Very High Density 802.11ac Networks

Basic Design & Deployment

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Agenda

- **Dimensioning very high density networks**
- **Choosing a channel plan & bandwidth**
- **Capacity planning methodology**
- **Basic RF design for very high density areas**
- **Example: Adjacent large auditoriums**
- **Q & A**

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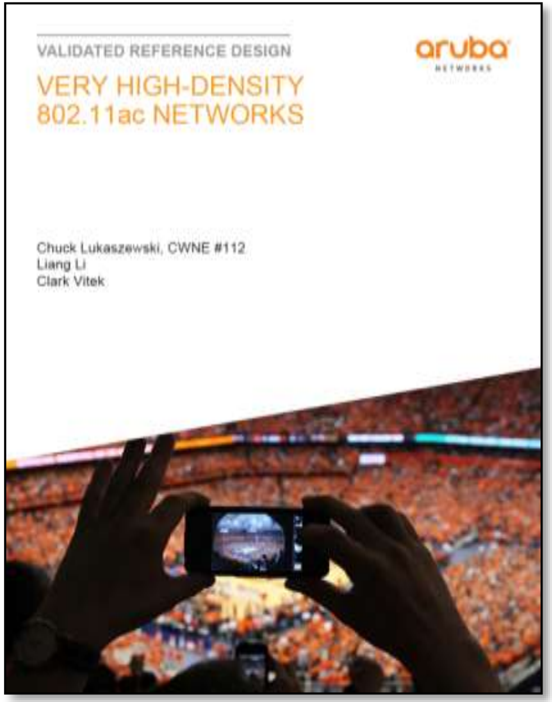
Talk Is Based on Very High Density VRD



- **100% 802.11ac**
- **End-to-end system architecture & dimensioning**
- **Detailed capacity planning methodology**
- **Addresses a wide range of customer use cases**
- http://community.arubanetworks.com/t5/Validated-Reference-Design/Very-High-Density-802-11ac-Networks-Validated-Reference-Design/ta-p/230891

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How Far We've Come

- **"Coverage" WLANs came first**
- **These evolved into "Capacity" WLANs (with limited HD zones)**
  - 250m^2 / 2500 ft^2 = 25 devices per cell
- **BYOD made every capacity WLAN a high-density network**
  - 3 devices/person = 75 per cell
- **HD WLANs from 2011 are now very high-density (VHD)**
  - 100+ devices per "cell". Devices may be associated to multiple BSS operators in same RF domain.

Waiting for the new Pope in St. Peter's Square

NBC Today Show, February, 2013, http://instagram.com/p/W2BuMLQLRB/

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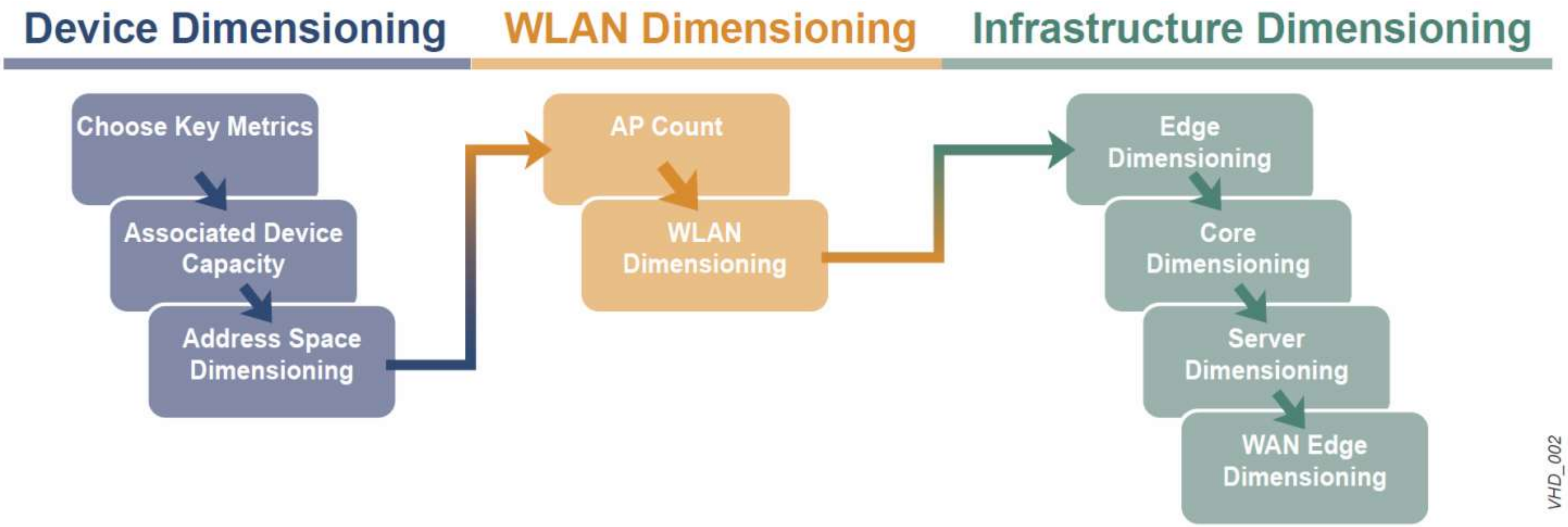
Dimensioning Very High Density Systems

Aruba VHD Dimensioning Methodology



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Step 1- Key Design Criteria for Typical VHD WLAN

Metric	Definition	Typical Value
Seating capacity	Number of people the facility can hold.	Varies
Average devices per person	Typical number of discrete Wi-Fi enabled devices carried by a person visiting the VHD facility.	1 to 5
Take rate	Percentage of seating capacity with an active Wi-Fi device.	50% - 100%
Associated device capacity (ADC)	Take rate multiplied by the average number of Wi-Fi enabled devices per person.	Varies
Seats or area covered per AP	How many square meters (square feet) or seats each AP must serve – essentially the physical size of a radio cell.	Varies
Associated devices per radio	The design target of how many associated devices should be served by each radio on an AP.	150
Average single-user goodput	What is the minimum allowable per-user bandwidth when multiple users are attempting to use the same AP?	512 Kbps to 2 Mbps
5 GHz vs. 2.4 GHz split	Distribution of clients across the two bands.	5 GHz: 75% 2.4 GHz: 25%

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Step 2 – Estimate ADC

- **Start with the seating / standing capacity of the VHD area to be covered**
- **Then estimate the take rate (50% is a common minimum)**
- **Choose the number of devices expected per person. This varies by venue type. It might be lower in a stadium and higher in a university lecture hall or convention center salon.**
  - For example, 50% of a 70,000 seat stadium would be 35,000 devices assuming each user has a single device
  - 100% of a 1,000 seat lecture hall where every student has an average of 2.5 devices would have an ADC equal to 2,500
- **More users should be on 5-GHz than 2.4-GHz. ADC should be computed by frequency band. In general you should target a ratio of 75% / 25%.**
- **Association demand is assumed to be evenly distributed throughout the coverage space.**

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Step 3 – Address Dimensioning

Table P2-2 Sample ADC and Address Space Estimates for Indoor 20,000 Seat Arena

User Group	Devices (Now)	Devices (Future)	%5 GHz	%2.4 GHz	Minimum Subnet Size
Guest / Fan	5,000 *(25% take rate)*	10,000 *(50% take rate)*	75%	25%	/18
Staff	100	300	100%	0%	/23
Ticketing	50	100	100%	0%	/24
POS	50	200	100%	0%	/24
Team	15	100	100%	0%	/24
TOTAL	**5,215**	**10,700**	**8,200**	**2,500**	-

Aruba recommends large flat VLANs for guest WLAN

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Step 3 – Address Dimensioning

Table P2-3 Sample ADC and Address Space Estimates for University Lecture Halls

User Group	Devices (Now)	Devices (Future)	%5 GHz	%2.4 GHz	Minimum Subnet Size
Student	20,000	45,000	75%	25%	/16
Faculty	2,000	4,000	100%	0%	/20
TOTAL	**22,000**	**49,000**	**37,750**	**11,250**	**-**

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Step 4 – Estimate AP Count

$$\text{AP Count} = \text{5-GHz Radio Count} = \frac{\text{Associated Device Capacity (5 GHz)}}{\text{Max Associations Per Radio}}$$

- **Plan for 150 associations per radio, and 300 per AP**
- **ArubaOS supports up to 255 per radio**
  - 150 = 60% loading with 40% headroom
- **All VHD areas experience inrush/outrush**
  - Planning for extra headroom allows for user “breathing”
- **Remember to increase max users in SSID profile**

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Step 7 – Core Dimensioning

- **Verify that ARP cache and forwarding tables in core switches are large enough to handle big flat user VLAN**
- **Controller-to-core uplinks are sized at 2X the WAN throughput computed in the capacity plan**
  - 1-2 Gbps OTA = 2-4 Gbps on controller uplink
- **Do not make controller default gateway**
- **First hop redundancy is critical**

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Step 8 – Server Dimensioning

- **DHCP/DNS – key metric is transaction time.**
  - Should be <= 5ms.
  - This is MUCH more critical than transaction rate.
    - Model at 5% of seating capacity over 5 minutes
    - 18K arena * 5% / 300 seconds = 3 discovers per second
  - Carrier-grade DHCP/DNS servers strongly recommended (Infoblox)
  - Lease times should be 2X duration of event (8 hours suggested)
  - Model DNS at 1 request/device/second
- **Captive portal rate = DHCP arrival rate**
- **RADIUS loads depend on whether guests using 802.1X**

