Understanding RF Fundamentals and the Radio Design of Wireless 802.11ax (Wi-Fi 6) Networks

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Session Abstract

This session focuses on understanding Radio Frequency part of designing and deploying a Wireless LAN Network. This session will start with a quick review of radio and then dive into High Efficiency 802.11ax networks. It will cover topics such as 802.11 radio, MU-MIMO, AP & antenna placements, how to read antenna pattern...

...Generally HOW THINGS WORK 😊
Agenda

• What is radio and how did we get here? Fast review of the past

• Deep dive into 802.11ax why it matters and what it addresses

• Understanding QAM modulation, OFDM, OFDMA, Fundamentals of Beam-forming both standards based and Cisco ClientLink – as well as BSS Coloring, Target Wake Time etc.

• 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 problem
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
Tomorrow is the most important thing in life. Comes into us at midnight very clean.

It’s perfect when it arrives and puts itself in our hands. It hopes we’ve learned something from yesterday.

Source: John Wayne’s Grave Marker
Newport Beach, California USA

Thank you for choosing this Cisco Live presentation today and wishing everyone a great tomorrow & 2019 year 😊

Now let's get started...
What is RF?

Wi-Fi name & timeline
Radio Frequency Principles &
How we got on these channels?
Battery is DC Direct Current
Typical home is AC Alternating Current

Frequency is how fast the AC current goes back and forth
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*.

*NOTE: This is why 2.4 GHz goes further vs. 5 GHz (given same amount of RF power, antenna gain etc).

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/ac 5 GHz
Wi-Fi .11ax enhancements to 2.4G and 5GHz

Waves travel back and forth so fast they actually leave the wire
Where did we get this spectrum?
Who was on it first? Why is it “unlicensed” 2.4 GHz travels further but limited channels

The first frequencies available for Wi-Fi use were in the 2.4 GHz range but was limited – 5 GHz open up more channels but certain channels are Dynamic Frequency Selection “DFS” we must leave if we detect a licensed user

IEEE Designators / Frequencies
802.11af – 54–790 MHz
802.11ah – 900 MHz
802.11b/g/n – 2.4 GHz
802.11a/ac – 5 GHz
802.11ax – (2.4 & 5 GHz)
802.11ad – 60 GHz

Note: A new 3.5 GHz band “CBRS” Citizens Broadband Radio Service is (evolving)... Service Provider / LTE
Radio Mobility & Portability Drive Innovation...

Evolution – Device side of things ↔ Radio Side of things

- 1978 Ham Radio w/Touch Tone Pad
- Early Cell Phones Looked like radios then became smaller
- Make it a computer then SHRINK IT AGAIN!
- Pack in lots more “bits of data” & SHRINK IT AGAIN!

- Morse code 1 RF Stream
- “bits of data” and portable (leg clamp)
- Voice then Video
- X25 Packet Radio
- Then “Wi-Fi” with MORE STREAMS...

Evolution – Device side of things

 Pack in lots more “bits of data” & SHRINK IT AGAIN!
Understanding Wi-Fi... Radio Improvements...

1997-2003
Bar Code Reader

2003
2.4 GHz

5 GHz

Cisco AP-1240
1-Spatial Stream w/2 Antennas for Diversity Per Band

More Antennas 4 per band
Multiple Spatial Streams
Multiple Radios – MRC Diversity
Wider Channels – Bonding
About performance & SPEED...

Early PTC DOS/Win
1 Antenna 1 Stream

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Wi-Fi Standards and Timeline

Cisco acquired Aironet in March of 2000 and made Wi-Fi a household name*

In 1999 Aironet a founding member of WECA along with Interbrand came up with the name “Wi-Fi”

1998 Aironet AP-4800E*

Aironet AP-4800E  FIRST 11 Mbps AP (1995/96)

In 1999 Aironet a founding member of WECA along with Interbrand came up with the name “Wi-Fi”

1998 Aironet AP-4800E*

*The AP-4800e was one of the very 1st Access Points to reach wired speeds @ 11 Mbps now 20 years later the new AP-4800 is the best in class 802.11ac Wave-2 Access Point

20 years later, Cisco-Aironet is still known for “best in class APs”

Wi-Fi Standards IEEE Timeline

Same fast speeds has Dual 5GHz + Hyperlocation, Cisco DNA Analytics + Intelligent Capture

**NEW 2018**
Cisco-Aironet AP-4800
Best in Class Enterprise APs are all about Cisco Innovation

**ClientLink TxBF**
Cisco Beamforming - improved coverage for 802.11a/g/n clients

**CleanAir Spectrum Analysis**
Identify interference – RF Spectrum Analyzer
Self Healing – Self Optimizing Wireless Network

**Hyperlocation (Precise Location)**
Wayfinding, client tracking, Bluetooth low energy beaconing

**XoR Radio Dual 5 GHz Flexible Radio + mGig**
Faster throughput – lower channel utilization – enhances HDX experience

**AP Sensor Functionality + Dedicated Hardware Sensors**
Wireless Performance Analytics, Real-time Client Troubleshooting and Proactive WLAN Health Assessment

**True Client Location Accuracy**
Cisco DNA Ready

**AP-1800s**
Understanding Wi-Fi 6

.11ax Building upon the Foundations of .11n and 802.11ac Wave-1 & 2
History of Industry-Leading Wi-Fi Innovations
For Every Major Change In WLAN Over The Last 20+ Years

- 802.11b/g
- 802.11n
- 802.11ac wave 1
- 802.11ac wave 2
- 802.11ax

- Autonomous Access Point
- Controller and Coordinated Access Points
- CleanAir: interference detection and mitigation
- Connected Mobile Experiences
- Application Visibility and Control
- Hyperlocation
- Flexible Radio Assignment (Dual 5GHz)
- Software Defined Access
- Intelligent Capture and real-time telemetry

What’s next? Wi-Fi 6

Cisco Wi-Fi Leadership

AP3500
AP3600
AP3700
AP3800
AP4800


Cisco mGig

NBASE-T®
Next Generation 802.11ax is also called “Wi-Fi 6”

Wi-Fi 6 is a “Generations” Approach similar to the Cellular Industry naming.

802.11ax       Wi-Fi 6
802.11ac       Wi-Fi 5
802.11n        Wi-Fi 4

Telecommunications Industry “generations” 3G, 4G, 4GLTE, 5G…

Note: 802.11ax and Wi-Fi 6 are interchangeable Engineering and Marketing Terms for same thing.

You may sometimes hear the term “HEW” High Efficiency Wireless also used.
Why does Wi-Fi 6 Matter? What is the big deal?

Performance and capacity

- 3–4x Performance and Capacity over 802.11ac wave 2: support high bandwidth applications like next generation video with 4K/8K and AR/VR

Determinism and reliability

- Cellular-like reliability and QoS, IoT optimized: APs service hundreds of connected devices with the right QoS and increased amount of data uplink/downlink

Battery savings

- Massive battery savings for mobile device with improved reliability & coverage

Cisco only - value differentiations

Software differentiation from the Access Point, from Catalyst Wireless Controllers and from Cisco DNA

Cisco - Hardware innovations

Cisco purpose-built RF ASIC – Best in Class AP designs

Let’s look at what Wi-Fi 6 is trying to address...
Problem - 802.11ac doesn’t help everyone equally...

Speed & performance YES but it needs to be better for all users and also spectrum efficient.

11ac was about speed but real need is parallel processing for spectrum efficiency

MU-MIMO only in DL
Not widely adopted

Pkt. Agg – Does *NOT* address Small packet latency of IP phones
Nor does it help IoT devices with battery life or 2.4 GHz spectrum inefficiencies

Everyone needs to get on NOW equally
More IoT, VoIP & more 2.4 GHz personal devices coming online

Need for more Parallel UL/DL Transmissions & OFDMA performance
Need for spatial frequency reuse and Spectral Efficiency (1024 QAM)

Need to drive standards into the Actual clients - AP scheduling and client participation becomes table stakes so the entire WLAN has RF efficiency improvements.
Next Generation Technology a Multi-Year Journey

Wi-Fi 6 benefits realized after clients reach critical mass, CY2020 and beyond
Sunday snapshot of clients @ CLEUR – Most are .11ac
“tweeted out” to show no .11g clients were online and 1.95TB of data flowed 😊

Early morning snapshot of the network

.11ac came out in 2014 However there are still .11n clients on the network

It will be at least 3-4 years before .11ax becomes the majority

BUT it will happen..
# Differences Wi-Fi 5 and Wi-Fi 6

**A look at the Physical Layer Enhancements in .11ax**

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<th>Wi-Fi 6</th>
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<td>Multi-User MIMO (one to many) &lt;upstream and downstream&gt; up to 8x8</td>
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<td>Modulation type OFDM</td>
<td>Modulation type OFDM, OFDMA OFDMA – Aggregates multiple users into single larger packets 4x longer Symbol Time 12.8 (us)</td>
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<td>Channel reuse – CSMA</td>
<td>Channel reuse – CSMA also Optimistic CSMA – supports parallel transmissions in nearby BSS’s “coloring”</td>
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**Take-aways...**

