

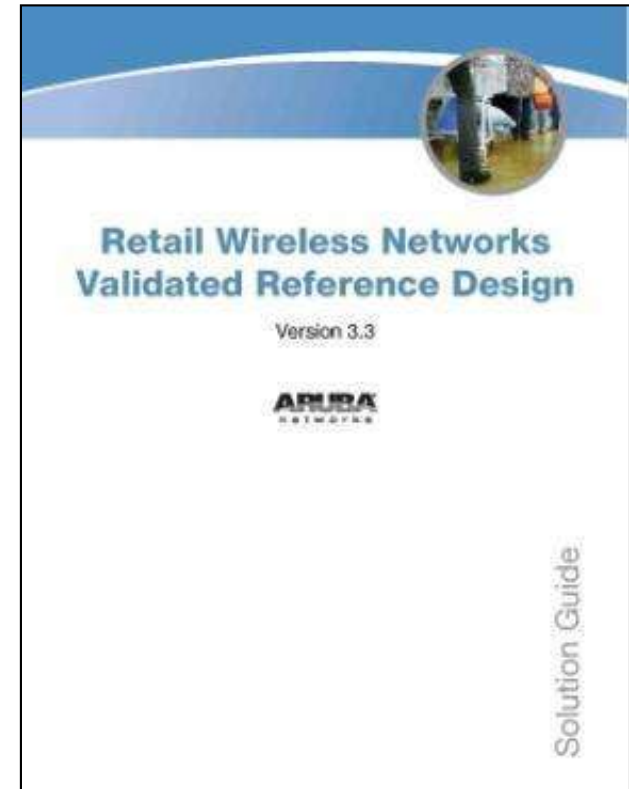


Wireless Design for Stores, Warehouses & Manufacturing Facilities

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More Information!

- Significant portions of this presentation are available for further study in the “Retail Wireless Networks Validated Reference Design”
- Aruba Design Guides web page
http://www.arubanetworks.com/technology/design_guides.php



Agenda

- **RF DESIGN CHALLENGES**
- Planning for Deployment
- RF Fundamentals
- Troubleshooting RF Issues
- Q&A



RF Challenges in Stores

Key Requirements

- High Reliability Required for Mission Critical Applications
- Limited installation Options (usually ceiling mount) due to Aesthetic requirements, cabling considerations
- Must work around “RF Hostile” structures such as freezers and large display cases / vaults
- Co-existence with guest systems, - “Would you like a Latte with that?”
- Can the RF design be rolled out to 100s or 1000s of stores?



RF Challenges in Warehouses

High Reliability Required for Mission Critical Applications

Limited installation Options

- Typically ceiling mount or wall mount at ends of racking only due to operational considerations

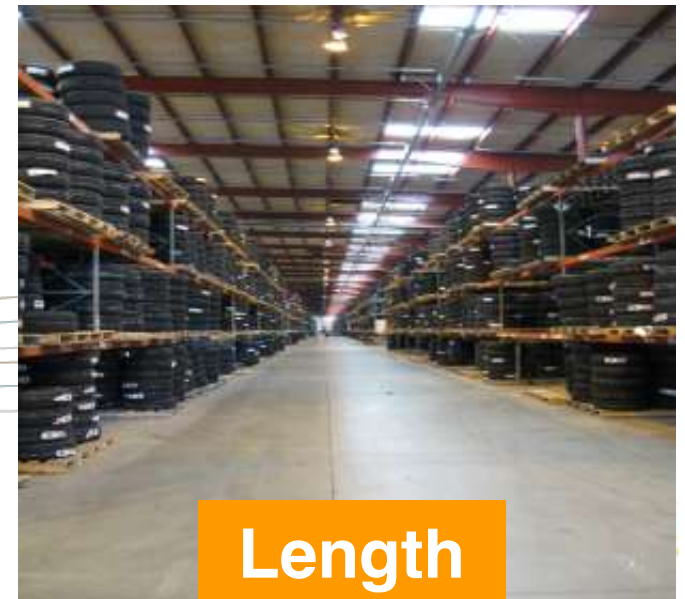
“RF Hostile” structures such as

- Racking, Freezers, Dividing Walls / Firebreaks
- The GOODS Stored (i.e. Butter, Tires, Books, etc.)

Variability

- Goods Stored – Type of Goods and Locations / stacking configuration
- Seasonal Variability in Layout and Loading
- “Flex” – Configurations and areas

Interference from Legacy Systems (FH) and other systems such as security cameras, etc.



RF Challenges in Manufacturing Plants

RF design challenges

- Hard to obtain clear LOS
- Significant RF multipath & higher delay spreads from scattering, reflections, and diffraction of typical structural & equipment features
- High absorption areas for
- Cable pathways around assembly lines, moving cranes
- Interference from other in-band transmission systems and EMI

Harsh environmental conditions

- High and low temperatures
- Grounding requirements to protect electronics
- Spray, particulate buildup, etc.
- Classified areas (ATEX or C1D2)
- Armored conduit for AC and POE circuits



**Multipath
Fading & EMI**



Environmental



RF Challenges for Outdoors

High Reliability Required for Mission Critical Applications

Limited Installation Options

- Typically large areas such as loading docks and lots at DC's must be covered from relatively few available installation locations on the buildings.
- Ability to extend installation flexibility with Mesh or remote mounting, but can be significant cost increase for “exotic” installations such as lightpoles.

Very Hostile RF structures
(*historically)

- Tractor/trailer rigs
- Shipping containers



Width



Agenda

- RF Design Challenges
- **PLANNING FOR DEPLOYMENT**
- RF Fundamentals
- Troubleshooting RF Issues
- Q&A



Planning for Deployment

- Inventory wireless devices
- Quantify facility requirements
- Develop coverage and client density model
- Identify pilot sites
- Perform virtual RF plan and site spectrum clearing walkthrough at pilot sites
- Document plan for deployment of pilot sites
- Execute pilot deployment
- Perform passive site survey post deployment to verify coverage
- Execute client testing at pilot site
- Fine tune plan for next site



Inventory Wireless Devices

- Identify all client device makes, models & applications
- Capture all device limitations (TX power, best encryption)
- Capture best firmware level
- Worksheets used for RF and Security designs

#	Make	Model	Operating System	Strongest Authentication Mode	Best Firmware Level	802.11 Radio Type	Maximum Output Power
A	Intermec	CK31	Win CE .NET	WPA2/802.1x	4.20	b/g	17 dBm
B	Symbol	9090G	Windows Mobile	WPA2/802.1x	5.1.70	a/b/g	20 dBm
C	Vocollect	Talkman T5	Proprietary Voice	WPA-PSK	4.20	b only	12 dBm
D	Symbol	6846	MS-DOS	WEP	—	b only	20 dBm
E	Xybernaut Atigo	S310LX	Windows XP	WPA2/802.1x	5.0	a/b/g	20 dBm



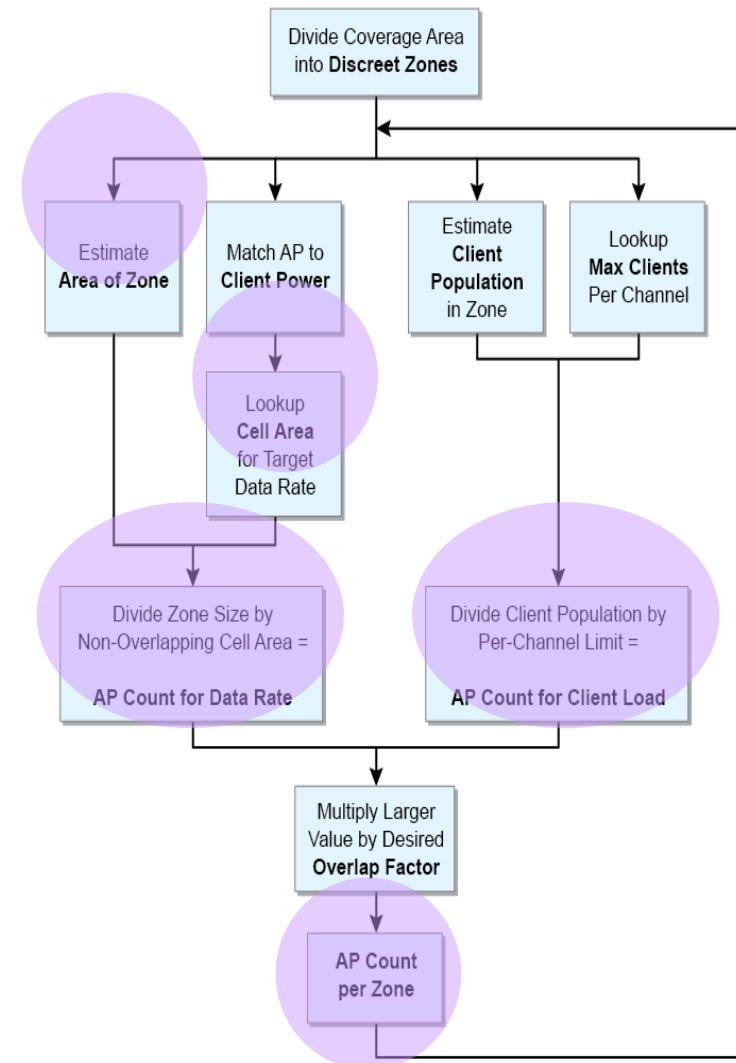
Quantify Facility Requirements

- Facility counts, sizes & types required for equipment BOM
- Ceiling height, WAN backhaul & redundancy also critical

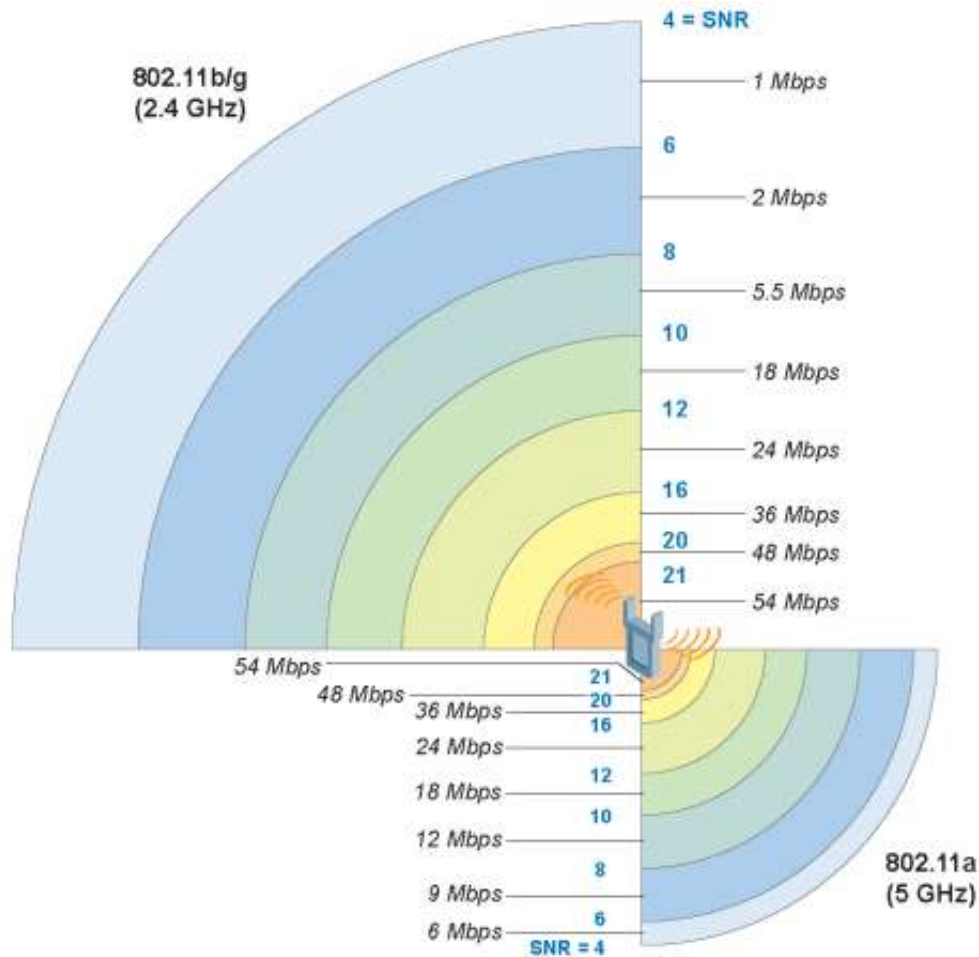
Facility Type	Qty	Facility Addresses / Store IDs	Average Square Footage	Max Ceiling Height	Digital Floor Plan Available	Country/ Regulatory Domain	WAN Backhaul Speed	WAN Link Type/ Latency	Local Controller
Distribution Centers									
● DC#1 (East)	1	See Excel listing	500,000	60 ft	Yes	USA	T1	25 ms	2 (1+1 VRRP)
● DC#2 (West)	1		350,000	60 ft	Yes	USA	T1	25 ms	2 (1+1 VRRP)
● DC#3 (Canada)	1		250,000	50 ft	Pending	Canada	384 Kbps	25 ms	2 (1+1 VRRP)
Retail Stores - USA									
● Size Band 1	104	See Excel listing	7,500 sf ²	15 ft	80%	USA	128 Kbps	50 ms	1
● Size Band 2	43		15,000 sf ²	15 ft	60%	USA	128 Kbps	50 ms	1
● Size Band 3	121		22,500 sf ²	15 ft	80%	USA	128 Kbps	50 ms	1
● Size Band 4	252		30,000 sf ²	30 ft	75%	USA	256 Kbps	50 ms	1
Retail Stores – Canada									
● Size Band 1	22	See Excel listing	7,500 sf ²	15 ft	55%	Canada	64 Kbps	75 ms	1
● Size Band 2	6		15,000 sf ²	15 ft	75%	Canada	64 Kbps	75 ms	1
● Size Band 3	31		22,500 sf ²	15 ft	80%	Canada	64 Kbps	75 ms	1
● Size Band 4	42		30,000 sf ²	30 ft	75%	Canada	64 Kbps	75 ms	1
Gas Stations – US	56	See Excel listing	1,000 sf ²	12 ft	75%	USA	64 Kbps	75 ms	0 (Remote AP)

Computing AP Count for Each Zone

1. Estimate area of zone.
2. Select minimum target data rate
3. Match AP power to least capable client device
4. Determine cell area for selected rate/power combination
5. Divide zone size by non-overlapping cell area to determine AP count (bandwidth plane).
6. Determine minimum AP count for desired client load (client plane).
7. Multiply the larger AP count by the desired overlap factor (redundancy plane).