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Step 9 – WAN Edge Dimensioning

- **WAN uplink bandwidth is estimated using the Aruba Total System Throughput process**
- **Minimum BW is dual, load-balanced 1Gbps links for a country with 20+ channels in 5-GHz using all/most DFS channels**
  - **Any VHD area with 20+ APs should easily be able to generate 1Gbps of load**
- **WAN uplinks >2Gbps may be required if RF spatial reuse is being attempted**
- **All edge equipment must be fully HA**

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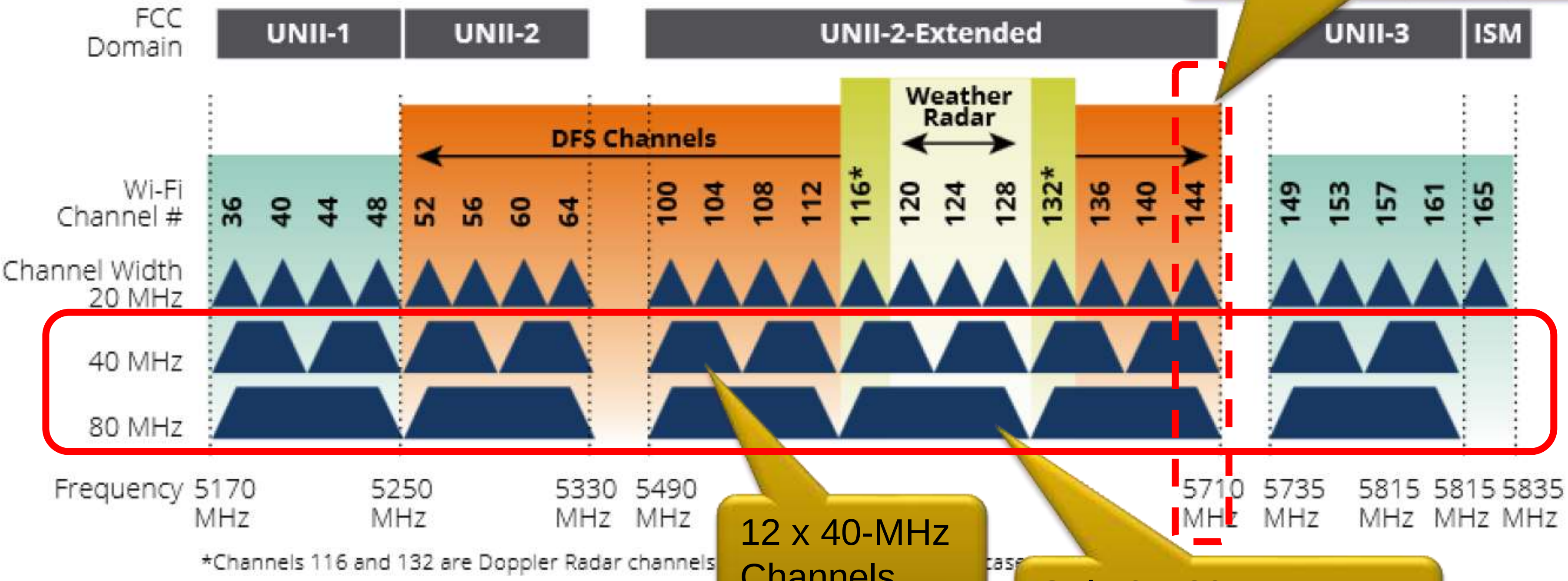
Choosing a Channel Plan & Bandwidth

Allowed Channels in FCC Countries



Do not use ch. 144 until 802.11ac > 50%

12 x 40-MHz Channels

Only 6 x 80-MHz Channels (2 non-DFS)

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General Rule

Use DFS channels for VHD areas!!

- The number of collision domains is the primary constraint on VHD capacity
- The number of STAs per collision domain is the second major constraint on capacity
- VHD networks are ultimately about tradeoffs

The benefit of employing DFS channels almost always* outweighs the cost.

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Balancing the Risks & Rewards

- **Client capabilities**
  - As of 2015, the vast majority of mobile devices shipping in USA support DFS channels
  - Non-DFS clients will be able to connect due to stacking of multiple channels (although perhaps at lower rates)
  - It is easily worth it to provide a reduced connect speed to a an unpredictable minority of clients, in exchange for higher connect speeds for everyone else all the time
- **Radar events**
  - It is worth having a small number of clients occasionally interrupted in exchange for more capacity for everyone all the time

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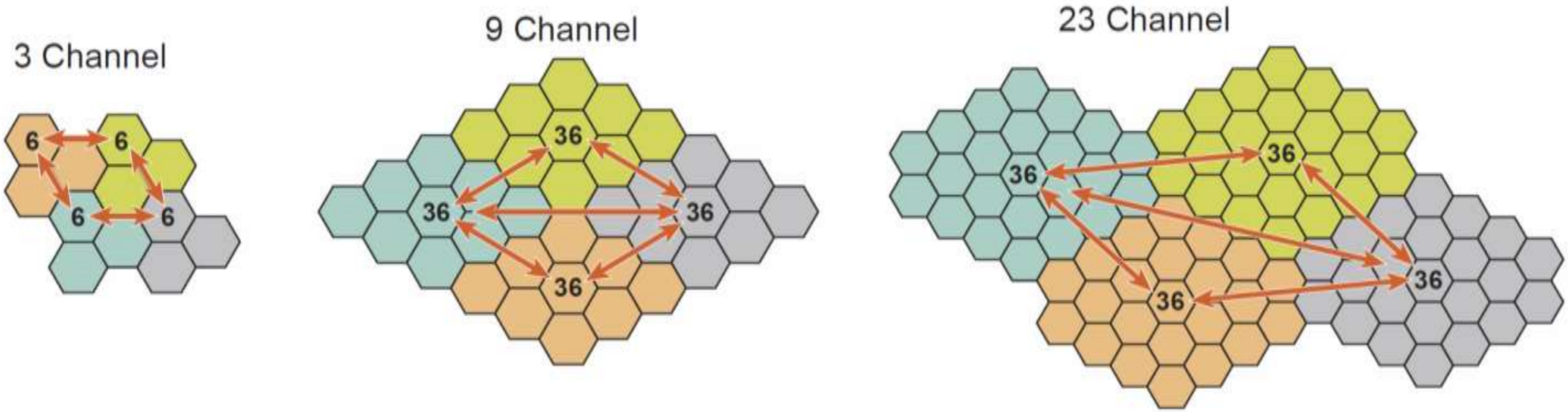
Why 20-MHz Channels – Reuse Distance

- **More channels = more distance between same-channel APs**



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Why 20-MHz Channels – More RF Reasons

- **Reduced Retries – Bonded channels are more exposed to interference on subchannels**
  - Using 20-MHz channels allows some channels to get through even if others are temporarily blocked

- **Higher SINRs – Bonded channels have higher noise floors (3dB for 40-MHz, 6dB for 80-MHz)**
  - 20-MHz channels experience more SINR for the same data rate, providing extra link margin in both directions

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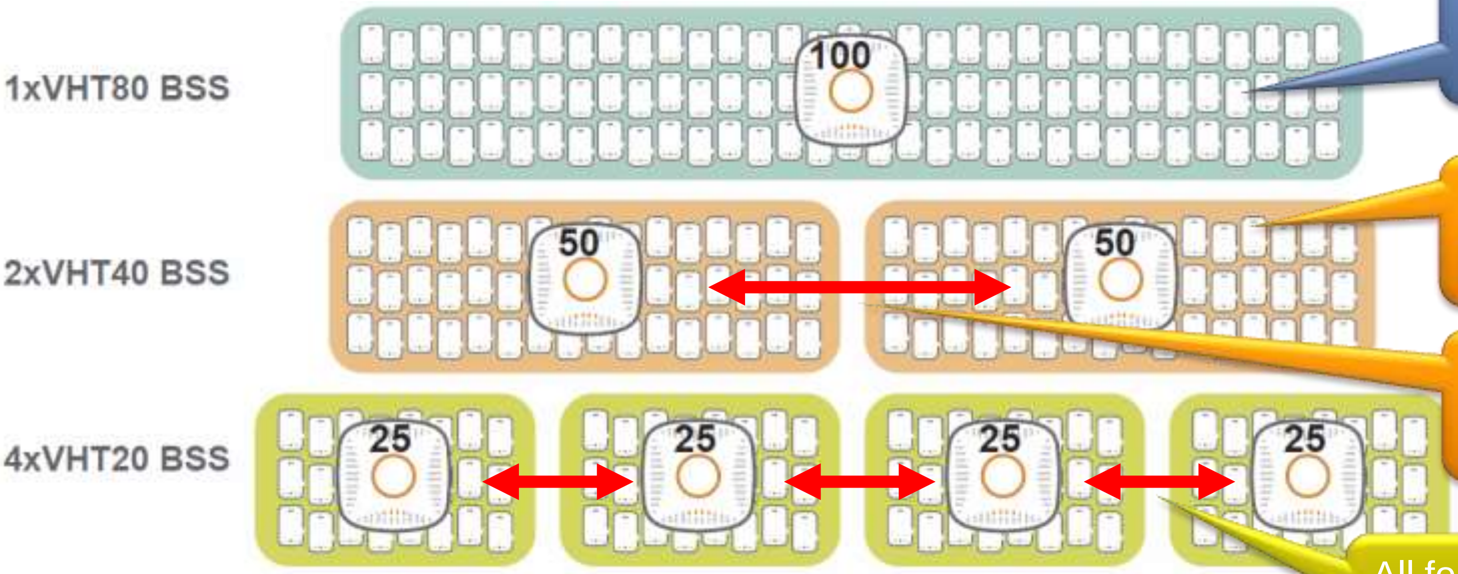
Why 20-MHz Channels - Performance

