CHAPTER 9

VoWLAN Design Recommendations

This chapter provides additional design considerations when deploying voice over WLAN (VoWLAN) solutions. WLAN configuration specifics may vary depending on the VoWLAN devices being used and the WLAN design. This chapter provides more details about key RF and site survey considerations that are generally applicable to VoWLAN deployments, which were introduced in Chapter 3, "WLAN Radio Frequency Design Considerations."

Antenna Considerations

The more demanding network requirements of VoWLAN impacts WLAN planning at all levels, down to the choice of antenna. Key antenna considerations are as follows:

- Access point (AP) antenna selection
- Antenna placement
- Handset antenna characteristics

AP Antenna Selection

Cisco recommends a diversity ceiling-mount antenna for voice applications. Ceiling mounted antennas offer a quick and easy installation. More importantly, they place the radiating portion of the antenna in open space, which allows the most efficient signal propagation and reception. Cisco recommends that all antennas be placed 1 to 2 wavelengths from highly reflective surfaces such as metal. The 2.4 GHz wave is 4.92 inches (12.5 cm) and the 5 GHz is 2.36 inches (6 cm). The separation of one or more wavelengths between the antenna and reflective surfaces allows the AP radio a better opportunity to receive a transmission, and reduces the creation of nulls when the radio transmits. Orthogonal frequency-division multiplexing (OFDM) used by 11g and 11a helps to mitigate problems with reflections, nulls, and multipath; however, good antenna placement and the use of appropriate antenna types provide a superior solution. The ceiling tile itself is a good absorber of signals transmitted into the area above the ceiling and reflected back into the coverage area.

Antennas come in many types and form factors; no single type or module of antenna is best for all applications and locations. For additional information on the performance of various antenna types, and the part numbers of Cisco Aironet antennas, see the Cisco Aironet antenna guide at the following URL: http://www.cisco.com/en/US/products/hw/wireless/ps469/products_data_sheet09186a008008883b.html.

When attaching antennas to an AP, Cisco recommends using the Cisco AIR-ANT5959 for 2.4 GHz and ANT5145V-R for 5 GHz for indoor voice applications. These two antennas provide the following advantages:

- Low gain omni-directional coverage and antenna diversity
- Decreased upward tilt angle, which reduces the coverage that may bleed through floor above, and also reduces the reflections that may come from air ducts and other metal objects above the ceiling tile
- Easy attachment to the T-bar on most ceiling tiles

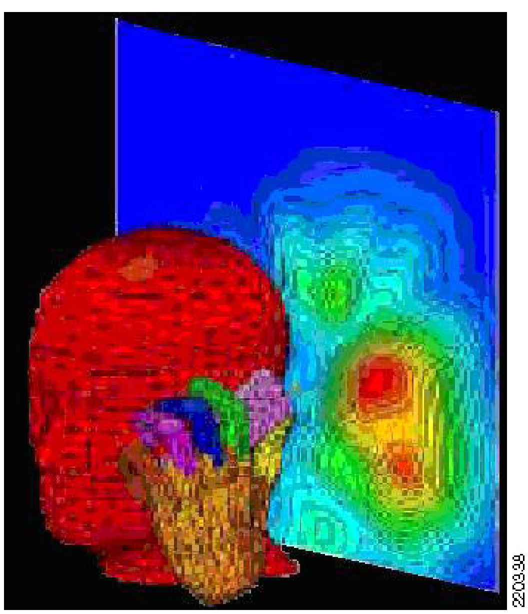
Higher gain antennas spread the signal on the horizontal plane, which creates a larger cell that also picks up more noise. This results in a lower signal-to-noise ratio (SNR), which increases the packet error ratio. SNR is defined by the following two criteria:

- Signal—The radiated energy transmitted from one radio that can be received uninterrupted by another radio. For Wi-Fi, this means that the transmitting radio is sending 802.11 protocol packets that the receiving radio is able to decode.
- Noise—Transmitted energy in the frequency range of the receiving radio that cannot be decoded by that radio.

The larger the difference in energy between the protocol packet and the background noise, the better the reception of the protocol packet and the lower the packet error rate and bit error rate. Coverage area design involves using channels to create the lowest possible packet error rate while maintaining a high call capacity.

Higher gain antennas can also reduce the number of calls on a Wi-Fi channel because of the increased coverage area. For voice, a ceiling-mounted antenna is preferred over a wall-mounted patch because the human head and body attenuate 5 dB of the signal (see Figure 9-1). Ceiling mounted antennas are better positioned to avoid more of this head and body attenuation than most wall-mounted antennas.

Figure 9-1 Head and Hand Attenuation



Antenna Positioning

Ceiling-mounted antennas typically have better signal paths to handheld phones. The recommended coverage cell size takes into consideration the signal loss because of the attenuation of the head and other obstacles. It is important to understand that the gain of antennas is reciprocal; gain applies equally to reception and transmission. Antenna gain is not an increase in transmitted power; the radio produces the transmitted power. The antenna is only a passive device. Gain is derived by focusing the signal of the radio into a direction, plane, and beam width, much in the same way a flashlight reflector focuses the light emanating from its bulb.

For a further discussion of WLAN RF planning, see Chapter 3, "WLAN Radio Frequency Design Considerations."

Handset Antennas

The Cisco Unified Wireless IP Phone 7920 and 7921G have antennas that extend from the main body of the phone. The way they are held in the hand does not significantly influence signal attenuation resulting from the hand.

For phones that integrate the antenna inside the body of the phone, the way the user holds the phone in the hand can influence signal attenuation by 4 dB. In some cases, a phone held against the head with the hand covering the antenna can result in a signal drop of 9 dB. The general rule for indoor deployments is that every 9 dB of signal loss reduces the coverage area in half. Figure 9-1 shows an example of the difference in radiating power from a handset when held to the head.

