What You Make Possible

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starts here.

Understanding RF Fundamentals and the Radio Design of Wireless Networks

BRKEWN-2017

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Session Abstract

In this session we will focus on the fundamentals of Radio Frequency (RF) and how we design wireless networks while keeping these in mind.

We will look at the impact of interference, both co-channel and external, and how we mitigate it's impact. We will also look at emerging approaches to deal with the challenges posed by RF.

Session Agenda – Objectives

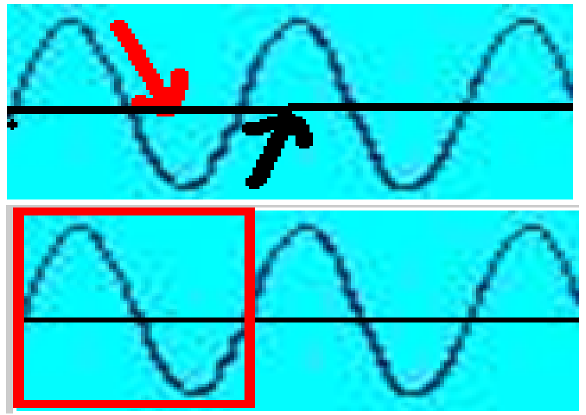
- What is radio and how did we get here?
- Basic 802.11 Radio Hardware & Terminology
- 802.11 Antenna Basics – Single, Diversity, Dual Band and MIMO Antennas
- Interpreting antenna patterns – Cisco Radio Facilities
- Diversity, Multipath, ClientLink Beamforming - 802.11n RF characteristics
- Choosing the right Access Point
- Placing the AP and the antennas properly

What is Radio?
How Did We End Up on These Frequencies?

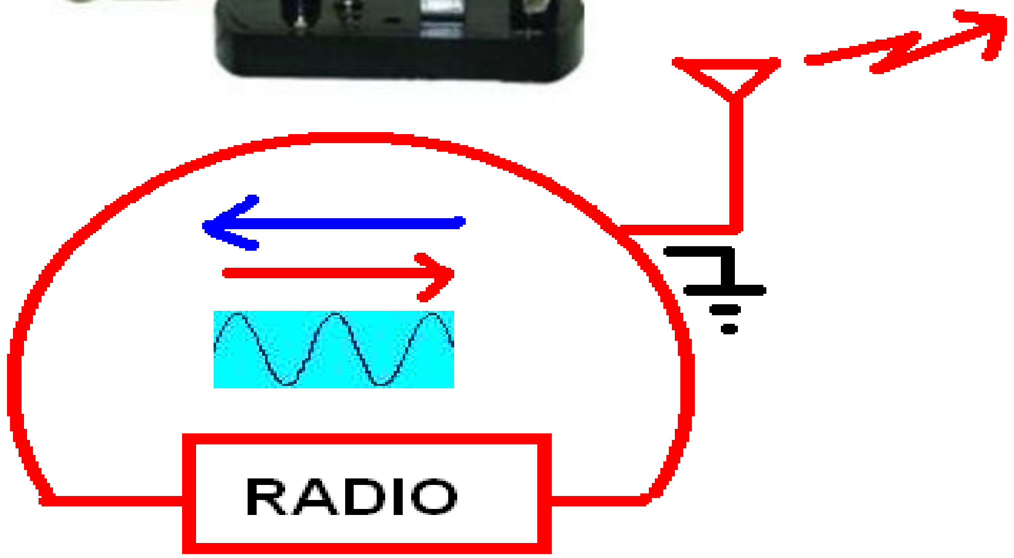
Basic Understanding of R

Battery is DC
Direct Current

Typical home is AC
Alternating Current



AC Frequency 60 Hz or 60 CPS – Cycles Per Second



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

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

Radio waves are measured in kHz, MHz and GHz

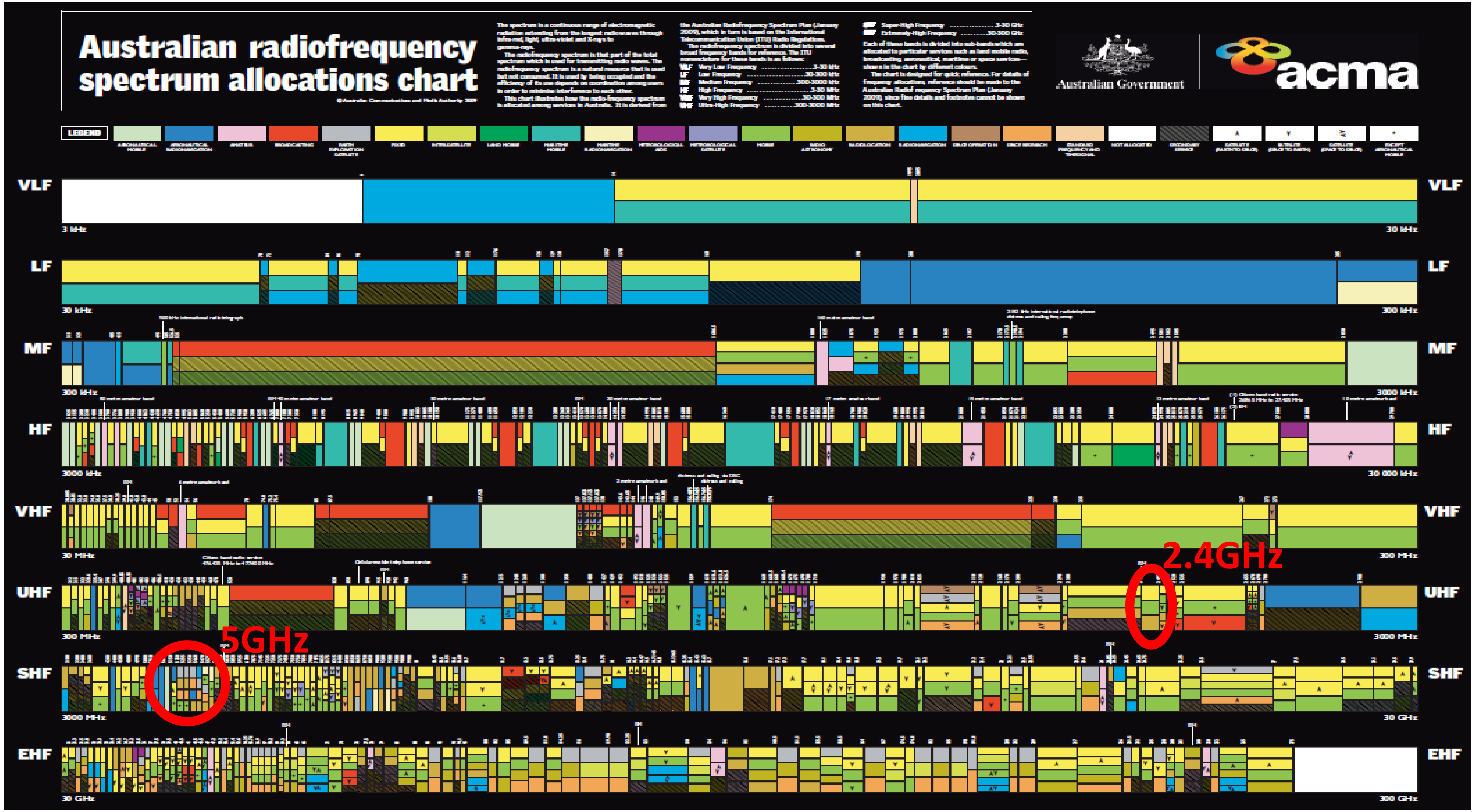
The lower the frequency, the physically longer the radio wave – Higher frequencies have much shorter waves, and as such, it takes more power to move them greater distances. This is why 2.4 GHz goes further then 5 GHz (given same amount of RF power).

Popular Radio Frequencies:

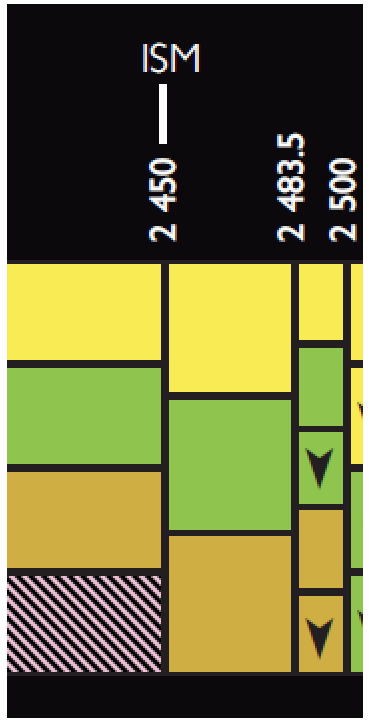
AM Radio 520-1610 KHz
Shortwave 3-30 MHz
FM Radio 88 to 108 MHz
Aviation 108-121 MHz
Weather Radio 162.40 MHz
GSM Phones 900 & 1800 MHz
DECT Phones 1900 MHz
Wi-Fi 802.11b/g/n 2.4 GHz
Wi-Fi 802.11a/n 5 GHz

Vintage RF Transmitter

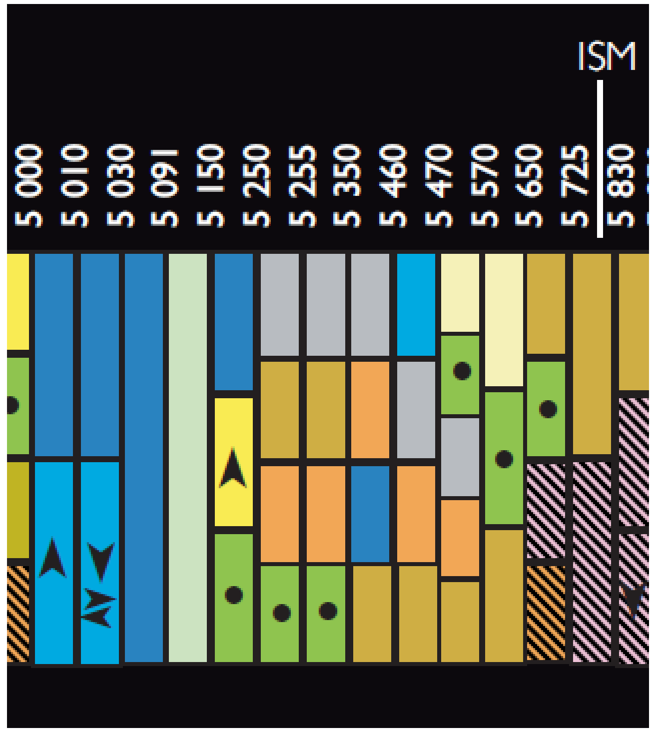
The Radio Spectrum in Australia



Wi-Fi Radio Spectrum



2.4 GHz



5 GHz

Wi-Fi is an "unlicensed" service

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

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

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

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

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

Wi-Fi Radio Spectrum 2.4 GHz

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

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

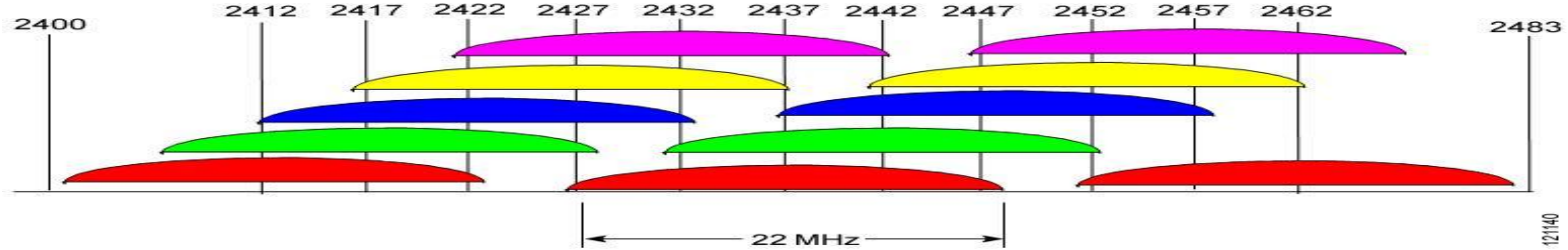
2.4 GHz and 5 GHz are different portions of the radio band and usually require separate antennas

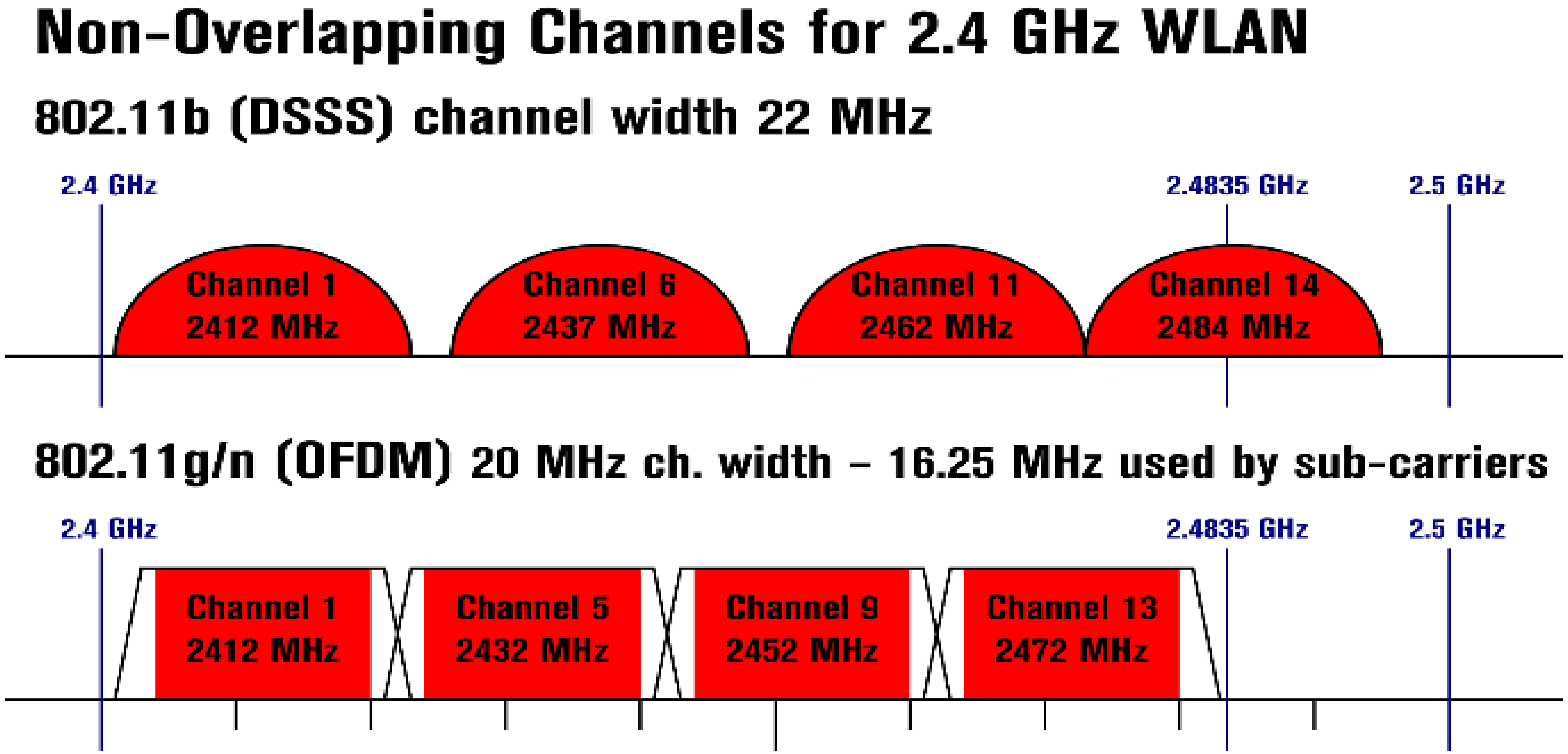
Even today, many portable devices in use are limited to 2.4 GHz only, including newer devices, but this is changing.

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

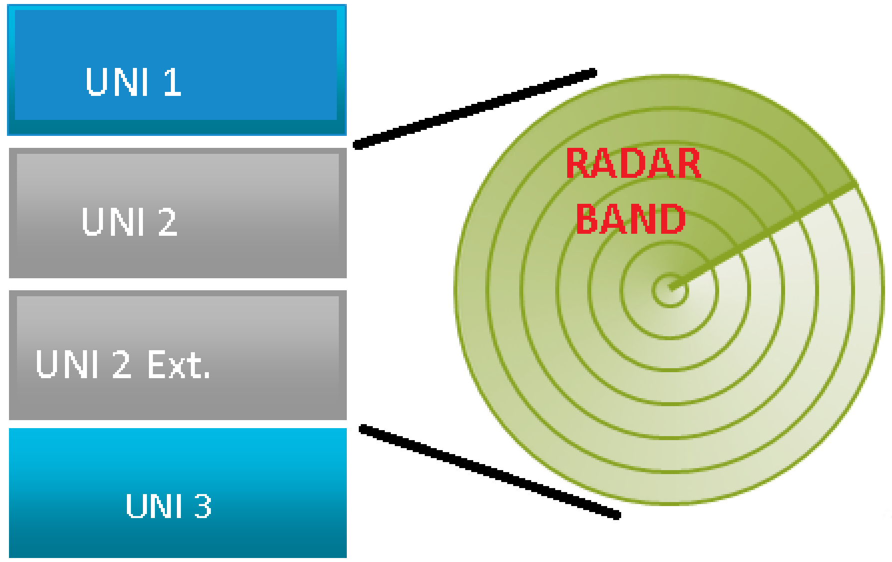
802.11b/g is 2.4 GHz
802.11a is 5 GHz
802.11n (can be either band) 2.4 or 5 GHz

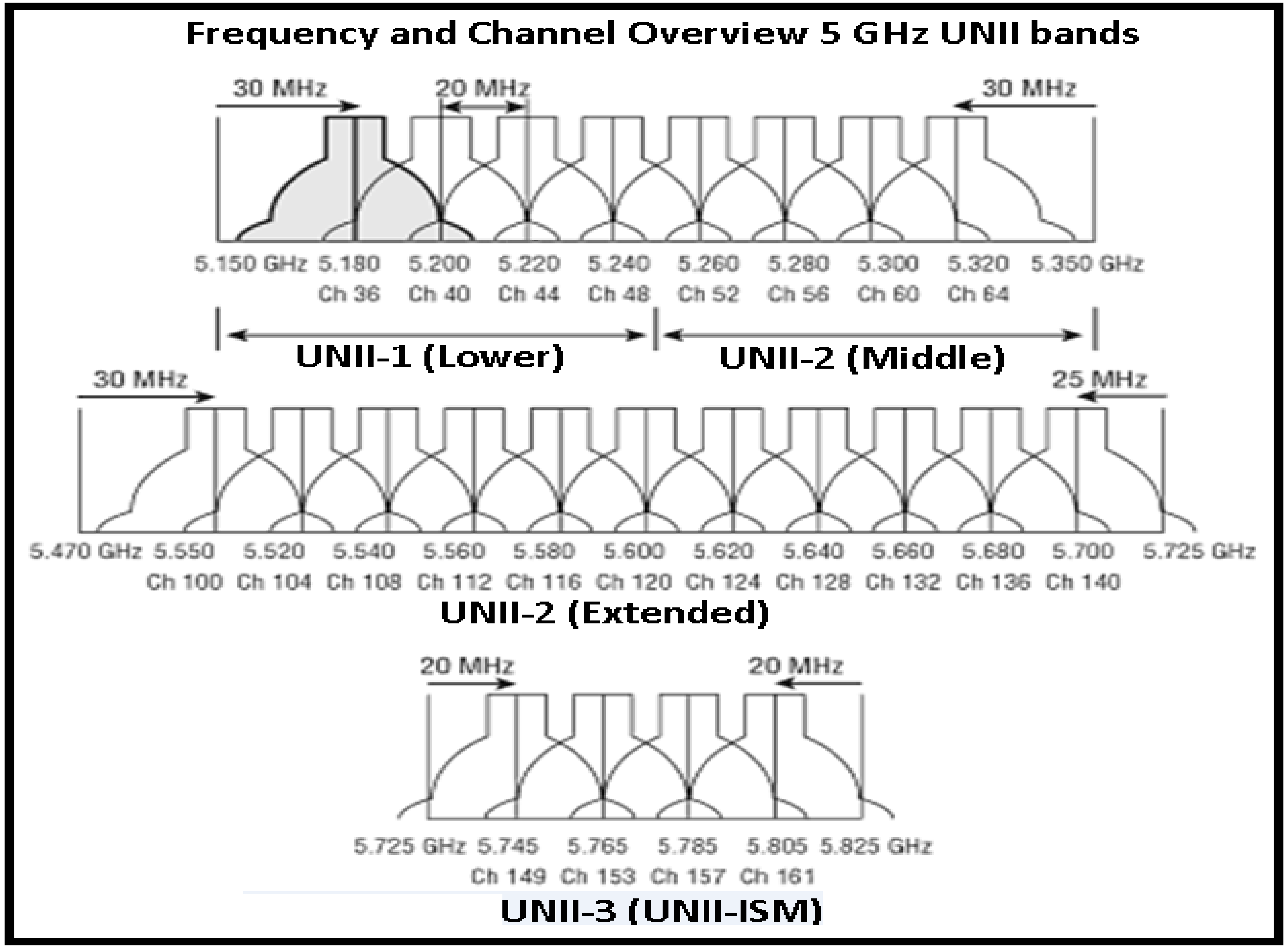
Wi-Fi Radio Spectrum 2.4 GHz





Wi-Fi Radio Spectrum 5 GHz Channels





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

Dynamic Frequency Selection (DFS) 5 GHz

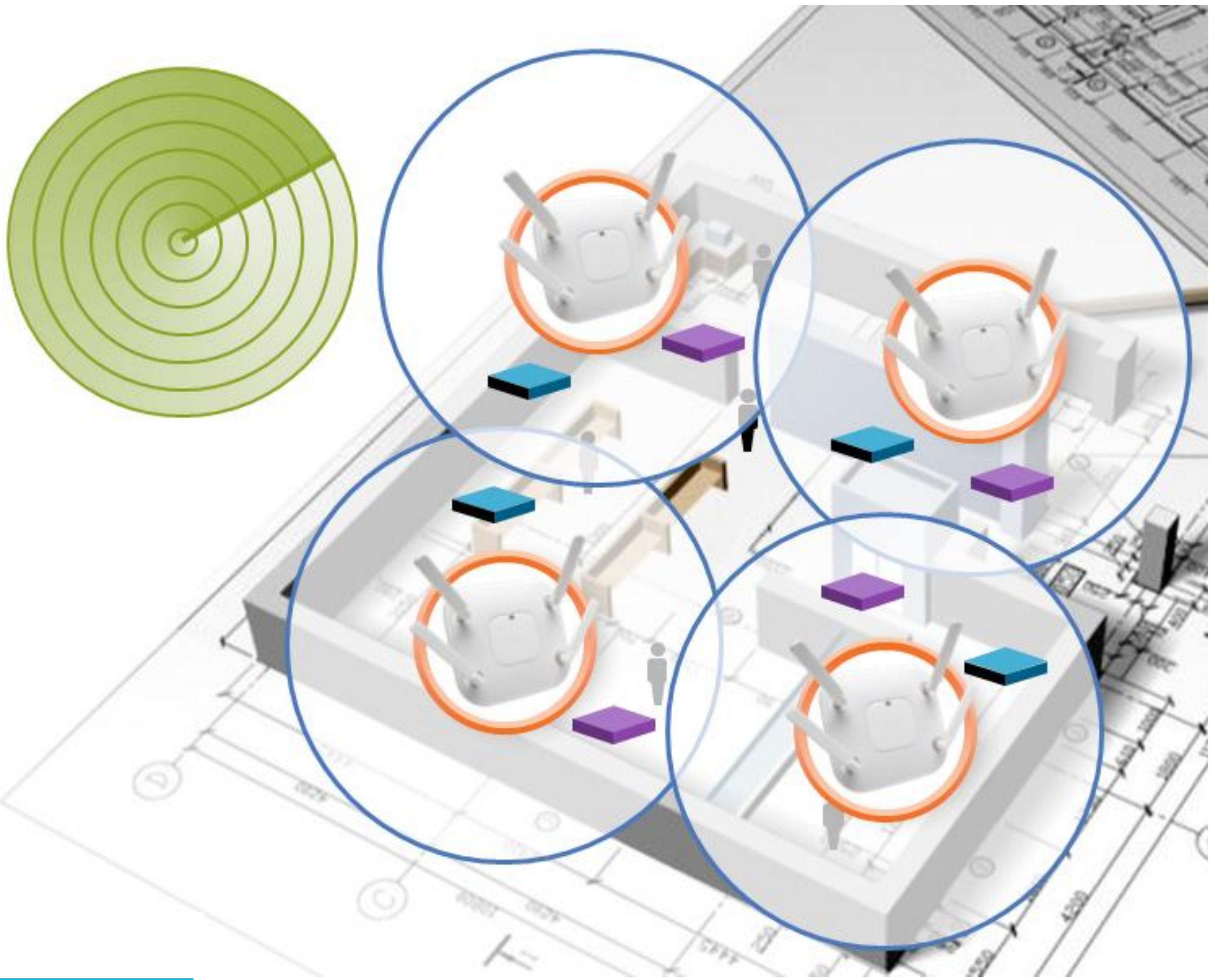
When Radar Signal is Present

Access Points detect radar activity and change channels so as not to cause interference with this licensed service.

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

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

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



Shared using DFS

UNI 1	UNI 2	UNI 2 Ext.	UNI 3

A Radio Needs a Proper Antenna

As the frequency goes up, the radiating element gets smaller

Antennas are identified by colour

Blue indicates 5 GHz

Black indicates 2.4 GHz

Orange indicates Both

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

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

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

Antennas are custom made for the frequency to be used. Some antennas have two elements to allow for both frequencies in one antenna enclosure. Cisco AP-3600 uses such antennas.

Basic 802.11 RF Terminology Hardware Identification

Common RF Terms

For Your Reference

- **Attenuation** – a loss in force or intensity – As radio waves travel in media such as coaxial cable attenuation occurs.
- **BER – Bit Error Rate** - the fraction of bits transmitted that are received incorrectly.
- **Channel Bonding** – act of combining more than one channel for additional bandwidth
- **dBd** – abbreviation for the gain of an antenna system relative to a dipole
- **dBi** – abbreviation for the gain of an antenna system relative to an isotropic antenna
- **dBm** – decibels milliwatt -- abbreviation for the power ratio in decibels (dB) of the measured power referenced to one milliwatt of transmitted RF power.
- **Isotropic antenna** – theoretical "ideal" antenna used as a reference for expressing power in logarithmic form.
- **MRC** – Maximal Ratio Combining a method that combines signals from multiple antennas taking into account factors such as signal to noise ratio to decode the signal with the best possible Bit Error Rate.
- **Multipath** – refers to a reflected signal that combines with a true signal resulting in a weaker or some cases a stronger signal.
- **mW** – milliwatt a unit of power equal to one thousandth of a watt (usually converted to dBm)
- **Noise Floor** – The measure of the signal created from the sum of all the noise sources and unwanted signals appearing at the receiver. This can be adjacent signals, weak signals in the background that don't go away, electrical noise from electromechanical devices etc.
- **Receiver Sensitivity** – The minimum received power needed to successfully decode a radio signal with an acceptable BER. This is usually expressed in a negative number depending on the data rate. For example the AP-1140 Access Point requires an RF strength of at least negative -91 dBm at 1 MB and an even higher strength higher RF power -79 dBm to decode 54 MB
- **Receiver Noise Figure** – The internal noise present in the receiver with no antenna present (thermal noise).
- **SNR – Signal to Noise Ratio** – The ratio of the transmitted power from the AP to the ambient (noise floor) energy present.
- **TxBF** – Transmit beam forming the ability to transmit independent and separately encoded data signals, so-called *streams*, from each of the multiple transmit antennas changing the timing so the client can best decode the information. Sometimes called Cisco Client Link.

Identifying RF Connectors

RP-TNC Connector

Used on most Cisco Access Points

"RP-SMA" Connector

Used on some Linksys Products

"N" Connector

Used on the 1520 and 1550 Mesh APs

"SMA" Connector

"Pig tail" type cable assemblies

Antenna Cables – LMR Series

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

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

LMR-600 is recommended when longer cable distances are required

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

Trivia: LMR Stands for "Land Mobile Radio"

For Your Reference

Some Antenna Cables Characteristics

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

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

LMR®-600
Flexible Low Loss Communications Coax

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

Foil shield and braid

LMR-400 3/8 inch
LMR-600 ½ inch

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

AIR-CAB-050-LL-R

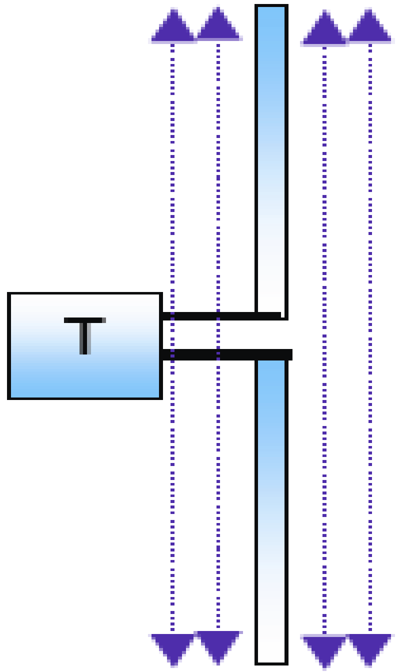
- AIR - Aironet
- CAB – Cable
- 050 - Length
- LL - Low Loss (LMR-400)
- R - RP-TNC connector

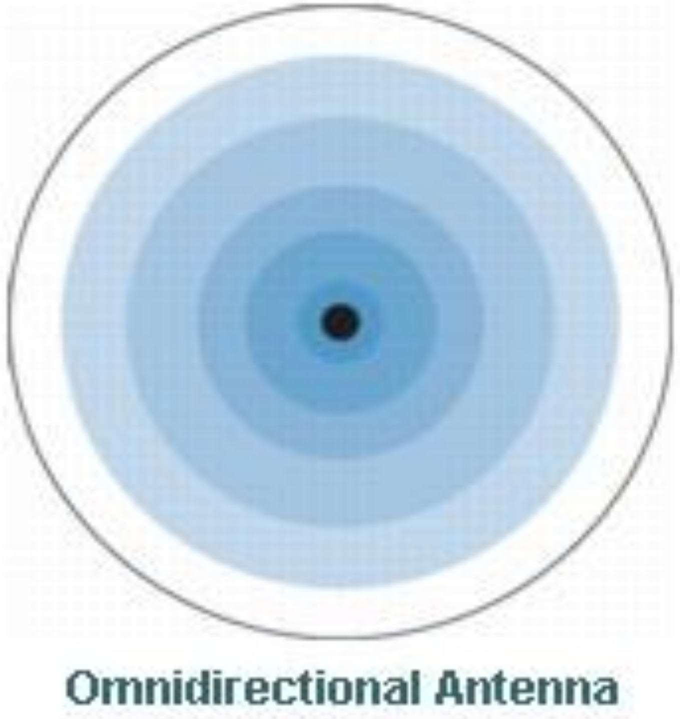
Cisco live!

