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Optimizing the 5 GHz Band in a Hospital

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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 networks (LANs) 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 medical Wi-Fi deployments, which present greater operational challenges and more stringent requirements than residential and commercial Wi-Fi networks.

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Scope

This document contrasts the key physical, regulatory, and interference characteristics of the 2.4 GHz and 5 GHz bands and how these characteristics impact critical Wi-Fi operational aspects such as performance and reliability. The document also provides recommendations for optimal dual-band deployments in hospitals, which are challenging environments for Wi-Fi operation.

Hospital Networks

Deploying reliable wireless LANs in hospitals is much more challenging than deploying wireless LANs 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. These devices use Wi-Fi for E-mail, Web browsing, and other applications that do not require a persistent network connection. Medical devices and other devices that operate in a hospital run business-critical applications that can be sensitive to any disruptions in network connectivity. *Hospital Wi-Fi connections must be very reliable, providing persistent connectivity.*
- Mobility – In an office, few devices are used while in motion. In a hospital, devices are used while on the move. While moving, a device may roam from one network infrastructure endpoint (typically an access point) to another, and that roam must be seamless to the application. *Hospital Wi-Fi devices scan and roam frequently, and reliable connectivity must be maintained even while devices are in motion.*
- Building materials – Offices are built mostly of wood, stone, and drywall which moderately absorb and attenuate RF signals. Hospitals have metal carts and beams that reflect RF signals as well as lead walls, paper products, and human bodies that absorb RF signals. *Hospitals present far greater connectivity challenges than residential and commercial environments.*

The 2.4 GHz and 5 GHz Operating Bands

The IEEE 802.11 wireless LAN standards include service on two frequency bands, 2.4 GHz and 5 GHz. 802.11b and 802.11g operate in the 2.4 GHz band. 802.11a operates in the 5 GHz band. 802.11n operates in both bands and promises to popularize dual-band operation.

Physical Characteristics of the 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).

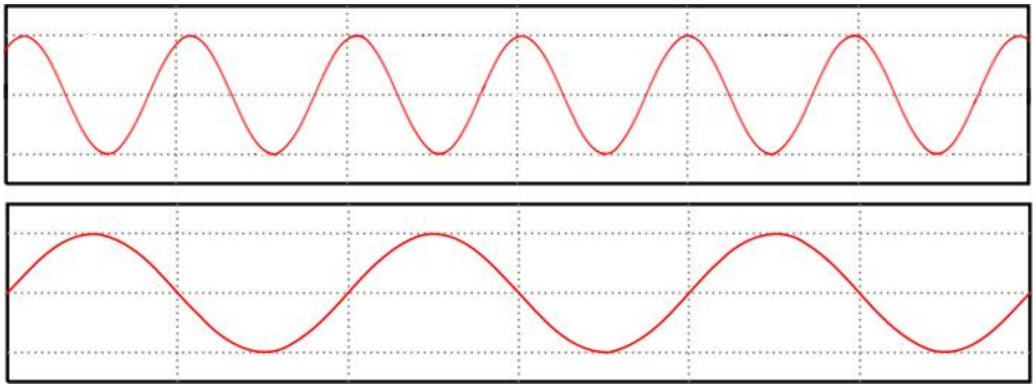

Figure 1: 2.4 and 5 GHz Wave Forms

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: A microwave oven operates at 2.4 GHz because that is the frequency at which the water in the food absorbs the microwave energy, creating heat. People, like food, are mostly water, and water absorbs 2.4 GHz energy. In a room crowded with people, devices that operate at 2.4 GHz are attenuated to a greater degree than devices that operate at 5 GHz.

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 Communications white paper on 802.11n by visiting http://www.summitdatacom.com/whitepapers.htm.

Regulations Applied to the 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. In many hospitals, the band is crowded with devices such as Wi-Fi radios, Bluetooth radios, baby monitors, cordless phones, and radio-controlled equipment. With much activity comes much interference, which can lead to connectivity problems.

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 (Europe, Africa, and portions of the Middle East) and the FCC regulatory domain (Americas and other countries), portions of the 5 GHz band also are used by weather and military radar systems that 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 applies only to devices with very high transmit power and antenna gain, so it rarely is 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. For details, see the section on scanning.

The table below shows 5 GHz channels, detailing the available DFS (D) and non-DFS (√) channels by regulatory domain.

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

Interference in the Bands

The 2.4 GHz band, historically the more popular band, has become overloaded. The 5 GHz band has more available spectrum and 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 a hospital environment.

