802.11ac: Essential Considerations

Getting Ready to Catch 11ac Wave 1

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Introduction

One of the greatest challenges facing Wi-Fi is getting the most out of the RF spectrum that 802.11 devices are allowed to use. And even though more RF spectrum may become available for Wi-Fi use in the US, it remains a finite and therefore precious resource. To support increasing numbers of Wi-Fi client devices and rising bit rates common with applications such as video streaming and video conferencing, users need to utilize this finite RF spectrum as efficiently as possible.

With the implementation of the 802.11ac standard, we see a significant improvement in how RF spectrum is used. In many ways 11ac picks up where 802.11n left off by building on many of the successful techniques used by 11n. With 11n we saw a number of very clever techniques introduced such as frame aggregation, MIMO and wider channels that effectively made more effective use of the RF spectrum. With 11ac we see enhancements to a number of innovations introduced by 11n plus one new feature, MU-MIMO, which is a radical departure from anything found in previous 802.11 standards.

This paper will introduce 11ac features, offer some guidance to those who are considering upgrading to 11ac, discuss deployment considerations, and provide an overview of AirTight Networks' first 802.11ac access point, the C-75.

802.11ac Features and Benefits

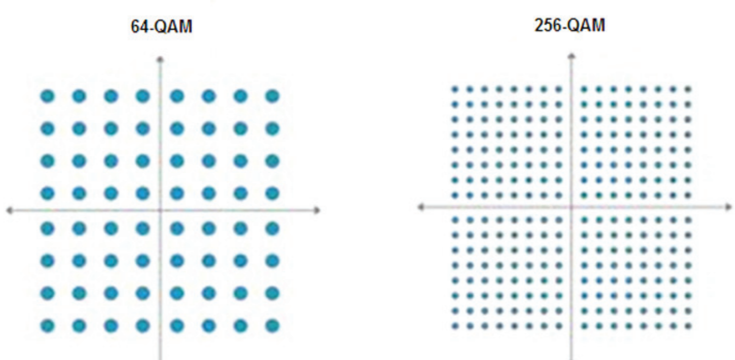
More Spatial Streams

With 11n we witnessed how effective it was at supporting multiple spatial streams to boost performance. And as it was with 11n, doubling the number of spatial streams in 11ac will double the amount of throughput capacity. The first implementations of 11ac devices (Wave 1) are currently available and typically see up to three spatial streams (3ss). When 11ac Wave 2 becomes available it will support up to eight spatial streams (8ss). Realistically however, it is unlikely that 8ss devices will be built anytime soon due to the cost and complexity of providing eight antennas. Most in the industry expect the first batch of Wave 2 products to support up to 4ss.

Higher Encoding Density

With 11n we have a modulation scheme with up to 64-QAM. With 11ac we see the introduction of 256-QAM. The top modulation coding sets of 11ac (i.e. MCS-8 and MCS-9) rely on 256-QAM and the higher encoding density of 256-QAM allows transfer of more data per MHz. However, 256-QAM rates can only be sustained over relatively short distances (typically up to 25 feet). As a result, many 11ac networks, at least initially, will likely be built such that 256-QAM rates will only be used for a fraction of overall coverage. The constellation diagrams for 256-QAM and 64-QAM provided below help illustrate how bits are packed closer together with 256-QAM compared to 64-QAM.

64-QAM vs. 256-QAM



Larger Frame Aggregations

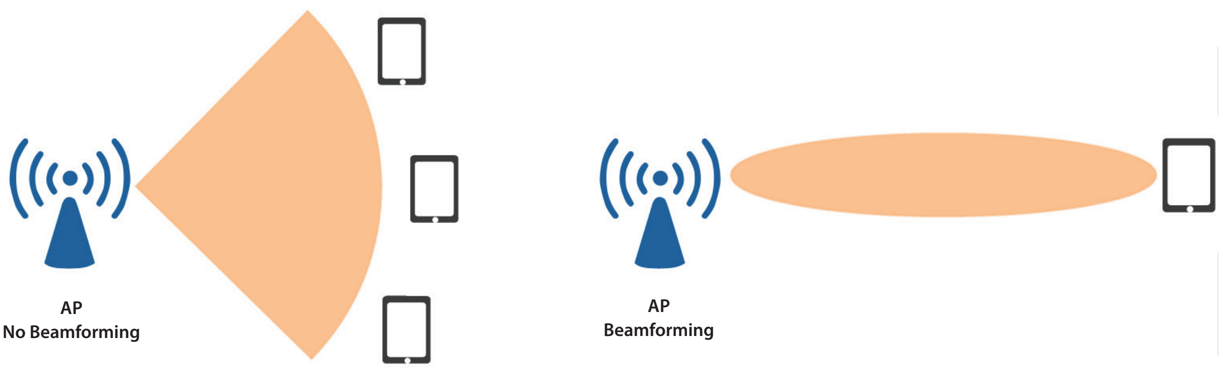
Frame aggregation was first introduced in 11n. With frame aggregation, each individual 802.11 unicast frame no longer needs to be acknowledged by the receiver. (Note: Multicast and broadcast frames are not acknowledged in 802.11.) Instead, fame aggregation allows blocks of frames to be acknowledged all at once increasing the efficiency of the 802.11 protocol. With 11n, aggregates can be up to 64k bytes. With 11ac, aggregations can be as large as 1M bytes.

