TOMORROW starts here.

Understanding RF Fundamentals and the Radio Design of Wireless Networks

BRKEWN-2017

Matt Fowler
Consulting Systems Engineer
CCIE Wireless #25725

Session Abstract

This session focuses on understanding the often overlooked Radio Frequency part of designing and deploying a Wireless LAN Network.

It discusses 802.11 radio, MIMO, APs and antennas placements, antenna patterns...

It covers the main environments such as carpeted offices, campuses and conference centres, and it provides feedback based on lessons learned from challenging deployments such as outdoor/stadium/rail deployments and manufacturing areas.

Session Agenda – Objectives

- What is radio and how did we get here?
- Basic 802.11 Radio Hardware & Terminology
- Antenna Basics – Single, Dual Band and MIMO Antennas
- Interpreting antenna patterns – Cisco/Aironet Richfield Ohio Facilities
- Understanding fundamentals of, Beamforming and Cisco ClientLink
- Basic understanding of 802.11n and 802.11ac fundamentals including MIMO, Channel bonding, Multi-path, Spatial Streams and Multiplexing…
- Installation challenges, when to use different APs – avoiding potential problems

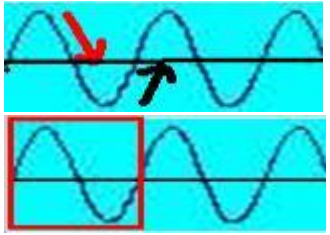



What is Radio?
How did we end up on these Frequencies?

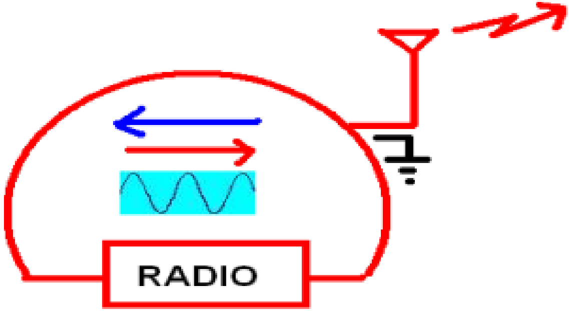
Basic Understanding of Radio…

Battery is **DC**
Direct **C**urrent

Typical home is **AC**
Alternating **C**urrent



AC Frequency 60 Hz or 60 CPS – Cycles Per Second



Waves travel back and forth so fast they actually leave the wire

How fast the AC current goes, is its “frequency”
AC is very low frequency 50-60 Hz (Cycles Per Second)

Radio waves are measured in kHz, MHz and GHz

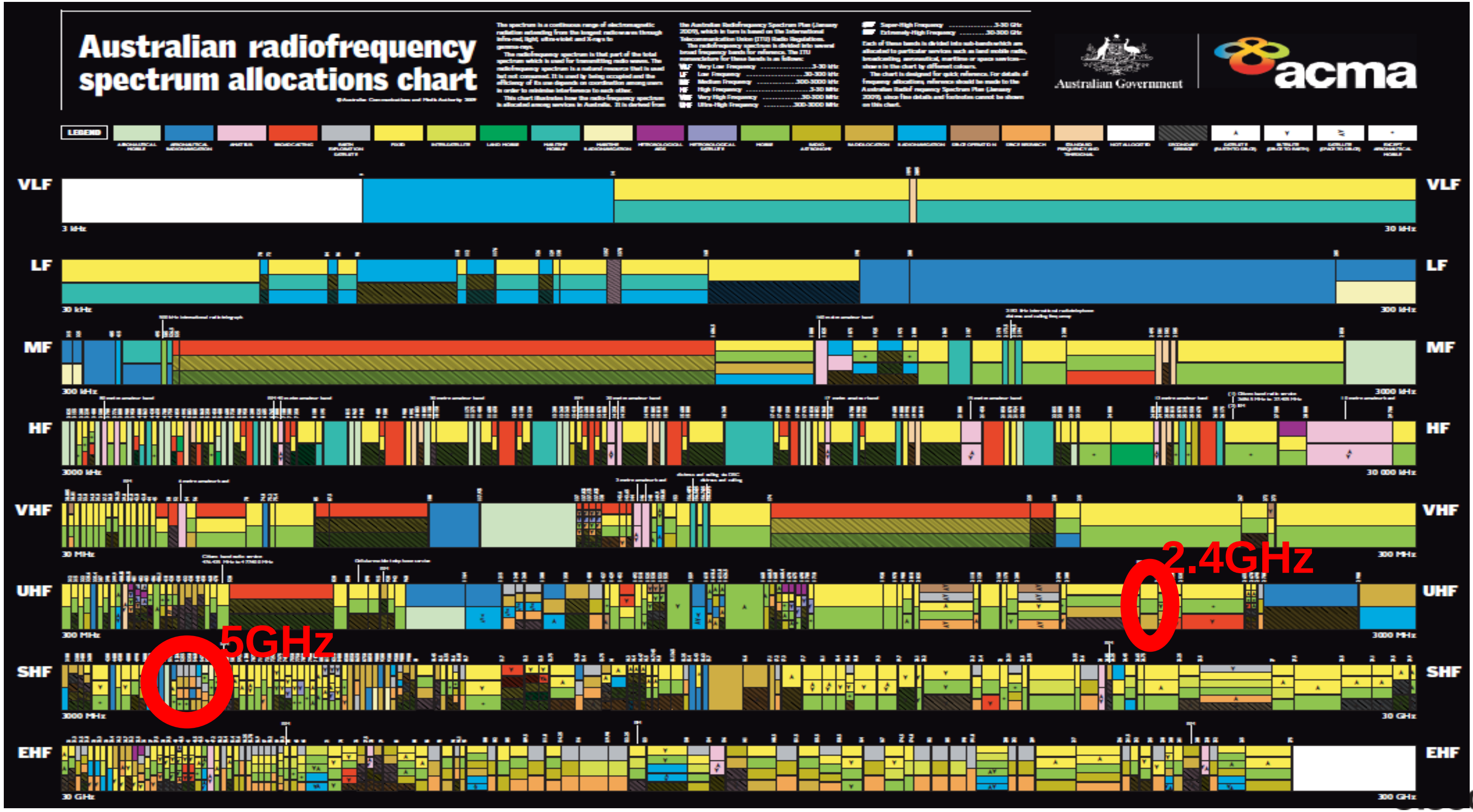
The lower the frequency, the physically longer the radio wave – Higher frequencies have much shorter waves, and as such, it takes more power to move them greater distances.
This is why 2.4 GHz goes further vs. 5 GHz
(given same amount of RF power).

Popular Radio Frequencies:

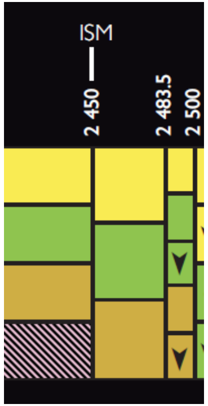
AM Radio 520-1610 KHz
Shortwave 3-30 MHz
FM Radio 88 to 108 MHz
Aviation   108-121 MHz
Weather Radio 162.40 MHz
GSM Phones 900 & 1800 MHz
DECT Phones 1900 MHz
Wi-Fi 802.11b/g/n 2.4 GHz
Wi-Fi 802.11a/n   5 GHz

Spark transmitter

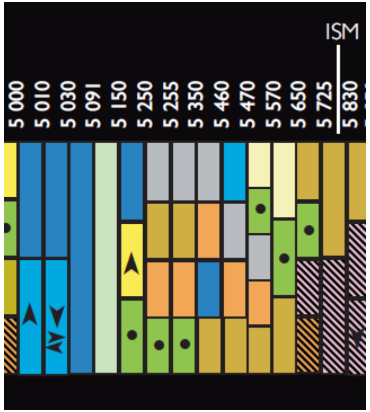
The Radio Spectrum in Australia



Wi-Fi Radio Spectrum



2.4 GHz



5 GHz

Wi-Fi is an "unlicensed" service

It has beginnings in the ISM (industrial Scientific Medical) band where it was not desirable or profitable to license such short range devices.

The first frequencies available for Wi-Fi use were in the 2.4 GHz range

As Wi-Fi popularity and usage increased, the regulatory bodies allocated additional spectrum in the 5 GHz band.

The spectrum we use today is also used by Amateur (Ham Radio) and other services such as radio location (radar).

There is more bandwidth in 5 GHz with mechanisms in place to co-exist with licensed services such as radar using Dynamic Frequency Selection

Wi-Fi Radio Spectrum 2.4 GHz

Even today, many portable devices in use are limited to 2.4 GHz only, including newer devices, but this is changing as newer 802.11ac (5-GHz) devices emerge

802.11b/g is 2.4 GHz
802.11a is 5 GHz
802.11n (can be either band) 2.4 or 5 GHz

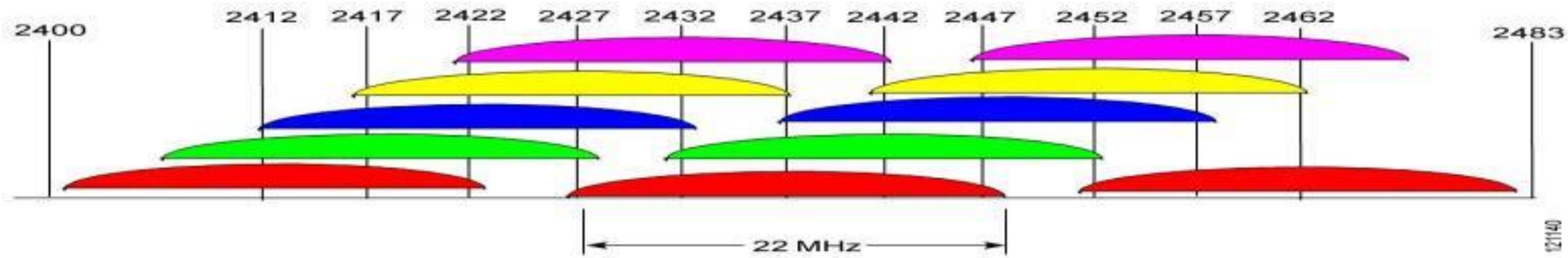
The 2.4 GHz spectrum in the US has 3 non-overlapping channels 1, 6 and 11.

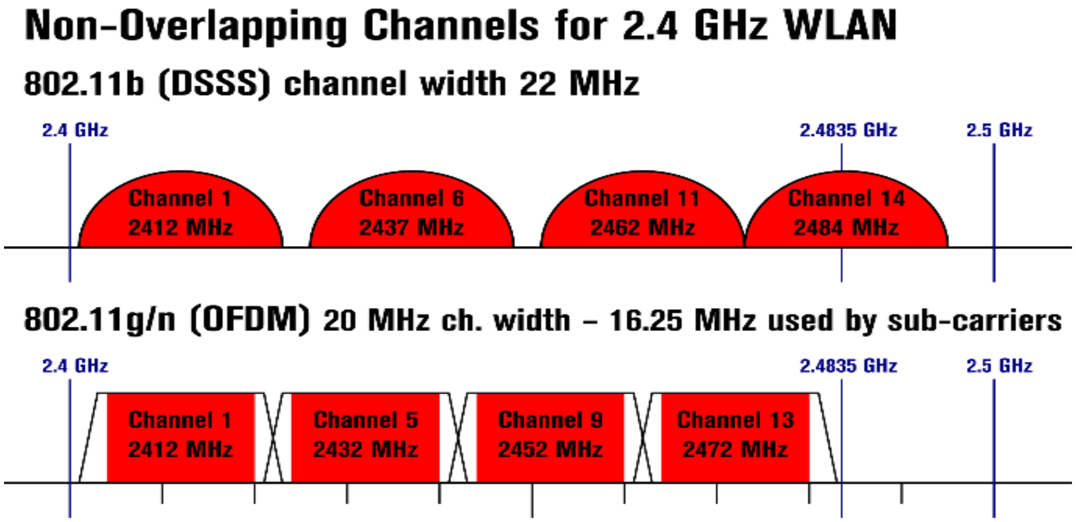
There are plenty of channels in the 5 GHz spectrum and they do not overlap

2.4 GHz and 5 GHz are different portions of the radio band and usually require separate antennas

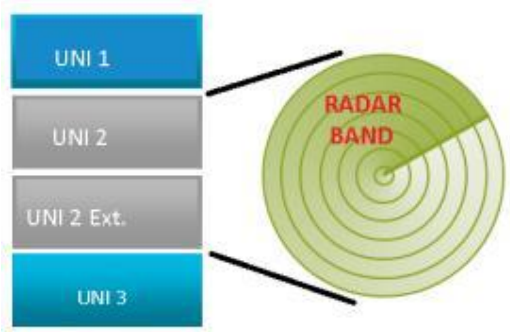
Most, if not all, 5 GHz devices also have support for 2.4 GHz - however there are still many 2.4 GHz only devices.

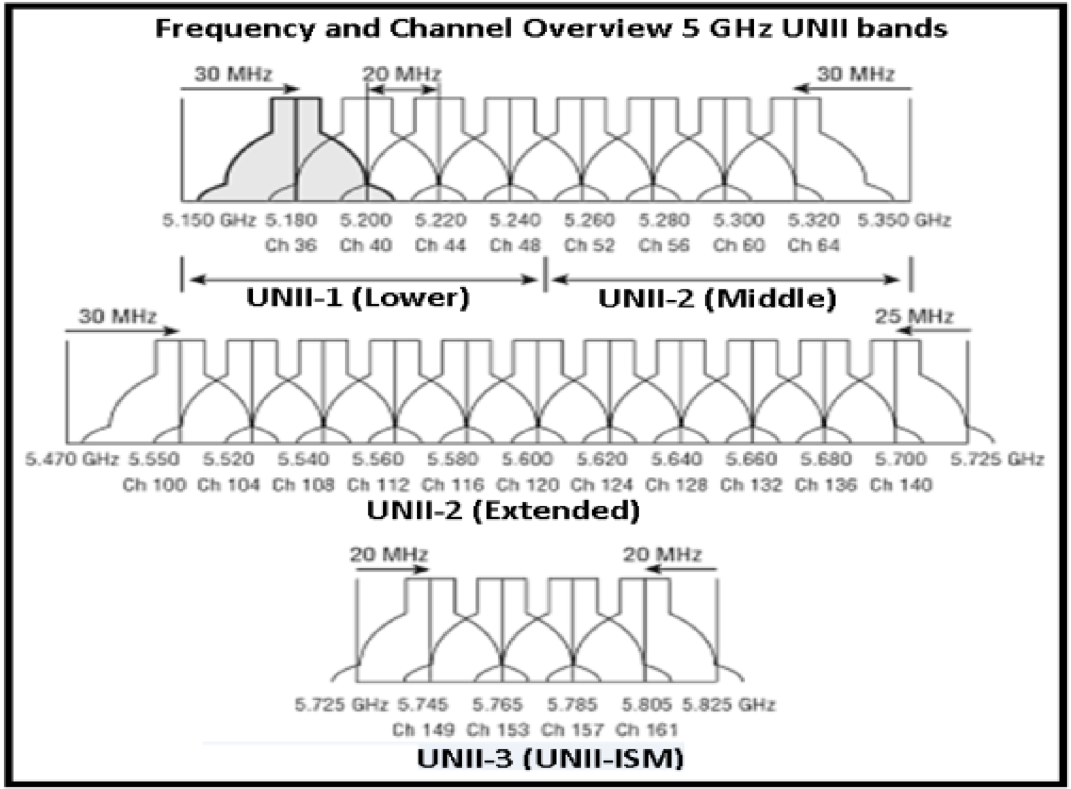
Wi-Fi Radio Spectrum 2.4 GHz





Wi-Fi Radio Spectrum 5 GHz Channels





Note: 5 GHz channels do not have the severe overlap that 2.4 GHz channels have but they use DFS to enable sharing of the band

Dynamic Frequency Selection (DFS) 5 GHz

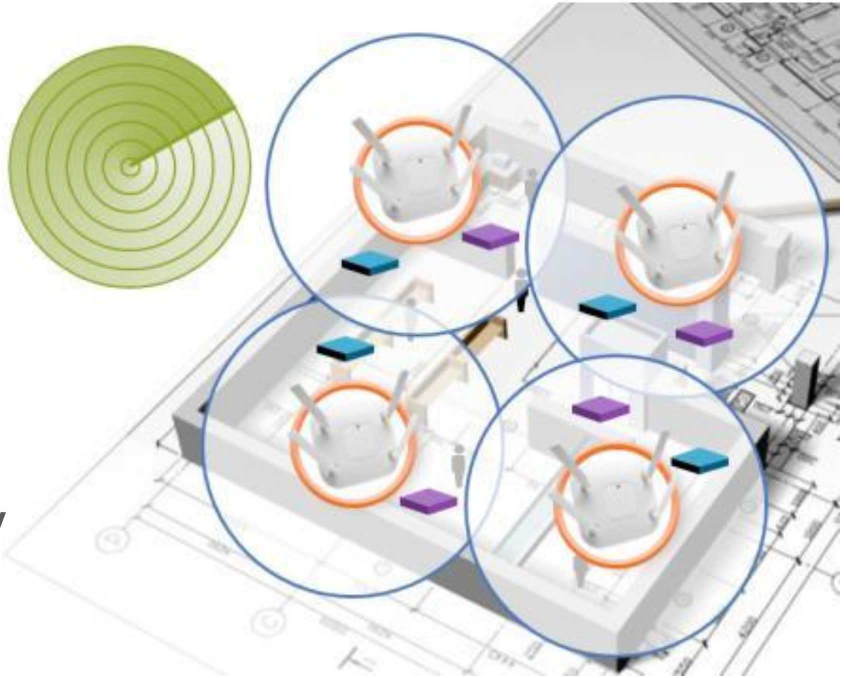
When Radar Signal is Present

Access Points detect radar activity and change channels so as not to cause interference with licensed services who have priority

This can result in lower available channels and loss of some UNI-2 and UNI-2 extended bands.

UNI-1 and UNI-3 bands are outside of the weather radar and do not change.

Radar signals may be present near airports, military bases or large cities



A Radio Needs a Proper Antenna

As the frequency goes up, the radiating element gets smaller

Antennas are identified by colour
Blue indicates 5 GHz
Black indicates 2.4 GHz
Orange indicates Both

Omni-Directional antennas like the one on the left, radiate much like a raw light bulb would everywhere in all directions

Directional antennas like this "Patch" antenna radiate forward like placing tin foil behind the light bulb or tilting and directing the lamp shade

Note: Same RF energy is used but results in greater range as it is focused towards one direction, at the cost of other coverage areas

Antennas are custom made for the frequency to be used. Some antennas have two radiating elements to allow for both frequency bands (2.4 and 5 GHz) in one antenna enclosure.

Complex Modulation Schemes

MCS Index	Number of spatial streams	Modulation
0	1	BPSK
1	1	QPSK
2	1	QPSK
3	1	16-QAM
4	1	16-QAM
5	1	64-QAM
6	1	64-QAM
7	1	64-QAM

Example of 802.11n Modulation Coding Schemes

High-density modulation schemes such as 64-QAM "Quadrature Amplitude Modulation" is used by 802.11n to get additional throughput higher than what is found in 802.11a/b/g. This is one of the advantages of 802.11n

Note: Newer 802.11ac modes can use up to 256-QAM

Radio technology has a lot in common with that old twisted pair phone line that started out at 300 baud and then quickly increased

In order to get faster data rates, (throughput) into the radio signal, complex modulation schemes as QPSK or 64 bit QAM is used.

Generally speaking, the faster the data rate the more powerful the signal needs to be at the receiver end to be properly decoded.

Take-away here is: 802.11n is a method of using special modulation techniques and is *not* specific to a frequency like 2.4 or 5 GHz

802.11n can be used in either band

Basic 802.11 RF Terminology
Hardware Identification

Common RF Terms

For Your Reference

- **Attenuation** – a loss in force or intensity – As radio waves travel in media such as coaxial cable attenuation occurs.
- **BER – Bit Error Rate** - the fraction of bits transmitted that are received incorrectly.
- **Channel Bonding** – act of combining more than one channel for additional bandwidth
- **dBd** – abbreviation for the gain of an antenna system relative to a dipole
- **dBi** – abbreviation for the gain of an antenna system relative to an isotropic antenna
- **dBm** – decibels milliwatt -- abbreviation for the power ratio in decibels (dB) of the measured power referenced to one milliwatt of transmitted RF power.
- **Multipath** – refers to a reflected signal that combines with a true signal resulting in a weaker or some cases a stronger signal.
- **mW** – milliwatt a unit of power equal to one thousandth of a watt (usually converted to dBm)
- **Noise Floor** – The measure of the signal created from the sum of all the noise sources and unwanted signals appearing at the receiver. This can be adjacent signals, weak signals in the background that don't go away, electrical noise from electromechanical devices etc.
- **Receiver Sensitivity** – The minimum received power needed to successfully decode a radio signal with an acceptable BER. This is usually expressed in a negative number depending on the data rate. For example the AP-1140 Access Point requires an RF strength of at least negative -91 dBm at 1 MB and an even higher strength higher RF power -79 dBm to decode 54 MB
- **Receiver Noise Figure** – The internal noise present in the receiver with no antenna present (thermal noise).
- **SNR – Signal to Noise Ratio** – The ratio of the transmitted power from the AP to the ambient (noise floor) energy present.

Identifying RF Connectors

For Your Reference

RP-TNC Connector

Used on most Cisco Access Points

"RP-SMA" Connector

Used on some Linksys Products

"N" Connector

Used on the 15xx Mesh and outdoor APs

"SMA" Connector

"Pig tail" type cable assemblies

Antenna Cables – LMR Series

For Your Reference

This is a chart depicting different types of Microwave LMR Series coaxial cable.

Cisco uses Times Microwave cable and has standardised on two types: Cisco Low Loss (LMR-400)
Ultra Low Loss (LMR-600).

LMR-600 is recommended when longer cable distances are required

Larger cables can be used but connectors are difficult to find and larger cable is harder to install

Trivia: LMR Stands for "Land Mobile Radio"

Some Antenna Cables Characteristics

For Your Reference

LMR®-400 TIMES MICROWAVE SYSTEMS
Flexible Low Loss Communications Coax

Frequency (MHz)	30	50	150	220	450	900	1500	1800	2000	2500	5800
Attenuation dB/100 ft	0.7	0.9	1.5	1.9	2.7	3.9	5.1	5.7	6.0	6.8	10.8
Attenuation dB/100 m	2.2	2.9	5.0	6.1	8.9	12.8	16.8	18.6	19.6	22.2	35.5
Avg. Power kW	3.33	2.57	1.47	1.20	0.83	0.58	0.44	0.40	0.37	0.33	0.21

LMR®-600
Flexible Low Loss Communications Coax

Frequency (MHz)	30	50	150	220	450	900	1500	1800	2000	2500	5800
Attenuation dB/100 ft	0.4	0.5	1.0	1.2	1.7	2.5	3.3	3.7	3.9	4.4	7.3
Attenuation dB/100 m	1.4	1.8	3.2	3.9	5.6	8.2	10.9	12.1	12.8	14.5	23.8
Avg. Power kW	5.51	4.24	2.41	1.97	1.35	0.93	0.70	0.63	0.59	0.52	0.32

Foil shield and braid

LMR-400 3/8 inch
LMR-600 ½ inch

LMR type cable has a Cisco P/N like this…

AIR-CAB-050-LL-R

AIR - Aironet
CAB – Cable
050 - Length
LL - Low Loss (LMR-400)
R - RP-TNC connector




Antenna Basics

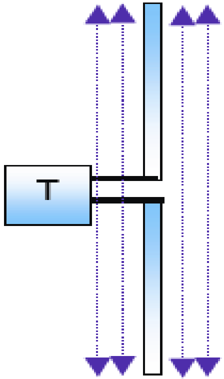
Antenna Basics

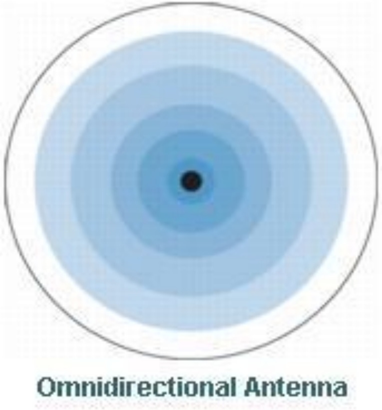
- Antenna - a device which radiates and/or receives radio signals
- Antennas are usually designed to operate at a specific frequency
- Some antennas have more than one radiating element (example Dual Band)
- Antenna Gain is characterised using dBd or dBi
  - Antenna gain can be measured in decibels against a reference antenna called a dipole and the unit of measure is dBd (d for dipole)
  - Antenna gain can be measured in decibels against a computer modeled antenna called an "isotropic" dipole <ideal antenna> and the unit of measure is

    dBi the "i" is for isotropic dipole which is a computer modeled "perfect" antenna
- WiFi antennas are typically rated in dBi.
  - dBi is a HIGHER value (marketing folks like higher numbers)
  - Conventional radio (Public safety) tend to use a dBd rating.
  - To convert dBd to dBi simply add 2.14 so a 3 dBd = 5.14 dBi

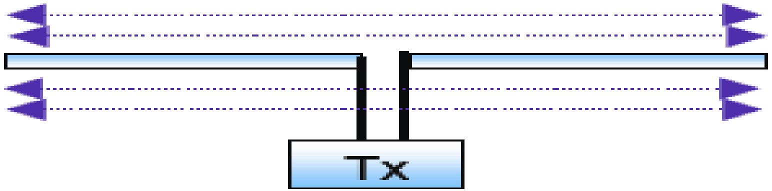
How Does a Omni-Directional Dipole Radiate?

