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# Table of Contents

**Introduction**

Introduction 4

**Increase in the Number and Types of Multimedia Devices**

Increase in the Number and Types of Multimedia Devices 5

**Moves Toward Video, Voice, and Other Real-Time Applications**

Moves Toward Video, Voice, and Other Real-Time Applications 5

**Other Drivers**

Other Drivers 6

**Assessing Current Residence Hall Design Strategy**

Assessing Current Residence Hall Design Strategy 6

Assessing the Offered Load 6

Assessing the Physical Environment 8

Problem with Hallway APs 10

**A Next Generation Wireless Architecture for Residence Halls**

A Next Generation Wireless Architecture for Residence Halls 13

Microcell Approach 13

5 GHz vs. 2.4 GHz 14

Capacity Planning for a Residence Hall Microcell Deployment 14

Available APs for Microcell Deployments 16

RF Design – Choosing Attenuation Type 16

RF Design – Separate Coverage Blankets 17

RF Analysis of Microcell Design 18

**Microcell Reference Design #1: High Attenuation**

Microcell Reference Design #1: High Attenuation 20

**Microcell Reference Design #2 - Low Attenuation**

Microcell Reference Design #2 - Low Attenuation 21

**Coping With Financial Constraints and Other Realities**

Coping With Financial Constraints and Other Realities 22

Alternative AP Density 22

Leveraging Existing Wire/Mesh Backhaul 22

**Additional Considerations**

Additional Considerations 22

Managing Available RF Spectrum 23

Airtime Fairness 24

Enabling Mobility 24

Quality of Service 24

SSID Count and Application Performance 24

Optimizing Multicast for Application Performance 25

**Contacting Aruba Networks**

Contacting Aruba Networks 27
Introduction

In recent years, higher education institutions have made significant investments in the capacity and density of their wireless networks in lecture halls, libraries, arenas, and even stadiums. However, the residence hall, where students spend a significant part of their time on campus, has tended to be left as a coverage-only model using hallway deployments. Administrators had good reasons: cabling and conduit costs, access logistics when maintenance is required, and concern over accidental damage or intentional theft of access points (APs). But when those reasons are combined with the RF-hostile construction that is typical of these structures due to age or fire code compliance, the result is a wireless network that increasingly underperforms the rest of the campus.

At the same time, a new age of mobile devices, personal entertainment systems, and multimedia applications is driving the need for a new, capacity-based Wi-Fi, residence hall infrastructure. Most of the tablets and other smart mobile devices that fuel the new wireless demand don’t even have an Ethernet port, which means that wireless is their only connectivity option. This emerging trend represents a whole new scale for consumption of wireless network resources and capacity. Many residence hall Wi-Fi networks began as networks of convenience and they were intended to supplement wired connectivity. Now the general move is for Wi-Fi to replace wired networks for many types of users, especially students. Coupled with the fact that many institutions explicitly or implicitly charge for network access as part of recurring IT fees, students can become quite vocal when the wireless-only network experience where they live is perceived as unsatisfactory.

This fundamental change in use brings with it a fundamental change in expectations of the wireless network in the residence hall:

- The network must be high performance. The network must be able to deliver a wire-like experience in each and every room.
- The network must work equally well, if not better, in 5 GHz to offload all possible traffic from the congested 2.4 GHz spectrum.
- The network must not only ensure secure access, but it also must support personalized device domains. These are akin to personal VLANs for peer-to-peer devices such as Apple TVs that use Layer 2-only protocols, without any incremental burden on IT staff.
- The network must also be highly-available, which requires not only redundancy but advanced functions like integrated spectrum analysis and adaptive RF for steering around sources of interference.

This guide presents a new wireless architecture to deliver a multimedia-grade experience to students living in residence halls. We will show that large numbers of low-power microcells located directly in the student rooms is the only effective solution to fully meet user expectations. We provide simple rules to determine the density of these microcells for different types of construction. We also provide migration options to enable many institutions to deploy this architecture without pulling additional cabling.
Increase in the Number and Types of Multimedia Devices

The University of Washington maintains one of the best collections of statistics depicting the drive towards capacity-based Wi-Fi. In the spring 2010, the University of Washington documented roughly 78,000 unique devices connecting to their Wi-Fi network. Of those devices, 47% were Windows, 25% were Mac OS, 24% were IOS (iPhone & iPad), and 2% were Android. Of that mix, they saw their most rapid growth from handheld devices such as iPad, iPhone, and Android devices. Together these accounted for over 18,000 unique devices. For the last four and a half years, they have experienced steady growth on wireless with the number of devices and usage roughly doubling every 18 months. These stats are updated regularly at http://www.freshlymobile.com/. Another recent study by the Educause Center for Applied Research shows that 89% of students own a laptop and 48.8% own a handheld device such as a smartphone or tablet from which they access the Internet (http://www.educause.edu/ecar/).

Many higher education environments are experiencing a shift towards multiple devices per user. Typically this includes at least one converged device (such as, iPhone, Droid, iPad, etc.) and a laptop. In addition, many students have several fixed residence-centric devices such as Vonage and/or a Netgear or Linksys Skype phone, plus X-Box, Wii, and PS3 gaming consoles for networked gaming. It should also be noted that these devices range in capability and intelligence. This range can be a factor in their ability to actively participate in various authentication and quality of service (QOS) schema or fairly contend for network resources. Less intelligent devices may require different methodologies that require little or no participation on their part, which places more requirements on the wireless infrastructure.

