



Radio Operating Frequencies and Data Rates

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This part of the CVD discusses radio operating frequencies that are used for WLAN networks. Also briefly discussed are 802.11 a/b/n/ac modulation techniques and the role of TPC and DCA in a radio frequency (RF) network.

Radio Frequency Bands

In the United States there are three radio frequency bands allocated for unlicensed industrial, scientific, and medical (ISM) usage, as shown in [Table 9-1](#).

Table 9-1 Radio Frequency Bands

RF Band	Uses
900 MHz (902 to 928 MHz)	Phones, medical equipment, RFID, etc.
2.4 GHz (2.4 to 2.4835 GHz)	IEEE 802.11b/g/n, Bluetooth, microwave ovens, analog video cameras, older DECT standard-based phones, etc.
5 GHz (5.15 to 5.35 and 5.725 to 5.825 GHz)	IEEE 802.11a/n and 802.11ac, analog video cameras, radars, older DECT standard-based phones, etc.

For our purpose we are interested in the IEEE 802.11b/n, 802.11a/n, and 802.11ac for Wi-Fi communication. Each range has different characteristics. The lower frequencies exhibit better range, but with limited bandwidth and thus lower data rates. The higher frequencies exhibit less range and are subject to greater attenuation from solid objects.

Regulatory Domains

Devices that operate in unlicensed bands do not require any formal licensing process, but when operating in these bands, the user is obligated to follow the government regulations for that region. The regulatory domains in different parts of the world monitor these bands according to different criteria and the WLAN devices used in these domains must comply with the specifications of the relevant governing regulatory domain. Although the regulatory requirements do not affect the interoperability of IEEE 802.11b/g/n and 802.11a/n/ac-compliant products, the regulatory agencies do set certain criteria in the standard, such as specifying the emission requirements for WLAN to minimize the amount of interference a radio can

generate or receive from another radio in the same proximity. It is the responsibility of the vendor to obtain certification for a product from the relevant regulatory body. Table 9-2 summarizes the current regulatory domains for Wi-Fi products, which include the main regulatory domains FCC, ETSI, and MKK.

Besides following the requirements of the regulatory agencies, many vendors also ensure compatibility with other vendors through the Wi-Fi certification program (<http://www.wi-fi.org>).

Table 9-2 Regulatory Domains

Regulatory Domain	Geographic Area
Americas or FCC (United States Federal Communication Commission)	North, South, and Central America, Australia and New Zealand, various parts of Asia and Oceania
Europe or ETSI (European Telecommunications Standards Institute)	Europe (both EU and non EU countries), Middle East, Africa, various parts of Asia and Oceania
Japan (MKK)	Japan
China	People's Republic of China (Mainland China)
Israel	Israel
Singapore ¹	Singapore
Taiwan ¹	Republic of China (Taiwan)

1. The regulations of Singapore and Taiwan for wireless LANs are particular to these countries only for operation in the 5 GHz band. Singapore and Taiwan are therefore only regulatory domains for 5 GHz operations; for operation in 2.4 GHz, they fall into the ETSI and FCC domains, respectively.



Note

See

http://www.cisco.com/c/en/us/products/collateral/wireless/aironet-1300-series/product_data_sheet0900aecd80537b6a.html for compliance information and also check with your local regulatory authority to find out what is permitted within your country. The information provided in Table 9-1 and Table 9-2 should be used as general guidelines.

Operating Frequencies

The 2.4 GHz band regulations have been relatively constant, given the length of time they have been operating. The FCC allows for 11 channels, ETSI allows for up to 13 channels, and Japan allows up to 14 channels, but requires a special license to operate in channel 14.

For 5 GHz, countries are moving to open the frequency range 5.250-5.350 GHz (UNII-2) and the frequency range 5.470 to 5.780 GHz for additional 802.11a channels. These various frequencies are covered in more detail in the specific 802.11 sections in this chapter.

802.11 Modulation Techniques

The IEEE 802.11 standard makes provisions for the use of several different modulation techniques to encode the transmitted data onto the RF signal. These modulation techniques are used to enhance the probability of the receiver correctly receiving the data and thus reducing the need for retransmissions. The techniques vary in their complexities and robustness to RF signal propagation impairments.