Transmit Beamforming (TxBF)

Transmit beamforming uses two or more transmit antennas to create constructive interference as a way to boost the signal strength at the client's location. While beamforming is part of the 11n specification, it is not consistently or widely implemented. This is mainly due to the number of alternative ways it can be implemented within the 11n standard. With 11ac however, beamforming is more clearly defined to ensure greater adoption by WLAN device manufacturers.

At first glance, it may seem counterintuitive that the potential signal strength gain of beamforming is inversely proportional to the number of antennas that the receiver has. Take the example of a 3ss 11ac AP transmitting to a 2ss client where the expected gain in signal strength using TxBF could be up to 3dBm. If we use the same AP but transmit to a 1ss 11ac client, the expected boost in signal strength using TxBF could be up to 7dBm. This is because the transmitting AP in each example can use all three of its antennas to send the same bits of data in a unique way in terms of phase and/or amplitude. The signals reach the receiver in an additive combination to effectively improve signal strength. The diagram below shows a simple illustration of an AP without and an AP with beamforming.

AP Without and With Beamforming

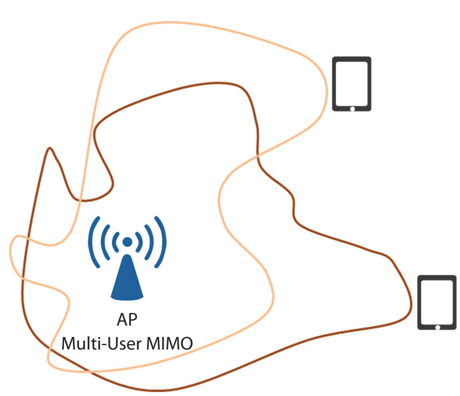


Multi-User MIMO (MU-MIMO)

MU-MIMO introduces a revolutionary approach that is a big departure from anything seen previously in Wi-Fi. MU-MIMO gives 802.11 switch-like functionality allowing an 802.11ac AP to transmit to as many as four devices simultaneously.

This Wave 2 feature supports one direction only for transmission from an AP to its clients. Like transmit beamforming, MU-MIMO uses sounding frames, channel state information and complex mathematics to beamform a signal to each client. MU-MIMO can accomplish simultaneous transmissions to multiple clients by using a combination of formed beams and null beams where the formed beams reach the intended clients and the null beams do not reach the other clients, as shown in the image below.

Multi-User MIMO



Wider Channels

With 11n we saw the introduction of 40 MHz channels. With 11ac there is support for channels up to 80 MHz for Wave 1 and up to 160 MHz for Wave 2. Doubling the channel width provides slightly more than double the throughput capabilities. It should be noted that we are likely to see many 11ac networks built with 20 MHz and 40 MHz channels, particularly in high client density deployments or where too few 80 MHz channels are available, such as areas lacking DFS channels. However there will still be many opportunities for 80 MHz channel plans and use of 80 MHz should be considered in high throughput environments.

Unless more spectrum is made available, it is unlikely that we will see networks with a 160 MHz channel plan as there are not enough channels to make this work. There is only a single 160 MHz channel available in the US and there are only two available in Europe. The table below lists the number of 40, 80 and 160 MHz channels available as of this writing, for Europe and the US including DFS channels.

Available 802.11ac Channels by Channel Width

Channel Width	Europe	US
40 MHz	9	10
80 MHz	5	5
160 MHz or 80+80 MHz	2	2

802.11ac Wave 1 vs. Wave 2

The 802.11ac standard consists of two major implementations, Wave 1 and Wave 2. While 802.11ac is currently approved only Wave 1 compatible APs and clients are currently available on the market. As of this writing, development of the Wave 2 products is just underway and Wave 2 devices are not expected to be readily available until 2015. Here is a quick look at how Wave 1 compares to Wave 2.