Moves Toward Video, Voice, and Other Real-Time Applications

Multimedia services such as Microsoft OCS, GoogleVoice, iChat, FaceTime, AppleTV, Skype, and others are increasingly common on college campuses and their residence halls. Applications such as Blackboard, Microsoft OneNote, and DYKnow have expanded their multimedia capability for teaching and learning. Standard media servers from Microsoft and Apple are being used in ever increasing numbers to distribute local and reference library multimedia content throughout campus. The use of podcasting and streaming has also skyrocketed. It is therefore only natural to see a huge increase in the consumption of multimedia on mobile devices in the residence hall. Due to the pervasiveness of wireless in some environments, the smart classroom has now become virtualized, which allows its capabilities to be delivered anywhere there is capacity to receive it.

Social networking apps such as Facebook and Twitter along with entertainment apps such as Netflix and Hulu have gone mobile. These prime examples show how personal multimedia communications are invading the residence hall and consuming massive amounts of precious wireless bandwidth. This shift to mobile also includes the convergence of Voice over Wi-Fi (VoWiFi), which provides better convenience due to poor cellular coverage or better cost models.

IPTV and other locally-generated video streaming are focused on the residence hall as well. The cable TV infrastructure is aging and campuses do not have the resources required to maintain separate networks. Combine that with the demand to propagate locally generated content, and many campuses are replacing their cable systems with some variant of IPTV. Digital signage is receiving more play as well. Originally, digital signage was conceived as a static medium to replace paper bulletin boards in residences halls and other campus venues. Now, digital signage is used to stream multimedia news channels and other locally generated video clips along with their static information components.
Other Drivers

More non-multimedia residential hall services are moving to IP as a transport. These services can impact the performance of latency-sensitive multimedia applications in those environments. Examples include physical security systems (door locks and video surveillance), vending machines, parking enforcement devices, and HVAC and other sensor-based systems. The cost and convenience of convergence on Wi-Fi is creating a preference over wired access for these services, which steadily is increasing the offered load. With the openness of Wi-Fi in most environments and the lack of tools employed to effectively characterize traffic, often this load is overlooked. Ultimately, this increase in baseline traffic must be characterized and considered when a capacity-based residential hall wireless infrastructure is deployed.

Assessing Current Residence Hall Design Strategy

Up to now, residence hall Wi-Fi infrastructure design strategy has been focused primarily on coverage, not capacity. Historically, this design model has been based on the premise that Wi-Fi is an overlay or network of convenience and it supplements the primary network access via wired Ethernet. This “best efforts” premise is no longer valid. Wi-Fi is now expected to be the primary service delivery network, capable of high performance with guaranteed service level agreements. Wi-Fi is expected to have robust security and high availability equivalent to wired infrastructure. Coverage must also be ubiquitous, not just relegated to common areas or selected venues because today’s communications paradigm is everything mobile at anytime from anywhere.

Assessing the Offered Load

To more fully characterize the impact of mobile devices and their associated applications and services, take a brief look at the potential load they place on the wireless infrastructure. Audio services, whether they are telephony or other types of audio, need per-session bandwidth in the range of 50 to 700 Kb/s, depending on the desired fidelity and compression selected. Typically, a full-duplex VoIP call consumes roughly 100 Kb/s. While not much capacity is consumed per session, the biggest concern with VoIP is insuring the minimum latency requirement. For voice calls, the minimum latency is 20 ms. If the latency is not kept within minimums, the audio becomes choppy or possibly unrecognizable. Voice quality is typically measured with a mean opinion score (MOS), which provides the perceived quality. Table 1 defines the MOS.

<table>
<thead>
<tr>
<th>MOS</th>
<th>Quality</th>
<th>Impairment</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Excellent</td>
<td>Imperceptible</td>
</tr>
<tr>
<td>4</td>
<td>Good</td>
<td>Perceptible, but not annoying</td>
</tr>
<tr>
<td>3</td>
<td>Fair</td>
<td>Slightly annoying</td>
</tr>
<tr>
<td>2</td>
<td>Poor</td>
<td>Annoying</td>
</tr>
<tr>
<td>1</td>
<td>Bad</td>
<td>Very annoying</td>
</tr>
</tbody>
</table>
Video is more complicated because the capacity requirements can be more wide ranging than audio, but latency still is a critical factor. Video is almost always accompanied by an audio component. Sometimes other latency-sensitive synchronization components that are required for gaming or animation are included as well. Table 2 and Table 3 provide a guide to the potential offered load of video.

**Table 2  Offered Loads of Various Video Frame Formats**

<table>
<thead>
<tr>
<th>Video Format</th>
<th>Picture Format</th>
<th>Application</th>
<th>Approximate Bit Rate for Different Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Motion - JPEG</td>
</tr>
<tr>
<td>QCIF</td>
<td>176 x 120i, 30 f/s (NTSC)</td>
<td>Lower quality NTSC/PAL analog for surveillance video</td>
<td>260 kb/s</td>
</tr>
<tr>
<td>CIF</td>
<td>352 x 240i 30 f/s (NTSC)</td>
<td>Full quality NTSC/PAL analog TV signal</td>
<td>520 kb/s</td>
</tr>
<tr>
<td>Low-rate digital video</td>
<td>176 x 144, 10 to 15 f/s</td>
<td>Internet video on smartphone screens</td>
<td>--</td>
</tr>
<tr>
<td>SD - TV</td>
<td>480i</td>
<td>&quot;talking head&quot; low-motion digital TV, e.g., video conferencing</td>
<td>--</td>
</tr>
<tr>
<td>DVD - TV</td>
<td>480i 640 x 480, 24p f/s (480i)</td>
<td>movie-quality digital TV (480i)</td>
<td>--</td>
</tr>
<tr>
<td>HD - TV</td>
<td>720p, 1080i 1920 x 1080, 24p f/s</td>
<td>Example: Bluray signals with full motion (720p, 1080i)</td>
<td>--</td>
</tr>
</tbody>
</table>