- 2.4 GHz enhancements for small packets and sleep (IoT)
- Double Streams Faster T-PUT (8x8 Certification still a bit fluid)
- Multi-User MIMO UP/DN and small packet (phone & IoT)
- OFDMA & Longer Symbol time helps with Outdoor Links and cellular offloading
- No change in Channel Plan
- Faster Modulation @ 1024-QAM
- Allows for additional channel utilization

**Low-Density Parity-Check (LDPC) - method of ECC used over noisy channels was optional now required in .11ax**
802.11ax Next-Generation Improvements

**Introduction of OFDMA**
Orthogonal Frequency-Division Multiple Access

**Introduction of Optimistic CSMA** (Parallel Transmissions)

**BSS Color** - Looks at Signal strength and identity of BSS essentially does CSMA on it’s own BSS but does not need to for other nearby cells if detected preamble is below a threshold

New Field called BSS Color in the preamble frame – allows additional channel utilization

**Modulation Coding**
- .11ac MCS 0-9
- .11ax MCS 0-11 (new 1024-QAM) 25% higher throughput

**More Radios (8x8)** – Note: First releases of 8x8 may be pre-standard MU-MIMO on UPLINK as well as DOWNLINK

**“Target Wait Time”** - Scheduled sleep and wake times (Power Saving)
Longer guard interval / preamble for outdoor applications (cellular offloading)
802.11ax is all about High Efficiency Wireless

These improvements are RF enhancements to make EVERY microsecond “ON THE AIR” matter.

• .11ax High Efficiency Wireless (HEW) is all about optimizing the time spend “ON THE AIR” and how much information is on the air during any given Micro Second “μS”

• Four things determine Air Time efficiency

  1. Data Rate (Modulation Density) or QAM – (how many Bit’s per Radio Symbol) 64 QAM is more robust but 1024 QAM is a lot faster

  2. Number of Spatial Streams & Spatial reuse (introduction of OFDMA and Resource Units)

  3. Channel Bandwidth – How Many Frequencies can we modulate at one time

  4. Protocol Overhead – Preamble/Ack/BA, Guard Interval “GI” etc.

Note: Channel Bonding reduces range as the power is spread out with each additional 20 MHz adding a 3 dB penalty in SNR and the greater the QAM the harder it is for the receiver to decode therefore it is more sensitive to noise.
11ax Data-rate Chart for 1 Spatial Stream
Complex Modulation, Guard Interval and channel bonding is key to single radio performance.

| MCS index | Modulation type | Coding rate | Data rate (in Mb/s)
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<tbody>
<tr>
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<td></td>
<td>20 MHz channels</td>
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<tr>
<td></td>
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<td>1600 ns GI</td>
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<tr>
<td>0</td>
<td>BPSK</td>
<td>1/2</td>
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<tr>
<td>1</td>
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<td>2</td>
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<td>3</td>
<td>16-QAM</td>
<td>1/2</td>
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<td>4</td>
<td>16-QAM</td>
<td>3/4</td>
<td>49, 52</td>
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<tr>
<td>5</td>
<td>64-QAM</td>
<td>2/3</td>
<td>65, 69</td>
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<tr>
<td>6</td>
<td>64-QAM</td>
<td>3/4</td>
<td>73, 77</td>
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<td>7</td>
<td>64-QAM</td>
<td>5/6</td>
<td>81, 86</td>
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<tr>
<td>8</td>
<td>256-QAM</td>
<td>3/4</td>
<td>98, 103</td>
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<td>9</td>
<td>256-QAM</td>
<td>5/6</td>
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<td>10</td>
<td>1024-QAM</td>
<td>3/4</td>
<td>122, 129</td>
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<tr>
<td>11</td>
<td>1024-QAM</td>
<td>5/6</td>
<td>135, 143</td>
</tr>
</tbody>
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Up to 1.2 Gb with 1 radio, up to 11 Gb* with 8 radios @ 160 MHz

*Devices were presented at CES 2018 with a top speed of 11 Gbit/s
Source: https://en.wikipedia.org/wiki/IEEE_802.11ax
1024-QAM 40 MHz Channel (314 Sq. meters)

- Single-antenna devices (smart-phone) should see MCS10-11 (Gigabit speeds) → 35% faster than 11ac
Understanding OFDM – RF Modulation Carrier

.11ax uses OFDM but also implements OFDMA for High Efficiency Wireless

The technology works by splitting the radio signal into multiple smaller sub-signals that are then transmitted simultaneously at different frequencies to the receiver.

Note: The wider the channel, the more sub-channels available however, range is reduced because the same amount of power is now spread across wider spectrum – so receiver has to work harder to hear the weaker signal.

*Note: .11ax subcarriers are much closer @ 78.125 kHz

Subcarrier spacing is 312.5 kHz apart and Protected by a Guard Interval (short or long)*
Guard Interval (GI) – Period of time between each an OFDM symbol (subcarrier) 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.

**802.11n/ac supports GI of 400nS & 800nS – (Shorter = faster rates)**

**802.11ax the guard interval is 0.8, 1.6 & 3.2 uS (longer = outdoor use)**

(.11ax subcarriers are more dense so the shorter GI of 400nS (0.4uS) is not used for .11ax rates)
Understanding an OFDM and OFDMA

Both divide into sub-channels (carriers) but OFDMA has more and the concept of Resource Units.

- **OFDM** divides the available spectrum into sub-channels that can be independently modulated and demodulated. **OFDMA** divides the same 20 MHz spectrum into many more smaller subcarriers that can carry small packets faster.

**Take-away** – all packets big and small get processed MUCH FASTER

**OFDMA** allows each subcarrier to handle multiple users.

**Take-away** – all packets big and small get processed MUCH FASTER
Understanding OFDMA Resource Units

Each RU can be a different modulation scheme or coding rate determined by control information, scheduling etc.

Up to 9 users per 20 MHz
Tiny RUs ideal for IoT

RU's are indexed

Min. RU size
For MU-MIMO

802.11ax (OFDMA) provides determinism at scale: Enabling high-quality voice/video/data services cost effectively

Linear **VOICE** delay

Consistent **DATA** throughput

Wi-Fi 6 is not only cost-effective & ubiquitous but is now capable of delivering SLAs
802.11ax RU & Target Wake Time Benefits for IoT
Better Battery Life and co-existence via RF efficiency improvements

- 802.11ax RUs and TWT available in 2.4/5G GHz for IoT
- Thanks to 2 MHz channels, Coexistence with other 2.4 GHz IOT technologies is much more effective
- Any Channel can be left blank (no 802.11ax) to allow other technologies to operate

Target Wake Time (TWT) provides an effective mechanism to schedule transmissions in time.

Phones and IoT devices can sleep conserving battery life and then wake to take advantage of multi-user transmissions, and coexist in high-density RF environments with ease.
Target Wake Time – Putting Devices to Sleep

• With Target Wake Time (TWT), the AP can schedule phones and IoT devices sleep for long durations (up to 5 years) and then wake the individual device up.

• Devices can be configured to wake up as a group to communicate at the same time sharing the channel for increased network capacity and reduced battery drain.

• Use of BSS Color field and UL/DL flag in preamble to enable intra PPDU power Saving
OFDMA Benefits for IOT

OFDMA, 375 kbps Low Power, Low Throughput

- Using a single 2 MHz Resource Unit the AP and client can exchange at 375 kHz for low throughput and low power consumption ideal for IoT

- 802.11a/g/n/ac allowed only ~6-6.5 Mbps minimum, creating wasted bandwidth and higher RF power consumed.

- Longer Distance benefit as the power used for a 20 MHz channel could be concentrated into a single 2 MHz RU
  - Better Link Budget
  - No more cost to battery
  - DCM (Dual Subcarrier Modulation) RU can be repeated in another subcarrier for resiliency
2.4 & 5G High Density issues given – limited channels
2.4 GHz only has 3 non-overlapping channels 5 GHz channels reduced with channel bonding

The limiting factor in a high density design is typically co-channel interference “CCI”. With only three non-overlapping Wi-Fi channels at 2.4 GHz, frequency reuse is high. Cells using the same channel can be too close (and this is sometimes unavoidable)

Wi-Fi CCA is very sensitive, so clients have to back-off and wait – Biggest contributor OBSS CCI is high density clients running too much Tx power.

