VALIDATED REFERENCE DESIGN

VERY HIGH-DENSITY 802.11ac NETWORKS

Planning Guide

Version 1.0

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Chapter P-1: Introduction

Many things have changed since Aruba published the industry's first design guide and associated performance data for high-density wireless LANs (HD WLANs) in 2010. Access points (APs) based on the IEEE 802.11ac Very High Throughput (VHT) standard have exploded into the market. They are rapidly replacing the 802.11n High Throughput (HT) APs that were the subject of that design guide.

Five years ago, high-density (HD) WLANs were comparatively rare. We defined an HD WLAN as a WLAN with 50 or more devices per cell. Except for large university lecture halls – which were the focus of that guide – it was quite unusual to find hundreds or thousands of Wi-Fi® clients in a single service area. Most customers considered a "dense" network to be one with a so-called "capacity" design of 250 m^2 (2,700 ft^2) per AP and a cell edge of -65 dBm. Such cells were considered somewhat small, and it was generally not expected to serve more than one device per person in each one. This density worked out to about 25 devices per cell in many organizations (assuming an average of 10 m^2 [110 ft^2] per person).

NOTE

Both metric and English units will be used throughout the VRD. For the convenience of users of English units, we round the converted metric value to the nearest multiple of 10 or 100 as appropriate.

Today, virtually every WLAN is a high-density network. Those "capacity" networks have become HD networks due to the rapid proliferation of bring your own device (BYOD) smartphones and tablets. Modern WLANs often serve a minimum of three devices per person, or up to 75 devices per cell, but the cell sizes have not changed. Wireless architects are now designing networks to accommodate **five to seven** Wi-Fi-enabled devices per person. A simple 20-seat boardroom could contain 60 user devices plus another 5-10 fixed multimedia devices.

Figure P1-1 Awaiting the New Pope in St. Peter's Square[1] Before and After the iPhone

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

Nowhere has Wi-Fi exceeded expectations more than large sporting stadiums and arenas. Pervasive Wi-Fi service is an increasingly common feature of such public venues. First generation designs sometimes struggled, especially considering that 5-GHz support was not common on smartphones for far too long. However, WLAN vendors have continuously improved their designs while the device manufacturers have advanced their products. Today, best-in-class stadiums with 70,000 seats or more have been proven to absorb multiple gigabits per second (Gbps) of offered load via Wi-Fi.

To help our customer and partner engineers succeed in meeting these new requirements, we have written this new validated reference design (VRD) exclusively about very high-density (VHD) WLANs. The guide captures the best practices of our field engineering teams. Aruba also built a dedicated VHD test facility with 300 of the latest 802.11ac devices to produce updated performance data. We are releasing this data to the public to assist in capacity planning.

What Is a Very High-Density WLAN?

Very high-density WLANs are defined as RF coverage zones with a large number of wireless clients and APs in a single physical space. In other words, a VHD WLAN is a single RF collision domain.

For purposes of this reference design, a VHD WLAN is one that is designed to serve at least 100 devices per cell. A VHD WLAN may serve as many as 500 devices per cell. Devices may belong to individuals, or they may be embedded for machine-to-machine or peer-to-peer service (such as an Apple TV or Chromecast device).

Where Are VHD WLANs Found?

With the proliferation of wireless-enabled personal and enterprise mobile devices, a surprisingly diverse range of facilities need VHD WLAN connectivity:

- Large meeting rooms
- Lecture halls and auditoriums
- Convention center meeting halls
- Hotel ballrooms
- Stadiums, arenas, and ballparks
- Concert halls and amphitheaters
- Casinos
- Airport concourses
- Passenger aircraft and cruise ships
- Places of worship
- Financial trading floors

The high concentration of users in any high-density environment presents challenges for designing and deploying a wireless network. The explosion of Wi-Fi-enabled smartphones means that each person could have three or more 802.11 NICs vying for service. At the same time, maximum VHD WLAN capacity varies from country to country based on the number of available radio channels. Balancing demand, capacity, and performance in this type of wireless network requires careful planning.

Plan of the VRD

Aruba is introducing a new and modular approach with this VRD. We recognize that the people who are interested in this topic have a wide range of knowledge levels and interest levels:

- IT managers want to understand enough about the concepts and requirements to justify capital and operating expenditures and put appropriate governance models in place for projects.
- Networking salespeople who call on IT customers need to prepare accurate bills of materials (BOMs) that are cost competitive.
- Wi-Fi engineers want proven configuration recipes to deploy a specific VHD use case quickly, and they may not have time or interest to learn about the underlying reasoning or physics.
- Wireless architects want detailed information about the technology and characteristics of systems to understand exactly how and why the recipes were developed.
- All audiences want industry-specific case studies that show exactly how to solve the problem in their specific environment.

To that end, Aruba is publishing this VRD as a series of three guides, plus individual scenarios that deal with specific deployment use cases. These guides can be mixed and matched as desired based on each reader's experience and interests. This organization is shown in Figure P1-2.

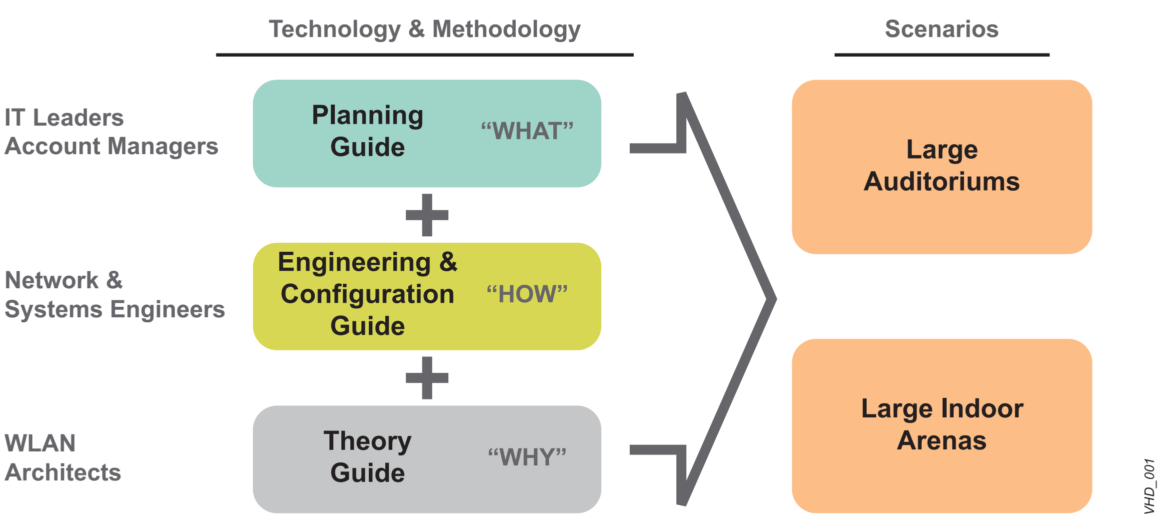


Figure P1-2 Organization of the Very High Density VRD

Functional Blocks of a Very High-Density WLAN

Very high-density WLANs are about much more than the Wi-Fi APs and controllers. VHD networks are truly end-to-end systems that must span end-user devices all the way to an internet service provider edge, along with all of the supporting servers and services in between.

To ensure fast, reliable service for VHD users, all of the component elements must be architected properly. Figure P1-3 shows the major functional blocks of a VHD system.

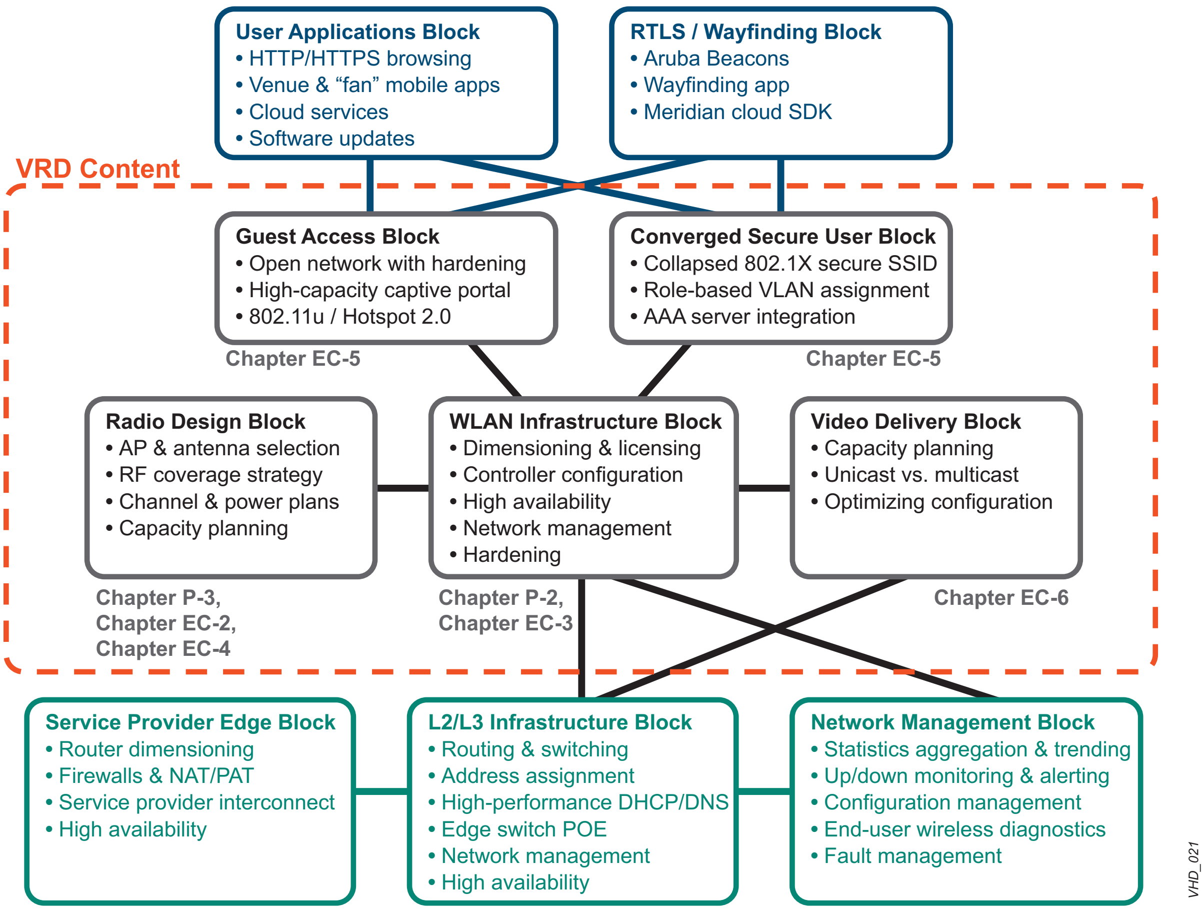


Figure P1-3 Functional Blocks of a VHD System

Most, if not all, of these blocks are independent systems in their own right. Each system must be architected, deployed, configured, and integrated with the others. Only after the entire system is integrated can you begin end-user testing of wireless devices.

The chapters of the Planning guide and the Engineering and Configuration guide that correspond to the major functional blocks of the WLAN are shown in Figure P1-3. In most cases, this VRD will not cover material that is already in other Aruba VRDs, unless a VHD-specific aspect must be explained.

How Do 802.11ac Technologies Affect High-Density Deployments?

On the surface, new technologies in 802.11ac would seem to imply many changes for high-density service areas as compared with previous best practice for 802.11n networks. However, closer inspection shows that the differences in configuration are fairly minor.

Let's consider each of the major aspects of 802.11ac.

Channel Bonding

802.11ac supports 80-MHz channels and potentially even 160-MHz channels. The vast majority of the speed increase in 802.11ac comes from wider channels made up of multiple 20-MHz channels that are bonded together.

However, for many years the best practice for 802.11n HD networks has been to avoid using channel bonding. Aruba was the first vendor to take this position publicly based on the research for our original High-Density Auditoriums VRD published in 2010. Since then, all major vendors have followed, some publishing additional data to independently confirm this view.

Our latest research confirms that 20-MHz channels remain the bandwidth of choice for HD and VHD service areas. Chapter EC-3: Airtime Management of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide explores this idea.

256 Quadrature Amplitude Modulation

802.11ac introduces two new modulation and coding schemes (MCS) that offer faster data rates at the PHY layer. These MCS rates are based on 256 Quadrature Amplitude Modulation (256-QAM).

However, the signal-to-interference-plus-noise ratio (SINR) needed to achieve MCS8 and MCS9 is very high; over 30 dB is required. Therefore, only users who are very close to an AP will have a chance to use such rates. Clients that are associated to APs that have been deployed on ceilings or catwalks may not achieve MCS8 or MCS9 because the distance is too great.

802.11n and older clients cannot use 256-QAM. Until 802.11ac clients are in the majority, even if the clients have adequate signal, we would not expect to see these data rates.

Therefore, Aruba expects that 802.11n HT data rates will continue to be the prevalent speeds achieved by devices in many VHD zones. MCS0 through MCS7 in 802.11ac are identical to 802.11n.

Multiple Spatial Streams

802.11ac defines up to eight spatial streams (SS). It's widely expected that four-stream AP products will become available by early 2016.

This development is exciting and it will increase overall system capacity. However, the progression of 802.11 is organic, and it will take many years to reach 8SS in an AP.