802.11 Antenna Basics

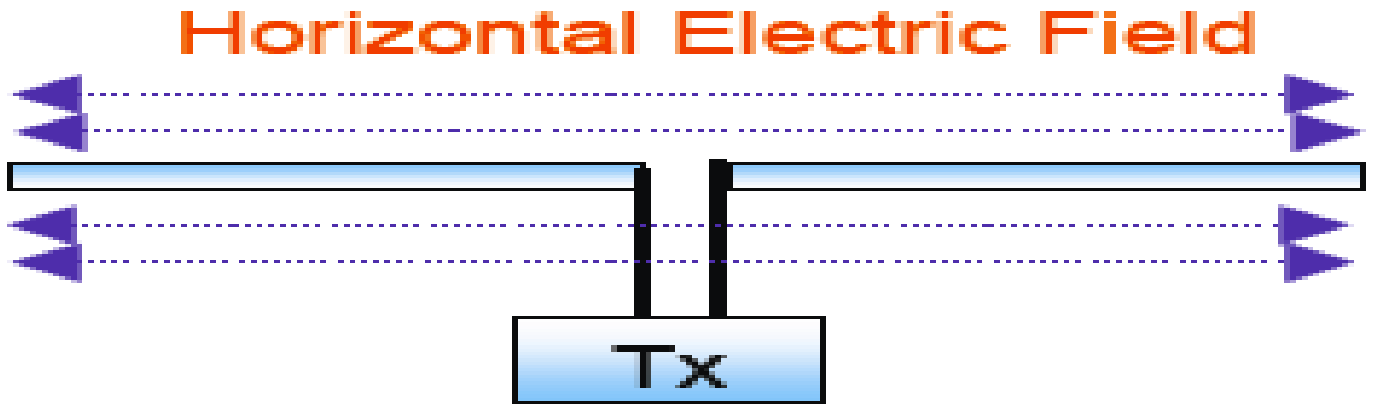
How Does a Omni-Directional Dipole Radiate?

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



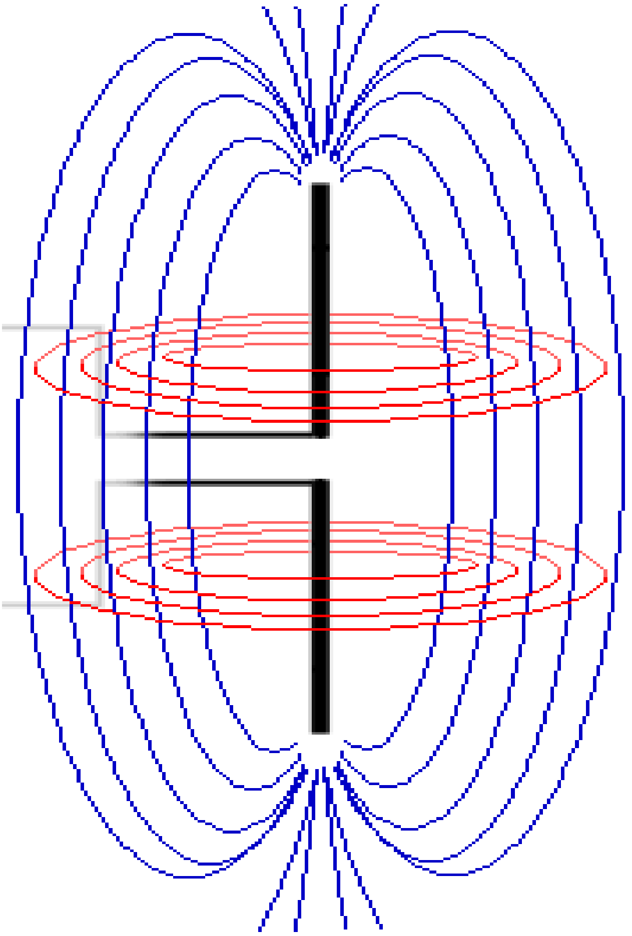


Low gain Omni radiates much like a bulb "360"

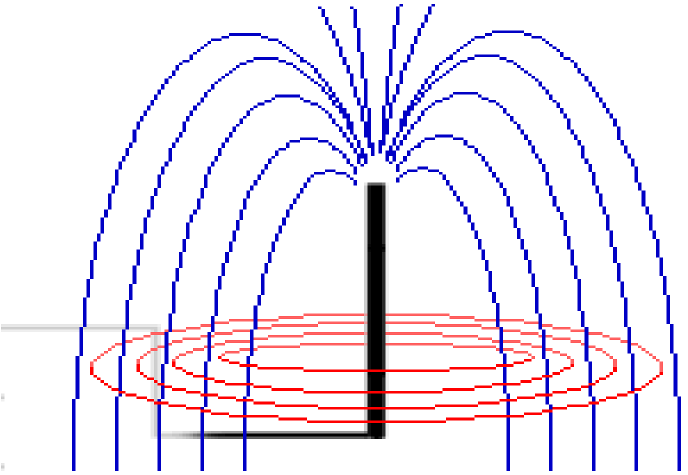


Antenna Theory (Dipole & Monopole)

Dipole



Monopole

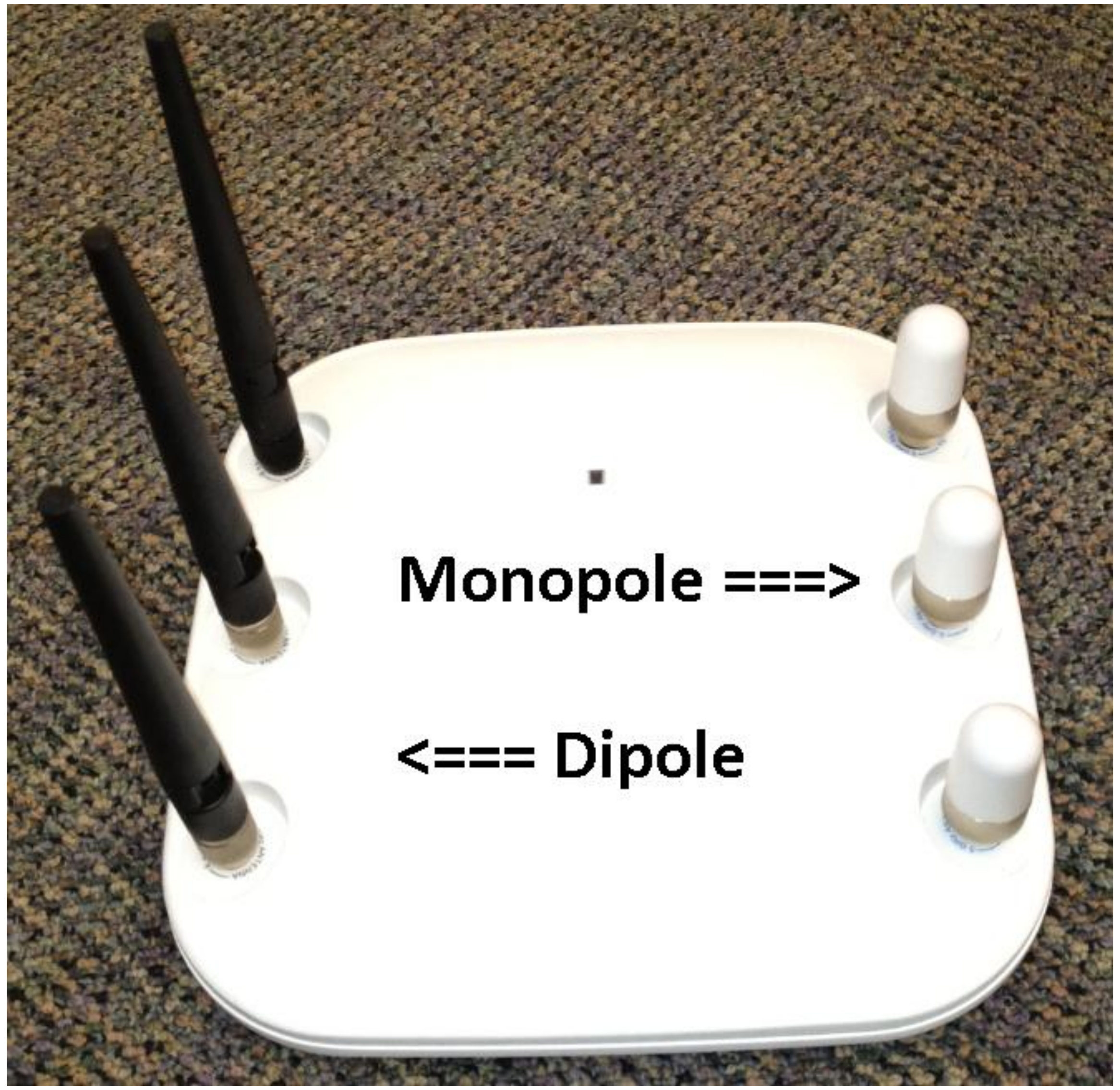


A Monopole requires a ground plane – (conductive surface)

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

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

Antenna Theory (Dipole & Monopole)



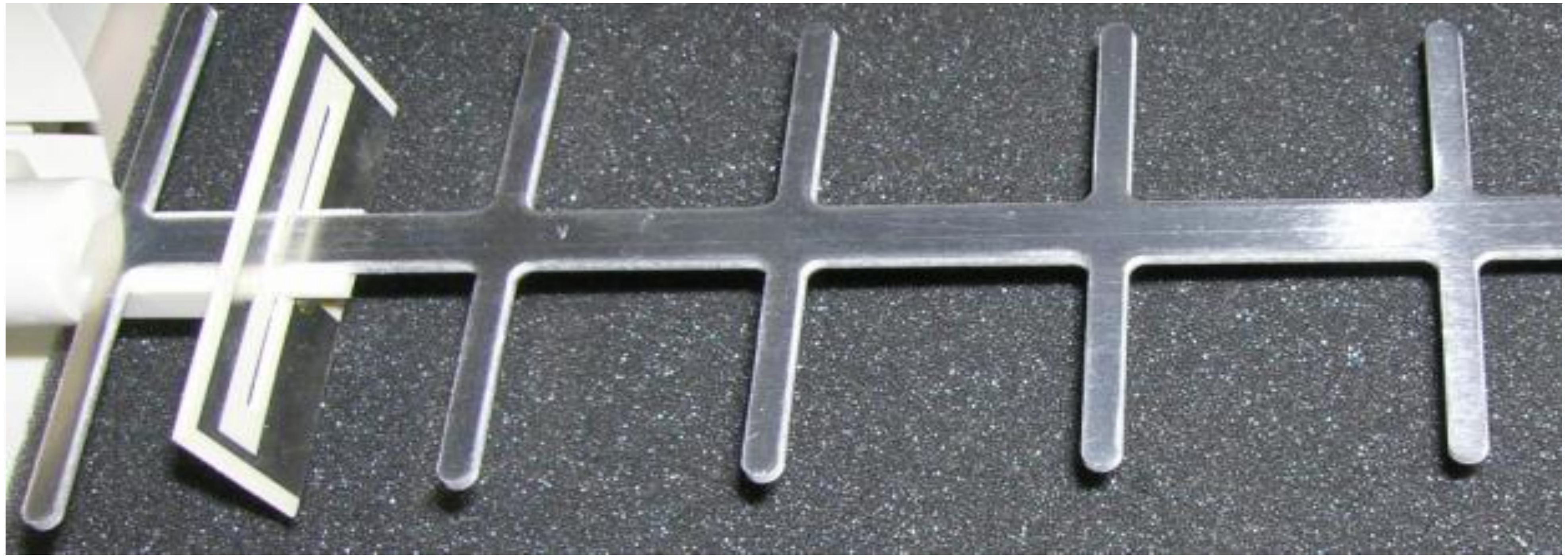
Monopoles were added to our antenna line primarily for aesthetics

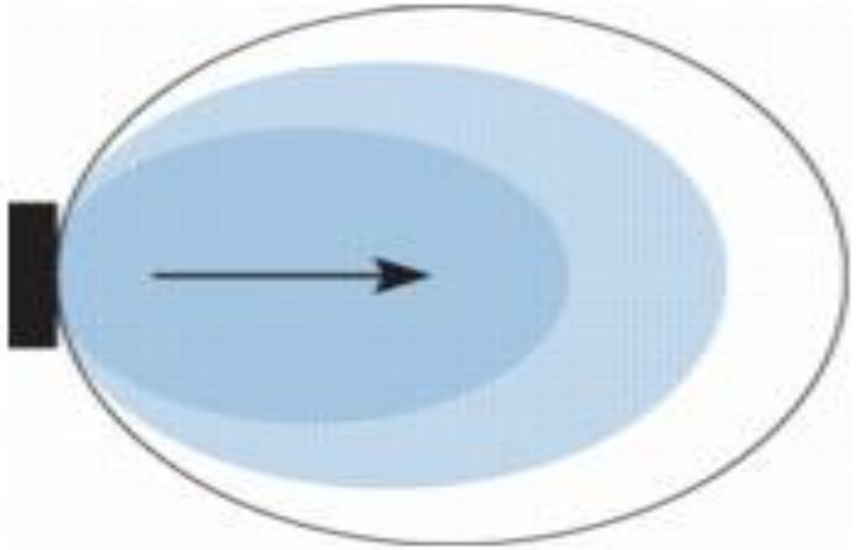
Monopoles are smaller and require a metal surface to properly radiate

How Does a Directional Antenna Radiate?

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

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





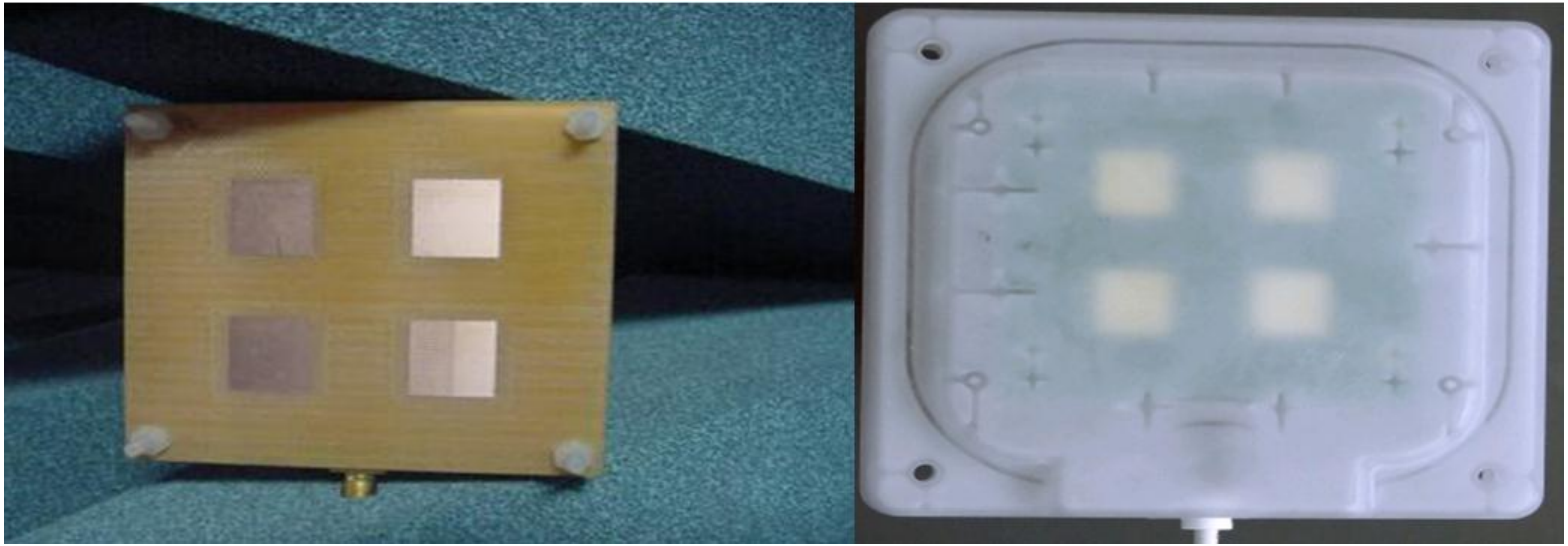
YAGI Antenna

A dipole called the "driven element" is placed in front of other elements. This motivates the signal to go forward into 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.



The 9.5 dBi Patch called AIR-ANT5195-R

Antennas Identified by Colour

For Your Reference

Cisco Antenna Colour Coding

Black indicates 2.4 GHz

Blue indicates 5 GHz

Orange indicates 2.4 & 5 GHz (used on AP-3600)

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

Guide to Antenna Part Numbers

For Your Reference

Understanding Cisco Antenna Part Numbers

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

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

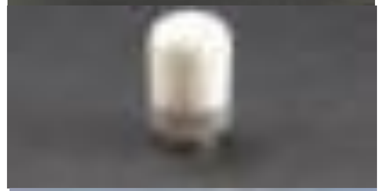
Most Common 802.11n Antennas

For Your Reference

Indoor Access Points (1262 and 3502e)

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




Dual Band Antennas for AP3600

For Your Reference

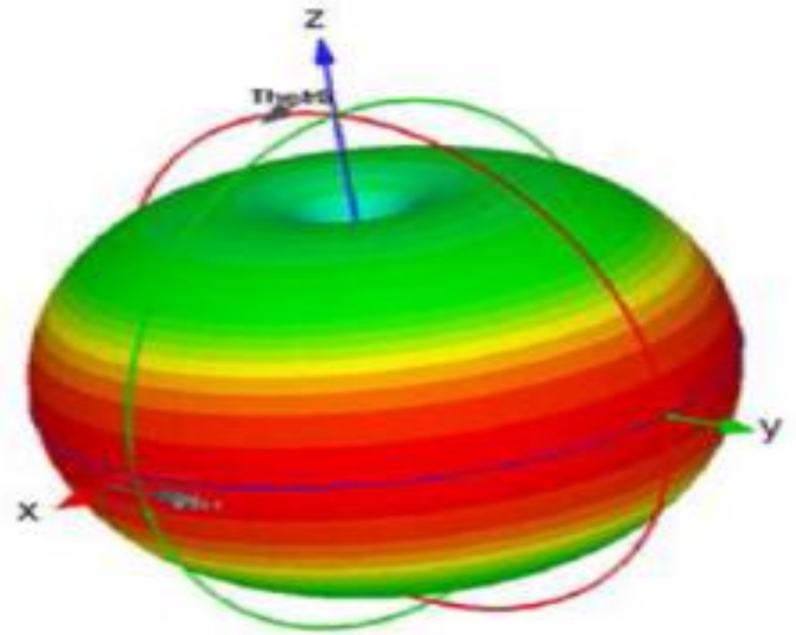
Product ID	Description	Gain
AIR-ANT2524DB-R AIR-ANT2524DB-R=	2.4 & 5 GHz -- Dual Band Dipole Dipole Ant., Black, RP-TNC connector (1)	2 dBi (2.4 GHz) 4 dBi (5 GHz)
AIR-ANT2524DG-R AIR-ANT2524DG-R=	2.4 & 5 GHz – Dual Band Dipole Dipole Ant., Gray, RP-TNC connector (1)	2 dBi (2.4 GHz) 4 dBi (5 GHz)
AIR-ANT2524DW-R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

Understanding and Interpreting Antenna Patterns

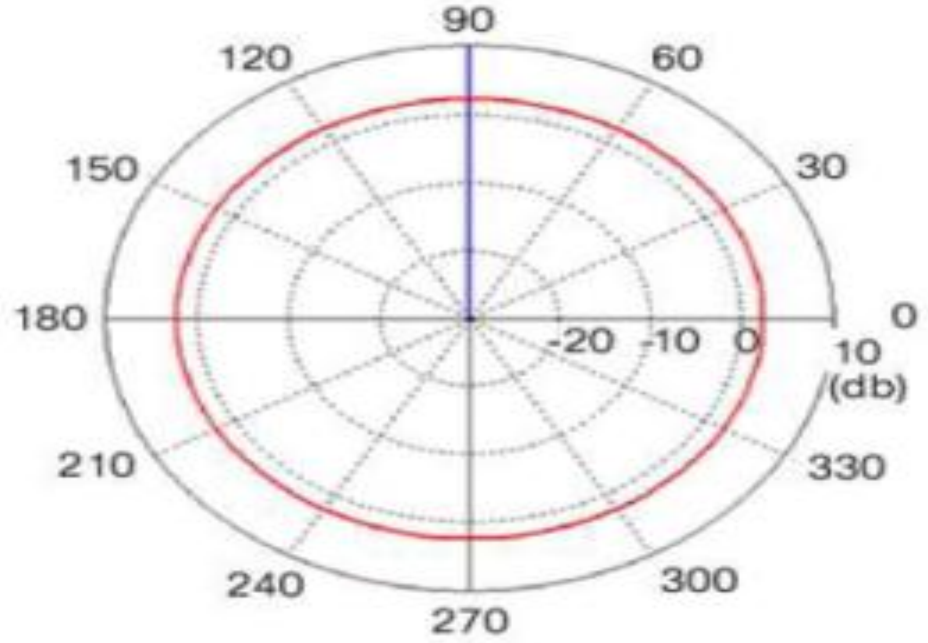
Understanding Antenna Patterns

Dipole (Omni-Directional)

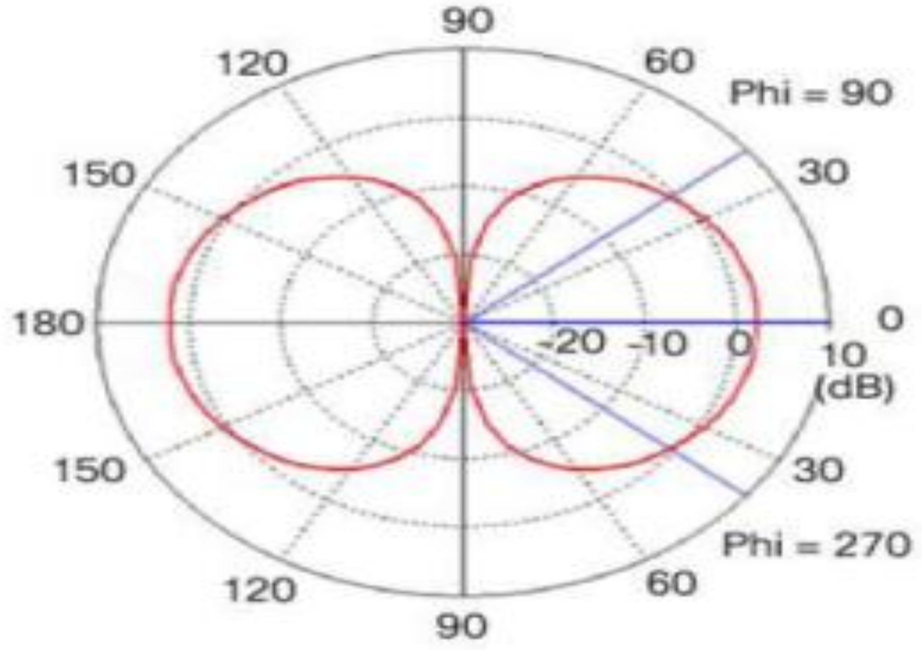
Dipole Antenna Model



Dipole 3D Radiation Pattern



Dipole Azimuth Plane Pattern

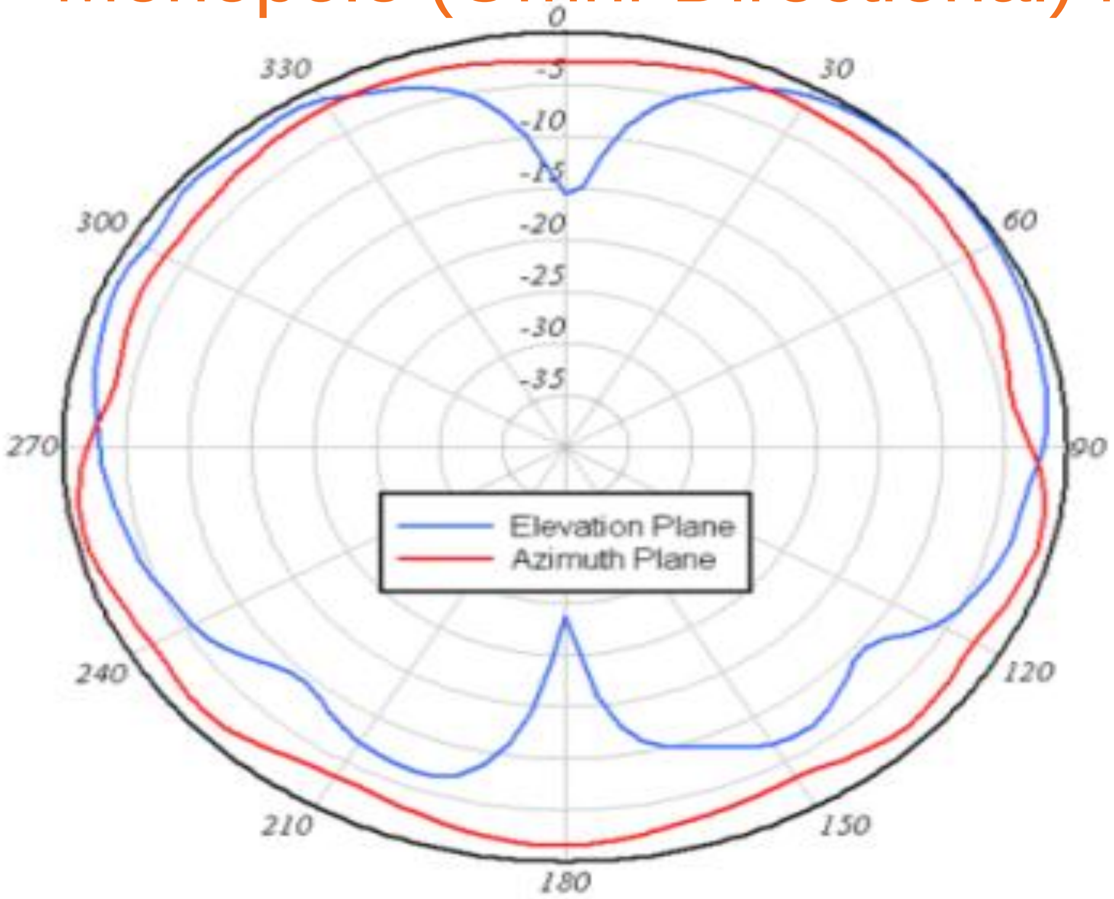


Dipole Elevation Plane Pattern

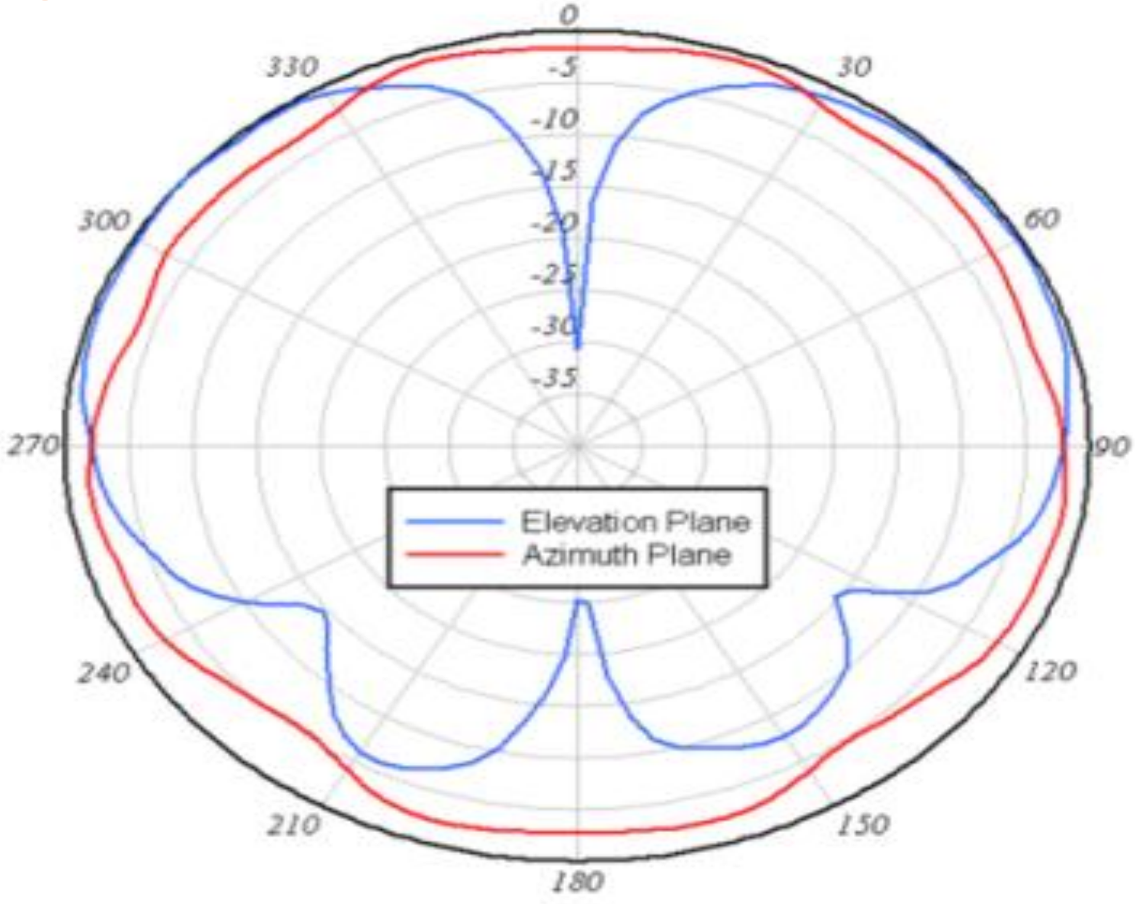
Low gain dipoles radiate everywhere think "light bulb"

Understanding Antenna Patterns

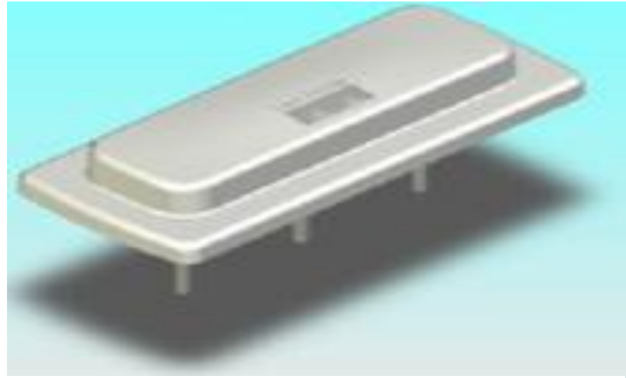
Monopole (Omni-Directional) MIMO

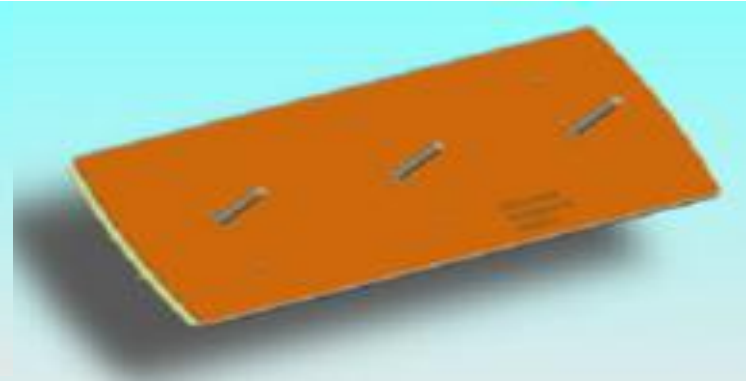


End Antenna



Middle Antenna

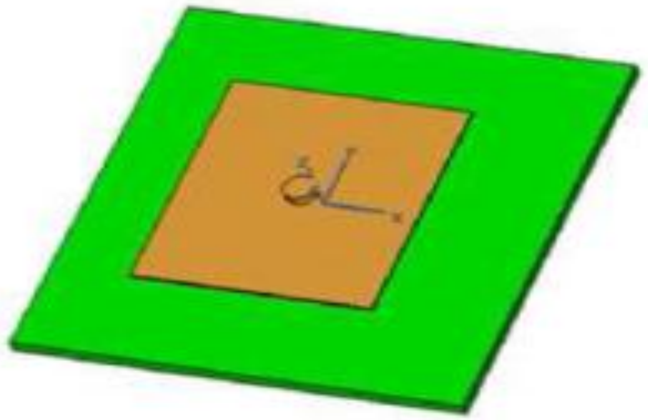




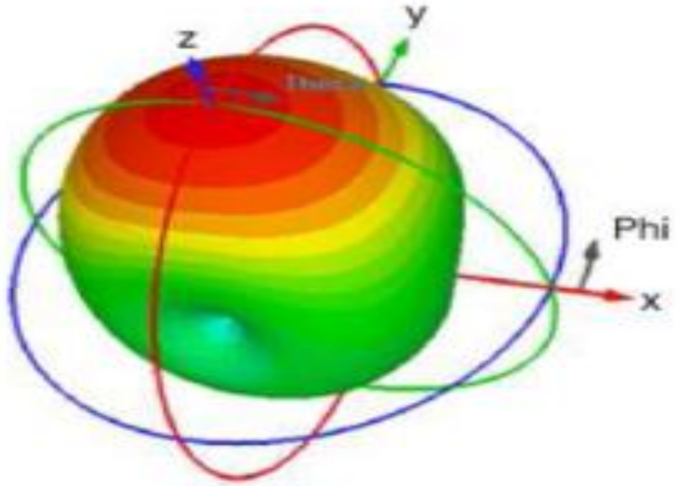
When three monopoles are next to each other – the radiating elements interact slightly with each other – The higher gain 4 dBi also changes elevation more compared to the lower gain 2.2 dBi Dipole

