
TOMORROW
starts here.
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Understanding RF Fundamentals and the Radio Design of Wireless Networks

BRKEWN-2017

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Systems Engineer

#clmel

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Agenda

- Background Story
- RF Fundamentals
- RF Network Design
- Key Takeaways

“Necessity is the mother of Invention”

- a para-phrase of Plato
(way before my time)

Dial up in 2004

No DSL on the farm

What did I know about microwaves?

Needed to Learn …

Not-so-long list

- Designed for small distances

Things I had to learn / overcome:

- Line of sight,
- Polarisation,
- EIRP (power output)
- Free-space loss,
- channel selection
- Fresnel Zone,
- Inverse Square law,
- Wavelength vs Frequency,
- ¼ wavelength
- Encoding etc. DSSS, OFDM … the list goes on

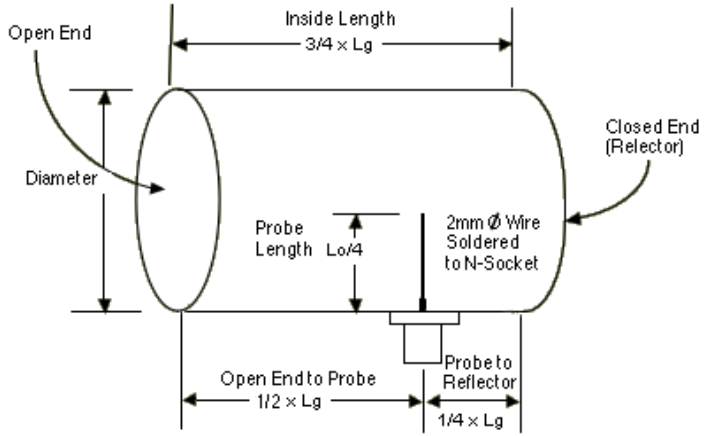
Fresnel Zone and Inverse Square

Fresnel Zone

Inverse Square

Wavelength vs Frequency

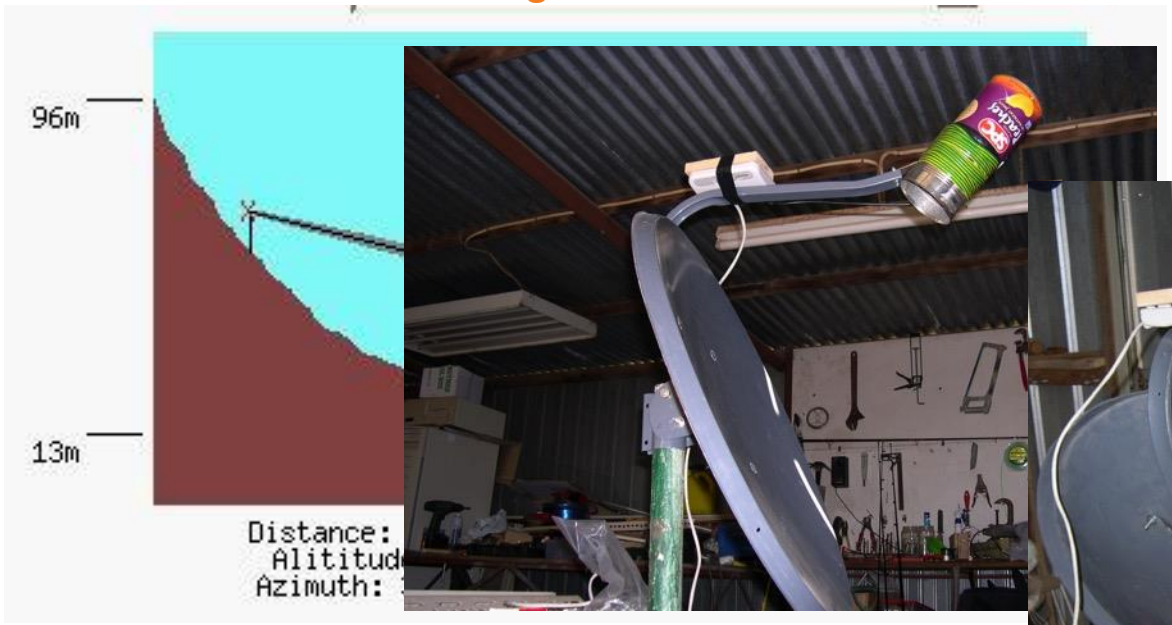
- λ = c / f （speed of light divided by frequency）
- 2.4 GHz ≅ 12.4 cm, （1/4 wavelength 3.14cm） 5GHz range≅ 5.8 cm – 5.1cm

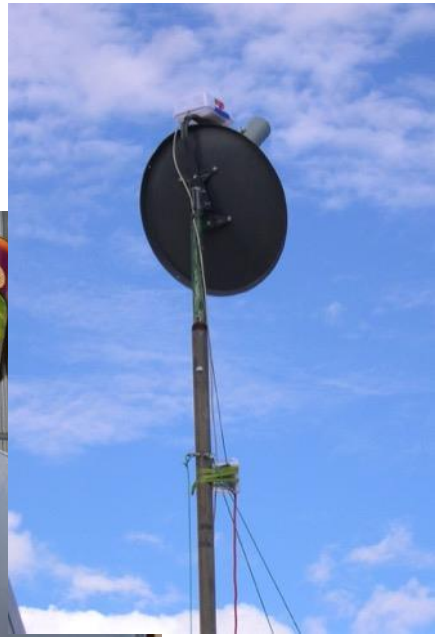


http://www.wikarekare.org/Antenna/WaveguideCan.html

What was the end result?

He created it and it was good!





Laws of Physics

Once we understood them …

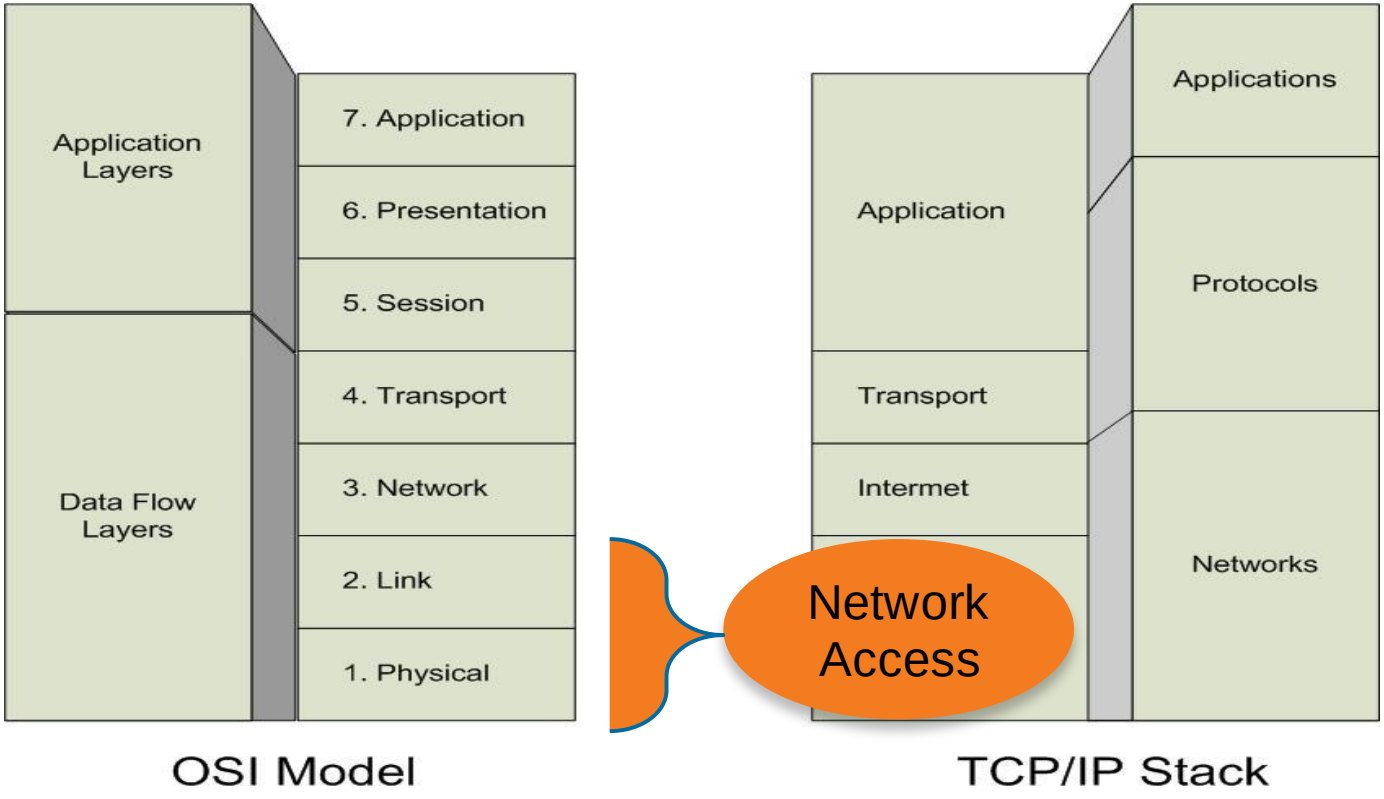
- 19.5 KMs to hills
- 27km to Pt Adelaide to DSL
- 1.5 M ADSL services
- 8 ms RTT
- Download speeds were awesome!
- 1 – 2 Mbit wireless throughput.

Layers - “Bottom up” Approach

Layered Model

- Why Layers?
- Independence between Layers
- Do you want Ethernet on
  1. Twisted Pair
  2. Radio / Wireless / Microwave
  3. Fibre Optics
- IPv4 or IPv6 (decnet, appletalk, etc)

OSI and TCP/IP Layered Models



Physical Layer for Wireless

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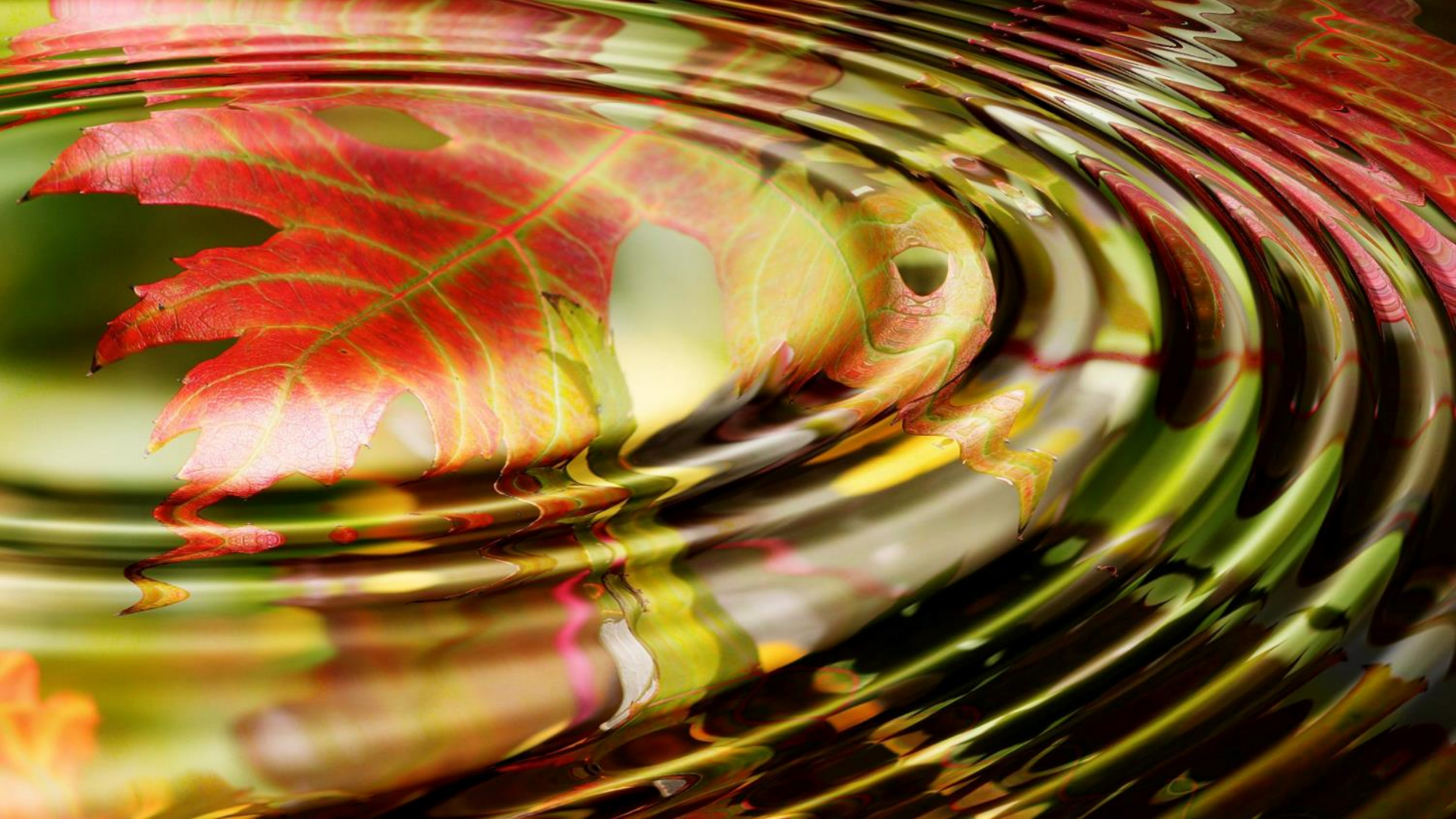


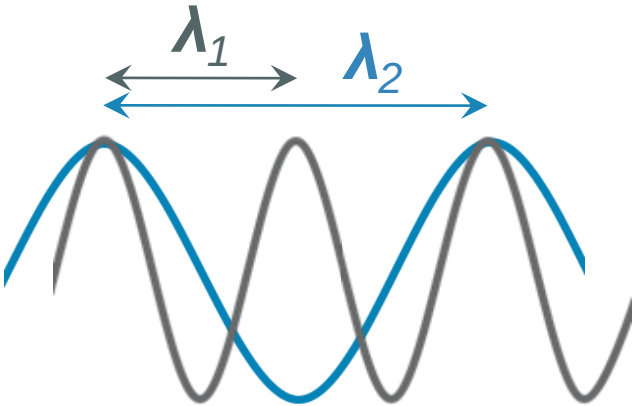
Electromagnetic Spectrum

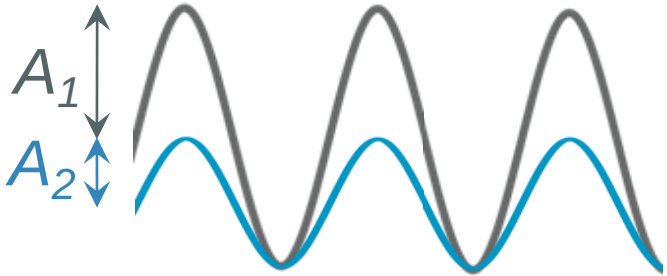
- Radio waves
- Micro waves
- Infrared Radiation
- Visible Light
- Ultraviolet Radiation
- X-Rays
- Gamma Rays

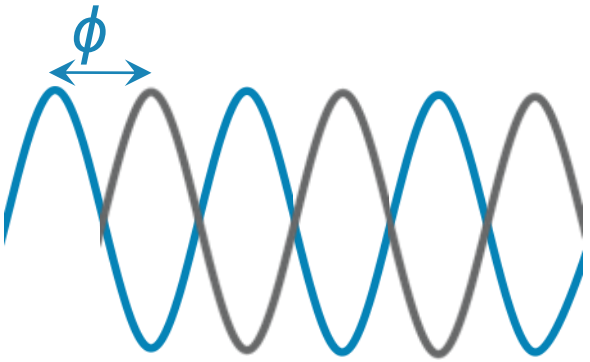
Colour	Frequency	Wavelength
Violet	668-789 THz	380-450nm
Blue	606-668 THz	450-495nm
Green	526-606 THz	495-570nm
Yellow	508-526 THz	570-590nm
Orange	484-508 THz	590-620nm
Red	400-484 THz	620-750nm

Radio Frequency Fundamentals

- Frequency and Wavelength
  - f = c / λ
    c = the speed of light in a vacuum
  - 2.45GHz = 12.3cm
  - 5.0GHz = 6cm
- Amplitude
- Phase

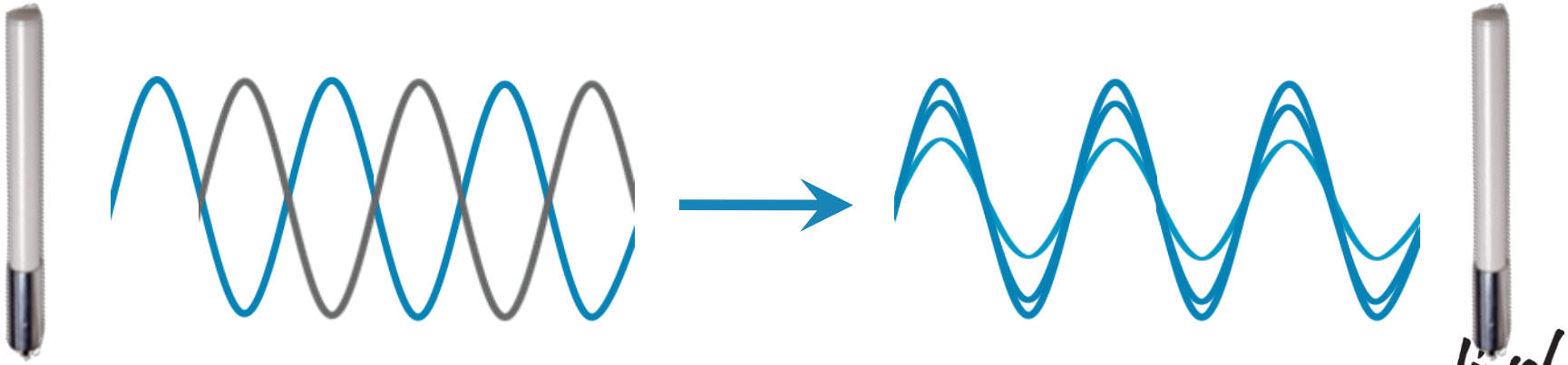






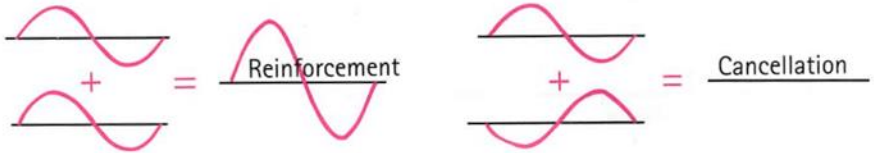
Radio Frequency Fundamentals

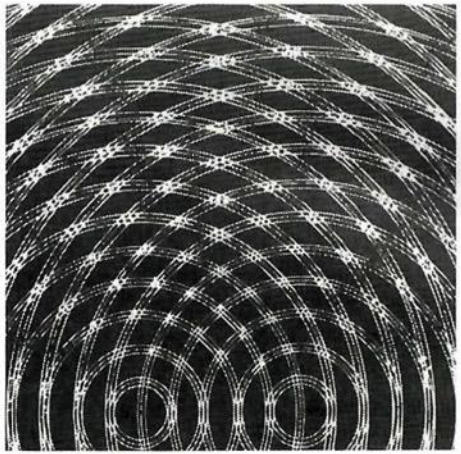
- Signal Strength
  - Gain and Amplification
  - Loss and Attenuation
- Wave Propagation
  - Attenuation and Free Space Loss
  - Reflection and Absorption

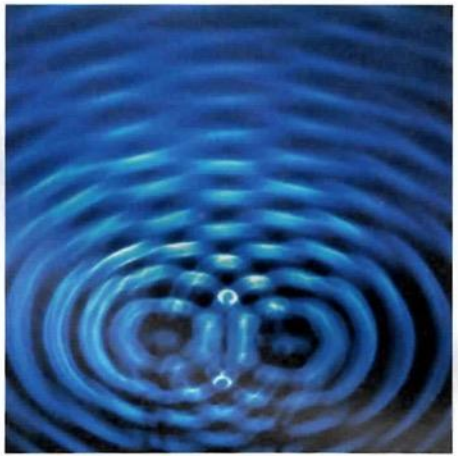


Physics of Waves

- In phase, reinforcement
- Out of phase, cancellation

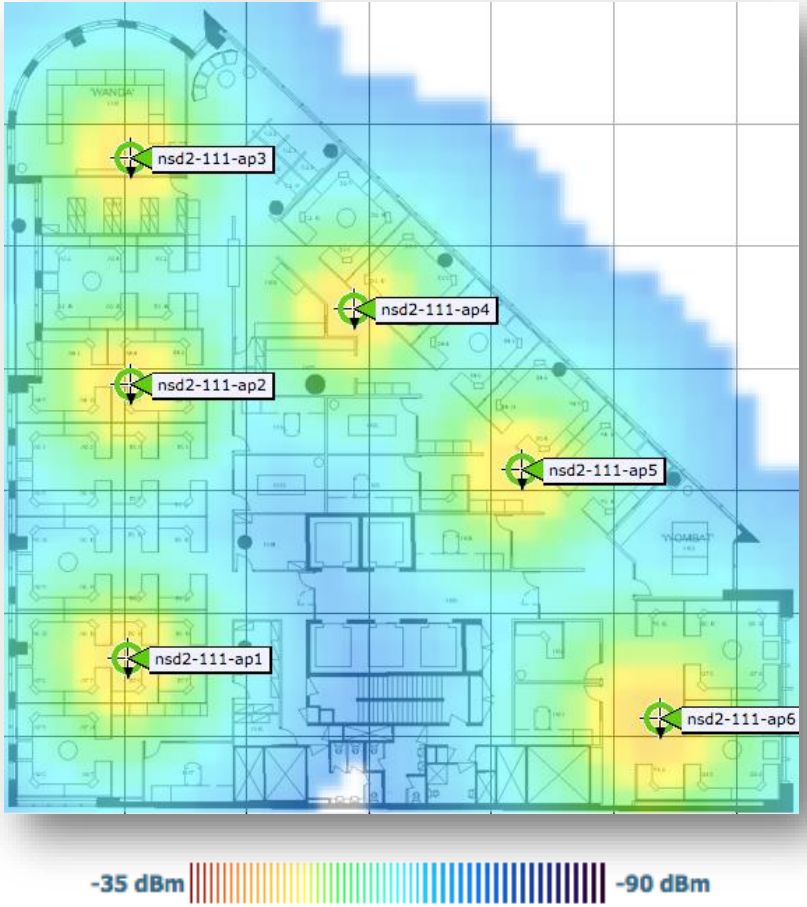






RF Mathematics

- dB is a logarithmic ratio of values (voltages, power, gain, losses)
  - We add gains
  - We subtract losses
- dBm is a power measurement relative to 1mW
- dBi is the forward gain of an antenna compared to isotropic antenna