The radio signal leaves the centre wire using the ground wire (shield) as a counterpoise to radiate in a 360 degree pattern



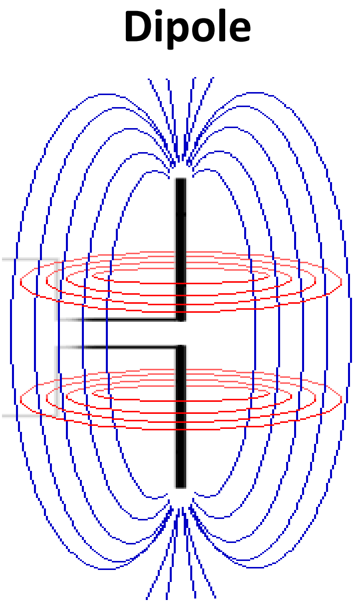


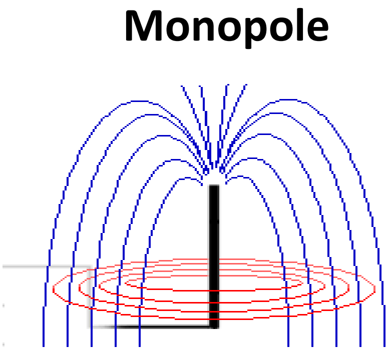
Horizontal Electric Field



Low gain Omni radiates much like a light bulb "360" degrees

Antenna Theory (Dipole & Monopole)



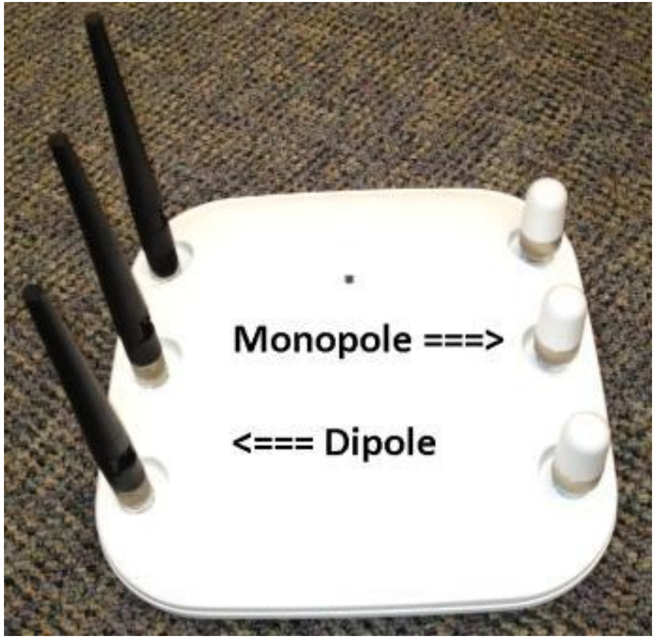


A Monopole requires a ground plane – (conductive surface)

808 Ft Broadcast Monopole WSM 650 AM (erected in 1932)

A dipole does not require a ground plane as the bottom half is the ground (counterpoise).

Antenna Theory (Dipole & Monopole)



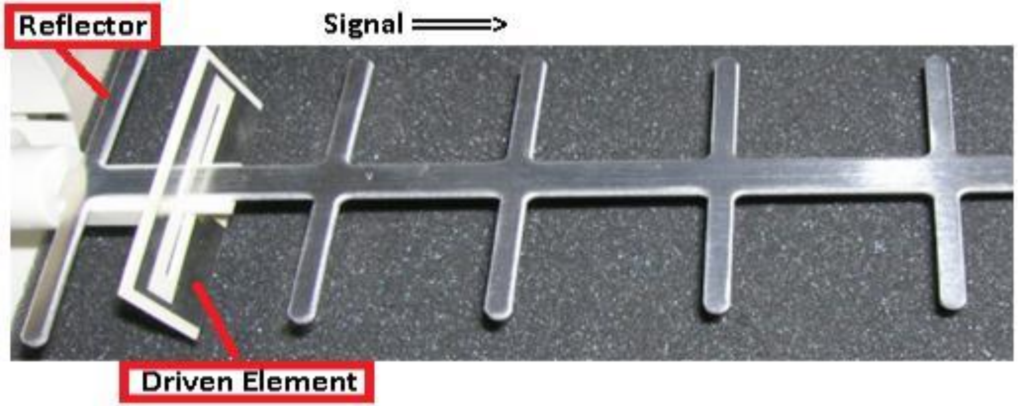
Monopoles were added to our antenna line primarily for aesthetics

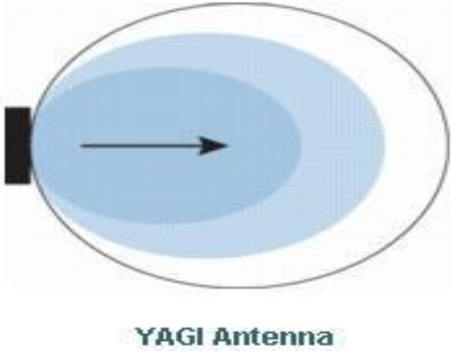
Monopoles are smaller and require a metal surface to properly radiate

How Does a Directional Antenna Radiate?

Although you don't get additional RF power with a directional antenna, it does concentrate the available energy into a given direction resulting in greater range.

Also a receive benefit - by listening in a given direction, this can limit the reception of unwanted signals (interference) from other directions for better performance



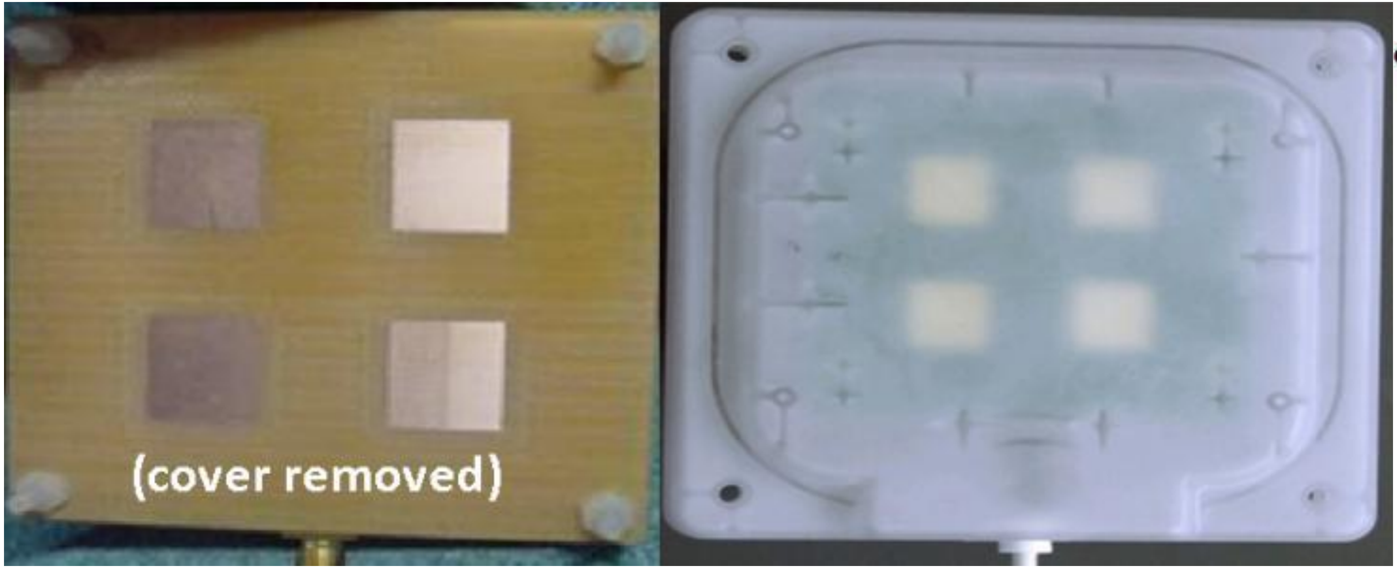


A dipole called the "driven element" is placed in front of other elements. This motivates the signal to go forward in a given direction for gain.

(Inside view of the Cisco AIR-ANT1949 - 13.5 dBi Yagi)

Patch Antenna: a Look Inside

Patch antennas can have multiple radiating elements that combine for gain. Sometimes, a metal plate is used behind the antenna as a reflector for more gain.



Patch and Yagi antennas favor the direction the antenna is pointed – like a flashlight

The 9.5 dBi Patch called AIR-ANT5195-R

Antennas Identified by Colour

For Your Reference

Cisco Antenna Colour Coding

Black indicates 2.4 GHz

Blue indicates 5 GHz

Orange indicates 2.4 & 5 GHz
(used on AP-1600, 2600 @ 3600)

Cisco antennas & cables are colour coded – Black or no markings indicate 2.4 GHz

Most Common Discrete 2.4 GHz Antennas

For Your Reference

Antenna	Description
	**AIR-ANT4941** 2.2 dBi Swivel-mount Dipole; most popular mounts directly to radio, low gain, indoor
	**AIR-ANT5959** 2 dBi Diversity Ceiling-mount Omni
	**AIR-ANT1729** 6 dBi Wall-mount Patch
	**AIR-ANT1728** 5.2 dBi Ceiling-mount Omni
	**AIR-ANT2452V-R** 5.2 dBi Diversitv Pillar-mount Omni

Single element antennas have one cable

Diversity antennas have two cables

MIMO (802.11n) can have three or more cables

Most Common Discrete 5 GHz Antennas

For Your Reference

Antenna	Description
	AIR-ANT5135D-R 3.5 dBi Omni-directional Antenna; Mounts directly to radio, low gain, indoor
	AIR-ANT5145V-R 4.5 dBi Omni-directional Diversity Antenna; unobtrusive, ceiling mount, low gain, indoor
	AIR-ANT5160V-R 6 dBi Omni-directional Antenna Ceiling or mast mount, indoor/outdoor
	AIR-ANT5170P-R 7 dBi Patch Diversity Antenna Directional, small profile, wall mount, indoor/outdoor
	AIR-ANT5195-R 9.5 dBi Patch Antenna; Directional, small profile, wall mount, indoor/outdoor

Single element antennas have one cable

Diversity antennas have two cables

MIMO (802.11n) can have three or more cables

Guide to Antenna Part Numbers

For Your Reference

Understanding Cisco Antenna Part Numbers

AIR – Aironet product line
ANT – Antenna
24xx – 2.4 GHz
50xx – 5.0 GHz
N – At least three antenna elements (802.11n)
P – Patch (usually directional)
V – Vertical (polarity usually Omni)
D – Dipole
DW – Dipole White
R – RP-TNC connector (indoor / outdoor FCC custom connector)
N – "N" type connector (usually outdoor or professional install)

When possible we try to put the gain in as well as in this example:
AIR-ANT2452V-R is a AIRonet ANTenna 2.4 GHz 5.2 dBi Vertical with RP-TNC
Note an "=" at the end indicates a replacement (single item) part number

Most Common 802.11n Antennas

Indoor Access Points (1262 and 3502e) <First Generation AP’s>

For Your Reference

These are Single Radiating Element antennas designed for Access Points that have single band 2.4 or 5 GHz connectors (black or blue colour)

Product ID	Description	Gain
AIR-ANT2451NV-R=	2.4 GHz 3 dBi/5 GHz 4 dBi 802.11n dual band omni antenna (6)	3 dbi / 4 dBi
AIR-ANT2460NP-R=	2.4 GHz 6 dBi 802.11n directional antenna (3)	6 dBi
AIR-ANT5160NP-R=	5 GHz 6 dBi 802.11n directional antenna (3)	6 dBi
AIR-ANT2422SDW-R=	2.4 GHz 2.2 dBi Short white dipole antenna (1)	2.2 dBi
AIR-ANT5135SDW-R=	5 GHz 3.5 dBi Short white dipole antenna (1)	3.5 dBi
AIR-ANT2450NV-R=	2.4 GHz 5 dBi 802.11n Omni wall mount antenna (3)	4 dBi
AIR-ANT5140NV-R=	5 GHz 4 dBi 802.11n Omni wall mount antenna (3)	4 dBi

Note: do *NOT* use on units with ORANGE label (1600, 2600 & 3600)

Most Common 802.11n Antennas

Indoor Access Points (1600, 2600 & 3600) <2nd Generation AP's>

For Your Reference

These are Dual Radiating Element antennas (use with Orange labels)

Product ID	Description	Gain
AIR-ANT2524DB-R AIR-ANT2524DB-R=	2.4 & 5 GHz -- Dual Band Dipole Dipole Ant., Black, RP-TNC connector (1)	2 dBi (2.4 GHz) 4 dBi (5 GHz)
AIR-ANT2524DG-R AIR-ANT2524DG-R=	2.4 & 5 GHz – Dual Band Dipole Dipole Ant., Gray, RP-TNC connector (1)	2 dBi (2.4 GHz) 4 dBi (5 GHz)
AIR-ANT2524DW-R AIR-ANT2524DW-R=	2.4 & 5 GHz – Dual Band Dipole Dipole Ant., White, RP-TNC connector (1)	2 dBi (2.4 GHz) 4 dBi (5 GHz)
AIR-ANT2566P4W-R=	2.4 & 5 GHz – Dual Band Directional (Patch) Directional Ant., RP-TNC connectors (4)	6 dBi (2.4 GHz) 6 dBi (5 GHz)
AIR-ANT2524V4C-R=	2.4 & 5 GHz – Dual Band Ceiling Mount Ceiling Mount Omni Ant., RP-TNC connectors (4)	2 dBi (2.4 GHz) 4 dBi (5 GHz)
AIR-ANT2544V4M-R=	2.4 & 5GHz – Dual Band Wall Mount Omni Wall Mount Omni Ant., RP-TNC connectors (4)	4 dBi (2.4 GHz) 4 dBi (5 GHz)

Use on antennas with Orange label *if using (1600) only use 3 antennas (4th unused)

Cisco live!

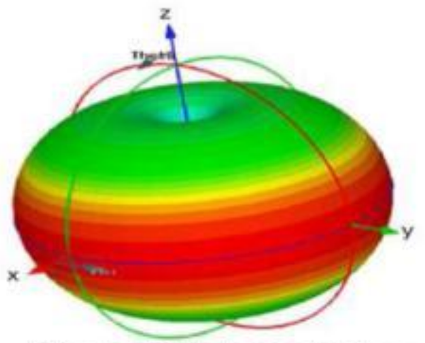



Understanding and Interpreting Antenna Patterns

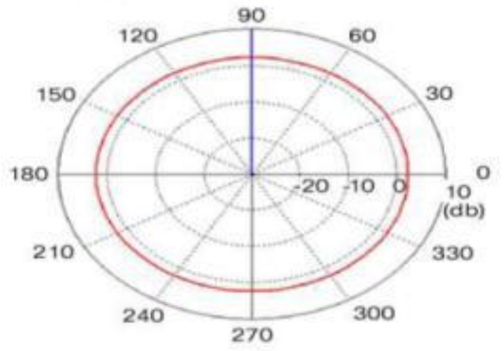
Understanding Antenna Patterns

Dipole (Omni-Directional)

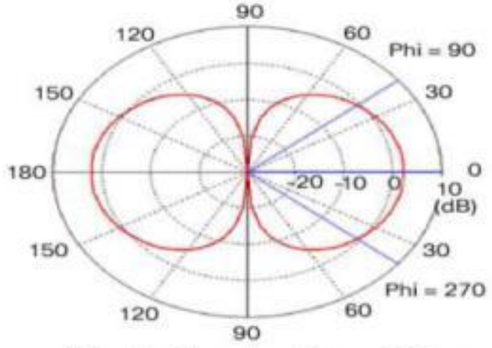
Dipole Antenna Model



Dipole 3D Radiation Pattern



Dipole Azimuth Plane Pattern

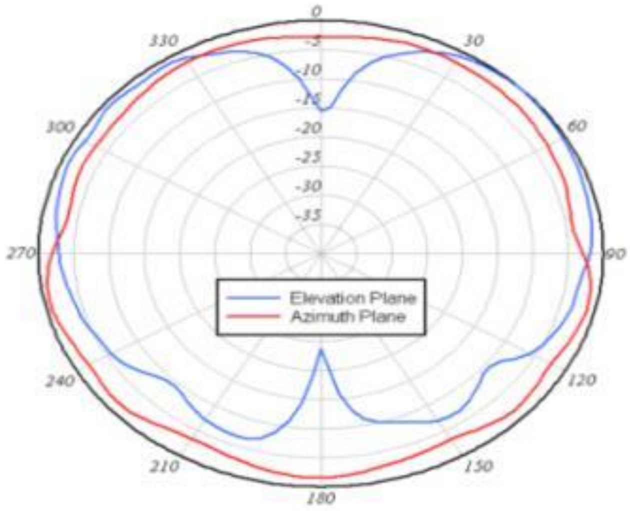


Dipole Elevation Plane Pattern

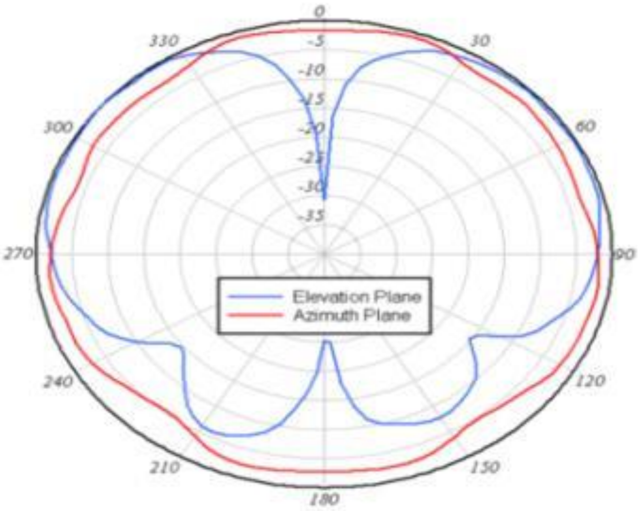
Low gain dipoles radiate everywhere think "light bulb"

Understanding Antenna Patterns

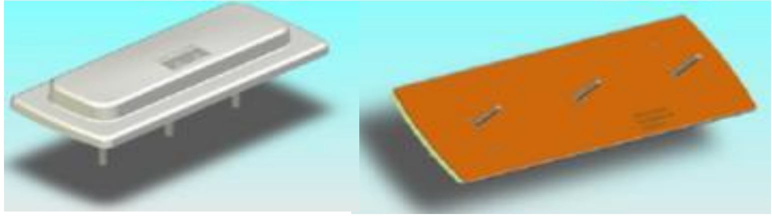
Monopole (Omni-Directional) MIMO



End Antenna

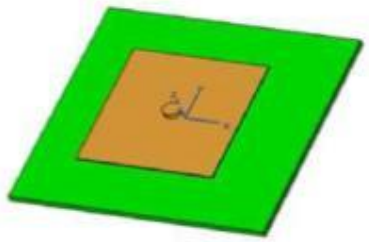


Middle Antenna

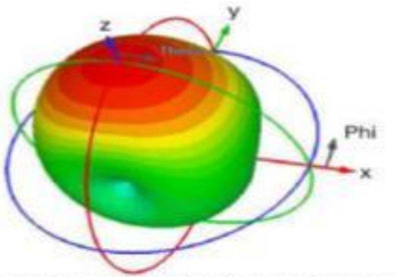


When three monopoles are next to each other – the radiating elements interact slightly with each other – The higher gain 4 dBi also changes elevation more compared to the lower gain 2.2 dBi Dipole

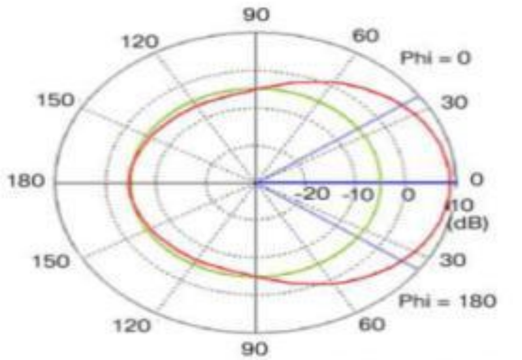
Understanding Antenna Patterns
Patch (Directional)