Understanding Antenna Patterns

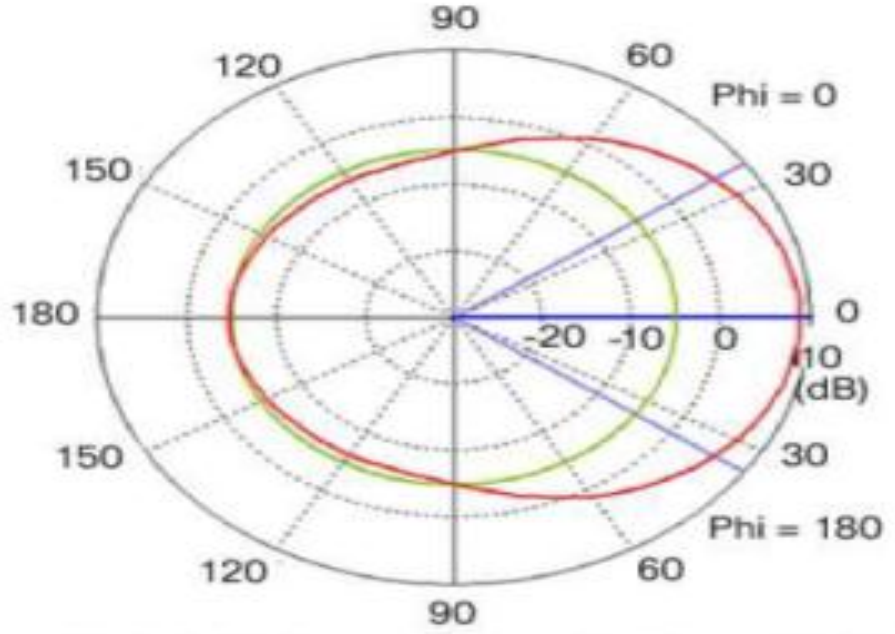
Patch (Directional)



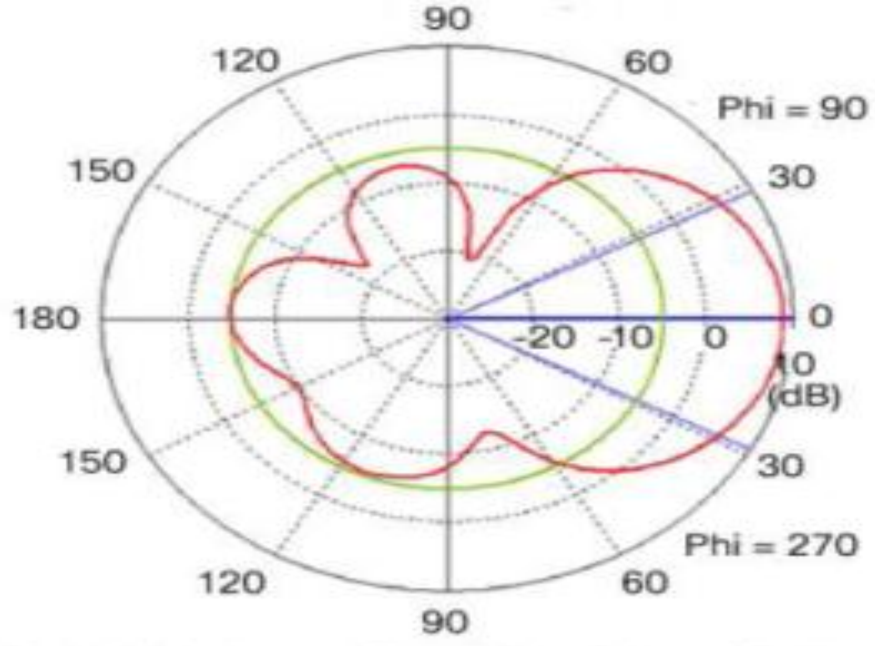
Patch Antenna Model



Patch Antenna 3D Radiation Pattern



Patch Antenna Azimuth Plane Patter

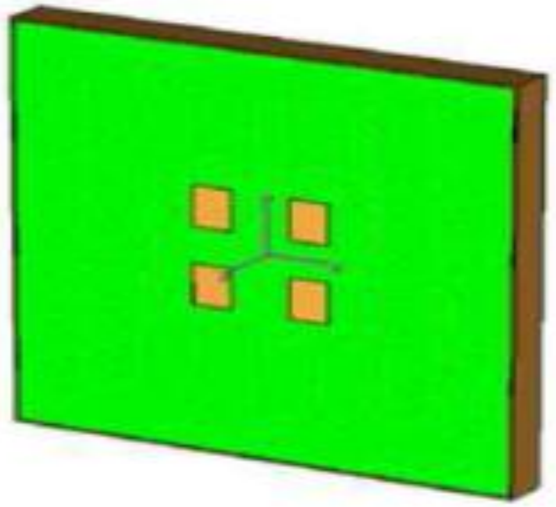


Patch Antenna Elevation Plane Pattern

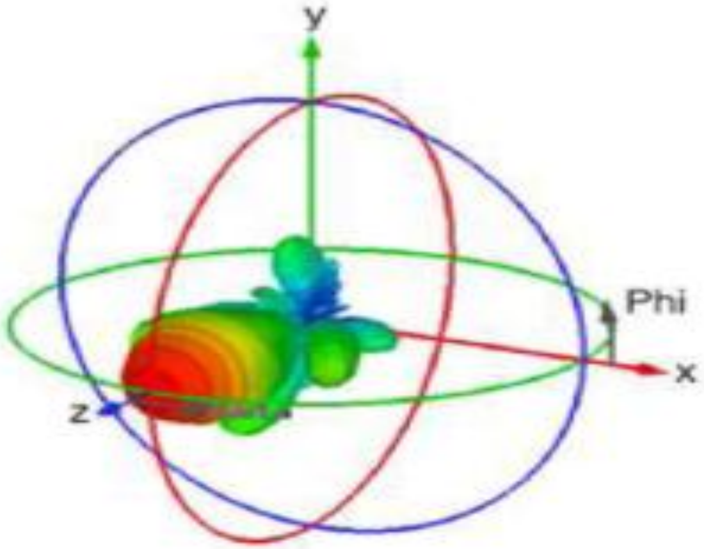
Patch Antenna

Understanding Antenna Patterns

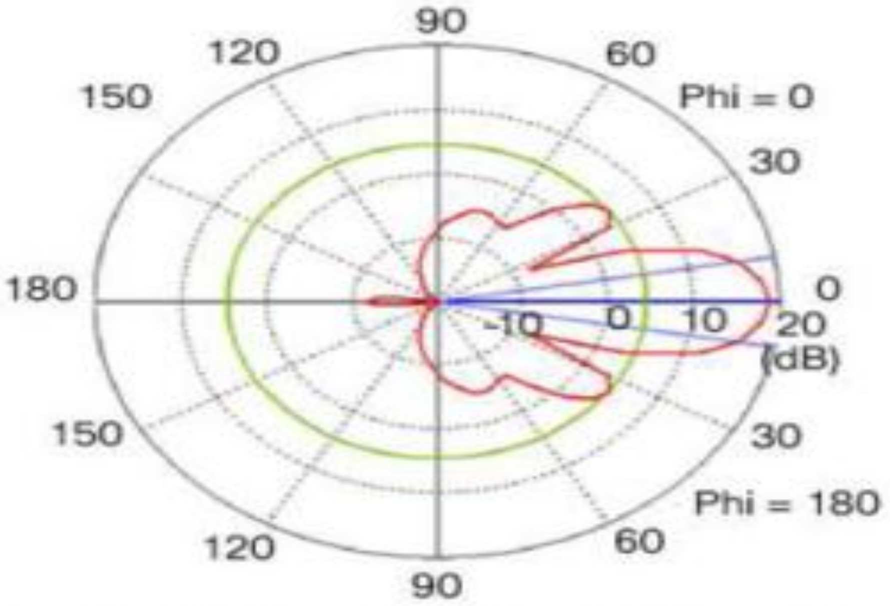
Patch (Higher Gain Directional)



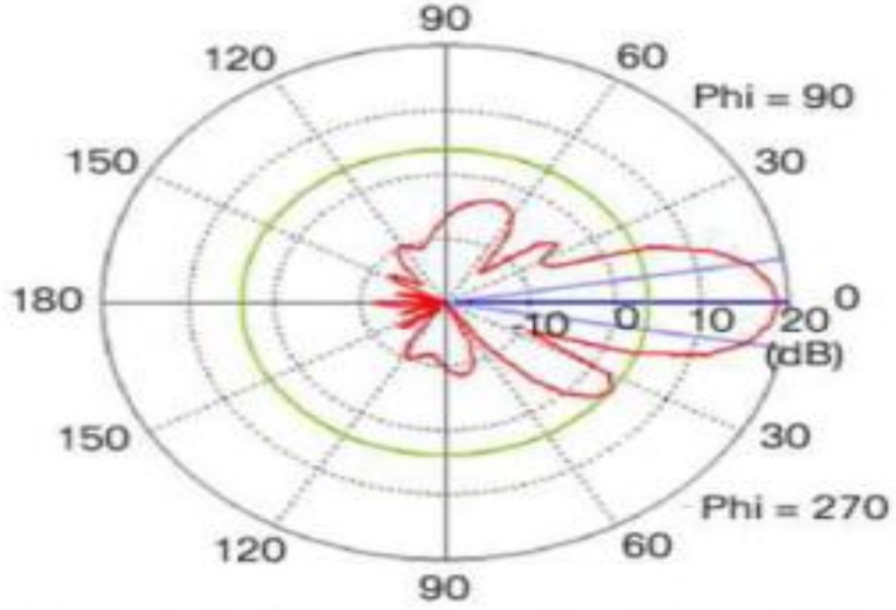
4x4 Patch Array Antenna



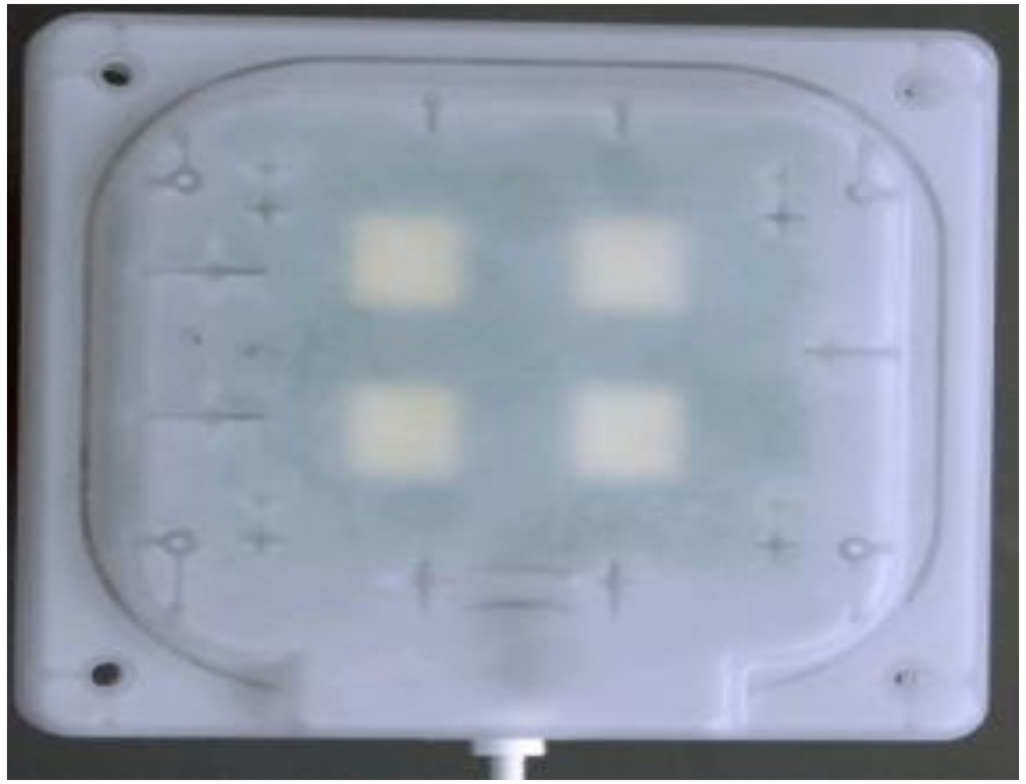
4x4 Patch Array 3D Radiation Pattern



4x4 Patch Array Azimuth Plane Pattern



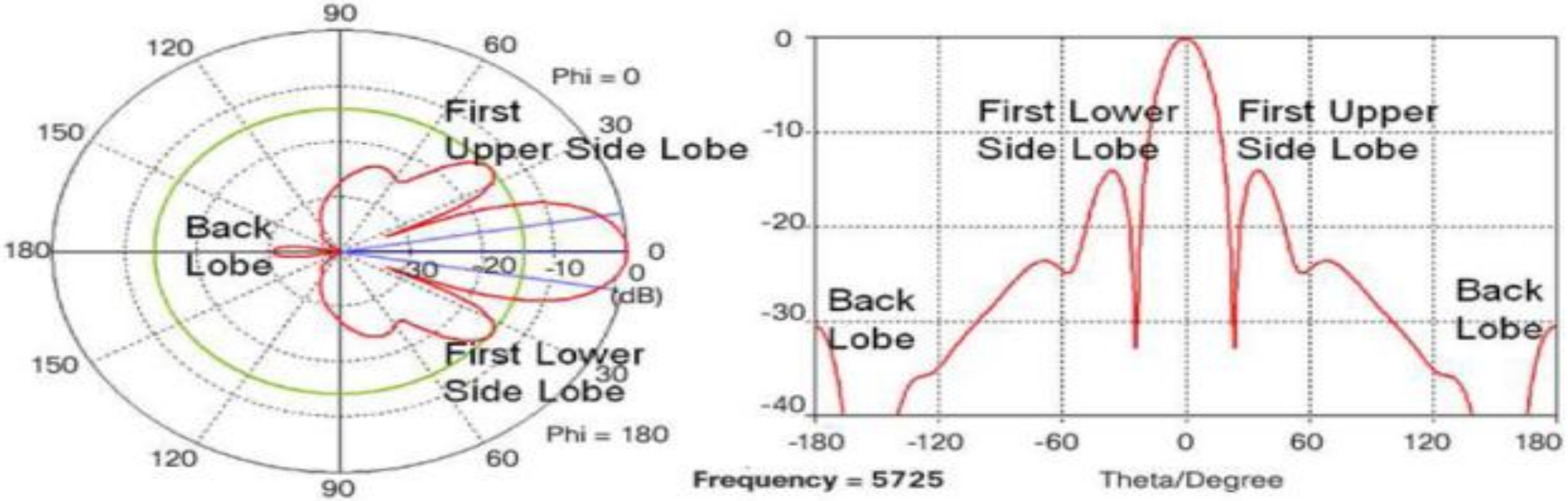
4x4 Patch Array Elevation Plane Pattern



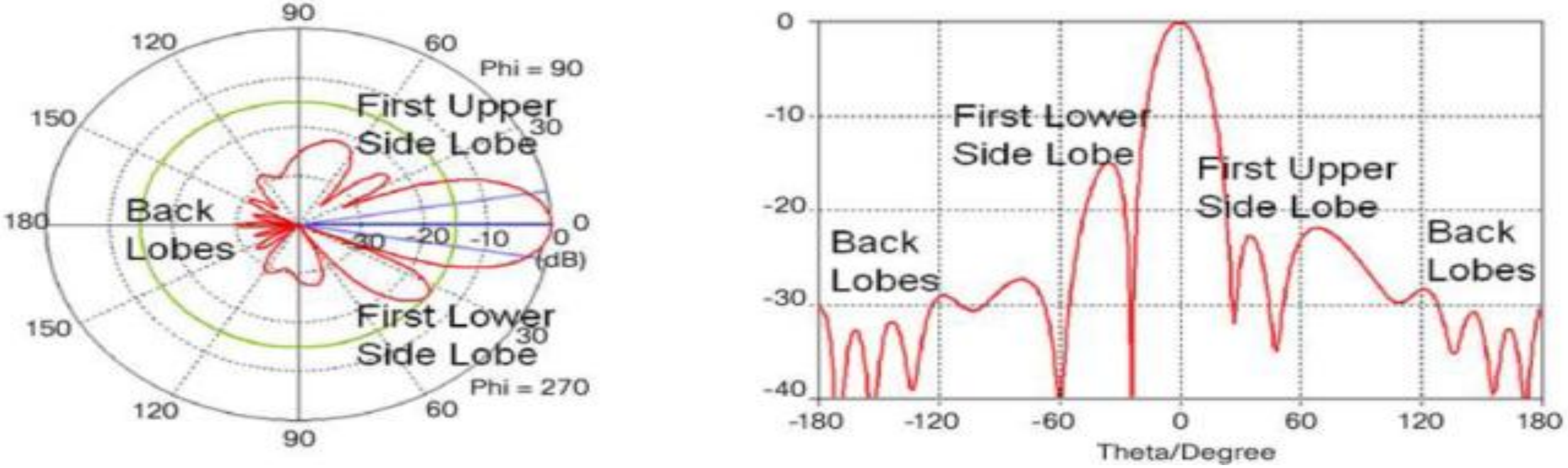
Four element Patch Array

Understanding Antenna Patterns

Patch (Higher Gain Directional)



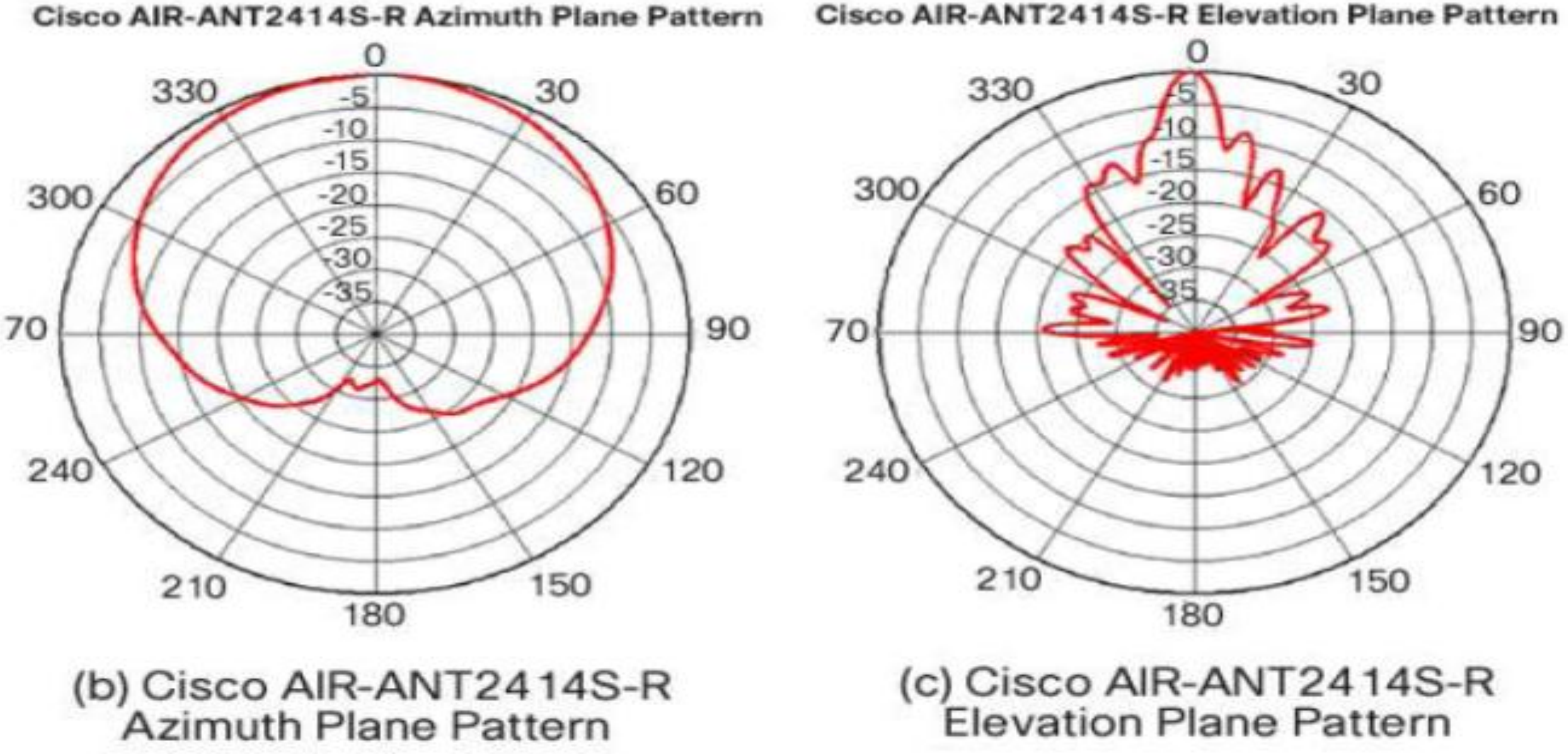
Elevation Plane Patterns of the 4 x 4 Patch Array in Polar and Rectangular Coordinates



Four element Patch Array

Understanding Antenna Patterns

Sector (Higher Gain Directional)



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

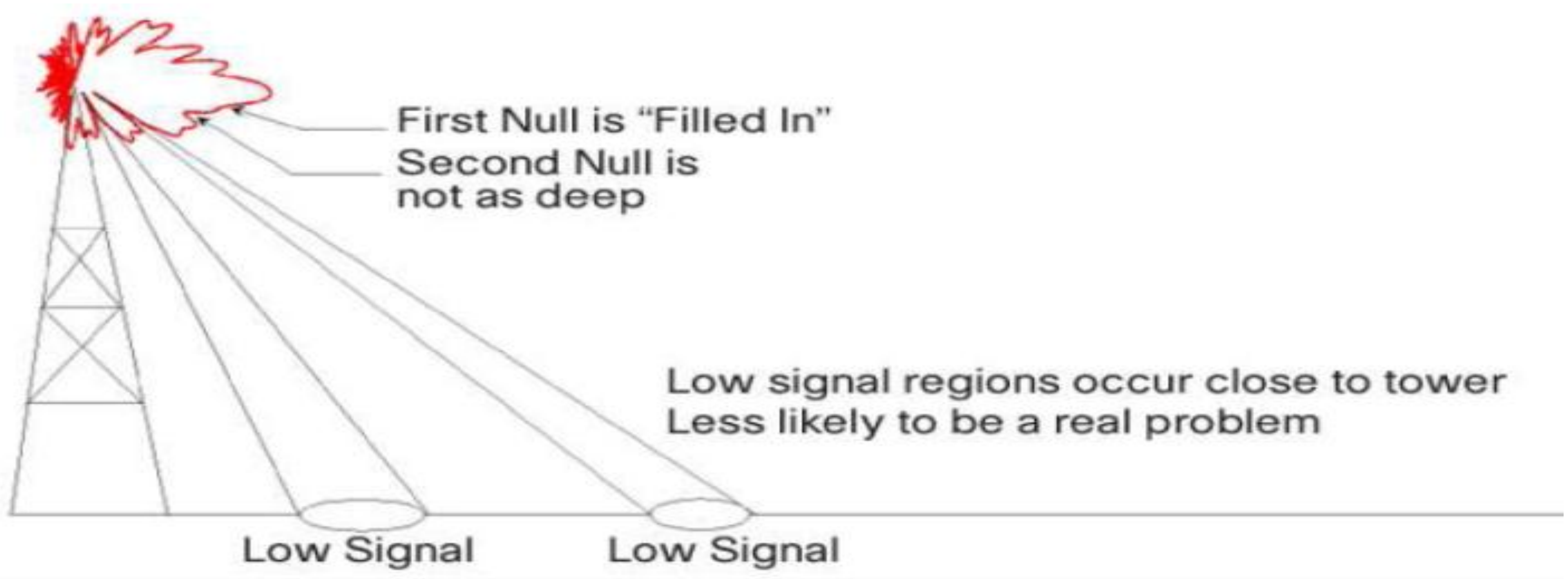
(c) Cisco AIR-ANT2414S-R Elevation Plane Pattern

Elevation plane has nulls due to high gain 14 dBi

AIR-ANT2414S-R
14 dBi Sector 2.4 GHz

Understanding Antenna Patterns

Sector (Higher Gain Directional)



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

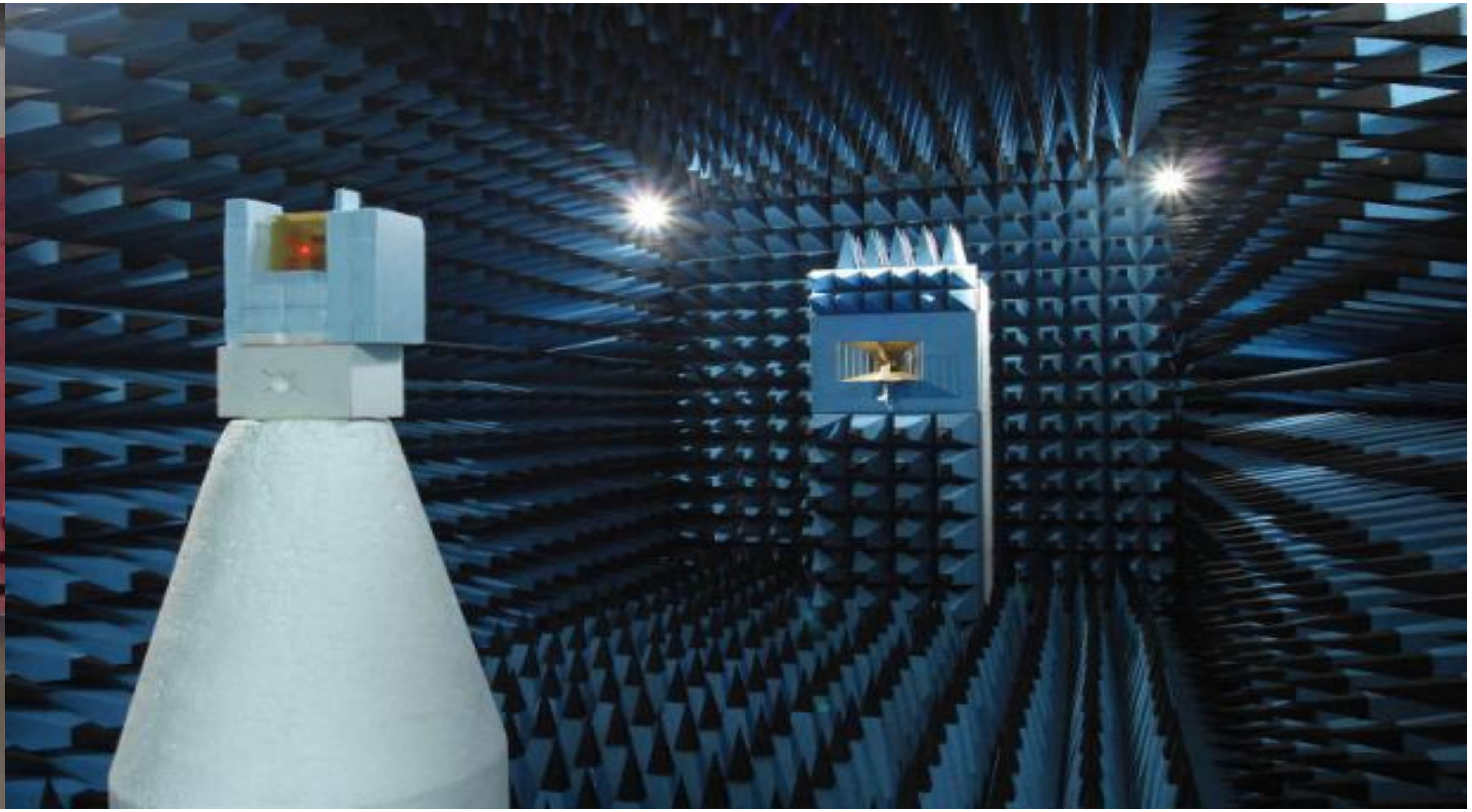
AIR-ANT2414S-R
14 dBi Sector 2.4 GHz

The Richfield Ohio (Aironet) Facility

A Quick Peek Where Antennas Are Designed...

