



## WLAN RF Design Considerations

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This chapter describes the basic information necessary to understand radio frequency (RF) considerations in planning for various wireless local area network (WLAN) environments. The topics of this chapter includes:

- Regulatory domains and RF considerations
- IEEE 802.11 standards
- RF spectrum implementations of 802.11b/g/n (2.4-GHz) and 802.11a/n/ac (5-GHz)
- Planning for RF deployment
- Radio resource management (RRM) algorithms and configuration
- RF Profiles and fine tuning

### RF Basics

In the United States there are three main bands (frequency ranges) allocated for unlicensed industrial, scientific, and medical (ISM) usage.

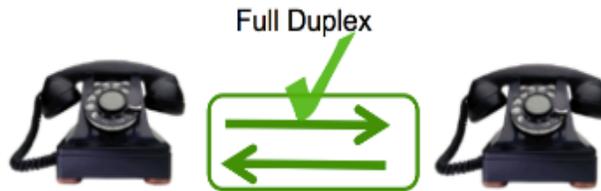
The ISM bands are designated as the:

- 900 MHz band: 902 to 928 MHz
- 2.4 GHz band (IEEE 802.11b/g/n): 2.4 to 2.4835 GHz
- 5 GHz band (IEEE 802.11a/n/ac):
  - 5.150 to 5.250 GHz (UNII-1)
  - 5.250 to 5.350 GHz (UNII-2)
  - 5.450 to 5.710 GHz (UNII-2e)
  - 5.725 to 5.875 GHz (UNII-3)

The 900 MHz band is not used for Wi-Fi. Each of the remaining bands has different characteristics and for Wi-Fi the pro's and con's depend on what your coverage and capacity goals are, and what is already occupying the spectrum in your location. See deployment considerations later in this chapter for more detail.

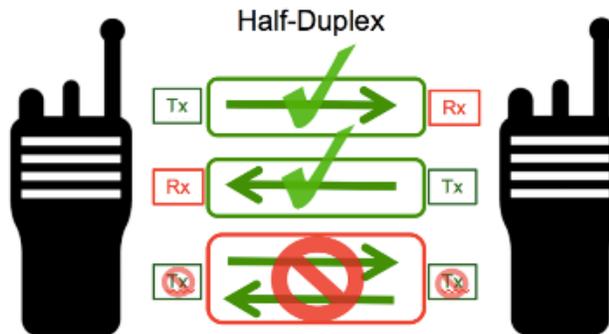
It is important to understand how Wi-Fi differs from modern day LAN implementations. A modern day wired LAN is most often a full duplex, switched infrastructure. This means that traffic is sent and received simultaneously and switched between active ports, so a client can both transmit and receive concurrently. A telephone conversation is full duplex – see [Figure 3-1](#).

**Figure 3-1 Example of Full Duplex Conversation**



Wi-Fi on the other hand is half duplex (Fig. 2), meaning we can either Transmit (Tx) to or Receive (Rx) from a client/AP on the medium, the clients and the network take turns accessing the medium – it is a shared broadcast and collision domain. Wi-Fi is contention based – meaning there are rules for stations trying to access the medium and collisions (due to two or more stations simultaneously accessing the medium) are worked out fairly so everyone gets a chance.

**Figure 3-2 Example of a Half-Duplex Conversation**



Separation of physical groups of clients is performed using different frequency assignments – or channels. For an access point operating on a given channel, there is a finite amount of airtime available and every client connecting to an access point shares the airtime that the AP's channel has to offer. The more clients that are actively using an AP, the less airtime each client will get individually. Supporting a higher data rate for one or more clients (more efficient use of airtime) will increase available airtime for all clients, and result in higher potential bandwidth to the individual user.

All clients on a given channel share a common collision domain that extends to other AP's operating on the same channel regardless of whose network they ultimately belong to. This means that other clients and access points using the same channel and can hear one another, share the available airtime. Each additional AP added to a channel brings with it management overhead on the air. The effect of this additional management traffic further reduces the total amount of airtime available for each user and constrains performance.

$\text{Bandwidth} = \text{Airtime} \times \text{Data Rate}.$

If you require more bandwidth than can be served from a single access point (i.e. you have many users in a small area) then multiple AP's will be required. When implemented on non overlapping channels, each AP provides an isolated chunk of airtime over its coverage area. AP's that are on the same channel must be kept out of range of one another. This is what Cisco's RRM manages for you –the power and the channel selection to coordinate multiple AP's and neighbors for optimal performance. (See [Radio Resource Management - RRM](#) below in this document.)

Channel assignment and reuse for the network is a big factor in determining the airtime efficiency and ultimately the bandwidth that can be delivered to the clients. When two AP's can hear one another on the same channel the result can be co-channel interference unless the overlapping BSS is managed

carefully. Whether co-channel interference is the result of your own AP's, or your AP and a neighbor doesn't matter— either way the AP's must share the channel. In order to produce a good physical design, four things must be considered:

- AP placement
- AP operating band (2.4 GHz or 5 GHz)
- AP channels selected
- AP power levels assigned

The goal in a good design is to produce even wireless coverage (similar conditions end to end) with minimal co-channel interference maximizing the available potential bandwidth for the client devices.

Cisco's RRM, Radio Resource Management, calculates and assigns the best channels and power combinations using measured, over the air metrics. Over The Air observations include Wi-Fi networks operating within the infrastructure as well as existing external users Wi-Fi and non-Wi-Fi of the spectrum. RRM will mitigate co-channel assignments and balance power, but if there are no open channels available, or the AP's are simply too close together the only choice remaining is sharing the channel with an existing user. This happens in congested environments and two different networks may have to share the same bandwidth. If one or the other is not busy – the other may use all of the bandwidth. If both become busy, they will share the bandwidth 50/50 due to 802.11's contention mechanisms (“listen before talk”) that are designed to ensure fair access.

## Regulatory Domains

Devices that operate in unlicensed bands do not require a formal licensing process by the end user. However equipment designed and built for operating 802.11 in the ISM bands is obligated to follow the government regulations for the region it is to be used in. “Unlicensed, does not mean “without rules”. Cisco Wireless equipment is designed and certified to operate and meet the regulatory requirements for specific regions. Regulatory designations are either included in the part numbers for pre provisioned AP's built for a specific region or more recently a Universal AP (UAP) which is provisioned on site (*See Universal AP Regulatory Domain Deployment Guide*).

The end user bears responsibility for correct implementation and ensuring that the correct equipment is used for the specified region. Your Cisco sales team can guide you in selection. For provisioning a universal AP – at least one AP must be provisioned using the smart-phone application to ensure the GPS location of the AP. This ensures that the AP is physically located in the region being activated for. Once provisioning of the first UAP is completed, other UAP's may be provisioned off the initial UAP with enable radio interfaces.

The regulatory agencies in different regions of the world monitor the unlicensed bands according to their individual criteria. WLAN devices must comply with the specifications of the relevant governing regulatory body. 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 product implementation. For example, the RF emission requirements for WLAN are designed to minimize the amount of interference any radio (not just Wi-Fi) can generate or receive from any other radio in the same proximity. It is the responsibility of the WLAN vendor to obtain product certification from the relevant regulatory body. And it is the responsibility of the installer to ensure that the resulting installation does not exceed those requirements. We recommend and certify the use of antenna's and radio combinations that meet regulatory requirements.

Besides following the requirements of the regulatory agencies, Cisco ensures interoperability with other vendors through various Wi-Fi Alliance (WFA) certification programs ([www.wi-fi.org](http://www.wi-fi.org)).

## Operating Frequencies

The 2.4-GHz band regulations of 802.11b/g/n have been relatively constant, given the length of time they have been in operation. The FCC (U.S) allows for 11 channels, ETSI (and most other parts of the world) allow for up to 13 channels, and Japan allows up to 14 channels but requires a special license and operating modes to operate in channel 14.

Countries that adhere to the 5.0-GHz band regulations of 802.11a/n/ac are more diverse in the channels they allow and their rules for operation. In general, with the advancement of 802.11ac most are now considering opening more spectrum for 5 GHz Wi-Fi – and all have more non overlapping channels in 5 GHz than is available anywhere in 2.4 GHz.

These frequency bands and their associated protocols can and do change as the technology evolves and regulatory rules change. All Cisco AP's regulatory certifications and allowed frequencies and channels are documented in their individual data. These documents are located under Access Points in [Cisco Reference Guides](#).

### 2.4 GHz - 802.11b/g/n

The 2.4 GHz band as it is commonly referred to consists of frequencies between 2400 MHz and 2483 MHz for a total of 83 MHz of usable spectrum in most of the world.

There are currently 3 protocol specifications permitted for 802.11 Wi-Fi operations in the 2.4 GHz band. 802.11b, 802.11g and 802.11n are standards created by the IEEE and agreed to by individual regulatory authorities around the world. Many other non Wi-Fi technologies also use the 2.4 GHz band for operation; Microwave Ovens, Baby Monitors, Gaming consoles, Bluetooth devices and cordless phones to name just a few. These other non Wi-Fi devices represent interference to Wi-Fi signals as they can and do interfere with Wi-Fi operations in the 2.4 GHz band. Consumer Wi-Fi devices also heavily use the 2.4 GHz band. Many older (but still in widespread use) consumer access points (or wireless routers as they are sometimes called) are single band devices that only operate with a 2.4 GHz radio. The aggregate of all the various users accessing the 2.4 GHz band combined with a limited amount of spectrum leads to this bands growing reputation for congestion.

Does this mean that you wont be able to successfully deploy Wi-Fi in 2.4 GHz? No. It simply means that the 2.4 GHz band will fill up faster and support less users than the 5 GHz band will. Congestion in the band is a local phenomenon and your location may be fine. A site survey will show you what you have to work with in your application.

### 802.11b

The 802.11b protocol was ratified as an amendment to the 802.11 standards in 1999. It added support for data rates of 5.5 and 11 Mbps and enjoys broad user acceptance and vendor support. 802.11b has been deployed by thousands of organizations, as it was the first standardized specification for modern Wi-Fi communications. It is the least efficient of all the protocols available today, which means that you will exhaust available airtime quite rapidly using this protocol and with less airtime; you can support less users. 802.11b is based on a single transmitter/receiver design and suffers from multipath frequency phenomena that affects reliability and makes design more difficult. What remains of true 802.11b clients can generally be found in application specific appliances such as bar code scanners or printers generally in Logistics, Retail or Health Care verticals. Modern day radios that are able to support 802.11b are generally all implemented on radios designed for 802.11n and improve the reliability (MRC Receivers), but not the efficiency of the 802.11b standard.

## 802.11g

The 802.11g protocol, which was ratified as an amendment to the 802.11 IEEE standards in 2003, operates in the same spectrum as and is backwardly compatible with the 802.11b specification. The 802.11g standard uses a completely different modulation technique (OFDM) and supports data rates of 6, 9, 12, 18, 24, 36, 48, and 54 Mbps. While backwardly compatible, this compatibility comes at a cost to airtime and additional management overhead required for 802.11b which reduces the overall gains that could be realized with 802.11g when operating in an 11g only client environment. Performance in a mixed 802.11b 802.11g environment will cost as much as 50% of a cell's potential capacity. Initial 802.11g radios like 802.11b designs also had a single receiver and transmitter and were subject to a lot of the same reliability issues in implementation.

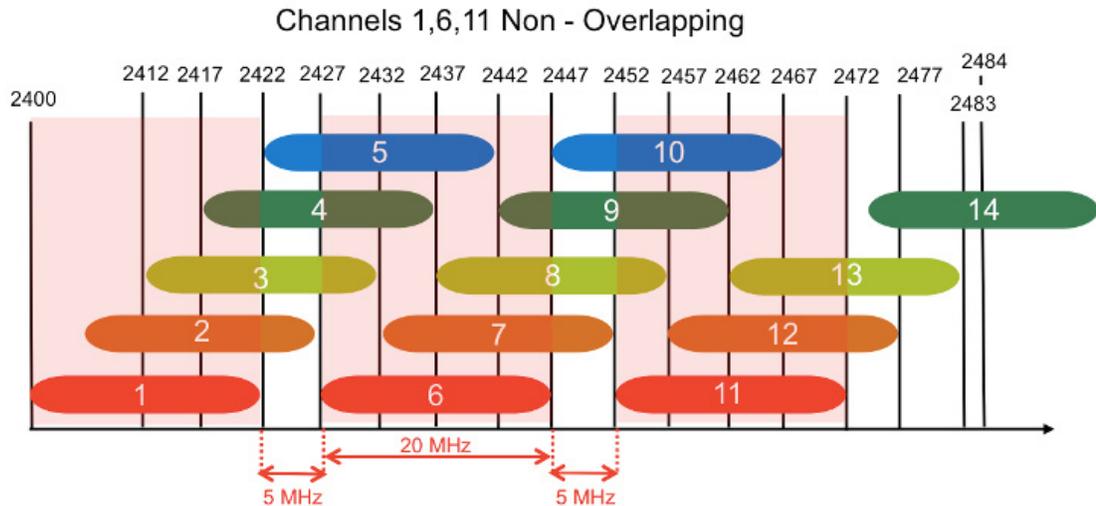
## 802.11n

The 802.11n protocol, which was ratified as an amendment to the 802.11 standards in 2009 allows for usage in either 2.4 or 5 GHz bands and introduces MIMO (multiple input, multiple output) using multiple radios allows for encoding multiple Spatial Streams simultaneously (i.e) up to 4 times the data in the same amount of airtime theoretically, 3 spatial Streams is the practical limit. The 2.4 GHz band supports data rates up to 216 Mbps (assuming 20 MHz channel and 3 spatial stream transmitter). 802.11n also specifies a wider channel operation at 40 MHz commonly referred to as a bonded channel as it requires two 20 MHz channels to make a single 40 MHz channel. We do not support bonding of channels in 2.4 GHz because of interference issues associated with only having 3 non-overlapping channels available (Figure 3-3). The number of devices, which support 3 spatial streams, is limited to higher end laptops and tablets as well as access points. Two spatial stream devices are more plentiful but still limited to Laptops and tablets, with only a few of the newest smartphones now support multiple spatial streams. In all cases, 802.11n products introduced a technology for receivers called MRC (Maximal Ratio Combining) a technique which relied on multiple receivers/antennas to mitigate the reliability issues associated with early 802.11b and 802.11g/a receivers and improved the overall reliability and performance of Wi-Fi. Therefore, modern 802.11n based radios improve on reliability when operating under the 802.11g standard.

## 2.4 GHz Wi-Fi Channel Planning

Channel plans for the 2.4 GHz band identify 14 Overlapping channels, but only 3 of these are Channels 1,6,11 are highlighted below, note that all other channels overlap or share boundaries and in the US only 1,6,11 are available for non-interfering channel operation.

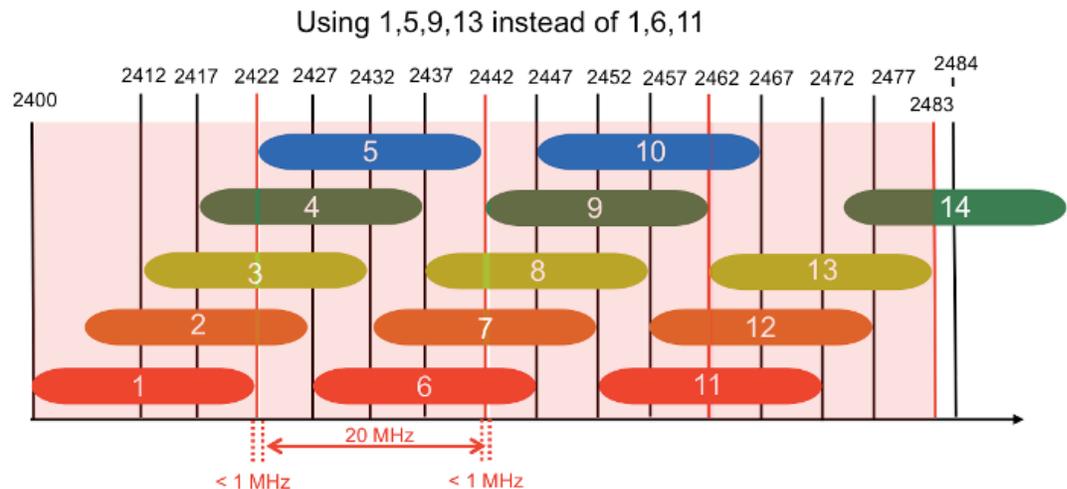
**Figure 3-3** 2.4 GHz Channels, Showing 1,6,11 Selected



**Note**

In some regulatory domains, it has been suggested that a 4 channel plan will work. This continues to come up time and again however without going into a lot of detail about what happens outside of the channel boundaries – there is simply not enough space between channels left for this to work practically in anything but the least dense environments. Also consider that the majority of the world agrees on 1,6,11 and most radios will default to this channel plan – in such a case if you have selected 1,5,9,13 any radio using the standard channels will interfere with at least one – in most cases 2 of your channels – We do not recommend it for these reasons.