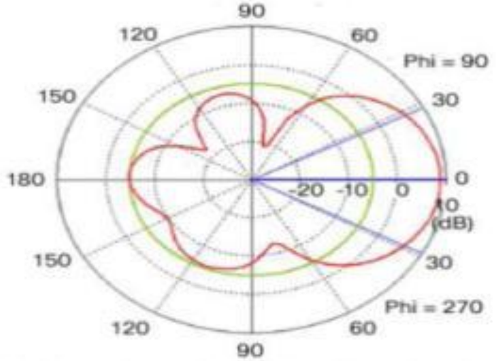
Patch Antenna Model



Patch Antenna 3D Radiation Pattern

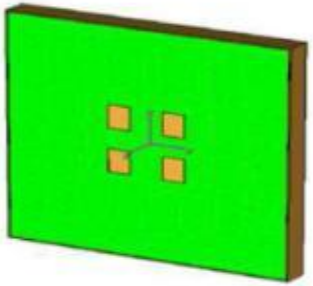


Patch Antenna Azimuth Plane Patter

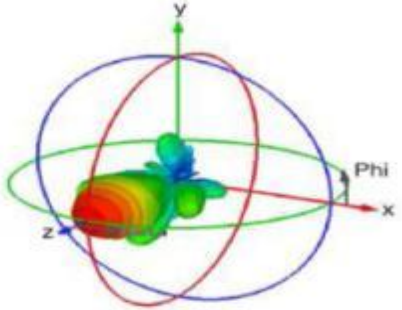


Patch Antenna Elevation Plane Pattern

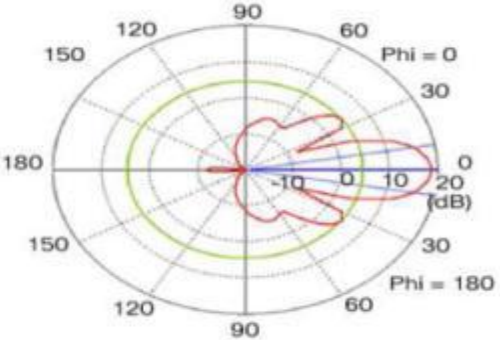
A low gain Patch Antenna



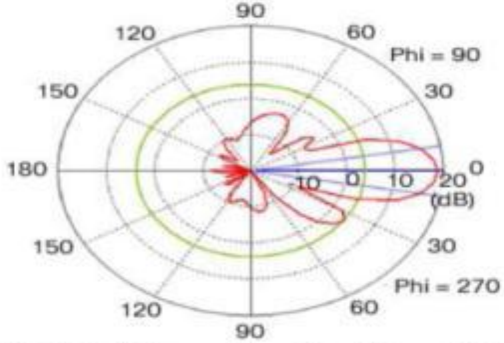
4x4 Patch Array Antenna



4x4 Patch Array 3D Radiation Pattern



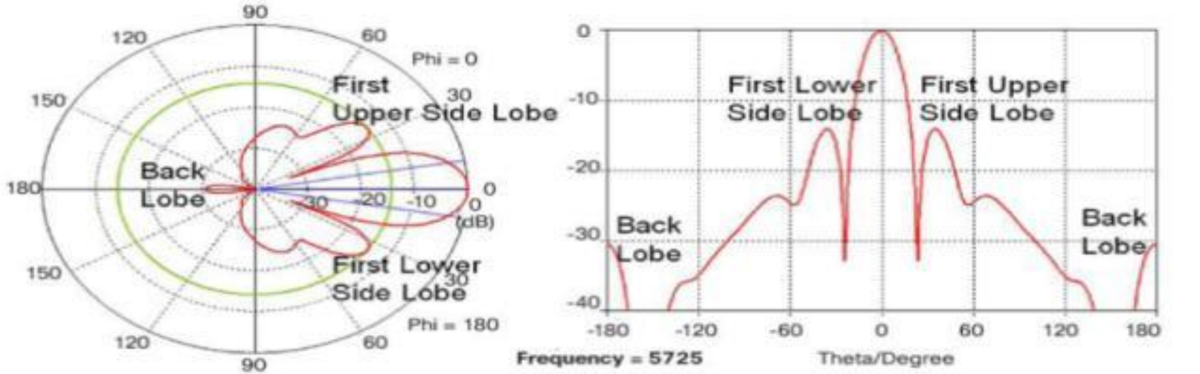
4x4 Patch Array Azimuth Plane Pattern



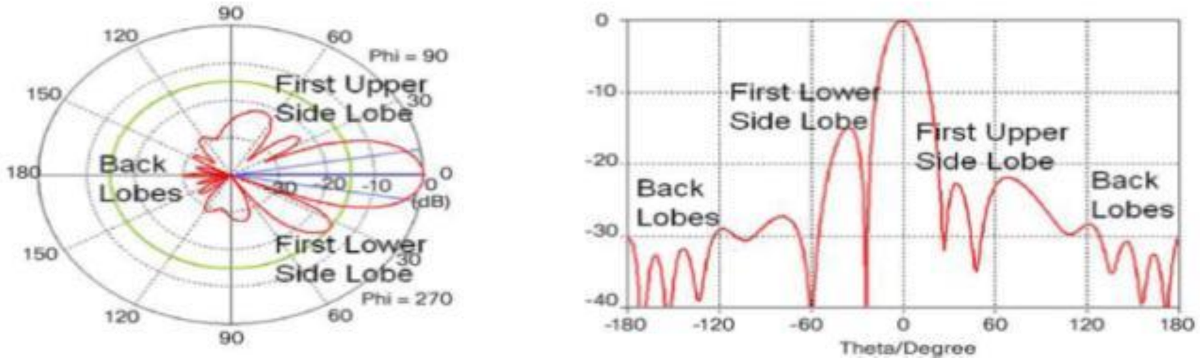
4x4 Patch Array Elevation Plane Pattern

A High Gain Four element Patch Array

Understanding Antenna Patterns
Patch (Higher Gain Directional)



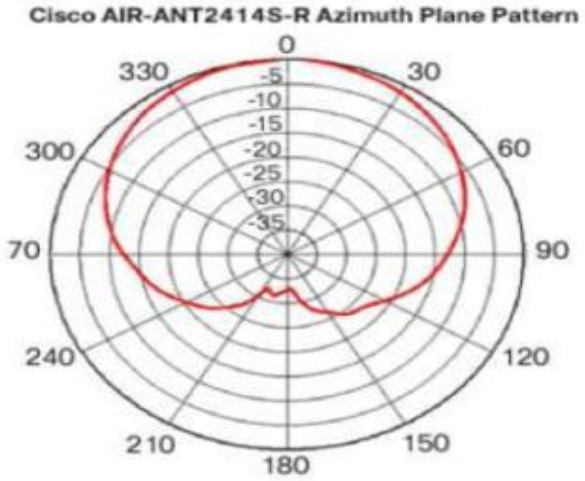
Elevation Plane Patterns of the 4 x 4 Patch Array in Polar and Rectangular Coordinates



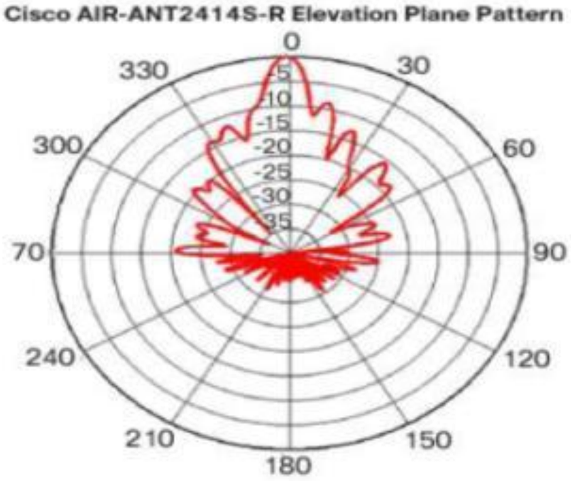
Four element Patch Array

Understanding Antenna Patterns

Sector (Higher Gain Directional)



(b) Cisco AIR-ANT2414S-R
Azimuth Plane Pattern



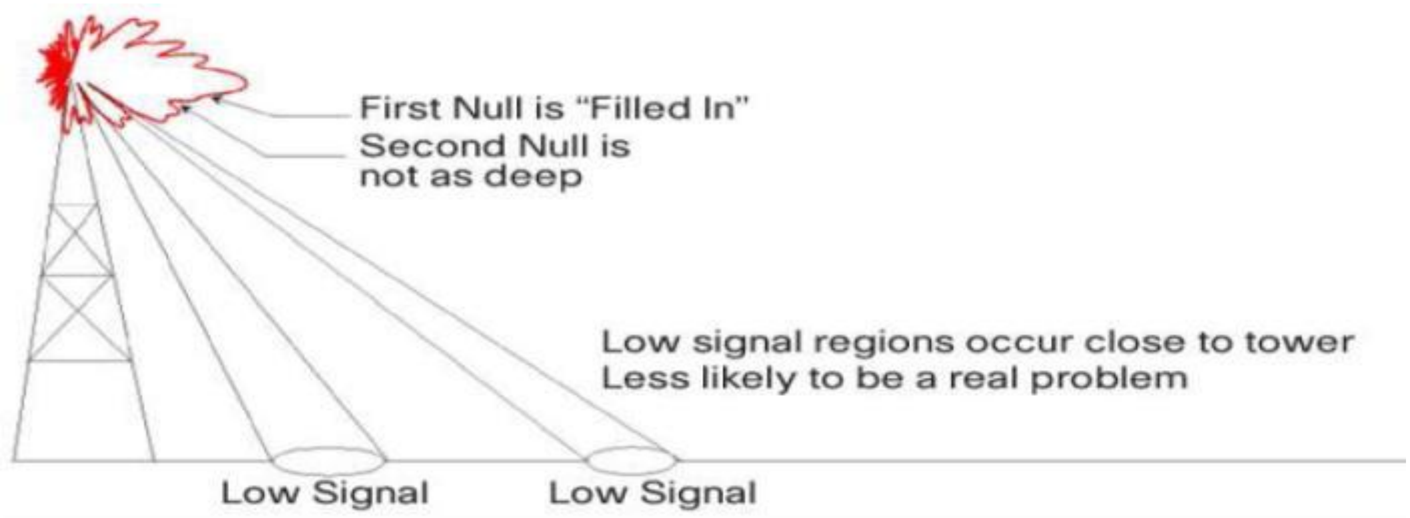
(c) Cisco AIR-ANT2414S-R
Elevation Plane Pattern

AIR-ANT2414S-R
14 dBi Sector 2.4 GHz

Elevation plane has nulls due to high gain 14 dBi

Understanding Antenna Patterns

Sector (Higher Gain Directional)



Elevation plane has nulls due to high gain 14 dBi but this antenna was designed with "Null-Fill" meaning we scaled back the overall antenna gain so as to have less nulls or low signal spots on the ground.

AIR-ANT2414S-R
14 dBi Sector 2.4 GHz

The Richfield Ohio (Aironet) Facility

A Quick Peek Where Antennas Are Designed...

The Richfield Ohio (Aironet) Facility

Qualifying Cisco and 3rd Party Antennas

Satimo software compatible with Stargate-64 System. Basic measurement tool is 8753ES Network Analyser.

Cisco Anechoic chamber using an 45 cm absorber all the way, around 1-6 GHz

Anechoic means "without echo"

The Richfield Ohio (Aironet) Facility

Regulatory Compliance Testing is Performed in this Chamber

Cisco Public

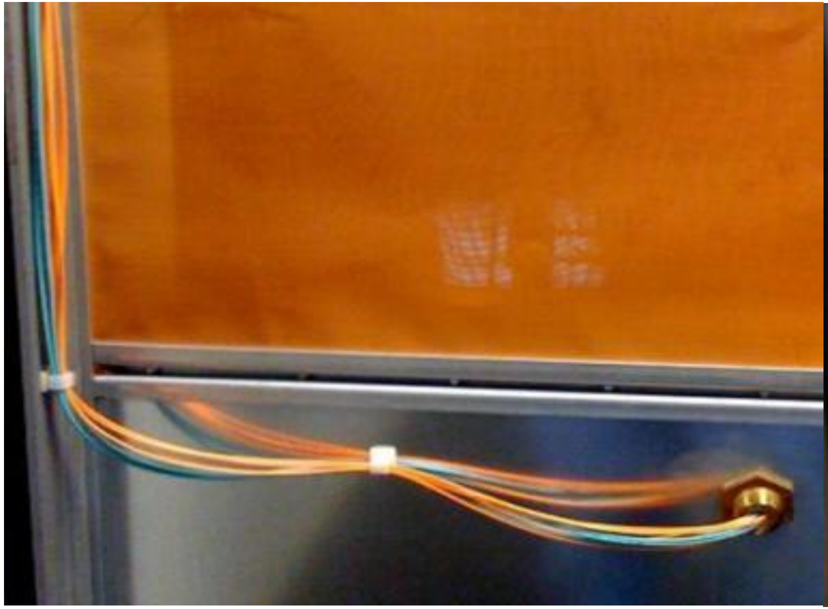
Yes We Have Just a Few Access Points Running…

RF Screen Rooms Everywhere

Copper Shielding (Faraday Cage)

RF Screen Rooms

Copper Shielding on Top Metal on Bottom



Cables are typically fibre and exit through well shielded holes

Doors have copper fingers and latch tight forming an RF seal

RF Screen Rooms

Copper Shielding (Faraday Cage)

Cisco Richfield Facility



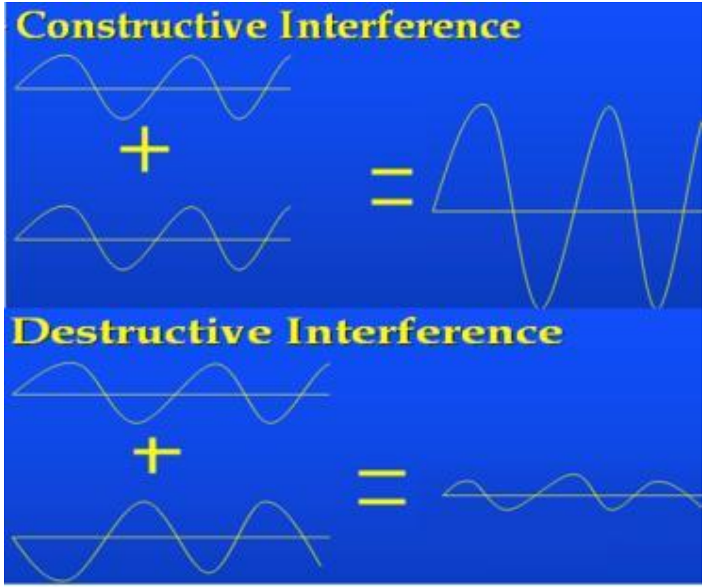

Understanding Multipath Diversity and Beamforming

Understanding Multipath

Multipath can change Signal Strength

As radio signals bounce off metal objects they often combine at the receiver

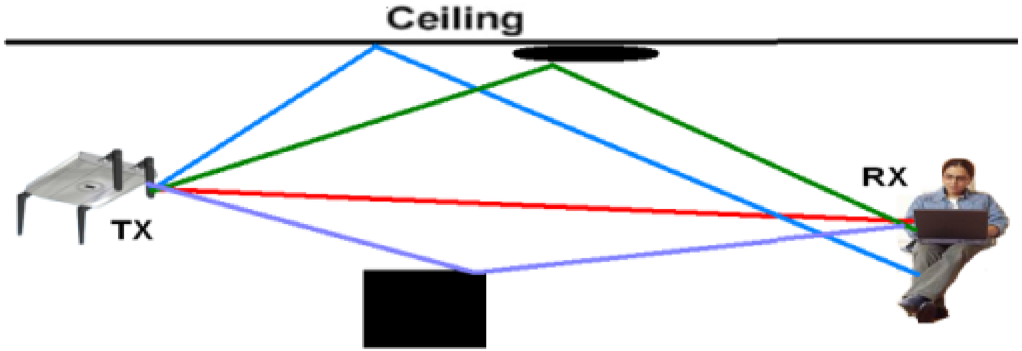
This often results in either an improvement "constructive" or a "destructive" type of interference

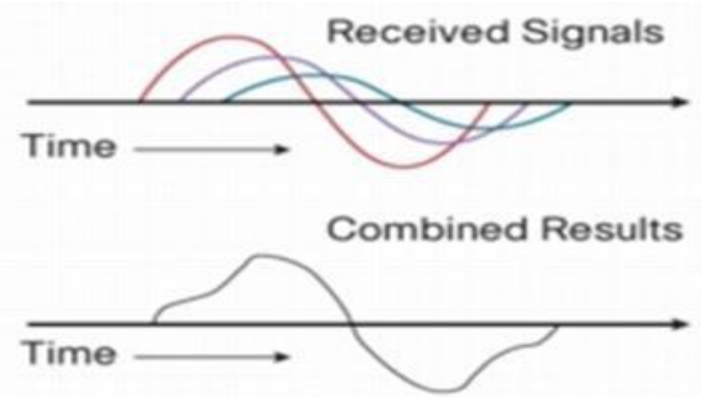


Note: Bluetooth type radios that "hop" across the entire band can reduce multipath interference by constantly changing the angles of multipath as the radio wave increases and decreases in size (as the frequency constantly changes). The downside is that throughput using these "hopping" methods are very limited but multipath is less of a problem

Understanding Multipath

Multipath Reflections Can Cause Distortion





As the radio waves bounce, they can arrive at slightly different times and angles causing signal distortion and potential signal strength fading

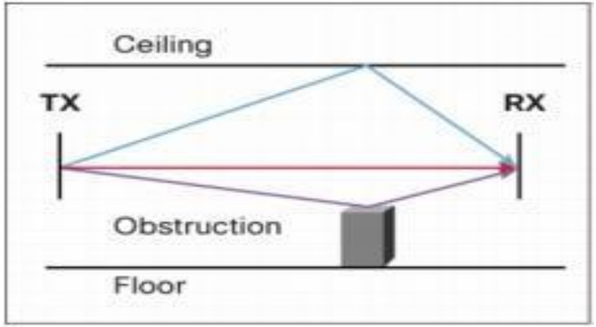
Different modulation schemes fair better – 802.11a/g uses a type of modulation based on symbols and is an improvement over the older modulation types used with 802.11b clients

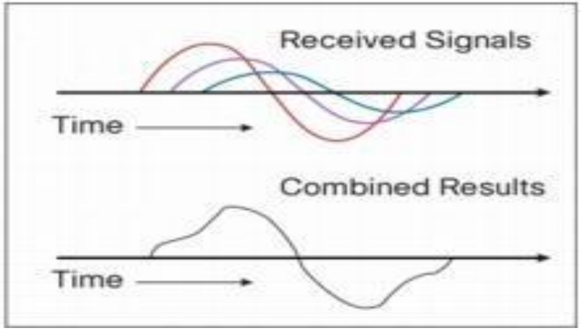
802.11n with more receivers can use destructive interference (multipath) as a benefit but it is best to reduce multipath conditions

Understanding Diversity (SISO)

802.11a/b/g had just one radio per band diversity was limited

Non-802.11n diversity Access Points use two antennas sampling each antenna choosing the one with the least multi-path distortion



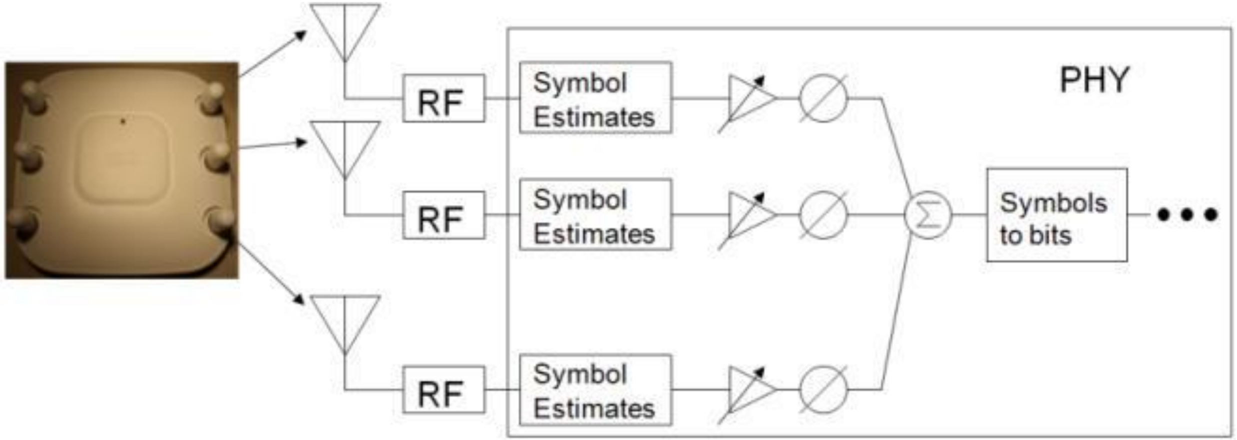


Cisco 802.11a/b/g Access Points start off favoring the right (primary antenna port) then if multi-path or packet retries occur it will sample the left port and switch to that antenna port if the signal is better.

Note: Diversity Antennas should always cover the same cell area

Understanding Diversity (MIMO)

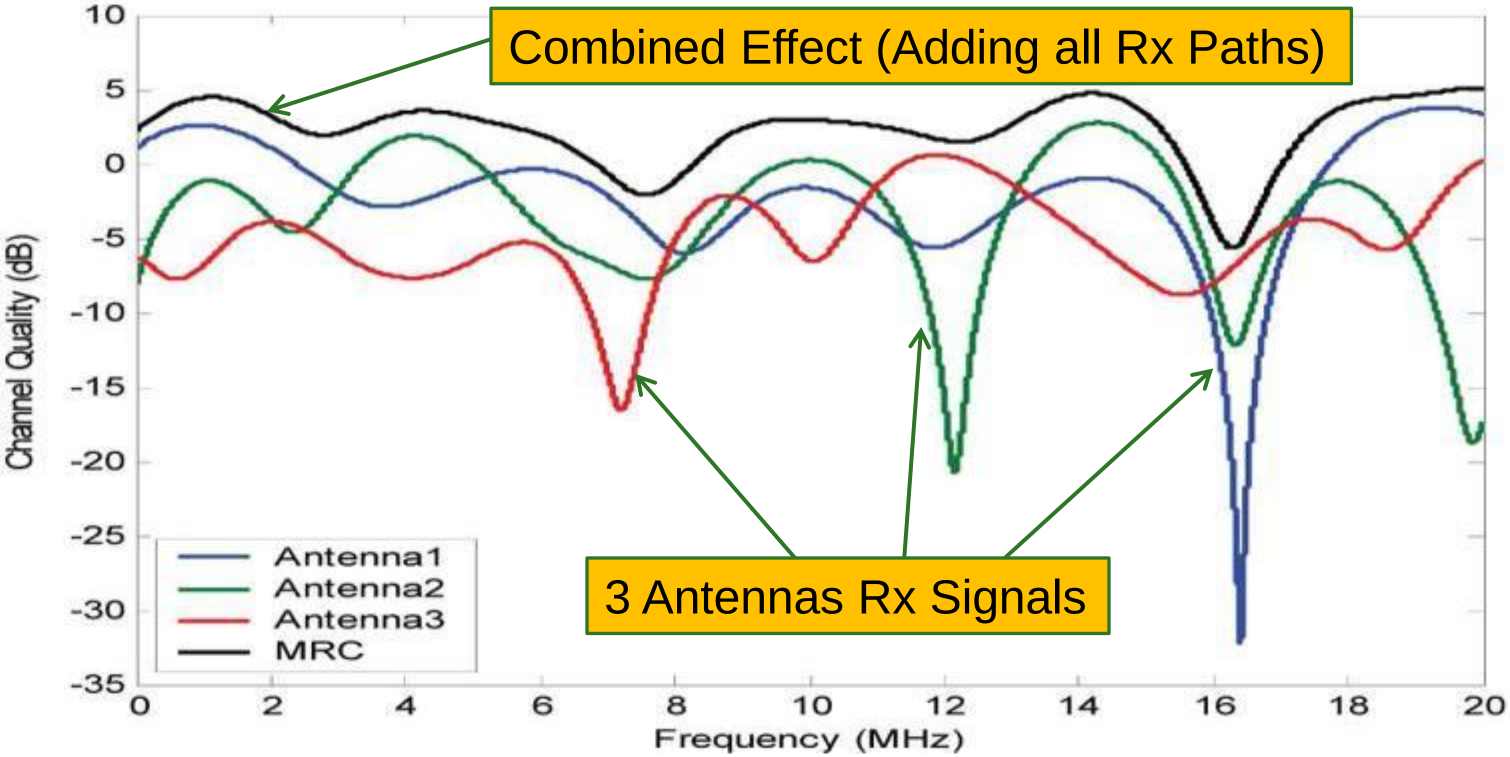
MRC Maximal Ratio Combining (Three Radios)



- **Receiver benefit as each antenna has a radio section**
- **MRC is done at Baseband using DSP techniques**
- **Multiple antennas and multiple RF sections are used in parallel**
- **The multiple copies of the received signal are corrected and combined at Baseband for maximum SNR (Signal to Noise) benefit**
- **This is a significant benefit over traditional 802.11a/b/g diversity where only one radio is used**