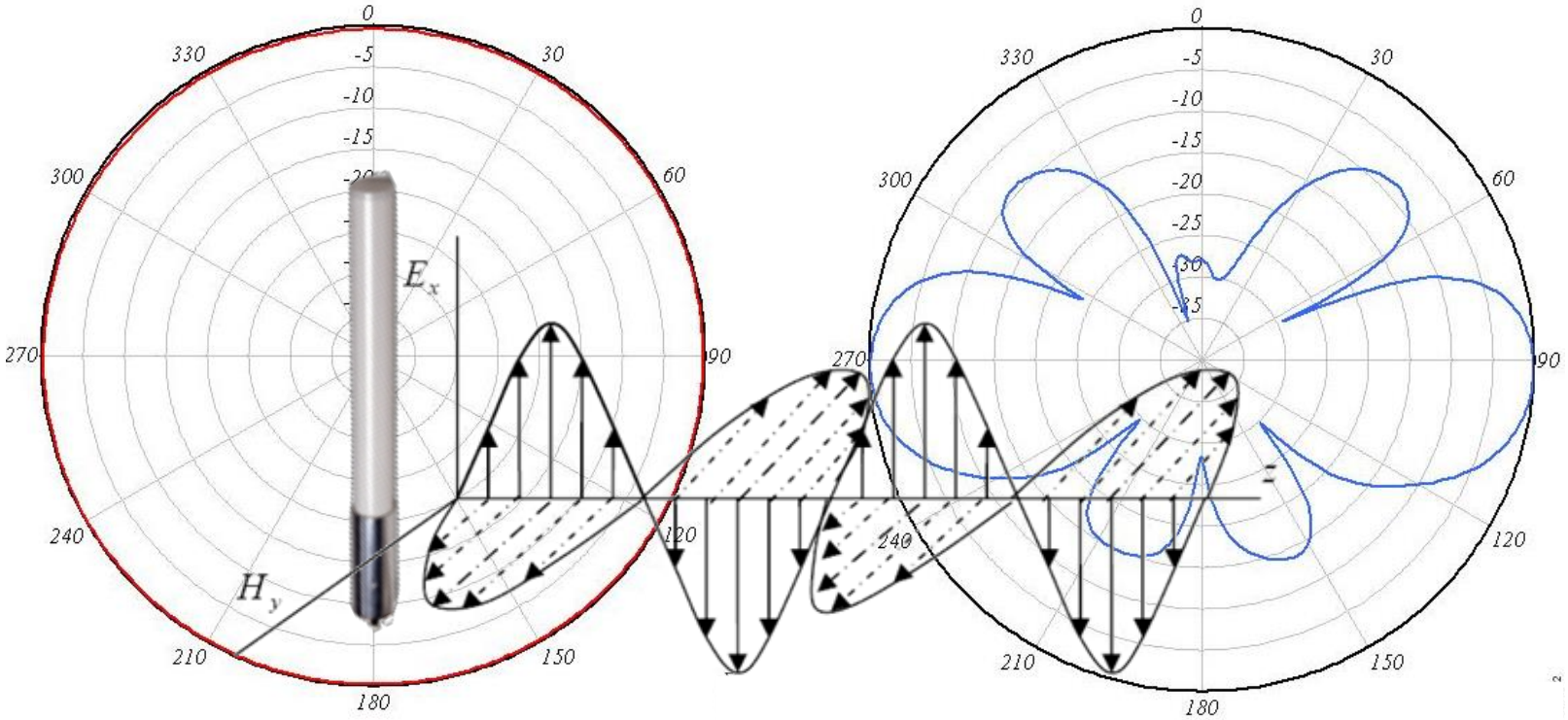


Interference and Signal to Noise Ratio

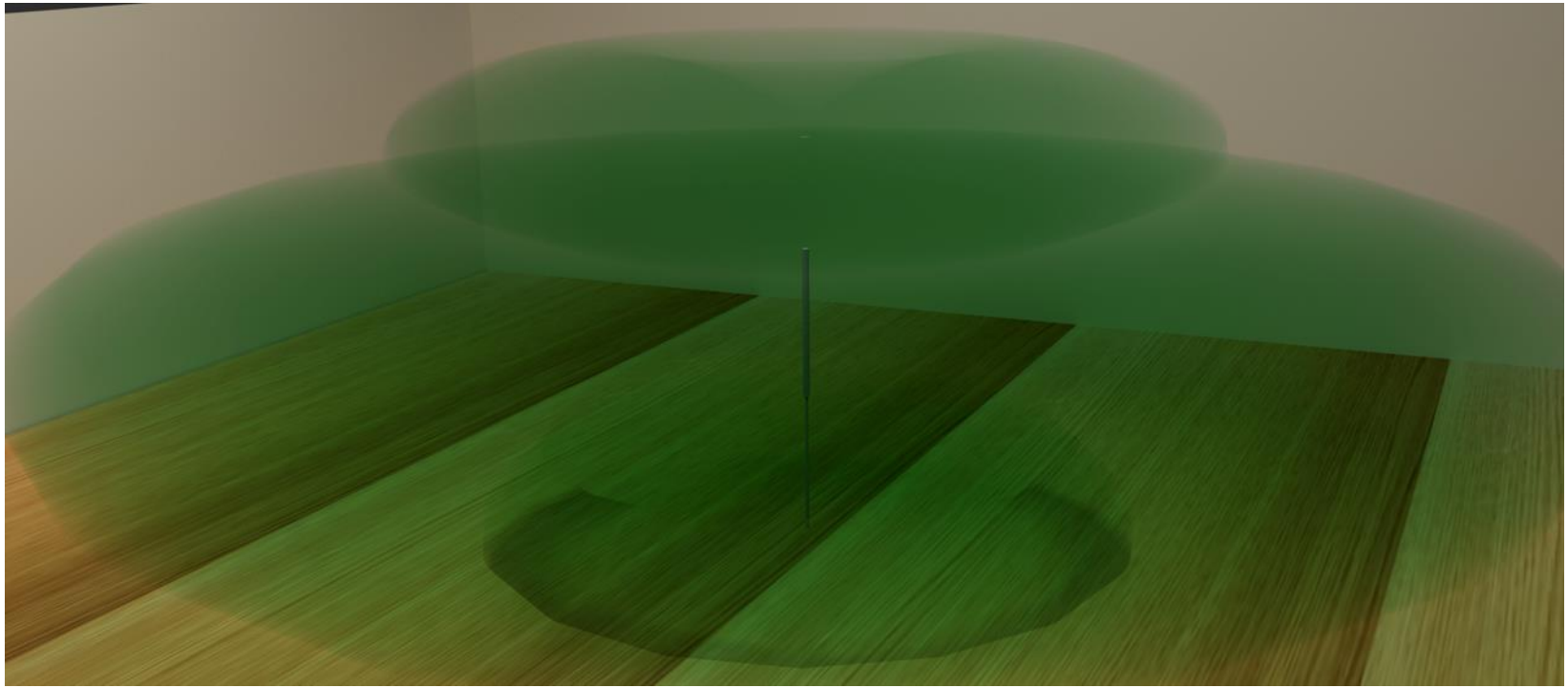
- Any RF signals other than what we want is interference
- SNR is a ratio
- The signal strength is a result of:
  - Transmit power
  - Receive sensitivity
- Increase the signal, or decrease the noise

Antenna Fundamentals

Omni-Directional Antennas



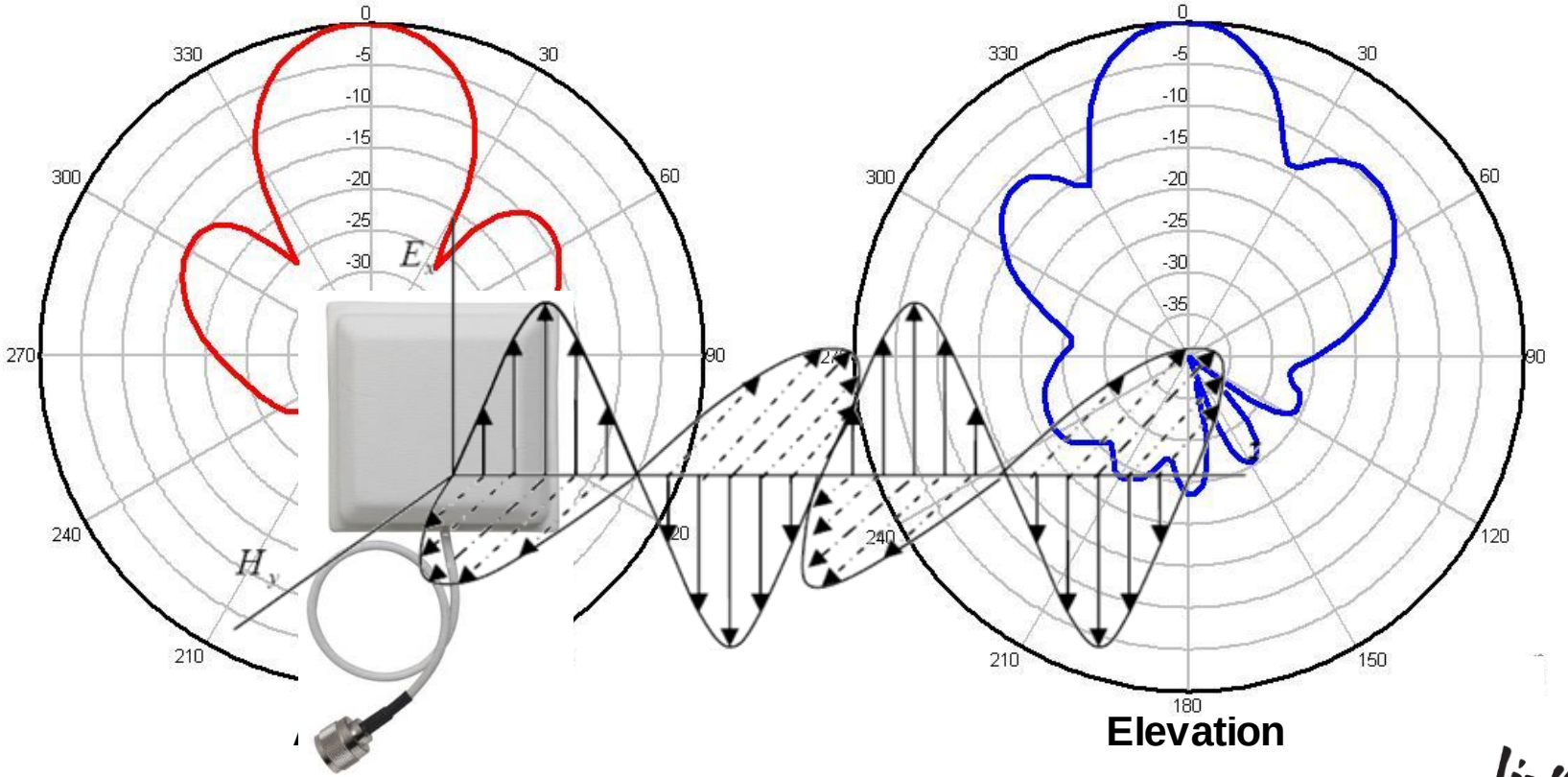
Omnidirectional Antenna Radition Pattern 3D



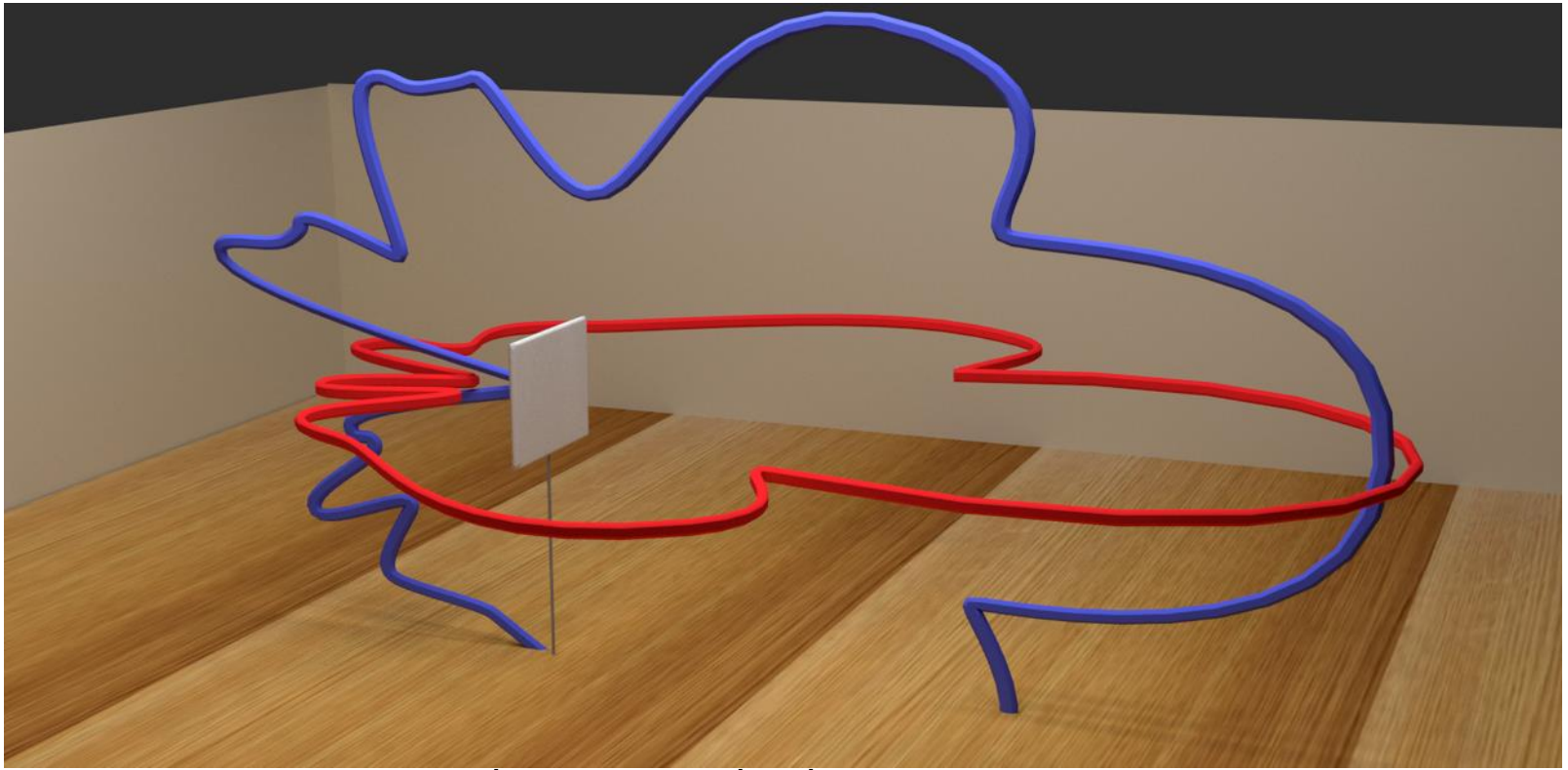
Not accurate or to scale; conceptual only

Antenna Fundamentals

Patch Antennas

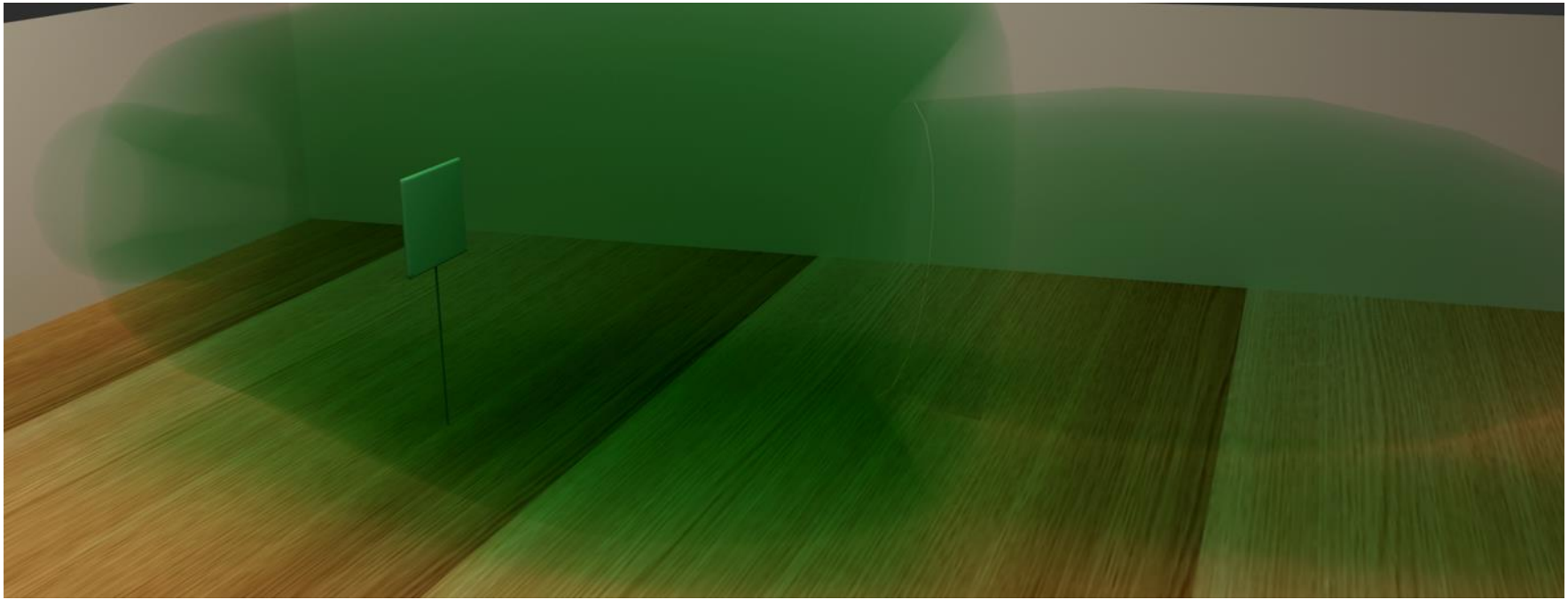


Panel Azimuth and Elevation in 3D



Not accurate or to scale; conceptual only

Panel EM field in 3D (Hypothetically)

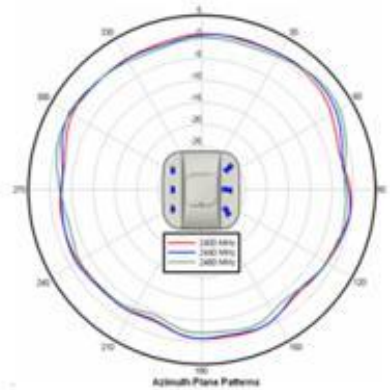


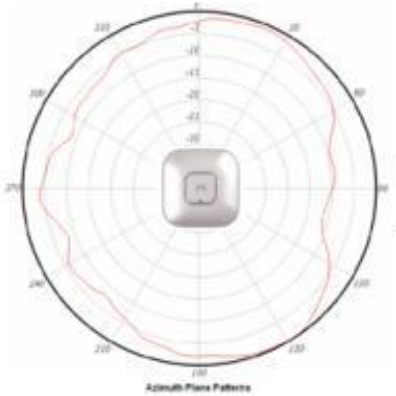
Not accurate or to scale; conceptual only

