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802.11ac Wireless Standard

Brent Marshall
Parkland College

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Wireless 802.11ac

Introduction

In 2011, the IEEE began development of the newest wireless 802.11 standard. This standard would be known as 802.11ac. Development of this standard continued until 2013 and was approved in January 2014. The new standard was touted as having many improvements over the 802.11n standard. Improvements such as higher data rates, more capacity, being ideal for multimedia, and being more robust.

These expanded capabilities are the result of newer technologies. 802.11ac has better beamforming support allowing for a more stable connection throughout the service range. It allows for multiple devices to be connected simultaneously by using more spatial streams and Multiple user- multiple-input and multiple-output(MU-MIMO). It also allows for more efficient use of the 5ghz spectrum by using wider channels and a bigger QAM.

Industry response

The industry responded to 802.11ac quite energetically, releasing products based on the 802.11ac standard before the standard was even fully approved. These early draft versions began to appear at the end of 2011. The first chip-set was the QAC2300 introduced by Quantenna on Nov 15th 2011. Less than one month later Redpine Signals released their 802.11ac chip for mobile devices. This trend continued into 2012 with many more companies following suite. This is interesting because the 802.11ac standards were not even fully approved until 2014. Not surprisingly the industry is also beginning to talk about 802.11ax which is due for release in 2019.

Currently the market is producing products that now claim to be “3rd wave” 802.11ac. There are chipsets which offer dual-band 8x8 5Ghz and 4x4 2.4Ghz capabilities along with MU-MIMO. Which utilizing the standard's full capabilities claim to be able to transmit at 10Gbps. You can already buy 802.11ac 8x8 gaming routers from Walmart.com. Though they still don't use the full capabilities of 802.11ac.

What is new

The 802.11ac standard is considered by some to be an evolutionary improvement upon 802.11n. It has improved upon several technologies such as larger QAM, bigger channel bonding, more spatial streams and better version of MIMO.

Instead of seeking to reinvent the wheel 802.11ac has mostly improved upon the technologies of 802.11n. A-MPDU was first used in the 802.11n standard and worked well enough that 802.11ac requires ALL packets be sent in A-MPDU. Beamforming was another technology introduced in 802.11n and implemented heavily in 802.11ac. MIMO has been updated to a new version called MU-MIMO.

Spatial Streams

The first of the new changes is the increase in spatial streams. The 802.11n standard supports at maximum 4 spatial streams. Utilizing the 5ghz band 802.11n can potential have 4x4. The 802.11ac standard has the capability of supporting up to 8 spatial streams and being an 8x8.

Spatial streams are what you have when you have 1 antenna broadcasting on 1 channel. This means that in a 4x4 802.11n device you will have 4 antennas each broadcasting on a different channel. In an 8x8 802.11ac device you will have 8 antennas and 8 channels to use. Naturally in order to take full advantage of 8x8 you would need 8 radio chains on both the access point and client. However in practice most client devices cap out at about 3 antennas. Phones usually have 1, tablets sometimes have 2 and some laptops have 3. However some of the other technologies in 802.11ac allow for other uses of those extra antennas.

MU-MIMO

This brings us to MU-MIMO, a new optional technology offered in the new 802.11ac standard. (SU-MIMO)Single user MIMO has existed for years and is currently what is used by 802.11n and early versions of 802.11ac. Its major limitation is that with SU-MIMO the access point can only communicate with one device at a time no matter how many antennas are present. This means that the access point must talk to each device in turn. In this way it is said that SU-MIMO is sort of like a hub with the devices talking to the AP one at a time.

With MU-MIMO that is not the case. With MU-MIMO an access point can communicate with as many devices simultaneously as the AP has antennas. This means that the AP can talk to several devices at the same exact time. Those who say SU-MIMO is like a hub, say this makes MU-MIMO more like a switch. This means that an MU-MIMO 802.11ac device with 4 antennas can communicate with 4 devices at the same time.

This is a great boon for areas with large amounts of device in a small area such in a lecture hall, sports stadium, warehouse floor and some hospitals that have embraced wireless devices in order to increase medical capabilities.