**Table 3  Offered Loads of Various Video Streaming Use Cases**

<table>
<thead>
<tr>
<th>Service</th>
<th>Bandwidth (H.264-codec)</th>
<th>One-way of Bidirectional over the WLAN</th>
<th>End-to-end Delay Tolerance (Including Network and codec)</th>
<th>Number of Channels (Unique Signals) Available</th>
<th>Simultaneous Viewers per Channel per Access Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable TV</td>
<td>1 to 4 Mb/s (SD) 6 to 10 Mb/s (HD)</td>
<td>One-way, downlink only</td>
<td>Channel changing affected after 300 msec</td>
<td>20 to 200</td>
<td>Occasionally</td>
</tr>
<tr>
<td>Live event video streaming</td>
<td>1 to 4 Mb/s (SD)</td>
<td>One-way, downlink only</td>
<td>300 msec target</td>
<td>1</td>
<td>Yes</td>
</tr>
<tr>
<td>Surveillance video</td>
<td>500 kb/s to 2 Mb/s</td>
<td>One-way, uplink or downlink</td>
<td>500 msec target</td>
<td>1 to 50 cameras</td>
<td>Seldom</td>
</tr>
<tr>
<td>Interactive video conferencing</td>
<td>1 to 2 Mb/s (SD for room scale)</td>
<td>Two-way</td>
<td>150 to 200 msec</td>
<td>Typically 1 to 5 groups</td>
<td>No</td>
</tr>
<tr>
<td>On-demand video</td>
<td>1 to 4 Mb/s (SD) 6 to 10 Mb/s (HD)</td>
<td>One-way, downlink only</td>
<td>300 msec target</td>
<td>Hundreds</td>
<td>No</td>
</tr>
</tbody>
</table>
A number of mobile applications (apps) are specific to higher education and are targeted at teaching and learning. These apps are in addition to the mobile apps that are popular within the social media and entertainment categories. Table 4 lists the most commonly found applications and their potential capacity demands.

### Table 4  Offered Loads of Common Network Applications

<table>
<thead>
<tr>
<th>Application</th>
<th>Typical Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haivision (stream)</td>
<td>2.5 Mb/s</td>
</tr>
<tr>
<td>DA Learning (stream)</td>
<td>1 Mb/s</td>
</tr>
<tr>
<td>AppleTV (stream)</td>
<td>2.5 Mb/s</td>
</tr>
<tr>
<td>FaceTime (stream)</td>
<td>900 Kb/s</td>
</tr>
<tr>
<td>Hulu/Netflix (stream)</td>
<td>2.5 Mb/s</td>
</tr>
<tr>
<td>Skype (stream)</td>
<td>150 Kb/s</td>
</tr>
<tr>
<td>Pandora (stream)</td>
<td>100 Kb/s</td>
</tr>
<tr>
<td>Blackboard (transaction + multimedia clips)</td>
<td>500 Kb/s</td>
</tr>
<tr>
<td>Facebook (transaction + multimedia clips)</td>
<td>500 Kb/s</td>
</tr>
<tr>
<td>Twitter (transaction)</td>
<td>50 Kb/s</td>
</tr>
<tr>
<td>Email (transaction)</td>
<td>50 Kb/s</td>
</tr>
<tr>
<td>Web surfing (transaction)</td>
<td>50 Kb/s</td>
</tr>
</tbody>
</table>

**Assessing the Physical Environment**

The reliability and performance of a Wi-Fi infrastructure depends heavily on characterizing and then leveraging the environment into which the components of the infrastructure are deployed. Assessing the residence hall environment is especially critical because of the high signal-to-noise ratio (SNR) levels required to deliver the fastest data rates is challenged by the signal attenuation incurred by building materials. Signal attenuation effects are two-fold. The effects hurt by increasing the minimum signal level required for reliable communication. However, simultaneously the same effects help to attenuate undesired or interfering signals. In the dense microcell architecture, we intentionally exploit this effect to deliver very high performance over smaller areas.

When the effect of building materials are considered, experience shows that the majority of residence hall deployments can be separated into three categories:

- New construction
- Legacy high attenuation
- Legacy low attenuation
New construction is subject to more stringent building codes than legacy or existing construction. Drywall, wood, and other flammable material have been replaced with concrete, cinderblock, and steel. As Table 5 shows, concrete, cinderblock, and steel highly attenuate Wi-Fi signals. When residence halls are constructed from these materials, room-to-room attenuation can be as high as 15 dB to 30 dB. The same levels of attenuation can be found for concrete and steel floors and ceilings as well.

### Table 5 Materials Attenuation Table

<table>
<thead>
<tr>
<th>Material</th>
<th>2.4 GHz</th>
<th>5 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior drywall</td>
<td>3 to 4 dB</td>
<td>3 to 5 dB</td>
</tr>
<tr>
<td>Cubicle wall</td>
<td>2 to 5 dB</td>
<td>4 to 9 dB</td>
</tr>
<tr>
<td>Wood door (Hollow - Solid)</td>
<td>3 to 4 dB</td>
<td>6 to 7 dB</td>
</tr>
<tr>
<td>Brick/Concrete wall</td>
<td>6 to 18 dB</td>
<td>10 to 30 dB</td>
</tr>
<tr>
<td>Glass/Window (not tinted)</td>
<td>2 to 3 dB</td>
<td>6 to 8 dB</td>
</tr>
<tr>
<td>Double-pane coated glass</td>
<td>13 dB</td>
<td>20 dB</td>
</tr>
<tr>
<td>Steel/Fire exit door</td>
<td>13 to 19 dB</td>
<td>25 to 32 dB</td>
</tr>
</tbody>
</table>

Legacy (pre-existing) construction spans a huge range of materials including stone, concrete, cinderblock, wood, drywall, and steel. Legacy environments built with stone, concrete, cinderblock, and steel show high levels of attenuation similar to new construction. Residence halls built with wood and drywall have significantly less attenuation; on the order of 3-4 dB room-to-room. Wood floors and ceilings also have 3-4 dB attenuation room-to-room, but you would typically use a figure of 10 dB for concrete.