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

The first diagram (Figure 2) 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 2: Real Time FFT (2.4 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.

Figure 3: Swept Spectrogram (2.4 GHz)

The next two diagrams (Figure 4 and Figure 5) 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 4 Real Time FFT (5 GHz)

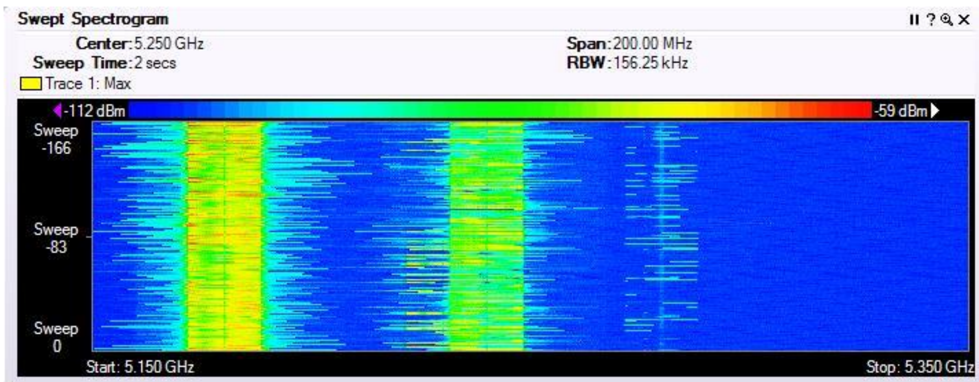

Figure 5: Swept Spectrogram (5 GHz)

A view of the active non-802.11 devices per channel (such as Figure 6) shows that, at any given time, there are:

- Several devices on every 2.4 GHz channel
- No devices on any 5 GHz channel

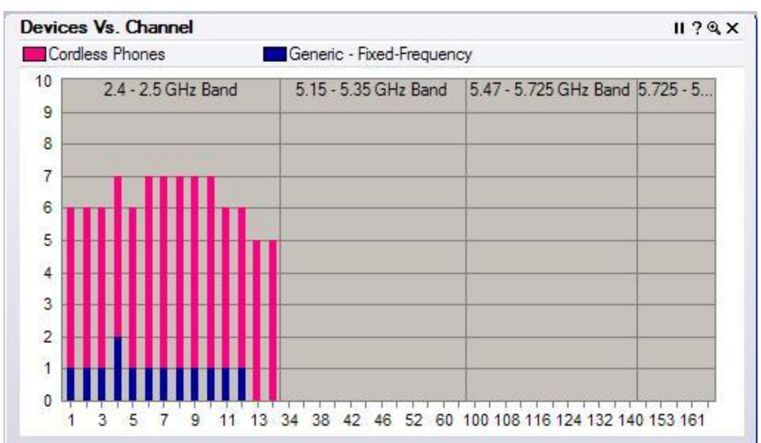

Figure 6: 2.4 GHz and 5 GHz Bands by Channel

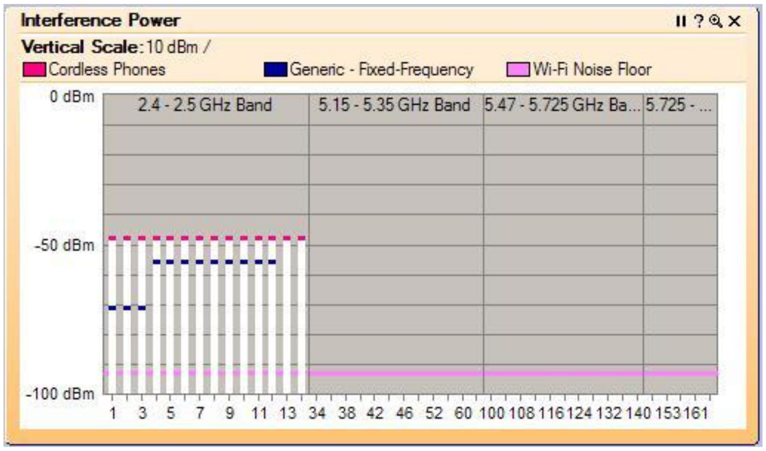

Figure 7: Interference Power by Band and Channel

A deeper look at the nature of the interferers (Figure 7) shows a strong (disruptive) signal strength of -50dBm on each 2.4 GHz channel due primarily to a FH cordless telephone system.