MRC Effect on Received Signal

Maximal Ratio Combining



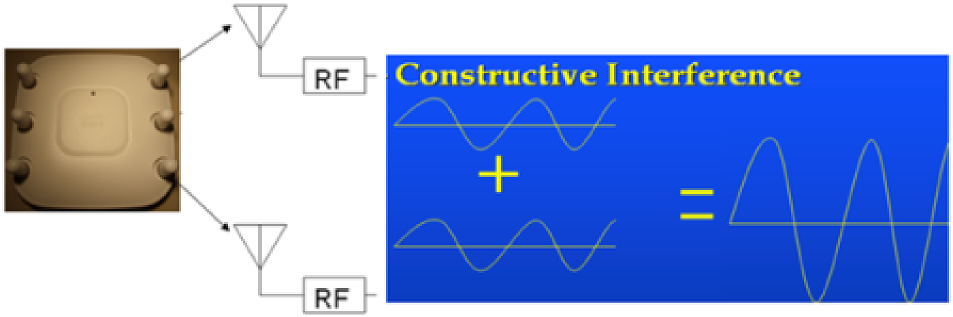
Understanding Client Link 1.0 & 2.0

Why You Want to direct (Beam-form) the signal to the client)

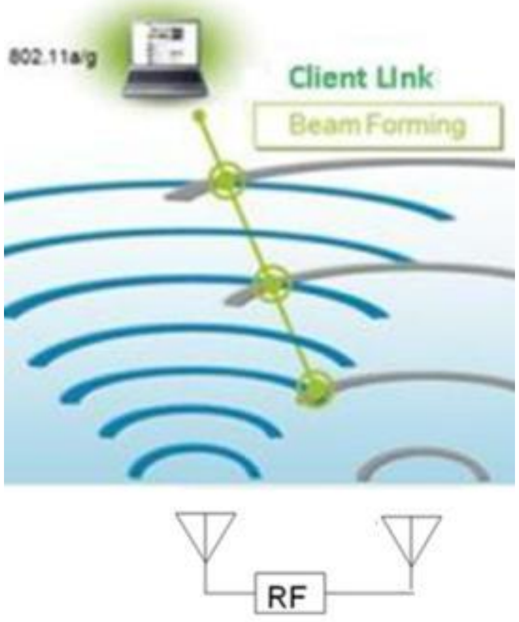
Beam-forming allows the signal to be best directed towards the client.
This results in a strong signal to the client reducing need for retries

Note antennas were moved in the picture for illustration purposes –
Never place antennas like this ☺

Simple Example of Beamforming

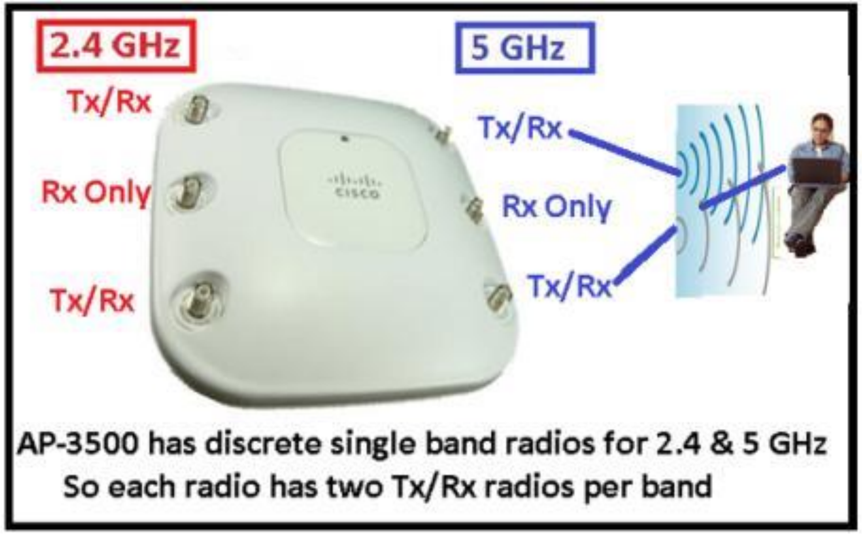


By changing the timing (phase) of the two transmitters, you can create a stronger signal (constructive interference) so the client can hear it better



Client Link doesn't only help at the edge of the network, but by pushing the signal directly at the client - it permits easier decoding maintaining higher data rate connectivity (rate over range) on the downlink side

Beamforming:
ClientLink 1.0 (Introduced in AP-1140)



AP1140, 1260 and 3500 can beamform to legacy 802.11a/g clients. This is called Client Link 1.0 and supports up to 15 clients per radio

Note: Client Link 1 & 2 works on the DOWNLINK (AP to CLIENT) so the client can better decode packets

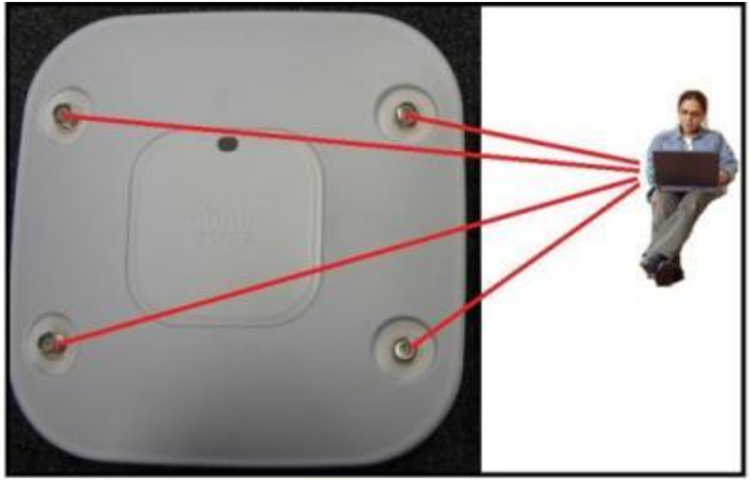
The AP-1140/1260/3500 has dual band radio support using single band antennas.

Each radio band (2.4 & 5 GHz) has separate independent radios Two transceivers (Tx/Rx) per band

This two transceiver design allows for beam-forming to legacy clients 802.11a/g - this is called Client Link.

2^{nd} Generation Series AP's with ClientLink 2.0

Client Link 2.0 is Client Link with Enhanced .11n Beam-forming



2600 & 3600 Series APs have <u>four transceivers per band</u> and all the antennas are used in the Client Link 2.0 beam-forming process

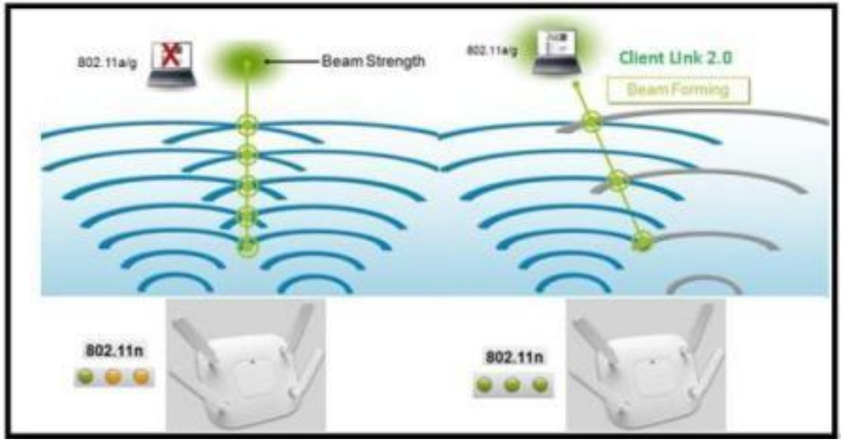
More radios, less antennas, all 8 radios (4 per band) are Transmit/Receive "Tx/Rx"

Cisco 2600 & 3600 Access Points fully support Cisco Client Link 2.0 (beam-forming) to 802.11a/g/n clients as well as 802.11n clients @ 1, 2 & 3 Spatial Streams

Take away – CLIENT LINK 2.0 beam-forms to all clients today improving the overall user experience and performance

Understanding Multipath and Beamforming

Why You Want More Receivers and Client Link 2.0



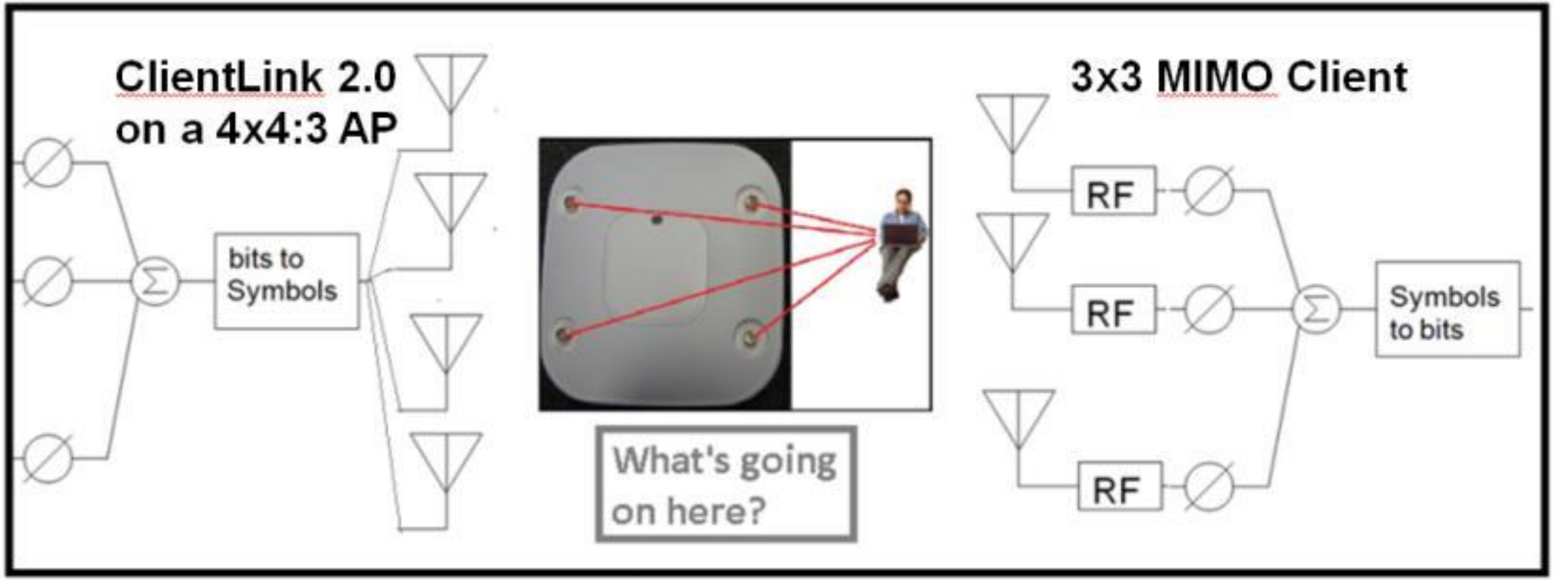
3600 with multiple transceivers
ONE EXTRA RADIO PER BAND then the competition
increases fidelity creating a more predictable and reliable 802.11n performance

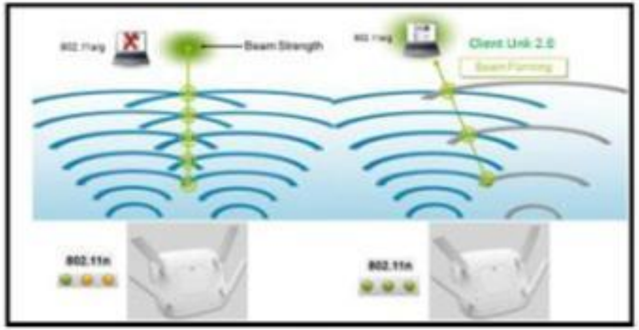
The picture above is an example of a 1-SS beam-form similar to what is done in Client Link 1.0 however – using Client Link 2.0 we can do this with multiple spatial streams.

The AP-3600 supports three spatial streams with four transceivers for even greater performance and then adds Client Link 2.0 enhancements

Client Link 2.0 benefits 802.11a/g/n 1-SS, 2-SS and 3-SS clients

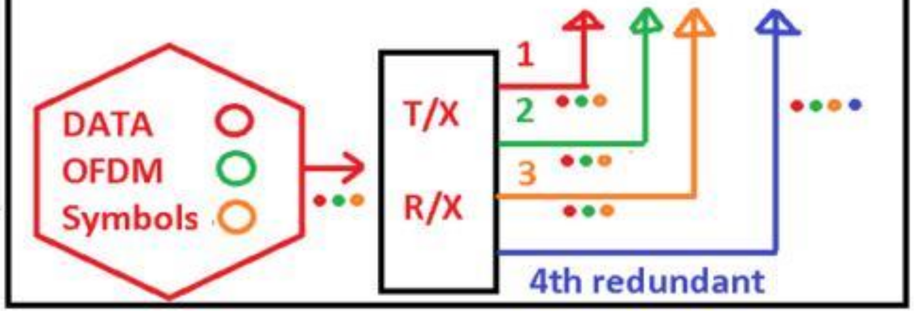
Note: You need 4 radios to beam-form to 3-ss clients no one else has this





Example of 1-SS but we can do up to 3-ss concurrently

All signals (streams) are adjusted to beamform, and parts of each stream are sent out all the antennas. When fading occurs on one stream - it has also been sent out the (redundant 4th radio as well)



Understanding 802.11n

Review of 802.11a and 802.11b/g

- 1 Transmitter & 1 Receiver (per band) – **up to 54 Mbps**
- Early diversity Access Points use two antennas with one radio per band sampling each antenna - choosing the one with the least multi-path distortion and then transmitting back on the same antenna
- Since speeds were only 54 Mbps 10/100 ports were fine
- Since PoE was 15.4W the radios had plenty of power the higher gain antennas above 6 dBi were permitted
- Both Indoor/Outdoor was permitted without frequency restrictions 802.11n introduced restrictions for outdoors creating the 3502P

Review – 802.11n "G1" First Generation APs

- Up to 3 radios per band – speeds up to 300 Mbps
- 2.4 GHz (802.11b/g/n) and 5 GHz (802.11a/n) – Support for 2-spatial streams
- Lots of antennas (typically 6) three for each band
- Antennas are single band single radiating elements identified by black and blue (5-GHz) colours
- Introduction of ClientLink (beam-forming)

AP-3500 has discrete single band radios for 2.4 & 5 GHz
So each radio has two Tx/Rx radios per band

Remember me?
I'm a 1250 →
Built like a tank
October 2007

Modularity is a GOOD THING
→

Review – 802.11n "G2" Second Generation AP-3600

- Up to 4 radios per band – <u>speeds up to 450 Mbps</u>
- Support for 3 Spatial Streams
  2.4 GHz (802.11b/g/n) and 5 GHz (802.11a/n)
- Antennas are dual band - dual radiating elements identified by an orange stripe resulting in the need for less physical antennas
- Introduction of ClientLink 2.0 better Beam-forming
- Introduction of upgrade option modules

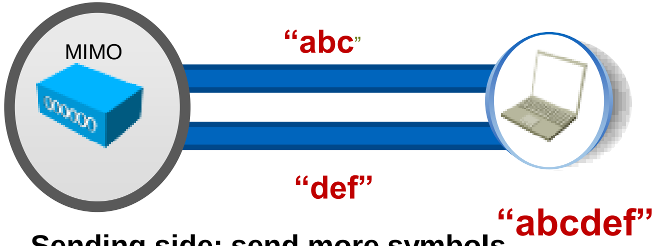
  Security Module & 802.11ac Module

Note: New .11ac module brings increased performance to the AP-3600 Access Point <u>up to 1.3 Gbps</u>

802.11n MIMO Terminology

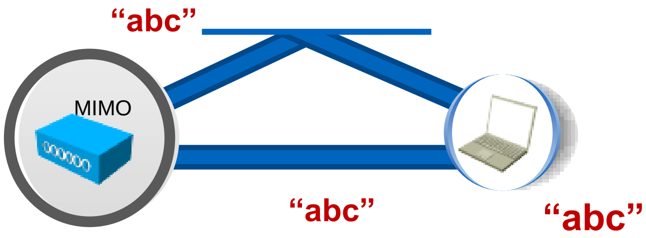
Understanding .11n components (Multiple Input Multiple Output)

Spatial Multiplexing – A method for boosting wireless bandwidth by taking advantage of multiplexing which is the ability within the radio to send out information over two or more transmitters concurrently (in parallel) known as "spatial streams".



Sending side: send more symbols, in parallel (spatial multiplexing)

MRC – Maximal Ratio Combining a method that combines signals from multiple antennas taking into account factors such as signal to noise ratio to decode the signal with the best possible Bit Error Rate.

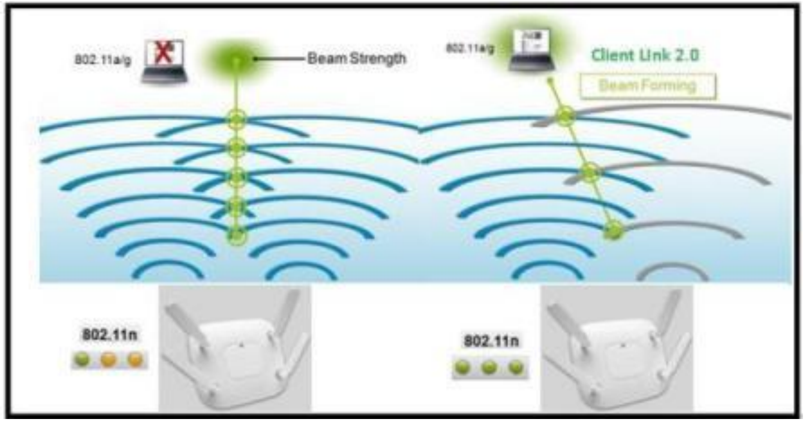


Receiving side: synchronise signals for better signal (Maximal Ratio Combining, MRC)

802.11n MIMO Terminology

Understanding .11n components (Multiple Input Multiple Output)

TxBF – Transmit Beam-Forming – Signals are sent on separate antennas that are coordinated to combine constructively at the receive antenna (.11n Enhanced Beam Forming) and Cisco ClientLink



802.11n (EBF) Enhanced Beam Forming

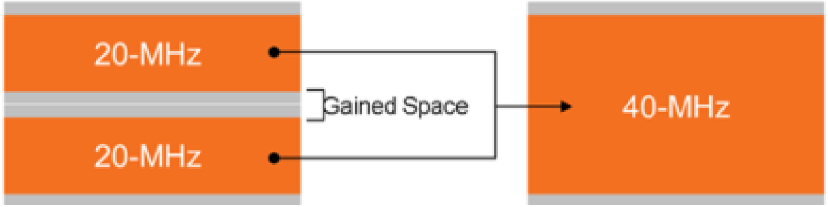
WLAN Client	
Works for Multiple Spatial Stream HT Clients	Not yet
Works for 1 SS HT Clients	Not yet
Works for Legacy Clients (11a/g)	None
General Requirements/Dependencies	
Requires Client Cooperation/Support	Yes
Requires Use of Channel Time for Sounding	Yes
Can be Used w/ Clients Currently on Market	No

EBF didn't happen in .11n so Cisco addressed with ClientLink

802.11n MIMO Terminology

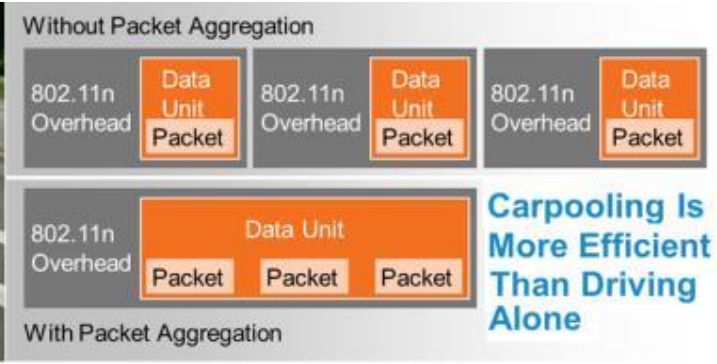
Understanding .11n/ac components (Multiple Input Multiple Output)

Channel Bonding – Use of more than one frequency or channel for more bandwidth. (Like going from a 2 lane highway to a 4 lane)



40 MHz = two aggregated 20 MHz channels plus gained space – (+2x speed)

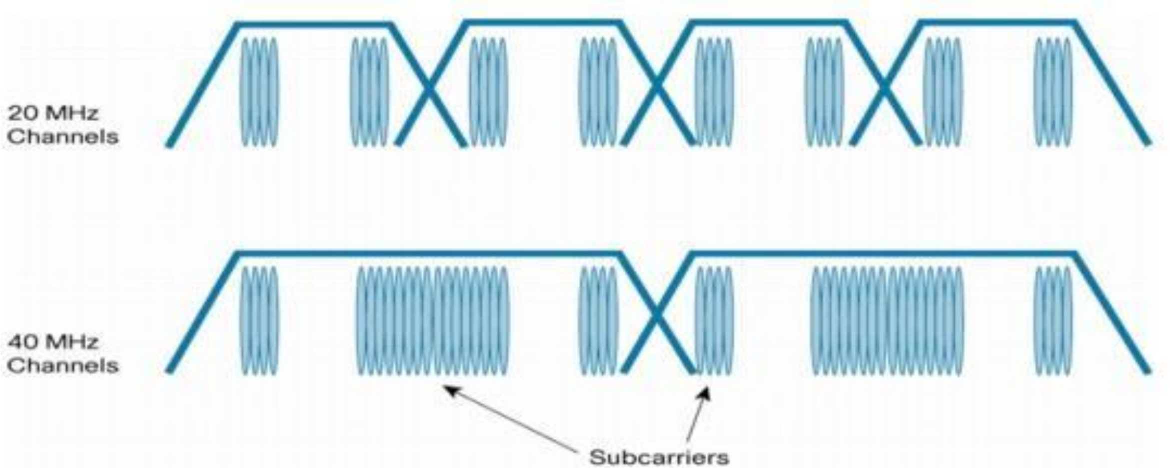
Packet aggregation – Permits more efficient use of the RF spectrum Reducing ACK times for more faster throughput



Channel Bonding – Subcarriers

802.11n can use both 20-MHz and 40-MHz channels.

The 40-MHz channels in 802.11n are two adjacent 20-MHz channels, bonded together.



When using the 40-MHz bonded channel, 802.11n takes advantage of the fact that each 20-MHz channel has a small amount of the channel that is reserved at the top and bottom, to reduce interference in those adjacent channels.