The Richfield Ohio (Aironet) Facility

Qualifying Cisco and 3rd Party Antennas



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

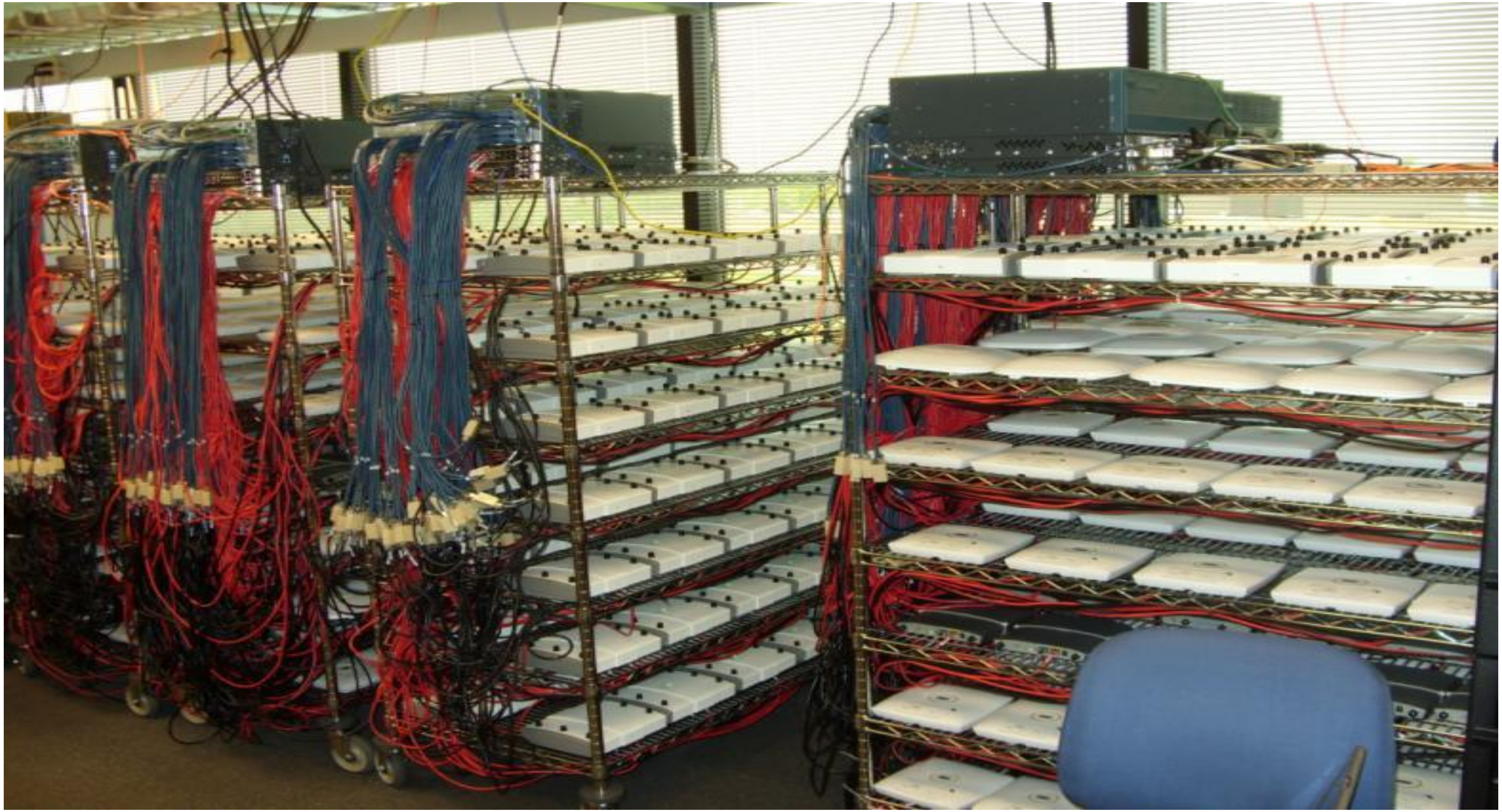
Cisco Anechoic chamber using an 45 cm absorber all the way, around 1-6 GHz

Anechoic means “without echo”

The Richfield Ohio (Aironet) Facility

Regulatory Compliance Testing Done in this Chamber

Yes We Have Just a Few Access Points

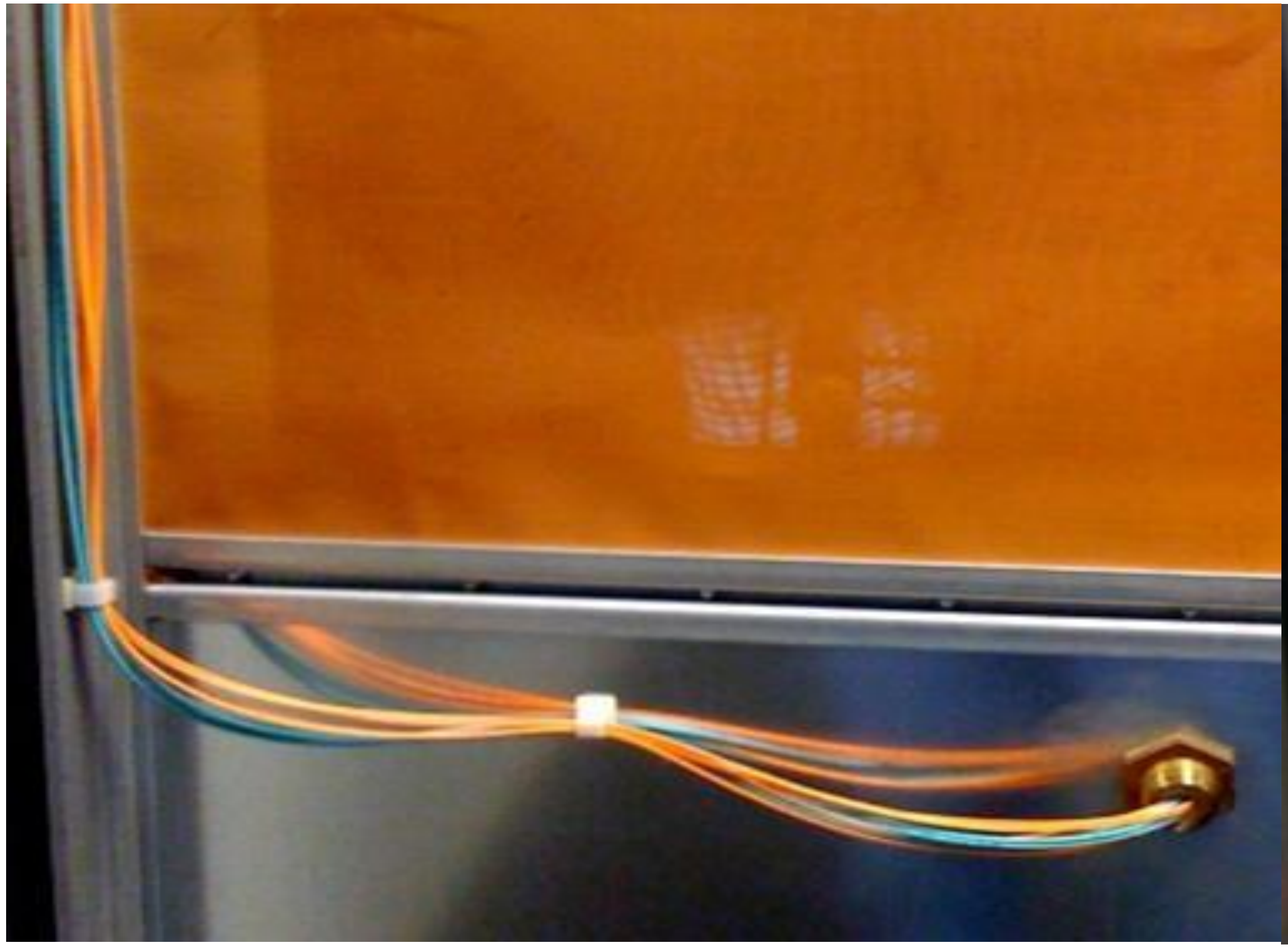


RF Screen Rooms Everywhere

Copper Shielding (Faraday Cage)

RF Screen Rooms

Copper Shielding on Top Metal on Bottom

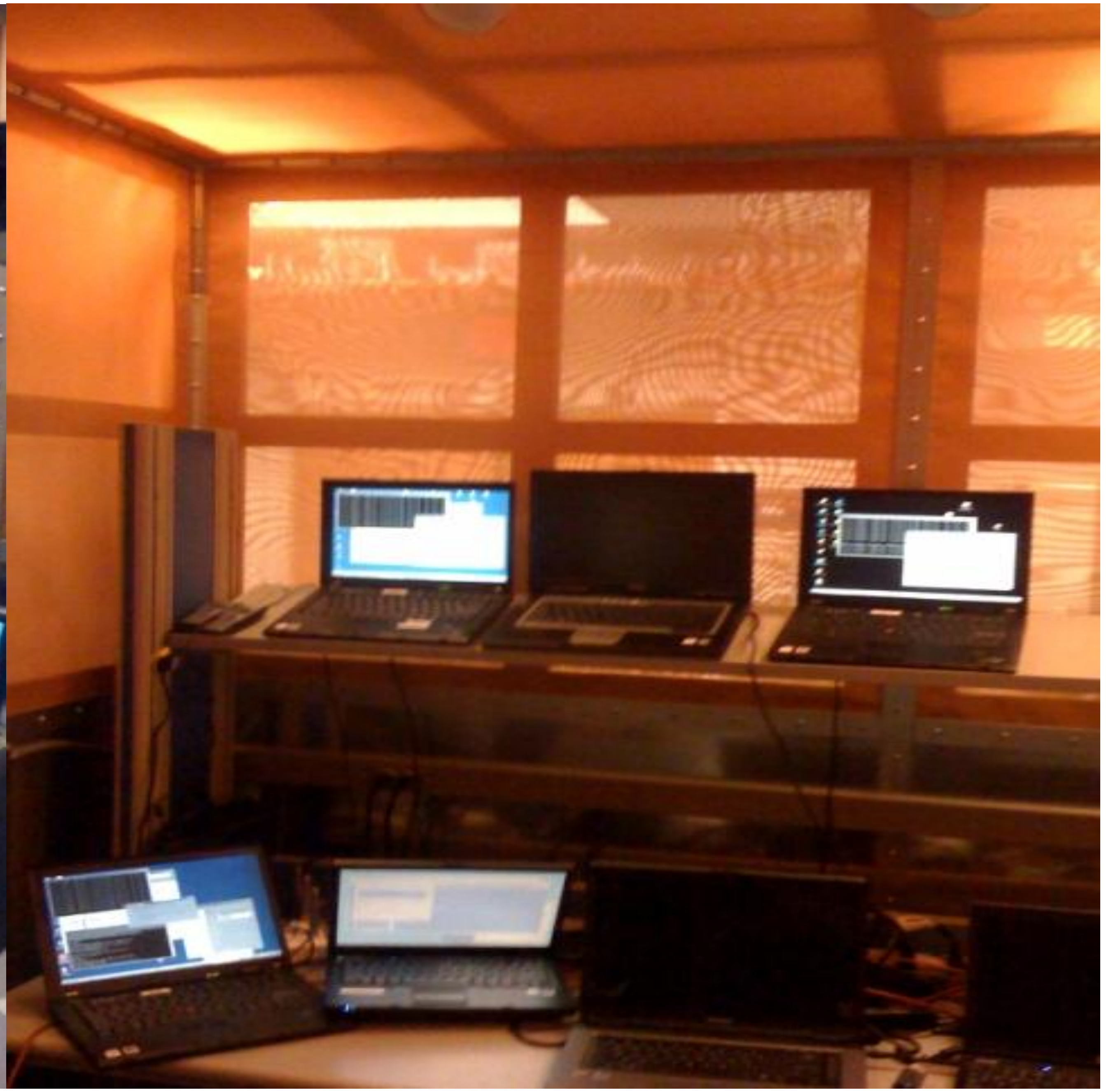


Cables are typically fibre and exit through well shielded holes

Doors have copper fingers and latch tight forming an RF seal

RF Screen Rooms

Copper Shielding (Faraday Cage)



Cisco Richfield Facility

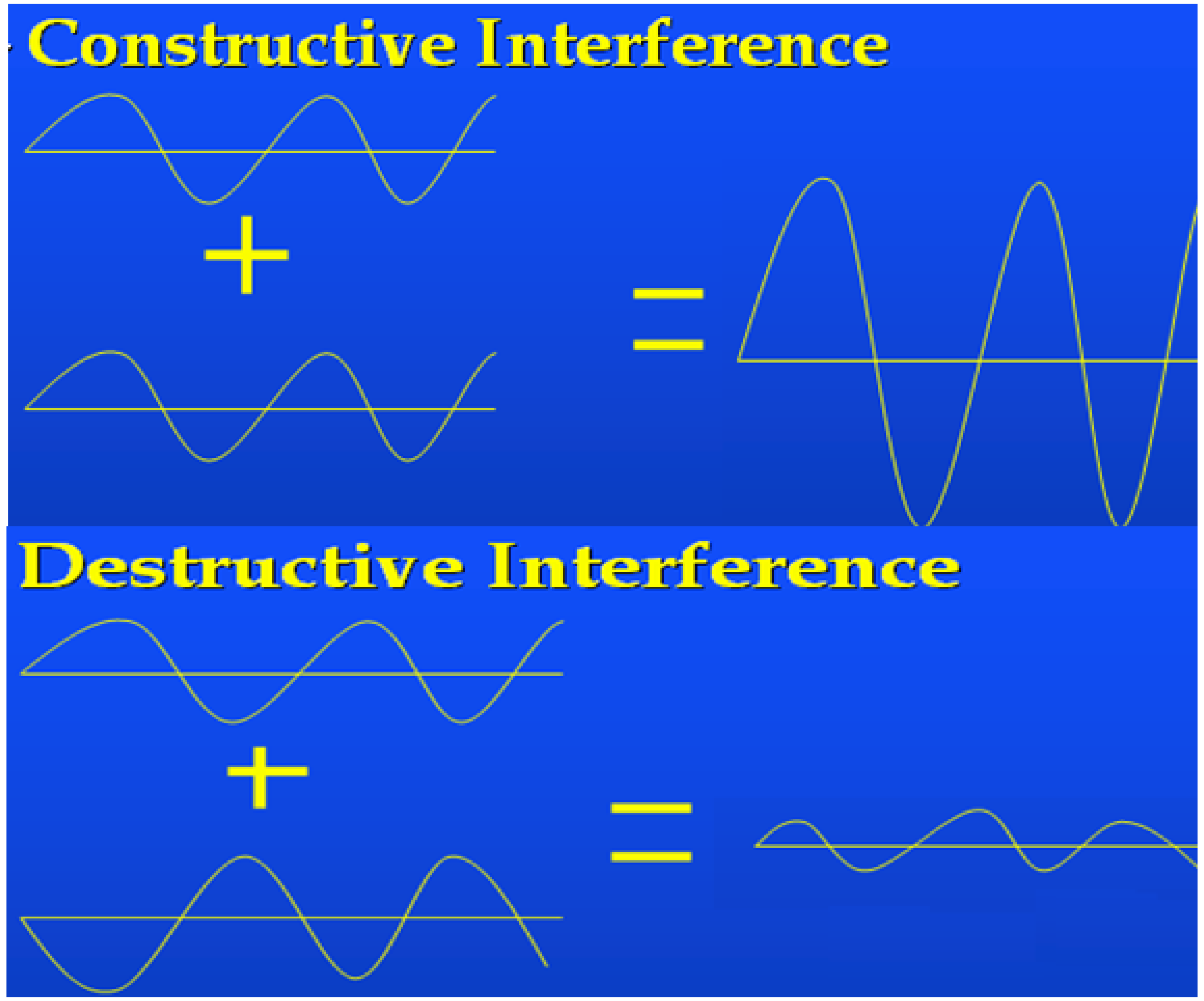
Understanding Multipath Diversity and Beamforming 802.11n

Understanding Multipath

Multipath Can Change Signal Strength

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

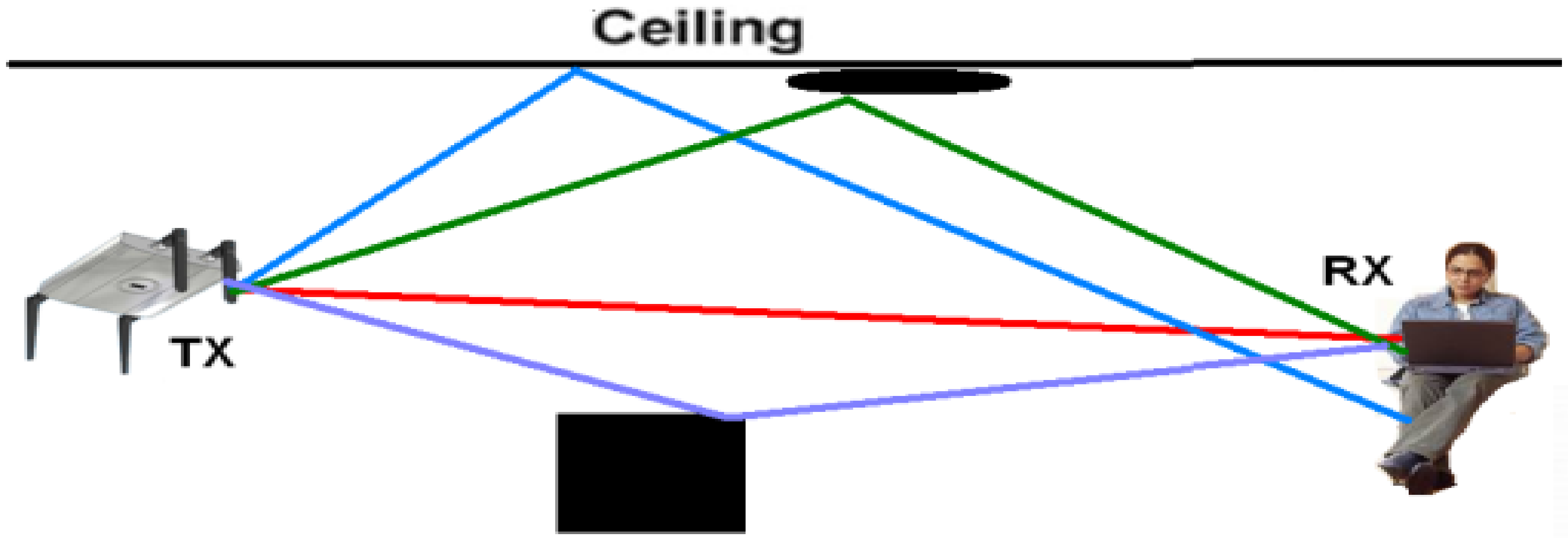
This often results in either an improvement “constructive” or a “destructive” type of interference

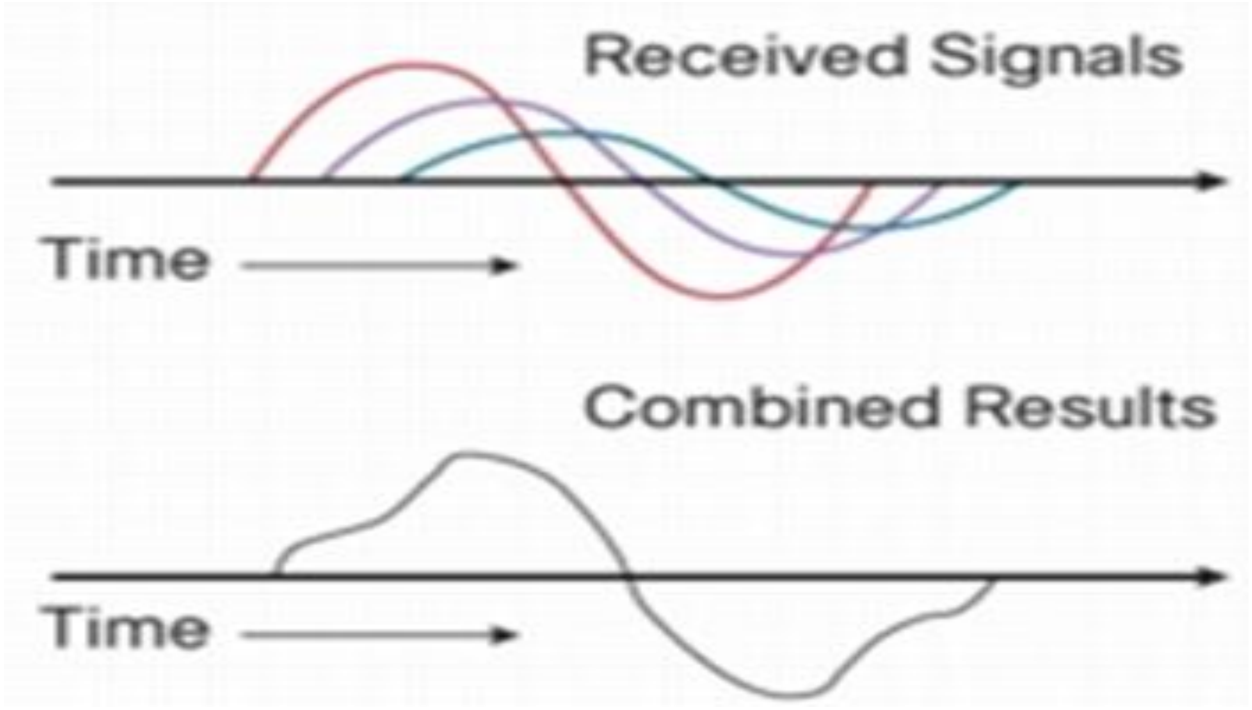


Note: Bluetooth type radios that “hop” across the entire band can reduce multipath interference by constantly changing the angles of multipath as the radio wave increases and decreases in size (as the frequency constantly changes) however throughput using these methods are very limited but multipath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

Understanding Multipath

Multipath Reflections Can Cause Distortion





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

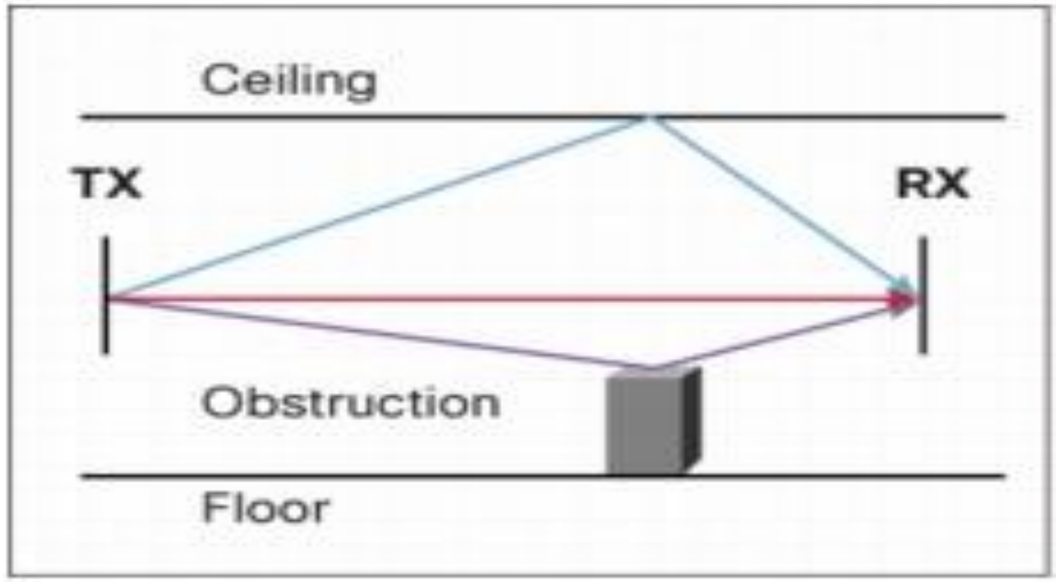
Different modulation schemes fair better – 802.11a/g uses a type of modulation based on symbols and is an improvement over the older modulation types used with 802.11b clients

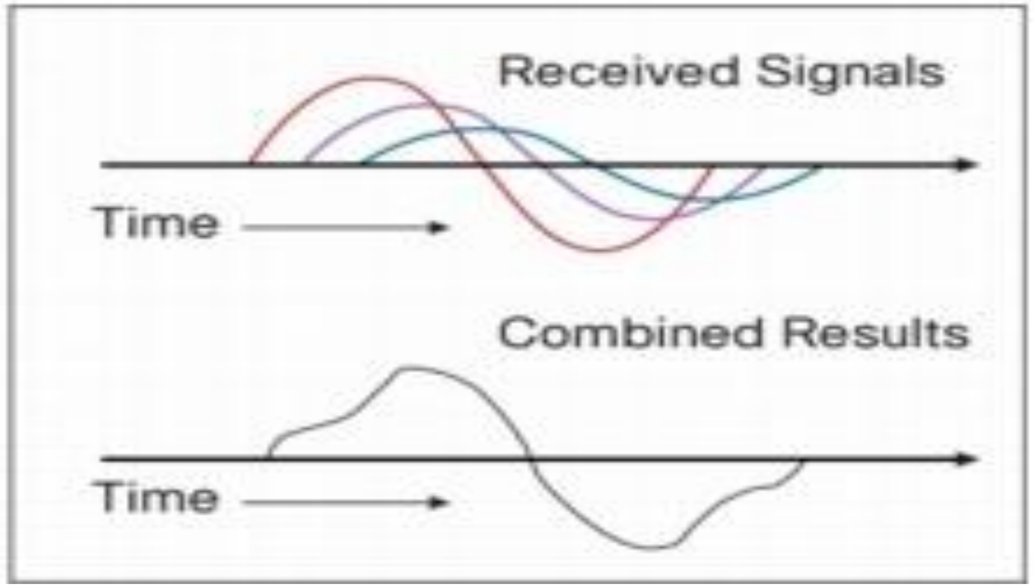
802.11n with more receivers can use destructive interference (multipath) as a benefit but it is best to reduce multipath conditions

Understanding Diversity (SISO)

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

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



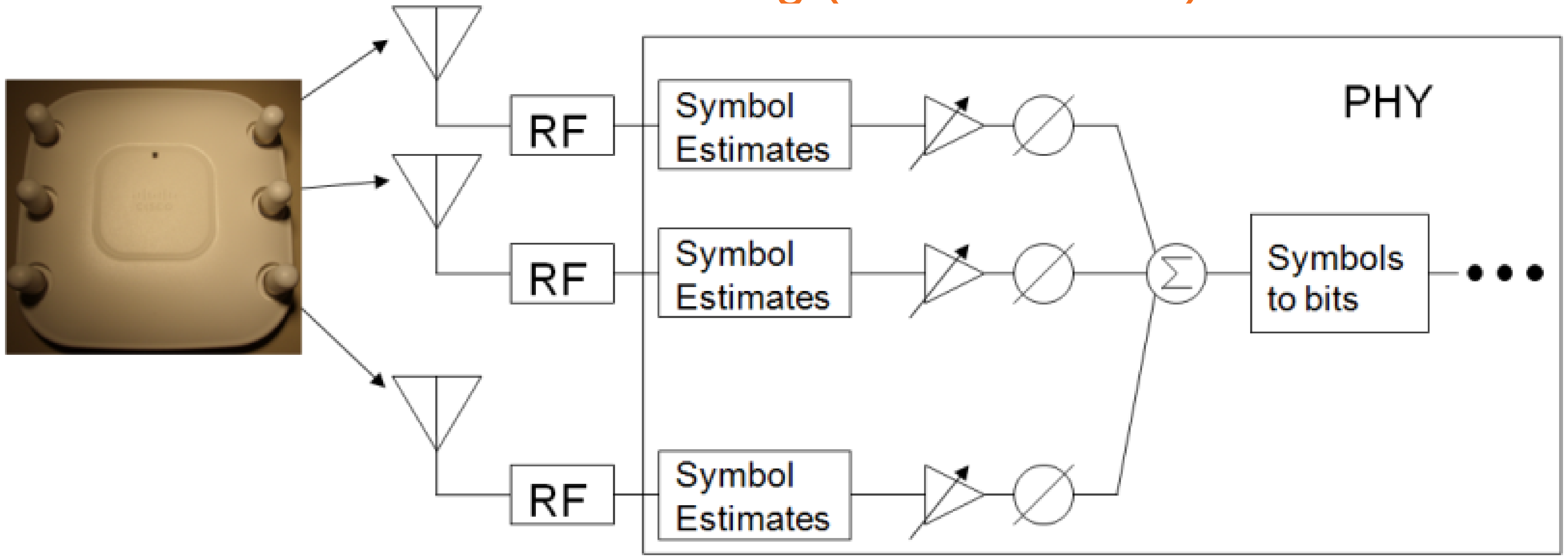


Cisco 802.11a/b/g Access Points start off favoring the right (primary antenna port) then if multi-path or packet retries occur it will sample the left port and switch to that antenna port if the signal is better.

Note: Diversity Antennas should always cover the same cell area

Understanding Diversity (MIMO)

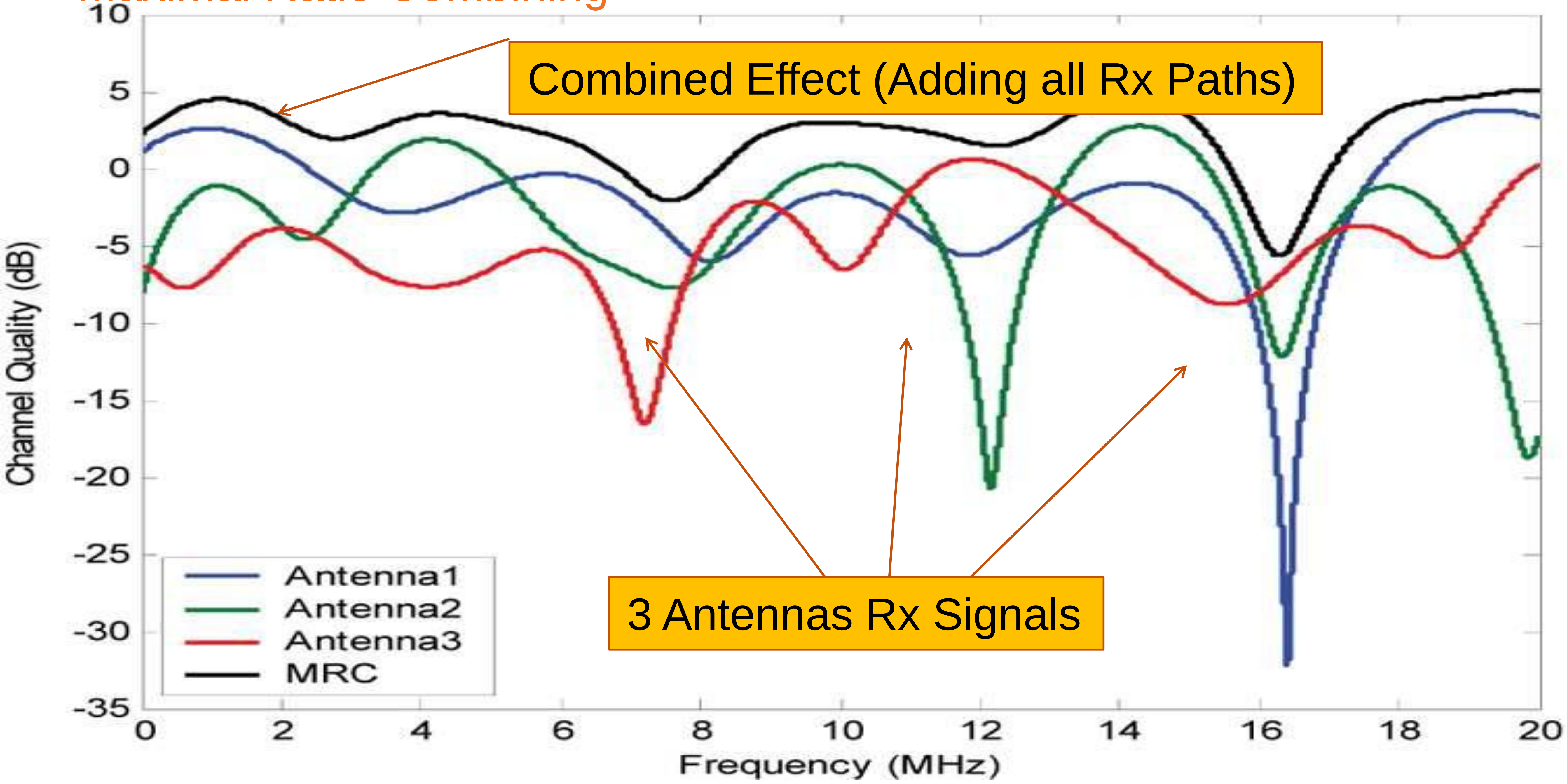
MRC Maximal Ratio Combining (Three Radios)