Let’s look at some actual site survey results to get a better sense of what these attenuation values mean in practice. The survey in Figure 1 shows a room-mounted AP at a major southeastern university with so-called “stick” construction that uses wood or aluminum studs covered by drywall. You can easily see that though signal does propagate across several rooms, the highest data rates are confined to a three-room area.

**Figure 1** Slower Attenuation of 5 GHz Signal Through Stud and Wallboard Construction
The 5 GHz Ekahau site survey in Figure 2 shows a room-mounted AP in a newly constructed residence hall built from concrete block with concrete and steel floors. The survey demonstrates that room-to-room attenuation follows the predicted material attenuation fairly closely.

**Figure 2    Rapid Attenuation of 5 GHz Signal Through Concrete Block Walls**

This level of attenuation poses a significant challenge for hallway-mounted APs. However, this survey result shows the potential of room-level microcells to deliver very high performance in a small area, without compromising the ability to reuse the same channel at short intervals.

**Problem with Hallway APs**

As one of the largest providers of wireless infrastructure to educational institutions, Aruba understands that the tradition of mounting APs in hallways has been driven by a serious cost/benefit analysis. Aruba finds that hallway deployments have been preferred for some or all of the following reasons in most campuses:

- Simplicity and lower cost of sticking to hallways
- High cost of cabling and conduit due to hard ceilings and block or concrete walls
- Difficulty of arranging for access to student rooms for maintenance
- Risk of damage or theft of AP located inside a room

Hallway deployments were generally fine for a “best effort” convenience coverage SLA for devices primarily on the 2.4 GHz band. However, Aruba has sent engineers onsite to numerous college and university customers who reported poor coverage with this type of deployment. Onsite investigations show that even for best efforts coverage, hallway deployments pose many serious problems.
First, consider the site survey results (Figure 3) for hallway-mounted APs in 2.4 GHz and 5 GHz. The same attenuation rules discussed earlier apply for signal moving from a hallway into a student room.

![Figure 3 Poor Coverage of Student Room from Hallway-Mounted APs](image)

Now let’s look at the same floor on an AP-by-AP basis. You can see that the hallway APs are only providing coverage to the rooms whose doors face the AP. The rooms on either side of the AP are not receiving a strong signal.

![Figure 4 Individual hallway AP coverage is very limited (2.4 GHz AirMagnet Survey)](image)
The next step is to compare the 5 GHz signal. In this case it is a little better than the 2.4 GHz signal in this particular building. Usually our engineers find the opposite to be true (higher frequencies attenuate more).

**Figure 5** Poor student room coverage from hallway-mounted APs (5 GHz AirMagnet Survey)

This example is used to illustrate that different building materials can attenuate lower frequency signals more quickly. However, not only is the overall 5 GHz coverage unacceptable, but the per-AP results show that the hallway signal is largely unusable in most of the student rooms.

**Figure 6** Individual hallway AP coverage is very limited (5 GHz AirMagnet Survey)
These charts show that the usable signal mostly is in the hallway, not in the student rooms. Interior rooms, such as a lavatory or individual bedrooms in a suite, suffer additional attenuation such that the signal may be completely unusable. 5 GHz is much more affected than 2.4 GHz.

Another serious problem caused by hallway deployments is that APs can actually reduce their power automatically unless an administrator overrides the action. The automatic power reduction happens because the APs have a great view of each other, so ARM thinks that it can safely decrease radio power on most channels. This effect can also occur between floors, since “stacking” APs on top of each other vertically produces a similar effect.

Conversely, when APs are located in student rooms they tend to hear one another at reduced signal levels. Their default behavior is to increase power rather than reduce it, if adjustments are necessary. Experience now shows that for multimedia-grade residence halls, the cost/benefit calculations support in-room AP deployments. However, the next section describes why hallway APs may still be useful if you use the “separate coverage blanket” deployment model to minimize cabling retrofit costs.

A Next Generation Wireless Architecture for Residence Halls

This section explains the microcell strategy and how to adapt it to any residence hall. Two reference design scenarios are presented that cover the vast majority of residence hall deployments. The main difference between the two scenarios is the physical characteristics of the environment into which the design will be deployed.

Microcell Approach

The primary way to increase capacity within any Wi-Fi system is to add APs. For residence halls, one of the best architectures for increasing AP density to meet the growing user demand for increased capacity is the “microcell” (Figure 7).

A microcell architecture uses APs that are set for very low transmit power with a small cell radius that covers only a few rooms at most. When the density of APs is increased to one per room (or no less than one for every three rooms), the number of client devices associated with an AP is kept very low. When the SNR level inside each cell is kept very high, the fastest data rates are always available.
combination of high rates and low user counts per cell dramatically increases the capacity for each client.

To successfully deploy such a high density of APs within a small physical area, the microcell infrastructure must provide control over three critical factors:

1. The infrastructure must insure that the SNR within the RF channel between the AP and client is kept at a minimum of 25 dB to insure that the highest data rate is available within that cell. A quick check of the noise floor can help identify potential interference that can result in data rate degradation. This information is readily available from ARM.

2. The infrastructure must dynamically adjust AP frequencies for maximum channel orthogonality between physically adjacent APs (in three dimensions). The microcell architecture requires that a minimum of five available channels be used within the deployment zone to minimize interference. This minimum of five channels also allows for channel reuse to scale the architecture to the desired size. Effectively, the primary service delivery frequency band of the microcell architecture must be 5 GHz where eight or more channels are available. The three to four usable 2.4 GHz channels now become an overlay for legacy or low-speed devices that are not capable of being steered to 5 GHz.

