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Evolution of the IEEE 802.11AC Standard

Much has been written about the evolution of the IEEE 802.11AC standard. The new standard has been described as 'the real 80211n' or '802.11n on steroids'. It is true that 802.11AC is fully compatible with 802.11n clients, but in truth 802.11AC unlocks new tools for network architects and access point system designers, leading to significantly higher speed and capacity. This paper will answer some of the common questions about the new technology, provide design considerations and use cases to illustrate the underlying value of 802.11AC for multiple markets.

The IEEE 802.11AC standard defines mandatory and optional features. Chipset vendors may further extend the optional features to differentiate their products. Interestingly, the only new mandatory features in the standard are VHT frame formats and support for 80MHz channels in the 5GHz band. All the other 802.11AC features existed in 802.11n or are marked as optional.

However, the industry recognizes that many of the optional features should be considered mandatory to realize the increased performance of 802.11AC.

 The key optional features of the 802.11AC standard are:

• Higher bit density
• Bonding more channels into the same transmission
• Increase the number of spatial streams
• Downlink Multi-user MIMO to support concurrent transmission to multiple clients

Higher Bit Density Using 256QAM

Optional in the standard, but considered a market requirement.

802.11AC VHT frames support new code rates and 256QAM bit density to increase the effective RF datarate. 256QAM adds about 33% more payload per transmission than 64QAM.

Design Consideration

256QAM will require higher Signal to Noise Ratio than 64QAM. Plan to provide between 35dB and 40dB of SNR. If the average noise floor is -90dB, this predicts an RSSI design between -50dBm and -55dBm. With proper cell design, hardware design, and enterprise grade software, co-channel interference can be minimized and 256QAM provided.

Advantage

With 802.11AC expect to find an aggregate speed and capacity improvement. Faster network speed results in less air congestion. Less air congestion provides greater capacity for wireless clients and less co-channel interference. Clients that are closer to the AP will easily achieve the 256QAM datarates, increasing the aggregate speed for the entire network.

> 256QAM adds more payload per transmission than 64QAM **33%**

Channel Bonding

Mandatory up to 80MHz. Optional up to 160MHz, but considered a market requirement.

With 802.11n, networks were commonly deployed using two 20MHz channels bonded together into a single 40MHz wide channel. For 802.11AC, we can now double that value, and bond four channels of 20MHz each into a single 80MHz channel. The specification allows for another doubling; up to 160MHz – but this introduces a problem. 160MHz requires eight 20MHz streams. In most regulatory domains, we have two 160MHz channels available, assuming that DFS channels are available at the site. This leads to another optional feature; 80+80. In 80+80 mode, the AP can bond channels that are not immediately adjacent to each other. For example, in the FCC domain, using 80+80 mode, we can create a single 160MHz channel by combining two non-adjacent 80MHz channels. There is always a limitation; each of the 80MHz channels are created from adjacent channels for example, we might bond channels [36, 40, 44, 48] + [149, 153, 157, 161].

Design Consideration

Locating eight channels to use for a single 160MHz channel can be difficult. For a large enterprise network, a manual task would be time prohibitive and could lead to co-channel interference. Rather than abandon the idea of 80MHz and 160Mhz channels, however, many chipset vendors implement algorithms to detect other channel use and automatically drop from 160 to 80 to 40 and eventually to 20MHz. This feature of 802.11AC is called dynamic bandwidth selection.

Advantage

By automating the channel width based on the inter-AP interference, each AP in the network has the maximum possible band width. The network architect does not need to manually set the channel widths to an arbitrarily low number.

Increased Spatial Streams

Mandatory to support one spatial stream, optional up to eight spatial streams. The industry recognizes that four spatial streams provide a good cost – benefit.

Spatial streams are combined using MIMO technology first released in 802.11n. Each spatial stream requires a radio chain, antenna element, and additional transmitter power. Mobile devices such as smartphones and tablets are optimized for long battery life, and are space constrained for the additional antenna element. As a result, most client devices support only one stream, or two streams at the most. Laptops may support three streams as they have more space and power available. Future improvements in integrated circuits, materials composition and battery technology may change this, but in the foreseeable future we have to deal with the capabilities of the current technology. The disparity between the AP and the client capabilities can be used to our advantage, using another optional 802.11AC feature which we will discuss next.

Design Consideration

Understand the type and capabilities of the clients in the network and the overall network design goal. Spatial stream combining is an automatic function in use for many years. There is little network design changes to leverage the spatial stream in 802.11AC.

