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VALIDATED REFERENCE DESIGN



# VERY HIGH-DENSITY 802.11ac NETWORKS

Scenario 2: Large Indoor Arena

Version 1.0

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## Scenario 2 – Large Indoor Arena

This scenario addresses large arena-style very high-density (VHD) facilities with 10,000 to 20,000 seats. Hundreds of such venues are distributed across nearly every country around the world. Aruba considers 10,000 seats as generally the starting size where external antennas may yield benefits to the RF architect. In this scenario, you learn how to dimension and design a hypothetical 18,000 seat arena.

### General Description

Arenas are multipurpose facilities that host various sporting, concert, and convention events. Arenas tend to have most or all of these attributes:

- Many more access points (APs) are required than available channels. (Between 50 and 150 APs are needed to meet the associated device capacity [ADC] target in the arena bowl area alone.)
- A single RF collision domain with little to no RF spatial reuse possible inside arena bowl area.
- Completely covered with permanent roof, and is temperature controlled.
- Ceiling height is 30–50 m (100–160 ft).
- Thousands of seats, generally arranged around an event floor.
- Seating is divided into sections identified by number.
- One or more levels of VIP skyboxes circle the floor.
- 100-250 events happen per year, and each event is open to the public for approximately 6-8 hours.
- A ticket is required to gain entry to the premises. Ticketing is done with mobile Wi-Fi®-enabled scanning terminals.
- Guests enter the bowl through small tunnels/passages (called “vomitories”).
- Outside the seating bowl on each level are concessions serving food and merchandise. These areas require VHD coverage as well.
- Significant, recurring interference (Wi-Fi and non-Wi-Fi) from third parties (visiting teams, performers, media) that changes by event.
- Catwalk system integrated with roof trusses.
- A dedicated press area high up with a good view of the floor.
- A basement service level underneath the entire facility houses office areas, locker rooms, kitchens, and other areas that need Wi-Fi.

Arenas may have different Wi-Fi usage profiles depending on the type of event. Each profile may necessitate enabling or disabling specific combinations of radios or software features to optimize the fan experience.

Multiple mission-critical applications must be ultra-reliable, fast and secure:

- Ticketing
- Point-of-sale, credit-card transactions
- Personal computer applications in back-office areas
- Press/media upload/download for photographs and video
- Building controls and automation



- It is increasingly common to find a “house” application that includes video programming as well as information about the events and performers or teams. Guests download these apps to their personal smart devices.

Some seating on the main floor of many arenas is retractable to increase the size of the floor for certain types of events. This factor may limit the mounting options for those seats.

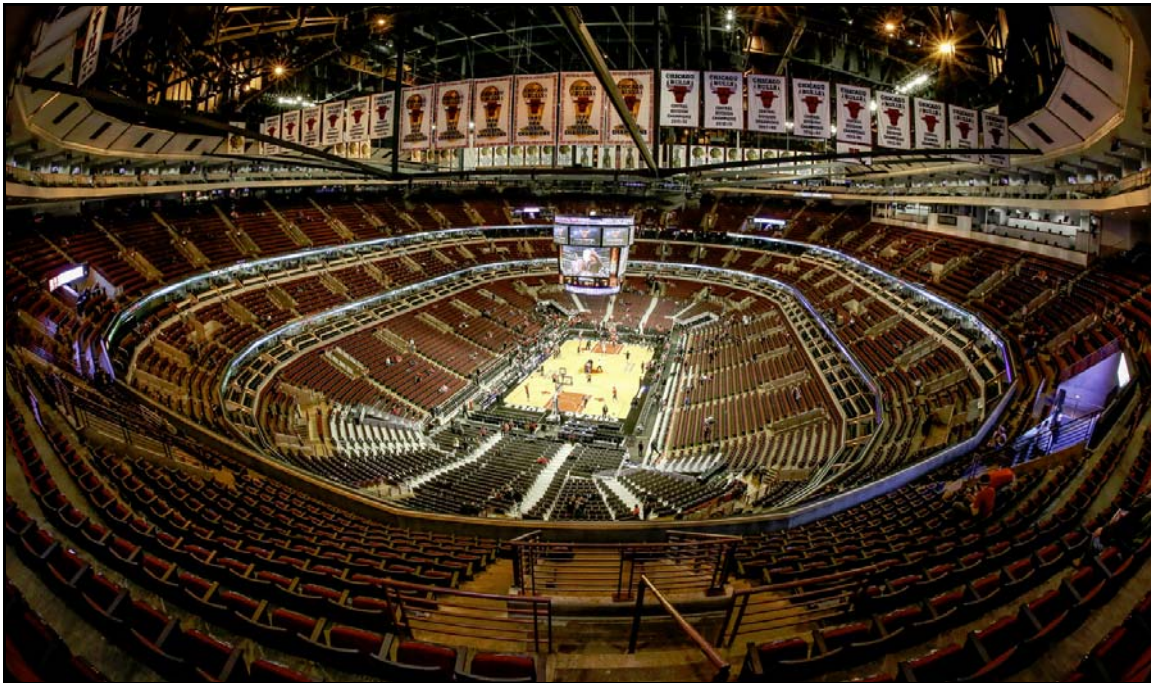
It is common to find a cellular distributed antenna system (DAS) deployed to enhance telephone service. DAS antennas and power levels may pose challenges for co-located Wi-Fi equipment.

## VRD Scenario Description

Our example in this scenario is a hypothetical 18,000-seat sporting arena. This arena is used primarily for hockey and basketball games, but it also hosts musical concerts many nights of the year. As with the other scenarios, Aruba expects readers to adapt the ideas and methods from this chapter to their own specific situation.

### Physical Layout

The bowl area of our example arena is arranged in three levels. A floor of VIP skyboxes is located between each of the three levels. The building is five stories high, plus the basement level. [Figure S2-1](#) shows a typical arena of this type.



**Figure S2-1** Typical 18,000-Seat Indoor Arena

Levels are subdivided into 20 to 35 numbered sections each. The number of sections increases with height. Seat counts vary widely from section to section. The user density is an average of 1 user per 0.5 m<sup>2</sup> (6 ft<sup>2</sup>) in the main bowl area. The angle or “rake” of the seating increases with height to provide a clear view of the floor. [Figure S2-2](#) is a typical seating chart.



**Figure S2-2 Seating Chart for Large Indoor Arena**

Outside the bowl area, a concourse level runs all the way around on four of the five levels. Food and merchandise concessions are on the inside of the concourse. The user density on the concourses averages 1 user per 1-2 m<sup>2</sup> (11-22 ft<sup>2</sup>), depending on the particular area.

Available mounting locations in the bowl and concourse areas are often far less than ideal, and aesthetic and cable routing considerations limit installation choices.

The underground service level is closed to the public except for VIPs, and it sits underneath the lower bowl seating area. It is characterized by a long racetrack-style tunnel that goes around the main floor. Numerous offices, workshops, locker rooms, and other back-of-house areas are here. The arena data center is often located on this level.

For simplicity, this validated reference design (VRD) example does not consider coverage outside the building. We assume the ticket takers are directly inside the first level doorways.

## Device Usage and Mix

The main usage profile used in an arena is: fan/guest (as defined in [Table EC2-8 on page 19](#) in the *Very High-Density 802.11ac Networks Engineering and Configuration* guide). Users primarily use a smartphone to stay connected while at the event. They may also have a tablet in a bag or purse. [Table S2-1](#) lists the device distribution that applies this usage profile from [Chapter EC-2: Estimating System Throughput](#) of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide.

**Table S2-1 VHD Spatial Stream Blend Lookup Table**

VHD Usage Profile	Devices / Person (Now)	Devices / Person (Future)	1SS Device	2SS Device	3SS Device
Fan / Guest	1	2	50%	50%	0%

Aruba believes that arena operators should expect that every single fan has one device today, whether they choose to use the Wi-Fi system or not. Over time, this may increase to two devices. The owner must decide what level of capacity the venue wants to support.