More important is that the radio capabilities of clients and APs are expected to diverge going forward. The 802.11ac multiuser multiple-input and multiple-output (MU-MIMO) feature is explicitly designed around the idea of an 8SS AP talking to four 2SS clients at the same time. Most clients will have not much more than 2SS capability in the future due to this design architecture. 2SS will also remain a limitation due to battery life, antenna design, and cost issues.

This divergence between AP and client capabilities is already happening in the market. Already, we see that 3SS APs are common, while smartphones and tablets are usually just 1SS or at most 2SS. The only devices shipping today with 3SS 802.11ac network adapters in them are high-end laptops. These are forecast to remain a tiny minority of the overall Wi-Fi enabled device population.

Stated more simply, the maximum data rate of today's client devices is expected to remain about the same in the future. However, more users may be served at the same time with the extra spatial streams on the AP.

Multiuser MIMO

Multiuser multiple-input and multiple-output (MU-MIMO) is an exciting future technology that allows an AP to serve up to four clients at the same time.

MU-MIMO is scheduled for delivery as part of "Wave 2" of 802.11ac. Products based on Wave 2 will arrive starting around early 2016 for enterprise APs, and most likely late 2015 for consumer APs. Mainstream smartphone, tablet, and laptop class devices should follow shortly thereafter.

Of all the 802.11ac technologies, MU-MIMO has the greatest potential to impact VHD environments. Aruba will update its guidance after these products are in the marketplace.

Transmit Beamforming

Transmit beamforming (TxBF) is one of the more exciting and impactful features of 802.11ac radios.

For the first time, beamforming is implemented in a standard manner and also in the radio baseband. Proprietary, specialized antenna arrays are not required. Clients and APs can beamform if they have multiple transmit antenna chains.

However, not all radio vendors have chosen to deliver beamforming in their current generation 802.11ac products. Therefore, TxBF should not be counted into link budget calculations except as extra upside margin.

Frame Aggregation (A-MSDU and A-MPDU)

To improve airtime efficiency, 802.11ac increases the maximum size of a MAC service data unit (MSDU) and the number of MAC protocol data units (MPDUs) that can be aggregated together.

In practice, research shows that the average frame size on most WLANs is relatively small, around 500 bytes[2] or less as explored in Chapter T-3: Understanding Airtime of the *Very High-Density 802.11ac Networks Theory Guide* and several public papers. This size is true for VHD and non-VHD areas. Therefore, aggregation is difficult to achieve in practice except for video traffic.

However, to use such large frames, the entire LAN and WLAN infrastructure must support jumbo frames from end to end. (This statement assumes that APs are using GRE tunnels to backhaul WLAN traffic to a controller, which is the recommended configuration in VHD environments.) Jumbo frames are not found in some older edge switches that connect APs due to cost.

So Why Write a New Guide?

If new 802.11ac technologies are not expected to play a significant role in high-density areas, then why write a new design guide?

- We know far more about how to successfully design and deploy HD and VHD networks than we did in 2010. We can now simplify the process for all but the largest sporting arenas.
- The most important change with 802.11ac is the broad support for Dynamic Frequency Selection (DFS) channels now present in the market. Though this varies from country to country, the need for

2. "Anatomy of WiFi Access Traffic of Smartphones and Implications for Energy Saving Techniques", *International Journal of Energy, Information and Communication* (IJEIC), 3(1):1-16. February, 2012.

80-MHz or even 160-MHz channels has led to efforts around the world to allocate more spectrum for Wi-Fi. The need for more Wi-Fi spectrum has, in turn, led to most 802.11ac-capable phones, tablets, and laptops to include DFS support. This development is important because significant additional capacity had largely been unused. DFS channel usage is discussed throughput this VRD.

NOTE

DFS channels are additional spectrum available for Wi-Fi operation that require compliance with dynamic frequency selection rules before they can be used. For detailed information on DFS functionality, see Appendix EC-C: DFS Surveys and Operating Rules of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide.

- Another critical difference is increasing CPU speed of the clients, and especially the wireless NICs. Faster client CPU speed has improved the achievable throughput in congested channels and renders the data we published in 2010 obsolete.
- In 2010, the tablet did not exist and smartphones were relatively new. The research Aruba published in the previous edition of this VRD was done entirely with laptops.
- There is a wide variation in the number of spatial streams supported by different devices that are common in VHD areas. Phones are usually, but not always, 1SS. Tablets are usually, but not always, 2SS. Laptops can be either 2SS or 3SS.
- Other aspects of the infrastructure, such as sizing DHCP or the LAN, have become critical to successful VHD networks. These aspects have not previously been described in an Aruba design guide.

The last four points mean that the usable throughput, or "goodput" that can be generated by a group of clients in a cell, is significantly higher than just a few years ago. Goodput is higher even when 20-MHz channels and non-VHT data rates are used. Therefore, it was necessary to go back in the lab and run extensive tests in many different configurations to characterize and quantify the performance that customers can expect in various scenarios.

Design Validation and Testing

Configuration recommendations in this VRD have been validated in over 100 VHD customer deployments. Aruba also constructed a VHD test lab with 300 devices. This lab produced many of the charts that appear in the Configuration and Theory guides.

More information on the testbed and test methodology can be found in Appendix T-A: Aruba Very High-Density Testbed of the *Very High-Density 802.11ac Networks Theory Guide*.

Reference Documents

This VRD focuses specifically on aspects of capacity planning, RF design, dimensioning, and software features to enable VHD operation. This VRD is meant to complement the other Aruba VRDs. As a result, the information in it overlaps with other VRDs only to address VHD-specific issues or to change our usual guidance.

This VRD does not address controller clustering and high availability, AirWave® design and deployment, ClearPass design and deployment, or other general topics that are not VHD-specific. Table P1-1 lists reference documents for other useful sources of information on these and related topics.

Table P1-1 Useful Technical Documents

Document Title	Author(s)	Link
Aruba Mobility Controllers VRD (v9)	Aruba Networks	http://community.arubanetworks.com/aruba/attachments/aruba/ArubaVDRs/4/1/Aruba%20Mobility%20Controllers-%20PDF.pdf
Campus Wireless Networks VRD (v8)	Aruba Networks	http://community.arubanetworks.com/aruba/attachments/aruba/ArubaVDRs/1/6/Campus%20Network%20Design%20v%208.pdf
Guest Access with ArubaOS VRD	Aruba Networks	http://community.arubanetworks.com/aruba/attachments/aruba/ArubaVDRs/14/1/Guest%20Access%20with%20ArubaOS.pdf
Managing & Optimizing RF Spectrum for Aruba WLANs	Aruba Networks	http://community.arubanetworks.com/aruba/attachments/aruba/ArubaVDRs/6/1/RFSpectrumWLANsAppNote_20120514.pdf
802.11ac In Depth, Aruba Networks	Aruba Networks	http://www.arubanetworks.com/pdf/technology/whitepapers/WP_80211acInDepth.pdf
Wi-Fi Certified Passpoint Architecture for Public Access	Aruba Networks	http://www.arubanetworks.com/pdf/technology/whitepapers/WP_Passpoint_Wi-Fi.pdf
Apple Captive Network Assistant Bypass with ClearPass Guest	Aruba Networks	http://community.arubanetworks.com/t5/Validated-Reference-Design/Apple-Captive-Network-Assistant-Bypass-with-ClearPass-Guest/ta-p/155618
ClearPass User Guide	Aruba Networks	• ClearPass Policy Manager 6.3 User Guide: http://community.arubanetworks.com/t5/Software-User-Reference-Guides/ClearPass-Policy-Manager-6-3-User-Guide/ta-p/168394 • ClearPass Guest 6.4 User Guide: http://community.arubanetworks.com/aruba/attachments/aruba/SoftwareUserReferenceGuides/29/1/ClearPass_Guest_6.4_User_Guide.pdf
Apple IOS8 Roaming Reference	Apple	http://support.apple.com/en-us/HT203068
Next Generation Wireless LANs: 802.11n and 802.11ac	Eldad Perahia, Robert Stacey	http://www.cambridge.org/er/academic/subjects/engineering/wireless-communications/next-generation-wireless-lans-80211n-and-80211ac-2nd-edition
802.11ac: A Survival Guide	Matthew Gast	http://shop.oreilly.com/product/0636920027768.do
Certified Wireless Analysis Professional (CWAP) Official Study Guide	David Westcott, David Coleman, Ben Miller, and Peter Mackenzie	http://www.wiley.com/WileyCDA/WileyTitle/productCd-0470769033.html
Certified Wireless Network Administrator Official Study Guide	David D. Coleman and David A. Westcott	http://www.wiley.com/WileyCDA/WileyTitle/productCd-111812779X.html

Other Aruba Technical Support Resources

- The complete suite of Aruba technical documentation is available for download from the Aruba support site. These documents present complete, detailed feature and functionality explanations that are outside the scope of the VRD series. The Aruba support site is located here:

  https://support.arubanetworks.com/

  This site requires a user login and is for current Aruba customers with support contracts.
- For more training on Aruba products or to learn about Aruba certifications, visit our training and certification page on our public website. This page contains links to class descriptions, calendars, and test descriptions: http://www.arubanetworks.com/training.php/
- Aruba hosts a user forum site and user meetings called Airheads. The forum contains discussions of deployments, products, and troubleshooting tips. Airheads Online is an invaluable resource that allows network administrators to interact with each other and Aruba experts. Announcements for Airheads in-person meetings are also available on the site:

  http://airheads.arubanetworks.com/
- The VRD series assumes a working knowledge of Wi-Fi®, and more specifically dependent AP, or controller-based, architectures. For more information about wireless technology fundamentals, visit the Certified Wireless Network Professional (CWNP) site at:

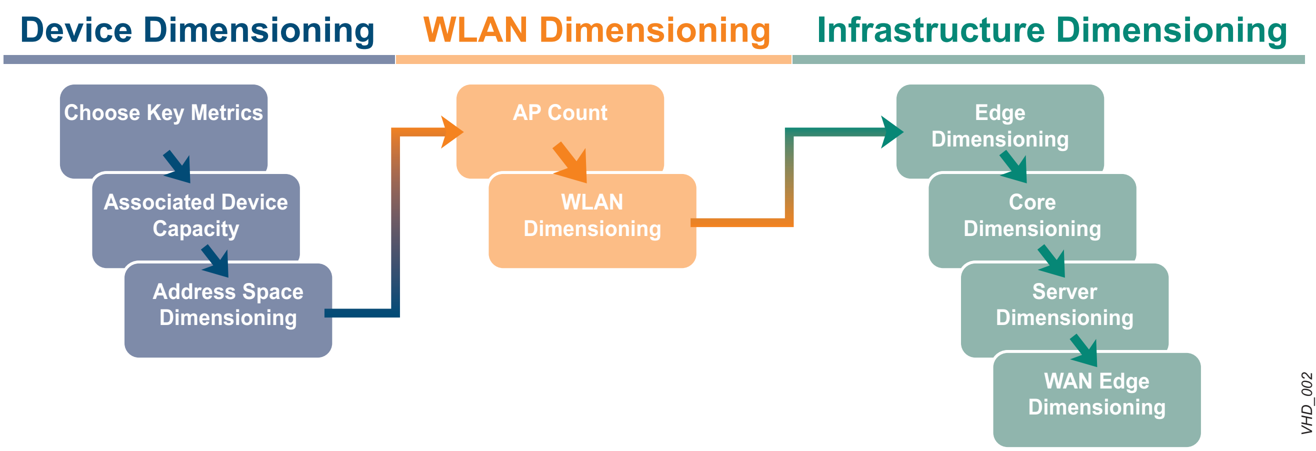
  http://www.cwnp.com/

Chapter P-2: System Dimensioning

In this chapter you will learn the key design parameters that drive the hardware and software quantities required to serve a very high-density (VHD) area. You will also learn how to estimate hardware and software quantities.

Dimensioning Process

The basic nine-step approach for system dimensioning is common to all VHD wireless networks. Some steps are specific to the WLAN itself, and others directly impact other functional blocks.



Choose Key Metrics

Table P2-1 lists the key design criteria for dimensioning a typical VHD wireless network.

Table P2-1 Key Design Criteria for a Typical VHD Wireless Network

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%

The rest of this chapter provides details and analysis of expected system capacity relative to these objectives.

Associated Device Capacity

All VHD capacity planning begins with the associated device capacity (ADC) requirement, which is the total number of devices that the WLAN is expected to carry.

Understanding the Concept

Every Wi-Fi AP has a limit on the number of devices that can be associated to it at the same time. An association is a specific relationship between a Wi-Fi device and an AP that is negotiated using the 802.11 MAC protocol. To be associated means that the device has been accepted onto the network and assigned an association ID (AID) that is unique to that device for the duration of its session.

The association limit generally applies separately to each radio in an AP. The AP limit is the sum of the two radio limits. For example, Aruba recommends using an associated device capacity of 150 per radio for planning purposes, or a total of 300 per AP.

150 associations per radio represents a loading level of about 60% of the actual maximum capacity of an Aruba radio. Aruba offers the highest association capacity in the industry. Up to 255 devices can be associated per radio, for a total of 510 devices per AP. We recommend the planning value of 60% in order to leave headroom for inrush/outrush and normal crowd density variations.