3. The microcell infrastructure must balance AP and client power levels to meet the required SNR while keeping them low enough to prevent interference with other APs or clients. As a quick check, each AP should see no more than 20 neighbors. Otherwise, power levels may be set too high or APs may be too closely spaced.

In the upcoming section we will describe how to configure the Aruba ARM technology with the parameters that are recommended in various deployment scenarios. Then the controller and its associated APs will successfully and autonomously manage all three key factors, which makes microcell deployment extremely simple and reliable.

5 GHz vs. 2.4 GHz

The multimedia-grade residence hall must use the 5 GHz band as the primary service band for students. Using the 5 GHz band as the primary band may be a mindset change for some network administrators. However, we must stop thinking of “offloading” the 2.4 band (which implies that 2.4 GHz is primary). Instead, we must think of the 2.4 GHz band as the “legacy” or safety-net band to provide service to those devices that are not capable of using the extra capacity and speeds of 5 GHz.

The 2.4 GHz band has only three to four low-capacity channels available, and it will never scale to deliver high-capacity services. However, the 2.4 GHz band plays a vital role, which is to “bridge the gap” and allow legacy and low-speed devices to communicate within the microcell infrastructure. Today, smartphones are included in this group, because most do not yet support 5 GHz. Smartphones are easily capable of overwhelming 2.4 GHz channels, so it is a good idea to partition their traffic on a separate band.

Capacity Planning for a Residence Hall Microcell Deployment

To be certain of the capacity offered by the microcell approach, let’s analyze the typical offered load that is expected. The following common requirements are used:

- Three users per room, two devices per user, which is six devices per room
- Capacity consumed per user based on typical applications or services (see Table 4)
These applications and services have been tagged to characterize their type of traffic. Stream traffic represents a constant load or demand for capacity. Clips denote streams of limited duration such as 30 seconds of video or audio associated with a web page. Transactional traffic represents very bursty data with short to long gaps between transmissions. These traffic characterizations are important because they characterize more fully the demand for capacity. For example, video traffic is not bursty, but rather it is a constant stream of latency sensitive information. As such, the streaming rate of video cannot be discounted as would typically be done for email or web-surfing traffic based on their statistically bursty nature.

For the typical residence hall user, multitasking (concurrent application usage) behavior has been characterized as one multimedia video stream concurrent with two transactional conversations. Specifically, one video stream concurrent with email and web surfing. Table 6 lists the bandwidth required per device in the typical residence hall room.

<table>
<thead>
<tr>
<th>Application</th>
<th>Continuous Bandwidth</th>
<th>Bursty Bandwidth</th>
<th>Total Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video stream</td>
<td>2.50 Mb/s</td>
<td>--</td>
<td>2.50 Mb/s</td>
</tr>
<tr>
<td>Email (transaction)</td>
<td>--</td>
<td>50 Kb/s</td>
<td>0.05 Mb/s</td>
</tr>
<tr>
<td>Web surfing (transaction)</td>
<td>--</td>
<td>50 Kb/s</td>
<td>0.05 Mb/s</td>
</tr>
<tr>
<td>Total bandwidth per device</td>
<td>2.50 Mb/s</td>
<td>0.1 Mb/s</td>
<td>2.60 Mb/s</td>
</tr>
</tbody>
</table>

The particular video application that the user will choose is unknown, so we must assume the highest capacity application available, which is Haivision at 2.5 Mb/s. The two transactional applications selected add an additional 100 Kb/s. However, this traffic is very bursty and can be discounted heavily. Statistically, this traffic offers little to no load.

The maximum offered load per user device is approximately 2.6 Mb/s. Demand for capacity will only grow, so 5.2 Mb/s will be allocated per user device to allow for growth and time to plan for and fund the next infrastructure refresh. If you assume that each user carries two devices and each room has three users, the total offered load per room is 31.2 Mb/s.
Available APs for Microcell Deployments

Table 7 lists the APs that can deliver primary coverage at 5 GHZ to meet the offered load, provide an overlay at 2.4 GHz, and provide features that are advantageous to a microcell infrastructure.

Table 7  Residence Hall AP Options

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<thead>
<tr>
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<th>Dual Radios</th>
<th>Single Radio</th>
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<tr>
<td>Model</td>
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<td>AP-105</td>
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<td></td>
<td></td>
<td>AP-93</td>
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<tr>
<td></td>
<td></td>
<td>AP-93H</td>
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<tr>
<td>Radios</td>
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<td></td>
<td>900 Mb/s total</td>
<td>600 Mb/s total</td>
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<td>Minimum PoE Type</td>
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Be aware that though these APs can support either two or three spatial streams, the associated device may support only a single stream. For example, currently all iPads and most smartphones are 1x:1 HT20 devices. They support a maximum of one spatial stream in a 20 MHz channel width. Therefore, the highest PHY-layer data rate they support is 65 Mb/s, or about 40 Mb/s of Layer 4 TCP traffic.

These lower bandwidth devices are another argument in favor of deploying many low-power microcells in the residence hall environment. We don’t want a 1x:1 HT20 device to effectively lower the throughput of a 3x:3 HT40 laptop in the room next door, which is like getting stuck behind a slow driver in the fast lane. Reducing the coverage radius of each cell ensure that the only devices any given student is interfering with are their own (and perhaps their immediate neighbors).

RF Design – Choosing Attenuation Type

As mentioned earlier, successful microcell deployment is dependent upon achieving three critical factors. Two of those factors (frequency orthogonality and power-level balance) depend on the how the RF signals propagate through building construction. The microcell architecture relies on a certain amount of signal attenuation through building materials to help isolate cells from one another. In other words, we make lemonade out of lemons by using the structure itself to enforce cell size and increase the gross capacity of the system.

