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Your Time Is Now

Understanding RF Fundamentals and the radio design of Wireless .11n/ac Networks

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Cisco Wireless Networking Group

Session code – BRKEWN-2017

Cisco EDCS-1570628

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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 centers, 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
- Understanding fundamentals of, Beam-forming and Cisco ClientLink
- Basic understanding of 802.11n and 802.11ac fundamentals including MIMO, MU-MIMO, Channel bonding, Multi-path, Spatial Streams, etc.
- Installation challenges, when to use different APs – avoiding potential problems

What We Won’t Be Covering

- Wireless Security (dedicated sessions for that)
- Clean Air (separate sessions for that)
- wIDS/wIPS (Wireless Intrusion Prevention Systems)
- High density deployments (separate session for that)
- LBS (Location Based Services) or Context Aware / CMX
- Walled garden, captive portals
- SP Wi-Fi, 3G/4G offload and Passpoint
- WLAN management (Cisco Prime)
- 802.11n/ac going beyond RF characteristics

What is **RF?**

Wi-Fi name & timeline
Radio Frequency Principles &
How did we get on these channels?

Why is it called Wi-Fi? Where did it come from?

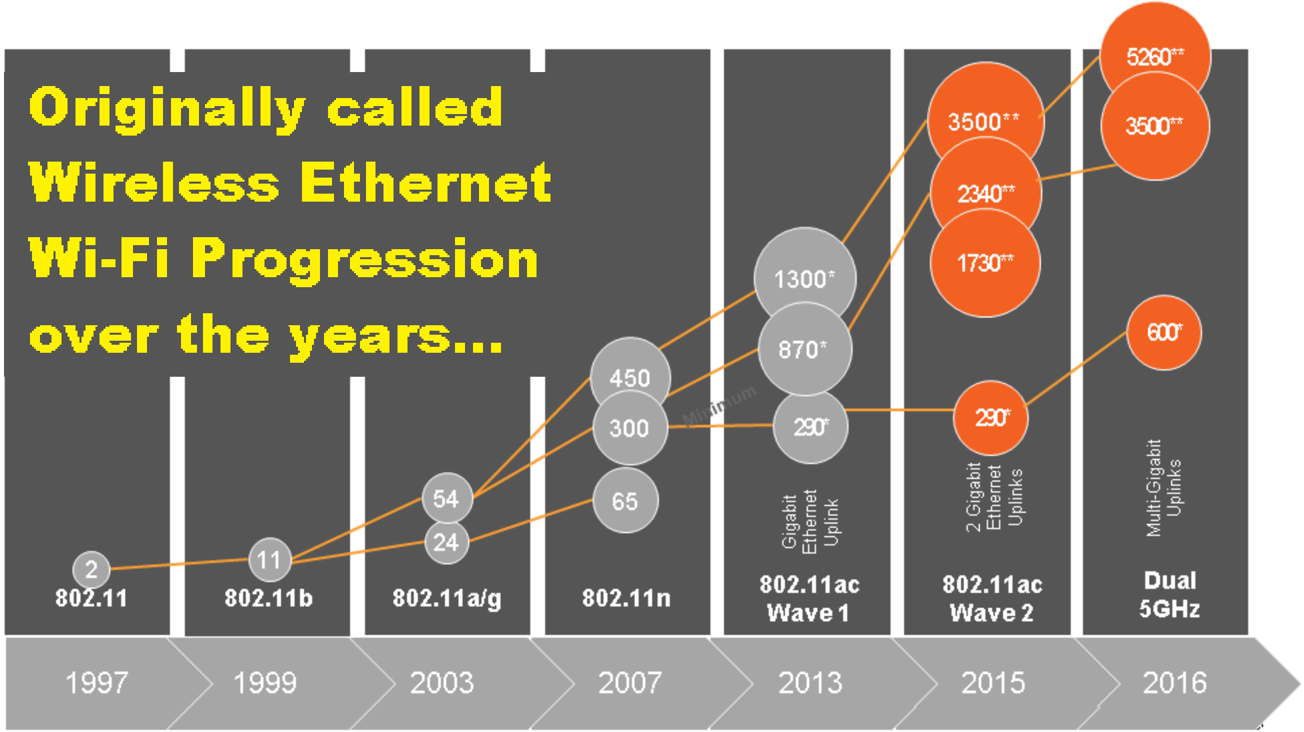
Aironet

In 1992 Aironet was the 1st in the industry to get both FCC and Canada DoC approval for Spread Spectrum technology*

Aironet Data-Span radio inside Telxon PTC-960

Originally called Wireless Ethernet

Wi-Fi Progression over the years…



*Aironet was known as Telesystems SLW & was renamed Aironet in 1993 by Telxon Corporation. In 1999 standard started to mature from 802.11b DSS to the catchy name "Wi-Fi" -- Cisco acquired Aironet in March of 2000 and made Wi-Fi a household name ☺

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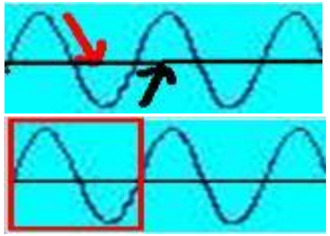
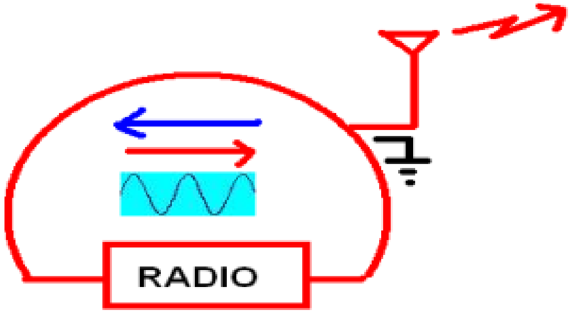
Basic Understanding of Radio…

Battery is DC
Direct Current

Typical home is AC
Alternating Current



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 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.

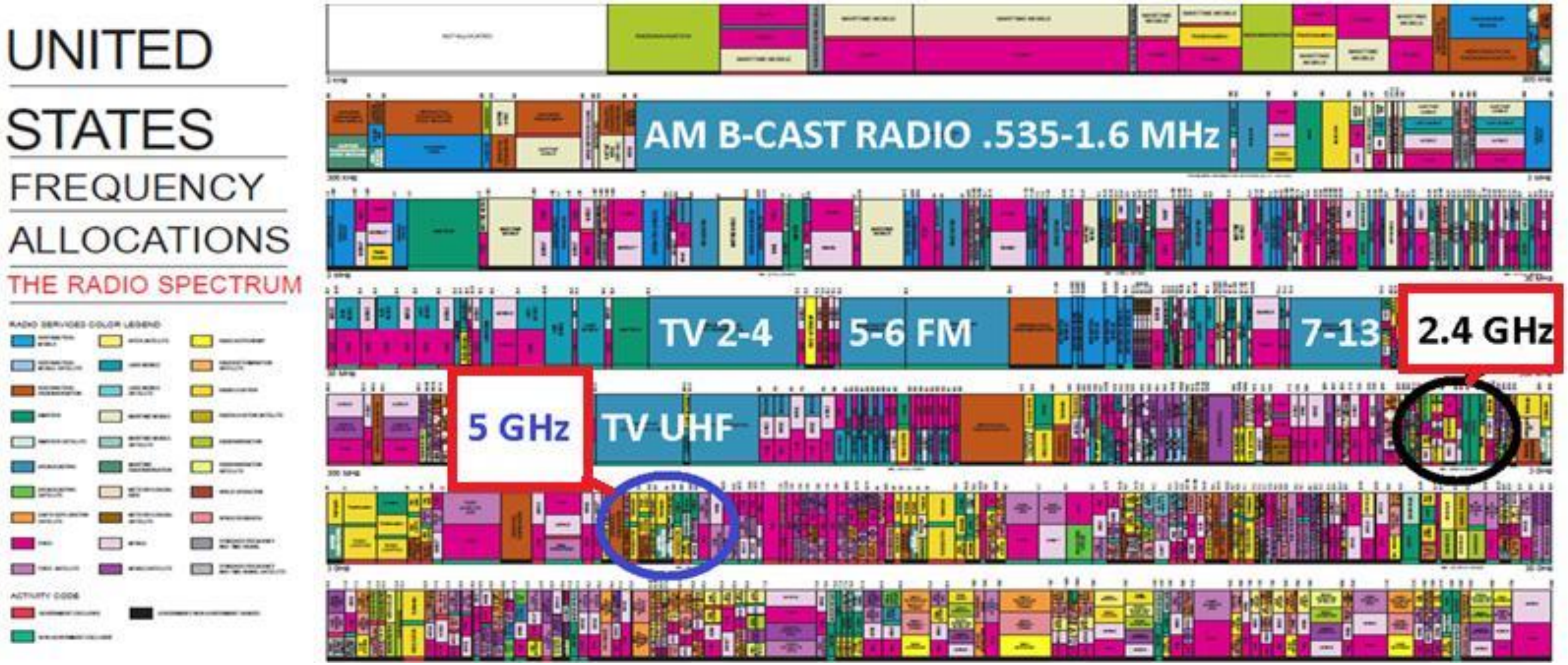
This is why 2.4 GHz goes further vs. 5 GHz
(given same amount of RF power).

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

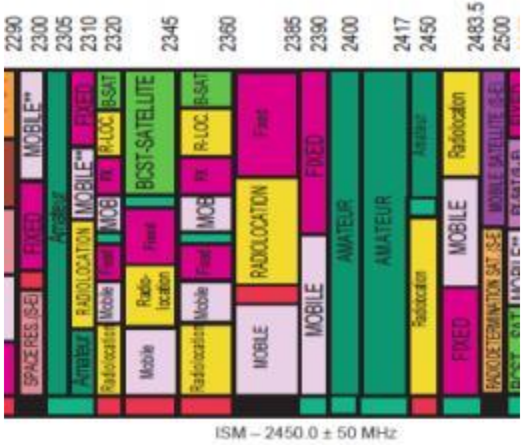
The Radio Spectrum in the United States

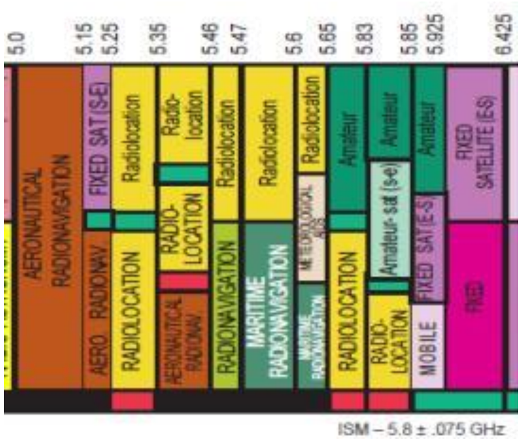


Source US Department of Commerce

http://www.ntia.doc.gov/osmhome/allochrt.pdf

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.

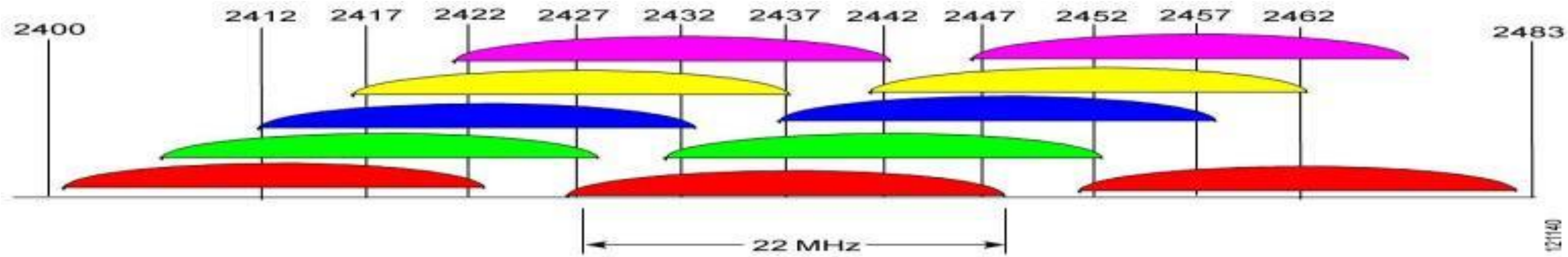
The first frequencies available for Wi-Fi use were in the 2.4 GHz range

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

There is more bandwidth in 5 GHz because there are mechanisms in place to co-exist with licensed services such as (RADAR)

Dynamic Frequency Selection (method of co-existing) with licensed services

2.4 GHz Wi-Fi Radio Spectrum (3 usable channels)



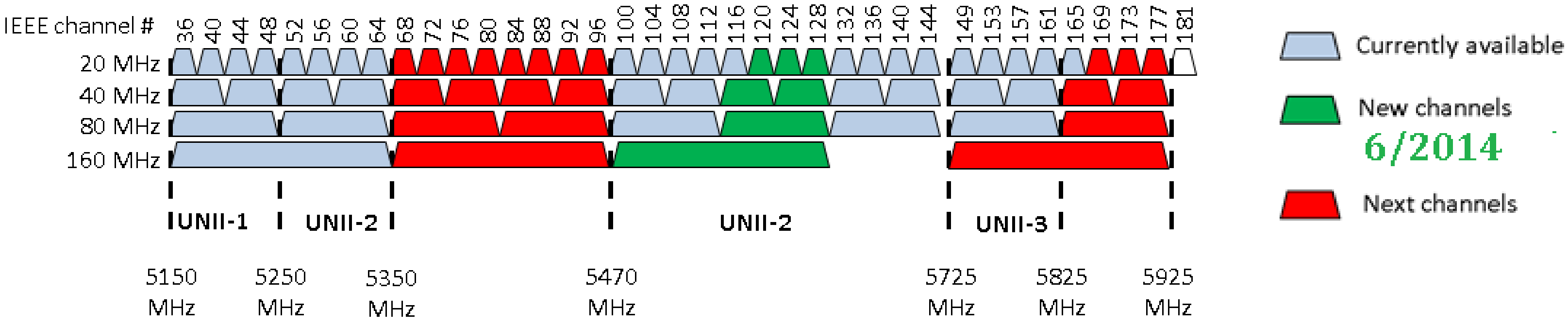
The 2.4 GHz spectrum in the US has 3 non-overlapping channels 1, 6 and 11.
Many more channels available on 5 GHz and they do not overlap

The IEEE standards break down like this…

802.11b/g is 2.4 GHz
802.11a is 5 GHz
802.11n (can be in either band) 2.4 or 5 GHz
802.11ac (is primarily 5 GHz only) at least for enterprise usage

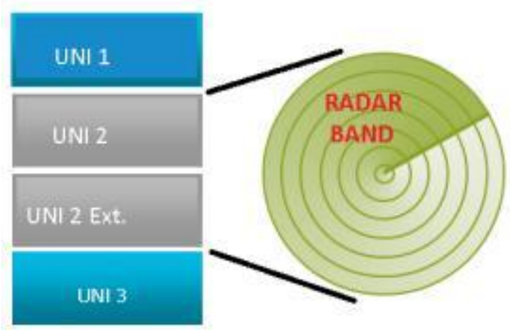
5 GHz US Wi-Fi Radio Spectrum - lots of channels

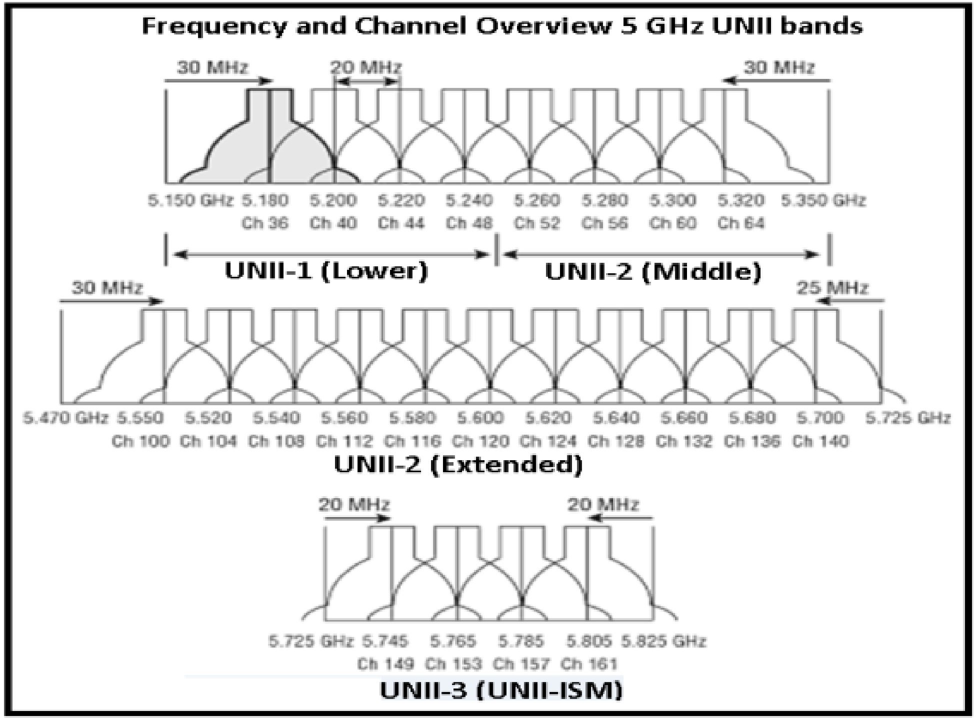
Opening up more 5 GHz spectrum (channels) for 802.11ac applications (FCC)



- **Cisco's dedicated Regulatory Team continues to lobby for more wide, non-overlapping channels enabling for better 802.11ac experience**
- **Current Unlicensed National Information Infrastructure (UNII) spectrum allows**
  - **6x** 80 MHz channels (**Five** in Canada and Europe)
  - **2x** 160 MHz channels (**One** in Canada)
- **Additional unlicensed use of 5.35-5.47 GHz and 5.85-5.925 GHz would allow**
  - **Thirty seven 20 MHz channels,**
  - **Eighteen 40 MHz channels**
  - **Nine 80 MHz channels**
  - **Four 160 MHz channels**

Wi-Fi Radio Spectrum 5 GHz Channels





Note: 5 GHz channels do not have the overlap that 2.4 GHz channels have but they often use ”DFS” Dynamic Frequency Selection 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

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 high density modulation schemes are 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 – more complex modulation happens at shorter distances

Basic 802.11 RF Terminology Hardware identification

For Your Reference

Common RF Terms

- **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.**

For Your Reference

Identifying RF Connectors

RP-TNC Connector

Used on most Cisco Access Points

“RP-SMA” Connector

Used on “cost reduced” products (Linksys...)

“N” Connector

15xx Mesh and outdoor APs

“SMA” Connector

“Pig tail” type cable assemblies

Antenna Cables – LMR Series

Trivia: LMR Stands for "Land Mobile Radio"

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

Cisco uses Times Microwave cable and has standardized 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

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

Cisco P/N for cable (breakdown)
AIR-CAB-050-LL-R

AIR - Aironet
CAB – Cable
050 - Length
LL - Low Loss
(LL=LMR-400, ULL=LMR-600)
R - RP-TNC
(connector type "R" and "N")

Antenna Basics
Different types of antennas

A Radio Needs a Proper Antenna

As the frequency goes up, the radiating element gets smaller

Antennas are identified by color
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

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.

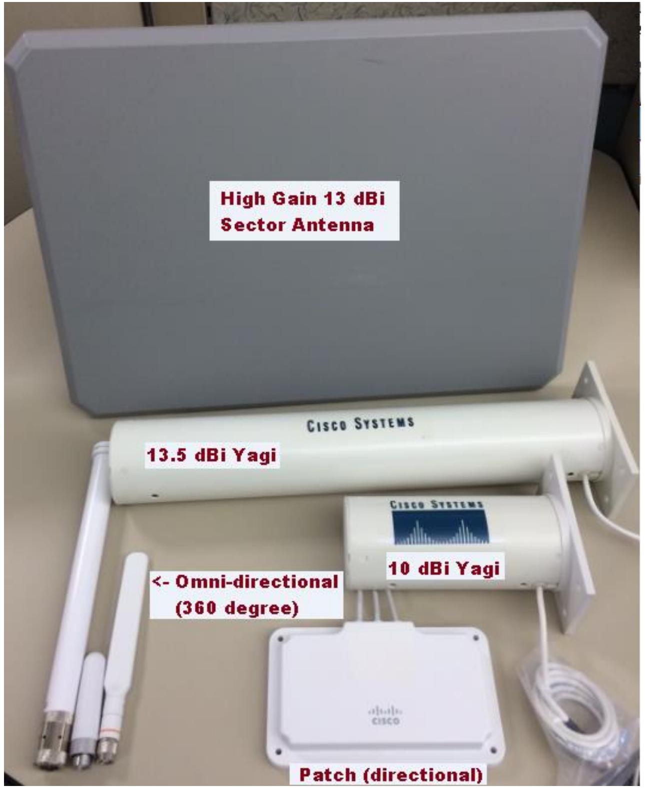
Note: Same RF energy is used but results in greater range as it is focused towards one direction, at the cost of other coverage areas

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 characterized 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
- Wi-Fi 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

Identifying different types of Wi-Fi antennas

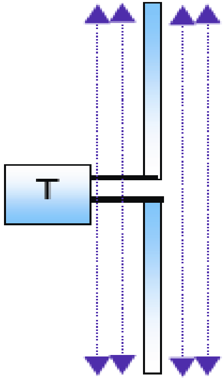


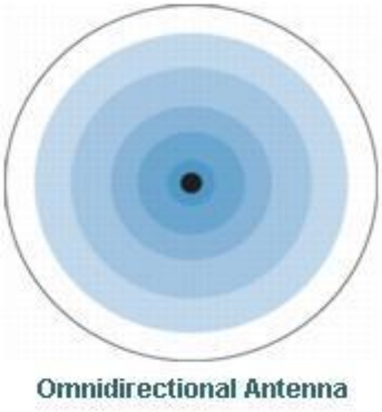
Higher gain antennas are physically bigger as they contain more radiating elements to help focus the energy in a given direction. <u>You don't get more RF power, you are just focusing the same amount of energy to go further</u>

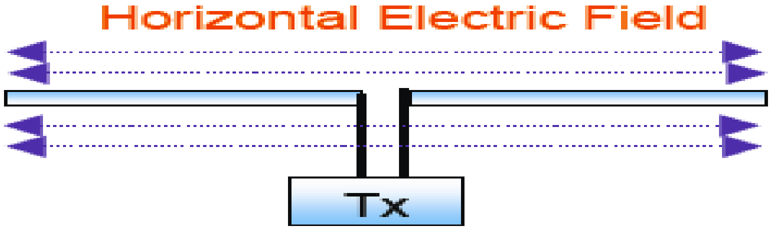
Think Omni versus Directional (focused)

How Does a Omni-Directional Dipole Radiate?

