Wi-Fi 802.11 ax vs 802.11 ay: Comparison

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Abstract: Recently, the wireless connection has become a preferred technology due to its ease in use and for its mobility; therefore a rapid development has emerged in the wireless technologies. Wi-Fi is the most common technology used today. This paper is a comparative study, it illustrates the basic characteristics of two of the under development wireless LAN systems 802.11ax and 802.11ay, this comparison helps users differentiate between these two types for future selection.

Keywords: IEEE 802.11, 802.11ax/ay

1. Introduction

IEEE 802.11 is part of the IEEE 802 set of LAN protocols, and specifies the set of media access control (MAC) and physical layer (PHY) protocols for implementing wireless local area network (WLAN) Wi-Fi computer communication in various frequencies, including but not limited to 2.4, 5, and 60 GHz frequency bands. They are the world’s most widely used wireless computer networking standards, used in most home and office networks to allow laptops, printers, and smartphones to talk to each other and access the Internet without connecting wires. They are created and maintained by the Institute of Electrical and Electronics Engineers (IEEE) LAN/MAN Standards Committee (IEEE 802). The base version of the standard was released in 1997, and has had subsequent amendments. The standard and amendments provide the basis for wireless network products using the Wi-Fi brand. While each amendment is officially revoked when it is incorporated in the latest version of the standard, the corporate world tends to market to the revisions because they concisely denote capabilities of their products. As a result, in the marketplace, each revision tends to become its own standard. The protocols are typically used in conjunction with IEEE 802.2, and are designed to interwork seamlessly with Ethernet, and are very often used to carry Internet Protocol traffic. Although IEEE 802.11 specifications list channels that might be used, the radio frequency spectrum availability allowed varies significantly by regulatory domain.

Unlike LTE (the protocol cellular data uses), 802.11 Wi-Fi is a protocol with no central management, which leaves all nearby devices duking it out for airtime like angry, unsupervised toddlers. There’s only so much you can do to fix this problem without radically overhauling and replacing 802.11 itself—but as new 802.11 protocols emerge, they do their best. If you don’t deal with this stuff for a living, it’s easy to get lost in all the different Wi-Fi protocols in the ether today. New additions have been released in sort of alphabetical order, but some are backwards-compatible and some aren’t. Some are "mainstream" and have broad consumer device support, and some are offshoot technologies rarely to be seen in anything you can buy at a big box store. It’s kind of a mess. If all this isn’t bad enough, the Wi-Fi Alliance has not-so-helpfully decided to replace some—not all!—of the 802.11 designations in consumer marketing with a supposedly simpler scheme. 802.11ac, which most of us are using now, becomes “Wi-Fi 5” under this new scheme. 802.11ax will be marketed as “Wi-Fi 6.” This new numeric designator conveniently ignores some protocols, unfortunately: neither 802.11ad nor 802.11ay will get “Wi-Fi Numbers” at all.

2. IEEE Standards

<table>
<thead>
<tr>
<th>Designation</th>
<th>Spectrum</th>
<th>single-MIMO PHY</th>
<th>notes</th>
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<tr>
<td>802.11a</td>
<td>5 GHz</td>
<td>54 Mbps</td>
<td>There was almost no consumer device adoption; it was prevalent in very early 2000s enterprise.</td>
</tr>
<tr>
<td>802.11b</td>
<td>2.4 GHz</td>
<td>11 Mbps</td>
<td></td>
</tr>
<tr>
<td>802.11g</td>
<td>2.4 GHz</td>
<td>54 Mbps</td>
<td></td>
</tr>
<tr>
<td>802.11n</td>
<td>2.4 GHz / 5 GHz</td>
<td>144 Mbps / 300 Mbps</td>
<td>802.11n devices must have a 2.4 GHz radio; one or more 5 GHz radios are optional.</td>
</tr>
<tr>
<td>802.11ac</td>
<td>5 GHz</td>
<td>433 Mbps</td>
<td>802.11ac protocol is 5 GHz only, but in practice all 802.11ac devices also offer a 2.4 GHz 802.11n radio.</td>
</tr>
<tr>
<td>802.11ad</td>
<td>60 GHz</td>
<td>~5 Gbps</td>
<td></td>
</tr>
<tr>
<td>802.11ax</td>
<td>2.4 GHz / 5 GHz</td>
<td>~500 Mbps</td>
<td>It’s a draft protocol scheduled to be ratified in 2019. It covers 2.4 and 5 GHz, with provisional support for 1-6 GHz at a later date.</td>
</tr>
<tr>
<td>802.11ay</td>
<td>60 GHz</td>
<td>~40 Gbps</td>
<td></td>
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PHY

