HIGH DENSITY WIRELESS NETWORKS

VALIDATED REFERENCE DESIGN (VRD)

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Agenda

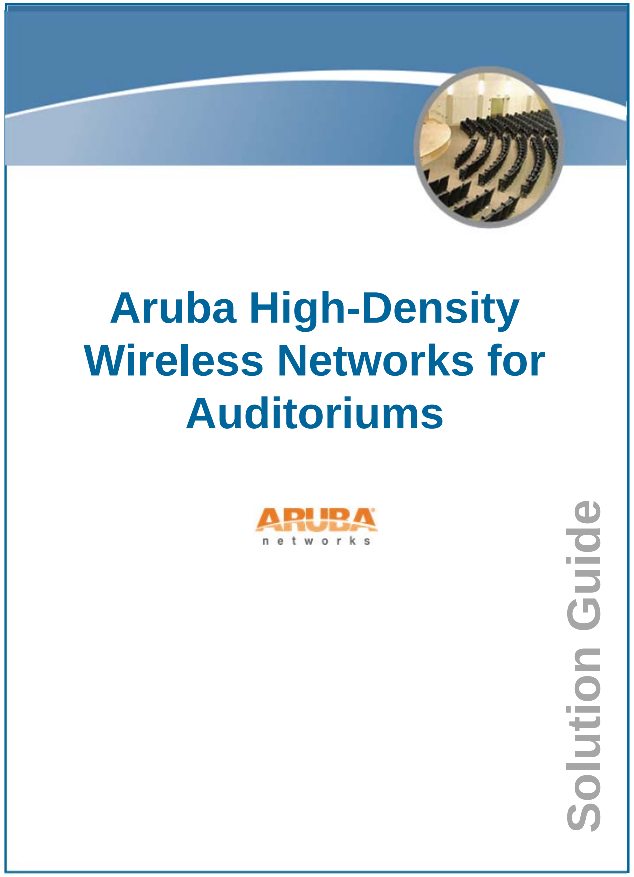
- **Capacity Planning for HD WLANs**
- **RF Design for HD WLANs**
- **Optimizing and Configuring ArubaOS**
- **Case Study #1 – Marina Bay Sands Singapore**
- **Case Study #2 – Turner Field**

Capacity Planning for High-Density WLANs

Aruba Validated Reference Designs

- **Aruba is the thought leader in our industry. We produce a library of Validated Reference Designs**
- **The High Density (HD) WLANs VRD covers ultra high capacity spaces such as auditoriums, arenas, stadiums and convention centers**
- **The recommendations have been field proven at dozens of customers**
- **VRDs are free to download from Aruba Design Guides web page:**

  http://www.arubanetworks.com/VRD



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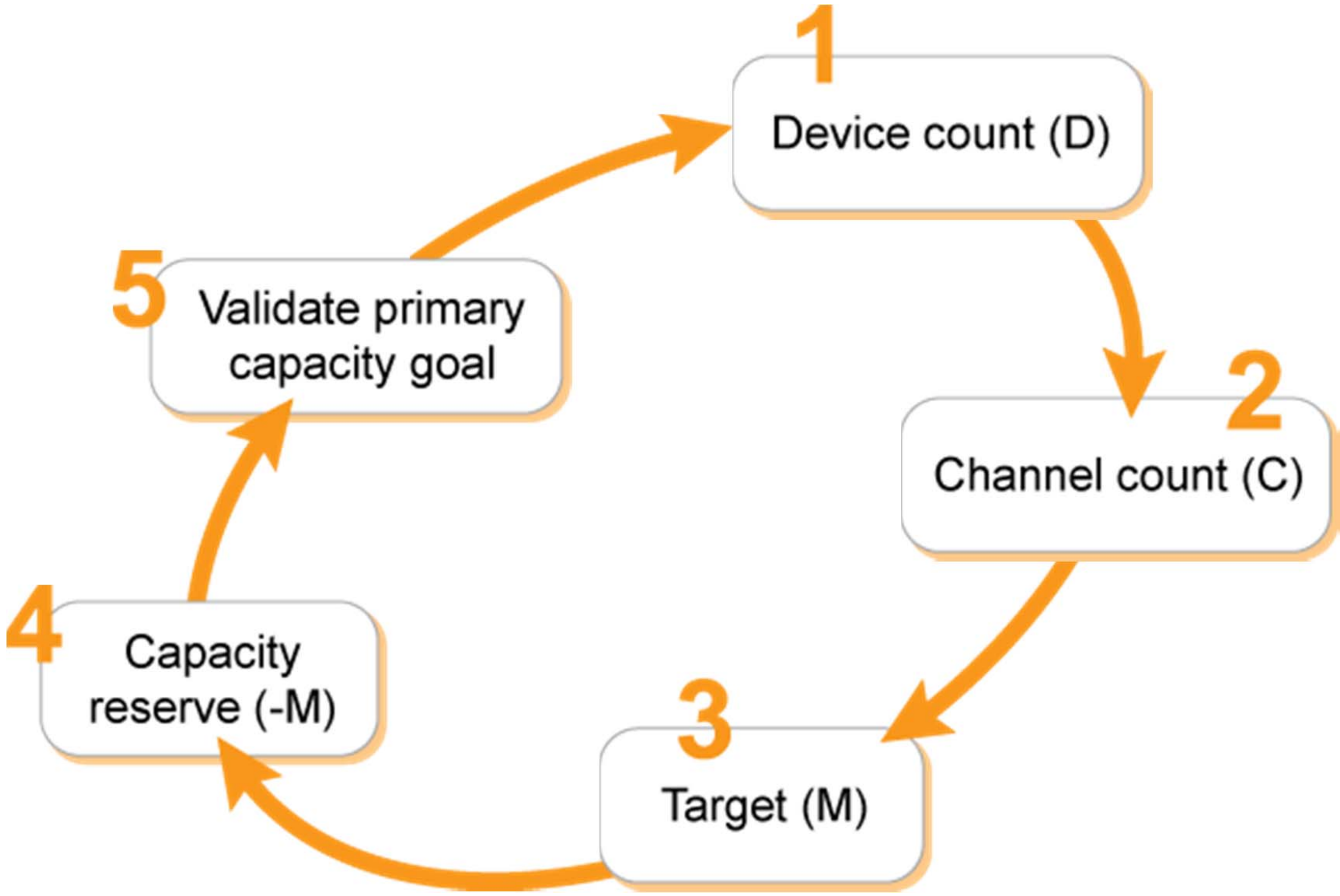
High Density Area Challenges

- Uncontrolled mix of device types, operating systems, driver levels, and radio types
- Multiple devices per person – up to three
- Per-user bandwidth needs can easily exceed what is allowed by WiFi and physics
- Simultaneous data plane spikes during roomwide events (slide advance, polling)
- Inrush/outrush demand increases load on network control plane, address space, etc.
- Power save behavior also loads control plane
- Most devices limited to 1x1:1 HT20 operation

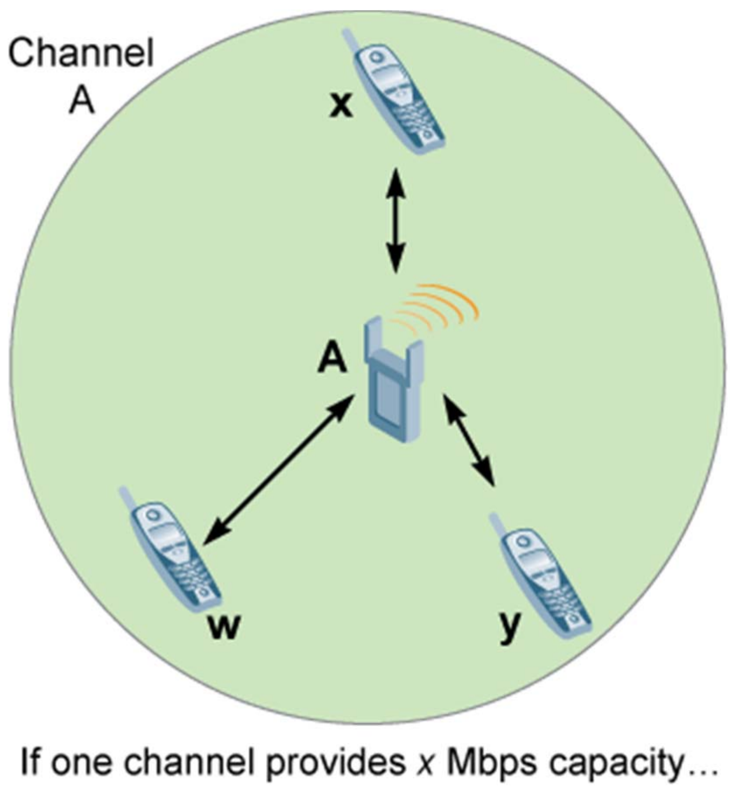
HD WLAN Capacity Planning Methodology



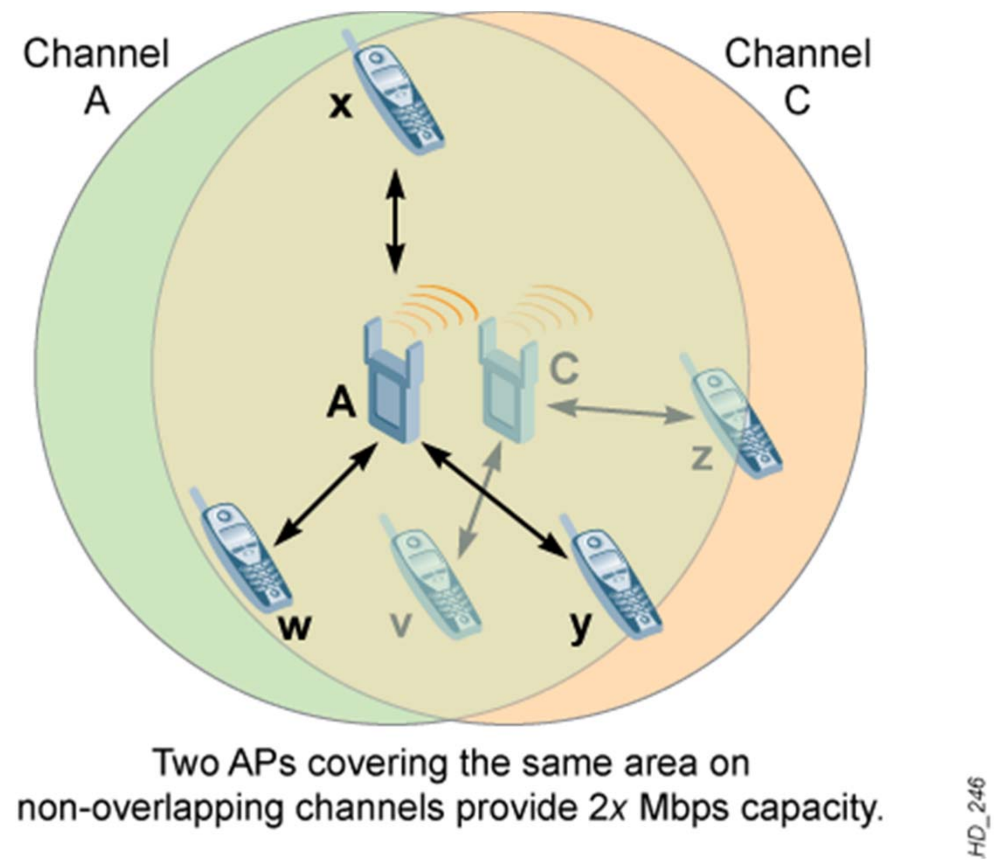
Step 1: Determine Device Count

- **Choosing a high-density WLAN capacity goal:**
  - **Total # of devices** = seats X devices per seat
    - A user may have a laptop & Wi-Fi smartphone
    - Each MAC address uses airtime, IP address, etc.
  - **Minimum bandwidth per device** – driven by mix of data, voice and video applications used
  - Common examples of a complete capacity goal:
    - Classroom has 30 students each needs 2 Mbps
    - Auditorium holds 500 people w/laptop at 350 Kbps for data and a voice handset at 128 Kbps
    - Trading floor of 800 people with 512 Kbps each
  - Try to plan for future capacity needs in the design
  - Number of seats may remain fixed, but number of devices may continue to proliferate

Step 2: Determine Channel Count
Overlapping vs. Stacking



Single Channel



Overlapping Channels

HD WLANs should always use the 5-GHz band for primary client service
Client chipset / driver also impact supported channels

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Step 2: Determine Channel Count
Channels Allowed by National Regulatory Agency

- **Channel bonding (HT40) reduces capacity in HD WLANs, so 20MHz channels should always be used in both bands**
- **Available channel count varies from country to country**
- **DFS channels have usability restrictions and may not be a good choice**

DFS Channels

Channel #	Frequency (MHz)	USA	Europe	Japan	Singapore	China	Israel	Korea	Brazil
36	5180	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
40	5200	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
44	5220	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
48	5240	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
52	5260	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
56	5280	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
60	5300	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
64	5320	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
100	5500	Yes	Yes	Yes	No	No	No	Yes	Yes
104	5520	Yes	Yes	Yes	No	No	No	Yes	Yes
108	5540	Yes	Yes	Yes	No	No	No	Yes	Yes
112	5560	Yes	Yes	Yes	No	No	No	Yes	Yes
116	5580	Yes	Yes	Yes	No	No	No	Yes	Yes
120	5600	No	No	Yes	No	No	No	Yes	No
124	5620	No	No	Yes	No	No	No	Yes	No
128	5640	No	No	Yes	No	No	No	Yes	No
132	5660	No	No	Yes	No	No	No	No	No
136	5680	Yes	Yes	Yes	No	No	No	No	Yes
140	5700	Yes	Yes	Yes	No	No	No	No	Yes
149	5745	Yes	No	No	Yes	Yes	No	Yes	Yes
153	5765	Yes	No	No	Yes	Yes	No	Yes	Yes
157	5785	Yes	No	No	Yes	Yes	No	Yes	Yes
161	5805	Yes	No	No	Yes	Yes	No	Yes	Yes
165	5825	Yes	No	No	Yes	Yes	No	Yes	Yes
Total without DFS		**9**	**4**	**4**	**9**	**5**	**4**	**9**	**9**
Total with DFS		**20**	**15**	**19**	**13**	**5**	**8**	**21**	**20**

Step 2: Determine Channel Count

20 MHz vs. 40 MHz Channels

- **High-throughput 40-MHz (HT40) channels**
  - Reduces number of radio channels by bonding them together to achieve higher throughput
  - Reduced max. number of client devices supported
  - HT40 channels not used on the 2.4-GHz band
  - Main benefit — ability to burst at the max. PHY
- **But**, auditoriums must support so many users in a single room that every possible channel is needed
  - Trade-off: Reduce max. burst rate in exchange for a greater total user capacity
- **Therefore**, most HD WLANs including auditoriums should use 20-MHz channel widths, also known as HT20

Step 2: Determine Channel Count
To DFS or Not to DFS?