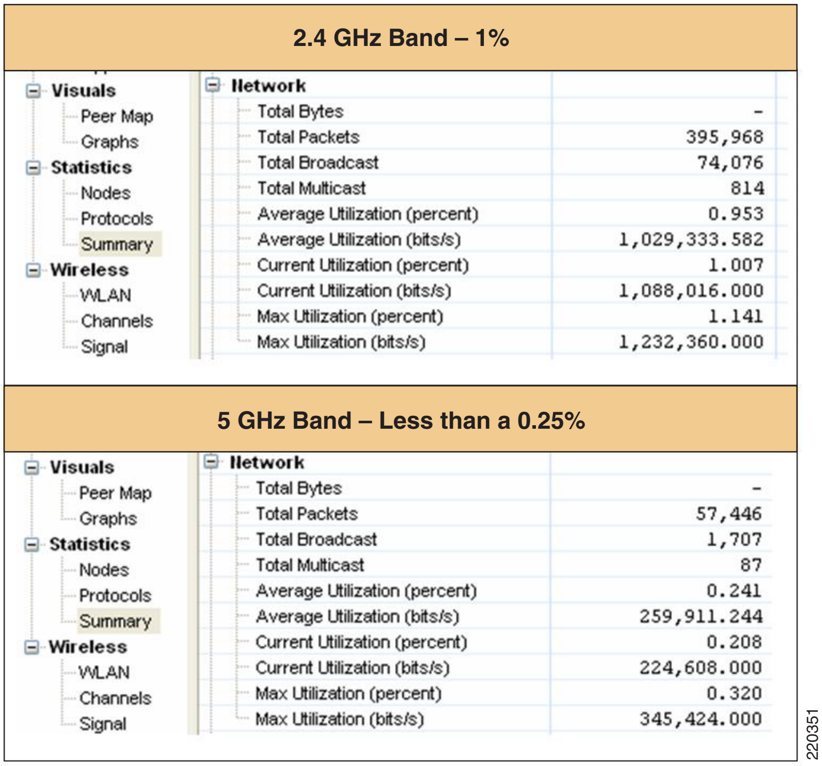
Handsets using the 2.4 GHz spectrum generally do not use diversity antennas because the 2.4 GHz wavelength is nearly five inches, so there is no practical antenna diversity option that can be implemented to improve signal reception. Therefore, the only improvement in link quality that can be achieved is at the AP. To provide optimum link quality between the phone and the AP, the AP needs to operate in its default configuration, which is with diversity enabled along with a diversity antenna.

Note that 802.11a handsets such as the Cisco 7921G do have a diversity antenna solution for the 11a radio.

Channel Utilization

The 802.11, 802.11b, and 802.11g standards use the same 2.4 GHz band. All must interoperate with each other, which introduces additional overhead reducing channel throughput. Many sites already have products using the Wi-Fi 2.4 GHz band. Additionally, there are many other products that use the same 2.4 GHz frequencies as used by Wi-Fi. Other products include Bluetooth, cordless phones, video game controllers, surveillance cameras, and microwave ovens. Because the 2.4 Ghz band is so "crowded", coupled with its channel allocation constraints, you should consider using the 5 GHz Wi-Fi band for new VoWLAN deployments. The channels available in 5 GHz are generally free of use at most sites (see Figure 9-2). Use of the UNII-2 channels for VoWLAN traffic requires the absence of radar. Cisco therefore recommends that there should be extra testing at any new site to see whether a channel in UNII-2 should be blocked out by configuration. The reason for this is that if an AP detects radar during normal use, it must leave the channel within ten seconds.

Figure 9-2 Typical Office Channel Utilization for 2.4 GHz and 5 GHz



Before the installation of the Cisco Unified Wireless Network, a site can be tested for channel interference and utilization with tools from AirMagnet, Wild Packets, Cognio, and others. The Wireless Control System (WCS) AP On-Demand Statistics Display report provides a spectrum review of the following:

- Noise by channel
- Interference by channel
- Client count versus RSSI
- Client count versus SNR
- Channel radar detection versus time

Dynamic Frequency Selection (DFS) and 802.11h Requirements of the APs

The Federal Communications Commission (FCC) of the United States, the European Telecommunications Standards Institute (ETSI), and other regulatory agencies have requirements regarding the use of radio frequencies. Portions of the 5 GHz band have been and are currently being used for radar, such as weather radar. Although most 5 GHz radar systems generally use higher frequencies with shorter wavelengths, there are still systems in place that overlap with some Wi-Fi UNII-2 bands. In 2006, the FCC opened the frequencies in the 5470–5725 MHz range to unlicensed use. With these additional frequencies came a requirement to maintaining an “interference-free” AP configuration. The AP must constantly monitor for radar pulses (typically from military, satellite, and weather stations), and must automatically switch to a “clean” channel if radar is detected.

When radar is detected, the system must do the following:

- Stop packet transmission within 200 ms
- Stop control transmissions within 10 seconds
- Avoid transmission on the channel for 30 minutes
- Scan the new channel for 60 seconds before transmission

Because of the radar requirements in the UNII-2, you should conduct a test for radar before going live with voice applications, because the required radar avoidance behavior may impact voice call quality. Cognio Spectrum Expert is also an excellent tool to test for the presence of radar. If radar is detected during such a test, the APs can then be configured to not use those channels.

Channels in the 5 GHz Band

Figure 9-3 shows the FCC 802.11a channel assignments. The DFS requirement includes the four original UNII-2 channels (52–64) and the new eight channels (100–116 and 132–140). The 5 GHz band now has 20 channels. These are non-overlapping channels, which means that they can all be co-located. 2.4 GHz has only three non-overlapping channels. A design allowing co-located channels in a coverage area aggregates the number calls obtainable in a coverage area.

Figure 9-3 802.11a Channel Allocation

Channel Identifier	36	40	44	48	52	56	60	64		149	153	157	161
Center Frequency	5180	5200	5220	5240	5260	5280	5300	5320		5745	5765	5785	5805
Band	UNII-1				UNII-2					UNII-3			

Channel Identifier	100	104	108	112	116	132	136	140
Center Frequency	5500	5520	5540	5560	5580	5660	5680	5700
Band	New UNII-2 Channels							

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See the Cisco website for compliance information and also check with your local regulatory authority to find out what is permitted within your country. The information provided in Table 3-2 and Table 3-3 should be used as a general guideline.

The channel-based design based on channels may be implemented to a single floor, as shown in Figure 9-4. In a multi-floor design, the channels can be separated between floors to reduce the possibility of co-channel interference.