The device mix for fan/guest is heterogeneous and completely uncontrolled. The devices are not owned or managed by the facility operator, so they cannot be optimized or guaranteed to have the latest drivers, wireless adapters, or even application versions. Any operating system of any vintage or device form factor could be in use. Wi-Fi radios will be a mix of generations from 802.11a/g through 802.11ac.

House devices are permanently part of the facility, but they can range widely from older, single-stream ticket scanners at gates to modern laptops in office areas.

## Application Usage and Bandwidth Expectation

Arenas have a complex set of applications whose criticality varies. House applications like ticketing and point-of-sale use very small transactions but require very low latency.

For the fan/guest usage profile, users who record video or audio of sessions in the arena do not generally need real-time networking. The media typically is buffered on the device and then uploaded asynchronously to whatever cloud service(s) they subscribe. [Table S2-2](#) lists the application mix and network requirements of common arena applications.

**Table S2-2 Network Characteristics of Common Arena Applications**

User Category	Application	Bandwidth	Latency	Duty Cycle
Ticketing	Ticket management system	Low	Real-time	Low
Point of Sale	Credit card transaction processing; inventory management	Low	Real-time	Low
Press/Media	General Internet usage	Low	Medium	Medium
	Photo & video upload/download	High	Low	Medium
Fan/Guest	General internet usage	500 Kbps	Medium	Low
	Email	Low	High	Low
	Social media – photos	Low	Medium	Medium
	Social media – videos	Medium	Medium	Medium
Office/Team	Office applications	Low	Low	Low

As with all VHD environments, connecting (associating) every device is the primary concern in the design and configuration. The secondary goal is to maximize the number of devices that can use the network at the same time. Generally speaking, application & device duty cycles will permit significant oversubscription of the air.

## Co-Channel Interference

Arenas suffer from extreme co-channel interference (CCI). It is normal to have anywhere from 5 to 25 APs on every channel, depending on the size of the arena and the coverage strategy employed.

To compound the problem, there is little to no RF spatial reuse inside indoor arena bowl areas, for several reasons:

- Most smartphones and tablets use the maximum allowed EIRP, which increases client-to-client and client-to-AP CCI.
- AP-to-AP distances are short – often less than 10 m (33 ft), which reduces free-space path loss and increases the signal-to-interference-plus-noise ratios (SINRs).
- Indoor channel model is very favorable to signal propagation (that is, a lower path loss exponent is used in the free-space path loss equation).
- The closed roof significantly increases multipath bounce.
- Modern multiple input, multiple output (MIMO) radios are very good at recovering bounced signals.

As a result, such facilities require special RF design consideration. Either specialized, highly directional antennas, special AP placements, or both are needed. Our hypothetical arena scenario intentionally considers this situation to illustrate how to approach this problem.

## Key Facts and Figures

Other key requirement inputs to the dimensioning process for our scenario are as follows:

- 18,000 seats
- 100 skyboxes
- 3 concourse levels
- 3,000 m<sup>2</sup> (32,000 ft<sup>2</sup>) per concourse level
- 5,000 m<sup>2</sup> (54,000 ft<sup>2</sup>) for service level
- 12 gates on main level
- 100 concessions
- 50 seats in upstairs pressbox

## Dimensioning

Given the scenario just described, we will map the requirements to the framework laid out in [Chapter P-2: System Dimensioning](#) in the *Very High-Density 802.11ac Networks Planning Guide*. Recall that dimensioning deals specifically with sizing the entire end-to-end system for a particular number of devices. Dimensioning does not address usable bandwidth. That is covered in the next section on capacity planning.



## Step 1 – Choose Key Dimensioning Metrics

Table S2-3 lists the suggested values for key top-level metrics that guide the dimensioning process for the arena.

**Table S2-3 Top-Level Metrics to Dimension the Arena Scenario**

Metric	Target
Take Rate	50%
Average devices per person	2
Associated devices per radio	150
Average single-user goodput	512 Kbps
5 GHz vs. 2.4 GHz split	5 GHz: 75% 2.4 GHz: 25%
Primary device duty cycle	10%

The absolute minimum device dimensioning Aruba recommends for any type of stadium or arena is 50% of seating capacity. If you assume two devices per person, additional headroom is available in the system when this limit is exceeded (even if only for special events like playoff games).

## Steps 2 and 3 – Estimate Associated Device Capacity and Subnet Size

For the fan/guest usage profile, we expect each user to have a minimum of one Wi-Fi-enabled device. However, within the expected lifetime of the network, this number may increase to two devices per person. The smartphone is the primary device. Table S2-4 is the planning table for the entire facility.

**Table S2-4 Large Arena ADC and Subnet Plan**

User Group	ADC (Now)	ADC (Future)	5-GHz ADC (Future)	2.4-GHz ADC (Future)	Minimum Subnet Size
Fan/Guest	9,000	18,000	<b>13,500</b>	4,500	/17
Ticketing	50	100	<b>100</b>	0	/24
Point-of-Sale	100	200	<b>200</b>	0	/24
Press/Media	50	100	<b>75</b>	25	/24
Staff / House	100	200	<b>200</b>	0	/24
<b>GUEST ADC</b>	9,000	18,000	<b>13,500</b>	4,500	/17
<b>SECURE ADC</b>	300	600	<b>575</b>	25	/24 (each)
<b>TOTAL ADC</b>	9,300	18,600	<b>14,075</b>	4,525	

The highlighted column in the center is the 5-GHz future ADC value, which totals 14,075 devices. This number is based on the 75% / 25% split defined in our key metrics.

We strictly used the “future” values for dimensioning. Arenas and stadiums typically use two planning ADCs. The guest ADC is used for planning AP counts in the bowl. The total ADC is used for dimensioning of wired and wireless network infrastructure.

From an address space perspective, typically all guest users are placed into the same VLAN wherever they are in the building. As discussed in [Chapter P-2: System Dimensioning](#) in the *Very High-Density 802.11ac Networks Planning Guide*, Aruba strongly advises using a single, flat VLAN for fan/guest traffic with

broadcast and multicast suppression enabled on the controller. However, staff and house devices go into one of several smaller secured VLANs based on user role. Each staff VLAN requires a /24 scope.

## Step 4 – Estimate AP Count

To follow the process from [Chapter P-2: System Dimensioning](#) of the *Very High-Density 802.11ac Networks Planning Guide*, we know that AP count is calculated by this formula:

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

We use this method for the main bowl seating area. Make sure that the 5-GHz ADC is only the actual bowl seat count, and that skybox seats are not included. Most published stadium “capacity” values combine bowl and skybox seat totals. (Skyboxes are typically 10 – 15% of total capacity.)

However, outside the bowl are several other types of VHD and non-VHD areas. For a complete arena Wi-Fi design, we must consider each different area on its own terms. [Table S2-5](#) is a summary of the metrics for each area type. If we apply these metrics to our hypothetical example, we can generate the AP count.

**Table S2-5 Large Arena AP Count Breakdown by VHD Area Type**

VHD Area Type	AP Count Metric	Scenario Metric	AP Count Method	AP Count	Notes
<b>Main Bowl</b>	Devices	18,600	150 devices per 5-GHz radio	124	<ul style="list-style-type: none"> <li>Make sure this is the actual bowl seat count, and that skybox seats are not included.</li> <li>“House” devices are not considered in the bowl area.</li> </ul>
<b>Skyboxes</b>	Rooms	100	1 AP for every 2 skyboxes	50	<ul style="list-style-type: none"> <li>Assumes normal signal propagation through one wall.</li> <li>May have to be increased for concrete block or poured concrete walls.</li> </ul>
<b>Concourses</b>	Area	9,000 m <sup>2</sup> (97,000 ft <sup>2</sup> )	1 AP per 100 m <sup>2</sup> (1,100 ft <sup>2</sup> )	90	<ul style="list-style-type: none"> <li>Applies to high-traffic areas in front of concessions, bathrooms, stores, ticket booths, where fans pack closely together for extended lengths of time</li> <li>Based on three devices per 1 m<sup>2</sup> (11 ft<sup>2</sup>), meaning that a radio with 300 devices of association capacity can serve a maximum of 100 m<sup>2</sup> (11,000 ft<sup>2</sup>).</li> </ul>
<b>Gates</b>	Count	12	2 APs per gate	24	<ul style="list-style-type: none"> <li>Two APs recommended for load balancing of transactions and redundancy</li> <li>May be redundant with concourse APs; reconcile against floorplan</li> </ul>
<b>Press</b>	Seats	50	1 AP per 25 seats	2	<ul style="list-style-type: none"> <li>Press users are typically the highest usage class of the venue, high-density deployments in their area is strongly recommended</li> <li>At least two APs are required for load balancing and redundancy</li> <li>Ensure extra attention is given to reduce signal bleed into bowl due to high utilization level and excellent sight lines</li> </ul>
<b>Service</b>	Area	5,000 m <sup>2</sup> (54,000 ft <sup>2</sup> )	1 AP per 100 m <sup>2</sup> (1,100 ft <sup>2</sup> )	50	Extra high density due to thickness of walls in most arena basements, and extensive use of concrete or concrete block
<b>TOTAL</b>				<b>340</b>	

We are not considering outdoor plazas, parking areas, or any other adjacent facilities in our example scenario. These areas would have to be addressed in a real deployment.