PHY is the “PHY”sical transport layer speed of a Wi-Fi connection—but actually it does not move data across the link that fast. Actual data transmission rates can be anywhere from 1/3 to 2/3 of PHY on a completely healthy link in reasonable transmission range. And as it is moved further away from an access point, the transmission rates fall to 1/10 of PHY or worse.

Ideally, PHY itself does not fall off as it is moved further from the nearest access point—a lower QAM means lower PHY and throughput, but longer reliable connection range—but the connections your devices negotiate between themselves frequently aren’t optimal.

Adding to the confusion, many of the protocols in this table support varying channel bandwidth settings, with higher
bandwidth meaning higher throughput, but fewer available channels and more problems with interference (and multiple MIMO streams as well). The table above assumes a single MIMO stream and the most common (not necessarily the largest) QAM and channel width settings.

3. MIMO Streams

MIMO is an acronym for Multiple Input / Multiple Output; it's a way of using multiple antennas to send multiple spatial streams of data from a single radio on a single channel. Broadly speaking, there are two types of MIMO—SU-MIMO, and MU-MIMO. The SU stands for Single-User, and no matter how many streams a device has available, it can only talk to one other device at a time. Got an 8-stream 802.11ac router that's currently talking to a single-stream, non-MU-MIMO 802.11ac device? Tough; you're only getting a single stream worth of transmission to that single device no matter how many other devices it has got clamouring for airtime.

MU-MIMO is Multi-User MIMO, and as the name suggests, it means that an access point can divide up its available MIMO streams between multiple clients. For example, a 4x4:4 access point (four transmit RF chains, four receive RF chains, and four simultaneous data streams possible) can simultaneously "talk" to one 2x2:2 laptop, and two 1x1:1 phones or tablets.

There are quite a few catches with this; the biggest is that all devices currently "talking" must support MU-MIMO. 802.11ac's implementation of MU-MIMO is download only; so while an 802.11ac MU-MIMO router can simultaneously deliver data to several MU-MIMO enabled client devices, any time one of them wants to request data from the router, all other traffic comes to a screeching halt.

![MIMO Streams Diagram](image)

Enlarge / MIMO is a scheme allowing the use of multiple antennas to simultaneously transmit or receive multiple spatial streams of data, using a single radio and channel.

All of this MU-MIMO stuff already exists in the real world, but vanishingly few of us have ever benefited from it. MU-MIMO capable routers are increasingly common, but MU-MIMO capable client devices are still rarer than hen's teeth. There's a reason for that, as Chuck Lukaszewski demonstrated in a WLPC presentation from 2016: MU-MIMO requires significantly increased power usage compared to SU-MIMO. And that makes it much less attractive in battery-powered devices.

4. 802.11ax, the next "normal" Wi-Fi

IEEE 802.11ax, marketed as Wi-Fi 6 by Wi-Fi Alliance[1][2], is one of the two Wi-Fi specifications standards, of IEEE 802.11, both expecting full deployment late 2019[3][4]; the other is ay. They can be thought of as High Efficiency Wireless. 802.11ax is designed to operate in all band spectrums between 1 and 7 GHz when they become available in addition to the 2.4 and 5 GHz already existing. Devices presented at CES 2018 showed a top speed of 11 Gbit/s.[5] For dense deployments, throughput speeds are 4x higher than IEEE 802.11ac, even though the nominal data rate is just 37% faster at most. Latency is also down 75%.[6] To improve spectrum efficient utilization, the new version introduces better power control methods to avoid interference with neighbouring networks, OFDMA modulation, higher order 1024-QAM modulation, and uplink direction added with the downlink of MIMO and MU-MIMO to further increase throughput, as well as dependability improvements of power consumption and security protocols such as Target Wake Time and WPA3.