- **Which Chariot test will deliver higher goodput?**



Each test uses the exact same 80-MHz bandwidth

Each test uses the exact same number of STAs

Both VHT40 BSS will victimize each other with ACI

All four VHT20 BSS will victimize each other

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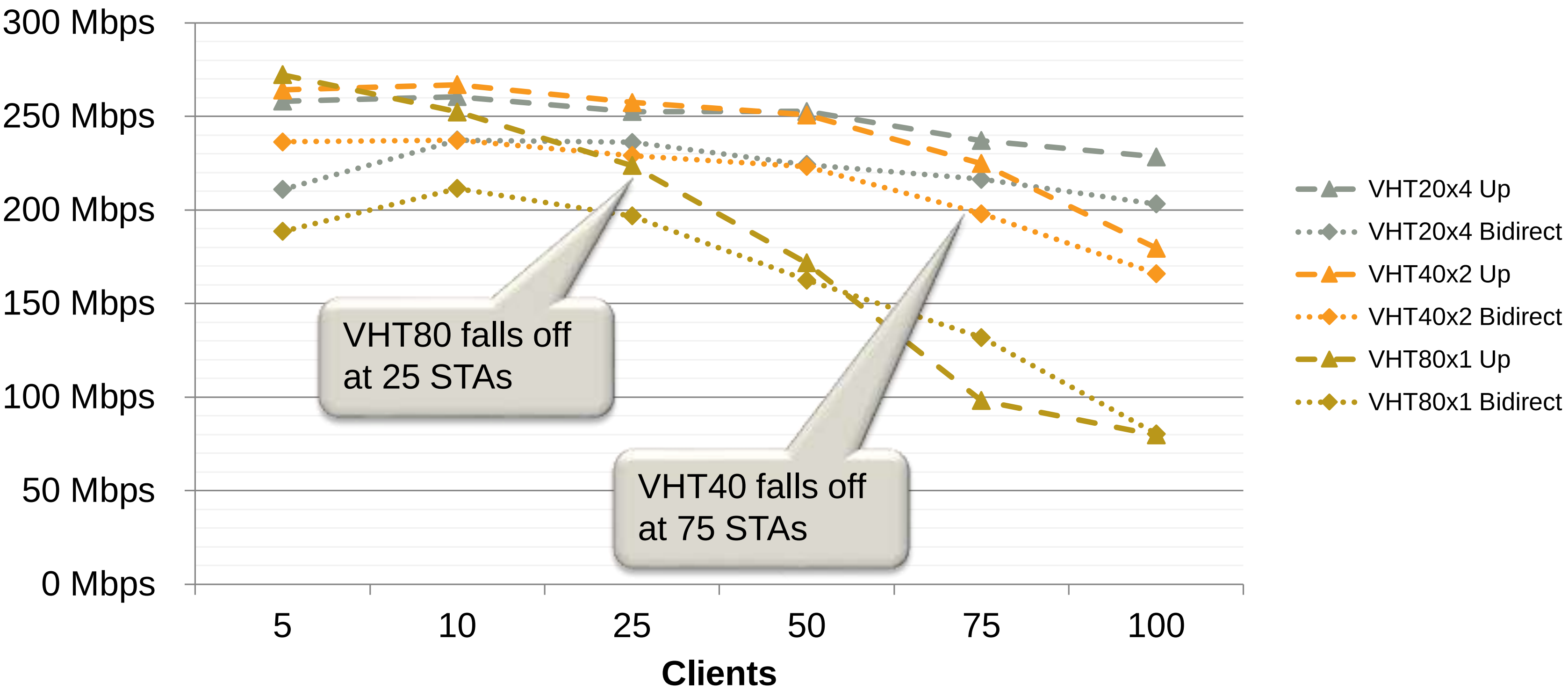
VHT20 Beats VHT40 & VHT80 – 1SS Client Example



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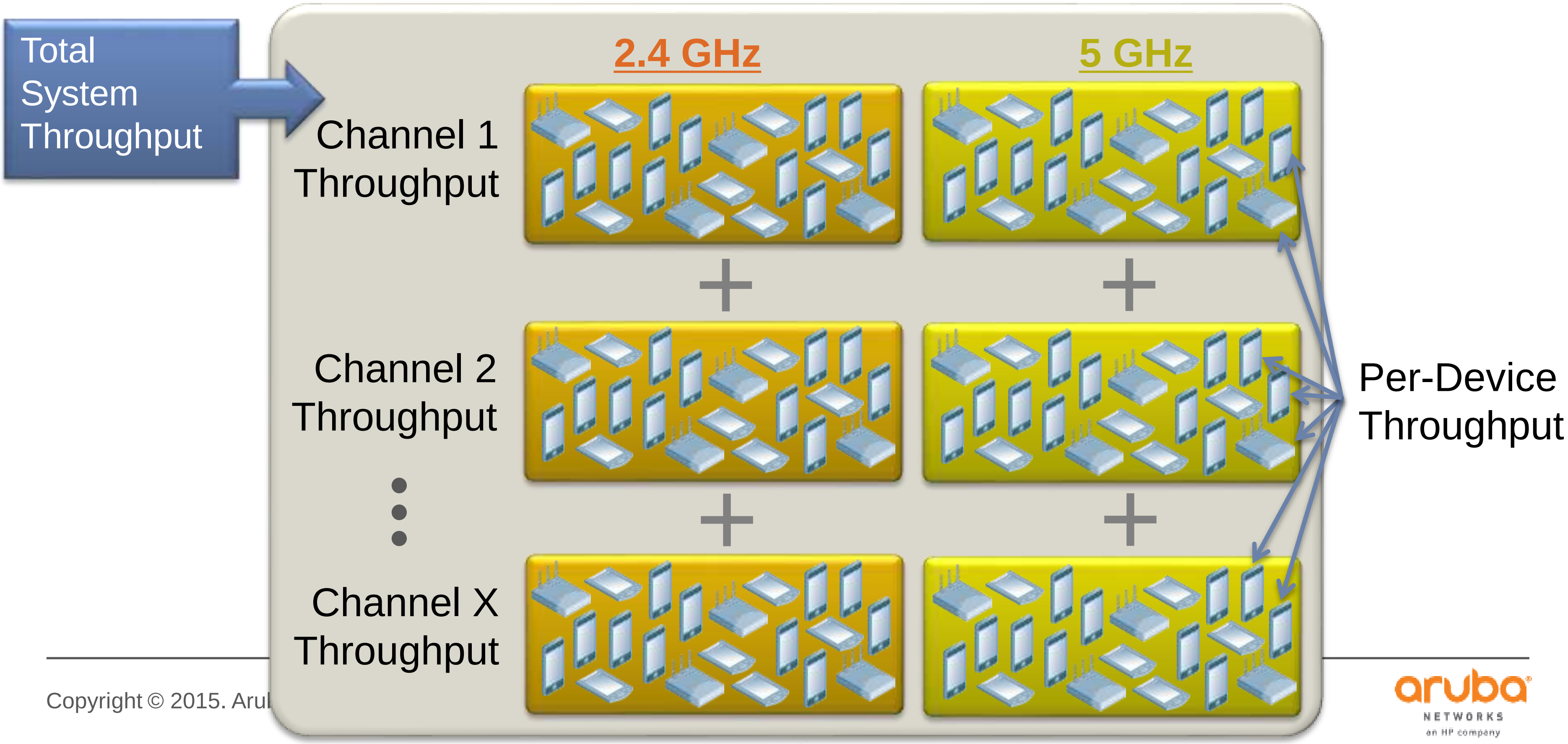
Capacity Planning Methodology

System vs. Channel vs. Device Throughput



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Total System Throughput Formula

$$TST = Channels * Average\ Channel\ Throughput * Reuse\ Factor$$

Where:

- ***Channels*** **= Number of channels in use by the VHD network**
- ***Average Channel Throughput*** **= Weighted average goodput achievable in one channel by the expected mix of devices for that specific facility**
- ***Reuse Factor*** **= Number of RF spatial reuses possible. For all but the most exotic VHD networks, this is equal to 1 (e.g. no reuse).**