NOTE

The ArubaOS default value is 64 devices per radio. In Chapter EC-5: SSIDs, Authentication, and Security of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide you will learn to increase this value to the maximum as part of our best practice configuration.

The associated device limit varies by manufacturer and sometimes by specific AP model, depending on the capabilities of their hardware and software. Some vendors specify different limits with encryption enabled on any SSID on the AP. Understanding this limit is a critical step in any vendor selection process for a VHD network.

The wireless architect must ensure that the WLAN has enough association slots and network addresses to accommodate all of the devices that will attempt to connect. Therefore, you must ensure that there are enough AP radios deployed in your VHD facility to absorb the full association load. This is easily calculated by estimating the total number of expected devices (or ADC), and dividing by the per-AP limit (assuming an equal division of devices across the 5-GHz and 2.4-GHz bands). In this VRD, you will learn to evaluate ADC separate for each frequency band, because larger VHD facilities typically require that at least 75% of the devices be migrated to the 5-GHz band.

This is a critical concept to understand. **The minimum number of APs required for any VHD system is determined by the ADC value and the per-AP association limit.** If you have fewer APs than this, there will not be enough association slots to accept devices onto the network. For certain types of VHD facilities - such as lecture halls and hotel ballrooms - the AP count is determined completely by the ADC.

For larger VHD facilities such as airports, arenas and stadiums, ensuring a consistent and high signal level is an additional consideration. In these facilities, more APs may be required depending on the RF coverage strategy chosen by the wireless architect. However, the maximum size of any given radio cell will still be determined by the association limit.

Guest Devices vs. Staff Devices

Most VHD networks typically support two broad categories of users: guests and staff. ADC must be estimated for both groups.

- Guest users come for a few hours to use the network and then leave.
- Staff users are always present and require secure connections.

As a general rule, guest users are treated as a single group by the network. They share the same wireless SSID, and a common set of policies is applied. Their device population is extremely heterogeneous, and is completely uncontrolled. Generally, guests need an open SSID with no encryption; which means that the guest VLAN must be hardened against attack.

By contrast, staff users often are put into many subgroups (and VLANs), with different device capabilities and network access policies for each one. For example, three common device groups in a stadium are ticket scanners, point-of-sale terminals, and team or venue devices. A convention center may differentiate between managers, catering, and housekeeping. A lecture hall may simply have faculty as the sole category of secure user.

In Chapter EC-5: SSIDs, Authentication, and Security of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide, we will explore the service architecture for guest and secure staff usage in more detail.

For dimensioning purposes, we must estimate the total quantities of both groups, including any subgroups.

Attributes of ADC for Guests

Associated device capacity for guest devices has these attributes:

- To figure ADC, usually you start by estimating the take rate (percentage of the seating capacity of the venue). 50% is a common minimum target.
- The ADC should include the number of devices expected per person. This number varies by venue type. It might be lower in a stadium and higher in a university lecture hall or convention center ballroom.
  - For example, 50% of a 70,000 seat stadium would be a guest ADC of 35,000 devices, if you assume that 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 a guest ADC equal to 2,500.
- If more devices attempt to connect than are budgeted, they may be rejected due to licensing or other limits.
- More users should be on 5-GHz band than 2.4-GHz band. So association capacity should be computed by frequency band. In general, you should target a ratio of 75%/25%. This ratio may increase the AP count needed to cover an area as compared with a 50%/50% ratio. In some countries, 5-GHz penetration is lower, so this type of balance may not be achievable today, but over time it will become possible.
- Association demand is assumed to be evenly distributed throughout the coverage space. If this is not the case, then the area might need to be subdivided to ensure adequate AP densities in each one.
- The ADC should reflect the total device forecast at the **end** of the service life of the network, for example, in five years. Generally, device adoption increases over time.

Attributes of ADC for Staff

For staff devices, ADC has these attributes:

- There are a fixed number of devices by subgroup or function.
- 100% of these devices are expected to connect to the network.
- Devices should use the 5-GHz band exclusively for maximum speed and reliability.
- Devices are owned by the facility, which controls their rate of growth and the frequency of refresh cycles.
- Even though certain devices may be clustered in particular areas, such as ticket scanners, Aruba recommends assuming an even distribution through the facility.
- The ADC should reflect the total number at the **end** of the service life of the network. Generally, adoption increases over time.

Address Space Dimensioning

There is a direct relationship between ADC and the number of MAC addresses and IP addresses that will be managed by the system.

Subnet Size

It is assumed that role-based access control is being used on the Aruba system to enforce policy for each user group. Therefore, upon successful authentication, the system derives a VLAN for each device. Aruba does not recommend or support multinetting, so each user group must have its own subnet in a separate Layer 2 VLAN.

Subnet size can be directly determined from the ADC counts you produce during the design stage.

Aruba strongly recommends using a single, flat Layer 2 VLAN for the guest network up to 65,536 devices (/16 network). If your ADC exceeds this figure, consult with your local Aruba systems engineer. Be sure to verify that all network equipment trunking this VLAN has adequately sized ARP and forwarding tables.

Capturing Device and Address Requirements

You can use Table P2-2 to capture all of the data that we have discussed so far. We will use the example of a 20,000 seat arena with a 25% current take rate that is expected to increase to 50% in the future, and one device per fan.

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**	**-**

Table P2-3 is an example for a large university with 20,000 students that share multiple large lecture halls ranging in size from 200 to 5,000 seats. Each student has three devices, and the future take rate target is 75%. The guest address space is common across all rooms. Faculty devices will double over the same time period.

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**	**-**

AP Count

After you determine the number of devices that must be served per frequency band, it is a relatively simple matter to calculate the AP count.

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

For this calculation, we take the number of devices expected on the most heavily used frequency band (5-GHz) and divide by our metric for maximum associations per radio (150). This yields the number of 5-GHz radios required, which in turn is the same as the AP count because each unit has a single 5-GHz radio.

Maximum Associations per Radio

For many years Aruba has recommended using a figure of 150 associations per radio for HD planning. This recommendation has been revalidated for 802.11ac and VHD networks. You should use this value unless special circumstances apply to your deployment.

VHD coverage should always be provided by dual-radio APs. Therefore, this coverage equates to 150 + 150 = 300 associations per AP. However, because 5-GHz is generally expected to have many more users than 2.4-GHz, you want to do your math on a per-radio basis.

When you plan the AP count, do not use the full Aruba capability of 255 associated devices per radio. You must leave extra headroom for the inrush and outrush of devices and poor device roaming behavior.

All VHD areas experience varying forms of inrush and outrush. For instance, a lecture hall completely empties and then rapidly fills up in the few minutes between classes. The few doors are closer to certain APs than others. You will observe that the first AP that a device chooses may not be optimal considering where the user sits. Either the Aruba ClientMatch feature or the device’s roaming algorithm eventually balances everything out, but it can take several minutes. So it is important to leave headroom in the maximum association target to ensure that the infrastructure can absorb such spikes.

In a stadium, fans are admitted through a small number of ticket gates before they can roam the facility freely. It is common to see “rolling load spikes” as devices move through the facility. APs near entrances can be extremely heavily loaded before the event begins, then drop to very low levels while the concourse and bowl areas fill up. The process reverses itself after the game.

150 associations per radio represents roughly a 60% loading of the maximum capability of the AP. APs in VHD areas should be configured to allow the full 255 device load (default in ArubaOS is 64 per radio). The 255 device association limit is supported on all Aruba AP models. It is supported in all operating modes as well. With Aruba products, this value is not reduced when encryption is used on the radio.

WLAN Dimensioning

This section is concerned strictly with choosing the correct size of controller model. For the recommended architecture of the WLAN infrastructure block, including license selection and redundancy architecture, refer to one of the VHD scenarios that applies to your environment. Each scenario includes a suggested end-to-end system architecture based on the scale of the deployment.

In an Aruba controller-based WLAN, APs tunnel user traffic over a wired network back to high-performance controllers in a data center environment. The number and type of controllers are determined by three main factors:

- User count
- AP count
- Redundancy architecture

In most non-VHD deployments, AP count is the most important factor. User count does not really factor into dimensioning. However, in VHD service areas, typically the user count is high and the AP count is much lower than the platform limit. So it is the user count that determines the controller model for VHD networks.

Sizing Controllers that Terminate APs

This discussion applies to controllers that terminate AP tunnel and user traffic. Depending on the exact architecture, this could be a master or local controller. In smaller deployments, master controllers may terminate APs to reduce the overall cost. For deployments with ADCs over 48,000 devices, Aruba recommends using dedicated master controllers that serve only as control plane and do not terminate AP tunnels.

NOTE

If you are not familiar with the Aruba master/local clustering architecture, refer to the *Aruba Mobility Controllers VRD*.

Very simply, the right controller for any VHD network with an ADC of less than 32,768 is determined by:

Platform Size >= Associated Device Capacity

For instance, using the arena example from Table P2-2, we have ADC of 10,700. It is a single building (not a campus), so we need not worry about any other APs or users. Table P2-4 shows that an Aruba 7210 is the minimum controller possible, regardless of whether an active/active or active/standby failover mode is used.

Table P2-4 Aruba 7200 Series Controller Models and Scaling Parameters

Model	7210	7220	7240
			
Maximum number of LAN-connected access points	512	1,024	2,048
Maximum number of users	16,384	24,576	32,768
Active firewall sessions	2,015,291		
Firewall throughput	20 Gbps	40 Gbps	40 Gbps
AES encrypted firewall throughput	6 Gbps	20 Gbps	40 Gbps
MAC Addresses per VLAN	64000	128000	128000
FW Session Creation Rate (1000 sessions/sec)	249	326	481
802.1x Auth Rate (transaction/sec), EAP ON	169	219	297
802.1x Auth Rate (transaction/sec), EAP OFF	115	185	220
Captive Portals (transactions/sec), 2K bit	81	114	132
1000Base-T ports	2		
10 Gigabit Ethernet ports (SFP+)	4		
Redundant PSU	Yes		

For VHD deployments with ADCs higher than the model 7240 platform limit of 32,768 users, you must subdivide the user populations across two or more separate local controller HA pairs (see Table P2-5).

Table P2-5 Example Controller Requirements for Stadiums of Different Size

Facility Example	Associated Device Count	Controller Solution
Basketball, Hockey	16K – 32K	two pairs of Aruba 7210
Baseball, Soccer	32K – 48K	two pairs of Aruba 7220
NFL Football, Soccer	48K – 64K	two pairs of Aruba 7240
College Football, Soccer	65K – 96K	three pairs of Aruba 7240
NASCAR	96K – 250K	one pair of Aruba 7240 for every 32K devices

Generally speaking, VHD deployments should use the Aruba 7200 series for local controllers. The exception is if the total ADC of the VHD service areas is significantly under the 7210 platform limit. However, even then Aruba recommends the 7210 as a minimum investment due to its significantly higher CPU speed and memory as compared with the 7000 series. The 7200 series also features optional redundant power supplies (except for the 7205). A redundant PSU is critical for VHD deployments.

VHD environments are characterized by extremely high transaction rates for controller processes for certain Aruba software features. ClientMatch must handle thousands of RF telemetry updates per minute, and AppRF must handle thousands of user session updates. Crypto performance may be less important unless the guest network is using WPA/WPA2 in a HotSpot 2.0 scenario. In that case, the centralized crypto engines of the 7200 family help deliver low latency in VHD scenarios when tunneling traffic back to the controller.

Sizing Dedicated Master Controllers

Master controllers perform many services in an Aruba master/local cluster. However, they are much less heavily loaded if they do not terminate AP and user traffic.

Aruba recommends a 7210 platform if you are deploying with dedicated masters. Do not use a 7205 or a 7000 series controller as a master in a VHD network.

Edge Dimensioning

APs receive power and network connectivity from edge switches. In most VHD deployments, the AP count directly determines the edge switch counts and locations.

A best practice when you deploy 802.11ac APs is to ensure that the edge switching infrastructure is sized correctly:

- Full gigabit ports downstream to the APs
- Full 802.3at Power-over-Ethernet that provides 30 watts on all ports
- Category 6A cabling between the switches and the APs
- Two or more 10 Gigabit-Ethernet SFP+ uplinks for redundant distribution or core links

The maximum data rate that a single AP generates on the wire is the highest MCS in a VHT20 channel. Per the data rate table in Appendix EC-B: 802.11ac Data Rate Table of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide, that is 346.7 Mbps for a four spatial stream (4SS) device. Therefore, you need not worry about exceeding 1 Gbps because channel bonding should never be used in VHD networks (see Chapter EC-2: Estimating System Throughput and Chapter EC-3: Airtime Management of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide). However, you can see that 100 Mbps switches will not do the job. Nor will they produce adequate power. If you are retrofitting a VHD network into an existing facility with older 100 Mbps switches, you must upgrade the edge.

The number of data closets (IDFs) is determined by the 100 meter Ethernet limit. For rough planning purposes, most IDFs in a typical very high density area serve between 10 and 20 APs. This can be lower or higher depending on the specifics of each facility.

Core Dimensioning

Associated device capacity has direct consequences for upstream infrastructure, such as address space, ARP cache size, forwarding/bridge table size, DHCP lease binding database size, firewall sessions, public IP addresses for NAT/PAT, captive portal sessions, system licenses, HA dimensioning, and so on.