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





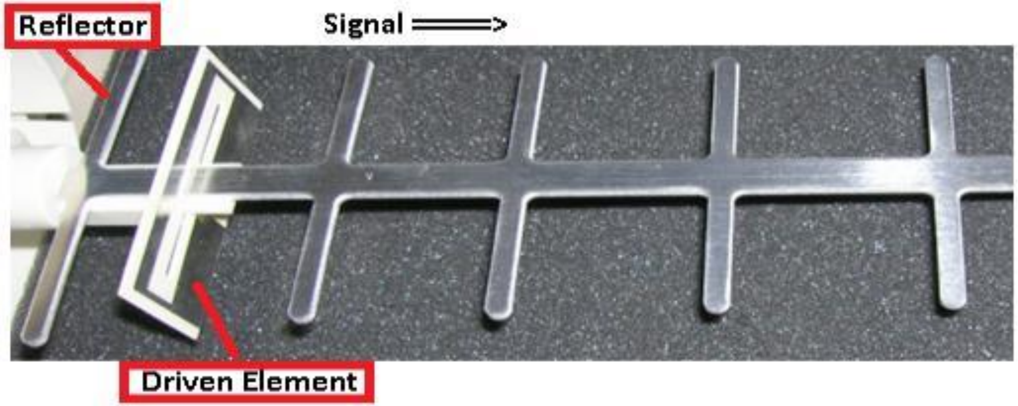


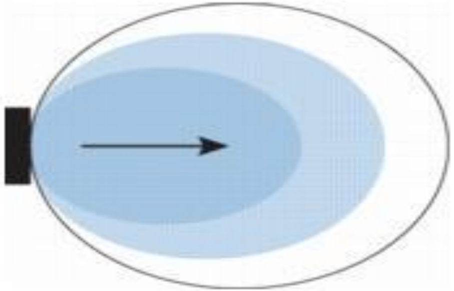
Low gain
Omni radiates much like a light bulb "360" degrees

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





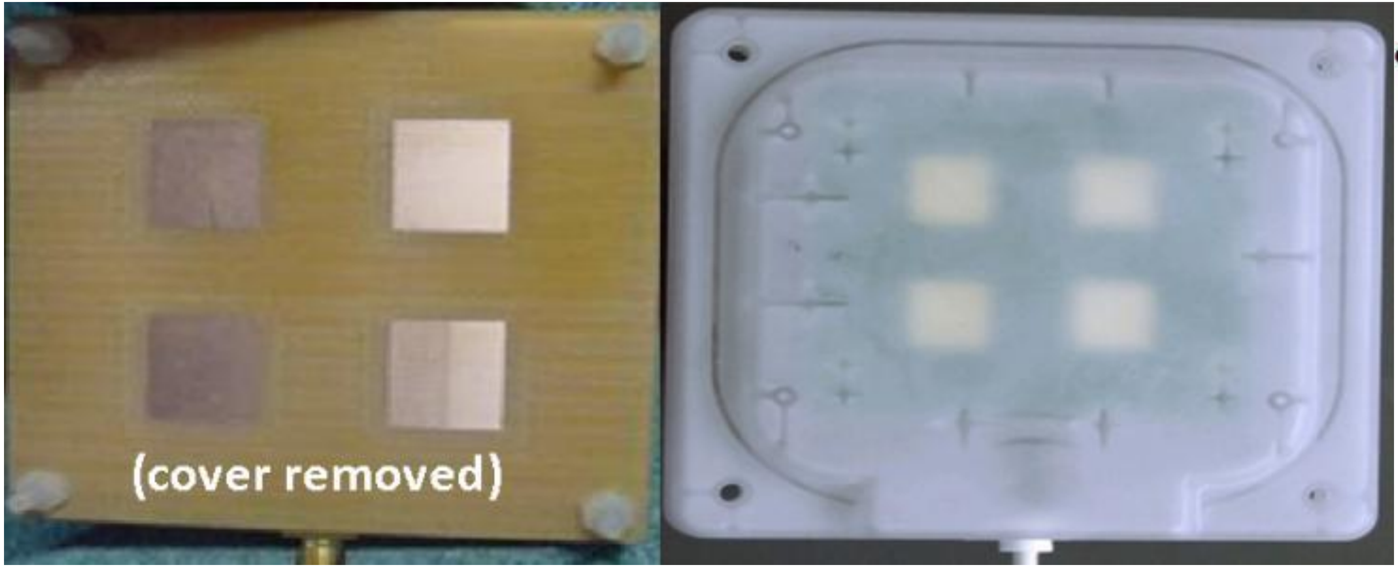
YAGI Antenna

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 designs favor the direction the antenna is pointed – like a flashlight

The 9.5 dBi Patch called AIR-ANT5195-R

Antennas Identified by Color

For Your Reference

Cisco Antenna
Color Coding Scheme

Black indicates: 2.4 GHz
Blue indicates: 5 GHz
(Single Radiating Elements)

Orange indicates:
2.4 & 5 GHz and are "DRE"

Used on 1600,1700,1850, 2600, 2700, 2800, 3600, 3700 & 3800 Series Access Points

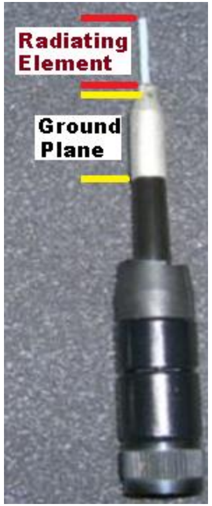
If the antenna is Single Band it has a Single Radiating Element (SRE) if the antenna is Dual Band (orange in color) it has a Dual Radiating Element (DRE)
(Older Dual Band antennas *not orange* may contain SRE's in each band)

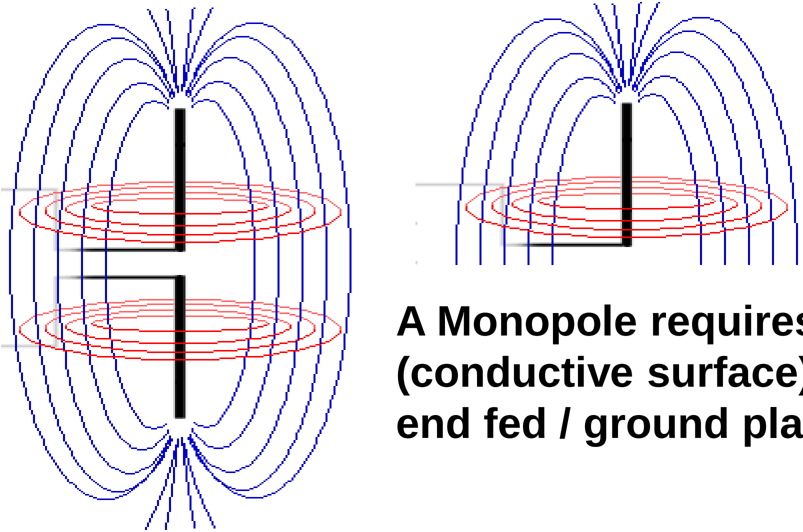
Specialty antennas

Antenna Theory (Dipole & Monopole)

Dipole

Monopole





A Monopole requires a (conductive surface) end fed / ground plane

808 Ft Broadcast Monopole
WSM 650 AM (erected in 1932)
Nashville Tennessee - Grand Ole Opry

A dipole does not require a ground plane as the bottom half <u>is the ground</u>

Produces a more uniform antenna pattern

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

Specialty antennas for Auditoriums & large venues

AIR-ANT2566P4W-R=

110x70
General-use patch antenna

AIR-ANT2566D4M-R=

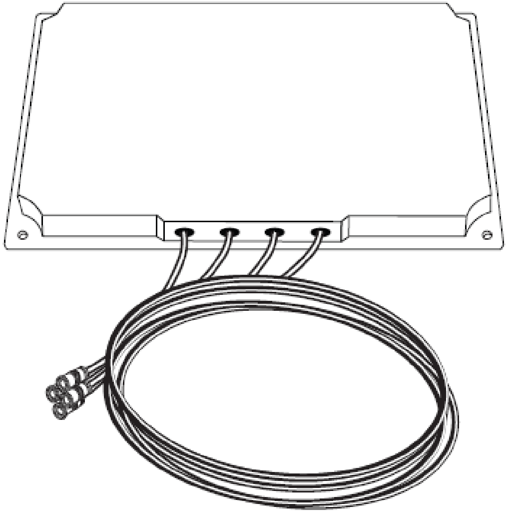
65x65
Medium ceilings/ auditoriums

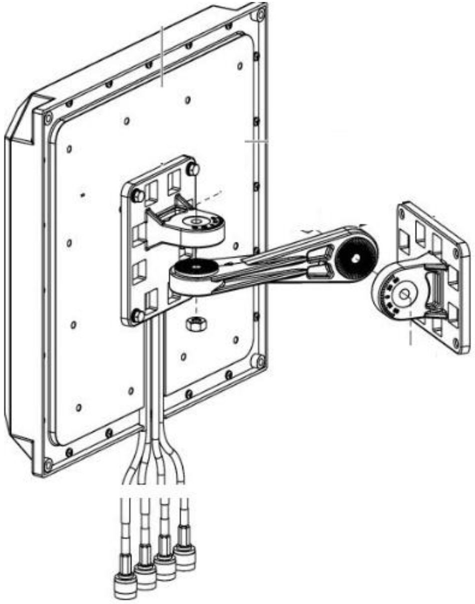
AIR-ANT2513P4M-N=

30x30
High ceiling's/ Stadiums

Specialty antennas for Auditoriums & large venues

General-use 6dBi
Hallways – aisles
110 X 55 Azimuth/Elev
AIR-ANT2566P4W-R=



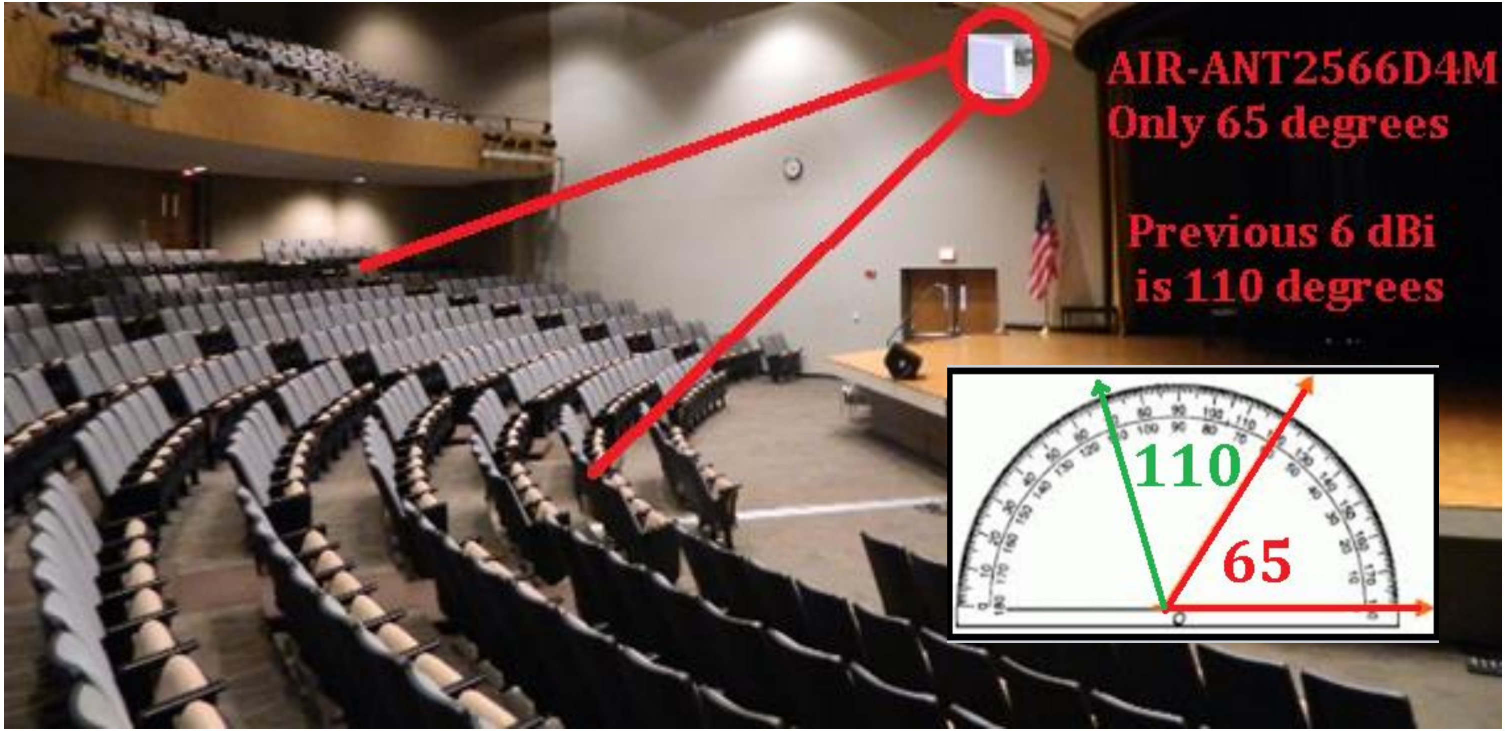


Medium ceilings 6dBi
Factories / auditoriums
65 x 65 Azimuth/Elev
AIR-ANT2566D4M-R=

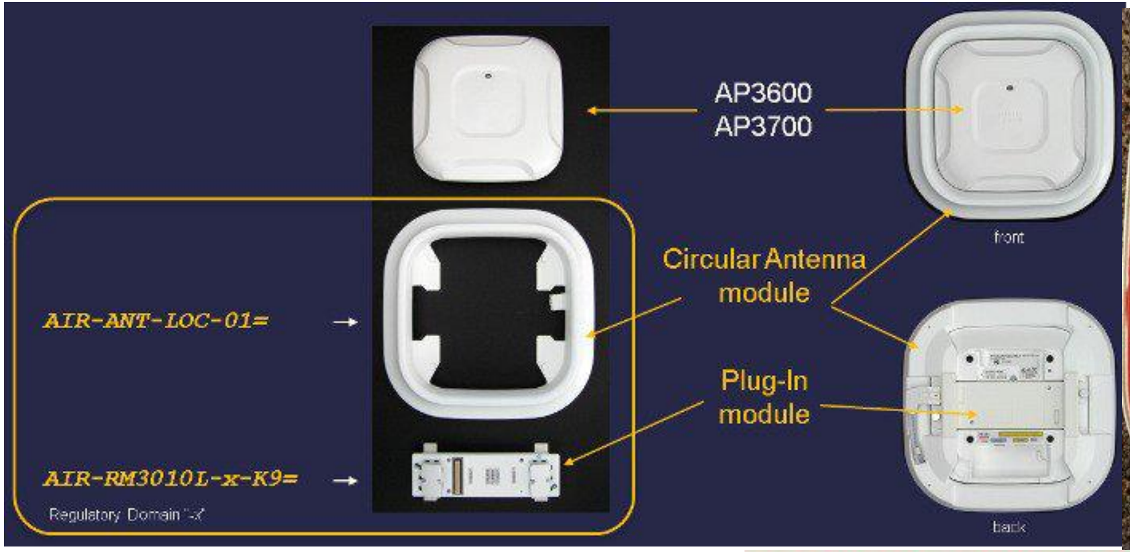
High ceilings 13dBi
Stadium usage
30 x 30 Azimuth/Elev
AIR-ANT2513P4M-N=

Use case – Solving the requirement for smaller footprint

Previous AIR-ANT2566P4W was too wide for some applications @ 110 degrees



Specialty Antennas - Hyperlocation

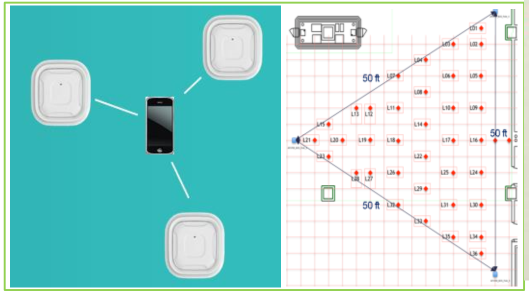


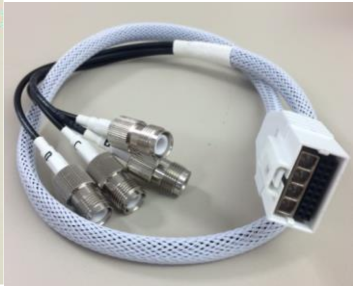
2.4/5G

2.4/5 Monitor

BLE

32 Element array





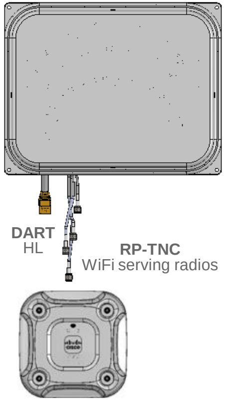
Specialty Location Antennas

AP3600/3700 add on
Enterprise office, retail,…
(horizontal install)

Omni Location + no WiFi

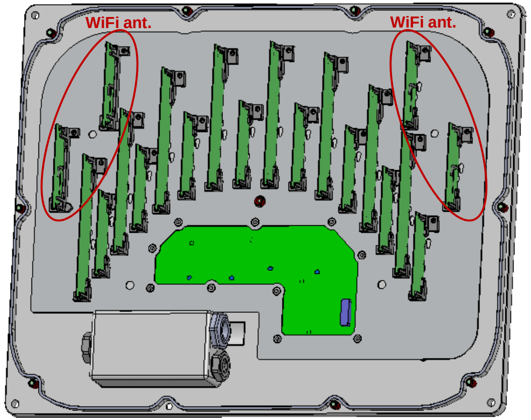
- **PID: AIR-ANT-LOC-01=**
- **3602i/e, 3702i/e**
- **Enterprise office, retail , …**
- **Horizontal install, on ceiling**
- **DART** (HL mod) **+ RP-TNC** (E ver., WiFi)
- **Dual-band**
- **≈ 2x12x12"**
- **Oct. 2015**

Large hall, warehouse, atrium,
high ceiling, Outdoors
(vertical install)



Directional Location + Directional WiFi

- **PID: AIR-ANT25-LOC-02=**
- **3602i/e, 3702i/e & 2802e, 3802e, 3802p**
- **Large Halls, Warehouse, Atriums**
- **Vertical install**
- **DART** (Location) **+ RP-TNC** (WiFi)
- **Dual-band**
- **≈ 2x14x18"**
- **3602/3702** **≈ Sep 2016**
- **2800/3800** **tbd**



WiFi Ant.: Az/El ≈ 105°/60°, Gain ≈ 3 dBi

Understanding and Interpreting Antenna Patterns

The Richfield Ohio (Aironet) Facility

Creating the patterns you see in the spec sheets

Satimo software compatible with Stargate-64 System. Basic measurement tool is Agilent 8753ES Analyzer.