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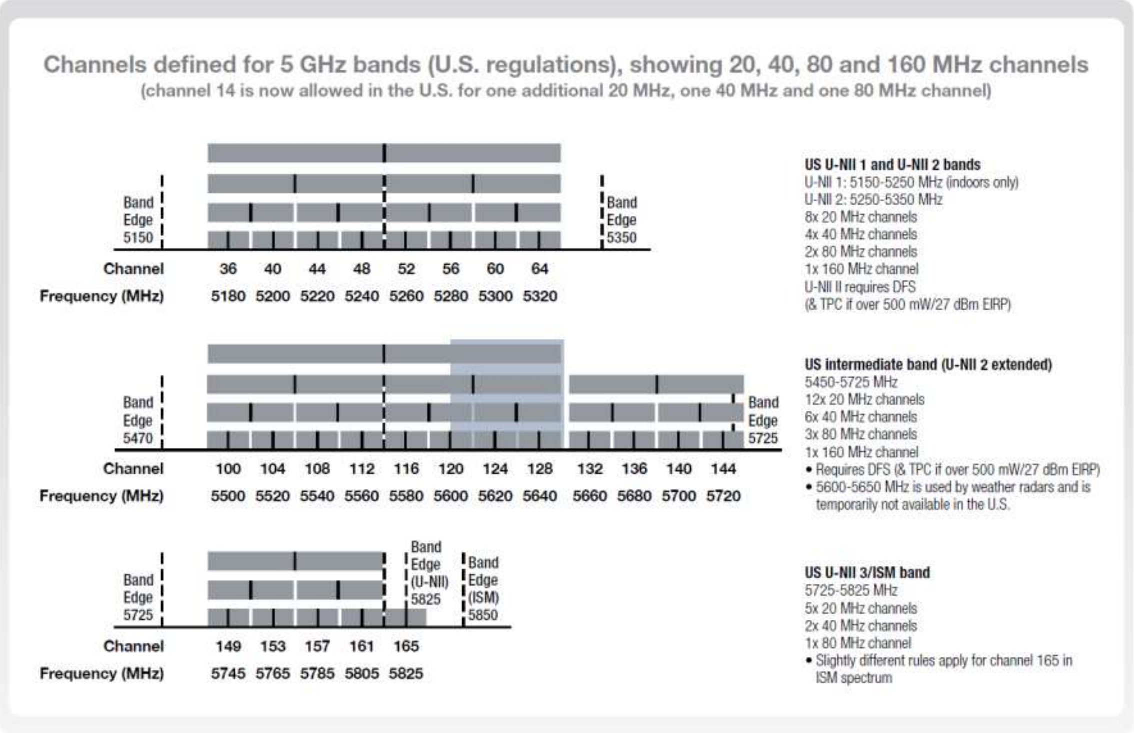
Step 1 – Choose Channel Count

- **US allows:**
  - 9 non-DFS channels
  - 13-16 DFS channels*
- **Deduct:**
  - Channel 144
  - House channel(s)
  - Proven radar channels
  - AP-specific channel limitations



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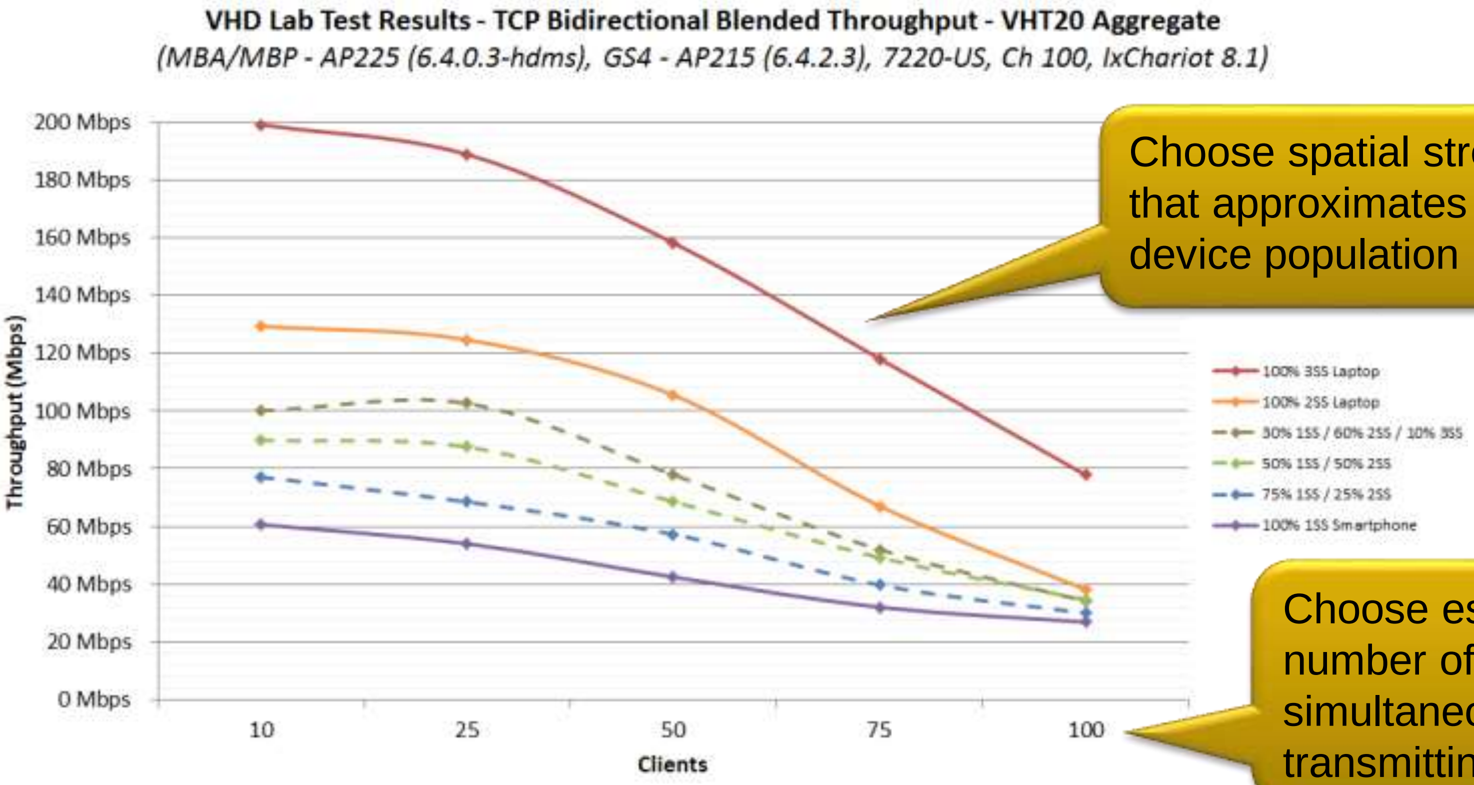
Step 2 – Choose Unimpaired Channel Throughput



Choose spatial stream mix that approximates expected device population

Choose estimated number of simultaneously transmitting clients

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Step 3 – Apply Impairment Factor

VHD Venue Type	Suggested 2.4-GHz Impairment	Suggested 5-GHz Impairment**	Rationale
Classroom / Lecture Hall	**10%**	**5%**	• Above average duty cycles • Little or no reuse of channels in the same room • Structural isolation of same-channel BSS in adjacent rooms • Minimal My-Fi usage
Convention Center	**25%**	**10%**	• Moderate duty cycles • Significant numbers of same-channel APs • Large open areas with direct exposure to interference sources • Non-Wi-Fi interferers • Higher My-Fi usage in booth displays, presenters, attendees
Airport	**25%**	**15%**	• Minimal duty cycles (except for people streaming videos) • Structural isolation of same-channel BSS in adjacent rooms • Heavy My-Fi usage
Casino	**25%**	**10%**	• Low duty cycles on casino floor • Low My-Fi usage
Stadium / Arena	**50%**	**25%**	• Low-to-moderate duty cycles • Significant numbers of same-channel APs • Large open areas with direct exposure to interference sources • Non-Wi-Fi interferers • High My-Fi usage

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Step 4 – Choose Reuse Factor

RF spatial reuse must be assumed not to exist unless proven otherwise in VHD facilities of 10,000 seats or less (RF = 1).

- **Reuse factor is the number of devices that can use the same channel at exactly the same time**
- **Reusing channel *numbers* is not the same as reusing RF *spectrum***

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Step 5 – Calculate TST By Band

Step 1 - Channels

Channel Type	USA 5-GHz Count
Non-DFS	9
DFS	11
Total	20

Step 2 – Unimpaired Throughput

Spatial Stream Mix	50 Concurrent	75 Concurrent	100 Concurrent
1SS Device	50 Mbps	38 Mbps	31 Mbps
2SS Device	100 Mbps	72 Mbps	51 Mbps
3SS Device	158 Mbps	118 Mbps	78 Mbps

Step 3 – Impairment

VHD Venue Type	Suggested 5-GHz **	Suggested 2.4-GHz
Lecture Hall	5%	10%
Convention Center	10%	25%
Airport	15%	25%
Casino	10%	25%
Stadium / Arena	25%	50%

Step 5 – Calculate TST By Band

#	Description	Channels	Unimpaired Throughput	Impaired 5-GHz TP	Impaired 2.4-GHz TP	Reuse	5-GHz TST	2.4-GHz TST
1	Non-DFS Lecture Hall	9 + 3	100Mbps	95Mbps	90Mbps	1	9 * 95Mbps = 855 Mbps	3 * 90Mbps = 270 Mbps
2	DFS Arena	20 + 3	40 Mbps	30 Mbps	20 Mbps	1	20 * 30Mbps = 600 Mbps	3 * 20 Mbps = 60 Mbps
3	DFS Stadium	20 + 3	40 Mbps	30 Mbps	20 Mbps	4	2.4 Gbps	240 Mbps

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Per-Device Throughput Formula

$$APDT = \frac{Total\ System\ Throughput}{Associated\ Device\ Capacity * Device\ Duty\ Cycle}$$

Where:

- ***Associated Device Capacity (ADC)*** **= Percentage of seating capacity with an active Wi-Fi device * average number of Wi-Fi devices per person. Typically computed per band.**
- ***Device Duty Cycle*** **= Average percent of time that any given user device attempts to transmit**

It is generally **impossible** to guarantee a specific per-device value in a VHD system.