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

MRC Effect on Received Signal

Maximal Ratio Combining

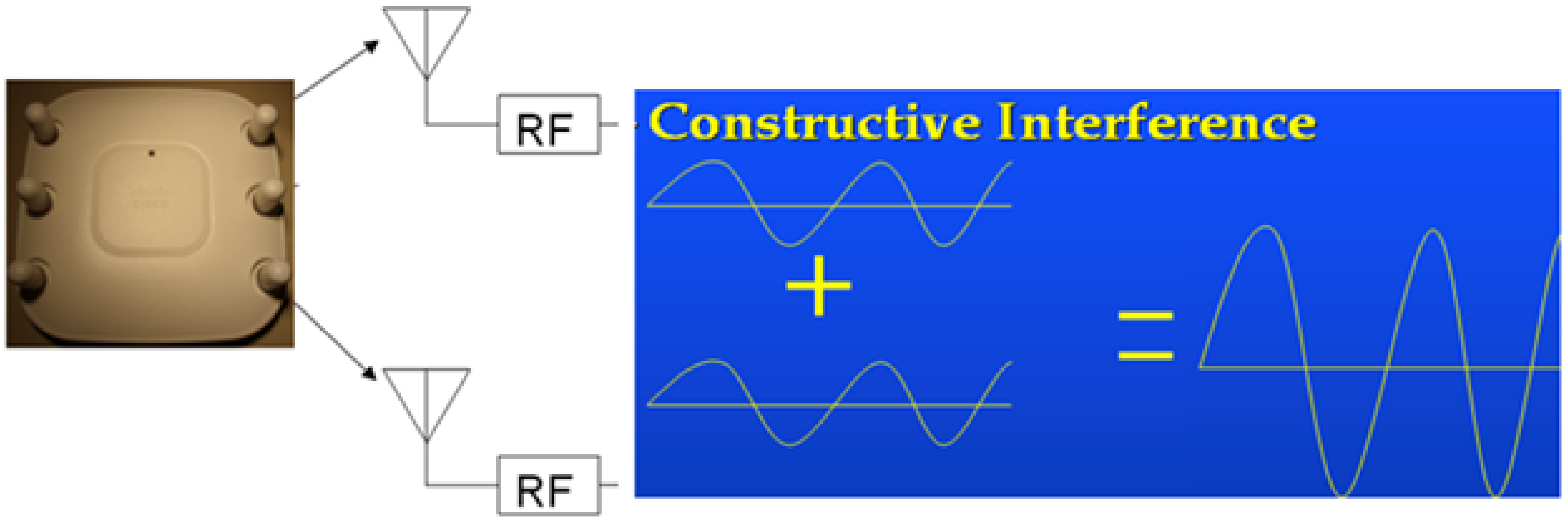


Understanding Client Link 1.0 & 2.0

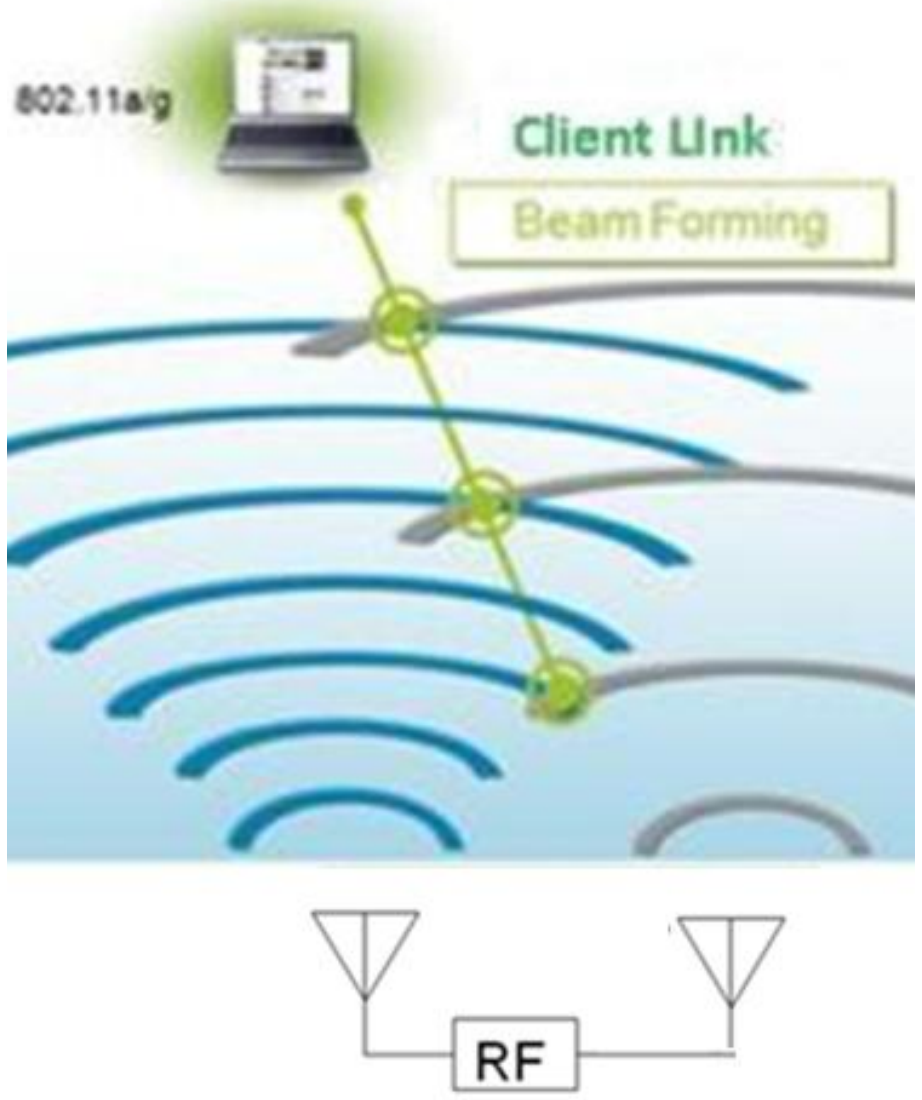
Why You Want to Beamform to the Client

Beam-forming allows the signal to be best directed towards the client
(for illustration purposes – please do not place antennas like this ☺)

Simple Example of Beamforming



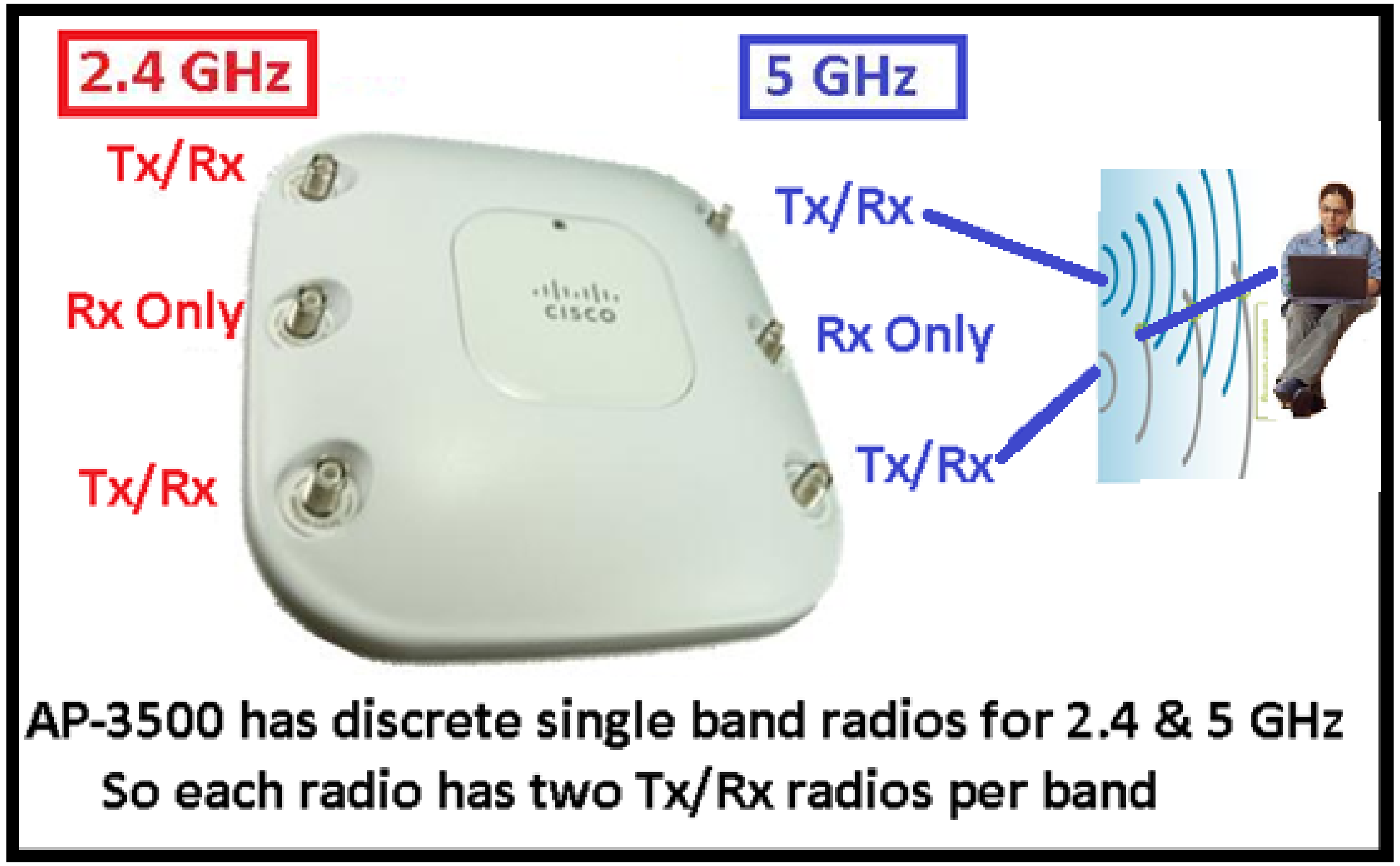
By changing the timing (phase) of the two transmitters, you can create a stronger signal (constructive interference) so the client can hear it better



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

Beamforming:

ClientLink 1.0 (Introduced in AP-1140)



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

<u>Each radio band is separate</u> allowing Two transceivers (Tx/Rx) per band to be used at a time (2.4 or 5 GHz)

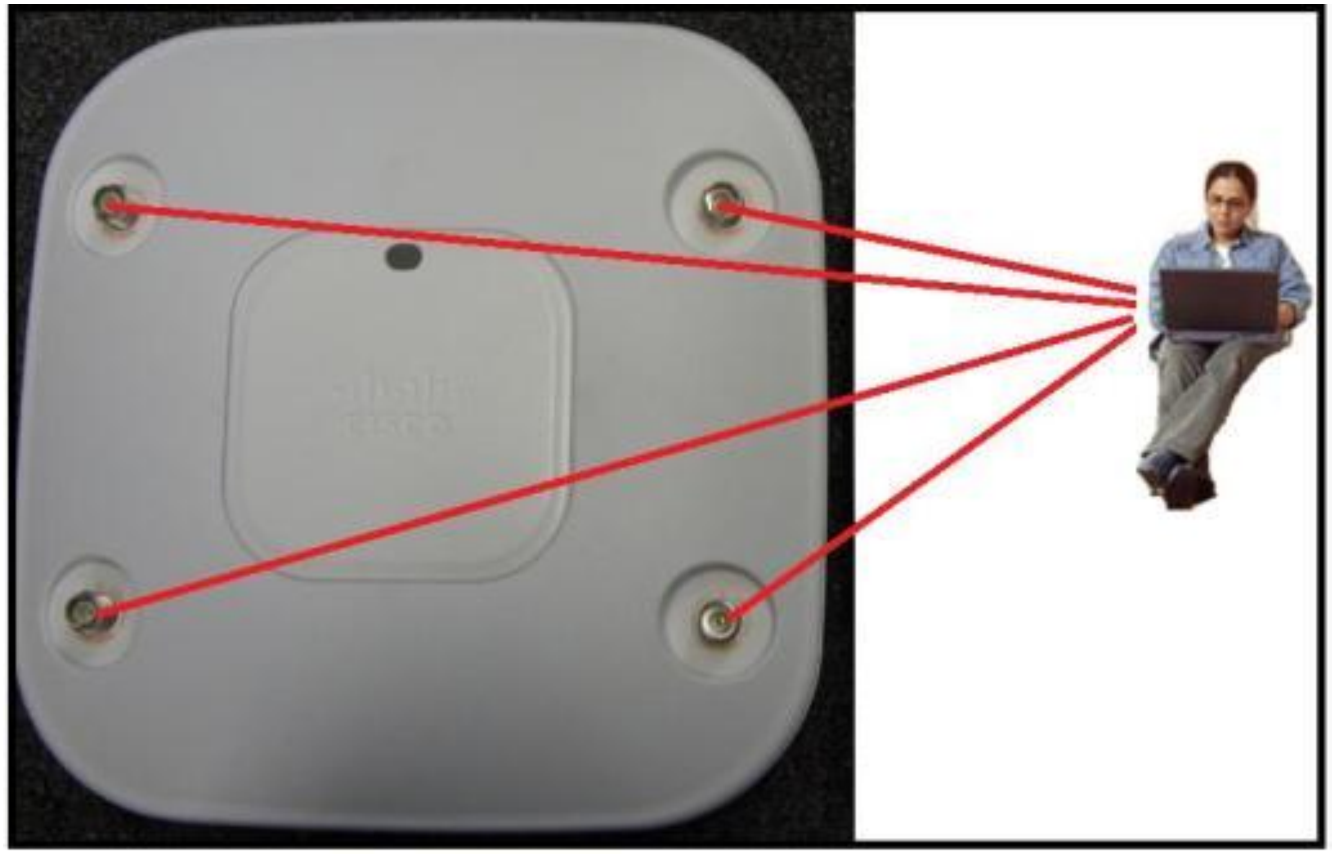
This two transceiver design allows for beam-forming to legacy clients 802.11a/g - this is called Client Link.

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

Note: Client Link 1 & 2 works on the <u>DOWNLINK</u> (AP to CLIENT)

AP-3600 Series with ClientLink 2.0

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



This new AP has four transceivers per band and all the antennas are used in the Client Link 2.0 beam-forming process

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

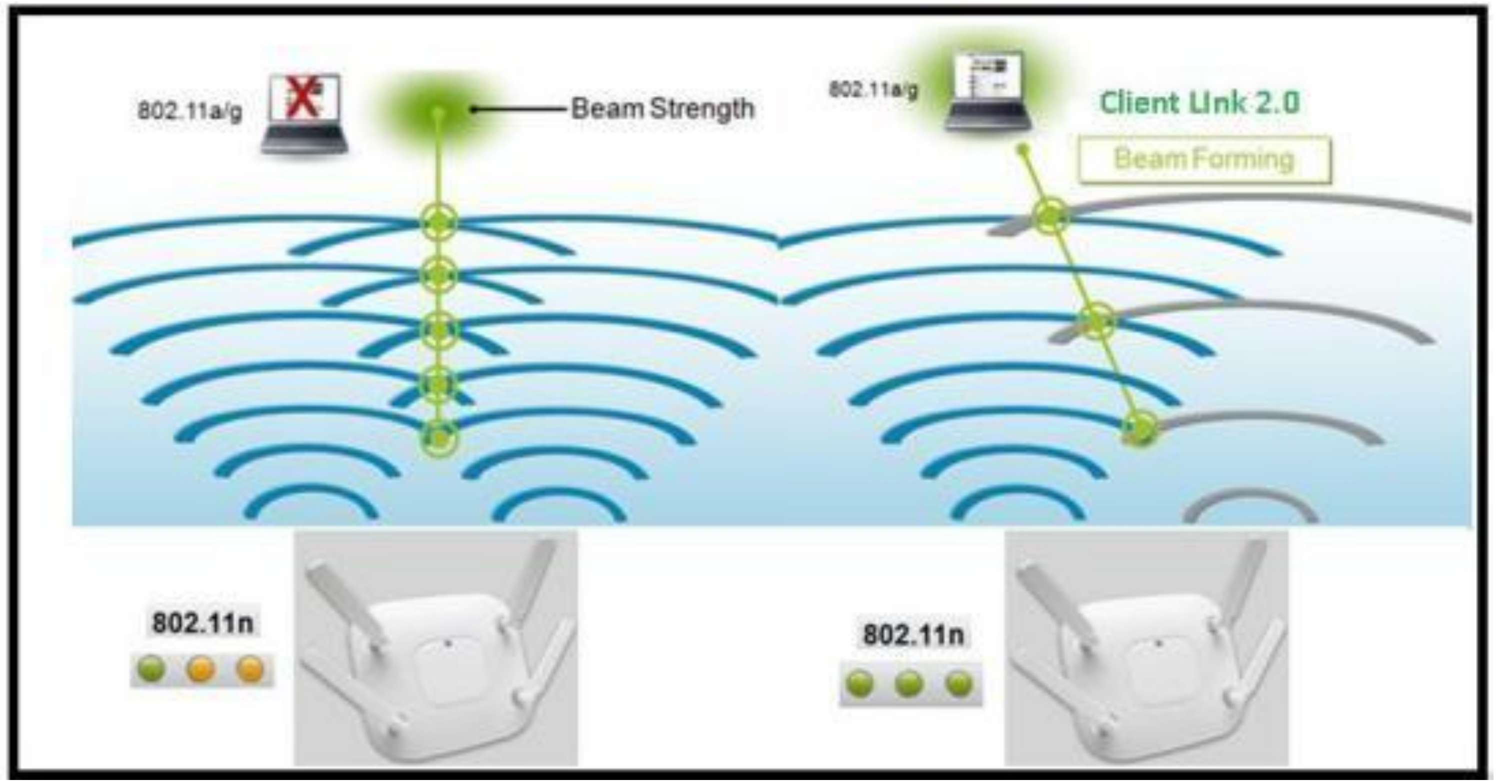
The newer AP-3600 fully supports Cisco Client Link 2.0 (beam-forming to 802.11a/g/n clients) not just legacy a/g but .11n @ 1ss, 2ss and 3ss improving all client devices (up to 128 clients per radio)

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

Cisco live!

Understanding Multipath and Beamforming

Why You Want More Receivers and Client Link 2.0



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

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

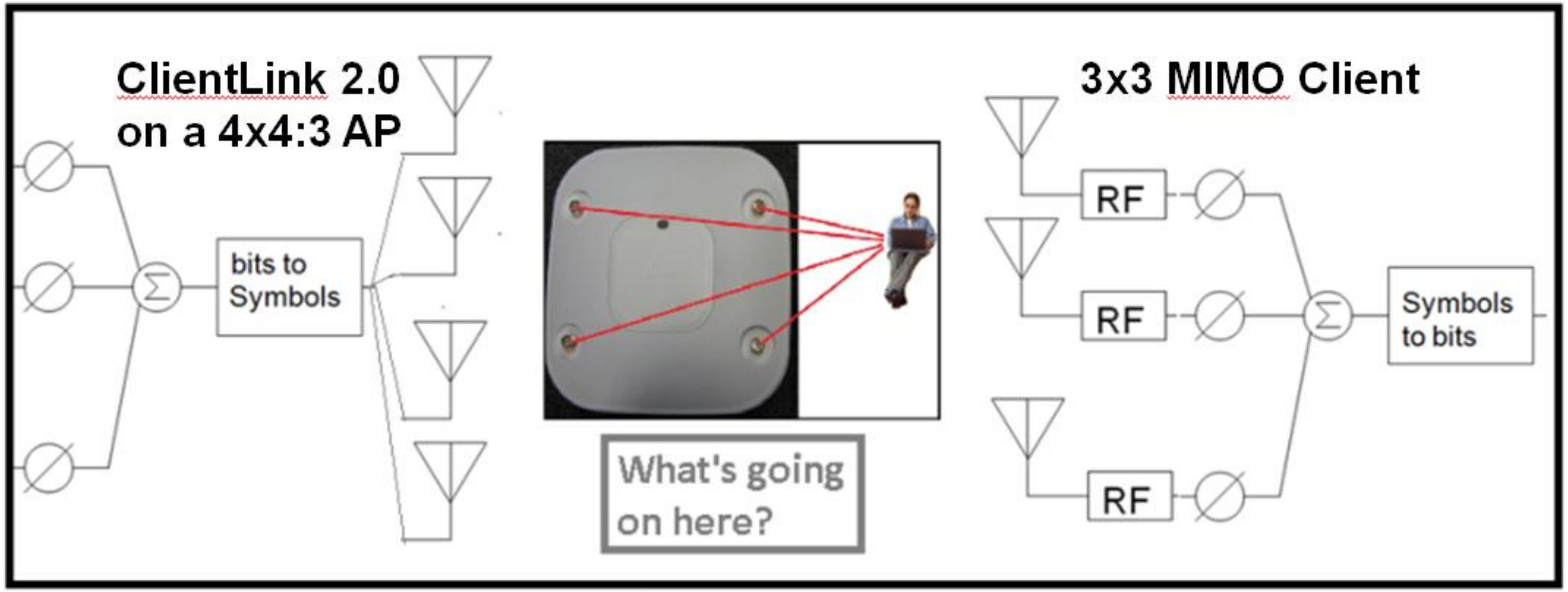
The AP-3600 supports three spatial streams with four transceivers for even greater performance and then adds Client Link 2.0 enhancements

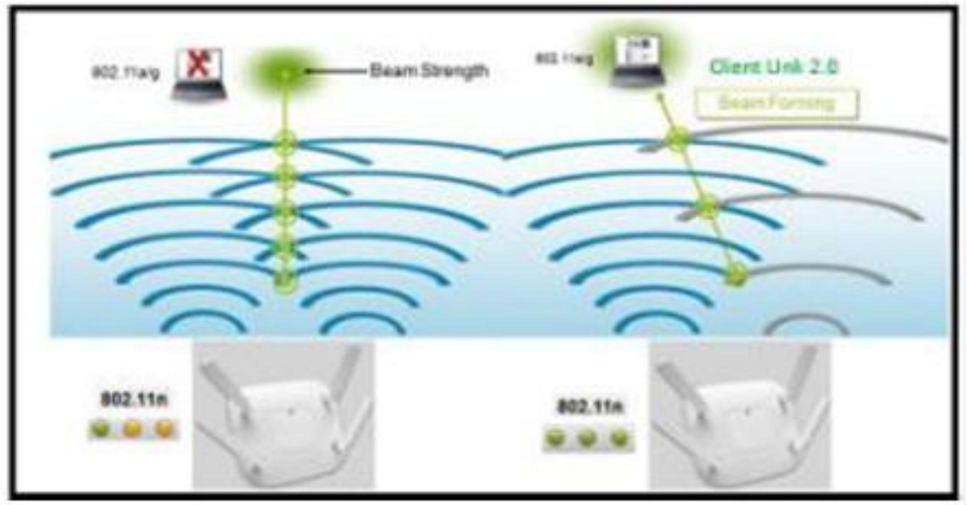
Client Link 2.0 benefits 802.11a/g/n 1-SS, 2-SS and <u>3-SS clients</u>

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

Understanding ClientLink 2.0 Beamforming:

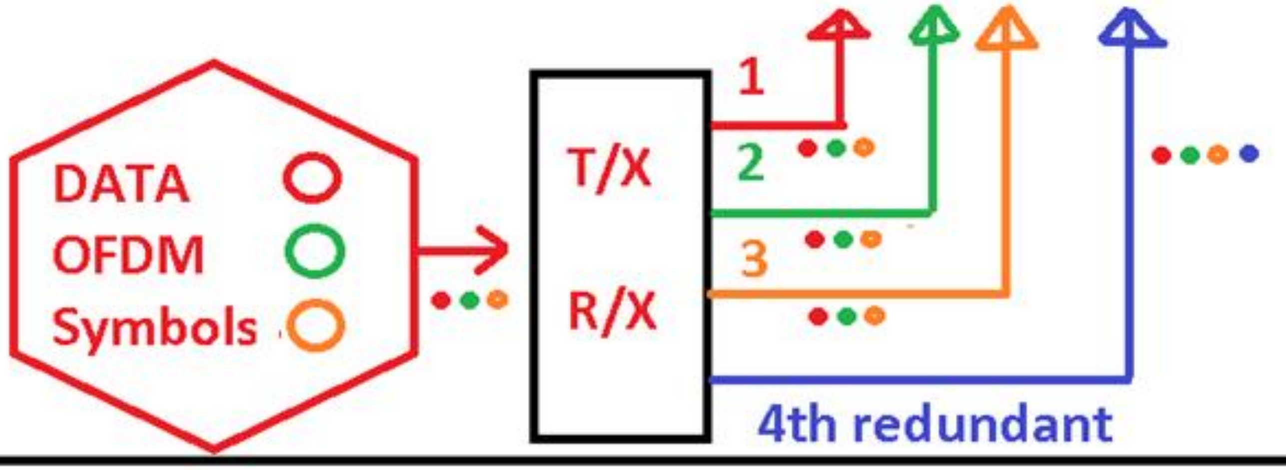
Full Picture





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

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



Understanding 802.11 MIMO Terminology

MIMO (Multiple-Input-Multiple-Output)

For Your Reference

Some RF components of 802.11n include:

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

TxBF – Transmit beam forming – The ability to transmit independent and separately encoded data signals, so-called "streams" from each of the multiple transmit antennas.

Channel Bonding – Use of more than one frequency or channel for more bandwidth.

Spatial Multiplexing – A technique for boosting wireless bandwidth and range by taking advantage of multiplexing which is the ability within the radio chipset to send out information over two or more transmitters known as "spatial streams".

Note: Most Cisco 802.11n Access Points utilise two transmitters and three receivers per radio module
Note: The 3600 AP uses 4 Transmitters and 4 Receivers.

MIMO is pronounced "My Moe" not "Me Moe"

Suggested Guidelines on Channel Bonding

20 MHz mode is suggested if…

– you have lots of voice clients.

– you have lots of non-11n capable 5 GHz clients

– you will be deploying a transition of mixed 11a & 11n infrastructure:

40 MHz (Bonded channel) mode is suggested if…

– You have few voice clients (less than 10 per AP)

– You expect to have predominantly 11n clients that support 40 MHz operation.

– You are doing bandwidth-intensive file transfers such as video downloads, wireless backups, etc.

MCS Index of 802.11n Rates

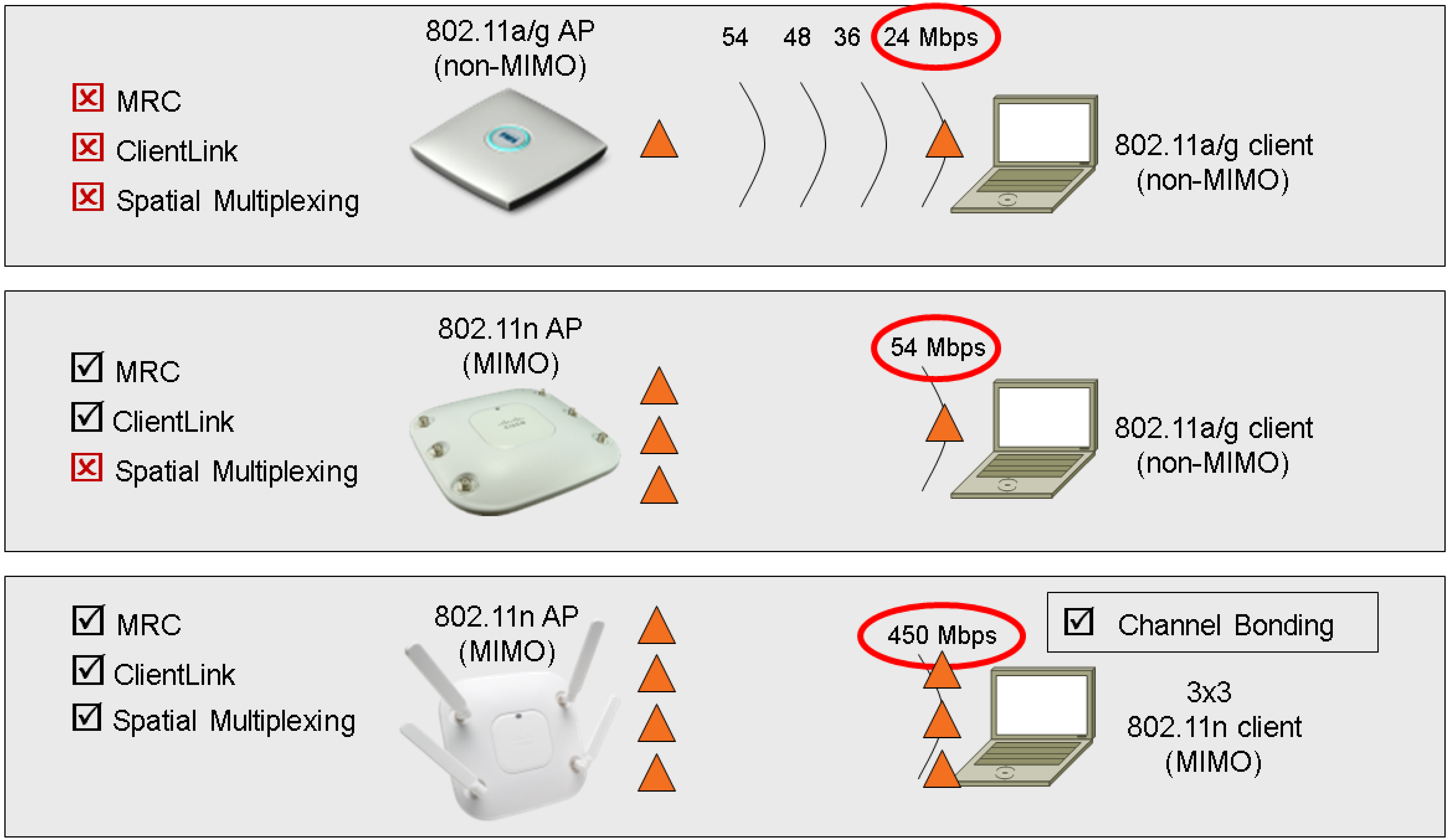
MCS	Coding	Modulation	Streams	Signal BW = 20 MHz		40 MHz	
				GI = 800 nS	GI = 400 nS	GI = 800 nS	GI = 400 nS
MCS0	1/2	BPSK	1	6.5	7.2	13.5	15
MCS1	1/2	QPSK	1	13	14.4	27	30
MCS2	3/4	QPSK	1	19.5	21.7	40.5	45
MCS3	1/2	16-QAM	1	26	28.9	54	60
MCS4	3/4	16-QAM	1	39	43.3	81	90
MCS5	2/3	64-QAM	1	52	57.8	108	120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

AP-3600 Supports 3 Spatial Stream MCS Rates

New

So to Recap: 802.11n Operation

Throughput Improves When All Things Come Together



Access Points and Features

Integrated Antenna? – External Antenna?