Advantage

Indoor wireless networks with multi-path reflections get a clear speed improvement when the number of spatial stream increases. Outdoor wireless networks will benefit from an AP-to-AP backhaul where four spatial streams can be used along with higher channel width to exceed a 1Gbps datarate. A side benefit of the four antenna elements is diversity reception. Access point designs with four antenna elements provide better multipath protection to increase accuracy of the received signal from the client.

DownLink (DL) Multi-User MIMO

Optional in the standard, but considered mandatory by the market requirements.

MU-MIMO has been written about extensively, and is a much anticipated new technology. As discussed above, there is a disparity between the AP and the client capability. The AP can transmit up to four spatial streams, but a mobile client device will only receive one, or at most, two of those streams. With MU-MIMO, the four spatial streams are steered to specific client devices at the same time. In theory, up to four MU-MIMO clients, running at one stream each (1SS), will be served by the AP at the same time. If a MU-MIMO client supports two streams (2SS), then two clients will be served two streams each, at the same time. Other combinations are also available.

MU-MIMO capability is highly complex and requires hardware accelerated code. MU-MIMO is not available in the first 802.11AC access points, nor available on the first 802.11AC mobile devices. MU-MIMO capable access points are shipping in 2015, with MU-MIMO clients coming in Q1-2016. Not to be overlooked is that 802.11AC MU-MIMO only works in the downstream direction. That is from the AP to the client. The communication from the client to the AP is the same as previous, single-user MIMO.

Design Consideration

MU-MIMO requires the client to provide a feedback matrix that describes the RF environment at the client, otherwise known as channel sounding. Channel sounding is also used for the standardized Explicit Transmit Beaming included in 802.11AC wave 1.

The AP uses this information to determine the best way to steer data to multiple clients into the same transmission time slot. In addition, MU-MIMO uses a technique called pre-coding. The coding is different for each MU-MIMO client to maximize receiver decorrelation. MU-MIMO works best when the clients are stationary e.g. a school classroom.

Advantage

When a significant number of client devices support MU-MIMO, the aggregate network throughput will increase. Along with the speed increase, the network capacity to support more devices will increase since each device takes less time to complete its transmission.

Frequently Asked Questions

Q. Is there a theme to 802.11AC? Should I upgrade my 802.11n?

A. Yes and Yes. 802.11AC as a fully released standard has a theme that is unique, and quite different from 802.11n. With 11n, all of the standard protocols were applicable to an enterprise access point or a home access point. There was little difference at the protocol layer. The differences between a home access point and an enterprise access point was seen in the client capacity controls, the backplane throughput, and intellectual property around managing a large RF environment with dozens, hundreds, or thousands of access points.

11AC by contrast, is an ambitious standard where different aspects of the standard are more applicable to one market vs another. For example, we can use MU-MIMO for high density networks such as classrooms, but we might not use 160MHz channel width. In a point to point network, we might use 80MHz or even 160MHz channels, but we would not use MU-MIMO. One theme of 11AC is customized, purpose built access points tailored to a market.

11AC is also about compatibility. Lack of vendor compatibility was a problem with 802.11n, there was not enforcement in the standard between vendor implementations. Transmit beamforming is a good example. 802.11n provided no guidance, leading to a host of smart antenna arrays with often un-provable performance and in-compatibility between vendors. In the 802.11AC standard, transmit beamforming is standardized and interoperable among vendors that comply with the specification.

Q. What is the difference between wave 1 and wave 2?

A. There is only one standard published by the IEEE as 802.11AC. Due to the complexity of the optional features, it requires multiple product releases. The chipset architects build upon previous work, for example MU-MIMO leverages the Explicit Transmit Beamforming released in wave 1. 802.11n went through similar phases from 2007 through 2009.

For 802.11AC wave 1, the key features are 80MHz channels, 256QAM, 5/6 Coding, Explicit transmit Beamforming, Dynamic Bandwidth selection and additional MAC layer enhancements. Wave 1 products support three spatial streams. When all these are combined together, we get a maximum RF datarate of 1.3Gbps on a single radio.

For 802.11AC wave 2, the key features are described in this document. The important optional features are 160MHz channels and downlink MU-MIMO. The use of wider channels and MU-MIMO builds upon features released in wave 1 chipsets.

Q. Why don't mobile devices support the full 802.11AC specification?

A. Power, space, heat and CPU speed. Smartphones dominate the mobile device market. In turn, consumer choice drives smartphone design. As a result, we find the smartphone manufacturers compete on a very consumer centric view; longer battery life, large functional displays, and high resolution cameras. For wireless network communication, each spatial stream requires an antenna element and additional power to drive the transmitter. Smartphones do not have the space, power or heat budget. Additionally, the CPU in current smartphones cannot handle four spatial stream processing even if space, power or heat were not an issue. Consumers are largely unaware of these technical details.