Direct-Sequence Spread Spectrum

The direct-sequence spread spectrum (DSSS) approach involves encoding redundant information into the RF signal. Every data bit is expanded to a string of chips called a chipping sequence or Barker sequence. The chipping rate, as mandated by the U.S. FCC, is 10 chips at the 1- and 2-Mbps rates and 8 chips at the 11-Mbps rate. So, at 11 Mbps, 8 bits are transmitted for every one bit of data. The chipping sequence is transmitted in parallel across the spread spectrum frequency channel.

Frequency-Hopping Spread Spectrum

Frequency-hopping spread spectrum (FHSS) uses a radio that moves or hops from one frequency to another at predetermined times and channels. The regulations require that the maximum time spent on any one channel is 400 milliseconds. For the 1- and 2-Mb FHSS systems, the hopping pattern must include 75 different channels and must use every channel before reusing any one. For wide-band frequency hopping (WBFH) systems, which permit up to 10-Mb data rates, the rules require the use of at least 15 channels and they cannot overlap. With only 83 MHz of spectrum, WBFH limits the systems to 15 channels, thus causing scalability issues. In every case, for the same transmitter power and antennas, a DSSS system has greater range, scalability, and throughput than an FHSS system. For this reason, Cisco has chosen to support only direct-sequence systems in the spread spectrum products.

Orthogonal Frequency Division Multiplexing

The orthogonal frequency division multiplexing (OFDM) used in 802.11a/n/ac and 802.11g data transmissions offers greater performance than the older direct-sequence systems. In the OFDM system, each tone is orthogonal to the adjacent tones and therefore does not require the frequency guard band needed for direct sequence. This guard band lowers the bandwidth efficiency and wastes up to 50 percent of the available bandwidth. Because OFDM is composed of many narrow-band tones, narrow-band interference degrades only a small portion of the signal, with little or no effect on the remainder of the frequency components.

**Note**

802.11 beacon frames are sent at the highest power at lowest possible data rate. For example, in a 2.4GHz 802.11n deployment, if all data rates are enabled, then beacons are sent at highest power at 1 Mbps data rate. At 1 Mbps, DSSS is used instead of OFDM. In a good WLAN deployment it is advisable to disable data rates that are not used. More deployment guidelines are discussed in later sections of this design guide.

2.4 GHz Operating Frequencies and Data Rates

Ratified in September, 1999, the 802.11b standard operates in the 2.4 GHz spectrum and supports data rates of 1, 2, 5.5, and 11 Mbps. 802.11b enjoyed broad user acceptance and vendor support for a number of years.

The 802.11g standard, which was ratified in June, 2003, operates in the same spectrum as 802.11b and is backward-compatible with the 802.11b standard. 802.11g supports the additional data rates of 6, 9, 12, 18, 24, 36, 48, and 54 Mbps.

The 802.11n standard, which was ratified in 2009, also operates in the same spectrum as 802.11b/g and is backward-compatible with the 802.11b standard. 802.11n made a fundamental shift in WLAN technology by introducing many new improvements over older 802.11b/g technology to provide much higher speeds. These new improvements include channel bonding to provide 40 MHz channels, MIMO (Multiple In Multiple Out) Antenna system, MRC (Maximum Ratio Combining) and Shorter Guard Intervals. The data rates in the 2.4 GHz spectrum can reach up to 72 Mbps with a single channel (20 MHz), single antenna mode. With a 20 MHz channel and multiple antennas, 802.11n data rates in the 2.4 GHz can reach up to 300 Mbps. By combining two 20 MHz channels, throughputs up to 600MHz can be achieved, however channel bonding is not a popular choice in a 2.4 GHz deployment due to various factors like RF interference and lack of overlapping channels.

**Note**

While 802.11n technology is supported in 2.4 GHz spectrum, Cisco Access Points cannot be configured to use 40 MHz channels in the 2.4 GHz spectrum by combining channels.

**Note**

The operating frequencies, modulation schemes and bands supported tables are discussed in [Appendix C, “802.11 Data Rates.”](#)

5 GHz Operating Frequencies and Data Rates

Operating in the unlicensed portion of the 5 GHz radio band, 802.11a is reasonably immune to interference from devices that operate in the 2.4 GHz band, such as microwave ovens, many cordless phones, and Bluetooth (a short-range, low-speed, point-to-point, personal-area-network wireless standard). Because the 802.11a standard operates in a different frequency range, it is not compatible with existing 802.11b or 802.11g-compliant wireless devices, but it does mean that 2.4-GHz and 5-GHz equipment can operate in the same physical environment without interference.