**Figure 3-4** 2.4 GHz Channels Showing 1/5/9/13 Selected



Valid strategies for reducing the congestion in 2.4 GHz include reduction in self interference by:

1. Disabling the 802.11b data rates – this will reduce the area of coverage/interference and eliminate the least efficient protocols from the air
2. Choosing a relatively high minimum mandatory data rates – this also reduces effective coverage/interference and data rates of 12-18 Mbps are used in high density deployments

3. No more than 3-4 SSID's (WLAN's) on any one AP, as each AP must broadcast each configured WLAN – this can dramatically reduce the management overhead associated with the physical channel
4. Eliminate known non Wi-Fi interference sources, [CleanAir](#) can help you identify, evaluate and locate these.

For interference coming from neighboring Wi-Fi networks that are not part of your solutions. All involve additional hardware and complexity in design. If you have a valid need for critical operations in 2.4 GHz it is recommended that you employ someone who has experience with this level of design.

## 5 GHz - 802.11a/n/ac

Operating in the unlicensed portion of the 5 GHz radio band, 802.11a/n/ac radios are immune to interference from ALL devices that operate in the 2.4 GHz band, including non Wi-Fi interference from consumer devices. The 5 GHz band available for Wi-Fi use can differ significantly around the world from 100 to 300 MHz, but in all cases there is more bandwidth available than in 2.4 GHz spectrums.

Because the 802.11a/n/ac standards operate in a different frequency range, 2.4 and 5 GHz band devices can operate in the same physical environment without interfering with each other. Most Cisco AP's support both 2.4 and 5 GHz dual band operation. There are three protocol specifications ratified for use in 5 GHz Wi-Fi, 802.11a, 802.11n and 802.11ac. The range of frequencies/channels is broken into different frequency segments in 5 GHz – and the range of frequencies has increased over time. In the United States we have:

- 5.150 to 5.250 GHz (UNII-1 - 4 Channels 36-48)
- 5.250 to 5.350 GHz (UNII-2 - 4 Channels 52-64)
- 5.450 to 5.710 GHz (UNII-2e - 12 Channels 100-144)
- 5.725 to 5.875 GHz (UNII-3 - 5 Channels 140-165)

All three protocols are backwardly compatible using identical mechanisms and work quite well together with no noticeable penalties for mixed operation apparent due to a common encoding technology. The primary differences are airtime efficiency.

Channel assignments in 5 GHz bands are much more straightforward in that all assignments are NON Overlapping channels with a minimum of 5 MHz separation maintained between channels.

### 802.11a

802.11a protocol, which was ratified as an amendment to the 802.11 standards in 1999 and is identical in most respects to the 802.11g standard except the band in which it operates and no need for backward compatibility for 802.11b. 802.11a supports speeds of 6, 9, 18, 24, 36, 48 and 54 Mbps. This is largely considered a legacy protocol in 2015 and you likely will not find many native 802.11a devices left in the wild. You may still see the 802.11a protocol in the air – but it is much more likely that this protocol is being used on a device that is natively at least an 802.11n device.

### 802.11n

802.11n protocol, which was ratified as an amendment to the 802.11 standards in 2009 allowed for operation in 2.4 GHz as well as 5 GHz. It also included several enhancements that allowed for wider channel operation (up to 40 MHz up from 20 MHz) with two times the channel width, one can expect twice the capacity or speed. This protocol introduced a new concept in radio design – MIMO – or Multiple Input, Multiple Output. Using multiple spatial streams allows simultaneous encoding of separate streams of data within the same signal and increased the density of data that could be sent at one time providing an order of magnitude increase in capacity and speed. The data rates for 802.11n

needed to accommodate a varying number of spatial streams (dictated by individual radio design) as well as the encoding method used. The new data rate structure adopted MCS (Modulation and Coding Scheme) as a substitute for the then standard Data Rate.

**Table 3-1 802.11n MCS 1-23 Data Rates**

| MCS Index | Spatial Streams | Modulation Type | Coding rate | Data Rate (Mbit/s) |           |                |           |
|-----------|-----------------|-----------------|-------------|--------------------|-----------|----------------|-----------|
|           |                 |                 |             | 20 MHz Channel     |           | 40 MHz Channel |           |
|           |                 |                 |             | 800 ns GI          | 400 ns GI | 800 ns GI      | 400 ns GI |
| 0         | 1               | BPSK            | 1/2         | 6.5                | 7.2       | 13.5           | 15        |
| 1         | 1               | QPSK            | 1/2         | 13                 | 14.4      | 27             | 30        |
| 2         | 1               | QPSK            | 3/4         | 19.5               | 21.7      | 40.5           | 45        |
| 3         | 1               | 16-QAM          | 1/2         | 26                 | 28.9      | 54             | 60        |
| 4         | 1               | 16-QAM          | 3/4         | 39                 | 43.3      | 81             | 90        |
| 5         | 1               | 64-QAM          | 2/3         | 52                 | 57.8      | 108            | 120       |
| 6         | 1               | 64-QAM          | 3/4         | 58.5               | 65        | 121.5          | 135       |
| 7         | 1               | 64-QAM          | 5/6         | 65                 | 72.2      | 135            | 150       |
| 8         | 2               | BPSK            | 1/2         | 13                 | 14.4      | 27             | 30        |
| 9         | 2               | QPSK            | 1/2         | 26                 | 28.9      | 54             | 60        |
| 10        | 2               | QPSK            | 3/4         | 39                 | 43.3      | 81             | 90        |
| 11        | 2               | 16-QAM          | 1/2         | 52                 | 57.8      | 108            | 120       |
| 12        | 2               | 16-QAM          | 3/4         | 78                 | 86.7      | 162            | 180       |
| 13        | 2               | 64-QAM          | 2/3         | 104                | 115.6     | 216            | 240       |
| 14        | 2               | 64-QAM          | 3/4         | 117                | 130       | 243            | 270       |
| 15        | 2               | 64-QAM          | 5/6         | 130                | 144.4     | 270            | 300       |
| 16        | 3               | BPSK            | 1/2         | 19.5               | 21.7      | 40.5           | 45        |
| 17        | 3               | QPSK            | 1/2         | 39                 | 43.3      | 81             | 90        |
| 18        | 3               | QPSK            | 3/4         | 58.5               | 65        | 121.5          | 135       |
| 19        | 3               | 16-QAM          | 1/2         | 78                 | 86.7      | 162            | 180       |
| 20        | 3               | 16-QAM          | 3/4         | 117                | 130       | 243            | 270       |
| 21        | 3               | 64-QAM          | 2/3         | 156                | 173.3     | 324            | 360       |
| 22        | 3               | 64-QAM          | 3/4         | 175.5              | 195       | 364.5          | 405       |
| 23        | 3               | 64-QAM          | 5/6         | 195                | 216.7     | 405            | 450       |

MIMO or the use of Multiple Spatial Streams requires separate transmitters and receivers in order to operate – 1 for each Spatial Stream being coded. More radios require more power and antennas, for this reason the exact number of spatial streams that a given radio supports is often a design decision related to available power and real estate on a given device. In practical terms the more power and space a device has, the more spatial streams it can support. Hence AP's with wired power sources mostly support multiple spatial streams, as do many laptops and tablets. Smartphones with limited battery and space generally support a single spatial stream (there are exceptions, but not many). You will also find a range of capabilities related to cost and performance. The transmitter is the real power drain –SISO or Single

input – Single Output) do support multiple receivers improving (and MRC – a dramatically improved receiver technology) even if they do not support multiple transmitters (and the ability to do multiple spatial streams). Notation for 802.11n radios is typically seen as 3x3:2 or 2x3:2 or 1x2:1 where as (#TX)x(#RX) and :# spatial streams supported.

## 802.11ac

802.11ac protocol which was ratified as an amendment to the 802.11 standards in 2013



### Note

There is only one 802.11ac standard, but there are two different timelines for bringing 11ac to market commonly referred to by the market as Wave 1 and Wave 2.

802.11ac built upon many of the lessons learned in 802.11n and permitted up to 8 spatial streams using up to a 160 MHz channel. The first Wave 1 products to market supported up to 80 MHz channels with three spatial streams. All devices Wi-Fi certified for 802.11ac W1 must operate at 20, 40 and 80 MHz channel width. In the 802.11n specification 40 MHz operation was vendor optional and allowed for a mismatch of client capabilities to network design. Not all 802.11n devices can take advantage of a 40 MHz channel plan and see no gain for the reduced number of channels.

As of this writing, Wave 2 products are just starting to hit the market and implement up to 4 spatial streams and a 160 MHz channel width, this is formed by bonding 2x80 MHz channels together as a single channel (consuming a total of 4x20 MHz channel assignments). Again, 4 spatial streams means 4 transmitters and receivers (and antennas) – so there is a real estate issue right away with 8 Tx/Rx chains for a single band radio.



### Note

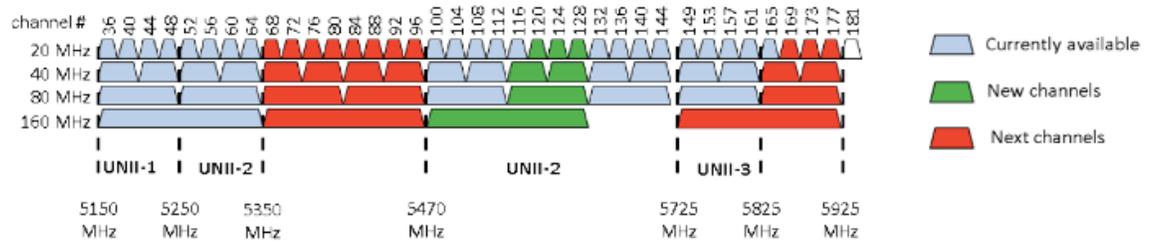
Just like 802.11n which supported up to 4 Spatial Streams, the practical limit was 3 Streams as gains from a fourth are miniscule. 8 Spatial Streams for 802.11ac is unlikely on a single 5 GHz radio. Pay attention as some manufacturers are marketing 4 ss on 2.4 and 4 ss on 5 GHz as 8 spatial streams – not quite the same thing. For More on Spatial Streams see [Fundamentals of Spatial Streams with Rob Lloyd](#) for an excellent short discussion.

The other major contribution to Wi-Fi coming with Wave 2 is MU-MIMO – That is Multi User MIMO. With 802.11ac MU-MIMO it will be possible to serve multiple clients on separate spatial streams simultaneously. For an in depth view of 802.11ac see: [802.11ac: The Fifth Generation of Wi-Fi Technical White Paper](#)

## US 5 GHz channel Plans

The creation of protocols that can consume ever larger channels (20/40/80/160 MHz) involves lot of pressure on the existing channels today. Due to regulatory restrictions, it is not always possible to bond channels in two separate frequency ranges (even though the 80+80 mode in 11ac enables this) – and today we have gaps between the channels defined, so there are real limits. In the US, more spectrum has already been granted (the return of channels 120, 124, 128) and facilitated the use of two 160 MHz channel possibilities. Additional spectrum has been requested to bridge gaps in ranges and is in currently under consideration to allow for more. World Wide, other regulatory agencies are taking note – as pressure is increasing every where. US Channel and band assignments for 20, 40, 80 and 160 MHz channels are depicted below with future requested allocations noted.

Figure 3-5 Current US 5 GHz 802.11 Wi-Fi channel plan



The data rate increases for 802.11ac come in three forms, either more spatial streams (1-8), wider channels (20/40/80/160 MHz) or expansion of encoding rates. 802.11n was limited to 2 channel widths, and 4 spatial streams (only 3 of which are practical) – so MCS 1-23 was used to define the speeds – with 0-7 defining the data rate for 1 spatial stream, and 8-15, 16-23 repeating those rates on first 2, then 3 spatial streams. We have 8 spatial streams now – so something needed to be done. I wish it were simpler – but MCS 0-9 now define the modulation and coding rate only. Multipliers are used to calculate the impact of additional spatial streams, and or additional channel widths. The table below shows up to 2 spatial streams and all channel widths. It’s not easier – but it is easier in the long run given the challenge. Note the multiplier rules below the table.

Table 3-2 802.11ac MCS Data Rates

| MCS Index | Modulation Type | Coding Rate | Spatial Streams | 20 MHz | 40 MHz | 80 MHz | 160 MHz |
|-----------|-----------------|-------------|-----------------|--------|--------|--------|---------|
| 0         | BPSK            | 1/2         | 1               | 7.2    | 15.12  | 32.4   | 64.8    |
| 0         | BPSK            | 1/2         | 1               | 14.4   | 30.24  | 64.8   | 129.6   |
| 1         | QPSK            | 1/2         | 1               | 14.4   | 30.24  | 64.8   | 129.6   |
| 1         | QPSK            | 1/2         | 1               | 28.8   | 60.48  | 129.6  | 259.2   |
| 2         | QPSK            | 3/4         | 1               | 21.7   | 45.57  | 97.65  | 195.3   |
| 2         | QPSK            | 3/4         | 1               | 43.4   | 91.14  | 195.3  | 390.6   |
| 3         | 16-QAM          | 1/2         | 1               | 28.9   | 60.69  | 130.05 | 260.1   |
| 3         | 16-QAM          | 1/2         | 1               | 57.8   | 121.38 | 260.1  | 520.2   |
| 4         | 16-QAM          | 3/4         | 2               | 43.3   | 90.93  | 194.85 | 389.7   |
| 4         | 16-QAM          | 3/4         | 2               | 86.6   | 181.86 | 389.7  | 779.4   |
| 5         | 64-QAM          | 2/3         | 2               | 57.8   | 121.38 | 260.1  | 520.2   |
| 5         | 64-QAM          | 2/3         | 2               | 115.6  | 242.76 | 520.2  | 1040.4  |
| 6         | 64-QAM          | 3/4         | 2               | 65     | 136.5  | 292.5  | 585     |
| 6         | 64-QAM          | 3/4         | 2               | 130    | 273    | 585    | 1170    |
| 7         | 64-QAM          | 5/6         | 2               | 72.2   | 151.62 | 324.9  | 649.8   |
| 7         | 64-QAM          | 5/6         | 2               | 144.4  | 303.24 | 649.8  | 1299.6  |
| 8         | 256-Qam         | 3/4         | 3               | 86.7   | 182.07 | 390.15 | 780.3   |
| 8         | 256-Qam         | 3/4         | 3               | 173.4  | 364.14 | 780.3  | 1560.6  |

**Table 3-2 802.11ac MCS Data Rates (continued)**

| MCS Index | Modulation Type | Coding Rate | Spatial Streams | 20 MHz | 40 MHz | 80 MHz | 160 MHz |
|-----------|-----------------|-------------|-----------------|--------|--------|--------|---------|
| 9         | 256-Qam         | 5/6         | 3               | 96.3   | 202.23 | 433.35 | 866.7   |
| 9         | 256-Qam         | 5/6         | 3               | 192.6  | 404.46 | 866.7  | 1733.4  |

1. MCS9 20 MHz not legal per specification for SS1, 2, 4, 5, 7, 8
2. Each spatial stream adds %100 (i.e.) MCS0 1ss data rate = 7.2 x2 for 2 ss, x3 for 3 ss
3. Channel width multipliers = 20 MHz speed x 2.1 for 40 , 4.5 for 80, 9 for 160, i.e. MCS0 20 MHz, 1ss = 7.2 Mbps x 2.1 for 40 MHz = 15.2

802.11ac is a quantum leap in efficiency for Wi-Fi. As for device support, more spatial streams means more power and antennas. Radio designs continue to improve and we are already seeing more multi spatial stream implementations in smaller devices. Today, a lot of the clients are limited at 1-2 spatial streams (ss), but all 802.11ac clients must support up to 80 MHz channel operation for certification. A 160 MHz channel is a tight squeeze in current spectrum allocations in the US – and ranges to impossible in some regulatory domains. For reference – a 3ss Wave1 client operating in 80 MHz today can achieve a data rate of 1.3 Gbps, We will be going faster too in the future.

## Understanding the IEEE 802.11 Standards

IEEE 802.11 is the working group within the Institute for Electrical and Electronics Engineers (IEEE) responsible for wireless LAN standards at the physical and link layer (Layers 1 and 2) of the OSI model, as compared to the Internet Engineering Task Force (IETF), which works on network layer (Layer 3) protocols. Within the 802.11 working group are a number of task groups that are responsible for elements of the 802.11 WLAN standard. Table 3-3 below summarizes some of the task group initiatives.