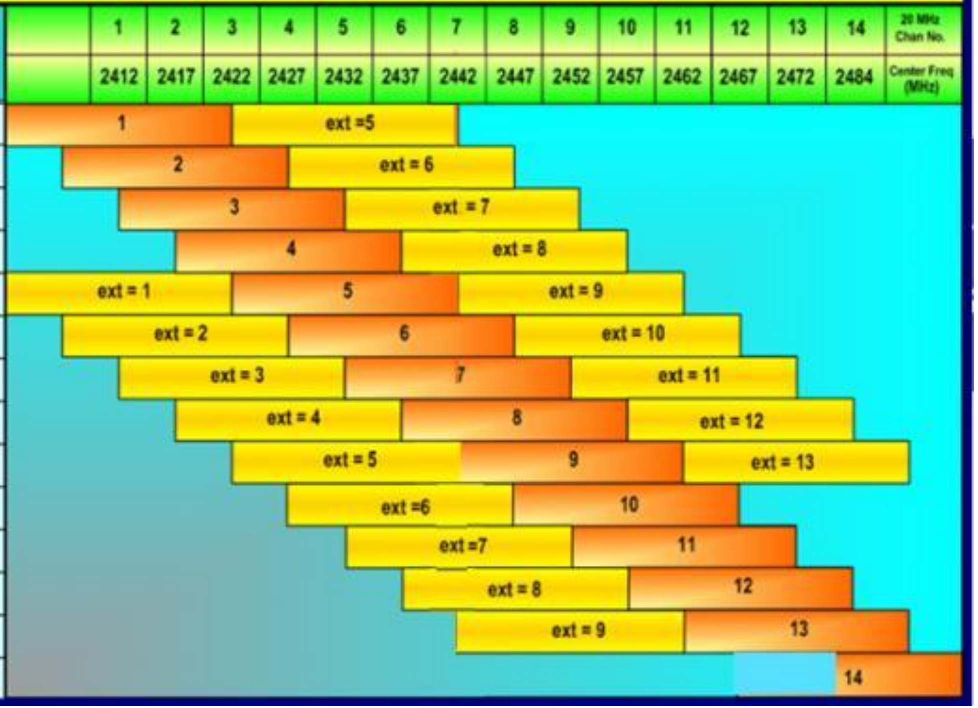
When using 40-MHz channels, the top of the lower channel and the bottom of the upper channel don't have to be reserved to avoid interference. These small parts of the channel can now be used to carry information. By using the two 20-MHz channels more efficiently in this way, 802.11n achieves slightly more than doubling the data rate when moving from 20-MHz to 40-MHz channels

2.4 GHz Channel Bandwidths

40 MHz Not Permitted or Supported (Enterprise WLAN)

2.4 GHz Bandwidths

Domain	Ch ID	Freq (MHz)	Center Ch 20 MHz	Center Ch 40 MHz	Cntrl Ch	Ext Ch	Exten Upper or Lower
US & ROW	1	2412	1	3	1	5	Upper
	2	2417	2	4	2	6	Upper
	3	2422	3	5	3	7	Upper
	4	2427	4	6	4	8	Upper
	5	2432	5	3, 7	5	1, 9	Low, Up
	6	2437	6	4, 8	6	2, 10	Low, Up
	7	2442	7	5, 9	7	3, 11	Low, Up
	8	2447	8	6, 10	8	4, 12	Low, Up
	9	2452	9	7, 11	9	5, 13	Low, Up
	10	2457	10	8	10	6	Lower
	11	2462	11	9	11	7	Lower
ROW	12	2467	12	10	12	8	Lower
	13	2472	13	11	13	9	Lower
	14	2484	14	NA	14	NA	NA



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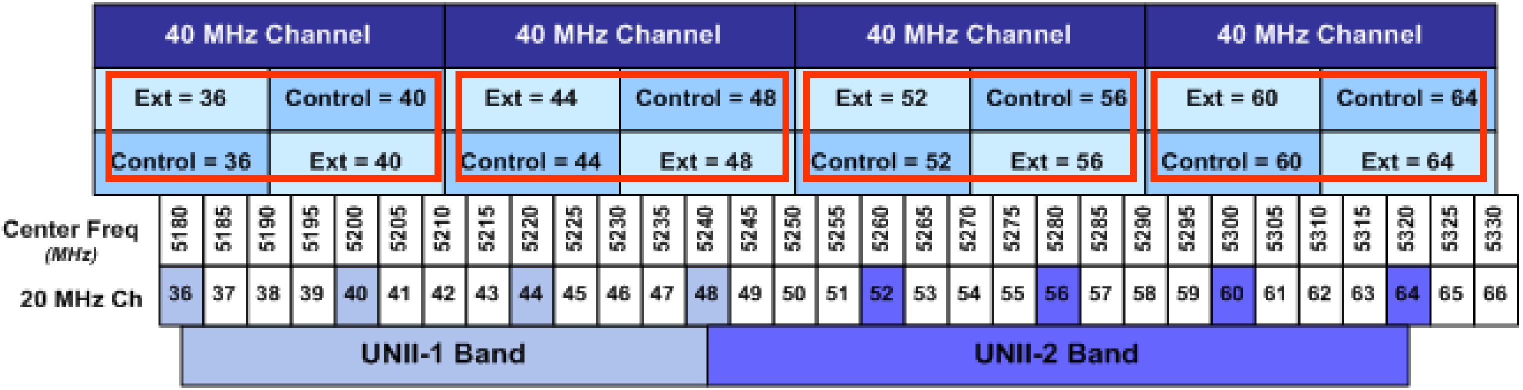
Example: ETSI Lower Band 5-GHz Channel Bonding



In 40-MHz you define the control channel this is the channel that is used for communication by Legacy .11a clients.

The Extension channel is the bonded channel that “HT” High Throughput “802.11n clients use in addition to the control channel for higher throughput as they send data on BOTH channels

Suggested Guidelines on Channel Bonding

20 MHz mode is suggested if…

- you have lots of voice clients.
- you have lots of non-11n capable 5 GHz clients
- you will be deploying a transition of mixed 11a & 11n infrastructure:

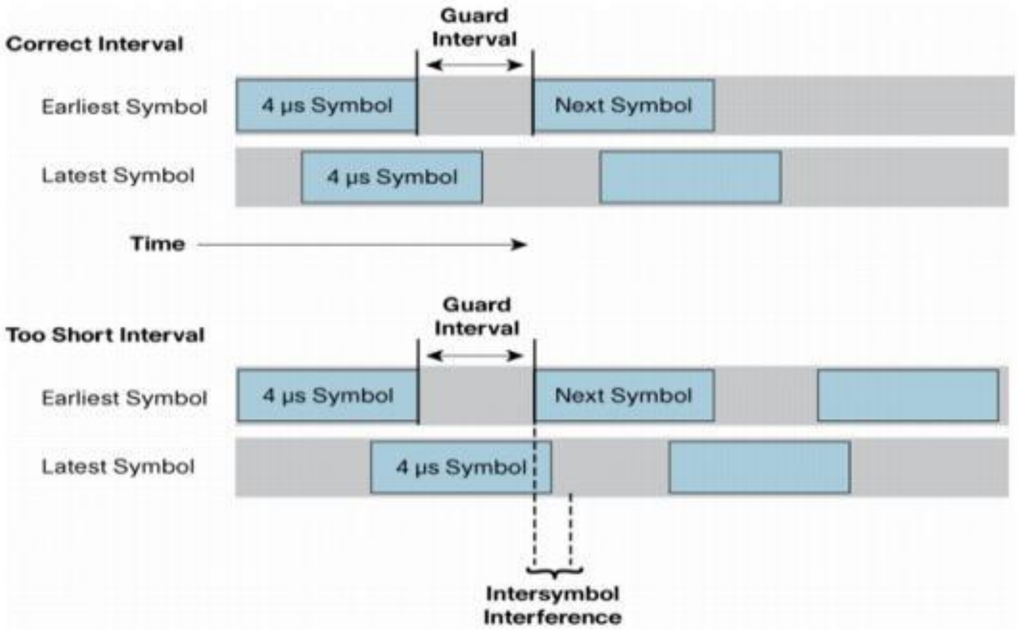
40 MHz (Bonded channel) mode is suggested if…

- You have few voice clients (less than 10 per AP)
- You expect to have predominantly 11n clients that support 40 MHz operation.
- You are doing bandwidth-intensive file transfers such as video downloads, wireless backups, etc.

Understanding Guard Interval

Guard Interval (GI) – Period of time between each a OFDM symbol that is used to minimise inter-symbol interference.

This type of interference is caused in multipath environments when the beginning of a new symbol arrives at the receiver before the end of the last symbol is done.



Default GI mode for 802.11n is 800 nanoseconds
If you set a shorter interval it will go back to the long guard interval in the event retries happen to occur

Cisco Public

802.11n Data Rates



AP-1040,1140, 1250,1260,3500
New AP-700 & 1600
can support
Up to 2-Streams
300 Mbps (MCS15)

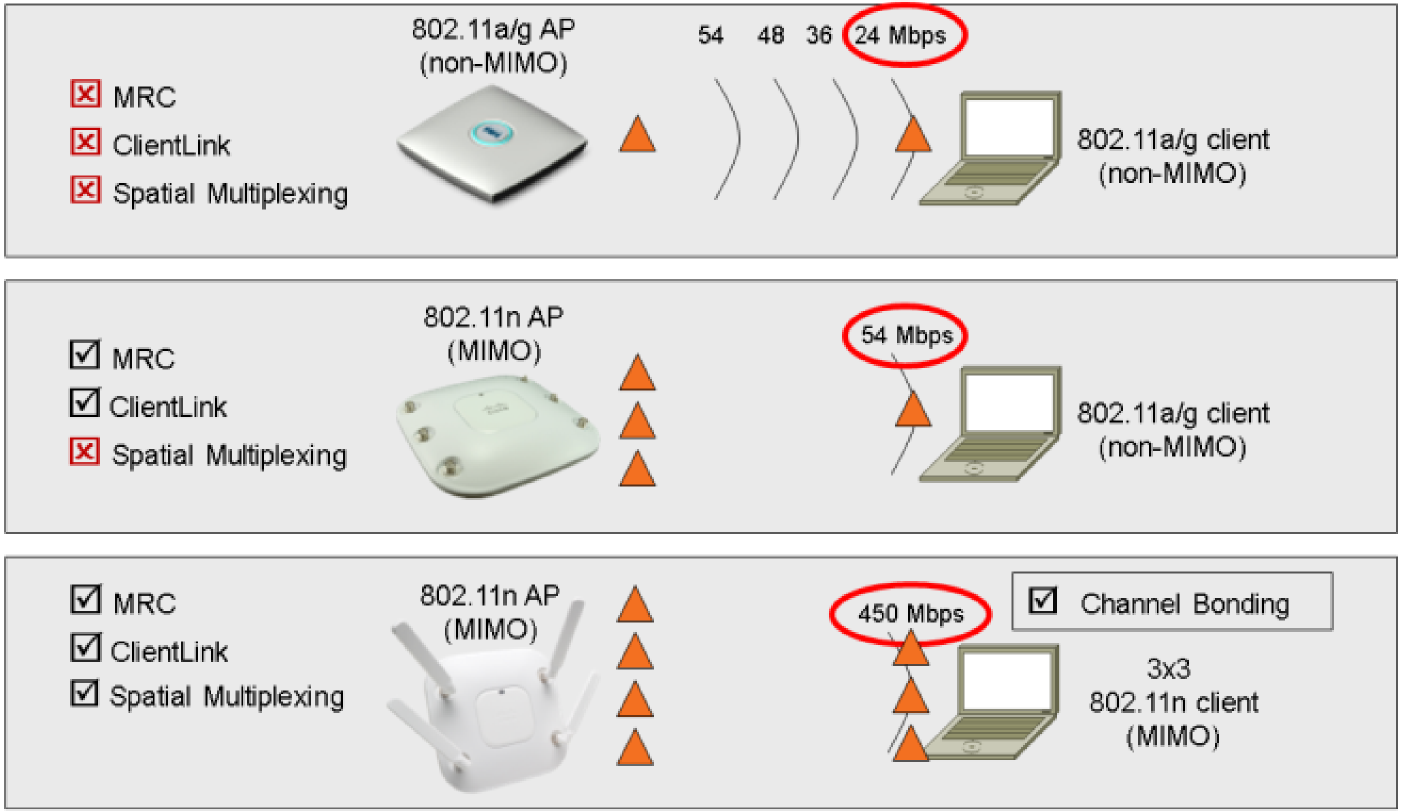
				Signal BW =20 MHz		40 MHz	
MCS	Coding	Modulation	Streams	GI = 800 nS	GI =400 nS	GI = 800 nS	GI =400 nS
MCS0	1/2	BPSK	1	6.5	7.2	13.5	15
MCS1	1/2	QPSK	1	13	14.4	27	30
MCS2	3/4	QPSK	1	19.5	21.7	40.5	45
MCS3	1/2	16-QAM	1	26	28.9	54	60
MCS4	3/4	16-QAM	1	39	43.3	81	90
MCS5	2/3	64-QAM	1	52	57.8	108	120
MCS6	3/4	64-QAM	1	58.5	65	131.5	135
MCS7	5/6	64-QAM	1	65	72.2	135	150
MCS8	1/2	BPSK	2	13	14.4	27	30
MCS9	1/2	QPSK	2	26	28.9	54	60
MCS10	3/4	QPSK	2	39	43.3	81	90
MCS11	1/2	16-QAM	2	52	57.8	108	120
MCS12	3/4	16-QAM	2	78	86.7	162	180
MCS13	2/3	64-QAM	2	104	115.6	216	240
MCS14	3/4	64-QAM	2	117	130	243	270
MCS15	5/6	64-QAM	2	130	144.4	270	300
MCS16	1/2	BPSK	3	19.5	21.7	40.5	45
MCS17	1/2	QPSK	3	39	43.3	81	90
MCS18	3/4	QPSK	3	58.5	65	121.5	135
MCS19	1/2	16-QAM	3	78	86.7	162	180
MCS20	3/4	16-QAM	3	117	130	243	270
MCS21	2/3	64-QAM	3	156	173.3	324	360
MCS22	3/4	64-QAM	3	175.5	195	364.5	405
MCS23	5/6	64-QAM	3	195	216.7	405	450



AP-2600, AP3600
can support
Up to 3-Streams
450 Mbps
(MCS23)
w/o .11ac module

So to Recap: 802.11n Operation

Throughput Improves When All Things Come Together



Cisco Public

802.11n "Things that never really got much traction"

- Greenfield header (pure 802.11n, for networks with no 802.11a/b/g stations) by the way this is a bad idea as you want to be a good RF neighbour. FYI - Greenfield will not be supported in 802.11ac.
- 4 Spatial streams for up to 600 Mbps (assuming bonded 40 MHz and short 400ns GI) just too many issues (lack of clients, PoE considerations etc.) FYI .11ac 3-SS Wave-1
- Channel bonding in 2.4 GHz for enterprise (just not enough channels) as you can only do so much on 2.4 GHz as there isn't that much spectrum. FYI- 802.11ac is 5 GHz only
- Explicit beam-forming (clients really didn't support this) FYI- Supported with .11ac
- Dual CTS protection (AP send to CTS when using Space Time Block Coding, STBC, which extends the range of the cell: one CTS for non-STBC stations (short range), and one CTS for STBC stations (longer range) FYI – New protections added with .11ac




Understanding 802.11ac

Why is 802.11ac Important?

This section will guide you in understanding 802.11ac Wave-1 and Wave-2

802.11ac devices are started to emerge especially mobile devices so there is a customer need for improved performance

Cisco AP-3600 with .11ac module

New .11ac clients starting to emerge

So Let's Talk About 802.11ac – Wave1

The Wi-Fi Alliance (WFA) is looking at Wave 1 today with the main features implemented being:

- Channel Bonding 80 MHz (mandatory)
- Faster modulation 256-QAM (optional)
- Ability to receive 1,2 & 3 Spatial Streams tested

  - 2SS is mandatory for non-battery-powered APs

  - Only 1SS is mandatory for battery powered AP's and clients

- WFA's focus is on 80 MHz, 1-3SS and 256-QAM with WFA compliant products likely sporting a new Wi-Fi Certified logo

802.11ac is happening in stages Referred to as "Wave-1 and Wave-2

Wi-Fi Alliance logo should look something like this

Wi-Fi CERTIFIED™ ac

So Let's Talk About 802.11ac

How is it like .11n?

802.11ac (Wave-1) introduces 256-QAM

Faster throughput happens when you can use more complex Modulation Coding Schemes (MCS) rates

MCS	Coding	Modulation	Streams
MCS0	1/2	BPSK	1
MCS1	1/2	QPSK	1
MCS2	3/4	QPSK	1
MCS3	1/2	16-QAM	1
MCS4	3/4	16-QAM	1
MCS5	2/3	64-QAM	1
MCS6	3/4	64-QAM	1
MCS7	5/6	64-QAM	1

802.11n 1-ss MCS up to 64-QAM
64-QAM uses 6 bits per symbol

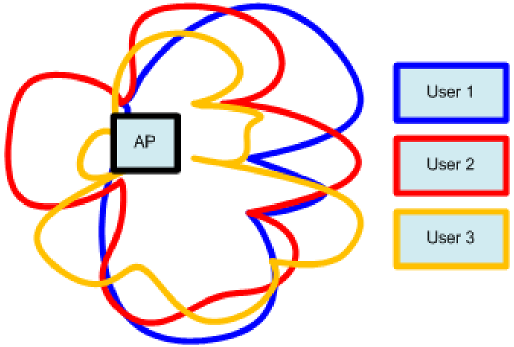
MCS	Coding	Modulation	Streams
0	1/2	BPSK	1
1	1/2	QPSK	1
2	3/4	QPSK	1
3	1/2	16-QAM	1
4	3/4	16-QAM	1
5	2/3	64-QAM	1
6	3/4	64-QAM	1
7	5/6	64-QAM	1
8	3/4	256-QAM	1
9	5/6	256-QAM	1

802.11ac 1-ss MCS supports 256-QAM
256-QAM uses 8 bits per symbol (up to 4x faster)

How about Multi-User MIMO (MU-MIMO)

Does it work? Any caveats?

- 802.11ac MU MIMO is like 802.11n MIMO, except instead of one client, there are up to four clients
  - AP does pre-coding for all the clients within the Multi-User group simultaneously
  - In MU pre-coding, when AP beam-forms space-time streams to one client, it simultaneously null-steers those space-time streams to the rest.
  - All users' MPDUs are padded to the same number of OFDM symbols
- MU-MIMO is technically risky and challenging:
  - Needs precise channel estimation (CSI) to maintain deep nulls
  - Precise channel estimation adds overhead
  - Rate adaptation is more difficult
  - Throughput benefits are sensitive to MU grouping



WFA Wave 2 certification:
• MU-MIMO

Null-steering:To send data to user 1, the AP forms a strong beam toward user 1, shown as the top-right lobe of the blue curve. At the same time the AP minimises the energy for user 1 in the direction of user 2 and user 3. This is called "null steering" and is shown as the blue notches. Same logic applies to red and yellow beams.

Beamforming – What Did and Didn't Happen

Review – Beamforming 802.11n and now 802.11ac

	802.11n (EBF) Enhanced Beam Forming	Client Link 2.0 (CVBF) Cisco Vector Beam Forming
WLAN Client		
Works for Multiple Spatial Stream HT Clients	Not yet	All
Works for 1 SS HT Clients	Not yet	All
Works for Legacy Clients (11 a/g)	None	All
General Requirements/Dependencies		
Requires Client Cooperation/Support	Yes	No
Requires Use of Channel Time for Sounding	Yes	No
Can be Used w/ Clients Currently on Market	No	All 11a/g/n

EBF Enhanced Beam-forming didn't make it in 802.11n but it's now in 802.11ac

Lots of channel sounding mechanisms and the industry could not decide at the time which one to use so everything was proprietary

This got a lot better with 802.11ac after a single sounding method was agreed upon.

Note: EBF changed to ECBF Explicit Compressed Beam Forming

Beamforming Efficiency Mechanisms

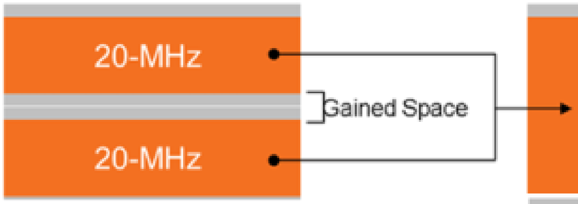
Single User and Multi-user MIMO

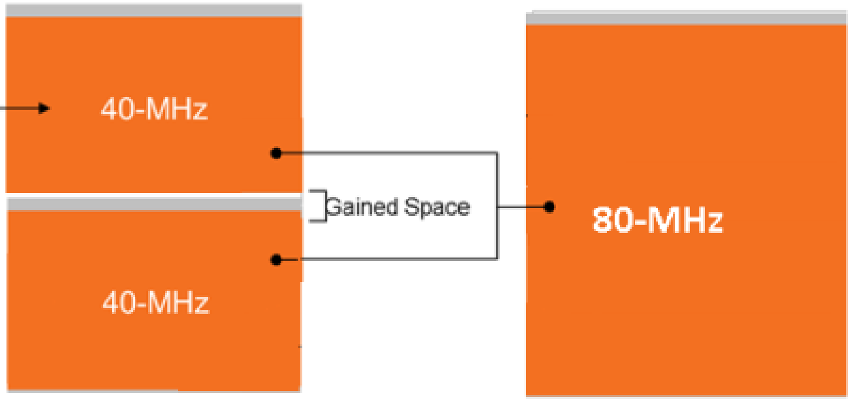
- **Channel sounding for SU & MU**
  - To make efficient use of a channel (and beam-form), stations need to know the channel characteristics – they can send test frames **[sounding frames]** of known structure, which allows the receiver to understand the channel specs, and beam-form or optimise back to the sender (AP or client).
  - **But for MU-MIMO, a unique sounding mechanism is important**, and 11ac community agreed on a single sounding mechanism - **Same mechanism is applicable for SU-MIMO –**
  - **(This is the method the AC module uses to beam-form back to clients)**
- **ACK for MU**
  - AP polls each client for ACK. This adds overhead, but is more robust
- **RTS/CTS for MU**
  - **No new RTS/CTS mechanism** is added for MU but the spec allows AP for proprietary mechanisms using conventional RTS/CTS
  - **Note: This still doesn't benefit legacy and 802.11n clients so ClientLink 2.0 is still important.**
  - **AP-3600's 11ac module uses IEEE channel sounding on AC clients**
  - **AP-3600 uses the integrated 11n radio and ClientLink 2.0 on N and legacy clients**

So let's talk about 802.11ac - How is it like .11n?

What about channel bonding?

Wave-1 allows up to 80 MHz channel bonding





802.11n can bond up to 40 MHz

Now we are on an 8 lane highway

802.11ac can bond up to 80 MHz (Wave-1)

***up to 160 MHz (Wave-2)**

So why is channel bonding so important?

MCS rates @ 1 Spatial Stream in Mbps

For Your Reference

MCS	Modulation	Ratio	20 MHz channel	40 MHz channel	80 MHz channel WAVE-1
			400 ns GI	400 ns GI	400 ns GI
0	BPSK	1/2	7.2	15	32.5
1	QPSK	1/2	14.4	30	65
2	QPSK	3/4	21.7	45	97.5
3	16-QAM	1/2	28.9	60	130
4	16-QAM	3/4	43.3	90	195
5	64-QAM	2/3	57.8	120	260
6	64-QAM	3/4	65	135	292.5
7	64-QAM	5/6	72.2	150	325
8	256-QAM	3/4	86.7	180	390
9	256-QAM	5/6	N/A	200	433.3

New Phones such as the HTC One & Samsung S 4 have support for 802.11ac Wave-1

More than 1-SS requires that the client have more radios which draw more power.

The goal is to enable devices to have more throughput with less battery draw

Most mobile devices will use 1-SS

Tablets & laptops can use 2-SS or more

Channel Bonding Wave-1 and Wave-2

.11ac MCS Rates @ 1-spatial stream -- (Wave1) typically supports up to 3-SS

For Your Reference

MCS	Modulation	Ratio	20 MHz channel		40 MHz channel		80 MHz channel WAVE-1		160 MHz channel WAVE-2	
			800 ns GI	400 ns GI	800 ns GI	400 ns GI	800 ns GI	400 ns GI	800 ns GI	400 ns GI
0	BPSK	1/2	6.5	7.2	13.5	15	29.3	32.5	58.5	65
1	QPSK	1/2	13	14.4	27.	30	58.5	65	117	130
2	QPSK	3/4	19.5	21.7	40.5	45	87.8	97.5	175.5	195
3	16-QAM	1/2	26	28.9	54	60	117	130	234	260
4	16-QAM	3/4	39	43.3	81	90	175.5	195	351	390
5	64-QAM	2/3	52	57.8	108	120	234	260	468	520
6	64-QAM	3/4	58.5	65	121.5	135	263.3	292.5	526.5	585
7	64-QAM	5/6	65	72.2	135	150	292.5	325	585	650
8	256-QAM	3/4	78	86.7	162	180	351	390	702	780
9	256-QAM	5/6	N/A	N/A	180	200	390	433.3	780	866.7

Cisco live!

Just One More EYECHART

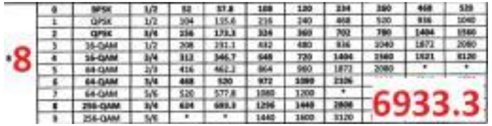
For Your Reference

802.11ac (Wave-2)
Up to 8 spatial streams.