Now this is not 4 antennas, 4 channels, 4 devices. Interestingly it appears the it can communicate with 4 devices simultaneously while using the same channel. This is accomplished at the cost of more intense signal processing and the utilization of beamforming technologies.

Wider channels

In 802.11n the maximum channel width with channel bonding was 40mhz, with 802.11ac the minimum is 80mhz with an optional 160mhz. Channel bonding is when you combine multiple channels together to improve speed. An 80Mhz channel has twice the data rate as a 40Mhz channel and 160Mhz has 4 times the data rate as a 40Mhz. However do to power usage over the multiple channels the overall range is slightly decreased.

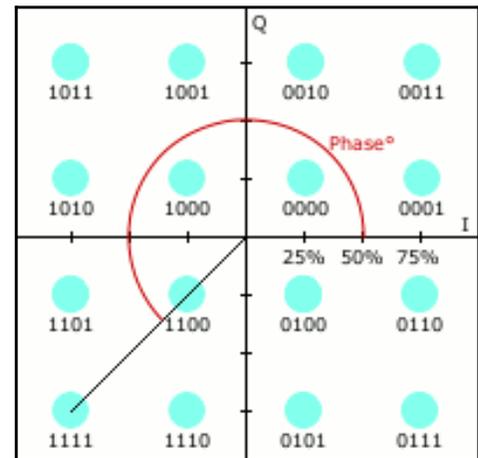
Bigger QAM

Now we will talk about QAM(Quadrature amplitude Modulation). 802.11n maxes out at

64-QAM while the new 802.11ac standard uses 256-QAM with some vendors offering an optional 1024-QAM. QAM is basically a combination of PSK(Phase shift keying) and amplitude modulation that is designed to allow a portion of signal to carry data more efficiently. How many of the combinations of amplitude and phase are referred to as constellation density.

To better understand here is a table and graphic of 16-QAM:

Binary	Amplitude	Phase	Binary	Amplitude	Phase
0000	25%	45°	1000	25%	135°
0001	75%	12°	1001	75%	112°
0010	75%	68°	1010	75%	158°
0011	75%	45°	1011	75%	135°
0100	25%	315°	1100	25%	225°
0101	75%	283°	1101	75%	203°
0110	75%	337°	1110	75%	247°
0111	75%	315°	1111	75%	225°



As we can see from the table and graphic, to represent the binary value of 1111 we need the amplitude shifted to 75% and the radio wave to be shifted 225° out of phase. We can also see that to represent 0000 we would need 25% amplitude and to shift the phase 45°. It is because of this arrangement that 16-QAM can represent in a value between 0 and 15(0000 and 1111) every symbol it transmits.

64-QAM allows a certain section of signal to possess a 64 values numbered between 0 and 63 (000,000 – 111,111), this is 6 bits of data. 256-QAM allows for the use 256 values numbered between 0 and 255(00,000,000 – 11,111,111). Basically 256-QAM allows for a symbol to be the equivalent of a full byte of data. Some vendors are even offering Higher values of QAM such as the 1024-QAM which allows for 10 bits, though this is not a part of the official 802.11ac standard it will be a part of the future 802.11ax standard.

256-QAM allows for much better use of the channels but it is not without it's own drawbacks. Having higher constellation density means higher level of QAM are more susceptible to interference. Luckily there are various technologies in 802.11ac devoted to increasing the robustness of the signals.

Beamforming

Beamforming is a really cool technology. It kind of works like the human ears but in reverse. In human hearing we have two ears that together can calculate the approximate location of a sound by noting the different arrival times at each ear. Likewise if you have two speakers you can time the sounds emitted to be stronger at specific points in space due to the waves ability to amplify each other when they arrive at the same point while in phase.

Beamforming uses these same principles to locate a device and time the transmissions so

that the signal is strongest when it gets to the devices physical location. This is a very important technology because it has the effect of increasing the signal's robustness. This also helps counter the 5Ghz bands weakness of being less penetrating the 2.4Ghz band. It also helps deal with QAM's increased susceptibility to interference.