Selecting a Target Cell Edge Data Rate

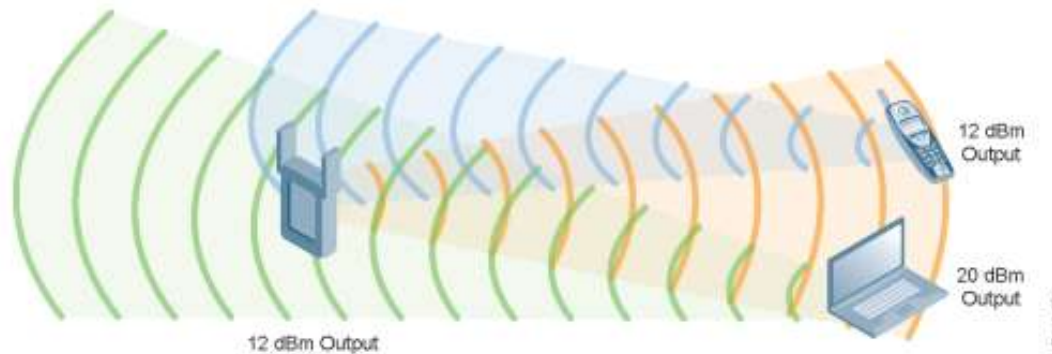


- Each 802.11 data rate requires minimum Signal-to-Noise Ratio (SNR) to demodulate
- Applications typically determine data rate
- Manufacturers of some voice & data devices recommend “minimum SNR”
- Aruba recommends 18Mbps minimum data rate for coverage reliability



Matching AP Output Power to Clients

- Match AP output power to the least capable client device

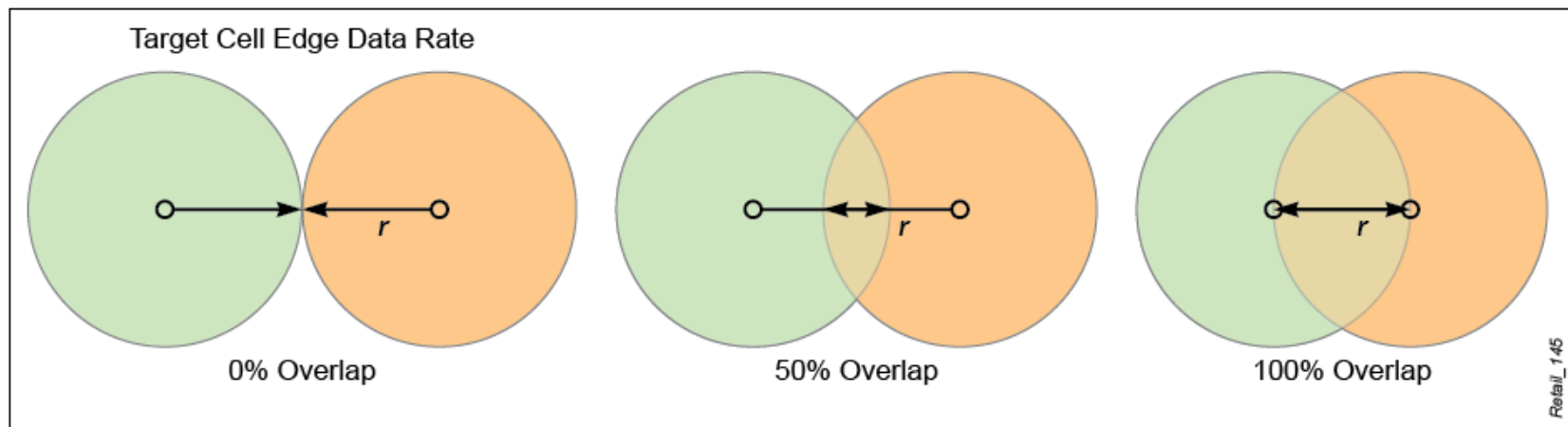


- Reasons why this is important
 - If the AP transmits at higher power than the client, the client may hear the AP, but the client may not have sufficient transmit power so the AP can hear the client
 - APs have greater receive sensitivity than do client devices

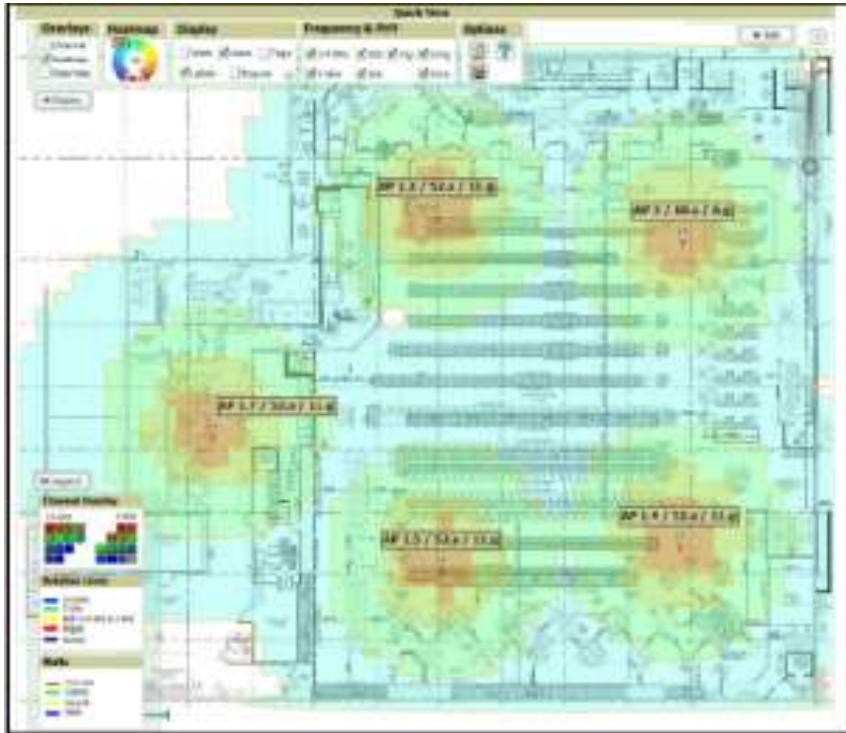


Cell Overlap Percentages

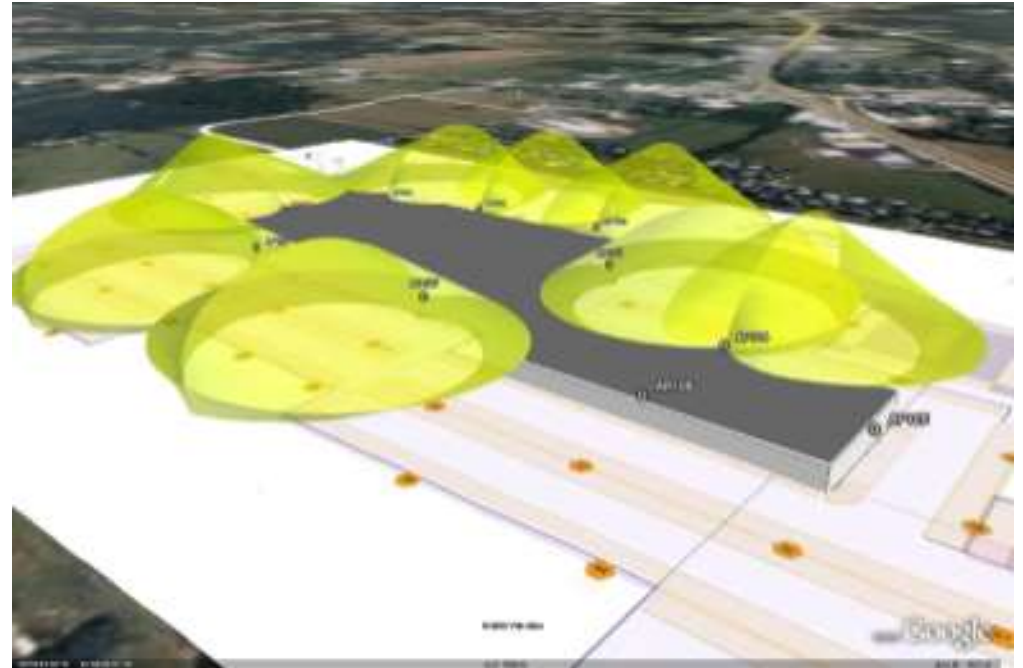
- The RF redundancy goal for a coverage zone is measured as a percentage of the cell radius that is common between adjacent cells.
- Cell overlap is necessary for smooth roaming.
- Aruba recommends a minimum 25% cell overlap even if no RF redundancy is desired.



Aruba's Virtual Survey Tools



AirWave VisualRF



Aruba Outdoor 3D Planner



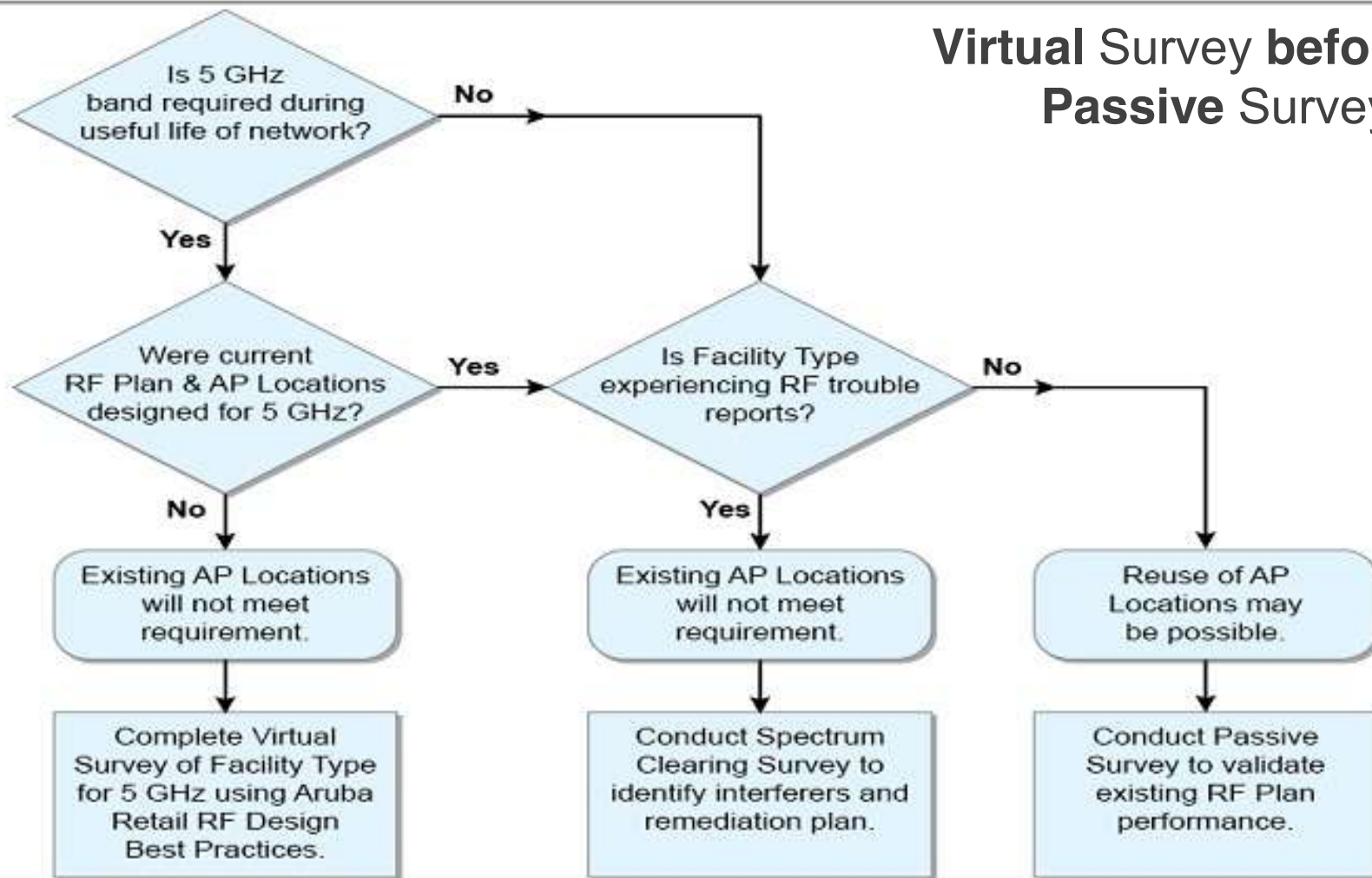
Types of Surveys

- Active Site Survey
 - Costly and time consuming
 - Harder to execute
 - Difficult to match operational conditions
 - Good to take measurements on representative locations and most difficult locations
 - Can show coverage with existing building materials and goods
- Virtual Survey
 - Uses modeling software for planning purposes
 - Less expensive and less time consuming
 - Can be used for large deployments of stores and warehouses



RF Site Survey Decision Tree

**Virtual Survey before and
Passive Survey after**



Retail_114



Site Spectrum Clearing and Walkthrough

- Particularly useful for pilot store sites and warehouses
- Note building materials, and ceiling and rack heights
- Identify challenging areas and situations
- Identify cabling and power requirements and IDF and MDF space and needs
- Identify 802.11 interference sources
- Identify non-802.11 interference sources
- Identify location of fixed client devices like scales, printers, and meat wrappers
- Identify office and employee common areas for laptop and voice coverage