Carpeted areas

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

Rugged areas

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

When to Use Integrated Antennas

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

When to Use External Antennas

Reasons to consider deploying a rugged AP

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

Rugged AP in ceiling enclosure

Outdoor–rated APs Used for Indoor Applications

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

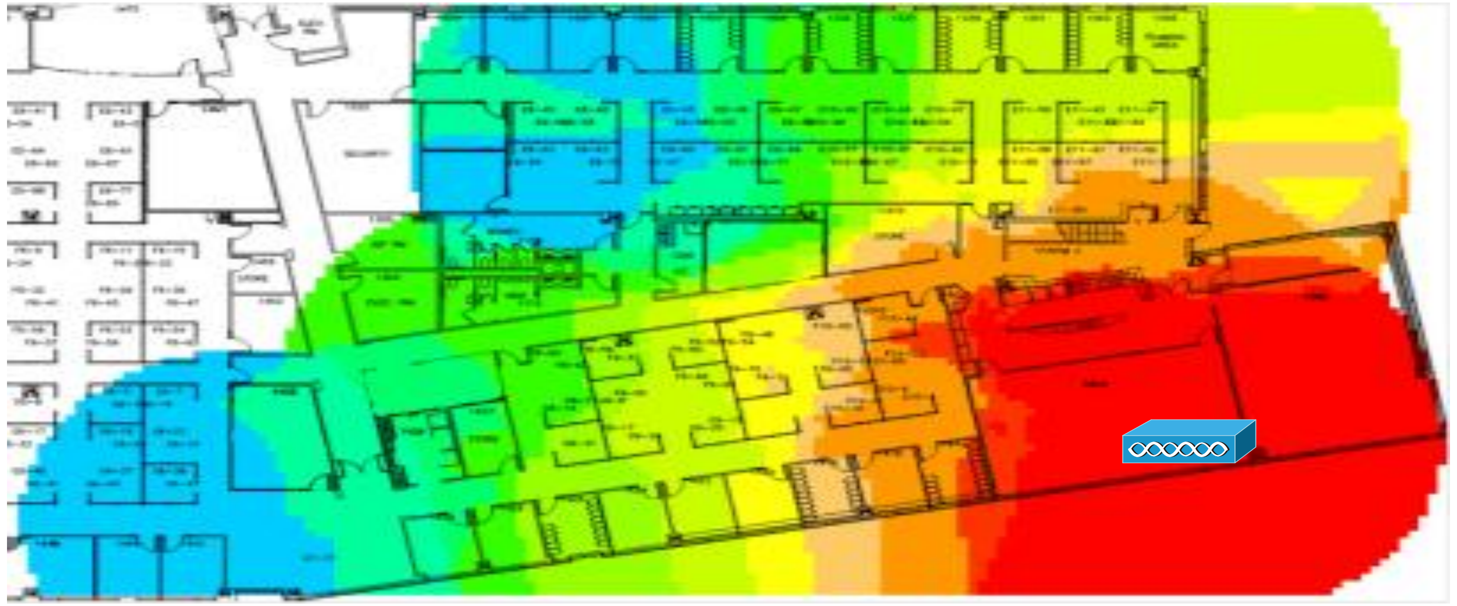
1552e +

Dual Band Omni
AIR-ANT2547V-N=

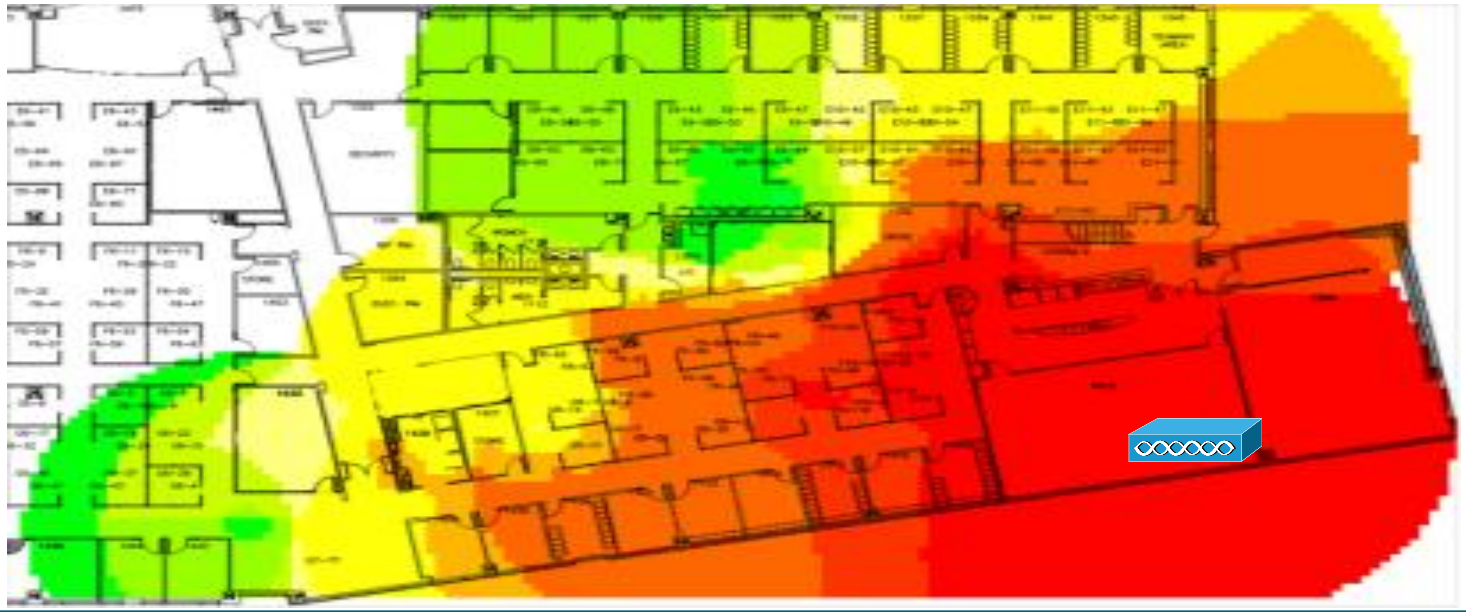
1552i (Integrated Ant)

Coverage Comparison – 5GHz up to MCS15

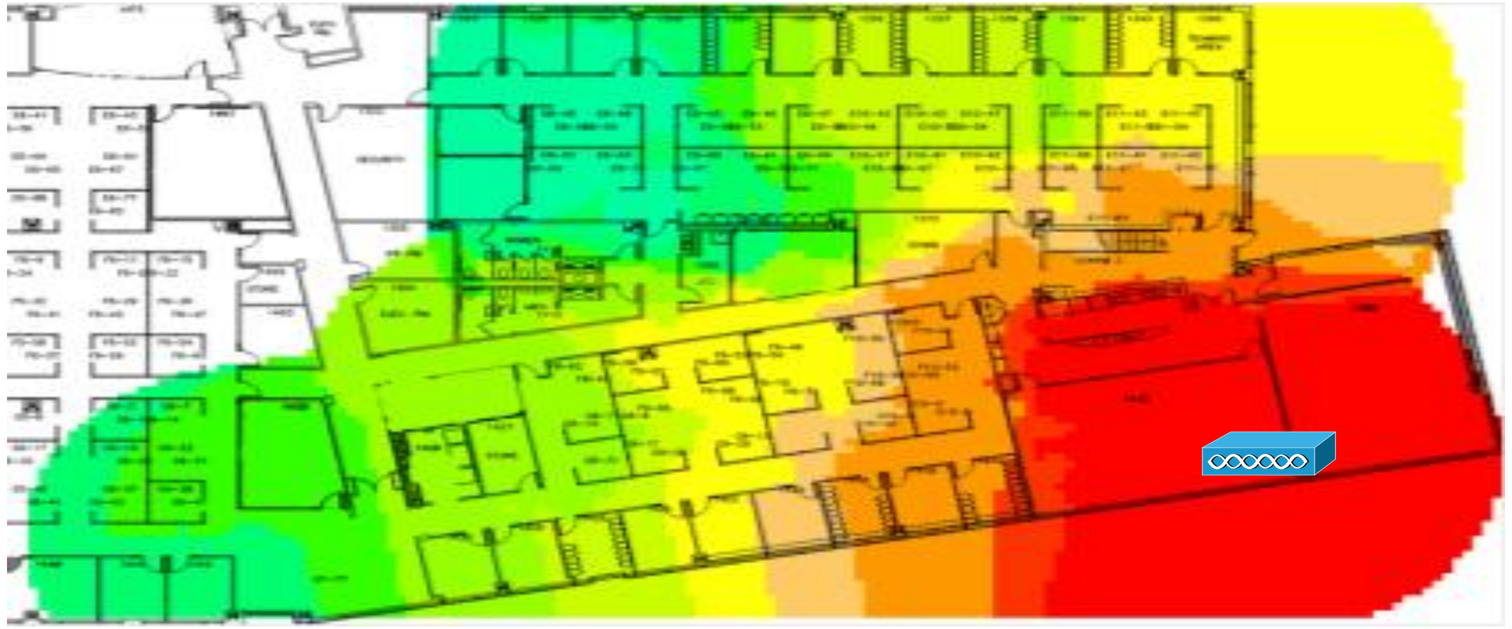
AP 1140



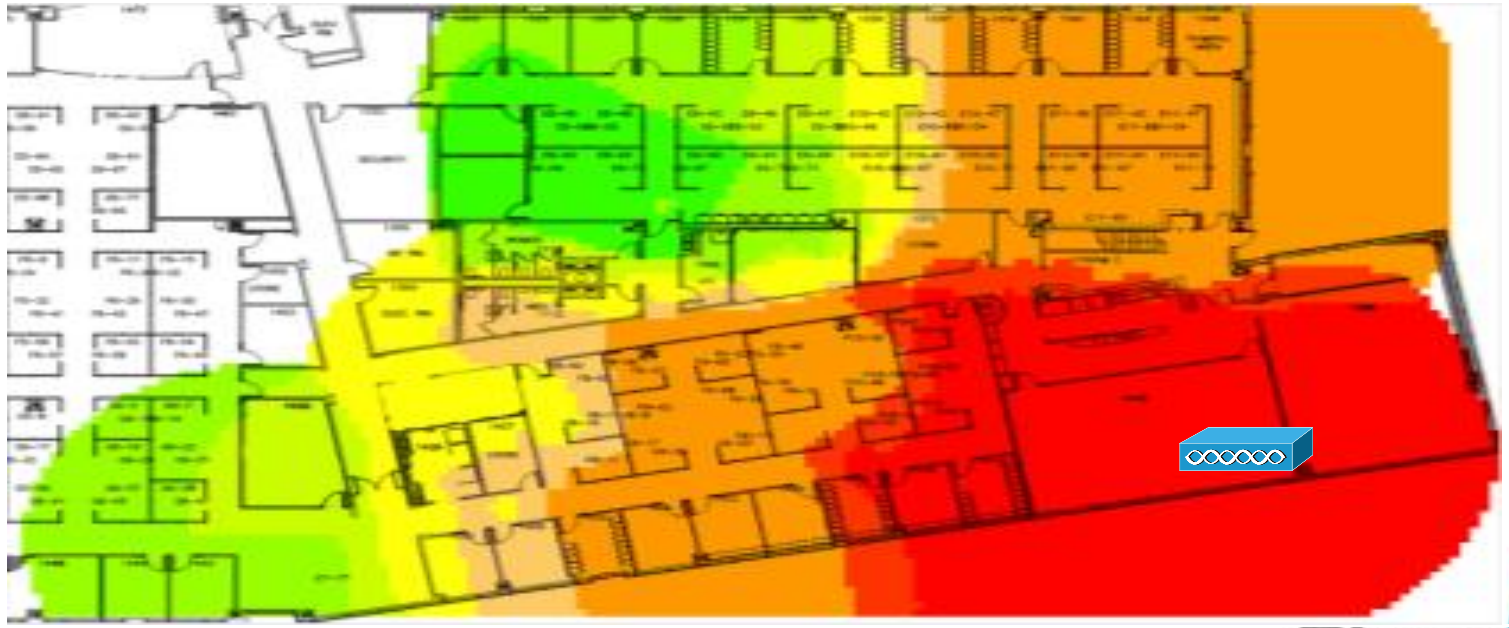
AP 3600 (4 dBi)

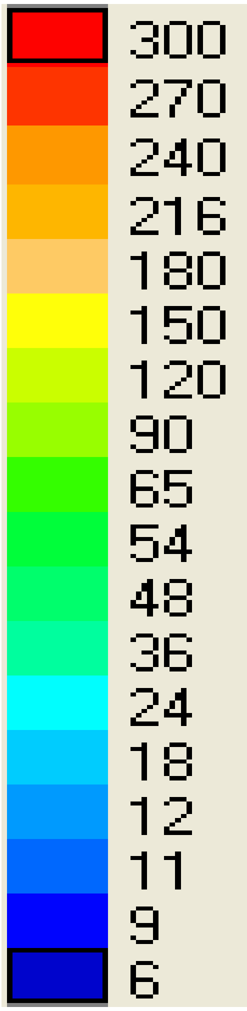


AP 3500i



AP 3500e (3.5 dBi)

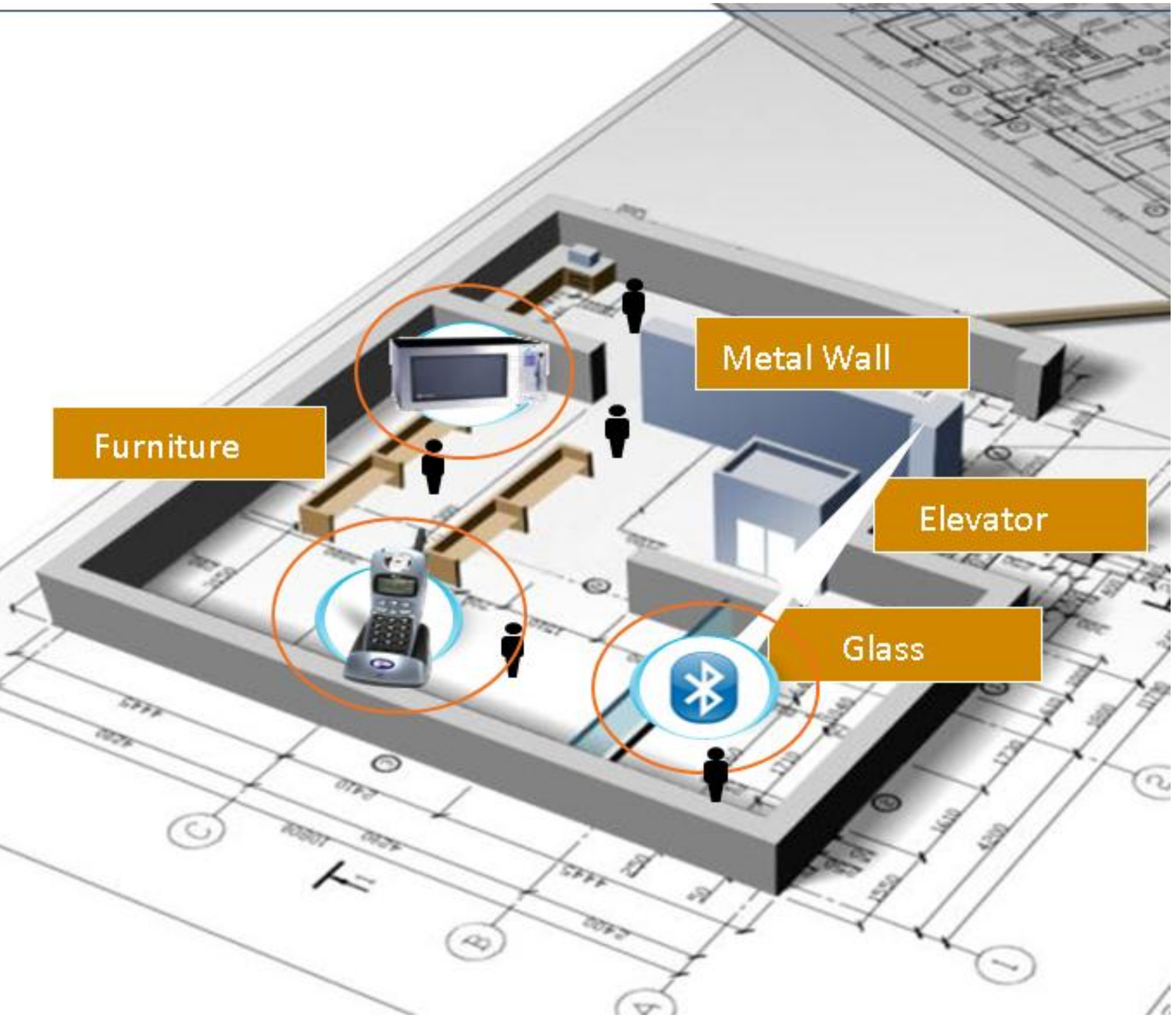




Installation and Deployment Considerations

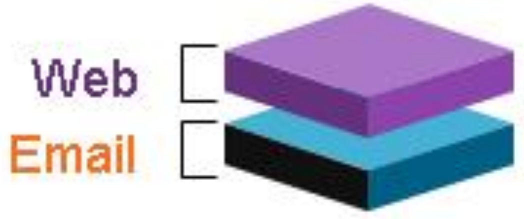
Site Survey Prepares for 802.11n

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

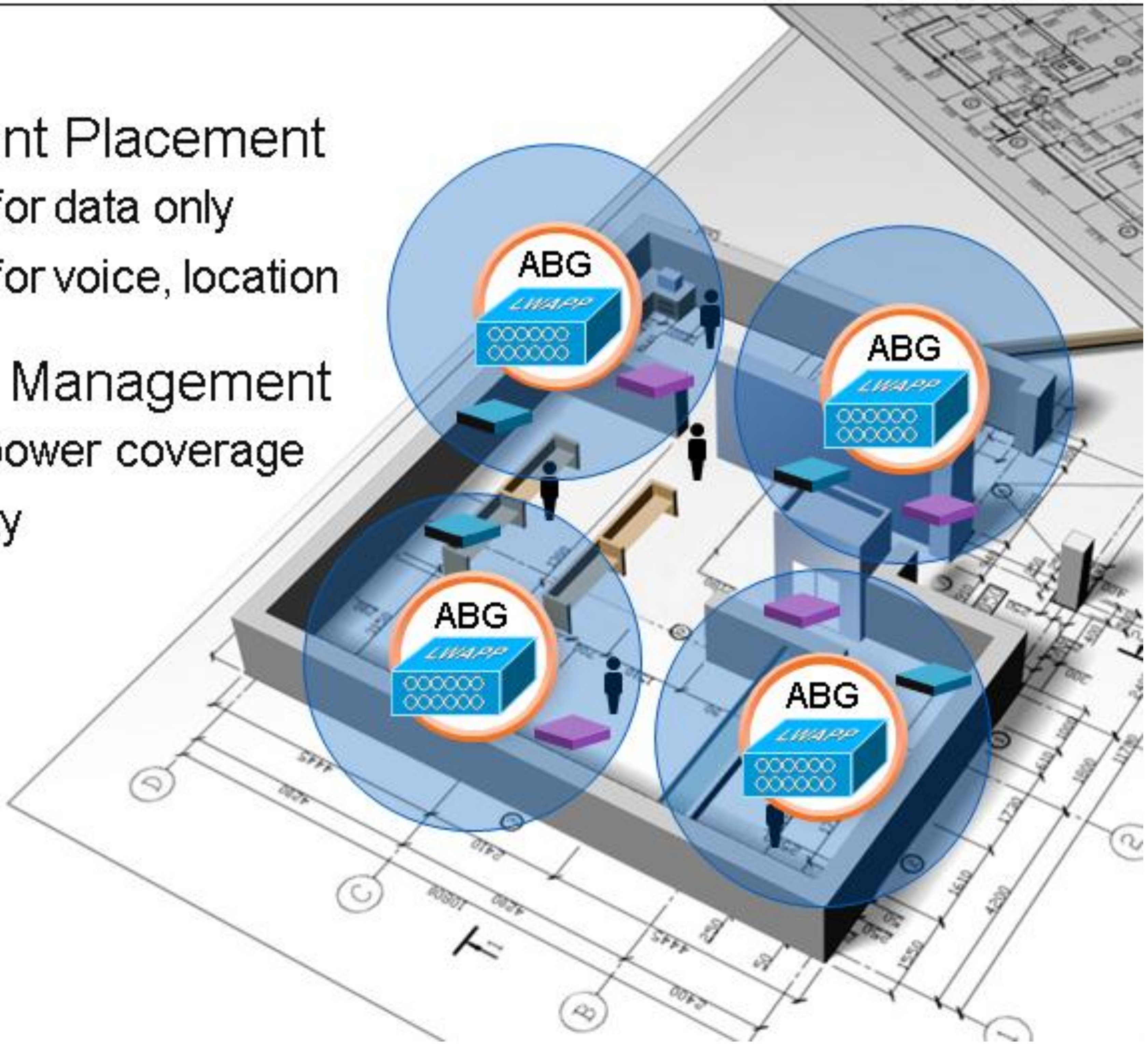


Access Point Placement (Legacy a/b/g)

- **ABG Access Point Placement**
  - 1 per 5,000 sq feet for data only
  - 1 per 3,000 sq feet for voice, location
- **Radio Resource Management**
  - Adaptive channel / power coverage
  - Operational simplicity



Several Supported Apps

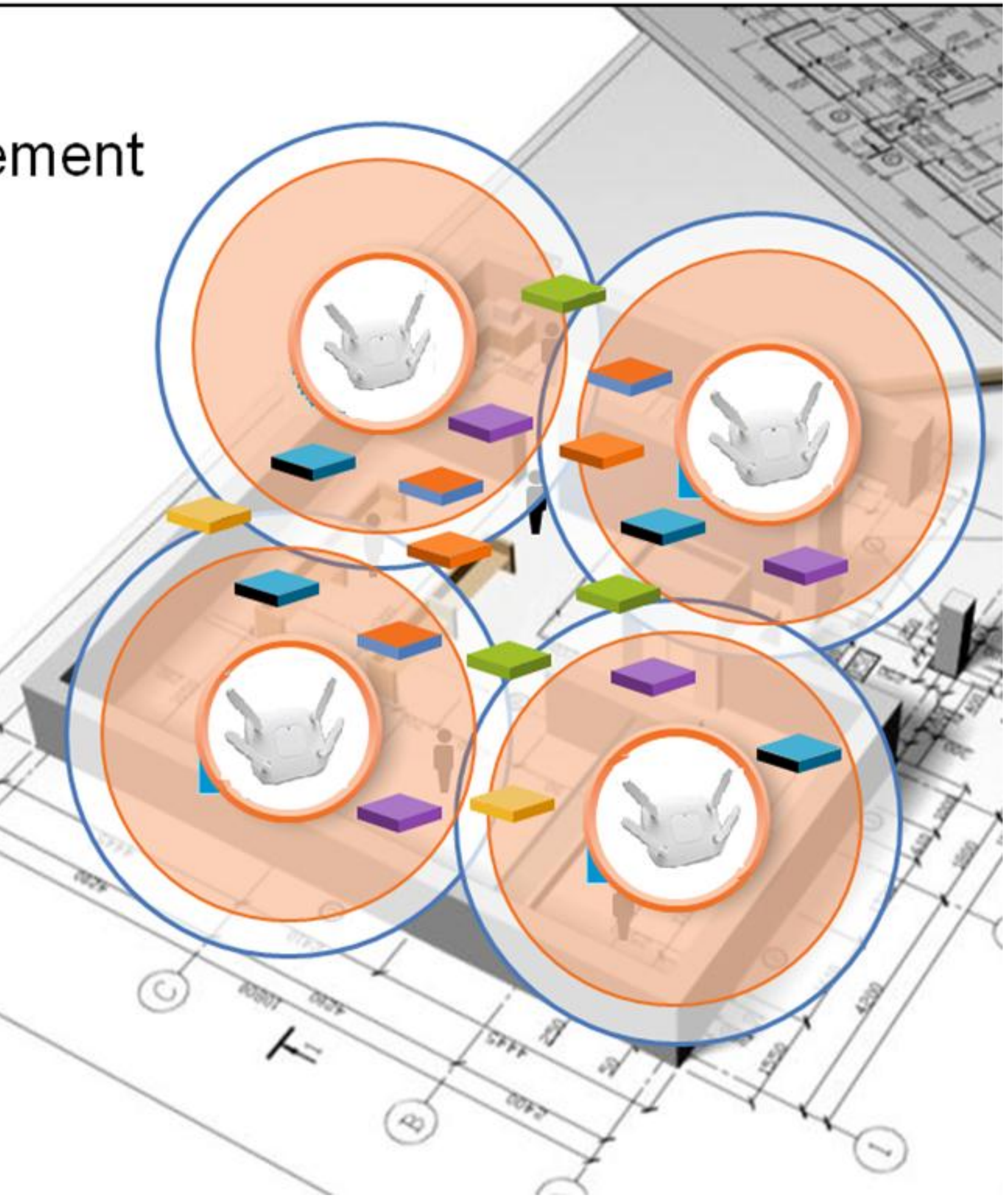


Access Point Placement (802.11n)

- .11n same 1 for 1 replacement
  Newer APs reuses existing Cisco AP bracket drill holes
- Improved coverage at higher data rates

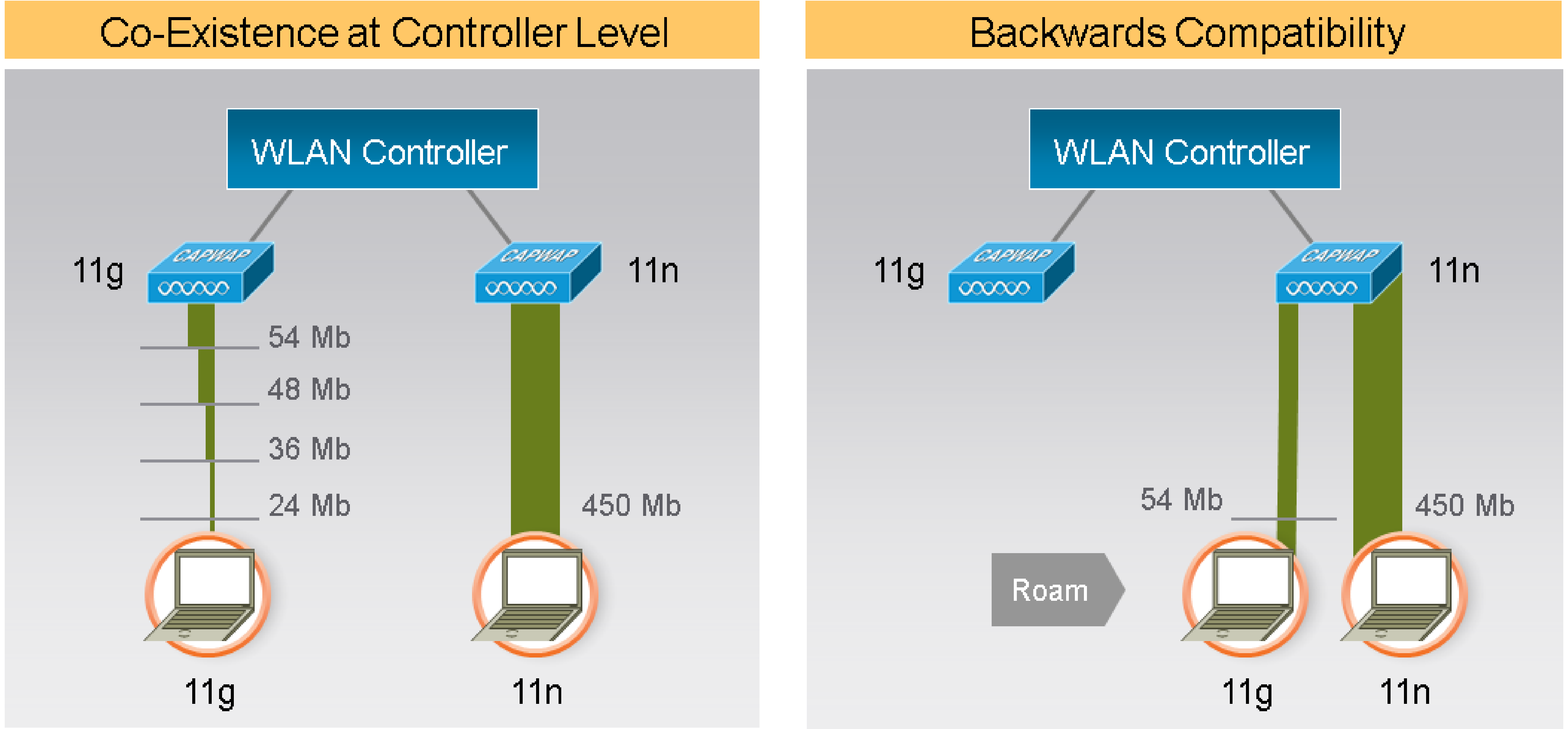
Supported Apps

802.11n is the same overlay however more applications supported at any given location

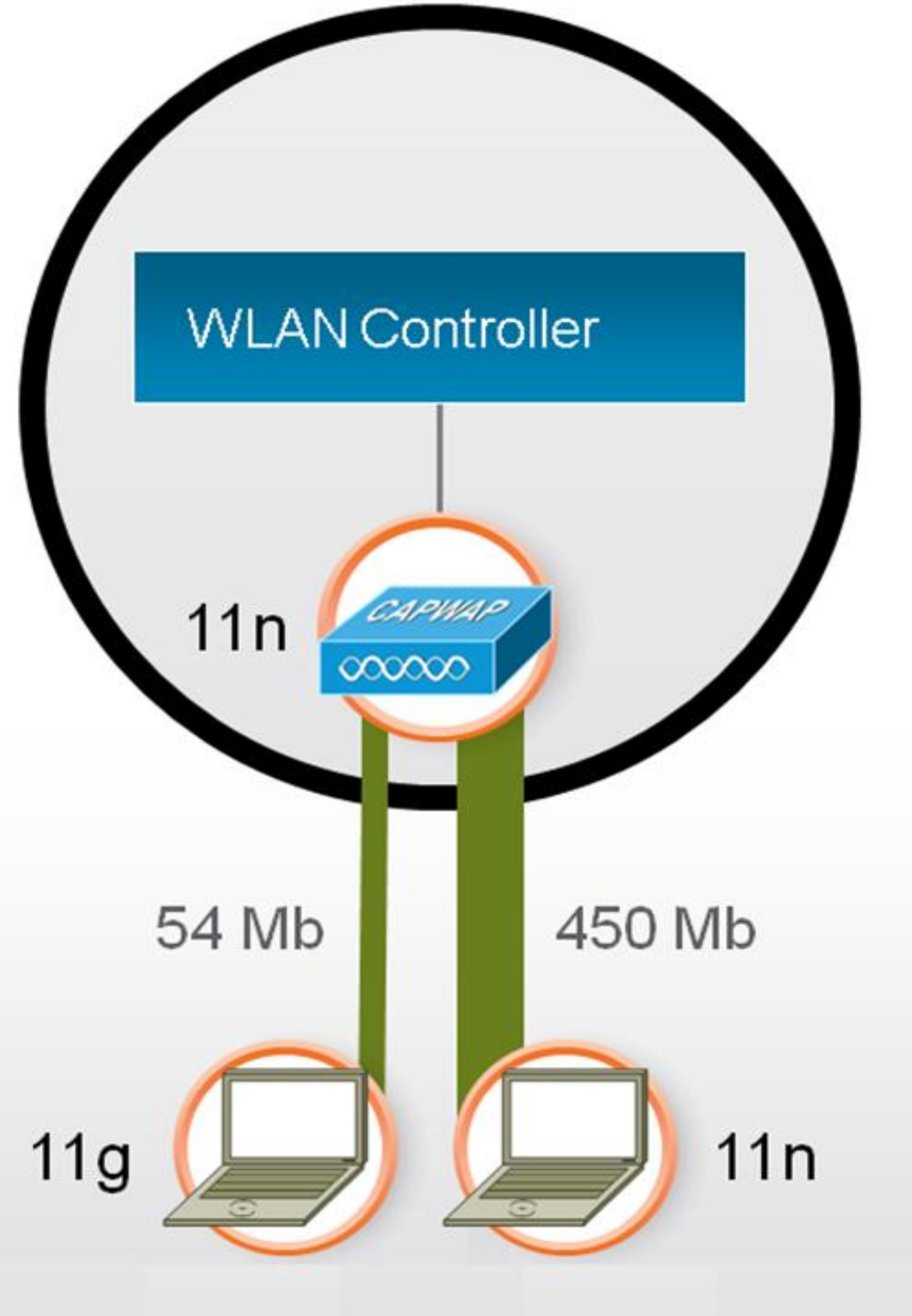


802.11n Support, Backward Compatibility and Co-existence

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



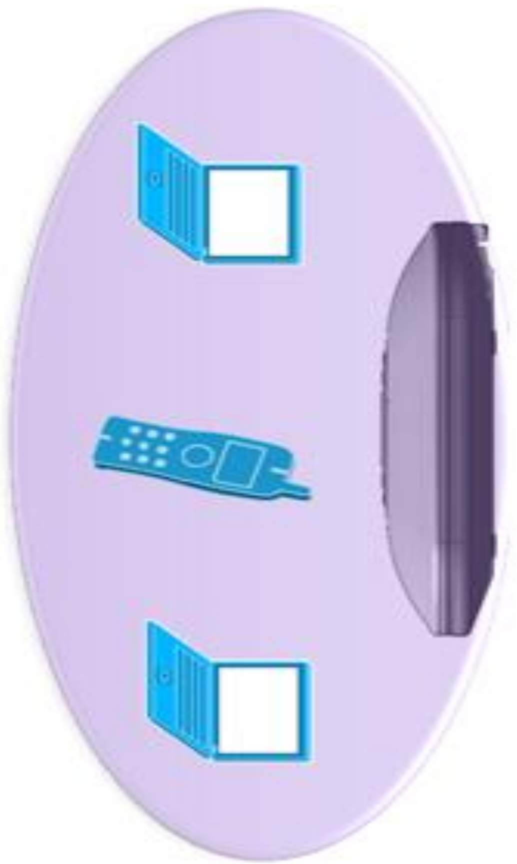
Mixed Mode Performance



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

Wall Mounting Access Point with Internal Antennas

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



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

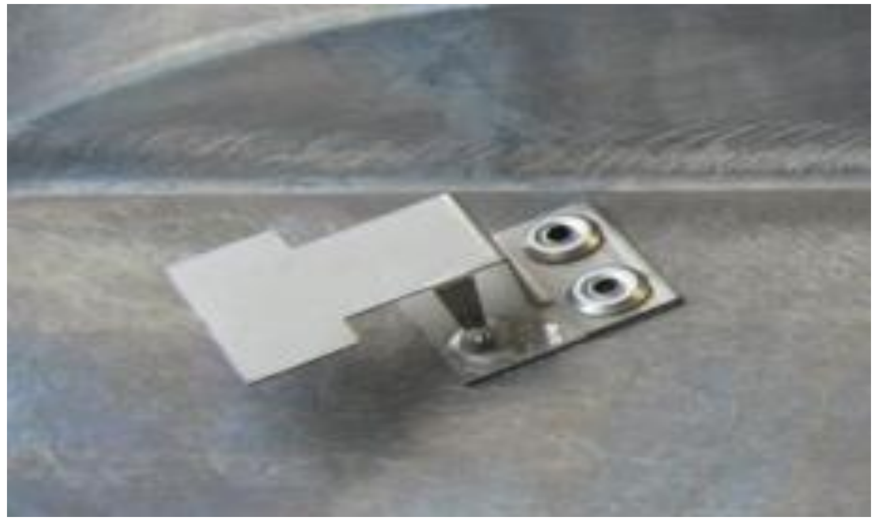
Coverage is always more uniform when installed on the ceiling tile or grid area

Access Points (Internal Antenna Models)