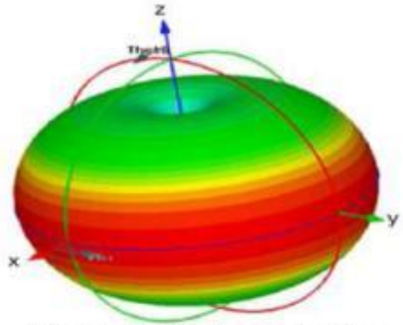
Cisco Anechoic chamber using an 45 cm absorber all the way, around 1-6 GHz

Anechoic means "without echo"

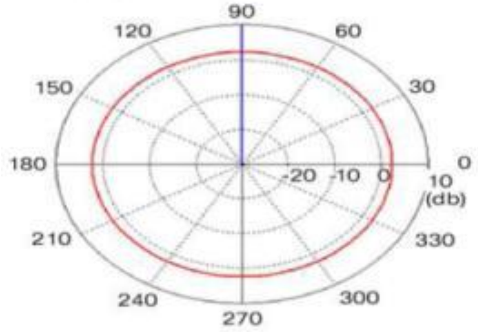
Understanding Antenna Patterns

Dipole (Omni-Directional)

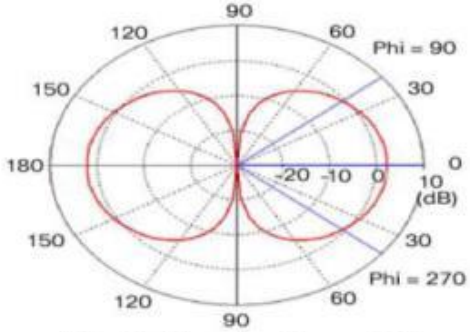
Dipole Antenna Model



Dipole 3D Radiation Pattern



Dipole Azimuth Plane Pattern

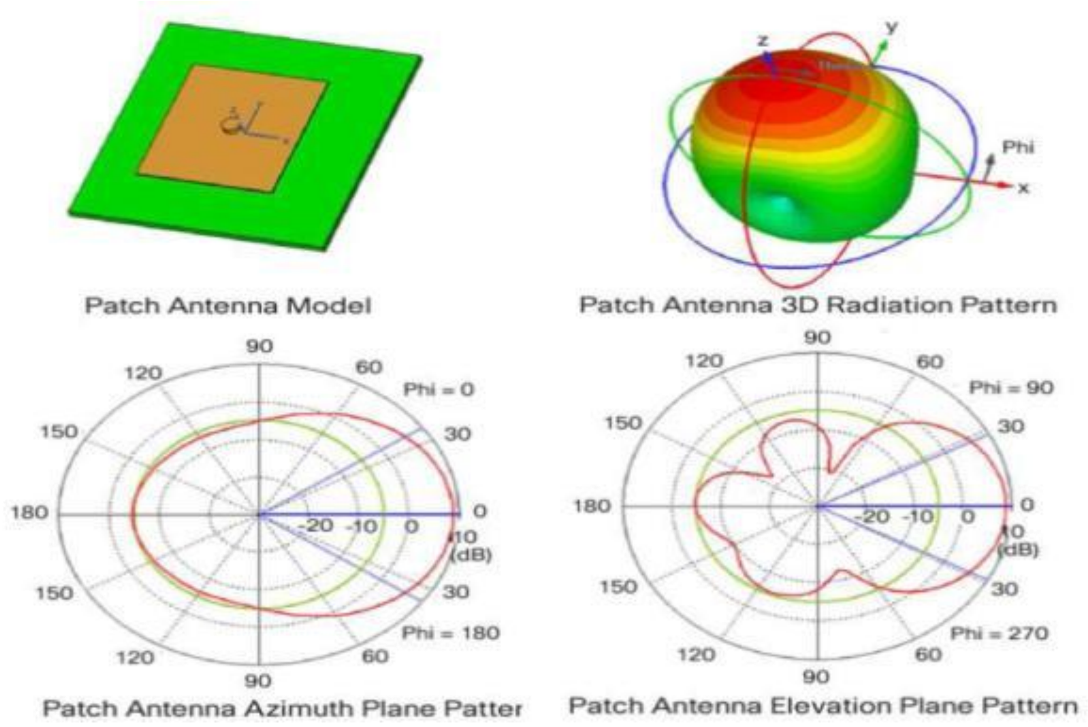


Dipole Elevation Plane Pattern

Low gain dipoles radiate everywhere think “light bulb”

Understanding Antenna Patterns

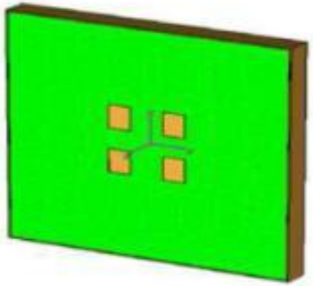
Patch (Directional)



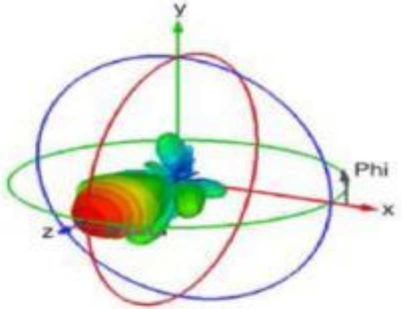
A low gain Patch Antenna

Understanding Antenna Patterns

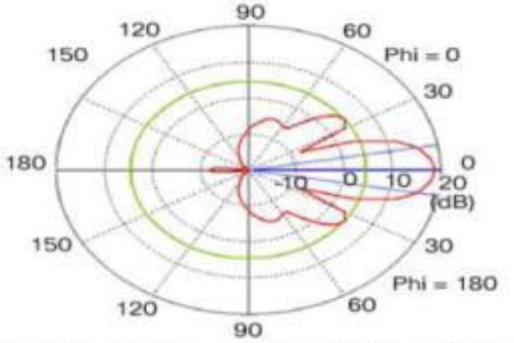
Patch (Higher Gain Directional)



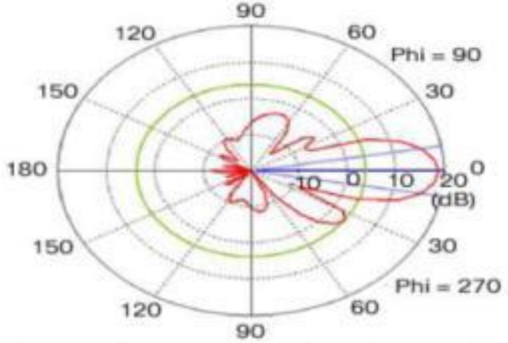
4x4 Patch Array Antenna



4x4 Patch Array 3D Radiation Pattern



4x4 Patch Array Azimuth Plane Pattern

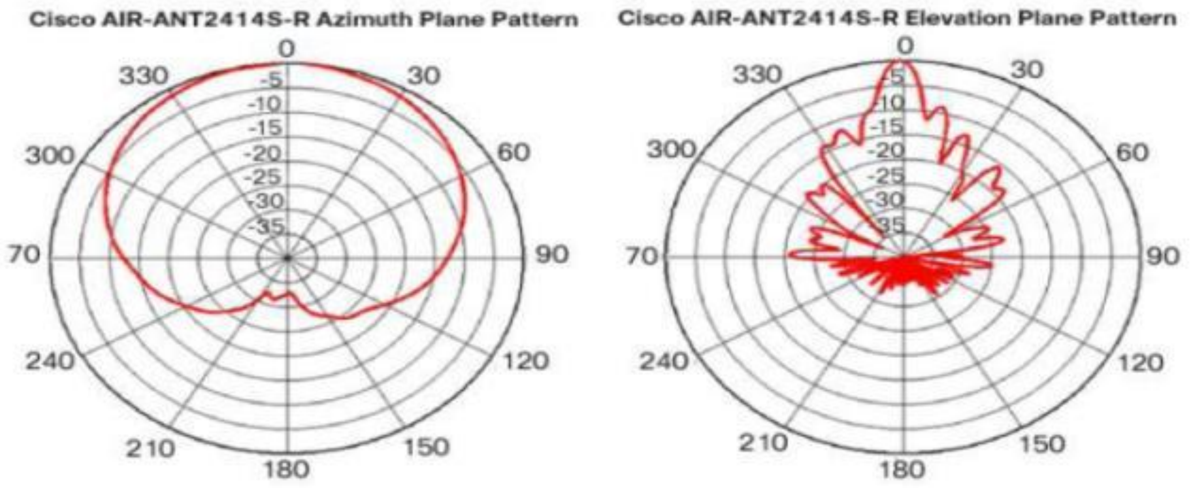


4x4 Patch Array Elevation Plane Pattern

A High Gain Four element Patch Array

Understanding Antenna Patterns

Sector (Higher Gain Directional)



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

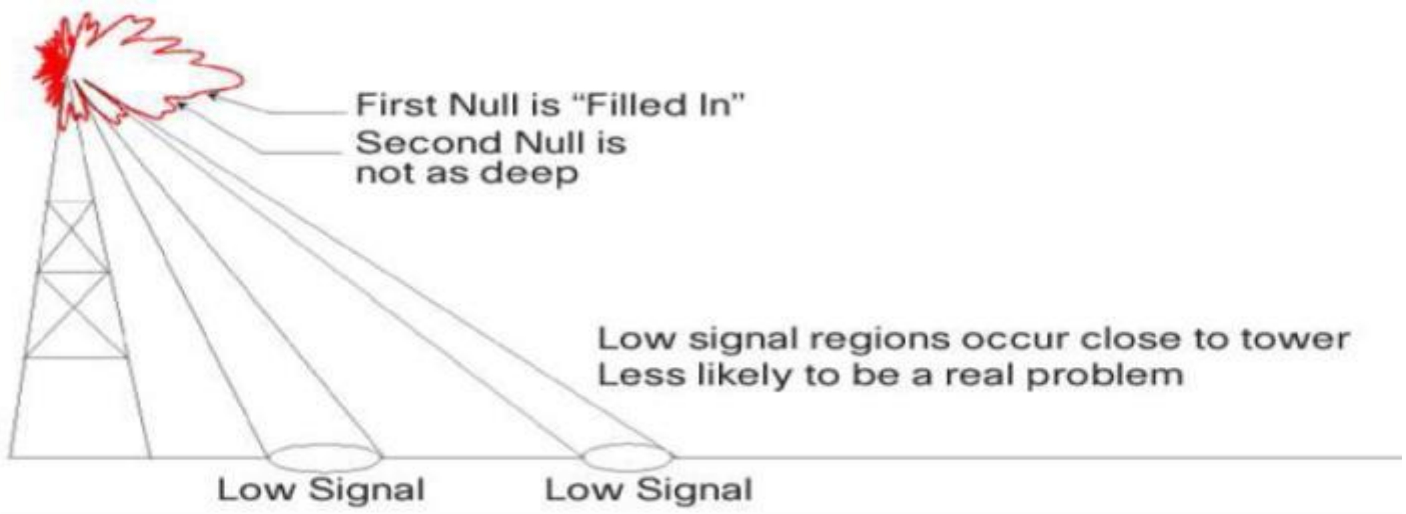
(c) Cisco AIR-ANT2414S-R
Elevation Plane Pattern

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

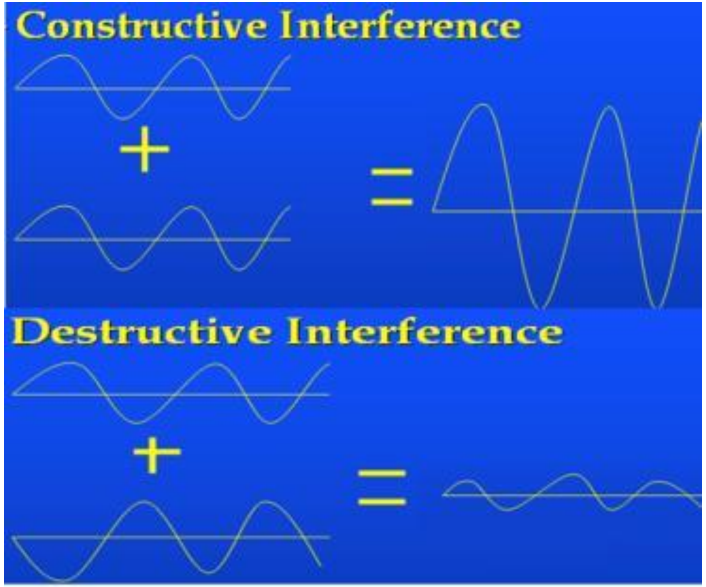
Understanding Multipath Diversity and Beamforming

Understanding Multipath

Multipath can change Signal Strength

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

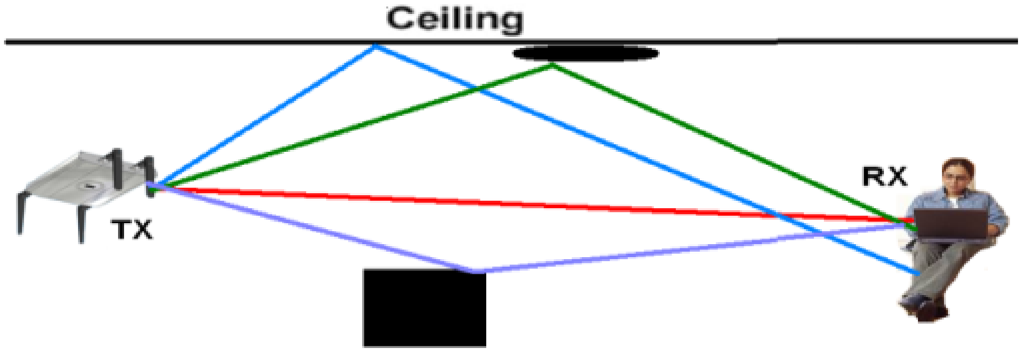
This often results in either an improvement "constructive" or a "destructive" type of interference

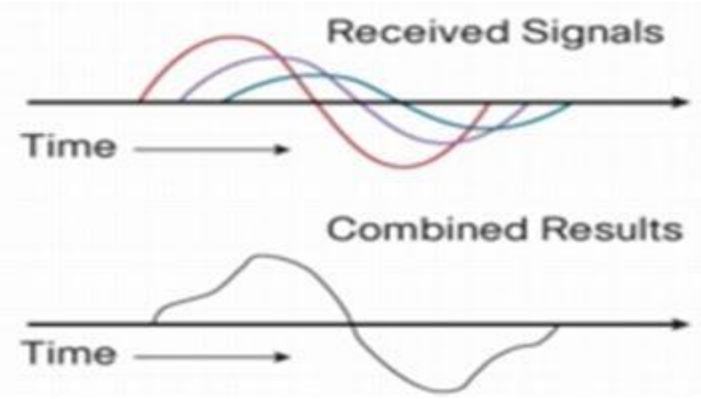


Note: Bluetooth type radios that "hop" across the entire band can reduce multipath interference by constantly changing the angles of multipath as the radio wave increases and decreases in size (as the frequency constantly changes). The downside is that throughput using these "hopping" methods are <u>very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

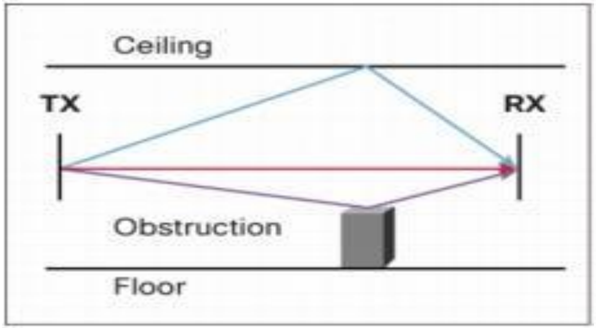
Different modulation schemes fair better – 802.11a/g uses a type of modulation based on symbols and is an improvement over the older modulation types used with 802.11b clients

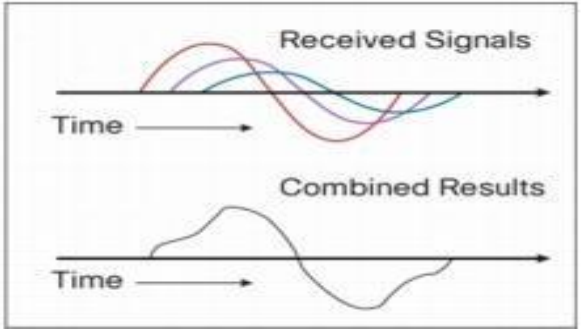
802.11n with more receivers can use destructive interference (multipath) as a benefit but it is best to reduce multipath conditions

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



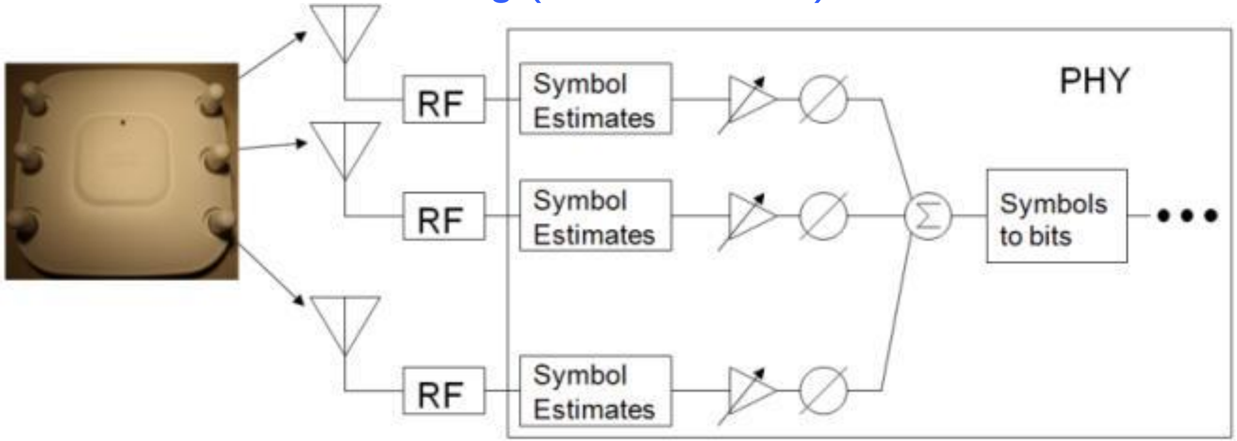


Cisco 802.11a/b/g Access Points start off favoring the right (primary antenna port) then if multi-path or packet retries occur it will sample the left port and switch to that antenna port if the signal is better.

Note: Diversity Antennas should always cover the same cell area

Understanding Diversity (MIMO)

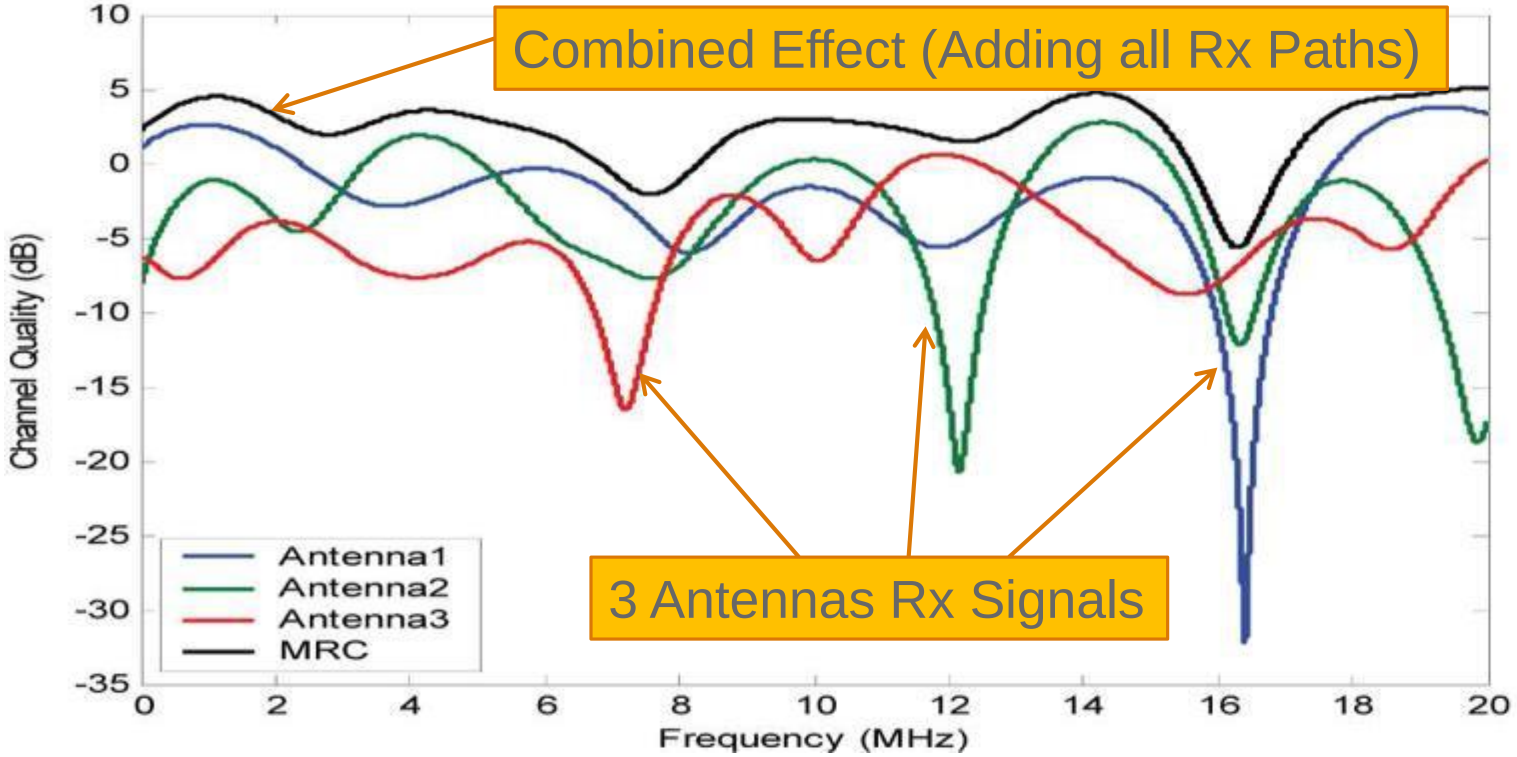
MRC Maximal Ratio Combining (Three Radios)