802.11ac Wave 1 and Wave 2 Comparison

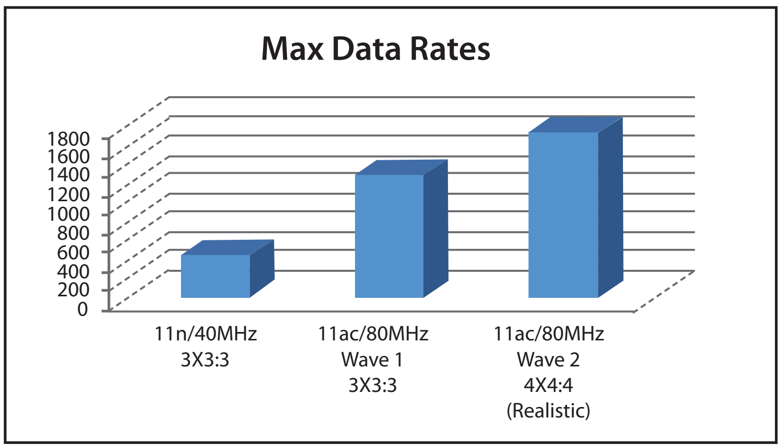
Feature	Wave 1	Wave 2 Realistic	Wave 2 Theoretical
Maximum spatial streams	3	4	8
Widest channels supported	80 MHz	80 MHz	160 MHz
Top modulation schemes	256-QAM	256-QAM	256-QAM
Peak data rates	1.3 Gbps	1.733Gbps	6.9 Gbps
Beamforming support	Yes	Yes	Yes
MU-MIMO support	No	Yes	Yes

On paper some of the differences in features are quite dramatic, when comparing Wave 1 to Wave 2 theoretical, which may lead some to consider waiting for Wave 2 products before upgrading to 11ac. However as mentioned previously, it is likely that Wave 2 APs will not support more than 4ss only, at least in the foreseeable future. This means that the difference in the top end speed of Wave 1 and likely top speed of Wave 2, which are 1.3 Gbps and 1.733 Gbps respectively for 80 MHz channels, will not be very significant. Also, it will likely be a number of years before APs that support 5ss or 6ss are available and the likelihood that 11ac clients will support more than 4ss is even less.

While MU-MIMO is a revolutionary innovation, it is unclear how much of a gain in performance it will yield in practice, particularly in early implementations of the feature. It is also uncertain just how widely it will be implemented on first generations of Wave 2 APs and client devices.

The graph below compares the top 11n rate (as implemented at 40 MHz), the top 11ac Wave 1 rate and the realistic top 11ac Wave 2 rate (at 80 MHz). For 11ac rates, an 80 MHz channel is used as this will likely be the widest channel used in most multi AP networks until more spectrum is made available.

11n vs. 11ac Wave 1 vs. 11ac Wave 2



When comparing the maximum data rates in the graph above, it is clear that the bigger gain in throughput capacity is realized when upgrading from 11n to 11ac Wave 1 rather than when going from Wave 1 to the Wave 2 (for the maximum data rate we are likely see in practice). As a result, adoption of Wave 1 technology now vs. waiting another year for Wave 2 may be a better investment, especially if the need for more throughput capacity or lower application latency has reached a critical stage.

Do you need 802.11ac?

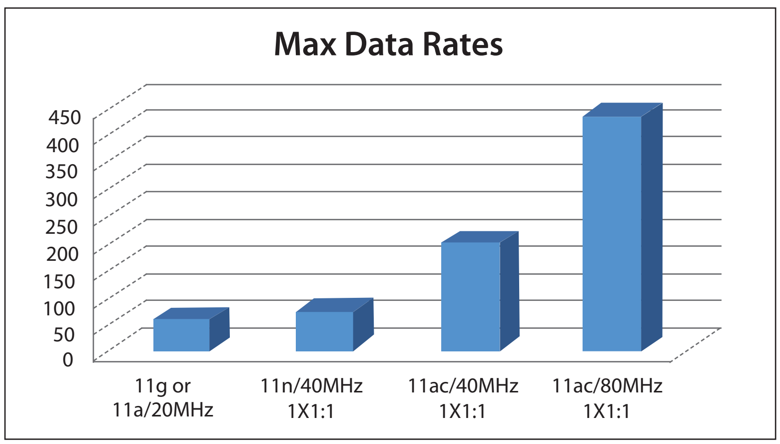
Whether or not 802.11ac is needed for portions of a deployment or pervasively throughout the installation is really use case driven. When designing a Wi-Fi network to meet use case requirements there are a number of elements that need to be considered including:

- Client types
- Client densities
- Applications in use
- Per client throughput SLAs
- Coverage area

While it is true that the vast majority of clients in use today are not 11ac, new 11ac client devices are beginning to show up in force. A number of very popular client devices are now using 11ac chips such as the new MacBook Air (2x2:2), MacBook Pro (3x3:3), HTC One (1x1:1) and the Galaxy S4 (1x1:1), to name a few.