But amplifying the signal is not the only thing this technology can do. It can also do something called null steering. Since the AC device can communicate with multiple devices simultaneously it needs a way to prevent its multiple messages from interfering with each other. This is done with beam null steering where the device can weaken or nullify its signals in locations that run the risk of interfering with each other. It can also be used to mitigate some of the noise levels in certain circumstances.

But this is just the parts that the AP does. Beamforming can be done by any device with multiple antennas. Furthermore the 802.11ac standards allow receiving devices to help with the beamforming process via a feature called sounding. However sounding has a high overhead and is not backwards compatible with the 802.11n version. Sounding one 80-MHz antenna can take about 250 microseconds which assuming a speed of 6.9Gps could cost 216M bytes of data.

All A-MPDU all the time

The 802.11n standard introduced the A-MPDU. Every payload that is transmitted has associated overhead. In some high speed scenarios the overhead can be greater than the payload. Frame aggregation is a solution to this problem. By combining multiple payloads under a single header transmissions could be made more efficient. In the case of A-MPDU error correction could also be achieved. It was found that by using A-MPDU for every frame you could gain some other advantages. For example when sending a maximum size frame at 6.93Gps using the A-MPDU could save 4 microseconds every transmission due to not having to send the size and duration info at the lowest MCS. This being said there were some limitations of the types of sizes that could be used, specifically they have to be full OFDM symbols but that could be easily cheated with padding. That padding can also be useful for MU-MIMO.

Bringing it together

The Channel bandwidth, increased QAM, and the number of the spatial streams are the three technologies that are responsible for the 802.11ac's increase in speed. This due to each one acting as a multiplier for the others. According to the Cisco white paper on the subject, the equation goes like this:

$$\frac{(Bandwidth \text{ as number of subcarriers}) \times (Number \text{ of spatial Streams}) \times (Data \text{ bits per Subcarrier})}{(Time \text{ per OFDM Symbol})} = \text{bps}$$

Using this we can calculate that a 160Mhz, 8 stream, 256-QAM, 3.6 microsecond OFDM symbol (short guard interval) gets 6933.3Bps or just short of 7Gbps. Naturally you will not get this kind of speed for a single device unless it supports all of these features and has 8 antennas and even then this is the theoretical and assumes no interference and everything works perfectly. These speeds even as a theoretical are still rather impressive.

These values also only reflect on the 5Ghz band with some of the newest and greatest routers

also implementing a 4x4 2.4Ghz scheme with some of these capabilities. This is seen in some of the high end gaming routers available for sale.

The MU-MIMO capabilities allow for the antennas not currently in use on one device to communicate to another. This means that even though it is unlikely for you to get the above speeds on a single device you will eliminate a lot of the bandwidth competition in your homes and at work which will allow you to get close to those speeds collectively across all your device. For example, 50Mbps to your phone pulling it's emails and instant messages, 1Gps to your console that's streaming Netflix, 2Gps to your kid who is both online gaming, streaming it to Twitch, and 500Mps to your spouse's tablet running Pandora, email, instant messenger, background updates, and some mobile game.

In the world of IOT (Internet of things) this may become an even greater issue. There are Wi-Fi printers, coffee makers, light bulbs, toys, drones, air conditioners, plant sensors, portable document scanners, bathroom scales, picture frames, thermostats, refrigerators, washers, dryers, and even LED light bulbs. These items are becoming increasingly common and can be found at many main stream retailers.

Viability

The 802.11ac has many new features. But before deciding if we should rush out and buy the newest and greatest 802.11ac router there are a few things to consider.

Interference

While many tout the lack of crowding in 5ghz band, it is incorrect to assume that every channel within that band is ripe for the taking. In the 5ghz band, channels(non-overlapping) 36, 40, 44, and 48(5.180-5.240GHz) are openly available worldwide and channels 149, 153, 157, 161, and 165(5.745- 5.825GHz) are available in North America. The rest of the 5GHz band (5.260-5.700GHz) must be implemented with DFS(Dynamic Frequency Selection). DFS is designed to detect radar and if it is detected and over a certain noise level it will force the AP off of that channel. The 5GHz band is used in weather radar as well as satellite up-links, military gear and a wide range of law enforcement systems. For example, the Department of homeland security has (UAS) unmanned aircraft systems that patrol the borders looking for things like drugs, these aircraft use the frequencies between 5.350Ghz and 5.470Ghz. Due to the large channel binding (160MHz) that 802.11ac allows, if you are near some of these federal systems DFS may activate reducing the AP's full capabilities.