## Step 5 – Dimension the WLAN Controllers

Refer to the controller table in [Chapter P-2: System Dimensioning](#) in the *Very High-Density 802.11ac Networks Planning Guide* and use the Total ADC count of 18,600 to determine that the minimum controller size for this deployment is an Aruba 7220. The 7220 is rated for 24,576 users.

If 1+1 high availability (HA) is required, then the customer needs two of these controllers.

The 7210 controller can also be used if the customer reduces the maximum user target to fit within the rated capacity of 16,384 users.



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Controller software licenses are per AP, so there is no difference in price for licenses based on the associated device target. Aruba recommends buying the maximum performance controller possible for VHD areas

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Due to the relatively small AP count, it does not make sense to use a dedicated master controller just for the VHD deployment. Aruba recommends a master/local deployment with each controller terminating half of the APs (and serving as failover for the other controller). Due to the mission-critical nature of the system and the size of the facility, you must have a backup controller.

## Step 6 – Dimension the Edge

To drive the APs in this example, you will need 340 full 802.3at gigabit power-over-Ethernet switch ports.

Aruba does not typically recommend dual-homing APs in large arenas. Using the recommended channel width of 20-MHz, it is not possible to saturate the gigabit backhaul connection of the AP. Additionally, many APs serve the bowl and any AP failure likely will not be noticed by users. The worst case is that they connect to a farther AP at a somewhat slower data rate. One exception to this recommendation is if APs are installed in a way that requires lifts or other special equipment to service the system.

Most existing arenas were not designed with dense Ethernet networking in mind. The Aruba experience is that multiple satellite telecom cabinets (IDFs) must be created to meet the 100 meter distance limitation. These cabinets could be placed discreetly inside closets or concessions.



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The overhead catwalk design proposed below will require two satellite IDFs to be installed on the catwalks themselves. Vertical data feed to the catwalks should be done via fiber.

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Newly constructed arenas will be designed with extensive Ethernet in mind for building control systems and security systems. As a result, new arenas will have adequate IDF counts.

A rough rule of thumb for an arena is that one IDF is required for every 800 seats. In our VRD scenario, 23 IDFs are needed. For 340 APs, a port density of 23 ports per IDF on average is needed. So each IDF needs one switch.

## Step 7 – Dimension the Core

The forwarding tables of the core switches must accommodate at least the guest ADC limit of 18,000 entries per VLAN. This table size and expected backplane speeds are inside the scaling limits of most common core switching platforms. Therefore, the details of the core are outside the scope of this scenario, except to remind you to connect the controllers based on Aruba best practice for a master/local cluster.

Remember that the uplink bandwidth that is required for controller interconnects is double the aggregate system bandwidth. Wi-Fi traffic from APs tunnels to the controller and makes a hairpin turn back to the edge firewall.

## Step 8 –Dimension the Servers

You must determine the proper size of the enabling servers that support the WLAN.

### DHCP Server

An ultra-fast DHCP server is critical to the success of this deployment. DHCP request frequency and binding database size generally are not the limiting factors in an arena/stadium. The transaction time is the key. End-to-end latency for the discover-offer-request-ack sequence should be 2 milliseconds or less.



Slow DHCP transactions appear to the user as being unable to connect to the Wi-Fi network.

The large fan/guest VLAN determines the required size of the DHCP and DNS servers. Total address binding database entries are the sum of all the client devices on all the VLANs. Use the total ADC, which is 18,600 in this scenario.

As for DHCP transaction frequency, Aruba has observed that 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 this example, that number is:

$$\text{Peak DHCP Discover Rate} = \frac{18,000 \text{ devices} * 5\%}{300 \text{ Seconds}} = 3 \text{ per second}$$

And the DHCP renewal rate is modeled as four times this value. Remember that smartphones and tablets tend to have extremely aggressive rates of inter-AP roaming.

Aruba recommends that you use a minimum lease time that is twice as long as a typical game/event. A good 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 this VRD scenario, use the guest ADC value to estimate a DNS query rate of 18,000 per second.

### Captive Portal and AAA Servers

The captive portal peak load should approximate the peak DHCP discover rate, and logins should occur only once per event. The captive portal session time limit should be set so that no one is forced to log in more than once per day.

RADIUS server load is negligible unless you are using 802.11u / PassPoint, which we do not consider in this example.

## Step 9 –Dimensioning the WAN

The WAN uplink bandwidth requirement is equal to the total system throughput (TST), which is calculated in the next section. Note that in many countries, it is easy to exceed 1 Gbps of offered load to the WAN link with a VHD network. This example does just that.

The TST computed in the example in the next section for a reuse factor value of 2.0 is 1,440Mbps. Remember to add a provision for non-Wi-Fi traffic. Therefore, the WAN links should total 2 Gbps, which can be achieved with load-balanced 1 Gbps links.



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WAN link utilization that is lower than expected can indicate problems with channel plans or simply low usage by the end users. Configure network monitoring platforms such as AirWave to monitor real-time usage as well as record usage over time to identify trends in usage.

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Edge firewalls and NAT/PAT devices must be sized for 18,600 individual devices.

## Capacity Planning

To estimate the available system throughput and per-user throughput in this scenario is easy and difficult at the same time. In [Chapter EC-2: Estimating System Throughput](#) of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide, you learned the system bandwidth formula:

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

As we work through this example, we choose values for each of these variables.

### Estimating Total System Throughput

Use the five-step TST process that is defined in [Chapter EC-2: Estimating System Throughput](#) of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide. Begin by establishing the basic facts that are required by the bandwidth estimation process.

#### Step 1 – Select Channel Count

For this scenario, we assume the arena is in the United States (or more generally any country that allows 21 channels for indoor operation in the 5-GHz band). Always use DFS channels with VHD areas of more than 5,000 seats. This decision gives us a total of 21 channels in 5 GHz + 3 channels in 2.4GHz = **24 channels total**.

You can adapt this to your own country or situation. Refer to the available channel list in [Appendix EC-A: Worldwide 5-GHz Channel Availability as of March 1, 2015](#) of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide. Remember the list of allowed and approved channels changes regularly.



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See [Chapter EC-3: Airtime Management](#) of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide for a detailed discussion of the advantages and risks of using DFS channels in VHD arenas. In general, the benefits significantly outweigh the risks, especially where channel reuse is limited.

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## Step 2 – Estimate Unimpaired Multi-Client Throughput

In this scenario, we already have defined the usage profile as fan/guest.

Using [Table EC2-13 on page 27](#) in the *Very High-Density 802.11ac Networks Engineering and Configuration* guide, choose the blended average bandwidth for the stadium/arena scenario. This choice yields an average channel throughput of 40 Mbps.



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This blended average is lower than some of the other VRD scenarios. This is due to most devices being 1SS smartphones.