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Step 1 – Estimate ADC

- **Start with the seating / standing capacity of the VHD area to be covered**
- **Then estimate the take rate (50% is a common minimum)**
- **Choose the number of devices expected per person. This varies by venue type. It might be lower in a stadium and higher in a university lecture hall or convention center salon.**
  - For example, 50% of a 70,000 seat stadium would be 35,000 devices assuming each user has a single device
  - 100% of a 1,000 seat lecture hall where every student has an average of 2.5 devices would have an ADC equal to 2,500
- **More users should be on 5-GHz than 2.4-GHz. ADC should be computed by frequency band. In general you should target a ratio of 75% / 25%.**
- **Association demand is assumed to be evenly distributed throughout the coverage space.**

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Step 2 – Choose a Device Duty Cycle

- **Subjective decision made by the network architect, based on expected user applications**

Category	Duty Cycle	User & Device Behavior Examples
Background	5%	Network keepalive / App phonehome
Checking In	10%	Web browsing / Checking email / Social updates
Semi-Focused	25%	Streaming scores / Online exam
Working	50%	Virtual desktop
Active	100%	Video streaming / Voice streaming / Gaming

- **This duty cycle is %Time *the user or device wants to perform this activity*.**
  - It is not the same as the application duty cycle!

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Examples

#	Description	Seats	Take Rate	Devices / Person	ADC
1	Lecture Hall	500	75%	2.5	938

Band Split	Duty Cycle	5-GHz TST	2.4-GHz TST
50/50	20%	855 Mbps	270 Mbps

5-GHz Per-Device Goodput	2.4-GHz Per-Device Goodput
$\frac{855\ Mbps}{469\ *\ 20\%} = 9\ Mbps$	$\frac{270\ Mbps}{469\ *\ 20\%} = 2.9\ Mbps$

500 * 75% * 2.5 = 938

938 / 2 = 469

#	Description	Seats	Take Rate	Devices / Person	ADC
2	DFS Arena	20K	50%	1	10K

Band Split	Duty Cycle	5-GHz TST	2.4-GHz TST
75/25	1[illegible]	[illegible]	[illegible]

5-GHz Per-Device Goodput	2.4-GHz Per-Device Goodput
$\frac{600\ Mbps}{[illegible]} = 800Kbps$	$\frac{60\ Mbps}{2500\ *\ 10\%} = 240\ Kbps$

20,000 * 50% * 1 = 10,000

10K [illegible]

If only 1 or 2 reuses is actually achieved, drops by 50-75%

#	Description	Seats	Take Rate	Devices / Person	ADC
3	DFS Stadium	60K	50%	1	30K

Band Split	Duty Cycle	5-GHz TST	2.4-GHz TST
75/25	10%	2.4 Gbps	240 Mbps

5-GHz Per-Device Goodput	2.4-GHz Per-Device Goodput
$\frac{2.4\ [illegible]}{22.5K\ *\ 10\%} = 1\ Mbps$	$\frac{240\ Mbps}{7.5K\ *\ 10\%} = 320\ Kbps$

60,000 * 50% * 1 = 30,000

30K * 75% = 22,500

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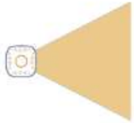
Basic RF Design for Very High Density Coverage Areas

RF Coverage Strategies

- **Radio coverage can be done in three ways, regardless of the type of area to be served.**

Overhead Coverage: APs are placed on a ceiling, catwalk, roof, or other mounting surface directly above the users to be served.



Side Coverage: APs are mounted to walls, beams, columns, or other structural supports that exist in the space to be covered.

Floor Coverage: This design creates picocells using APs mounted in, under, or just above the floor of the coverage area.

- **APs with integrated antennas are used for any VHD area of under 5,000 seats (very few exceptions)**

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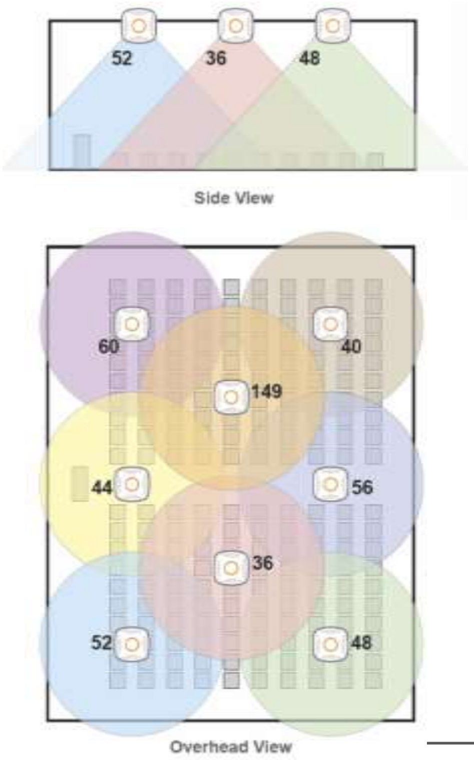
Overhead Coverage



- **Overhead coverage is a good choice when uniform signal is desired everywhere in the room.**
- **No RF spatial reuse is possible because of the wide antenna pattern and multipath reflections.**
- **Integrated antenna APs should always be used for ceilings of 10 m (33 ft) or less.**
- **Note the 20-MHz channel width, and that no channel number is used more than once.**
  - This is an example of a static, non-repeating channel plan intentionally chosen by the wireless architect.
- **Requires access the ceiling with minimal difficulty or expense to pull cable and install equipment.**

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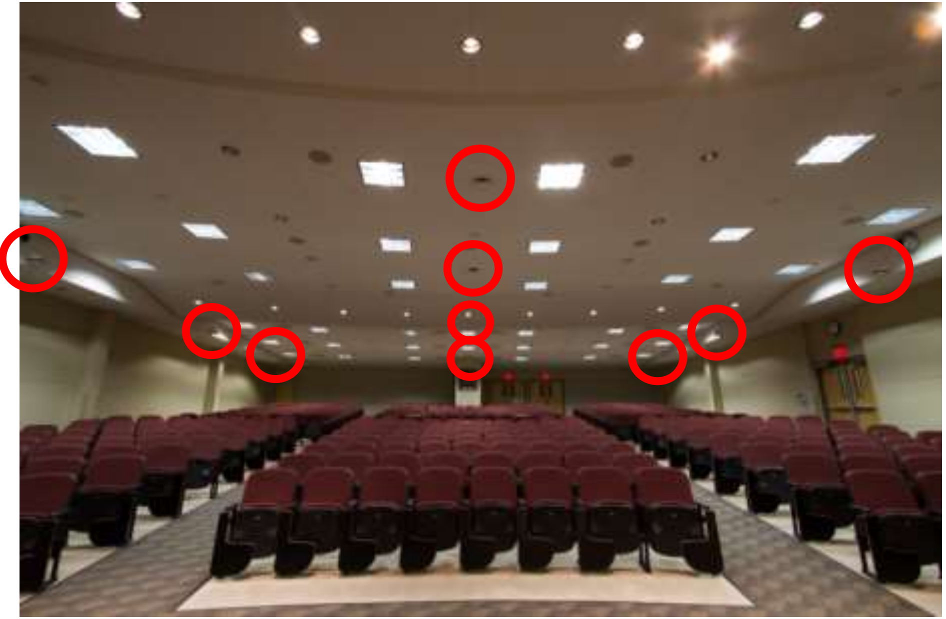
Examples – Overhead Coverage #1



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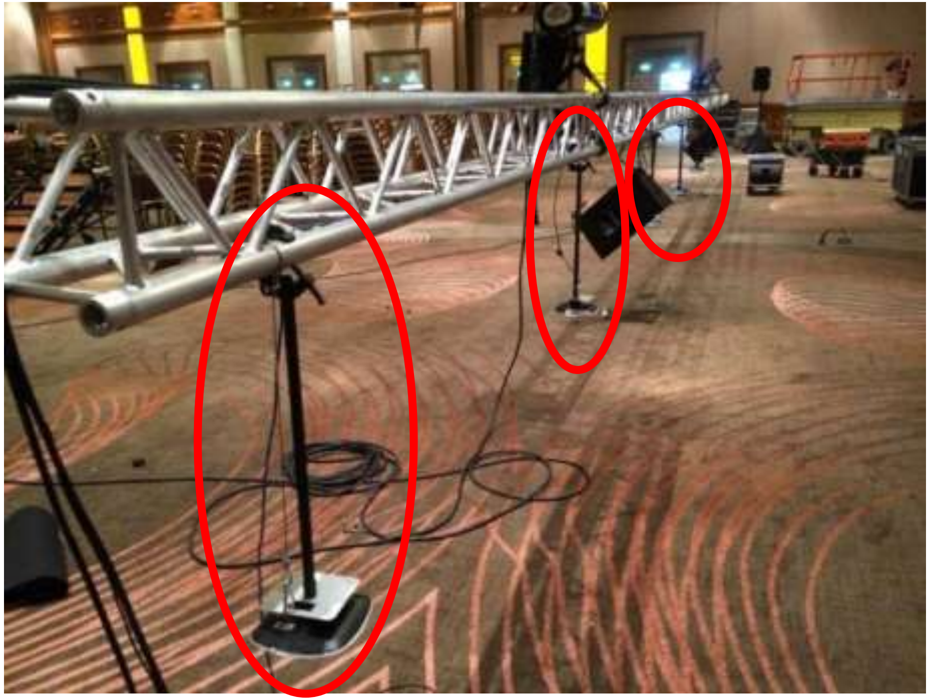
Examples – Overhead Coverage #2