Stability and range

Despite the 5GHz band having less penetration than the 2.4GHz band. Thanks to the implementation of beamforming and MU-MIMO connections are stronger at much longer distances. The 5ghz band is less crowded than the 2.4Ghz band leading to less interference. Wireless devices have seen a huge surge in popularity in recent years. Wireless keyboards, wireless mice, and of course the IOT devices that are becoming increasingly popular all use the 2.4Ghz band making it more crowded by the day. The use of A-MSDU leads to more efficiency and stability.

These are great if you need a fast reliable single in a wider area which doesn't degrade rapidly the further you move away from the AP.

Multi-device environments

In most wireless implementations the wireless access point can only speak to one client at a time. In 802.11ac the AP is capable of talking to as many clients as it has antennas. In a 4x4 environment the AP can communicate with up to 4 devices simultaneously. In recent years there has been a rise in the BYOD(Bring your own device) trend among companies, with employees, contractors and other officials bring multiple wireless devices with them each consuming network resources.

For example in hospitals you may have officials from Joint Commission coming in to review your campus, and they will bring their own laptops and require the ability to get onto the internet. If your facility deals with residential children you will have DCFS coming with their laptops as well. Also in hospitals there is a move towards utilizing tablets and laptops for keeping track of flows and for medication distribution.

Newer devices and services try to sell themselves as having greater capabilities, but these capabilities come with higher demands which will put a greater and greater strain on your wireless environment. Also as storage becomes greater on these devices so will the size of the operating systems and the available apps, which will in turn lead to bigger patches and updates.

In retail and warehouse situations you are also seeing an increase in things like hand held scanners that are used for keeping track of inventory. Or in extreme situations like Amazon, the controls of their robotic workers.

In the world of security there are also wireless security systems which can be deployed much more cheaply than traditional security cameras that require either A. Ethernet and power cables ran or B. Ethernet and expensive POE switches or injectors(Some of which are proprietary and don't follow the 802.3af/at standards).

In home environments entire families have their own wireless device, cell phones are considered a minimum nowadays and even children are given them in order to be able to contact their parents in emergencies. Giving your child a cell phone is considered a safety precaution. More and more home electronics are being created with intention of being controlled wirelessly. The current trends in home entertainment are moving away from a television with cable and more towards streaming services that allow for the customized viewing of multimedia.

Internet Bottlenecks

According to the Akamai Q1 2016 report the average internet speed in the USA is 15.3Mbps with a peak of 67.8Mbps. In an environment with a single device that is simply using the internet the average 802.11n AP can more than exceed this. In a multi-device environment where you can have streaming or gaming the MU-MIMO can maintain what little internet speed you have and not waste time making these devices wait in turn. For example say you were watching a stream from Netflix on your PS4 your spouse was on their tablet chatting on Facebook your two kids were both on Facebook as well. In a SU-MIMO environment the AP

would have to communicate with each of the 4 devices in turn which while you're technically not using your full home internet connection you still may experience some choppiness with your stream. Now if all four of you are streaming you are still going to get that choppiness cause you still only have that 15.3Mbps speed.

Backwards compatible

Like many 802.11 standards AC is considered backwards compatible. Kind of, keep in mind AC lives on the 5Ghz band, so by default it is at least backwards with 802.11n/a. With dual band AC devices you can have backwards compatibility with pretty much everything else.

Future Proof

While 802.11ac devices may not be a complete saturation of the market now, that may not always be the case. As time progresses more and more devices will support the 802.11ac standard. If working in an environment that may potentially see an increase in wireless devices, such as hospitals, classrooms, stadiums, warehouses, retail, and such the new standard may be very attractive. It is also predicted that much like the AC standard is an evolution of the N standard, the 802.11ax standard will be an improvement upon the 802.11ac standards. The new AX standard is due for release around 2019. Though just like the AC standard, early "Draft releases" are already available such as the Quantenna QSR10G-AX chipset. This new standard will be backwards compatible and allow the use of 802.11ac's fuller capabilities.