Why PHY? There isn't much improvement in PHY going from 802.11ac to 802.11ax; instead, the big improvements are more subtle than that. Thankfully, these improvements are also more useful. The biggest problem most people have with Wi-Fi, increasingly, isn't so much "it doesn't go fast enough" as it is "it can't handle multiple devices well enough." This is exactly where 802.11ax should shine brightest, thanks to several new or improved features. The most important ones are OFDMA, bi-directional MU-MIMO, trigger-based random access, spatial frequency reuse, and target wake time.

OFDMA

In a nutshell, OFDMA allows an access point to offer each connected client device one or more Resource Unit (RU). Each RU consists of several extremely narrow-bandwidth "tones," or subchannels, within the overall Wi-Fi channel itself. And this makes it possible for multiple client devices to transmit simultaneously, whenever they feel like doing so, without having to worry about packet collisions. This also greatly mitigates the problem of extremely long-range, low-throughput devices that nevertheless end up hogging all the airtime because their QAM rate is so low, or their error-and-retry rate so high.

Bi-directional MU-MIMO

What OFDMA does for the spectrum, bi-directional MU-MIMO does for the available spatial streams. 802.11ax's new implementation allows multiple client devices to share the available streams from the access point for both download and upload. I hesitate to make any bold, sweeping predictions without real-world devices in hand, but this stream-sharing should stack multiplicatively with OFDMA's channel-sharing, potentially allowing (number of available RUs) x (number of spatial streams) total clients to simultaneously transmit without interfering with one another.

Trigger-based Random Access

Trigger-based random access works with OFDMA to improve situations with multiple client devices even in the
absence of directly assigned RUs. In addition to directly assigning RUs to individual clients, the access point can designate multiple RUs as "randomly" available. A device which wants to upload a little bit of data but doesn't have a directly assigned RU can randomly pick one of these pooled RUs. With luck, they'll pick different RUs from the random pool even when several devices try to transmit simultaneously. If two particularly unlucky clients do decide to transmit on the same RU at the same time, they'll fall afoul of CSMA/CA and have to back off and retry after a randomly determined pause, just like they would with current protocols.

**Spatial frequency reuse**

Spatial frequency reuse is yet another feature which improves Wi-Fi performance and predictability in RF-dense environments. Without this feature, a device or access point must remain "silent" while any other device transmits, even if that device doesn't belong to the same network. With spatial frequency reuse, coloring allows a device to decide whether simultaneous transmission is permissible.

Let's say there are four devices in play; A, B, X, and Y. Device B would like to transmit to access point A, but device Y is already transmitting to access point X on the same spectrum. This isn't normally permissible, but if B can determine that Y isn't transmitting to A, then B can transmit to A simultaneously—so long as B adjusts its output power low enough that the B->A transmission won't interfere with the Y->X transmission.

Maybe this won't help someone with 50 devices and one router who lives in a farmhouse with no competing networks, but it's a serious upgrade for someone in an apartment complex surrounded by competing routers on all sides, or someone in a big house with tons of devices and multiple access points.

**Target Wake Time**

TWT makes me hopeful we might actually see the rest of these features implemented in the small, portable devices we actually use (unlike the current generation of MU-MIMO). It gets a little hairy trying to explain how and why it works, but basically it schedules devices to explicit, non-competing (or at least less-competing) timeframes. This in turn allows battery-powered devices to leave the radio "asleep" for longer periods, significantly decreasing how much power is consumed by active Wi-Fi connections.

**5. 802.11ay, the next "Wi-Gig"**

802.11ay is a type of WLAN in the IEEE 802.11 set of WLANs. It will have a frequency of 60 GHz,[3] a transmission rate of 20-40 Gbit/s and an extended transmission distance of 300–500 meters. It is likely to have mechanisms for channel bonding and MU-MIMO technologies.[2] It was originally expected to be released in 2017, but has been delayed until 2019.[4] 802.11ay will not be a new type of WLAN in the IEEE 802.11 set, but will simply be an improvement on 802.11ad.[5] Where 802.11ad uses a maximum of 2.16 GHz bandwidth, 802.11ay bonds four of those channels together for a maximum bandwidth of 8.64 GHz. MIMO is also added with a maximum of 4 streams.[2] The link-rate per stream is 44Gbit/s, with four streams this goes up to 176Gbit/s. Higher order modulation is also added, probably up to 256-QAM.[6] Applications could include replacement for Ethernet and other cables within offices or homes, and provide backhaul connectivity outside for service providers.[7]

Assuming there is a clear line of sight from access point to client and no interference from competing 802.11ay devices on the same channel, it's not unreasonable to expect overall PHY rates of 10 Gbps or more, with actual data transmission rates of well over 1 Gbps—as fast or faster than current wired Ethernet connections. It is able to sustain a reasonably reliable 802.11ay connection on the other side of a single wall from the access point, but it won't see transmission rates anywhere near that high. A human also walking through the path would be enough to further degrade or even completely kill throughput.