As described in “Assessing the Physical Environment,” the majority of residence hall environments can be divided into one of three scenarios; new construction (high attenuation), legacy (existing) construction with high attenuation, and legacy construction with low attenuation.
From a signal attenuation perspective, these three environments can be collapsed into two design scenarios: high attenuation and low attenuation (see Table 8).

**Table 8  Planning Categories**

<table>
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<tr>
<th>Type</th>
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<th>Room-to-Room Attenuation</th>
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<tr>
<td>High Attenuation</td>
<td>Stone, Concrete, Cinder Block, Steel</td>
<td>15 to 20dB</td>
<td>10 to 20dB</td>
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<td>Low Attenuation</td>
<td>Wood, Sheetrock</td>
<td>3 to 10dB</td>
<td>10 to 20dB</td>
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Select the appropriate type for each of your residence halls to determine which microcell density to deploy. If you are not sure or are new to RF design, the best practice is to survey a small portion of that environment (one or two floors) with AirMagnet Survey, Ekahau Survey, or a similar tool. Verify that the average attenuation falls within the range of the selected scenario. Then use the following design scenarios as a template for AP density, placement, and associated controller configuration.

**RF Design – Separate Coverage Blankets**

Aruba has an especially powerful and cost-saving method for customers that need to retrofit existing construction and do not have spare in-room cabling or the funding or physical ability to pull new cables to each room. This technique is also a great option if you do not want to purchase dual-radio APs for every location in a residence hall to save money. Aruba calls it using “separate coverage blankets.”

A critical concept of this next-generation wireless architecture is that the 5 GHz and 2.4 GHz bands do different jobs. Therefore, they need not use the same coverage strategy. In fact, instead of using a single “blanket” of dual-radio APs everywhere, you deploy two separate “blankets” of single-radio APs. Figure 8 shows what separate coverage blankets look like.

![Figure 8](Image)

**Figure 8  Separate Single-Radio Coverage Blankets**

Single-radio APs are less expensive than dual-radio APs, and 5 GHz is the primary service band. So you can cover the student rooms at lower overall cost by placing AP-93 or AP-93H at the required...
density. In the hallways, which typically provide 2.4 GHz service anyway, deploy more single-radio AP-93H in 2.4 GHz only to provide the legacy coverage blanket.

The AP-93H is an excellent choice for a single-band microcell AP. The AP-93H provides the required bandwidth to meet the offered load. The AP-93H also integrates a four-port, managed Ethernet switch to connect wired devices, such as an Ethernet-enabled HDTV, gaming device, VoIP phone, or any wired device. As mentioned previously, any additional offered load from wired devices must be considered as part of the total design. Otherwise, backhaul bandwidth maybe adversely affected.

This approach offers tremendous cabling cost savings for retrofits. Typically, the hallway APs already exist, so no new wiring is required in a split-coverage blanket design. In the student rooms, you can plug the existing Cat5E cable into the AP-93H and provide up to four wired ports, so no functionality is lost. In other words, you can have a microcell deployment with virtually no cost other than the APs.

**RF Analysis of Microcell Design**

Aruba customers are beginning to deploy the 5 GHz microcell design with great success. To bring the discussion full circle, let’s review some AirMagnet site survey results from a microcell deployment. Figure 9 shows a composite of a residence hall after in-room APs have been deployed. This particular dorm is a high attenuation facility with concrete block walls between individual rooms.

![Figure 9: Microcell deployment provides excellent coverage across entire floor (5 GHz AirMagnet Survey)](image)

The improvement in overall coverage is immediately obvious as compared with the composite survey of hallway APs in Figure 3 on page 11. If we look deeper, on a room-by-room basis, the difference is even more marked. Figure 10 shows four randomly selected rooms on this floor. You can see that while there is some room-to-room signal bleed, that overall attenuation falls off very rapidly as predicted above.
The result of the microcell approach can be seen as room-level Wi-Fi cells, similar in performance to personal APs but with all the advantages of centralized management and policy enforcement.

**Figure 10**  Room-by-room propagation of selected microcells (5GHz AirMagnet Survey)
Microcell Reference Design #1: High Attenuation

Consider a hypothetical residence hall with the following characteristics:

- Four floors per building or wing
- 20 rooms per floor
- Concrete construction between floors
- Concrete or cinder block construction between rooms
- Three users per room with two devices per user
- Per-user offered load of 10 Mb/s, total room offered load of 30 Mb/s

High-attenuation structures are by far the best for microcell because we have little choice but essentially to provide one cell per room/suite. With 20-30 dB of SNR drop across the wall, we can fully harness the building itself to create islands of coverage that do not interfere with one another. Figure 11 shows the high-attenuation microcell structure with one AP per room/suite.

![Figure 11](image_url)

**Figure 11** High-Attenuation Microcell with One AP Per Room/Suite

For maximum performance and compatibility with the latest laptops, the dual-radio AP-135 is recommended to provide a primary service delivery at 5 GHz that is capable of supporting the total offered load while offering 2.4 GHz overlay coverage. APs are placed on the ceiling of each room and use their integral downtilt antennas to limit signal propagation into adjacent rooms and the hallway. Wall mounting is also acceptable with these APs if preferred or required due to cabling or other restrictions. For wall mounting, place the AP roughly 3 feet above the floor to reduce the attenuation effect of furniture and other items in the room itself.