Single spatial stream clients, such as tablets and smartphones, stand to gain the biggest boost in performance with 11ac. The following graph compares maximum data rates for legacy clients (11g or 11a), single spatial stream 11n clients (11n/1ss)* and single spatial stream 11ac clients (11ac/1ss). There are two things that are quite striking about the graph below. Notice how legacy and 11n/1ss clients share similar top data rates and how much higher the maximum data rate is for 11ac/1ss clients (80 MHz) than 11n/1ss clients. With this observation in mind it is not hard to understand why the prevalence of single stream devices is often cited as a big driver for adoption of 11ac.

11n vs. 11ac Wave 1 vs. 11ac Wave 2



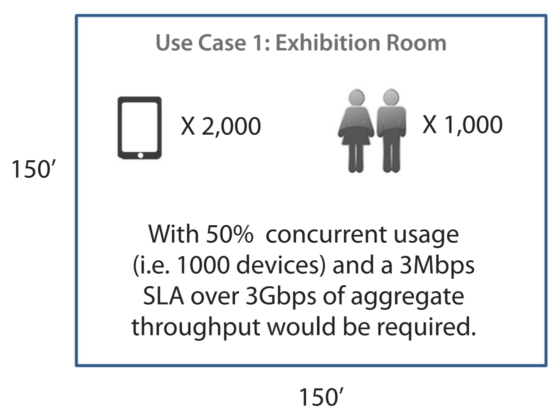
* Data rates shown for 11n/1ss are for 20 MHz channels as the majority of these types of devices that are currently in use do not support 40 MHz channels.

Use Cases

In this section two use cases are presented where 11ac would be required and a third use case is shown where 11ac would not be needed. It should be noted that these use case examples use first order approximations since true WLAN design is beyond the scope of this paper. Also worth noting is that for these examples, clients are expected to receive similar amounts of throughput. In actual production networks, throughput levels may vary among clients even when airtime scheduling mechanisms are used.

Use Case 1: Hospitality – Exhibition Room

This first example use case is for a 30,000 square foot, open area exhibition room that can accommodate up to 2,000 attendees. One of the main goals of the design is to be able to provide a 3 Mbps SLA to each active device. Providing the aggregate level of throughput needed to meet the stated SLA for that many devices would be a very tall order for 11n, even if all channels (including DFS channels) were available.



If only half of the attendees were to use the network concurrently, the aggregate throughput demand would be over 3 Gbps (i.e. 1000 users x 3 Mbps = 3 Gbps). It would be very difficult to provide this much aggregate throughput using 11n in this particular room because the space is open making it unlikely that channels could be reused as a way to provide additional capacity.

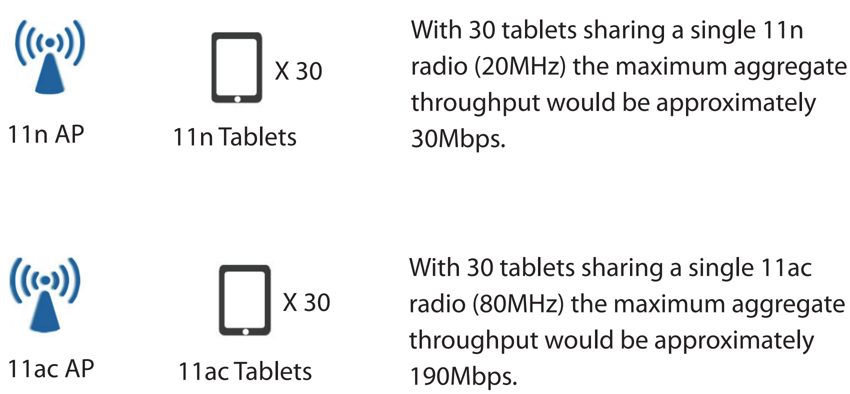
This first use case is sometimes referred to as high density/high throughput (HDHT). High density refers to high client density for the given area and high throughput refers to the high aggregate throughput demands for the area. It is important to stress the point of factoring in the fixed size and open environment of the Exhibition room which prevents the reuse of Wi-Fi channels. However, with a large enough area, even legacy APs can provide an SLA of 3 Mbps to 1000 devices because Wi-Fi channels can be reused again and again.