- **The DFS 5-GHz band, with up to twenty 20-MHz channels, can achieve high performance in a 500-seat auditorium**
- **Without DFS, the goal can be achieved but with oversubscribed radios & lower per-client throughput**

So why wouldn't everyone use DFS?

- **Three significant exceptions could adversely affect HD WLAN performance with DFS enabled:**
  - Proximity to radar sources in the 5250-MHz to 5725-MHz band
  - Lack of DFS support on critical client devices
  - The Receive Sensitivity Tuning-Based Channel Reuse feature of ArubaOS is needed

Step 3: Choose Concurrent User Target
Aruba High Density Testbed

- **Environment** – Open air test
- **Clients** - 50 late-model laptops with mix of manufacturers, OS and wireless adapter/driver
- **Goal** – Mimic the uncontrolled, heterogeneous environment that exists in most auditoriums
- **Procedure** – Run scaling tests from 1 to 50 clients and measure how throughput changes with load

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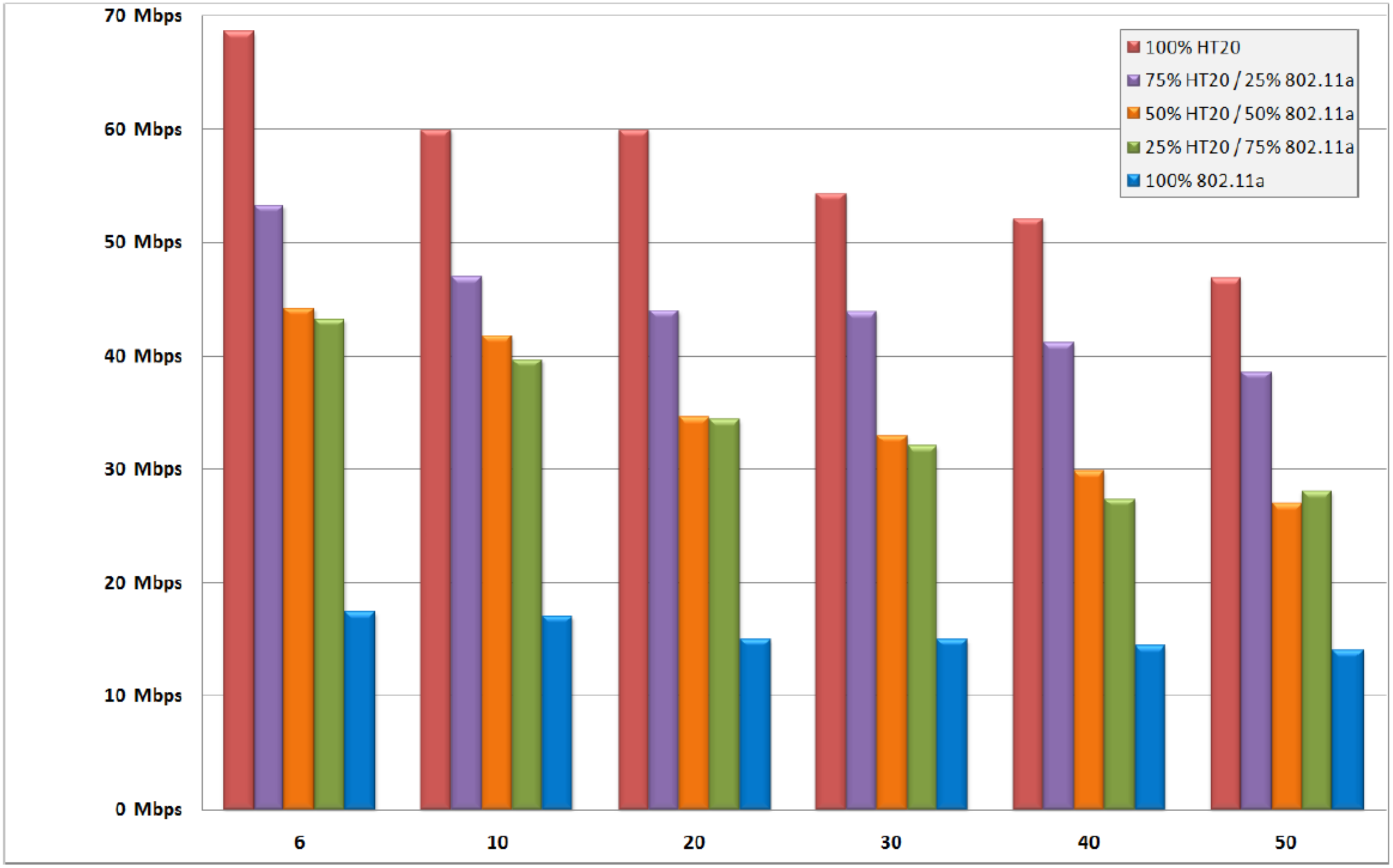
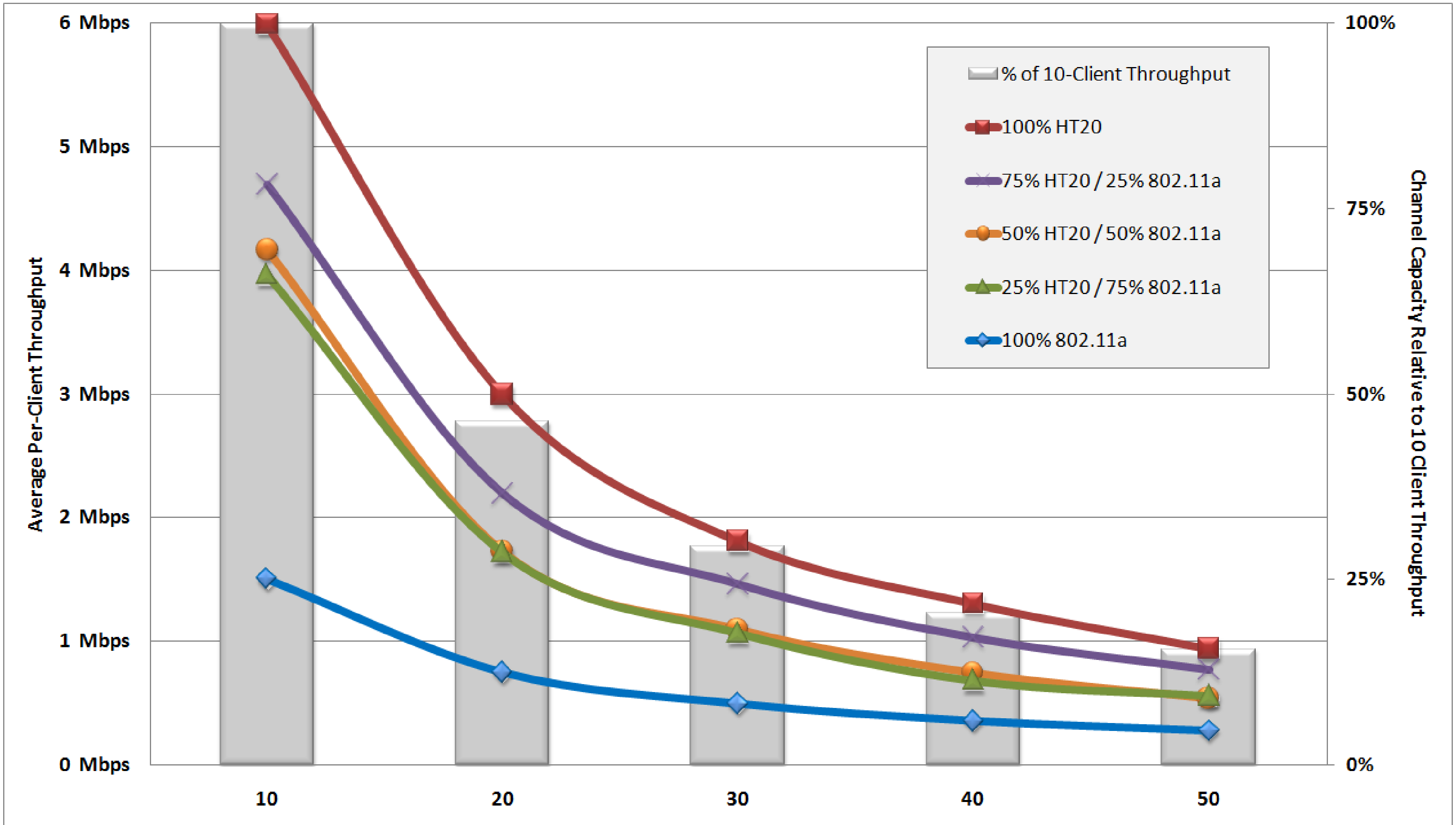
Step 3: Choose Concurrent User Target
Measured 20MHz Channel Capacity