Figure 9-4 Single Floor Channel Design

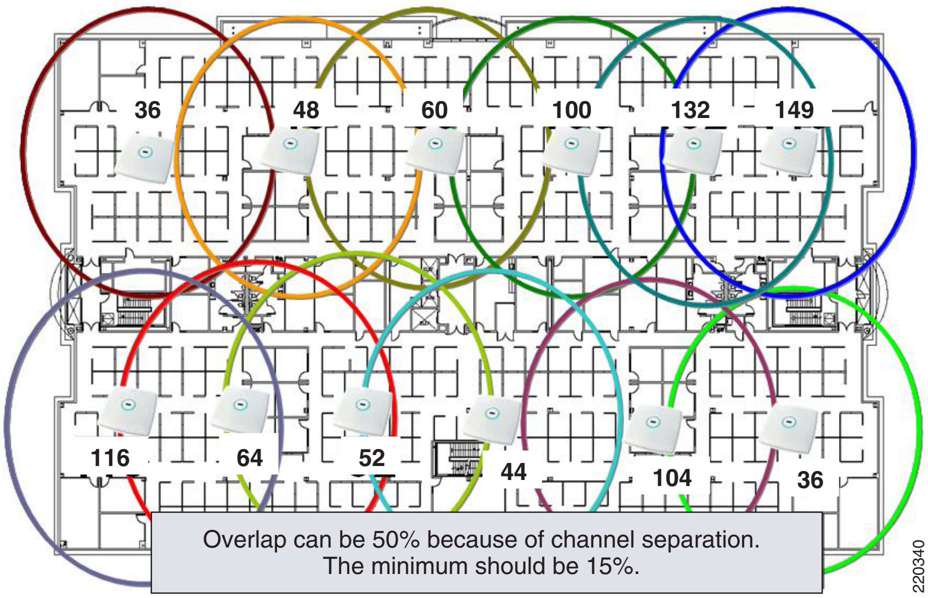
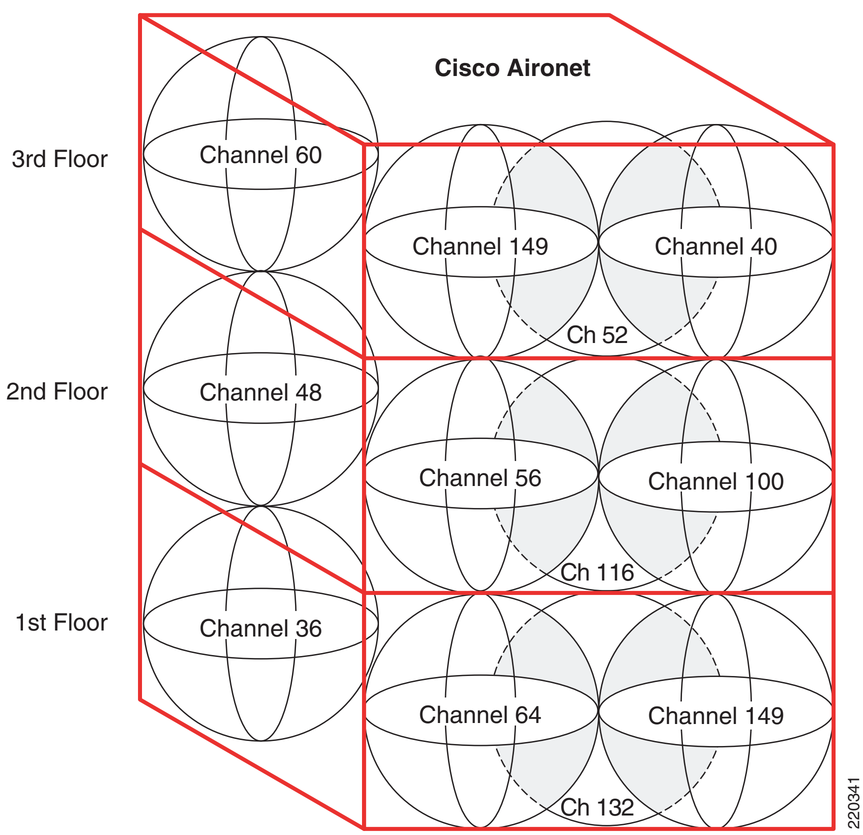


Figure 9-5 illustrates the vertical channel separation.

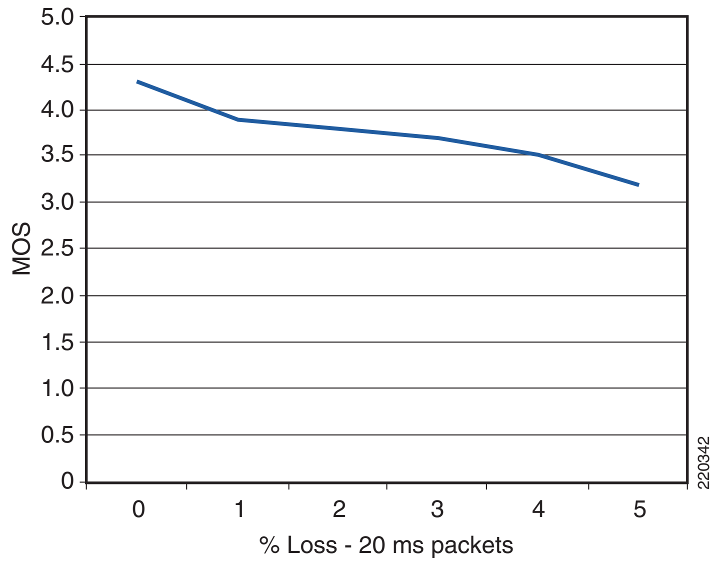
Figure 9-5 Vertical Channel Separation



Call Capacity

The number of calls on a Wi-Fi channel is limited by a number of factors. First, the media used by the AP and VoWLAN clients is the RF spectrum, which cannot be shielded from electromagnetic interference like shielded twisted-pair CAT 5 cable. The closest Wi-Fi comes to segmentation is channel separation. This open shared media of 802.11 creates the possibility for high packet loss. Most of this packet loss is addressed through retransmission of 802.11 frames, which in turn causes jitter. Figure 9-6 illustrates the packet loss relationship as a mean opinion score (MOS).

Figure 9-6 Effective Packet Loss Graphic



In 802.11a as well as 802.11g, the highest coverage range is achieved by the lowest data rate, which is 6 Mbps. The lowest packet error rate is also at 6 Mbps, for the same given power level.

An acceptable coverage area for voice is an area that maintains a packet error rate of 5 percent or less. The MOS scores are ranked as follows:

- 4.4—Top G.711 MOS score
- 4.3–4.0—"Very satisfied" to "satisfied"
- 4.0–3.6—"Some users satisfied"

Figure 9-6 shows that a packet error rate of 5 percent reduces the MOS to a level of "some users satisfied" quality of speech.