Use Case 2: Classroom Video

This use case is for a middle school that uses video as a key part of its curriculum. The school intends to expand the use of video and to regularly use HD video content as more of it becomes available. The school will provide each student with a tablet. The combination of HD video and tablets, which are typically single spatial stream devices, is challenging for 11n, particularly when up to 60 students attempt to access one or two 11n APs at the same time. As mentioned previously, with 11ac we can achieve a major gain in performance for 1ss 11n clients, particularly since the majority of these clients do not support 40 MHz channels.

As seen in the image below, the potential aggregate throughput for an 11ac design of approximately 190 Mbps is much greater than for an 11n design of approximately 30 Mbps. When we consider that a single HD video stream can run at bit rates of 3 to 6 Mbps it is clear that the 11n option will not work.

Use Case 2: Classroom Video



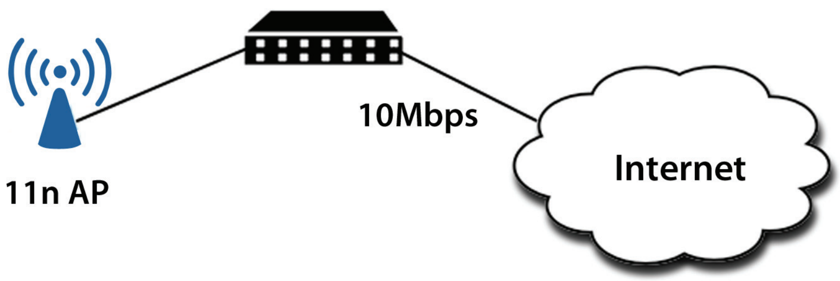
This second use case is sometimes referred to as low density/high throughput (LDHT). While the client density is low in this example, the aggregate throughput required is quite high for one or two APs.

What the exhibition room and middle school use cases share in common is a need to support high throughput for a given area. In these scenarios 11ac can really help. While 11ac may seem complicated with all of the techniques used to boost performance, at a certain level it simply comes down to the fact that, based on a one-to-one comparison, 11ac can deliver much higher throughput capacity than 11n for a given area and a given number of APs. 11ac accomplishes this using the same 5 GHz spectrum available to 11n, but in a more efficient way.

Use Case 3: Quick Service Restaurant

For this use case we have a small quick service restaurant (QSR) where the connection to the Internet is 10 Mbps and there are no locally hosted application servers for either the staff or the patrons. The maximum number of customers and staff members inside the restaurant at any time is not expected to exceed 60. Just knowing this information about the use case is enough for us to determine that 11n is more than adequate for the restaurant. We know this because all traffic is destined to the 10 Mbps Internet link and the capacity of a single 11n AP can exceed this without any difficulty.

Use Case 3: QSR



Even if all clients are legacy (e.g. 11g and /or 11a) a single 11n AP can easily fill up a 10Mbps link to the internet.

Use case 3 is an example of a low density/low throughput (LDLT) network. We can safely say that 11n APs will be more than capable of handling these types of environments. The key assumptions are that the throughput demands for this type of deployment are likely to remain low, that Internet connection speeds will remain at 10 Mbps, and application services will not be locally hosted (e.g. video gaming).

How do you deploy 802.11ac?

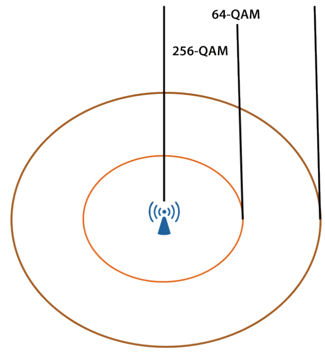
As mentioned previously, 11ac builds on features that were first introduced with 11n, but the differences between 11n and 11ac can profoundly affect the way 11ac networks are designed, particularly if an 11ac network is to be built for optimal performance. This section provides an overview of the main points to consider prior to deploying an 11ac network.

Signal Strength

Modulation and coding scheme (MCS) rates that use 256-QAM require higher signal strengths compared to 64-QAM. With 256-QAM there are 256 possible combinations of amplitude and phase shift in a single RF symbol, compared to only 64 combinations with 64-QAM. With 256-QAM, more bits of information are packed into each symbol, which leaves less room for error when the receiver decodes the signal. The higher the signal strength and signal to noise ratio (SNR), the more likely the receiver will successfully read the frame.