5-GHz Aggregate Mixed-Mode TCP Client Scaling Performance

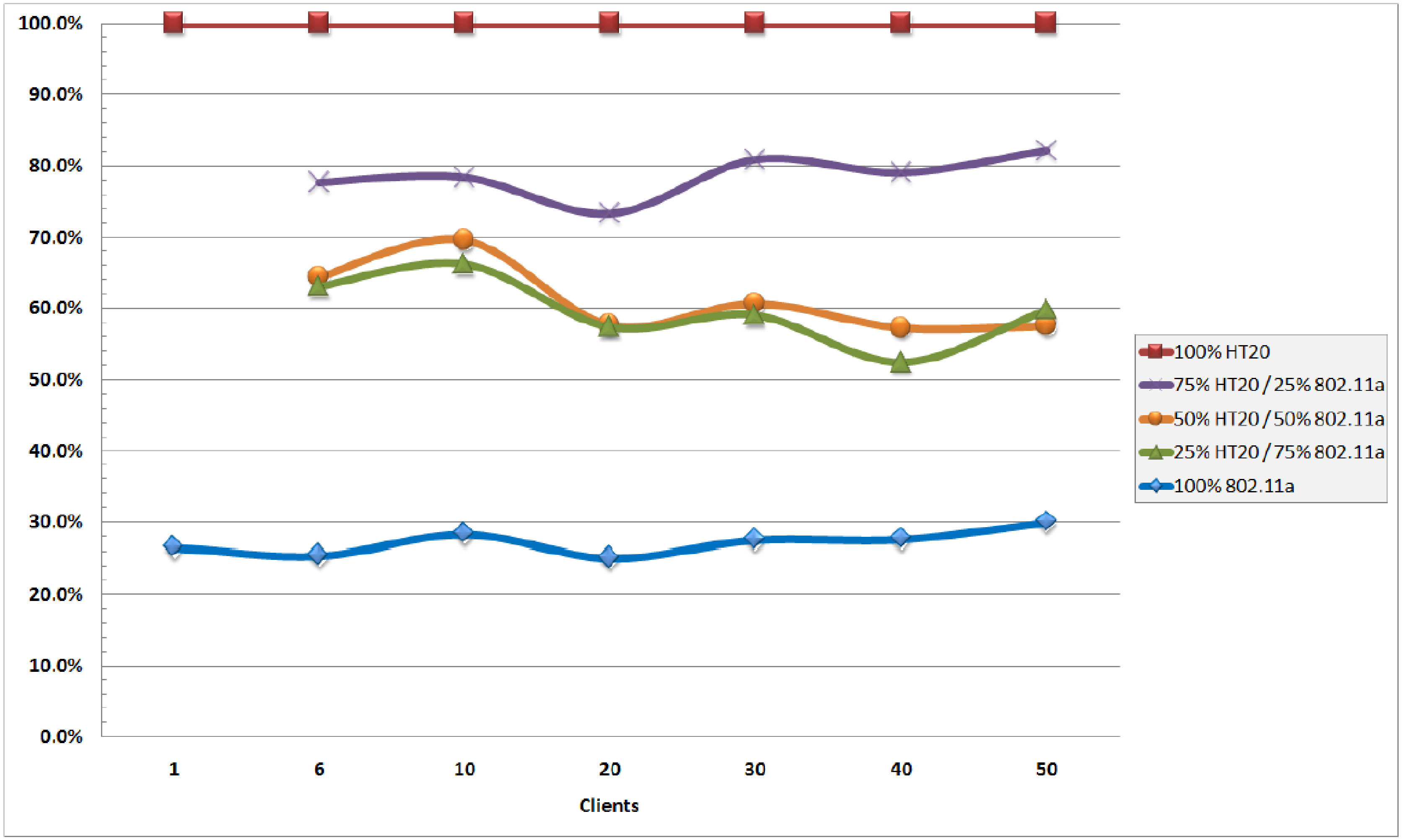
Step 3: Choose Concurrent User Target

Tradeoffs Between Bandwidth and User Count



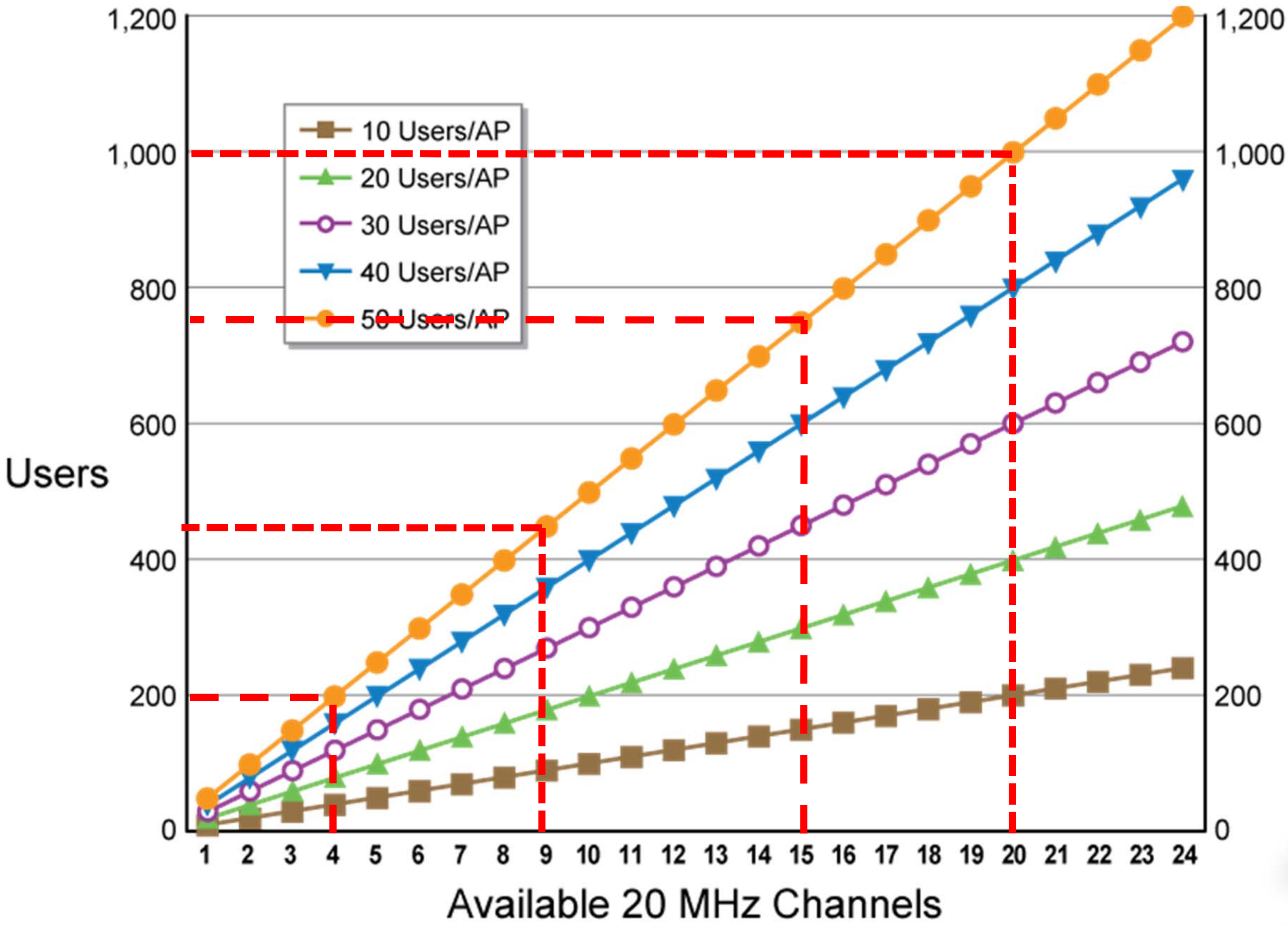
5-GHz Per-Client Mixed-Mode TCP Client Scaling Performance

Step 3: Choose Concurrent User Target
Relative Performance of Channel Mixes



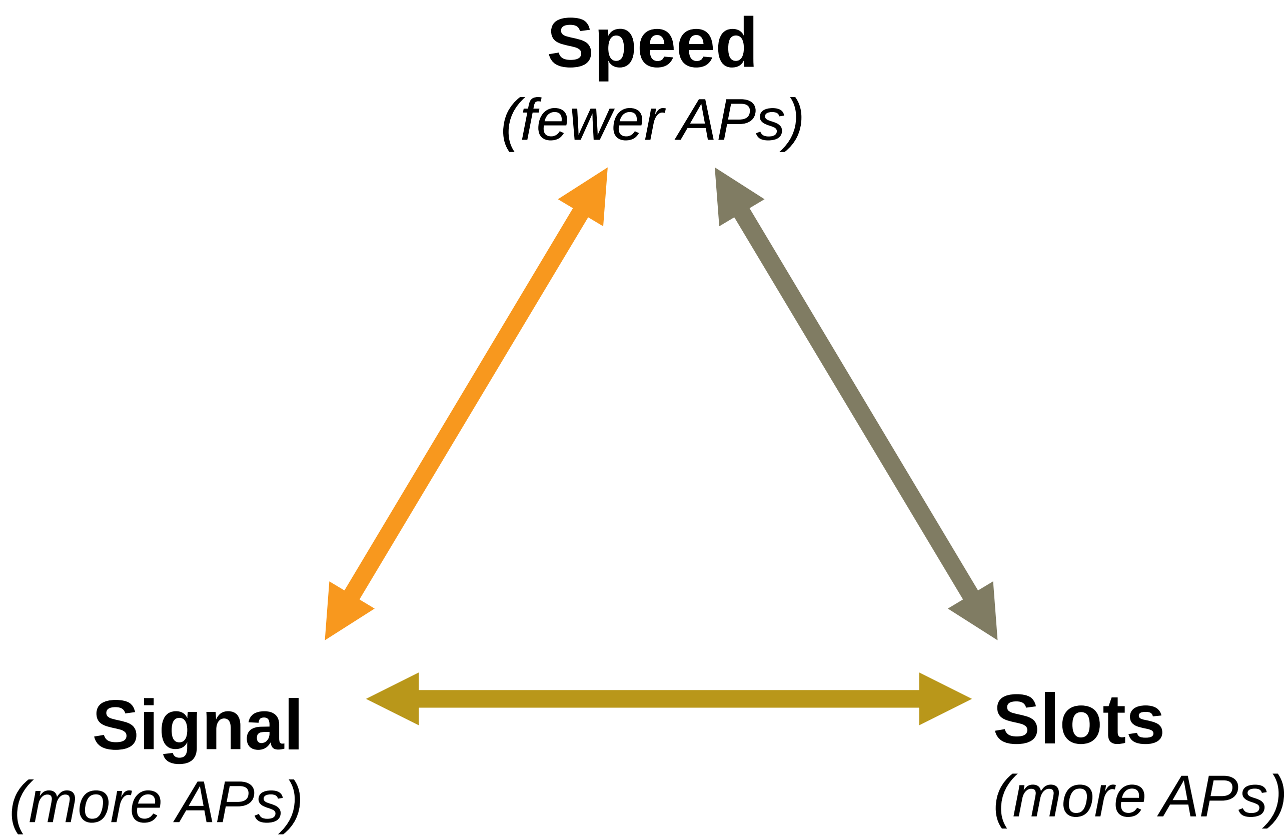
5-GHz Per-Client Mixed-Mode TCP Client Scaling Performance

Step 4: Determine Total Capacity



Channel Reuse Revisited

Choosing the Lesser Evil



Step 5: Validate Capacity Goal

- **Validate whether the entire HD coverage area will meet the capacity goal you chose in Step #1.**
- **It is common for the wireless architect to have to follow an iterative process and compromise between channel count, radio loading and minimum per-client throughput.**
- **If the capacity prediction in Step #4 falls short of the capacity goal, repeat the first four steps until you achieve the best balance to achieve your goal.**
- **For large auditoriums over 500 seats, you should be prepared to accept a per-client throughput of 500 Kbps or less, assuming a 50/50 mix of .11n and .11a stations and nine usable channels.**

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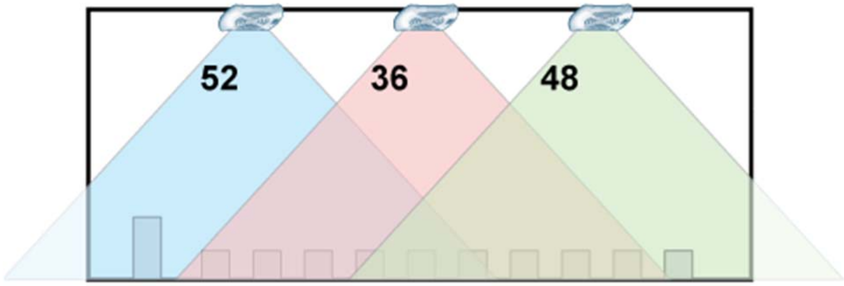
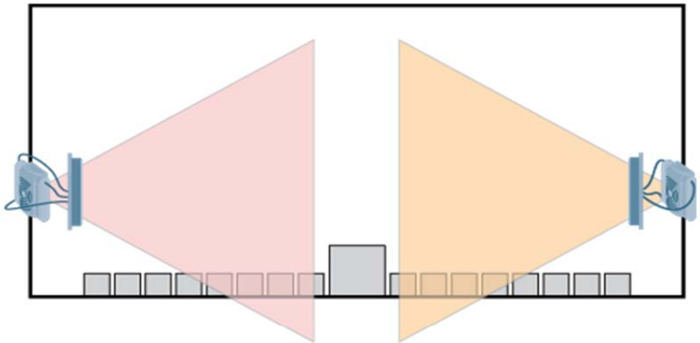
RF Design for High-Density WLANs

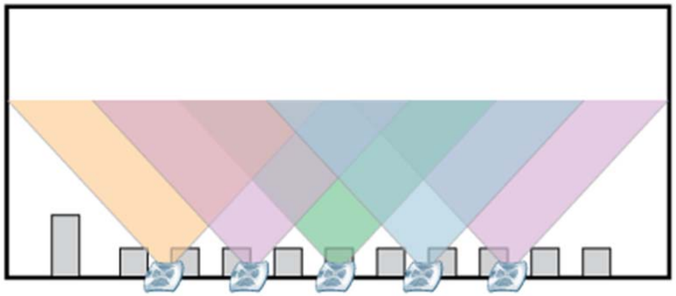
Coverage Strategies for Auditoriums



Overhead coverage is a good choice when uniform signal is desired everywhere in the auditorium



Wall installations are most often seen where ceiling or under-floor access is not possible or too expensive.



By far the best coverage strategy for auditoriums is mounting under, in, or just above the floor.

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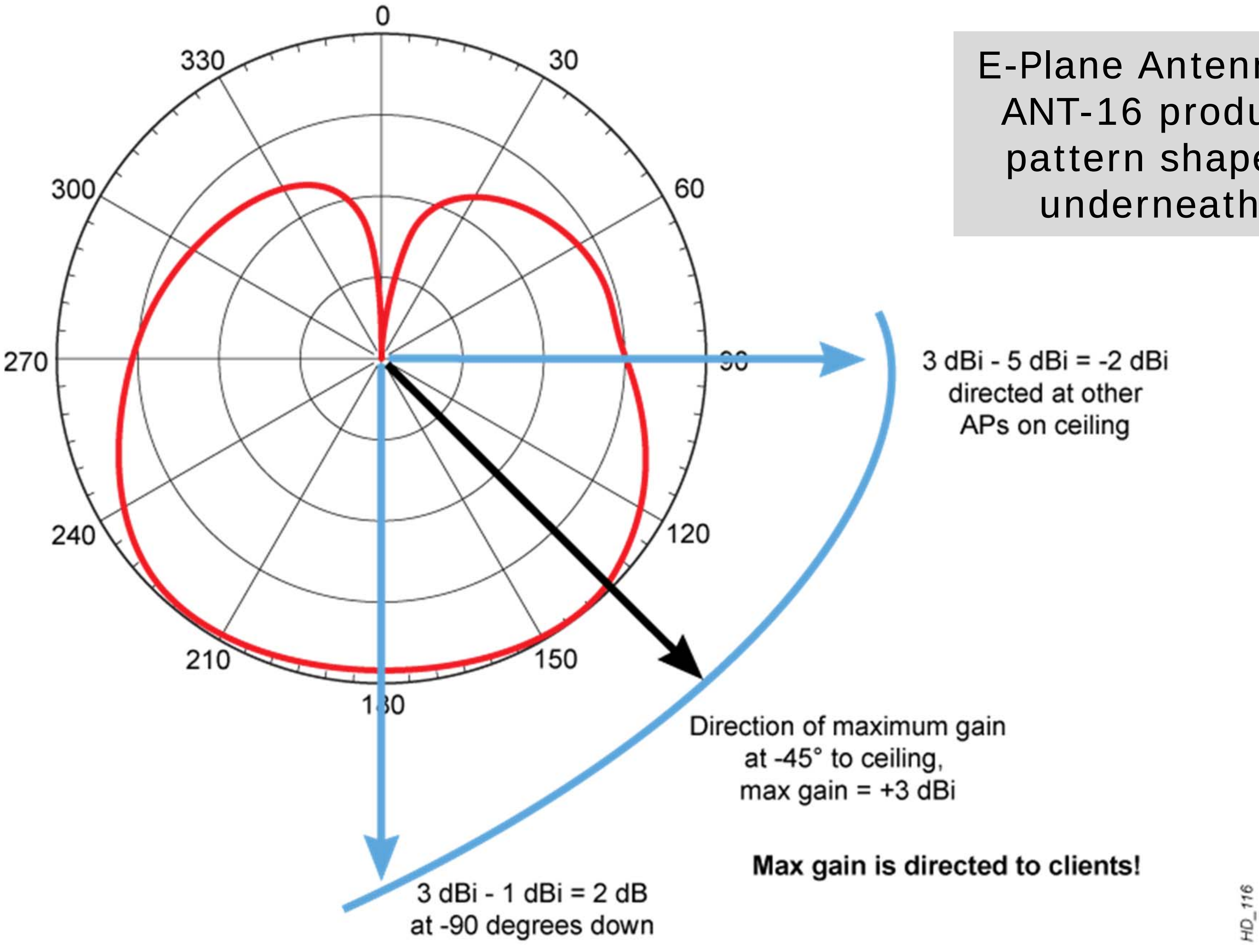
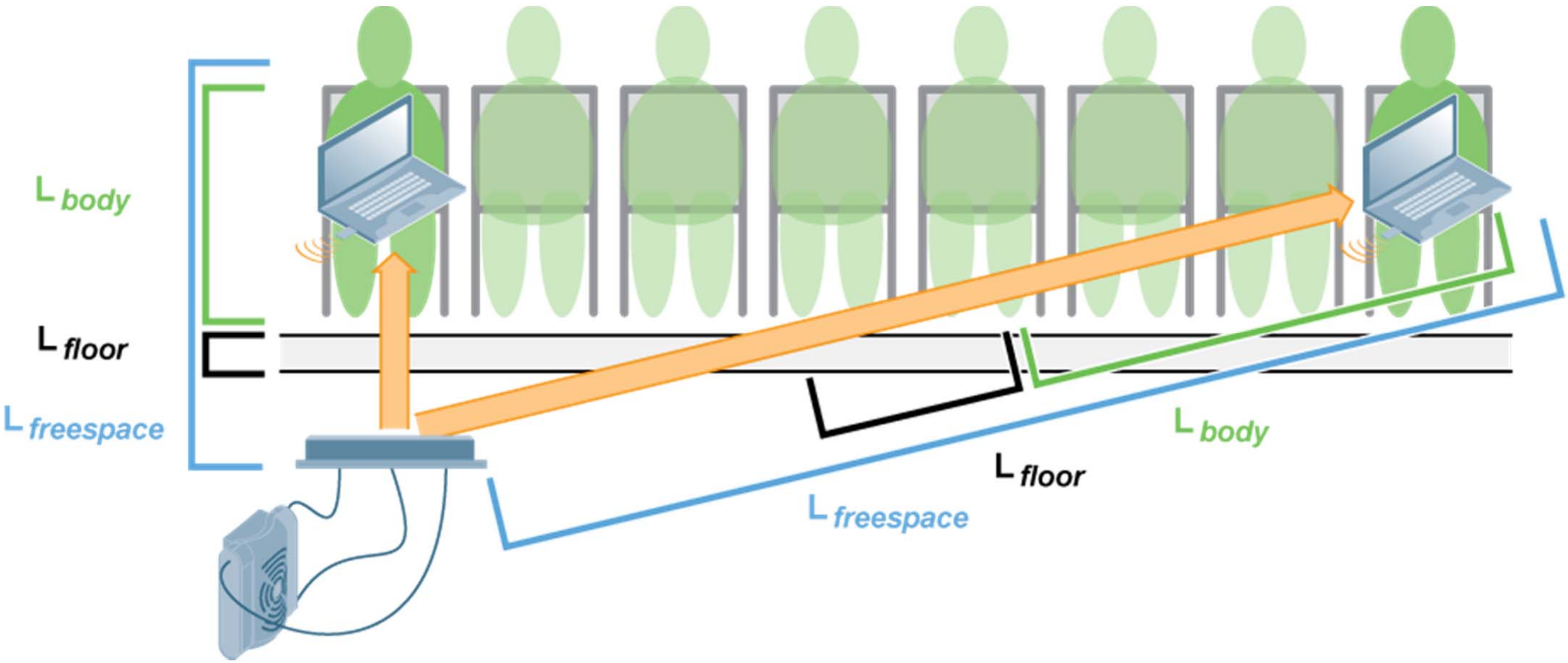
Overhead Coverage — RF Radio Patterns