The coverage area edge for a phone is where the coverage area drops the MOS to the "very satisfied" category. This coverage area edge is referred to as a *cell edge* in this chapter. A cell edge with a 1 percent packet error rate is needed for voice because of the likelihood of multiple phone clients, data clients, co-channel interference, and other un-accounted for interferers. Cell edge and coverage design are defined in detail in other sections of this chapter.

If 802.11 and 802.11b are not required to support legacy 2.4 GHz Wi-Fi clients, Cisco recommends disabling the rates of 1, 2, 5.5, and 11. If those rates are disabled, one or more 802.11g data rates must be set to "required". The data rate of 6 is generally the recommended data rate to be set to "required", but this depends on the cell size design requirements, which may require using a higher bit rate. If possible, an 802.11g-only network is recommended rather than a 802.11b/g network. Most data clients and phone clients recognize the data rates advertised by the AP in its beacons and probe response.

Therefore, the clients send their management, control, multicast, and broadcast packets at the "required" data rates as advertised by the AP. The clients can send their unicast packets at any of the data rates advertised by the AP. Generally, those unicast packets are sent at a data rate that provides the highest reliable data rate for the link between the AP and client. The AP is capable of sending unicast packets at a data rate that is unique to each client link.

SNR is an important consideration for packet reception. The receiving radio is either the AP radio or the phone radio. The SNR is not likely to be the same at both radios of the link. SNR and multipath interference must be considered at the AP and at the coverage area edge. Path loss can be assumed to be the same at both ends of the link.

Cisco recommends for voice applications that the cell edge be determined by using the actual phone at the desired data rate. The voice packets sent between the AP and the phone in Wi-Fi applications are generally unicast RTP G711 packets with a typical size of 236 bytes. The Real-Time Transport Protocol (RTP) packet is based on UDP and IP protocols, and therefore RTP is connectionless. The signal strength, SNR, data rate, and error rates of the phone call can be seen from the AP statistics, either on the standalone AP or the Lightweight Access Point Protocol (LWAPP) controller. A sample of a phone client's cell edge dBm values for 802.11g and 802.11a are shown in Figure 9-7 and Figure 9-8. The call stream statistics are shown in Figure 9-9. The stream metrics can be viewed on the WCS after the voice metrics are enabled. The path to enable the metrics is Configure > Controller > ipaddress > 802.11bg > Voice Parameters > Enable Voice Metrics.