802.11ay is, for the most part, just an even-faster 802.11ad, but with the same limitations. 802.11ay can bond channels and streams, but it still fares poorly if it can't get a clear line of sight.

**What would 11ay be used for?**

It remains to be seen how soon the high speeds of 11ay will really be needed for internal uses, as 802.11ac — including Wave 2 products — are already pretty robust. But Peraso's Lynch says that if 11ad doesn’t quite do it for you given its distance limitations, “11ay will finally be the technology that would let you snip that Ethernet cord — you no longer have to run Ethernet cables to everyone’s desk… there’s enough wireless bandwidth in ay.”

The advent of the 5G era has created a platform for carriers' business to evolve and adapt to the exponentially increasing number of connections, such as 10-fold higher workloads over the 4G era. Most of those we spoke with about 11ay were more enthusiastic about its potential as a fixed point-to-point or point-to-multipoint outdoor backhaul technology, especially in light of scaled back fiber rollout plans by providers like Google and Verizon in the face of extraordinary costs associated with such implementations. “I’m more bullish on using ad & ay for backhaul (instead of mesh) in the case of campus & city networks — provided that it has a useful range,” says Claus Hetting of Hetting Consulting and Chairman of the Wi-Fi Now event. But it’s possible that 11ay could find a role in internal mesh and backbone networks as well as for other uses such as providing connectivity to VR headsets, supporting server backups and handling cloud applications that require low latency. “I believe that eventually, there will be enterprise applications for this - but it’s probably a few years into the future, given that we will have 802.11ax fairly soon & because there’s still a lot of 5 GHz band available for that (and ac),” Hetting says. On the consumer side, the trend over the past year has really been to get rid of cables, so 802.11ay as an HDMI or USB replacement would be "a beautiful application," says Bernd Jungbluth, senior test engineer for testing laboratory TUV Rheinland. "It could make more of the equipment intuitive," as Bluetooth and Near Field Communication have done for certain applications, he says.
6. Conclusion

Despite the obvious congruency of 802.11ax and 802.11ay, one isn’t a successor to the other. 802.11ax is the protocol which will succeed 802.11ac as the next mainstream Wi-Fi protocol we all use at home and in coffee shops, hotels, and so forth. If you’re into the Wi-Fi Alliance’s new, supposedly simpler marketing, it’s Wi-Fi 6, compared to today’s Wi-Fi 5... assuming we conveniently ignore the Wi-Fi 4 that’s on the 2.4 GHz radio all of our Wi-Fi 5 devices also have.

Just as 802.11ac is backwards-compatible with 802.11n (which is itself backwards-compatible with 802.11b and 802.11g), 802.11ax will be backwards-compatible with 802.11ac. 802.11ax is still a draft protocol. While it is still under development, a few routers supporting the 802.11ax draft are already publicly available, including Netgear's Broadcom-powered RAX-80 and Qualcomm-powered RAX-120 models.

802.11ay should not be confused with the similarly named 802.11ax that is also set to be released in 2019. Although they boast similar speeds, the 802.11ay standard is designed to reach farther and run at much higher frequencies. The lower frequency of 802.11ax prevents it from reaching these distances but enables it to penetrate walls, something that the 11ay standard struggles to do.[8]

The great thing about 60 GHz is that it punches through water vapor very easily, making high-throughput, moderate-range outdoor connections much less affected by weather than they are with 2.4 GHz or 5 GHz radios. It also attenuates pretty rapidly through atmospheric gases, which means "last mile" connections can operate pretty close to one another without mutually interfering. The unfortunate thing about 60 GHz is that it can't punch through solid obstructions such as walls, furniture, or glass very well at all.

References

[2] Wi-Fi Alliance® introduces Wi-Fi 6
[3] Here come Wi-Fi 4, 5 and 6 in plan to simplify 802.11 networking names
[11] "Millimeter wave spectrum has key role in 802.11ay wireless".