E-Plane Antenna Pattern of AP-ANT-16 produces a coverage pattern shaped like a "cone" underneath the antenna.

Picocell Coverage - Link Budget Analysis



Picocell link budget formula

PRX = PTX – Lfreespace – Lfloor – Lbody + GTX + GRX

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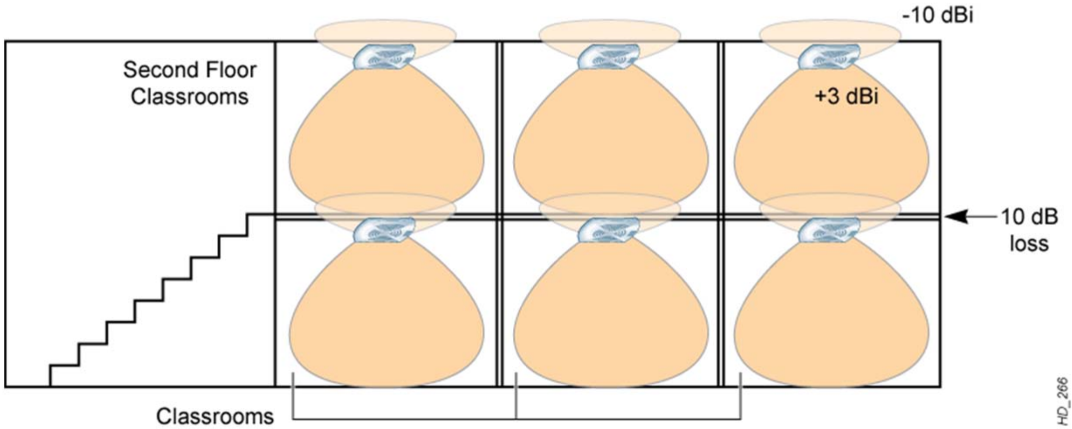
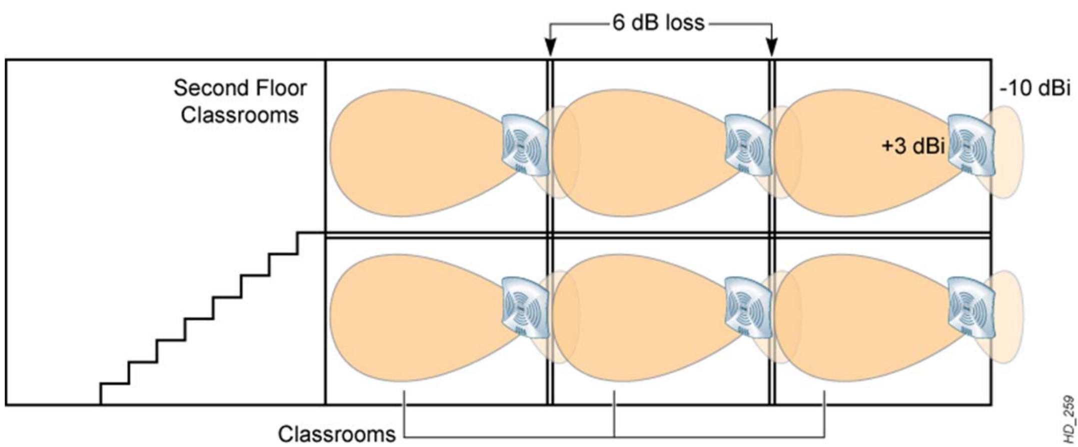
AP Coverage Strategies – Pros and Cons

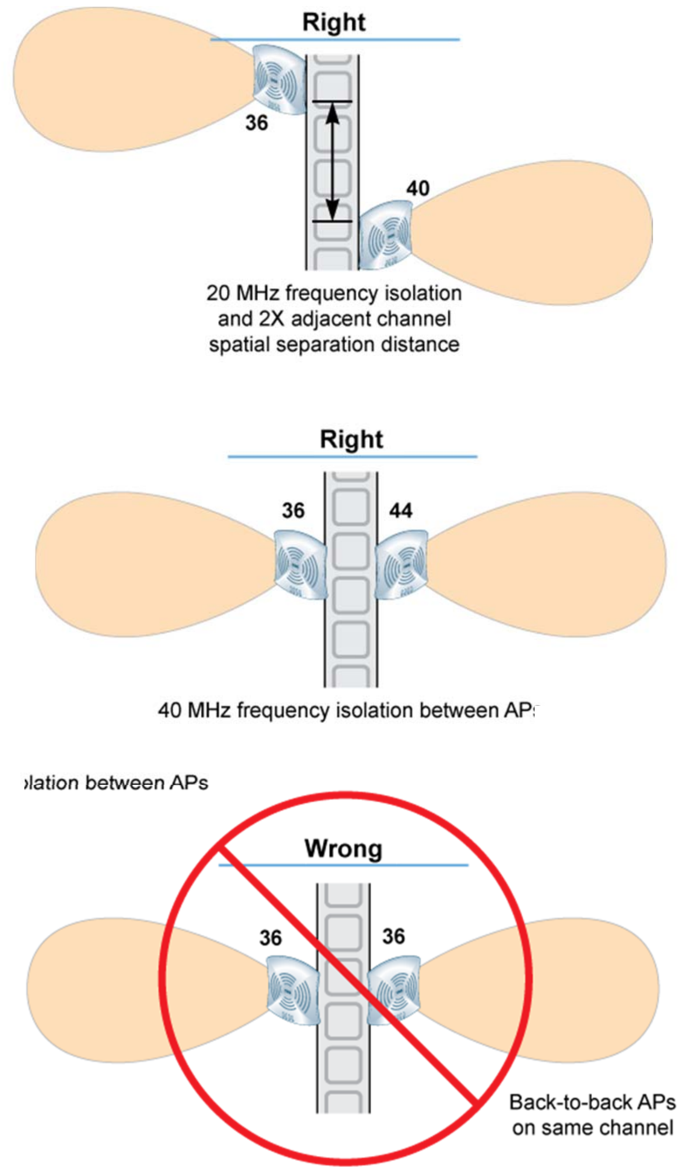
Strategy	PROs	CONs
Overhead Coverage	• Can be concealed inside ceiling. • Mounted above eye level. • Uniform signal, APs evenly spaced. • Clear line-of-sight to devices. • Minimal human-body attenuation. • Better CCI/ACI control.	• Channel reuse not possible. • Difficult to pull cable.
Side Coverage	• Easy to install and pulling cable. • Columns can be used to deliberately create RF shadows.	• Channel reuse not possible. • Inconsistent signal levels. • Increased body attenuation. • Harder to control CCI/ACI. • Signal bleed outside area.
Floor Coverage	• Channel reuse possible. • Higher AP densities can be achieved. • APs can be easily concealed. • More uniform signal in the room. • Clear line-of-sight to devices. • Minimal human-body attenuation. • Better CCI/ACI control.	• Access underneath the auditorium. • Availability of cable pathways beneath the floor.

Adjacent HD WLANs



AP-105 Integrated Directional Antenna to Isolate Adjacent HD WLANs





Optimizing & Configuring ArubaOS for High-Density WLANs

Essential Aruba Features for HD WLANs

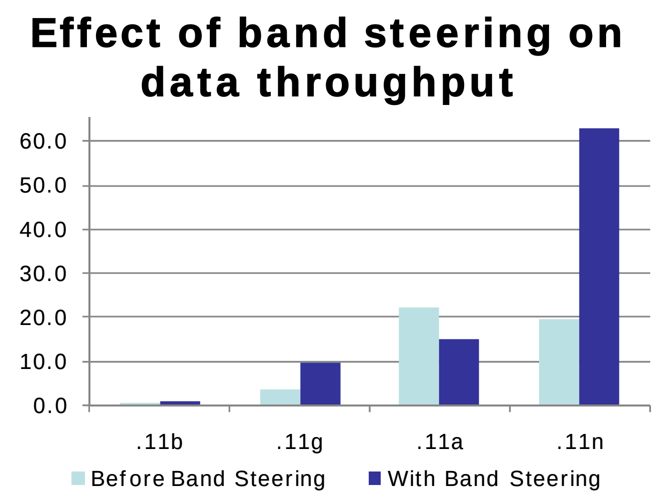
Optimal Channel Distribution	Optimal Client Distribution	Optimal Power Control	Optimal Airtime Management
• Even distribution of channels w/ARM • Enable load-aware, voice-aware, video-aware scanning • Repurpose unneeded 2.4-GHz radios with Mode-Aware ARM or static assignment • Enable DFS channels if used	• Shift all 5-GHz capable devices off 2.4-GHz band w/Band Steering • Even distribution of clients w/Spectrum Load Balancing	• Restrict maximum allowable EIRP w/ARM to minimize cell overlap • Control power on clients w/802.11h TPC • Minimize CCI and ACI w/Receive Sensitivity Tuning Channel Reuse	• Ensure equal access to medium w/Airtime Fairness feature • Limit "chatty" protocols • Enable Multicast Rate Optimization and IGMP Snooping • Enable Dynamic Multicast Opt. for video • Eliminate low legacy rates by reducing rate adaptation

Optimal Channel Distribution

- **Optimize the distribution of RF spectrum to APs and clients to make best use of scarce spectrum**
  – Use as many allowed RF channels as possible and ensure they are properly distributed
- **ARM Channel Selection**
  – Aruba ARM uses distributed channel reuse mgmt. algorithm
  – This iterative process converges quickly on optimum channel plan for the entire network
- **Mode-Aware ARM**
  – Dynamically shifts surplus radios in the same RF neighborhood to become air monitors
  – Mode-Aware ARM is disabled by default
  – APs cannot be individually configured for Mode-Aware

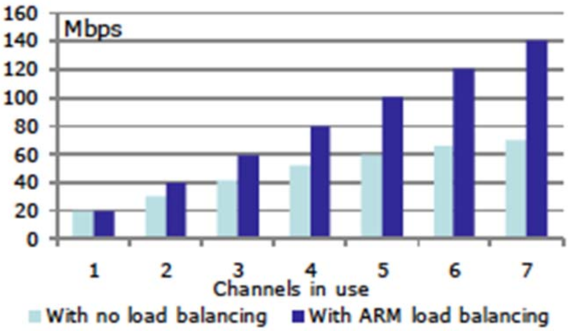
Optimal Client Distribution

- **Employ ARM to optimally distribute clients between frequency bands**
- **Band Steering:**
  – Enterprise WLANs have both 2.4-GHz & 5-GHz bands. But, most clients connect at 2.4 GHz, even if it is the most crowded.
  – **Solution** — HD WLAN "steers" 5-GHz clients to that band reducing contention for 2.4-GHz band.



- **Spectrum Load Balancing:**
  – Spectrum load balancing moves clients away from congested APs or RF channels into those with available capacity.
  – The number of clients on a given channel, rather than per-AP is the dominant predictor of data capacity.