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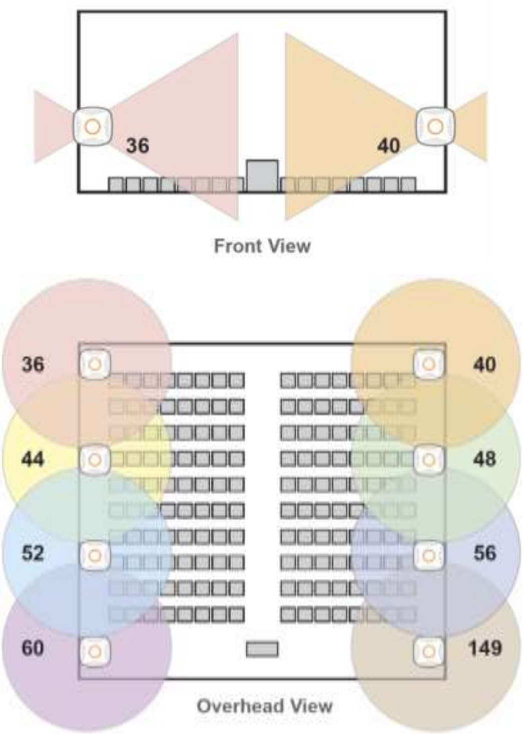
Side Coverage



- **Wall, beam, and column installations with side-facing coverage are very common in VHD areas.**
- **Some ceilings are too difficult to reach, others have costly finishing that cannot be touched, or there may be no ceiling such as open-air atriums.**
- **No RF spatial reuse in indoor environments is possible when mounting to walls or pillars.**
- **50% of the wall-mounted AP signals are lost to the next room (and 75% of the signal in the corners).**
- **Note that adjacent APs on the same wall always skip at least one channel number.**

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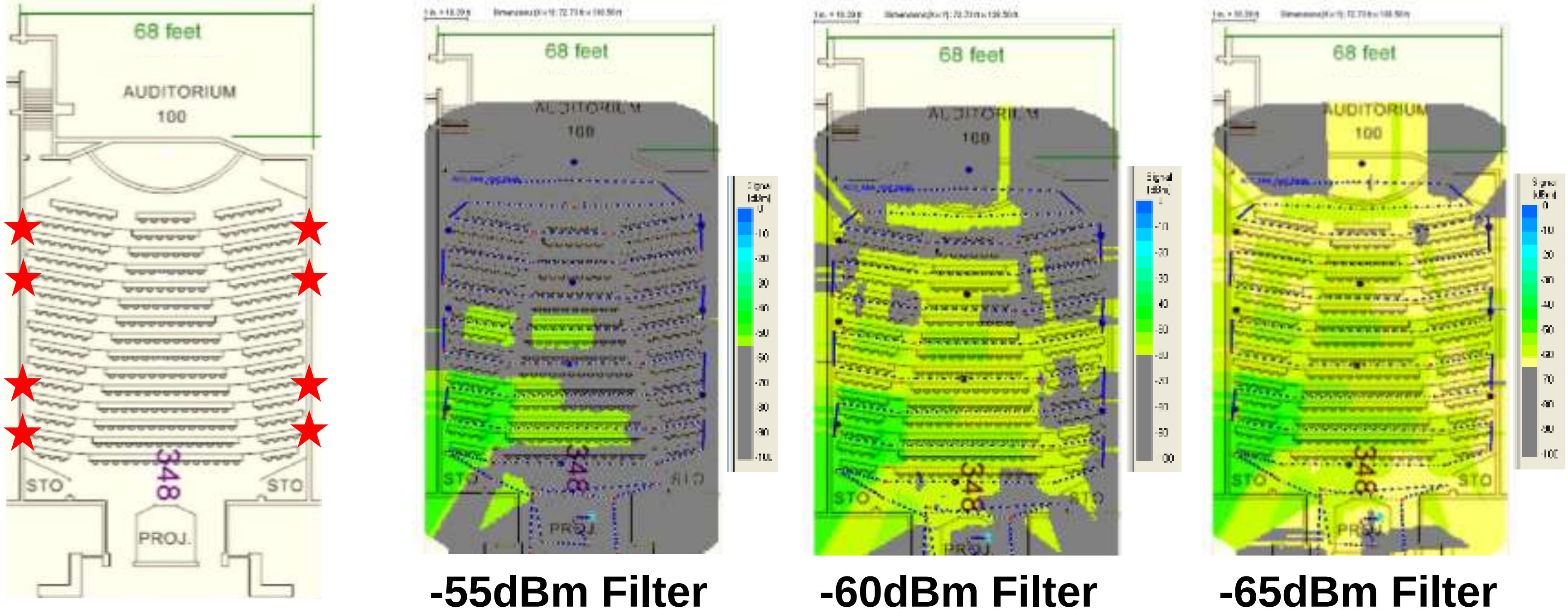
What Does No RF Spatial Reuse Mean?



-55dBm Filter **-60dBm Filter** **-65dBm Filter**

Every AP can be heard everywhere in the room

Examples – Side Coverage

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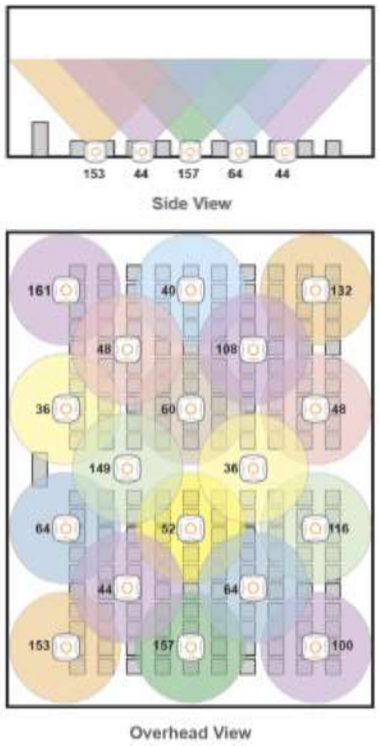
Floor Coverage



- Venues <= 10K seats should always use overhead or side coverage.
- Above > 10K seats, a more exotic option called "picocell" has been proven to deliver significant capacity increases.
- Density of picocell can be much higher than overhead or side coverage.
- Picocell design leverages absorption that occurs to RF signals as they pass through a crowd (known as "crowd loss").
- Cost and complexity of picocells may not always justify the extra capacity generated.

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Examples - Picocell

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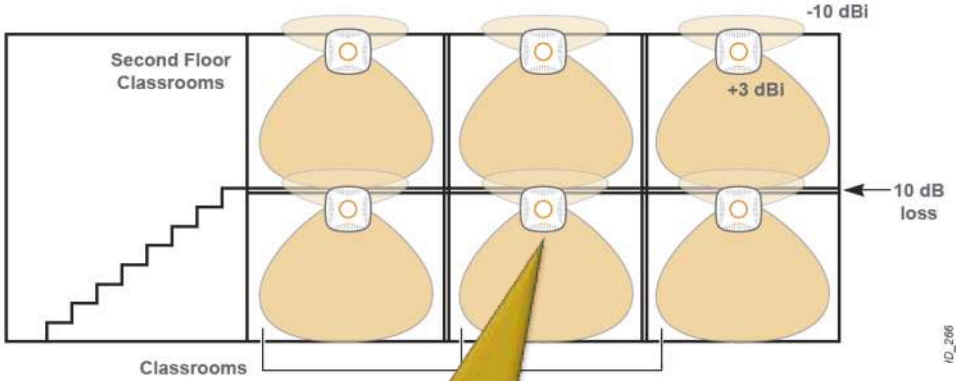
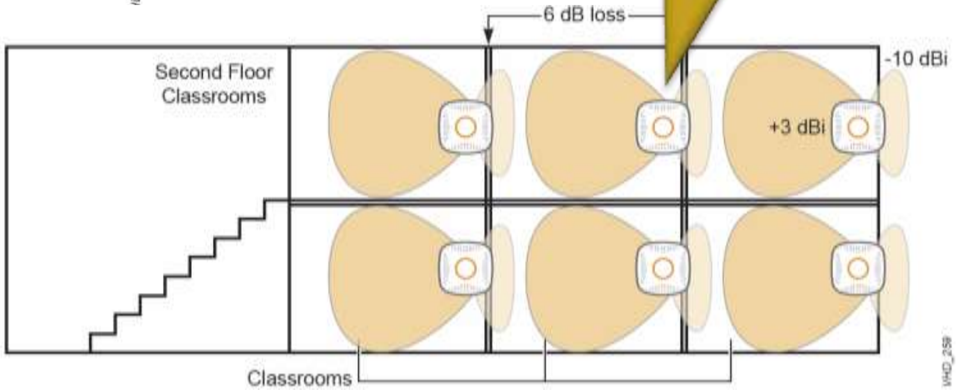
AP Placement for Adjacent VHD Areas



Place APs all facing same direction. Stagger horizontal placements.