- 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



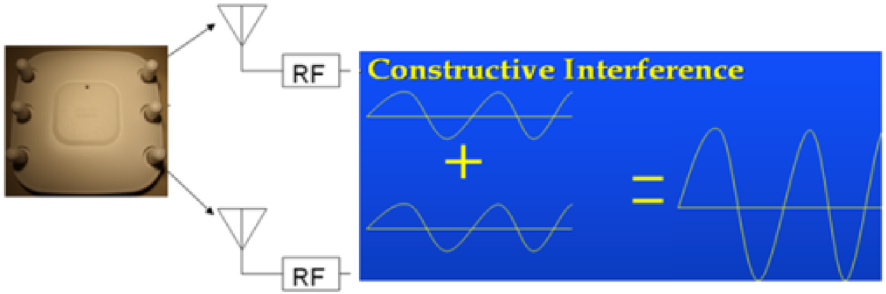
Understanding Client Link

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

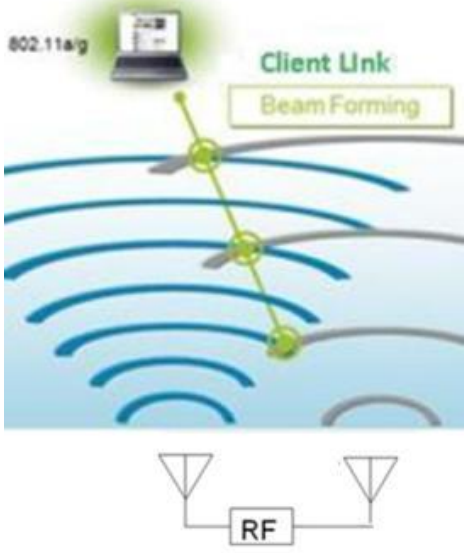
Beam-forming allows the signal to be best directed towards the client.
This results in a strong signal to the client reducing need for retries

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

Simple Example of Beamforming



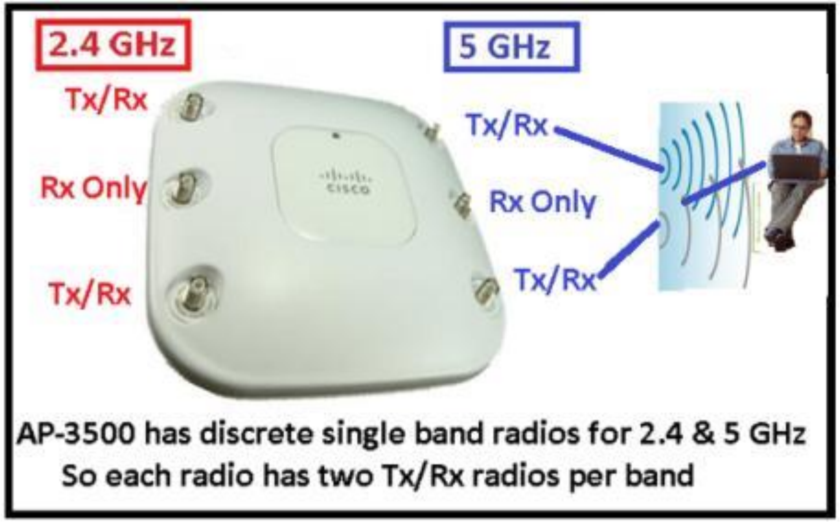
By changing the timing (phase) of the two transmitters, you can create a stronger signal (constructive interference) so the client can hear it better



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 first introduced in the AP-1140 helped OFDM and Single stream clients



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

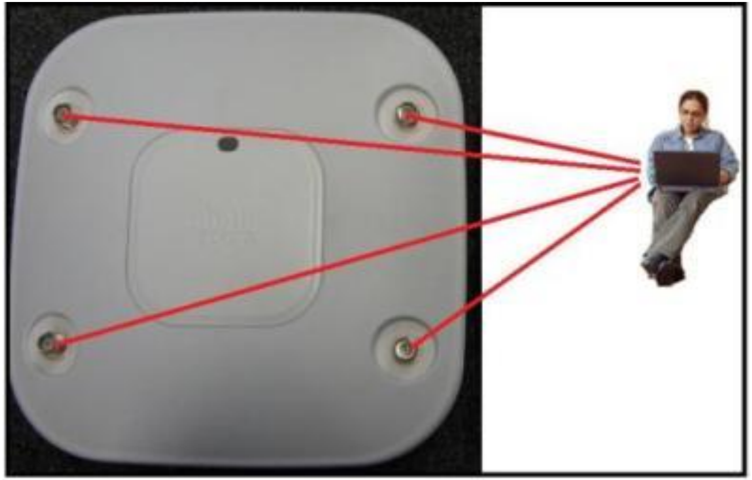
The AP-1140/1260/3500 has dual band radio support using single band antennas.

Each radio band (2.4 & 5 GHz) has separate independent radios Two transceivers (Tx/Rx) per band and 1 additional receiver.

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

2nd 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 four transceivers per band 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

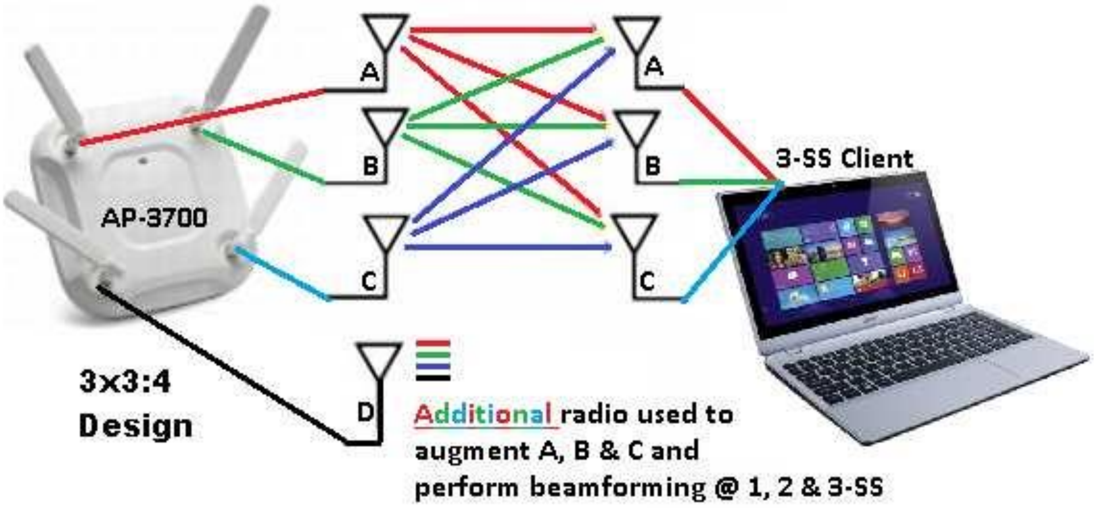
Beam-forming Spatial Streams (ClientLink 3.0)

All the features of ClientLink 2.0 + 3-ss 11ac Clients

The extra radio "D" is used to augment spatial stream data and is used in beam-forming

Note .11n had support for beam-forming but was never adopted so there was no TxBF without ClientLink

Client-Link performs beam-forming on legacy 11a/g/n clients as well as 802.11ac 3-ss clients.



Note: Only Cisco APs can beam-form a 3-SS signal as it requires 4 transmitters - most APs on the market don't have this additional radio for reliability and performance

The additional radio assists in both transmit and receive.

256QAM Heat Map: Cisco vs. other .11ac products

- **ClientLink 3.0 helps the Cisco AP and clients maintain faster datarates with less retries**
- **Cisco's 11ac AP has a significant 256 QAM advantage over the competition 11ac AP using ClientLink and 4x4:3**
- **The Test:**

  Use a MacBook Pro (3ss) and record the data rate in 40+ locations in a cubicle environment while running traffic to the client.

ClientLink 3.0 YouTube video:

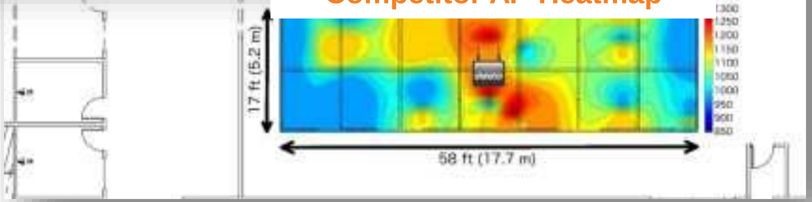
- http://www.youtube.com/watch?v=0q_shbSpOIA

Modulation	MCS	PHY Rate (Mbps)	Percentage
64QAM	m7	975	0%
256QAM	m8	1170	15%
256QAM	m9	1300	85%

Cisco AP Heatmap

Modulation	MCS	PHY Rate (Mbps)	Percentage
64QAM	m7	975	49%
256QAM	m8	1170	44%
256QAM	m9	1300	7%

Competitor AP Heatmap



Cisco live!

Understanding 802.11n

Before .11n - Review of 802.11a and 802.11b/g

- **Only 1 Transmitter & 1 Receiver (per band) – up to 54 Mbps**
- **Early non .11n 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**

NOTE: This is LEGACY technology so for best performance on enterprise networks consider disabling .11b rates

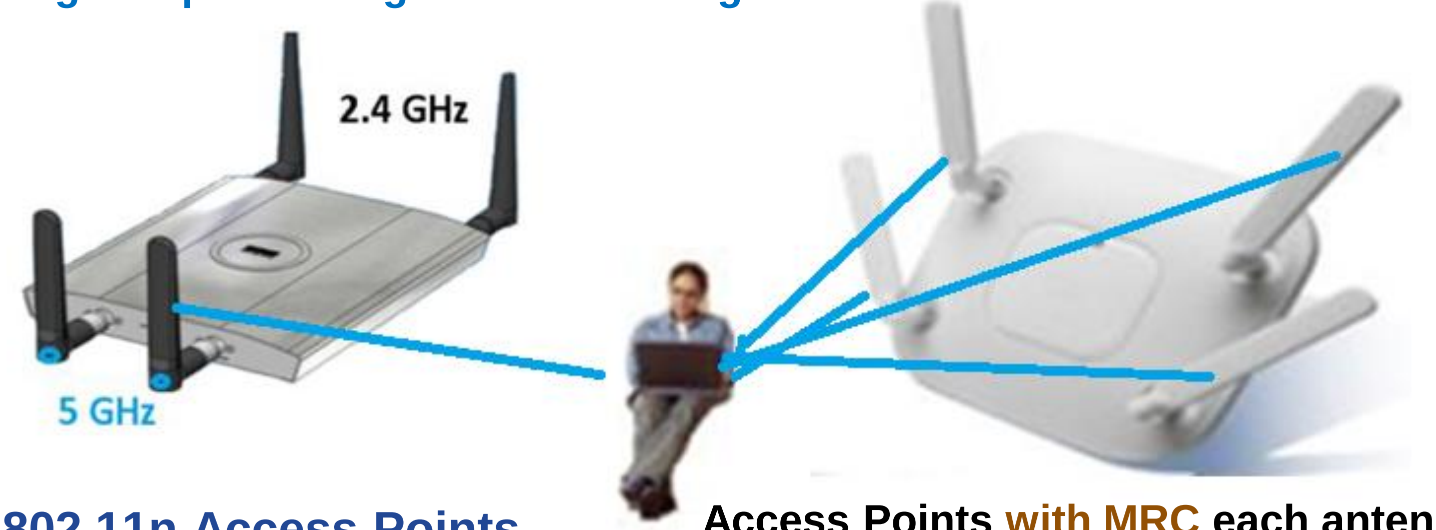
Elements of 802.11n - Terminology

For Your Reference

- **MIMO – Multiple Input Multiple Output** when radio signals called "streams" are being transmitted or received simultaneously
- **MRC – Maximal Ratio Combining** the ability to combine the received signals from multiple antennas (receivers) to reassemble and decode the spatial stream
- **Spatial Stream** – Transmitted signal - multiple transmitted signals called streams can carry redundant or different information on each transmitted stream.
- **Spatial Multiplexing** – ability to simultaneously send multiple streams of data and decode with multiple receivers to increase channel capacity (throughput).
- **Packet Aggregation** – combining packets into a single MAC layer frame to reduce overhead from packet headers for more efficiency
- **Channel Bonding** – Using more than one channel (combining them) for more bandwidth.
- **TxBF** – Transmit Beam-forming used in 802.11ac and in 802.11n with Cisco ClientLink
- **4x4:3** – Terminology for number of transmitters, receivers and spatial streams supported

MRC - Maximal Ratio Combining

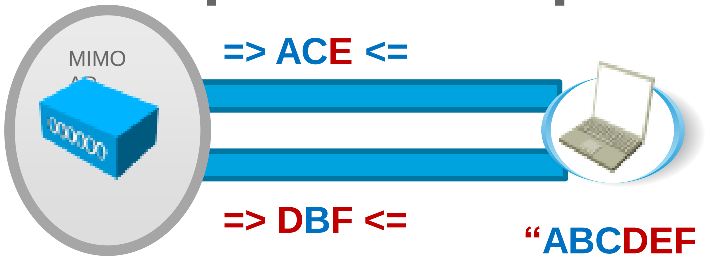
Receiving and processing the received signal from the client



Pre-802.11n Access Points had NO MRC and used only 1 radio per band sampling the 2 antennas picking the best one.

Access Points with MRC each antenna has a dedicated receiver and combines the signal received on all antennas to best decode and process the information with less retries.

MIMO - Spatial Multiplexing (transmitting streams)



Sending side: send more symbols,
in parallel (spatial multiplexing)
Each occurrence is a “stream” complementing the other

Left
Channel
Audio
“ABC”

Right
Channel
Audio
“DEF”

Clients such as tablets and smart phones typically support only 1 or 2 spatial streams as they typically don’t have the battery or physical space for multiple radios. Larger clients (laptops and desktops) often support 3 Spatial Streams

More streams means more information can be sent at the same time (faster throughput)

Similar to FM radio stations which use fixed channels but each channel has 2 “audio” streams

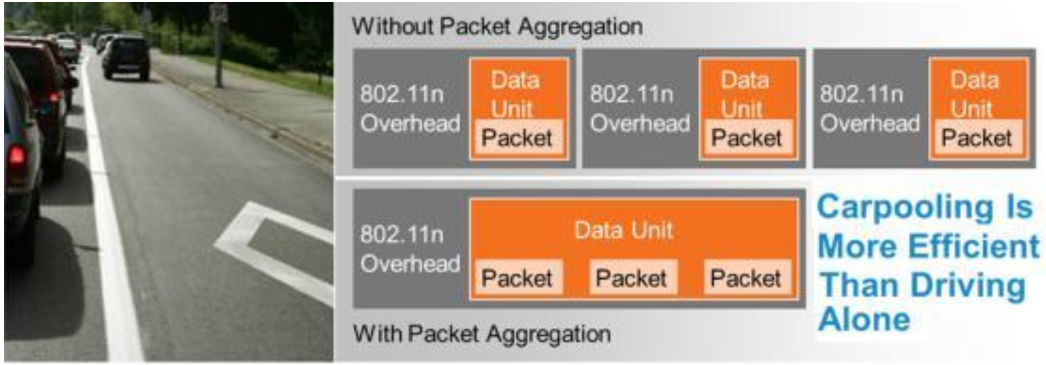
In our case we have two or more “data” streams…

802.11n MIMO terminology

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)

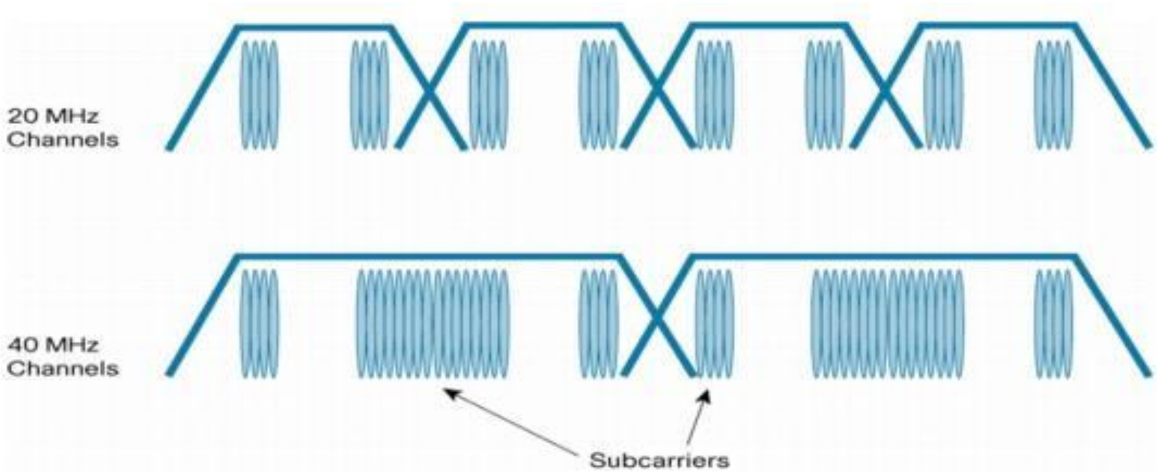
Packet aggregation –
Permits more efficient use of the RF spectrum Reducing ACK times for more faster throughput



Channel Bonding – Subcarriers

802.11n can use both 20 & 40 MHz channels.

The 40-MHz channels in 802.11n are simply 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…**

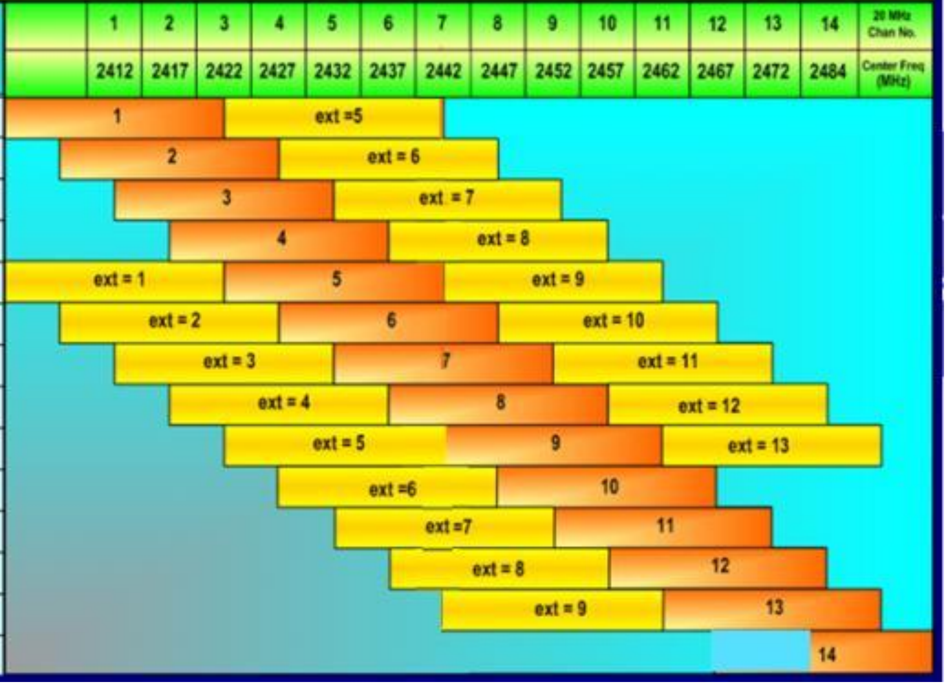
802.11n achieves slightly more than doubling the data rate when moving from 20-MHz to 40-MHz channels

2.4 GHz Channel Bandwidths

40 MHz Not Permitted or Supported (Enterprise WLAN) as not enough spectrum

2.4 GHz Bandwidths

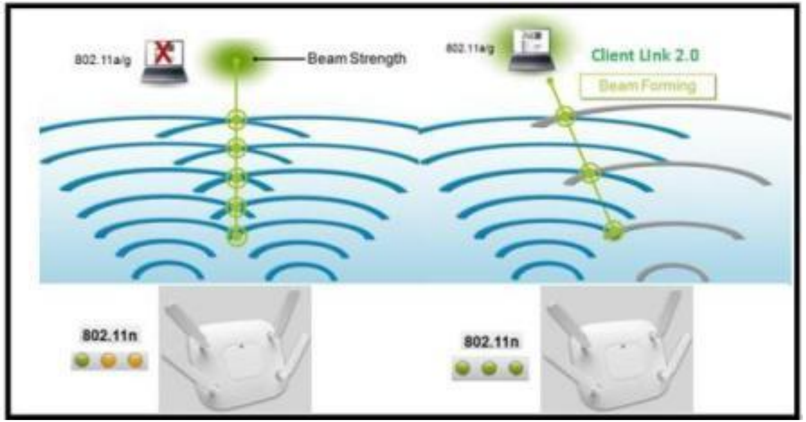
Domain	Ch ID	Freq (MHz)	Center Ch 20 MHz	Center Ch 40 MHz	Cntrl Ch	Ext Ch	Exten Upper or Lower
US & ROW	1	2412	1	3	1	5	Upper
	2	2417	2	4	2	6	Upper
	3	2422	3	5	3	7	Upper
	4	2427	4	6	4	8	Upper
	5	2432	5	3, 7	5	1, 9	Low, Up
	6	2437	6	4, 8	6	2, 10	Low, Up
	7	2442	7	5, 9	7	3, 11	Low, Up
	8	2447	8	6, 10	8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



802.11n MIMO terminology

Understanding .11n components (**M**ultiple **I**nput **M**ultiple **O**utput)

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



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

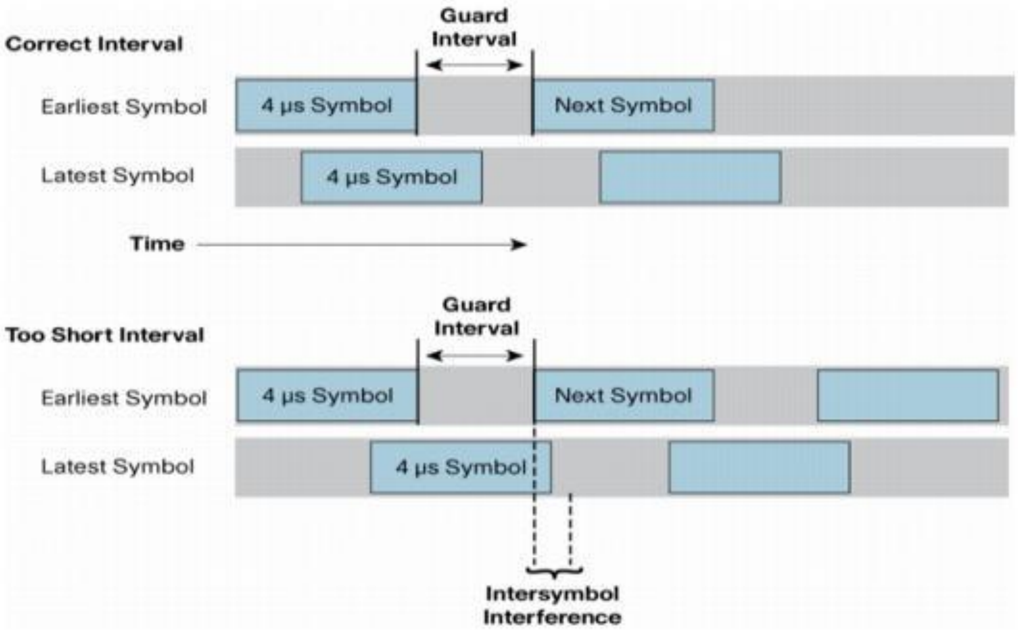
802.11n (EBF) Enhanced Beam Forming

WLAN Client	
Works for Multiple Spatial Stream HT Clients	Not yet
Works for 1 SS HT Clients	Not yet
Works for Legacy Clients (11 a/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

Understanding Guard Interval – 800 or 400?