Figure 32 *Data Capacity Improvement with ARM Load Balancing*



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Optimal Airtime Management

- **Ensuring equal access with Airtime Fairness**
  – Maintain application performance in high-density areas with scheduled airtime fairness
- **Limiting “Chatty” protocols**
  – Use ACLs and controller settings to restrict traffic
- **Enabling Multicast Rate Optimization**
  – ARM can reduce medium multicast traffic time
- **Enabling Dynamic Multicast Optimization for video**
  – Deliver multicast frames with unicast headers, improving reliability over the air, QoS, and channel utilization
- **Limiting supported data rates:**
  – 48 and 54 Mbps for 802.11a/g
  – 6.5 and 11 Mbps for 802.11b

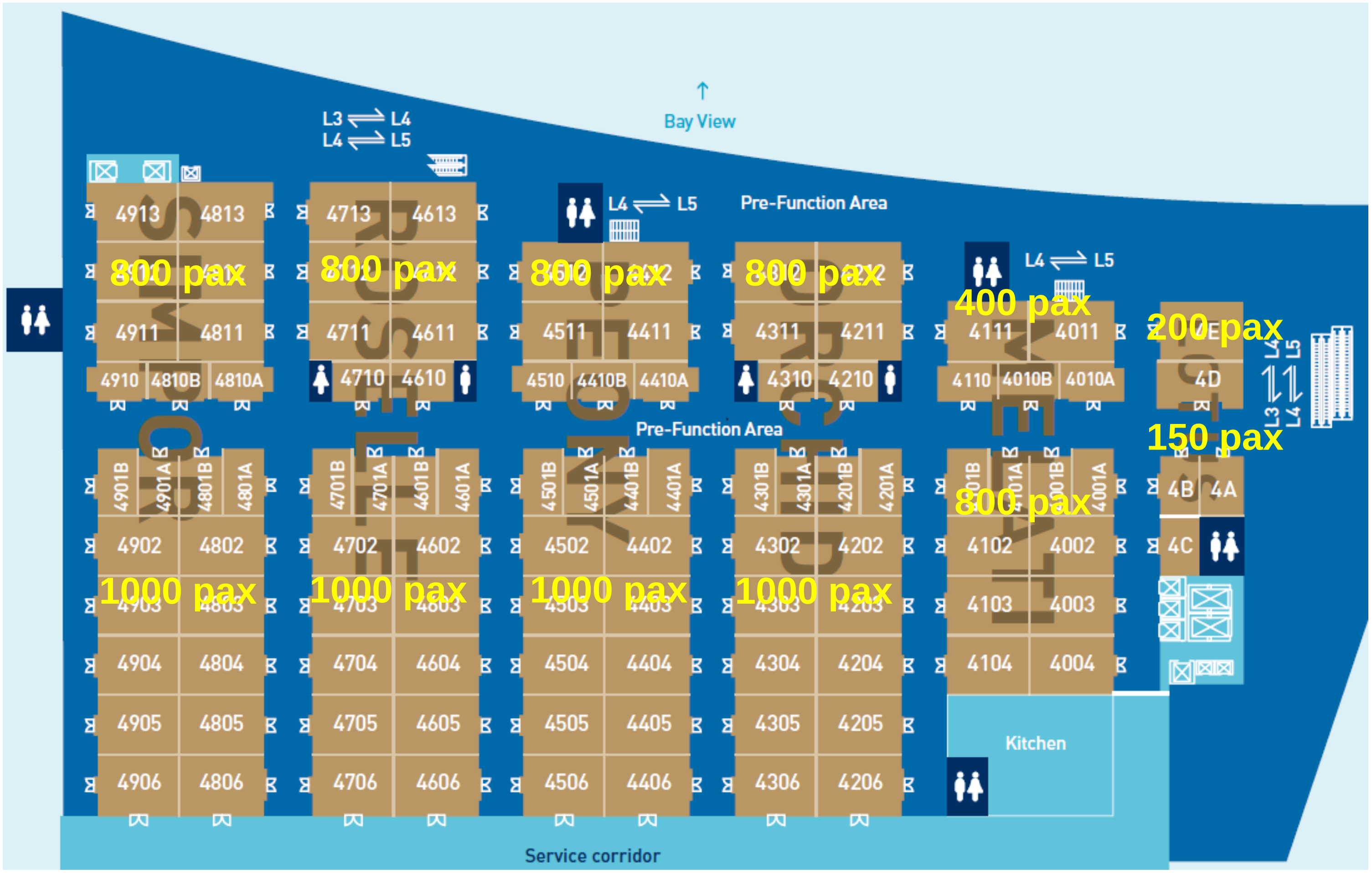
Case Study #1

Marina Bay Sands Singapore
&
Young Presidents Asia Conference

Marina Bay Sands Overview

- Huge convention center located in Singapore
- 5 levels of convention halls
- Grand ballroom on level 5
- Can be over 5000 users per level
- No control over client devices—can be any type of device
- Distribution of 2.4 GHz and 5.0 GHz clients changes from one event to another

Marina Bay Sands Level 4 possible capacity



Over 8000 total users possible

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Marina Bay Sands Level 4 Single Room

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MBS Technical Requirements

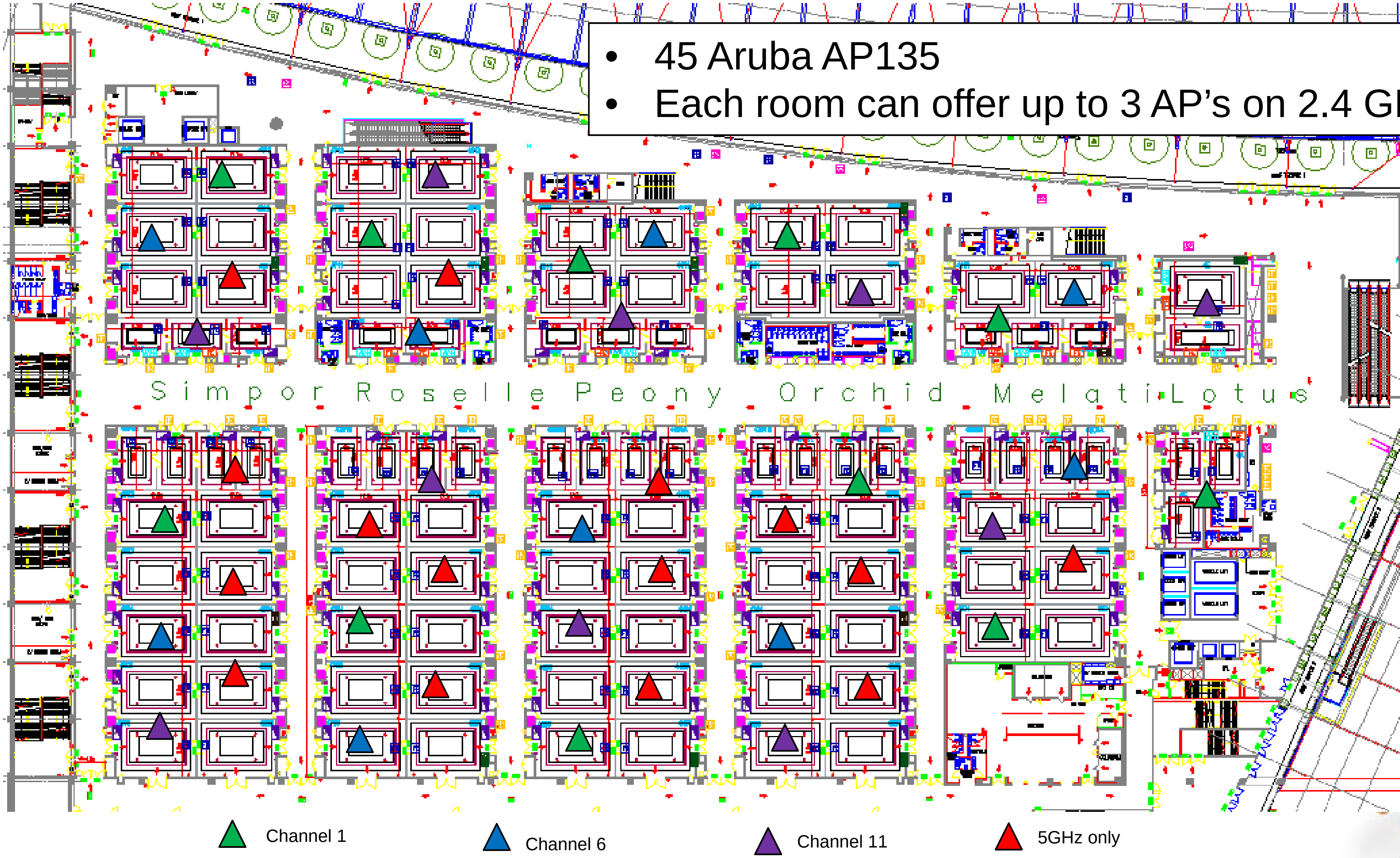
- **Dynamic configuration required that can be adapted easily to conference events**
- **SSID's offered and areas of coverage changes from one event to the next**
- **Might be only 1 AP needed for one event, while for large events all AP's must be enabled for coverage and to support expected client density**
- **Conference goers may bring in their own AP's that interfere with the MBS service**

MBS Design - Level 4

- Series of rooms that are largely self contained user spaces
- Channel reuse within each room is not possible
- 2.4 GHz channels are statically set to ensure 3 non-overlapping channels per room
- 2.4 GHz transmit power is statically set to 15 dBm
- 5.0 GHz channels and transmit power are automatically configured with ARM—ARM has configured all AP’s to use max power
- Signal overlap from one room to the next is minimal
- Interference is minimal
- Ceiling placement gives Line of Sight (LOS) to clients and provide strong coverage
- SNR is strong within each room giving excellent performance

MBS RF Plan – Level 4

- 45 Aruba AP135
- Each room can offer up to 3 AP's on 2.4 GHz



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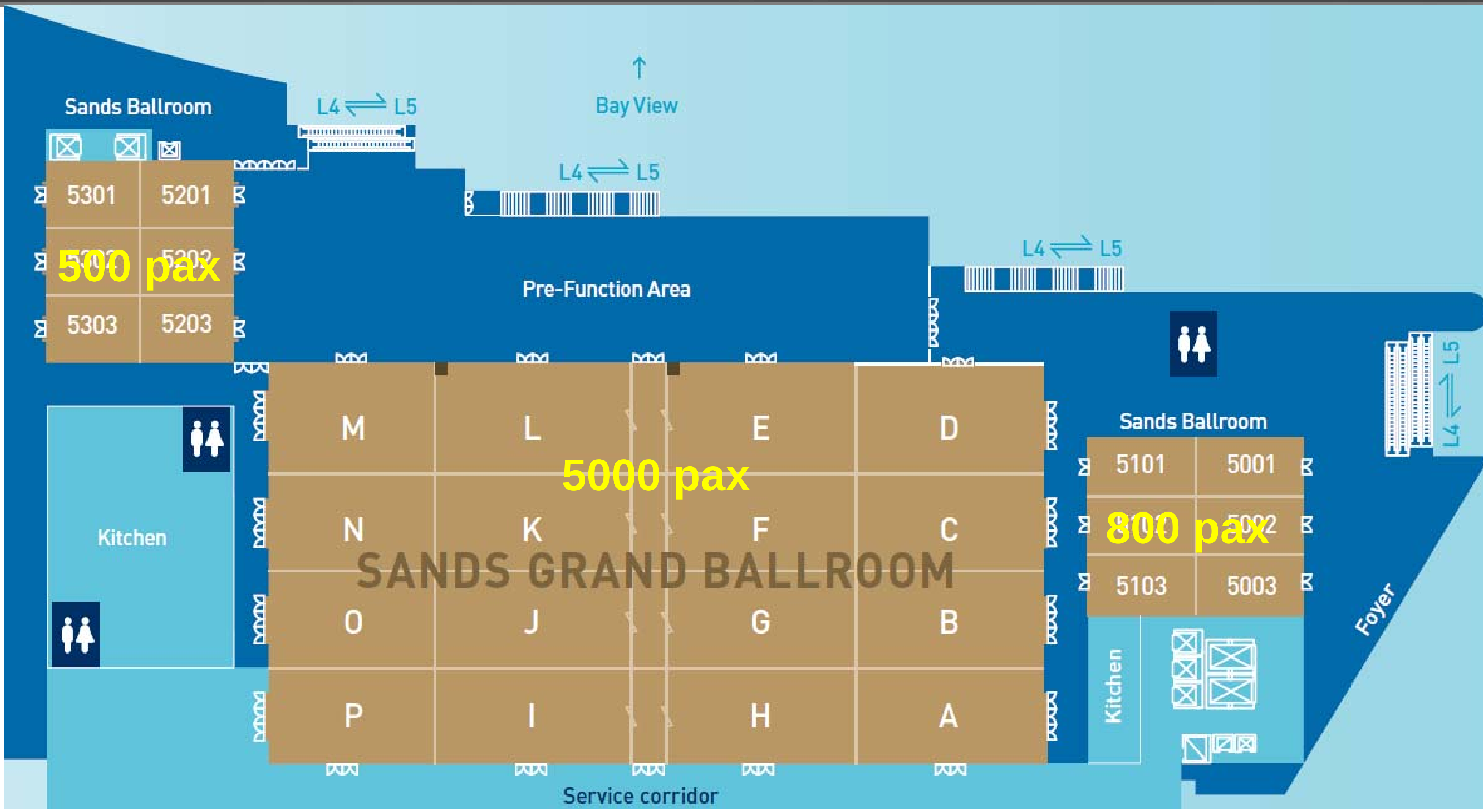
MBS Design - Level 5

- Grand ballroom is on level 5
- Client density requires more AP's while vast open area mean AP's hear each other quite well
- To handle user count channel reuse is mandatory
- 2.4 GHz channels are statically configured in grand ballroom and pre-function foyer to ensure adjacent AP's are on different channels
- Interference from Audio-Visual system on 2.4 GHz is significant in Grand ballroom
- 5.0 GHz channels and transmit power are configured via ARM
- Ceiling placement gives Line of Sight (LOS) to clients and provide strong coverage
- SNR is strong within each room giving excellent performance