ARP Cache Size and Forwarding Table Limit

Aruba recommends using a single, flat VLAN for the guest SSID. You must verify that each core or distribution switch trunking the VLAN is specifically sized to handle the ARP table and the forwarding table for the guest user subnet.

Table size is not usually a problem for arenas or convention centers with an ADC value of less than 32,000 devices. Most core switches on the market support at least 32,000 entries for each of these tables. However, for large venues, such as 80,000-seat football or 250,000-seat racetracks, explicitly verify the table sizes with your switch vendor.

Backplane Throughput

All edge-to-core interconnects in a VHD network should be redundant 10 Gigabit (10G) connections. However, aggregated 10G links are not usually necessary due to inherent speed limitations of wireless.

VHD WLANs are inherently self-throttling on the air, due to the shared nature of the medium and the very limited number of channels. In addition, because VHD networks should never use channel bonding, the maximum PHY data rate on any single radio will be no more than 346.7 Mbps for a 4SS client, or 173.3 Mbps for a 2SS client.

In Chapter EC-2: Estimating System Throughput of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide, you will learn to size the anticipated offered load from the network. This load depends on channel count, usable throughput per channel, and the amount of RF spatial reuse that can be obtained. In practice, a well-designed VHD network should be capable of generating a range from 1-2 Gbps of goodput. Exceeding 2 Gbps is possible, but it is more difficult and costly to achieve.

In general, the core switch bandwidth will be double this value because of the hairpin turn that all traffic must take through the controller due to AP tunnels. So a 1-2 Gbps over-the-air value becomes 2-4 Gbps on the controller uplink port(s), which is well within the carrying capacity of a single 10G link.

If you are designing a VHD deployment where you expect to achieve a significant level of RF spatial reuse, these values should be checked carefully. However, RF spatial reuse is exceedingly rare.

First Hop Redundancy

It was stated above that the core switching fabric as well as all edge links should include Layer 1 redundant connections. This can be accomplished in a variety of ways and is specific to the switching vendor used by the customer.

In addition, it is essential to provide for first-hop redundancy of the default gateway. Particularly when employing very large subnet sizes for guest WLANs as recommended in this VRD. The default gateway IP address should survive the loss of either side of a collapsed core without being visible in any way to WLAN clients.

Server Dimensioning

Three principal types of enabling servers are required for a successful VHD deployment: A DHCP/DNS server for network addressing, a captive portal to register guest users, and a RADIUS server to authorize staff users. Each one must be properly dimensioned.

DHCP/DNS

The large fan/guest VLAN determines the required size of the DHCP and DNS servers.

DHCP server size depends on these two metrics:

- **Request/renew transaction time:** This time should be **very** fast. Aruba recommends less than 5 ms. Slow DHCP transaction times can be extremely visible to end users, and can create a negative user experience.
- **Total address binding database entries:** This number is the sum of all the client devices on all the VLANs, which is the total ADC.

The actual DHCP request/renew transaction rate typically is not a concern. The typical peak arrival rate for fans attending an event is 5% of seating capacity in five minutes. This peak is usually reached 20-30 minutes before the scheduled event start. For an 18,000 seat indoor sporting arena, this would be 18,000 * 5% / 300 seconds = 3 discovers per second. So it is not the transaction rate, but rather the transaction time that is important. For this reason, carrier-grade DHCP servers are **strongly** recommended. Aruba has seen problems with open source DHCP servers running on off-the-shelf servers in venues larger than 10,000 seats.

DHCP renewals may be modeled at 4:1 over the DHCP discover/offer/request/ack rate at the peak.

Aruba recommends using a DHCP lease time that is twice as long as a typical game/event. A common value is 8 hours.

DNS server size depends on venue size. A good rule of thumb here is 1 query per second per device. In our 18,000 seat arena scenario, that would be simply 18,000 DNS queries per second.

Captive Portal

Captive portal peak load should approximate the peak DHCP discover rate of 5% over 5 minutes, and logins should occur only once per event. The captive portal session time limit should be set so no device is forced to log in more than once per day. See Table P2-4 on page 20 for captive portal transaction rates of the various Aruba controller models.

RADIUS

RADIUS server load varies depending on the type of facility. In large public venues such as airports or stadiums where most guests are on an open network, the RADIUS load is negligible. Typically, the number of staff or house devices is far less than the number of guests.

In a university lecture hall where students may be using per-user credentials to log in via 802.1X, the load will be greater. However, in this case one would normally expect the institution had adequately sized servers already. See Table P2-4 on page 20 for 802.1X transaction rates of the various Aruba controller models.

Guest networks using 802.11u / PassPoint are not considered in this VRD.

Server Redundancy

It goes without saying that all enabling server infrastructure for the VHD WLAN should be deployed in a fully redundant manner for any facility of 1,000 seats or more. The exact high availability (HA) design will vary from system to system and with facility size.

Be sure to observe and plan for the following minimum redundancy considerations:

- DHCP servers must be completely fault tolerant. Any loss of functionality will appear as an inability to connect to the WLAN.
- DNS services should be fault tolerant. Loss of DNS services will create a poor user experience to associated users.
- Captive portal servers should be deployed in a clustered fashion. This is discussed in Chapter EC-5: SSIDs, Authentication, and Security of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide in the context of Aruba's ClearPass product.
- RADIUS servers supporting facility staff and back-of-house operations must be deployed in a redundant fashion. ClearPass clustering is a good solution.

WAN Edge Dimensioning

Bandwidth

In Chapter EC-2: Estimating System Throughput of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide, you will learn how to estimate total system throughput that can be expected from a VHD system. The output of that process is a value that defines the absolute minimum size of the WAN uplink.

Aruba strongly recommends a minimum of redundant 1G WAN links for most VHD deployments. As can be seen from the math in the last few sections, a well-designed VHD WLAN should achieve 1 Gbps of sustained load in any country that supports 20 or more channels, and 2 Gbps is possible. Dual, load-balanced 1G WAN connections will support this load well.

It is common to find stadiums and arenas with 2 x 45 Mbps or 2 x 100 Mbps connections to the WAN. Such networks are almost certainly delivering a negative user experience by dropping traffic that is successfully getting on the air. Based on usage data from stadiums with multigigabit uplinks, it is clear that the minimum base load in most VHD networks should be 1 Gbps.

If you are designing for a country that allows fewer than 10 channels, or you have decided not to use DFS channels, then a smaller WAN link may be appropriate. Even in that case, maintain a minimum 500 Mbps of uplink capacity.

As you go through the capacity planning process in the Engineering and Configuration guide, if you think that your specific deployment will generate more than 2 Gbps on a sustained basis, then the WAN pipe should be adjusted accordingly.

Sessions

Edge firewalls and NAT/PAT devices should be sized based on the total ADC count.

WAN Edge Redundancy

Just as with critical enabling server infrastructure, the WAN edge must be designed for complete fault tolerance. Aruba recommends employing that each of the following key edge components be architected for as close to hitless failover as possible:

- Service provider WAN links
- Border routers
- NAT/PAT devices
- Edge firewalls

The larger the seating capacity of the venue, the more investment must be made here. But even a small VHD facility of 1,000 seats or less can rarely if ever afford uplink outages.

Chapter P-3: RF Design

Very high-density (VHD) WLANs are characterized by large numbers of APs that serve a comparatively small physical area. From a radio perspective, even a 100,000-seat stadium is a small area, considering that radio signals travel across a standard football field or pitch in under 300 nanoseconds.

Wireless architects have four over-arching responsibilities in a VHD area:

1. To ensure that a minimum 25dB – 30dB SINR is available everywhere in the service area (after accounting for signal loss due to human bodies)
2. To ensure an adequate number of radios to absorb the full associated device capacity (ADC) target expected on each frequency band
3. To minimize AP-to-AP interference
4. To protect every microsecond of airtime on every available channel from being used unnecessarily or inefficiently

This chapter focuses on the first three duties and is meant for a more general audience. Responsibility #4 is so complex that we devote a separate chapter just to that topic in both the Engineering and Configuration guide and the Theory guide.

The importance of those four responsibilities cannot be overstated. After they are met, a host of secondary responsibilities must also be balanced into any VHD design:

- To minimize interference from co-located high-power cellular DAS or other radio systems
- To comply with all local building codes and safety requirements
- To blend the system into the structure with the least visual impact

To that end, RF coverage in high-density WLANs is achieved by carefully combining the number of APs chosen in the dimensioning step with the physical space to be served.

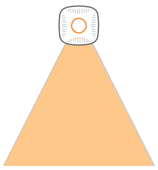
Placing many APs in close proximity to one another and enabling them to operate with minimal interference requires excellent understanding of basic radio principles like antenna patterns, transmit power and receive sensitivity. These principles must be balanced against building limitations like room shape, ceiling height, cable pathway availability, and aesthetics. This chapter will teach you how to approach this balance successfully.

To see how the general approaches presented in this module are applied to specific types of venues, refer to the relevant VRD scenario guide.

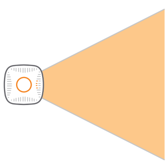
Coverage Strategies for Very High-Density Areas

A "coverage strategy" is a specific method or approach for locating APs inside a wireless service area. Generally, any given coverage strategy requires a specific antenna pattern to provide a specific directionality and gain. This is true whether we are using APs with integrated antennas or connectorized APs with external antennas. Integrated antenna APs have specific radiation pattern and gain just as external antennas do.

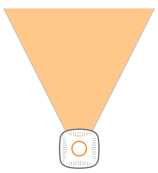
The three basic strategies that are available to the wireless architect are overhead, side, and floor coverage. Each strategy has advantages and disadvantages that are described in this chapter. These methods should never be combined inside a single coverage zone, to ensure that signal levels are as consistent as possible throughout the coverage area. However, different strategies may be used in adjacent spaces to great effect, especially in larger VHD structures like convention centers and stadia. Examples of using different strategies in adjacent spaces are considered at the end of this chapter.



Overhead Coverage: APs are placed on a ceiling, catwalk, roof, or other mounting surface directly above the users to be served. Depending on the height difference, one can use APs with integrated antennas or connectorized APs with specially chosen external antennas. In either case, the direction of maximum gain is oriented downward.



Side Coverage: APs are mounted to walls, beams, columns, or other structural supports that exist in the space to be covered. Generally, APs are placed no more than 4 m (13 ft) above the heads of the crowd to be served. Either directional or omnidirectional antennas can be used, with the direction of maximum gain aimed sideways with a shallow down-angle.



Floor Coverage: This design creates picocells using APs mounted in, under, or just above the floor of the coverage area. This strategy is the only one that can allow for spatial reuse of channels inside a room of 1,000 m^2 (10,700 ft^2) or less. In general, picocells use APs with integrated antennas to minimize the required space under the seat.

These three strategies are general approaches that can be applied to any situation. It does not matter whether you are designing for indoors or outdoors, a conference room or an arena, or a permanent or a temporary deployment.

After you have decided on one of these approaches, other choices must be made, such as whether to use integrated or external antennas, mounting method, minimum AP-to-AP spacing, and how APs will connect to the LAN.

Overhead Coverage – Integrated Antennas

Integrated antenna APs should always be used for ceilings of 10 m (33 ft) or less.

Ceilings are a common AP mounting location because generally they allow an unobstructed view down to the wireless clients. By distributing APs consistently and evenly across a ceiling, you can limit AP-AP adjacent-channel interference and provide very uniform signal levels for all client devices at floor level. Figure P3-1 shows what a simplified overhead coverage deployment would conceptually look like. Note the use of 5-GHz channel numbers, a 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. See Chapter EC-4: Channel and Power Plans of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide for an in-depth discussion on channel and power plans.