For more information on these working groups *see*: <http://www.ieee802.org/11/>

**Table 3-3 IEEE Task Group Activities**

| Task Group | Project  |
|------------|--|
| MAC        | Develop one common MAC for WLANs in conjunction with a physical layer entity (PHY) task group.   |
| PHY        | Develop three WLAN PHYs—Infrared, 2.4 GHz FHSS, 2.4 GHz DSSS.                                    |
| a          | Develop PHY for 5 GHz UNII band.   |
| b          | Develop higher rate PHY in 2.4 GHz band.   |
| c          | Cover bridge operation with 802.11 MACs (spanning tree).   |
| d          | Define physical layer requirements for 802.11 operation in other regulatory domains (countries). |
| e          | Enhance 802.11 MAC for QoS. (see Chapter 5)  |
| f          | Develop recommended practices for Inter Access Point Protocol (IAPP) for multi-vendor use.       |
| g          | Develop higher speed PHY extension to 802.11b (54 Mbps).   |

**Table 3-3 IEEE Task Group Activities (continued)**

| <b>Task Group</b> | <b>Project</b>   |
|-------------------|--|
| h                 | Enhance 802.11 MAC and 802.11a/n/ac PHY-Dynamic Frequency selection (DFS), Transmit Power control (TPC).   |
| i                 | Enhance 802.11 MAC security and authentication mechanisms.   |
| j                 | Enhance the 802.11 standard and amendments to add channel selection for 4.9 GHz and 5 GHz in Japan.  |
| k                 | To facilitate roaming, an 11k capable client associated with an AP requests a list of suitable neighbor APs. The 802.11k capable AP responds with a list of neighbor APs on the same WLAN along with their current Wi-Fi channel numbers.                            |
| m                 | Perform editorial maintenance, corrections, improvements, clarifications, and interpretations relevant to documentation for 802.11 family specifications.  |
| n                 | Focus on high throughput extensions (>100 Mbps at MAC SAP) in 2.4 GHz and/or 5 GHz bands.  |
| o                 | Provide Fast Handoffs in Voice over WLAN (goal is around 50 ms)  |
| p                 | Focus on vehicular communications protocol aimed at vehicles, such as toll collection, vehicle safety services, and commerce transactions using cars.  |
| r                 | 802.11r introduces a new concept of roaming where the initial handshake with the new AP is done even before the client leaves the current AP. This is called Fast Transition (FT)  |
| s                 | Define a MAC and PHY for meshed networks that improves coverage with no single point of failure.   |
| t                 | Provide a set of performance metrics, measurement methodologies, and test conditions to enable manufacturers, test labs, service providers, and users to measure the performance of 802.11 WLAN devices and networks at the component and application level.         |
| u                 | Provide functionality and interface between an IEEE 802.11 access network (Hotspot) and any external network.  |
| v                 | Provide extensions to the 802.11 MAC/PHY to provide network management for stations (STAs).  |
| w                 | Provide mechanisms that enable data integrity, data origin authenticity, replay protection, and data confidentiality for selected IEEE 802.11 management frames including but not limited to: action management frames, de-authentication and disassociation frames. |
| ac                | This amendment specifies enhancements to the 802.11 MAC and PHY to support very high throughput (500-1000 Mbps) in the 5 GHz bands.  |

## Deployment Considerations

### Should I design for 2.4 or 5 GHz?

Wi-Fi is a relatively mature technology today. While there are still places where Wi-Fi is not present, it is hard to find any place where there are people and places, that doesn't have some signal coverage today. A good way to look at this is: the more independent neighbors you have – the more Wi-Fi interference you either already have – or possibly will. This is often at its worst in multi-dwelling facilities where many disparate company offices share a single building and spectrum.

This is of critical importance, since Wi-Fi passes through walls and floors and must operate and accept all interference from other Wi-Fi and non Wi-Fi devices alike. What this means is that to the degree that your network devices can hear other networks – they will share the available airtime with those other networks. If you and your neighbor are both heavy users, in the areas that your networks overlap you will both get less bandwidth than the connection speeds would suggest. For both networks waiting on the other to access the channel will cost time (and less time on the air leads to less throughput).

Using 2.4 GHz in a congested metropolitan city, multi dwelling facility, or shopping mall will enjoy variable success at best and frequently can be unusable at worst. Best Practices recommends three non-overlapping channels in most of the world. In a densely deployed environment with multiple different network owners– someone is always trying the other 8-10 channels in hope that this will buy some advantage in an over filled spectrum. Most often, it does not; in fact choosing channels that overlap others makes it worse for everyone.

When two AP's are on the same channel, the contention mechanisms of each allow for fair access to the channel between them. An AP on a different but overlapping channel can't demodulate the 802.11 packets on the overlapped frequencies and it appears only as noise. Without the 802.11 mac layer, no coordination is possible between the two AP's. Errors, and collisions increase for both AP's cell's increasing utilization and wasting precious airtime. If you live in a region where a 4 channel plan is possible (1, 5, 9, 13) keep in mind that many client drivers will not enable channels 12 and 14 by default. Also most consumer and many AP systems default to using channels 1, 6, 11. Under these conditions channel 6 will interfere with both channel 5 and 9, and channel 11 interferes with 9 and 13 and vice versa. If your neighbors are using 1, 6, 11 – you should too – it will perform better.

If an application is critical to business operations, plan on using 5 GHz. Once upon a time – this was more difficult to do as 5 GHz devices were less prevalent. This is not the case today as most manufacturers are focusing on 802.11ac as the standard for their products and 802.11ac only operates in 5 GHz.

If you absolutely must deploy a critical function on 2.4 GHz understand why and what is driving that requirement (specifically which devices) and consider replacing these with updated hardware. You can only put so many 2.4 GHz radios in close proximity to one another and once the channels are full – they are full.

A look at the Wi-Fi Alliance certification database ([Wi-Fi Alliance certification product-finder](#)) confirms that 5 GHz support is plentiful in today's devices. Consider these findings from the latest results

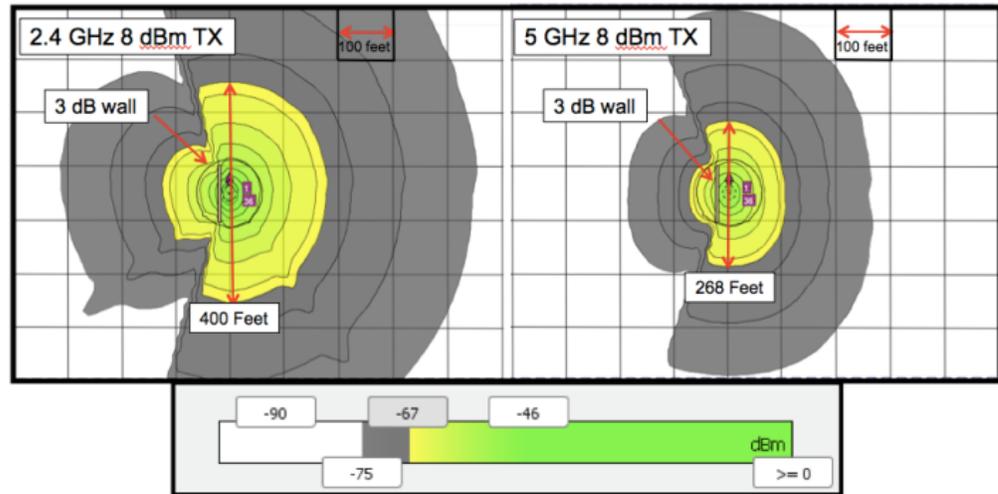
- As of August 2015 – 2,409 Smartphones/tablets have certified 5 GHz 802.11n operation.
  - 477 of which were certified in 2013
  - 591 in 2014/15 – all 802.11ac
  - Total WFA certifications for the same period is 3167 putting 2.4 GHz only devices at 24% of the current Market (this down from 32% 6 months previous)
  - The majority of these being low end consumer gear

**Table 3-4 Pro's and Con's 2.4 vs. 5 GHz**

| Frequency Band | Pro  | Con  |
|----------------|--|--|
| 2.4 GHz        | Good Range - As frequency increases, propagation distance decreases (assuming equivalent transmit power) | Less AP's can be configured in the same physical space due to mutual interference, less capacity                                   |
|                | Higher penetration of objects - better range indoors   | Less AP's can be configured in the same physical space due to mutual interference, less capacity                                   |
|                | Less Spectrum/channels   | Increased congestion   |
|                |  | Increased risk of interference from improper implementation-rogues   |
|                |  | Favorite band for non-Wi-Fi devices - increased interference in general  |
|                |  | Not enough channels to use bonded channels and increase throughput - increased interference  |
| 5 GHz          | Less range/ self interference, more AP's possible, more users  | Less range generally means more AP's possibly required (higher power levels for UNII_3 is generally only supported by the AP side) |
|                | More Channels - bandwidth - Capacity   |  |
|                | Less consumer Wi-Fi devices and non Wi-Fi. Less congestion   |  |
|                | 802.11ac - only in 5 GHz   |  |
|                |  | less range - not as suitable for low density hotspot coverage models   |

In [Figure 3-6](#) you can see the difference in usable signal for both the 2.4 GHz band on the left, and the 5 GHz signal on the right using the same Tx power setting. In the Unii-3 band – power can be increased to 23 dBm and 5 GHz can cover more than 2.4 GHz but only in that band. The numbers of people who will share the fixed bandwidth available for the AP in each are contained within the cell's footprint.

**Figure 3-6 Propagation Distance of 2.4 GHz and 5 GHz**



### What Protocols should I enable?

There are multiple protocol standards available in the 802.11 standard, in fact everything that has been ratified since 1999 is still required for WFA certification and present in all hardware that supports the band it belongs to. That doesn't mean that you need to use it though. The choices you make in deciding which protocols to support (and which NOT to) can have a big impact on your networks efficiency.

By efficiency we mean the use of airtime. The faster a station can get onto and off of the air, the more airtime will be available for other stations. 802.11b as previously mentioned was one the first protocols implemented in 2.4 GHz. Today it is truly a unique example amongst all other Wi-Fi protocols as both the coding and modulation methods are completely different than every other protocol that has been ratified since.

As a group – the legacy protocols of 802.11b, a and g all used a wide guard interval of 800 ms. The guard interval is a time space between radio symbols (characters) being transmitted that ensures they do not collide in the air. 802.11n and 802.11ac have an optional short Guard Interval, but in practice all products implement this option. You can see the gains that a short guard interval provides in the 802.11n data rate chart (Table 3- 1 802.11n MCS 1-23 data rates), they are significant.

802.11n and 802.11ac also provide for block ACK, or block acknowledgments, which allows for higher efficiency gains by allowing a large block of packets to be acknowledged all at one. The legacy protocols all send a packet – get a response – one by one. This adds a considerable number of frames to the transaction for reliability that is largely no longer needed with modern standards.

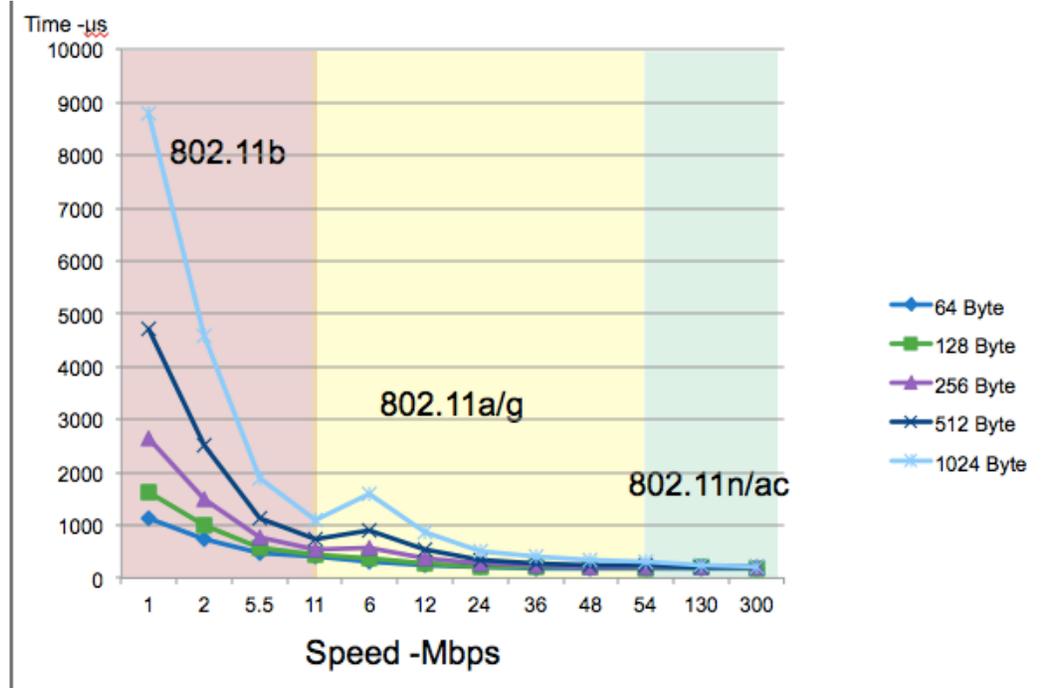
Think about it this way - a golf cart has 4 wheels and a steering wheel just like an automobile– but you would hardly let it enter a formula one race. Imagine the outcome of that – and that's pretty much what happens in a no holds barred Wi-Fi network.

Figure 3-7 below compares the airtime requirements of different protocol standards and data rates using different sized packets over the air. This shows airtime ( $\mu$ s) consumed per packet, before any gains from aggregation are realized. It is easy to see that even a modest 802.11n or ac speed can move twenty 1024 byte packets before 802.11b can move 1.

**Note**

The lower the data rate – the longer the airtime required for a given packet size. Less over all data can be accommodated within each second. Less available bandwidth is the result.

**Figure 3-7 Airtime of Packets by Speed and Size**



As a network architect, the concern is to provide services that everyone can use. The good news is that by and large there are very few environments where you will find a “real” requirement for native 802.11b or legacy protocols today.

Cisco WLC’s have several options available for implementing the most popular and necessary speeds. The various network types and decision points is detailed later in this document to ensure you to understand the need of implementing a well-tuned network from the start.

### What is a DFS channel, should I use them?

Many of the channels available in 5 GHz are known as DFS channels. DFS stands for Dynamic Frequency Selection and along with TPC (Transmit Power Control) define co-existence mitigations (i.e., detect and avoid) for radar while operating in the UNII-2 and UNII-2e bands (channels 52-144). These mechanisms are detailed in an amendment to the 802.11 standard.

The 802.11h standard was crafted to solve problems like interference with satellites and radar which also legally use the 5 GHz band as primary users. A primary user has priority over the frequency range of UNii-2 and UNii2e. It is Wi-Fi’s job, as a condition of using these frequencies, to not interfere with any primary users. While this standard was introduced to primarily address European regulations, it is used by many other regions of the world today to achieve the same goals of more operational 5 GHz spectrum for Wi-Fi.

In 2004, the US added channels 100-140 in the UNII-2e (e stands for extended) band with rules requiring 802.11h certification which allow us to peacefully coexist with Primary licensed users of the 5 GHz frequencies in this range. For Europe these channels represent most of their available 5 GHz spectrum today. Before the rules and mechanisms were worked out, Europe was limited to only 4 channels in 5 GHz. At the same time in the US we had UNII-1, 2 and 3 for a total of 13 channels.

In order to not interfere with licensed band users – the requirement is pretty straightforward:

1. The Wi-Fi equipment must be able to detect radar and satellite emissions
2. Before using a channel in this range – a “channel master” (an Infrastructure AP) must first listen for 60 seconds and determine that the channel is clear of Radar
3. If a radar signal is detected, the Wi-Fi channel master – and all the clients associated to it have to abandon the channel immediately and not return to it for 30 minutes at which time it can be cleared again for Wi-Fi use if no radar emissions are detected.

Unii-2e channels got a bad name early in 2004 in the US. Clients were slow to adopt the new rules initially – so using these channels in the infrastructure meant you could inadvertently configure a channel that some clients wouldn't be able to use – creating a coverage hole for that client type. There was also undue concerns about DFS operations in a production network. The concern was if DFS detected radar, a channel change followed by waiting a full minute before resuming transmissions was viewed as disruptive – however the behavior is not disruptive as RRM places the AP into a non DFS channel. The channel is blocked for 30 minutes and then made available again to RRM by means of background scanning. Once the channel is available we can choose to use it or remain on the current channel – depending which is better for the clients.

It has been a decade since the addition of these channels and 802.11h logic. In Europe DFS is and has been making 5 GHz Wi-Fi possible and even flourish. Client vendors vary, the majority support the DFS channels just fine as there is no additional logic required by the client.

If you are within 5 Miles of an airport or shipping port and have concerns, evaluate by monitoring the channel range with Cisco AP's. Cisco leads the industry in certified hardware models and function for DFS operation and flexibility, monitoring the channels will alert you to any potential interference and identify the affected channels.

## Site Survey

A site survey is an important tool. It will tell you who is operating around you – and more importantly where and how much that interferes with your intended coverage zones. It also allows identification of mounting locations, existing cable plants, infrastructure requirements, architectural oddities, and yields a plan to get the coverage your particular application requires. Because RF interacts with the physical world around it, and all buildings and offices are different so is each network to a degree. Unfortunately, there is no one size fits all for Wi-Fi. There are recommendations by deployment type and it is possible to generalize what is likely to be encountered. If you have not done a site survey in a while – keep in mind what has changed since the last one before you decide against it.