Designed Primarily for Ceiling (Carpeted) Installations

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

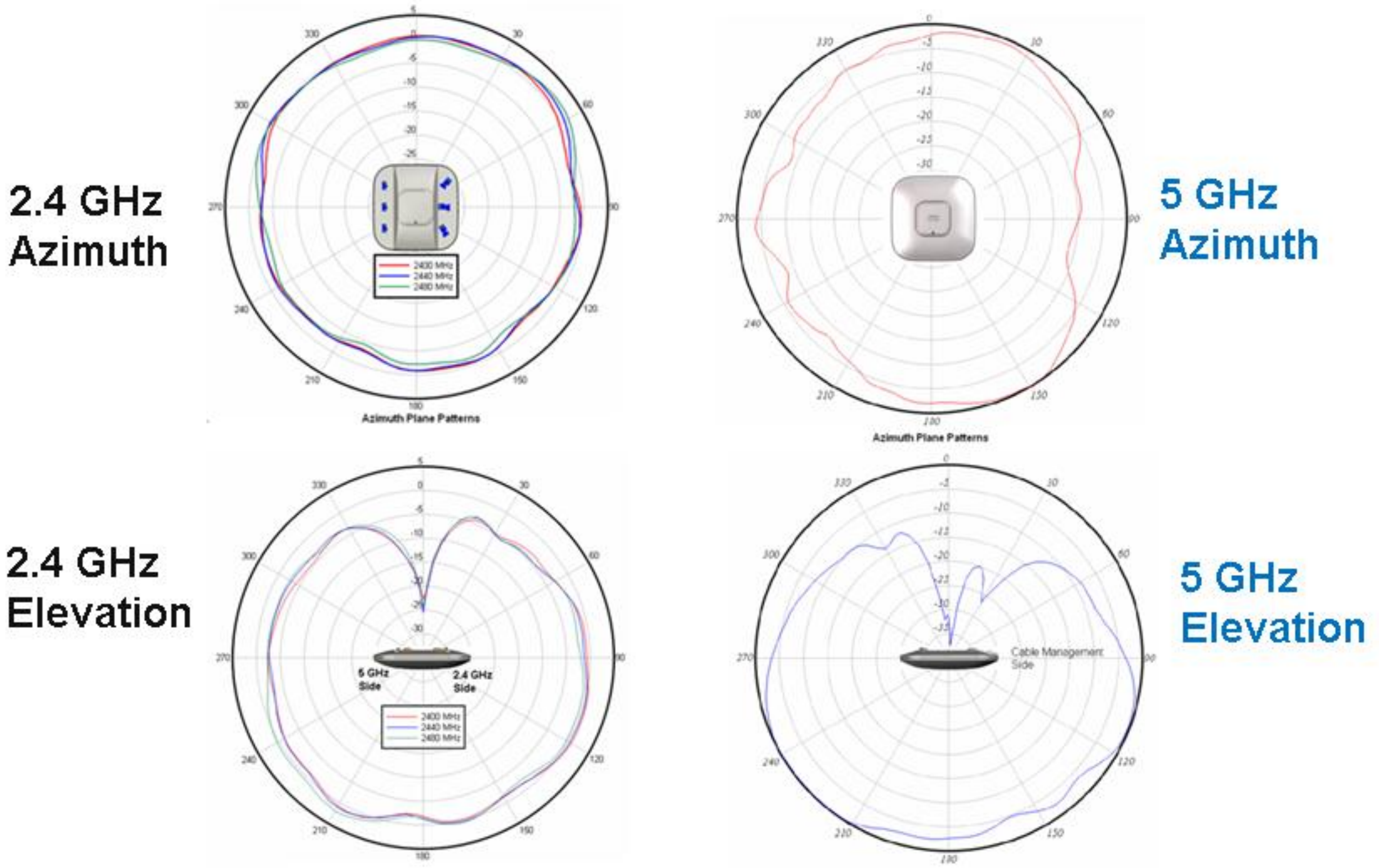
4 dBi @ 2.4 GHz
3 dBi @ 5 GHz



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

Antenna Patterns – Internal Access Points

Azimuth and Elevation Patterns for 2.4 GHz & 5 GHz



Wall mounting AP-1260, 3500e & 3600e

Orientation of the Dipoles if Wall Mounting

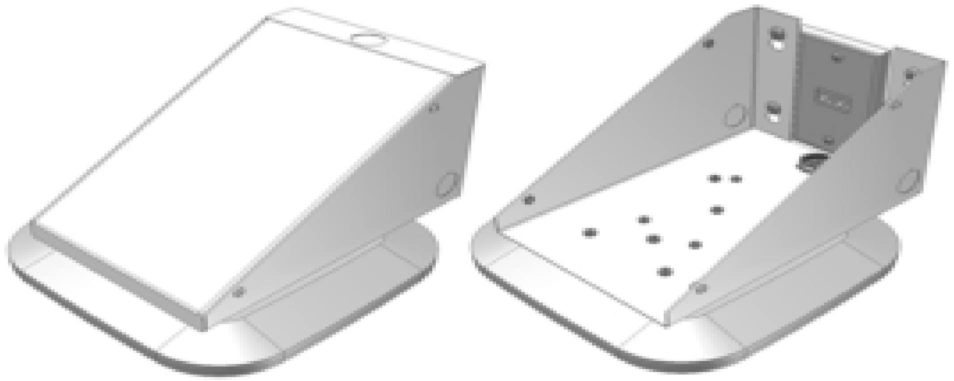
Note: The ceiling is usually higher and a better location for RF.

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

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

Aironet 802.11n Wall Mount (Style Case)

Third Party Wall Mount Option is Available



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

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

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

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

What About Mounting Options?

Different Mounting Options for Ceiling APs

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

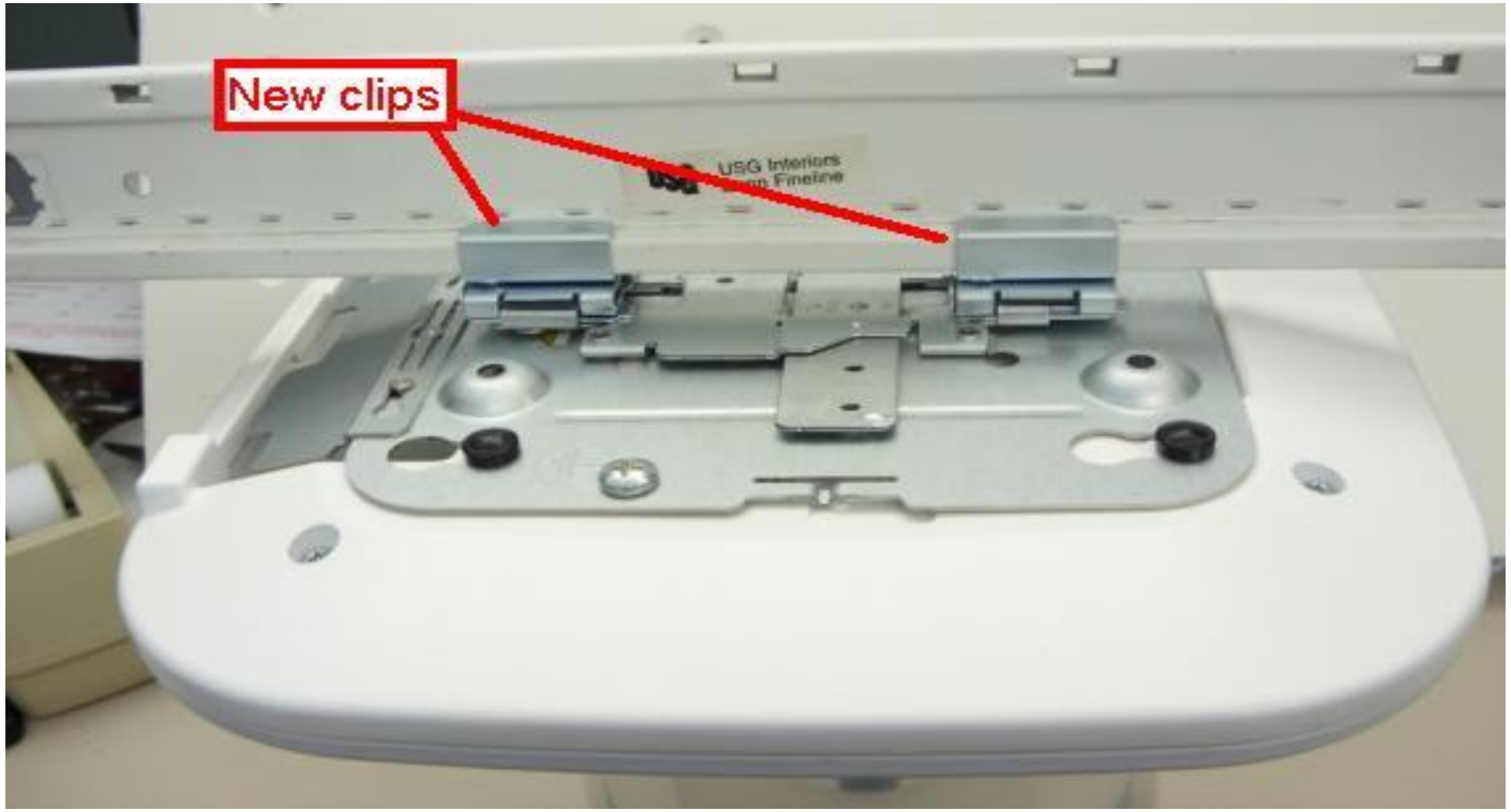
Locking enclosures and different colour plastic "skins" available from third party sources such as

www.oberonwireless.com

www.terrawave.com

Clips Adapt Rail to “T” Bracket.

Attaching to Fine Line Ceiling Rails



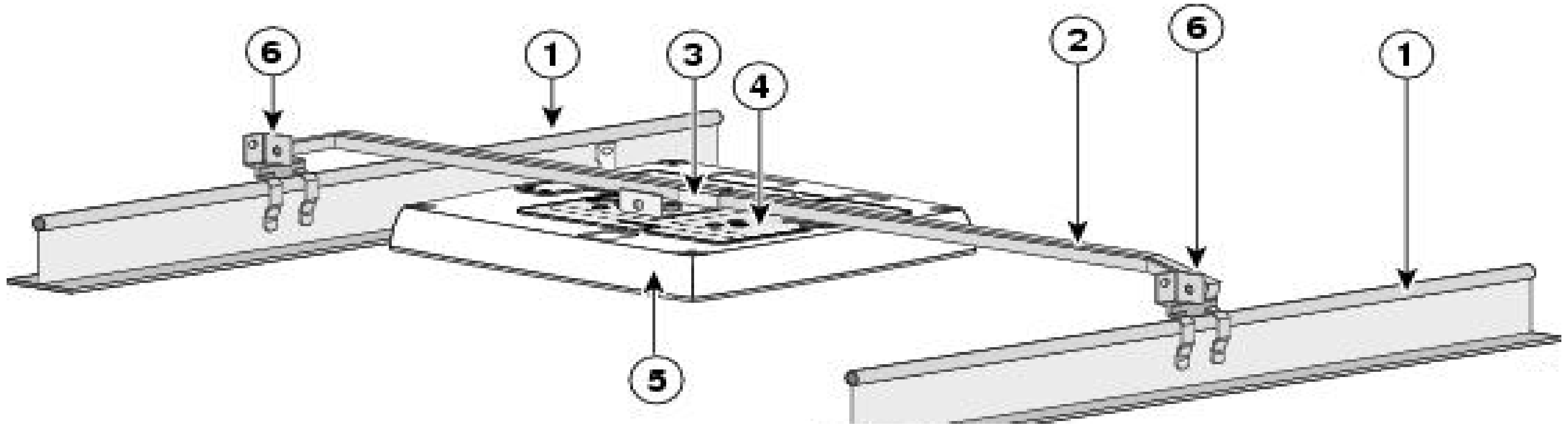
If the ceiling rail is not wide enough or too recessed for the “T” rail this can be addressed using the optional clips

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

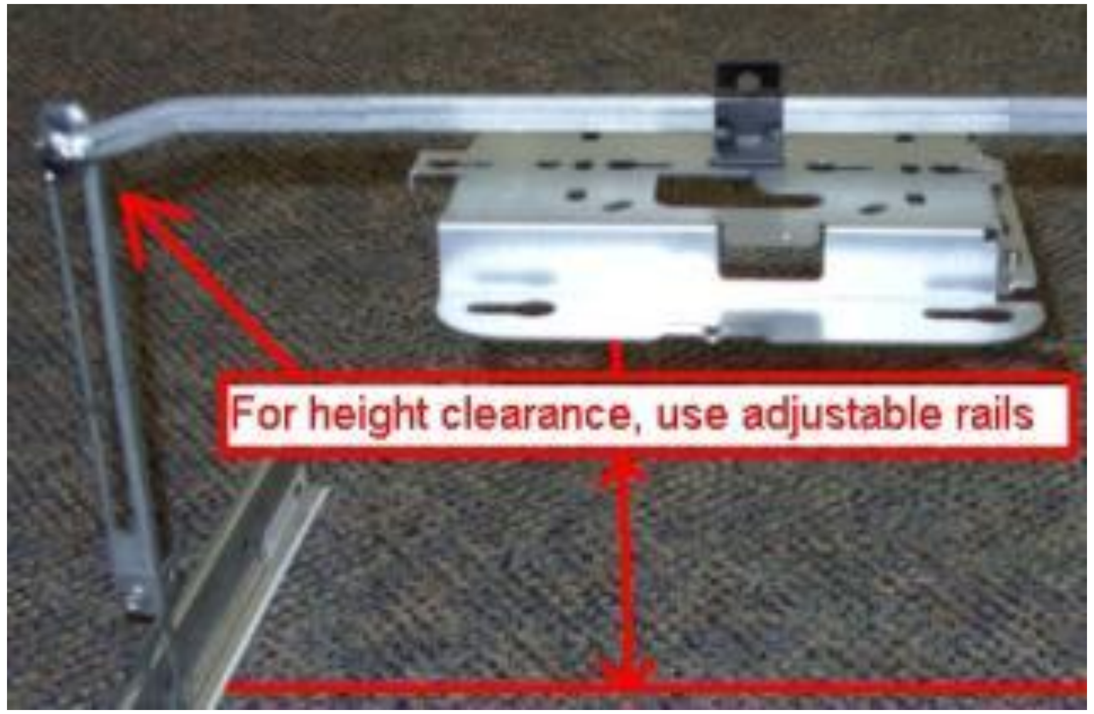
Installation above the Ceiling Tiles

An Optional Rail Above the Tiles May Be Used

T-Bar Grid Mounting Bracket Parts



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



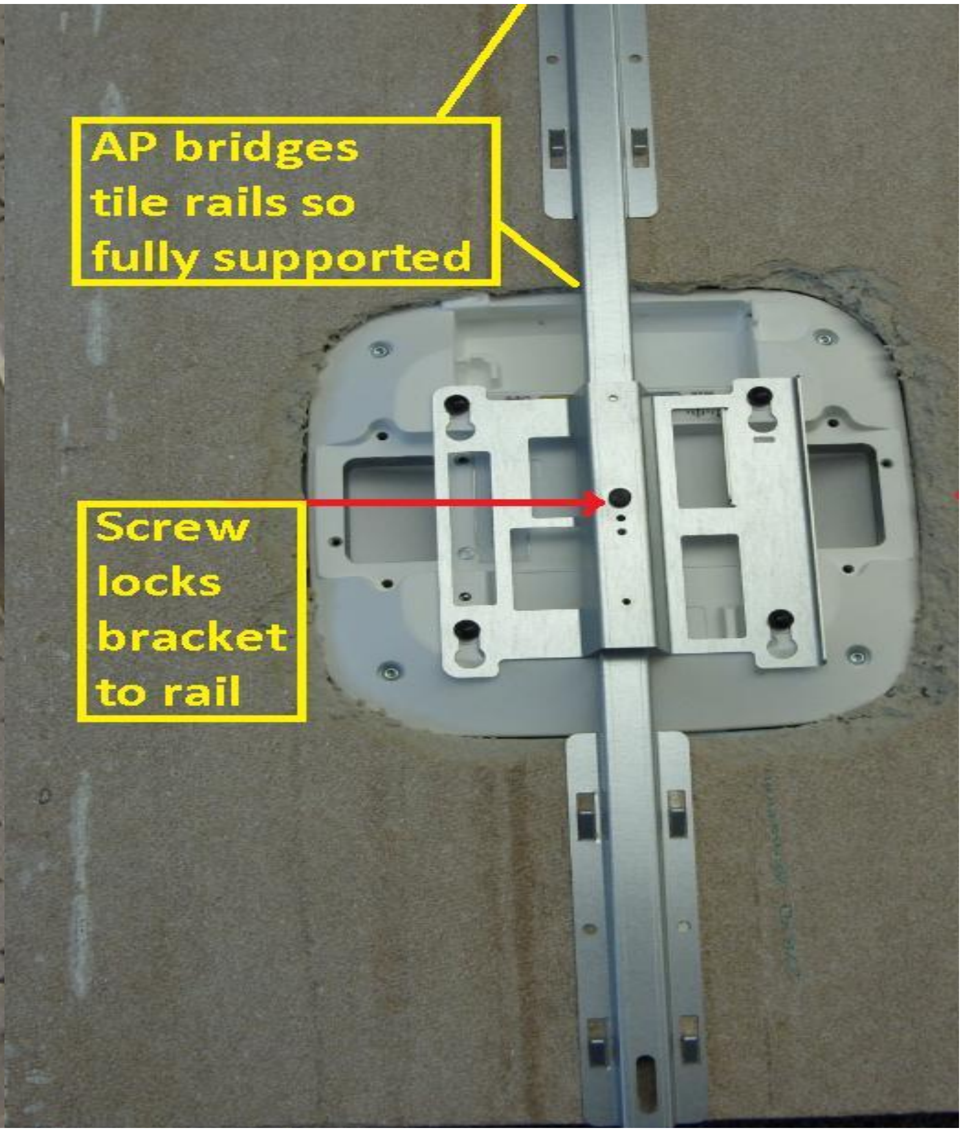
Note: The AP should be as close to the tile as practical

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

AP Placement Above False Ceiling Tiles Areas

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

Integrated Ceiling Mount – Public Areas



Flush mount bracket part number is <u>AIR-AP-BRACKET-3</u>
This is a <u>Cisco factory bracket</u> that can be specified at time of order
Full strut on right provides support across two ceiling rails (earthquake areas)

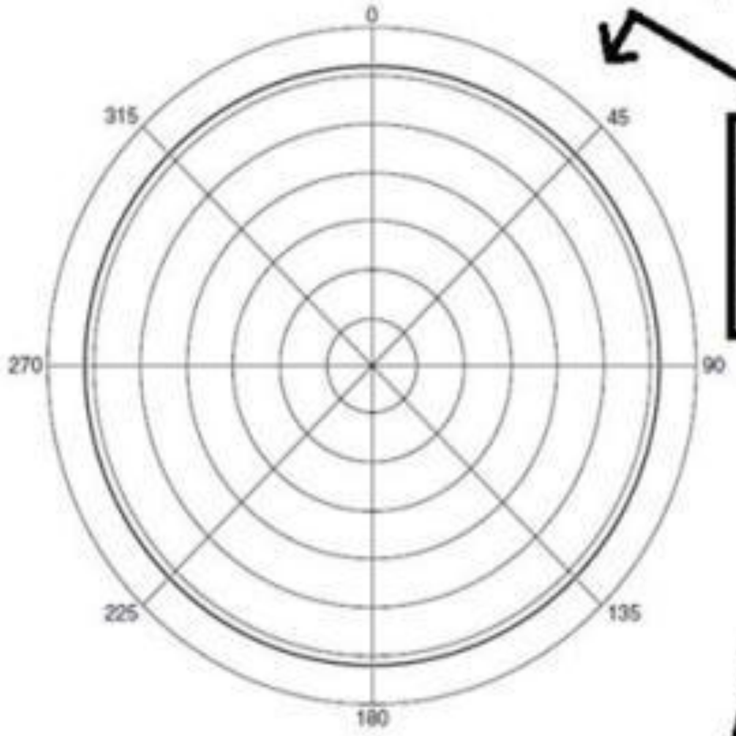
Antenna Placement Considerations

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

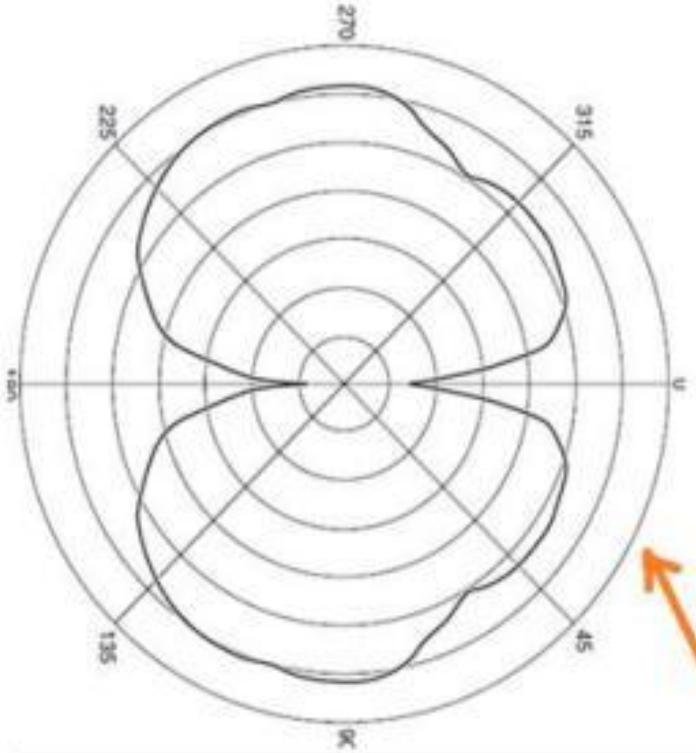
Never mount antennas near metal objects as it causes increased multipath and directionality

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

Orientation of the Dipoles if Wall Mounting



When the antenna is upright, the signal is a uniform 360 degrees



When the antenna is sideways the pattern is no longer a uniform 360 degree pattern it takes on the pattern above.

This is ok for diversity receive only antenna (middle one) it is not recommended for transmitter antennas as the polarity is also wrong we prefer vertical polarity for best performance

Cisco live!

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

Orientation of the Dipoles if Wall Mounting

Dipoles pointing UP or Down are in <u>vertical polarity</u>

This is ideal for uniform coverage.

Dipoles pointing sideways are in <u>horizontal polarity.</u>

Note: Cisco recommends transmitting antennas use vertical polarity

Installations that went wrong…

Above ceiling installs that went wrong

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

Dipole antennas up against a metal box and large metal pipes create unwanted directionality and multipath distortion – This increases packet retries

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

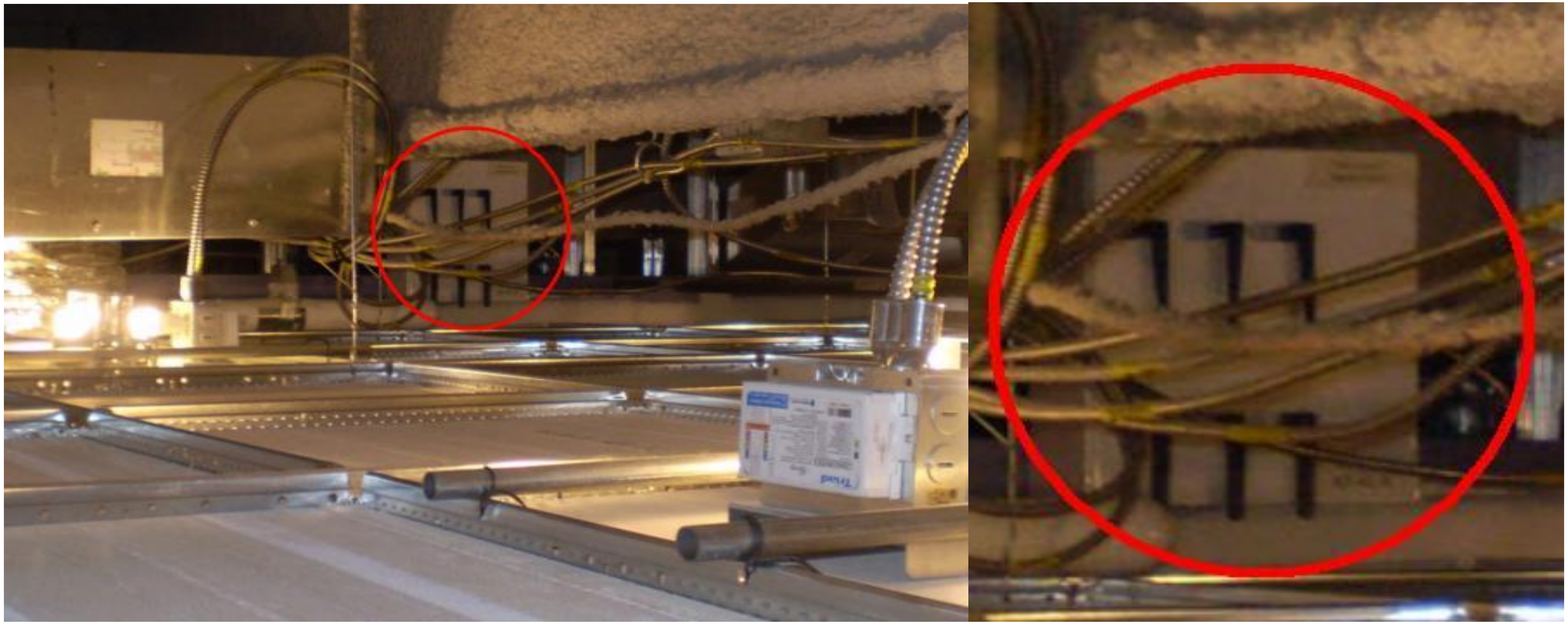
It is now essentially a directional patch suffering from acute multipath distortion problems.

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

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

Above Ceiling Installs that Went Wrong

Huh?? You Mean it Gets Worse?



Other Installations that Went Wrong

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

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

Installations that Went Wrong

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

Mount the box and the antennas
in a downward fashion

Installations that Went Wrong

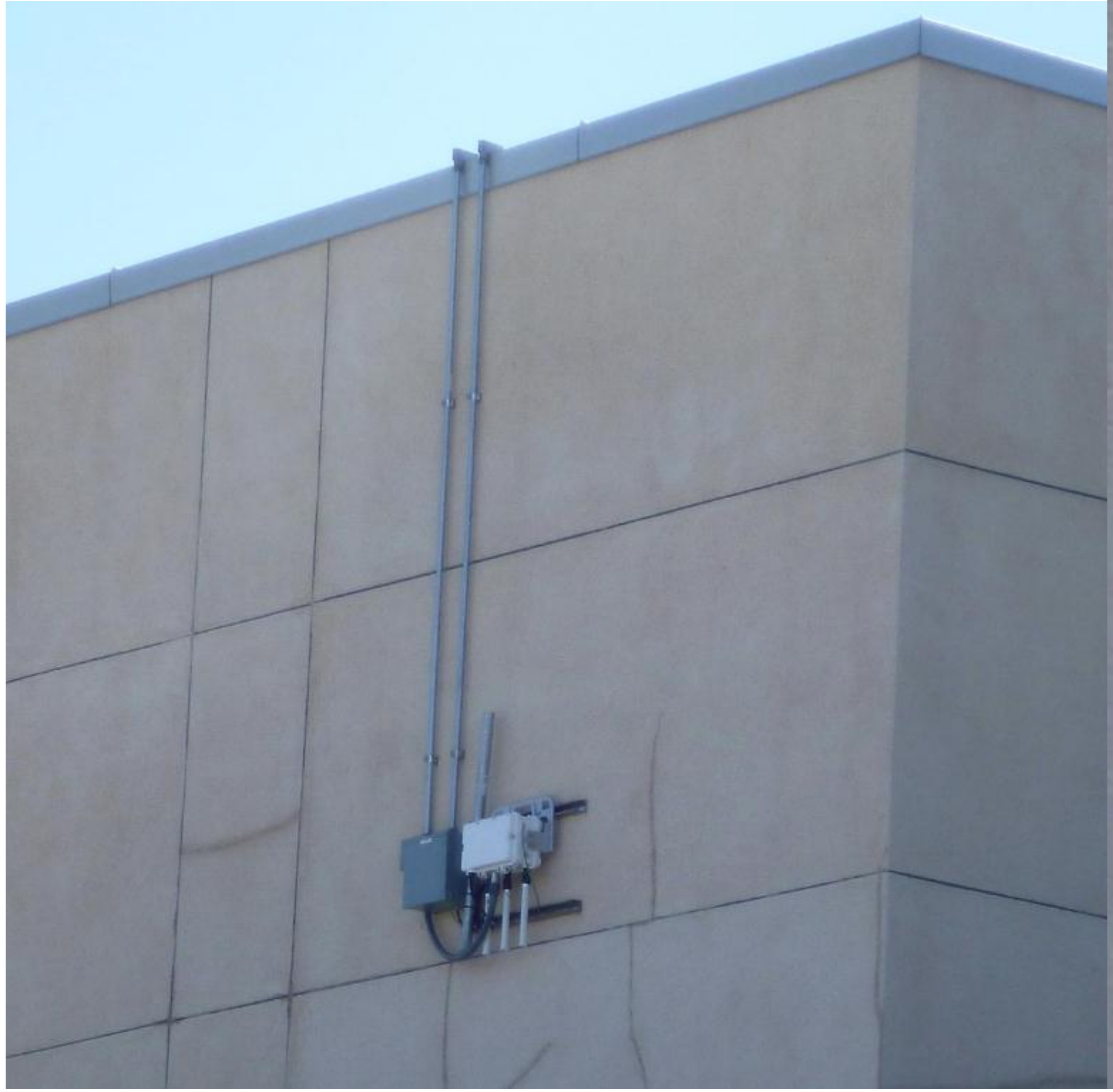
Sure is a comfy nest - glad this model runs pretty warm

Installations that Went Wrong - Mesh

GOOD INSTALL

BAD INSTALL

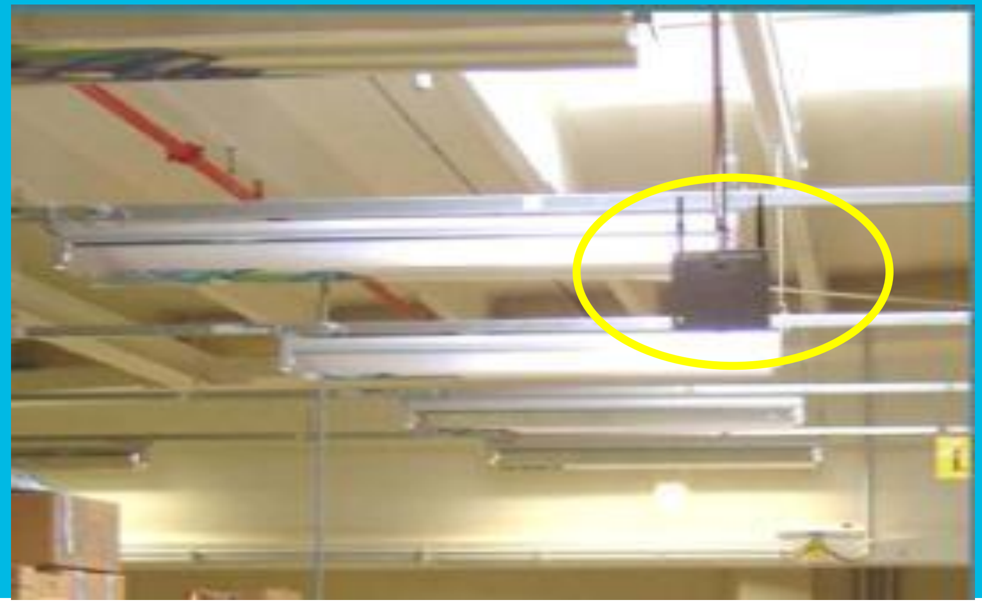
Installations that Went Wrong - Mesh



Building aesthetics matters – Antennas obstructed

Minimise the Impact of Multipath

- Temptation is to mount on beams or ceiling rails
- This reflects transmitted as well as received packets
- Dramatic reduction in SNR due to high-strength, multipath signals