Guard Interval (GI) –
Period of time between each a OFDM symbol that is used to minimize 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

Data Rates for 802.11n

(speeds are based on channel width and streams)

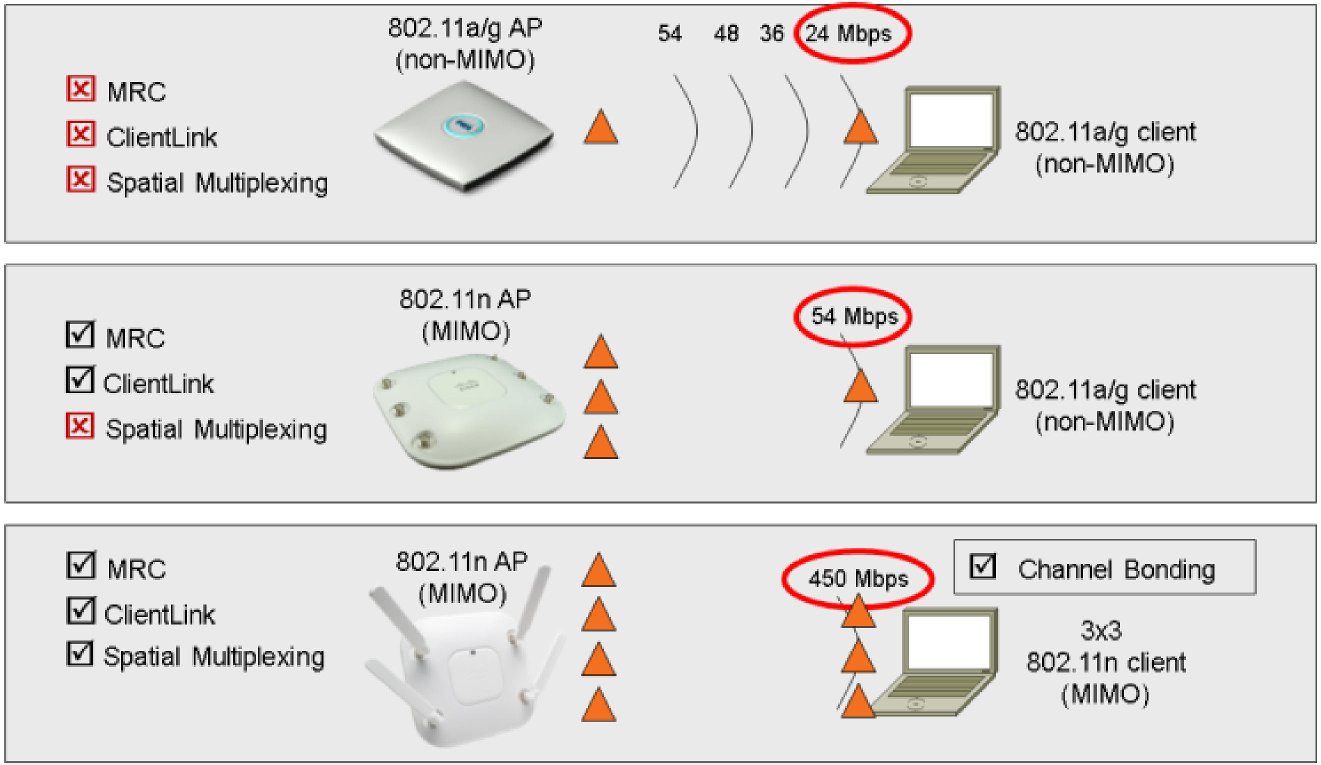
				Signal BW =20 MHz		40 MHz	
MCS	Coding	Modulation	Streams	GI = 800 nS	GI =400 nS	GI = 800 nS	GI =400 nS
MCS0	1/2	BPSK	1	6.5	7.2	13.5	15
MCS1	1/2	QPSK	1	13	14.4	27	30
MCS2	3/4	QPSK	1	19.5	21.7	40.5	45
MCS3	1/2	16-QAM	1	26	28.9	54	60
MCS4	3/4	16-QAM	1	39	43.3	81	90
MCS5	2/3	64-QAM	1	52	57.8	108	120
MCS6	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-700,1040,1140, 1250,1260,1600 & 3500 can support
Up to 2-Streams
300 Mbps using .11n rates

AP-2600,2700, 3600 & 3700 can support
Up to 3-Streams
450 Mbps using .11n rates

So to Recap: 802.11n Operation

Throughput Improves When All Things Come Together



Understanding 802.11ac

Building upon the 802.11n foundation

Operating Mode Comparisons –
Identifying differences between each of the different standards

802.11n	802.11ac Wave 1	802.11ac Wave 2
2.4 and 5.0 GHz band	5.0 GHz band only	5.0 GHz band only
3X3 or 4X4 MIMO	3X3 or 4X4 MIMO	4X4 MIMO
Single User MIMO (one to one)	Single User MIMO (one to one)	Multi-User MIMO (one to many)
Fast Ethernet wired equivalent	Gigabit Wi-Fi wired equivalent	Multi-Gigabit Wi-Fi capable
Usually 20 MHz Channel Width	Usually 20 or 40 MHz Channel Width	Usually 40 or 80 MHz Channel Width (160 MHz can also be supported)
Single FE or GE uplink	Single GE uplink	Dual GE uplinks or mGig uplink
PoE (802.3af) for full operation	PoE+ (802.3at) for full 4X4 operation	PoE+ (802.3at) for full 4X4 operation
Support for AES128 Encryption	Support for AES128 Encryption	Support for AES256 Encryption

Elements of 802.11ac – Wave2

802.11ac (Wave-2) improvements over (Wave-1)

- **Ability to use 1, 2, 3 (and now 4) Spatial Streams**

  An extra Spatial Stream does give you a bump in data rate @ 80MHz 1733 vs.1300 Mbps

- **Same channel bonding 20, 40, 80 (now 160 MHz)**

  1st Generation Wave-2 "1K" Series AP only support 80 MHz
  2nd Generation Wave-2 "2K" & "3K" support 160 MHz

- **Standards Based TxBF now implemented in Wave2**

  Only 11ac Wave-2 clients participate in .11ac transmit beamforming
  All other .11a,g,n,ac clients still need ClientLink for performance

- **Multi-User MIMO (MU-MIMO) support**

  Happens in Wave-2 for 11ac Wave 2 clients only
  No benefit for 11a/b/g/n clients or Wave 1 Clients

Wave-2 is based on the IEEE 802.11ac final standard ratified December 2013

For more see this URL:

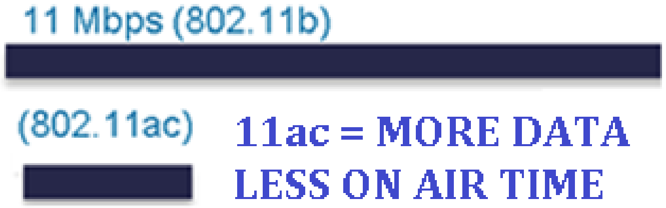
So what's driving .11ac?

The airwaves are a shared medium to improve performance, you need to be <u>spectrum efficient</u>
802.11ac is all about optimization to do that

The goal is <u>faster throughput for everyone</u>
ability to support lots of Wi-Fi tablets, phones and laptops - <u>Moving data faster via these techniques:</u>

- **Spatial Streams – Sending data out of more than 1 antenna**
- **Channel Bonding – using more than 1 channel**
- **256 QAM - More complex modulation**
- **Guard interval – cutting down on symbol time**
- **MIMO – Multiple Input Multiple Output**
  Use of multiple radios at the same time Tx/Rx
- **MU-MIMO – Multi-User MIMO**
  Sending data to <u>MORE than one user at a time</u>

GET OFF THE AIR
<u>STOP TALKING</u>



11ac = MORE DATA
LESS ON AIR TIME

General thoughts – Why do I need 802.11ac?

Because it builds on 802.11n foundation adding faster throughput and performance

- **Need for more throughput – smart phones and tablets usually have only 1 radio**
- **Channel Bonding and more complex modulation (256-QAM) does more with only 1 radio**
- **Logical progression for significant performance from earlier technologies**
- **11b (11Mb), 11a/g (54Mb), 11n (600Mb), 11ac Wave1 (1300Mb), 11ac Wave-2 (2340Mb)**
- **Beam-forming implemented in 11ac Wave-2 but ClientLink needed for all other clients.**

802.11ac clients are emerging with laptops and tablets supporting 3 Spatial Streams and even smart phones supporting 1 & 2 spatial streams @ 80 MHz

(4-ss and/or 160 MHz is also possible)

Why is channel bonding & 11ac so important?

Phones such as the HTC One & Samsung S4 have support for 802.11ac

MCS	Modulation	Ratio	20 MHz channel	40 MHz channel	80 MHz channe 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

Max N rate

More than 1-SS requires the client have more radios which draws more power from the battery.

Most smart phones and some tablets will use 1-SS

More powerful tablets & laptops use 2 & 3-SS

The goal is to save physical size and battery life yet increase throughput

How else can you get to 433 Mbps with one radio?

Channel Bonding Wave-1 and Wave-2

For Your Reference

.11ac MCS Rates @ 1-spatial stream Wave 1 @ 80 MHz Wave-2 can support 160 MHz

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

802.11ac Data Rates @ 1,2 & 3 Spatial Streams (Wave1)

802.11n was 450 Mbps at 40 MHz bonded @ 3-SS.

.11ac can achieve nearly the same speed @ 1-Spatial Stream

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

802.11ac rates @ 1 Spatial Stream

802.11ac Data Rates

XX RATE NOT SUPPORTED

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

Using Wave-2 & 4SS (Last “Eyechart”)

For Your Reference

.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

1 stream (80MHz) is 433 Mbps
2 stream (80MHz) is 866 Mbps
3 stream (80MHz) is 1300 Mbps
4 stream (80 MHz) is 1733 Mbps (Wave 2)
3 stream (160 MHz) is 2340 Mbps (Wave 2)

Note: While 4-SS appears attractive, it is very difficult to maintain a 4-SS link given you cannot beam-form a 4-SS signal given you only have 4 antennas

Beamforming requires N+1 antennas

802.11ac Data Rates

* RATE NOT SUPPORTED

				Mb/s							
				20 MHz Guard Interval		40 MHz Guard Interval		80 MHz Guard Interval		160 MHz Guard Interval	
Spatial Streams	MCS Index	Modulation	Coding	800ns	400ns	800ns	400ns	800ns	400ns	800ns	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	*	*
4	0	BPSK	1/2	26	28.9	54	60	117	130		
	1	QPSK	1/2	52	57.8	108	120	234	260		
	2	QPSK	3/4	78	86.7	162	180	351	390		
	3	16-QAM	1/2	104	115.6	216	240	468	520		
	4	16-QAM	3/4	156	173.3	324	360	702	780		
	5	64-QAM	2/3	208	231.1	432	480	936	1040		
	6	64-QAM	3/4	234	260	486	540	1053	1170		
	7	64-QAM	5/6	260	288.9	540	600	1170	1300		
	8	256-QAM	3/4	312	346.7	648	720	1404	1560		
	9	256-QAM	5/6	*	*	720	800	1560	1733.3		

Not all Wave-2 products support 160 MHz

Cisco live!

So how do these data rates apply in the real world?

Smartphones 210 Mbps*

1 stream (80MHz) is 433 Mbps

Tablets 460 Mbps*

2 stream (80MHz) is 866 Mbps

High End Laptops +680 Mbps*

3 stream (80MHz) is 1300 Mbps

Note: This is why GigE is fine for 802.11ac (Wave-1) Access Points – Now lets look at Wave-2

4SS	Desktops
3SS	Desktops / Laptops
2SS	Laptops / Tablets
1SS	Tablets / Smartphones

Wave-2 with 4 stream (80 MHz) is 1733 Mbps
No 4-ss clients exist in the market today

Real throughput changes dynamically based on number of spatial streams, channel bonding MCS (radio data-rate) negotiated

The actual throughput is less than the MCS data-rate due to overhead

*Assumes 70% MAC efficiency and half duplex

802.11ac Wave-2 Access Points

Current lineup of new APs
Understanding new features

Cisco Aironet Indoor Access Points Portfolio

Industry’s Best 802.11ac Series Access Points

Enterprise Class
1830

- 802.11ac W2
- 870 Mbps PHY
- 3x3:2SS
- Spectrum Analysis*
- Tx Beam Forming
- USB 2.0

New

Enterprise Class
1850

- 802.11ac W2
- 2.0 Gbps PHY
- 4x4:4SS
- Spectrum Analysis*
- Tx Beam Forming
- 2 GE Ports, USB 2.0

New

Mission Critical
2800

- 5 Gbps PHY
- 4x4:3SS – 160 MHZ – MU-MIMO
- 2 Ethernet Ports, 2xGbE
- Dual 5 GHz
- HDX Technology
- USB 2.0
- StadiumVision
- CleanAir 160MHz, ClientLink 4.0, Videostream

Best in Class
3800

- 5 Gbps PHY
- 4x4:3SS – 160 MHZ – MU-MIMO
- 2 Ethernet Ports, GbE + mGig (1G, 2.5G, 5G)
- Dual 5 GHz
- HDX Technology
- USB 2.0
- StadiumVision
- CleanAir 160MHz, ClientLink 4.0, Videostream
- Side Mount Modular Architecture

Enterprise | Mission Critical | Best In Class

So why did we design the AP3800?

AP-3700 Series

AP-3800 Series

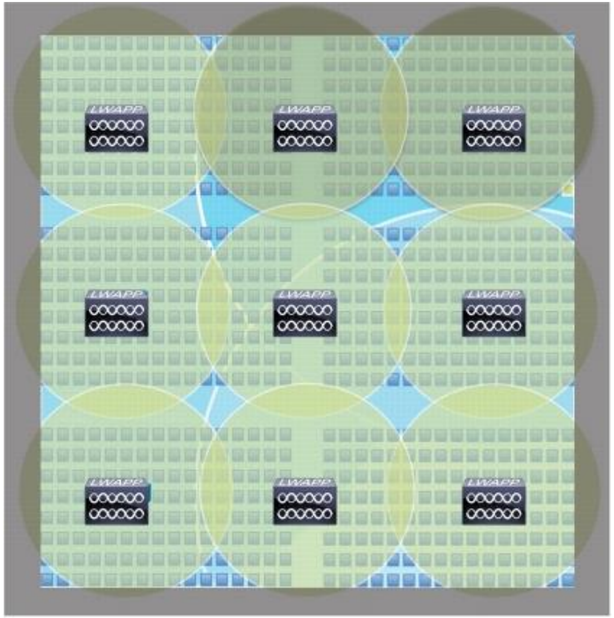
- Solves the problem of over 2.4 GHz coverage with XOR Radio design
- XOR allows many new types of installations using single Eth drop.
- Additional Ethernet port + mGiG port maintains value in existing CAT-5 cable structure by exceeding GbE spec via mGiG or 2nd Eth using LAG.
- Enhanced 160 MHz capability, MU-MIMO support etc.
- Module support has been enhanced now located on side of AP
- Ability to support antenna arrays for location (via DART connector)

Dual 5 GHz in one AP? What is an XOR Radio?

- 2.4 GHz and 5 GHz on the same silicon
- Allows choice of RF band (either 2.4 GHz or 5 GHz)
- Allows Serial scanning of all 2.4 and 5 GHz channels
- Role selection is manual or Automatic – RRM supported
- Similar in design as previous (WSSI/WSM modules) however this XOR radio is also a transceiver so it can service clients
- Allows for creation of Micro/Macro cells (internal model)
- Allows for creation of any combination cells (external model)

Why can there too much 2.4 GHz Coverage?

- APs with overlapping coverage cells should not be on the same channel, because this can lead to increased channel utilization and contention.
- As you create smaller cells for High Density Applications (HDX) the 2.4 GHz cells can become too large resulting in the need to turn off some of the radios.
- Using XOR those disabled 2.4 radios can now become additional active 5 GHz radios
- **Note:** This can all happen manually or dynamically using FRA (Flexible Radio Assignment)

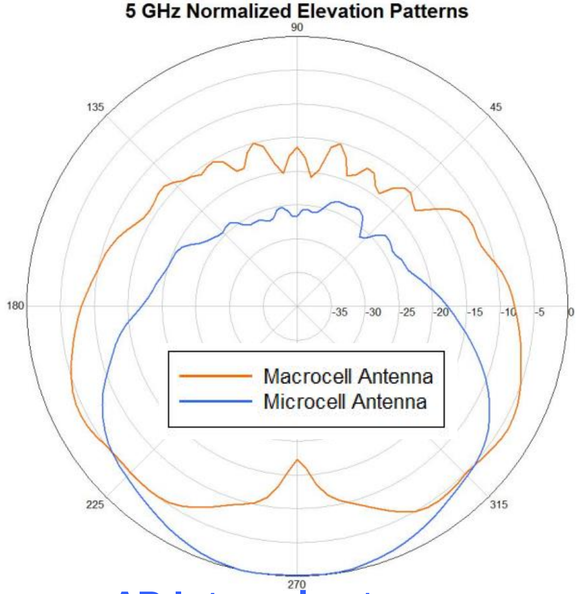


When you create smaller cells for HDX undesirable 2.4GHz overlap can occur due to limited 2.4G channels

Macro/Micro Dual 5 GHz Cell
Instant Capacity

Dual 5 GHz Macro/Micro <u>increases efficiency</u>

- Two 5 GHz radios address capacity - creating Macro/Micro cells increasing usable “air time”
- Conference centers and other venues can double capacity using their existing cable plan
- Using external 2800/3800 any combination of Macro/Micro or Omni & directional combinations are supported – Like 2 AP’s in one housing.
- mGiG leverages throughput investment
- RF isolation happens with polarity/frequency/PWR diversity (smart antenna designs)



AP Internal antenna patterns 2800/3800

AP2800/3800 “I” series antenna system (cover removed)

Previously in the controller Access Point radios were defined as…

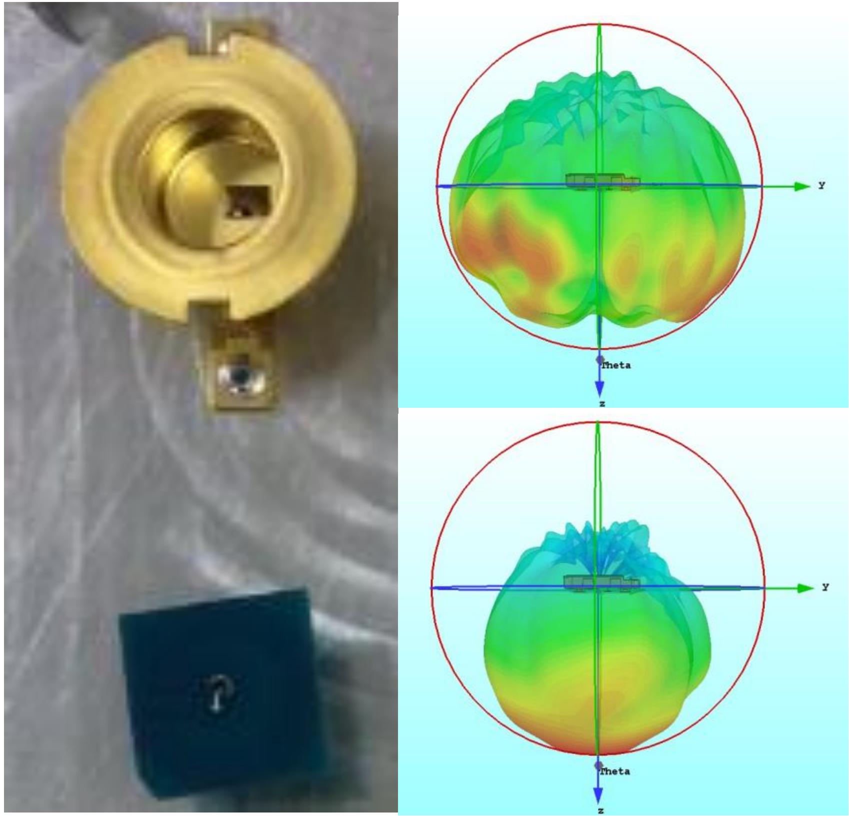
Radio 0 = 2.4 GHz <OR> 5 GHz
Radio 1 = 5.0 GHz

Using “Flexible Radio Assignment”
Radio “0” can be configured as 2.4 GHz (default) or as an additional 5 GHz radio.