.11ac MCS rates (unlike 802.11n) don't exceed 0-9 -- but rather **it is 0-9** and then you **call out how many Spatial Streams** so a chart like this is quite extensive.

Depicted to the right are only streams 2 & 3 out of the 8 possible spatial streams.

1 stream (80MHz) is 433 Mbps
2 stream (80MHz) is 866 Mbps
3 stream (80MHz) is 1300 Mbps



802.11ac Data Rates

* RATE NOT SUPPORTED

Mb/s

Spatial Streams	MCS Index	Modulation	Coding	20 MHz Guard Interval 800ns	20 MHz Guard Interval 400ns	40 MHz Guard Interval 800ns	40 MHz Guard Interval 400ns	80 MHz Guard Interval 800ns	80 MHz Guard Interval 400ns	160 MHz Guard Interval 800ns	160 MHz Guard Interval 400ns
2	0	BPSK	1/2	13	14.4	27	30	58.5	65	117	130
	1	QPSK	1/2	26	28.9	54	60	117	130	234	260
	2	QPSK	3/4	39	43.3	81	90	175.5	195	351	390
	3	16-QAM	1/2	52	57.8	108	120	234	260	468	520
	4	16-QAM	3/4	78	86.7	162	180	351	390	702	780
	5	64-QAM	2/3	104	115.6	216	240	468	520	936	1040
	6	64-QAM	3/4	117	130	243	270	526.5	585	1053	1170
	7	64-QAM	5/6	130	144.4	270	300	585	650	1170	1300
	8	256-QAM	3/4	156	173.3	324	360	702	780	1404	1560
	9	256-QAM	5/6	*	*	360	400	780	866.7	1560	1733.3
3	0	BPSK	1/2	19.5	21.7	40.5	45	87.8	97.5	175.5	195
	1	QPSK	1/2	39	43.3	81	90	175.5	195	351	390
	2	QPSK	3/4	58.5	65	121.5	135	263.3	292.5	526.5	585
	3	16-QAM	1/2	78	86.7	162	180	351	390	702	780
	4	16-QAM	3/4	117	130	243	270	526.5	585	1053	1170
	5	64-QAM	2/3	156	173.3	324	360	702	780	1404	1560
	6	64-QAM	3/4	175.5	195	364.5	405	*	*	1579.5	1755
	7	64-QAM	5/6	195	216.7	405	450	877.5	975	1755	1950
	8	256-QAM	3/4	234	260	486	540	1053	1170	2106	2340
	9	256-QAM	5/6	260	288.9	540	600	1170	1300	*	*

Cisco live!

Expected 802.11ac Client Throughput (take-away)

1 stream (80MHz) is 433 Mbps
2 stream (80MHz) is 866 Mbps
3 stream (80MHz) is 1300 Mbps

(Now let's drop it to ~70% MAC

BW (MHz)	#Spat Strm	MCS (QAMr5/6)	PHY rate (Mbps)	MAC thruput (Mbps)*
80	1	64	290*	210
80	1	64	330	230
80	1	256	430	300
80	2	64	650	460
80	2	256	870	610
80	3	64	980	680
80	3	256	1300	910

802.11ac Performance Table

What's the real expected throughput?*
*** Assumes 70% MAC efficiency**

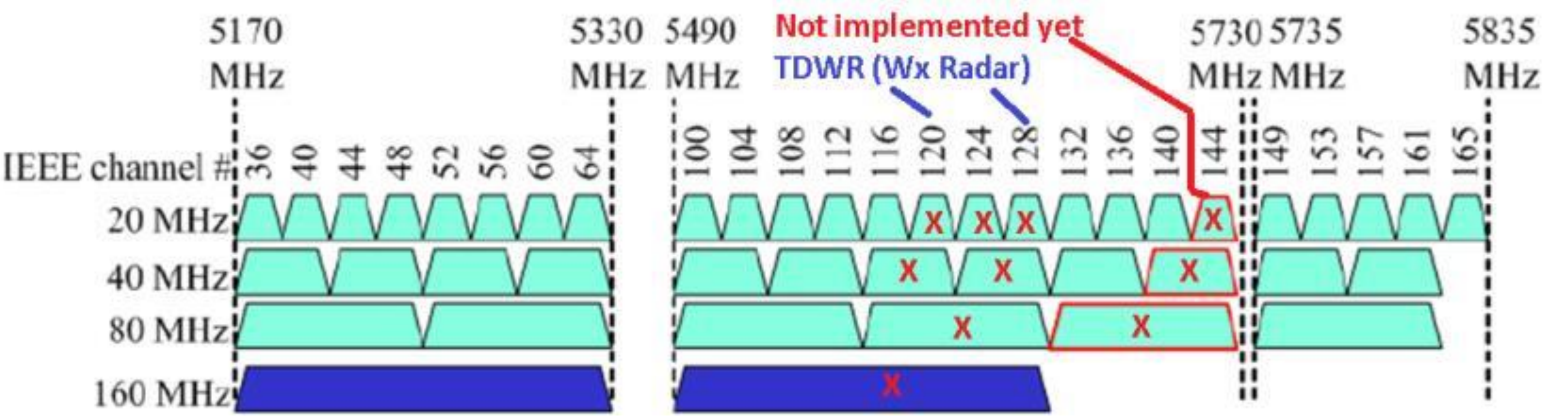
Smartphones from 210 Mbps*

Tablets from 460 Mbps*

High End Laptops from +680 Mbps*

Let's talk about 802.11ac - How is it like .11n?

US- Theater – FCC channel allocation plan

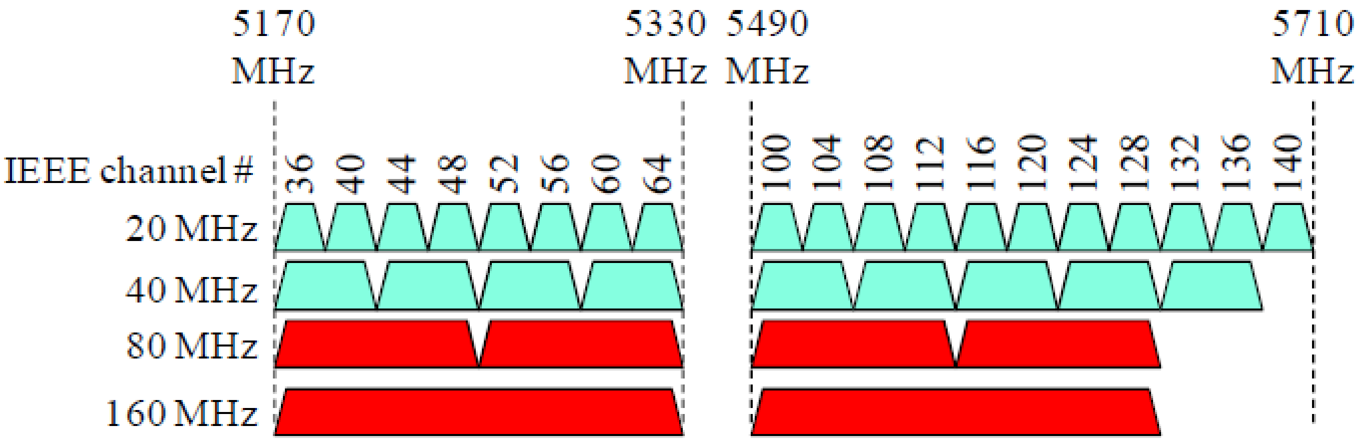


The 80 MHz channel uses two adjacent, non-overlapping 40 MHz channels. The 160 MHz (Wave-2) may be formed by adjacent or non-contiguous channels. TDWR channels not available today.

Note: **Channel 144 (in red) is new** and likely more channels will be allocated in 5 GHz to hopefully allow for more than two channels @ 160 MHz (Wave-2) depending on the frequencies they may not be adjacent

Let's talk about 802.11ac - How is it like .11n?

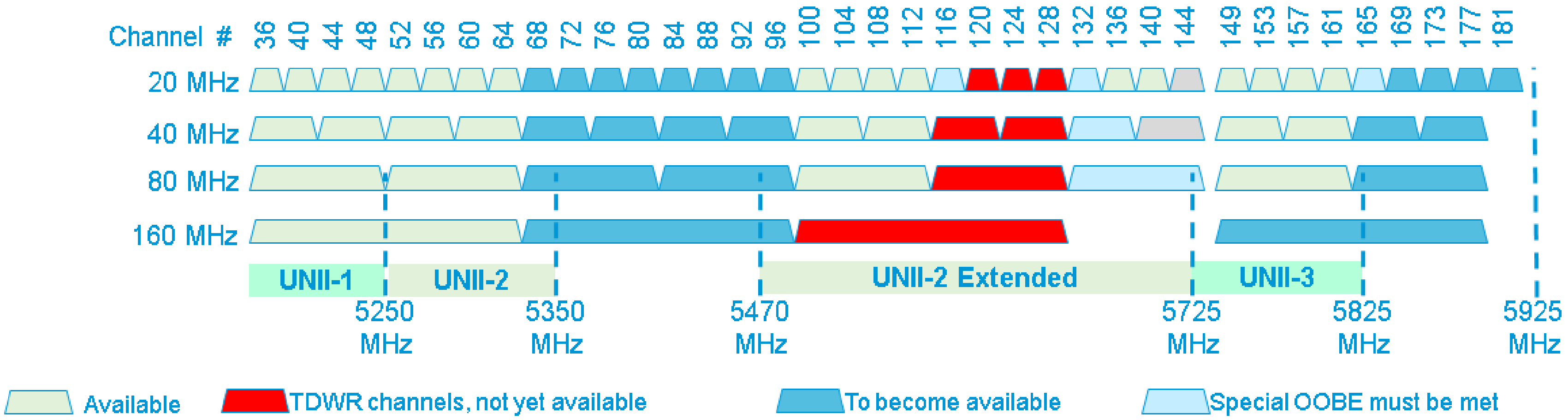
ETSI and Japan channel allocation plan



80 MHz bonding (Wave-1) 160 MHz (Wave-2)

Note: Efforts are underway globally to expand the number of channels in the 5 GHz band. China probably is progressing a bit quicker then others but everyone sees the need.

What's the Plan to get More Channels (future)



- In the US there are currently 22/10/5/1 channels with bandwidth 20/40/80/160MHz channels
- With opening up of 5.35-5.47GHz & 5.85-5.925GHz, the number of channels increases to 34/16/8/3
- If the industry manages to take back the TDWR channels, the number of increases to 37/18/9/4

Since we are talking about the future (Wave-2)

What are likely to be the minimum requirements?

(Wave-2) Minimum requirements for enterprise will likely include: 256-QAM, 3-SS and 160 MHz

- **For Wave 2, initially it is expected that 160 MHz devices will appear with 1-3SS (typical) with perhaps 4-SS supported with likely data rates of 867-2600 Mbps.**
- **Likely data rates up to 3.5 Gbps PHY and over 2 Gbps MAC (IEEE approval late 2013)?**
- **Will require faster than GigE speeds requiring either 10GbE or perhaps two GbE cables / hybrid**

Future proofing new installations (cabling considerations)

- **A single GbE cable is fine for (Wave-1)**
- **Wave-2 will exceed GbE speeds so for now, it is recommended for new installs requiring Wave-2 that you pull two CAT6a cables until this standard is better defined.**
- **A pair of CAT6a cables allows you to fall back to using 2 GbE ports for some iterations of (Wave-2) if required. If the second cable isn't needed it can be used to bring the console port back.**
- **CAT5e cables may be used or one of each for cost savings but not for 10GbE.**

Choosing the Right Access Point Model Integrated or External Antennas?

Access Point Portfolio

Cisco – Aironet 802.11n + 802.11ac

Access Point Portfolio
Cisco – Aironet Second Generation Access Points

AP-3600 with 802.11ac Module

Cisco – Aironet 3600 + AC module

- Field-upgradable 802.11ac module for the 3600 Series, enables a seamless migration to next generation wireless
  - No rip and replace of APs, power down, plug-in the module and go!
- 802.11ac Wave-1, 5 GHz Module
  - 1.3 Gbps PHY (80 MHz @ 3SS)
  - 3 Spatial Streams, 20/40/80 MHz channels, 256 QAM
  - Explicit Beam Forming support as per the 802.11ac specification
- AP3600 operates 3 active radios, 2.4 and 5 GHz integrated and the 802.11ac 5 GHz module
  - Supporting b/g/n on 2.4 GHz and a/ac/n on 5 GHz
- 18w of Power required for the 3600 with the 802.11ac Module installed
  - Power draw with 802.11ac Module exceeds 15.4 Watts (802.3af), and will require either Enhanced PoE, 802.3at PoE+, Local Supply or Power Injector 4
- Universal Mounting Brackets (Bracket-2) required, or Ceiling Mounting Brackets (Bracket-3)

3600 AC MODULE P/N
AIR-RM3000AC-x-K9=
AIR-RM3000ACxK910= (10 pack)

WSSI (monitor) MODULE P/N
AIR-RM3000M=
AIR-RM3000M-10= (10 pack)

Integrated Antenna? – External Antenna?

Carpeted areas

Integrated antenna versions are designed for mounting on a ceiling (carpeted areas) where aesthetics is a primary concern

Rugged areas

Use for industrial applications where external or directional antennas are desired and or applications [requiring higher temperature ranges]

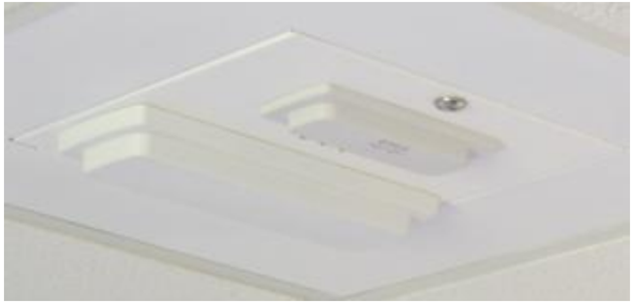
When to Use Integrated Antennas

- **When there is no requirement for directional antennas and the unit will ceiling mounted**
- **Areas such as enterprise carpeted office environments where aesthetics are important**
- **When the temperature range will not exceed 0 to +40C**

When to Use External Antennas

Reasons to consider deploying a rugged AP

- When Omni-directional coverage is not desired or greater range is needed
- The environment requires a more industrial strength AP with a higher temperature rating of -20 to +55 C (carpeted is 0 to +40 C)
- The device is going to be placed in a NEMA enclosure and the antennas need to be extended
- You have a desire to extend coverage in two different areas with each radio servicing an independent area - for example 2.4 GHz in the parking lot and 5 GHz indoors
- Requirement for outdoor or greater range Bridging application (aIOS version)
- Requirement for WGB or mobility application where the device is in the vehicle but antennas need to be mounted external



Rugged AP in ceiling enclosure

Outdoor–rated APs Used for Indoor Applications

- **Harsh environmental conditions (e.g. refrigerated rooms, condensing humidity…)**
- **12V DC powered or 100-480V AC**
- **ATEX Class I Division 2 (potentially explosive areas)**

1552e

Dual Band Omni
AIR-ANT2547V-N=

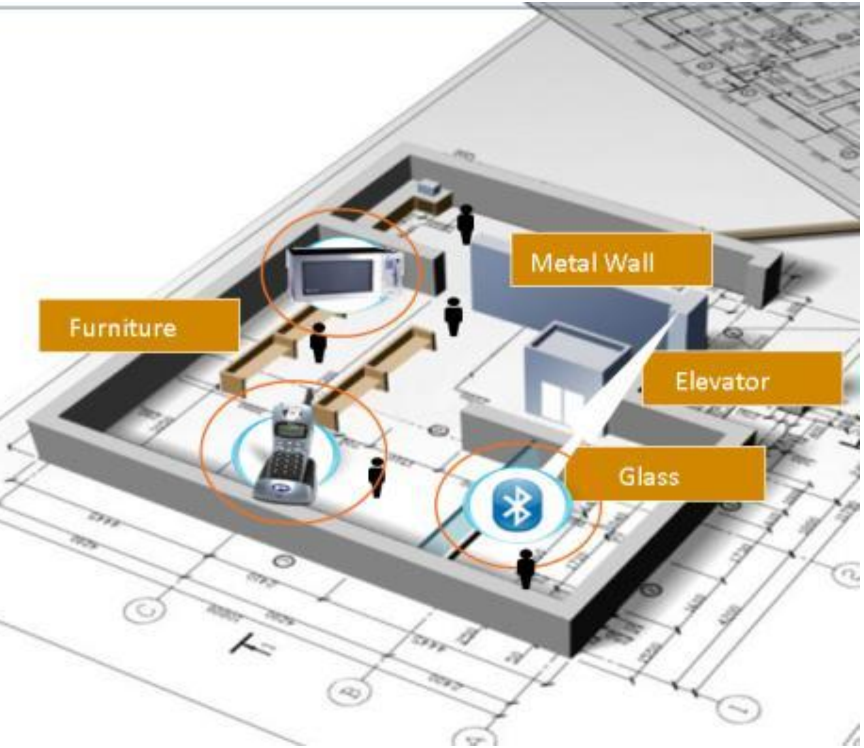
1552i (Integrated Ant)




Installation and Deployment Considerations

Site Survey Prepares for 802.11n

- Recommended to optimize 11n deployment
- Survey reveals effects of building characteristics on the wireless spectrum
- Measure RF variations due to human activity and time of day
- Survey with client types that you plan to implement (11n, 11abg, VoIP, location tags)
- Spectrum intelligence to detect interference



Access Point Placement (Legacy a/b/g)

ABG Access Point Placement

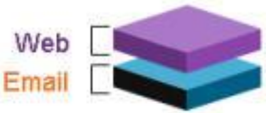
1 per 5,000 sq feet for data only

1 per 3,000 sq feet for voice, location

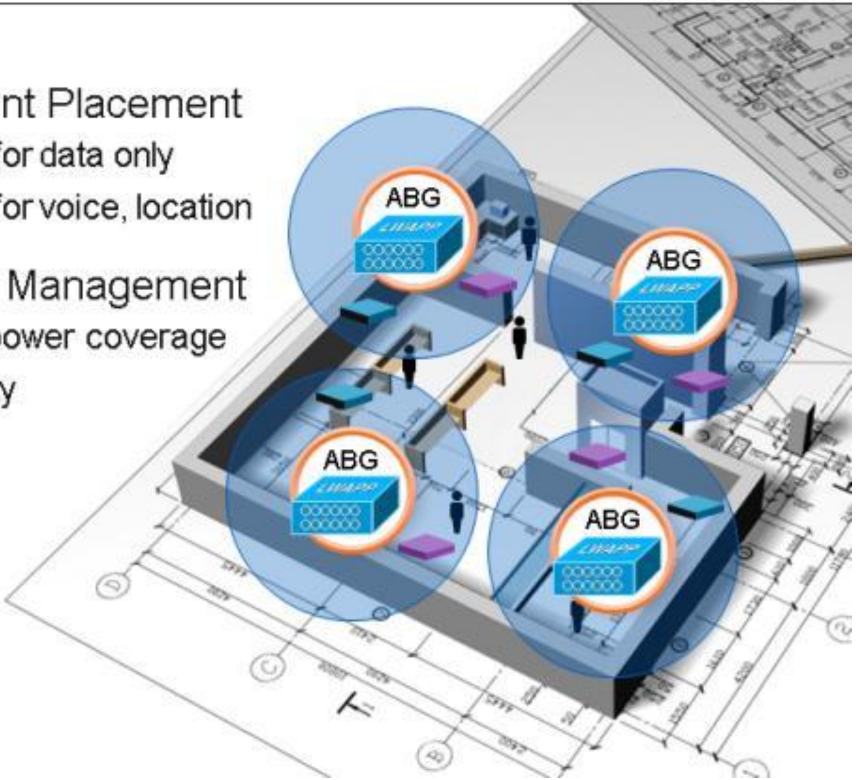
Radio Resource Management

Adaptive channel / power coverage

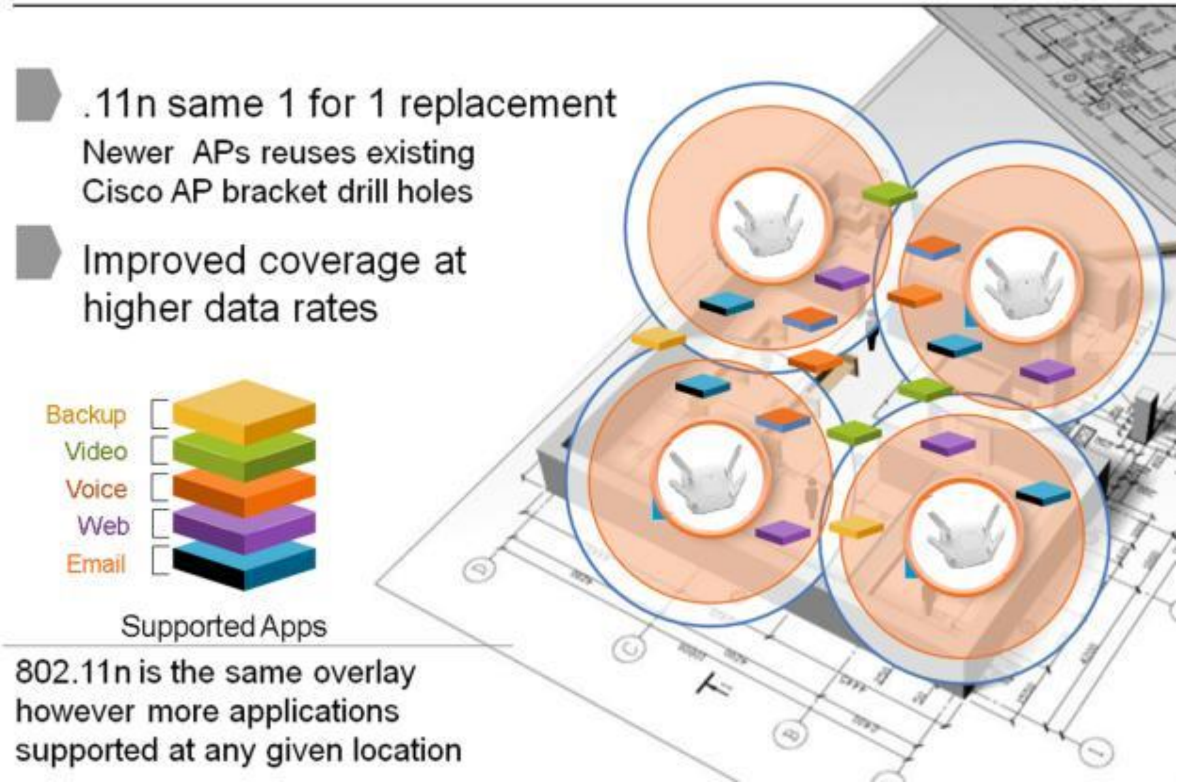
Operational simplicity



Several Supported Apps

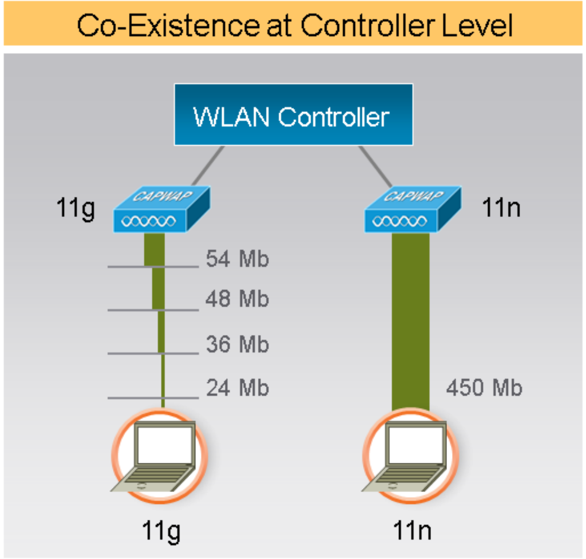


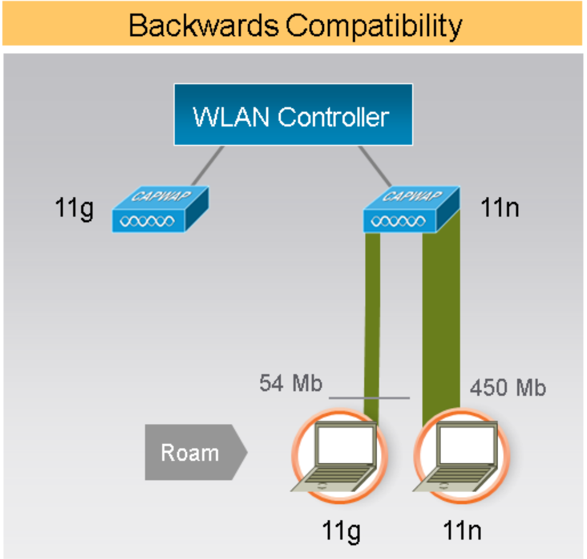
Access Point Placement (802.11n)