Directional antennas and Cisco’s RX-SOP (adjustable squelch) is used today
But not dynamic and requires RF experience
BSS Coloring – Spatial Reuse & addressing interference

Basic service Set “BSS” and Overlapping Basic Service Set “OBSS”

- **BSS Color** – All devices within a BSS send the same value (color), which will be different than other nearby BSSs (or OBSSs)
  - Each BSS (AP) uses a different “color” (6 bits in the preamble)
  - Each user (station) learns its BSS color upon association, allowing it to identify other BSS’s as OBSS
  - Stations detecting the same BSS color (intra-BSS) use a lower RSSI threshold for deferral which reduces Intra BSS collisions
  - Stations detecting a different BSS color (Inter-BSS) use a higher RSSI threshold, which allows more simultaneous transmissions

- **OBSS Packet Detection** is dynamic and managed by the AP
  - If a station reduces its TX power, the device can raise its inter-BSS CCA thresholds and transmit
  - TX Power reduction is based on Sounding Packets
  - Effectively RF locating the Client within the cell
  - The closer the client is to the AP, THE LOWER it’s transmitted power can be

**Benefit - Overcomes the problem of Clear Channel Assessment limitations**
Benefits of OFDMA & BSS Coloring

• IOT and VoIP – OFDMA allows parallel processing of multiple clients greatly reducing jitter and latency of packets both large and small.

• OFDMA and BSS Coloring are enhancements that also benefit 2.4 GHz where many IOT clients operate and/or High-density networks are desired.

• Outdoor distances increase as additional Guard Interval time, longer preamble and narrower subcarriers are easier to decode better in interference prone areas.

• Algorithms for BSS coloring reward the client by letting it transmit if it can reduce power (making airwaves more efficient) allowing more clients on the air at the same time. *Channel reuse now possible for higher performance.*
Understanding MU-MIMO & Spatial Streams

There is a lot to this... so a short review of RF fundamentals is necessary...
Understanding Multipath Diversity and Beamforming
Understanding Multipath

Multi-path 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 introduced OFDM modulation based on symbols and is an improvement over the older modulation types used with 802.11b clients – .11ax added OFDMA increasing Guard Interval to help with Multipath.

Access Points with more receivers can use destructive interference (multipath) as a benefit but it is best to try and reduce multipath conditions.
Understanding Antenna 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 for simplicity) with .11ax supports 8 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

Combined Effect (Adding all Rx Paths)

3 Antennas Rx Signals
MIMO – Multiple Input Multiple Output
Spatial Multiplexing (transmitting streams) first introduced in 802.11n

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...
802.11ax Spatial Streams – Up from 4 to 8 SS

- Some Access Points support 4-SS others 8-SS
- Spatial reuse is not new, however what we can do with it expands under 802.11ax
- Spatial multiplexing allows for a 1–1 increase in the spectrum under ideal conditions
- Higher modulation densities require higher SNR to protect against corruption
- 802.11ax provides 8 SS which can be mixed and matched to reinforce signal and increase SNR on any of the other SS’s data

The Fundamentals of Spatial Streams – TechWise TV
https://www.youtube.com/watch?v=EeK4ISiN0Dw
 Transmit Beamforming (TxBF) Spatial Streams

For a long time IEEE Standards based beamforming was not implemented.

.11n & acW1 TxBF not adopted
.11acW2 TxBF implemented
.11ax MUST support

ClientLink – Cisco method of TxBF (Transmit Beamforming)
Supports .11a/g/n/acW1

4x4:3 = 4 Transmitters, 4 Receivers and support for 3 Spatial Streams

ClientLink works on downlink
Stronger signal = less retries maintaining higher datarates
Multi-User MIMO (MU-MIMO)

Review of 802.11ac Wave-2 and then 802.11ax
Multi-User MIMO (MU-MIMO) introduced 11ac Wave-2

How does it work? Why is it an advantage?

Some folks like to use the analogy of “Hub” and “Switch” SU ver. MU (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 reducing interference.

This is Single-User MIMO

Spatial Streams are limited to
The # of receivers on the client
any additional radios on the AP
are used for beamforming

This is Multi-User MIMO

Data can be directed to
Different clients in
Concurrent streams in a
1+1, 1+1+1 or 1+2 stream
combination

Max 3SS simultaneously
Multi-User MIMO (MU-MIMO) .11ac Wave2

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 anywhere we want.

While TxBF (directing) the signal at say User1, you have to also create a NULL or lower signal for Users 2 & 3 etc.
Multi-User MIMO (MU-MIMO) \(11\text{ac Wave-2}\)

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.
Multi-User MIMO (challenges) .11ac Wave-2

• **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.? Wave-2 clients supporting MU-MIMO can be found here [http://wikidevi.com/wiki/List_of_802.11ac_Hardware](http://wikidevi.com/wiki/List_of_802.11ac_Hardware)
Wi-Fi 6 enhancements to Multi-User MIMO

The previous slides for .11acW2 holds true for .11ax - HOWEVER... there are NEW supported features:

- MU-MIMO is now supported in Uplink and Downlink
- 8 MU-MIMO transmissions (users in a group) up from 4
- MU Station UL and DL ACKs come back in parallel USING OFDMA
- AP calculates a channel matrix for each user and simultaneous steer beams to different users (creating groups and managing)
- Each MU-MIMO transmission may have its own MCS rate
- Larger RU frames 106 and above are used for MU-MIMO
- MU and SU-MIMO is decided by AP w/MU- favoring larger packets

106 (102+4) is the minimum RU size for MU-MIMO
Wi-Fi 6 - 802.11ax
Design and Deployment considerations
When should I refresh to Wi-Fi 6?
Depends – 802.11ac product are good for several years – 11ax clients are a year away

- Where are you in your major purchasing cycle? Do you have to spend money soon or risk losing it? Most enterprise life cycles (based on funding) refresh laptops/phones every 2-3 years and WLAN infrastructure every 3-5 years.

- Where are you today? .11n? .11ac Wave 1 or Wave 2? – If you have .11acW2 you can easily afford to wait.

- If you tend to keep infrastructure a really long time stretching it out 5-7 years you may want to wait for .11ax to mature a bit.

- Regardless of .11ax or .11ac you are still using the same applications so little has changed. How is your network today? .11ax is about spectrum efficiency and you won't see improvement over 11ac until you have .11ax clients at ~30%

Wi-Fi 6 Timeline

By 2020 only about 40-50% of clients will be shipping – .11ax adoption may be slow because people have recently adopted to .11ac as Wave-2 is still pretty fresh.
Thoughts on using .11ac & .11ax

Early .11ax APs only standards based – Wave-2 can be a better fit.

<table>
<thead>
<tr>
<th>Application / Thoughts</th>
<th>802.11ac Wave 2</th>
<th>Early 802.11ax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Enterprise WLAN, public venue, Hospital, where connectivity and stability most important</td>
<td>AP28/38/4800 are best in class – Proven and mature technology – advanced features</td>
<td>High potential but lots of features and complexity that can introduce new challenges</td>
</tr>
<tr>
<td>Upgrading a smaller WLAN, or a new area or building – Desire to have cutting edge technology</td>
<td>Good Choice</td>
<td>Opportunity to get next generation at price parity with backward compatibility with 802.11ac</td>
</tr>
<tr>
<td>Need for Hyperlocation, advanced analytics, CleanAir, Best in class WLAN</td>
<td>Excellent choice with AP-4800</td>
<td>First AP releases will not have &quot;best in class&quot; features but will concentrate on the standards</td>
</tr>
<tr>
<td>College or University where students are bringing in the very latest technology – Desire to showcase latest and greatest technology</td>
<td>AP-4800 good choice for great performance and high density areas – suggest Hybrid approach best in class W2 with some areas 802.11ax</td>
<td>Great choice as some students actually make their college decisions based on Wi-Fi having the latest standards and fastest speeds.</td>
</tr>
<tr>
<td>Small to medium size business, running older 802.11g/h – It’s time to upgrade as I have budget</td>
<td>Good – Significant improvements over .11n Many options from 18x/28/38/4800 series</td>
<td>Might be a better choice if it appears you hold on to technology for a long time</td>
</tr>
<tr>
<td>I recently upgraded my network .11ac with AP-4800s – Now I see 802.11ax is available –</td>
<td>The AP-4800 is the BEST ACCESS POINT TODAY .11ax products with best in class features not due until 2020 also to realize true .11ax performance the network needs 20-30% .11ax clients</td>
<td>Consider small deployment in areas where you think you may have 2.4 GHz issues as newer IoT clients and BSS coloring feature may help</td>
</tr>
<tr>
<td>I have a requirement for outdoor wireless, I understand 802.11ax had outdoor enhancements</td>
<td>Cisco has a line of outdoor Access Points that are very good and available today</td>
<td>Outdoor .11ax and clients at least a year away but could deploy indoor AP in NEMA enclosure</td>
</tr>
</tbody>
</table>
Cisco–Aironet Indoor AP Product Portfolio
The industry’s most comprehensive and innovative access point portfolio

Good - Enterprise class
Ideal for small to medium-sized deployments

Better
Mission critical

Best in class
High density

1815 Series
Indoor/high-powered Indoor Wall plate/teleworker
- 2x2:2 SS 80 MHz
- 867 Mbps performance
- Tx beamforming
- Integrated BLE
- Max transmit power (dBm) per local regulations
- 3 GE local ports, including 1 PoE out
- Local ports 802.1X ready
- USB 2.0

1830/1850 Series
- 3x3:2 SS 80 MHz/4x4:3 SS 80 MHz
- 867 Mbps or 1.7 Gbps performance
- 1 or 2 GE ports uplink
- Internal or external antenna (1850)
- Tx beamforming
- USB 2.0