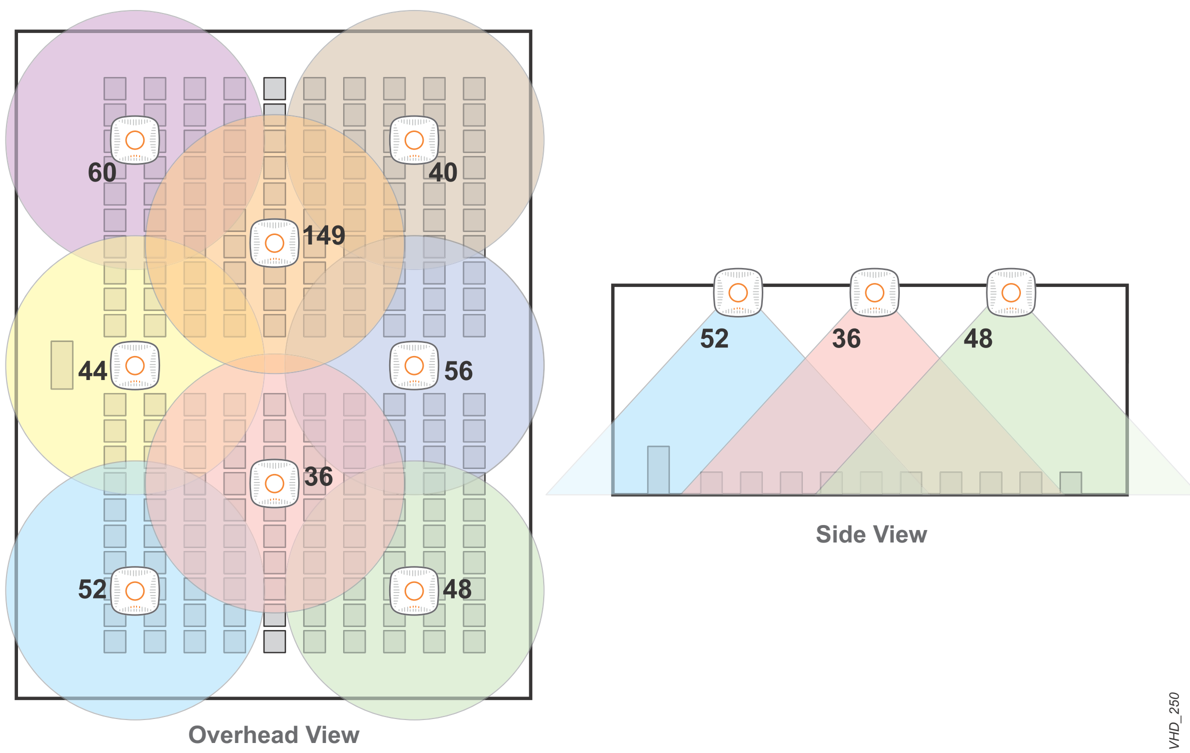


Figure P3-1 Sample of Simplified Overhead Coverage Deployment

Overhead coverage is a good choice when uniform signal is desired everywhere in the room. Overhead APs are usually out of view above eye level, even in a hotel ballroom with high ceilings. Of course, it must be possible to access the ceiling without too much difficulty or expense to pull cable and install equipment. Figure P3-2 on page 29 shows an example of overhead coverage using 10 APs to serve a lecture hall at the University of Iowa. Note that the APs on either side of the room are considered overhead because the APs face down.

Figure P3-3 on page 30 shows an example of a temporary overhead installation mounted to the speaker trusses for a large ICANN conference at a hotel in Asia.

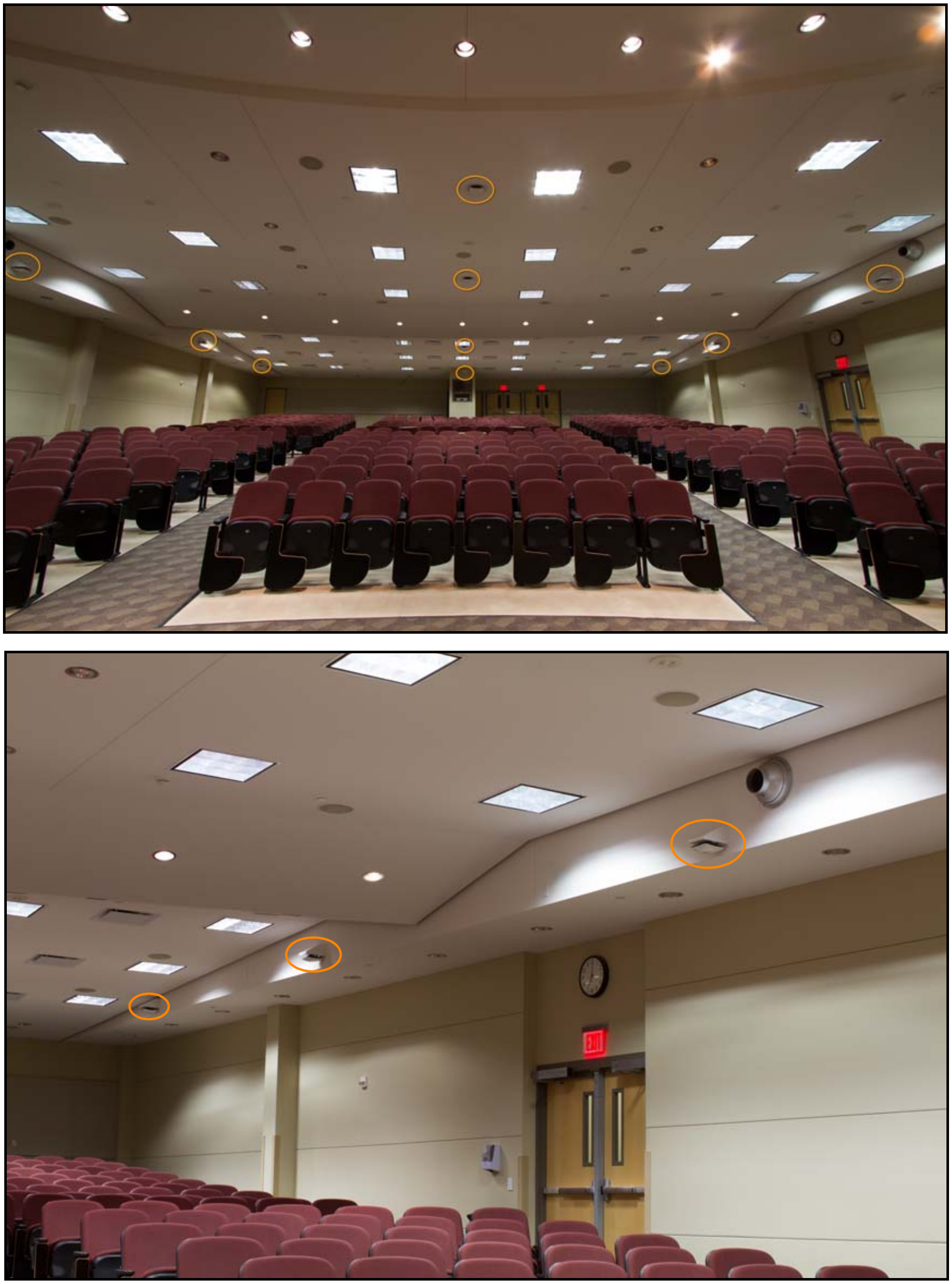


Figure P3-2 Overhead Coverage in Lecture Hall at University of Iowa

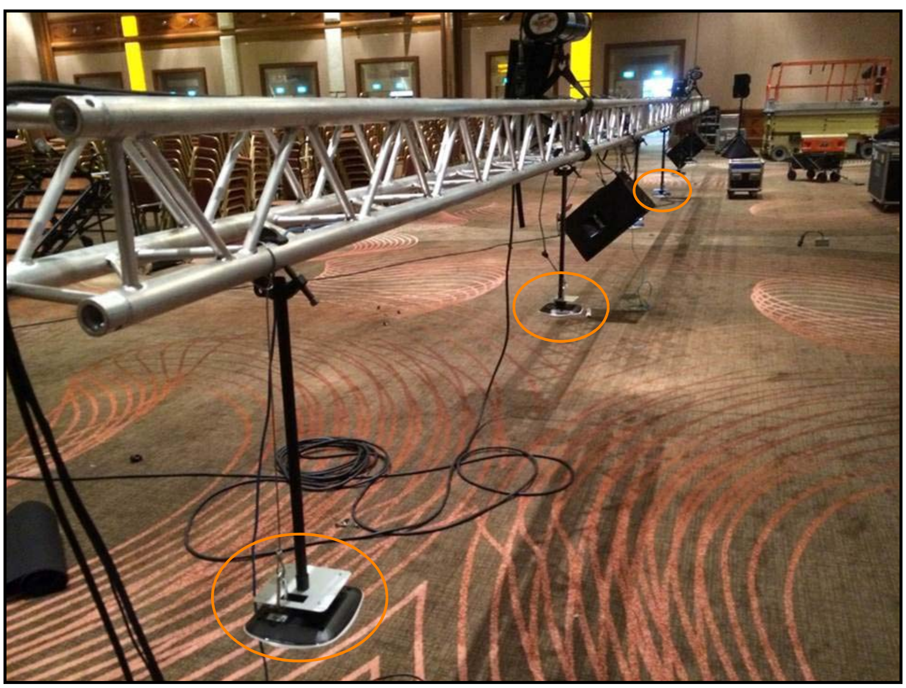


Figure P3-3 Temporary Convention Center Deployment for ICANN 52 Conference

In all indoor VHD areas using integrated antennas, no RF spatial reuse is possible with overhead coverage because of the wide antenna pattern and multipath reflections. This limitation applies even to areas underneath balconies. You should expect that due to multipath propagation, every AP will be available with high signal strength everywhere in the auditorium.

APs that serve VHD users should always be placed below the ceiling so that they have a clear, unobstructed view of the client devices. If the APs must be concealed, then external antennas must be used below the ceiling. Another option is to recess an internal antenna AP into the ceiling material (if possible) and cover it with speaker cloth that is color-matched to the rest of the ceiling.

For a more in-depth discussion of co-channel interference and spatial reuse limitations in indoor venues, please see Chapter T-5: Understanding RF Collision Domains of the *Very High-Density 802.11ac Networks Theory Guide*.

Table P3-1 summarizes the advantages and disadvantages of overhead coverage.

Table P3-1 Advantages and Disadvantages of Overhead Coverage

Advantages	Disadvantages
• APs that are mounted above eye level are harder to notice. • Signal in the room is more uniform when APs are evenly distributed. • APs overhead provide a clear line-of-sight to user devices and minimal human-body attenuation.	• Cell size cannot be smaller than about 300 seats (150 m^2 / 1,600 ft^2). • RF spatial reuse is not possible. • It is difficult to pull cable to some ceiling locations. • Architects have aesthetic concerns about certain finished ceilings.

Overhead Coverage – External Antennas

To minimize cost and complexity, overhead coverage with external antennas should be avoided for all deployment types except convention centers and indoor sporting arenas with over 10,000 seats. In those facility types, high-gain, highly directional antennas are almost always required.

The minimum ceiling height to consider external antennas is 15 meters (50 ft).

For a very high-ceiling environment, you have a choice of mounting platforms. Usually some type of maintenance catwalk system exists, and the roof trusses are often exposed. A third option may exist in certain sporting venues with a cantilevered overhang that covers seating areas underneath from sun or rain. It may be possible to mount directly to the overhang, but detailed structural engineering analysis may be needed to do so for building code and life safety reasons.

Refer to *Very High-Density 802.11ac Networks Scenario 1: Large Adjacent Auditoriums* guide or *Very High-Density 802.11ac Networks Scenario 2: Large Indoor Arena* guide for further discussion on this topic.

Side Coverage

Wall, beam, and column installations with side-facing coverage are very common in VHD areas. Sometimes there is no ceiling, as in the case of open-air atriums in malls, airports, or train stations. Some ceilings are too difficult to reach, others have costly finishing that cannot be touched, and in all cases, pulling new cable and conduit through a large space can be cost-prohibitive. The same issues apply to floor mounting. In these cases, side coverage is the only other option.

Side installations come in every variety you can think of, because no two VHD areas are the same. Common examples include these:

- Lecture halls and hotel ballrooms where APs with integrated antennas can be placed only along the sides of the room, mounted to speaker stands or simply placed on temporary tables
- Flush-mount to beams or columns in arenas or stadiums, with APs or antennas aimed sideways with some down angle
- Wall or parapet mounts that surround outdoor plazas
- Hallway or column mounts in long linear corridors in airports
- Very large auditoriums with pillars or columns in the center and walls that are too far apart to provide required minimum 25-30 dB SINR levels
- Temporary structures like tents or open air fairs

As with overhead coverage, RF spatial reuse in indoor environments is almost never possible when mounting to walls or pillars. For outdoor deployments with less multipath reflection, it may be possible to achieve limited reuse. Great care must be taken to orient antenna patterns to minimize AP-to-AP interference.

Figure P3-4 is a concept drawing of a simplified, wall-based, side-coverage solution that uses integrated omnidirectional antennas. Note that adjacent APs on the same wall always skip at least one channel number, and never use adjacent channels. This is intentional. For more information, see Managing Adjacent VHD WLANs later in this chapter.

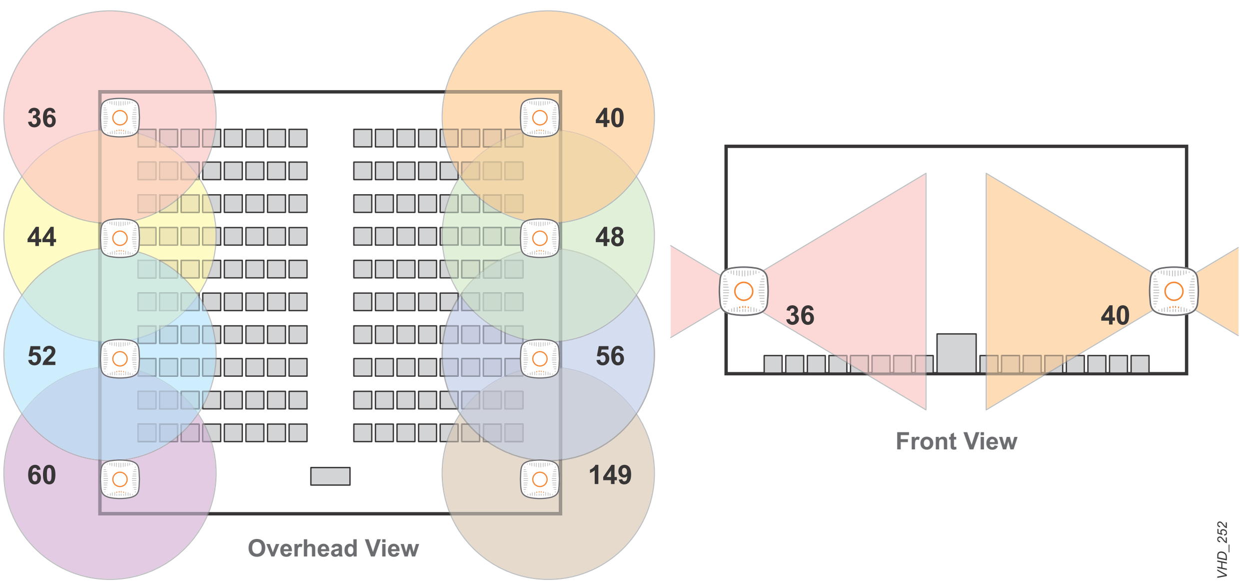


Figure P3-4 Simplified Side-Coverage Example with Integrated Antenna

Figure P3-4 is meant to show AP position and antenna pattern, not the actual signal propagation. In fact, even in the very largest auditoriums, every AP will be able to hear every other AP.