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## Step 3 – Apply Impairment Factor

Suggested impairments for both frequency bands and for various VHD facility types are presented in [Table EC2-13 on page 27](#) in [Chapter EC-2: Estimating System Throughput](#) of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide. To keep this example simple, we do not differentiate between frequency bands. Choose a flat 25% impairment.

Applying 25% to the previous step yields an impaired average channel throughput of 30 Mbps.



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Impairments in 2.4-GHz band for stadiums & arenas should be in the 50% range. For a real deployment, you should compute TST for each band separately.

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## Step 4 – Select Reuse Factor

Indoor arenas have virtually no ability to achieve RF spatial reuse.

We already know that the network is going to be subjected to significant CCI, with the 124 bowl APs and the 50 skybox APs all able to hear one another. In the USA, this number is almost nine times more radios than available channels (174 APs vs. 21 channels), if we assume that DFS channels are used. Stated another way, an average of 8 APs will be on every channel in 5 GHz, and 58 APs per channel in 2.4 GHz.

Using highly directional antennas does not create significant spatial reuse in indoor environments. In fact, Aruba research has shown that the reuse factor value can be as low as 0.5 in the lower bowl sections due to hidden node effects when directional antennas are used.<sup>1</sup> At the same time, reuse factor values of up to 2.0 were seen in the upper level closer to the APs.

For dimensioning purposes, Aruba recommends using a reuse factor value of 1.0 in arenas.

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1. Chuck Lukaszewski, Clark Vitek, and Liang Li, "In Situ Spectrum Reuse Measurements in Indoor 20,000 Seat Arena," IEEE 802.11ax Task Group, May 2014

## Step 5A – Calculate System Throughput for Bowl Seating

Table S2-6 calculates the possible aggregate bandwidths for reuse factor values from 0.5 through 2.0.

**Table S2-6 Total System Bandwidth Estimate**

Reuse Factor	Channels	Avg. Channel Bandwidth	Aggregate Bandwidth
RF = 0.5	24	30 Mbps	360 Mbps
RF = 1.0	24	30 Mbps	720 Mbps
RF = 1.5	24	30 Mbps	1,080 Mbps
RF = 2.0	24	30 Mbps	1,440 Mbps

If you use the reuse factor target of 1.0, **you expect that on average the maximum goodput that could be generated in our bowl example is 720 Mbps**. This value includes the 2.4-GHz and 5-GHz bands.

Skybox users count against this total because they are part of the same RF collision domain.

## Step 5B – Calculate System Throughput for Concourses and Service Level

An experienced WLAN architect should be able to increase the total system bandwidth outside the bowl area. To achieve this increase, concourse APs must be placed very carefully so that they cannot be heard inside the bowl. In this way, you can achieve some incremental spatial reuse.

With a good plan and favorable building construction, it is reasonable to expect another full reuse in the concourses. However, some of the latest arena designs employ “open concourse” designs without the usual concessions, bathrooms or other blocking structures. In these arenas, it may not be possible to isolate the bowl seating from the concourse APs. Onsite active RF surveys are required to measure actual signal propagation.

**Combining the bowl and concourse values, we get a planning value of 1,440 Mbps for our scenario with 24 channels.** Use this value for WAN edge dimensioning.

Total core network bandwidth for Wi-Fi will be more than double this value due to the hairpin turn through the controller and tunnel encapsulation overhead.

## Per-User Bandwidth

Now we can estimate average per-user bandwidth. Recall this formula from [Chapter EC-2: Estimating System Throughput](#) of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide:

$$\text{Average Device Throughput} = \frac{\text{Average Channel Throughput}}{\text{Instantaneous User Count}}$$

Which can be rewritten as this formula:

$$\text{Average Device Throughput} = \frac{\text{Total System Throughput}}{\text{Active Device Capacity} * \text{Device Duty Cycle}}$$

From our key dimensioning metrics table, we chose 10% as the duty cycle for primary devices. In an arena, we assume that all devices are primary devices. Use this formula to figure the average device throughput for the bowl:

$$\text{Average Device Throughput} = \frac{720 \text{ Mbps}}{18,000 * 10\%} = \frac{720 \text{ Mbps}}{1,800} = 400 \text{ Kbps}$$

Remember that these numbers are **averages** with comparatively low duty cycles and enabling DFS channels. By definition, this analysis assumes that an even distribution of clients attempts to use the Wi-Fi system over time. This assumption is true for basic email and social media updates. However, the assumption is not valid if you expect any continuous duty-cycle applications. Examples are live event video or on-demand video replay features. To model these applications, consult with your local Aruba systems engineer.



Average device throughput outside the bowl should be somewhat higher because they are less exposed to CCI.

## RF Design

Aruba recommends an overhead coverage strategy for large arenas, to leverage the catwalk system that exists in most arena ceilings. Roof trusses can also be used where catwalks either do not exist or have poor coverage angles. The general concept of this strategy is to provide focused RF coverage using directional antennas that are mounted above the coverage areas. The mounting locations typically are 10-30 m (33-100 ft) above the intended coverage areas.

### Key RF Design Metrics

First, establish the quantitative targets that the RF design must deliver (see [Table S2-7](#)). Remember that these values are net of crowd losses, so when performing acceptance site surveys you would be looking for larger values.

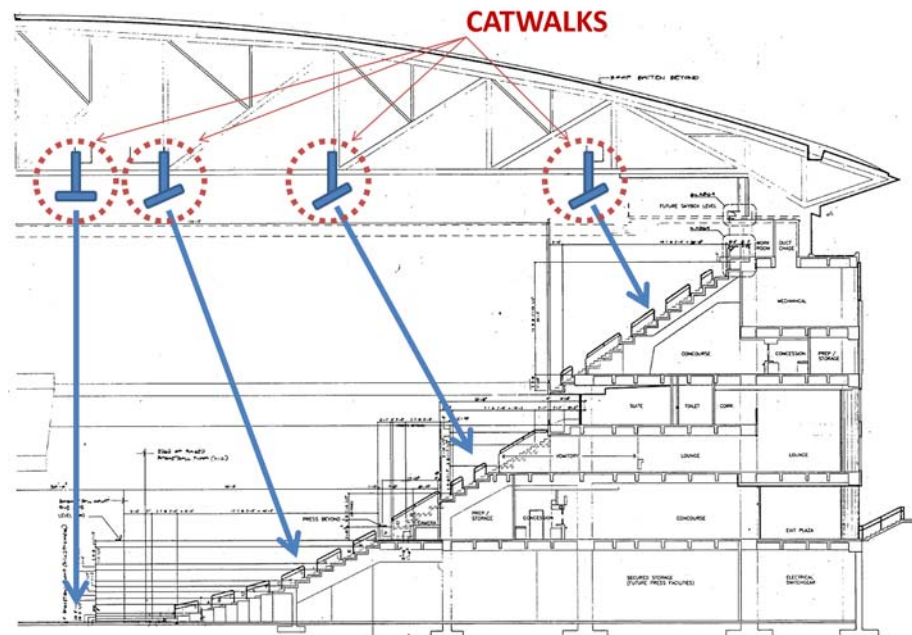
**Table S2-7** Radio Design Metrics

Metric	Target
Minimum cell edge SINR	25 dBm
Minimum cell edge RSSI	-65 dBm

Note that different devices have different radio capabilities, so these values vary significantly across the population. Devices with more than one spatial stream benefit from the maximal ratio combining (MRC) feature of 802.11, which increases SINR. These metrics should be interpreted as applying to the least capable device in the arena.