2800 Series
- 4x4:3 SS 160 MHz
- 5 Gbps performance
- 2.4 and 5 GHz or dual 5 GHz
- 2 GE ports uplink
- Cisco CleanAir® and ClientLink
- Internal or external antenna
- Smart antenna connector
- USB 2.0

3800 Series
- 4x4:3 SS 160 MHz
- 5 Gbps performance
- 2.4 and 5 GHz or dual 5 GHz
- 2 GE ports uplink or 1 GE + 1 Multigigabit (5G)
- StadiumVision™
- Internal or external antenna
- Smart antenna connector
- USB 2.0
- Modularity for investment protection

4800
- 4 embedded radios (3 Wi-Fi and 1 BLE)
- 4x4:3 SS 160 MHz
- 5 Gbps performance
- 2.4 and 5 GHz or dual 5 GHz
- 2 GE ports uplink or 1 GE + 1 Multigigabit (5G)
- Embedded Hyperlocation
- Real-time analytics and packet capture
- Cisco CleanAir and ClientLink
- Internal antenna
- USB 2.0
- Integrated BLE

Understanding Power via PoE
1 Future availability
2 Available for high-powered only

802.3af (15.4W) PoE
Available for high-powered only

802.3at (30W) PoE
Available for teleworker only

802.3af (15.4W) PoE
Available for high-powered only

802.3at (30W) PoE
Available for teleworker only
Cisco AP-4800 – Our Very Best Flagship AP

OUR BEST ACCESS POINT – Most advanced .11ac Wave-2 AP with NO EQUAL

- Intelligent Capture
- Built-in Hyperlocation
- Unique Cisco DNA Analytics Radio w/ (Digitally switched antenna array)
- Innovations beyond the Wi-Fi specification – permits security monitoring, packet capture, instant network analysis
- Increasing network capacity without impacting client serving radios.

Early .11ax (first iterations) won’t be “best in class” – so for large public venues today they lack core features found in products like the AP-4800
Right Now = Catalyst 9800, 4800 AP and Cisco DNA

Cisco DNA Center
- Design, Provision, Automate
- 360° Context Graph
- Apple iOS WiFi Analytics

Catalyst 9800 Wireless Controller
- Always-on
- Secure
- Deploy Anywhere

Aironet 4800 Access Point
- Intelligent Capture
- 24x7 dedicated monitoring radio
- <3m median Hyperlocation accuracy

Digitize people, spaces and things with Cisco DNA Spaces
Automate provisioning and policy on an infrastructure designed for IBN

Streaming telemetry and insights to take the right action at the right time
Cisco-Aironet Access Points for Outdoor Applications

**1540**
- 802.11ac Wave 2, MU-MIMO
- 2x2:2, 80MHz, 867 Mbps
- Ultra low profile
- Internal antenna model (I)
- Internal directional antenna model (D)
- PoE (802.3af) power
- Centralized, FlexConnect, Mesh® and Mobility Express

**1560**
- 802.11ac Wave 2, MU-MIMO
- 3x3:3, 80MHz, 1.3Gbps (I)
- 2x2:2, 80MHz, 867Mbps (E/D)
- Internal or External antenna model (I/E)
- Internal directional antenna model (D)
- SFP
- Flexible Antenna Ports
- CleanAir and ClientLink
- Centralized, FlexConnect, Mesh and Mobility Express

**1570**
- 802.11ac Wave 1
- 4x4:3 80 MHz; 1.3 Gbps
- External antenna model (EAC)
- Cable Modem model (IC/EC)
- SFP
- GPS
- PoE Out 802.3at (Ext Ant. only)
- Flexible Antenna Ports
- CleanAir and ClientLink
- Modularity (Ext Ant. only)
- Centralized, FlexConnect and Mesh Cable Modem Version Only (IC/EC)
- DOCSIS 3.0, 24x8
- Internal or External antenna
.11ax Installations - What do you have installed today?

• Before refreshing to Wi-Fi 6 it’s time to do a review of your existing WLAN issues as well as identifying any new location, BLE or IoT requirements

• 1:1 replacement assumes the AP was installed in the best place to begin with?

• While new Wi-Fi 6 features might be able to help mitigate a bad or poor design NOTHING BEATS reviewing what is in place now and INSTALL IT RIGHT the 1st time 😊
Newer .11ax APs will have more radios up to 8x8

1st APs will be standards based “GOOD” with later APs being BEST IN CLASS (3rd half 2019)

There will be .11ax models that only support 4x4 while others will support 8x8

Wi-Fi 6 (.11ax)
4x4:4

Wi-Fi 6 (.11ax)
8x8:8

When using mGig (NBASE-T)
4x4 port up to 2.5G
8x8 will have support for 5G

External antenna models will likely require more RF connectors or the use of a Cisco DART connector.

DART connectors allow multiple and/or smart antennas to be installed with one insertion. Faster install time & smaller connector footprint.
Think about upgrading to N-Base-T
If I have it and I’m having trouble then what? – Look at the cable system

### Troubleshooting mGig (N-Base-T)

<table>
<thead>
<tr>
<th>Cable Type</th>
<th>Port Speed</th>
<th>Total Cable Length</th>
<th>6x4x1 Bundled Cable Length</th>
<th>Patch Panel Cable and 3 Connectors</th>
<th>Mitigation Plan to improve performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat 5e</td>
<td></td>
<td></td>
<td></td>
<td>10m (2x5)</td>
<td>Upgrade cable to Cat 6A</td>
</tr>
<tr>
<td></td>
<td>10GE</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5GE</td>
<td>100m</td>
<td>&gt;30m</td>
<td>10m</td>
<td>1) Use “Downshift” 2) Reduce number of connectors 3) Change patch cable to solid core cable 4) Reduce bundled cable length to be &lt;30m 5) Use Cable Diagnostic or Cable Tester to determine end-to-end Cable quality</td>
</tr>
<tr>
<td></td>
<td>5GE</td>
<td>100m</td>
<td>&lt;30m</td>
<td>5GE</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5GE</td>
<td>55m</td>
<td>Fully bundled</td>
<td>5m</td>
<td>5GE</td>
</tr>
<tr>
<td></td>
<td>5GE</td>
<td>100m</td>
<td>Fully bundled</td>
<td>10m</td>
<td>5GE</td>
</tr>
<tr>
<td></td>
<td>2.5G</td>
<td>100m</td>
<td>Fully bundled</td>
<td>10m</td>
<td>2.5GE</td>
</tr>
<tr>
<td></td>
<td>5GBASE-T</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5GBASE-T Assured</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.5GBASE-T</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5GBASE-T Assured</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: ALSNR support risk for 2.5G and 5G applications

<table>
<thead>
<tr>
<th>ALSNR Risk</th>
<th>Category 5e</th>
<th>Category 6</th>
<th>Category 6A</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Assured</td>
<td>Assured</td>
<td>Assured</td>
</tr>
<tr>
<td>Medium</td>
<td>Assured</td>
<td>Assured</td>
<td>Assured</td>
</tr>
<tr>
<td>Low</td>
<td>Assured</td>
<td>Assured</td>
<td>Assured</td>
</tr>
</tbody>
</table>

For Your Reference
http://www.panduit.com/ccurl/901/950/nbase-t-white-paper.0.pdf
Cisco Multigigabit Products

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 Multigigabit Switch
Downlinks:
- 24 x GE/mGig/10GT
- EEE, MACSec
- PoE/PoE+/UPOE
Uplinks:
4x10GE SFP+, 2 x 40G (NEW), 8x10G (NEW)
Site Survey? What tool do I use for Wi-Fi 6?

In a recent webinar Ekahau stated their tool will be ready for .11ax in the 1st half of 2019

https://www.ekahau.com/

A good URL to find .11ax clients when they become available
https://wikidevi.com/wiki/List_of_802.11ax_Hardware

http://www.ibwave.com/

For more on Wi-Fi 6 Spectrum analysis, and best practices see Cisco Live session BRKEWN-3010

https://enterprise.netscout.com/
Upgrading Access Points 1:1 or another survey?

Access Points have always had similar heat maps – The design goal is to maintain a uniform coverage cell between products but improve the connection experience (faster speeds less retries)

- AP-3800 & .11ax 4x4
- AP-3800 and .11ax 8x8
- Keep Access Points mounted at least 2 meters away from each other
- Rule of thumb - Europe 1 AP per 250 Sq. Meters - US 1 per 2500 Sq Ft.
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,
2.4 GHz Channels and Bandwidths

40 MHz Not Permitted or Supported (Enterprise WLAN) as not enough spectrum
5 GHz Channels and Bandwidths - 20/40/80/160

- **US-A/B**: Existing Channel, In works, US-B
- **Europe**: UNII-1, UNII-2, NEW!
- **India**: UNII-2, NEW!
- **China**: UNII-3, NEW!