Range

Range is the greatest distance between Wi-Fi infrastructure and a client device where a Wi-Fi connection can be established and maintained. Due to the physical characteristics of the 2.4 GHz and 5 GHz waveforms, devices operating in the 2.4 GHz band typically provide greater range than those operating in the 5 GHz band. Range at 5 GHz also is comparative less because transmit power at 5 GHz band tends to be less than transmit power at 2.4 GHz.

Lower data rates allow for operation at greater distances than higher data rates, and so lower data rates at 2.4 GHz also lead to greater range there. Wi-Fi radios that operate in the 2.4 GHz band support 802.11b (in addition to 802.11g or 802.11n), and 802.11b supports lower data rates than the 802.11a and 802.11n standards in the 5 GHz band. 802.11b's lowest rates of one megabit per second (1 Mbps) and 2 Mbps, however, may be insufficient for even the most modest performance requirements of today's network applications. Some hospitals turn off these lowest rates, even though they allow for greater range, because connections at such low data rates are of no operational benefit.

Improvements in 5 GHz radios have led to greater range at 5 GHz. 802.11a and 802.11b were ratified in 1999, but for years 802.11a radios were less mature than their 802.11b (and 802.11g) counterparts. Thanks to improved radio designs in recent years, today's 802.11a devices provide far better performance than earlier versions. 5 GHz radio design work now is being applied not just to 802.11a radios but also to 802.11n radios that operate in the 5 GHz band.

Here are two other reasons why 5 GHz radios are closing the range gap with 2.4 GHz radios:

- The 2.4 GHz band has become "a victim of its own success" and is overcrowded with devices. Interference between devices 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.
- 802.11n infrastructure devices support MIMO (multiple input, multiple output) features such as transmit beam forming and maximal ratio combining that can improve coverage patterns and even range for all client devices by leveraging multipath propagation. Because the 5 GHz waveform is subject to greater multipath propagation than the 2.4 GHz waveform, 5 GHz client radios gain more range and coverage benefits from 802.11n infrastructure than do 2.4 GHz client radios.

- Today, clients and APs that support 5 GHz also support 2.4 GHz. 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, it must find an AP to which to connect. When its connection to that AP becomes tenuous, it must find an AP that offers a better connection. The process of searching for an AP is referred to as scanning. There are two types of scanning:

- Active scanning – For each channel on which an AP may be operating, the client transmits a probe request and waits to receive a probe response. Based on probe responses, the client determines the best AP to which it can associate.
- Passive scanning – Instead of transmitting probe requests, the client listens on each channel for beacon frames transmitted at regular intervals by APs.

An AP will respond to a probe request within 20 milliseconds (ms), whereas an AP may take 100 ms or longer to issue a beacon. Because a client spends less time on each channel waiting for information from APs, active scanning is more efficient than passive scanning.

While doing active or passive scanning, a client device is incapable of sending and receiving "payload" data. Because of this, long scans have a negative impact on applications that require a persistent network connection. Medical devices should use Wi-Fi radios that allow scan times to be minimized.

Because wireless clients cannot detect the presence of radar, they 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.

Given that a passive scan may take hundreds of milliseconds per DFS channel, the use of DFS channels for highly mobile devices is discouraged, especially in the FCC and ETSI regulatory domains where there are 15 DFS channels.

Note: By default, dual-band Wi-Fi radios from Summit Data Communications turn off scanning on DFS channels.

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.

Conclusion and Recommendations

The 5 GHz operating band presents greater challenges to networking professionals than does the 2.4 GHz band in areas such as range and mobility. The 5 GHz band is attractive, however, because it offers greater network capacity and relatively uncluttered airwaves. The need to incorporate 5 GHz operation into hospital 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 with years of experience in dual-band Wi-Fi networks, recommends the following when utilizing 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 hospital Wi-Fi networks and given the ever-increasing and unpredictable application requirements for these networks, it is important that networking professionals 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, spacing between APs should be determined based on 5 GHz requirements rather than 2.4 GHz requirements, especially APs that support 802.11a but not 802.11n.
- Dual-band client radios, including those that support 802.11a/b/g but not 802.11n, benefit from a dual-band 802.11n infrastructure, namely more reliable connectivity and greater range. 802.11n essentially improves the 5 GHz band for all client devices, including those that support 802.11a but not 802.11n. Network administrators should upgrade to dual-band 802.11n infrastructure as resources allow.
- 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 only passive scanning is allowed, 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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