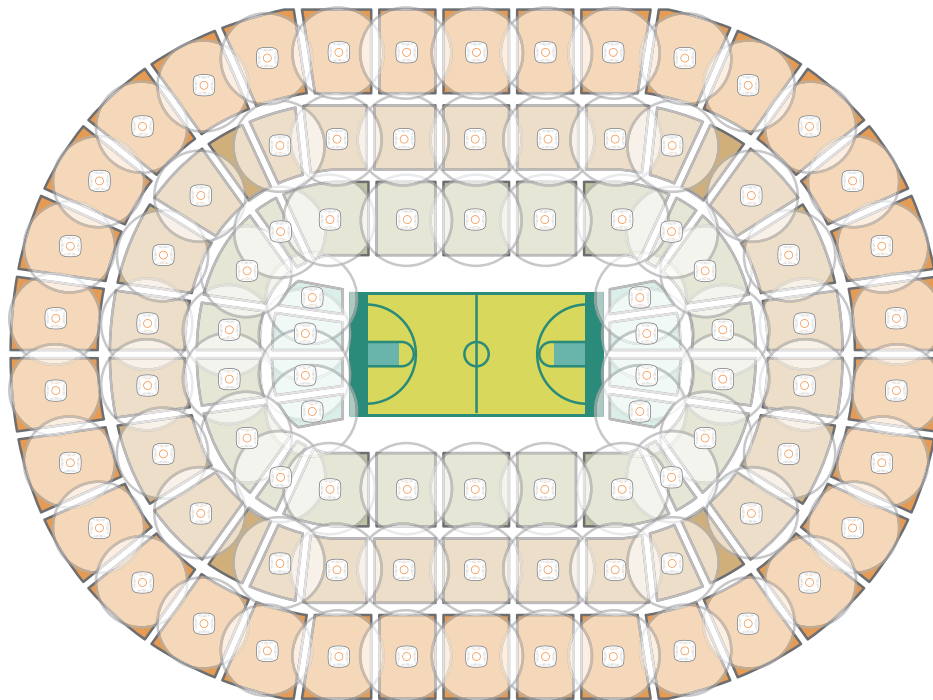
## Catwalk Strategy Overview

The catwalk strategy is best visualized in the cutaway diagram in [Figure S2-3](#). This figure depicts four separate “tiers” of coverage, with each tier covering 10-15 seating rows.



**Figure S2-3** Elevation View of Antenna Coverage with Catwalk Strategy

Looking down from overhead, this strategy looks like [Figure S2-4](#). This figure shows the four tiers of coverage. More APs serve the higher sections because there are simply more sections as the distance from the court increases.

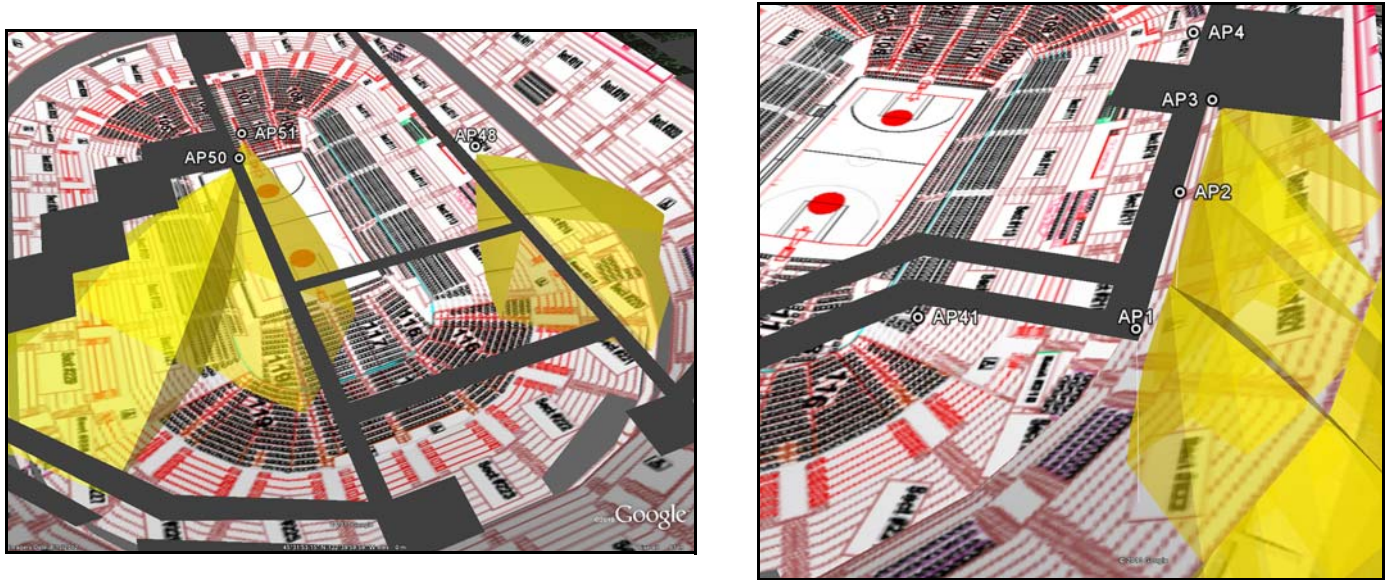


**Figure S2-4** Overhead View of AP Coverage with Catwalk Strategy



Based on the distance to the catwalks and height above the various sections, the down-tilt angles vary and in general are aimed at the center of the section they are covering.

Figure S2-5 shows what this strategy looks like in three dimensions.



**Figure S2-5 3D View of AP Coverage with Catwalk Strategy**

To do a full overhead coverage plan, 1 - 2 APs are required per section, per tier. Higher-gain, narrower antennas are used for low sections, and lower-gain, wider antennas are used for high sections. Skybox APs must be carefully placed in the very rear of the skybox to reduce interference with the bowl APs.

## Evaluating Catwalk Feasibility

An arena is a good candidate for overhead catwalk coverage if it meets these characteristics:

- Overhead mounting structures are located 10-30 m (33-100 ft) above and in front of the seating area.
- The APs can be placed in the center of the arena shooting away from the court, as opposed to behind the seats shooting inward at each other.
- Minimal obstructions are in the path between the proposed mounting locations and the clients, that is, no heavy concrete decks, existing DAS antennas, light fixtures, or metal ceilings.
- The APs can be mounted very closely aligned to their coverage area, not offset, or “shooting across” other coverage areas.
- The APs can be mounted with some spacing between them on the mounting structure, typically 3-10 m (10-33 ft) is recommended, but closer spacing may be acceptable when downtilt separation is available.

Overhead APs and antennas are not an “all or nothing” strategy. In some venues, it may be appropriate to use this strategy in combination with others such as under seat, under concrete deck, or above drop ceiling and wall mount APs. However, take care when you combine strategies to ensure that overlapping coverage is as intended. Typically, the overhead strategy provides the least obstructed RF path to the clients and the highest available antenna gain, which clients will prefer to associate to instead of APs mounted by other strategies.



Depending on the available mounting structures overhead, a typical deployment for an indoor venue such as a basketball or hockey arena could be expected to cover all of the bowl areas with overhead and catwalk APs. Only the enclosed area of suites, concourses, offices, and outdoor areas are left to be covered by other strategies.

## Creating the AP Layout – Bowl

To develop a detailed plan for a catwalk strategy:

1. Obtain a seat map in digital form. You can get this from the customer, from a ticketing web site, or just by Googling “<arena name> seating chart”. Use a graphics editor to convert the chart to greyscale for easier reading.
2. In a graphics editor, lay out a preliminary plan for all of the bowl APs you obtained in the dimensioning step. For our example, that is 124 APs.
  - a. A simple way to do this is to mark out three or four tiers (based on the venue size).
  - b. Starting at section “101” or equivalent, place an AP in every tier. Try to center the AP on each section, or partial section.
  - c. Then work your way around until you have placed all the APs in every tier in every section.
3. Obtain a floor plan or other map of the catwalk system that shows the catwalk layout relative to seating or event floor. This coverage strategy seeks to place APs linearly along the walks or structures at some interval, so to start, you must know how long the catwalks are to compute AP-AP separation. Ideally the catwalks should be inspected in person.
4. Center every AP in front of its targeted section, and use the spacing determined by the section widths below. At the corners the spacing will be tighter, so it may be worthwhile to combine small “pie shaped” sections at the corners with the adjacent larger sections for planning purposes.
5. Avoid co-location of APs. Maintain 10 m (33 ft) of linear separation, which often lined up with the spacing (center to center along the rows) of the sections below.