Same rules apply to wall deployments. Use rear lobe to your advantage.



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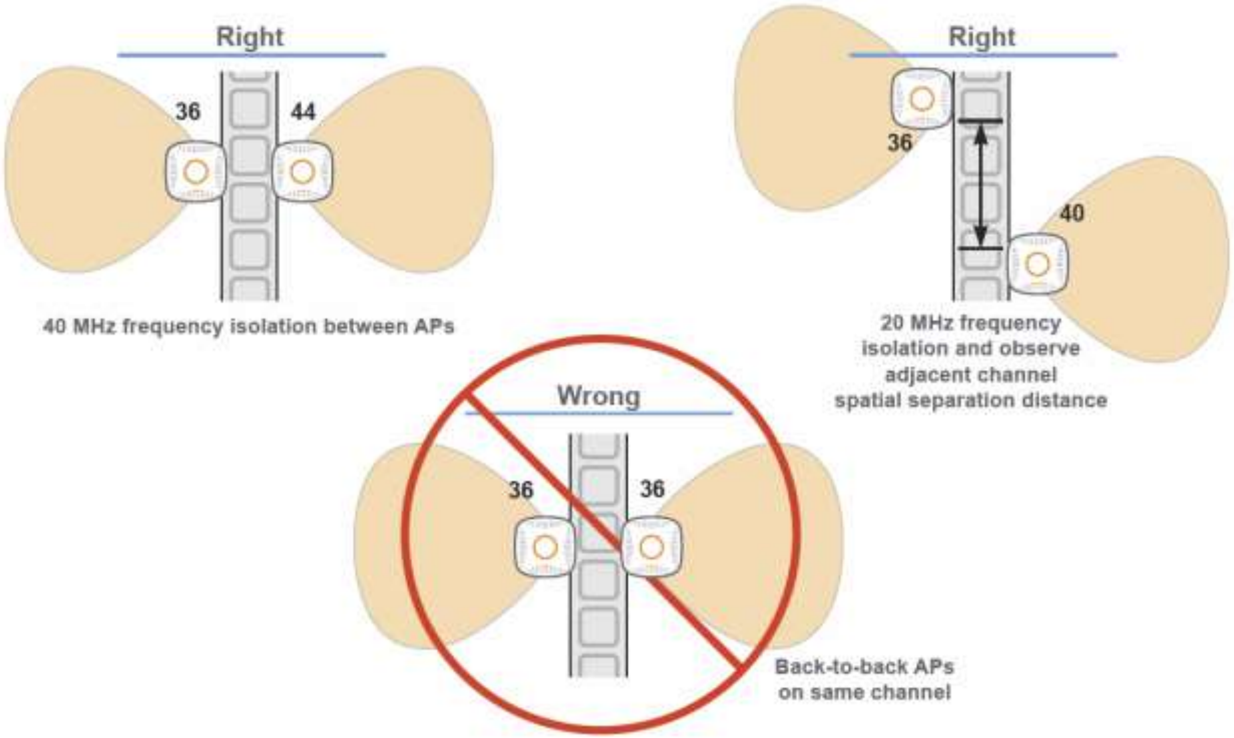
Back-to-Back APs on Same Wall



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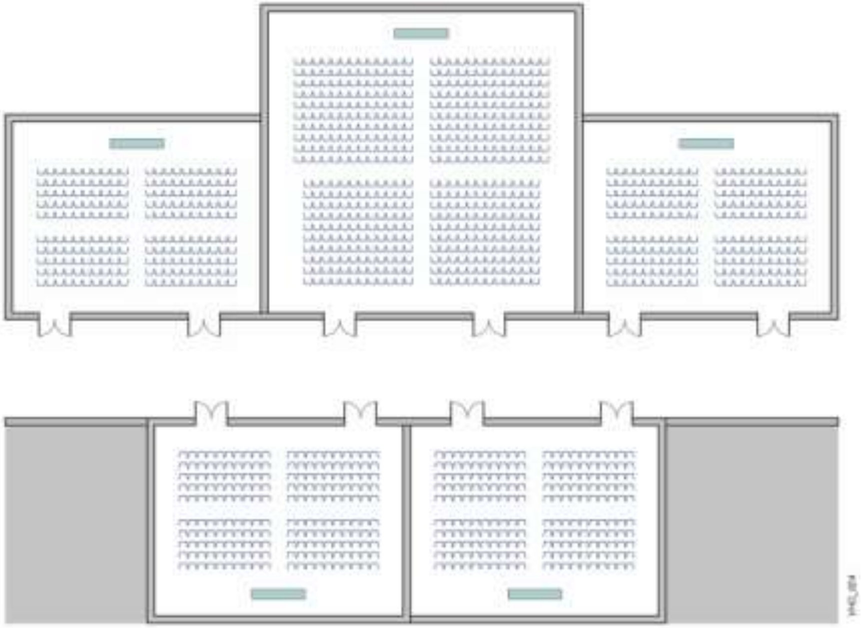
Example:
Adjacent Large Auditoriums

Typical Multi-Auditorium Scenario

- **Hotel conference center or university building with multiple adjacent auditoriums**
- **Dimensioning metrics:**

Metric	Target
Take Rate	100%
Average devices per person	Work/study – 5 Fan/guest - 2
Associated devices per radio	150
Average single-user goodput	1 Mbps
5 GHz vs. 2.4 GHz split	5 GHz: 75% 2.4 GHz: 25%



Physical Layout

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Understanding Offered Load in Auditoriums

Table S1-1 VHD Spatial Stream Blend Lookup Table

VHD Usage Profile	Devices / Person (Now)	Devices / Person (Future)	1SS (%)	2SS (%)	3SS (%)
Work/Study	3	5	30%	60%	10%
Fan/Guest	1	2	50%	50%	0%

Table S1-2 Network Characteristics of Common Auditorium Applications

User Category	Application	Bandwidth	Latency	Duty Cycle
Work/Study	Play courseware (non video)	500 Kbps	Medium	Medium
	Play courseware (video streaming)	1 Mbps+	Low	High
	Test / exam / quiz	Under 250 Kbps	Real-time	Synchronized bursts
Fan/Guest	General internet usage	500 Kbps	Medium	Low
	Email	Under 250 Kbps	High	Low
	Social media	500 Kbps	Medium	Low
	Photo/video cloud sync	1 Mbps+	High	Low

- **Common apps are web browsing, email, and office collaboration.**
- **Class presentation and exam software, are bursty with high concurrent usage.**
- **Cloud service latency is not visible to users.**

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Step 2/3 - Estimate Associated Device Capacity

Start with seating capacity

Use per-user device to estimate ADC

Break out by frequency band.

Determine address space

Table S1-4 … and Subnet Plan for Fi… llrooms

Room Number	Seats	ADC (Now)	ADC (Future)	5-GHz ADC (Future)	2.4-GHz ADC (Future)	Minimum Subnet Size
Room A	200	600	1,000	750	250	/22
Room B	200	600	1,000	750	250	/22
Room C	500	1,500	2,500	1,875	625	/20
Room D	200	600	1,000	750	250	/22
Room E	200	600	1,000	750	250	/22
Staff / House	--	25	75	75	0	/24
GUEST ADC	**1,300**	**3,900**	**6,500**	**4,875**	**1,625**	**/19**
STAFF ADC	**--**	**25**	**75**	**75**	**0**	**/24**
TOTAL ADC	**1,300**	**3,925**	**6,575**	**4,950**	**1,625**	

Estimate staff / facility devices separately

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Step 4 - Estimate the AP Count

$$\text{AP Count} = \text{5-GHz Radio Count} = \frac{\text{Active Device Capacity (5 GHz)}}{\text{Max Associations Per Radio}}$$

Table S1-5 AP Count for Five Ballrooms

Room Number	5-GHz Guest	5-GHz Staff	Total 5-GHz Devices	Devices per Radio	AP Count
Room A	750	15	765	150	6
Room B	750	15	765	150	6
Room C	1,875	15	1,890	150	13
Room D	750	15	765	150	6
Room E	750	15	765	150	6
Hallway	500	15	515	150	4
TOTAL	5,375	90	5,465		41

Take 5-GHz ADC

Divide by per-radio metric

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Calculate System Throughput (Excluding CCI)

Table S1-8 System Throughput Calculation Excluding CCI

Room Number	AP Count	Channels – USA (DFS)	Channels – China (no DFS)	Avg. Channel Bandwidth	Aggregate Bandwidth – USA	Aggregate Bandwidth - China
Room A	6	9	9	67 Mbps	603 Mbps	603 Mbps
Room B	6	9	9	67 Mbps	603 Mbps	603 Mbps
Room C	13	16	12	67 Mbps	1,072 Mbps	804 Mbps
Room D	6	9	9	67 Mbps	603 Mbps	603 Mbps
Room E	6	9	9	67 Mbps	603 Mbps	603 Mbps
Hallway	4	7	7	67 Mbps	469 Mbps	469 Mbps
TOTAL	**41**				**3,953 Mbps**	**3,685 Mbps**