Antenna Fundamentals

Internal Antennas

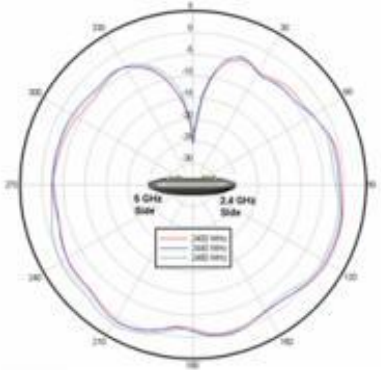
2.4 GHz Azimuth

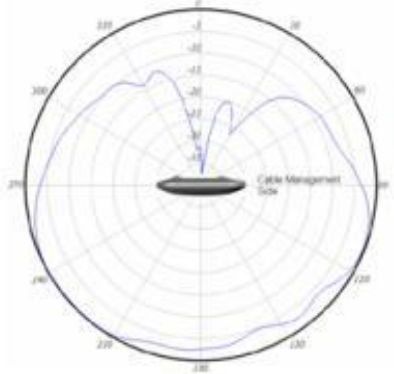




5 GHz Azimuth

2.4 GHz Elevation

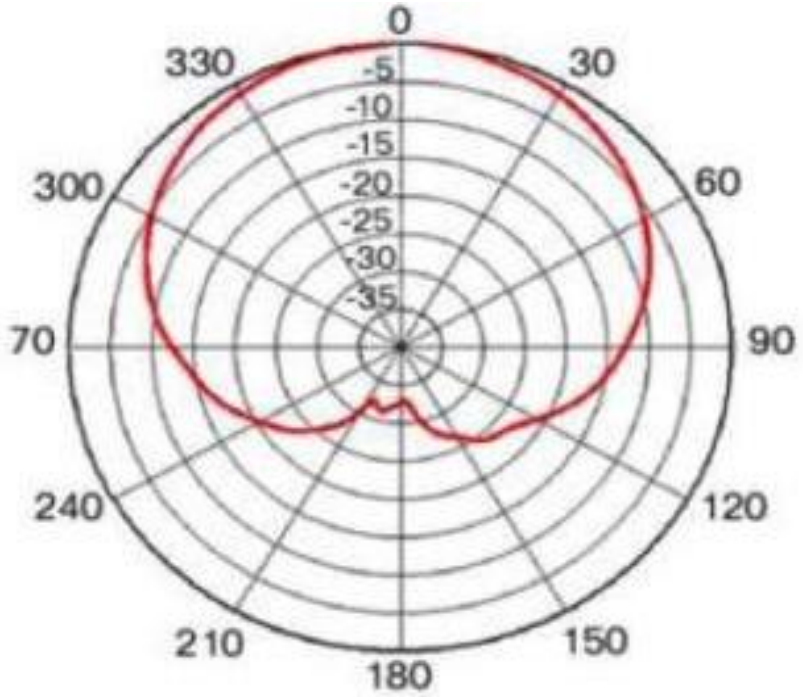




5 GHz Elevation

Antenna Fundamentals

High-Gain Antennas

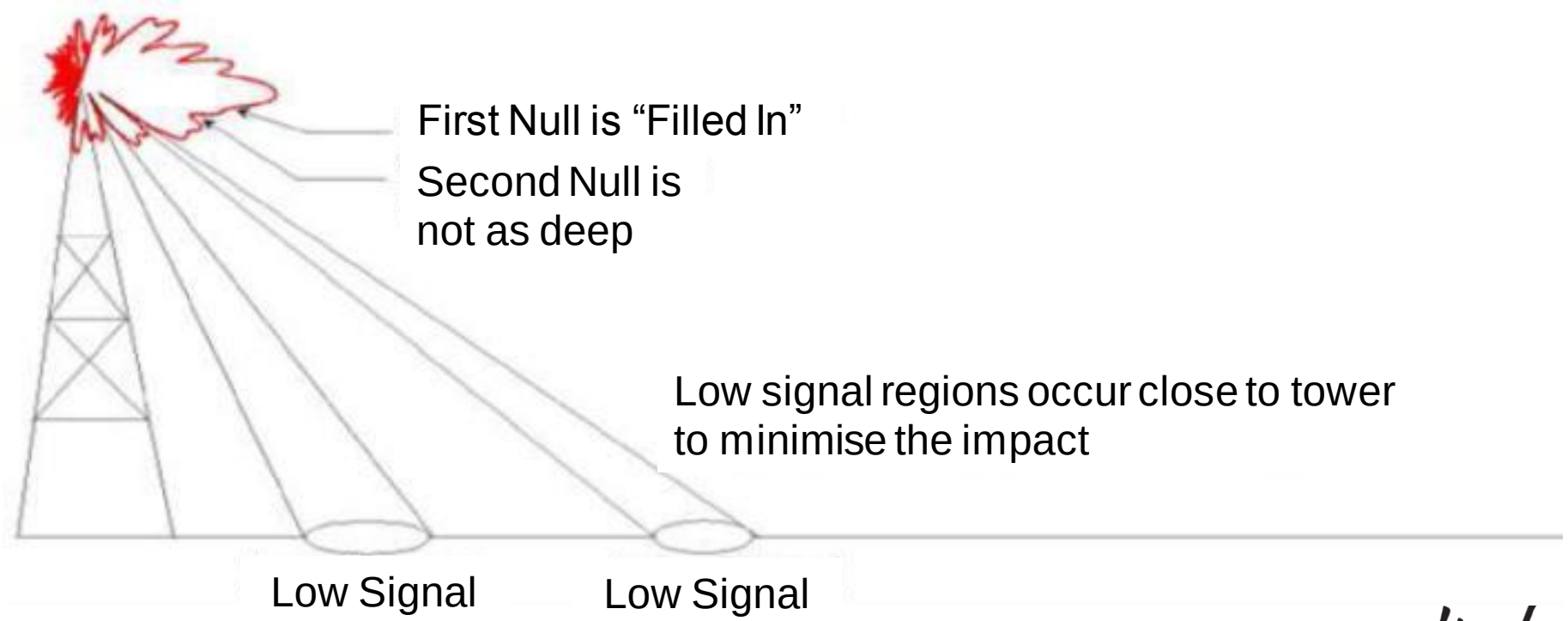


Azimuth

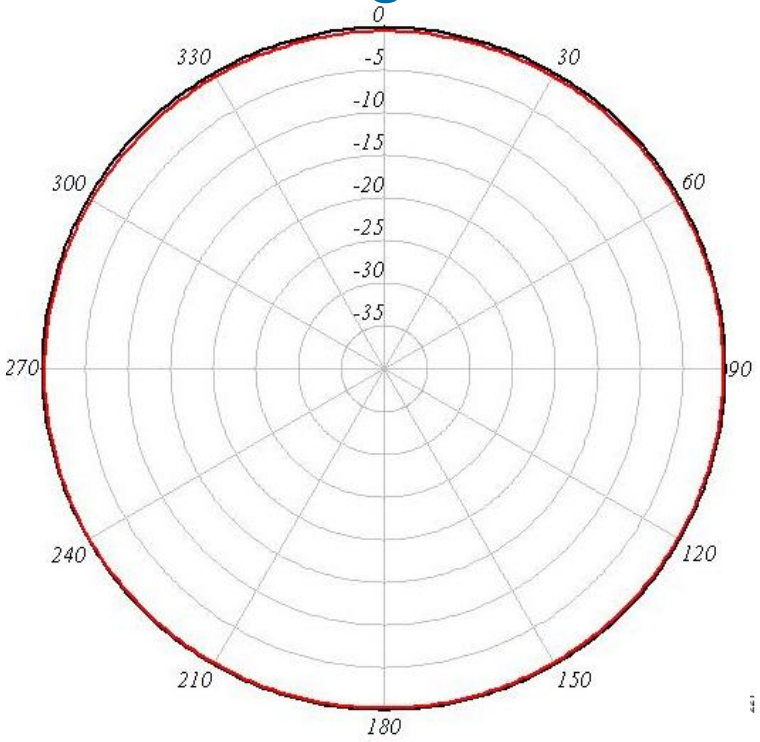
Elevation

Antenna Fundamentals

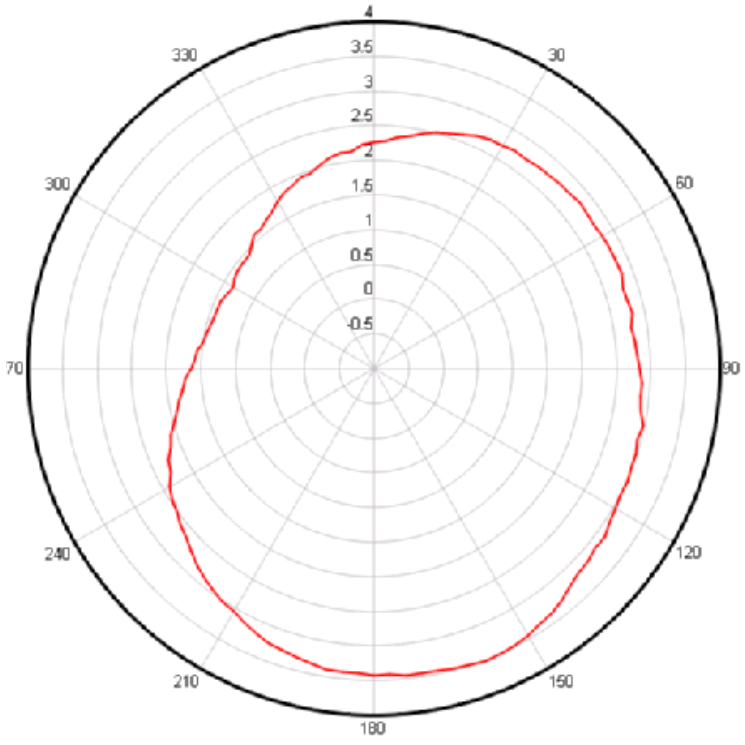
High-Gain Antennas



Antenna Design

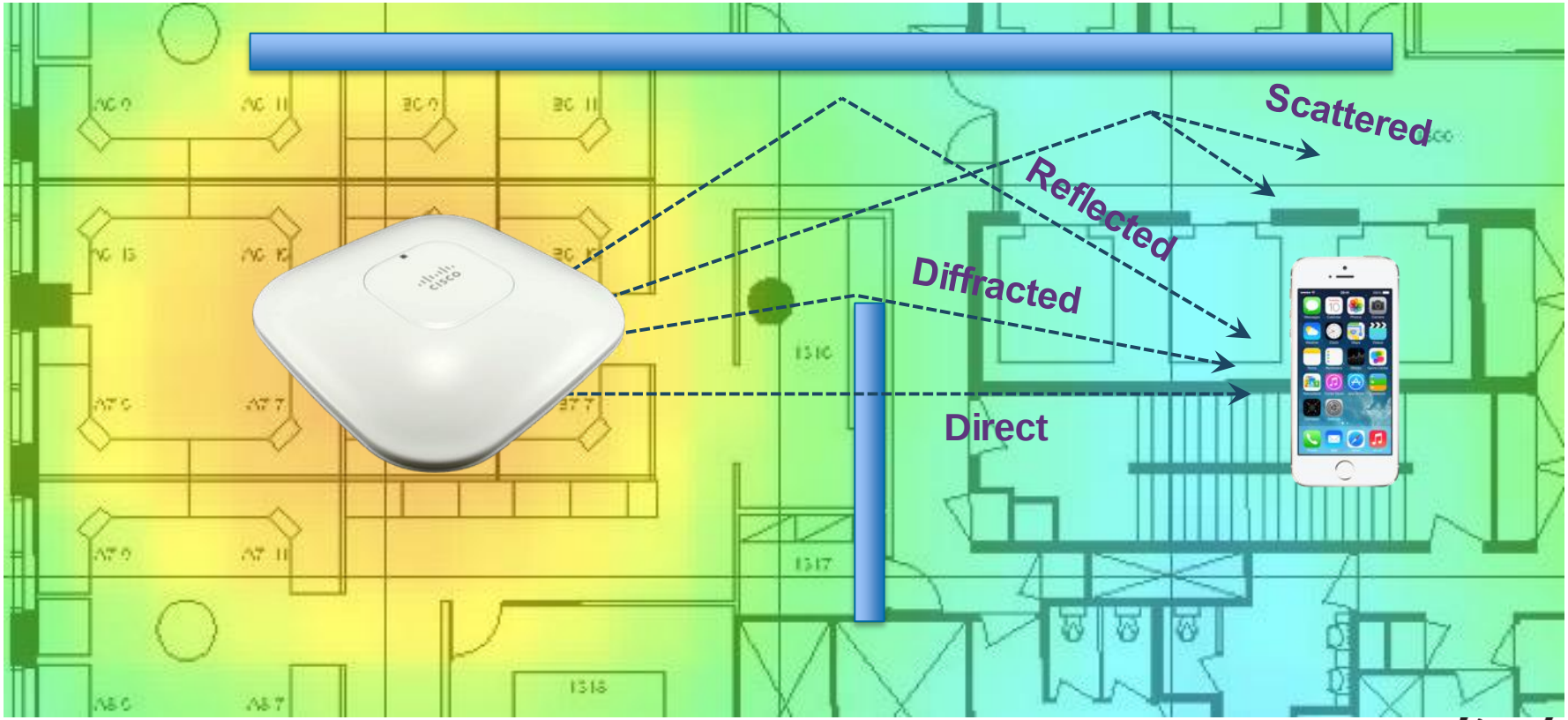


Cisco 2.4GHz Antenna

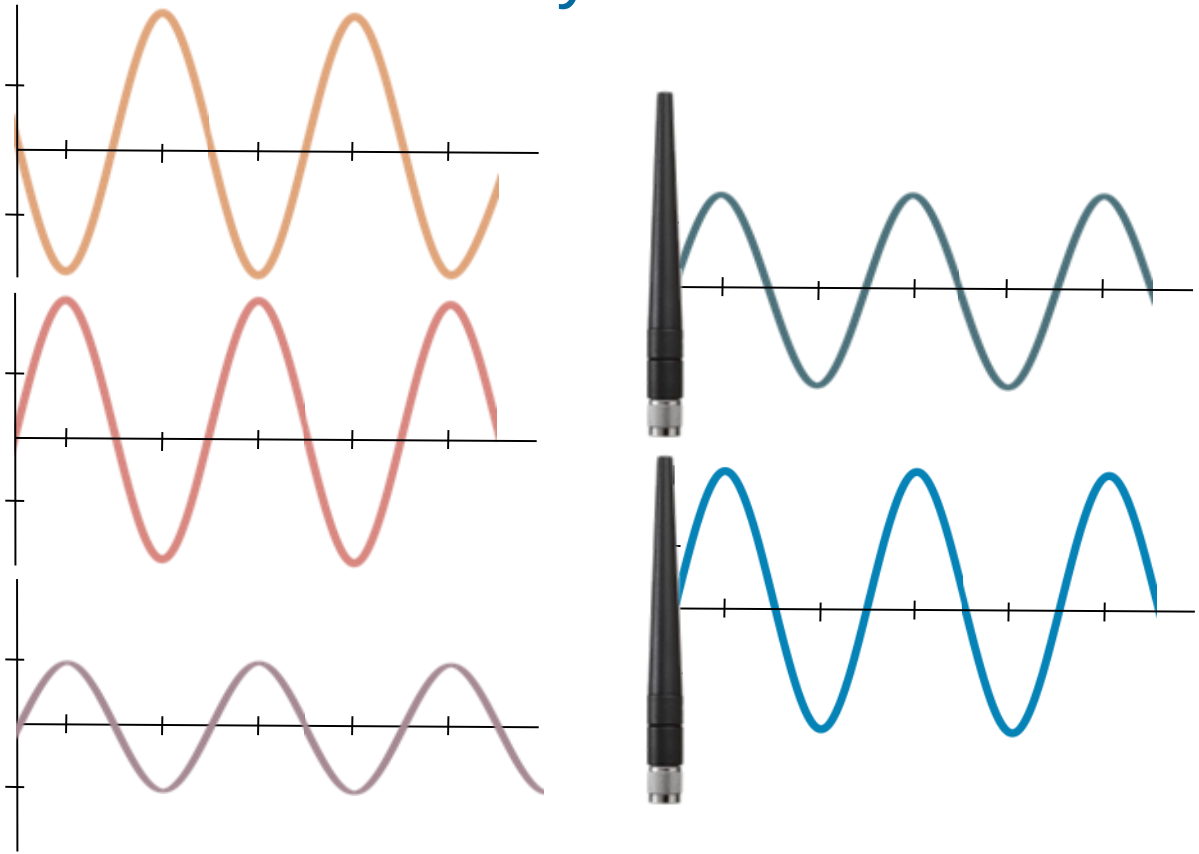


Combined 2.4 and 5GHz Antenna

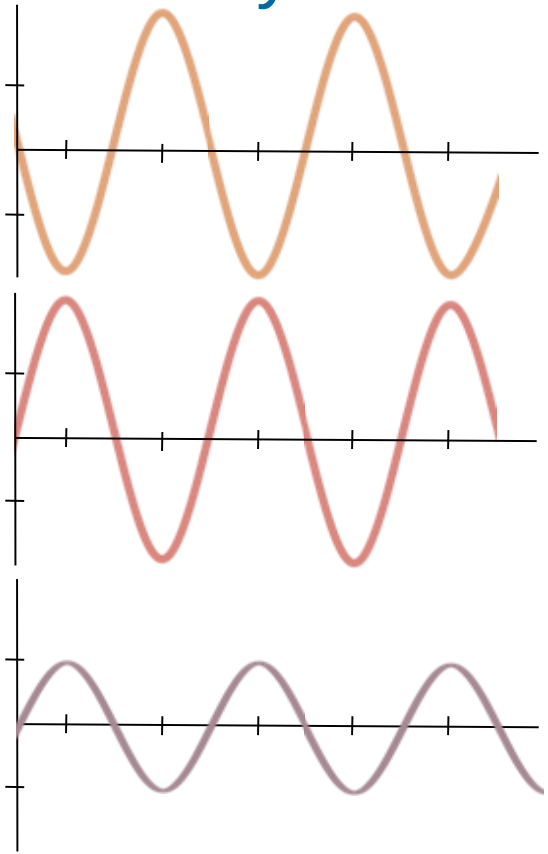
Multipath Propagation

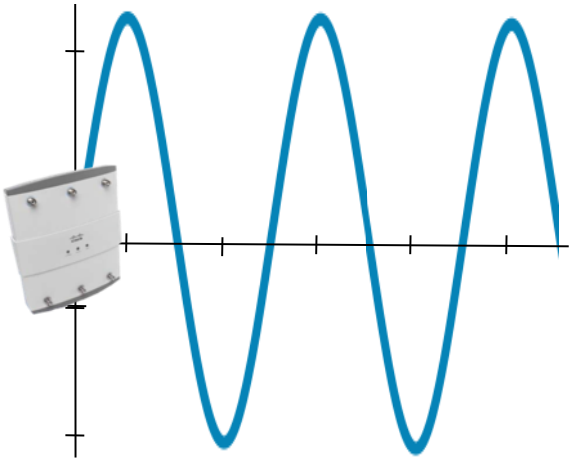


Antenna Diversity



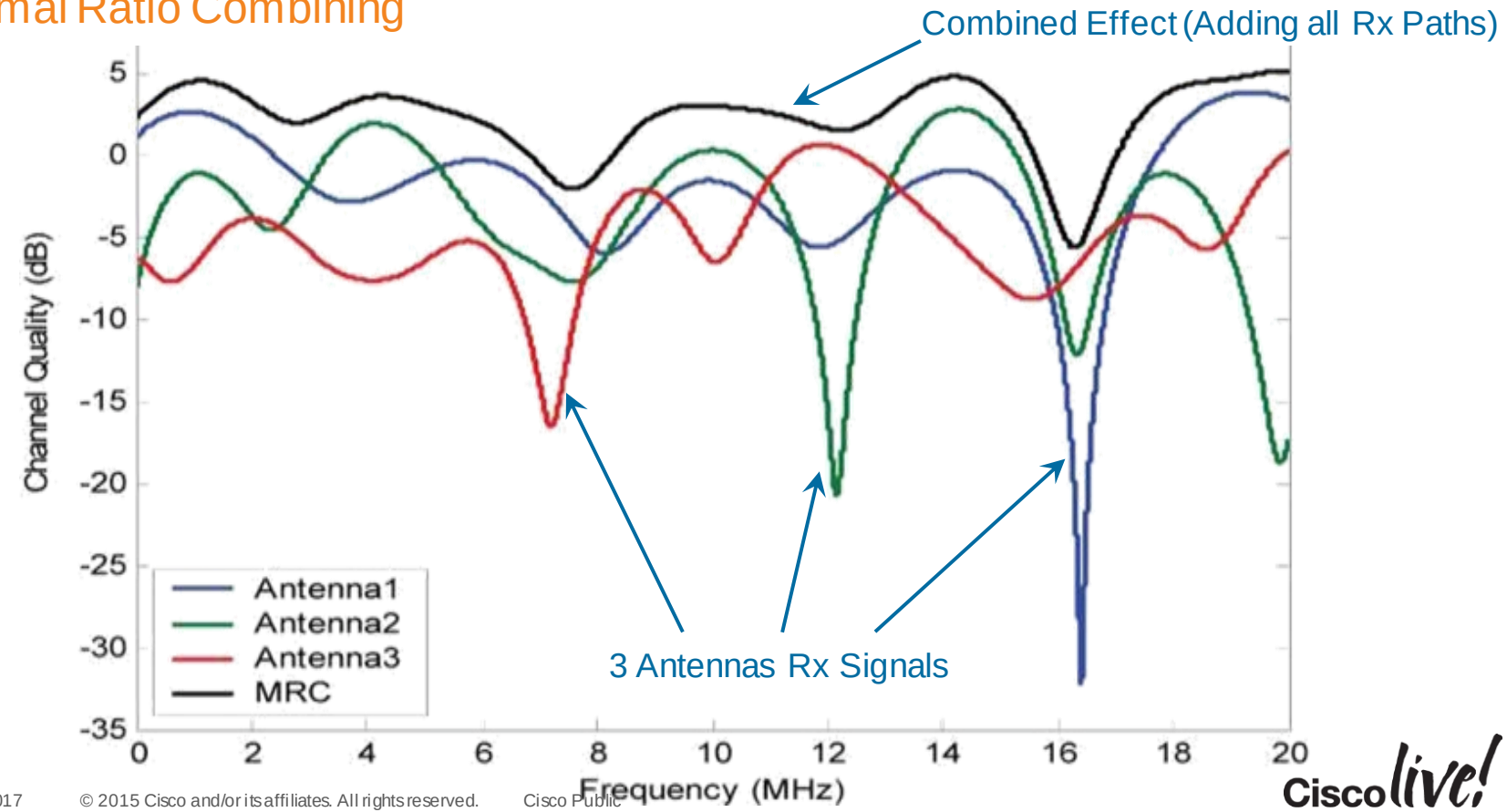
Diversity Combining





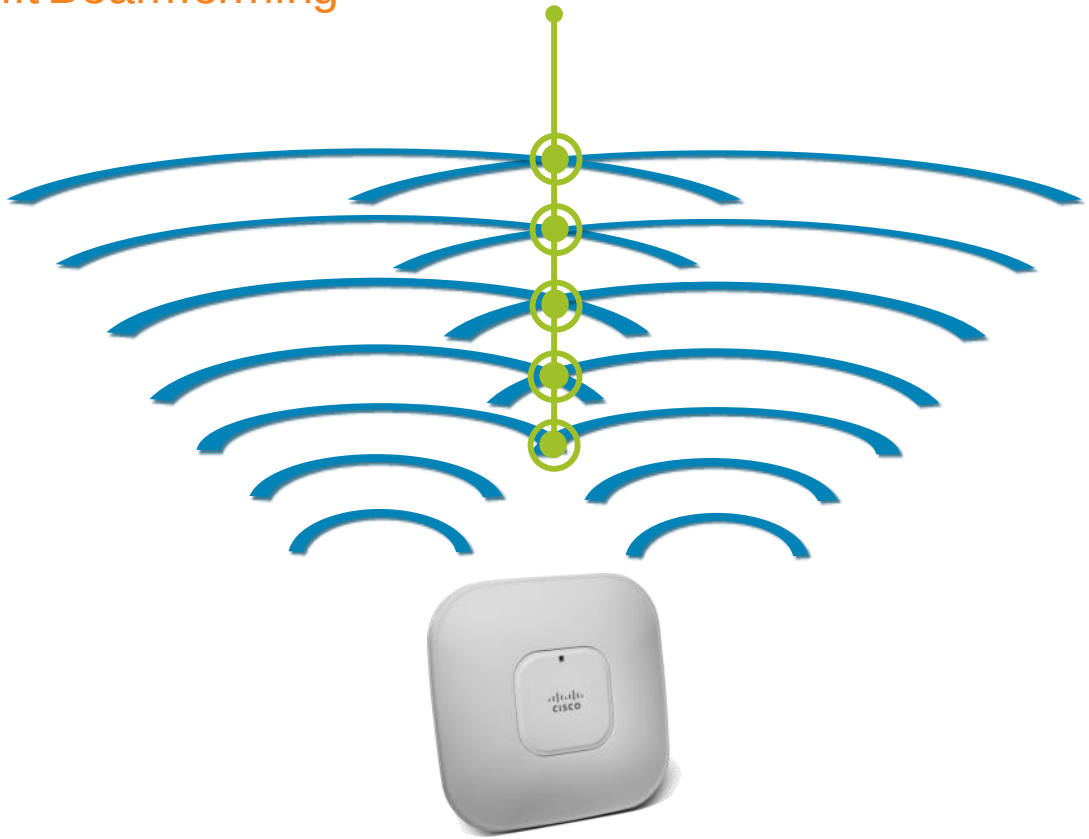
Multiple Input Multiple Output

Maximal Ratio Combining



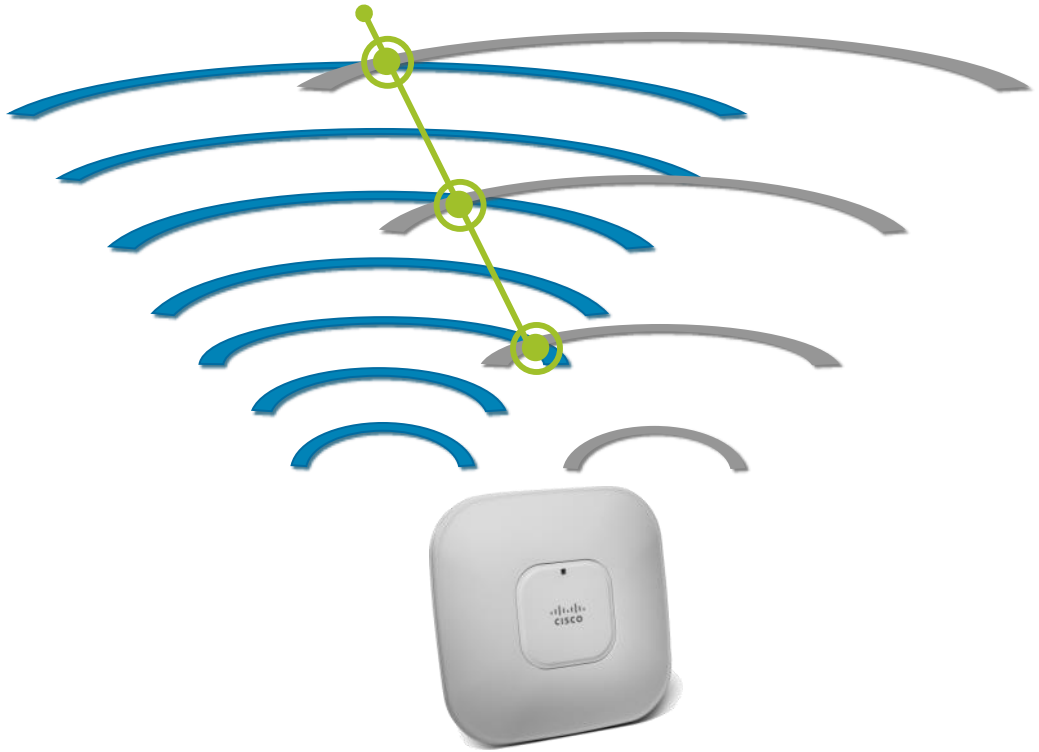
Multiple Input Multiple Output

Implicit Transmit Beamforming



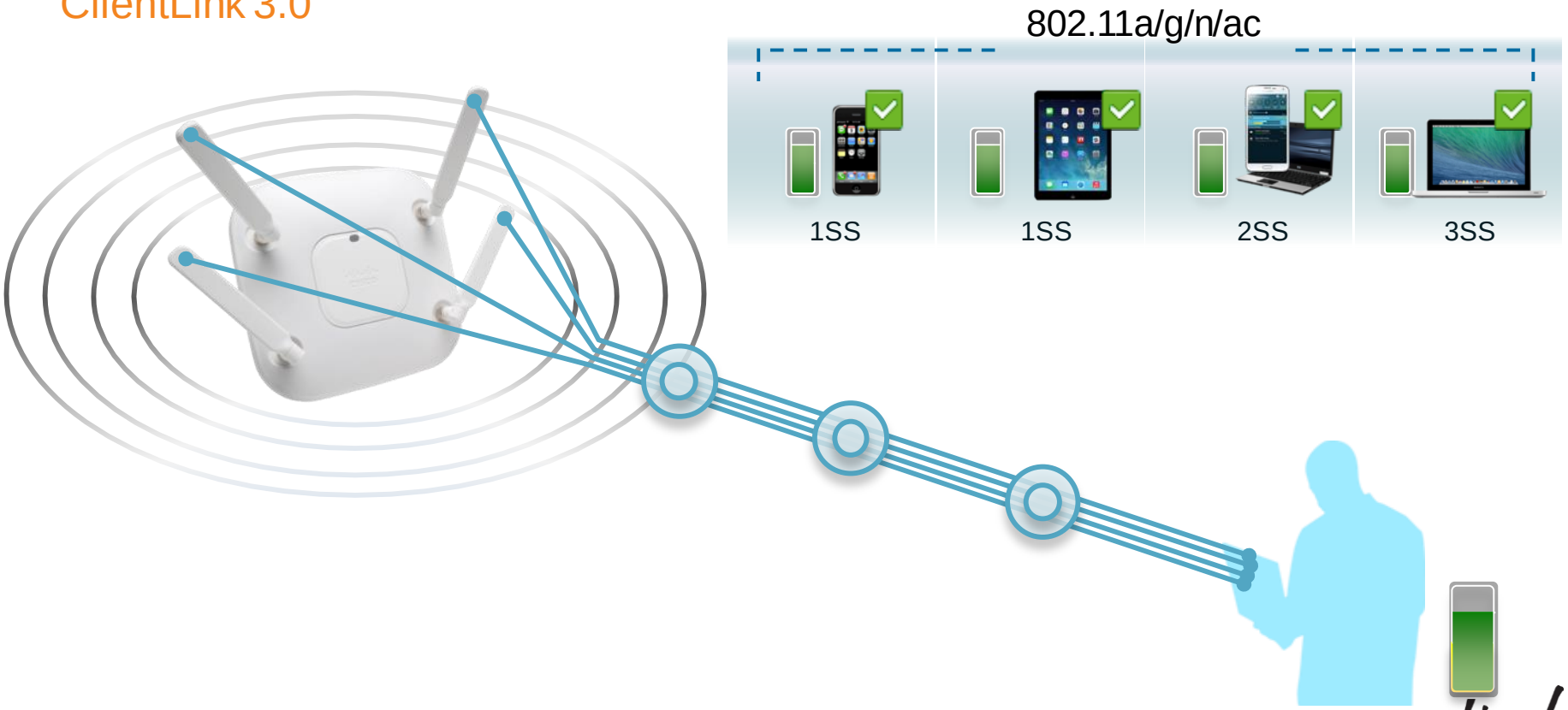
Multiple Input Multiple Output

Implicit Transmit Beamforming



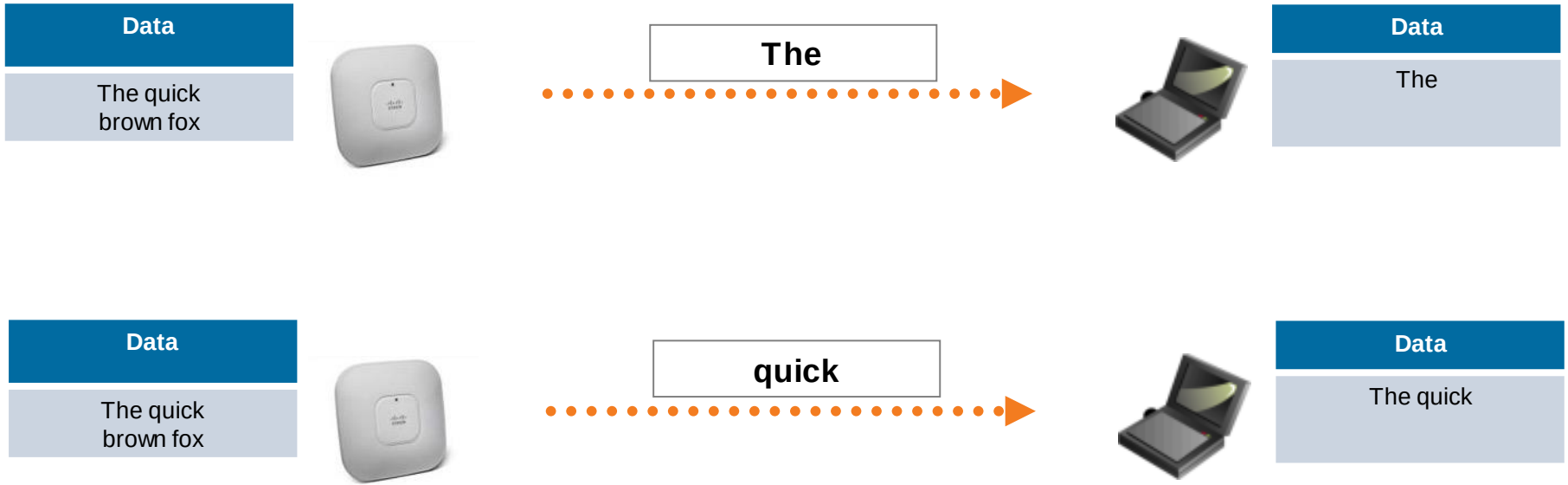
Multiple Input Multiple Output

ClientLink 3.0



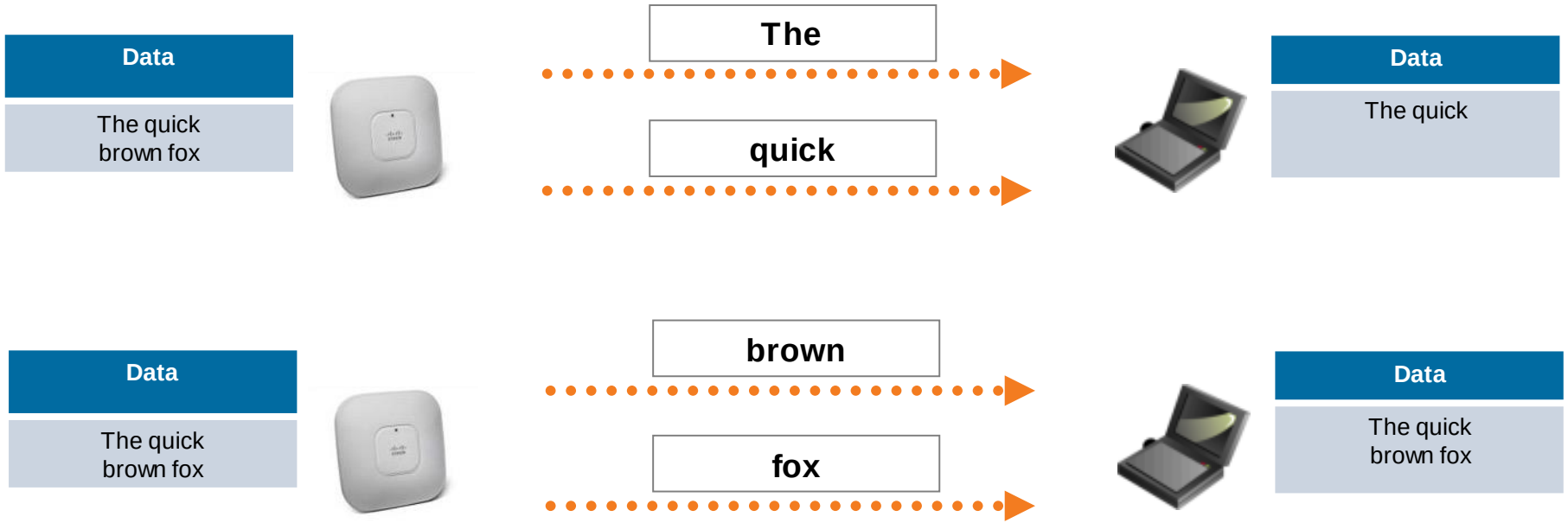
Multiple Input Multiple Output

Spatial Multiplexing

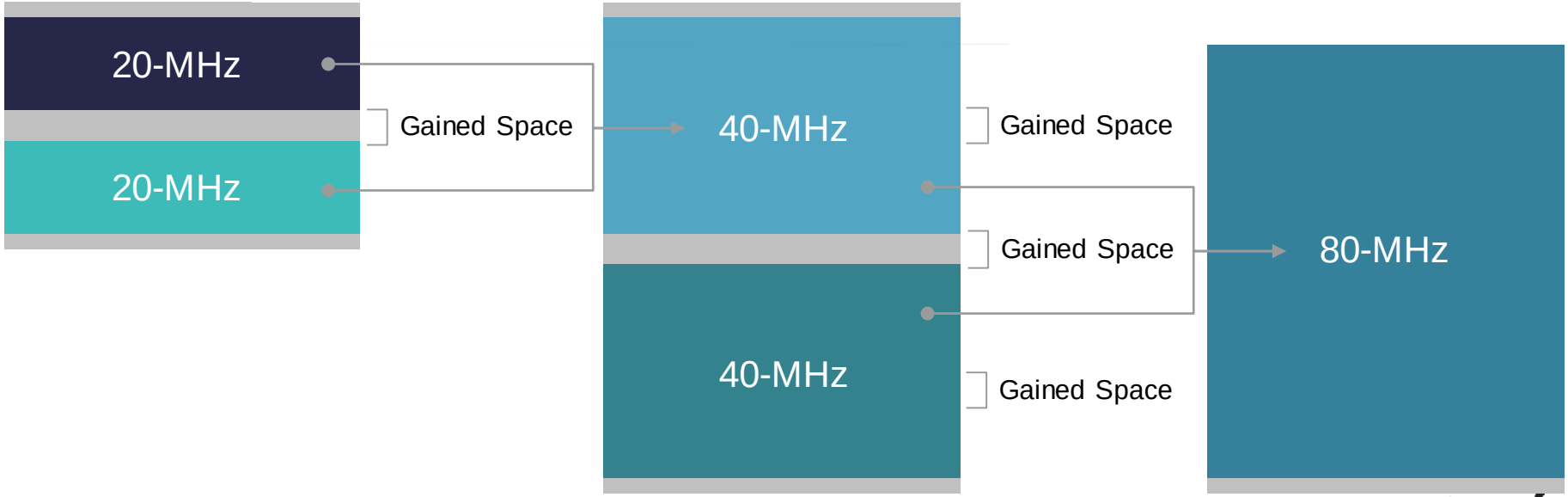


Multiple Input Multiple Output

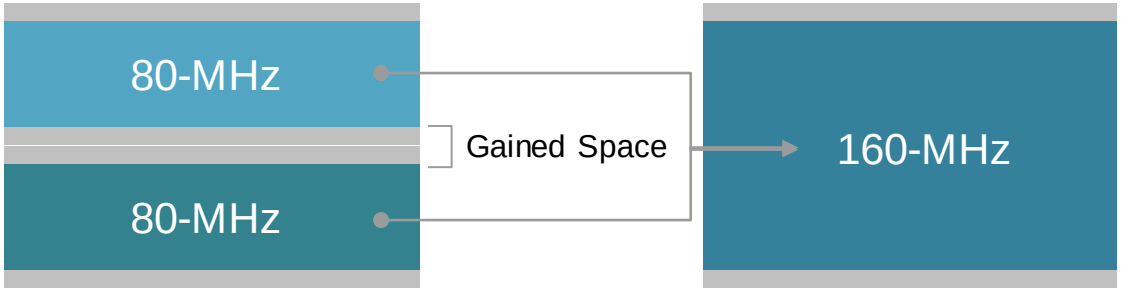
Spatial Multiplexing



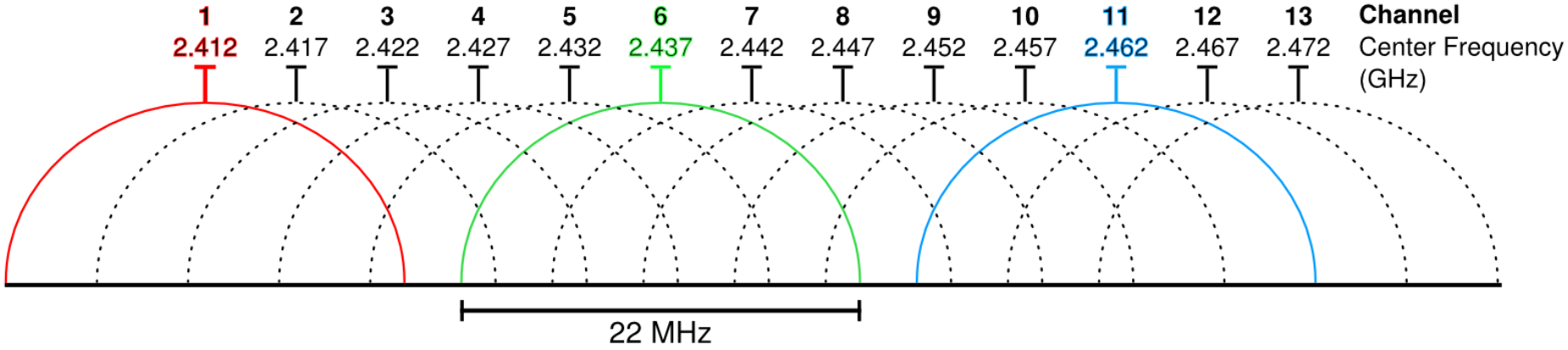
Channel Bonding



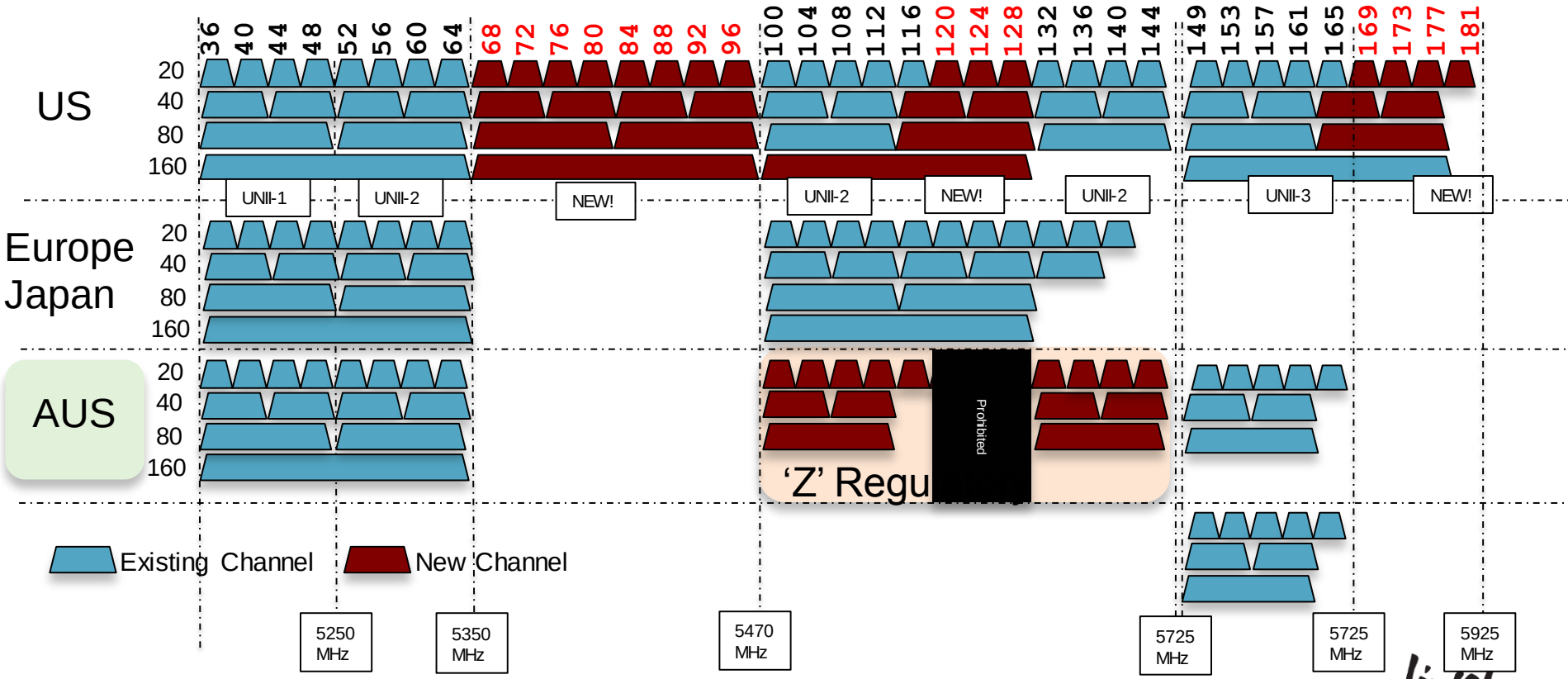
Channel Bonding



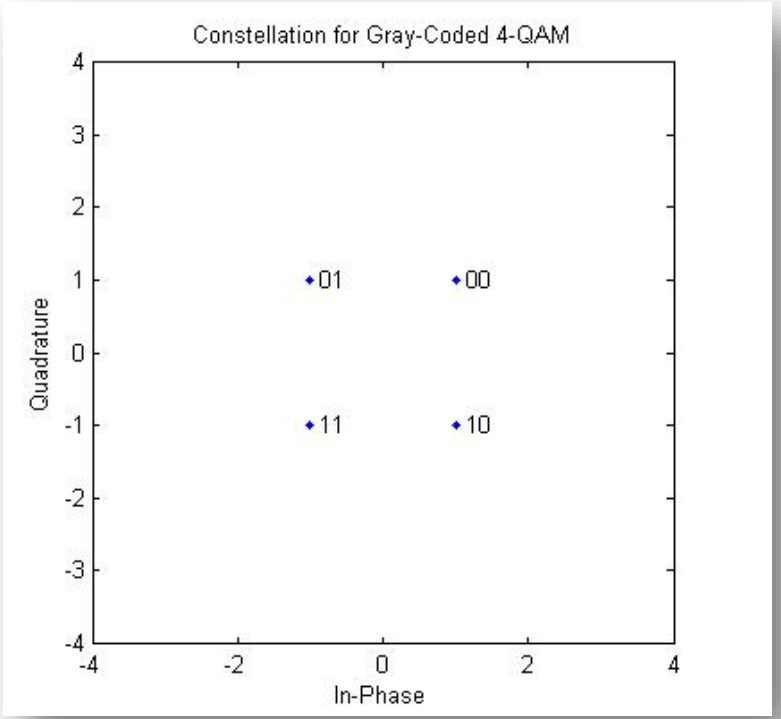
2.4GHz Channels



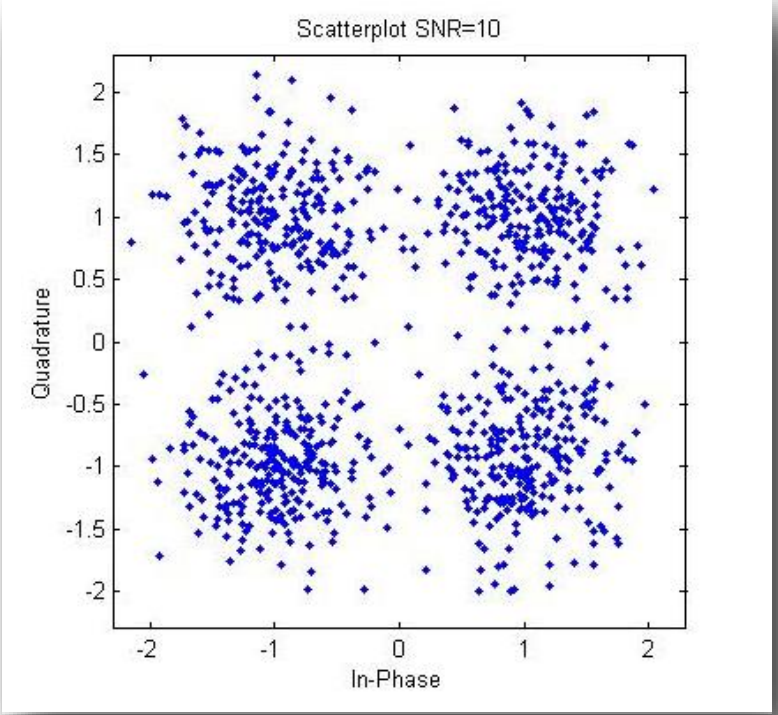
5 GHz 20/40/80/160 MHz Channels



Modulation, SNR and Data Rates

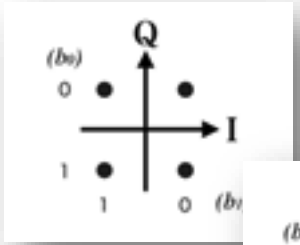


4-QAM

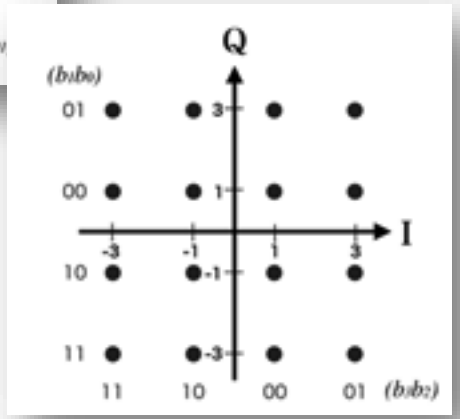


SNR=10

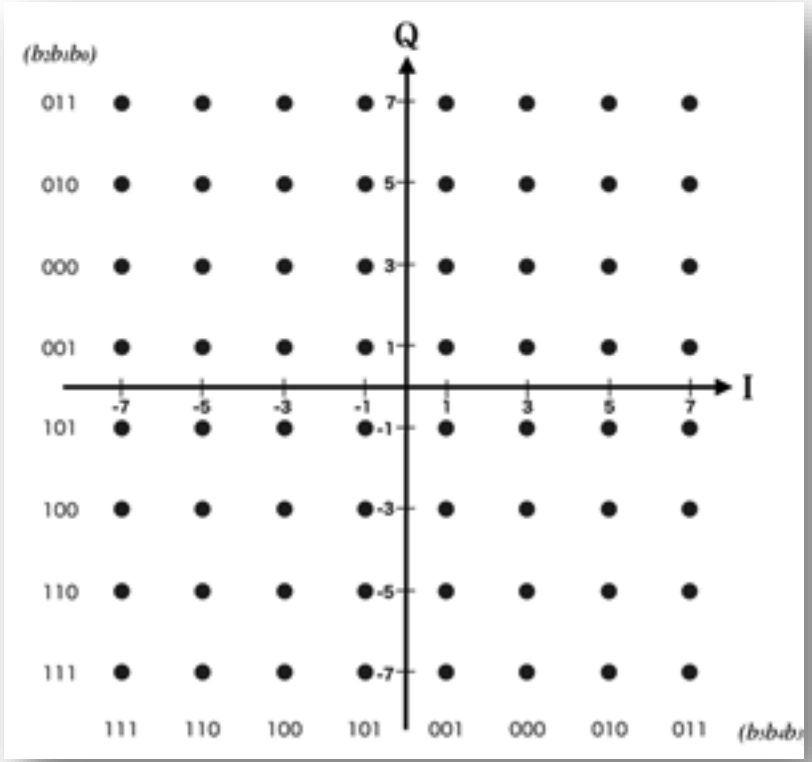
Rate vs Range and the Laws of Physics



4-QAM

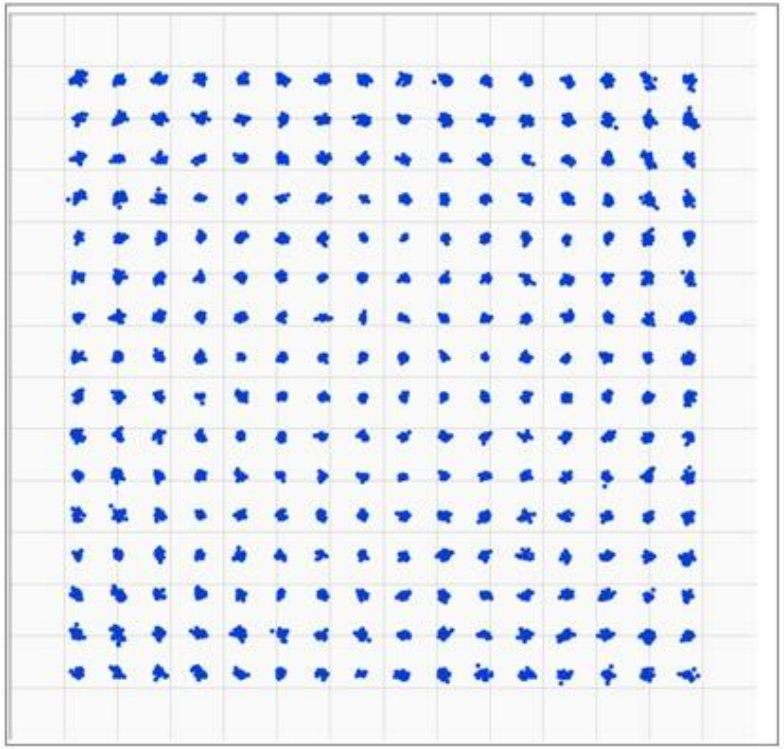


16-QAM



64-QAM