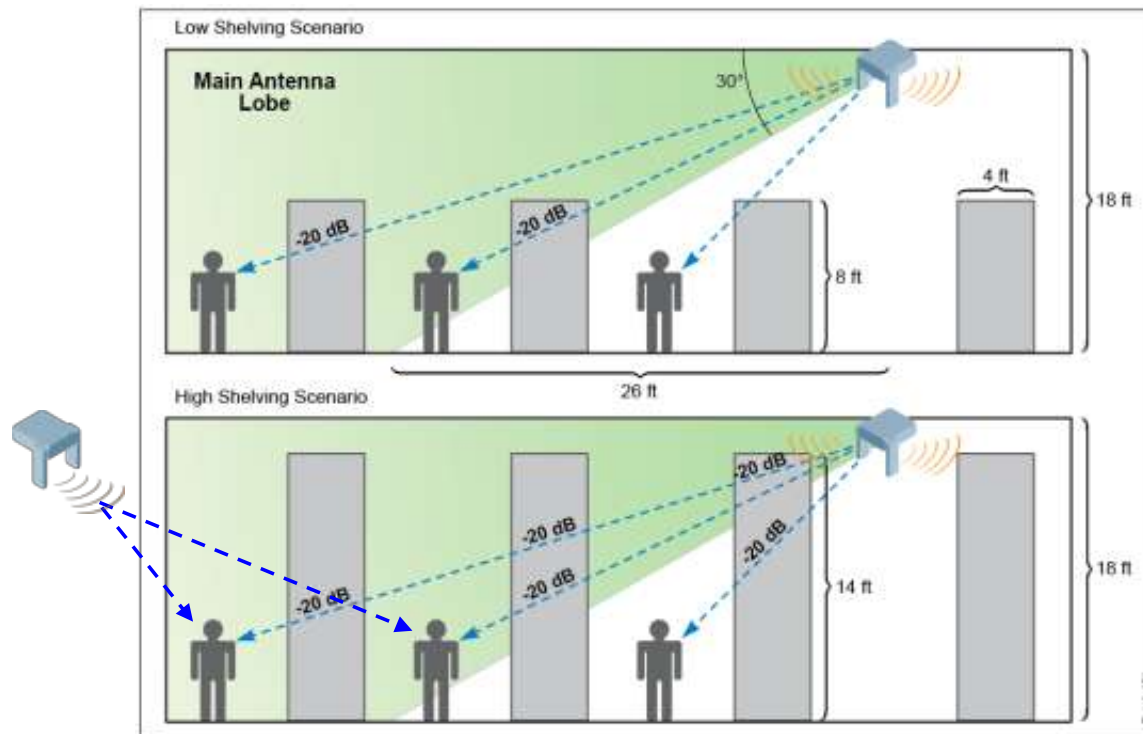


AP Placement & Antenna Summary

- Vertical coverage is especially important in warehouse environments to get coverage in between shelving and stacks and ensure that intended signals reach the clients.
- Low gain, downtilt omnidirectional antennas are ideal for warehouse and high-ceiling store environments because:
 - Low gain limits range to a predictable area around the AP and reduces AP-AP interference
 - Low gain limits users per AP to a controlled area
 - Downtilt omni pattern provides users at ground level a higher signal than APs see from each other
 - Adaptive Radio Management (ARM) functionality is improved for autocalibration of the RF network and realtime visualization.
- The downtilt omni antenna is ideal to work in conjunction with ARM to ease the setup and management of a warehouses and large stores



AP Placement – Adjusting for High Shelving

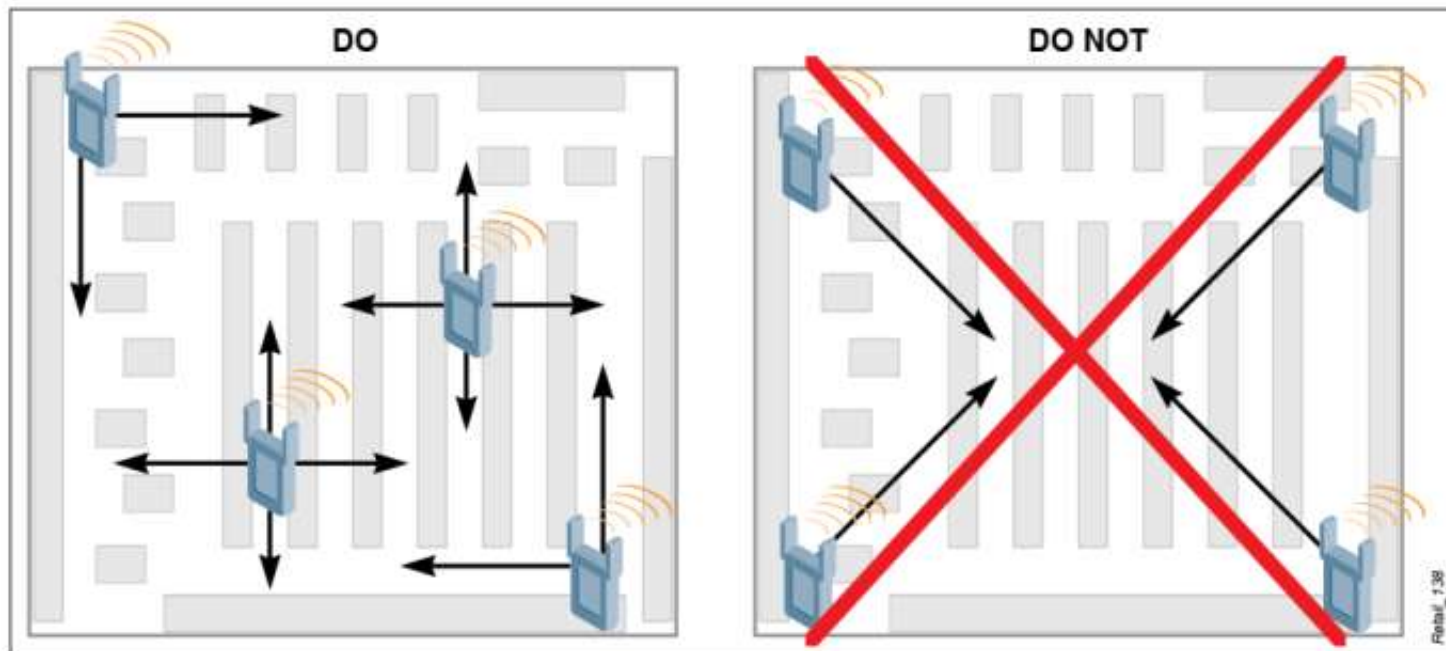


As shelving gets higher, place APs more closely together (above every 2nd aisle or every 3rd aisle) to overcome attenuation from shelving



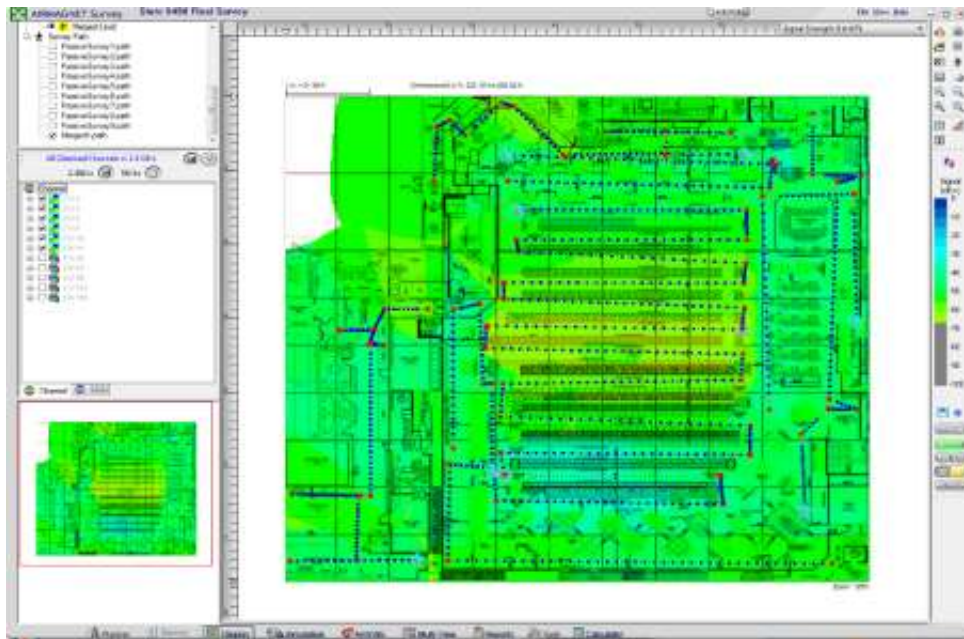
AP Placement in Retail Stores

- Place APs in opposite corners of a store to create LOS down all four sides.
- Use corner and interior APs to create uniform RSSI to handheld clients. Do not attempt to cover from perimeter.
- Place interior APs 10-15 feet down from the endcap, on alternating ends of the store.



2.4 or 5.0 ?

- Design for 5 GHz to future proof for 802.11n and for newer client devices
 - Cabling for 5 GHz today avoids the cost of “two trips to the ceiling”
- Cable plant designed for 900 MHz or 2.4 GHz will not meet expectations for 5 GHz
- 5 GHz has more available channels and less interference sources



2.4 GHz meets -67dBm criterion

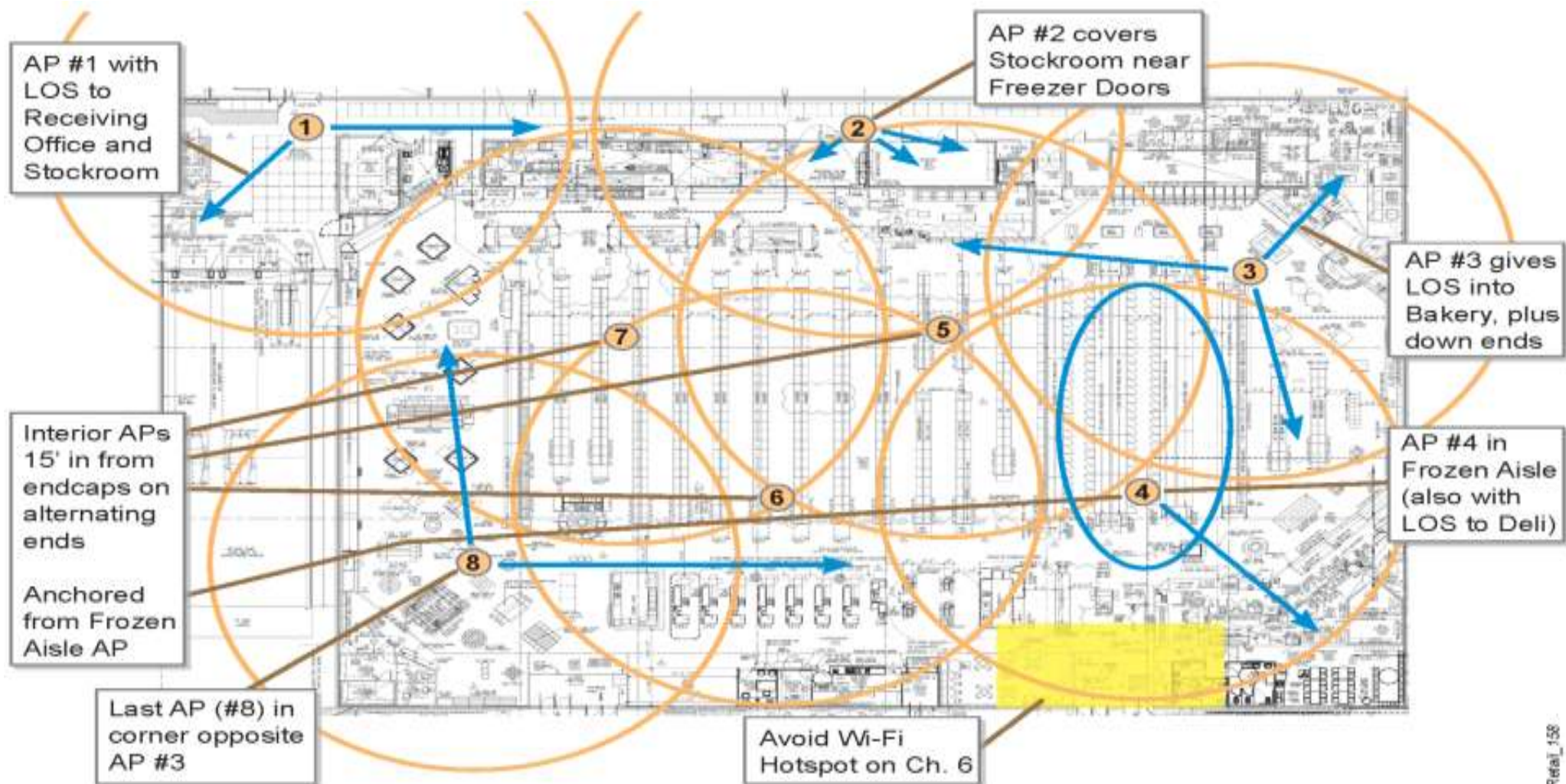


5 GHz does not achieve -67dBm

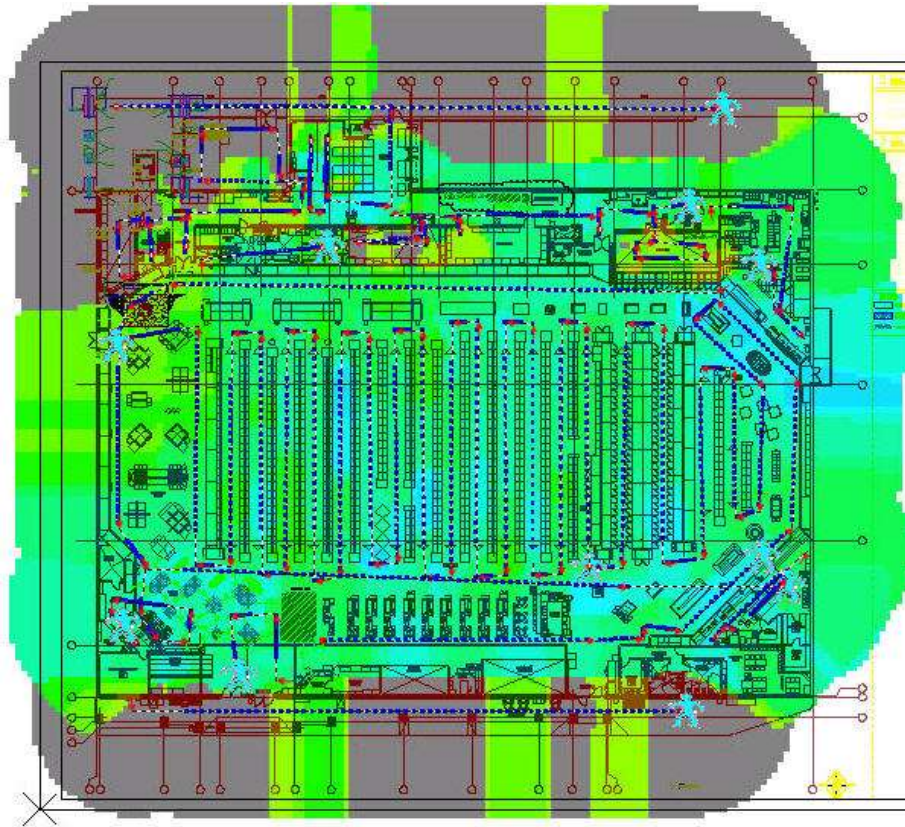


Side Coverage Strategy – Store Example

- 50,000 square foot store with 8 APs (48Mbps Target Rate @ 17dBm)
- Contains receiving area, a large stockroom, freezers, and coolers