If configured as a 5 GHz radio the 2.4 GHz radio is disabled and the 5 GHz micro-cell antennas are used.

Micro-cell antenna is 6 dBi @ 5 GHz
Macro-cell antenna is 5 dBi @ 5 GHz

Difference in antenna designs allow for RF co-existence



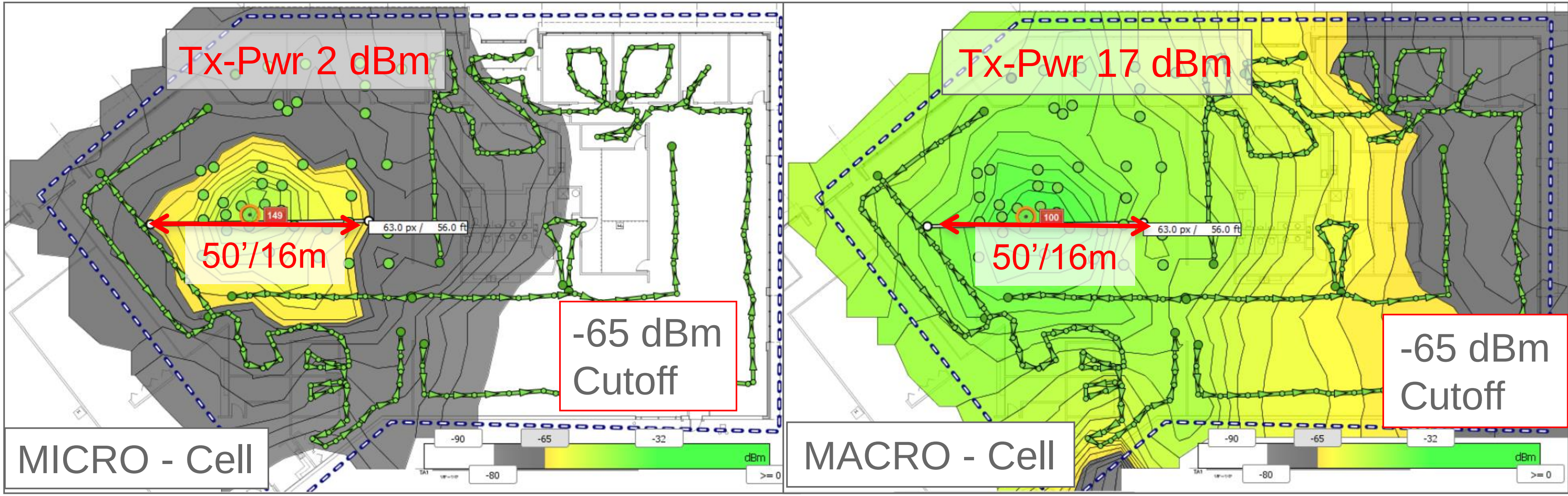
Conventional AP footprint (Macro-Cell) uniform 360 Degree coverage

By using spatially-efficient and compact antenna design along with different channels & Tx RF power – BOTH radios can co-exist internally

Smaller AP footprint (Micro-Cell) uniform 360 Degree but for smaller coverage area (high density) deployments

Dual Serving 5 GHz Integrated Radios

RF survey AP-3800i using (Micro & Macro) cells

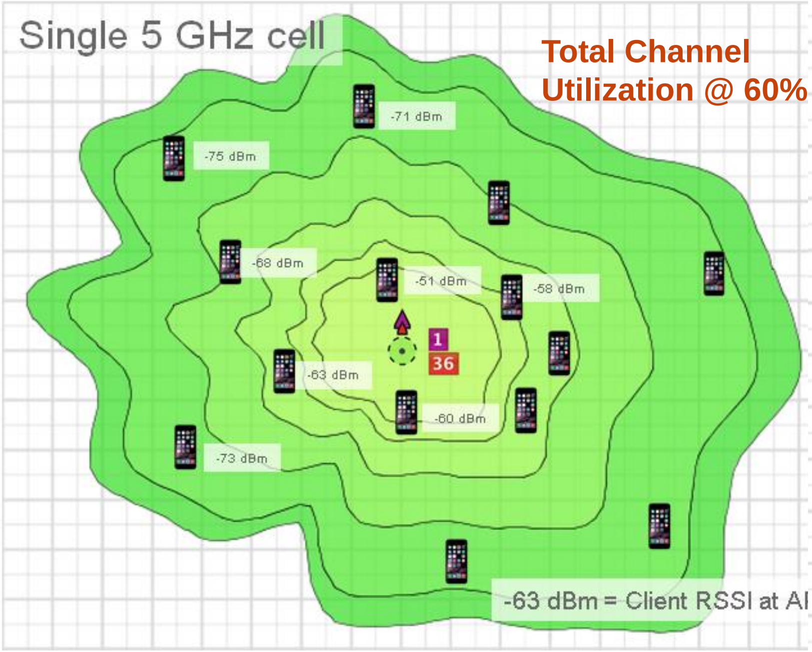


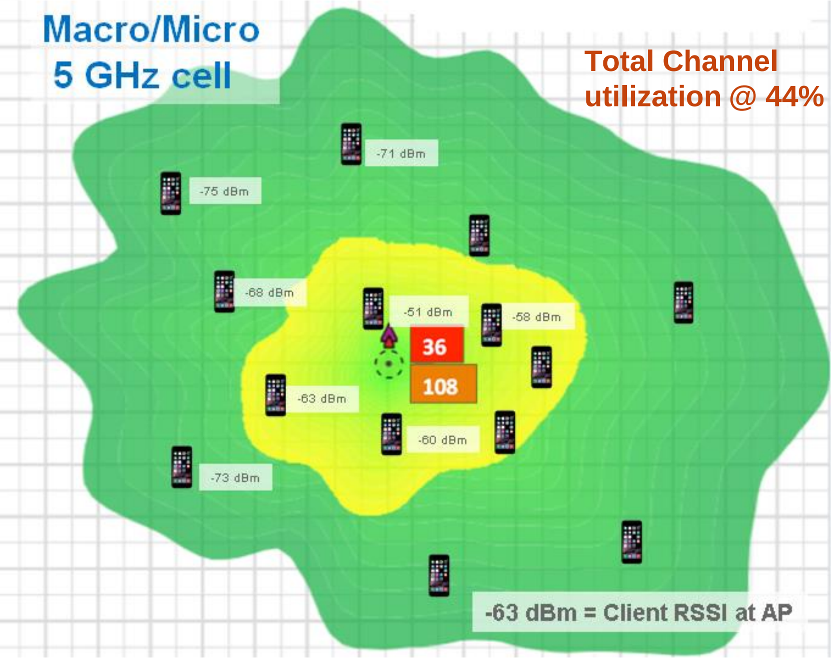
Using Micro/Macro RF utilization for clients improves

Lets see how that's done…

Cisco live!

Single Cell versus Macro/Micro Cell





Single channel 36 utilization at 60% (clients far away take longer airtime)

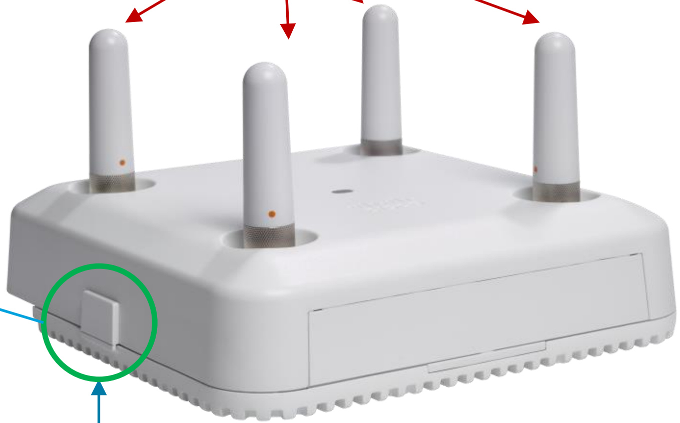
Using Micro/Macro (Dual 5 GHz) Channel 36 @ 20% & Channel 108 @ 24%

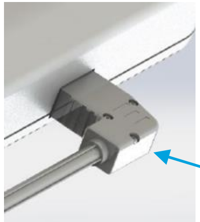
Take-away -- LESS retries, faster data-rates & less channel utilization

Now let's look at External Antenna Models

Smart Antenna Connector – 2800 / 3800

Primary Antenna Connectors – Dipole and Cabled Antennas



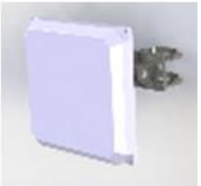


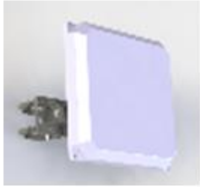
Smart Antenna Connector

Second Cabled or Location Antenna*

- Cisco pioneered intelligent antenna connector
- Sleek design
- Allows a second cabled antenna to be connected to the Access Point
    - Dual 5 GHz
    - Band specific antennas
    - Location antennas*
- Antenna versatility for challenging coverage deployments - High Density locations, auditorium classrooms, stadiums, arenas, convention centers, …

Dual 5 GHz “E” model Macro-Macro cells or Micro-Micro cells or any combination





Stadium antenna deployments for different coverage areas or higher density areas

ANT-2566 in different directions or even back-to-back tilted downward for Factory and warehouse deployments

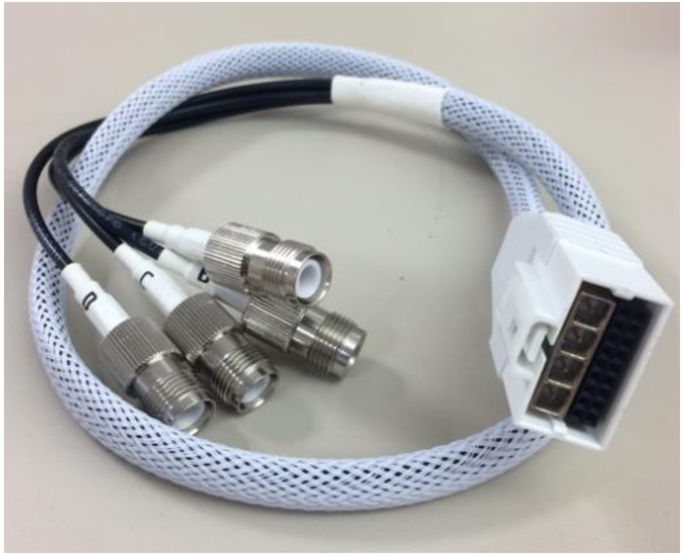
Cable allows for secondary 5 GHz radio antenna to be physically spaced away from the primary radio allowing for Macro-Macro operation

Omni + directional deployments

New Smart Antenna Connector "DART"

Allows for future "smart antennas" and single cable design for RF and digital*

*This permits all 4 antenna ports from the secondary 5 GHz radio to adapt to existing antennas and/or hyperlocation (selected models)



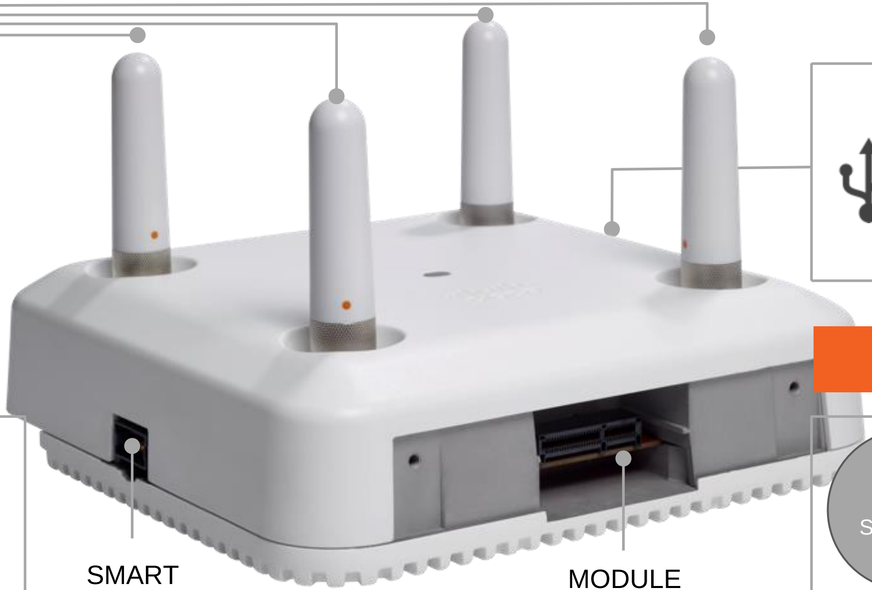
2800e and 3800e versions use a smart RF connector "DART" which carries digital signals as well as 4 RF connections from the secondary 5 GHz radio (smart antenna)

Cisco PID AIR-CAB002-DART-R

Adapter cable allows existing external antennas to be used with the secondary 5 GHz radio

Meet Any Wi-Fi Use Case

Expandability and Investment Protection



USB:
- Bluetooth Beacon
- Other

Self-Discover / Self-Configure
- Other
- Stadium Panel Antenna
- Directional Antennas
- location Antennas

Potential Future Expandability
- 3G and LTE Small Cell Offload
- Bluetooth Beaconing
- Other
- Custom Application Using Linux
- Future Wi-Fi Standard
- Video Surveillance

New features:

PoE Powering Options
N-BaseT (mGig) &
MU-MIMO overview

Understanding Cisco Mid-Span Power Injectors

For Your Reference

AIR-PWRIN2 & 3 (pre-802.11n) APs

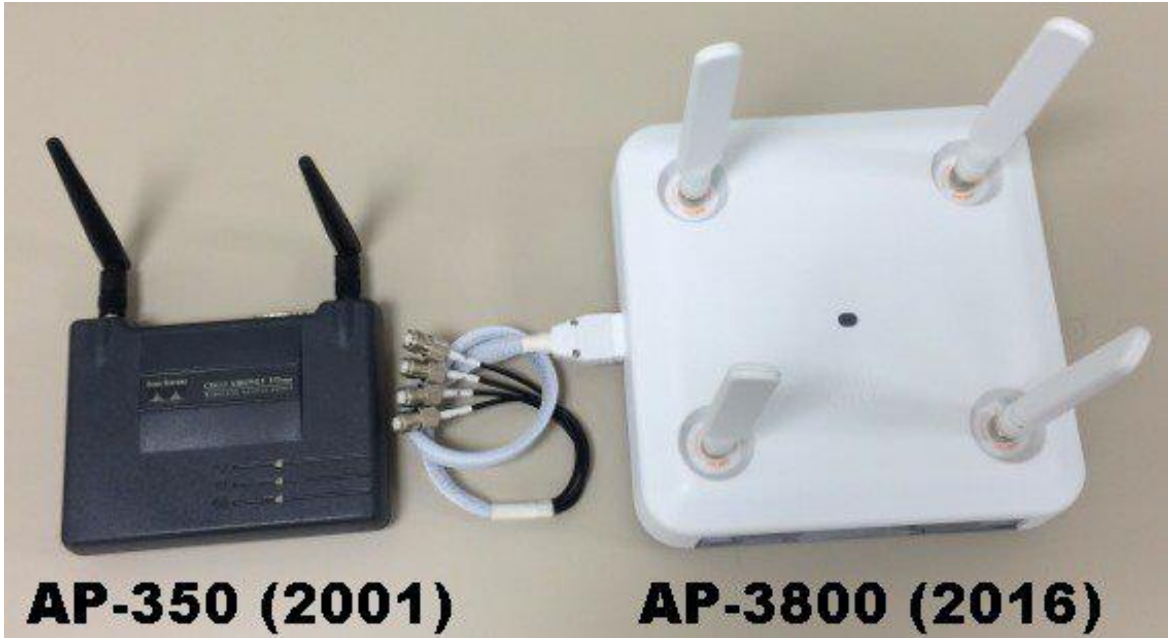
AIR-PWRIN4 802.3af (15.4W) and pre-standard (30W)
Designed for .11n and .11ac Wave1 indoor Enterprise APs

AIR-PWRIN5 802.3af (15.4W) low cost injector
Designed for Access Points that use 15W or less

AIR-PWRIN6 802.3af (15.4W) & 802.3at (30W) injector
Designed for all current Enterprise .11n, .11ac Wave1 and Wave 2

Note: AIR-PWRINJ6 is recommended for all newer Enterprise indoor Access Points (replaces earlier injectors) for most applications.