All is not lost. As described in this document, downlink MU-MIMO is an acknowledgement that mobile clients will be one or two stream in the foreseeable future. By leveraging this new technology, the network can make the most of the 802.11AC standard.
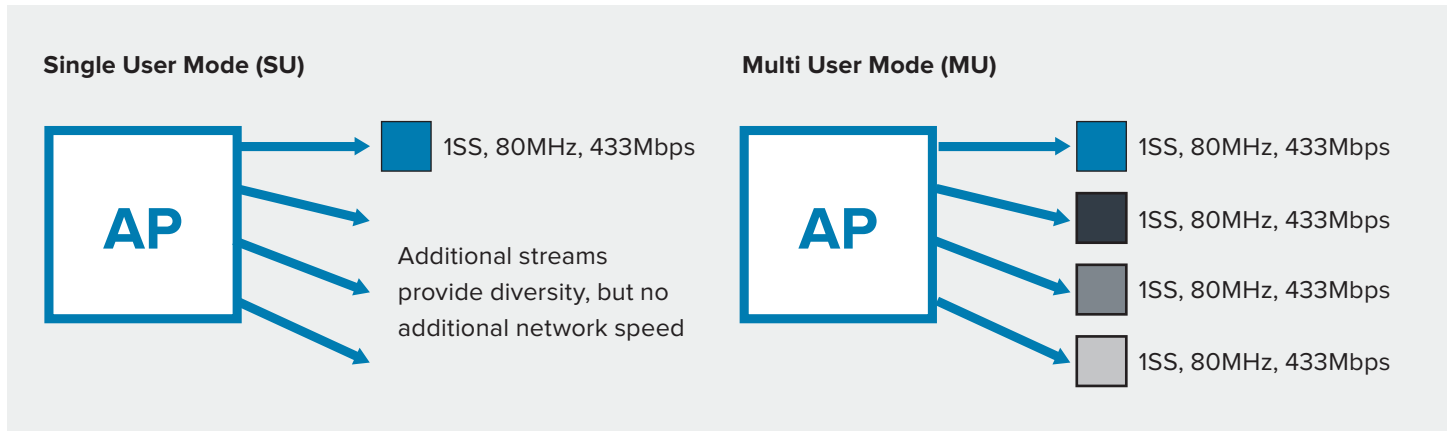
...downlink MU-MIMO is an acknowledgement that mobile clients will be one or two stream in the foreseeable future.

Q. How much real benefit will MU-MIMO provide?

A. Demonstrations of pre-release MU-MIMO clients show a speed improvement of 2.5x up to 3.5x. Real-world results will become obvious in late Q1-2016 when consumer MU-MIMO clients are available in the market.

In theory, MU-MIMO will support up to four concurrent clients running at 1SS each. Other combinations are also supported such as two clients with 2SS each. Let's consider the theoretical maximum throughput using four 1SS clients and a single 80MHz channel. Bear in mind, this is THEORETICAL:

Single User Mode (SU)

AP

1SS, 80MHz, 433Mbps

Additional streams provide diversity, but no additional network speed

Multi User Mode (MU)

AP

1SS, 80MHz, 433Mbps

1SS, 80MHz, 433Mbps

1SS, 80MHz, 433Mbps

1SS, 80MHz, 433Mbps

In the real-world, there are many factors that will limit the MU-MIMO aggregate throughput:

1. If the clients are moving, the Feedback Matrix will be invalid and MU-MIMO will rely on precoding.
2. If the clients are close together and located at a far distance from the AP, it will be difficult to differentiate the clients. With close clients at long distance, beamforming is less effective.
3. MU-MIMO requires multiple clients in an available client pool to select the transmission candidates. Fewer clients connected to the AP may not provide spatial differentiation.
4. Failure of the algorithm to calculate a masking signal due to interfering RF noise and ineffectiveness of transmit beamforming in high multipath environment.
5. Other algorithm or protocol failure.

Q. Is this backward compatible?

A. 802.11AC wave 2 access points will operate in SU mode for legacy clients. If a network has only legacy or wave 1 11AC clients – the benefits of 802.11AC wave 2 is better power and throughput at range due to the four antenna elements. Additionally, four antenna elements provide a boost in receiver sensitivity and transmit diversity.

Consumer MU-MIMO devices will begin shipping in Q1-2016. The algorithms will allow the access point to support these new devices alongside the legacy devices. However, only MU-MIMO clients will benefit from MU-MIMO.