With such a dense microcell AP deployment, AP power must be set appropriately to minimize propagation beyond the room in which the AP is deployed. At 5 GHz, the appropriate range is from 3 dBm to 6 dBm. Due to its increased propagation through building material, coupled with its limited number of non-overlapping channels, 2.4 GHz must be handled differently. The deployment is too dense to turn on a 2.4 GHz radio in every room. As such, the 2.4 GHz power range is set from 9 dBm to 15 dBm. ARM analyzes and determines which 2.4 GHz radios to enable (using the Mode-Aware ARM feature). With signal attenuation between rooms at 15-20 dB, signals propagate only as far as two rooms before dropping into the noise. If DFS channels are in use, currently only 20 channels are available in the United States. If DFS channels are not in use, channel reuse is still assured with 9 non-overlapping channels available, which allows the architecture to scale to any desired size.
APs are backhauled over Gigabit Ethernet to their associated controller using new or existing wiring. APs are powered via standard 802.3af PoE. Aruba appreciates the cost and difficulty to retrofit existing construction with new Cat5E/6 wiring. Fortunately, many institutions are decommissioning wired LAN ports in residence halls, which can simply be reused in many cases for the in-room microcell AP. If some of your residence halls have no free cables and you must maintain one link to each room for a phone or other device, use the single-radio AP-93H with an integrated 4-port switch and accessory passthrough port.

**Microcell Reference Design #2 - Low Attenuation**

The second reference design scenario addresses a residence hall with better RF signal propagation:

- Four floors per building or wing
- 20 rooms per floor
- Concrete construction between floors
- Drywall construction between rooms
- Three users per room with two devices per user
- Per-user offered load of 10 Mb/s, total room offered load of 30 Mb/s

In this type of structure, the AP is placed in the middle room of every three adjacent rooms and its integral antenna is used to create a microcell that encompasses all three rooms. APs are also staggered across the hallway from one another to help manage propagation of adjacent channel interference between APs. In three dimensions, the room APs should also be staggered vertically rather than stacked on top of each other in the same position on each floor. Imagine a three-dimensional checkerboard pattern.

![Figure 12](image-url)  
**Figure 12**  
*Low Attenuation Microcell with One AP for Every Three Rooms/Suites*

It is even more critical here than in the High Attenuation scenario for AP power to be set appropriately. AP power must be set to minimize propagation beyond the room in which the AP is deployed and the
adjacent rooms served. At 5 GHz, the appropriate range is from 15 dBm to 18 dBm. Due to its increased propagation through building material coupled with its limited number of non-overlapping channels, the 2.4 GHz band again must be handled differently. The deployment is likely too dense to turn on a 2.4 GHz radio in every room, especially because building material attenuation is so low. As such, the 2.4 GHz power range is set from 9 dBm to 15 dBm, then ARM analyzes and determines which 2.4 GHz radios to enable.

As in the High Attenuation scenario, APs are backhauled over Gigabit Ethernet to their associated controller using new or existing wiring. Power to the AP is supplied over the Ethernet backhaul cable as well, which allows better options for power-fail management of critical services such as wireless VoIP. Any additional offered load from wired devices must be considered as part of the total design. Otherwise, backhaul bandwidth maybe adversely affected.

**Coping With Financial Constraints and Other Realities**

Moving from a coverage-based to a capacity-based infrastructure certainly requires new investment. However, depending on the specifics of the deployment, some alternatives might be used to reduce or delay that investment.

**Alternative AP Density**

For some, the cost of deploying an AP per room may be prohibitive. If the required SNR of 25 dB can be maintained, the number of deployed APs may be reduced based on the actual building attenuation. This determination demands that a comprehensive site survey be performed to fully characterize the environment. In areas where the measured attenuation will allow, the number of APs deployed may be reduced by a factor of three or four. However, more consideration must now be given to the total microcell offered load. If an AP must cover more rooms, the total channel capacity is reduced, which ultimately impacts the available per-user capacity. In addition, it becomes harder to balance signal power to prevent adjacent channel and co-channel interference from reducing channel capacity.

**Leveraging Existing Wire/Mesh Backhaul**

Two options exist to help reduce the cost of backhauling APs to the building switch/controller. In cases where previous infrastructure (either wired or wireless) is being replaced, existing wiring may be leveraged to backhaul the new APs if sufficient capacity can be obtained from that wire. Alternatively or used in conjunction with existing wire, wireless mesh backhaul may be deployed as an alternative to installing new wire.

**Additional Considerations**

To achieve the required capacity and reliable performance within the residence hall as described in this document, the deployed infrastructure must be smart and dynamic. The wireless environment is changing constantly with devices roaming in and out, people and objects moving about, and often the RF environment is noisy. These changes are too rapid to be managed manually, thus we depend heavily on the intelligence of the infrastructure to adjust dynamically to its environment.

When you build a capacity-based infrastructure, consider several factors to assure its success.
Managing Available RF Spectrum

Until white space or other frequency allocations are available, currently two frequency bands are available for Wi-Fi deployments: 2.4 GHz and 5 GHz. Within the 2.4 GHz segment, eleven 20 MHz channels have been allocated. As these channels overlap RF spectrum, only three channels out of these 11 are available for use. (In the past, some customers have used a four-channel plan, but this is suitable only for very low duty-cycle deployments. Residence halls are not that type of deployments.) With only three orthogonal channels available, capacity is extremely limited. Thus, while possible on a small scale, 2.4 GHz is not the best choice for capacity-based environments.

At 5 GHz, up to 20 non-overlapping channels of 20 MHz each are available. The substantial increase in spectrum over 2.4 GHz results in much greater available capacity. 5 GHz is the only real choice for propagating multimedia.

To preserve the 2.4 GHz spectrum for those clients who cannot use anything else, the AP and its associated controller should be capable of steering devices from 2.4 GHz to 5 GHz where possible. “Band-steering” clients away from 2.4 GHz frees up precious, limited capacity for 2.4 GHz-only devices and gives 5 GHz-capable devices access to greater capacity.
Airtime Fairness

As organizations increasingly support a “bring your own device” environment, it becomes more important to have the infrastructure manage access to airtime, so that older devices do not jeopardize the wireless resource and starve newer high-throughput clients. Airtime fairness techniques dynamically manage the per-client airtime allocation. Before airtime is allocated, Airtime Fairness looks at traffic type, client activity, and traffic volume, which ensures that all clients have acceptable performance for multimedia applications. Airtime Fairness is especially important in high-density environments, and is a critical component in any capacity-based infrastructure.