Figure 9-7 11g Client Statistics

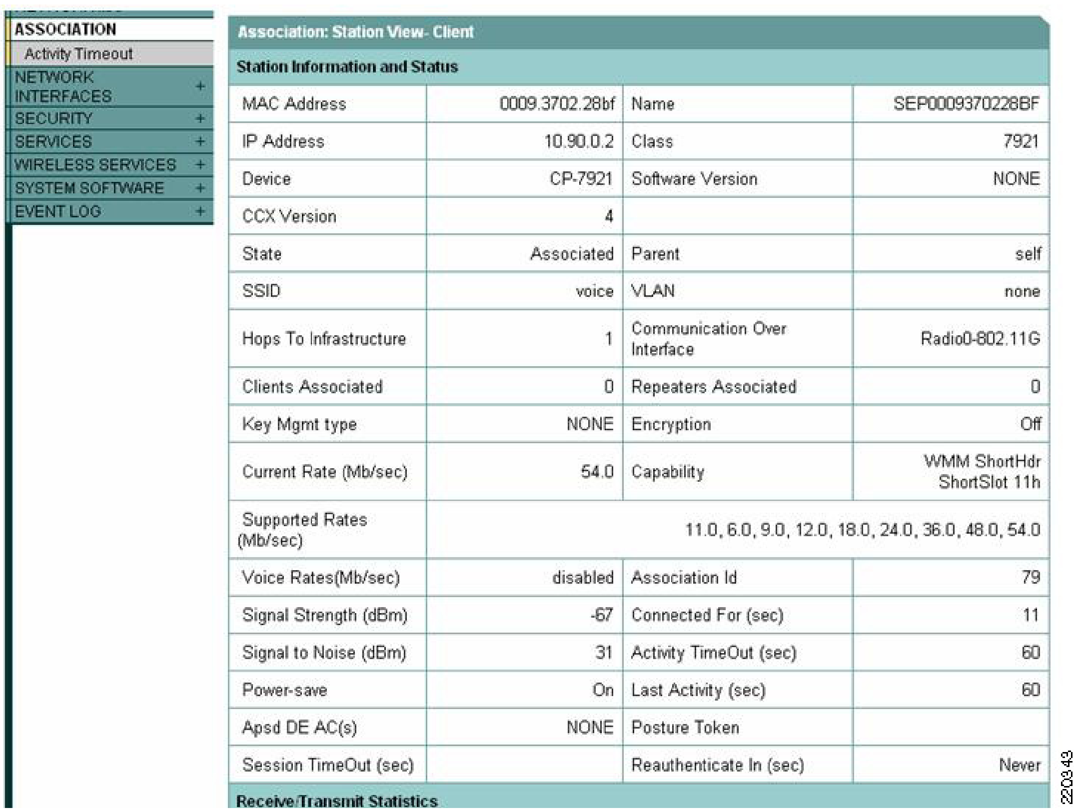


Figure 9-8 11a Client Statistics

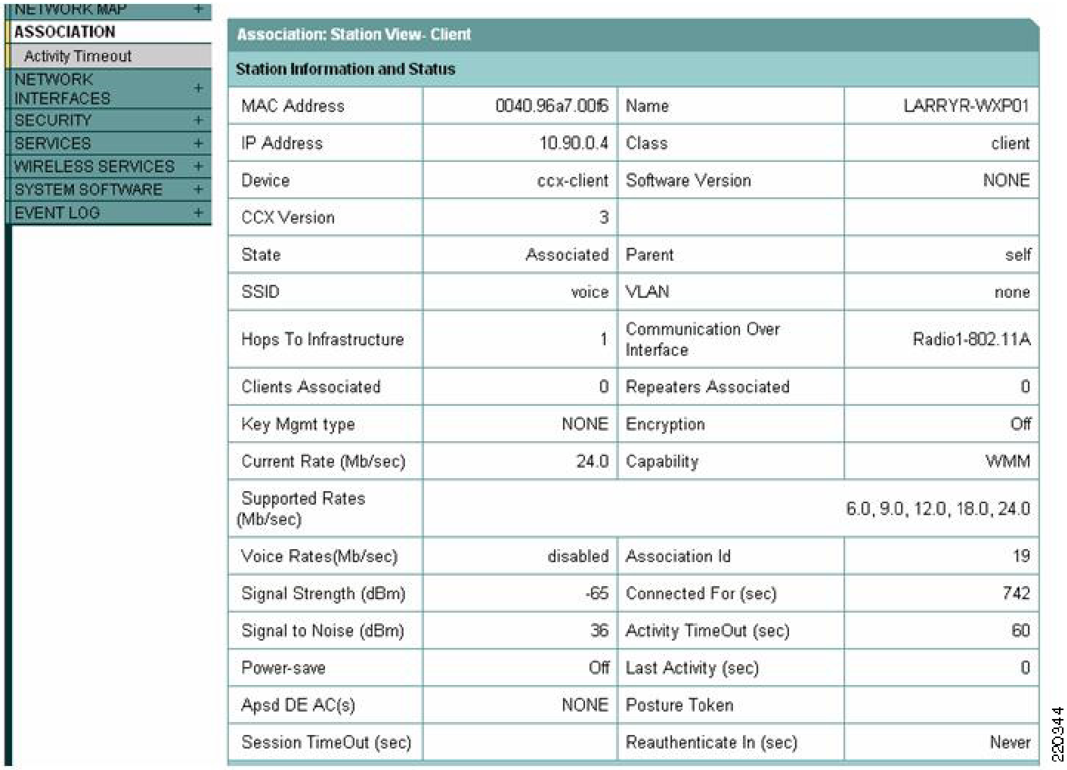
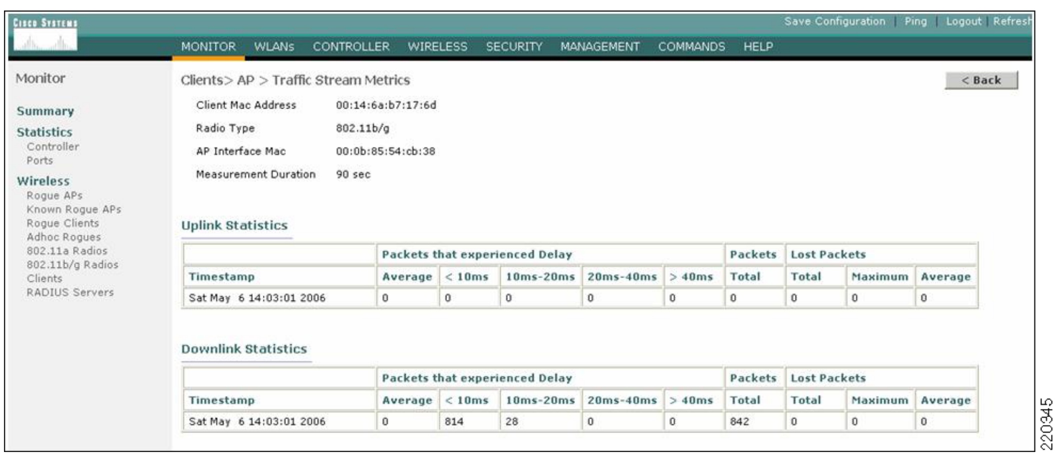
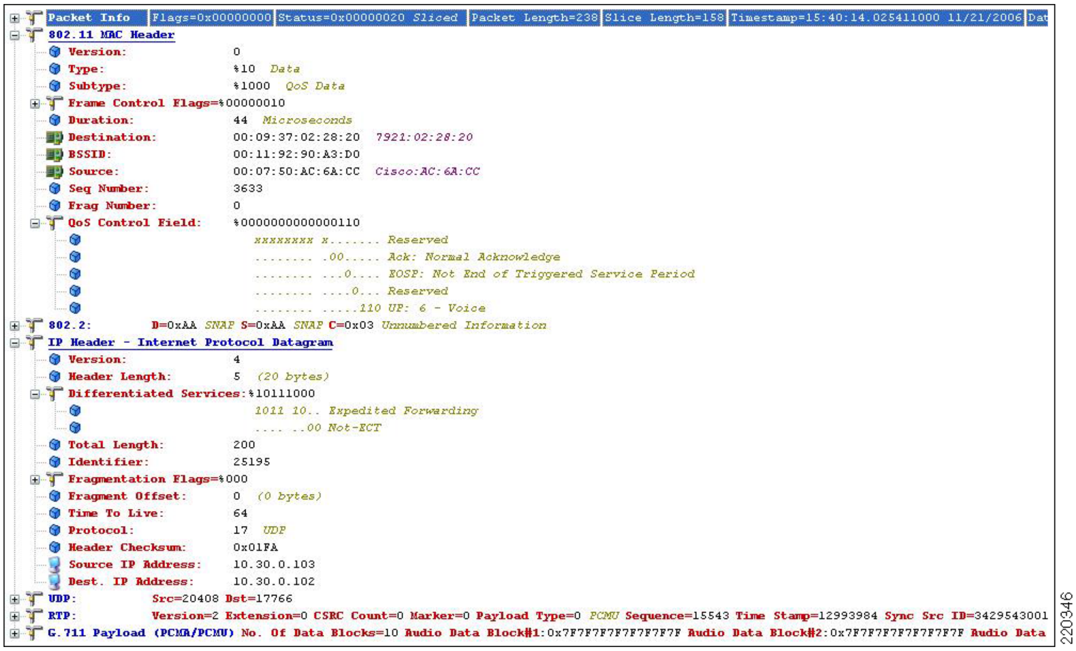


Figure 9-9 WLC Call Metrics



A decoded RTP packet is shown in Figure 9-10. The packet is originated by a 7960 phone. The over-the-air QoS marking is changed from the QoS baseline marking of 5 to a user priority of 6, which follows the 802.11e specification. Call statistics on the Cisco 7920 and 7921 phones can be viewed on the phone or by browsing into the phone using the IP address of the phone. After that cell edge is determined by testing with an actual phone, those numbers can then be adapted, using more automated tools, to complete the coverage design for the site.

Figure 9-10 Sample VoWLAN Capture



When multipath interference is present at a location where signal level measurements are being taken, it is quite likely that the reported values will fluctuate from packet to packet. A packet may be as much as 5 dB higher or lower than the previous packet. It may take several minutes to obtain an average value for a given measurement location.