Choosing between these two technologies (802.11b/g/n and 802.11a/n/ac) does not involve a one-for-one trade-off. They are complementary technologies and will continue to coexist in future enterprise environments. Those responsible for implementing these technologies must be able to make an educated choice to properly plan 2.4 GHz and 5 GHz networks. Proper WLAN capacity planning should be undertaken to ensure that devices both in 2.4 GHz and 5 GHz get adequate bandwidth for their use.

WLAN capacity planning is discussed in more detail in [Chapter 15, “Access Point Placement and Separation.”](#)

The 5 GHz band in which 802.11a/n/ac operates is divided into several different sections. Each of the Unlicensed National Information Infrastructure (UNII) bands presented in [Table 9-3](#) was originally intended for different uses, but all can currently be used by indoor 802.11a/n/ac with appropriate power restrictions. Initially, the FCC defined only the UNII-1, UNII-2, and UNII-3 bands, each of which had four channels. The channels were spaced 20 MHz apart with an RF spectrum bandwidth of 20 MHz, thereby providing non-overlapping channels using 20 MHz channel width.

There are differing limitations on these three UNII bands. Restrictions vary between them for transmit power, antenna gain, antenna styles, and usage. The UNII-1 band is designated for indoor operations and initially had a restriction of permanently attached antennas. The UNII-2 band was designated for indoor or outdoor operations and permitted external antennas. The UNII-3 band was intended for outdoor bridge products and permitted external antennas, but the UNII-3 band can now be used for indoor or outdoor 802.11a/n/ac WLANs as well.

[Table 9-3](#) summarizes the channels available and restrictions on them.

Table 9-3 Channels Available

UNII band	Channels Available	Restriction
UNII-1, 5.150 to 5.250 GHz	36, 40, 44, 48	Not Applicable
UNII-2, 5.250 to 5.350 GHz	52, 56, 60, 64	Requires Dynamic Frequency Selection (DFS) to avoid Radars and Transmitter Power Control (TPC)
UNII-2 5.470 to 5.725 GHz	100, 104, 108, 112, 116, 120, 124, 128, 132, 136, 140	Requires Dynamic Frequency Selection (DFS) to avoid Radars and Transmitter Power Control (TPC)
UNII-3 5.725 to 5.825 GHz	149, 153, 157, 161, 165	Don't require DFS or TPC

**Note**

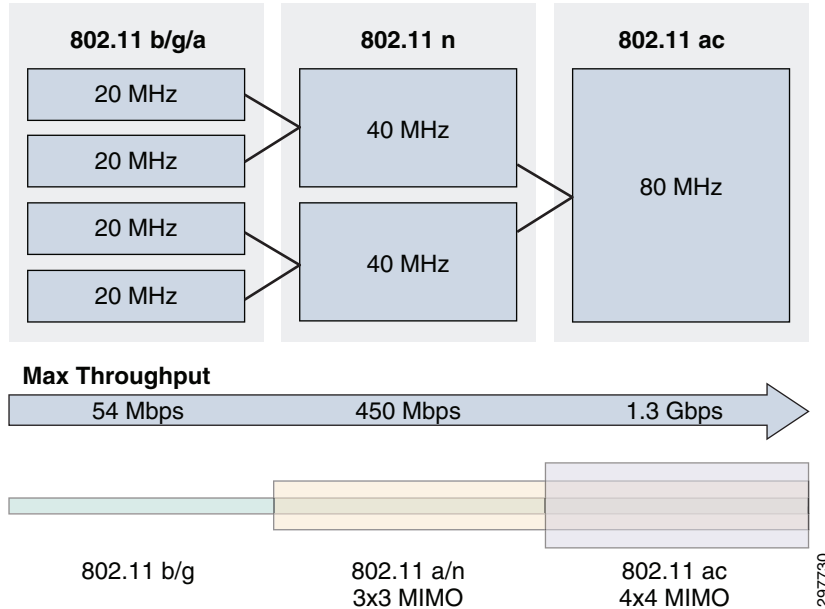
Not all channels in a given range can be used in all of the regulatory domains. Refer to [“802.11 Data Rates”](#) for information on supported channel and regulatory domain.