A signal strength of approximately –64 dBm or greater is needed to support the top 64-QAM data rates with 20 MHz channels.
A signal strength of approximately –52 dBm or greater is needed for the top 256-QAM rates with 80 MHz channels. This can have a big impact on how 11ac networks are designed. To help illustrate how this may affect WLAN network designs, a simple comparison of 64-QAM and 256-QAM rate coverage areas is provided below.

Coverage Comparison: 64-QAM vs. 256-QAM



Switching Infrastructure

When conditions are right, a single 11ac AP can achieve throughput rates approaching 1 Gbps. In order to accommodate such rates, edge switches need to have 10 Gbps connections back to distribution switches and distribution switches will need 10 Gbps (or greater) connections to core switches.

Controller Connectivity

For WLAN systems that require data traffic to be tunneled back through controllers, upgrading to 11ac typically means upgrading controllers to support 10 Gbps uplinks. This is due to the high throughput capability of 11ac which can easily oversubscribe 1 Gbps controller uplinks. For cloud-based or controller-less solutions this is a non-issue.

AP Connectivity

Because an 11ac Wave 1 AP is capable of throughput approaching 1 Gbps, each AP should be connected via one or two GigE connections. For Wave 2 APs, the general recommendation is to provide two GigE connections per AP because Wave 2 APs will be able to support data throughput rates well beyond 1 Gbps.

PoE

While there are some exceptions, most enterprise-grade 11ac APs typically require 802.3at PoE to support full functionality. Operating these APs on 802.3af PoE will reduce functionality which cancels many of the benefits of migrating to 11ac. Some of the ways these 11ac APs may be handicapped when operating on 802.3af power are:

- **Spatial streams disabled**
- **Spectrum sensors disabled**
- **Ethernet ports disabled**
- **Radios disabled**
- **WIPS sensing disabled**

Disabled AP vs. Switch Upgrade

Because the vast majority of the PoE installed base is at 802.3af rather than 802.3at, customers migrating to 11ac will need to carefully consider following options:

- Upgrade the switching infrastructure to provide 802.3at PoE—Increases the cost of the 11ac migration
- Use the existing 802.3af PoE switching infrastructure—Limits availability of key features on most 11ac APs
- Choose an 11ac platform that supports full functionality over 802.3af PoE—Ideal solution if available

Cabling Plant

Cat-5e cabling is the minimum cable rating recommended for 11ac Wave 1 APs. For new cabling plants, the recommendation is to install Cat-6 or Cat-7 cable. Additionally, because 11ac Wave 2 APs will be capable of throughput well beyond 1 Gbps, the recommendation is to run two cables for each Wave 2 AP drop.

Channel Width Planning

Because doubling channel width provides slightly more than double the throughput capacity, wider channels are preferred for networks where high throughput is required. However, other factors need to be considered such as channel availability, client density, regulatory region, etc. The general recommendation is to use 80 MHz channels if four or more 80 MHz channels are available and client densities are not very high. For stadium and arena deployments, where client densities can be extremely high, the use of 40 MHz or even 20 MHz channels are preferable.

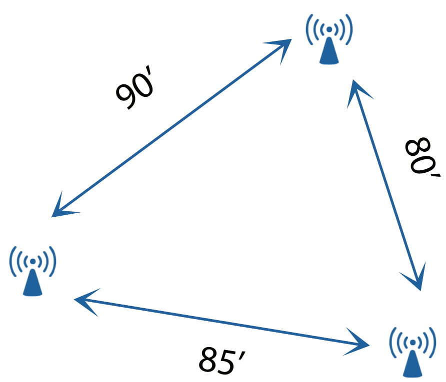
One-for-One AP Replacement

Many early 11ac deployments where done by simply replacing the existing 11n APs with 11ac APs. Reports back on how well this approach worked have been very positive. In fact, there have been many customers stating publicly that after replacing their existing 11n APs with 11ac APs, their networks have seen a significant improvement in performance, even without upgrading their client population to 11ac devices. Many WLAN equipment manufacturers have attributed this improvement in performance to a number of factors such as better radios, more CPU power, as well as other components inside the new 11ac APs. While these one-for-one AP replacements may not result in a migration plan that is fully optimized for 11ac performance, it is still likely improve results for the existing client set.