1. The protocols and radio technology
2. How the users will use the network (likely everyone, and for almost anything)
3. How many clients the network supports (likely a lot more users count as at least two devices these days and many have more)
4. The primary use of the network (very likely changed since the initial plan and implementation)

While early WLAN designs focused on coverage in order to get a few casual users signal everywhere, today's WLAN designs are more focused on capacity – as the number of users has increased – and what we are demanding of the network has gone up exponentially. A capacity design requires more AP's in closer proximity to manage the number of users who are sharing the bandwidth of the cell. Increasing placement density should have a plan.

If you decide to conduct your own survey and plan – tools are important. There are multiple free tools on line and available as downloads. However if you want professional results – you need professional tools.

The free tools can provide simple solutions for smaller less complex projects. But if you are looking to provide ubiquitous multi media coverage in a multi-floor/multi building campus – you need a good tool to balance the elements that will be required for success. Planning tools have evolved with the radio technologies and applications in use today. A familiarity with the design elements and applications is required to produce a good plan.

Cisco Prime Infrastructure has a planning tool built in – and you can import and export maps and plans between CPI and many top Survey and Planning applications such as Ekahau ESS, Airmagnet Pro Planner and Survey.

For more on Site Surveys – See [Site Survey Guidelines for WLAN Deployment](#)

Having a site survey done for 802.11ac now – will yield good information that can be used again and again as the network grows and continues to evolve. It depends on the size of your project and level of knowledge with regards to Wi-Fi if this is something that you should contract out in part or as a whole.

## Planning for RF Deployment

### Different Deployment Types of WLAN Coverage

How much WLAN coverage you set in the design of your wireless network depends largely on the usage and density of clients you require. With limited exceptions, all designs should be deployed to minimize retransmission and data rate shifting while supporting good client roaming and throughput. Wireless networks can be deployed for data-only, voice, video, and location-aware services or more frequently these days, a combination of all of these. The difference between these application types is minimal today with the requirements of each largely describing good solid capacity based coverage. Location Aware services adds some AP placement criteria for good location triangulation and guidelines on Hyper-Location technologies. Real Time Multi-media (voice and video) applications have different latency requirements for two way live implementations. But by and large all describe a minimum coverage level that needs to be achieved to make the application viable for the number of users you expect in any given area.

For the majority of campuses and enterprise installations coverage and capacity are the primary concern and easily achievable. High Density Client implementations or High interference locations – like shopping malls or apartment buildings may require additional equipment like external antenna's to properly implement to scale. For more on application specific guidelines, recommendations and configurations – see the following guides for in depth information:

- [Best Practices Location-Aware WLAN Deployment guide](#)
- [Microsoft Lync Client/Server in a Cisco Wireless LAN](#)
- [Cisco Jabber and UCM on a Cisco Wireless LAN](#)
- [Application Visibility and Control Feature Deployment Guide 8.1](#)

- [Wireless LAN Design Guide for High Density Client Environments](#)
- [Cisco Wireless Mesh Access Points, Design and Deployment Guide, Release 8.1](#)

## Coverage Requirements

Most application specific coverage guidelines describe the signal level or coverage at the cell edge required for good operation as a design recommendation. This is generally a negative RSSI value like -67 dBm. It's important to understand that this number assumes good signal to noise ratio of 25 dB with a noise floor of -92 dBm. If the noise floor is higher than -92 dBm then -67 dBm may not be enough signal to support the minimum data rates required for the application to perform it's function.

For Location-Aware services, deploying a network to a specification on -67 dBm is fine – however what matters to Location-Aware applications is how the network hears the client – not how the client hears network. For Location-Aware we need to hear the client at three AP's or more at a level of  $\geq -75$  dBm for it to be part of the calculation. (-72 is the recommended design minimum)

Clients are a big consideration when planning coverage. They come in all shapes and sizes these days, and as a result individual implementations can and do vary widely on their opinion of a given RF signal. For instance, the laptop you are using for Surveying may show -67 dBm at the cell edge, the tablet might show -68 dBm, and the smartphone may show -70 dBm. These are all very different opinions and affect roaming and data rates that each individual will use. Overbuilding to accommodate this varying opinion assures a trouble free installation. When taking measurements using the device that will support the application is the best approach. Understanding that your smartphones are generally 5 dB off your survey tool will let you develop good rules for design (like add or subtract 5 dB to what ever the reading is from your survey tool). Then test and tune the resulting implementation.

## High Density Client Coverage Requirements

One thing that can dramatically affect the success of a network is High Client Density areas. As mentioned earlier – every client contained within an AP's Cell Boundary is sharing the potential bandwidth (airtime) of that cell. Using simple math to illustrate this – we will use the rule of 555 simply for illustration of the concept. Sharing 1 Gbps equally for 200 concurrent clients at 5 GHz each client will cost you 5 msec of airtime and receive 5 Mbps.

$$1000 \text{ Mbps}/200 = 5 \text{ Mbps}$$

$$1 \text{ sec}/200 = 5 \text{ msec}$$

In reality, more clients will bring more overhead, collisions and errors with the varying conditions across a cell. Some clients will get more than 5 Mbps, and some will get less. This is an average view of the cell only. A good average cell throughput under similar conditions will provide an accurate prediction of the mileage you will get.

Providing more bandwidth is as simple as changing the equation, if you need to support 100 clients at 2-5 Mbps, you will need another AP on a different channel to provide more bandwidth to share between the clients. You can add more AP's to get additional capacity, as long as you use different channels. You can re-use existing channels to accomplish this at scale, provided that the first re-use of a channel cannot be heard by another AP using that channel.

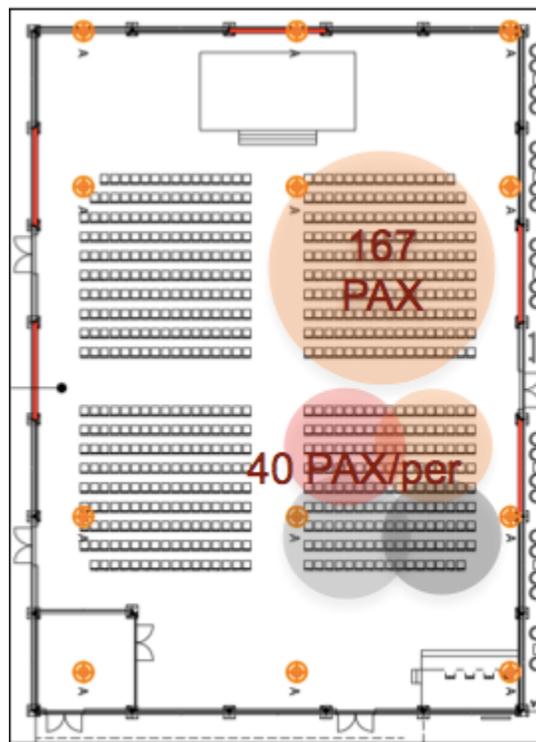
If two AP's on the same channel can hear one another, then they will share the channel equally (assuming each is equally busy). The 802.11 specifications have contention mechanisms built into the specification that ensure this. But you really have not increased the bandwidth for these users – since both cells are sharing a channel (each getting 50% of the airtime), and now we have 2 AP's which effectively doubles the management traffic further reducing the available airtime.

In 2.4 GHz where we only have 3 usable channels, channel re-use becomes a problem far sooner than at 5 GHz where we have many more channels to choose from. Propagation characteristics also come into play – since 2.4 GHz will be heard farther away than 5 GHz you are further limited to the number of re-uses in a smaller physical area with 2.4 GHz options.

In 5 GHz, we have multiple channel widths to consider. The wider the channel width selection the fewer overall channels you will have (but in exchange, the greater capacity per cell).

Larger cells cover more users, in order to increase bandwidth in a given physical area; smaller cells will yield more capacity. In the graphic below, each seating section accommodates 167 seats (seats are represented as PAX in [Figure 3-8](#)), we could cover the entire section with one access point, or by designing smaller cells we can get 4 AP's serving the same area for a 4x increase in available bandwidth.

**Figure 3-8** User vs. Cell Density



For most Enterprise installations higher density conference rooms and the like can be handled just fine using internal Omni Directional antenna AP's. Cisco's RRM will handle the channel and power required to make it work. At a certain point – with too many AP's being too close together – RRM will configure for the most optimal efficiency possible, but there must be spectrum available or it can do nothing. You can only turn the AP's power down so much, and the Omni directional antenna pattern will hear other adjacent AP's and the user experience will suffer. Coverage levels at 2500 sq feet per AP and up should be fine at 5 GHz with 20/40 MHz channels. For 2.4 GHz requirements at cell densities going below 2500 sq feet, you will likely need directional antennas to physically limit the transmit and receiver patterns of the AP and get useful smaller cells.

There are many features that have been specifically developed to manage and configure High Density client/AP environments; they are part of a group of features known as HDX (High Density Experience). See the HDX deployment guide below for specifics of each feature:

## High Density Experience (HDX) Deployment Guide

### Roaming and Voice Coverage Requirements

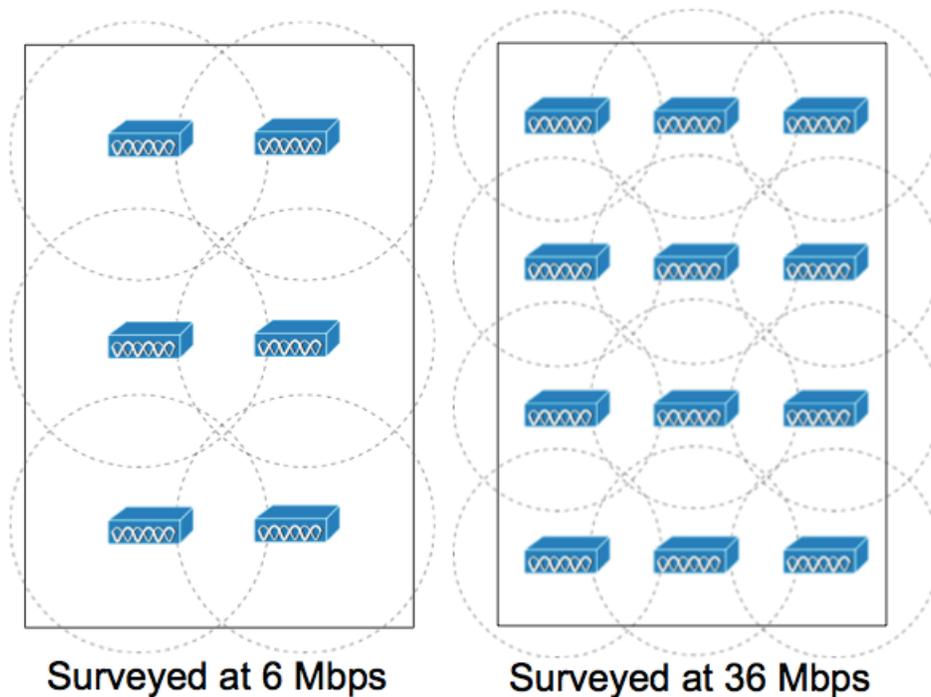
Client Roaming enables a client to move from one AP's coverage zone into another AP's coverage zone minimizing interruption in service/coverage. This is the very essence of mobility. There are many factors that must be considered in order for this to be effective. For instance, how the client transitions its association and authentication from one AP to another must be considered as well as the time it takes to do so. An often-overlooked aspect is the network design itself. In order for a client to roam – there must be something to roam to. Cells must overlap with good coverage in order for a client to gracefully leave coverage of one cell and establish association within coverage on another without delay. Too little overlap encourages “sticky” clients, meaning a client holding onto an AP well after it moves into the coverage area of another AP.

When designing for network coverage, consider the amount of overlap in the required signal range you are getting. Overlap should be 10-15% (15-20% for Voice) of the total coverage area. Voice is particularly sensitive as the conversation is real time – and any coverage lapse will result in broken audio or potentially a lost call. An easy way to calculate overlap – measure the distance from the AP that you reach -67 dBm – multiply that distance x 1.4 for 15-20% or 1.3 for 10-15% and that's where your next AP goes.

Data rates are also matter, as the usable cell size increases with lower data rates and decreases with higher data rates. Higher Data Rates require a higher SNR, and since the noise floor is theoretically constant – the closer the client is to the signal (the AP) the higher the SNR and the resulting data rate will be. We can enforce minimum data rates in configuration, and when a client can no longer support a given data rate – it will have to move.

Figure 3-9 shows the Cell overlap and the effect that data rates have on cell size.

**Figure 3-9 Cell Density and Overlap at different data rates**



A good physical design enables and supports roaming at the physical layer. Only the client decides when to roam though and the decisions it makes are based on the clients observation of the network. There have been multiple amendments added to the 802.11 specification specifically to help clients make better decisions based on network infrastructure observations. See these guides for additional information on Roaming and configuring Cisco hardware/software to enable good roaming transitions. Cisco supports 802.11r, 802.11k, and 802.11v which assists capable clients in making good decisions and affords some control from the infrastructure to enforce design goals:

- [High Density Experience \(HDX\) Deployment Guide - see Optimized Roaming](#)
- [802.11 WLAN Roaming and Fast-Secure Roaming on CUWN](#)
- [802.11r, 802.11k, and 802.11w Deployment Guide, Cisco IOS-XE release 3.3](#)

## Location-Aware Coverage Requirements

Location –Aware deployments differ slightly from other types in that the goal of the installation is to provide good location resolution of Clients, Tags, and IOT sensors in context of where they are on a given map. We derive this information in its most basic form Client RSSI readings obtained by multiple AP’s (a minimum of 3 AP’s are required to Triangulate on the clients position). The pattern that you choose to deploy your AP’s can have a big effect on the networks ability to “locate” a client accurately.

For good Location resolution, the APs are laid out in a staggered pattern with AP’s defining the borders and corners. It is possible to get coverage using AP’s in a straight line down the middle of both sections – however this would not provide enough AP’s to hear and triangulate on clients in all locations (remember – we need 3). Coverage and capacity requirements for this floor require so many AP’s to start with, so it is quite likely given your coverage requirements that you already have what is needed to perform good location calculations.

Figure 3-10 2.4 Example of a Single Floor Location AP Placement



The [Best Practices-Location Aware-WLAN Design Considerations](#) is a must read chapter and still quite relevant as the physical requirements for the design have not changed. The entire document [Wi-Fi Location Based Services 4.1 Design Guide](#) is a good reference for Theory, particularly the first chapter [Location Tracking Approaches](#) will familiarize you with the technology.

## Power Level and Antenna Choice

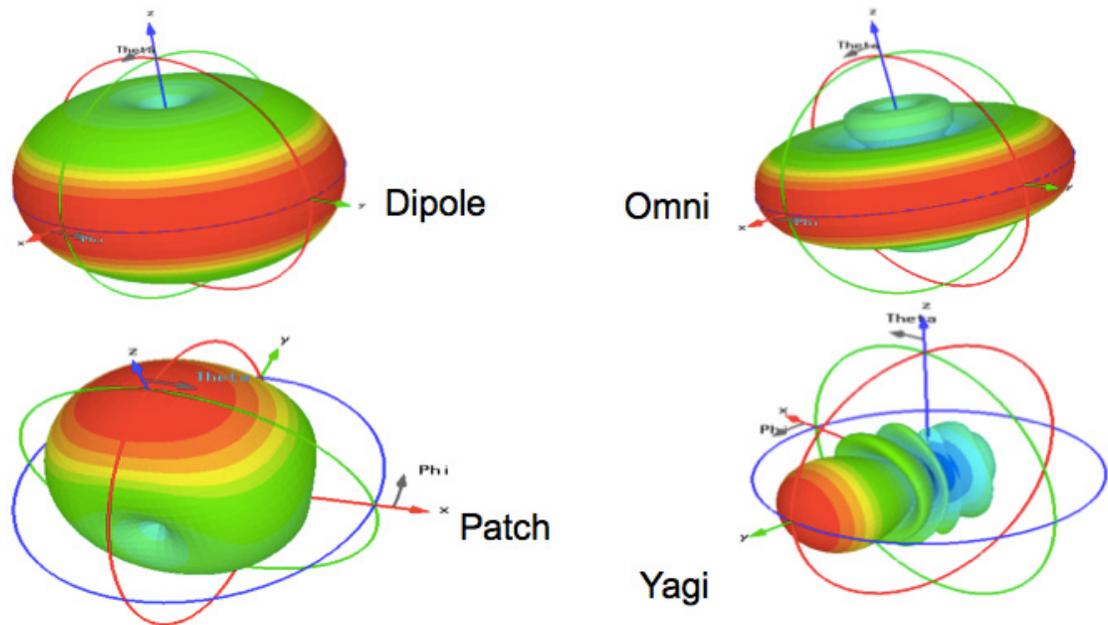
Power level and antenna design choice go hand-in-hand to determine AP placement/coverage results. Together, these two variables determine where and how powerful the RF is in any given place in the environment. Along with choosing the correct antenna to produce the required coverage area, we recommend you to use RRM to control the power level and provide the optimal channel/power plan. For more information, see *RRM* section below in this document.