More powerful APs draw more PoE power



AP-350 had 1 radio and only utilized 6 Watts

AP-3800 has 12 Radios, mGig, powerful CPU, lots of RAM Powers at 30W w/o module

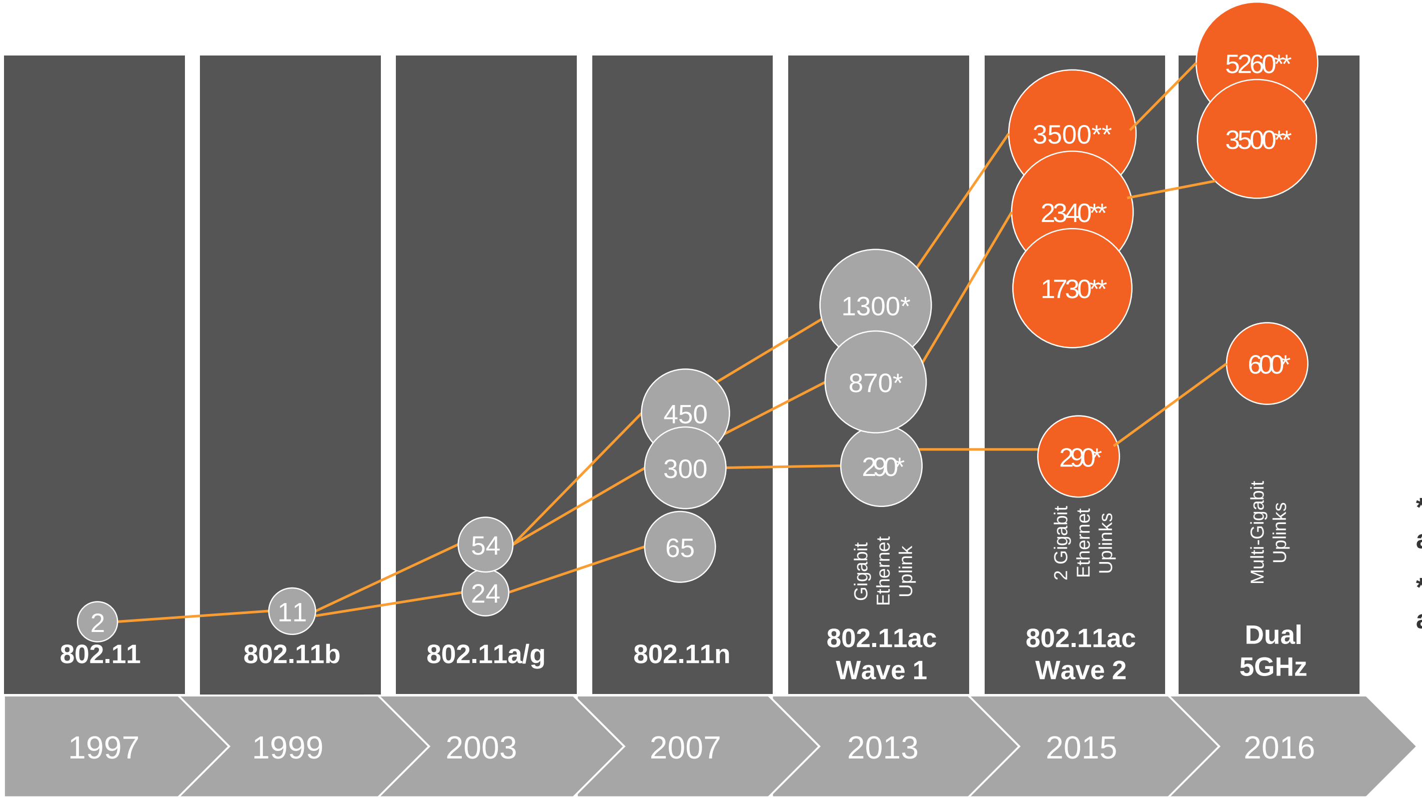
AP-2800 Powers at 26 Watts

Local Power Supply - Cisco PID = AIR-PWR-50
AIR (Aironet) PWR (Power) 50 (50 Watt)

AP-3800 also supports local 50W power supply
For use with option modules – uPoE also supported

Wi-Fi Connectivity Speed Timeline

Need for Gigabit Wi-Fi as Primary Access



4SS	Desktops
3SS	Desktops / Laptops
2SS	Laptops / Tablets
1SS	Tablets / Smartphones

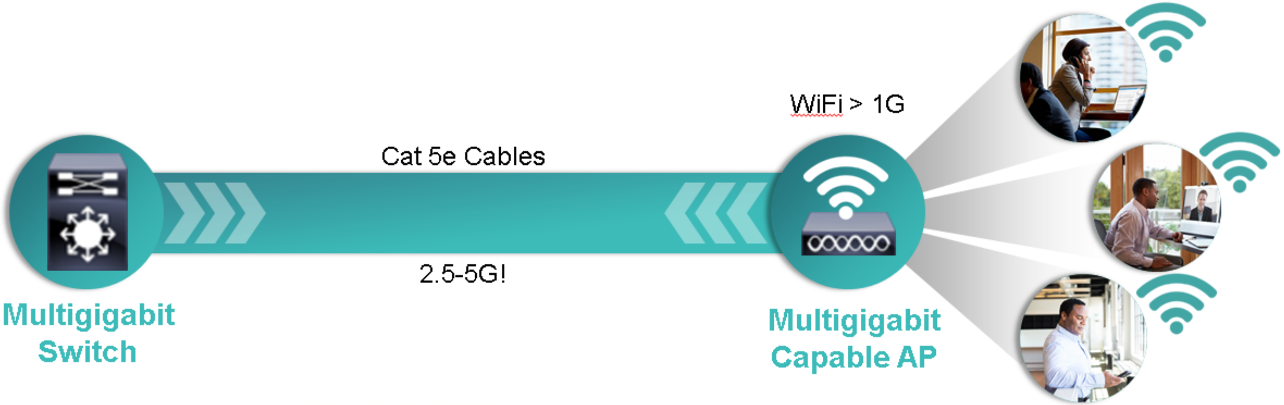
● = Connect Rates (Mbps)

SS = Spatial Streams

***Assuming 80 MHz channel is available and suitable**

****Assuming 160 MHz channel is available and suitable**

Cisco Multigigabit (mGig) using NBASE-T



Cisco Multigigabit with NBASE-T ™

Is a game-changing innovation allowing enterprise networks to evolve beyond 1G

Enables 2.5 and 5 Gbps up to 100m on legacy cables

Supports all PoE standards up to 60W

Delivers up to 5X Speeds in Enterprise without replacing Cabling Infrastructure

3800 mGig Cabling Support – Maximum Flexibility

Cable Type	FE	1G	2.5G	5G
Cat5e	●	●	●	● * 55-100m
Cat6	●	●	●	●
Cat6a	●	●	●	●

- Auto-negotiation of cable type of speeds supported
- *5G speeds limited to distance of 55m impacted with 6-n-1 bundles on Cat5e

What if I’m not able to get mGig speeds?

Troubleshooting mGig (N-Base-T)

Cable Type	Port Speed	Total Cable Length	6-a-1 Bundled Cable Length	Patch Panel Cable and 3 Connecters	Mitigation Plan to improve performance
Cat 5e	10GE	N/A	N/A	N/A	Upgrade cable to Cat 6a
	5GE	100m	>30m	10m (2x5)	1) Use “Downshift” 2) Reduce number of connectors 3) Change patch cable to solid core cable 4) Reduce bundled cable length to be <30m 5) Use Cable Diagnostic or Cable Tester to determine end-to-end Cable quality
	5GE	100m	<30m		5GE
	5GE	55m	Fully bundled	10m	5GE
	2.5G	100m	Fully bundled	10m	2.5GE

Downshift

Option that permits system to detect and lower speeds when noise occurs rather than maintaining a fixed value

Cisco Multigigabit Products

For Your Reference

4500E

- Best In Class Modular Access
- New 48 Ports Line Card
- 12 Ports of Multigigabit per slot
- Up to 96 multigigabit ports per system

3850

- Industry leading Fixed Access
- 24 & 48 Port Stackable Switches
- 24 & 12 Multigigabit Ports
- New Uplinks

3560CX

- NG Workspace switch
- Multigigabit in smallest form factor
- POE/POE+
- Instant Access support

48-port Catalyst 3850 Multigigabit Switch

Downlinks:

36 x 1G LineRate 10/100/1000BASE-T, PoE/PoE+/UPoE, EEE, MACSec

12 x GE/mGig/10GT – LineRate, 100M/1GE/mGiG/10GBASE-T, PoE/PoE+, PoE/PoE+/UPoE, EEE, MACSec

Uplinks:

4x10GE SFP+, 2 x 40G (NEW), 8x10G (NEW)

24-port Catalyst 3850 Mulitgigabit Switch

Downlinks:

- 24 x GE/mGig/10GT
- EEE, MACSec
- PoE/PoE+/UPOE

Uplinks:

4x10GE SFP+, 2 x 40G (NEW), 8x10G (NEW)

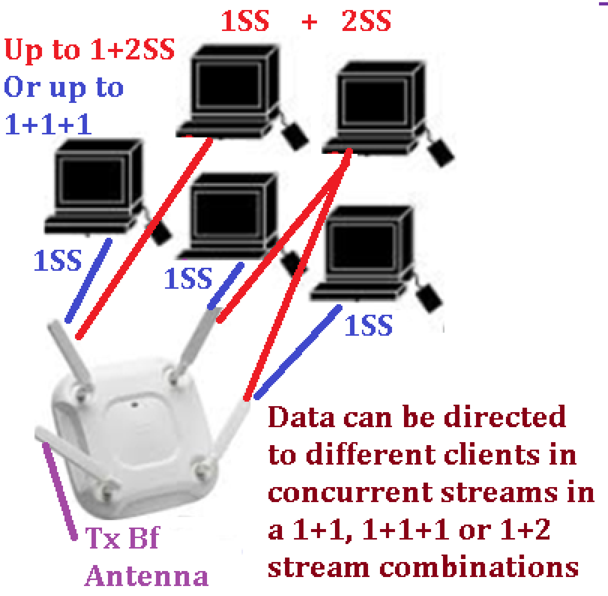
Multi-User MIMO (MU-MIMO) 11ac Wave-2 feature

How does it work? Why is it an advantage?

Some folks like to use the analogy of "Hub" and "Switch" (not exactly accurate) but in MU-MIMO Clients are able to benefit in the downstream link for higher aggregate throughput by essentially "tuning out" (nulling) portions of the RF to better decode their traffic.

This is Single-User MIMO

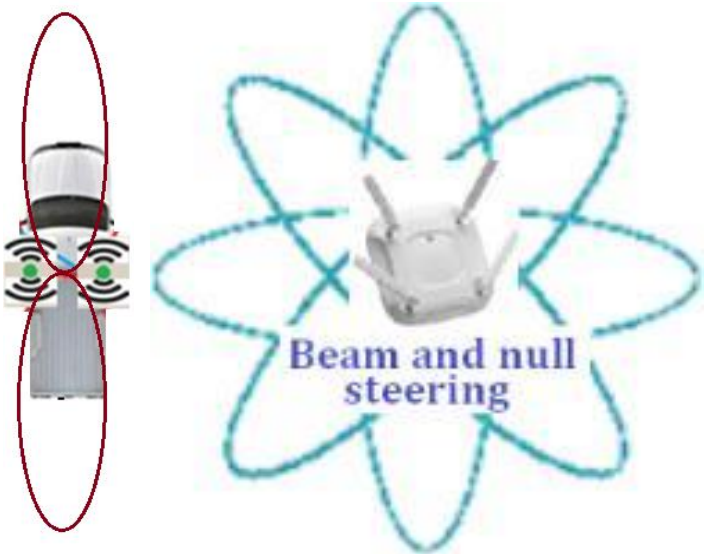
This is Multi-User MIMO

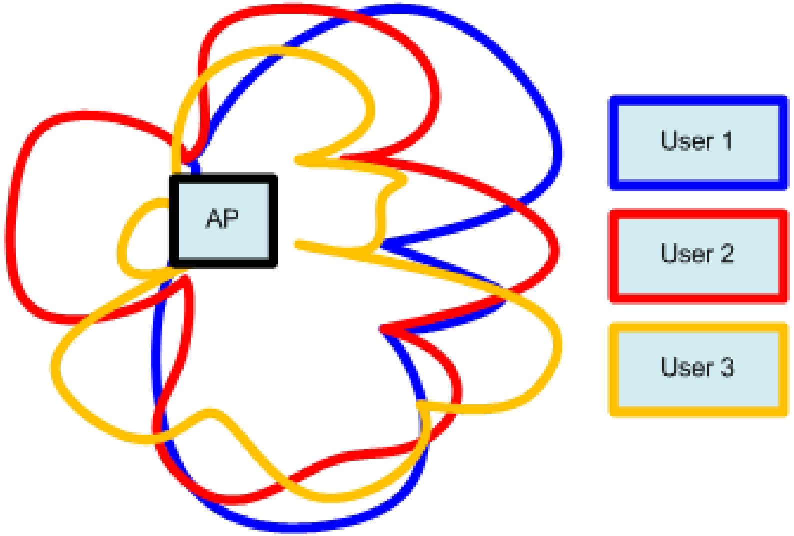


Max 3SS simultaneously

Multi-User MIMO (MU-MIMO)

Occurs when TxBF is able to focus the RF at a client while creating a null to the other clients



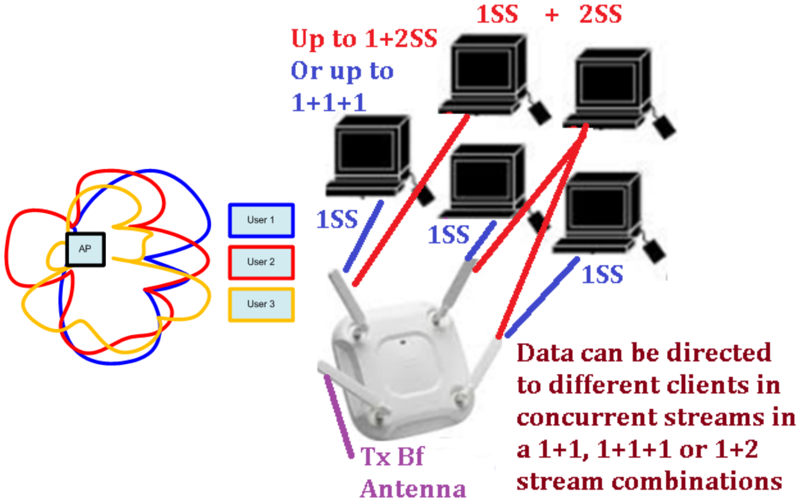


Similar to what the truck did with two antennas , using TxBF we have 4 antennas, and can place the signal <u>anywhere we want</u>

While TxBF (directing) the signal at say <u>User1</u>, you have to <u>also</u> create a NULL or lower signal for <u>Users 2 & 3 etc.</u>

Multi-User MIMO (MU-MIMO)

Performs TxBF, while nulling and also sending similar size data packets using 4th antenna TxBF



Each Wave-2 client sends CSI (Channel State Information) about how to best beam-form to it.

The AP then determines how it will beam-form and null to each of the 2-3 clients and then clusters these “ideal” clients into groups.

On a per-packet-basis each member of a group receives a similar size packet at the same time (downstream).

AP is using the 4th antenna to beam-form and null. In reality the clients are ideally spaced apart around the AP and not clustered together like the diagram depicts.

Understanding Multi-User MIMO (challenges)

- **MU-MIMO is complex and challenging:**
  - **Requires precise (CSI) channel state information to maintain deep nulls so each MU-MIMO client can properly decode its data without too much interference from the other clients**
  - **MU-MIMO CSI, pre-coding group data adds overhead as does their acknowledgements etc. The more MU-MIMO clients there are the more likelihood that the "law of diminishing returns" kicks in**
  - **Rate adaptation is SLOW – Wave-2 clients to be integrated into new laptops, tablets and phones**
  - **Lower quality clients – may be sensitive to MU grouping overhead, client driver version issues, they might report less helpful data in the "sounding" CSI data etc.?**
  - **Possible performance enhancements using Cisco's custom ClientLink technology <implicit> beamforming When using it along with the standards <explicit> beamforming provides Cisco products with *BOTH* methods of TxBF determination. This could be used to augment the client's CSI data for better NULLS and TxBF**

Note: Being able to design at the chipset layer may allow for significant enhancements in MU-MIMO processing beyond what "off the shelf" silicon can provide, look for these improvements in the Cisco 2K and 3K (Wave2) implementations going forward.

Multi-User MIMO – Client side of things…

What's happening right now with MU-MIMO and new APs and Clients?

Wave-1 clients do not support MU-MIMO and Wave-2 clients are just starting to appear

Access Point Objectives

Cisco's first Wave-2 AP was designed to enter the market quickly with an Entry Level (1K) Series AP (AP-1850) so Wave-2 clients will have an early Wave-2 AP to connect with using MU-MIMO

Newer Wave-2 APs (2K & 3K) Series now leverage enterprise features such as Mgig, ClientLink, Dual 5 GHz radios etc. for best in class performance.

Most Wave-2 clients are phones but many phones are on two year contracts – things just don't turnover that fast (.11a/g/n and .11ac Wave 1) Will be the majority of clients for next few years

Also from a client card perspective, Less radios = less cost, this makes 160MHz attractive

Wave-2 Clients can be found here http://wikidevi.com/wiki/List_of_802.11ac_Hardware

Installation and Deployment Considerations

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 <u>requiring higher temperature ranges</u>

Access Points for indoor & outdoor applications

- **Harsh environmental conditions (e.g. refrigerated rooms, condensing humidity…)**
- **Low voltage power (battery) or 100-480V AC applications**
- **ATEX Class I Division 2 (potentially explosive areas)**

1552h

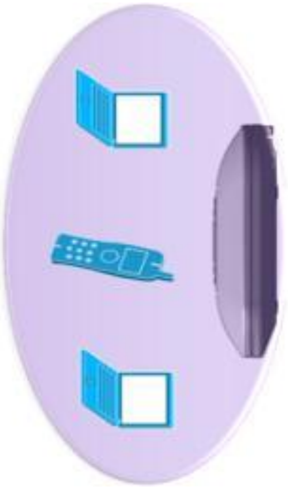
1570

1530 (Integrated Ant)

Wall Mounting Access Point with Internal Antennas

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

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



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).

Wall Mounting Access Points w/Dipole Antennas

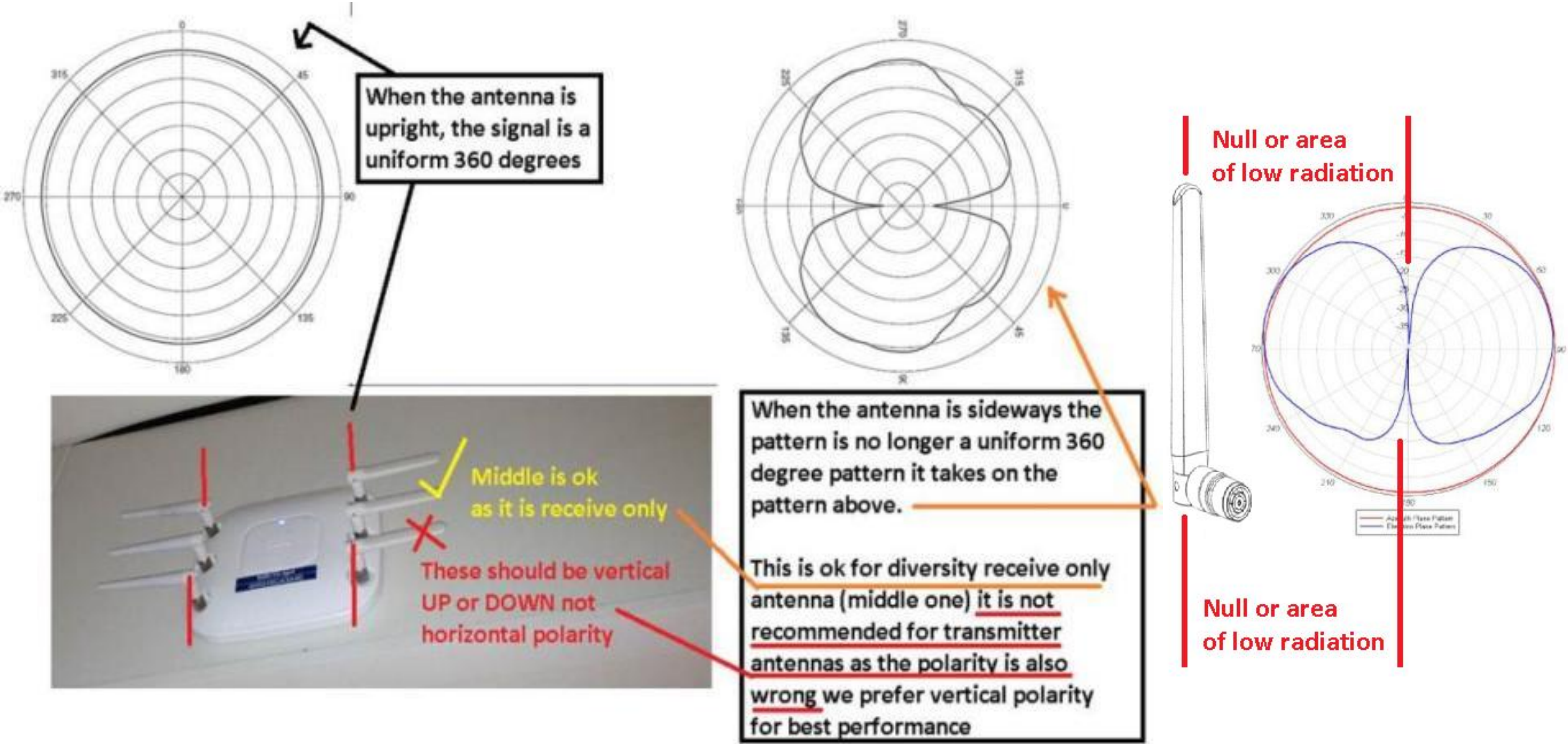
Orientation of the dipoles when wall mounting

If using advanced features like location or voice, try to locate the AP on the ceiling for best RF performance. If mounting the AP on a wall orient the dipoles in a vertical 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 a "wedge" type wall bracket (above).

Wall Mounting Access Points with Dipole Antennas

Orientation of the Dipoles if Wall Mounting



Wall Mounting Access Points with Dipoles

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

What About Mounting Options?