Note that half of the wall-mounted AP signals are lost to the next room (and 75% of the signal in the corners). The wireless designer can exploit this signal bleed in some cases, but otherwise it represents a waste of signal. Figure P3-5 shows an example of Aruba 220 series APs mounted in a vertical orientation on the wall. In this lecture hall at a university in the eastern United States, the finished woodwork on the ceiling meant that overhead coverage was not possible. This is a common reason to choose side coverage.

Figure P3-5 Side Coverage Deployment in University Lecture Hall

As you can see, an infinite variety of side-coverage scenarios are possible. Table P3-2 provides a summary of the advantages and disadvantages of side coverage for high-density areas.

Table P3-2 Advantages and Disadvantages of Side Coverage for VHD Areas

Advantages	Disadvantages
• Easier and less expensive access to install APs and pull cable. • Avoids modification to expensive finished ceilings. • Easier access for AP maintenance.	• RF spatial reuse is not possible. • Signal levels are lower in the center of the room than on the sides. • Harder to control CCI/ACI between rooms. • Signal bleed outside of the desired coverage area is wasted. • Walkway clearance. • Aesthetics. • Cell size cannot be smaller than about 300 seats (150 m^2 / 1,615 ft^2).

Underseat Coverage (Picocells)

For venues with less than 10,000 seats, your VHD designs should always use overhead or side coverage. Above this size, a third and more exotic option called "picocell" has been shown to deliver significant capacity increases in some cases. However, the additional cost and complexity of picocells may not always justify the extra capacity generated.

In a picocell design, the AP is mounted underneath user seating (but above the floor). We flip the overhead model upside down and use one of the integrated antenna AP models that point back at the ceiling. As you can see by comparing Figure P3-1 and Figure P3-6, the density of picocell can be much higher than overhead or side coverage. One reason is that the picocell design leverages the natural human body loss that occurs to RF signals as they pass through a crowd (also known as "crowd loss" or "crowd effect"). Another reason is that we can sometimes use lower EIRP levels because of the reduced free space loss as compared with having APs up on the ceiling or far away on walls.

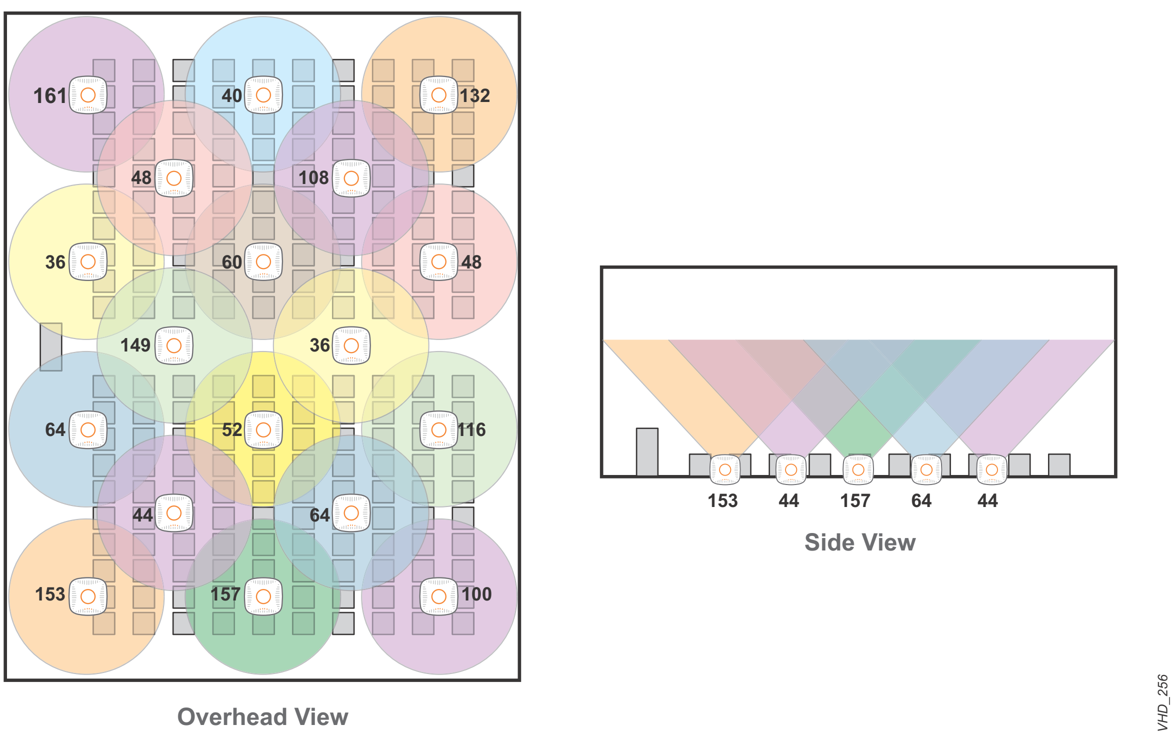


Figure P3-6 Example of Simplified Picocell Coverage

Underseat mounting requires a way to pull cable to each AP location. Pulling cable can be done via surface mounting above the floor or by penetrating the floor from underneath. APs are typically placed in small enclosures that are permanently mounted underneath or behind seats. Figure P3-7 shows two examples of picocell deployments in stadiums. In each case, there is an Aruba AP-225 inside the enclosure. In the photo on the left, the AP is facing up and is attached to the bottom of the enclosure with a mount kit. The Ethernet cable comes from behind via a penetration (core) of the concrete. In the photo on the right, the AP is mounted vertically and facing forwards. The cable is run via a surface-mount raceway that is secured against tampering.

Figure P3-7 Examples of Underseat Picocell Coverage in Stadiums

If you are interested in this type of installation, talk to your Aruba systems engineer.

Table P3-3 provides a summary of the advantages and disadvantages of underseat coverage for high-density areas.

Table P3-3 Advantages and Disadvantages of Underseat Coverage for VHD Areas

Advantages	Disadvantages
• Significant capacity boost is possible via increased RF spatial reuse. • Higher AP densities can be achieved. Cell size can be as small as 75 seats (40 m^2 / 431 ft^2). • Signal is more uniform in the room when APs are evenly distributed. • CCI/ACI control is better between adjacent VHD WLANs. • Easy to access for maintenance.	• Need cable pathways beneath the floor or the ability to install surface-mount raceways. • Must prevent tampering with or damage to APs. Usually this requires protective enclosures at additional cost. • Additional cost and complexity due to coring of concrete.

Use One Strategy Per Area

Do not mix mounting strategies in the same VHD area without a good reason. Speak to your Aruba systems engineer before doing so.

Each coverage strategy must be carefully designed to ensure a uniform signal level throughout the coverage area and to control AP-to-AP interference inside and outside the space. Mixing strategies reduces performance and increases interference.

Some deployments have multiple adjacent VHD WLANs, such as a multistory university building with multiple lecture halls on each floor. Another example is a convention center with many adjacent ballrooms. When you plan such deployments, use the same strategy (overhead, side, or picocell) in all rooms to ensure that coupling between individual rooms is consistent across the deployment.

In very large VHD facilities, it is common to find high density gathering places outside the main seating areas. A good example is the walkways or concourses that surround the seating bowl in a stadium. Another example is the large hallways between ballrooms in a convention center. These areas typically have very different usage profiles than the seated areas. In these cases, break down a structure into different VHD “subdomains”. In this case, it is permissible (even desirable) to change strategies between VHD subdomains. In this case, the strategies are carefully chosen to be as “orthogonal” as possible to the other domains so as to minimize interference. See the *Very High-Density 802.11ac Networks Scenario 1: Large Adjacent Auditoriums* guide and the *Very High-Density 802.11ac Networks Scenario 2: Large Indoor Arena* guide for further discussion.

Choosing an Access Point Model

To choose an access point model, consider your budget and the performance expectations of your users.

VHD environments are characterized by high traffic loads with continuous duty cycles. Due to the shared nature of the wireless medium and the CSMA/CA process used by Wi-Fi stations to acquire the channel, collisions and retry packets also occur at far higher rates than non-VHD networks. Therefore, it is a general rule that higher performance APs can produce more total throughput from a given group of client devices.

The last few years have shown that the performance and radio capabilities of client devices are increasing constantly. Cloud services and always-on applications mean that the load that your network experiences today may be much less than the loads you will experience in 3-5 years. For all these reasons, Aruba strongly recommends that you buy the highest performance AP that you can afford for VHD areas, even if the rest of your deployment is a more economical model. Use the right tool for the job.

Aruba VHD Access Points

Aruba offers a complete line of indoor, hardened, and outdoor (IP-68 rated) 802.11ac models. Table P3-4 compares the indoor AP family. Each model comes in an integrated antenna and a connectorized version.

Table P3-4 Aruba 802.11ac Indoor APs

	Low Cost	Medium Performance	Maximum Performance
Model	**AP-204 / AP-205** 	**AP-214 / AP-215** 	**AP-224 / AP-225** 
MIMO	2x2:2	3x3:3	3x3:3
CPU	Broadcom 53014A Single core, 1 GHz	Freescale P1010 Single core, 800 MHz	Freescale P1020 Dual core, 800 MHz
Memory	SDRAM – 128 MB Flash – 32 MB	SDRAM – 256 MB Flash – 32 MB	SDRAM – 512 MB Flash – 32 MB
Radio	Broadcom BCM43520	Broadcom BCM43460	
Antenna / Connectors	Integrated downtilt antenna; or 3 diplexed RP-SMA connectors		
Max Conducted Power	+21 dBm (18dBm per chain)	+23 dBm (18dBm per chain)	+23 dBm (18dBm per chain)
Maximum EIRP	+25 dBm (2.4-GHz) +27 dBm (5-GHz)	+28 dBm (both bands)	+26.5 dBm (2.4-GHz) +27.5 dBm (5-GHz)
Operating Temp	0°C to +50°C		
Power	802.3af POE		802.3at POE

Table P3-5 compares the hardened and fully outdoor models.

Table P3-5 Aruba 802.11ac Hardened and Outdoor APs

	Extended Temperature	IP-68 Rated		
Model	**AP-228** 	**AP-274** 	**AP-275** 	**AP-277** 
MIMO	3x3:3			
CPU	Freescale P1020 Dual core, 800 MHz			
Memory	SDRAM – 512 MB Flash – 32 MB			
Radio	Broadcom BCM43460			
Antenna	3 RP-SMA connectors per band (6 total)	**AP-274:** 3 N connectors per band (6 total) **AP-275:** Integrated 5 dBi multipolarized omni		Integrated 85 x 85° sector
Max Conducted Power	+28 dBm (23 dBm per chain)			
Maximum EIRP	+36 dBm			
Operating Temp	-40°C to +60°C	-40°C to +65°C		
Power	802.3at POE	110 – 220 VAC or 802.3at POE		

All Aruba AP models support the full maximum number of associated devices per radio and per AP (255 and 510 respectively).

All three indoor models are economical, flexible, and aesthetically pleasing. They can be mounted directly in the user space. The integrated antenna can be oriented up, down, or sideways so that it can be used with all three coverage strategies.

The AP-228 is fully temperature hardened and is suitable for use in outdoor enclosures driving external antennas from Murmansk to Riyadh to Singapore. Likewise, the fully outdoor AP-270 series APs support a wide range of operating temperatures.

To ensure maximum speed and compatibility with future devices, Aruba recommends that you purchase only 802.11ac APs for VHD areas. If you have an existing 802.11n deployment, consider upgrading your high-density locations to 802.11ac now, regardless of your anticipated timing for the balance of your system. 802.11n and 802.11ac systems are designed to coexist.

Choosing an Access Point – Performance

As you would expect from the CPU and memory differences, there are inherent performance differences between the 205, 215, and 225 (see Figure P3-8 and Figure P3-9). These differences are the first and most important consideration, before you consider other feature differences.

