4 GHz band. This is particularly the case when operating according to the 802.11a standard.
- The spatial multiplexing capabilities of the 802.11n standard provides for substantial performance and reliability improvements over legacy standards (802.11a in particular). 802.11n infrastructure devices are widely available today and provide these benefits to 802.11n and legacy 802.11a, 802.11b, and 802.11g client devices. To allow for reliable operation on the 5 GHz band in particular, network administrators should upgrade to an 802.11n infrastructure as resources allow.
- Although 802.11n radios are not widely available on the small handheld mobile devices that are often found in industrial Wi-Fi networks, dual band 802.11a/b/g radios are increasingly available on these devices. These dual band client devices gain much of the performance and reliability benefits provided by an 802.11n infrastructure. By deploying these dual band client devices in conjunction with an 802.11n infrastructure, network professionals gain the capacity of the 5 GHz band and much of the benefit of 802.11n without waiting for the availability of 802.11n on all types of clients.
- Although the number of channels available in the 5 GHz band provides for increased network capacity, it also results in longer scan times which can impact performance and reliability. This is particularly the case when passive scanning, as with DFS channels. Therefore, network architects should not configure APs for operation on DFS channels (unless absolutely necessary) and should remove these channels from the scan list on client devices.

Note: Dual band client devices from Summit Data Communications turn off scanning on DFS channels by default.

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