- **Channels**:
  - Existing Channel: 36, 40, 44, 48, 52, 56, 60, 64
  - In works: 68, 72, 76, 80, 84, 88, 92, 96
  - UNII-1: 149, 153, 157, 161, 165, 169, 173, 177, 181

- **Bandwidths**:
  - US: 20, 40, 80, 160 MHz
  - Europe: 20, 40, 80, 160 MHz
  - India: 5250, 5350, 5470 MHz
  - China: 5725, 5825, 5925 MHz

Cisco live!
Channel Bonding – Subcarriers – Example 20 & 40MHz

802.11n,ac&ax can use both 20 & 40 MHz channels.

Trading distance for throughput as bonded channels decreases RF by 3-dB power spread across band

When using the 40-MHz bonded channel it takes advantage of the fact that each 20-MHz channel had a small amount of the channel that is reserved at the top and bottom, to reduce interference in those adjacent channels so it gains extra subcarriers.

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/ac/ax achieves slightly more than doubling the data rate when moving from 20-MHz to 40-MHz channels – this also happens going from 40 to 80 MHz and 80 to 160 MHz.

.11ac and .11ax can bond all the way up to 160 MHz Channels
Wi-Fi 5 GHz Channels & Dynamic Frequency Selection

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.

When Radar is present – (near Airports or Military areas) This can result in lower available channels and loss of some UNI-2 and UNI-2 extended bands (negotiated with licensed users of the band).

Access Points detect radar activity and change channels so as not to cause interference with licensed services who have priority.
**Integrated Antenna? – External Antenna?**

**Integrated Antenna**

- Aesthetics (carpeted areas)
- No additional antenna costs
- Less “things” to install
- Hyperlocation more elegant
- Sometimes better for high ceilings

**External Antenna**

- Industrial applications high temp.
- External or directional antennas are desired (inside/outside) use
- Dual 5 GHz (Macro/Maco)
- Longer Range
Wall Mounting Access Point with Internal Antennas

Wall mounting is acceptable for small deployments such as hotspots, kiosks, transportation or small coverage areas. **But NOT for Enterprise deployments.**

Coverage is always more uniform 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 as the pattern is directional (up/down).
Mounting APs and Third Party Solutions

3rd Party in-tile mounts, Plastic skins to change AP color etc. can improve some installs - see AP-4800 deployment guide for more

http://cs.co/9000Dcum8
Thoughts on Cisco Partner Solutions...

Installations/aesthetics can often be enhanced by the use of Third Party Solutions

- Creative ceiling solutions (above/below) tile
- Outdoor NEMA enclosures
- Changing the color of an AP
- Bracketry / Tripods for antenna and AP co-location
- Solar / Battery Options
- Site Survey hardware/software
- Rugged mounting for mining/Earth moving vehicles
- Custom Application antennas*

* Cisco does not certify or test Third Party antenna solutions

Popular Cisco Partner URLs

- Oberon Wireless
- AccelTex Solutions
- Ventev

Never Paint an Access Point use a “skin” instead

Skins for blending (hiding) AP

Courtesy of AccelTex Solutions
Understanding Cisco Access Point Colors

What is the RAL or Pantone color used for Cisco WLAN Products?

**RAL** is a color matching system used in Europe [https://en.wikipedia.org/wiki/RAL_colour_standard](https://en.wikipedia.org/wiki/RAL_colour_standard)

**Pantone LLC** is a U.S. Corporation best known for its Panton Matching System (PMS) a proprietary color space used in a variety of industries. [https://en.wikipedia.org/wiki/Pantone](https://en.wikipedia.org/wiki/Pantone)

Cisco does not use these methods of color so there is no official recommendation or match to such system. Cisco Systems, Inc. has two popular colors used for its Aironet Brand of WLAN products.

- **Cisco Light Gray** used on most indoor Access Points and most antennas
- **Cisco Medium Gray** used on most outdoor Access Points and some outdoor antennas

**Indoor AP’s (Cisco Light Gray)**
- Semi-Gloss Texture Powder Coating:
  - Cardinal Industries C031-WH120 (Indoor/Outdoor)
  - Sherwin Williams HWT2-J2453 (Indoor)
  - Akzo Nobel JA343C (Indoor/Outdoor)
- High-Gloss Smooth Powder Coating:
  - Cardinal Industries T009-WH12 (Indoor/Outdoor)
  - Sherwin Williams UWS8-J2653 (Indoor/Outdoor)

**Outdoor AP’s (Cisco Medium Gray)**
- Low Bake Wet Paint for Plastic:
  - Akzo Nobel Paint code: 820-EJS-10227
- High Bake Wet Paint for Sheet metal (can be used for touch-up):
  - Akzo Nobel Paint code: 821-EJS-10318
- Indoor Powder Coating:
  - Texture Finishing. Akzo Nobel Paint Code: EL57GC
  - Texture Finishing. Sherwin Williams Paint code: SW-HAT2-J2622
  - Smooth Finishing. Akzo Nobel Paint Code: EL58GC
- Outdoor Powder Coat:
  - Texture Finishing. Sherwin Williams Paint code: SW-DAT1-J3487
  - Smooth Finishing. Sherwin Williams Paint code: SW-PAS2-J3547

Painting voids Warranty
Mixing AP types and use of External Antennas

• It is recommended that you do not mix Access Points of different models types in a "salt and pepper" fashion.

• Keep like Access Points together especially the AP-4800 as it has special Cisco DNA features like Intelligent Capture that diminishes in performance when clients roam across non-AP4800 Access Points.

• If you have need to External antennas, use the AP2800/3800e with the smart antenna connector if will give you the most flexibility

• Don’t mount the AP in the IDF closet and then remote the antennas

• Keep all antenna cable runs as short as possible

• Mount the AP as close to the USERS as you reasonable can
Integrated antenna versions are designed for mounting on a ceiling (carpeted areas) where aesthetics is a primary concern.

Adapter can take you from DART to same RP-TNC as on the AP.

DART insertion (antenna or adapter) causes the XOR radio 2.4 or additional 5 GHz radio to go out this secondary antenna port.

Without the DART installed both 2.4 and 5GHz are on the Primary TNCs.
Identifying RF Connectors

RP-TNC Connector
Used on most Cisco Access Points

“N” Connector
15xx Mesh and outdoor APs

“RP-SMA” Connector
Used on “cost reduced” products (Linksys...)

“DART” Connector
.11ax multiple antennas & location services
Keep all antenna cables as short as possible
Cables introduce loss and more potential points of failure

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

Trivia: LMR Stands for “Land Mobile Radio”
Some cables are Plenum (low smoke rated)
Some Antenna Cables Characteristics

--

### LMR-400
Flexible Low Loss Communications Coax

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

### LMR-600
Flexible Low Loss Communications Coax

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

---

Foil shield and braid
LMR-400 3/8 inch
LMR-600 ½ inch

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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”)

---

For Your Reference
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

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.

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

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

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. You don’t get more RF power, you are just focusing the same amount of energy to go further.

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.
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.

Cisco 9.5 dBi Patch – AIR-ANT5195-R
Antennas Identified by Color

Cisco Antenna Color Coding Scheme

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

Orange indicates both: 2.4 & 5 GHz (Dual Radiating Elements)

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

A Single Band antenna it has a Single Radiating Element (SRE)
If antenna is Dual Band (orange in color) it has a Dual Radiating Elements (DRE)

Note: Dual Band antennas not orange in color may contain SRE’s in each band
FlexPort - Some products the antenna port is configurable

You choose if it is a Single or **Dual Radiating Element** (creating different cells indoors/outdoors)

**default DRE mode with**
2.4 and 5 GHz on antennas

**Single band antenna**
**SRE Mode**
2.4GHz or 5 GHz when DART is in use*

* AP-3800e If used in receive only for monitoring it will serially cycle both bands for analytics

**FlexPort supported**
On some models
Indoor & outdoor

2.4 & 5GHz **DRE**

2.4 GHz **SRE**

5 GHz only **SRE**

**Orange dot indicates DRE capable antenna**

**Default**
**Not Used**

**SW Configure**
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)

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)

A High Gain Four Element Patch Array
Specialty antennas
A dipole does not require a ground plane as the bottom half is the ground. Produces a more uniform antenna pattern.

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
Antenna Theory (Dipole & Monopole)

Monopoles were added to our antenna line primarily for aesthetics

Do not use Monopoles if the connectors don’t have a metal surface to radiate from

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天花板s/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=

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

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

Higher gain
For use with “P” series Access Points
Use case – Solving the requirement for smaller footprint

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

Isolation things you should know
Access Point Ceiling Placements
Deployment guides available for Hyperlocation, High Density, BLE etc.

There is no ONE WAY – Access Point Placement DEPENDS...

- High Density differs from conventional 1 per sq X
- Hyperlocation & Wayfinding requires placement on a MAP
- Indoor Mesh is different requires less APs
- IoT and voice may have different requirements

Assess for the PRIMARY Purpose of the WLAN

Example of a Hyperlocation AP layout

Space them at least 2 meters (6Ft) apart
Co-Locating antennas and creating RF Isolation

You get isolation via several methods...