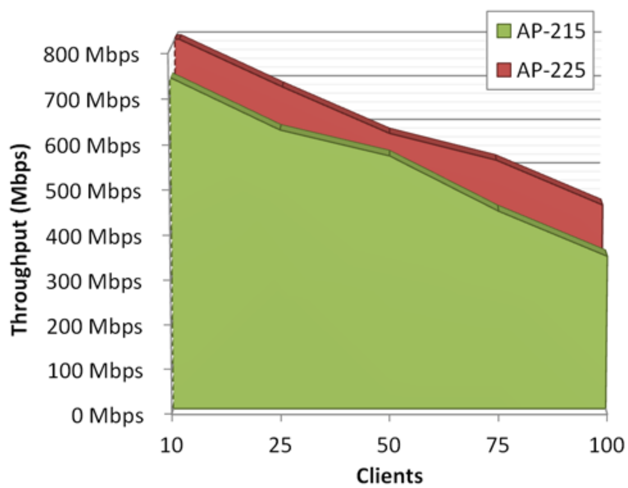


Figure P3-8 3SS Laptop in VHT80 Channel

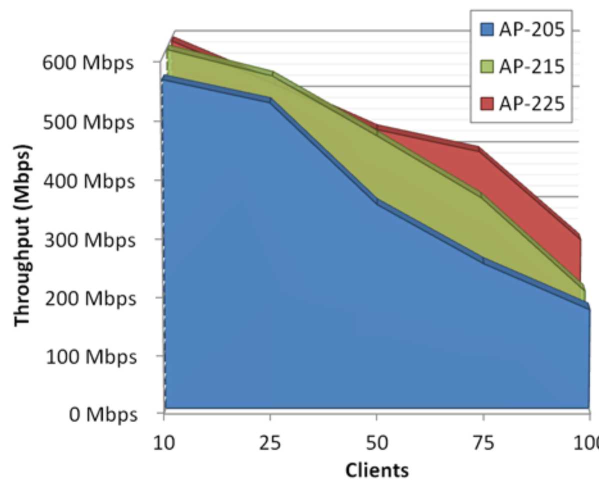


Figure P3-9 2SS Laptop in VHT80 Channel

Figure P3-8 compares the bidirectional TCP performance of 100 different 3SS MacBook Pro laptops on both the AP-225 and AP-215. These AP models are both 3x3:3, so they support the full spatial stream capability of the laptops. The figure shows how total throughput changes as we increase the concurrent station count from 10 to 100. It is expected that total throughput drops from left to right due to decreasing MAC-layer efficiency and increasing collision counts. (For more information on this phenomenon, see Chapter T-3: Understanding Airtime of the *Very High-Density 802.11ac Networks Theory Guide*.) The key message of Figure P3-8 is that the faster dual-core processor in the AP-225 is able to support higher loads with 3SS clients.

Figure P3-9 on the right shows the bidirectional TCP throughput of 100 different 2SS MacBook Air (MBA) laptops. The laptops are tested against all three Aruba indoor AP models. When communicating with the AP-225 and AP-215, the MBAs are limited to 2SS data rates. There are three key observations in this figure:

- The AP-225 supports more throughput when more than 50 stations attempt to use the WLAN simultaneously
- The AP-215 is very comparable with the AP-225 up to 50 concurrent stations
- The AP-205 is best for smaller deployments with a maximum of 25 concurrent users

You can see that the high-density performance increases as we move from the AP-205 to the AP-225. Faster CPU, more CPU cores, and more memory all deliver higher performance at high client loads. For maximum future-proofing, Aruba strongly suggests that you buy the most capable AP you can afford. It is completely acceptable to use AP-225s in VHD areas even if your deployment is standardized on AP-205 or AP-215 everywhere else.

NOTE

All Aruba hardened and outdoor APs are based on the AP-225 platform. The performance curves for AP-225 also apply to those products.

Choosing an Access Point – Spatial Streams

Another important AP selection factor is the expected mix of client devices. Will three spatial stream (3SS) devices be part of your device population now or in the future? If the answer is yes, then you must purchase a three-stream AP to fully support them.

Figure P3-10 shows the performance of a single client type – a 3SS MacBook Pro - against the AP-205 and AP-225. The AP-205 supports two streams, while both the AP-215 and AP-225 support three. The AP-225 offers an extra stream, so the clients can achieve far higher throughputs. Faster throughput means that each client gets off the air faster, which allows other stations to use the wireless medium.

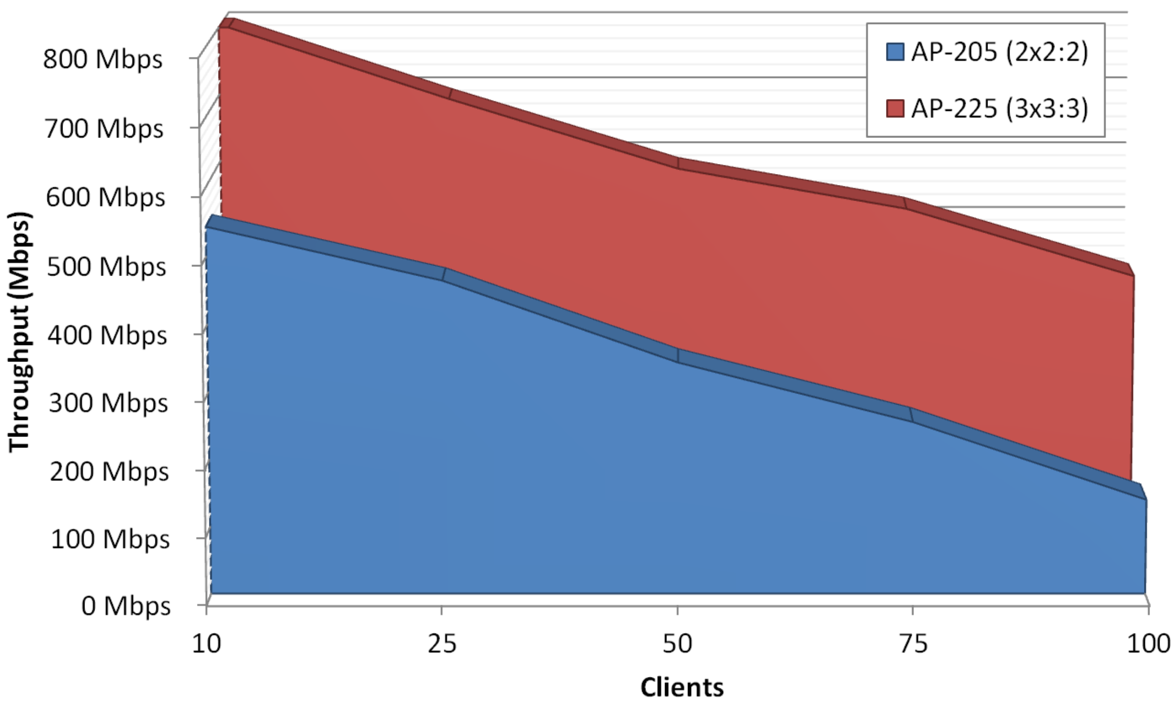


Figure P3-10 3SS Clients Require 3SS APs to Achieve Maximum Performance

Choosing an Access Point – Seat Count

Finally, what is the seat count of your VHD area? What is your total ADC target?

The amount of control and management traffic on the wireless medium scales directly with client count. requires The AP must receive, process, and handle every transmission, even if the transmission is not destined for that AP. Therefore, in larger seat counts, you must use higher-performing APs. Table P3-6 lists the AP model that is recommended for the size of the facility.

Table P3-6 Recommended AP Model by Facility Size

Facility Size	Seats	AP Model
Lecture Hall	200 - 1K	Any
Performance Hall	1K – 5K	AP-215, or AP-220 series
Indoor Arena	5K – 20K	AP-220 series
Large Stadium	40K – 100K	AP-220 series or AP-270 series
Convention Center	20K – 200K	AP-220 series or AP-270 series

Choosing External Antennas

External antennas should almost never be used for VHD areas of 10,000 seats or less. If you think that your specific design situation requires antennas, consult with your local Aruba systems engineer.

Minimum Spacing Between APs

APs in VHD areas should be distributed evenly throughout the space, in accordance with whatever coverage strategy has been selected.

- For overhead coverage, APs should be evenly spread around the ceiling area to be covered. APs should never be clustered.
- For side coverage, APs should be spaced evenly down the length of the wall, beam, or whatever mounting surface is used.
- Floor picocells have some complexity to them. In general they should be evenly spaced as well.

Minimum AP-to-AP spacing should never be less than 2 m (6.5 ft) when using external directional antennas. The minimum AP-to-AP spacing when using integrated antennas is 5 m (16 ft). You should strive to make AP-to-AP distances as equal as possible.

NOTE

Sometimes clustering is unavoidable in stadiums, convention centers, and other high-ceiling locations due to limited mounting locations on catwalks or roof trusses. In this case, be certain to compute and observe the minimum AP-to-AP separation for the antenna models being used. Clustering often forces the use of external highly directional antennas to minimize AP-to-AP interference.

Figure P3-11 shows a conference center auditorium, and circles are used to display even AP spacing in the coverage area. (The circles are only a tool used to assist the designer with spacing and are not the actual RF coverage for individual APs. Each of these APs would be able to be heard throughout the entire facility.).

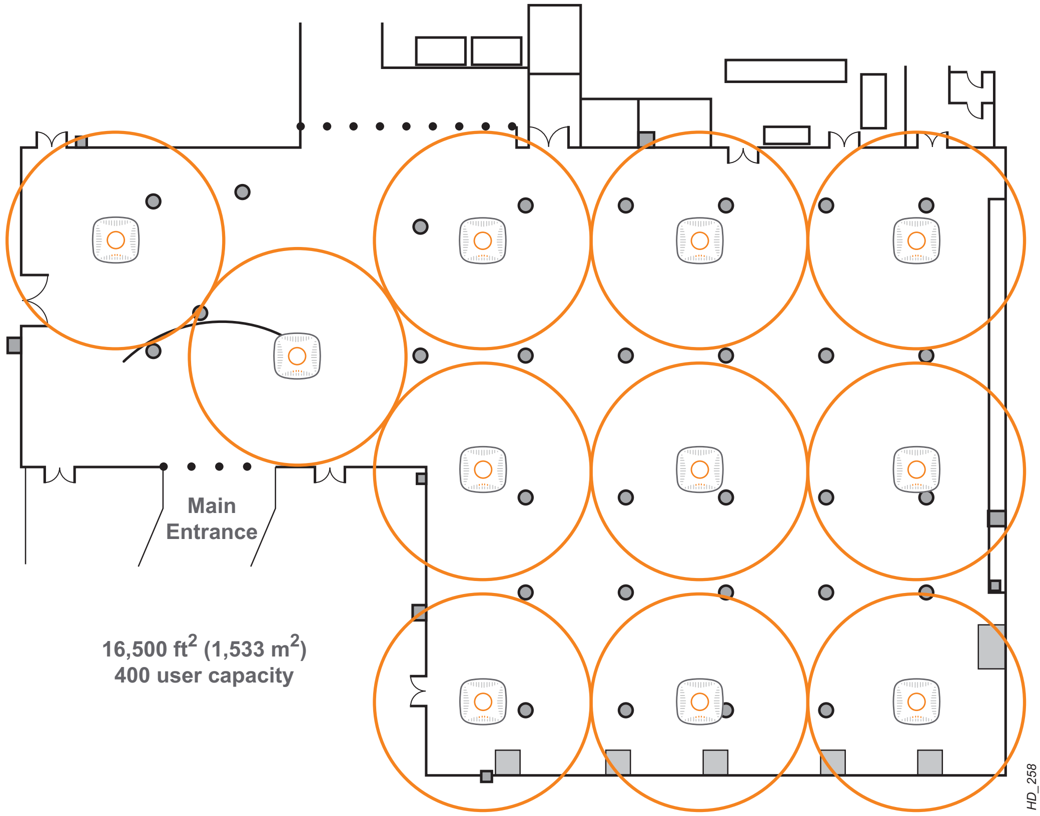


Figure P3-11 Example of Even AP Distribution at Conference Center

What About Adjacent Channel Interference?

The fact is that there is adjacent channel interference (ACI) and co-channel interference (CCI) in virtually every high-density deployment. It is a fact of life, and it is extremely difficult to control.

So long as APs are evenly distributed, with minimum separation distances observed, ACI can be safely ignored in most VHD areas of 10,000 seats or less. To be clear, this is not to say that there is no impairment due to ACI. What we are saying is that there is little you can do about it beyond ensuring that AP-to-AP ACI is minimized through good separation practices.

Use Aruba ARM to assign channels as recommended in Chapter EC-4: Channel and Power Plans in the *Very High-Density 802.11ac Networks Engineering and Configuration* guide. It is a good idea to monitor the channel plans that ARM produces to verify that they make sense. Sometimes external factors, such as WLANs in adjacent rooms or floors, can produce unexpected results. In these cases, adjustments may be necessary.

Minimum Spacing from Cellular DAS Antennas

Cellular operators are rapidly deploying networks in the 2.3-GHz, 2.5-GHz and 2.6-GHz frequency bands around the world. When cellular radios operating in these frequencies are deployed in close proximity to Wi-Fi equipment using the 2.4-GHz band, interference can occur due to the higher power levels used on the licensed bands. It is common to find cellular distributed antenna systems (DAS) deployed in VHD facilities like stadiums and arenas to provide enhanced service for mobile subscribers. This potentially poses a threat to the Wi-Fi system.

Aruba APs include a feature called Advanced Cellular Coexistence, which is essentially filtering circuitry to protect against unwanted emissions from cellular radios. However, given the already very challenged nature of Wi-Fi networks in the 2.4-GHz band it is a good idea to observe minimum separation distances as an extra measure of caution.