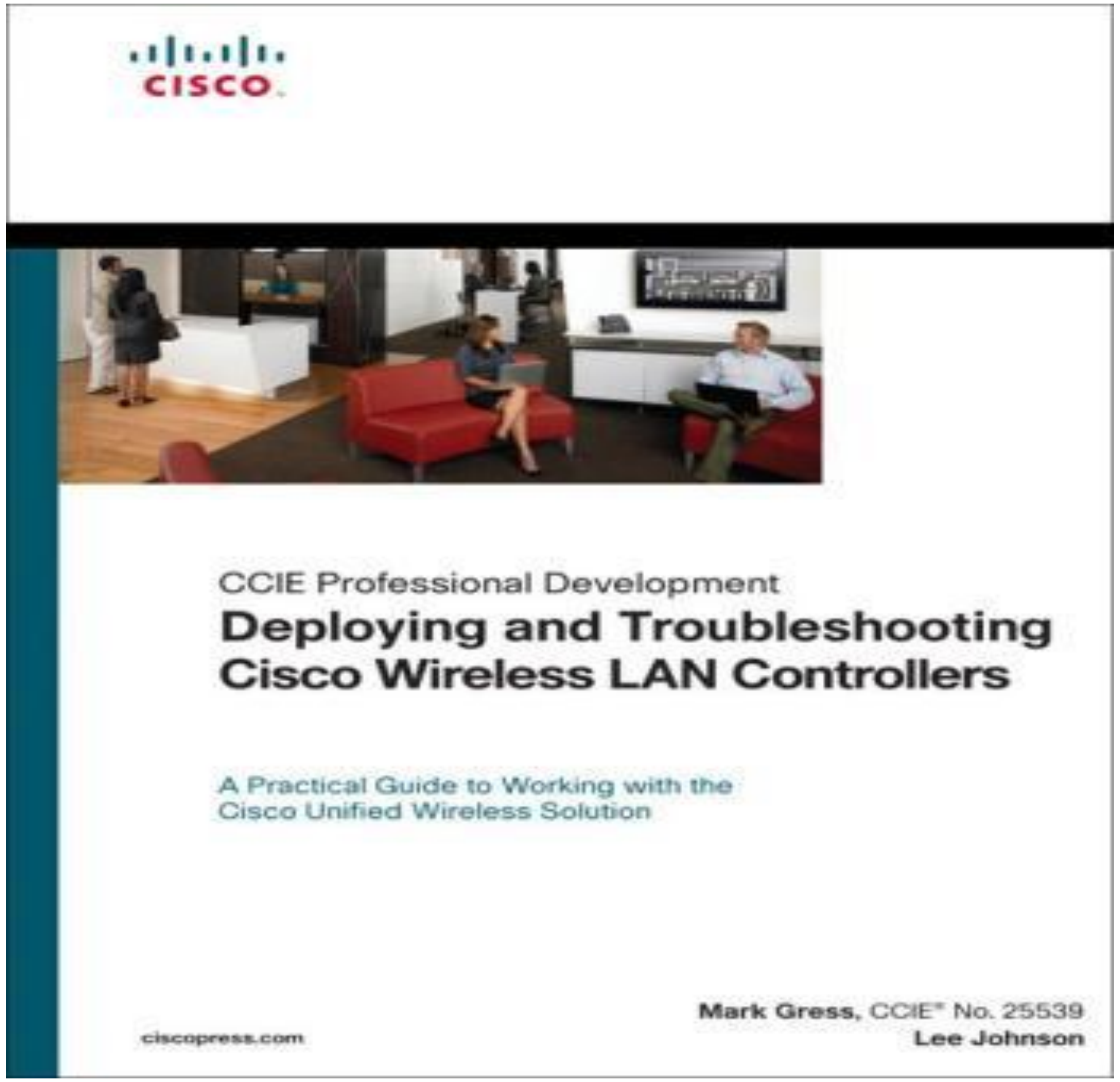
Try to minimise Reflections When Choosing Locations

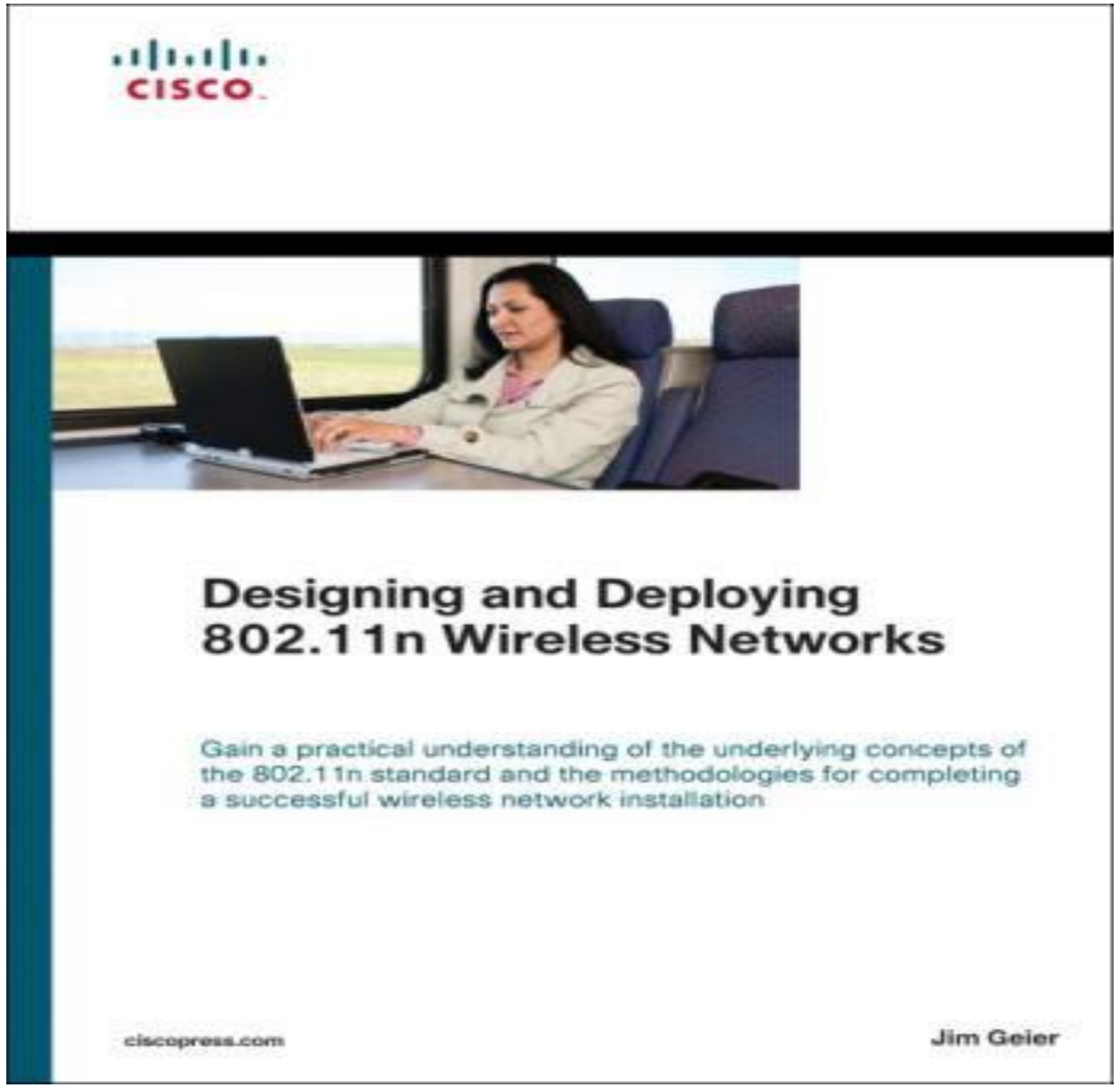
Summary

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

"RF Matters"

Recommended Reading





Also see the Cisco AP-3600 deployment guide at this URL

http://www.cisco.com/en/US/products/ps11983/products_tech_note09186a0080bb9102.shtml

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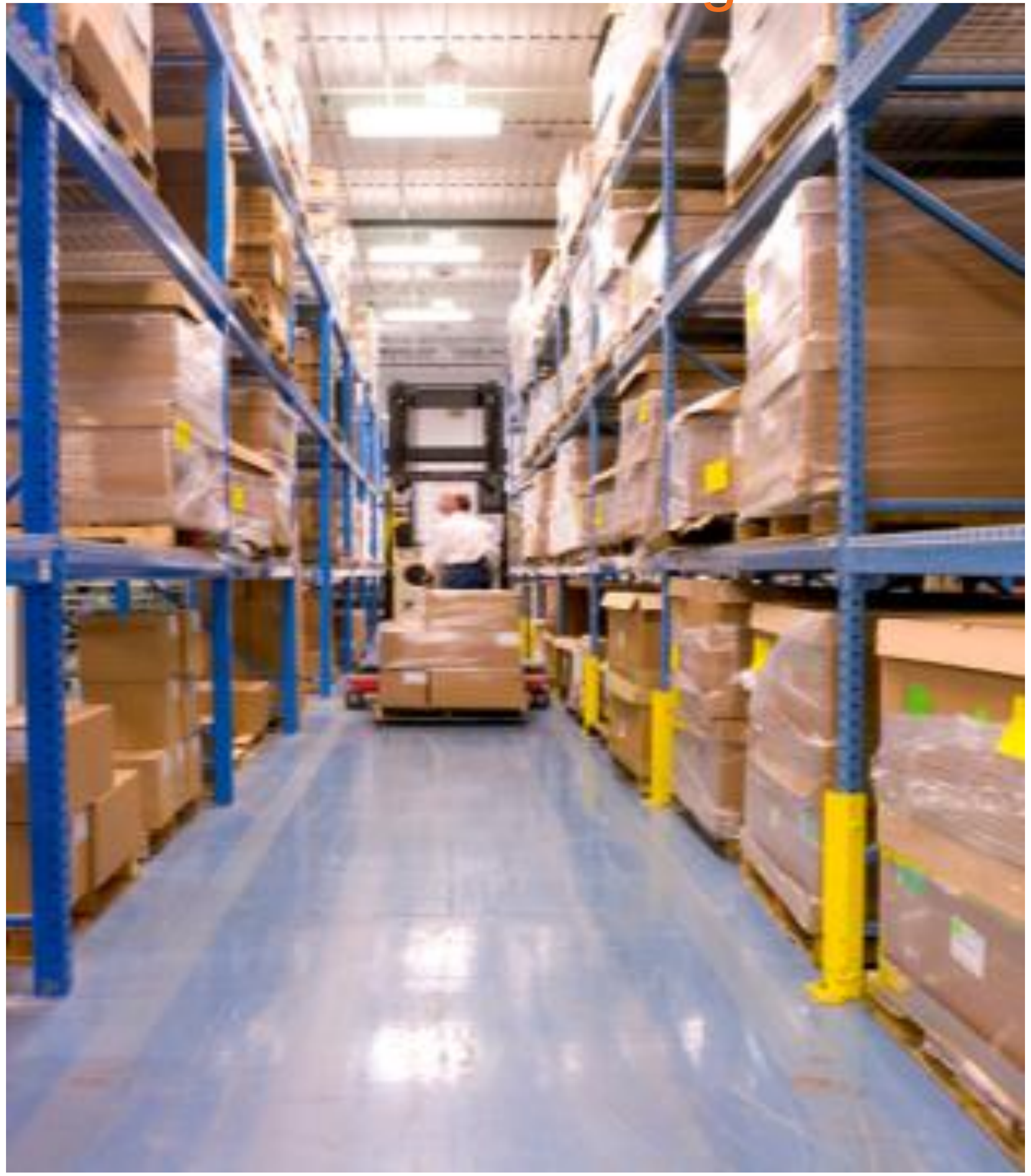
Reference slides

Warehouse Design

As Stock Levels Change so Does Coverage



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

Warehouse Design

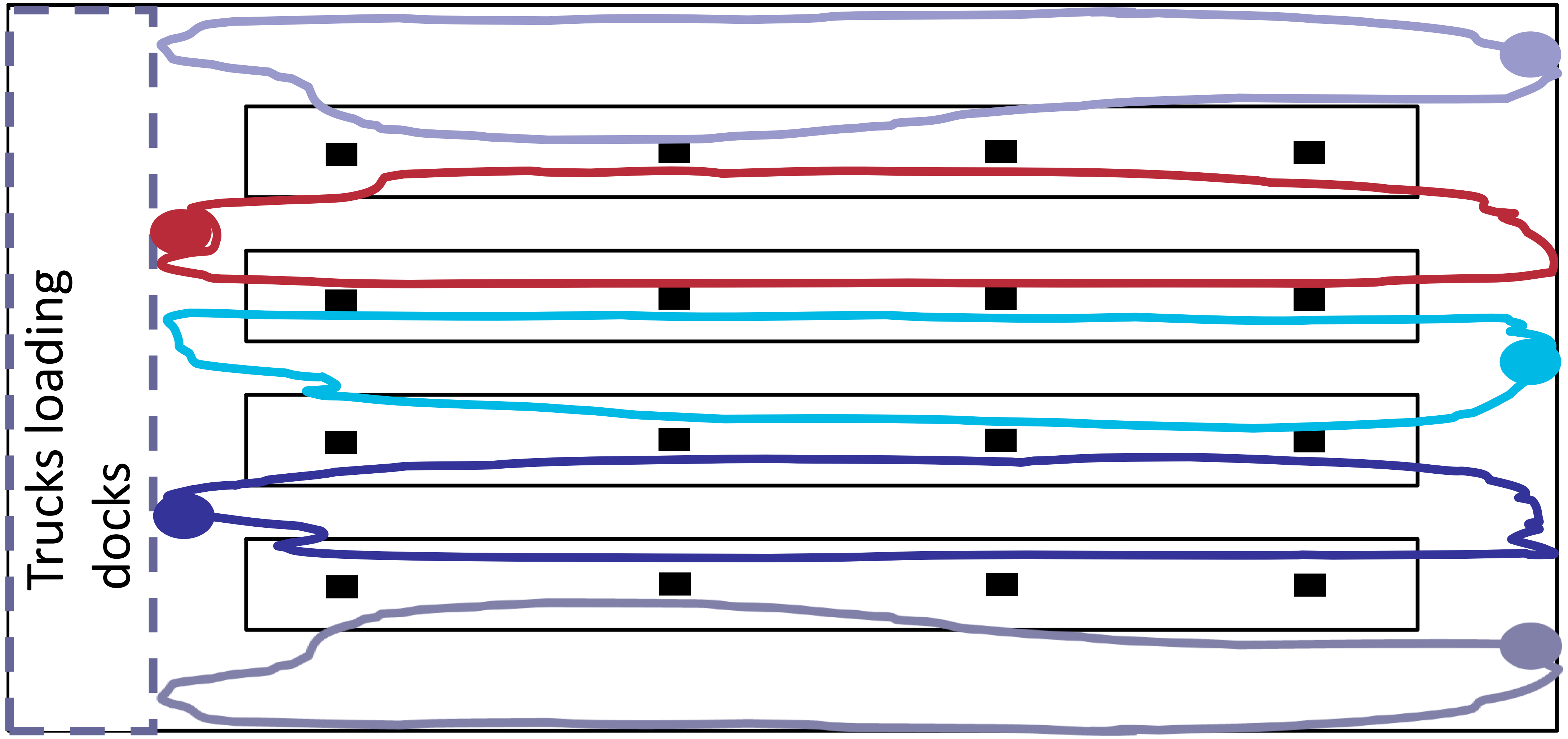
As Stock Levels Change so Does Coverage

Maximum Tx power

Patch or Yagi antennas

Easy power

Easy Ethernet drop



Null spots have to be corrected

Warehouse Design

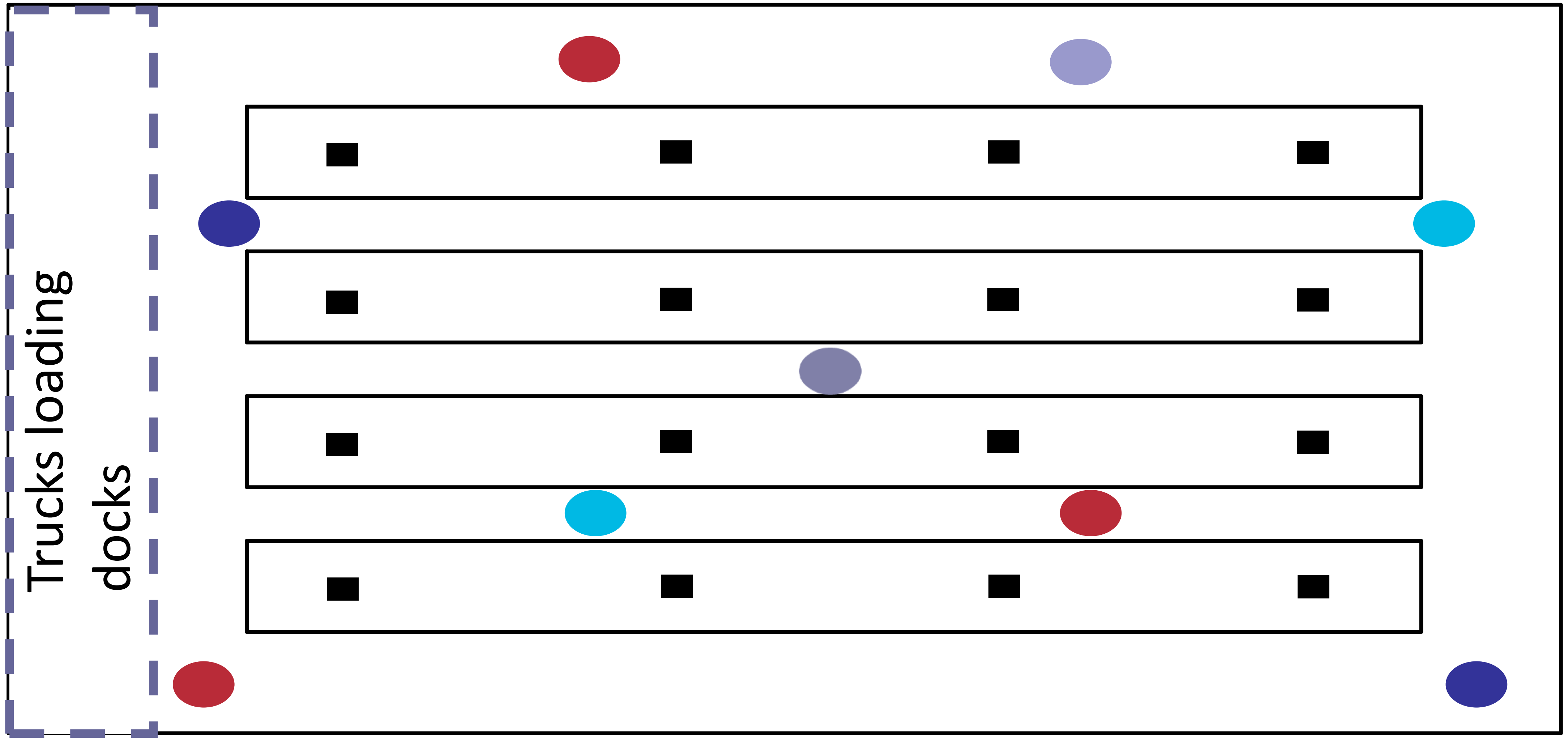
As Stock Levels Change so Does Coverage

Reduced Tx power (RRM)

Omni directional antennas

More APs (+ power drops)

AP wire distance to nearest switch



More difficult to deploy

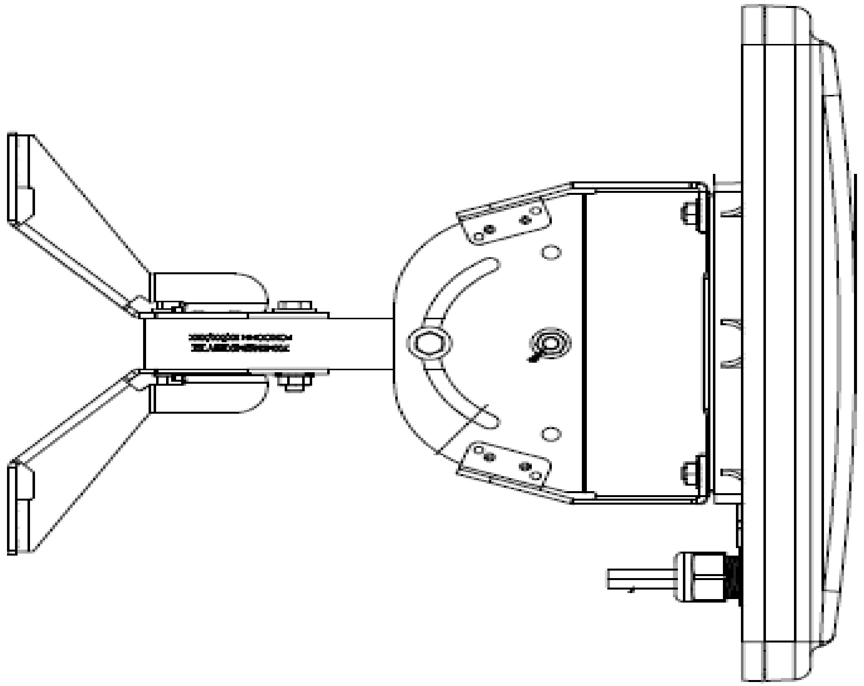
Placement of APs can be cumbersome

Stadium and Sporting Venues

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

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

AIR-CAP3502P-x-K9

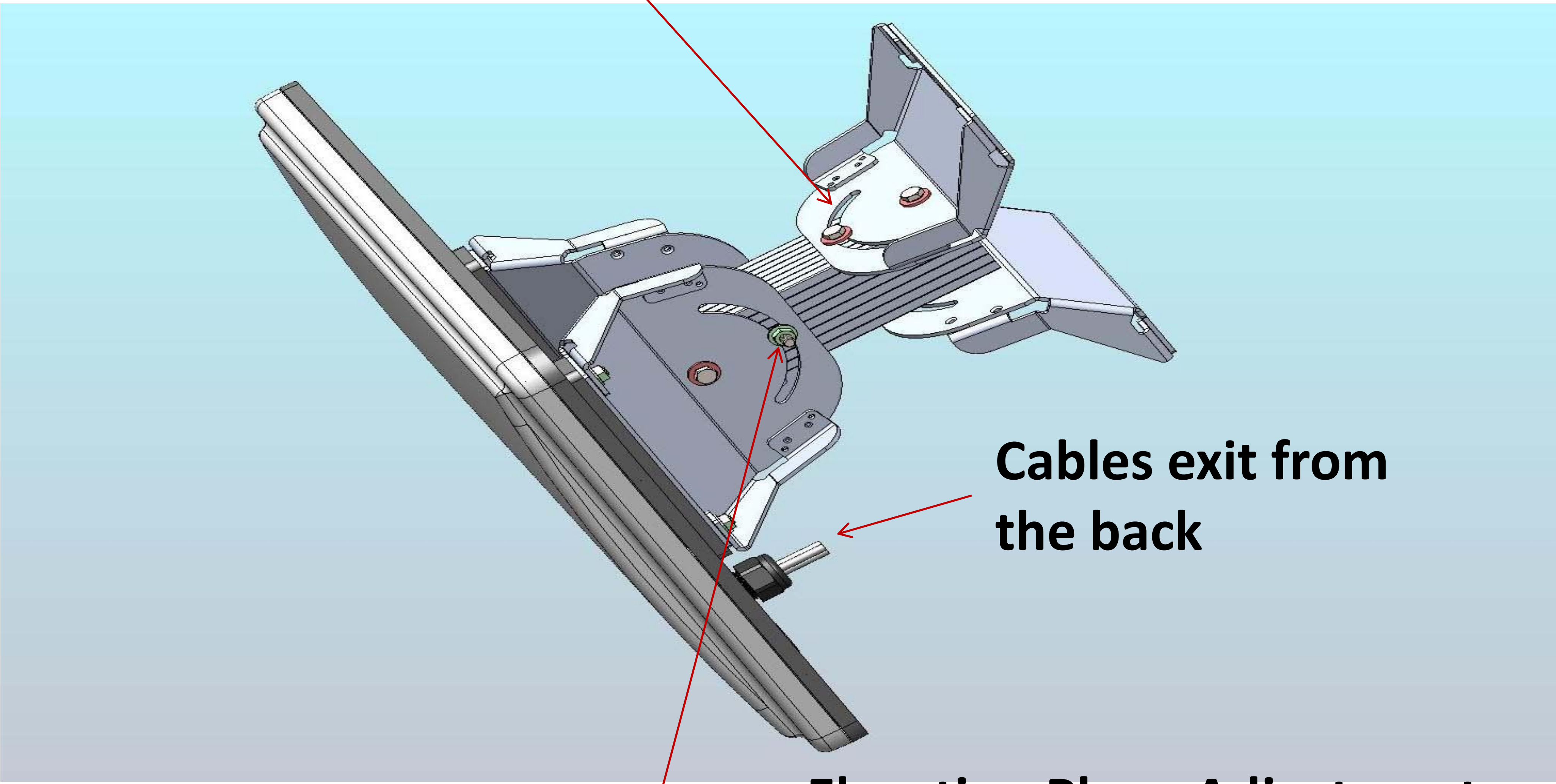


AIR-ANT25137-R=

Stadium Designs

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

Azimuth plane adjustment +/- 20 degrees



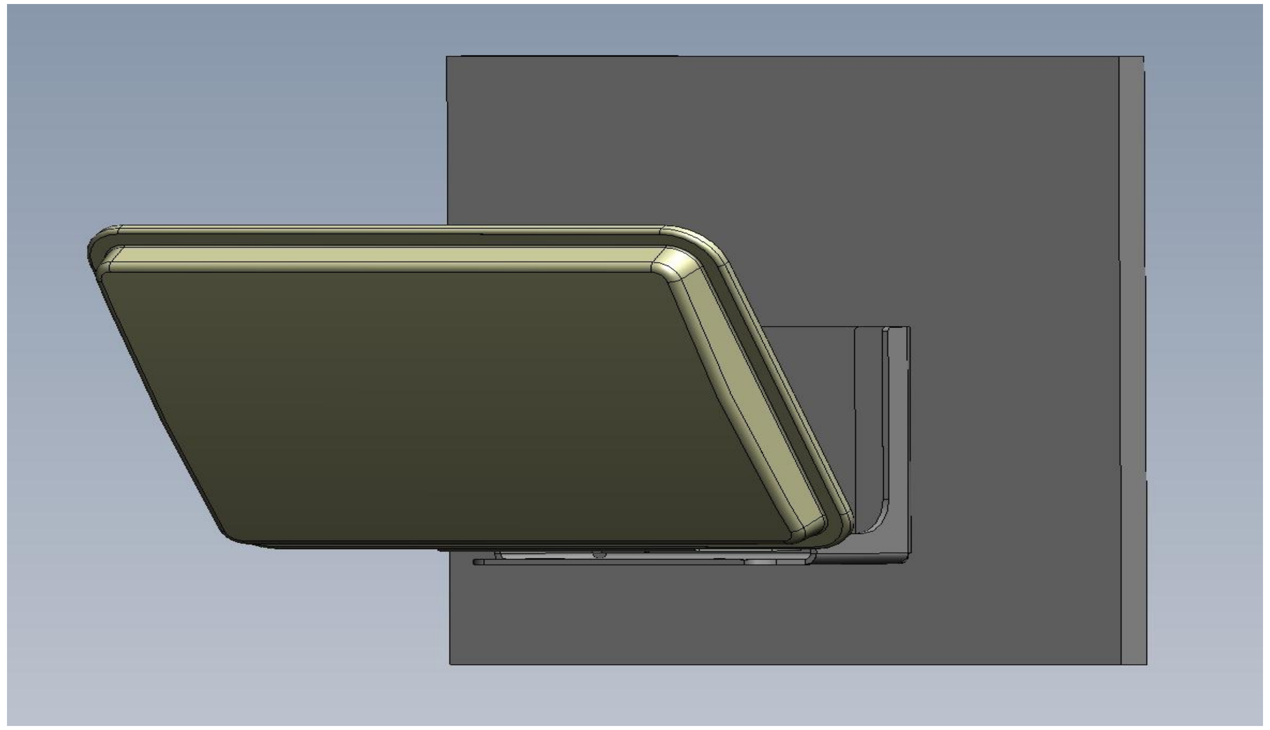
Cables exit from the back

Elevation Plane Adjustment, +/- 60 degrees

Was there a Need for this Antenna?

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

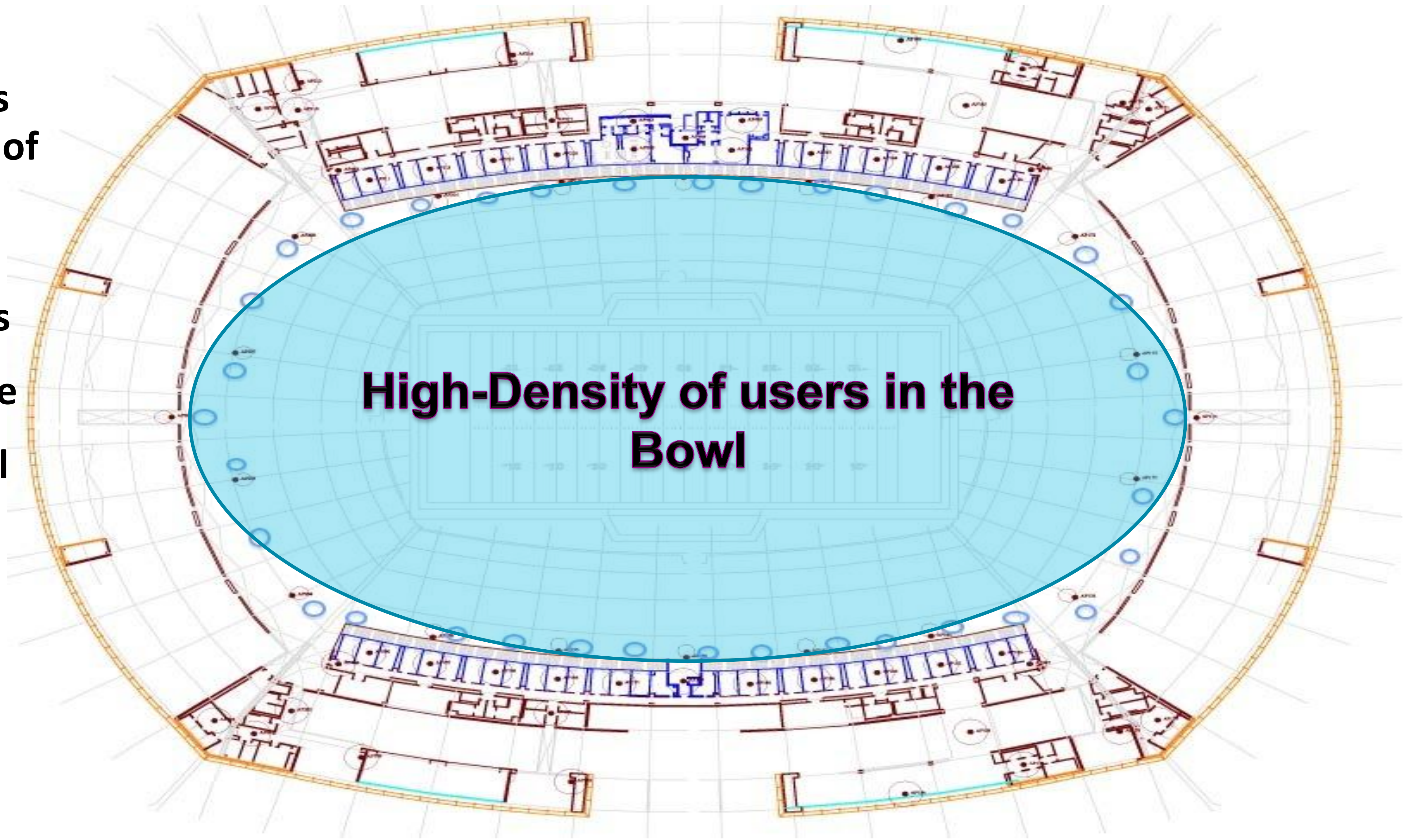
Discrete antennas for 2.4 GHz and 5 GHz were unsightly and was labor intensive to mount and align.



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

High-Density Design - Bowl

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



Bowl Seating RF Cell Footprint

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