However, **much** closer spacing may be possible if necessary due to mounting limitations or if needed to get additional capacity into larger sections (as close as 1-2 m [3-7 ft]). In cases where APs must be co-located, generally no more than two APs per mounting location are used. Adjacent channels cannot be used (for example, channels 1 and 11 or 36 and 44 are fine, but channels 1 and 6 or 36 and 40 are not). Vertical angular separation of greater than 45 degrees must be used to limit AP-to-AP interference.

6. Cross check the AP count that results from analysis of the available mounting locations against the AP count from the dimensioning step.

If you see a significant difference in the numbers, consider adjusting the parameters in the dimensioning model. In most cases, small differences of a few assumptions (such as the percentage of users that will use the system, or the 2.4-GHz or 5-GHz split) can make large changes in the required AP counts.

Adjust the dimensioning plan parameters until the target AP count matches the available AP count based on mounting location availability.

7. Avoid a “circular firing squad” where all APs are aimed toward the center of the arena.

## Creating the AP Layout – Other Areas

Follow the procedures listed below to produce RF coverage plans for the other parts of the facility outside the main seating bowl.

### Skyboxes

Aruba recommends that you plan for one AP for every two skyboxes. This number is adequate for most stud or “stick” construction in western countries. For solid concrete-based construction, such as is common in the Middle East and Asia, you may need an AP in each suite. Validate this layout during the survey phase. Set up a test AP and take measurements with a site survey utility such as AirMagnet Survey Pro or Ekahau Survey Pro.

To create the plan, obtain the floorplans for the skybox levels. For each level, start at skybox number one. Place an AP every two suites. Use your judgment, and don’t just follow the map! Often the skyboxes are not contiguous. They may only be on one side. They may vary in size or shape.

### Concourses and Gates

For all concourse areas, lay out one AP for every 100 m<sup>2</sup> (1,100 ft<sup>2</sup>) on the floorplans. This density is to ensure that high-traffic areas in front of concessions, bathrooms, stores, and ticket booths are adequately served.

To maximize spatial reuse opportunities, concourse APs should **never** be placed with a clear line of sight into the bowl. Aruba suggests these guidelines:

- Wall mounting (for example, side coverage) is completely acceptable in the concourses. Better bowl performance is achieved if you wall-mount the concourse APs facing **away** from the bowl.
- Regardless of orientation, concourse APs should be centered on concessions, bathrooms, and other blocking structures. (In other words, mount APs between vomitory entrances).
- Gate APs should be placed to the left and right of each entrance, to provide mutual support in event of an AP or switchport problem. Place these APs so they do not have line of sight to the bowl.

In general, you will want to use standard indoor APs with integrated antennas on the concourses. APs should be placed below the ceiling. If necessary, the AP can be placed in a standard plastic enclosure for physical safety of the AP, aesthetics, or other reasons.

Aruba generally does not recommend using APs with external antennas to cover concourse areas. Indoor arenas have reasonably low ceilings or walls that can be used, even around open atrium areas. Antennas should be considered only if the available mounting structures are over 10 m (33 ft) above the concourse. This is general guidance only; some arenas especially newer models with “open concourse” plans are too exposed to the seating bowl and may require antennas to limit CCI. Ultimately, the radio architect is responsible to make this decision.

For hallways outside skyboxes, dedicate a few APs to cover elevator banks, and possibly a handful of APs to provide line-of-sight coverage in the hallway itself. However, the suite APs themselves should do a good job of lighting up the hallway.



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Skybox APs must always be placed in the rear of the suite to limit bowl interference. This placement means that they will strongly cover any hallway or lounge area on the other side of the wall.

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## Press/Media

Use standard indoor APs with integrated antennas for press areas. Like skyboxes, the APs should be placed as far back as possible. Ideally, they should have no line of sight to any seats even on the far side of the arena.

## Service Level

For pervasive coverage of the service level, lay out one AP for every 100 m<sup>2</sup> (1,100 ft<sup>2</sup>) on the floor plan. This density is due to thickness of bearing walls in most arena basements, and extensive use of concrete or concrete block.

## Choosing APs and Antennas

### Choose an AP Model

For all venues over 5,000 seats, the highest performing AP available from Aruba must be used. As of this writing, that AP is the AP-220 series.

### AP Processing Power

Aruba strongly discourages using lower-performing hardware for venues over 5,000 seats. After radio channel capacity, the second greatest limiting factor for total performance is the CPU speed of the AP. AP processing power is important because of the extremely large amount of control and management frames that occur in a VHD environment.

Every transmitted frame triggers an interrupt on the AP CPU when it is received, and then must be decoded. VHD environments are dominated by massive volumes of small frames and collision fragments. Therefore, being able to process these quickly and get to the next one is the key to delivering a good user experience.

For additional detail, see the AP performance charts in [Chapter P-3: RF Design](#) of the *Very High-Density 802.11ac Networks Planning Guide*.

### Antenna Connectors

For bowl APs that feed external antennas, the antenna governs which AP you choose.

- 30°x30° pattern – Use AP-228 (with ANT-2x2-2314 & ANT-2x2-5314)
- 60°x60° pattern – Use AP-224 (with AP-ANT-38)

Due to their high 14 dBi gain, the narrow 30°x30° beamwidth antennas cannot be dual-band. You must have separate units. Therefore, choose an AP that has separate antenna connectors for both bands (six connectors for a 3x3 AP). This AP is the AP-228 for RP-SMA connectors.



The AP-274 is another option with nondiplexed antenna connectors. However, as an outdoor unit, it cannot use indoor-only channels. The AP-228 has been certified as an indoor AP.

By contrast, the wider 60°x60° beam 7.5 dBi antenna is dual-band, therefore it can be used directly with the AP-224, which has three prediexed antenna ports. Be very careful of side lobes when using all but the narrowest beamwidth antennas. The side lobes on most 60° x 60° and wider antennas are comparatively powerful, and may strongly acquire signals from directions you do not want.

## External Antenna Selection




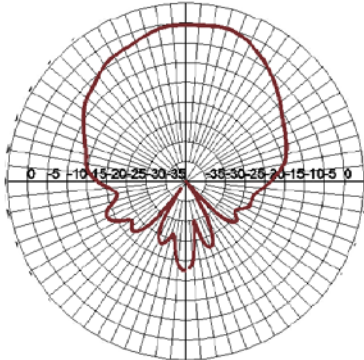
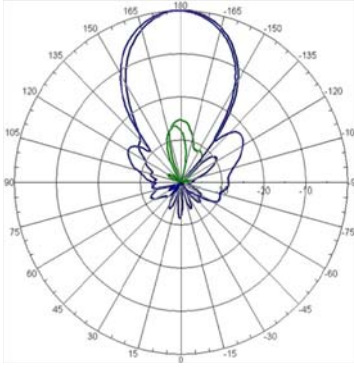
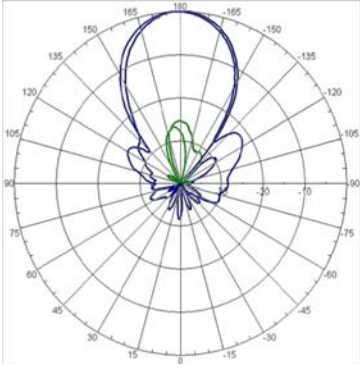
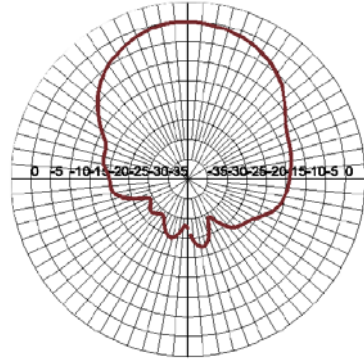
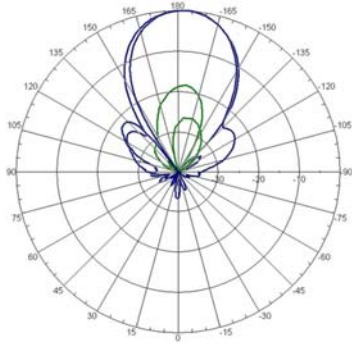
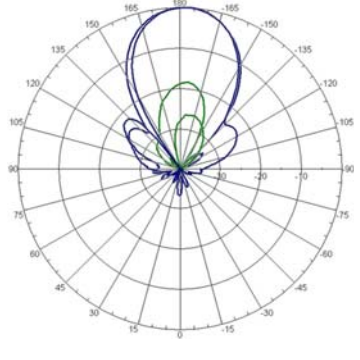
For the bowl, the antenna choice depends on the beamwidth required. Large arenas typically require four tiers of APs as shown in [Figure S2-4](#). Use these beamwidths for each tier:

- **First two tiers:** Use narrow beamwidth 30°x30° pattern.
  - 5 GHz – ANT-2x2-5314
  - 2.4 GHz – ANT-2x2-2314
- **Third tier (if required):** Could be either 30° x 30° or 60° x 60° depending on exact geometry of ceiling and seats. In general, you should use the 30° x 30° antenna unless the antennas are less than 15 meters (50 ft) from the seats. In that case, use the 60°x60° pattern.
  - 5 GHz – ANT-2x2-5314
  - 2.4 GHz – ANT-2x2-2314
- **Upper tier:** Use wider beamwidth 60°x60° pattern if the antennas are less than 15 m (50 ft) from the seats.
  - Dual-band – ANT-3x3-D608

Smaller arenas may only require two or three tiers of APs and antennas. Use your judgment and adapt these guidelines as necessary to the situation.

Table S2-8 lists the specifications for these antennas. All models include mount kits in the box.

**Table S2-8 Recommended Directional Antennas for Arenas**

	60°x60°	30°x30°	
<b>Model</b>	AP-ANT-38	ANT-2X2-2314	ANT-2X2-5314
			
<b>Band</b>	Dual band	2.4 GHz to 2.5 GHz	4.9 GHz to 6.0 GHz
<b>Elements</b>	3 (Linear vertical and dual slant +/- 45°)	3 (Linear vertical and dual slant +/- 45°)	
<b>Gain</b>	7.5 dBi	14 dBi	
<b>E-Plane (Vertical) Antenna Pattern</b>			
<b>H-Plane (Horizontal) Antenna Pattern</b>			

## Stadium Antennas

All three antennas shown in Table S2-8 have been designed specifically for stadiums and arenas. What does that mean exactly, and why should you care?



Small AP-to-AP distances, especially in catwalk deployments, require that the side lobes and rear lobes of the antennas be strongly reduced. Aruba designed these antennas to have exceptional side lobe performance, specifically for arena/stadium customers. You can see from the pattern plots that the side lobes on the narrow beam antennas average 30 dB down from the peak gain, while the rear lobes are nearly 35 dB down. Also, the pattern symmetry of both antenna elements is quite clean.

The 7.5-dBi antenna is 15 dB down on the sides and up to 25 dB down on the rear lobe.

## Antenna Patterns

See [Chapter P-3: RF Design](#) of the *Very High-Density 802.11ac Networks Planning Guide* for a detailed analysis of all three antenna models. Your local Aruba SE can obtain specific heatmap models for any combination of height and tilt that your specific situation requires.

## Channel Planning

In large arena and stadium networks, it is a best practice to use static, repeating channel plans in the bowl area, and use dynamic channel plans everywhere else.

The main reason for using a static plan in the bowl is the large number of APs in very close proximity (with high SINRs). From the controller point of view, the APs are not sufficiently differentiated from one another to make an accurate automated decision. In addition, highly directional antennas can make it difficult to interpret readings because the controller has no knowledge of the three-dimensional design of the system.

Fortunately, Aruba ARM can produce static and dynamic channel plans. So we use ARM everywhere in the building, but it is configured differently in different areas. See [Chapter EC-4: Channel and Power Plans](#) of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide for a discussion of how to configure ARM to construct “automatic” static channel plans.

## Reserved Channels

Due to the extremely high number of fans that need service in an arena, it is preferable not to set aside any reserved “house” channels. You want to provide as much capacity as possible for the fans.

That said, you may find it useful or necessary to sacrifice up to two channels for the following uses:

- Ticketing
- Point of sale
- Press
- Team
- Performers

If you are using DFS channels, you likely have enough channels available to consider setting aside up to two channels for house use. You can use the same channels for all of these purposes.

Aruba recommends that these channels be upper non-DFS channels, to avoid interoperability issues.

Press users can be tricky, as they tend to have older equipment. More than two APs will be in the press areas anyway, so you can put up extra channels in that area. The goal is to offload media traffic from the fan channels because the press can be very heavy users.

For a visiting entertainer or team, their IT personnel should be informed of the house channels. You may provision a temporary SSID for their use. Be sure to follow up and verify with your own analysis equipment that the visitors actually configured their equipment to use the house channels!

To reserve channels:

- Remove the desired channel(s) from the regulatory domain profile for the APs serving the bowl.
- Install dedicated APs where you want the reserved channels.
- APs can be a member of only one AP group, so the APs that use these house channels cannot be provisioned into the bowl group. That means extra APs are required to implement reserved channels.
- Provision the house APs into separate group(s), with a regulatory domain profile that has only the reserved channel(s).
- Configure appropriate virtual AP profiles that are available only on those APs (channels).

## Airtime Management

For any VHD area of 5,000 seats or more, you must employ the full suite of Aruba airtime management features. The fastest way to destroy the user experience is to waste extremely scarce airtime on unnecessary transmissions.

You must be fanatical and uncompromising. Small concessions quickly add up to huge performance impacts.

[Chapter EC-3: Airtime Management](#) of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide explains the overall strategy in depth. The critical points for a large arena are:

- Use a SSID profile that eliminates low data rates.
- Eliminate beacons:
  - Force all stadium vendors to use the same system (zero tolerance for “third party” APs).
  - Converge all secure users onto a single, shared 802.1X SSID.
  - Provide the secure SSID only on 5 GHz.
- Hunt down and destroy every third-party AP in the building.
- Stop “chatty” protocols via ACLs and broadcast/multicast control features of ArubaOS. Do not run broadcast- or multicast-based applications, if at all possible.



As of this writing, video usage in stadiums is quite low with take rates under 10% of unique user counts. Unicast video – or multicast-to-unicast conversion – is recommended and can easily accommodate this level of demand.

- Do not allow IPv6 on the fan SSID.
- Minimize probe request/response traffic through good RF design (high SINR) and enable controller features to limit such traffic.