MBS Level 5 - Possible User Capacity



Over 6000 total users possible

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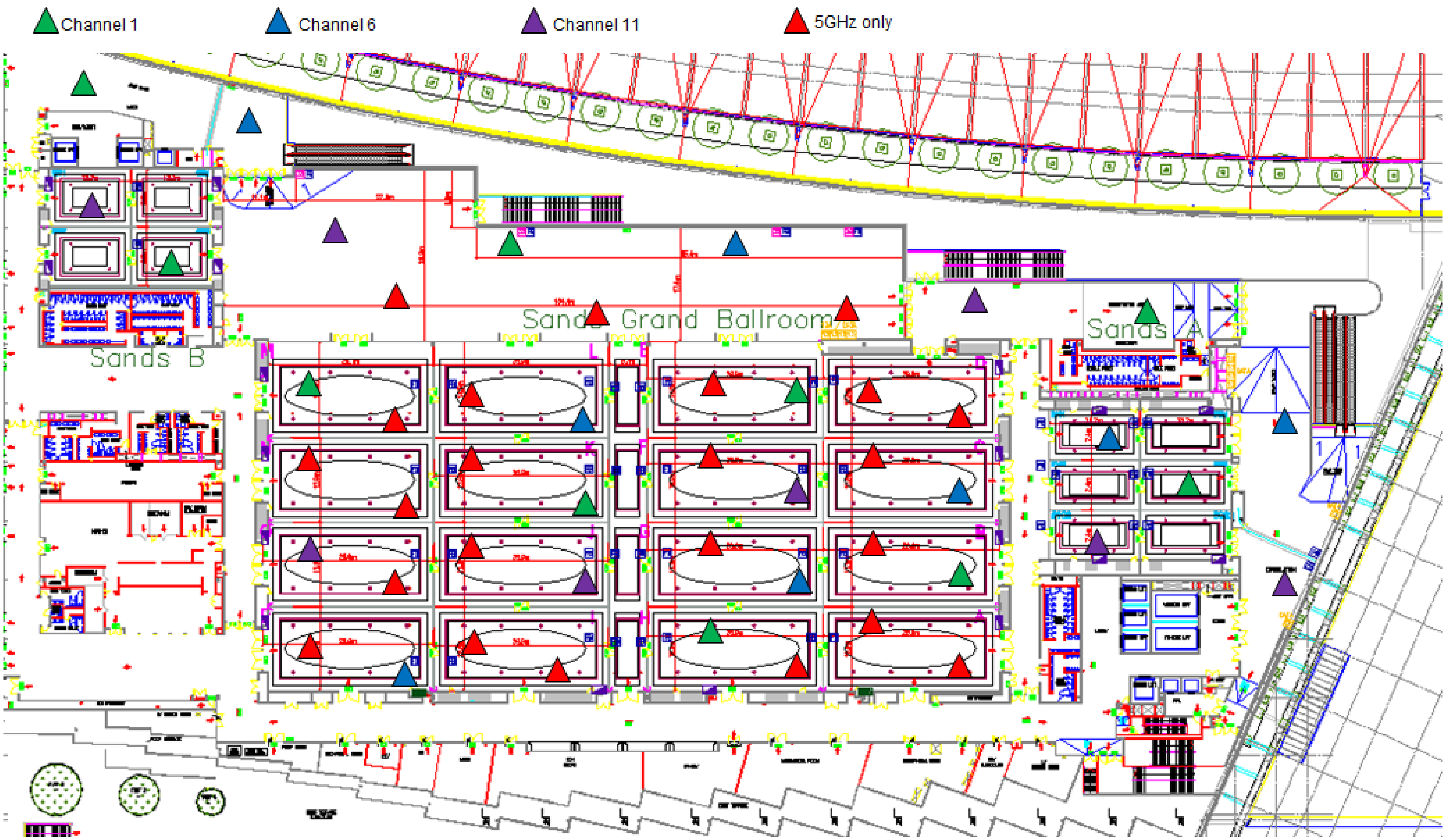
MBS Level 5 – RF Design



AP's hear each other quite well in Grand ballroom making channel reuse difficult

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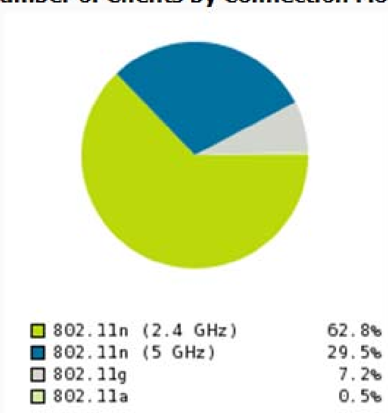
MBS in Action - YPO Asia Event
AirWave Connection Report

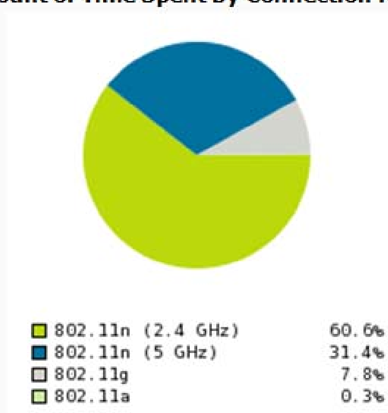
Session Data by Connection Mode

Connection Mode	Number of Clients	% of Clients	Amount of Time	% of Time	MB Used	% of MB Used	Average Signal Quality	Number of Sessions
802.11n (2.4 GHz)	1925	62.83%	427 days 4 hrs 30 mins	60.57%	32712.77	35.31%	21.26	48828
802.11n (5 GHz)	903	29.47%	221 days 7 hrs 30 mins	31.38%	57002.04	61.53%	25.02	20143
802.11g	221	7.21%	54 days 20 hrs 28 mins	7.78%	2728.33	2.95%	24.87	4651
802.11a	15	0.49%	1 day 23 hrs 23 mins	0.28%	192.33	0.21%	23.94	180
4 Connection Modes		100.00%	705 days 7 hrs 53 mins	100.00%	-	100.00%		73802

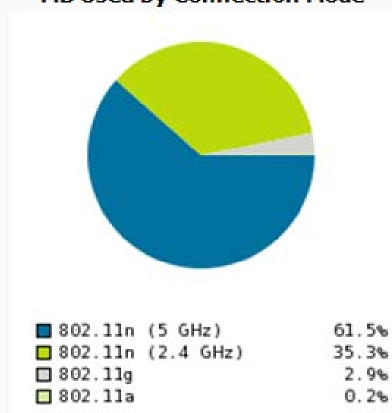
Number of Clients by Connection Mode



Amount of Time Spent by Connection Mode

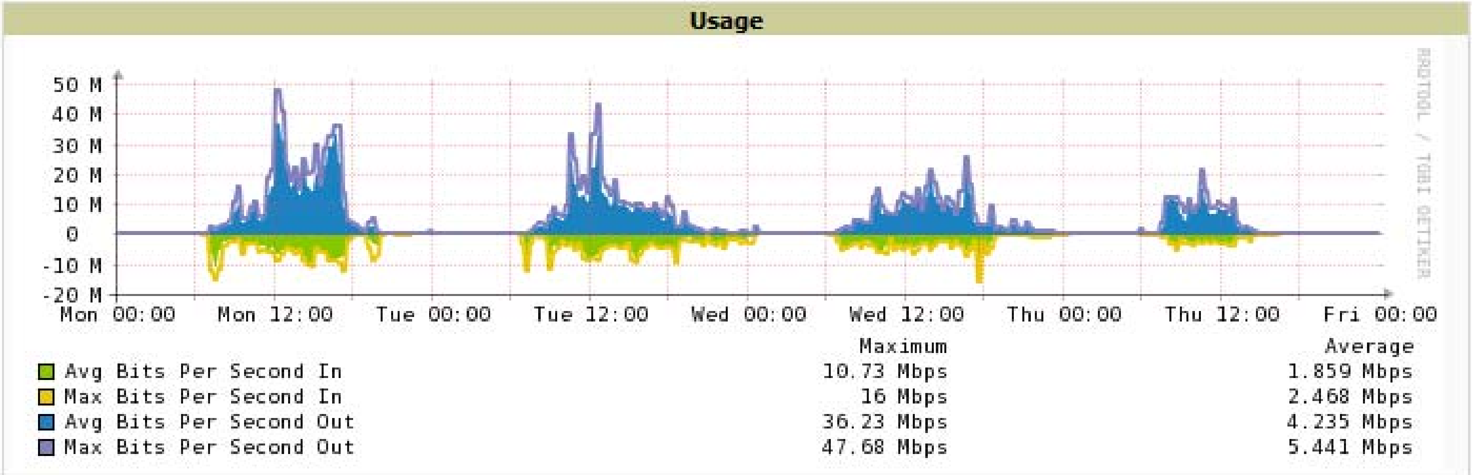


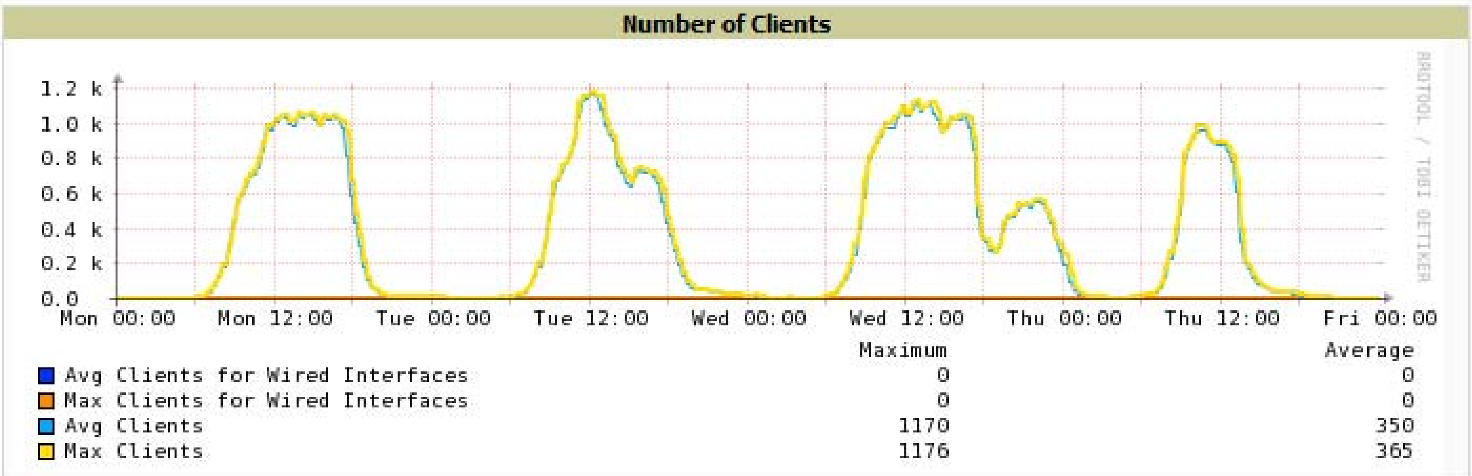
MB Used by Connection Mode



MBS in Action - YPO Asia Event

AirWave User Count & Bandwidth Report





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MBS in Action - YPO Asia Event
AirWave Device Type & Manufacturer Report

Device Type Summary

Device Type	Count	% of Total
Apple iPhone	1098	47.82%
Apple iPad	474	20.64%
Windows 7	133	5.79%
Apple Mac	104	4.53%
RIM BlackBerry	81	3.53%
RIM	60	2.61%
Unknown	45	1.96%
Android	42	1.83%
Windows XP	25	1.09%
Apple	25	1.09%
RIM BlackBerry 9900	22	0.96%
RIM BlackBerry 9700	18	0.78%
Windows Vista	13	0.57%
RIM BlackBerry 9800	13	0.57%
RIM BlackBerry 9780	12	0.52%
Samsung GT-N7000	11	0.48%
Samsung GT-I9100	10	0.44%

Device Manufacturer Summary

Device Manufacturer	Count	% of Total
Apple	1683	73.30%
Unknown	363	15.81%
RIM	167	7.27%
Samsung	54	2.35%
HTC	19	0.83%
Motorola	10	0.44%
6 Device Manufacturers	2296	100.00%

MBS in Action - YPO Asia Event
AirWave Client Session Summary

Client Session Summary	
Number of sessions:	73802
Number of unique clients:	2296
Number of guest users:	0
Number of unique APs:	98
Average session duration:	13 mins
Total traffic (MB):	92635.47
Average traffic per session (MB):	1.26
Average traffic per client (MB):	40.35
Average bandwidth per client (Kbps):	13.31
Average signal quality:	28.64

MBS in Action - YPO Asia Event
AirWave Max Concurrent Client Report

Most Utilized by Maximum Number of Simultaneous Clients

Rank ▲	AP/Device	Number of Clients	Max Simultaneous Clients	Total Data (MB)	Average Usage (Kbps)
1	MIC05-AP12	0	209	10738.58	248.58
2	MIC04-AP01	0	198	3922.18	90.79
3	MIC04-AP20	0	177	8032.21	185.93
4	MIC05-AP28	0	172	5344.77	123.72
5	MIC05-AP14	0	168	5938.36	137.46
6	MIC05-AP24	0	147	1605.28	37.16
7	MIC05-AP10	0	138	401.85	9.30
8	MIC05-AP38	0	137	224.56	5.20
9	MIC04-AP34	0	136	4583.72	106.11
10	MIC05-AP33	0	136	289.79	6.71

Most Utilized by Usage

Rank ▲	AP/Device	Number of Clients	Max Simultaneous Clients	Total Data (MB)	Average Usage (Kbps)
1	MIC05-AP42	0	113	24700.90	571.78
2	MIC04-AP02	0	39	24076.36	557.32
3	MIC04-AP35	0	24	16307.60	377.49
4	MIC05-AP43	0	84	11017.67	255.04
5	MIC05-AP12	0	209	10738.58	248.58
6	MIC04-AP22	0	133	10329.32	239.10
7	MIC04-AP46	0	21	9685.50	224.20
8	MIC04-AP03	0	15	8945.79	207.08
9	MIC04-AP20	0	177	8032.21	185.93
10	MIC04-AP36	0	74	7763.23	179.70

Case Study #2

Turner Field – Atlanta

"Up and Out" RF Design

- **Three interleaved "blankets" of APs to cover the lower sections, club level, and upper sections respectively:**
  - Lower deck antennas are mounted under the club seats and aimed "<u>out</u>" to the field
  - Upper deck antennas are mounted underneath the floor and aimed straight "<u>up</u>" through the concrete. In the middle
  - A blanket of APs is installed in the club suites above the ceiling.
- **The stadium structure itself is used to minimize interference between blankets**