Cost

The most spectacular of the 802.11ac abilities however are still quite expensive. For an 802.11ac device, that can get 5.2Gps, is going to cost you about \$1000. While the full power 8x8 chipsets exist, as of this writing no commercially available access point could be found using the full capability of the 802.11ac standard.

Conclusion

The 802.11ac standard is full of new and exciting technology. But like many newer technologies the infrastructure is not fully there to support all of its capabilities. That being said the capabilities that are supported can be very attractive. The ability to support multiple devices simultaneously and stream multimedia with less delays is enough to place this technology on many users radar. In both homes and businesses.

In businesses more mobile devices are being deployed for everything from inventory management in retail to the tracking of medication distribution in hospitals. Increasingly customers, traveling businessmen, and government officials are expecting there to be a Wi-Fi available for use. You can find Wi-Fi hotspots in many restaurants and stores. Many professionals live in the email on their phones and laptops.

At home many people stream from services such as Hulu, Netflix, YouTube, and Facebook. People are also streaming to sites, like Twitch and Facebook Live. More and more there are video calls via services like Skype and VOIP.

Gaming has now been accepted as mainstream and is moving heavily into the mobile device arena. Everyday there are more online games being released for mobile phones creating pressure for faster and faster wireless speeds for mobile devices.

With the IOT, the home environment is beginning to incorporate many more wirelessly controlled devices. 802.11ac was designed with these uses in mind.

References

Web archive of Quantenna's press release for when they released the first ac device. Note that they did it the same year the 802.11ac standard started development. This company seems to be the cutting edge guys.

https://web.archive.org/web/20111117213344/http://www.quantenna.com/pressrelease-11_15_11.html

This is Quantenna's current product line. They have full power 802.11ac 10Gps chipsets and the “draft 1.0” 802.11ax chipset.

<http://www.quantenna.com/products/>

This is a detailed report on the various federal systems that run on the 5Ghz band. Lot of information.

<https://www.ntia.doc.gov/report/2013/evaluation-5350-5470-mhz-and-5850-5925-mhz-bands>

This was a random blog I found, it is where I found the link to the report about all the federal systems on the 5Ghz band. If you don't want to read the full NTIA report this will give you a quick gist.

<https://wirednot.wordpress.com/2014/01/07/what-else-is-in-the-5-ghz-spectrum-hint-its-not-just-weather-radar/>

This site has some nifty charts of the 5Ghz band, which ones have DFS. It also visualizes some of the problems with the 160Mhz channel bonding.

<http://www.smallnetbuilder.com/wireless/wireless-features/31694-why-80211ac-will-kill-the-5-ghz-wi-fi-band>

Cisco's white paper on the new AC standard. Easier to understand than Wikipedia.

http://www.cisco.com/c/en/us/products/collateral/wireless/aironet-3600-series/white_paper_c11-713103.html

This shows the various combinations of QAM, spatial streams, encoding, channel width, and guard interval. It also show their effect upon data rate. At full power on the 5Ghz band you can get a little under 8Gps.

<http://mcsindex.com/>

Akamai state of the internet report Q1 2016 <https://www.akamai.com/us/en/multimedia/documents/state-of-the-internet/akamai-state-of-the-internet-report-q1-2016.pdf>

<http://faculty.ccri.edu/jbernardini/JB-Website/ETEK1500/1500Notes/802.11n-NextGen-Cisco.pdf>

Videos

What is mu-mimo? Video

<https://www.youtube.com/watch?v=8kTrceXOZXQ>

Modulation & QAM Basics

<https://www.youtube.com/watch?v=d7I5NbFfBiU>

Beamforming for 802.11ac

<https://www.youtube.com/watch?v=QKj0PsTXHr8>

Pictures

Digital 16-QAM with example constellation points by Chris Watts created 11 July 2011

https://en.wikipedia.org/wiki/Quadrature_amplitude_modulation#/media/File:QAM16_Demonstration.gif