AP Call Capacity

A key part of the planning process for a VoWLAN deployment is to plan the number of simultaneous voice streams per AP. When planning the voice stream capacity of the AP, consider the following points:

Note A call between two phones associated to the same AP counts as two active voice streams.

- The utilization of an unlicensed (shared) 802.11 channel is the real determinant for the number of simultaneous voice streams an AP may carry.
- Because the channel utilization and AP performance determine the number of voice streams, same channel and next channel separation are very important. Two APs in the same location, operating on the same channel do not provide double the number of voice streams. In fact, there can be fewer voice streams than one AP would provide.
- Cell capacity or bandwidth determines the number of voice streams that can be simultaneously conducted.
- The handset QoS features supported in the handsets and VoWLAN deployment should be considered.

- Various handsets have different WLAN QoS features and capabilities that impact the features that are enabled in the WLAN deployment, and ultimately determine the per-AP call capacity of the AP. Most VoWLAN handsets provide guidance on the number of calls per AP supported by that phone; this should be considered a best case figure for situations where the handset is able to use its optimal QoS features and has full access to the channel capacity.

The actual number of voice streams a channel can support is highly dependent on a number of issues, including environmental factors and client compliance to WMM and the Cisco Compatible Extension specifications. Figure 9-11 shows the Cisco Compatible Extension specifications that are most beneficial to call quality and channel capacity. Simulations indicate that a 5 GHz channel can support 14–18 calls. This means a coverage cell can include 20 APs, each operating on different channels, with each channel supporting 14 voice streams. The coverage cell can support 280 calls. The number of voice streams supported on a channel with 802.11b clients is 7; therefore, the coverage cell with three APs on the three non-overlapping channels supports 21 voice streams.

Figure 9-11 Cisco Compatible Extension VoWLAN Features

How Cisco Compatible Extensions Benefits VoWLAN Call Quality	
Feature	**Benefit**
CCKM Support for EAP-Types	Locally Cached Credentials Means Faster Roams
Unscheduled Automatic Power Save Delivery (U-APSD)	More Channel Capacity and Better Battery Life
TSPEC-Based Call Admission Control (CAC)	Managed Call Capacity for Roaming and Emergency Calls
Voice Metrics	Better and More Informed Troubleshooting
Neighbor List	Reduced Client Channel Scanning
Load Balancing	Calls Balanced Between APs
Dynamic Transmit Power Control (DTPC)	Clients Learn a Power to Transmit At
Assisted Roaming	Faster Layer 2 Roams

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Figure 9-11 shows the following:

- Cisco Centralized Key Management (CCKM) provides for faster client roaming for Extensible Authentication Protocol (EAP)-authenticated client, which benefits call quality.
- Call Admission Control (CAC) also benefits call quality and can create bandwidth reservation for E911 and roaming calls.
- Assisted Roaming and Neighbor List benefit call quality and battery life.
- Voice Metrics can benefit management.
- Unscheduled Automatic Power Save Delivery (U-APSD) and Dynamic Transmit Power Control (DTPC) benefit battery life.
- Load balancing and DTPC benefit call quality.

Several of the Cisco Compatible Extensions features have more than one benefit.

The amount of buffer memory, CPU speed, and radio quality are key factors of the performance of an AP radio. QoS features prioritize the voice and data traffic in the channel. For a further discussion of QoS, see Chapter 5, "Cisco Unified Wireless QoS."

The 802.11e, WMM, and Cisco Compatible Extension specifications help balance and prevent the overloading of a cell with voice streams. CAC determines whether there is enough channel capacity to start a call; if not, the phone may scan for another channel. The primary benefit of U-ASPD is the preservation of WLAN client power by allowing the transmission of frames from the WLAN client to trigger the forwarding of client data frames that are being buffered at the AP for power saving purposes. The Neighbor List option provides the phone with a list that includes channel numbers and channel capacity of neighboring APs. This is done to improve call quality, provide faster roams, and improve battery life.

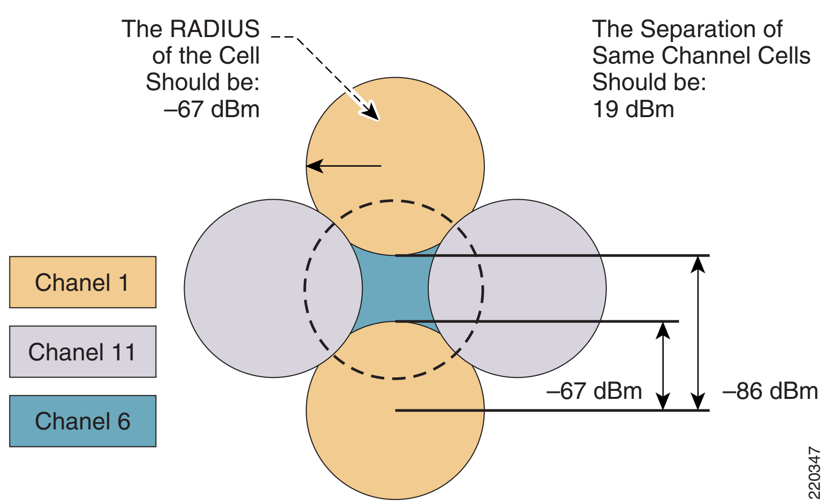
For a further discussion of U-APSD and CAC, see Chapter 3, "WLAN Radio Frequency Design Considerations."

Cell Edge Design

Guidelines for deploying 802.11b/g/a VoWLAN handsets recommend a design where a minimum power of -67 dBm is present at the cell boundary (see Figure 9-12). This practice creates cell sizes that are smaller than those used in data WLAN designs of the past. The -67 dBm threshold is a general recommendation for achieving a packet error of one percent, which requires an SNR value of 25 dB or greater (local noise conditions impact this requirement). Therefore, when determining the likely channel coverage area for a particular phone type, both signal strength and noise, measured at the phone, must be verified using the client statistics offered through the AP. See Figure 9-8 and Figure 9-11 for determining these values on the standalone and LWAPP APs.

The -67 dBm signal strength measurement has been used by 802.11b phone vendors for a number of years, and tests indicate that this same rule of thumb measurement also works well for 802.11g and 802.11a phone clients.

Figure 9-12 Cell Edge Measurements



Note The -86 dBm separations shown in Figure 9-12 is simplified and is considered ideal. It is very unlikely that this 19 dBm of separation can be achieved in most deployments. The most important RF design criteria are the -67 dBm cell radius, and the 20 percent recommended overlap between cells. Designing to these constraints optimizes channel separation.