Example of a post-deployment store site survey



- Airmagnet site survey filtered at -65dBm for SSID on 5.0 band
- Note lack of coverage outside store
- Note holes in freezers in back of store

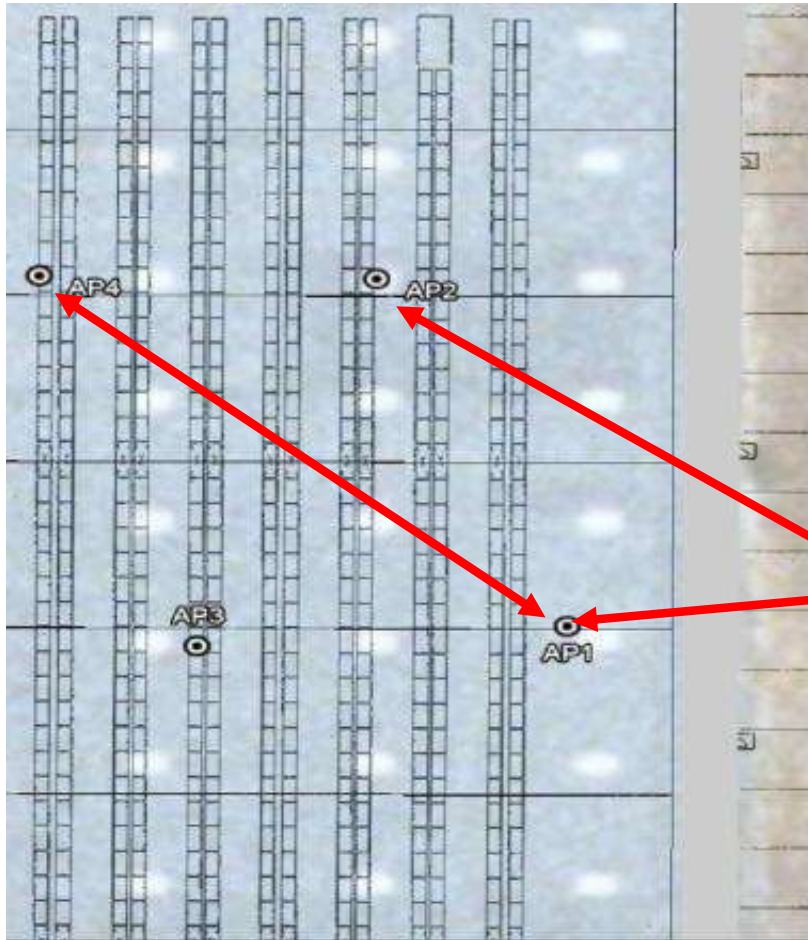


AP Guidelines for Warehouses & DCs

- For general dry goods, overhead mounting is recommended and we typically assume reliable coverage can be provided by next aisle over, but not more than 1 aisle. This may be extended if survey suggest goods are “low absorption”
- The recommendation for every other aisle placement as shown in the following slides allows up to approximately 20 dB loss in goods stored without reduction in coverage reliability because coverage is only assumed “through the goods” for a maximum of 1 aisle
- For cold/frozen storage, wall mount strategy is more typical and every row should have 1 AP with clear line of sight to the antenna. Typically cold/frozen loss is too high (>30 dB) to assume reliable coverage across aisles for long distances required
- Use downtilt omnidirectional antennas when ceilings are above 25 ft (standard low gain / integrated omnis such as AP65 and AP70 OK for lower heights)
- Use wall mount 60 degree sector (~7 dBi) antennas for cold/frozen areas or whenever wall mounting is desired over ceiling mount APs.



Overhead Strategy – Dry Goods Example

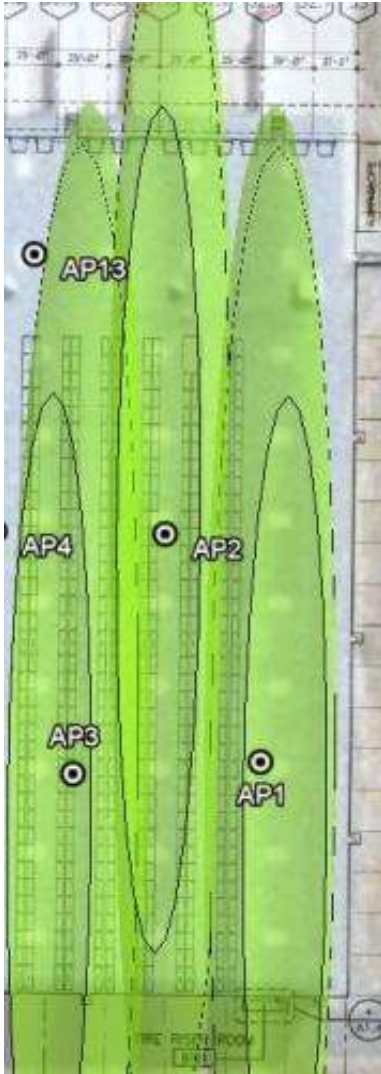


Every 4th AP approximately
150 ft minimum separation

AP in every other row
approximately 1/3 from
alternating end of row



Overhead Strategy – Dry Goods Example



Every Other row has no AP but overlapping coverage through goods is provided from 2 adjacent row APs.

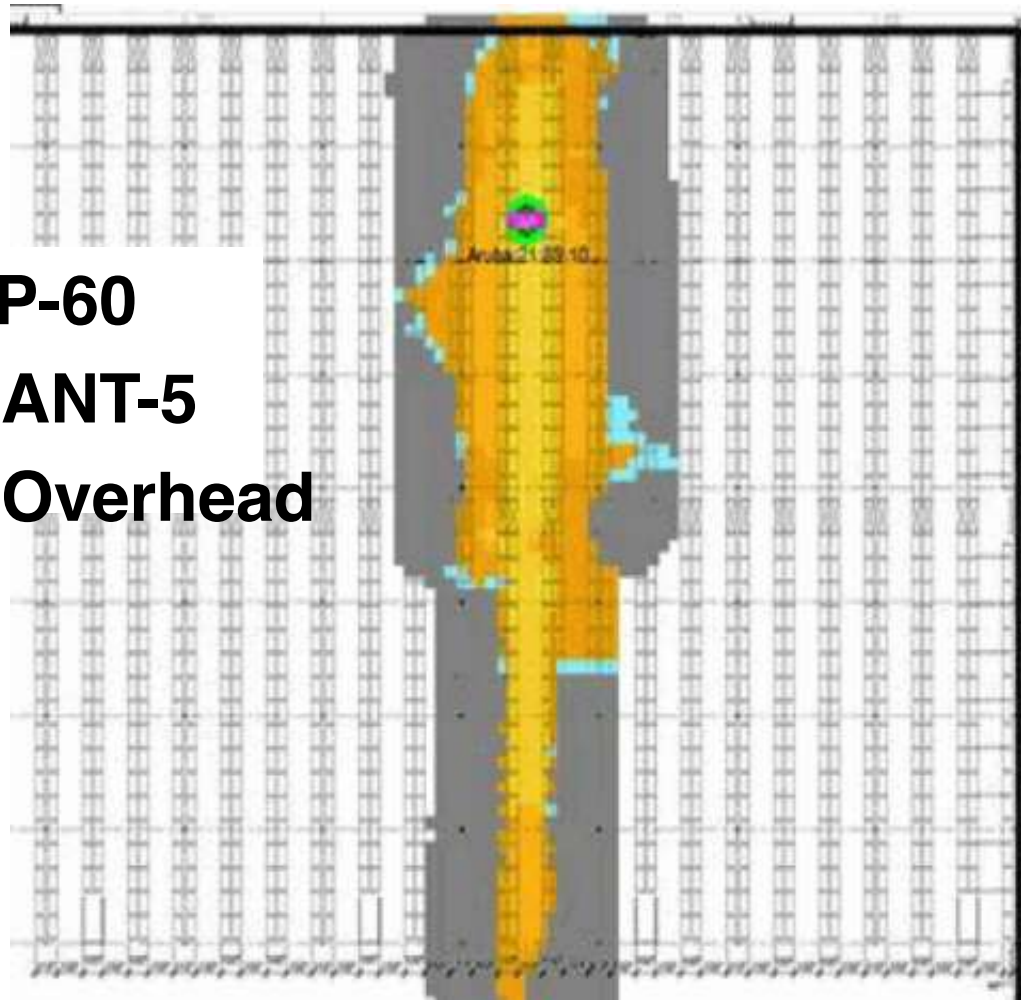
(see rows between AP1 and AP2 and between AP2 and AP3)

Patterns shown assume 20 dB additional loss (worst case) through goods compared to free space and 15 dB SNR (-70 dBm coverage)