• Physical separation of the antennas
• Height separation of the antennas
• Antenna polarity separation
• Use of directional antennas so energy is focused away from each other
• Use of LOWER transmit power
• Use of frequencies that are further apart

The best way isn’t always possible
That doesn’t mean it won’t work 😊
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.
Placements Healthcare Deployments

Access Points in infection control areas can be wiped down with SPOR-KLENZ 105.

AP2800/3800/4800 has a new plastic Lexan 945 – for better use in high temperatures and hospital clean room areas.

Note: 2700/3700 use Cycloy C2800
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

Watch Polarity
How close can you put them...

Sometimes it's just for testing

Sometimes it's actually deployed this way – you never know

Space them at least 2 meters (6Ft) apart
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 - When it does it is expensive to fix and no one is happy

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 the bldg. lights should be in the clear and as near to the users as possible
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

Sways in wind ==> Too much weight

Too Close
Installations that Went Wrong - Mesh
Installations that Went Wrong – Mesh

Building aesthetics matters – Antennas obstructed
Outdoor Weatherproofing

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.

www.coaxseal.com
Summary


- 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”
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
### Best Practices Summary

#### Make it Easy  Make it work

<table>
<thead>
<tr>
<th>INFRASTRUCTURE</th>
<th>SECURITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enable High Availability (AP and Client SSO)</td>
<td>Enable 802.1x and WPA/WPA2 on WLAN</td>
</tr>
<tr>
<td>Enable AP Failover Priority</td>
<td>Enable 802.1x authentication for AP</td>
</tr>
<tr>
<td>Enable AP Multicast Mode</td>
<td>Change advance EAP timers</td>
</tr>
<tr>
<td>Enable Multicast VLAN</td>
<td>Enable SSH and disable telnet</td>
</tr>
<tr>
<td>Enable Pre-image download</td>
<td>Disable Management Over Wireless</td>
</tr>
<tr>
<td>Enable AVC</td>
<td>Disable WiFi Direct</td>
</tr>
<tr>
<td>Enable NetFlow</td>
<td>Peer-to-peer blocking</td>
</tr>
<tr>
<td>Enable Local Profiling (DHCP and HTTP)</td>
<td>Secure Web Access (HTTPS)</td>
</tr>
<tr>
<td>Enable NTP</td>
<td>Enable User Policies</td>
</tr>
<tr>
<td>Modify the AP Re-transmit Parameters</td>
<td>Enable Client exclusion policies</td>
</tr>
<tr>
<td>Enable FastSSID change</td>
<td>Enable rogue policies and Rogue Detection RSSI</td>
</tr>
<tr>
<td>Enable Per-user BW contracts</td>
<td>Strong password Policies</td>
</tr>
<tr>
<td>Enable Multicast Mobility</td>
<td>Enable IDS</td>
</tr>
<tr>
<td>Enable Client Load balancing</td>
<td>BYOD Timers</td>
</tr>
<tr>
<td>Disable Aironet IE</td>
<td><strong>MESH</strong></td>
</tr>
<tr>
<td>FlexConnect Groups and Smart AP Upgrade</td>
<td>Disable 802.11b data rates</td>
</tr>
<tr>
<td><strong>BEST PRACTICES (AireOS)</strong></td>
<td>Restrict number of WLAN below 4</td>
</tr>
<tr>
<td><strong>WIRELESS / RF</strong></td>
<td>Enable channel bonding – 40 or 80 MHz</td>
</tr>
<tr>
<td>Set Bridge Group Name</td>
<td>Enable BandSelect</td>
</tr>
<tr>
<td>Set Preferred Parent</td>
<td>Use RF Profiles and AP Groups</td>
</tr>
<tr>
<td>Multiple Root APs in each BGN</td>
<td>Enable RRM (DCA &amp; TPC) to be auto</td>
</tr>
<tr>
<td>Set Backhaul rate to &quot;Auto&quot;</td>
<td>Enable Auto-RF group leader selection</td>
</tr>
<tr>
<td>Set Backhaul Channel Width to 40/80 MHz</td>
<td>Enable Cisco CleanAir and EDRRM</td>
</tr>
<tr>
<td>Backhaul Link SNR &gt; 25 dBm</td>
<td>Enable Noise &amp;Rogue Monitoring on all channels</td>
</tr>
<tr>
<td>Avoid DFS channels for Backhaul</td>
<td>Enable DFS channels</td>
</tr>
<tr>
<td>External RADIUS server for Mesh MAC Authentication</td>
<td>Avoid Cisco AP Load</td>
</tr>
<tr>
<td>Enable EAP Mesh Security Mode</td>
<td><strong>For Your Reference</strong></td>
</tr>
</tbody>
</table>

Recommended Reading
Cisco Enterprise Wireless Book & 4800 Deployment Guide

http://cs.co/wirelessbook

http://cs.co/9000Dcum8
EN Booksprints

http://cs.co/cat9000book
http://cs.co/sdabook
http://cs.co/programmabilitybook
http://cs.co/wirelessbook
http://cs.co/assurancebook
Questions?
Use Cisco Webex Teams (formerly Cisco Spark) to chat with the speaker after the session

How
1. Find this session in the Cisco Events Mobile App
2. Click “Join the Discussion”
3. Install Webex Teams or go directly to the team space
4. Enter messages/questions in the team space
Complete your online session survey

• Please complete your Online Session Survey after each session

• Complete 4 Session Surveys & the Overall Conference Survey (available from Thursday) to receive your Cisco Live T-shirt

• All surveys can be completed via the Cisco Events Mobile App or the Communication Stations

Don’t forget: Cisco Live sessions will be available for viewing on demand after the event at ciscolive.cisco.com
Continue Your Education

- Demos in the Cisco Showcase
- Walk-in self-paced labs
- Meet the engineer 1:1 meetings
- Related sessions
Thank you
Reference Material & Things worth knowing

Deeper Dive into 4800 Understanding Micro/Macro Cells
Best in Class Wave-2 AP “or” Best in Class Location Based Services AP?

Customers had to choose which technology to deploy or perhaps deploy an overlay?

AP-2800 or AP-3800 Wave-2

- 802.11ac Wave 2: High-Performance 5Gbps.
- 2.4, 5GHz or Dual 5GHz.
- 4x4:3SS 160MHz.
- MU-MIMO
- 2 GE or 1 GE + 1 mGig (5G)
- Flexible Radio Architecture
- Dual 5 GHz
- Cisco DNA Sensor, Spectrum Intelligence and more...

AP-3600 or AP-3700

With Hyperlocation module

- Analytics, Asset tracking, Proximity Marketing
- Navigation and Wayfinding “true blue dot” experience
- 1 to 3 meter location accuracy (Wi-Fi Clients)
- BLE Beacon – Five centrally managed Beacons
- FastLocate – Frequent location updates (Wi-Fi Clients)
- Spectrum Intelligent Monitoring Radio and more...
Next-Generation Wave 2 802.11ac Access Point

- Industry leading 4x4 MIMO:3 spatial streams (SS)
  Wave 2 802.11ac access points
- Tri-radio, 802.11ac Wave 2, 160 MHz
- Built-in BLE Radio
- Combined Data Rate of 5.2Gbps
- 2 x 5 GHz: 4x4: 3SS supporting
  - SU-MIMO / MU-MIMO
  - Flexible Radio Assignment: 2.4GHz, Dual-5GHz, Wireless Security Monitoring, and Cisco DNA-C Assurance
- 1 x 2.4GHz/5GHz for Cisco DNA Analytics, Wireless Security monitoring, and Hyperlocation
- Gigabit Ethernet and multi-Gigabit Ethernet (1G, 2.5G, 5G)
- Built-in Hyperlocation Antenna Array 16 elements <3m Accuracy (median)
- HDX Technology
- USB 2.0
- Analytics-enabled, Cisco DNA Ready

Cisco Aironet® 4800

Redefining Analytics and Location
Combining Proven Technologies

Hyperlocation + AP-3800i + Additional Analytics Radio = AP-4800

Hyperlocation Components

AP-4800 Integrated Solution

Proven Hyperlocation + 3800 Technology in one AP & 1 cable drop

Improved Capability
- 802.11acW2
- WiFi & BLE AoA
- Time Based solutions
- + All the core features of the AP-3800

Combining Proven Technologies

AP-3800 Dual 5GHz

Cisco 16 element Antenna Array
1-3m Accuracy

Hyperlocation Module

Hyperlocation Components

Dual 5GHz XOR + another analytics Hyperlocation XOR radio

Inside AP-4800 Dual 5GHz XOR + another analytics Hyperlocation XOR radio

Hyperlocation Modules

Antenna components

AP-3800

Hyperlocation AP36/3700

40% smaller

12x12"

12x12"

9.9x8.7"

Hyperlocation Components

Hyperlocation Components

Hyperlocation Components

Hyperlocation Components

Hyperlocation Components

Antenna components

AP-4800

Hyperlocation + Analytics
AP-4800 is a more advanced AP than the AP-3800

Similar to the AP-3800i but it has an additional Flexible Radio for Analytics + Advanced Hyperlocation antenna array