## Recommended Security Model

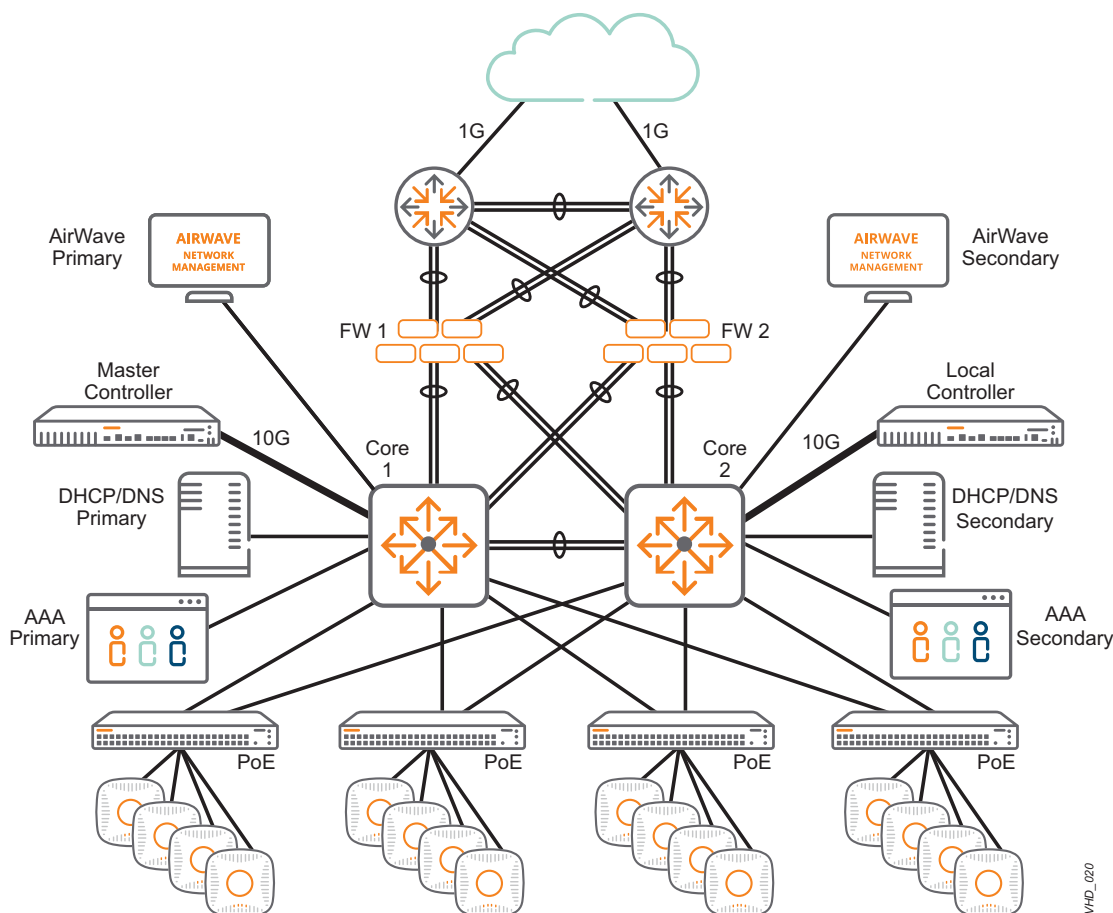
Guest services should be provided via an open SSID that is redirected to a captive portal.

Secure access for facility employees should be provided via an 802.1X SSID using WPA2/AES encryption. Use the facility's existing AAA server. If the facility is deploying wireless for the first time, ClearPass includes a built-in AAA server that can be used to create secure per-user credentials.

For additional information on the access architecture, see [Chapter EC-5: SSIDs, Authentication, and Security](#) of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide.

## End-to-End Architecture

The minimum redundant system-level architecture for a large arena that serves 18,600 possible devices is shown in [Figure S2-6 on page 26](#). It is assumed that the entire core switching fabric and supporting server appliances in the onsite data center are fully redundant. Per Aruba best practice, controllers should be one-armed to the core with spanning tree disabled. Each controller handles half of the user load when the system is operating normally.



**Figure S2-6 Fault-Tolerant VHD System Design for Large Arena**

We know from the system bandwidth calculation that we can generate a maximum load of 720 Mbps of over-the-air goodput in the bowl for the 24-channel example. The concourse and service areas may generate another 720 Mbps, for a total maximum of about 1.4 Gbps. Actual load on the controller uplinks will be up to about 3 Gbps for these two reasons:

- Layer 2 tunnel overhead and AP management traffic
- All traffic hairpins through controller

Therefore, controllers should have 10G Ethernet links to the core fabric. The 7220 controller includes four 10G interfaces.

A high-performance DHCP server that can handle low-latency transaction rate and a large database is important. DHCP/DNS, ClearPass, and AirWave servers should be fully redundant.

Captive portal services are provided by a ClearPass guest server. The captive portal is used to enroll guest users and to obtain their agreement to the facility terms of service. ClearPass must be licensed for 9,300

users immediately to meet the current ADC. Additional license capacity can be purchased in the future based on how AirWave reports are trending.

An AirWave server is mandatory because of the multicontroller deployment. AirWave is needed to roll up the user statistics from the separate controllers as well as to provide long term trending. (The controller dashboards show only the last 15 minutes of activity). AirWave may or may not be deployed in HA based on available budget. An AirWave failure does not impact service.

Moving toward the WAN, the firewall must be sized for NAT/PAT for 18,600 devices with a typical number of sessions.

The minimum link speed from the core all the way to the Internet is 1.5 Gbps in this scenario.

## Bill of Materials

### Wireless LAN

Table S2-9 is the BOM for the wireless portion of the network as shown above, and it assumes redundant controllers and redundant servers.

**Table S2-9 BOM for the Scenario Wi-Fi Network**

Part Number	Description	Quantity
7220	Aruba 7220 Mobility Controller with 4x 10GBase-x (SFP/SFP+) and 2x dual media (10/100/1000BASE-T or SFP) ports. Includes one 350W AC power supply.	4
PSU-350-AC	350W AC Power Supply. May be used as a redundant power supply or field-replaceable spare for 7200 Series	4
SFP-10GE-SR	10GBASE-SR SFP+; 850nm pluggable 10GbE optic; LC connector; up to 300 meters over multi-mode fiber (Type OM3) or 400 meters with OM4	8
LIC-256-AP	Access Point License (256 Access Point License)	1
LIC-128-AP	Access Point License (128 Access Point License)	1
LIC-SEC-256	Security Software Bundle (256 AP License) with Policy Enforcement Firewall (PEFNG) and RF Protect (RFP) licenses	1
LIC-SEC-128	Security Software Bundle (128 AP License) with Policy Enforcement Firewall (PEFNG) and RF Protect (RFP) licenses	1
AP-225	Aruba AP-225 Wireless Access Point, 802.11ac, 3x3:3, dual radio, integrated antennas	216
AP-220-MNT-W2	Aruba Access Point Mount Kit (box style, secure, flat surface). Contains 1x flat surface wall/ceiling secure mount cradle	216
AP-224	Aruba AP-224 Wireless Access Point, 802.11ac, 3x3:3, dual radio, antenna connectors	35
AP-220-MNT-W1	Aruba Access Point Mount Kit (basic, flat surface). Contains 1x flat surface wall/ceiling mount bracket. Color: black	35
AP-ANT-38	AP-ANT-38 Dual Band, 60 Degree Sector, 8 dBi, 45 and Vertical Polarization, 3 Element MIMO, 3 x RPSMA pigtails 75cm (30in). Wall anchors for flush mount included. Optional pan/tilt bracket AP-ANT-MNT-3.	35
AP-228	Aruba AP-228 Indoor Hardened Wireless AP, 802.11ac, 3x3:3, dual radio, 6 x RPSMA connectors	89
AP-270-MNT-ADP	Aruba AP-228 adapter to allow use of outdoor mount series AP-270-MNT-XX	89

**Table S2-9 BOM for the Scenario Wi-Fi Network (Continued)**

Part Number	Description	Quantity
AP-270-MNT-H1	AP-270-MNT-H1 Aruba 270 Series Outdoor AP Hanging Mount Kit. Mount for hanging or tilt install for AP-270.	89
ANT-2X2-2314	2.4 GHz, 14 dBi, 30 x 30, H and V polarized MIMO High-Gain Directional Panel Antenna, 2 x N-Type female connectors, Cable NOT Included. Outdoor rated.	89
ANT-2X2-5314	5.15-5.9 GHz, 14 dBi, 30 x 30, H and V polarized MIMO High-Gain Directional Panel Antenna, 2 x N-Type female connectors, Cable NOT Included. Outdoor rated.	89
AFCSJMTM-00	RP-SMA/M to N/M, 60cm; used between indoor products and splitter	356
AW-500	AirWave license for 500 devices	1
AW-500-FR	AirWave failover license for 500 devices	1
CP-VA-25K	Aruba ClearPass Policy Manager 25K Virtual Appliance - RADIUS/TACACS+ server with advanced policy control for up to 25,000 unique endpoints. Includes 25 endpoint Enterprise License	1
LIC-CP-GM-10K	Guest License for Aruba ClearPass Policy Manager - 10,000 endpoints	1

This BOM excludes:

- Server appliances for AirWave and ClearPass
- DHCP/DNS server software and appliance
- WAN edge hardware

## Controller Configuration

The best practice ArubaOS configuration for VHD environments is common to almost all of the VRD scenarios. Read [Chapter EC-3: Airtime Management](#) of the *Very High-Density 802.11ac Networks Engineering and Configuration* guide for detailed instructions.