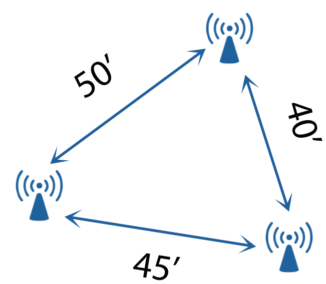
AP Density

As indicated earlier, higher signal strength is required to support 256-QAM. With this in mind, it is reasonable to conclude that higher AP densities would be required to support 256-QAM MCS rates. Rate and range testing of 11ac APs and 11ac clients reveal that MCS-8 and MSC-9 are only achievable when clients are within approximately 25 feet of an AP. Therefore, for network to be optimized for 11ac performance, APs should be placed approximately 50′ apart (line-of-sight). This is a considerably higher AP density than for 11n networks where APs are typically between 70 to 100 feet apart.

11n AP Spacing Example



11ac AP Spacing Example



The image below shows approximate area where 64-QAM data rates can be supported with six 11n APs.

64-QAM Coverage with 11n APs

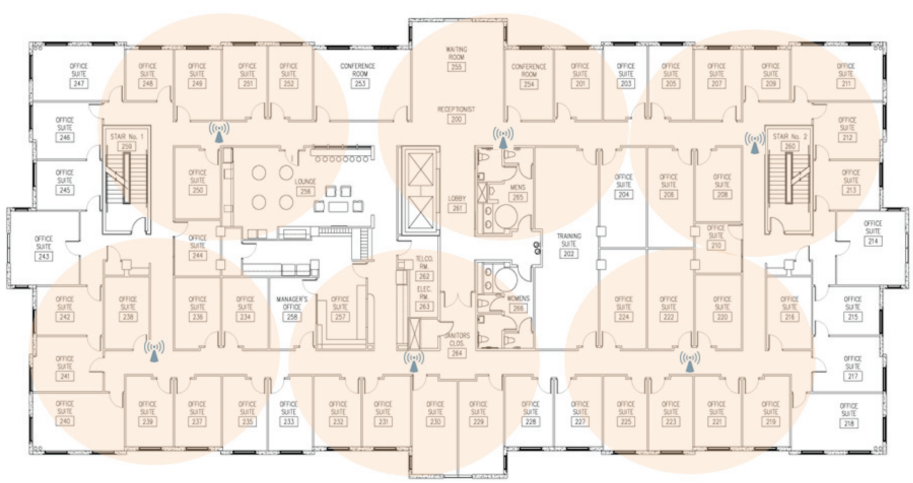
The next image shows approximate coverage for 256-QAM data rates using six 11ac APs.

256-QAM Coverage with 11ac APs for 1-to-1 AP Swap

In this example, a one-for-one replacement is actually a sound approach. As can be seen in the image above, coverage for 256-QAM, while not completely blanketing the floor plan, enables 11ac clients to use 256-QAM data rates in most of the office space. And because coverage for 64-QAM extends well beyond that of 256-QAM, the building would still be well provisioned.

In the image below four additional 11ac APs have been added to extend nearly full coverage for 256-QAM.

256-QAM Coverage with Additional 11ac APs



It should be noted the three previous images are presented just to illustrate a point and actual coverage patterns are typically much more irregular. Also, there was no mention of channels being used for the three diagrams above. If 11ac APs were added to an existing channel plan, the new APs should be configured to use channels that are not in use in their areas. Adding APs using the same channels as APs nearby (i.e. within -85dBm) is not recommended because two adjacent or nearby APs sharing the same channel would have a negative impact on performance due to the effects of co-channel interference (CCI).

AP Transmit Power

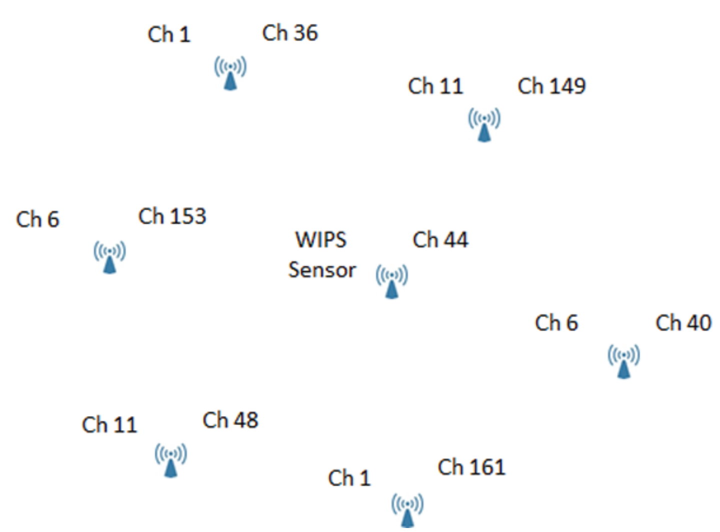
AP transmit power for the 2.4 GHz radios may need to be reduced significantly particularly if the APs are deployed at higher densities than is customary with 11n deployments.