802.11a uses 20 Mhz channels. 802.11n can use 20 or 40 MHz channels. 802.11ac is defined up to 160 MHz channels. However current implementations (802.11ac Wave 1 products) can use 20, 40, or 80 MHz channels. The way channels are used is through channel bonding, i.e., taking adjacent channels and bonding them together to create a bigger spectrum (channel) that facilitates higher data rate. The 802.11n standard, which was ratified in 2009, also operates in the same spectrum as 802.11a and is backward compatible with the 802.11a standard. 802.11n made a fundamental shift in WLAN technology by introducing many new improvements over older 802.11a technology to provide much higher speeds. These new improvements include channel bonding to provide 40 MHz channels, MIMO (Multiple In Multiple Out) Antenna system, MRC (Maximum Ratio Combining), and Shorter Guard Intervals. With a 20 MHz channel and multiple antennas, 802.11n data rates in the 5 GHz can reach up to 300 Mbps. By combining two 20 MHz channels into a 40MHz channels, throughputs up to 600MHz can be achieved. Similarly by combing even more channels into an 80Mhz channels for 802.11ac, throughputs up to 1.3Gb can be achieved.

**Note**

There are not many commercial implementations of APs which go beyond 3x3 MIMO with three spatial streams however. Therefore you are unlikely to currently find an AP with higher than 450 Mbps data rates for 802.11n.

Figure 9-1 Comparison of Different Protocols

**Note**

A good discussion on 802.11n data rates can be found at:

http://www.cisco.com/c/en/us/products/collateral/wireless/aironet-1250-series/design_guide_c07-693245.html#wp9001157.

A note on the DFS and TPC: Dynamic Frequency Selection instructs a transmitter to switch to another channel whenever a particular condition (such as the presence of a radar signal) is met. Before transmitting, the DFS mechanism of a device monitors its available operating spectrum, listening for a radar signal. If a signal is detected, the channel associated with the radar signal is vacated or flagged as unavailable for use by the transmitter. The transmitting device continuously monitors the environment for the presence of radar, both prior to and during operation. Portions of the 5 GHz band are allocated to radar systems, which allows WLANs to avoid interference with incumbent radar users in instances where they are collocated.

TPC allows the AP to negotiate power levels with a WLAN client during that association process. The AP can inform that WLAN client of the range of allowable transmit power to be used with that AP and may reject clients unable to meet those levels. The WLAN client is able to adjust its transmit power level within the range specified in the TPC negotiations. This ensures that interference from the WLAN is minimized and allows the WLAN client to optimize battery life.

**Note**

Both DFS and TPC are discussed in greater detail in [Radio Resource Management](#) in [Chapter 20](#), “Post-Deployment Radio Frequency Tuning.”

802.11ac

802.11ac is a faster and more scalable version of 802.11n. 802.11ac couples the freedom of wireless with the capabilities of Gigabit Ethernet. 802.11ac achieves its raw speed increase by pushing on three different dimensions:

- More channel bonding, increased from the maximum of 40 MHz in 802.11n and now up to 80 or even 160 MHz (for 117% or 333% speed-ups, respectively).
- Denser modulation, now using 256 quadrature amplitude modulation (QAM), up from 802.11n's 64QAM (for a 33% speed burst at shorter, yet still usable, ranges).
- More multiple inputs, multiple outputs (MIMO). Whereas 802.11n stopped at four spatial streams, 802.11ac goes all the way to eight (for another 100% speed-up).

**Note**

Current Wave 1 of 802.11ac supports only up to 4x4 spatial streams.

The design constraints and economics that kept 802.11n products at one, two, or three spatial streams have not changed much for 802.11ac, so we can expect the same kind of product availability with first-wave 802.11ac products built around 80 MHz and delivering up to 433 Mbps (low end), 867 Mbps (mid-tier), or 1300 Mbps (high end) at the physical layer. Second-generation products promises still more channel bonding and spatial streams, with plausible product configurations operating at up to 3.47 Gbps.

802.11ac is a 5 GHz-only technology, so dual-band APs and clients will continue to use 802.11n at 2.4 GHz. However 802.11ac clients operate in the less crowded 5 GHz band.

**Note**

Current Wave 1 of 802.11ac implementations support up to 80 MHz channels only. Wave 2 of 802.11ac implementation will support up to 160 Mhz channels.

**Note**

Because of increased width, there are now far fewer channels available for 802.11ac in 5 GHz. To get maximum throughput both client and AP should support 802.11ac. In general you also need good SNR ratio across all four sub 20 Mhz channels to achieve highest throughput.

**Note**

For a more detailed discussion around 802.11ac, see:
http://www.cisco.com/c/en/us/products/collateral/wireless/aironet-3600-series/white_paper_c11-713103.html.