Overhead Strategy – Dry Goods Example

AP-60
AP-ANT-5
40 feet Overhead



~350 feet

20 ft per aisle pitch, including shelves



Overhead Strategy – Tires Example



AP Location

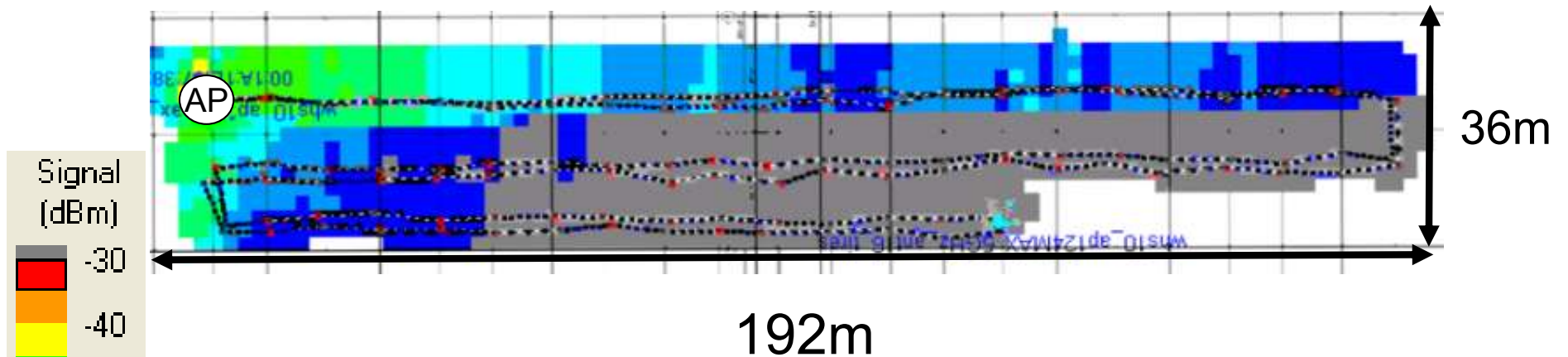


View from AP Location

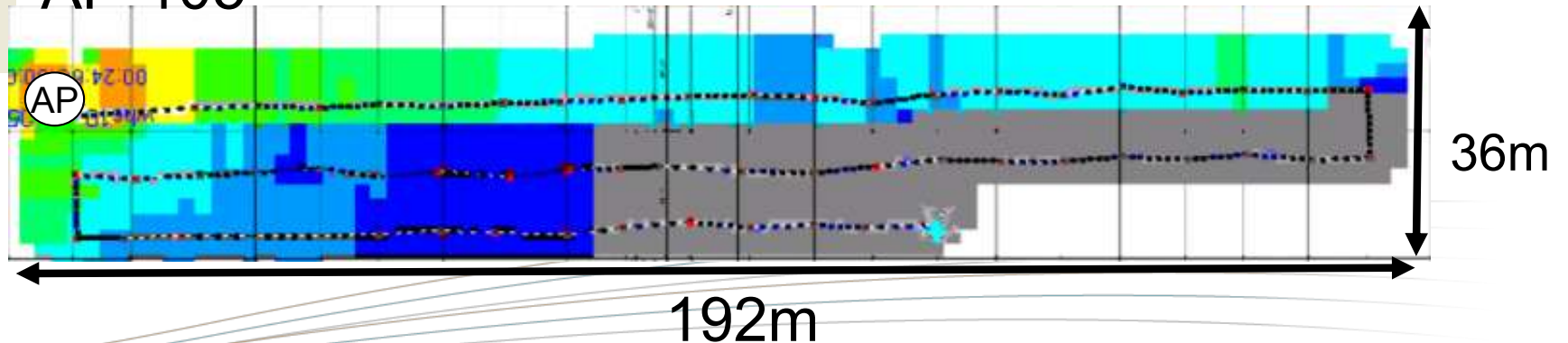


Overhead Strategy – Tires - 2.4 GHz

AP-124 with AP-ANT-16

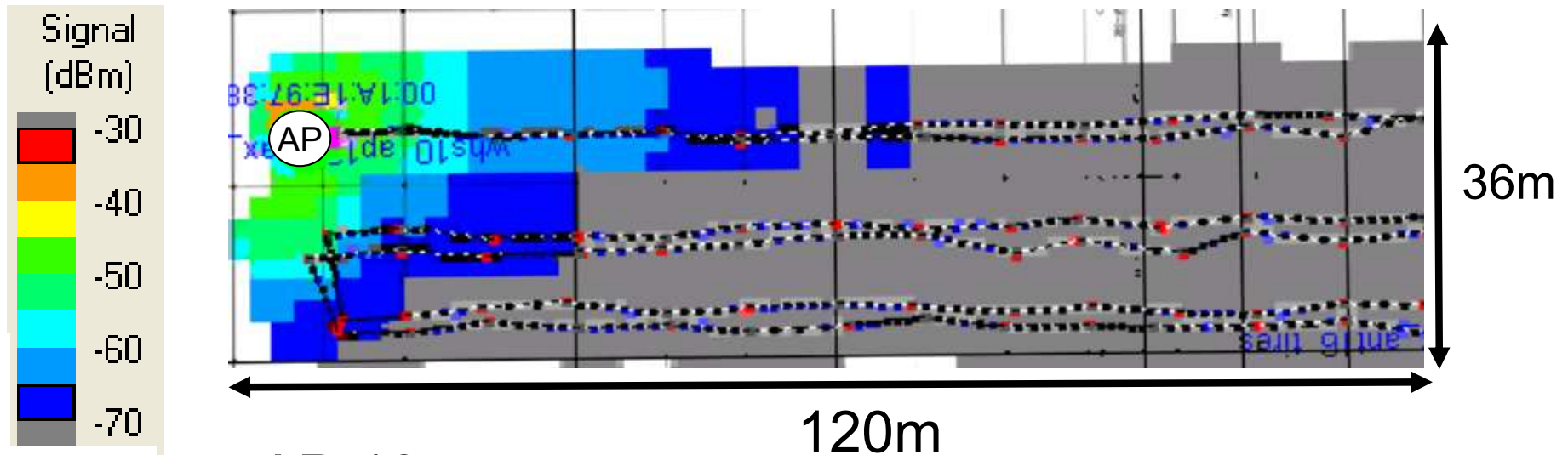


AP-105

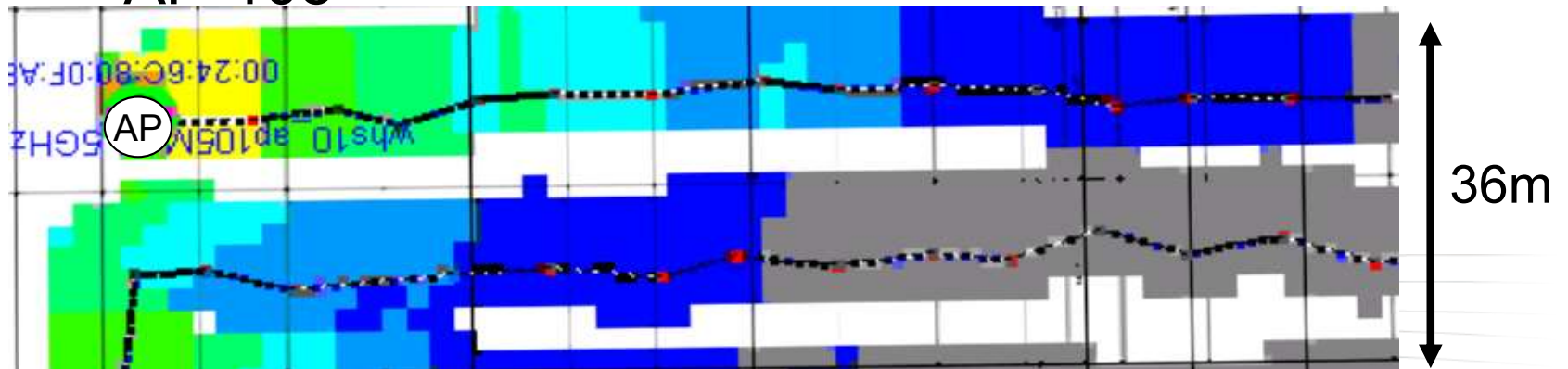


Overhead Strategy – Tires - 5 GHz

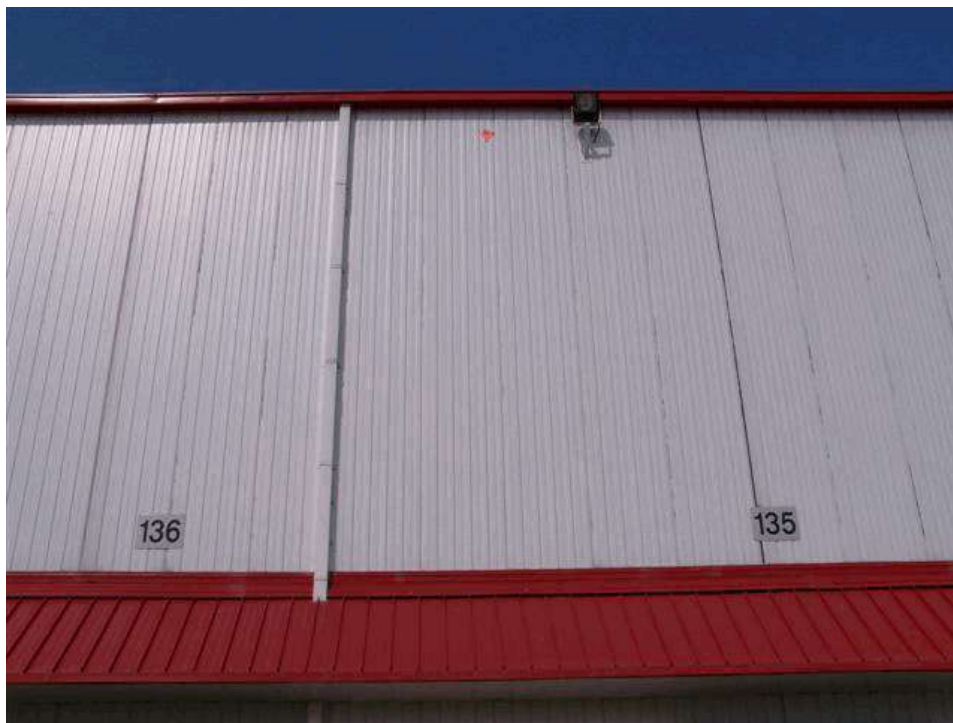
AP-124 with AP-ANT-16



AP-105



Outdoor Areas



250 feet



Agenda

- RF Design Challenges
- Planning for Deployment
- **RF FUNDAMENTALS**
- Troubleshooting RF Issues
- Q&A



RF Fundamentals: Design Considerations

The Goods Stored

- Quantifying the characteristics of Different Materials (the “Butter” meter)
- Coverage vs. Coverage Reliability

Antennas and Antenna Patterns

Managing AP to AP Interference and effects on performance



Characterizing Goods: Absorption Characteristic

Microwave Absorption Analysis

- Goods are placed in a reverberation chamber and excited simultaneously by multiple modes and random incidence wavefronts of varying frequency.
- During the test, the specific absorption rate is monitored to determine the absorption characteristic.



Characterizing Goods

Alternatively, if limited to 2.4 GHz studies, this reverberation chamber is usually more accessible

- Check the break room



The Goods Stored, Absorption & Reflection

All products have different RF characteristics and can be thought of in relative terms with respect to their Absorption and Reflection characteristics

- **Absorption Goods**

- Low Absorption – Air, low density paper goods, apparel
- Higher Absorption – Rubber, plastics, general dry goods (grocery)
- Highest Absorption – Liquids, Frozen Goods and Butter

- **High Reflection Goods**

- Metal parts and machinery/handling equipment

In general High Absorption goods affect RF much more than High Reflection goods

In stacks of goods, waves propagate in both the materials and spaces of air. So, variations in % loading (or packing density) of goods can also have significant effects.



Coverage Vs. Coverage Reliability

The “Butter Test”

- In thinking about Wi-fi and the effect of goods stored, how fast something would heat up in the microwave gives a quick idea of the relative absorption rate of different goods
- Actual experiments performed at own risk!
- Most warehouses and stores contain goods of varying absorption characteristics, coverage is not only affected by the goods differently in different areas the coverage may change as stocking levels/locations of different goods vary from day to day
- The ability of an RF coverage design to survive these changes is called “**Coverage Reliability**”



Coverage Reliability Basics

For low data rate applications it is very easy to show coverage based on standard 802.11B/G typical access point characteristics

- Raw Values
 - +20 dBm output power, 6 dBi antenna
 - Coverage Radius (1 Mbps, 802.11b) = **2.7 Km!**
 - Required SNR= 4 dB

Reliable Coverage however requires adjustments

- Actual AP or Client Power minimum (15 dBm)
- Actual Antenna Gain in direction of clients (will discuss in Antenna section)
- Loss due to materials/walls
- Higher minimum desired SNR for day to day variability of materials and losses

Because dB is a logarithmic scale, even a few small changes can make a big difference



Coverage Reliability Example

12 dBm client + 3 dBi antenna (15 dBm EIRP)

Loss of materials (compared to free space)

- Dry Goods (10 dB – 20 dB)
- Wet/Frozen Goods (20-30 dB)
- Concrete walls/freezer walls/(butter) (20 dB - ?)

Variability of Goods

- If designing for minimum SNR (4 dB) then what happens when goods stored are even 1 dB more lossy than on day when survey was performed.
- Recommended SNR Minimum is 10 dB – 15 dB to allow for some variability in the stored goods (corresponds approximately to -75 dBm to -70 dBm minimum signal levels in facility)

Using above assumptions and 20 dB loss, coverage radius is reduced to approximately 60-80 meters (from 2.7 Km)



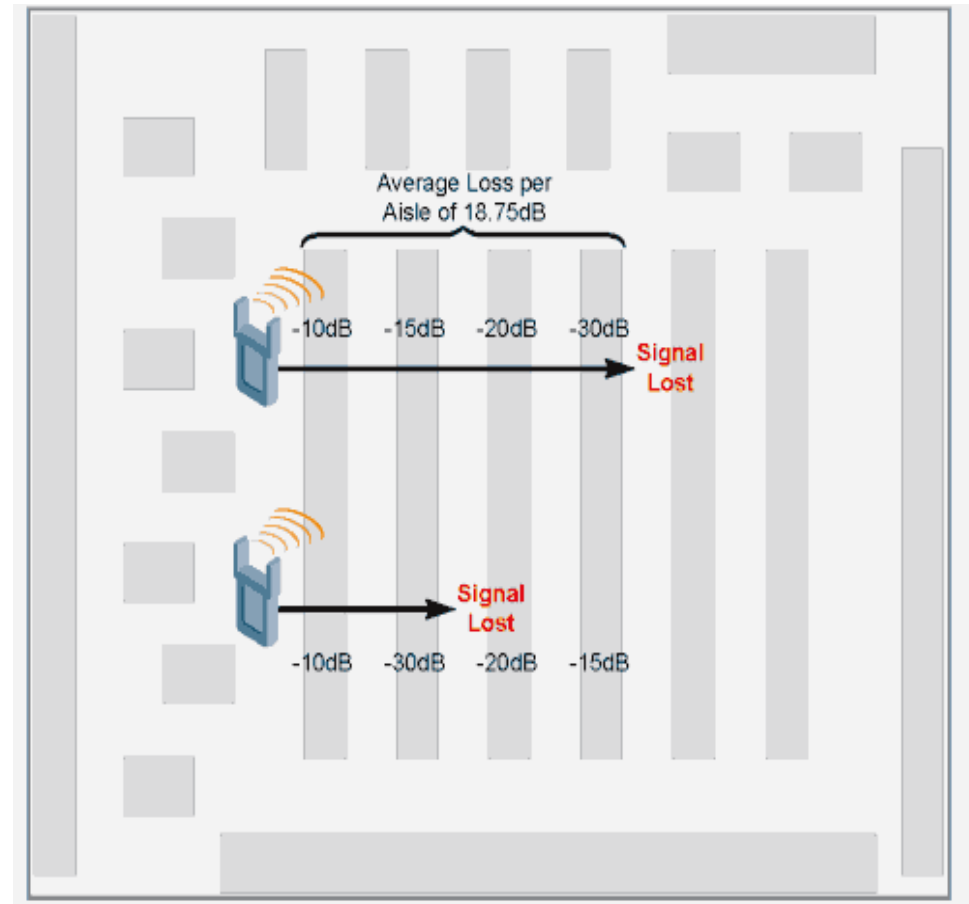
Coverage Reliability Example

Every row of goods is a potential uncertainty due to discontinuity

- Planning that relies on close range for connectivity is more reliable than plans that rely on large distance that must span multiple discontinuities

Same Average Loss, but

- Ordering on top end of row results in loss of coverage (-40 dB) after 4th aisle, whereas
- Stackup at bottom end of row is lost after only 2 aisles



Planning for Coverage Reliability

All goods have varying absorption.

- At planning stage some knowledge or estimate of the relative absorption compared to air and/or butter is useful as a

A typical site survey is a snapshot of one day

Coverage reliability must be by DESIGN and not exclusively by survey...