- Wi-Fi APs and antennas should not be placed any closer than 5m (16 ft) from a DAS antenna if they are located in the main beam of the DAS antenna.
- Wi-Fi APs and antennas should not be placed any closer than 2m (7 ft) from a DAS antenna if they are clearly outside of the main beam of the antenna.

Following these precautions will help ensure maximum performance in co-located deployments. There is no interference risk to the cellular system from a Wi-Fi system due to the low power levels used by Wi-Fi.

Aesthetic Considerations

In many VHD areas, aesthetics requirements can significantly limit where and how you can place APs. The availability of suitable mounting locations can have a significant impact the performance of the overall RF design. In the auditorium shown in Figure P3-12, different ceiling heights, dense users, and tightly controlled aesthetics severely limit the options available to the wireless architect.

Figure P3-12 Expensively Furnished Rooms Pose AP Placement Challenges

However, Aruba cannot advocate strongly enough the importance of proper placement. Wi-Fi is fundamentally a line-of-sight technology. Concealing APs behind almost any kind of building materials will negatively affect the performance of a VHD system. Sometimes the impact is severe.

As a general rule, APs with integrated antennas must be placed in the user space, with a clear line-of-sight to the user seating.

Aruba has spent significant sums on the industrial design of each and every one of its APs. Great care has been taken to make them look attractive. Remember that high up on a ceiling, they tend to blend in with all of the other ceiling furniture (such as smoke detectors, occupancy sensors, and public address speakers). The status lights on the AP can be disabled so that they cannot be seen from the ground.

It is our experience that if you work with a facilities team or building architects, a suitable compromise can be worked out. But in such meetings, you must take a firm stand that the performance of the system cannot be compromised, otherwise the investment is not justified.

If the APs absolutely cannot be placed in the user space, then it is necessary to switch to external antennas, which nevertheless must be surface mounted in the user space. This means penetrations and pigtails, with suitable fixed mounting for the AP above the ceiling surface. Often times, the cost of this step will settle the argument over placing APs on the ceiling.

Your Aruba systems engineer can help you position the performance impact of undesirable mounting locations with architects and facilities teams.

Managing Adjacent VHD WLANs

It is common to find adjacent VHD spaces at universities, hotels, movie theaters, and convention centers, either on the same level or spanning multiple floors. In these cases, it's virtually certain that each VHD space will interfere with its neighbors and reduce overall throughput. To minimize this effect, follow the design principles in this section.

Overhead Coverage

If you've already selected an overhead coverage strategy using integrated antennas, your VHD networks will likely coexist without any further action. The front-to-back ratio of the AP's antennas is a measure of the rejection of signals from the opposite side. This ratio will also diminish interference so long as all the antennas are aligned in the same direction.

Figure P3-13 shows an elevation view of a two-story building with wireless installed in all the auditoriums. An overhead coverage strategy has been selected. Floors generally absorb more RF energy than walls. (10-15 dB is a typical range.). The diagram also shows the 10 dBi front-to-back reduction assuming the APs are facing downwards. The combination of the floor loss and the pattern reduction will minimize CCI effects as much as possible.

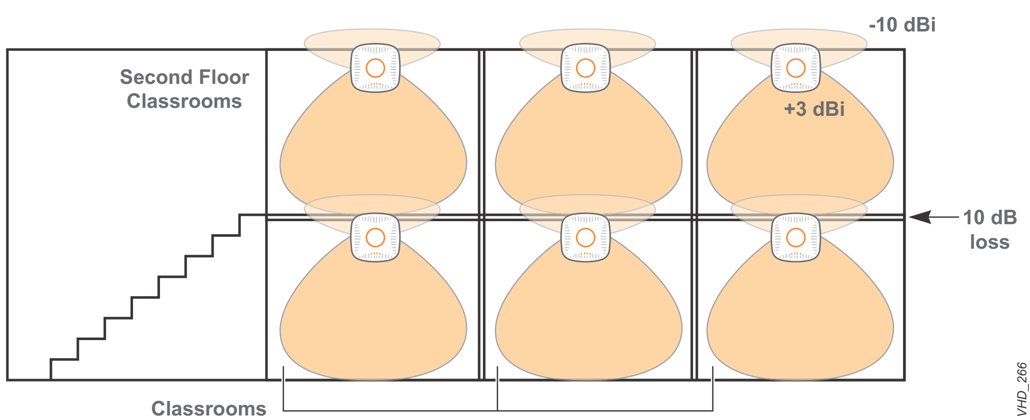


Figure P3-13 Using Integrated Antenna APs to Isolate Adjacent VHD WLANs

NOTE

APs should not be placed directly above one another. If possible, stagger the APs in each room slightly from the room underneath. Ensure that your channel plan varies the channel number between APs that are above one another.

Side Coverage

Figure P3-14 shows the same two-story building using a side-coverage strategy. Wall-mounted APs help reduce the noise between classrooms (typically 6 dB) on the same floor and also help to reduce the noise between the upper and the lower floors. For smaller rooms, it's a good idea to put all the APs on one wall facing the same direction. This will reduce both ACI and CCI.

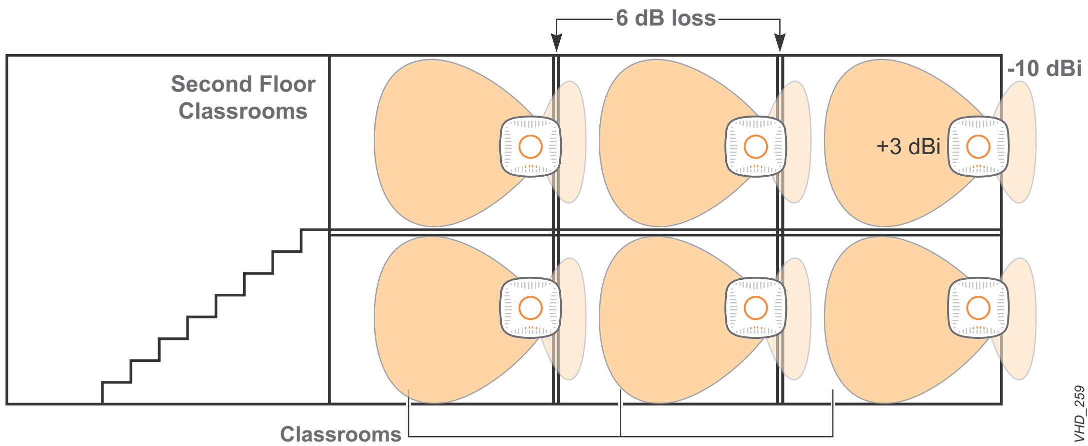


Figure P3-14 Using Integrated Antenna APs to Isolate Adjacent VHD WLANs

Side Coverage with Back-to-Back APs

If the individual VHD spaces are very large, you may need to put APs on both sides of the room to improve signal in the center. This placement can result in APs placed on opposite sides of the same wall. Figure P3-15 shows the right and wrong ways to design this.

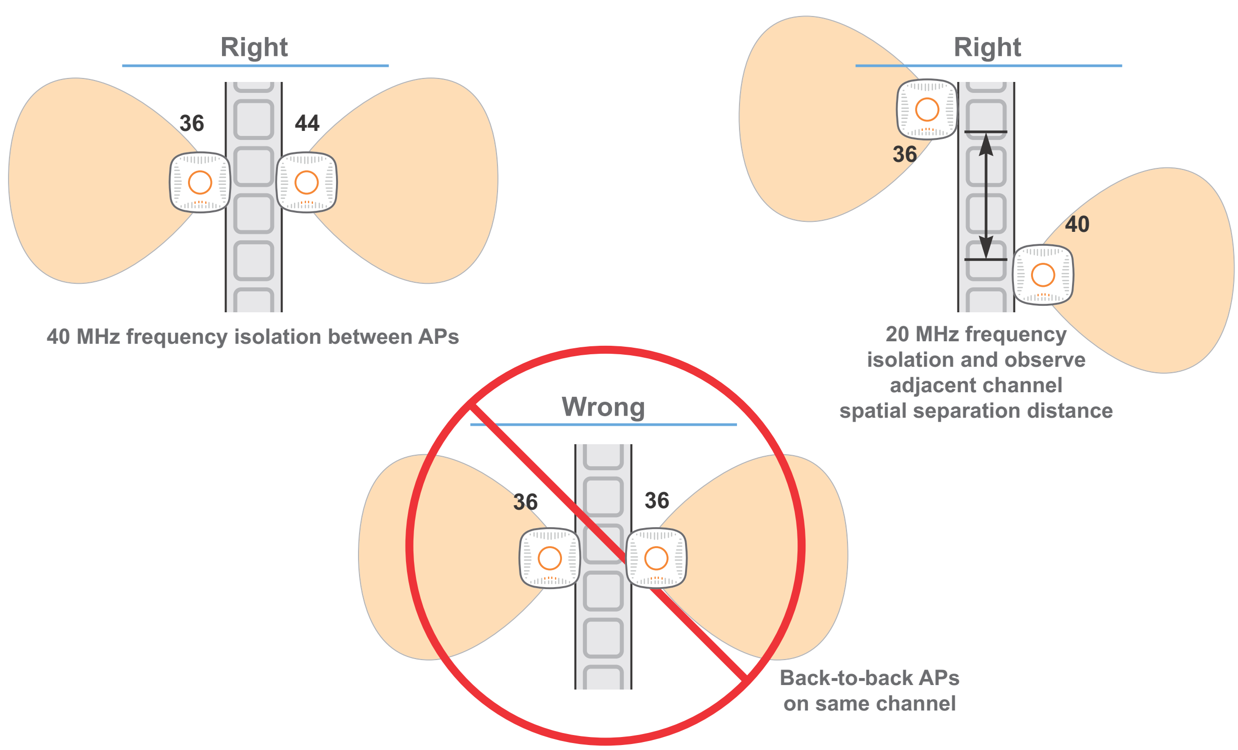


Figure P3-15 Back-to-Back AP Placement

The most important mitigation here is to ensure that the minimum 2 meter separation distance is observed. More distance is better.

In addition, never place back-to-back APs or antennas on the same channel. Even with 20 dB front-to-back ratios, interference will be significant. Instead, make sure there are at least 40 MHz of separation in the channels (36 and 44 for instance).

ARM will usually take care of this for you. However, in very dense VHD buildings with multiple high density spaces, sometimes ARM is forced to make decisions that might not seem correct. Because it has no knowledge of the physical layout of the APs. Monitor your channel assignments after deployment and make any adjustments you think necessary.

Appendix P-A: Contacting Aruba Networks

Contacting Aruba Networks

Web Site Support	
Main Site	http://www.arubanetworks.com
Support Site	https://support.arubanetworks.com
Software Licensing Site	https://licensing.arubanetworks.com/login.php
Wireless Security Incident Response Team (WSIRT)	http://www.arubanetworks.com/support/wsirt.php
Support Emails	
Americas and APAC	support@arubanetworks.com
EMEA	emea_support@arubanetworks.com
WSIRT Email Please email details of any security problem found in an Aruba product.	wsirt@arubanetworks.com

Validated Reference Design Contact and User Forum	
Validated Reference Designs	http://www.arubanetworks.com/vrd
VRD Contact Email	referencedesign@arubanetworks.com
AirHeads Online User Forum	http://community.arubanetworks.com

Telephone Support	
Aruba Corporate	+1 (408) 227-4500
FAX	+1 (408) 227-4550
Support	
● United States	+1-800-WI-FI-LAN (800-943-4526)
● Universal Free Phone Service Numbers (UIFN):	
■ Australia	Reach: 1300 4 ARUBA (27822)
■ United States	1 800 9434526 1 650 3856589
■ Canada	1 800 9434526 1 650 3856589
■ United Kingdom	BT: 0 825 494 34526 MCL: 0 825 494 34526

Telephone Support	
● Universal Free Phone Service Numbers (UIFN):	
■ Japan	IDC: 10 810 494 34526 * Select fixed phones IDC: 0061 010 812 494 34526 * Any fixed, mobile & payphone KDD: 10 813 494 34526 * Select fixed phones JT: 10 815 494 34526 * Select fixed phones JT: 0041 010 816 494 34526 * Any fixed, mobile & payphone
■ Korea	DACOM: 2 819 494 34526 KT: 1 820 494 34526 ONSE: 8 821 494 34526
■ Singapore	Singapore Telecom: 1 822 494 34526
■ Taiwan (U)	CHT-I: 0 824 494 34526
■ Belgium	Belgacom: 0 827 494 34526
■ Israel	Bezeq: 14 807 494 34526 Barack ITC: 13 808 494 34526
■ Ireland	EIRCOM: 0 806 494 34526
■ Hong Kong	HKTI: 1 805 494 34526
■ Germany	Deutsche Telkom: 0 804 494 34526
■ France	France Telecom: 0 803 494 34526
■ China (P)	China Telecom South: 0 801 494 34526 China Netcom Group: 0 802 494 34526
■ Saudi Arabia	800 8445708
■ UAE	800 04416077
■ Egypt	2510-0200 8885177267 * within Cairo 02-2510-0200 8885177267 * outside Cairo
■ India	91 044 66768150