Rate vs Range and the Laws of Physics



256-QAM Constellation

Rate vs Range and the Laws of Physics

Protocol and Channel Width	MCS Value Achieved by Clients at Various Signal to Noise Ratio (SNR) Levels											
	0	1	2	3	4	5	6	7	8	9	10	11
IEEE_802.11b 20 MHz	None	None	None	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1	MCS 2
IEEE_802.11ag 20 MHz	None	None	MCS 0	MCS 0	MCS 1	MCS 2	MCS 2	MCS 2	MCS 2	MCS 3	MCS 3	MCS 4
IEEE_802.11n 20 MHz	None	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1	MCS 2	MCS 2	MCS 3
IEEE_802.11n 40 MHz	None	None	None	None	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1
IEEE_802.11ac 20 MHz	None	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1	MCS 2	MCS 2	MCS 3
IEEE_802.11ac 40 MHz	None	None	None	None	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1
IEEE_802.11ac 80 MHz	None	None	None	None	None	None	None	None	MCS 0	MCS 0	MCS 0	MCS 1
IEEE_802.11ac 160 MHz	None	None	None	None	None	None	None	None	None	None	None	MCS 0

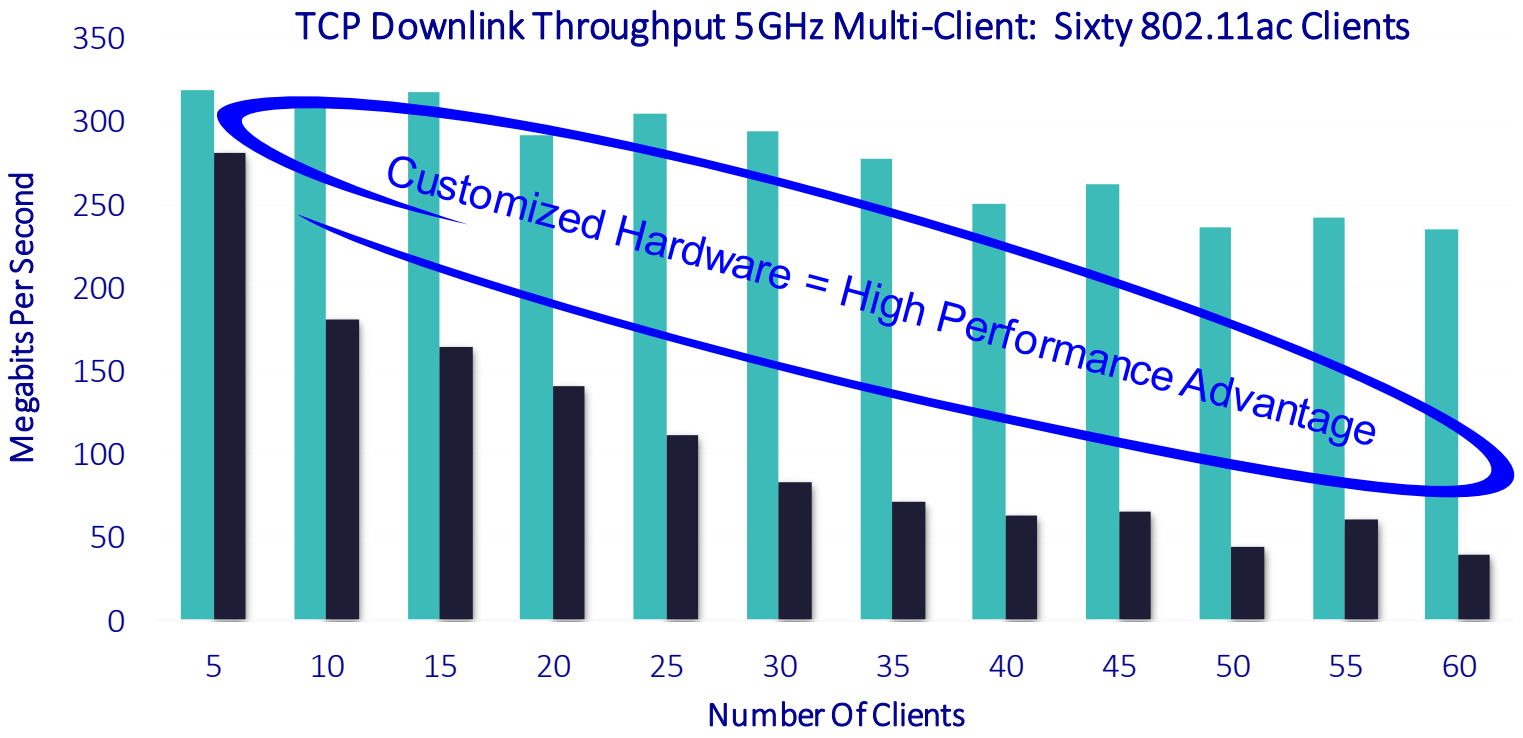
Protocol and Channel Width													
	12	13	14	15	16	17	18	19	20	21	22	23	24
IEEE_802.11b 20 MHz	MCS 2	MCS 2	MCS 2	MCS 2	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3
IEEE_802.11ag 20 MHz	MCS 4	MCS 4	MCS 4	MCS 5	MCS 5	MCS 5	MCS 6	MCS 6	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7
IEEE_802.11n 20 MHz	MCS 3	MCS 3	MCS 3	MCS 4	MCS 4	MCS 4	MCS 5	MCS 5	MCS 6	MCS 6	MCS 6	MCS 6	MCS 6
IEEE_802.11n 40 MHz	MCS 2	MCS 2	MCS 3	MCS 3	MCS 3	MCS 3	MCS 4	MCS 4	MCS 4	MCS 5	MCS 5	MCS 6	MCS 6
IEEE_802.11ac 20 MHz	MCS 3	MCS 3	MCS 3	MCS 4	MCS 4	MCS 4	MCS 5	MCS 5	MCS 6	MCS 6	MCS 6	MCS 6	MCS 6
IEEE_802.11ac 40 MHz	MCS 2	MCS 2	MCS 3	MCS 3	MCS 3	MCS 3	MCS 4	MCS 4	MCS 4	MCS 5	MCS 5	MCS 6	MCS 6
IEEE_802.11ac 80 MHz	MCS 1	MCS 1	MCS 1	MCS 2	MCS 2	MCS 3	MCS 3	MCS 3	MCS 3	MCS 4	MCS 4	MCS 4	MCS 5
IEEE_802.11ac 160 MHz	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1	MCS 2	MCS 2	MCS 3	MCS 3	MCS 3	MCS 3	MCS 4

Rate vs Range and the Laws of Physics cont.