An antenna gives the wireless system three fundamental properties:

- Gain—A measure of increase in power introduced by the antenna over a theoretical (isotropic) antenna that transmits the RF energy equally in all directions. Gain also affects received signals and can assist weaker client devices by increasing the signal presented to the receiver.
  - Front To Back Ratio or FTB – the opposite of gain is signal rejection – the opposite direction of the gain in an antenna is less sensitive than the focus of the antenna, and this property can be used to isolate your cell from unwanted signals behind the antenna for instance.
- Direction—The shape of the antenna transmission pattern. Different antenna types have different radiation patterns that provide various amounts of gain in different directions. A highly directional antenna will produce a very tight beam pattern. Outside of the area of focus, signals erode quickly which allows more cells to be placed in the same physical space without interference.
- Polarization—Indicates the direction of the electric field. An RF signal has both an electric and magnetic field. If the electric field is orientated vertically, the wave will have a vertical polarization.

A good analogy for how an antenna works is the reflector in a flashlight. The reflector concentrates and intensifies the light beam in a particular direction similar to what a parabolic dish antenna does to an RF source in a radio system. The antenna however is both the ears and the mouth of the AP – so characteristics of a given antenna work for both transmit and receive. Many different antenna designs exist to serve different purposes some of the more familiar designs appear below in Fig. 11

**Figure 3-11 Antenna design types**



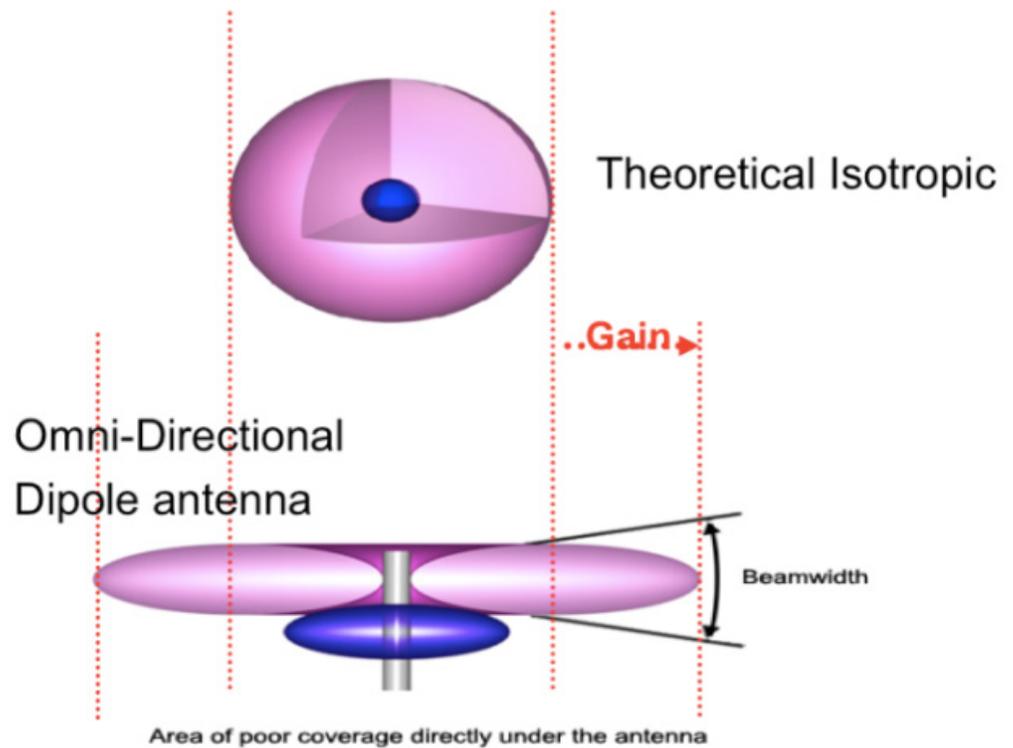
Gain and direction mandate range, speed, and reliability while polarization affects reliability and isolation of noise.

For more information on antenna selection, see the [Cisco Aironet Antennas and Accessories Reference Guide](#)

## Omni-Directional Antennas

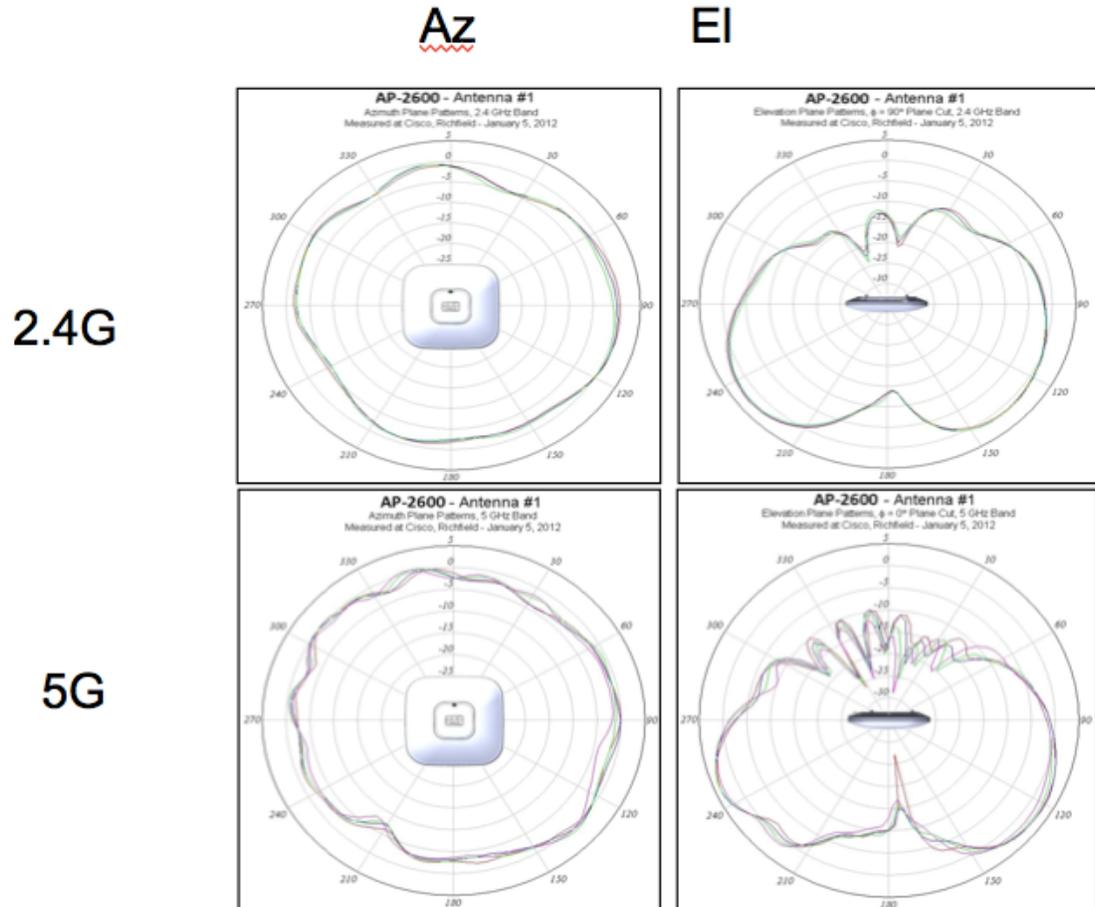
Omni-directional antennas have a different radiation patterns compared to isotropic antennas; the isotropic antenna is theoretical and therefore all physical antennas are different to the isotropic antenna. Any change in shape of the radiation pattern of an isotropic antenna is experienced as gain and increases directionality. The dipole Omni-directional antenna features a radiation pattern that is nearly symmetric about a 360 degree's axis in the horizontal plane and 75 degrees in the vertical plane (assuming the dipole antenna is standing vertically). The radiation pattern of an Omni-directional antenna generally resembles a donut in shape and hence is directional. The higher the rated gain in dBi of a given Omni-Directional antenna, the more focused the energy is (generally in the vertical plane) and directional it becomes. See the comparison between an isotropic and Omni-Directional dipole antenna in Fig. 12 below. Note the views are from the side.

Figure 3-12 *Isotropic Antenna vs. Omni-Directional*



Most modern day internal antenna AP models beginning with the AP 1140 use internal antenna stubs with multiple transmitters and receivers. Unlike the simple Dipole antenna, this produces a pattern that has an improved donut shape. In the antenna plots below – note the elevation plane and how the energy is predominantly focused downward in Fig. 13.

Figure 3-13 Cisco AP 2600i 2.4 and 5 GHz Radiation Patterns



This makes the AP least sensitive on the back – the part that is facing the ceiling in most installations.

Omni-Directional antenna's work well, and are easy to implement – to a point. If you are faced with increasing the density of AP's to accommodate more capacity requirements, then you will see increasing channel utilization from self-interference. This happens because the antenna pattern is designed for maximum coverage. 3000-6000 sq ft (280 -560 sq meters) of coverage per AP can be managed with the internal antennas, if your coverage requirements are at the minimum or denser than this, you should consider directional antennas.

## Directional Antenna's

A directional antenna differs from an Omni-Directional antenna in that the energy is focused in a particular way to achieve different coverage goals. Most people assume that a directional antenna is used specifically for gain – to increase power. While it can be used for that reason and achieve greater distances, it is more often used in Wi-Fi to control the size (and shape) of the transmit and receive cell.

For current Cisco indoor AP's (3600e, 2600e, 3700e, 2700e the antenna selections are all dual band (each antenna covers 2.4 and 5 GHz) patch type antenna's designed for different coverage distances. The 3 most popular are below.

Figure 3-14 Cisco Directional Antenna's for High Density applications

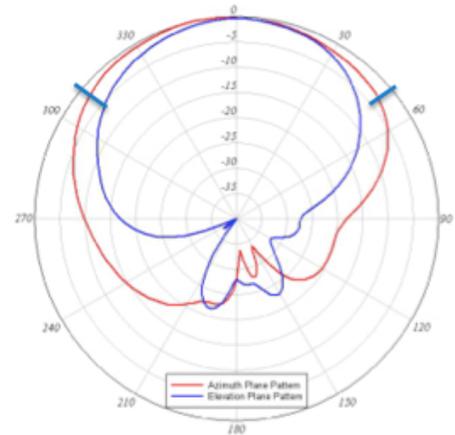
| Photo   | Name/Part No.  | Beam  | Use Case   |
|---|--|---|--|
|  | <b>Dual-Band Stadium Antenna</b><br>3702p + AIR-ANT2513P4M-N | <b>2.4/5GHz</b><br>30°/30° Az<br>30°/30° Elev | Primary overhead coverage (10-30 m)                            |
|  | <b>Dual-Band Patch Antenna</b><br>3702e/p + Air-ANT2566D4M-r | 65°/65° Az<br>65°/65° Elev                    | Augmentation and medium distance HD coverage (5-10m to client) |
|  | <b>Dual-Band Patch Antenna</b><br>3702e/p + AIR-ANT2566P4W-R | 105°/125° Az<br>70°/60° Elev                  | Augmentation and short-distance HD coverage (<5m to client)    |

Each antenna is designed for a specific purpose in mind. One of the things about antenna selection that must be considered is the Beamwidth. Beamwidth describes coverage area of an antenna, however it does not describe how hard or soft the edge of that coverage is. For that you need to look at the antenna's pattern in a plot.

The plot below is from one antenna of the AIR-ANT2566D4M-R antenna, it is designed to provide good coverage over a general area. The beamwidth of this antenna at 2.4 GHz 105° x 70° and describes the point where the peak gain of the antenna falls by 3 dB. What's important in a directional antenna is what happens after that 3 dB. Note the blue marks on the antenna plot below at the rated beamwidth, the gain falls sharply after the rated beamwidth. This is exactly what needs to happen to put more AP's closer together for higher capacity.

**Figure 3-15** Antenna Plot for AIR-ANT2566D4M-R antenna

**Azimuth and Elevation Radiation Patterns  
Left Antenna - 2.4 GHz Band**



If the antenna can not hear, it may not interfere with your AP. We only have 3 channels in 2.4 GHz; channel re-use in a dense deployment is already a problem there. With a good antenna, you can make the cell size smaller and get more radios closer together and provide adequate capacity in your design for 2.4 GHz users. 5 GHz has more channels, however with 20/40/80 MHz Channel widths, we are using channels up faster, and cell isolation is becoming more of a problem.

Other problems that can be solved using directional antennas include high interference environments – a shopping mall for instance – most of the stores in a shopping mall will have installed some kind of Wi-Fi, and this creates interference for your Wi-Fi. Using directional antennas, you can isolate your store from the neighbors by focusing the ears of the AP inward, and making the receive sensitivity less behind the antenna. The front to Back ratio of an antenna is responsible for this – think of it like cupping your hands over your ears to hear a distant sound – when you do this you focus the sound energy into your ears, but you also shield your ears to the surrounding noise and this produces a better Signal to Noise ratio – you experience it as better more intelligible sound. Putting a directional antenna on your AP will focus it's ears and it will experience a better sound with less noise as well.

## RF Deployment Best Practices

Some design considerations can be addressed by general best practice guidelines. The following applies to most situations:

- We recommend, for a given AP the number of users per AP be:
  - 30 to 50 for data-only users
  - 10 to 20 voice users

This number should be used as a guideline and can vary depending on the AP model, handset or application in use. Check your handset/application requirements

- The AP data rates should be limited to those designed and for which the site survey was performed. Enabling lower data rates can cause increases in co-channel interference and greater throughput variations for clients. A common minimum data rate to start with is 12 Mbps.

- The number of APs depends on coverage and throughput requirements, which can vary. For example, the Cisco Systems internal information systems (IS) group currently uses one AP per 3000 square feet of floor space.

## Radio Resource Management - RRM

Cisco RRM, Radio Resource Management has been around for a long time now. What most people are not aware of is that RRM's collection of algorithms has seen updates with every release of code since 4.1. The rate of change in these algorithms is for a good reason; the questions keep changing and so must the answers. Technology has gone from balancing simple coverage based Wi-Fi networks operating in a single 20 MHz channel to accommodating channel and power solutions for 20, 40, 80, and soon 160 MHz channels all inter-operating in the same spectrum. And in most cases – backward compatibility and a mix of protocols must be considered as well. Even if your organization has standardized – you almost assuredly have neighbors and internal resources that have not.

### What RRM Does

RRM consists of four algorithms:

1. RF Grouping
2. DCA (Dynamic Channel Assignment)
3. TPC (Transmit Power Control)
4. CHDM (Coverage Hole Detection and Mitigation)

RRM is a big subject, but it was designed to manage the RF environment in a dynamic way with little to no user intervention. A brief description of the algorithms will be useful in understanding the configuration tasks. RRM's default settings are generally the best fit initially. In a new controller the Day 0 setup wizard will allow you to fine tune many settings by picking the deployment type that you are working with. Advanced configuration can also be achieved manually

### RF Grouping

The RF Grouping Algorithm is responsible for identifying and grouping under an elected or chosen leader – all resources that belong to the same network – WLC's and AP's alike. This forms the RF Group and becomes a logical configuration domain. The Network resources are identified by the RF Group Name, which was entered on the initial controller configuration. The group name is shared by all the WLC's on the same network. AP's connected to the controllers learn the group name from their controller and in turn broadcast it over the air in NDP messages for other AP's to hear and report back to their controllers.

### Automatic RF Grouping

RF Grouping is automatic by default, and in a multiple controller configuration – any controller belonging to the same RF group will participate in an election process designating 1 or more WLC's as the RF Group Leader(s). The 2.4 GHz (802.11b,g,n) band and the 5 GHz (802.11a,n,ac) band each must have their own RF Group Leader. Both RF Group Leaders can, but do not have to reside on the same physical controller. Seeing 2 RF Group Leaders – each controlling just one band is not unusual.

Automatic RF Groups must have AP's that can hear one another over the air in order to form. You MUST, connect your AP's to the controllers that you want to form as a group first else each controller will assume that it is its own RF Group Leader. If your design incorporates a single controller on each site, and the sites are geographically separated each controller will be its own group leader for both bands at each site.

### Static RF Grouping

Static RF Grouping allows user selection of the RF Group Leader(s) and manual assignment of group members. All WLC's must have a wired network path to one another – there is no over the air component so active AP's are not necessary to form a static group but wired connectivity between the controllers is a must. Once the RF Group is created – RRM operates the same using over the air metrics.

### RF Group Leader WLC Hierarchy

There are a number of controller models, and some are more capable than others. In both Auto and Static mode, there is a hierarchy applied that prevents a 2500 series controller from becoming the group leader over an 8520 controller. The largest most capable controller should be selected as the group leader.

The RF Group Leader is where all measurements, configurations, and calculations that are being used to manage the RF Group and RRM will be sent and stored. The WLC configuration on the RF Group Leader is the configuration that is used by RRM for the RF Group. It is important to synchronize the RRM configurations on all of your controllers, in automatic RF Grouping mode – the RF Group leader can change for several reasons – and if the configuration is different, then the behavior of the RF Group will change when the leader changes.