- This is due to potential day to day or seasonal variations in goods stored and loading level of the shelves.
- Every stack that the coverage must penetrate should be viewed as a discontinuity and potential for additional uncertainty



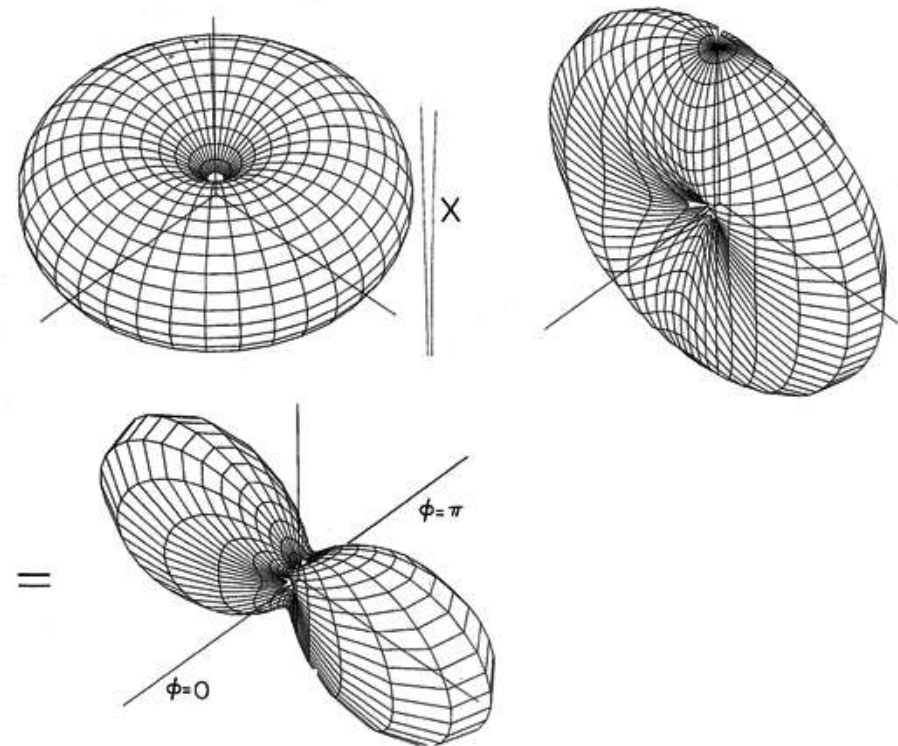
Design Considerations - Antennas

Radiation Pattern

- All Antennas radiate in 3 Dimensions.
- Antennas do not create or destroy power, but they can “focus” energy into a tighter region of 3D space. This focusing effect is called “Gain”

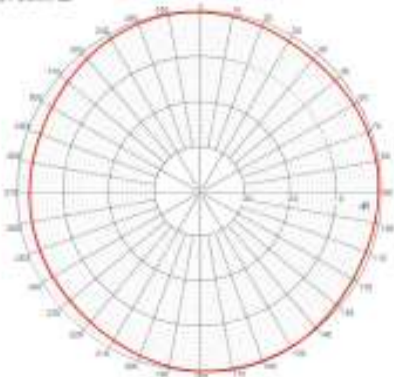
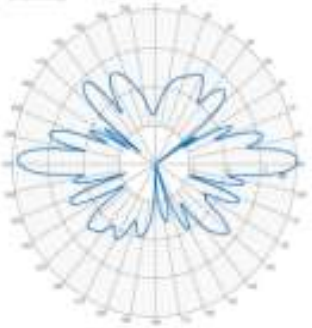
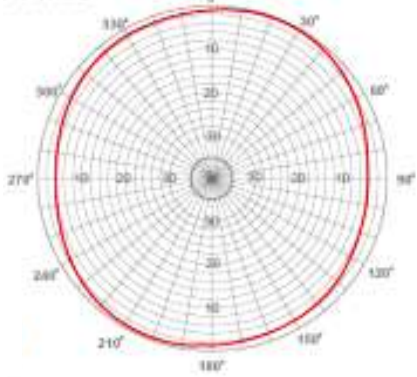
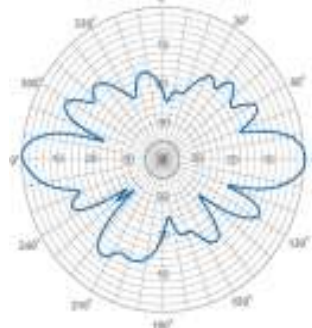
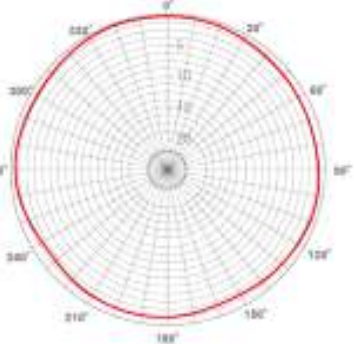
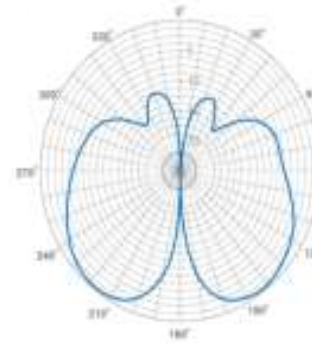
Gain

- Higher the gain, the more tightly focused the coverage in a particular direction
- Higher gain is typically achieved by focusing the vertical direction, which actually reduces energy distributed up/down in order to direct energy farther horizontally
- High gain antennas are typically not appropriate for situations where both horizontal and vertical coverage are needed, as in a warehouse deployment



An antenna that radiates like a sphere in all directions is called the “Isotropic” radiator and is a special case with Gain=1 (or in dB, =0 dBi)

Omni-directional Antenna Patterns

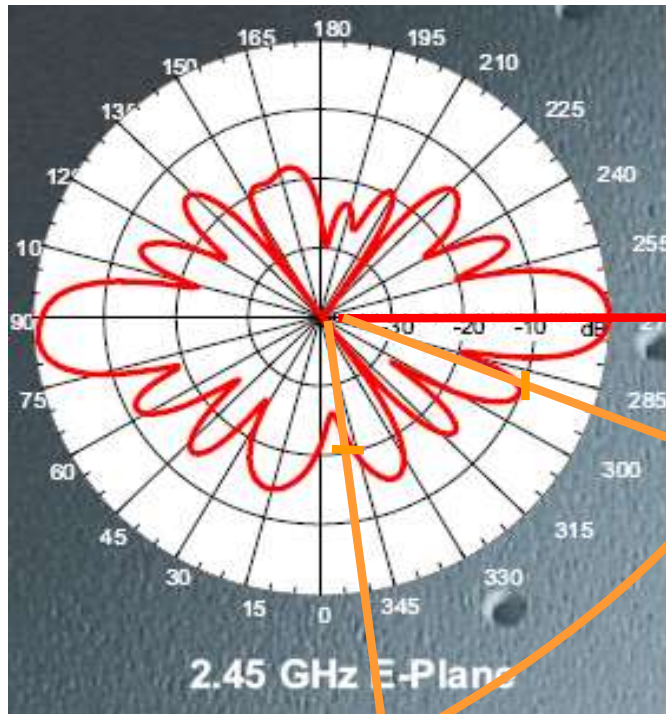
	Azimuth (H-plane)	Elevation (E-plane)
High Gain Antenna 10 dBi Vert BW: 8° Max Range: 500m		
Lower Gain Antenna 5 dBi Vert BW 18° Max Range: 285m		
Down Tilt Antenna 3 dBi Vert BW 60° Centered at -45° Max Range 226m		

Antenna Comparison

- The following examples look at the these antennas for suitability in a warehouse (or high ceiling) environment with ceiling mounted APs.
- In this environment,
 - The clients may have an obstructed view of the AP
 - Up at the ceiling height the APs have a clear view directly to the other APs causing potential AP-AP interference
- The challenge
 - Ensure coverage gets to the ground to reach the clients
 - Minimize AP to AP interference for APs operating on the same channel (about every 4th AP deployed for a typical 3 channel plan)



Vertical Coverage: High Gain Omni Pattern



Direction of Maximum Gain at 0°, Gain=8 dBi

$8\text{dBi} - 10\text{dB} = -2\text{ dBi @ } -20^\circ$

Highest gain is directed
At next AP instead of clients!

This way up



$8\text{dBi} - 20\text{dB} = -12\text{ dBi}$

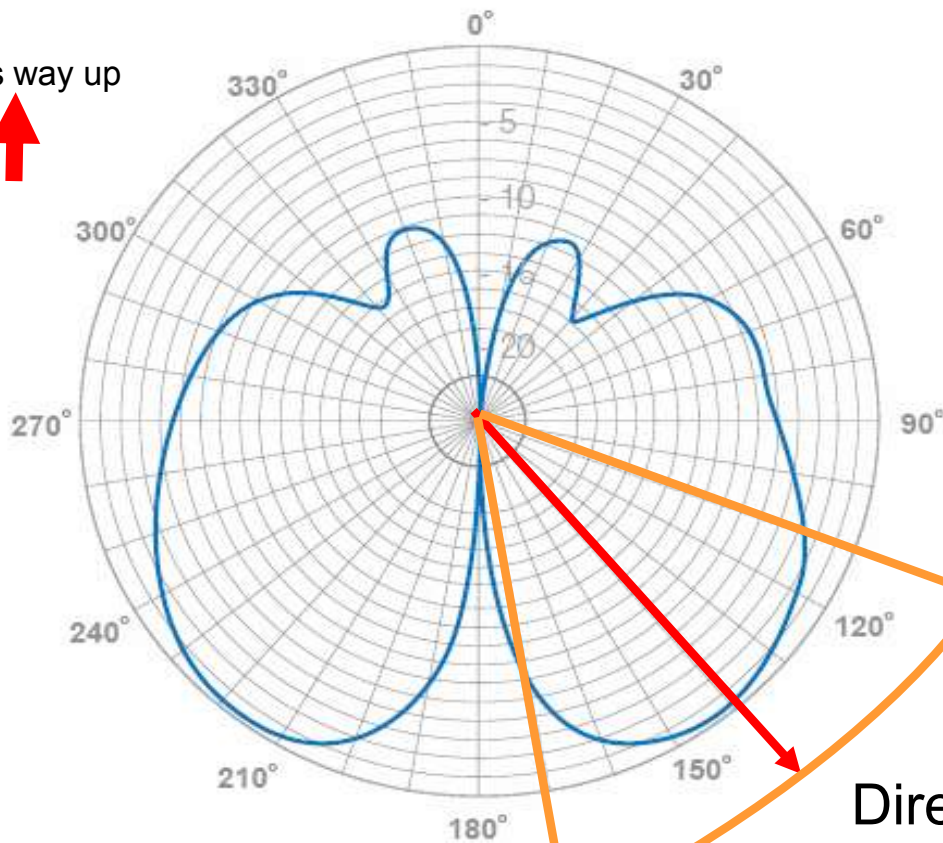
@ 80° Weakest signal is directed to clients!

High Gain Omnidirectional
(8 dBi, 2.4 GHz)



Vertical Coverage: Downtilt Omni

This way up



Downtilt
Omnidirectional
+3 dBi Gain at -45°
“downtilt” angle in the
E-plane (Vertical
Direction)

$$3 \text{ dBi} - 3 \text{ dB} = 0 \text{ dBi @ } -20^\circ$$

Direction of Maximum Gain
@ -45° to ceiling
Max Gain = +3 dBi

$$3 \text{ dBi} - 5 \text{ dB} = -2 \text{ dBi @ } -80^\circ$$

Max Gain is Directed to Clients!



Std/High Gain Omni OR Downtilt Omni ?

Std/High Gain Omni

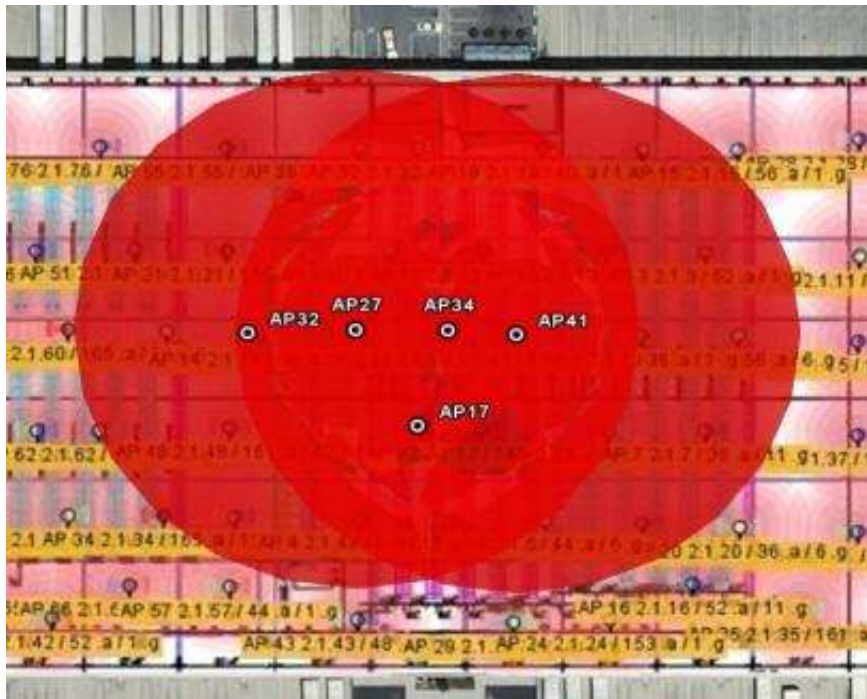
- Highest Gain in direction of Aps
- Increased AP to AP interference
- -12 to -2 dBi Gain towards clients

Low Gain Downtilt

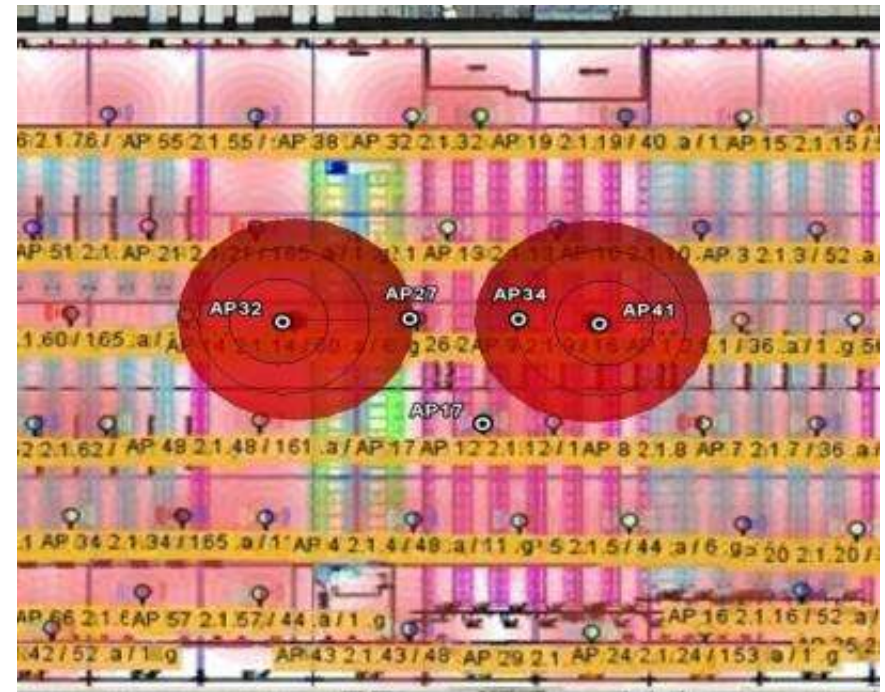
- Maximum gain directed towards clients
- Reduced AP to AP interference
- -2 to +3 dBi Gain towards clients (5 to 10 dBi higher)



Antenna Comparison (Plan View)



High Gain Omni (8 dBi)



Downtilt Omni (3 dBi)

The Horizontal Range of the down tilt antenna is much less than the high gain antenna.