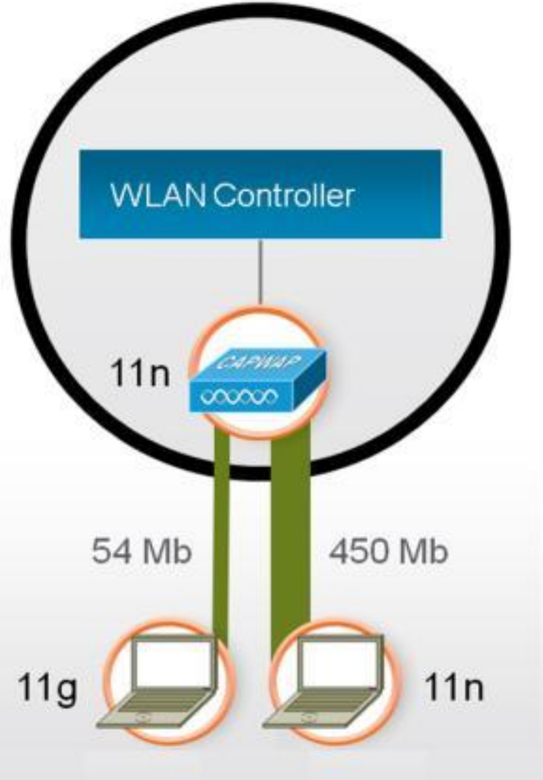
802.11n Support, Backward Compatibility and Co-existence

- Co-existence of ABG/N APs
- Benefits of 11n accrued to ABG clients
  - MIMO benefits ABG clients on the AP receive side from MRC
  - MIMO benefits AG clients on the AP transmit side from ClientLink



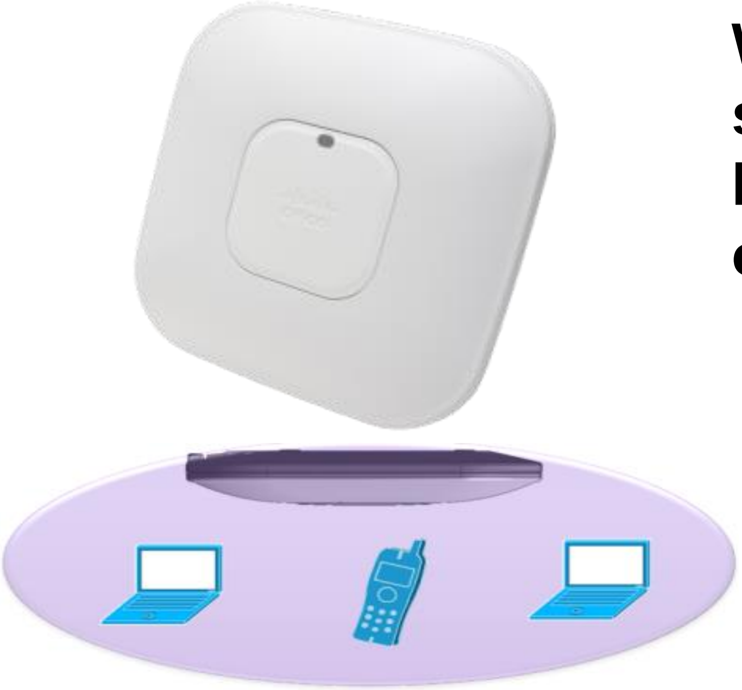


Mixed Mode Performance

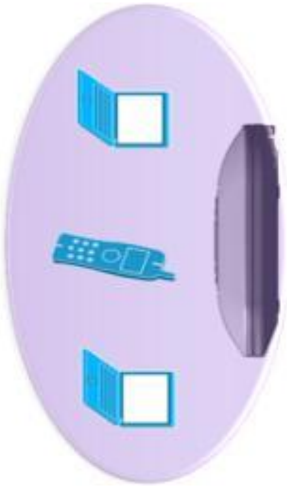


- 3 Modes of operation supported
  - Legacy
  - Mixed
  - Green Field
- Mixed mode experiences slight performance impact due to ABG clients
- 11n clients still transmit at full performance
- PHY and MAC for 11n provides co-existence and protection for ABG clients
- Note: Green Field not supported on Cisco Enterprise WLAN

Wall Mounting Access Point with Internal Antennas



Wall mounting is acceptable for small deployments such as hotspots, kiosks, transportation or small coverage areas.



Note: Wall mounting may create unwanted coverage areas on the floor above or below - This is not desirable for voice as it may cause excessive roams and is directional as metal is behind the antennas (backside).

Coverage is always <u>more uniform</u> when installed on the ceiling tile or grid area

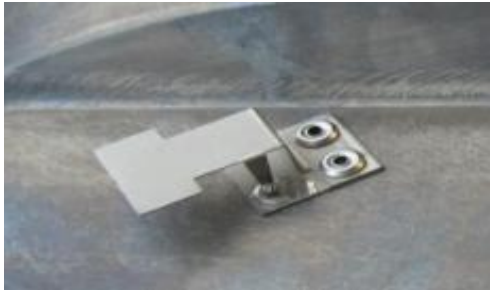
Access Points 3500i

Designed Primarily for Ceiling (Carpeted) Installations

AP-3500 Access Point has six integrated 802.11n MIMO antennas

4 dBi @ 2.4 GHz

3 dBi @ 5 GHz

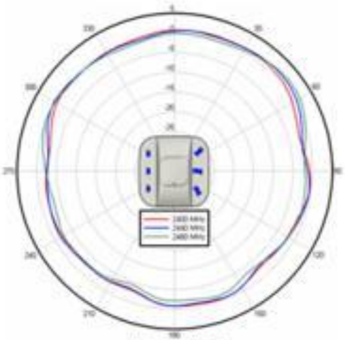


Note: Metal chassis and antennas were designed to benefit ceiling installations as the signal propagates downward in a 360 degree pattern for best performance

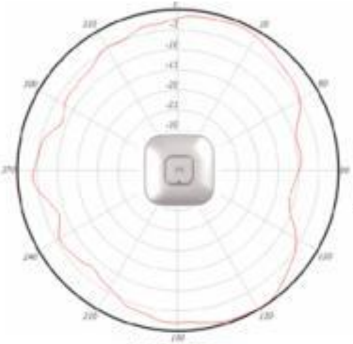
Antenna Patterns – Internal Access Points

Azimuth and Elevation Patterns for 2.4 GHz & 5 GHz

2.4 GHz Azimuth



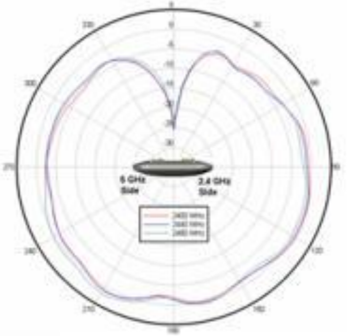
Azimuth Plane Patterns

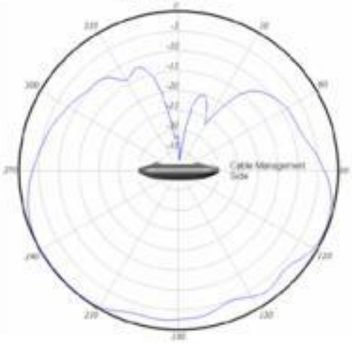


Azimuth Plane Patterns

5 GHz Azimuth

2.4 GHz Elevation





5 GHz Elevation

Access Points 3600 with Module Installed

Designed Primarily for Ceiling (carpeted) installations

AP-3600 antenna system with module installed

This shows how the module antennas are extended into the radiation ground plane for best performance

Module antennas (top) extend next to the four dual band integrated antennas

Wall Mounting AP-1260, 3500e & 3600e

Orientation of the Dipoles if Wall Mounting

Note: The ceiling is usually higher and a better location for RF.

If using advanced features like location or voice try to locate the AP on the ceiling, or when mounting the AP on a wall orient the dipoles in this configuration.

Because dipoles on a wall can easily get orientated wrong as people touch and move them. Better still might be to use a Patch antenna or use the Oberon wall bracket. Be aware walls can add directional properties to the signal as they can have wiring, metal 2x4 construction and the wall attenuates the signal behind the AP limiting a nice 360 degree coverage.

Aironet 802.11n Wall Mount (Style Case)

Third Party Wall Mount Option is Available

This optional wall mount best positions the Access Point dipoles for optimum performance – Recommended for Voice applications If you MUST mount the Access Point on a wall.

Ceiling is a better location as the AP will not be disturbed or consider using patch antennas on wall installations

Oberon model 1029-00 is a right angle mount works with "I" and "e" models

http://www.oberonwireless.com/WebDocs/Model1029-00_Spec_Sheet.pdf

What About Mounting Options?

Different Mounting Options for Ceiling APs

Cisco has options to mount to most ceiling rails and directly into the tile for a more elegant look

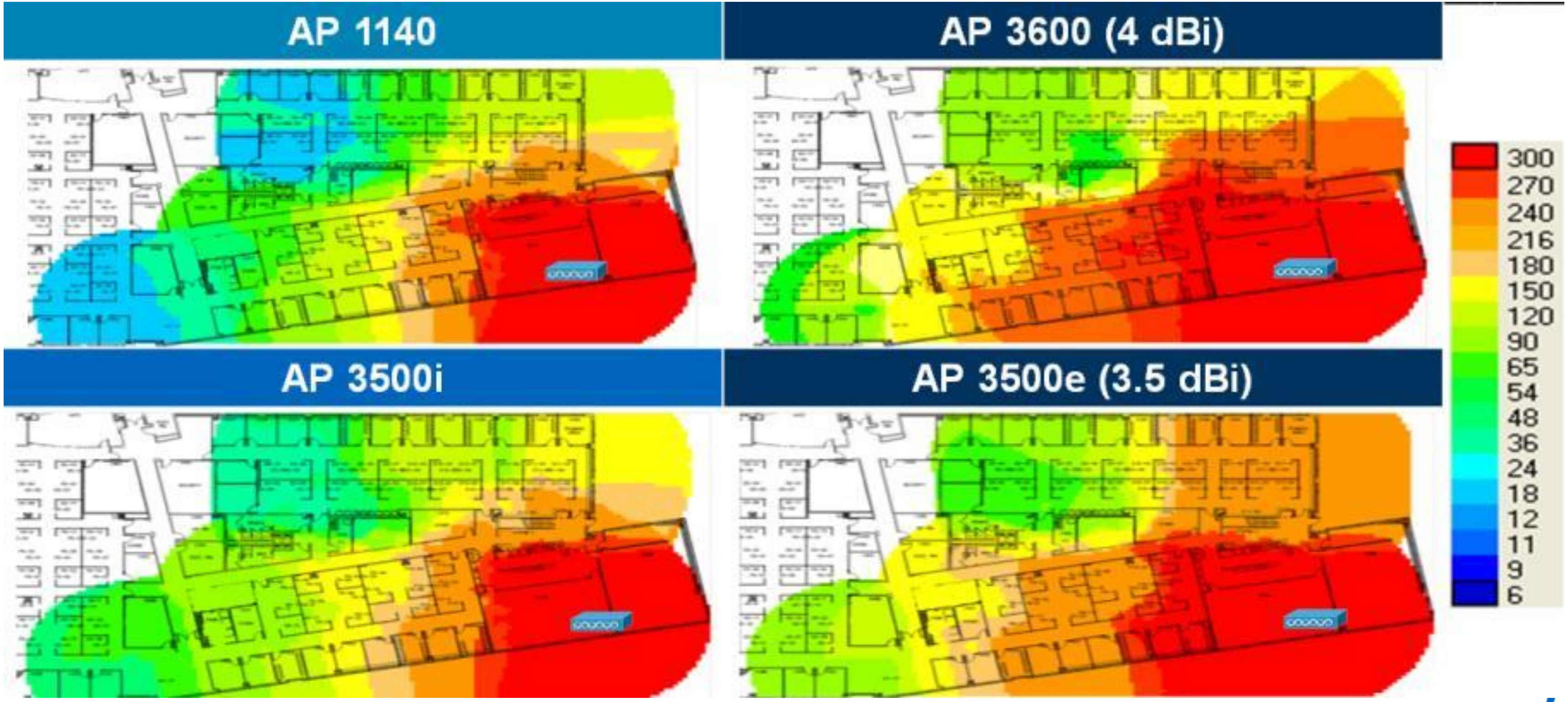
Locking enclosures and different colour plastic “skins” available from third party sources such as

www.oberonwireless.com

www.terrawave.com

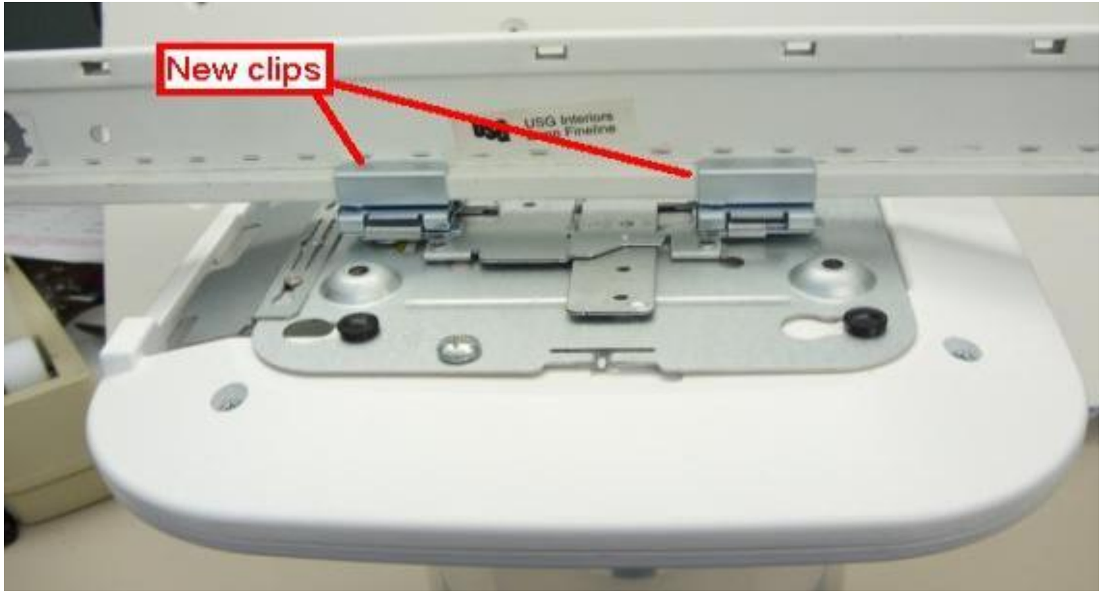
Access Point Coverage Comparison

5-GHz up to MCS15



Clips Adapt Rail to "T" Bracket.

Attaching to Fine Line Ceiling Rails

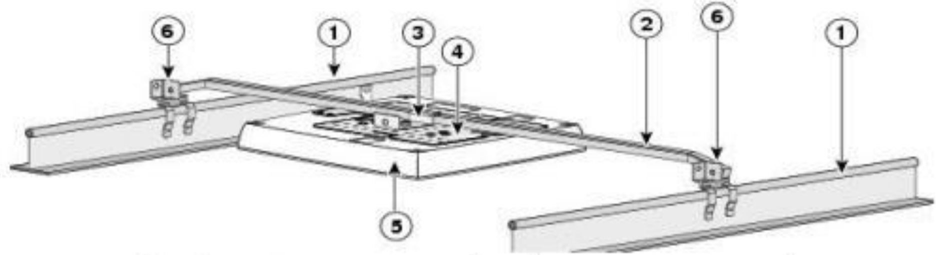


If the ceiling rail is not wide enough or too recessed for the "T" rail this can be addressed using the optional clips

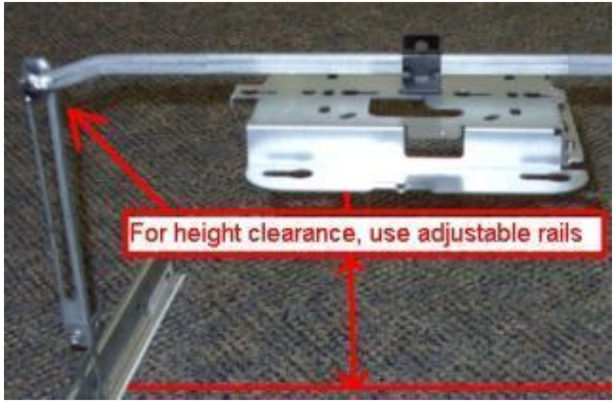
Part Number for ceiling clips is AIR-ACC-CLIP-20=
This item is packaged in 20 pieces for 10 Access Points

Installation Above the Ceiling Tiles
An Optional Rail Above the Tiles May Be Used

T-Bar Grid Mounting Bracket Parts



1	Suspended ceiling T-rail	4	Optional mounting bracket
2	T-bar box hanger	5	Access point
3	Bracket mounting clip	6	T-rail clip



Note: The AP should be as close to the tile as practical

AP bracket supports this optional T-bar box hanger item 2 (not supplied) Such as the Erico Caddy 512 or B-Line BA12

AP Placement Above False Ceiling Tiles Areas

- When placing the Access Point above the ceiling tiles (Plenum area) Cisco recommends using rugged Access Points with antennas mounted below the Plenum area whenever possible
- Cisco antenna have cables that are plenum rated so the antenna can be placed below the Plenum with cable extending into the plenum
- If there is a hard requirement to mount carpeted or rugged Access Points using dipoles above the ceiling – This can be done however uniform RF coverage becomes more challenging, especially if there are metal obstructions in the ceiling
- Tip: Try to use rugged Access Points and locate the antennas below the ceiling whenever possible

Integrated Ceiling Mount – Public Areas

Flush mount bracket part number is **AIR-AP-BRACKET-3**

This is a **Cisco factory bracket** that can be specified at time of order

Full strut on right provides support across two ceiling rails

Making it ideal for safety in (earthquake prone areas)

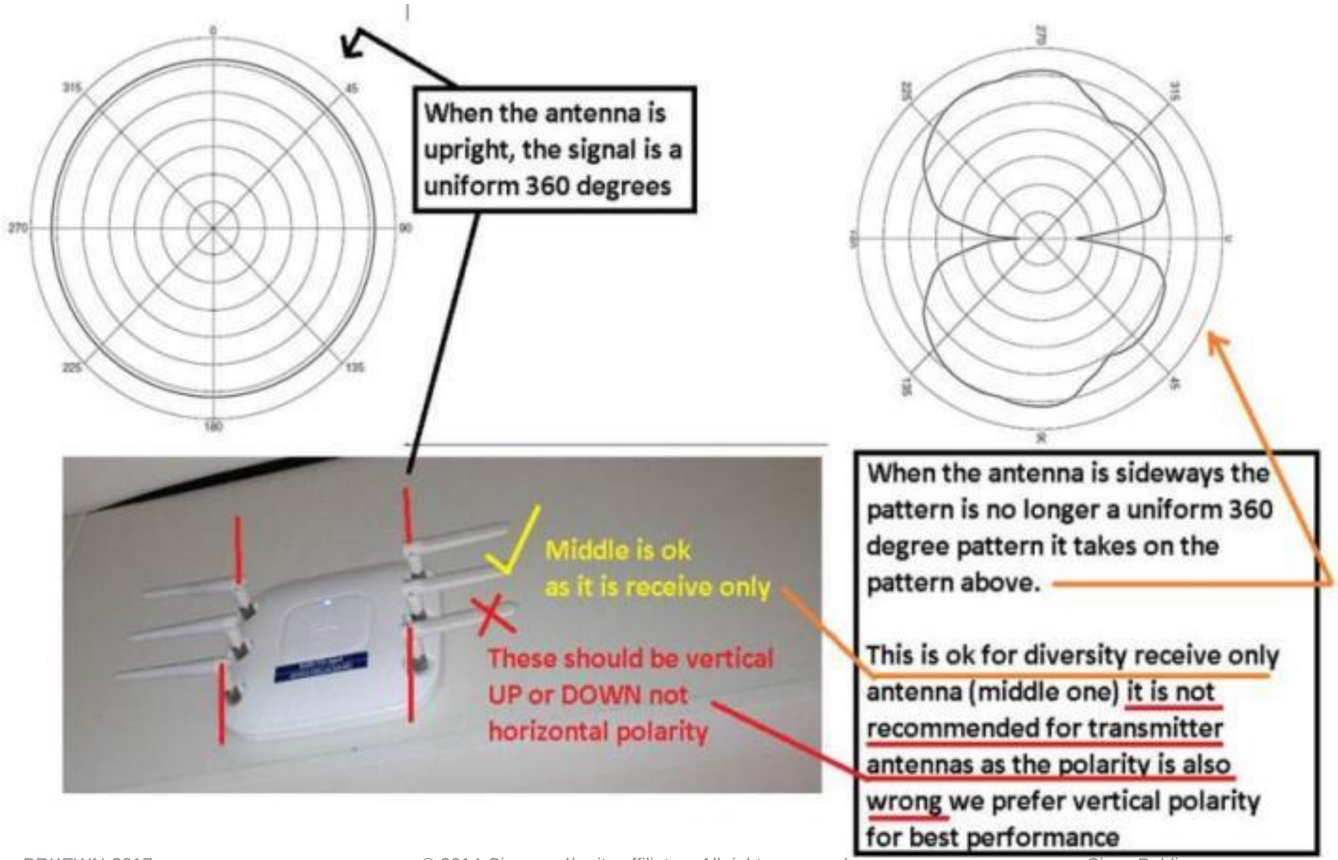
Antenna Placement Considerations

- AP antennas need placements that are away from reflective surfaces for best performance
- Avoid metal support beams, lighting and other obstructions.
- When possible or practical to do so, always mount the Access Point (or remote antennas) as close to the actual users as you reasonably can
- Avoid the temptation to hide the Access Point in crawl spaces or areas that compromise the ability to radiate well
- Think of the Access Point as you would a light or sound source, would you really put a light there or a speaker there?

Never mount antennas near metal objects as it causes increased multipath and directionality

Wall Mounting AP-1260e, 3500e & 3600e

Orientation of the Dipoles if Wall Mounting



Wall Mounting AP-1260e, 3500e & 3600e

Orientation of the Dipoles if Wall Mounting

Dipoles pointing UP or Down are in vertical polarity

This is ideal for uniform coverage.

Dipoles pointing sideways are in horizontal polarity

Note: Cisco recommends transmitting antennas use vertical polarity




A look at some installations that went wrong

Installations that went wrong

NEVER EVER MIX ANTENNA TYPES

Antennas should always cover the <u>same RF cell</u>

<u>watch polarity</u>

Above Ceiling Installs that went wrong

Yes it Happens and When it Does it is Expensive to Fix and No One is Happy

Dipole antennas up against a metal box and large metal pipes. This creates unwanted directionality and multipath distortion – This also creates nulls (dead areas) and creates packet retries

When a dipole is mounted against a metal object you lose all Omni-directional properties.