Protocol and Channel Width	25	26	27	28	29	30	31	32	33	34	35	36
IEEE_802.11b 20 MHz	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3
IEEE_802.11ag 20 MHz	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7
IEEE_802.11n 20 MHz	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7
IEEE_802.11n 40 MHz	MCS 6	MCS 6	MCS 6	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7
IEEE_802.11ac 20 MHz	MCS 7	MCS 7	MCS 7	MCS 7	MCS 8	MCS 8	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9
IEEE_802.11ac 40 MHz	MCS 6	MCS 6	MCS 6	MCS 7	MCS 7	MCS 7	MCS 7	MCS 8	MCS 8	MCS 9	MCS 9	MCS 9
IEEE_802.11ac 80 MHz	MCS 5	MCS 6	MCS 6	MCS 6	MCS 6	MCS 6	MCS 7	MCS 7	MCS 7	MCS 7	MCS 8	MCS 8
IEEE_802.11ac 160 MHz	MCS 4	MCS 4	MCS 5	MCS 5	MCS 6	MCS 6	MCS 6	MCS 6	MCS 6	MCS 7	MCS 7	MCS 7

Protocol and Channel Width	37	38	39	40	41	42	43	44	45	46	47	48	49	50
IEEE_802.11b 20 MHz	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3
IEEE_802.11ag 20 MHz	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7
IEEE_802.11n 20 MHz	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7
IEEE_802.11n 40 MHz	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7	MCS 7
IEEE_802.11ac 20 MHz	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9
IEEE_802.11ac 40 MHz	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9
IEEE_802.11ac 80 MHz	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9
IEEE_802.11ac 160 MHz	MCS 7	MCS 8	MCS 8	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9	MCS 9

RF Matters



802.11n

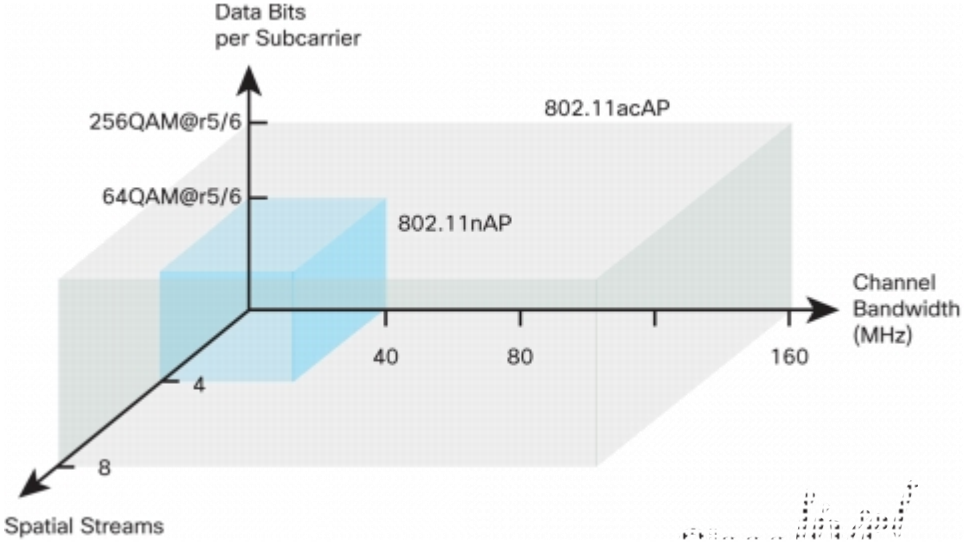
- 2.4 and 5GHz
- Channel Bonding
  - 40 MHz Channels
  - 5GHz band only
- Modulation
  - 64-QAM
- Spatial Streams
  - Support for up to 4
  - Only 3 Ultimately Deployed

- 40MHz Channel and 3 SS = 450Mbps
  - 20MHz Channel = 216.70Mbps
- 40MHz Channel and 2 SS = 300Mbps
  - 20MHz Channel = 144.40Mbps
- 40MHz Channel and 1 SS = 150Mbps
  - 20MHz Channel = 72.20Mbps

802.11ac

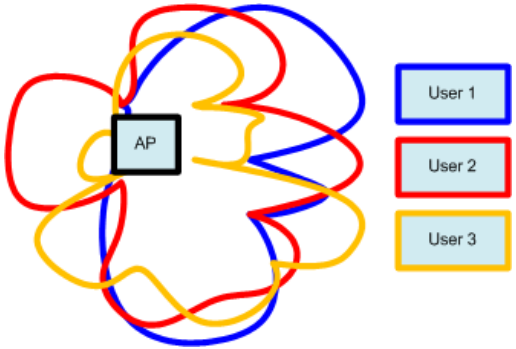
- 5GHz only
- Channel Bonding
  - 80 and 160MHz Channels
- Modulation
  - 256-QAM
- Spatial Streams
  - Support for up to 8

- 80MHz Channel and 3 SS = 1.3Gbps
- 80MHz Channel and 2 SS = 866.6Mbps
- 80MHz Channel and 1 SS = 433.3Mbps



802.11ac Wave 2

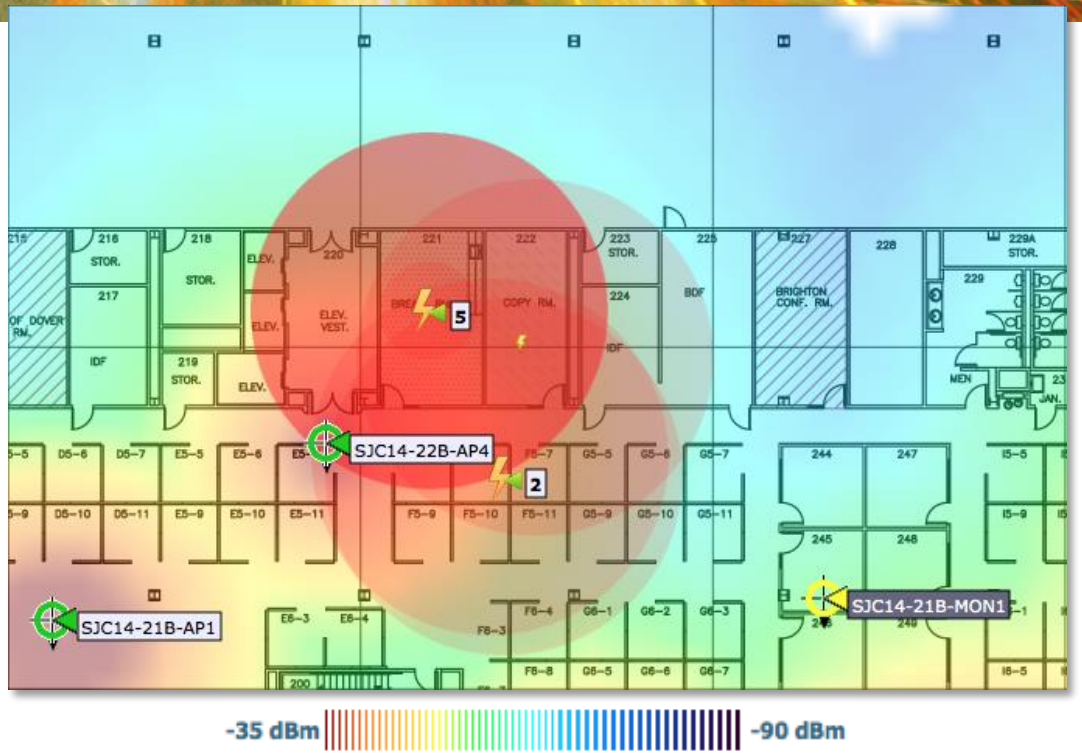
- 160MHz Channels
  - 160MHz Channel and 1 SS = 866.7Mbps
  - 160MHz Channel and 3 SS = 2.34Gbps
  - 160MHz Channel and 4 SS = 3.47Gbps
  - 160MHz Channel and 8 SS = 6.93Gbps!
- MU-MIMO
  - Will provide for improved channel utilisation

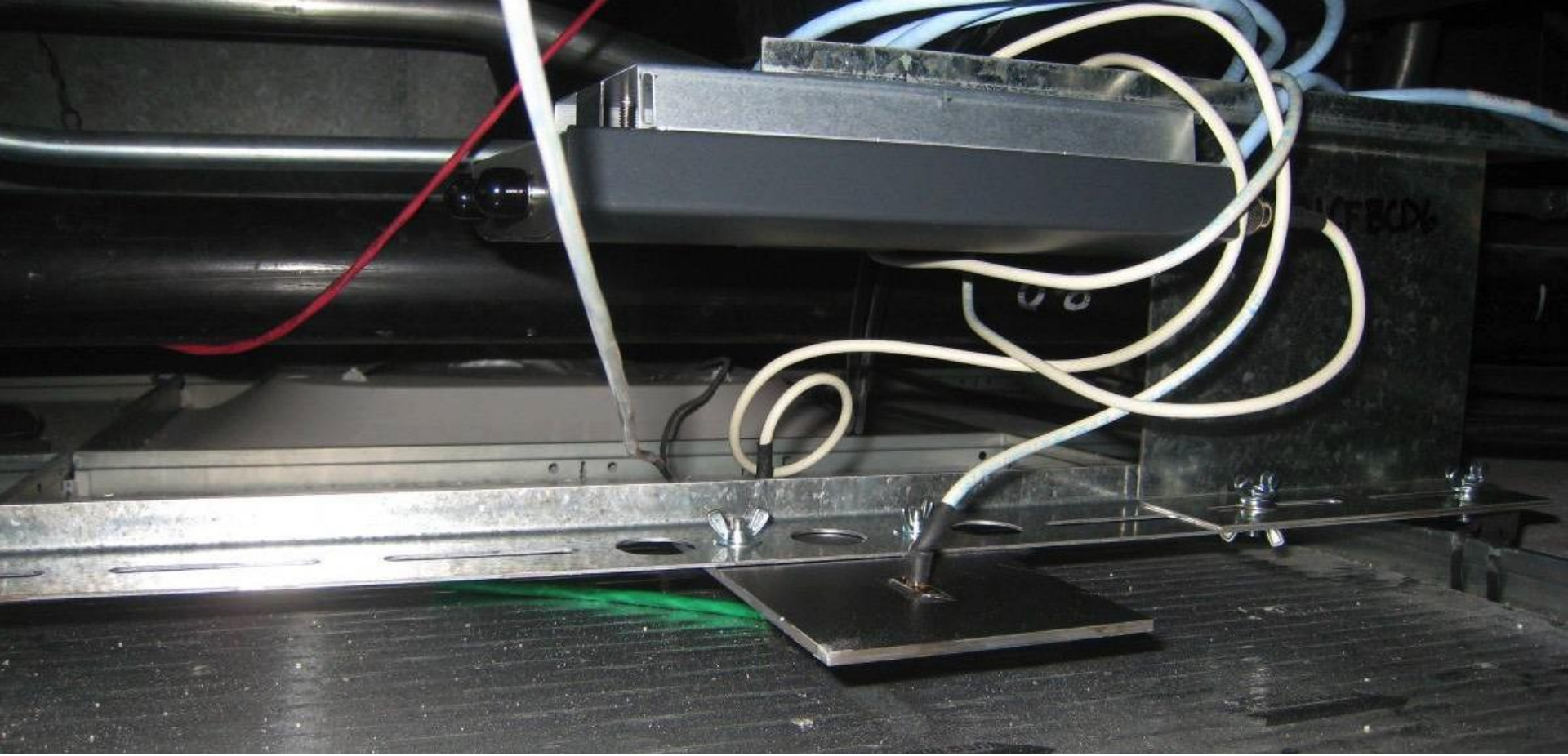


Site Surveys

AP and Antenna Placement

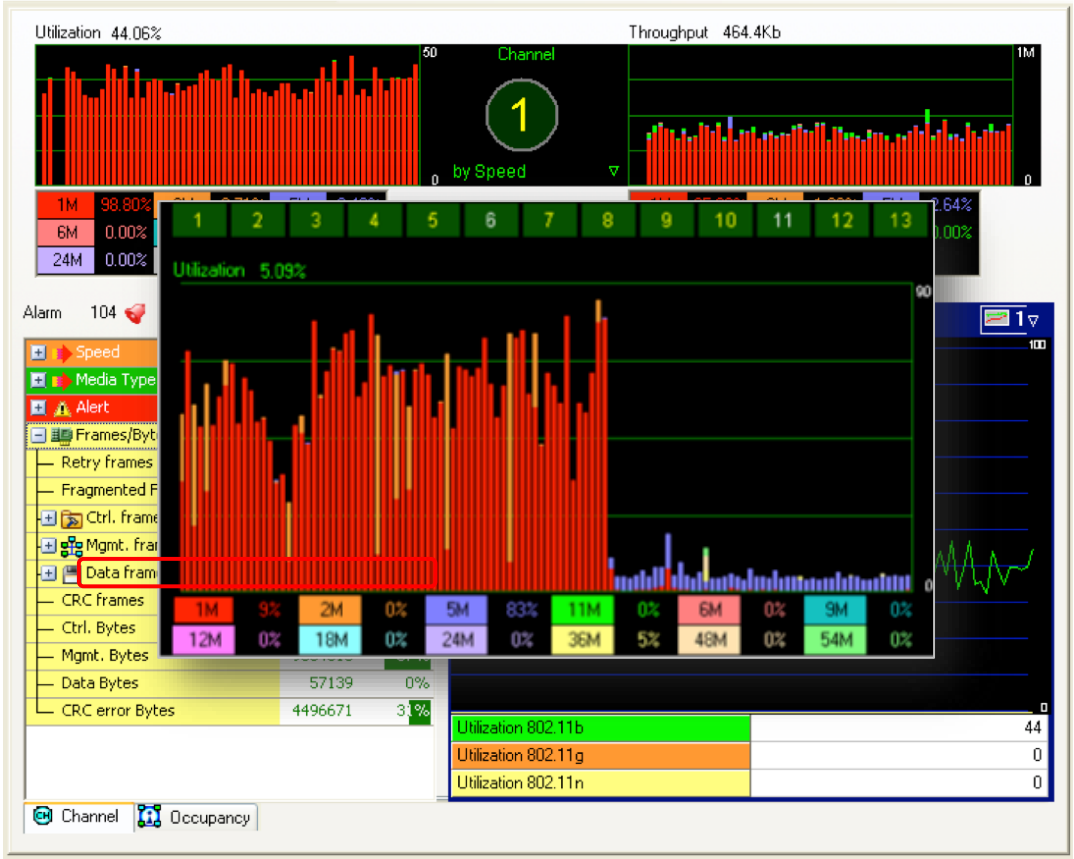
- Consider underlying requirements
  - Number of Users
  - Application Types
    - Data
    - Voice
    - Video
  - Location accuracy
- AP placement considerations
  - Consider environmentals
  - Characterise the -67dBm edges
  - For location a *minimum* of three AP should be able to hear the device with a a signal strength of -75dBm or higher
- Understand existing spectrum use
  - Interference mitigation





Channel Utilisation

- One simple change reduced the utilisation to 5%
  - Remove the low rates
- Large cells = Low density
  - More users spread across a larger area, connecting at lower data rates
- Small cells = High density
  - Removing lower data rates constrains cell size

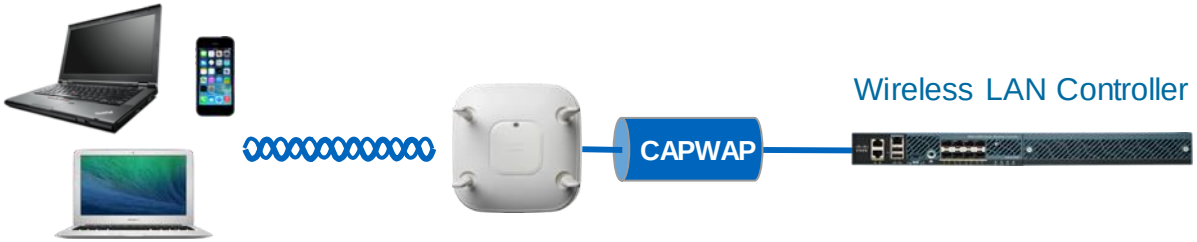


Understanding the MAC Layer

Cisco live!

802.11 Fundamentals

Beacons and Probes

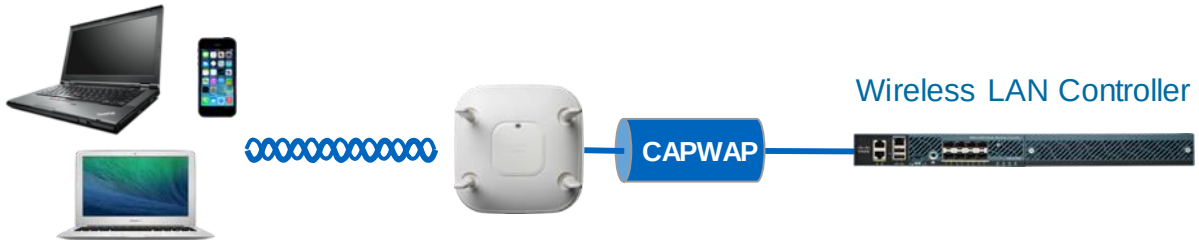


Beacon — SSID = blizzard, Security = WPA2-Enterprise

Beacon — SSID = ciscolive, Security = Open

802.11 Fundamentals

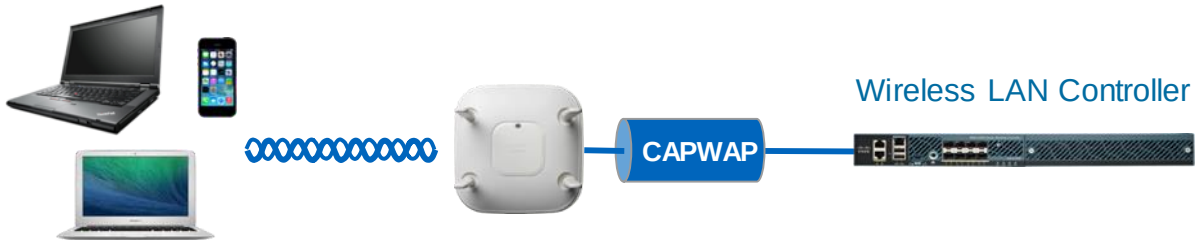
Beacons and Probes



Probe Request →	SSID = blizzard
← Probe Response	SSID = blizzard, Security = WPA2-Enterprise
Probe Request →	SSID = ciscolive
← Probe Response	SSID = ciscolive, Security = Open
Probe Request →	SSID =
← Probe Response	SSID = blizzard, Security = WPA2-Enterprise
← Probe Response	SSID = ciscolive, Security = Open

802.11 Fundamentals

Association



Association Request →	SSID = blizzard
← Association Response	SSID = blizzard, Security = WPA2-Enterprise
Disassociation Request →	SSID = blizzard
← Disassociation Response	SSID = blizzard
Reassociation Request →	SSID = blizzard
← Association Response	SSID = blizzard, Security = WPA2-Enterprise

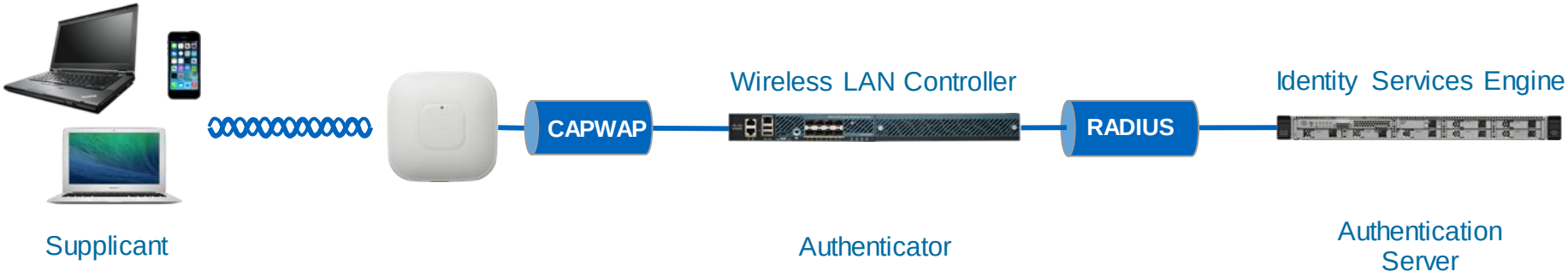
Robust Security Network

802.11i and Wireless Protected Access

WPA	• A snapshot of the 802.11i Standard • Commonly used with TKIP encryption
WPA2	• Final version of 802.11i • Commonly used with AES encryption
Authentication Mechanisms	• Personal (PSK – Pre-Shared Key) • Enterprise (802.1X/EAP)