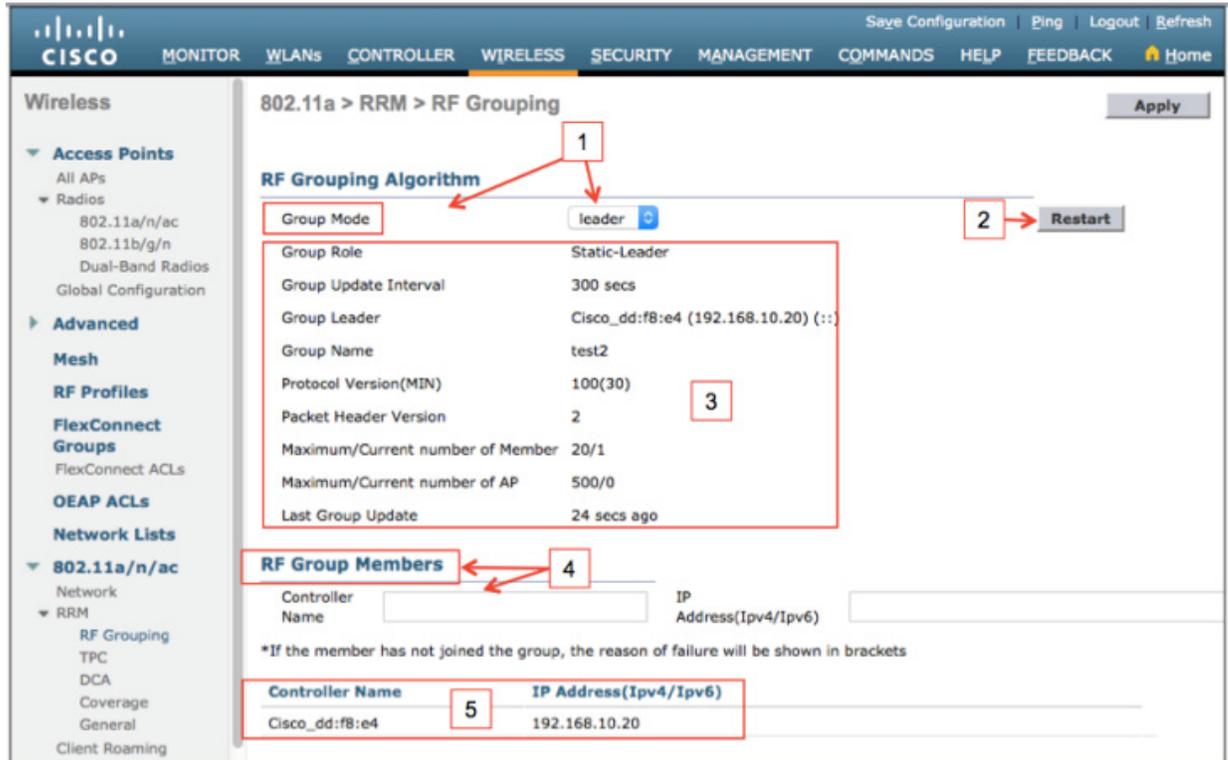
Configurations at the RF Group Leader level are considered Global – as they affect the entire RF Group. RRM allows for RF Profiles; which can be created and applied to individual AP groups that span multiple controllers and override the global configurations to allow localization for a different RF environment. A High Client Density vs. a Coverage model design will require different Data Rates and TPC thresholds at a minimum to function properly. RF Profiles can be applied to AP Groups (collections of AP's in different coverage models for instance) and a separate configuration can be applied to each.

For more information on the specifics of RRM's RF Grouping Algorithm see - [RRM RF Grouping Algorithm](#) which covers grouping mechanisms, as well as over the air measurement activities and intervals.

### RF Grouping Configuration

On the WLC GUI, Navigate to the Wireless, 802.11a/n/ac or 802.11b/g/n, RRM, RF Grouping

Figure 3-16 RRM RF Grouping UI configuration



1. Group Mode—The default mode for the RF Grouping algorithm is AUTO this should be fine for most installations Use the Static mode – by selecting Leader and adding member WLC’s if you have many controllers operating in a shared RF domain. If you are selecting Static, there is a practical limit to the number of AP’s that can be configured within an RF Group. For all controllers up to the 5500 series this is 2x the licensed AP count, for 75xx and 85xx the limit is 6000 AP’s. Design your RF Grouping to keep groups of AP’s and controllers together for like spaces and buildings. Whats important to the RF group is AP’s that can hear one another and need to be configured together should be in the same RF Group and managed by the same RF Group Leader. Create a new RF Group for geographically separated facilities.
2. Restart—after changing the mode – and applying the changes – the restart button –“restarts” the grouping algorithm
3. Information— informs the user of the status for the viewed controller on current mode, the current RF Group Leader, the protocol version (important as not all version will play together – see [Cisco Wireless Solutions Software Compatibility Matrix](#) IRCM section, the algorithms interval, current AP and member controller counts.
4. RF Group Member—used for adding member controllers to a Static leader
5. List of current members and status—full list of member status messages can be found in - [RRM RF Grouping Algorithm](#)

## DCA – Dynamic Channel Assignment

Dynamic Channel Assignment is responsible for monitoring the spectrum, and choosing the best channel plan to place the AP's on. Interference is the primary concern, the less interference there is the more bandwidth (airtime) we can use. To do this DCA monitors four parameters

- Signal—any Wi-Fi signal created by my network/RF Group
- Noise—any RF signal that is not identified as Wi-Fi; this includes collisions and packets too low to be demodulated as well.
- Interference—any Wi-Fi signal that is from Rogue devices or devices not part of my RF Group
- Load—The relative channel utilization of AP's in the RF Group

The user has control of how to prioritize the above metrics in DCA configuration, all 4 are always used but weighting in the calculation can be adjusted. DCA will grade each channel based on the 4 factors above as observed by each individual AP and make a determination on the best channel for that AP to operate on in its environment.

DCA selections include Channel Bandwidth, for 802.11n and 802.11ac AP's this selects the operating channel width that will be configured, 20/40/80 MHz selections may be made. Unless you are certain of your operating environment and design, current best practice is 40 MHz (2 x 20 MHz channels) operations in most enterprise locations. Using 80 MHz channels consumes 4 x 20 MHz channels for each channel and can introduce unwanted interference in the infrastructure unless you have designed for this specifically.

DCA knows the regulatory for every connected AP, and can manage multiple countries and domains without fear of violating local rules. DCA also monitors all DFS channels for Radar; it manages the channels that are available and selects alternate channels if Radar is detected. Decisions for every AP in the RF Group are made at the RF Group Leader level, and sent back to the local controller for configuration to the associated AP.

Channel Changes can be disruptive on an active network, for that reason DCA has two main operating modes.

- Steady State—Normal
- Startup Mode—Aggressive

Under normal operation – we assume a good initial channel plan after startup has run (see Startup Mode below for more information). DCA then dampens channel changes slightly by applying a hysteresis for operational steady state. This hysteresis determines just how much better a channel must be before allowing the AP to switch to that channel. The Hysteresis is user selectable; the default is medium and is generally adequate. Wi-Fi is bursty in nature and RF conditions can and do change frequently, though mostly for short durations. Channel changes based on short duration bursts will result in frequent and disruptive channel changes; DCA manages whole network channel plans based on trends. Basing network wide changes on isolated or short peak events tends to create problems for clients. RRM does remain sensitive to serious issues and can manage very quick changes for emergencies. See EDRRM in DCA configuration below for the notable exceptions to this rule.

Startup Mode assumes no hysteresis; it is intended for aggressively selecting an initial channel plan and spreading out the radios coverage in the selected spectrum.

This is important to remember when you are making changes to your network such as–

- Adding additional radios
- Changing channel width assignments (adding 802.11n or 802.11ac radios)
- Removing Radios from service

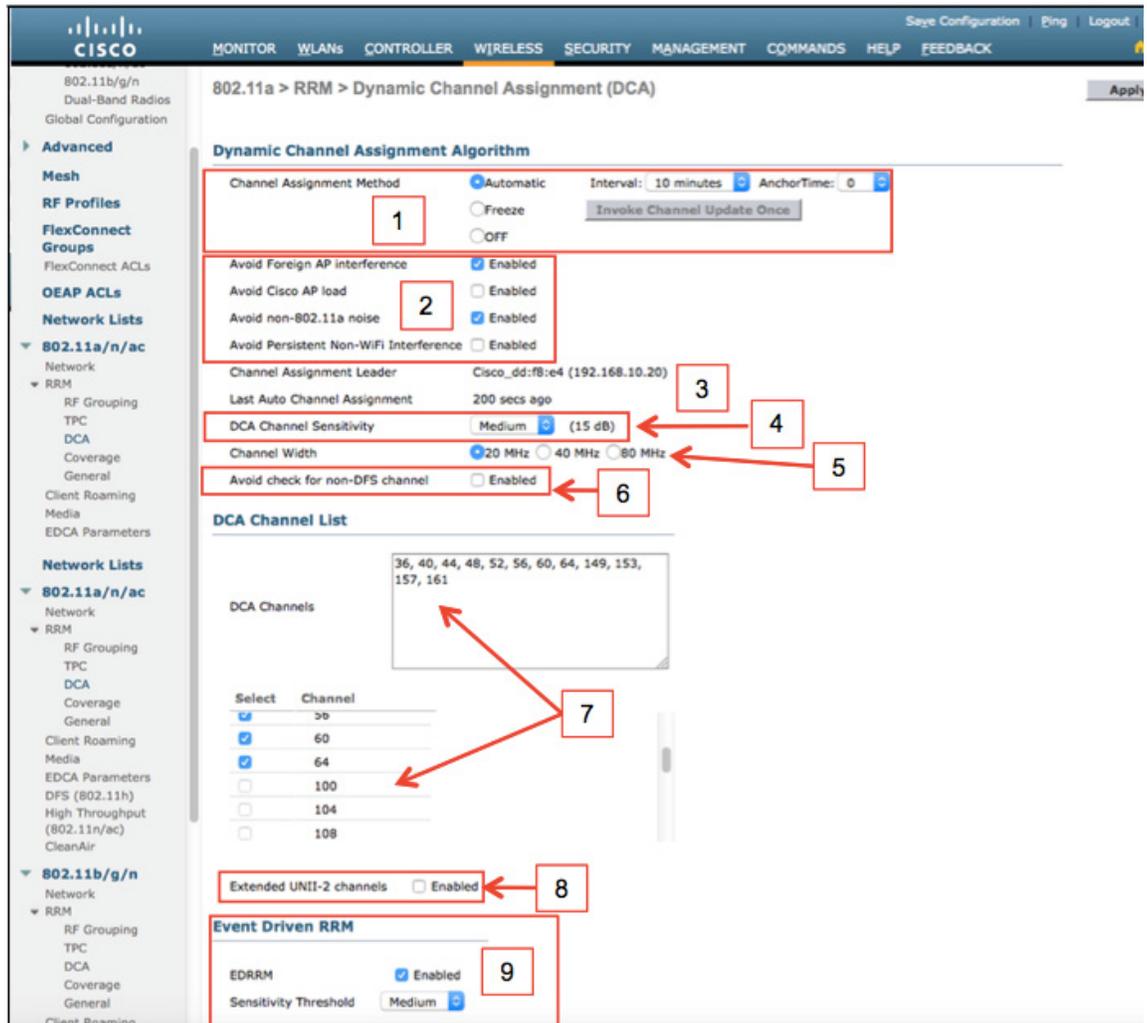
All of these things represent a major change to the operating environment, and invoking startup mode will ensure the best solution to the new question. RRM will adjust for these under normal conditions but it will do so with the Hysteresis applied and may not result in the most optimal answer for the new operating environment.

The default DCA settings are quite adequate; a majority of networks are running with these settings today. Changes to the defaults should be understood and implemented only to solve issues.

### DCA Configuration

Default settings for DCA are shown below. The defaults should be adequate for most installations, exceptions will be noted below. The DCA configuration screen is displayed below – 5 GHz is shown here for example, the notable differences from the 2.4 GHz screen is the channel width selection (4) below. We do not support Bonded channels in 2.4 GHz as there are not enough channels or spectrum for this to be practical in a multi AP installation.

Figure 3-17 DCA Configuration at 5 GHz

**DCA Configuration elements:**

1. Change Assignment Method - controls how and if DCA runs, Automatic is the default setting.
  - Automatic—DCA runs every 10 minutes (600 seconds)
    - The DCA Interval may be changed using a range of 10 minutes to 24 hours, and an anchor time may be selected. Selected Anchor times are 0-23 representing a 24 hour clock – setting the anchor time of 3 (3 AM) with an interval of 4 will run DCA every 4 hours beginning at 3 AM.
  - Freeze—After a DCA run is completed, the channel plan is frozen, DCA continues to run but makes no changes. Depressing the Invoke Channel Update Once button – does exactly that – and will run channel changes in conjunction with the NEXT scheduled DCA run – this overrides the Freeze on demand – for one cycle and permits channel changes for that cycle only.
  - Off—Turns the DCA function Off (not recommended – see below)
2. These selections allow for tuning of what and how DCA makes decisions

- Avoid Foreign AP interference—Default is selected, this counts neighbor rogue AP's and encourages DCA to work around them. If you are in a congested area, it may be better to disable this contribution. In a congested neighbor environment this can initiate a lot of channel changes – try the default first though.
  - Avoid Cisco AP Load—The default is Disabled. This measures Load only on Your (Cisco) AP's. This contribution makes DCA more sensitive to conditions and encourages MORE channel changes. In practice, Client experience is better riding through transient load peaks.
  - Avoid Non-802.11 Noise—The default is selected – This prioritizes Noise contribution which is defined as any signal that can not be demodulated as 802.11, this includes a lot of noise which is unintelligible 802.11 due to collisions, or simply being too low for proper demodulation. This should always be selected.
  - Avoid Persistent Non-WiFi Interference—The default is Disabled, if you have CleanAir AP's, this selection allows for contribution of Non-Wi-Fi persistent signals such as Microwave Ovens, Outdoor Bridges, Video Surveillance Cameras and should be selected. When CleanAir discovers such a device, it allows for the addition of a Bias to the affected channel for the detecting AP to encourage a better channel selection – even if the device is not active at the moment. Microwave oven's operate heavily during the lunch hour and again late afternoon – this makes RRM remember and avoid the impacted channels on devices that can hear the interference full time for 7 days and expires if no other detections have been made in that time.
3. Channel Assignment Leader – identifies the group leader mac and IP address of the Group leader for this band, Last Auto Channel Assignment tells you in seconds how long ago DCA ran.
  4. DCA Channel Sensitivity – The default is Medium. This setting determines the Hysteresis used to make a channel change decision. DCA compares the score of the current channel against all other possible channels – and will change to a better channel IF it meets or exceeds this metric. Medium is 10 dB better in 2.4 GHz and 15 dB better in 5 GHz. Low= 5 dB (more aggressive) and High=20 dB (less aggressive) for both bands. This determines how Much better a channel must be in order to change.
  5. Channel Width – The Default is 20 MHz This selects the Global Channel Width, selections can also be overridden at the RF profile, or individual radio level. This only affects 802.11n and 802.11ac capable AP's, a selection of 80 MHz will set 802.11n Radios to 40 MHz
  6. Avoid Check for non-DFS channels – The default is disabled. DFS requires that there be at least one non-DFS channel available in the DCA channel list. If you are deploying Outdoor AP's in ETSI regulatory – there are no non DFS channels available for outdoor – selecting this prevents the enforcement of requiring a NON-DFS channel.
  7. DCA Channel List – the top part shows you what channels are currently configured, the list allows you to select and deselect channels. Adding or deleting channels requires that the band (2.4 or 5 GHz) be disabled before making changes.
  8. Extended UNii2 channels- the default for this is disabled, enabling will add channels 100-144 automatically to the DCA channel List. This is a best practice today – especially for 802.11n/802.11ac 40/80 MHz channel selection.
  9. Event Driven RRM – EDRRM is enabled by default – best practice is to enable. EDRRM allows RRM to work with CleanAir Air Quality (AQ) and permits a CleanAir AP that experiencing a classified catastrophic interference to mitigate it by changing channels. What do we mean by catastrophic? In the event a non Wi-Fi interference source broadcasts at 100% duty cycle, it will completely block the channel for that AP, neither clients or AP will be able to speak because they listen before they talk – and every time they listen, they will hear energy. The decision is made on the AP and independent of DCA (this happens within 30 seconds). RRM will know of this change and prevent the AP from changing back for a period of 1 hour. There are 4 sensitivity thresholds

**Table 3-5 ED-RRM AQ Event Threshold Mapping**

|        |                                  |
|--------|----------------------------------|
| Low    | AQ=35                            |
| Medium | AQ=50 (default)                  |
| High   | AQ=60                            |
| Custom | User Threshold - be careful here |

- For new installations – ensure that ALL of your AP's are mounted and associated with the controller before restarting the controller or initiating DCA reset
  - DCA can be restarted and initialized at the command line with the command `config 802.11a/b channel global restart` - to verify operation check the DCA config page in the GUI under `wireless=>802.11a/b=>RRM=>DCA` will display Startup.