It is now essentially a directional patch suffering from acute multipath distortion problems.

Add to that the metal pipes and it is a wonder it works at all

Tip: Access Points like light sources should be in the clear and near the users

Above Ceiling Installs that went wrong

Huh?? You Mean it Gets Worse?

Other Installations that went wrong

Ceiling mount AP mounted on the wall up against metal pipe (poor coverage)

Outdoor NEMA box not weatherised (just keeping the packets on ice)

Installations that went wrong

Patch antenna shooting across a metal fence
Multipath distortion causing severe retries

Mount the box horizontal and extend the antennas down and not right up against the metal enclosure

Installations that went wrong

Sure is a comfy nest –

Glad this model runs pretty warm

Installations that went wrong - mesh

GOOD INSTALL

Installations that went wrong - mesh

Installations that went wrong - mesh

Building aesthetics matters – Antennas obstructed

Outdoor Weatherproofing

www.coaxseal.com

Coax-Seal can be used with or without electrical tape.

Taping first with a quality electrical tape like Scotch 33+ vinyl allows the connection to be taken apart easier.

Many people tape then use Coax-Seal then tape again this allows easy removal with a razor blade.

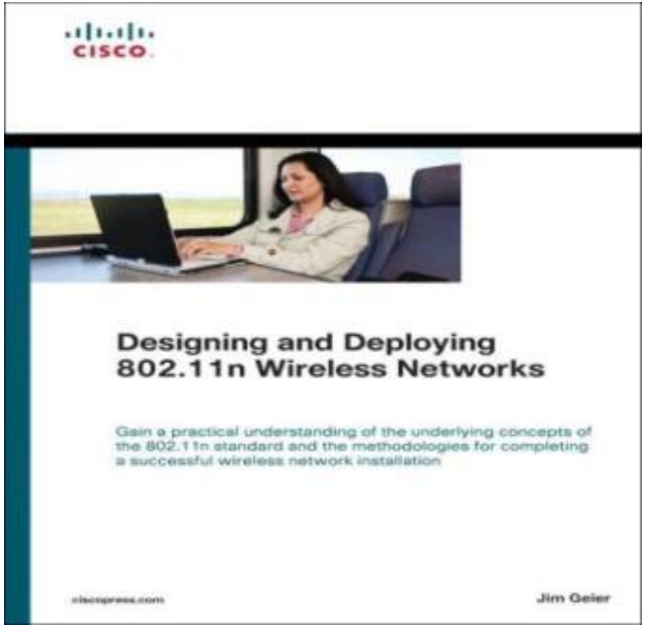
Note: Always tape from the bottom up so water runs over the folds in the tape. Avoid using RTV silicone or other caustic material.

Summary

- Cisco provides well engineered Access Points, Antennas, and Radio Resource Management features in the controllers
- However, you need to understand the general concepts of Radio, otherwise, it is very easy to end up implementing a network in a sub-optimal way – Whenever possible; verify coverage and mount the APs as close to the users as practical / possible

"RF Matters"

Recommended Reading



Also see the Cisco AP deployment guide at this URL

http://www.cisco.com/en/US/docs/wireless/technology/apdeploy/2600_2600_3600_DG.pdf




Q & A

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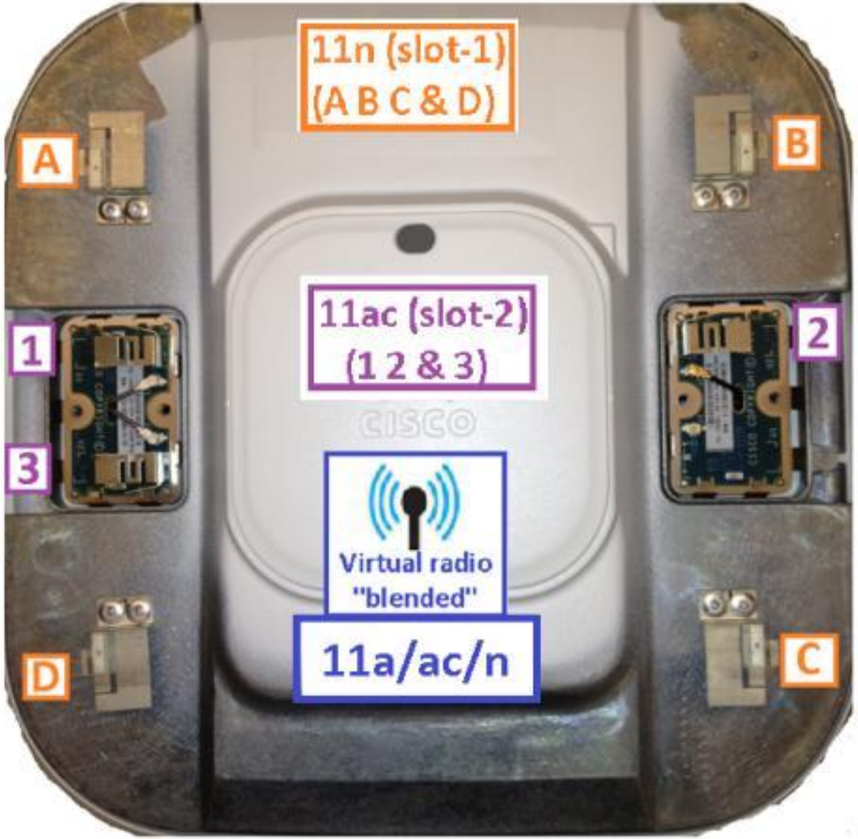
Reference Slides

Radio Antenna Identification…



Working as ONE virtual radio

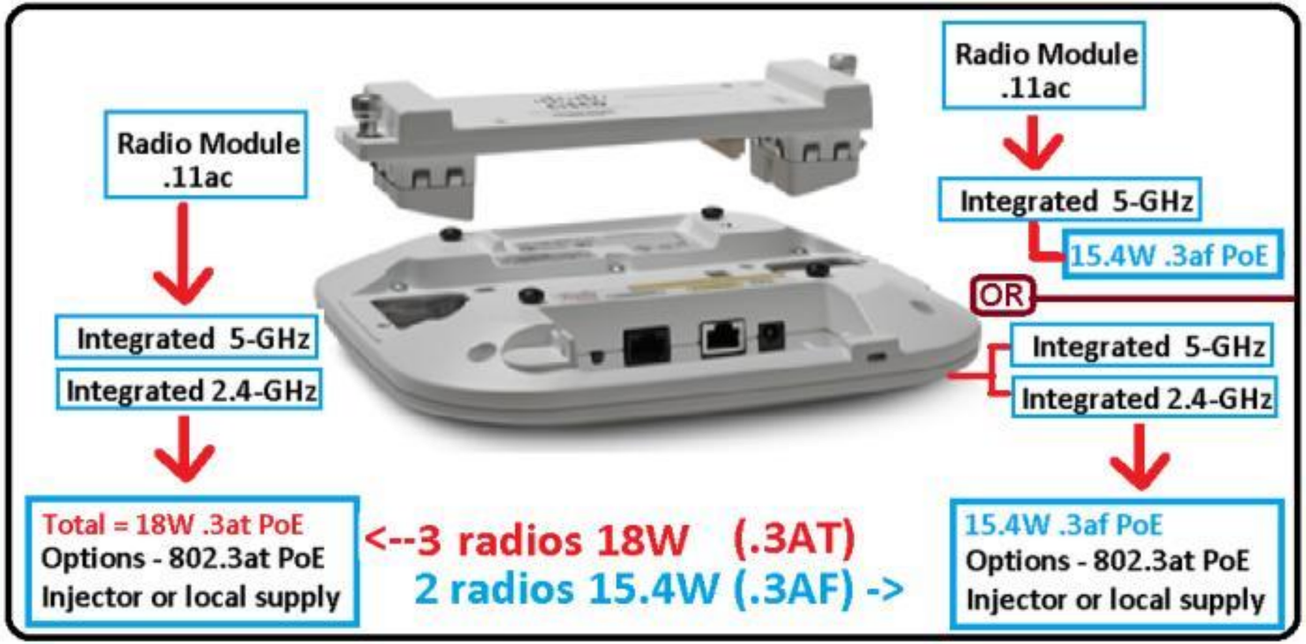
Radios work together in tandem (blended) to maintain proper radio isolation and performance

Three Separate and Discrete Radios…

The two 5-GHz radios (integrated and module) **work in TANDEM and use same SSIDs** so they do not compete with each other. They work in concert to support same channels (with internal radio taking lead on frequency selection) and the module performing the AC “overlay”

AP has a dual-core uP with the radio module on one core supporting up to 50 .11ac clients

Power over Ethernet – AC Radio Module



To get the module running on .3af PoE (15.4W) it is possible to disable the 2.4 GHz radio & restart.

AIR-PWR-INJ5 (PoE) Injector

Does not support three radios

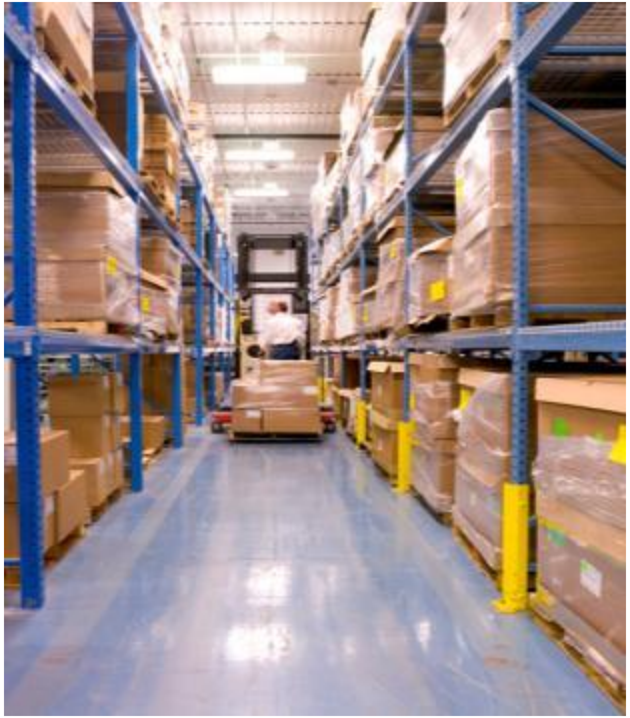
Use injector - 4

All 3 radios (module + 2 internal radios) requires 18W (802.3at) source "PoE +"

If the switch doesn't support this - the module will be disabled by (default) until a proper source of power is applied such as PoE injector Cisco AIR-PWR-INJ4 or local 48VDC supply AIR-PWR-B

Warehouse Design

As Stock Levels Change so Does Coverage



You can suspend an AP from the ceiling or use patch or Yagi on walls

Warehouse Design

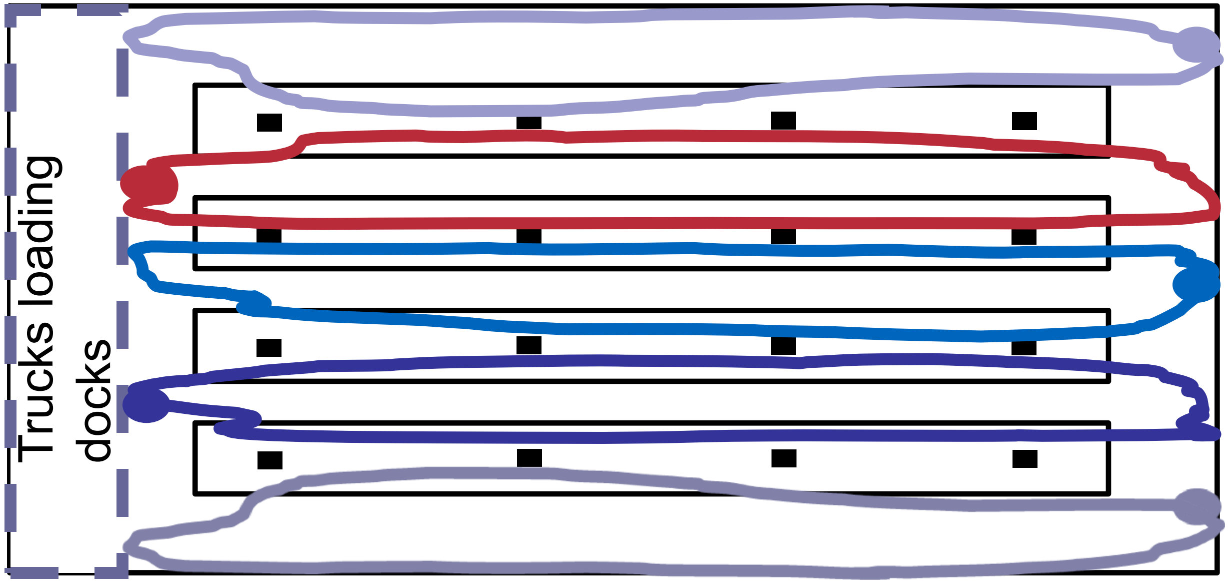
As Stock Levels Change so Does Coverage

Maximum Tx power

Patch or Yagi antennas

Easy power

Easy Ethernet drop



Null spots have to be corrected

Warehouse Design

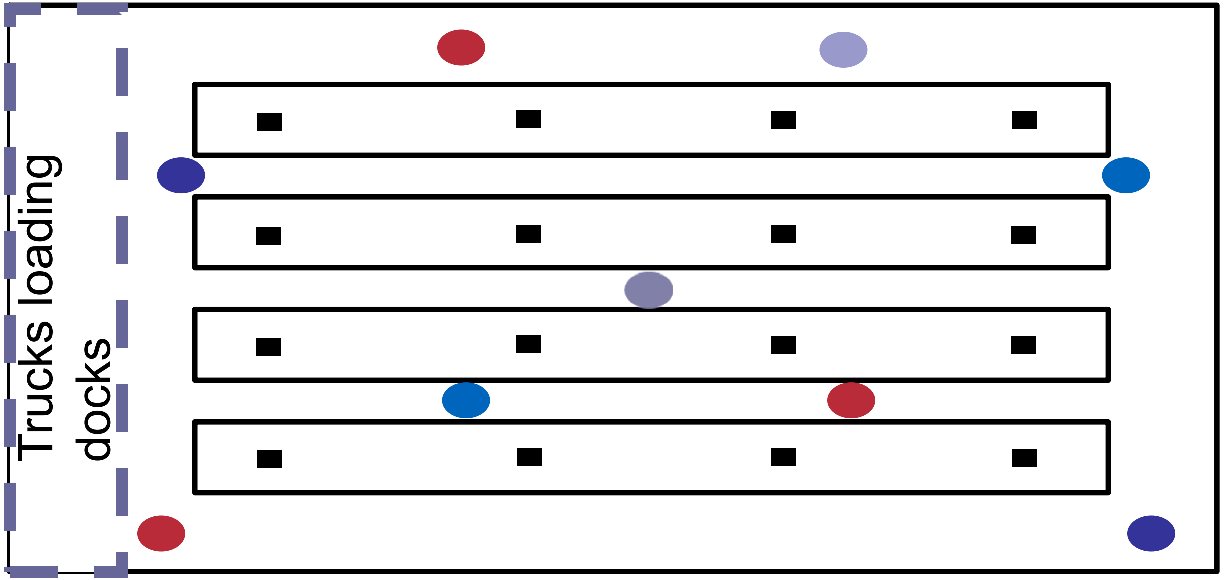
As Stock Levels Change so Does Coverage

Reduced Tx power (RRM)

Omni directional antennas

More APs (+ power drops)

AP wire distance to nearest switch



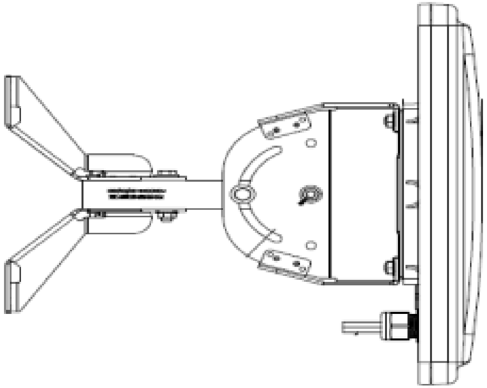
Can difficult to deploy - Placement of APs can be cumbersome

Stadium and Sporting Venues

AIR-CAP3502P-x-K9 and AIR-ANT25137-R=

- Program to release a new 3500e “style” of AP that is certified for use with a higher gain antenna
- Program includes design and development of a new high gain antenna to go with the AP
  - Aesthetically pleasing
  - Single radome for both 2.4 and 5 GHz elements

AIR-CAP3502P-x-K9

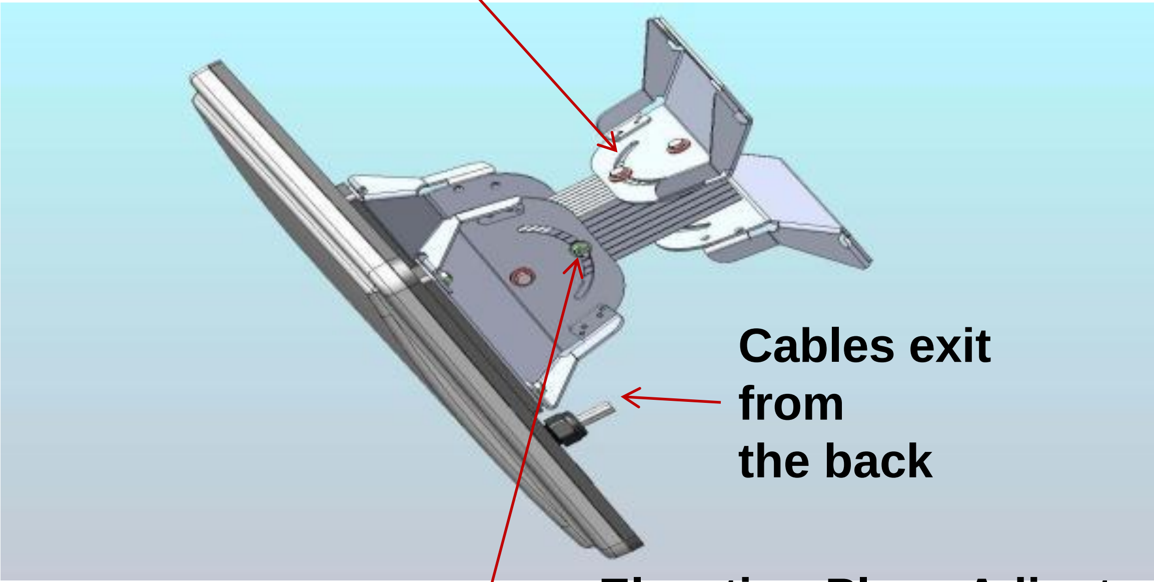


AIR-ANT25137-R=

Stadium Designs

Stadium Antenna is Cisco (AIR-ANT25137NP-R=)

Azimuth plane adjustment +/- 20 degrees



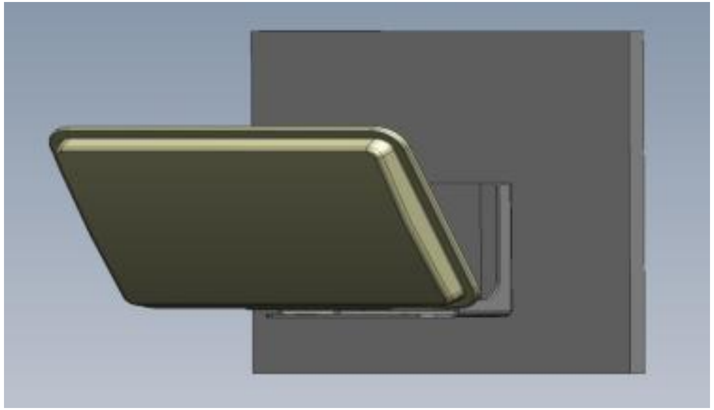
Cables exit from the back

Elevation Plane Adjustment, +/- 60 degrees

Was there a Need for this Antenna?

Yes, part of the problem was the 3500 Series was limited to antenna gains of 6 dBi so we needed a special model AP that could use higher gain antennas (AP-3502P)

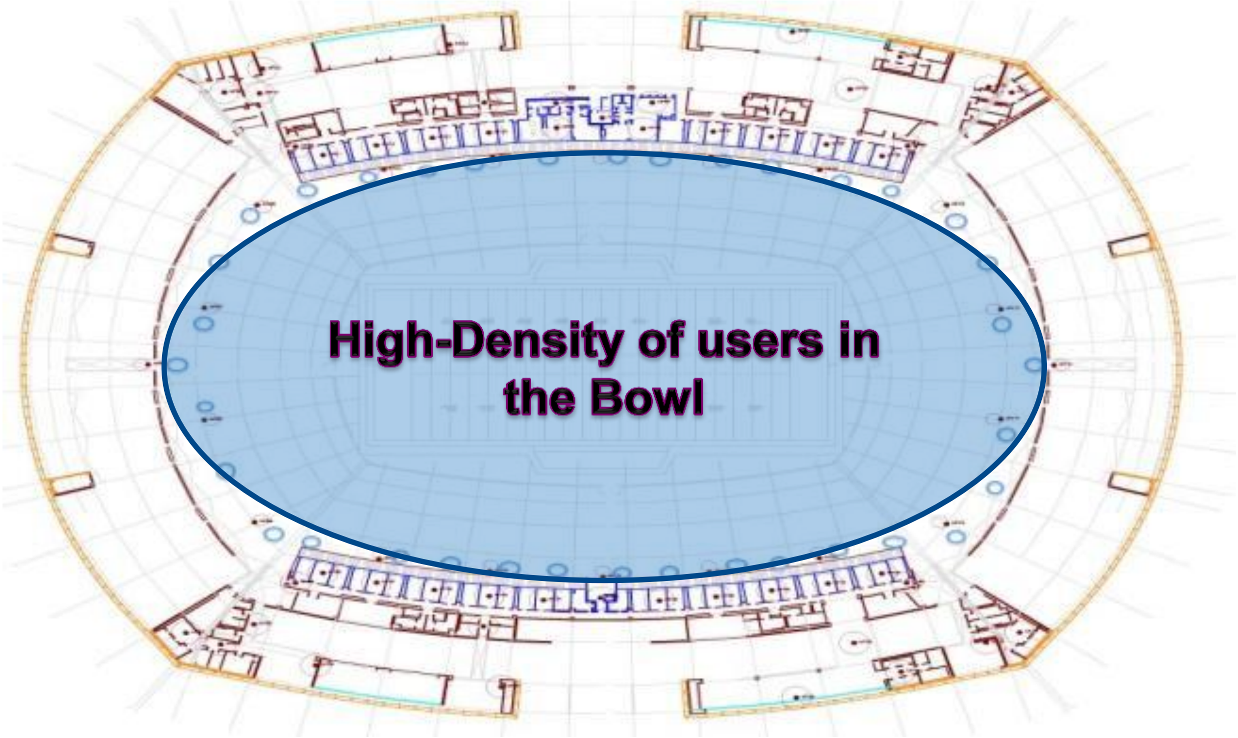
Discrete antennas for 2.4 GHz and 5 GHz were unsightly and was labor intensive to mount and align.



Similar performance designed into one housing that supports both 2.4 and 5 GHz MIMO antennas

High-Density Design - Bowl

- ✓ Coverage area divided into cells to support anticipated number of users
- ✓ Directional antennas create WLAN cells within seating areas
  - Lower power, interference
- ✓ Down-tilt to control the vertical RF beam width
  - Lower interference
- ✓ Design and install 2.4 GHz and 5 GHz



Bowl Seating RF Cell Footprint

- Overlapping cells should use non-overlapping channels (3 non-overlapping channels in the 2.4 GHz domain)
- Radio Resource Management (RRM) automatically sets the AP channel and power
- Limitations on where APs can be mounted and pointed influences cell coverage