For 5 GHz cells, there is less concern about same channel separation because of the number of available channels. There are 20 channels in 802.11a, so a two-channel separation is almost always possible, in contrast to the 2.4 GHz band where there are only three channels that do not overlap in frequency.

For both 5 GHz and 2.4 GHz, the cell edge needs to be at the floor level where a packet error rate of 1 percent is maintained at the highest data rate desired for a given channel. In the case of 802.11b, that data rate is 11 Mbps. Thus, from the center of the AP location to a point on the floor where the phone signal is seen by the AP, the cell edge is -67 dBm.

802.11g and 802.11a phone clients may be capable of rates up to 54 Mbps. Current chip sets support 54 Mbps, but transmit power capabilities do differ. Cisco highly recommends that all links between phone clients and APs be established using matching transmit power levels. (see Dynamic Transmit Power Control, page 9-14).

Coverage cells can be created for specific data rates. For a high density deployment or a deployment where a large number of calls are required within a small floor space, 802.11a is recommended because of the number of channels and the 54 Mbps data rate. The lower data rates in 802.11a can be disabled, the 24 Mbps data rate can be set to “required”, while the rates of 36 to 54 can be left enabled.

After setting the cell edge of -67 dBm, determine where the error rate of 1 percent occurs, and then examine the SNR value.

The -67 dBm cell edge may be determined as follows:

- Set the phone to its desired transmit power.
- Set the AP to a matching transmit power.
- Place the AP and the desired antenna in the location where the phone will be used.
- With an active call, or while sending and receiving packets equal in size to the G711 codec, measure the signal level out to the –67 dBm cell edge.

Carefully examine the data sheets of the particular phone device to determine the transmit power levels and data rates supported by the phone device in a particular Wi-Fi band. The data sheets for Cisco Unified Wireless IP Phones can be found at http://www.cisco.com/en/US/products/hw/phones/ps379/index.html. Consult the vendor website for phones from other vendors.

The 80211a maximum transmit power levels vary on different channels and with different AP models. The 802.11g maximum transmit power levels vary by model. Cisco Aironet AP data sheets should be carefully examined to determine which AP model supports which data rates. Figure 9-13 shows an example of the maximum 802.11a transmit power in dBm by channel.

Figure 9-13 Channel Power Assignment

5GHz	UNII-1				UNII-2				UNII-3			
Channel	36	40	44	48	52	56	60	64	149	153	157	161
Max Tx Power	11	11	11	11	11	17	17	17	17	17	14	11

New UNII-II							
100	104	108	112	116	132	136	140
11	17	17	17	17	17	17	17

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The maximum permissible transmit power across the 5 GHz band varies by as much as 6 dB. This means that when using the maximum allowed transmit power throughout a site that allows all channels, there will not be equal cell coverage on all channels. It also means that if dynamic channel selection is used, the cell coverage edge may change based on the channel number. However, dynamic channel selection can be tuned (see Chapter 3, "WLAN Radio Frequency Design Considerations.") The default mode of dynamic channel selection accounts for the difference of maximum transmit power level by channel.

Cell transmit power on all APs should not exceed the maximum or desired transmit power of the phone. If the phones maximum or set transmit power is 13 dBm, Cisco recommends that all APs have a maximum transmit power of 13 dBm. Therefore, the maximum transmit power on the AP should be set to an equal level or, if not possible, the next higher transmit power level. Equal transmit power is recommended to avoid one-way audio. The AP generally has better receiver sensitivity and diversity support than the phone, so it should be able to receive the slightly lower strength phone signal. See Dynamic Transmit Power Control, page 9-14 for more information on equal transmit powers.

Dual Band Coverage Cells

Chapter 3, "WLAN Radio Frequency Design Considerations," illustrates 2.4 GHz and 5 GHz band channel coverage design. For a dual mode AP to provide equal cell coverage on both the 2.4 GHz channel and the 5 GHz channel, the 2.4 GHz channel must have an equal (or more likely lower) transmit power than the 5 GHz channel. At most sites, the noise level in the SNR formula will be lower by perhaps 10 dB. The receiver sensitivity of 802.11g radios is generally 2 dBm better than the same data rate on the 11a radio. As an example, the data sheet for the 7921G has the receive sensitivity of -78 dBm at the data rate of 36 Mbps for 802.11g, and -76 dBm for 802.11a. Therefore, given the anticipated better noise floor of 10 dB, the 802.11a cell can do better by 8 dBm. Other details such as the difference in path loss between 802.11g and 802.11a keep this from being a direct ratio. However, if the same coverage cells are desired, reducing the 802.11g network by one or two power levels from the 11a network should accomplish this goal.

Dynamic Transmit Power Control

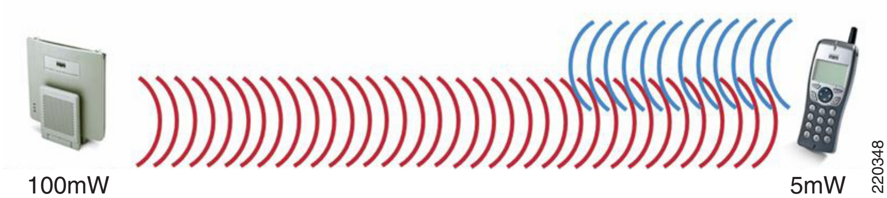
Cisco Aironet APs by default have DTPC enabled. DTPC is automatic with Wireless LAN Controllers and is configurable on the standalone APs. Clients need to support a minimum of Cisco Compatible Extension v2 capabilities to use DTPC.

DTPC accomplishes the following:

- Sets the phones transmit power to match the transmit power of the AP
- The AP advertises its transmit power for the clients to learn
- Prevents one-way audio; that is, RF traffic is only being heard in one direction

DTPC allows the phone to automatically adjust its transmit power to that of the APs. In the example shown in Figure 9-14, this means that the phone changes its transmit from 5 mW to 100 mW.