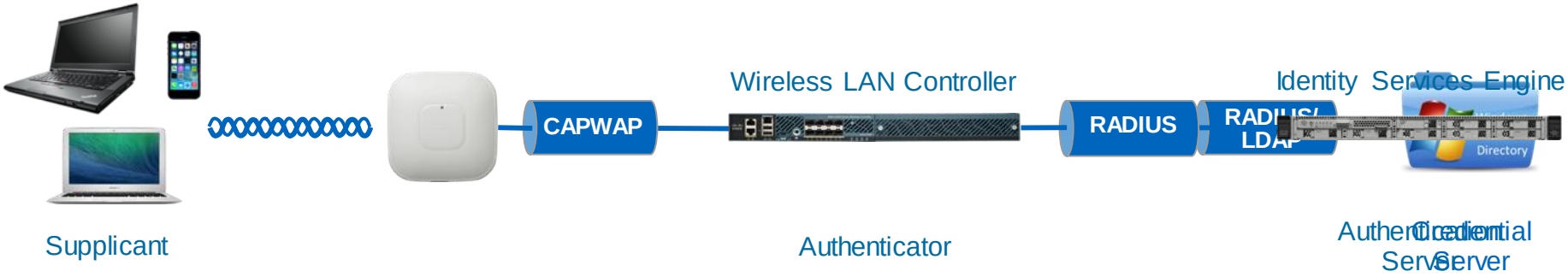
802.11 Fundamentals

Authentication



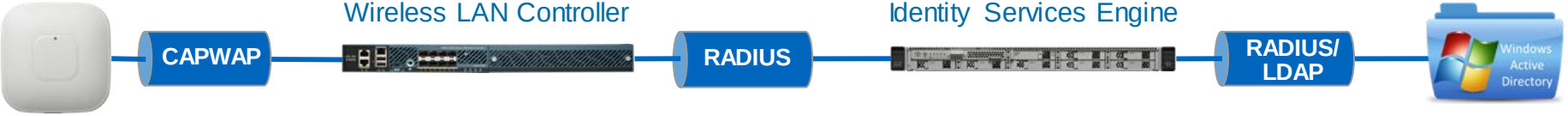
802.11 Fundamentals

Authentication



802.11 Fundamentals

Authentication



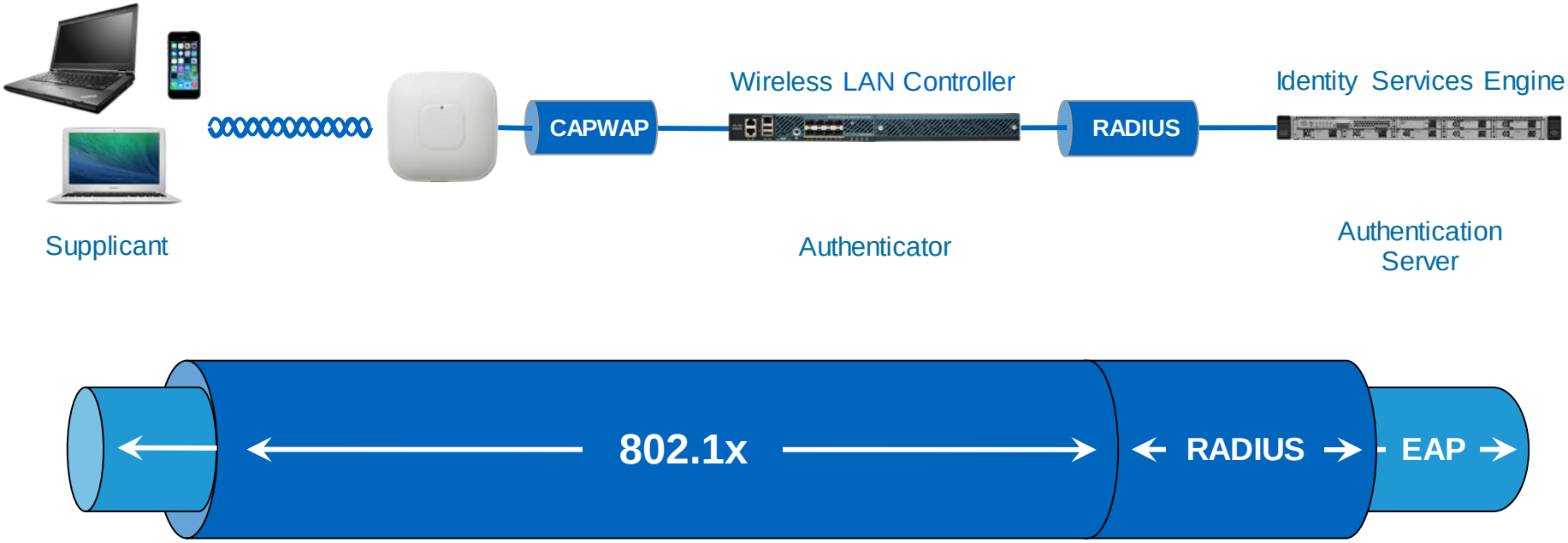
Authenticator

Authentication Server

Credential Server

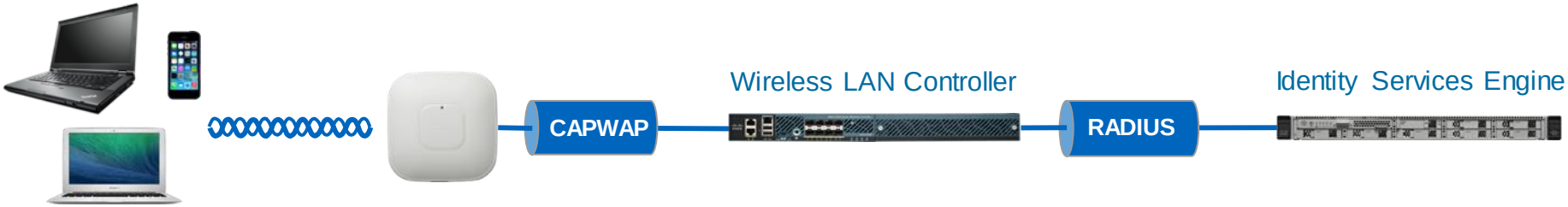
802.11 Fundamentals

Authentication



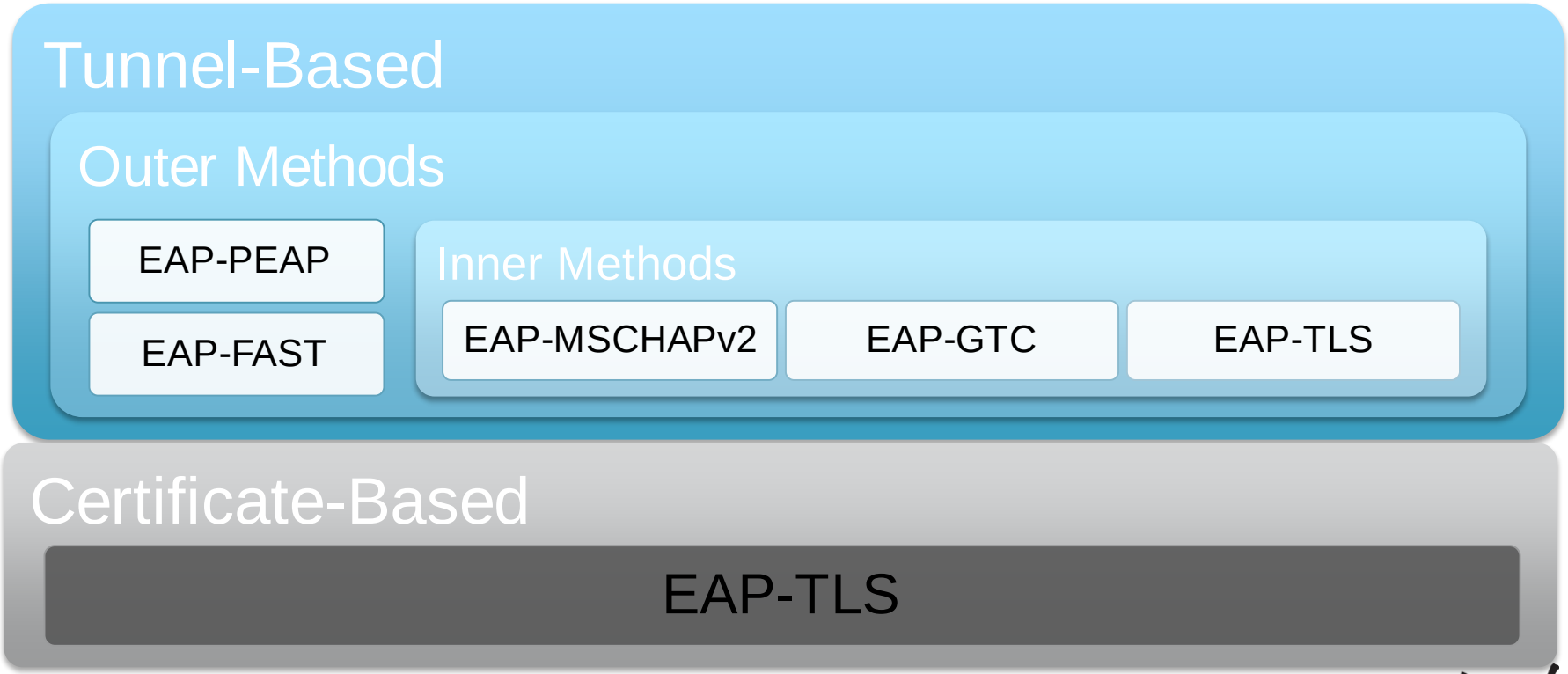
802.11 Fundamentals

Authentication



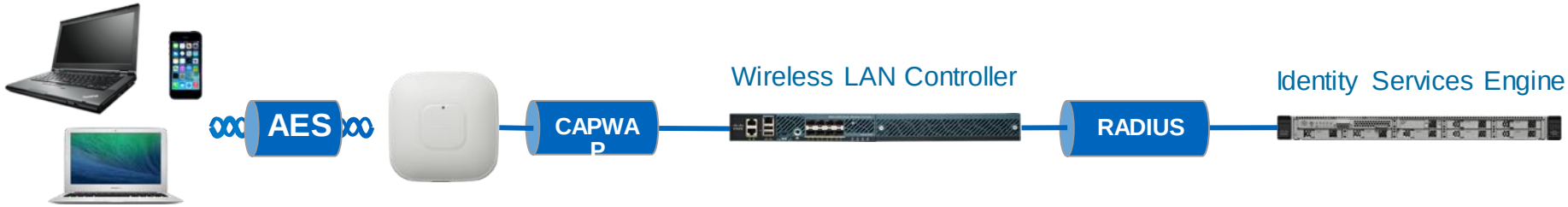
WPA-Enterprise

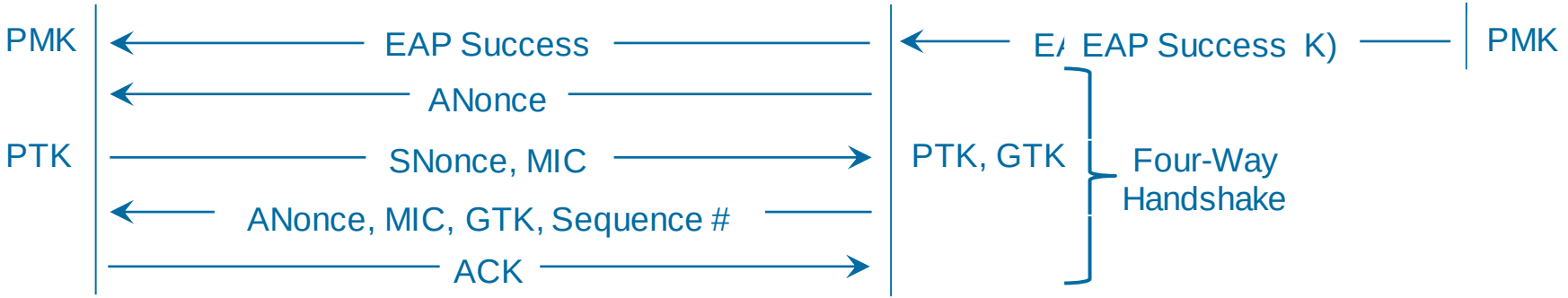
802.1x and Extensible Authentication Protocols



802.11 Fundamentals

Encryption





PTK = SHA(PMK + ANonce + SNonce + AP MAC + STA MAC)

Quality of Service

802.11e and Wi-Fi Multimedia

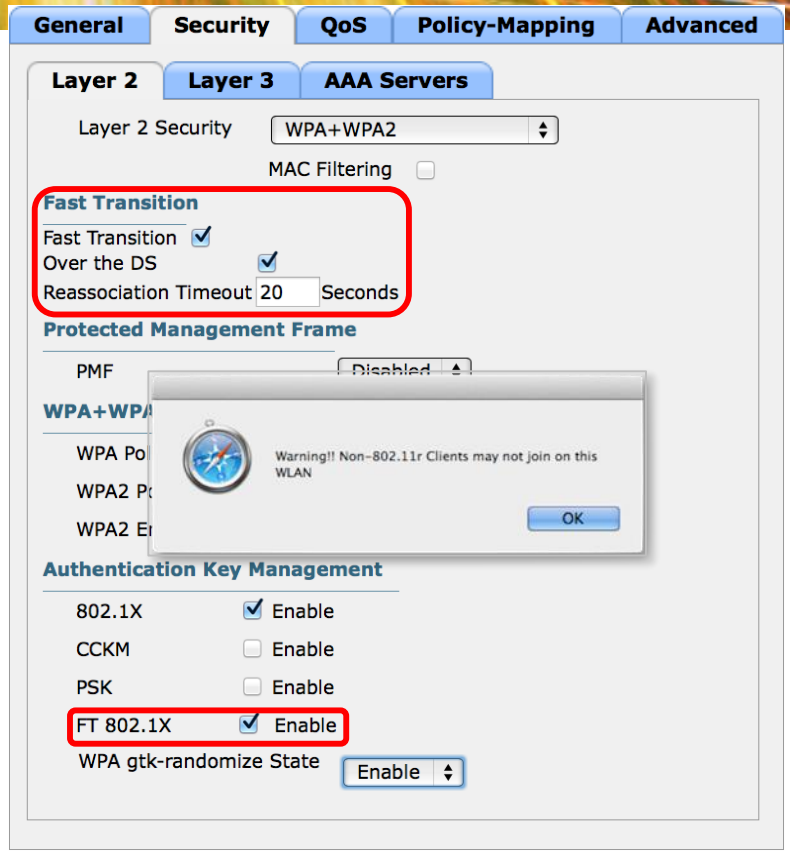
- Wired and wireless networks are fundamentally different
  - Half-duplex
  - Shared medium
  - CSMA/CA
  - Susceptible to latency and jitter
- Mapping between the wireless and wired network is key
- QoS is per SSID so consider the implications of client applications
  - Application Visibility and Control

- 802.11e
  - Wireless QoS
  - Defines eight priority levels to differentiate level of service
- Wi-Fi Multimedia (WMM)
  - Wi-Fi Alliance interoperability standard
  - Four access categories defined
  - Prioritisation based on application requirements
    - Voice
    - Video
    - Best effort
    - Background

Secure Fast Roaming

802.11k, 802.11r and Voice-Enterprise

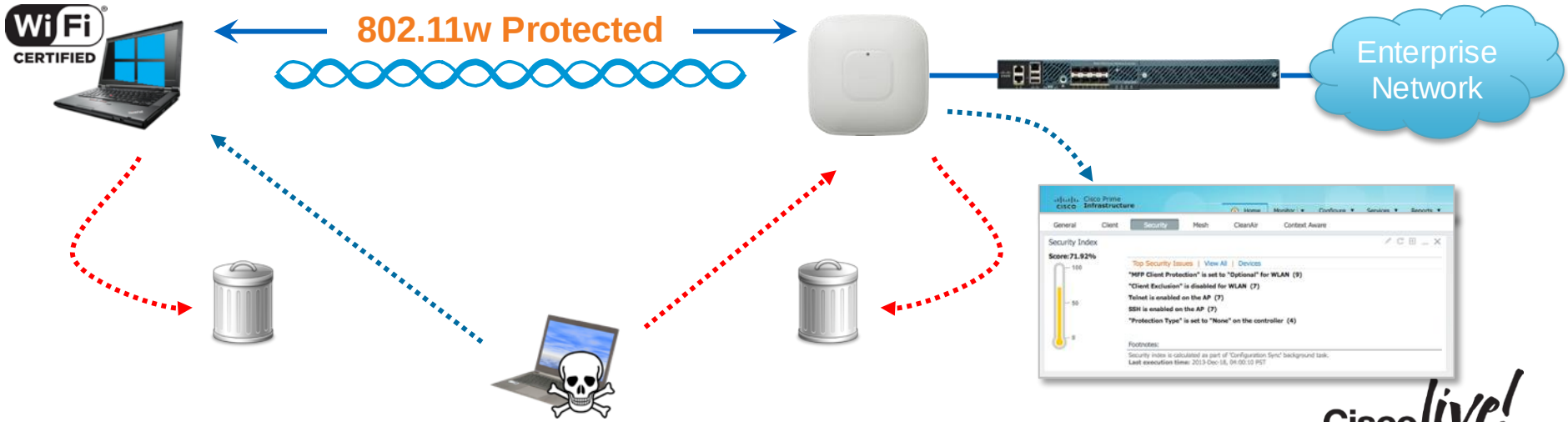
- Client channel scanning and AP selection
  - Improved via 802.11k Neighbour Lists
- Re-authentication of client device and re-keying
  - 802.11r based on CCKM
  - Available in Voice-Enterprise certified clients
  - Due to changes to 802.11 management frames, older client drivers may not understand the 11r response frame
- In *highly controlled test environments*, 802.11r roam times around 5-8ms



Management Frame Protection

802.11w and Protected Management Frames

- Unicast Management Frames
  - Confidentiality and Integrity Protection
- Multicast Management Frames
  - Integrity Protection



Future Developments

802.11u and Passpoint, 802.11af and TVWS

- 802.11u
  - Network Discovery and Selection
    - Access Network Query Protocol (ANQP)
  - Provides the ability to add features that improve interworking of Wi-Fi devices with external networks
    - Quality of Service Mapping
    - Emergency Services
  - Current Cisco features that utilise this protocol
    - Hotspot 2.0 / Passpoint
    - Mobility Services Advertisement Protocol (MSAP)
    - Mobile Concierge

- 802.11af
  - TV White Space
  - UHF – 300 MHz to 3 GHz
  - VHF – 30 MHz to 300 MHz

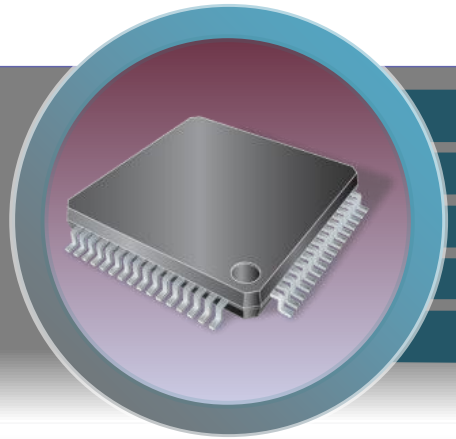
- A*STAR Singapore Gardens Pilot

Understanding Cisco HDX

Cisco live!

Optimising Network Performance and End-User Experience

HDX Made Possible by Custom ASIC Capabilities



Turbo Performance
Scales to Support More Devices Running High Bandwidth Apps

Optimised Roaming
Intelligently Decides the Proper Access Point as People Move

Cisco CleanAir® 80Mhz
Remediates Device Impacting Interference

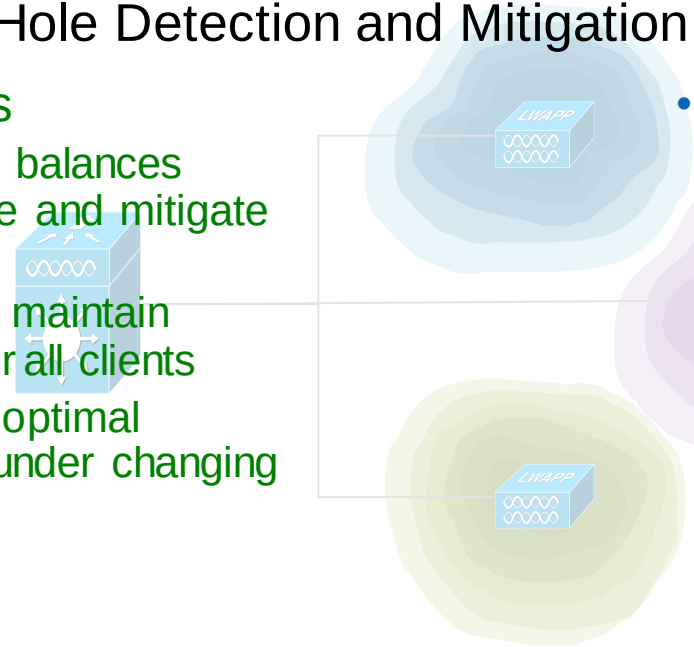
Cisco ClientLink 3.0
Improves Performance of Legacy and Current Devices

Cross-AP Management*
Directs Wireless Signal for Better Coverage

Radio Resource Management

- Dynamic Channel Assignment
- Transmit Power Control
- Coverage Hole Detection and Mitigation

- What It Does
  - Dynamically balances infrastructure and mitigate changes
  - Monitor and maintain coverage for all clients
  - Provide the optimal throughput under changing conditions

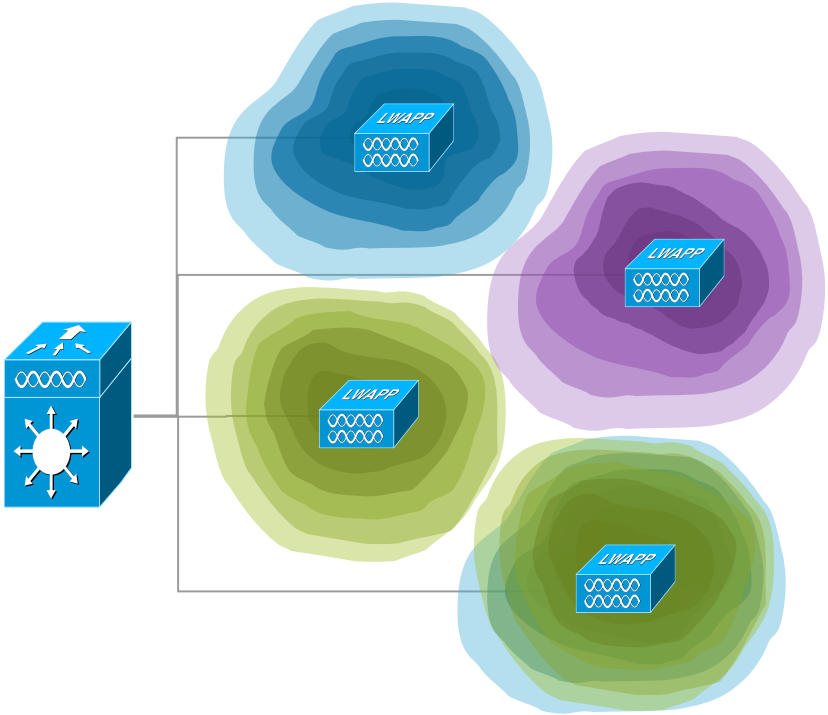


- What It Does *NOT* Do
  - Substitute for a site survey
  - Correct an poor design
  - Manufacture spectrum or otherwise counteract the laws of physics…

Dynamic Channel Assignment

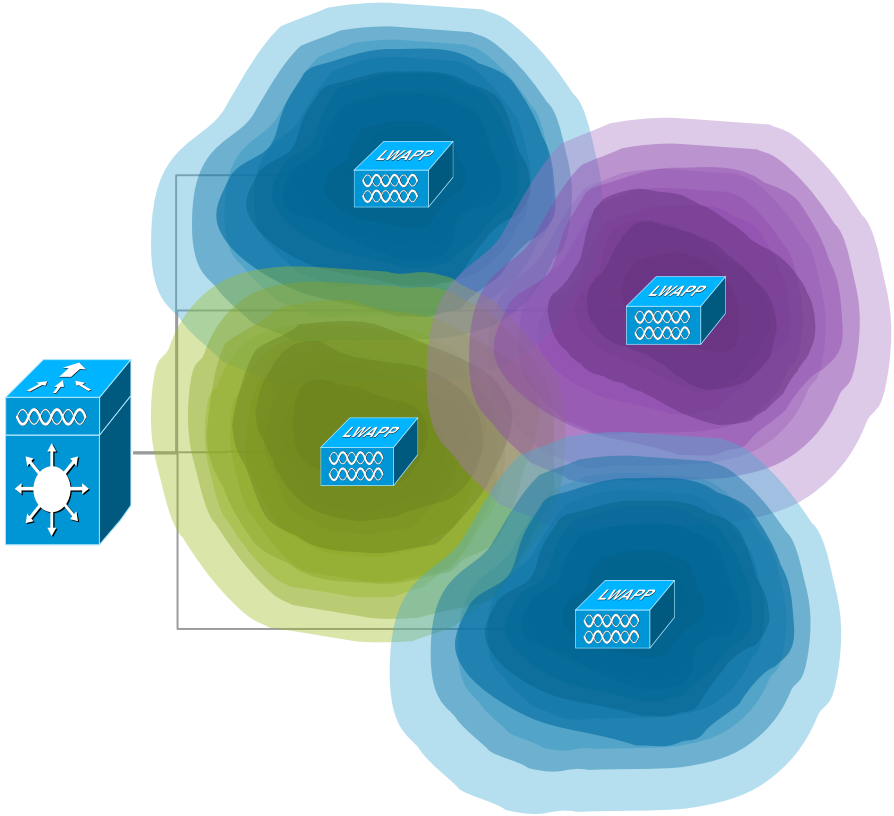
	High	Medium	Low
2.4 GHz	5dB	15dB	30dB
5 GHz	5dB	20dB	35dB

DCA Threshold Values



Transmit Power Control

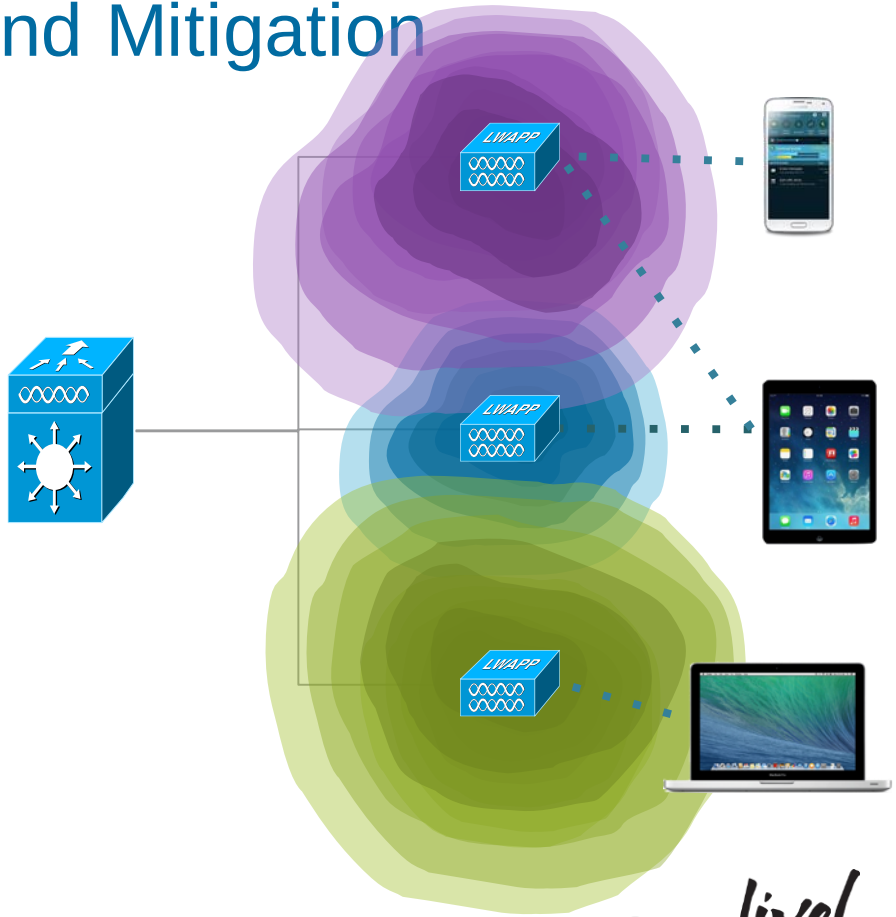
- Power not optimised
- RF signals bleed
- Causes interference



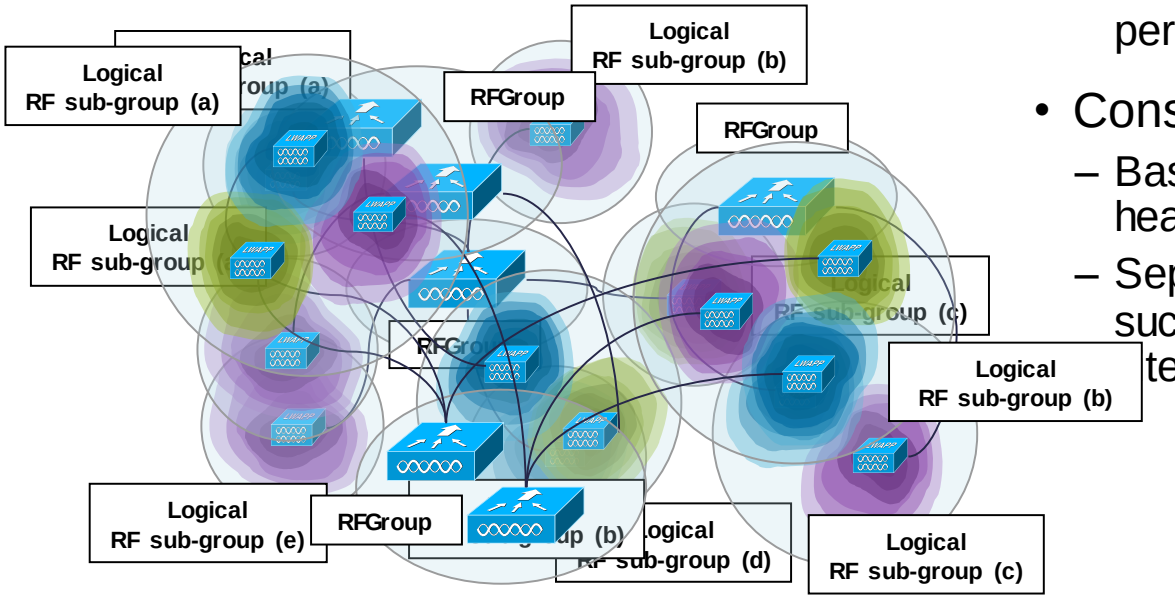
TPC algorithm examines radio to radio path loss