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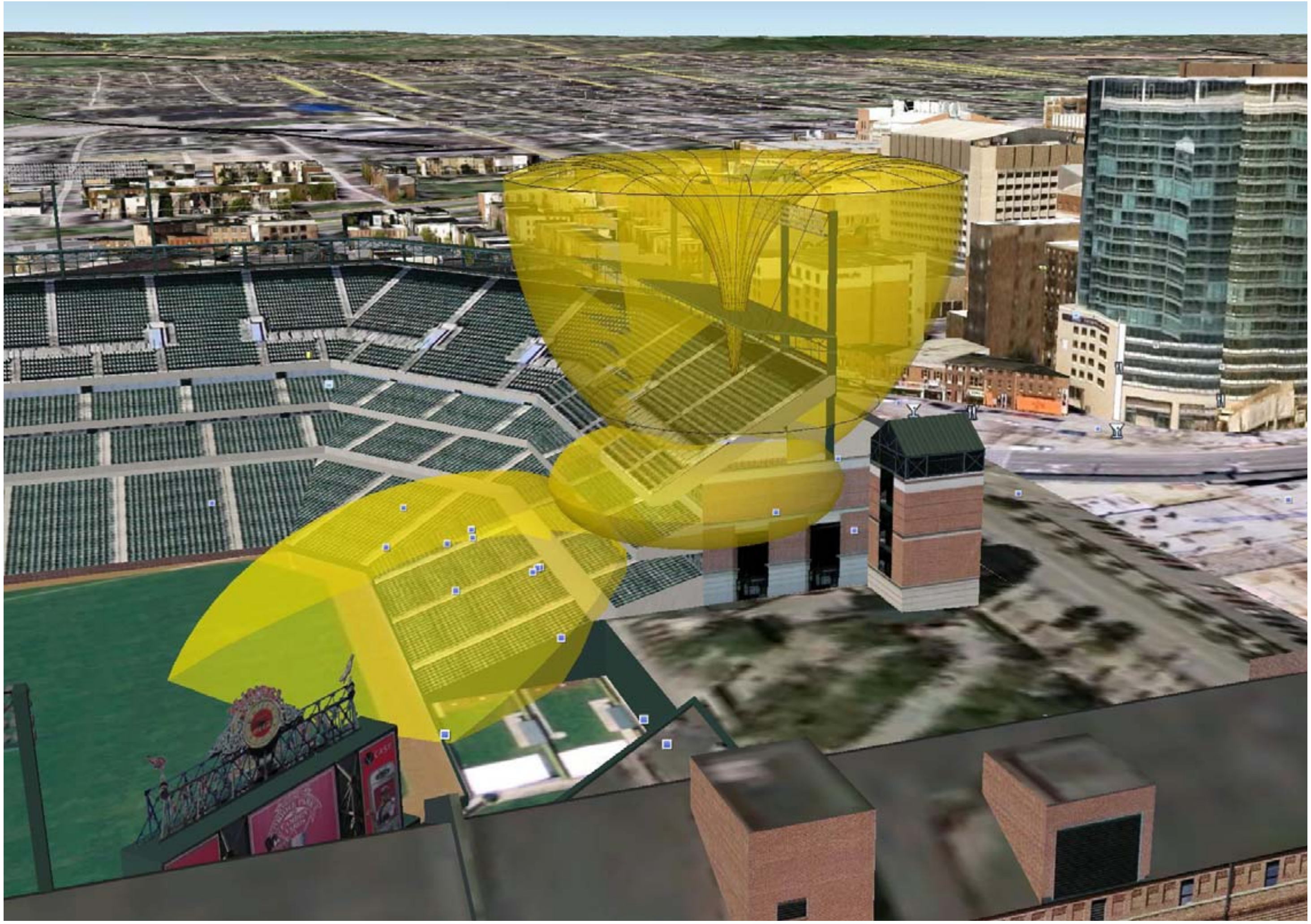
RF Design – 3 Independent RF “Blankets”



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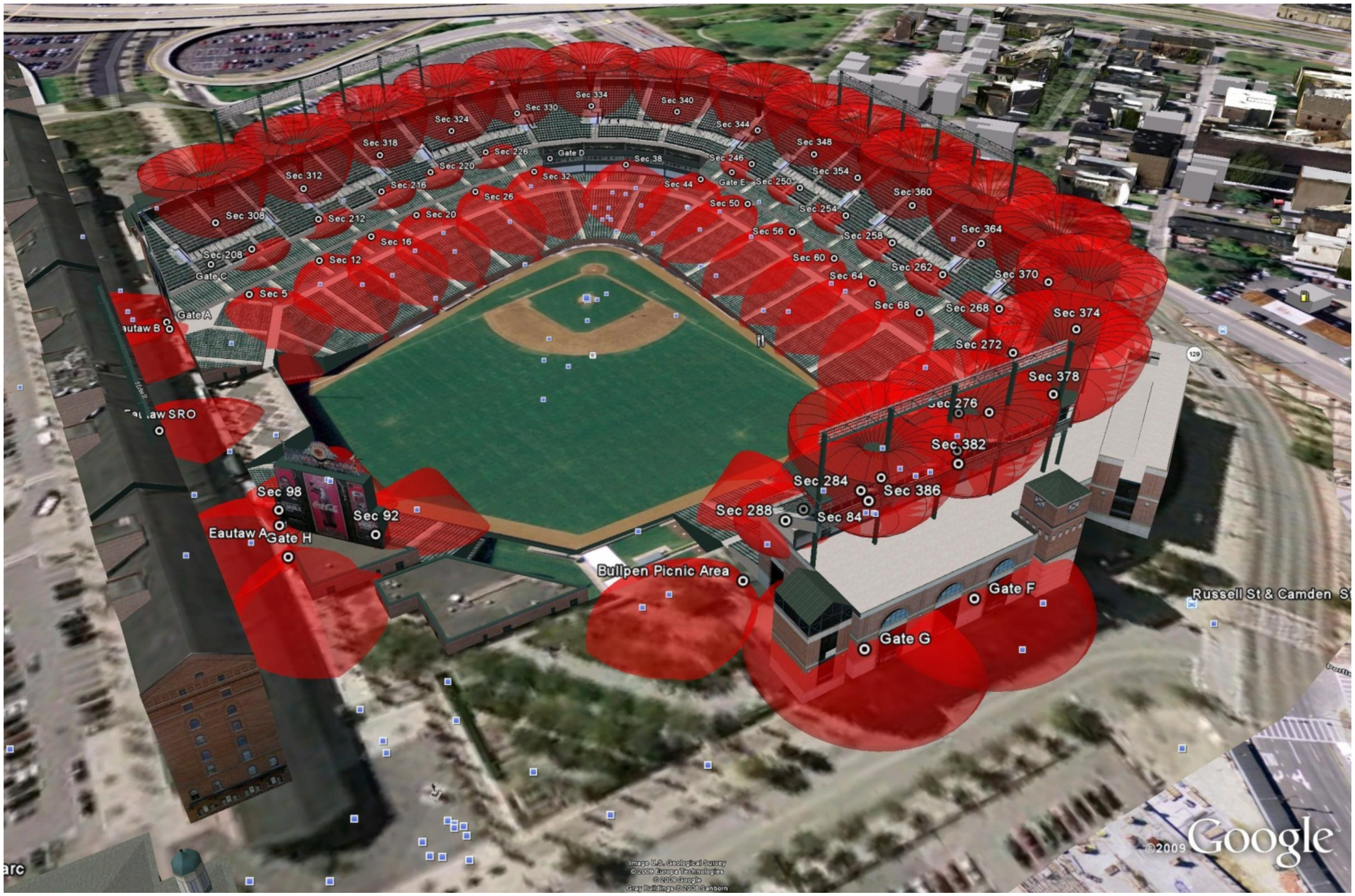
RF Design – Full Scale 3D Model



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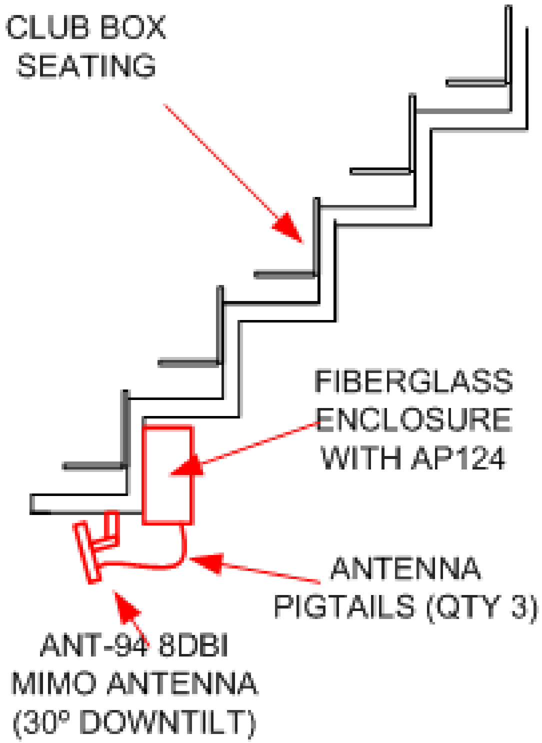
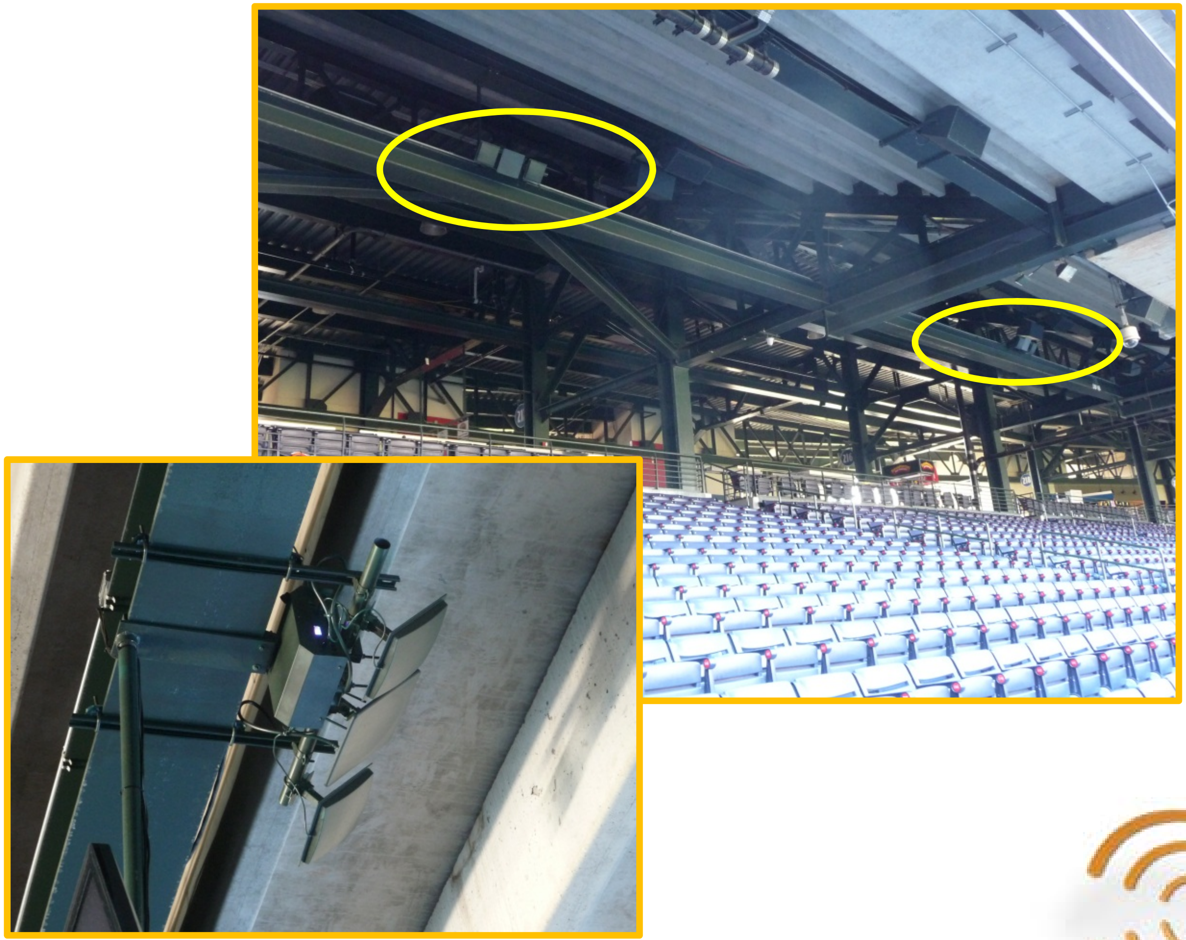
Physical Installation – Lower Blanket

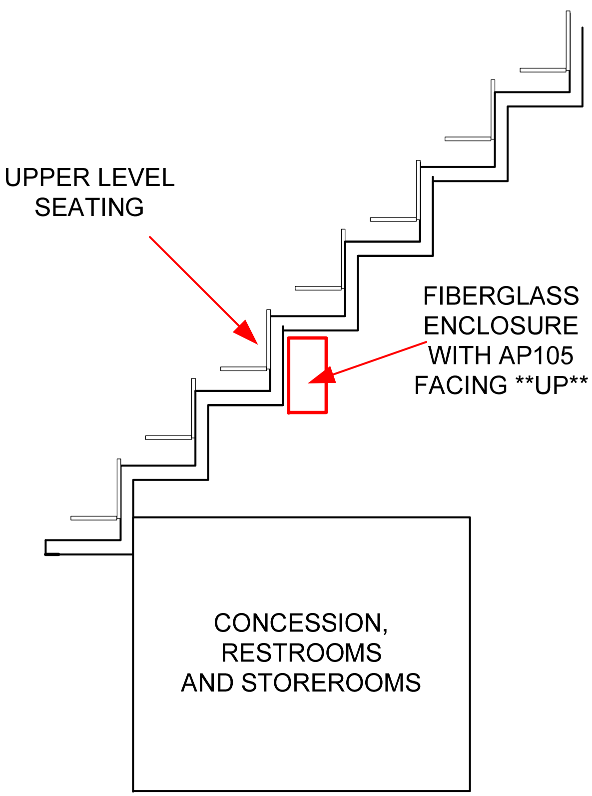
APs mounted directly above the 200 sections, with 30ºx30º high gain directional antennas aimed at row 10