**Figure 3-18 DCA**

DCA Channel Sensitivity Medium STARTUP (5 dB)

- Re- initialize DCA any time there is a major change to the requirements of the channel plan
  - Change in channel bandwidth (20/40/80)
  - Adding additional AP's
  - Changing DCA channels (adding or subtracting UNII2e channels for instance)
- Default options are best, with the exception of “Avoid Foreign AP Interference” which may be unchecked if your installation has a lot of rogue neighbors and channel changes happen daily for this reason.

## TPC – Transmit Power Control

The other component critical in Wi-Fi is the transmit power of the Radios in the AP. TPC uses over the air messages to hear and measure every AP in the RF Group. By keeping track of how each AP hears other AP's and how other AP's hear our own AP we can adjust the power dynamically to provide the best coverage (cell size) without causing interference to our neighbors. The TPC calculation keeps track of regulatory requirements like Maximum Power as this changes in most regulatory region depending on which channel and band you are using. There are two different methods for TPC calculation presently with TPCv1 being the default and TPCv2 as an alternative for higher density deployment coverage.

Since TPC relies on measurements over the air between AP's to calculate the optimal power levels, it really does not know how the client at the floor level will hear it. For that reason there is a range of coverage levels than can be selected within the algorithm to tune the environment the value is a dBm value that you want at the edge of the cell you are configuring and allows for tuning to different AP placements and mounting solutions. For instance, in a high ceiling environment the AP's may be located 60 feet (18 meters) apart, with the floor being 25 feet (8 meters) below, in this case the default value of -70 may be inadequate to allow for sufficient power and coverage at the floor level and a value of -60 will.

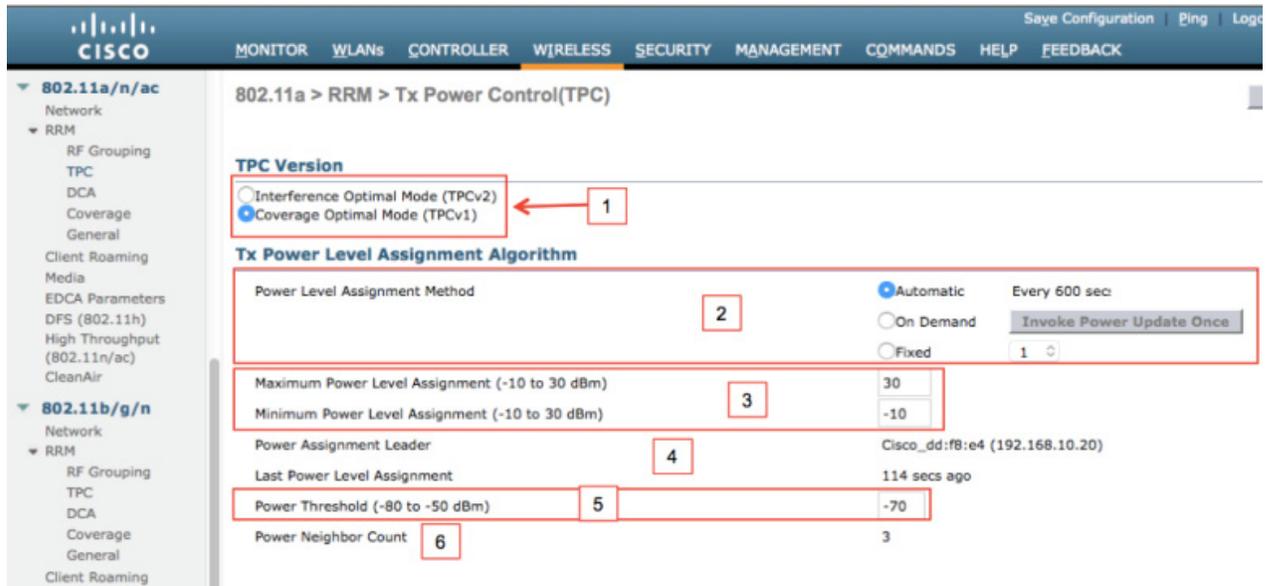
TPC also has overrides that can be applied through RF Profiles or at the global level for a whole WLC that allow the administrator to designate a minimum and maximum power level that the AP's will not exceed. This is useful for tuning in High Client Density environments and can correct for poor AP placement options as well.

We will cover more on how to tune TPC for optimal coverage in the best practices below.

## TPC Configuration

The default selections for TPC should be adequate for a normal enterprise office environment. The default TPC user threshold assumes a 10 ft (3 meter) ceiling height.

**Figure 3-19 TPC Configuration UI**



1. Choose TPC Version – TPC v1 is the default selection. TPCv2 can be used for higher density designs and coupled with channel mode will yield better capacity if AP's are closer together with less reduction in power. Installations where AP cell size is 3K sq feet and under in large open areas should consider this – coupled with the command line argument “channel mode”. This limits TPCv2 functionality to only looking at neighbors on the same channel. Only one version may be selected as this is a global command affecting the entire RF group. If this is selected on a member controller – it will have no effect on the RF group unless that controller becomes the Group Leader.
2. Power Level Assignment Algorithm
  - Automatic—Default and runs at 600 second (10 minute) intervals.
  - On Demand—Will only run on the next scheduled interval (600 seconds) if Invoke Power Update is depressed. Power levels are frozen unless the Invoke command is received but TPC continues to run in the background.
  - Fixed—Allows a manual power level to be assigned to all AP's; this is not recommended for several reasons.
    - All AP's will be on the Selected Power Level indication; however depending on the 5 GHz channel assignment, may have very different power output in dBm. See [Reference Guides](#) under Access points and refer to Channels and Maximum Power for your model under documentation.
    - This excludes all AP's from the TPC algorithm.

3. Min/Maximum power level assignment—Default is “Disabled” (note that values of -10 and 30 dBm are not supported on ANY Cisco AP). This is a per controller override – and allows setting a minimum and maximum power level that will be allowed on ALL AP’s attached to that controller. If TPC attempts to apply a setting higher or lower than the local controllers Min/Max, it is overridden by this setting. See above for Channels and Maximum power as the entry is in dBm and will produce the closest max or minimum power to an actual allowed power on the AP being applied to. This setting can also be made at the RF Profile level and applied to a select AP group – this is recommended for larger deployments containing multiple coverage and capacity zones.
4. Power level assignment leader – identifies the active RF Group leader for the band. Last power level assignment shows seconds since last assignment was made.
5. Power Threshold (-80 to -50 dBm) – This tells the TPC algorithm the value you want for the cell edge. TPC uses this the threshold value for neighbors in the calculation to determine the optimal power level of the AP’s.
  - TPCv1—The default is -70 dBm and assumes a normal office space with 10 foot ceilings, if your application has High Ceilings – 15-20+ feet you may need to adjust this threshold up to receive adequate power at the floor. The measurement is made using NDP packets between AP’s. If the AP’s have all been placed in a hallway, this can negatively affect coverage in rooms on either side of the hallway – measurements should be taken – mitigation may require different placement of the AP’s.
  - TPCv2—The default is -65 dBm.
6. Power Neighbor Count – Display only – three neighboring AP’s are required for TPC to work properly. This means that three AP’s must Logically see each others as neighbors – as they should if in close proximity to one another. If this is not the case, a power level will be chosen based on the nearest neighbors settings for consistency. This condition can affect AP’s that are at the very edge of a covered area.

## CHDM- Coverage Hole Detection and Mitigation

CHD measures the client. The goal for the rest of RRM is to produce the best coverage possible, CHD monitors the clients associated to each AP to determine if the client is receiving adequate coverage based on the AP’s measurement of the client RSSI. This assumes that the client is not willfully maintaining a connection to an AP when there is a closer AP available. Clients alone decide when to roam, and there is the phenomenon of a “sticky” client. CHD monitors for those as well by looking at all AP’s that can hear the client, if the client should and could be on a better AP, it is marked as a false positive event. If a client is not sticky, and it’s RSSI is falling below the threshold of coverage, we will alert and report on the clients location and the AP it was associated with.

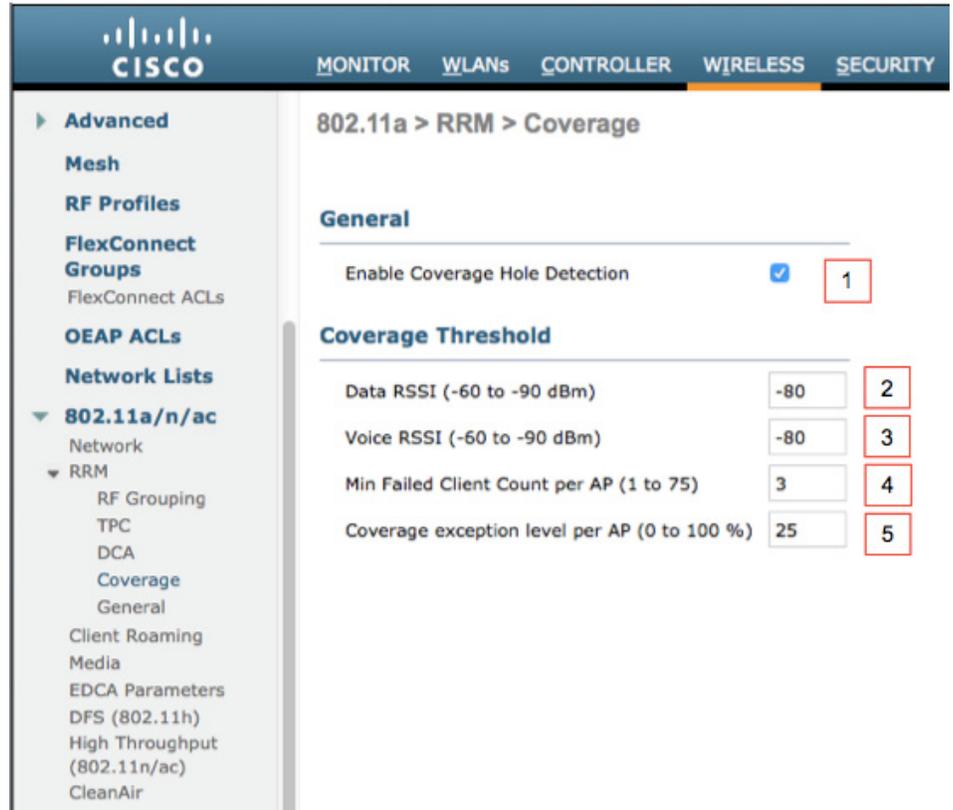
In the early days, CHD also has a mitigation component that would increase the power output of the AP it is associated too to mitigate the coverage problem. This functionality is still in the algorithm, however it is heavily weighted to ensure that is a good decision. These days, we take a more direct approach using a feature called Optimized Roaming which takes it’s direction from CHD derived metrics and for sticky clients actively intervenes by sending a Dis-associate to encourage the client to roam to a better AP.

Sticky clients operate at lower data rates generally and can drag down the performance of an entire cell. CHD monitors the client RSSI as well as SNR, and even the data rate to ensure that we understand how the network is perceived by the associated clients. The default configurations are generally sufficient, optimized Roaming is a separate configuration and will also be covered in Best Practices below.

## Coverage Hole Detection and Mitigation (CHDM)

Coverage Hole Detection monitors the Client RSSI on the associated AP.

Figure 3-20 Coverage Hole Detection Configuration UI



1. Enable/Disable Coverage Hole Detection—The default is enabled. This can be overridden on individual WLAN's as well as in RF Profiles.
2. Data RSSI threshold—The default is -80 dBm
3. Voice RSSI Threshold—The default is -80 dBm
4. Minimum Failed Client Count per AP—The default is 3. This determines how many clients must exceed either the voice or the data threshold from above in order for a Coverage Hole to be alerted, this also works in conjunction with the Coverage Exception Level below.
5. Coverage Exception Level per AP – this setting determines what percentage of total clients on a given AP need to exceed the threshold to declare a coverage hole and works in conjunction with minimum Failed Clients from above.

Coverage Hole detection and Mitigation is highly tunable with the exception of the thresholds, the default settings are generally sufficient. Minimum client count and coverage exception work together and the default count of 3 clients with a coverage exception of 25% says for example that if 3 clients are below the threshold – in order to act there must be 12 clients currently associated ( $3=25\%$  of 12). CHDM also listens for clients on every AP in order to determine if a failed client is really in a coverage whole, or if it is simply not roaming. In the event that we can hear a client from an AP better than the one it is currently associated too, this will be counted as a false positive and not count towards a coverage hole event. If both conditions are met, Coverage Hole Mitigation can increase the AP's power by one power level to attempt to fix the coverage. RRM will then re-evaluate coverage requirements on the next DCA and TPC run.

## RF Profiles

RRM at the Global Level set's configuration parameters that apply to every AP associated with the RF Group. Back when Wireless LAN Controllers had relatively low maximum numbers of AP's (e.g., 100), that was fine. Things change, and not only have AP limits jumped up so have users consumption of network resources. Different use cases like High Client Density or Capacity model vs. Coverage models require different optimizations to be efficient and meet design goals. In High Density, we are asking to optimize users experience when close to a lot of AP's – at minimal distances. For Coverage we are optimizing for maximum cell coverage and reliable connection at distance from the AP in thin coverage.

RF Profiles allows for modifications to be applied to select groups of AP's contained in the same AP Group. You can configure an RF Profile for each radio on the AP, 2 RF Profiles per AP Group may be applied. The classic use case for this is a lecture hall or large theater where a high Capacity design is required to manage a high client density. Surrounding this theater however are hallways and open areas where coverage is the bigger concern. A single global RRM setting for all of these AP's will result in a configuration that is likely not optimized for either environment. Placing the AP's inside the theater in one AP group (perhaps grouped with AP's from other High Client density locations) and the AP's in the coverage areas like hallways and open areas in another AP group. Now you can configure RF Profiles that optimize the required configurations to the intended design.

RF Profiles allow control over many functions beyond RRM's algorithms; many of the HDX features can also be customized for a specific group. On the controller's Wireless menu – select /Wireless/Advanced/RF Profiles:

**Figure 3-21 Pre-configured RF Profiles**

| Profile Name                                    | Radio Policy | Applied |
|---|--------------|---------|
| <a href="#">High-Client-Density-802.11a</a>     | 802.11a      | No      |
| <a href="#">High-Client-Density-802.11bg</a>    | 802.11b/g    | No      |
| <a href="#">Low-Client-Density-802.11a</a>      | 802.11a      | No      |
| <a href="#">Low-Client-Density-802.11bg</a>     | 802.11b/g    | No      |
| <a href="#">Typical-Client-Density-802.11a</a>  | 802.11a      | No      |
| <a href="#">Typical-Client-Density-802.11bg</a> | 802.11b/g    | No      |

1. Example pre-built RF Profiles
2. New—To create a custom RF Profile
3. Enable Out of box—To place any new AP's into the Out of Box AP group; which has the radios disabled. Persistent is checked if you want Out of Box (OOB) to remain in effect across re-boots of the controller.

We'll cover the configuration options contained in an RF Profile first. Then we'll cover the intended use and configurations for the example profiles. In order to create a new RF Profile, go to **Wireless > RF Profiles** and select "New...." (Fig. 19 bullet 2) and open the New RF Profile dialogue.

**Figure 3-22**      **New RF profile dialogue**

RF Profile > New

RF Profile Name: Example\_1

Radio Policy: 802.11a (dropdown menu showing 802.11a and 802.11b/g)

We will cover the configuration options contained in an RF Profile first. Then we will cover the intended use and configurations for the example profiles. In order to create a new RF Profile, go to **Wireless > RF Profiles** and select “New....” (Fig. 19 bullet 2) and open the New RF Profile dialogue.

### RF Profile - General

**Figure 3-23**      **RF Profile General Tab**

RF Profile > Edit 'Example\_1'

General   802.11   RRM   High Density   Client Distribution

Profile Name: Example\_1

Radio policy: 802.11b/g

Description: [text input field]

On the general tab – you can enter a short description regarding the use of this profile; you have 64 characters max. The general Tab Identifies what band the profile is created for and the RF Profile name – neither of these can be edited after creation. If a mistake was made on the name during creation, you need to delete the profile and re-create with the correct name.