Coverage Hole Detection and Mitigation

- Based on the SNR or RSSI detected at the AP
- Not all detected holes are legitimate
- Detect poorly roaming clients
- Differentiate between data and voice clients



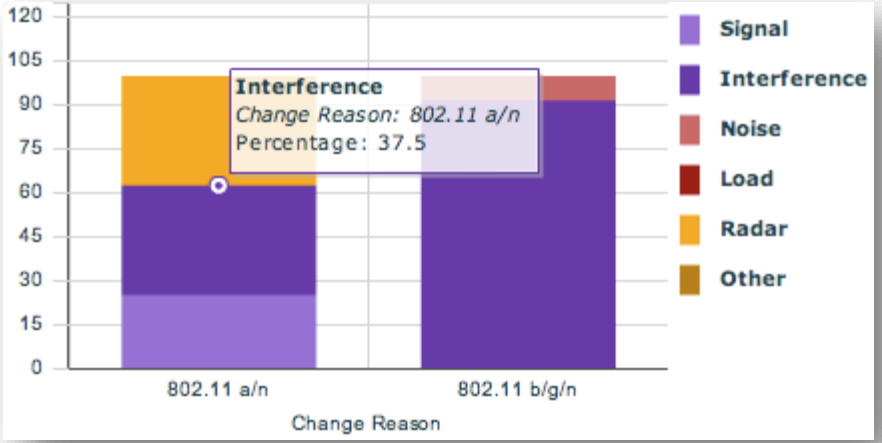
RF Groups



- RRM is calculated on a per RF Group basis
  - APs listen for Neighbour Messages
  - RF sub-groups can be inter-controller or intra-controller
  - RF groups and sub-groups apply per PHY
- Consider RF Group Definition
  - Base upon APs which *should* be able to hear and impact one another
  - Separate where it makes logical sense, such as separate buildings or physical sites

Radio Resource Management Dashboard

- Gain visibility into the RRM changes in your network
- Understand why changes are occurring
- Understand what changes might benefit your network



RRM Statistics (Last 24 Hours)

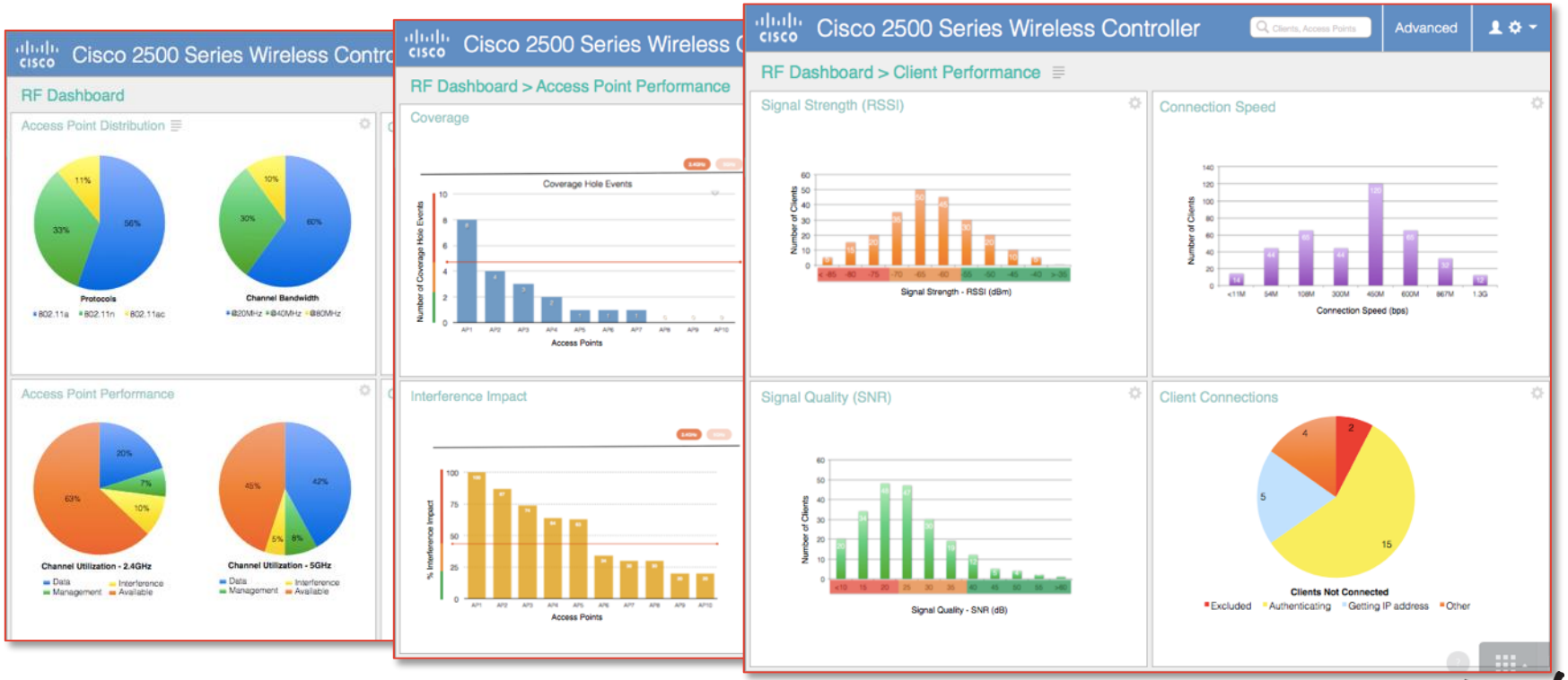
Statistics
Number of RF Groups
AP's at max. power (a/n)
AP's at max. power (b/g/n)
Total Configuration Mismatches

Coverage Hole - APs reporting coverage holes [Top 5] (Last 24 Hours) | View All

AP Name	MAC Address	Radio	Events	RF Group	Map Location	Event Time
nsd2-71-ap6	00:18:74:48:69:60	802.11 b/g/n	17	mobilitygroup	North Sydney > North Sydney (NSD2) > Floor 7	08/10/2008 08:59 PM
nsd2-101-ap2	00:18:74:48:34:b0	802.11 b/g/n	6	mobilitygroup	North Sydney > North Sydney (NSD2) > Floor 10	08/10/2008 09:55 PM
nsd2-101-ap2	00:18:74:48:34:b0	802.11 a/n	6	mobilitygroup	North Sydney > North Sydney (NSD2) > Floor 10	08/10/2008 07:37 PM
nsd2-141-ap1	00:18:74:48:69:a0	802.11 b/g/n	6	mobilitygroup	North Sydney > North Sydney (NSD2) > Floor 14	08/10/2008 06:47 PM
nsd2-71-ap5	00:18:74:48:8c:70	802.11 b/g/n	6	mobilitygroup	North Sydney > North Sydney (NSD2) > Floor 7	08/10/2008 10:00 PM

Radio Resource Management Dashboard

8.1 Advanced Preview



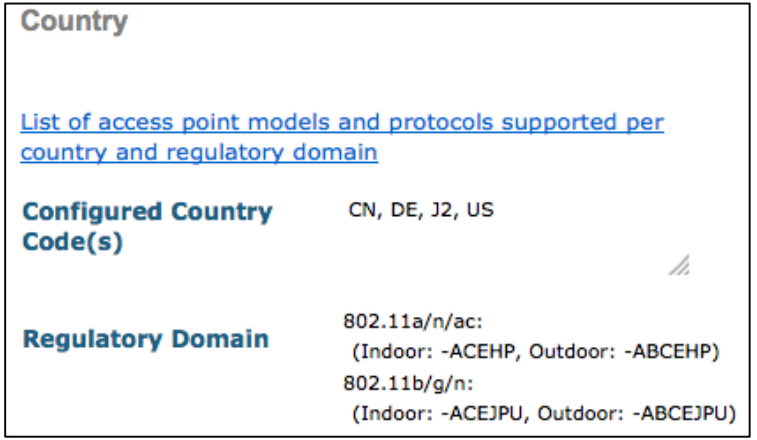
RF Profile DCA Use Cases

- RF Policies
  - Selection of channels to split functions
  - Vendors vs House
  - Free Channels for demo's
- Role Based
  - Indoor vs Outdoor
  - Higher vs Lower Power
- Remember the rules
  - For DFS channels, you must have at least one NON DFS channel available to switch to or if Radar Detected – no operations for 30 Minutes
- Multi Country Support

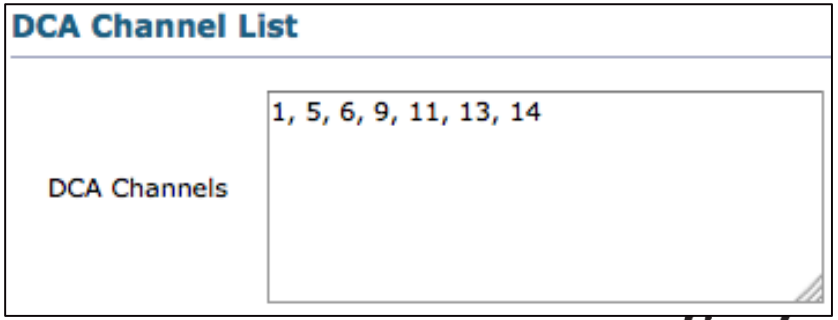
Multi Country

- Networks Must be disabled (802.11a/b)
- 20 countries max per controller – Today….
- All countries operating on a controller must be added under Wireless=>Country
- In order for a channel to be available for selection in an RF Profile, it must first be available in Global DCA ->

WLC/GUI - Wireless=>Country

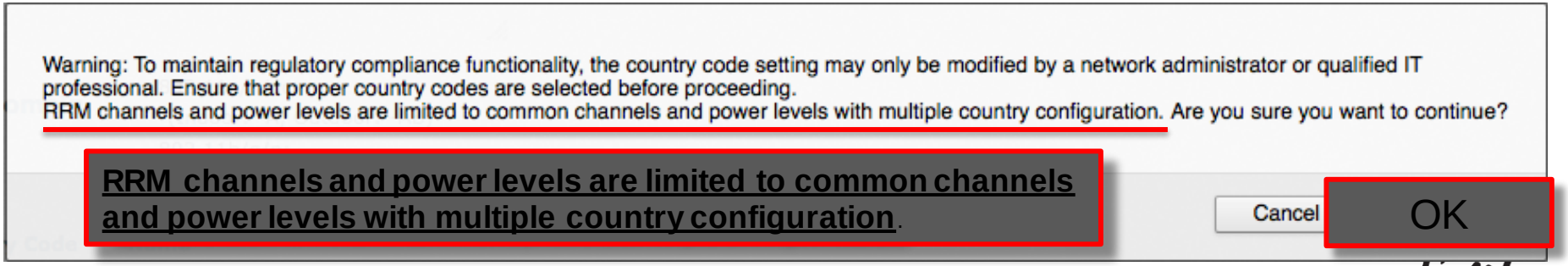


WLC/GUI - Wireless=>802.11a/b=>DCA



Multi Country

- Create RF Profiles – and assign Channels
- AP's can only scan channels that are within their regulatory – so no information for non regulatory channels will be gathered
- DCA can only assign a channel for an AP against data gathered by that AP. – no scan – no data -no assignment
- Erroneous Error messages regarding RRM's handling of multiple regulatory domains still exist – power through



Multi-Country WLC - DCA

DCA Use Case - Fira De Barcelona, Gran Via

- Located Barcelona Spain
- 8 Grand Halls
- Numerous indoor and outdoor hospitality areas
- Multiple classrooms and meeting rooms
- 50 Restaurantls
- Core elevated walkway spanning the venue
- 4K Vendors and 85K attendees

MWC – GSMA RF Policy

- RF Policy for MWC 2015
  - More Isolated channel groups for vendors
  - 2.4 GHz off in halls unless specifically requested
  - Else 2.4 is free for all

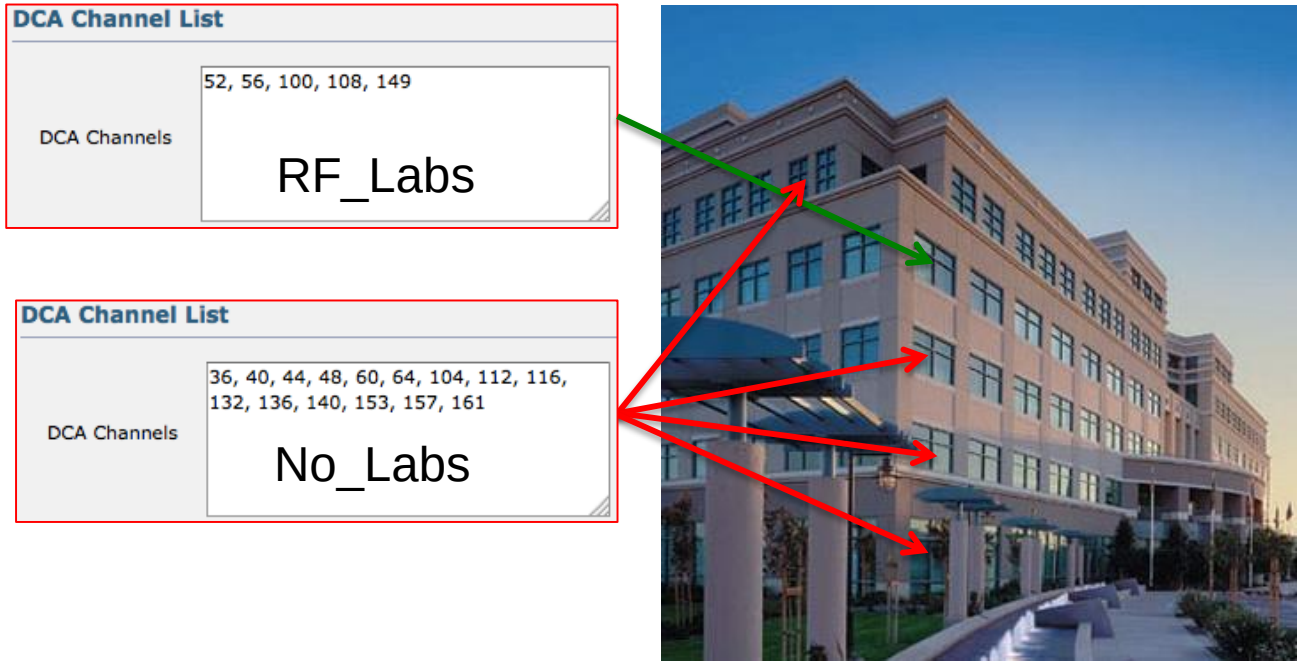
MWC 2014 Profile Numbers

- MWC – 2014 - AP Groups and RF Profiles -
  - 216 AP groups
  - 86 RF profiles
  - Power, Channel, data-rates, and HDX thresholds. Main SSID's numbered 3,
  - with 240 additional Vanity SSID's

Enterprise

- Requests for different channel plans – per floor
- Sometimes – functional groups require different access
- RF Labs – always a source of contention in an otherwise enterprise setting
- Sensible requests can be accommodated –
- At the end of the day, it's your spectrum, what's your Priority

Enterprise



DCA Channel Assignments - Coverage or Capacity

Assigning by use case and capabilities

- Select UNii3 channels for less dense areas, larger cell sizes provides coverage when crowds are not an issue
- Select UNii1 Ranges to separate transition areas, less cell size provides less interference with adjacent coverage
- Select UNii2/UNii1 Ranges for Dense coverage models

TPC Min/Max in Profiles

High Density Deployments

- Min/Max Power Levels – not everything is as it seems
- Tx power tables differ by:
  - AP model
  - Configured antenna gain
  - Channel (i.e. UNII1/2,2e/3)
- Show Controller (AP CLI) is your friend
  - Best way to see exactly what your power/channel capabilities and configurations are

- TPC Min
  - Prevents installations from cooling down when venue's are empty – can be 10 dB difference in perceived signal at the floor
- TPC Max
  - Set to prevent UNii3 and UNii2 cells from being overly large or small. Pick max power level supported in UNii1 +1 dB and apply to all.
- Produces even cells matching design goals
- Supports other HDX features by enforcing consistent cell sizes
- Optimised roaming relies on how the AP hears the client

Receive Start of Packet Threshold (RX-SOP)

Rx Sensitivity

- What is it good for?
  - Tuning out:
    - Distant rogues
    - Distant co-channel APs (self-interference)
    - Distant clients
- **Beneficial if optimised cautiously**
- **Dangerous if not optimised properly**
- Fine line between significant performance improvements and under-serving clients at the cell edge

- Does not impact the actual energy on the channel, rather it impacts the AP's sensitivity to it
- Reduces RX sensitivity of the AP to a predetermined power level
  - e.g. ignore everything coming into the radio at lower than -80dBm
- Must be careful not to "deafen" the AP to the point that it can't hear TX from a valid client's radio
- Antenna placement is key

Distant Rogues

Live Nation, Outdoor concert series

QBSS – all full

The Scenario

- Large Outdoor Music festival
- AS providing Wi-Fi coverage, 3500 series AP's
- Rogue Neighbour – Motorola sending full QBSS load – seen by our 1 Cisco AP at -80 dBm mounted on a tower
- Effectively set channel Utilisation on channel 1 to 80% and causing an outage

Solution and Outcome

- Rudimentary RX-SOP command in special build had been created
- New AP image and setting RX-SOP to -78 effectively reduced Channel Utilisation from 80% to 40% and connectivity improved dramatically
- The feature was now proven in the field

Co-Channel APs

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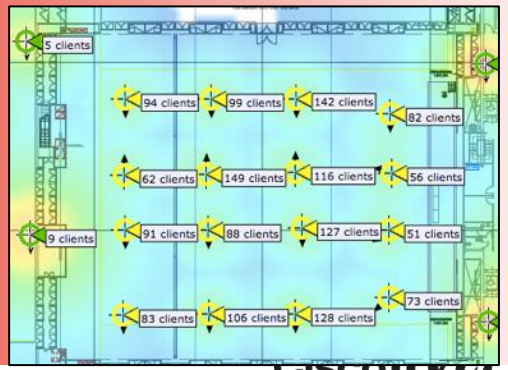
Channel Utilisation – all full

The Scenario

- High density deployment, channels at a premium
- **Antenna's and design optimised for max density**
- **No single cell under -60 dBm**
- **Data Rates and channel plan optimised**
- **Channel Utilisation still an issue**

Solution and Outcome

- Apply RX-SOP to match cell boundaries
- Different coverage zones require different settings
- Inside theatre – aggressive settings - Capacity
- Outside – more conservative – coverage
- This is a fine tune on a well implemented design – otherwise there will be trouble



Using RX-SOP

Design for These 3 Key RF Relationships

- How clients hear APs

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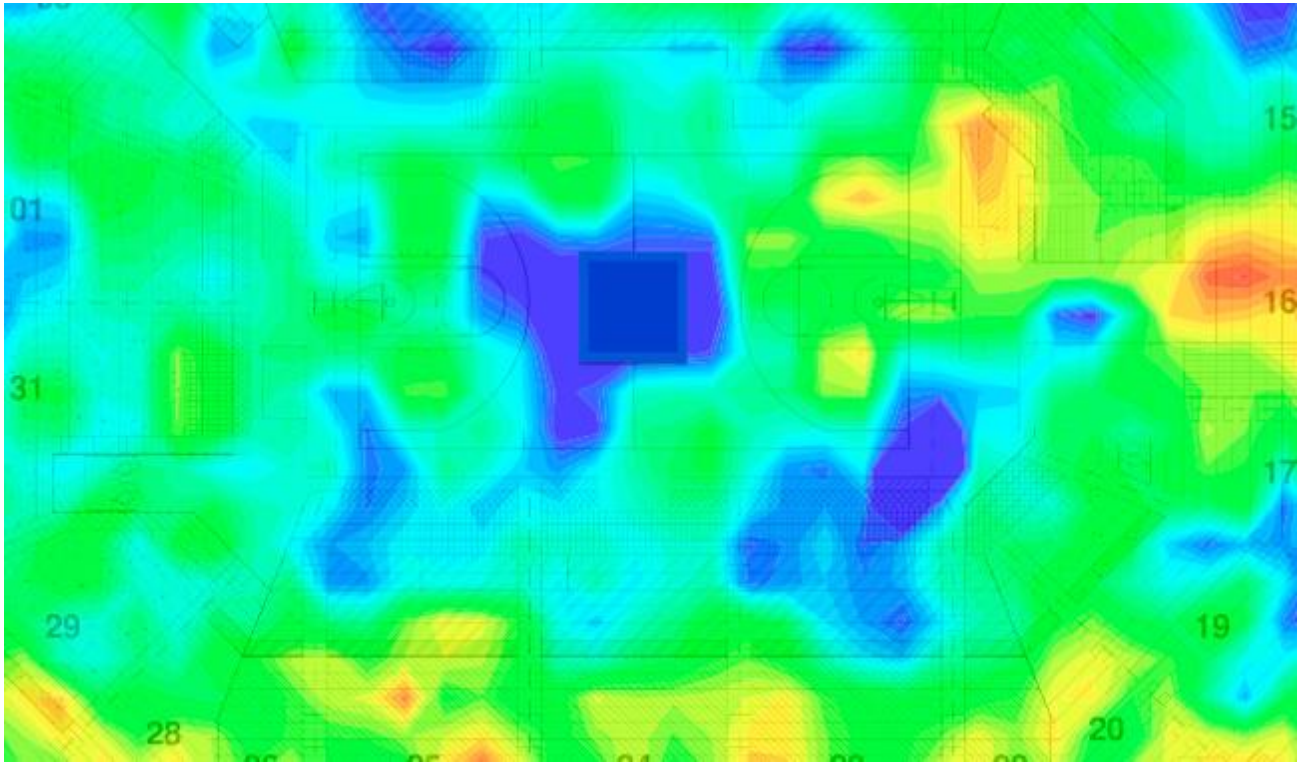
How Clients Hear APs

Site Survey



Using RX-SOP

Design for These 3 Key RF Relationships

AP to Client

Client to AP

- How clients hear AP's
- How AP's hear clients

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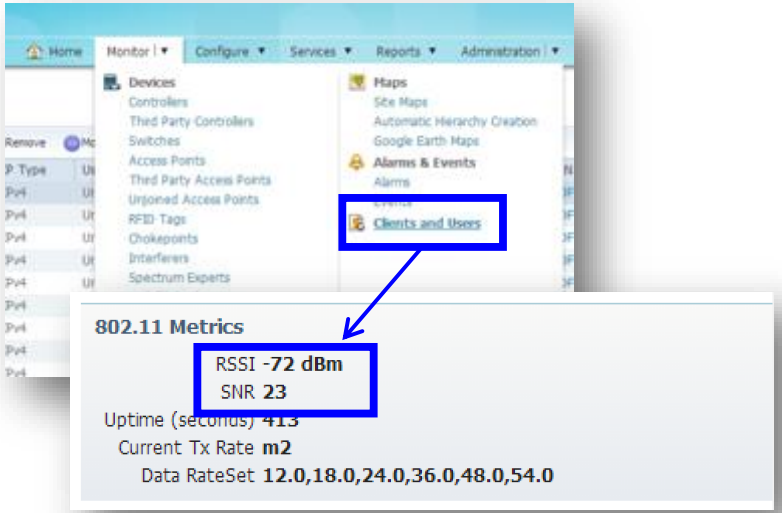
How APs Hear Clients

From WLC: "show client detail"

```
(Cisco Controller) >show client detail 0c:30:21:00:1c:36
Client MAC Address.............................. 0c:30:21:00:1c:36
<snip>
Client Statistics:
      Number of Bytes Received.................... 10389
      Number of Bytes Sent........................ 2205
      Number of Packets Received.................. 49
      Number of Packets Sent...................... 22
      Number of Interim-Update Sent............... 0
      Number of EAP Id Request Msg Timeouts....... 0
      Number of EAP Request Msg Timeouts.......... 0
      Number of EAP Key Msg Timeouts.............. 0
      Number of Data Retries...................... 59
      Number of RTS Retries....................... 0
      Number of Duplicate Received Packets........ 0
      Number of Decrypt Failed Packets............ 0
      Number of Mic Failured Packets.............. 0
      Number of Mic Missing Packets............... 0
      Number of RA Packets Dropped................ 0
      Number of Policy Errors..................... 0
      Radio Signal Strength Indicator............. -70 dBm
      Signal to Noise Ratio....................... 23 dB
Nearby AP Statistics:
      BAR-AP6-4B-S111(slot 0)
        antenna0: 47 secs ago..................... -73 dBm
        antenna1: 47 secs ago..................... -71 dBm
```

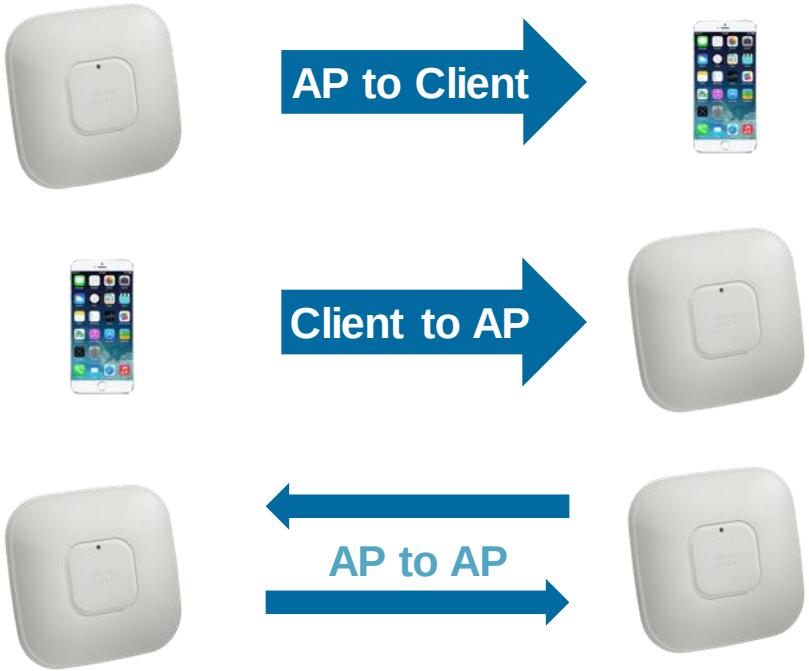
From Prime Infrastructure: Monitor -> Clients and Users