- Location Array antenna is now integrated
- Bluetooth Low Energy radio is now integrated
- Embedded analytics/location radio is now integrated

Hyperlocation antenna array

Cisco DNA Analytics, Monitoring and Location Radio

= AP-4800

Best in Class
AP-4800 Overview

AP-4800 is the next evolution of Cisco’s Wave-2 Access Point, redefining RF Excellence

• In addition to all the features supported by the AP-3800i the new AP-4800 contains the following new components:
  • **Built-in Hyperlocation antenna Array**, 16 Element Antenna Array for Hyperlocation, and packet monitoring
  • **Analytics Capabilities** providing event driven real-time data captures. This provides Real-time visibility into Cisco DNAC and potential 3rd party analytics
  • **3rd Flexible (receive only radio)**, specifically for Analytics, Hyperlocation, Wireless Security Monitoring, and future functionality using the programmable digital antenna array.
  • **Built-in BLE Radio capable of BLE TX/RX.** This is similar to the BLE radio in the WSM module for the AP3700
  • **Hyperlocation AoA technology**, Location accuracy on Wi-Fi similar to the AP3700 + HL module
  • Full Flexible Radio Assignment Operating modes, such as Dual-5GHz while performing Hyperlocation
  • Note: Module port on AP3800 is not available on the AP-4800 (it is used internally for the Analytics Radio)

• **Code version supported below, will be introduced with a special version of 8.7**

<table>
<thead>
<tr>
<th>WLC</th>
<th>Cisco Prime</th>
<th>CMX</th>
<th>Cisco DNA</th>
<th>ISE</th>
<th>SDA Mode</th>
<th>ME Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.7 Special</td>
<td>3.4</td>
<td>10.5</td>
<td>1.2</td>
<td>2.3 / 2.4</td>
<td>8.8</td>
<td>8.8</td>
</tr>
</tbody>
</table>
So why did we design the AP4800?

- Allows for High Density deployments solving the problem of over 2.4 GHz coverage.

- Using a Flexible Radio design gives you the choice of either 2.4/5GHz or Dual 5 GHz. Using Flexible Radio Assignment (FRA) this can happen dynamically (predefined conditions) or user assigned into a static state.

- Enhanced 160 MHz capability, MU-MIMO support etc.

- Has Hyperlocation (precise location mapping of clients) 1-3 Meters

- Has a Cisco DNA Analytics Radio for location and Cisco Intelligent Capture for troubleshooting and packet capture w/Client location and CleanAir SI
AP4800 mounted on the ceiling

AP4800
Length 9.9” (251.46mm)
Width 8.68” (220.47mm)
Thickness 2.87” (72.9mm)
Weight 5.6 lbs (2.54 kilograms)

AP3800i
Length 8.66” (219.96mm)
Width 8.68” (220.47mm)
Thickness 2.46” (62.48mm)
Weight 4.6 lbs (2.09 kilograms)

Note: Ceiling gridwork will hold 25 lbs without support wire AP = 5.6 lbs
Third party solutions & backside of AP-4800

3rd Party in-tile mounts, Plastic skins to change AP color etc. can improve some installs - see AP-4800 deployment guide for more

http://cs.co/9000Dcum8
Macro/Micro Dual 5 GHz Cell

Instant Capacity

- Dual 5 GHz Macro/Micro increases efficiency
- 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-4800 Antenna System Overview

Most Advanced co-existent Antenna System (25 Elements) in a Single Access Point

- **(16)** Element Directional Antenna Array (Digitally Switched) for Location tracking
- **(4)** 2.4/5GHz Macro Antenna Elements
- **(4)** 5GHz Micro Cell Antenna Elements
- **(4)** Omni-Directional Elements (Digitally Switched) for 24x7 Monitoring & Analytics / Cisco DNA Assurance

Total Antenna Elements = 25
Why Dual 5 GHz in the AP-4800 Matters

Flexible radio (AP-3800) won Cisco’s 2017 Pioneer Award for RF Innovation – and why it is in the 4800

AP2800/3800/4800 has Dual 5 GHz - A dual 5 GHz AP creating micro/macro cells with the ability to beamform (using Client-Link) will significantly enhance all 802.11a,g,n & .11ac Wave-1 Clients.

Note: Standards Based Beamforming only works with .11w2 and .11ax

Take-away:
Using Dual 5 GHz Means Equal Client Airtime
Faster overall data-rates & less channel utilization

Single 5 GHz Channel

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

Dual 5 GHz Channels

- Using Micro/Macro (Dual 5 GHz)
  Channel 36 @ 20% channel utilization
  Channel 108 @ 24% channel utilization.
APeX Access Point Module Development

AP-3800 overview and a program to encourage 3rd party development via module for the AP-3800 “Internet of things” creating an AP ecosystem
Smart Antenna Connector – 2800e / 3800e

Primary Antenna Connectors – Dipole and Cabled Antennas

- Cisco designed 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…

Smart Antenna Connector

Second Cabled or Location Antenna*
Dual 5 GHz “E” model Macro-Macro cells or Micro-Micro cells or any combination

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

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

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
Review of AP-3800i/e Port Functionality
Expandability and Investment Protection

- PRIMARY ANTENNAS
- Self-Discover / Self-Configure
- Other
- Panel Antenna
- Directional Antennas
- Antennas
- SMART ANTENNA PORT
- MODULE PORT
- Bluetooth Beacon
- Other
- Wall Cell Offload
- Bluetooth Beaconsing
- Video Surveillance
- Custom Application Using Linux
- Future Wi-Fi Standard
Design on the developer board then create custom modules – AP has filtering for cellular co-existence, can supply power etc.
## Module SDK Supported through Devnet

[http://Developer.cisco.com/site/devnet/overview](http://Developer.cisco.com/site/devnet/overview)

### 3 simple steps to becoming a DevNet member

<table>
<thead>
<tr>
<th>Step 1</th>
<th>Step 2</th>
<th>Step 3</th>
</tr>
</thead>
</table>
| Create a Cisco ID >  
(if you don’t already have one) | Log in to DevNet and create your account > | Complete your profile (at any time) and earn points towards Cisco DevNet badges. |

---

### DevNet Benefits

- ✓ Set your profile to customize your notifications
- ✓ Use the Learning Labs
- ✓ Get answers on the community forums
- ✓ Receive loads of support
- ✓ Download APIs and SDKs
- ✓ Access fully-tooled sandboxes
Understanding 802.11ac

Building upon the 802.11n foundation
So to Recap: 802.11n Operation

Throughput Improves When All Things Come Together

- MRC
- ClientLink
- Spatial Multiplexing

802.11a/g AP (non-MIMO)

54 48 36 24 Mbps

802.11a/g client (non-MIMO)

- MRC
- ClientLink
- Spatial Multiplexing

802.11n AP (MIMO)

54 Mbps

802.11a/g client (non-MIMO)

- MRC
- ClientLink
- Spatial Multiplexing

802.11n AP (MIMO)

450 Mbps

3x3

802.11n client (MIMO)

- Channel Bonding
# Data Rates for 802.11n

(Lots of MCS rates based on modulation, streams, channel width and GI)

<table>
<thead>
<tr>
<th>MCS</th>
<th>Coding</th>
<th>Modulation</th>
<th>Streams</th>
<th>Signal BW = 20 MHz</th>
<th>Signal BW = 40 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>GI = 800 nS</td>
<td>GI = 400 nS</td>
<td>GI = 800 nS</td>
<td>GI = 400 nS</td>
</tr>
<tr>
<td>MCS0</td>
<td>1/2</td>
<td>BPSK</td>
<td>1</td>
<td>6.5</td>
<td>13.5</td>
</tr>
<tr>
<td>MCS1</td>
<td>1/2</td>
<td>QPSK</td>
<td>1</td>
<td>13</td>
<td>27</td>
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<tr>
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</table>

**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**

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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.
## Operating Mode Comparisons

Identifying differences between each of the different standards

<table>
<thead>
<tr>
<th></th>
<th>802.11n</th>
<th>802.11ac Wave 1</th>
<th>802.11ac Wave 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2.4 and 5.0 GHz band</strong></td>
<td>2.4 and 5.0 GHz band</td>
<td>5.0 GHz band only</td>
<td>5.0 GHz band only</td>
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<tr>
<td><strong>3X3 or 4X4 MIMO</strong></td>
<td>3X3 or 4X4 MIMO</td>
<td>3X3 or 4X4 MIMO</td>
<td>4X4 MIMO</td>
</tr>
<tr>
<td><strong>Single User MIMO (one to one)</strong></td>
<td>Single User MIMO (one to one)</td>
<td>Multi-User MIMO (one to many)</td>
<td></td>
</tr>
<tr>
<td><strong>Fast Ethernet wired equivalent</strong></td>
<td>Gigabit Wi-Fi wired equivalent</td>
<td>Multi-Gigabit Wi-Fi capable</td>
<td></td>
</tr>
<tr>
<td><strong>Usually 20 MHz Channel Width</strong></td>
<td>Usually 20 or 40 MHz Channel Width</td>
<td>Usually 40 or 80 MHz Channel Width (160 MHz can also be supported)</td>
<td></td>
</tr>
<tr>
<td><strong>Single FE or GE uplink</strong></td>
<td>Single GE uplink</td>
<td>Dual GE uplinks or mGig uplink</td>
<td></td>
</tr>
<tr>
<td><strong>PoE (802.3af) for full operation</strong></td>
<td>PoE+ (802.3at) for full 4X4 operation</td>
<td>PoE+ (802.3at) for full 4X4 operation</td>
<td></td>
</tr>
<tr>
<td><strong>Support for AES128 Encryption</strong></td>
<td>Support for AES128 Encryption</td>
<td>Support for AES256 Encryption</td>
<td></td>
</tr>
</tbody>
</table>
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)**
  1\(^{st}\) Generation Wave-2 “1K” Series AP only support 80 MHz
  2\(^{nd}\) 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:

www.wi-fi.org
So what’s driving 802.11ac?