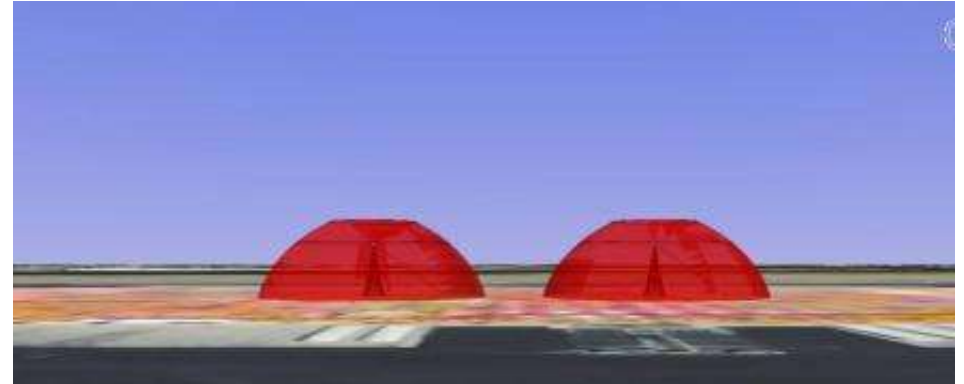


Antenna Comparison (Elevation View)



High Gain Omni

- APs interfere with other APs on the same channel
- But coverage does not reach the clients on the floor.



Down tilt Omni

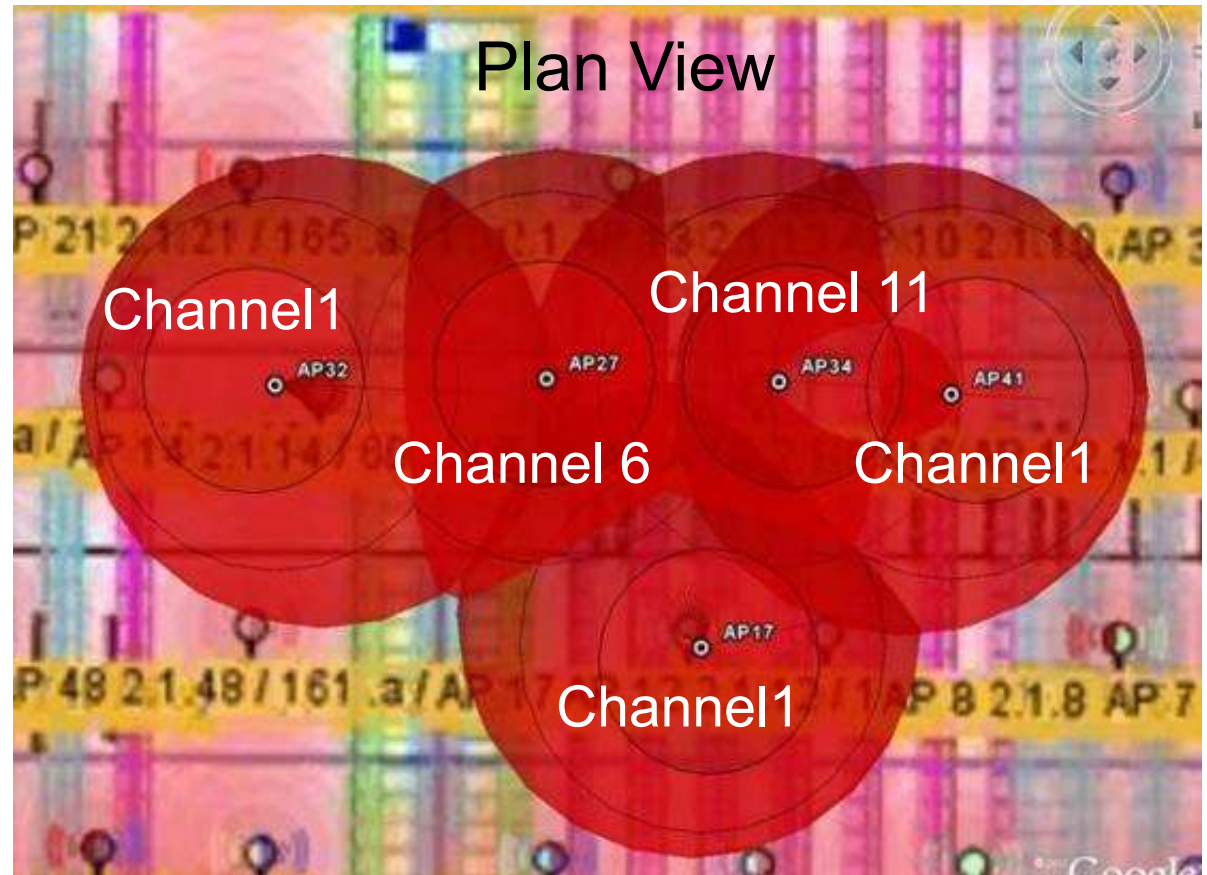
- Coverage does not overlap at the AP height.
- Has omni coverage that reaches the clients on the floor



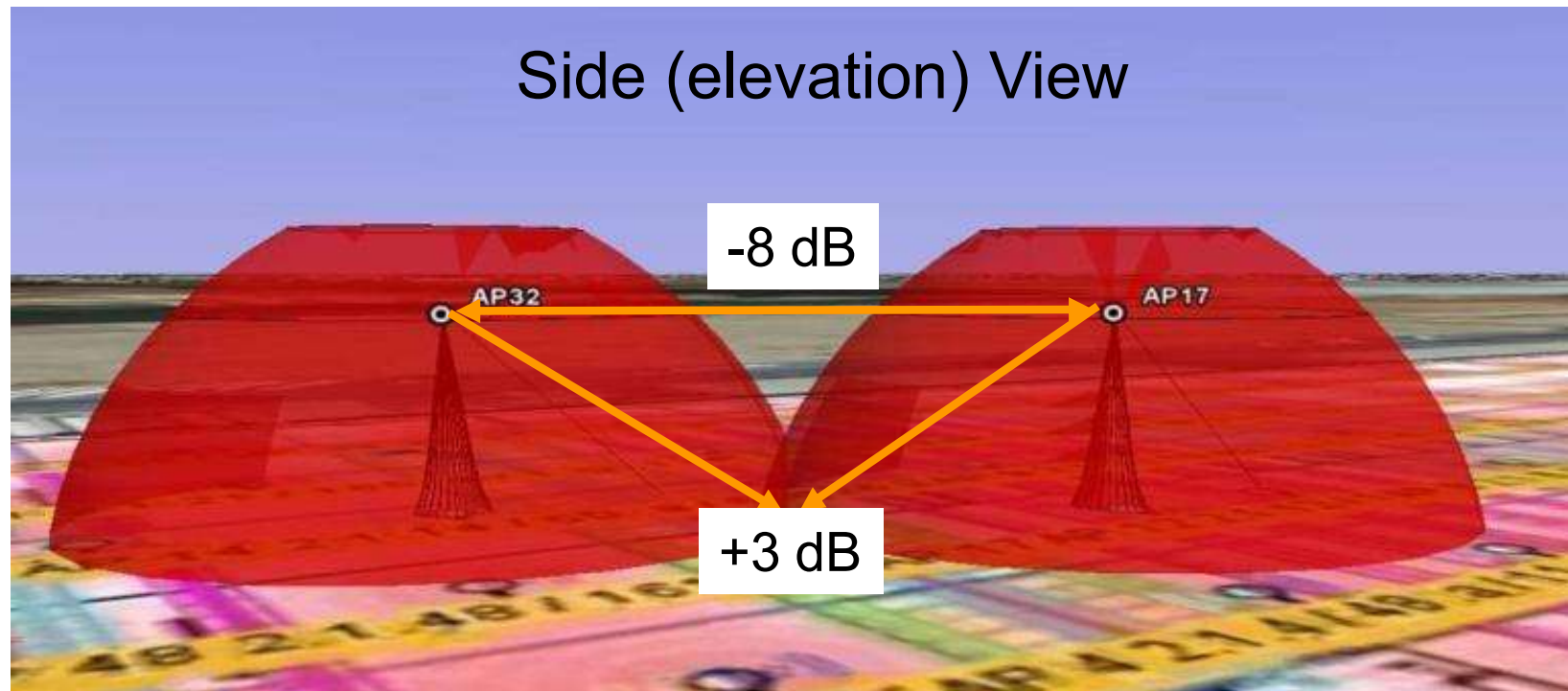
Downtilt OmniDirectional – Interference Management

Aruba ARM will automatically set channels and power.

In the this example, three (of 5 APs) are shown on Channel 1 due to the surrounding APs.



Downtilt Omni – Interference Management



Maximum gain at 45 degrees down

- Reduced AP to AP interference
- AP to AP signal ~11 dB below the signal seen by clients standing on the ground



Coverage – Vertical vs. Horizontal

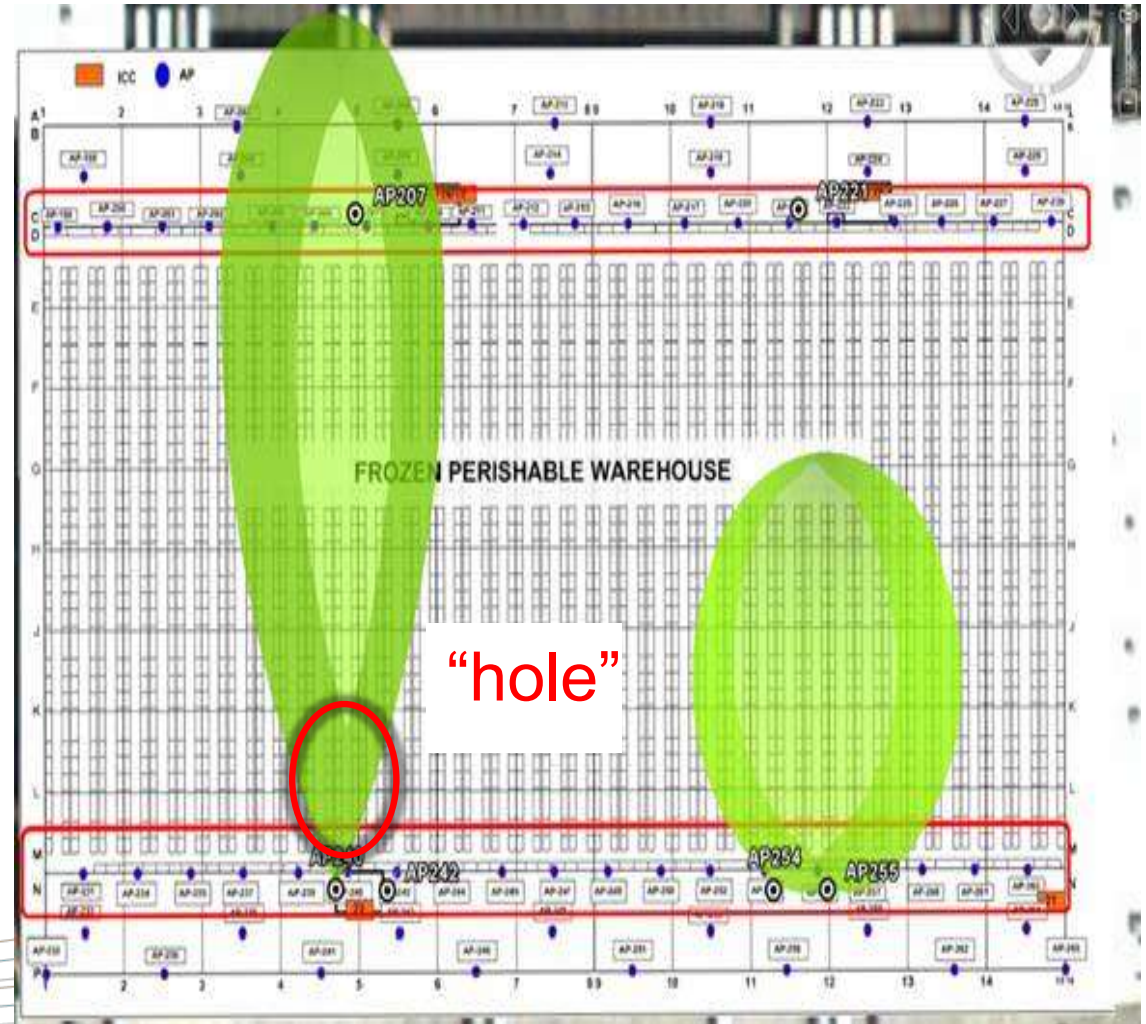
- High Gain antennas are useful for extending horizontal range.
- However, low gain down tilt omni-directional antennas are useful for improving vertical coverage
- Use of high gain antennas is generally not recommended in warehouse environments compared to lower gain antennas with wide vertical beamwidth
- The following slides illustrate another situation (wall mounting antennas) where a slightly different challenge is presented but the use of high gain antennas still can present unexpected problems