From Autonomous AP: "**show dot11 association all-client**"

Using RX-SOP

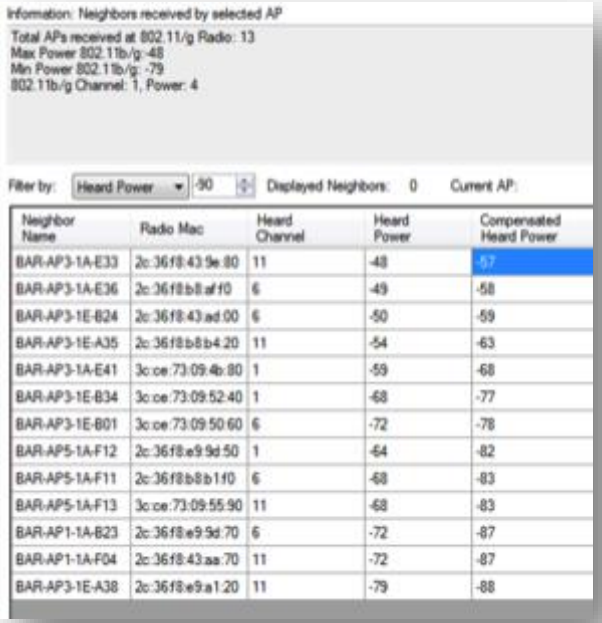
Design for These 3 Key RF Relationships



- How clients hear APs
- How APs hear clients
- How APs hear each other

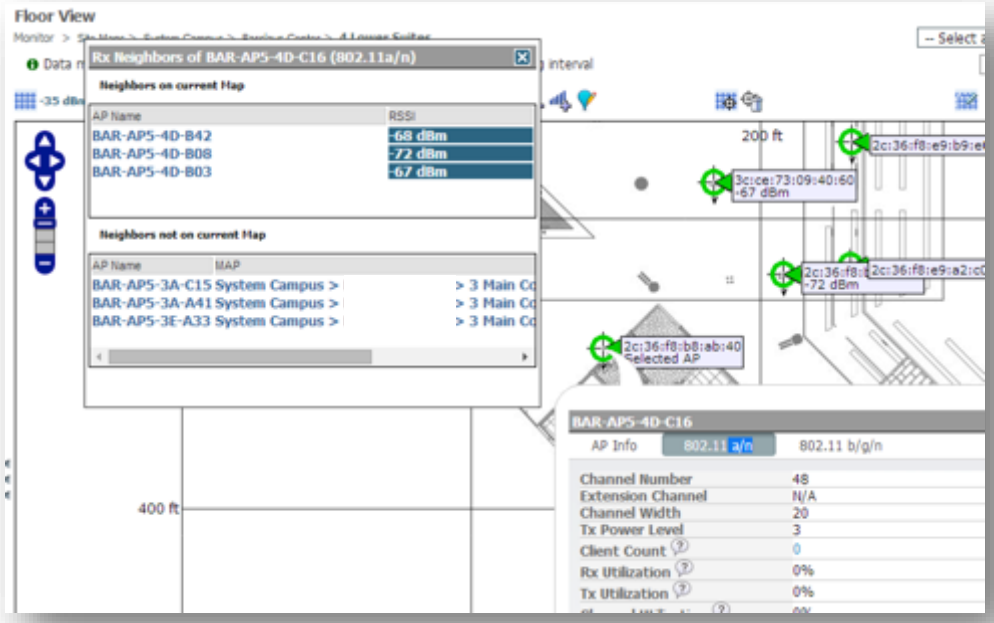
How APs Hear Each Other

WLC Config Analyser



Neighbor Name	Radio Mac	Heard Channel	Heard Power	Compensated Heard Power
BAR-AP3-1A-E33	2c:36:f8:43:9e:80	11	-48	-57
BAR-AP3-1A-E36	2c:36:f8:b8:af:f0	6	-49	-58
BAR-AP3-1E-B24	2c:36:f8:43:ad:00	6	-50	-59
BAR-AP3-1E-A35	2c:36:f8:b8:b4:20	11	-54	-63
BAR-AP3-1A-E41	3c:ce:73:09:4b:80	1	-59	-68
BAR-AP3-1E-B34	3c:ce:73:09:52:40	1	-68	-77
BAR-AP3-1E-B01	3c:ce:73:09:50:60	6	-72	-78
BAR-AP5-1A-F12	2c:36:f8:e9:9d:50	1	-64	-82
BAR-AP5-1A-F11	2c:36:f8:b8:b1:f0	6	-68	-83
BAR-AP5-1A-F13	3c:ce:73:09:55:90	11	-68	-83
BAR-AP1-1A-B23	2c:36:f8:e9:9d:70	6	-72	-87
BAR-AP1-1A-F04	2c:36:f8:43:aa:70	11	-72	-87
BAR-AP3-1E-A38	2c:36:f8:e9:a1:20	11	-79	-88

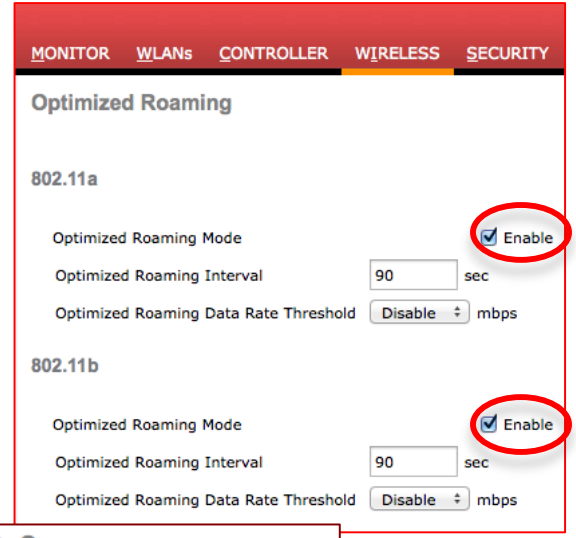
Prime Infrastructure Maps

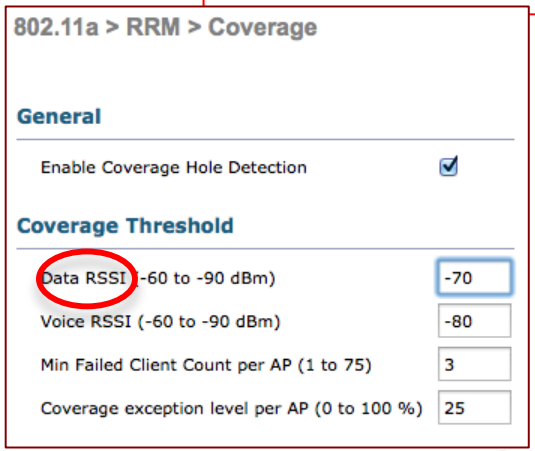


HDX – Optimised Roaming

3G/4G Hand-Off Optimisation

- Defines the RSSI threshold and minimum data rate at which the client will be sent a disassociation request
- Four parameters:
  - Enable/Disable
  - Interval between radio checks
  - Data Rate threshold
  - RSSI threshold
    - Defined by RRM Coverage Hole Detection
    - Either Globally or in an RF Profile
- Triggers on a pre-coverage hole event





RX-SOP Configuration

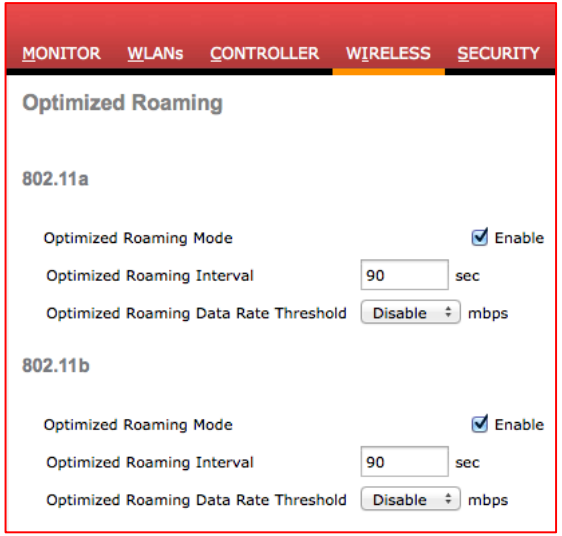
- Settings:
  - High, Medium, Low, Auto
- Auto is default behaviour
  - Leaves RX-SOP function linked to CCA threshold for automatic adjustment
- Most networks can support a LOW setting and see improvement
- Affects all packets seen at the receiver
- Custom thresholds
  - Per RF Profile (CLI Only)
  - BUT – on 8.0+ watch for involuntary reset of thresholds when performing other configuration tasks on profile
- Understand how the network sees the client at the furthest reach of your intended cell
  - Leave at least 10dB cushion (i.e. body in front of client)
  - Example: if you hear your furthest client at -71, try -81
- Start conservative, go only more aggressive if your data supports it

RX SOP Thresholds			
802.11 Band	High Threshold	Medium Threshold	Low Threshold
5 GHz	-76 dBm	-78 dBm	-80 dBm
2.4 GHz	-79 dBm	-82 dBm	-85 dBm

HDX – Optimised Roaming

Data Rates vs RSSI

- RSSI Threshold has a 6dB hysteresis buffer
  - Client must move 6dB above the threshold to rejoin the network
  - When enabled, **all** clients **must** exceed the threshold+6dB to associate
- Data Rates do not have a buffer
  - Clients can re-join the network as soon as they can support the data rate threshold
  - Data Rate settings are legacy and logically map to closest MCS rate
  - When both are set, then both thresholds must be met for the disassociation request to be sent to the client
    - It is not recommended to use with the Low Client RSSI check enabled
  - Currently supports 32 clients per radio
    - Not recommended for High Density deployments… yet



HDX – Optimised Roaming

Useful Commands

- (Cisco Controller) >debug airewave-director prealarm enable

```
*apfMsConnTask_3: Oct 07 19:34:59.024: Processing Client Stats Data

*apfMsConnTask_3: Oct 07 19:34:59.024: Failed Link Status , prealarm event ....

*apfMsConnTask_3: Oct 07 19:34:59.024: Processing Client Stats Data

*RRM-DCLNT-5_0: Oct 07 19:34:59.025: Activating OptimizedRoaming on client  80:BE:05:38:C7:8A ....

*RRM-DCLNT-5_0: Oct 07 19:34:59.025: [CHD] Airewave Director: Coverage Hole Check on 802.11a AP clients 3 level 25 F4:0F:1B:B2:91:B0(1)

*RRM-DCLNT-5_0: Oct 07 19:34:59.025: [CHD]: failed/totalClientCount/threshold (0/2/3)
```

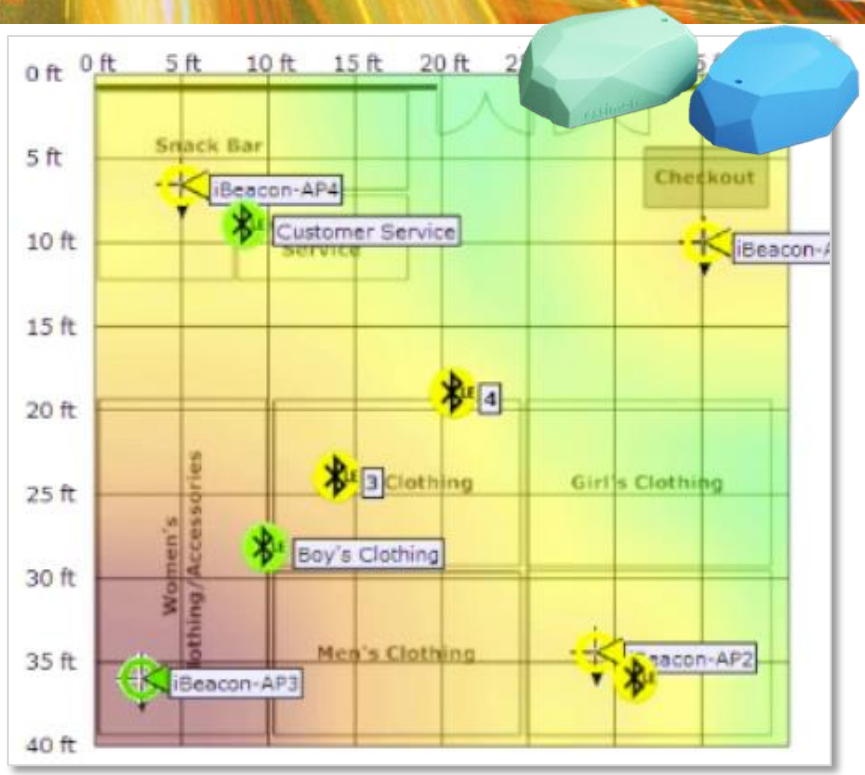
- (Cisco Controller) >show advanced 802.11a optimized-roaming stat

```
OptimizedRoaming Stats
  802.11a OptimizedRoaming Disassociations....... 1
  802.11a OptimizedRoaming Rejections............ 0
```

Spectrum Intelligence

CleanAir and iBeacon

- iBeacons use Bluetooth Low-Energy to send advertising signals
- Smart phone applications using simple RSSI information figure out micro-location & apps then fetch relevant advertising content
- BLE /iBeacons can be used to improve the way finding experience



iBeacon

Understanding RF and RRM Best Practice

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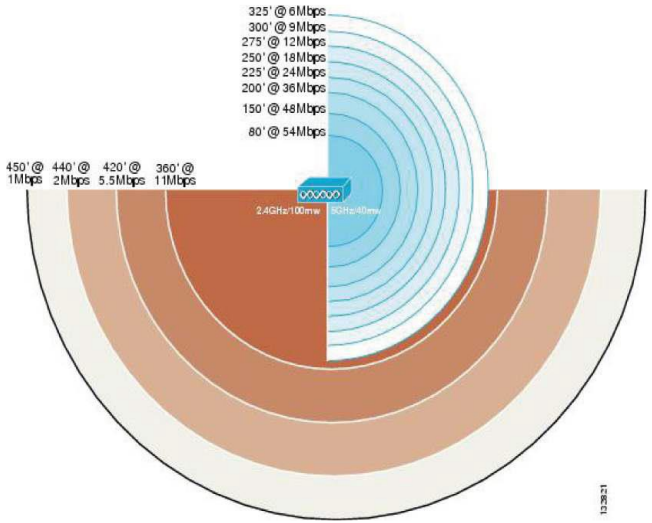
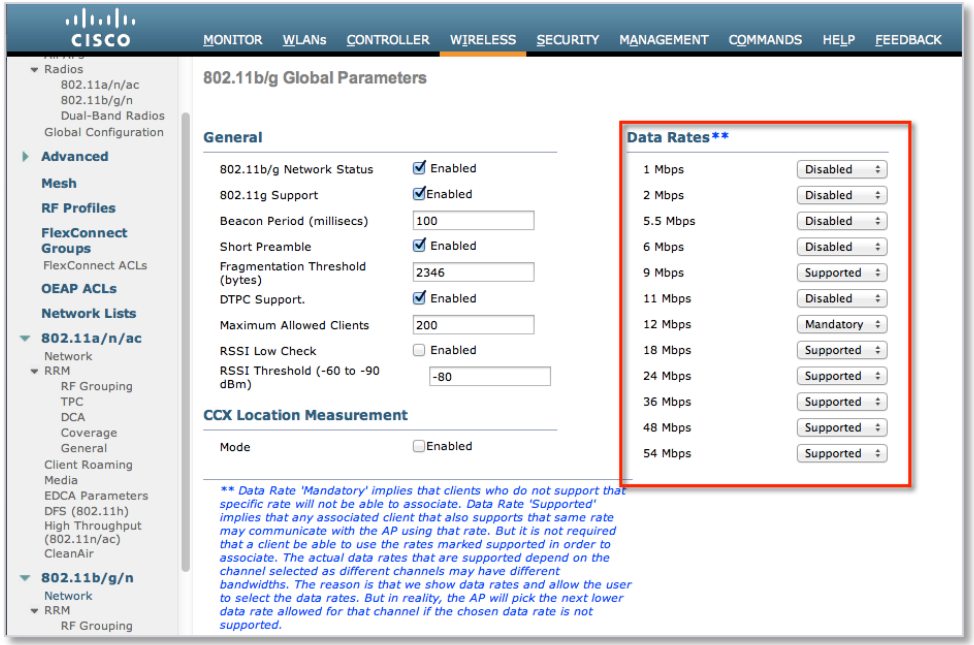
RF Best Practices

Disable 802.11b Data Rates

- Management frames are sent at the lowest mandatory data rate
  - 1 Mbps Mandatory : Channel Utilisation 67%
  - 6 Mbps Mandatory : Channel Utilisation 23%





RF Best Practices

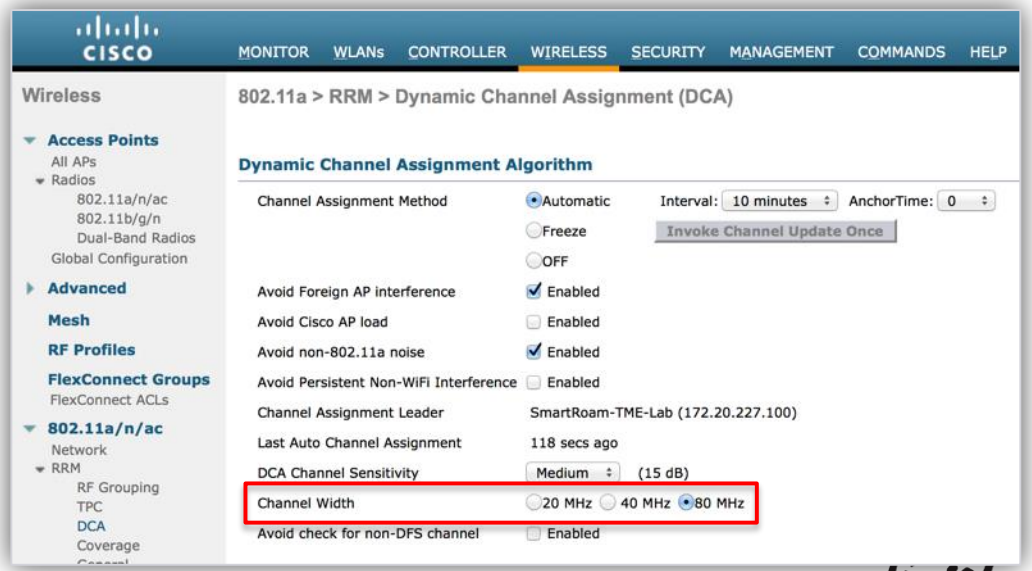
Minimise the Number of WLANs

- Each SSID requires separate beacons and probes
  - Sent at the lowest mandatory data rate
- More SSIDs means less RF space for data traffic
  - Ideally keep to no more than 3 SSIDs

RF Best Practices

Enable Channel Bonding

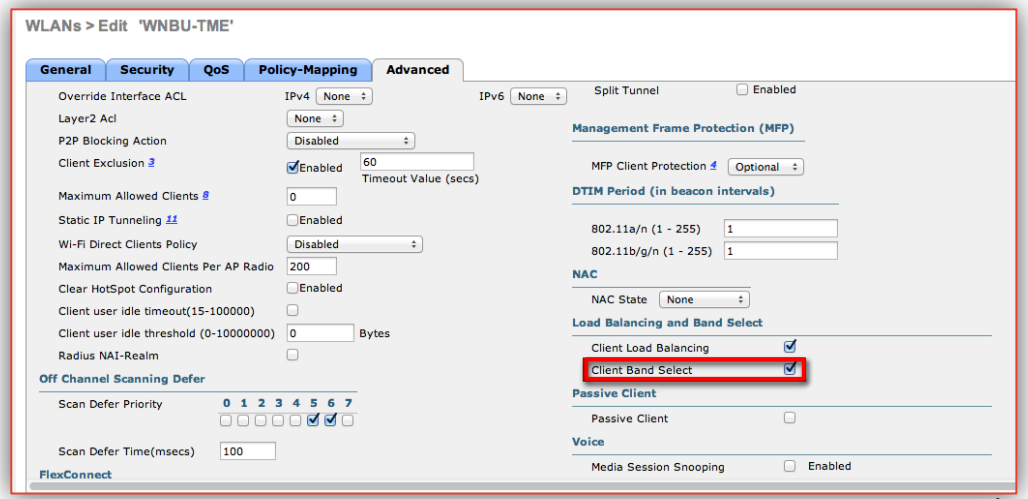
- Channel bonding enables 40 or 80 MHz wide channel
  - Results in 2x or 4x bandwidth increase
  - For extreme high density deployments, stay at 20MHz to reduce cell size



RF Best Practices

Enable Client BandSelect

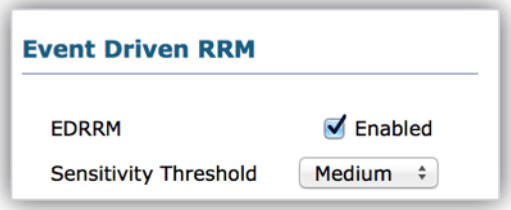
- Directs dual-band client to favour 5GHz
  - Rejects association requests on 2.4GHz from 5GHz capable clients
  - Not recommended for voice deployments



RF Best Practices

Enable Event Driven RRM

- Triggers RRM to run at a certain level of interference
  - High sensitivity is 60
  - Medium sensitivity is 50
  - Low sensitivity is 35
- Medium sensitivity threshold is recommended

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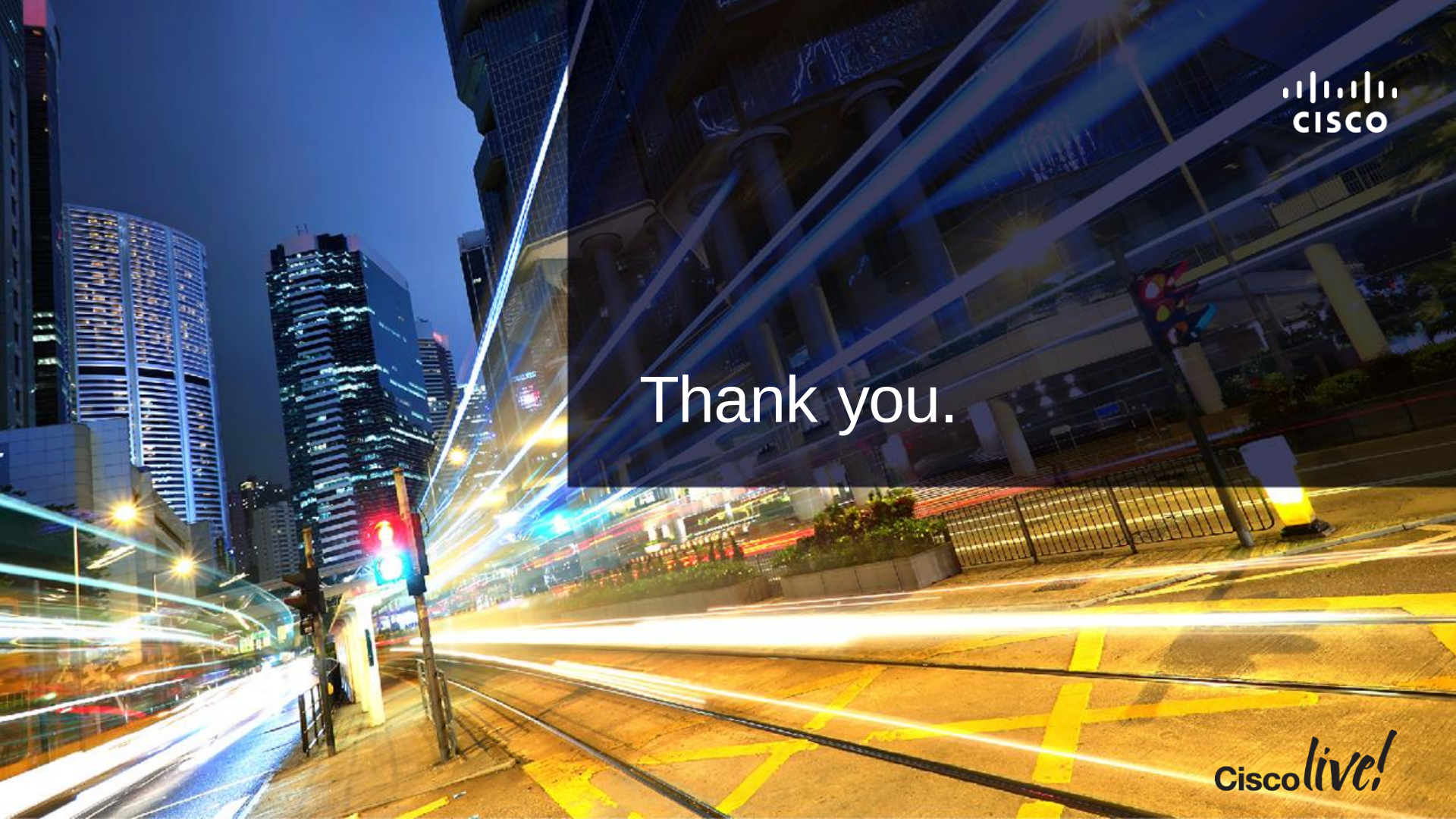
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