The airwaves are a shared medium to improve performance, you need to be **spectrum efficient**. 802.11ac is all about optimization to do that.

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

- **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 **MORE than one user at a 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 802.11n & 802.11ac so important?

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

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

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

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

<table>
<thead>
<tr>
<th>MCS</th>
<th>Modulation</th>
<th>Ratio</th>
<th>20 MHz channel</th>
<th>40 MHz channel</th>
<th>80 MHz channel - WAVE-1</th>
<th>160 MHz channel - WAVE-2</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td>800 ns GI</td>
<td>400 ns GI</td>
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<td>400 ns GI</td>
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<td>BPSK</td>
<td>1/2</td>
<td>6.5</td>
<td>7.2</td>
<td>13.5</td>
<td>16</td>
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<tr>
<td>1</td>
<td>QPSK</td>
<td>1/2</td>
<td>13</td>
<td>14.4</td>
<td>27</td>
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<tr>
<td>2</td>
<td>QPSK</td>
<td>3/4</td>
<td>19.5</td>
<td>21.7</td>
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<tr>
<td>3</td>
<td>16-QAM</td>
<td>1/2</td>
<td>26</td>
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<tr>
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<td>3/4</td>
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<td>43.3</td>
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<td>6</td>
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<td>3/4</td>
<td>59.5</td>
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<td>121.5</td>
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<td>5/6</td>
<td>65</td>
<td>72.2</td>
<td>135</td>
<td>150</td>
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<td>256-QAM</td>
<td>3/4</td>
<td>78</td>
<td>86.7</td>
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<tr>
<td>9</td>
<td>256-QAM</td>
<td>5/6</td>
<td>N/A</td>
<td>N/A</td>
<td>180</td>
<td>200</td>
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</table>
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

<table>
<thead>
<tr>
<th>MCS</th>
<th>Modulation</th>
<th>Ratio</th>
<th>20 MHz channel</th>
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<th>80 MHz channel WAVE-1</th>
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<td>0</td>
<td>BPSK</td>
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<td>7.2</td>
<td>15</td>
<td>32.5</td>
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<td>1</td>
<td>QPSK</td>
<td>1/2</td>
<td>14.4</td>
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<tr>
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<td>QPSK</td>
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<td>21.7</td>
<td>45</td>
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<td>1/2</td>
<td>28.9</td>
<td>60</td>
<td>130</td>
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<tr>
<td>4</td>
<td>16-QAM</td>
<td>3/4</td>
<td>43.3</td>
<td>90</td>
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<td>64-QAM</td>
<td>2/3</td>
<td>57.8</td>
<td>120</td>
<td>260</td>
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<tr>
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<td>64-QAM</td>
<td>3/4</td>
<td>65</td>
<td>135</td>
<td>292.5</td>
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<tr>
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<td>64-QAM</td>
<td>5/6</td>
<td>72.2</td>
<td>150</td>
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<tr>
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<td>256-QAM</td>
<td>5/6</td>
<td>N/A</td>
<td>200</td>
<td>433.3</td>
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</table>

802.11ac rates @ 1 Spatial Stream
Using Wave-2 & 4SS (Last “Eyechart”)

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

<table>
<thead>
<tr>
<th></th>
<th>4SS</th>
<th>3SS</th>
<th>2SS</th>
<th>1SS</th>
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<tbody>
<tr>
<td>Data Rate</td>
<td>Desktops</td>
<td>Desktops / Laptops</td>
<td>Laptops / Tablets</td>
<td>Tablets / Smartphones</td>
</tr>
</tbody>
</table>

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

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

Note: This is why GigE is fine for 802.11ac (Wave-1) Access Points – Wave-2 can exceed GigE

Wave-2 with 4 stream (80 MHz) is 1733 Mbps
No 4-ss mobility clients exist in the market today only PCIe (desktop clients)
Understanding Cisco Mid-Span Power Injectors

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

AP-3800 also supports local 50W power supply
For use with option modules – uPoE also supported
More powerful APs draw more PoE power

**AP 2800 & AP 3800 - Power Requirements**

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>AP Functionality</th>
<th>PoE Budget @ PSE (Watts)</th>
<th>802.3af PWRINJ6</th>
<th>802.3at PoE+ PWRINJ6</th>
<th>802.3bt uPoE</th>
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<tbody>
<tr>
<td>2800</td>
<td>PoE 802.3at</td>
<td>2800 – Out of the Box (8.2.x.x)</td>
<td>All Features Enabled*</td>
<td>25W</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>3800</td>
<td>PoE 802.3at</td>
<td>3800 – Out of the Box (8.2.x.x)</td>
<td>All Features Enabled*</td>
<td>30W</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>3800</td>
<td>PoE 802.3bt (uPoE)</td>
<td>3800 – Out of the Box (8.2.x.x)</td>
<td>All Features Enabled*</td>
<td>52W</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

* USB support not available at FCS may increase power up to 3W
Wi-Fi Connectivity Speed Timeline

Need for Gigabit Wi-Fi as Primary Access

*Assuming 80 MHz channel is available and suitable
**Assuming 160 MHz channel is available and suitable

- 802.11
- 802.11b
- 802.11a/g
- 802.11n
- 802.11ac Wave 1
- 802.11ac Wave 2
- 802.11ac Wave 2
- Dual 5GHz

= Connect Rates (Mbps)

= Spatial Streams

<table>
<thead>
<tr>
<th>Year</th>
<th>802.11</th>
<th>802.11b</th>
<th>802.11a/g</th>
<th>802.11n</th>
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<th>2015</th>
<th>2016</th>
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<td>1300*</td>
<td></td>
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</tr>
<tr>
<td>2015</td>
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<td></td>
<td></td>
<td>290*</td>
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<td></td>
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<td>2340**</td>
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<tr>
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<td></td>
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<td>3500**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td></td>
<td></td>
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<td>3500**</td>
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<tr>
<td>2016</td>
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<td>5260**</td>
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</tr>
<tr>
<td>2016</td>
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<td></td>
<td></td>
<td>600*</td>
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</tr>
<tr>
<td>2016</td>
<td></td>
<td></td>
<td></td>
<td>3500**</td>
<td></td>
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<tr>
<td>2016</td>
<td></td>
<td></td>
<td></td>
<td>5260**</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td></td>
<td></td>
<td></td>
<td>600*</td>
<td></td>
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</tbody>
</table>

Gigabit Ethernet Uplink
2Gigabit Ethernet Uplinks
Multi-Gigabit Uplinks
Multi-Gigabit Uplinks
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

<table>
<thead>
<tr>
<th>Cable Type</th>
<th>FE</th>
<th>1G</th>
<th>2.5G</th>
<th>5G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat5e</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>55-100m</td>
</tr>
<tr>
<td>Cat6</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Cat6a</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>

- 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)

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

**Downshift**: Option that permits system to detect and lower speeds when noise occurs rather than maintaining a fixed value.
Cisco Multigigabit Products

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 Multigigabit Switch
Downlinks:
24 x GE/mGig/10GT
- EEE, MACSec
- PoE/PoE+/UPoE

Uplinks:
4x10GE SFP+, 2 x 40G (NEW), 8x10G (NEW)
Specialty Antennas - Hyperlocation

- **AP3600**
- **AP3700**
- **Circular Antenna module**
- **Plug-In module**

**AIR-ANT-LOC-01=**
**AIR-RM3010L-x-K9=**

**2.4/5G**
**Monitor**
**BLE**
**32 Element array**

**SMART ANTENNA PORT “DART”**

- **Cisco live!**

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Specialty Location Antennas

**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
- \( \approx 2 \times 12 \times 12" \)
- Oct. 2015

**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
- \( \approx 2 \times 14 \times 18" \)
- 3602/3702 \( \approx \) Sep 2016
- 2800/3800 \( \text{tbd} \)

**Large hall, warehouse, atrium, high ceiling, Outdoors**

- Vertical install
- DART (Location) + RP-TNC (WiFi)
- Dual-band

**AP3600/3700 add on**

- Enterprise office, retail, ...
- (horizontal install)