For each transmit opportunity, the access point can do one of three things; 1) it can transmit multiple streams to multiple clients, 2) it can transmit single user (SU) management packets and for 802.11AC wave 1 clients, or 3) it can transmit single user (SU) 802.11an frames to legacy clients. Since wave 2 AP can support SU and MU concurrently, the network speed is guaranteed to increase as compared to SU only clients.

Single User Mode (SU)
Used for management frames also for 11AC wave 1 and legacy 11n

Multi-User (MU)
4 clients, 1SS each

Multi-User (MU)
2 clients, 2SS each
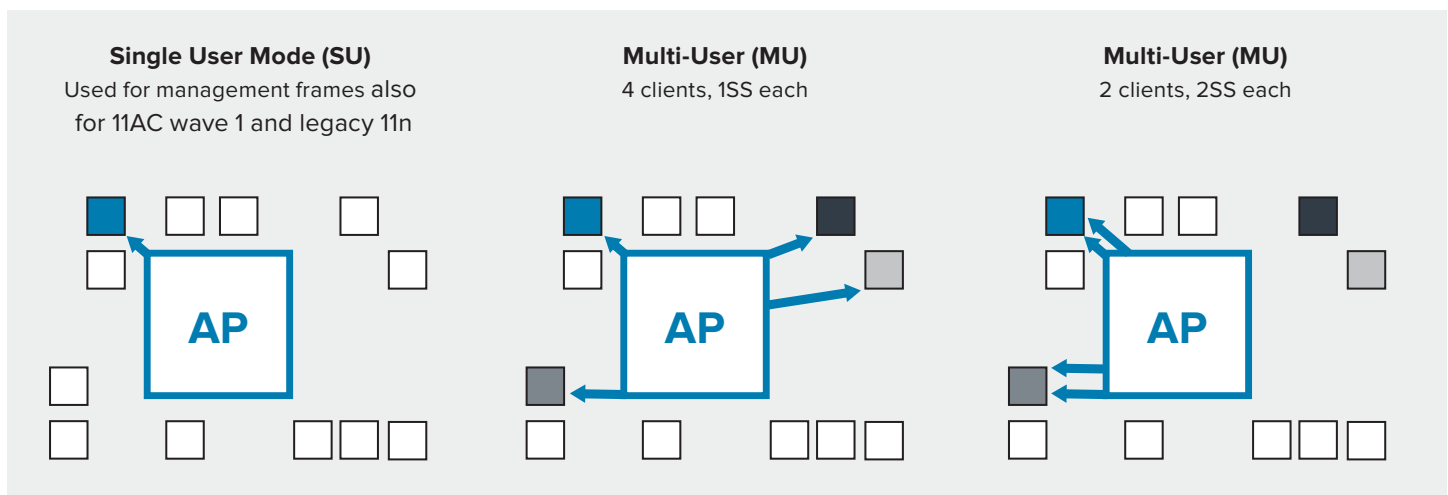
Q. Do I need to upgrade my wired network to support wave 2?

A. New technology is now available to increase the Ethernet speeds over category 5e up to 2.5Gbps at standard structured cable distances. This means a single Cat5e cable that connects the existing 802.11n access point can be used to deliver 2.5Gbps for a next generation 802.11AC wave 2 access point.

Over time, as more client devices support MU-MIMO, the aggregate network throughput will increase beyond the current one Gigabit per second that is commonly deployed. Enterprises will do well to monitor their network for peak and average throughput using wired packet capture utilities.

Q. Do I need to re-engineer my wireless network to support wave 2?

A. You should make full use of all available channels in the 5GHz band, including the channels classified as DFS. Note the number of channels classified under DFS for the selected countries in the chart below. For example, in the FCC regulatory domain under current rules, 15 channels out of a possible 25 channels are classified as DFS. Many 802.11n networks today avoid DFS channels due to possible complications in using those channels.

To fully utilize the band width, use an RF spectrum analysis solution that includes automatic radar detection and avoidance in the DFS channels. This technology will become available in 2016, and will be a key to fully utilizing all available band width, speed and network capacity afforded by the 802.11AC standard.

Available Channels in US FCC, ETSI, and China. Other countries have their own specific set.

DFS / TPC Channels | Available

| 5.17 – 5.33GHz | 5.35 – 5,49GHz | 5.49 – 5.725GHz | 5.725 – 5.825GHz |

Channels: 36 40 44 48 52 56 60 64 | 68 72 76 80 84 88 92 96 | 100 104 108 112 116 120 124 128 132 136 140 144 | 149 153 157 161 165

US: 20 / 40 / 80 / 160
EU: 20 / 40 / 80 / 160
CH: 20 / 40 / 80 / 160

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