Take AP count

Convert to channels

Multiply by estimated channel capacity

Total maximum load if zero CCI

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Understanding CCI & Estimating Reuse Factor

Same-channel APs are widely spaced

DFS channels minimize reuse

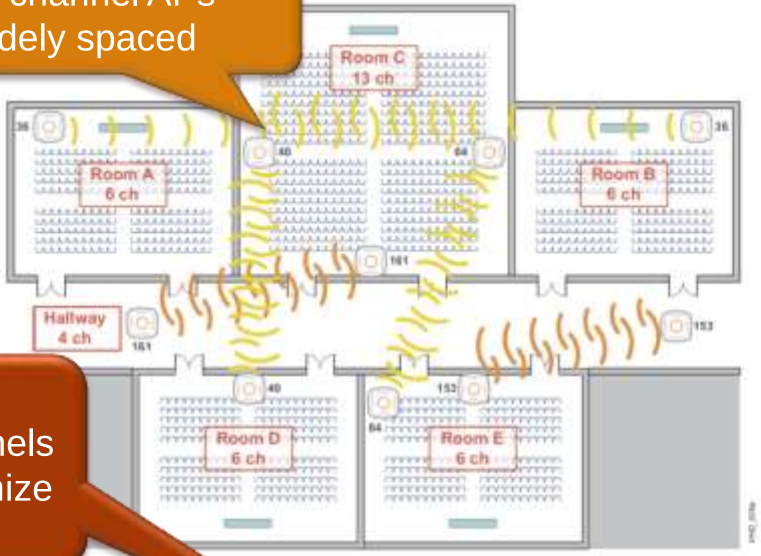

Figure S1-3 ...timated 5-GHz CCI with 21-Channel DFS Plan

Channel Group	AP Count	2.4-GHz Channels	5-GHz Channels
Room A	6	1, 6, 11	36, 52, 100, 116, 140, 149
Room B	6	1, 6, 11	36, 52, 100, 116, 140, 153
Room C	13	1, 6, 11	40, 48, 104, 108, 112, 132, 44, 56, 60, 64, 161, 165, 136
Room D	6	1, 6, 11	40, 48, 104, 108, 112, 136
Room E	6	1, 6, 11	44, 56, 60, 64, 161, 157
Hallway	4	1, 6, 11	149, 154, 157, 165

Avoiding DFS channels means greatly increased CCI

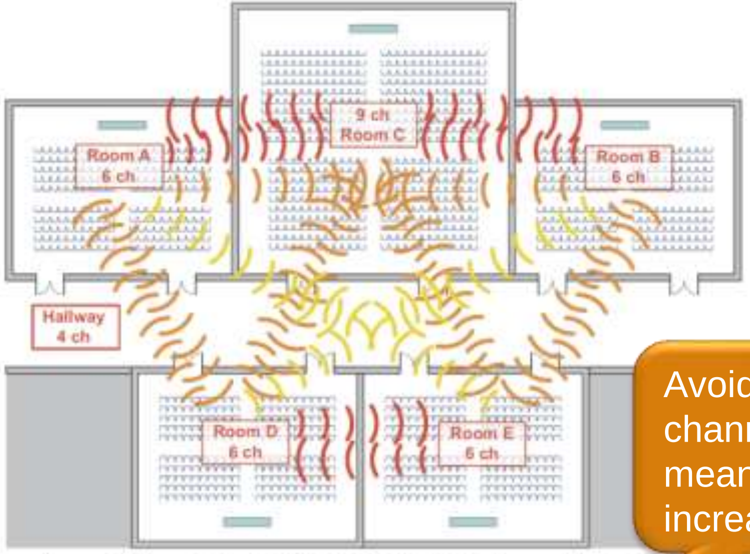

Figure S1-4 Estimated 5-GHz CCI with 9-Channel Non-DFS P...

Channel Group	AP Count	2.4-GHz Channels	5-GHz Channels
Room A	6	1, 6, 11	36, 40, 44, 48, 149, 153
Room B	6	1, 6, 11	36, 40, 44, 48, 157, 161
Room C	13	1, 6, 11	36, 40, 44, 48, 149, 153, 157, 161, 165
Room D	6	1, 6, 11	36, 40, 44, 48, 157, 165
Room E	6	1, 6, 11	36, 40, 44, 48, 149, 153
Hallway	4	1, 6, 11	153,157,161,165

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Calculate Total System Throughput (Including CCI)

Table S1-9 System Throughput Calculation Including CCI

Reuse Factor	AP Count	Channels – USA (DFS)	Channels – China (no DFS)	Avg. Channel Bandwidth	Aggregate Bandwidth – USA	Aggregate Bandwidth - China
RF = 1.0	41	24	12	67 Mbps	1,608 Mbps	804 Mbps
RF = 1.5	41	24	12	67 Mbps	2,412 Mbps	No reuse
RF = 2.0	41	24	12	67 Mbps	3,216 Mbps	No reuse

Most likely outcomes

Model different reuse factors

Revised capacity for DFS scenario

Revised capacity for non-DFS scenario

The TST directly dimensions the required WAN uplink.

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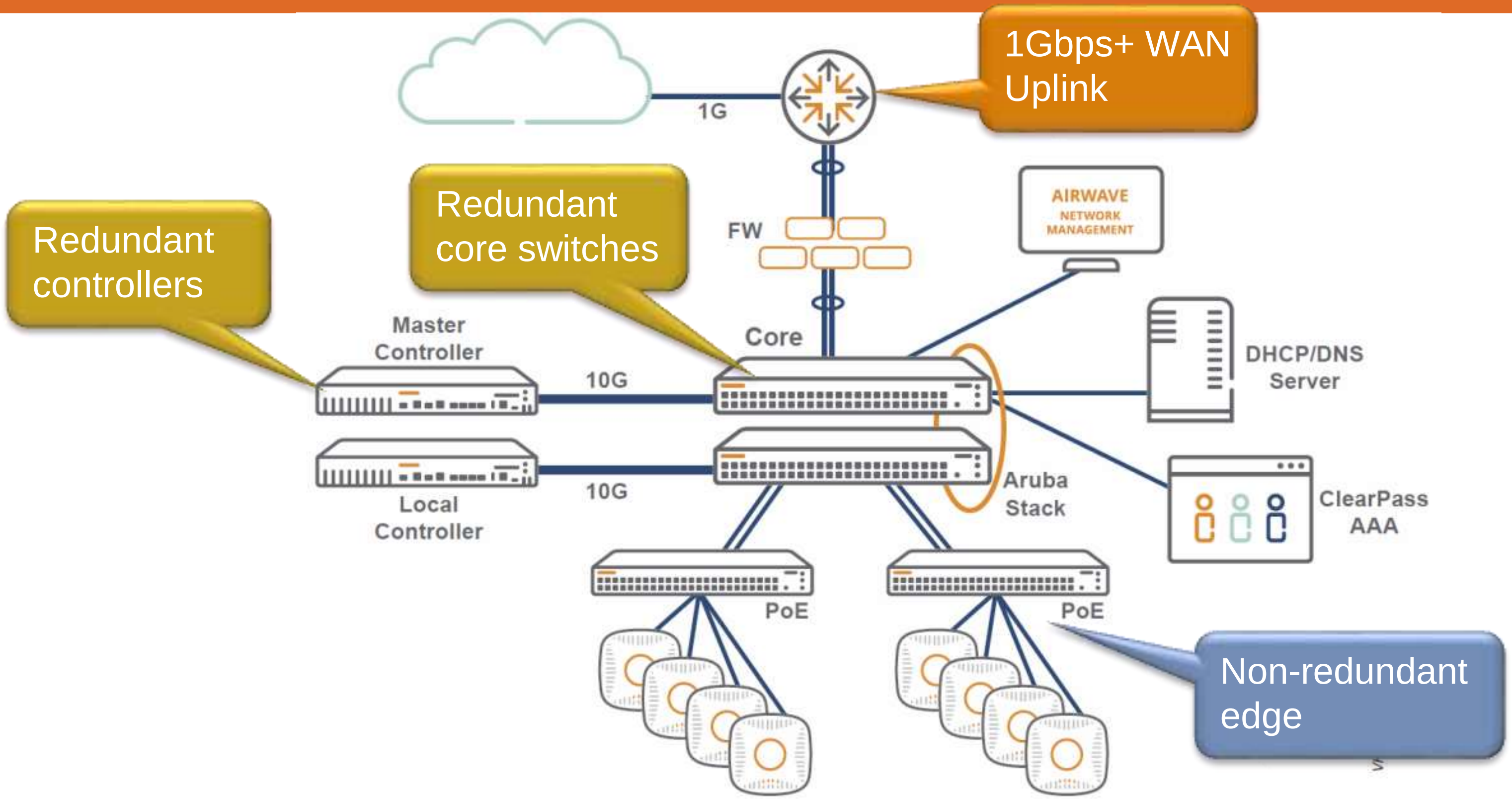
End-to-End Architecture



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Questions?