Enabling Mobility

First and foremost, enabling mobility means deploying a ubiquitous Wi-Fi infrastructure within the residence hall and most likely beyond. With converged clients, such as the iPhone, Blackberry, and Android derivatives, an acceptable user experience is achieved only if the client is allowed to roam. This requires network ubiquity.

Though not supported by some clients, standards-based techniques such as Opportunistic Key Caching and PMK-Caching should be used wherever possible in the wireless infrastructure to promote faster roaming among APs. Active initiatives in the Wi-Fi Alliance such as IEEE 802.11k and 802.11r seek to standardize these capabilities.

Mobile address management is critical as well, and it requires mechanisms to preserve or re-establish connectivity while maintaining sessions. Emerging “fast roaming” technology should be explored for voice environments to preserve call quality and continuity.

Quality of Service

A capacity-based Wi-Fi infrastructure must support QoS from end to end. On the Wi-Fi side, adherence to 802.11e is required. QoS should then be mapped appropriately and seamlessly from Wi-Fi to the edge and through the core. In some situations, devices cannot conform to 802.11e. The Wi-Fi system should provide additional mechanisms to identify then map traffic to other mechanisms in the system that will deliver or assist in providing the required level of service. For example, video traffic can be segregated by mapping it to a specific set of SSIDs, which are then mapped to appropriate VLANs in the edge and the core. This mapping allows devices that associate with that SSID to use those services at the required level of QoS. Preferably, the Wi-Fi system would support traffic segregation on a per-session basis. This option is better for converged multimedia communications and a more granular approach to managing bandwidth and policy. The ability to identify and manage multiple streams from one device or even one application without the need for separate VLANs is even better.

SSID Count and Application Performance

Another negative effect that comes from adding an SSID for every device type or application is reduced air quality. Every new SSID adds management traffic to the air and negatively impacts application performance. It is critical to reduce SSIDs and use other means to prioritize traffic and segment users.
Optimizing Multicast for Application Performance

In the quest to preserve precious wireless bandwidth, multicast can be quite effective given the right content paradigm. Anytime video content is broadcast, as opposed to requested on-demand, multicast can potentially save significant bandwidth. For example, if one channel of standard broadcast quality CNN video were streamed using MPEG-2, it would consume 2 Mb/s of bandwidth. If 50 people associated with an AP and 20 of them chose to watch CNN, a unicast delivery scenario would mean each user would receive their own copy of the broadcast. That is 20 users requiring 2 Mb/s each or 40 Mb/s of wireless bandwidth being steadily consumed. In a multicast scenario, the content is streamed only once per AP and every user on that AP accesses that same stream. Thus only 2 Mb/s per AP is consumed, which leaves plenty of bandwidth for other uses.

However, multicast suffers from two critical disadvantages. Per the 802.11 standard, multicast traffic is not acknowledged. Clients cannot indicate to the transmitter that they missed a packet and because there is no retransmission mechanism. Any errors due to lost packets cannot be corrected. Multicast over Wi-Fi compounds this difficulty. Wireless frames are subject to loss and corruption over the air. These factors are addressed in a unicast connection using 802.11 protocol features such as acknowledgements, retransmission, and rate adaptation. But with 802.11 multicast, there is no acknowledgement or adaptation, and therefore some level of frame loss is inevitable. The error rate can be reduced by adjusting the modulation rate, given a constant over-the-air SNR. For instance, if the rate is reduced from 48 Mb/s to 24 Mb/s, the error rate is improved, provided that the noise level does not change. Because of the lack of acknowledgements, 802.11 multicast traffic is usually transmitted at a much lower rate than would be used for unicast traffic. Slower transmission of 802.11 multicast traffic takes more time on the air, which consumes more of the network data capacity, but provides a margin of safety in case RF conditions deteriorate.

The other disadvantage with multicast over Wi-Fi is that the modulation rate is set for the worst case among the client population, which is normally the client that is most distant from the AP. For example, if four clients on an AP subscribe to a multicast group and connect with unicast traffic rates at 36, 36, 24, and 18 Mb/s, then the multicast stream must be transmitted at a maximum of 18 Mb/s. A safer figure would be 12 or 9 Mb/s, which gives a better SNR to improve error rates and throughput. Despite this improvement in SNR and thus throughput, clients associated at higher rates are throttled back to this slower rate. (See Figure 15.)

---

**Figure 15**  Multicast Traffic Uses the Lowest Data Rate
Experience has shown that though multicast can conserve bandwidth, the reality of Wi-Fi is that it may take some bandwidth away due to increased errors rates. To effectively propagate the content, the modulation rate must be lowered at the expense of network capacity. A capacity-based Wi-Fi infrastructure must be flexible and accommodating and allow selection of the best methodology for multimedia propagation in a given environment. These critical multicast optimization techniques support multimedia in capacity-based environment:

- The Wi-Fi infrastructure should automatically adapt by tracking the transmit rates that are sustainable for each associated client and using the highest possible common rate for multicast transmissions.
- The Wi-Fi infrastructure must support IGMP snooping and IGMP proxy. Ideally these features should be supported at the central controller, so that it can identify which APs and clients need particular transmissions and block all others. This ability makes the overall network significantly more efficiency.
- The Wi-Fi infrastructure automatically should select the best transmission mechanism based on real-time network and video usage information. When multicast is transmitted as unicast over the air, it can be transmitted at much higher speeds and has an acknowledgement mechanism to ensure reliability. The network should make this conversion when appropriate and then automatically switch back to multicast when the client count increases high enough that the efficiency of unicast is lost.
## Contacting Aruba Networks

### Web Site Support

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### 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 (UFIN):

- **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
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