Figure 9-14 Client and AP Power Matching

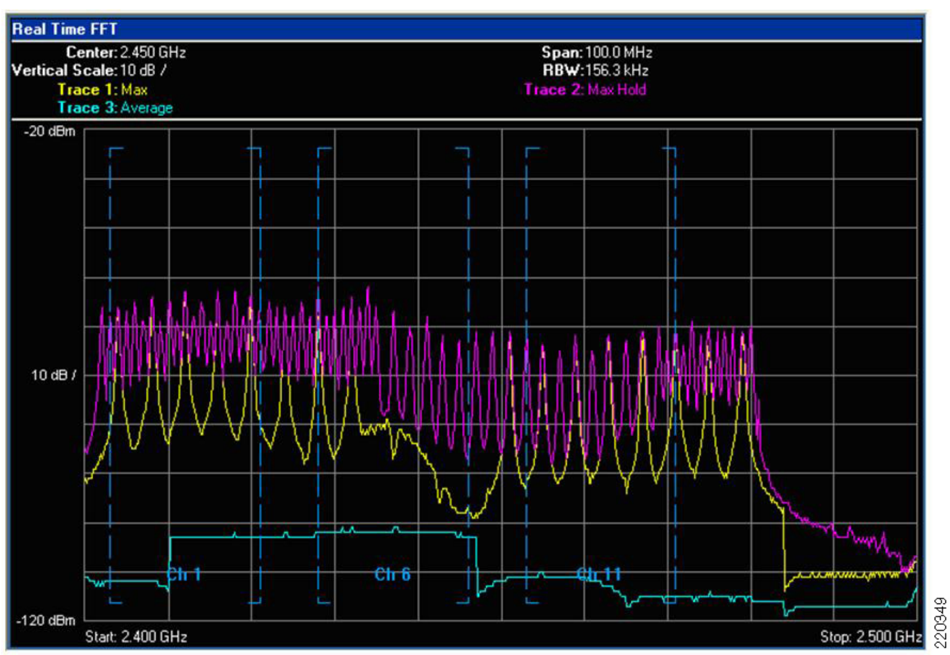


The licensing requirements of 802.11g and 802.11a mean that clients do not have 100 mW transmit powers. Cisco highly recommends that the maximum configured transmit power on the access be no higher than the client phone devices hardware supports. A phone with a slightly lower transmit power than the AP is better than the AP using less power than the phone, but having matching transmit powers lessens the likelihood of one-way audio (the typical user experience of "can you hear me…. I can't hear you").

Interference Sources Local to the User

Interference can be local to the user, but is also likely to affect nearby users. Bluetooth (BT) is a popular RF protocol used in personal area networks that interferes with Wi-Fi 2.4 GHz channels. Figure 9-15 shows that the actual BT signal does span all the 2.4 GHz channels used by 802.11b/g clients. This graphic is taken from an 802.11g call with a BT headset linked to the phone. Figure 9-16 also shows the jitter caused by the BT headset.

Figure 9-15 Bluetooth (BT) Signal Pattern in the 802.11b/g 2.4 GHz Spectrum of a Typical BT Earpiece

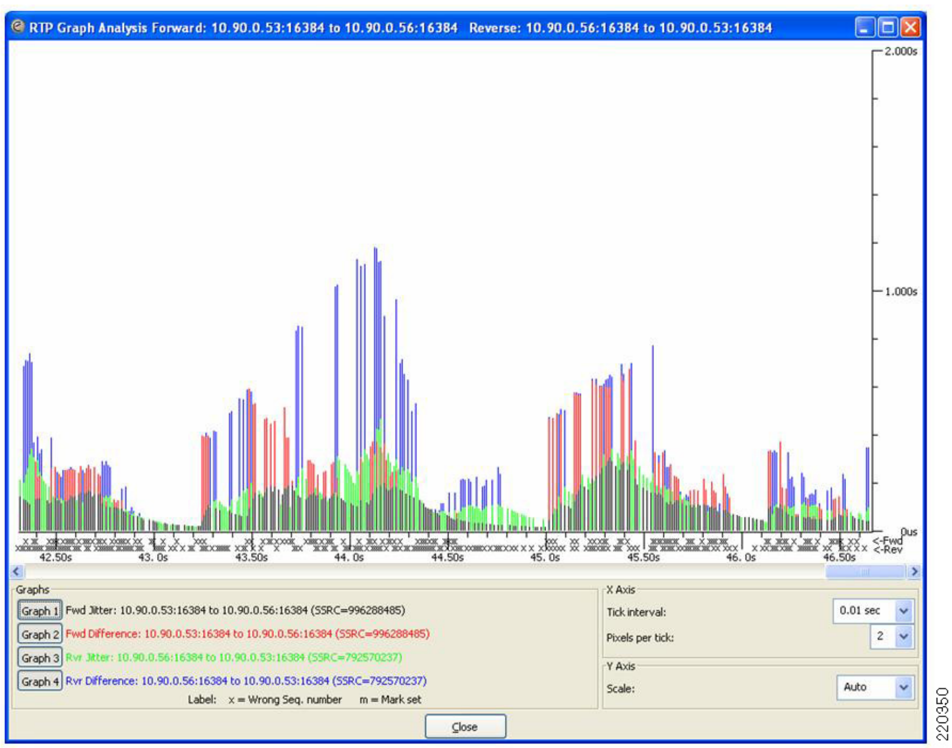


The **PINK** is the Max Hold line, or the line that shows the maximum transmit power that was reached during the test. The **YELLOW** shows the maximum transmit power in the last sample period of ten seconds. The **TURQUOISE** shows the average transmit power over the period of the test. The **vertical dashed** lines separate the three non-overlapping 802.11b/g channels **Ch1, Ch6,** and **Ch11.** The charting is from 2.400 GHz on the left to 2.500 GHz on the right. From the right edge of the Ch11 vertical blue line is the part of the 802.11 spectrum used in Europe and Japan. This capture was done with an AP and clients configured for the North American regulatory domain. This graph shows that the BT earpiece was easily transmitting outside of FCC regulations.

Notice that the BT signal is very narrow. BT transmits data on a single MHz of frequency, stops the transmission, moves to another frequency in the 802.11 2.4 GHz band, and then transmits data. This is repeated continually. The 802.11b and 802.11g signals are sent with a combined 22 MHz of frequency. The radio remains on that 22 MHz of frequency. This grouping of 22 MHz is referred to as the channel. The Max Hold line shows how strong the BT is while in search mode. The signal level is above that of a 50 mW (17 dBm) OFDM 802.11g radio. A signal of this strength and duration causes 802.11b/g phones to drop the VoWLAN call. Lesser strength BT signals cause jitter, resulting in a lower MOS value.

Figure 9-16 shows an example of an Ethereal jitter analysis of three simultaneous phone calls, each using a BT earpiece.

Figure 9-16 Jitter Analysis Example



All three calls were on the same AP, and were calls to other phones on this AP.