2.4 GHz vs. 5 GHz Radios

As many 11ac networks will use more 5 GHz channels than 2.4 GHz channels, the reuse of 2.4 GHz channels (e.g. 1, 6 and 11 for the US) will be greater. At some point the reuse of 2.4GHz channels becomes counterproductive due to the adverse effects of co-channel interference (CCI). Therefore, it may be recommended that some of the 2.4 GHz radios be provisioned as sensors or even disabled.

The image below shows an example channel plan using 20 MHz channels for both 2.4 GHz and 5 GHz channels. The AP in the center has had its 2.4 GHz radio configured as a fulltime WIPS sensor

Channel Plan with WIPS Sensor



About AirTight Networks 802.11ac Solution

The C-75 is the first 802.11ac AP from AirTight Networks. It is a dual radio, 3ss Wave 1 access point. An overview of the C-75 hardware features is shown below.

C-75 Hardware Features

- **Dual radio 11ac AP**
    - Radio1: 11n/3x3:3/2.4GHz
    - Radio2: 11ac/3x3:3/5GHz/Wave 1
- **1 GigE wired backhaul port (Eth1)**
- **1 RJ45 console port**
- **Full feature functionality using 802.3af power**
- **Two models**
    - C-75—internal antennas
    - C-75-E—external antennas

C-75

C-75-E

Efficient Design

Unlike most enterprise-class 11ac APs that require 802.3at power to operate with full functionality, AirTight's energy efficient C-75 design allows it to operate with no feature impairment while using 802.3af power. This eliminates the need for a costly 802.3at PoE switch upgrade.

High Value

The C-75 also delivers high price/performance value compared to other vendors 11ac APs. Performance tests have revealed that the C-75 is able to deliver higher amounts of throughput for the cost of an AP (i.e. Mbps/AP cost).

About AirTight Networks

AirTight Networks is a global provider of secure Wi-Fi solutions that combine its patented and industry-leading wireless intrusion prevention system (WIPS) technology with the next generation cloud-managed, controller-less Wi-Fi architecture. This unified approach allows enterprises for the first time to benefit from Wi-Fi access while concurrently protecting their networks 24/7 from wireless threats at no additional cost. AirTight's customers include global enterprises across virtually all industries and range from those who overlay AirTight WIPS™ on top of other WLAN solutions, to those who leverage the AirTight Cloud Services™ to manage AirTight Wi-Fi™, WIPS, and regulatory compliance (e.g., PCI) across tens of thousands of locations from a single console. AirTight owns 29 granted U.S. and international patents on WIPS and cloud-managed wireless security, with more than 20 additional patents pending. For more information, please visit: www.airtightnetworks.com.

The AirTight Infrastructure

Like all Airtight Networks access points, the C-75 supports high availability, Wi-Fi analytics, social media integration, performance monitoring, preflighting for plug and play setup and can be managed remotely via public or private cloud. The C-75 is also fully supported by Airtight Planner—a software tool used to determine the number of APs needed to meet desired Wi-Fi coverage and capacity for specific environments.

Summary

With 802.11ac, there are a number of enhancements to features that were initially introduced by the 11n standard, such as multiple spatial streams, wider channels, frame aggregation, etc. The 11ac standard also introduced a completely new switch-like feature MU-MIMO. All of these features are what enable 11ac devices to use the 5 GHz Wi-Fi RF spectrum more effectively than previous technologies.

At some point in the near future, it will be difficult to purchase new 11n APs and clients so the decision of whether to opt for 11ac will be made for all of us. Until then, network and business requirements will be the main factors for determining when and where 11ac is needed. While there may be some advantages over 11n in terms of coverage due to a combination of better radios and the effects of beamforming in 11ac, the likely driving force behind most upgrades to 11ac in the near term will be the need to provide higher throughput capacity.

High aggregate throughput demands can be the result of a dozen or so devices simultaneously using high bit rate applications such as HD video streaming, 100s of devices using medium bit rate applications, or 1000s of devices using low bit rate applications. Any area that has high aggregate throughput requirements should be considered as a candidate for upgrading to 11ac.

Before deploying 11ac there are a number of items that should be considered as "must haves" such as Cat-5e (or better) cables and 10 GigE uplink ports on edge switches. Other factors, such as planning for higher density AP coverage, should be considered as well, particularly if 11ac networks are to be designed to extract peak performance from this new technology.

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White Paper: Taking the EZ Street : 802.11ac: Essential Considerations [Doc ID: ATN-WP-0414-001-00-EN]

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