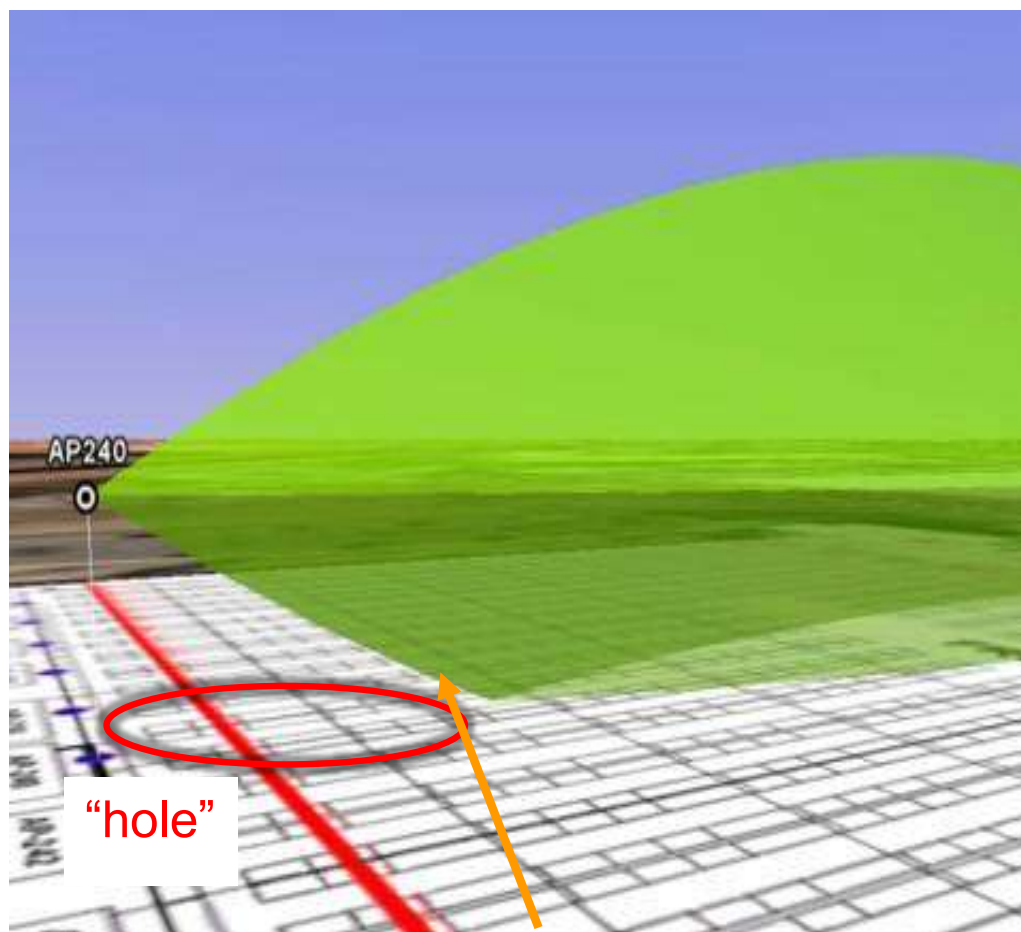
Wall Mounted Antennas

In this example (of a frozen perishable warehouse) APs must be mounted on the walls at 30 foot height and cover the aisles lengthwise. The antenna on the left is 13 dBi antenna, on the right is a 5 dBi antenna

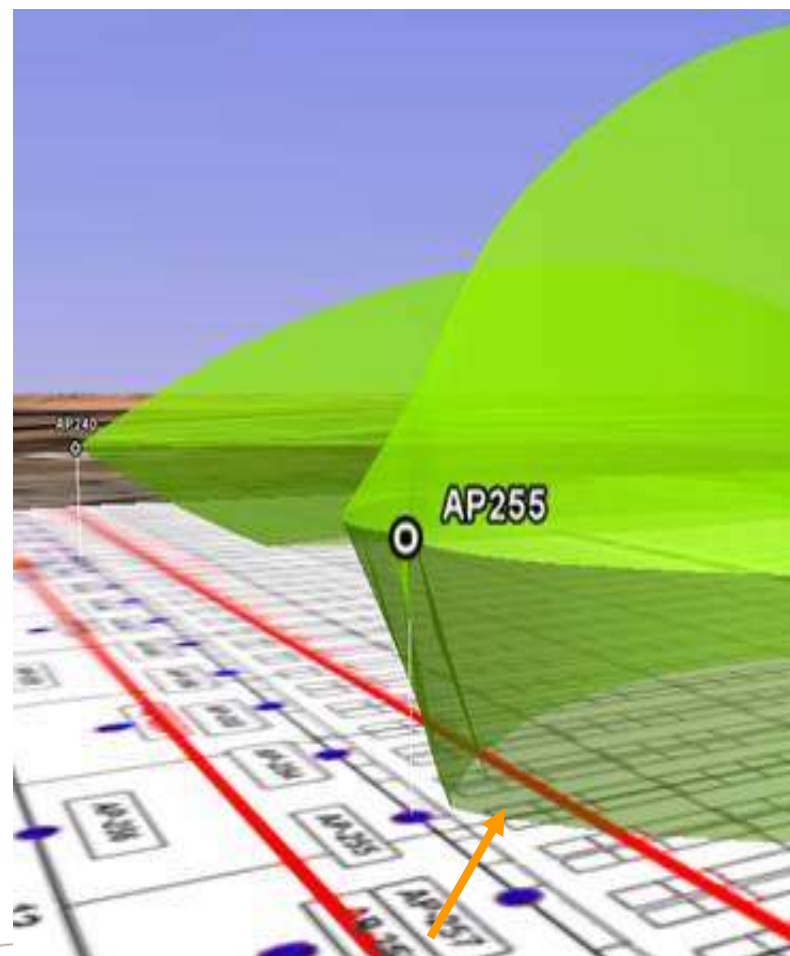
The darker area is a **coverage "hole"** close to the AP caused by the high gain antenna pattern having very narrow vertical characteristics. This "hole" extends about $\frac{1}{4}$ the way down the aisle and will be a region of poor connection reliability



Wall Mounted Antennas – 3D View



High Gain Antenna Pattern
(narrow vertical beamwidth)



Low Gain Antenna Pattern
(wide vertical beamwidth)



Antennas (Summary)

Vertical coverage critical in high ceiling environments to get coverage in between shelving and stacks and ensure that intended signals reach the clients.

Low gain, downtilt omnidirectional antennas are ideal for high ceiling installation environments because:

- Low gain limits range to a predictable area around the AP and reduces AP-AP interference
- Low gain limits users per AP to a controlled area
- Downtilt omni pattern provides users at ground level a higher signal than APs see to each other (interference mitigation)
- Adaptive Radio Management (ARM) functionality is improved for autocalibration of the RF network and realtime visualization.

The downtilt antenna is ideal and will work in conjunction with ARM to ease the setup and management of a high ceiling environment AP deployment.

Special Note : Aruba AP105 is the only Aruba AP with an integrated Downtilt omnidirectional pattern antenna



Agenda

- RF Design Challenges
- RF Fundamentals
- Planning for Deployment
- **Troubleshooting RF Issues**
- Q&A



Troubleshooting User Issues

- What symptoms are being reported?
- Where in the network flow is the problem likely occurring?
 - Can the client establish an association with the AP?
 - Can the client authenticate if 802.1x is being used?
 - Did the client get an IP address
 - Are there application issues?
 - Does the problem happen while the client is stationary or while the client is roaming?
 - What is the SNR between the client and the AP?
 - Did any network events occur at the time of the problem that might be a clue as to the cause of the problem?
 - Is there any interference on the RF spectrum?

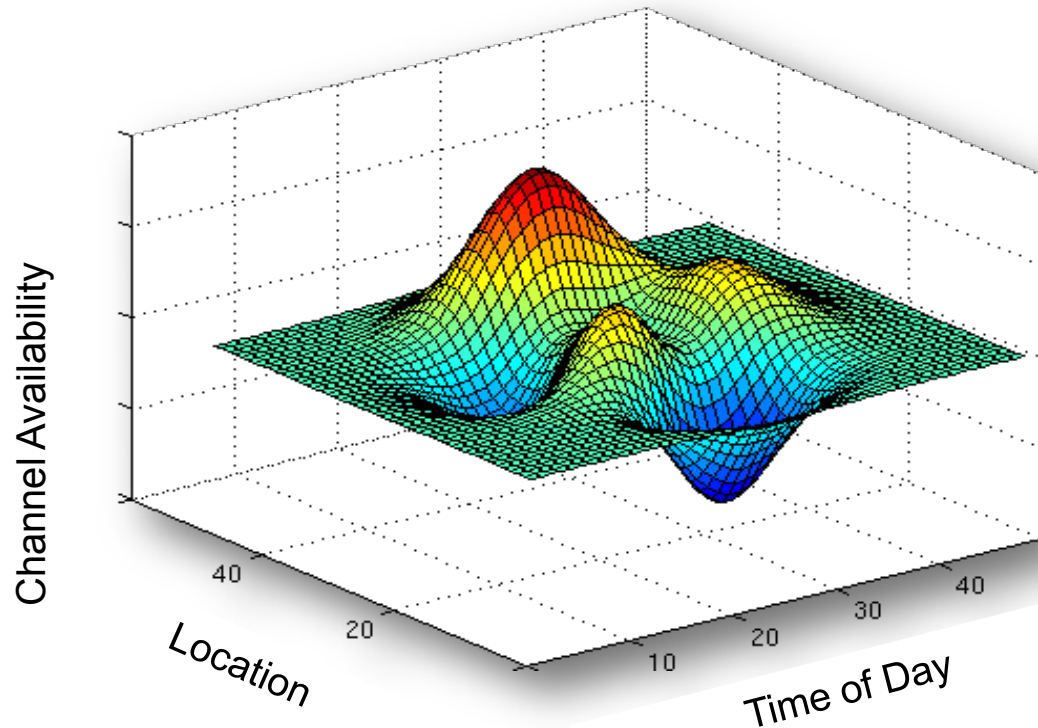


Troubleshooting RF Issues – Detecting Interference using AP Statistics

- Using statistics on the AP to detect likely interference. On Aruba APs, the user can look at detailed radio stats that record, among other things, phy errors, crc errors, retries, etc.
- If the ratio of phy errors to transmitted frames is high and the phy error count is increasing rapidly, then the possibility of interference exists.
- If the number of retries is increasing rapidly, it may indicate interference, or the possibility of weak SNR between the client and AP.
- There are lots of stats on Aruba APs that can help troubleshoot RF issues-client SNR, 802.11 retries, noise levels on a channel, etc.

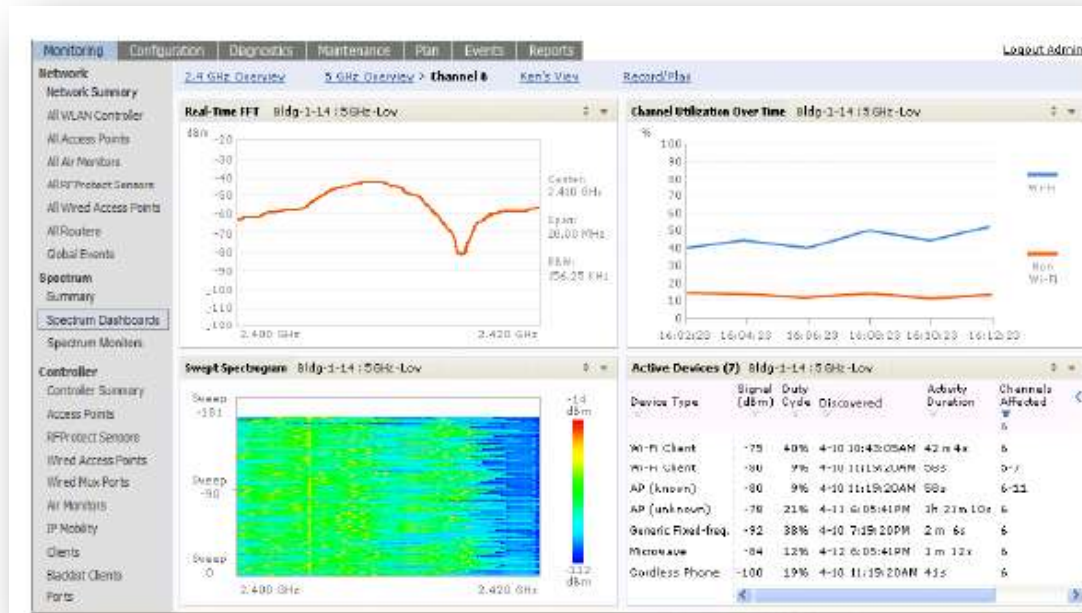


The Challenge: Dynamic RF Environments



- Interference is both inevitable and unpredictable
 - Varies by device (microwave, cordless phone), usage pattern (time variance), location (local emissions regulations, construction)
- Must be managed to ensure reliable Wi-Fi operation

Spectrum Analysis: Diagnostic Gold Standard



- ✓ Active Devices By Device Type
- ✓ Active Devices By Channel
- ✓ Active Devices Trend
- ✓ Channel Quality
- ✓ Channel Quality Trend
- ✓ Channel Utilization
- ✓ Channel Utilization Trend
- ✓ FFT Power
- ✓ FFT Duty Cycle
- ✓ Interference Power
- ✓ Swept Spectrogram
- ✓ Channel Quality Spectrogram

- Spectrum analysis identifies interference and its sources
 - There is no substitute for real-time analysis at the point-of-problem
- Best integrated into the WLAN infrastructure
 - Hand-held tools are useful only when IT staff are on-site and interference is present – an unlikely combination in distributed enterprises