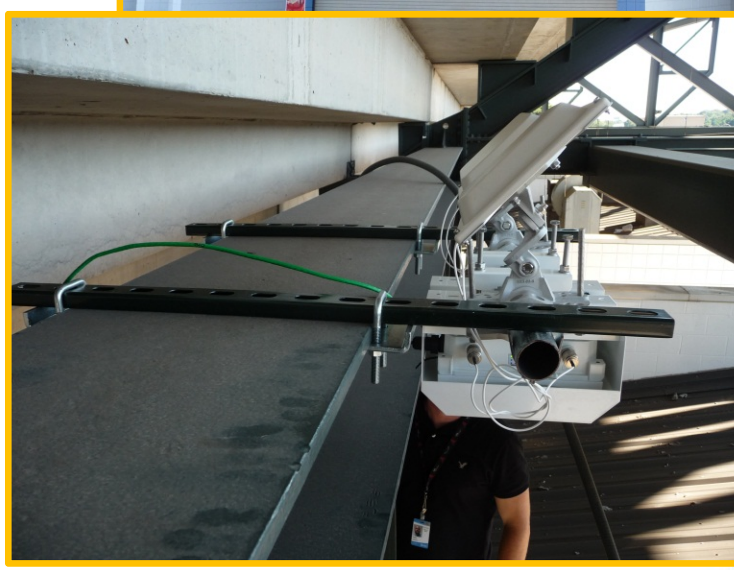




Physical Installation – Upper Blanket

APs mounted underneath 400 sections, with dual 60ºx60º directional antennas aimed to match slope of stands





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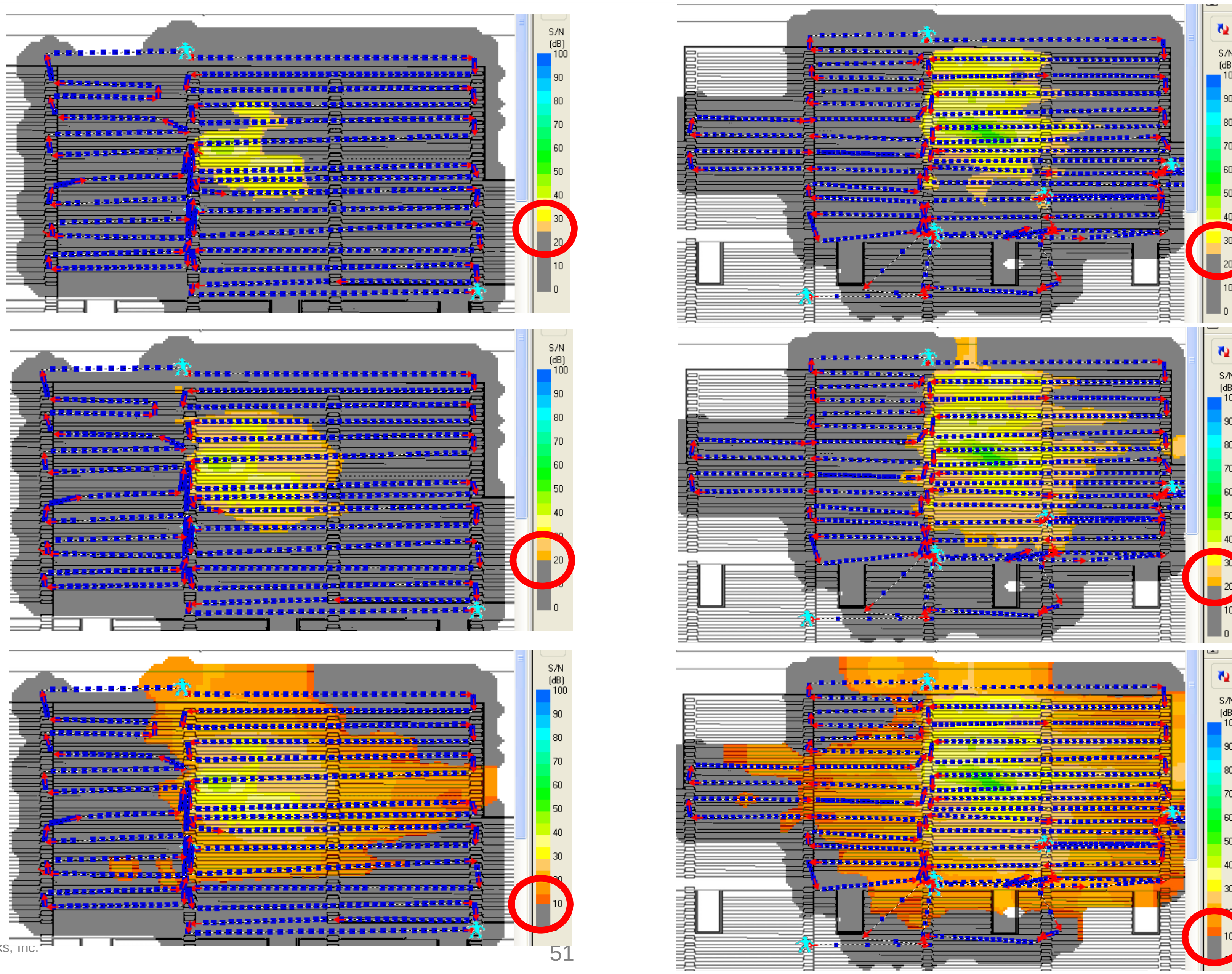
Typical AirMagnet Survey – Ch 6 – SNR

25dB SNR

20dB SNR

10dB SNR

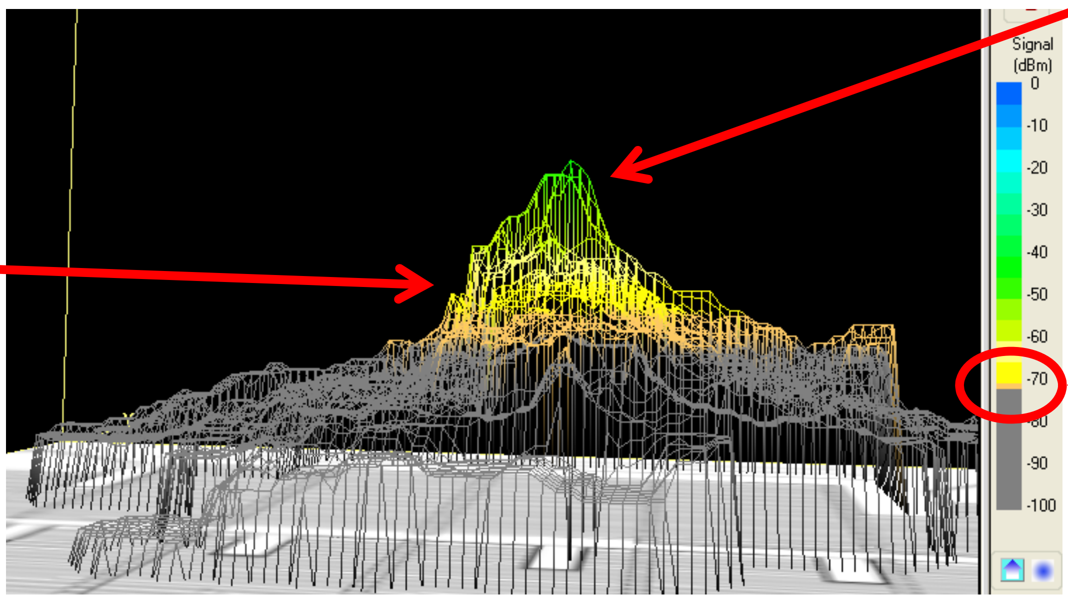


Typical Picocell RF Rolloff – 3D Side View

View is as if standing on top of section 18, looking down at field

Steep fall-off is due to steel beam next to AP

APs must be mounted midway between beams for optimal signal dispersal



Increase in TX power concentrated directly above AP, with smooth roll-off expanding cell slightly side-to-side

Views are filtered for RSSI at -72dBm or higher

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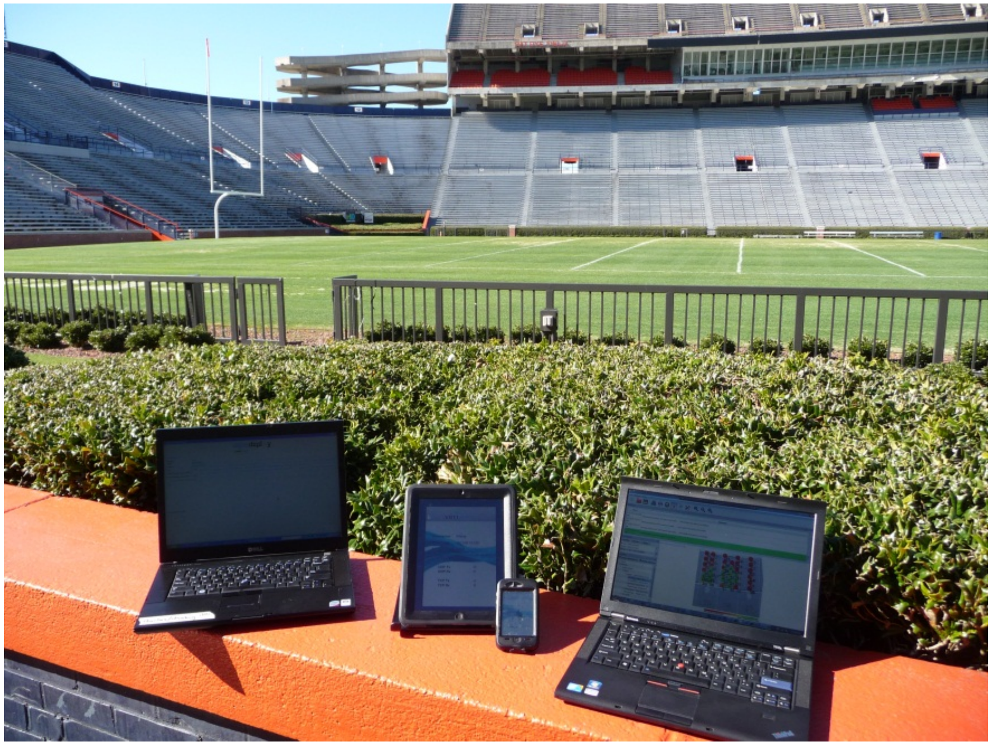
Typical WaveDeploy Throughput Test

- **WaveDeploy is a new WiFi validation tool from VeriWave**
- **Multiple test clients, mix-and-match**
  - Lightweight native agent for each OS
  - Fully automated test console
  - Able to run TCP, UDP, voice, video tests and more
- **An iPad, iPhone 3GS and Windows 7 laptop were tested by Aruba**



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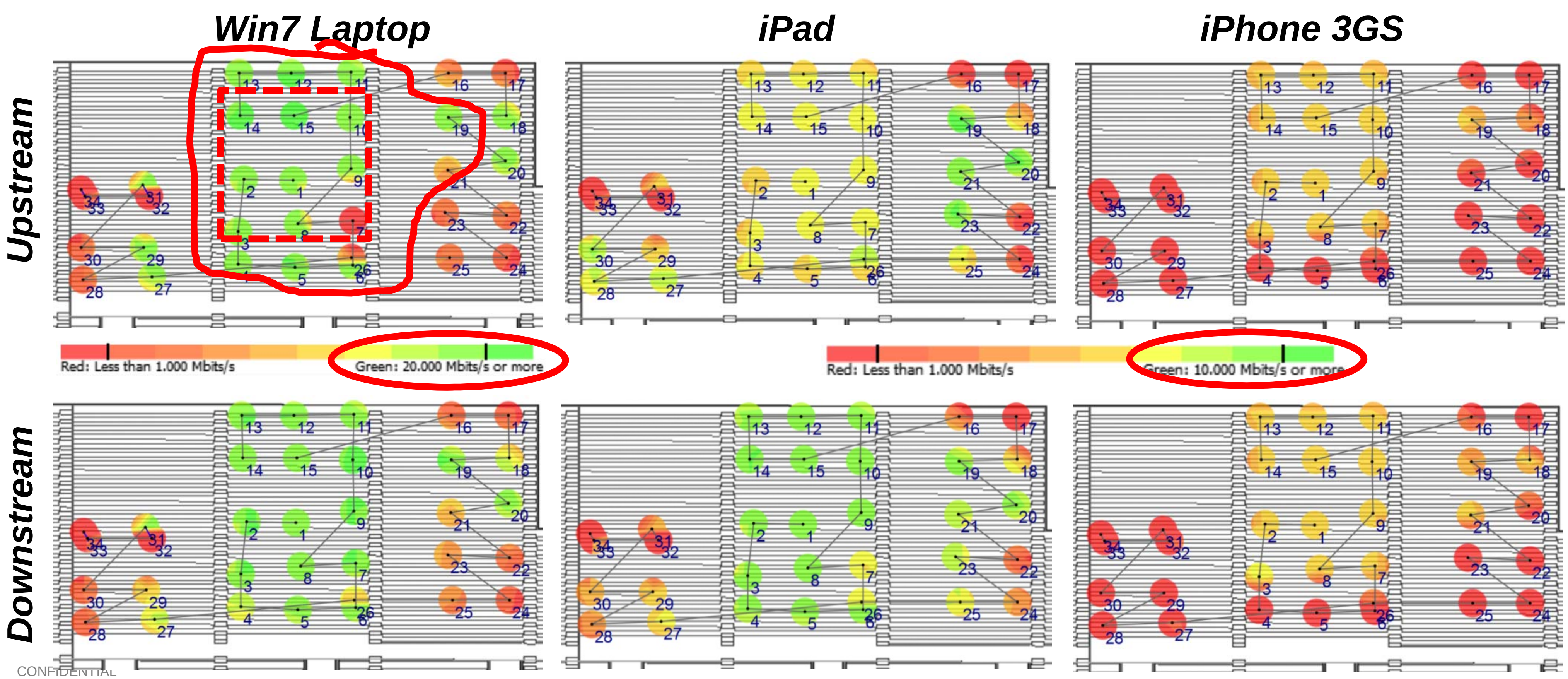
Typical WaveDeploy TCP Speed Test

- **Tests were worst case (device on top of aluminum bench)**
- ***iOS devices use different throughput scale than laptop***
- **Performance correlates well with measured RF cell size**
- **Downstream performance generally better than upstream**



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LAS VEGAS 2012

Thank You