Different Mounting Options for Ceiling APs

Cisco has options to mount directly into the tile for a more elegant look

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

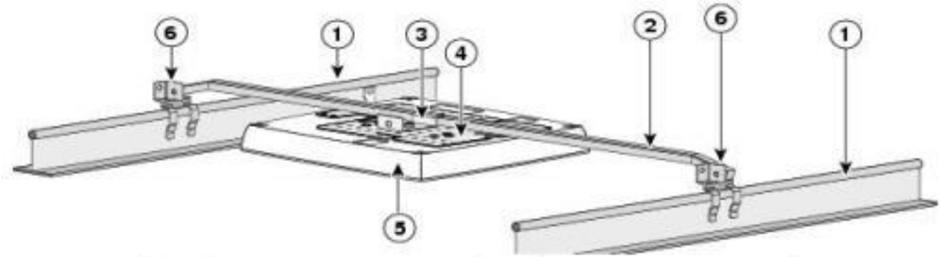
www.oberonwireless.com

www.terrawave.com

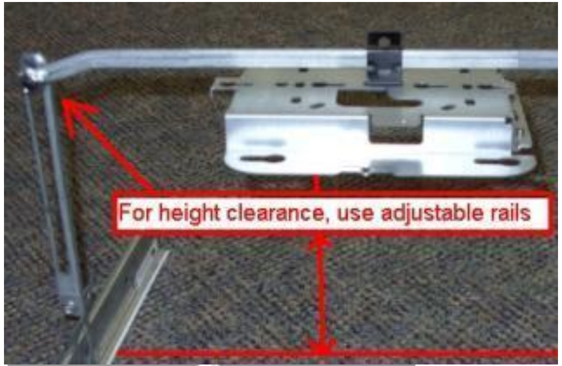
Installation above the Ceiling Tiles

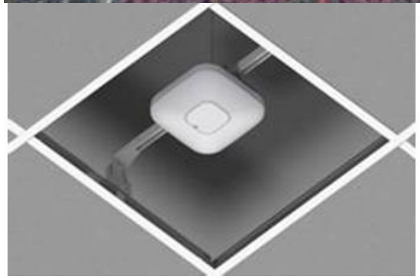
An Optional Rail Above the Tiles May Be Used

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





Mount AP as close to the inside of the tile as possible

Note: The AP / antenna should be very close to the back of the tile

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

AP Placement Above False Ceiling Tile 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 products have cables that are plenum rated so the antenna can be placed below the Plenum area 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 locate the antennas below the ceiling whenever possible

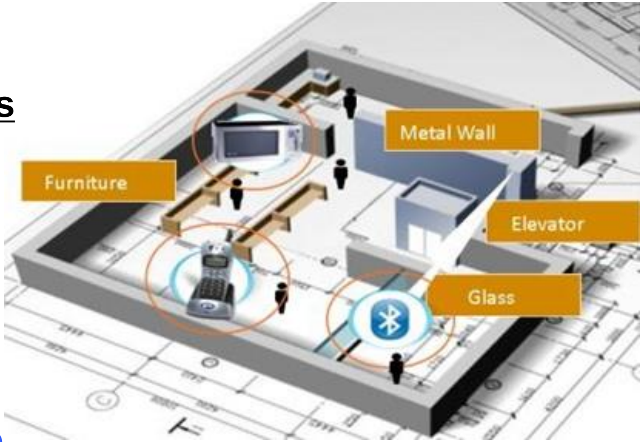
Antenna Placement Considerations

- **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

Site Survey

- Checking Wi-Fi coverage - As you bond channels and use complex modulation like 256-QAM, best performance occurs the closer the client is to the AP, so always try to physically place the AP as close to the actual users as possible
  - Let RRM manage the channel selection and RF power
  - Use the BandSelect feature to push clients to 5 GHz
  - Spectrum Intelligence (CleanAir) to detect interference
  - Use 5 GHz as much as possible (2.4 is limited 1,6 & 11)
  - If a warehouse (don't survey when it is empty)
  - Beware of environment (hospital metal doors) etc.



Doors, metal cabinets, furniture, walls & objects all effect WLAN coverage
Tip: Check coverage with the worse client you have

See Cisco Access Point Deployment guide at this URL
http://www.cisco.com/c/en/us/td/docs/wireless/technology/apdeploy/7-6/Cisco_Aironet_3700AP.html

Upgrading Access Points 1:1 or another survey?

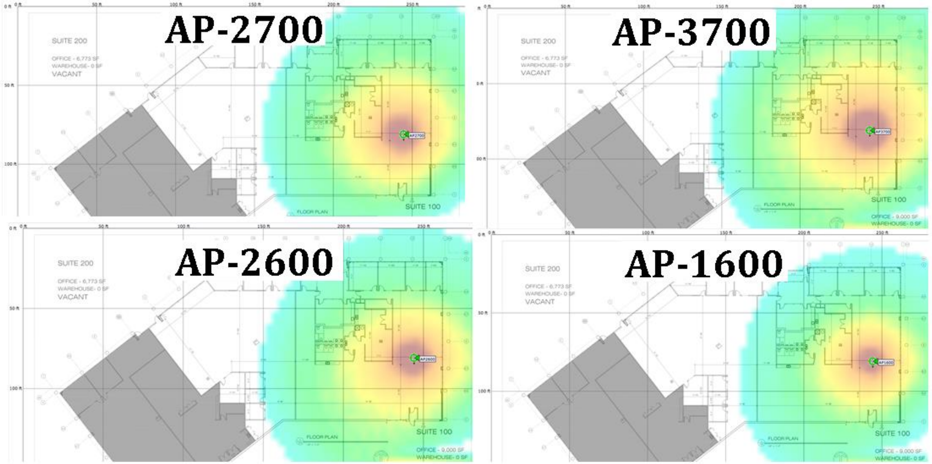
Question: If I replace my Access Points with a newer 802.11ac Access Point do I have to resurvey? Is the spacing the same between 11n and 11ac?

Answer: 11ac builds upon 11n, and cell sizes are similar. Years ago the guidelines were

1 per 5,000 Sq Feet for data only and 1 per 3,000 sq. feet for voice & location (US)

We now recommend 1 per 2,500 sq feet and no longer break it down by applications.

In Europe we now recommend 1 AP per 250 square meters

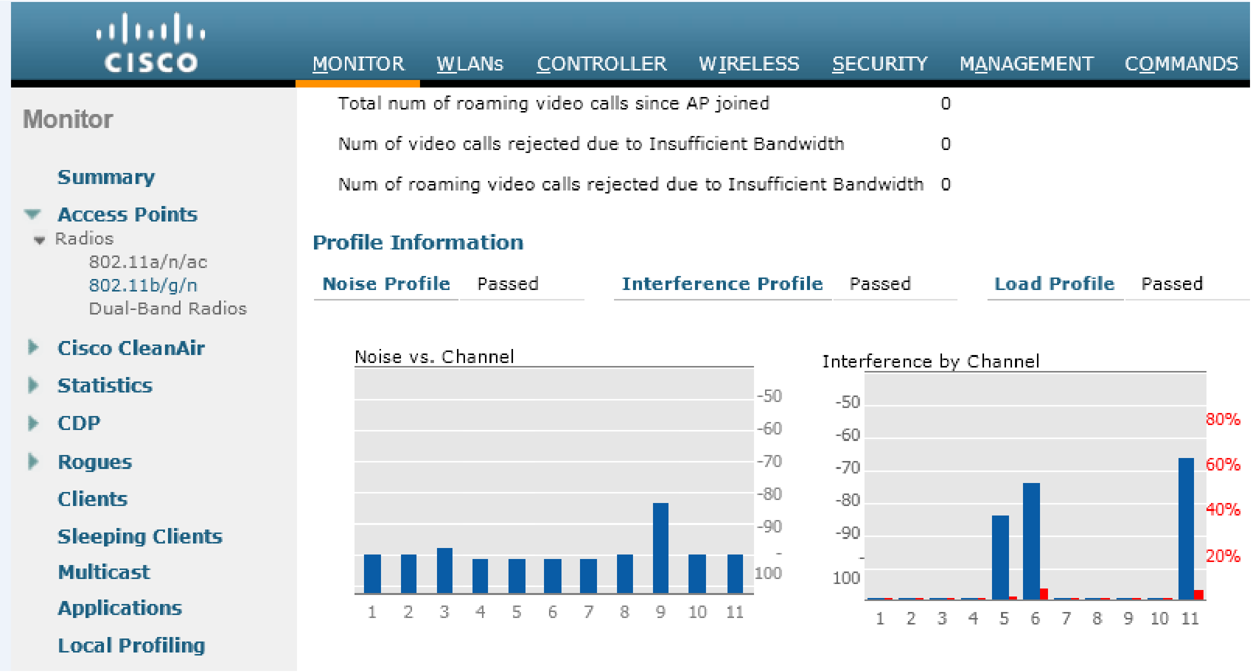


Access Points have always had similar heat maps – There will always be slight differences but the goal is to maintain uniform coverage with less retries

It is always a good idea to check and verify coverage.

Is there a way to see co-channel interference or noise?

Answer: For each AP, you can go to **Monitor > AP > choose a radio**, and see the interference levels reported at this AP position, for all channels,



How do I cut down on co-channel interference?

Question: How do I mitigate co-channel interference

Answer: You can try a few things…

1. Try to balance out the coverage by configuring a lowest MCS rate to set or scale the cell size and then disabling lower rates to reduce the cell footprint.

2. If warehouse or large open areas consider using directional antennas (patch/sector) to minimize cell overlap instead of dipole or Omni-directional antennas.

3. If high ceilings use patch/sector to angle down and then perhaps correct (TPC) Transmitter Power Control threshold to keep AP from cutting power too far back. Additionally consider lowering the antenna and using a wall mount.

4. If lots of voice – disable "Avoid Cisco AP Load" to keep clients sticky

Is there a minimum receiver sensitivity for 11ac?

For Your Reference

Question: **All these different modulation techniques, bonding channels etc. all impact range. Is there a minimum receiver sensitivity to successfully decode these so I know my cell sizes?**

Answer: **Yes - The chart on the right is taken from the IEEE 802.11 Spec. All Cisco Access Points meet these minimums. Also refer to Access Point specification sheets as well.**

Modulation	Rate (R)	Minimum sensitivity (20 MHz PPDU) (dBm)	Minimum sensitivity (40 MHz PPDU) (dBm)	Minimum sensitivity (80 MHz PPDU) (dBm)
BPSK	1/2	–82	–79	–76
QPSK	1/2	–79	–76	–73
QPSK	3/4	–77	–74	–71
16-QAM	1/2	–74	–71	–68
16-QAM	3/4	–70	–67	–64
64-QAM	2/3	–66	–63	–60
64-QAM	3/4	–65	–62	–59
64-QAM	5/6	–64	–61	–58
256-QAM	3/4	–59	–56	–53
256-QAM	5/6	–57	–54	–51

Important "Best Practices" for 802.11ac Wave 1 or 2

- ✓ **5.0 GHz Gigabit WLAN to leverage more and cleaner channels / spectrum**
- ✓ **-65 to -67 RSSI to solve for Data, Voice, Video, Location, & High Density**
- ✓ **10 - 20% cell overlap to optimize roaming and location calculations / transactions**
- ✓ **Separate SSIDs for Corporate and Guest Access with Guest being Rate Limited**

Wi-Fi Signal Strength - RSSI

- -65 to – 67 = Data, Voice, Video, Location, High Density
  - 1 Access Point per 2,500 square feet / every 50 feet
- -68 to – 69 = Data, Voice, Multicast & Unicast Video, Location
- -70 to – 71 = Data, Unicast Video
- -72 or greater = Data Only

802.11ac Wave 1

- 40 MHz channel width – 1 cable for GE

802.11ac Wave 2

- 80 MHz channel width – 2 cables for GE
- 80 MHz channel width – 1 cable for mGig

Cable Category

- Category 5E or better for GE or mGig

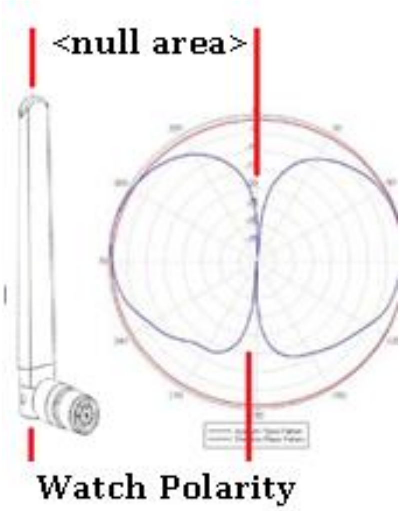
A look at some installations that went wrong

Installations that Went Wrong

NEVER EVER MIX ANTENNA TYPES

Antennas should always cover the same RF cell

Watch dipole orientation



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

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.

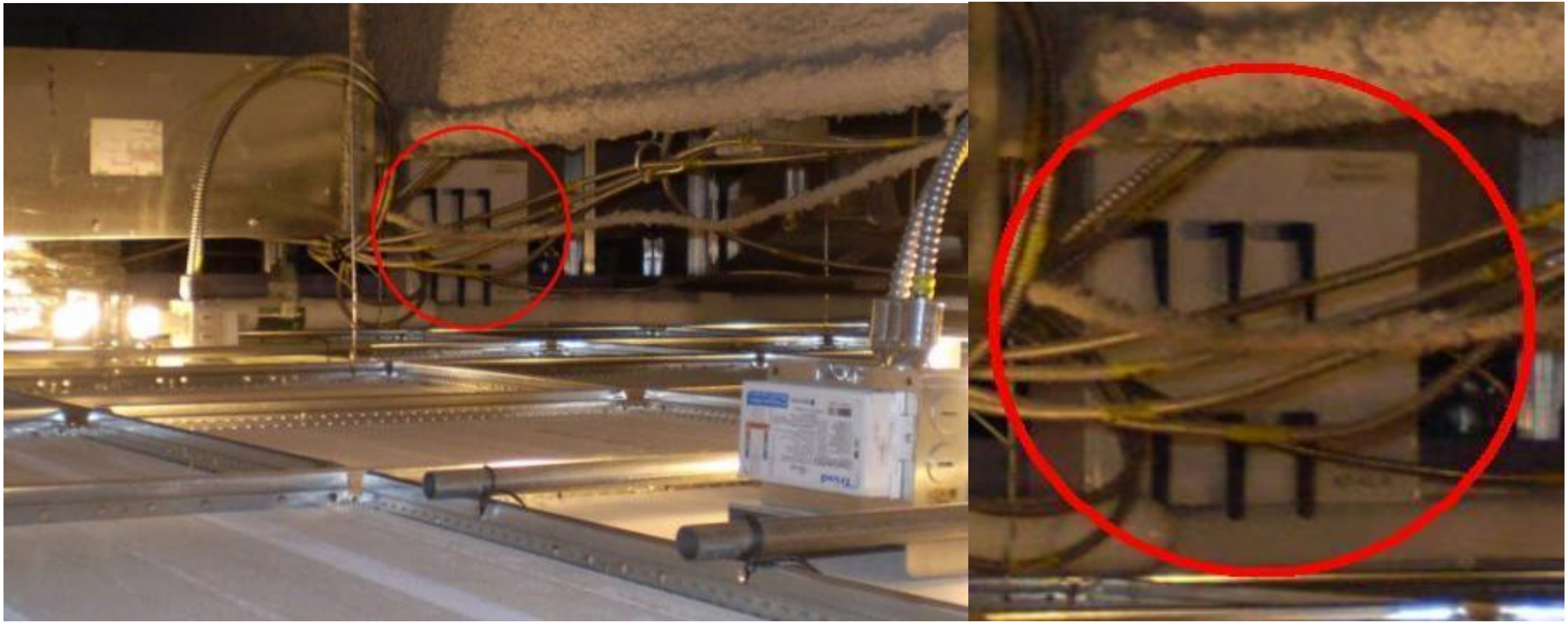
It is now essentially a directional patch suffering from acute multipath distortion problems.

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

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 weatherized (just keeping the packets on ice)

Installations that Went Wrong – Really???

RF works poorly through metal or plastic coated metal cages

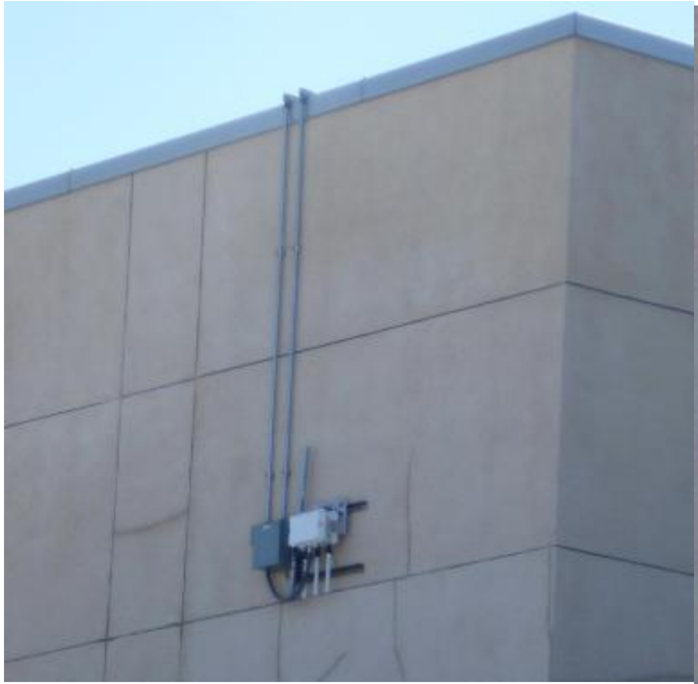
Installations that Went Wrong - Mesh

GOOD INSTALL

BAD INSTALLS

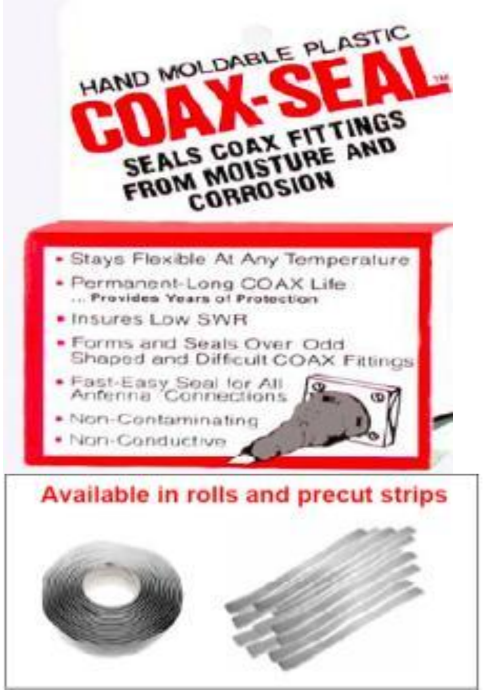
Installations that Went Wrong - Mesh

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.

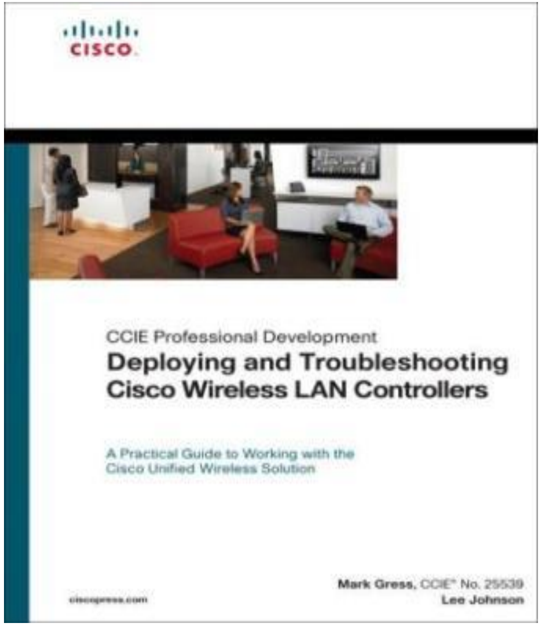
Note: Always tape from the bottom up so water runs over the folds in the tape. Avoid using RTV silicone or other caustic material.

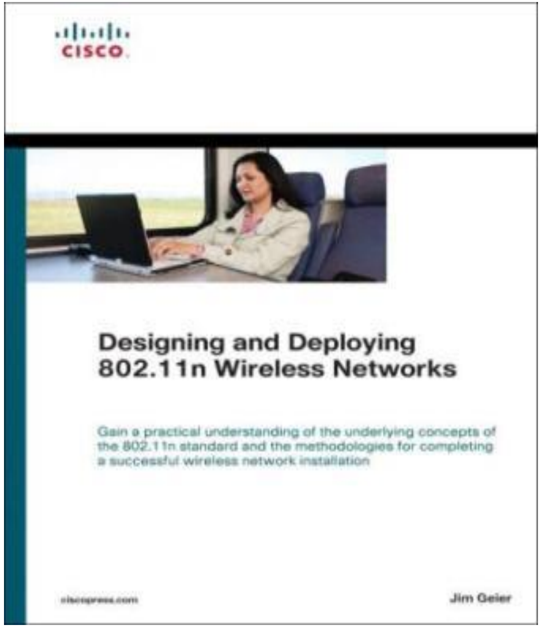
Summary

- 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 guides at this URL

http://www.cisco.com/c/en/us/td/docs/wireless/technology/apdeploy/7-6/Cisco_Aironet_3700AP.html

http://www.cisco.com/c/en/us/td/docs/wireless/controller/technotes/8-3/b_cisco_aironet_series_2800_3800_access_point_deployment_guide.pdf

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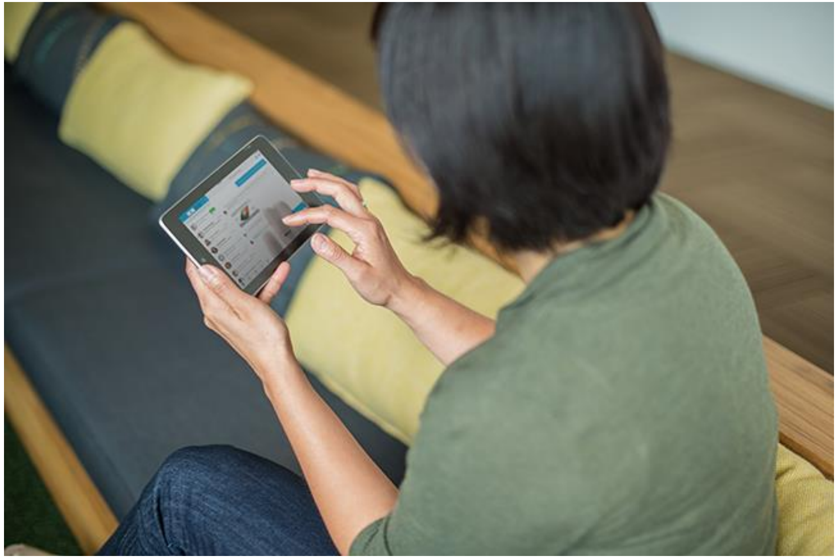

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