### RF Profile - 802.11

The 802.11 tab gives you control over the network settings which are controller specific not global. These settings in RF Profiles override the controller Global configuration for the AP group it is applied to

Figure 3-24 RF Profile 802.11 tab

| Data Rates <sup>1</sup> |           | MCS Settings |   |
|-------------------------|-----------|--------------|---|
| 1 Mbps                  | Disabled  | 0            | <input checked="" type="checkbox"/> Supported |
| 2 Mbps                  | Disabled  | 1            | <input checked="" type="checkbox"/> Supported |
| 5.5 Mbps                | Disabled  | 2            | <input checked="" type="checkbox"/> Supported |
| 6 Mbps                  | Supported | 3            | <input checked="" type="checkbox"/> Supported |
| 9 Mbps                  | Mandatory | 4            | <input checked="" type="checkbox"/> Supported |
| 11 Mbps                 | Disabled  | 5            | <input checked="" type="checkbox"/> Supported |
| 12 Mbps                 | Supported | 6            | <input checked="" type="checkbox"/> Supported |
| 18 Mbps                 | Supported | 7            | <input checked="" type="checkbox"/> Supported |
| 24 Mbps                 | Mandatory | 8            | <input checked="" type="checkbox"/> Supported |
| 36 Mbps                 | Supported | 9            | <input checked="" type="checkbox"/> Supported |
| 48 Mbps                 | Supported | 10           | <input checked="" type="checkbox"/> Supported |
| 54 Mbps                 | Supported | 11           | <input checked="" type="checkbox"/> Supported |
|                         |           | 12           | <input checked="" type="checkbox"/> Supported |
|                         |           | 13           | <input checked="" type="checkbox"/> Supported |
|                         |           | 14           | <input checked="" type="checkbox"/> Supported |
|                         |           | 15           | <input checked="" type="checkbox"/> Supported |
|                         |           | 16           | <input checked="" type="checkbox"/> Supported |

The 802.11 tab allows selection of data rates and their mode. On a Cisco AP a data rate can be in one of 3 states

1. Disabled—not allowed by the AP
2. Supported—allowed but not required by the AP
3. Mandatory—The client must support this data rate

The Minimum (lowest) Mandatory Data Rate (in the example above 9 Mbps) determines the speed at which the beacon and all other subsequent broadcast messages will be sent at. In order for a client to associate with an AP using 9 Mbps as the minimum Mandatory data rate, the client must be able to complete association at 9 Mbps or faster or the client will not be allowed to join the AP. This effectively limits the cell size of the AP to clients close enough to support 9 Mbps. This is a good default value for average installations. In higher client density the value may be 12 Mbps, or in extreme high client density designs where cell sizes are at their minimum you may even select 18,24 or 36 Mbps depending on the design requirements.

The second Highest Mandatory data rate (24 Mbps in the example above) will be the default multicast speed if auto multicast is not set (it is by default)

A data rate that is marked as supported, may be used by the client and the AP will honor it.

A data rate that is marked disabled will not be honored by the AP.

MCS data rates can be selected or de-selected only. Deselecting these rates will prevent the AP from using them. All Data rates and selections are broadcast to potential clients in the beacon frame, and your changes here will be reflected in the beacon message.

## RF Profile - RRM

Figure 3-25 RF Profiles RRM tab

The screenshot shows the RRM configuration page with the following details:

- TPC (1):**
  - Maximum Power Level Assignment (-10 to 30 dBm): 30
  - Minimum Power Level Assignment (-10 to 30 dBm): -10
  - Power Threshold v1(-80 to -50 dBm): -70
  - Power Threshold v2(-80 to -50 dBm): -67
- Coverage Hole Detection (3):**
  - Data RSSI(-90 to -60 dBm): -80
  - Voice RSSI(-90 to -60 dBm): -80
  - Coverage Exception(1 to 75 Clients): 3
  - Coverage Level(0 to 100 %): 25
- DCA (2):**
  - Avoid AP Foreign AP Interference:  Enabled
- Profile Threshold For Traps (4):**
  - Interference (0 to 100%): 10
  - Clients (1 to 200): 12
  - Noise (-127 to 0 dBm): -70
  - Utilization (0 to 100 %): 80
- DCA Channel List (2):**
  - DCA Channels: 1, 6, 11
  - Table:

| Select                              | Channel |
|-------------------------------------|---------|
| <input checked="" type="checkbox"/> | 1       |
| <input checked="" type="checkbox"/> | 6       |
| <input checked="" type="checkbox"/> | 11      |

The RRM tab within an RF Profile allows for overriding the global parameters set at the RF Group Level.

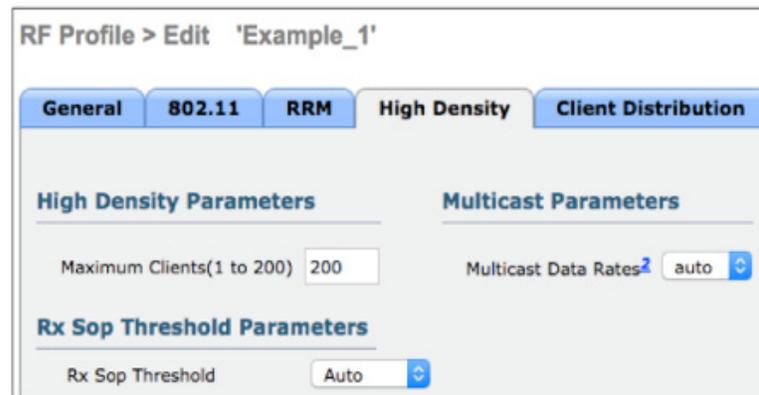
1. TPC, allows for a custom Min/Max power level to be assigned for the entire AP Group, also a custom TPC threshold for either TPCv1 or 2. NOTE: Selection of the TPC version is a global selection only and either the TPCv1 or v2 threshold will be used as appropriate.
2. DCA, while not all the features of DCA are included at the RF Profile level the most important are, for instance avoiding foreign AP interference may well perform better disabled in a rogue rich environment. You can also set custom channel plans using a copy of the DCA channel list. In order for a channel to be available within the RF Profile – it must be selected at the global DCA channel List.

3. Coverage Hole Detection, is replicated completely and applies to all WLAN's assigned to the AP Group, individual WLANs may have coverage hole enabled or disabled on the global configuration per controller.
4. Profile Threshold For Traps, allows setting of other thresholds within the RF profile – for instance in a high client density area – more of everything will be normal – this allows you to make trap alert messages useful for an AP group which otherwise may be set too low.

### RF Profile - High Density

The High Density tab allows for optimizing certain HDX features at the RF Profile level on an AP group.

**Figure 3-26** RF Profile High Density tab



- High Density Parameters, allows selection of the maximum number of allowed clients on a radio interface. This selection will simply deny access to any client number over the selected number. The default value is 200. It is recommended to leave this at the default value.
- Rx SOP, allows selection of a RX Start Of Packet Sensitivity threshold – the selections are High, Medium, Low, auto – the default is Auto. A thorough understanding of RX-SOP how it works and the settings is highly advised. RX-SOP changes the receive sensitivity by setting a threshold RSSI that a logical packet must meet in order to be received as Wi-Fi. *See – [High Density Experience Features Release 8.0](#) for more on RX-SOP settings.*
- Multicast Parameters – the default is Auto, or you may select a single dedicated data rate that all multicast packets will use.

### RF Profiles – Client Distribution

The Client Distribution tab gives you control over Load Balancing and Band Select options

Figure 3-27 RF Profiles Client Distribution tab

RF Profile > Edit 'Example\_1' < Back Apply

General **802.11** RRM High Density **Client Distribution**

| Load Balancing          |   | Band Select                        |                          |
|-------------------------|---|------------------------------------|--------------------------|
| Window(0 to 20 Clients) | 5 | Probe Response                     | <input type="checkbox"/> |
| Denial(1 to 10)         | 3 | Cycle Count(1 to 10 Cycles)        | 2                        |
|                         |   | Cycle Threshold(1 to 1000 msecs)   | 200                      |
|                         |   | Suppression Expire(10 to 200 secs) | 20                       |
|                         |   | Dual Band Expire(10 to 300 secs)   | 60                       |
|                         |   | Client RSSI(-90 to -20 dBm)        | -80                      |
|                         |   | Client Mid RSSI(-90 to -20 dBm)    | -80                      |

- Load Balancing, allows setting of a threshold on an AP at which additional clients will be denied with a status code of 17 which states that the AP can not process this request now because it has too many clients, you can select the number of clients 0-20 and the number of denials that will be sent before admission is granted. This is important, as client devices do not universally support status code 17. Load Balancing can be better ensured by the selection of proper data rates and good network design.
- Band Select, 802.11b/2.4 GHz profile only – Selection of the probe response box enables band Select configuration at the RF Profile level and overrides the configuration settings at the global level allowing for more aggressive band Select operation on a selected AP group only.

## WLAN Express

With release 8.0 we've included a new day 0/1 startup dialogue that guides the user through questions targeting best practices for Wireless LAN Controller deployment. The configuration dialogue and options are designed to support the [Cisco Wireless LAN Controller Configuration Best Practices](#). The dialogue supports the application of suitable RF settings for low, medium, and high Client/AP density and will apply suitable selections for data rates, and features designed to support higher density environments. While no building or installation is ever the same, generalizations can be applied based on the density of the Access Point deployment and intended number of clients.

In addition to the startup dialogue, there are 3 pre-configured RF profiles contained on the controller that you can use for reference or apply as is. The configuration settings for these are below.

Table 3-6 Pre-configured RF Profiles

|                             | Dependency  | Typical<br>(Enterprise -<br>Default Profile)                                | High Density<br>(Throughput)  | Low<br>Density<br>(Coverage<br>Open<br>Space)                     | Legacy<br>(if disabled<br>RF opt) |
|-----------------------------|---|---|---|---|-----------------------------------|
| TPC Threshold               | Global per band<br>Specific RF Profile per<br>band                                  | Default   | -65 dBm<br>(5GHz)<br>-70 dBm<br>(2.4GHz)                                    | -60 dBm<br>(5GHz)<br>-65 dBm<br>(2.4 GHz)                         | Default                           |
| TPC Min                     | Global per band<br>Specific RF Profile per<br>band                                  | Default   | 7 dBm   | Default   | Default                           |
| TPC Max                     | Global per band<br>Specific RF Profile per<br>band                                  | Default   | Default   | Default   | Default                           |
| Rx Sensitivity<br>(rxsop)   | Global per band<br>(Advanced Rx Sop)<br>RF profiles                                 | Default   | Medium  | low   | Default                           |
| Coverage RSSI<br>Threshold  | Global per band<br>data and voice RSSI in<br>(Coverage)<br>RF Profile               | Default   | Default   | Higher  | Default                           |
| CCA<br>Threshold            | Global per band<br>802.11 a only (hidden)<br>RF Profile                             | Default   | Default   | Default   | Default                           |
| Coverage<br>Client<br>Count | Global Per band<br>(Coverage Exception)<br>RF Profiles (Coverage<br>Hole Detection) | Default   | Default   | Lower<br>(1-3)  | Default                           |
| Data Rates                  | Global per band<br>(network)<br>RF Profiles   | 12 Mbps<br>mandatory<br><br>9 supported<br>1, 2, 5.5, 6, 11<br>Mbps disable | 12 Mbps<br>mandatory<br><br>9 supported<br>1, 2, 5.5, 6, 11<br>Mbps disable | CCK rates<br>enable<br>1, 2, 5.5, 6,<br>9,11,12<br>Mbps<br>enable | default                           |
| Band Select                 | Per WLAN basis  | Enable  | Enabled   | Disable   | Enable                            |

**Table 3-6 Pre-configured RF Profiles (continued)**

|                 | <b>Dependency</b>                            | <b>Typical<br/>(Enterprise -<br/>Default Profile)</b> | <b>High Density<br/>(Throughput)</b> | <b>Low<br/>Density<br/>(Coverage<br/>Open<br/>Space)</b> | <b>Legacy<br/>(if disabled<br/>RF opt)</b> |
|-----------------|--|---|--------------------------------------|--|--|
| SI              | Global per band (Clean Air)                  | Enable  | Enable                               | Enable   | Enable                                     |
| ED-RRM          |  | Disable   | Disable                              | Disable  | Disable                                    |
| PDA             | Global per band (DCA)                        | Enable  | Enable                               | Enable   | Enable                                     |
|                 | Global per band (802.11a/802.11b channel...) |   |                                      |  |  |
| Load Balancing  | Per WLAN basis                               | Disable   | Enabled                              | Disable  | Disable                                    |
| DCA Sensitivity |  | Default   | High                                 | High   | Default                                    |
| Channel         | Global per band (DCA) RF Profiles            | Default   | Default                              | Default  | Default                                    |

### High Density

High Density in this context should be thought of as any area where the average cell size is 3000-2000 sq feet (280-185 sq meters) and multiple AP's have been deployed for Capacity reasons. Typical client counts would be 50-100 clients per cell.

AP's spaced at a distance of roughly 60 feet (18 meters) = 3000 sq ft cell size.

AP's spaced at a distance of 50 feet (15 meters) = 2000 sq ft cell size

If you are engineering a specific theater, or lecture hall and increasing capacity to handle a density of 1 user per sq/meter you should follow the design recommendations for minimum data rates and power levels.

### Typical Density

Typical density will apply to most every other area of an enterprise installation, or common areas and cube's where active clients are spread out a bit but continuous coverage is provided. The average cell size would be 3000 – 5000 sq feet (280-460 m sq) and the average number of users per cell would be 10-30.

AP's spaced at a distance of 60 feet (18 meters) = 3000 sq ft cell size.

AP's spaced at a distance of 80 feet (24 meters)= 5000 sq ft cell size

### Low Density

The low density threshold is provided for very large cells of 5000 sq feet or more. In this profile – all data rates are enabled, and power levels are increased through the TPC threshold to provide coverage over the maximum distance of the cell edge. Lower data rates mean higher airtime utilization per user,

so the capacity is limited by airtime in this configuration. This would be a fine configuration for an individual hot spot application or for outdoor coverage of an open field. This is also very close to the default AP configurations if no selection is made.

## RF Power Terminology

The terms such as dB, dBi, dBr and dBm are used to describe the amount of change in power measured at points in a system, as perceived by the radio or compared to a reference power level. The following sections cover their differences and provide general rules for their use. Effective isotropic radiated power (EIRP) is also described.

### dB

The term dB (decibel) is mainly used to describe attenuation or amplification of the signal level. dB is a logarithmic ratio of a signal to another standardized value. This means that the dB by itself is not a measurement. For example, dBm is where the signal level value is being compared to 1 milliwatt of power, and dBW is where the value is being compared to 1 watt of power.

The mathematical equation is:

$$\text{power (in dB)} = 10 * \log_{10} (\text{signal/reference})$$

Substituting in real numbers (signal 100 mW, reference 1 mW) provides a value in dB of 20 (100 = 10 squared; taking the exponent 2 and multiplying by 10 gives you 20).

Keep in mind that it is logarithmic, meaning that it increases or decreases exponentially and not linearly, and it is a ratio of a given value to a reference. Also keep in mind that every increase of 10 dB represents a multiplication by 10 (for example, 0 dBm = 1 mW, 10 dBm = 10 mW, 20 dBm = 100mW, and 30 dBm = 1000mW (1W)).

Given that it is logarithmic, there are general rules to take into consideration. An increase or decrease of 3 dB means that the signal doubled (double the power) or halved, respectively. An increase or decrease of 10 dB means that the signal went up by 10 times or down to 1/10th of the original value.

Indoor and outdoor WLAN deployments each offer separate challenges in RF deployments that need to be analyzed separately. However, there are a few general rules for indoor use. For every increase of 9 dB, the indoor coverage area should double. For every decrease of 9 dB, the indoor coverage area should be cut in half.

### dBm

The term dBm (dB milliwatt) uses the same calculation as described in the dB section but has a reference value of 1 mW (0.001 W). Power in Wi-Fi is always below 1 mW.

Taking into consideration the example given above in the dB section, if the power increased from 1 mW to 100 mW at the radio, the power level would increase from 0 dBm to 20 dBm.

Besides describing transmitter power, dBm can also describe receiver sensitivity. Receiver sensitivity is represented as minus dBm (-dBm) because the relatively low transmit power used in Wi-Fi – received signals are always below 1 mW. The sensitivity indicates the lowest power the receiver can effectively receive before it considers the signal unintelligible.

## dB*i*

The term dB*i* (dB isotropic) describes the forward gain of a real antenna compared with the hypothetical isotropic antenna. An isotropic antenna (a theoretical or imaginary antenna) is one that sends the same power density perfectly in all directions.

Antennas are compared to this ideal measurement, and all FCC calculations use this measurement (dB*i*). For example, a Cisco omni-directional AIR-ANT4941 antenna has a gain of 2.2 dB*i*, meaning that the maximum energy density of the antenna is 2.2 dB greater than an isotropic antenna.

## Effective Isotropic Radiated Power (EIRP)

Although transmitted power based on the radio setting is rated in either dBm or milliwatts, the maximum energy density coming from an antenna from a complete system is measured as EIRP, which is a summation of the dB values of the various components. EIRP is the value that regulatory agencies such as the FCC or ETSI use to determine and measure power limits, expressed in terms of maximum energy density within the first Fresnel of the radiating antenna. EIRP is calculated by adding the transmitter power (dBm) to antenna gain (dB*i*) and subtracting any cable losses (dB). For example, if you have a Cisco Aironet bridge connected to a solid dish antenna by a 50 foot length of coaxial cable, substituting in the numbers gives the following:

- Bridge: 20 dBm
- 50 Foot Cable: -3.3 dBm (negative because of cable loss)
- Dish Antenna: 21 dB*i*
- EIRP: 37.7 dBm

For more information and fun math *see* the Cisco tech Note: [RF Power Values](#).

