qorvo®

Future Proofing Wi-Fi

Where is Wi-Fi Heading?

Wireless Connectivity Front End Solutions

Designing for 802.11ax Wi-Fi: Common Challenges and Tips to Overcome Them

MOUSER ELECTRONICS

Contents

Foreword

By Rodney Hsing,
Qorvo Director of
Global Distribution

A Successful Journey Begins with Vision

Solving problems, simplifying and improving lives. At Qorvo, we envision this and so much more.

We are helping customers at the center of communication, building solutions that meet the growing demands of a connected world. Our radio frequency (RF) expertise and core technologies are critical and life-changing, and our values and commitment to a better world are serving on the ground, at sea, and in the air.

Qorvo is ready today with next-generation RF smarts and solutions that connect and protect people, places, and things—faster and further with more reliability. We power more efficient networks and devices, mission-critical defense systems, and emerging commercial and consumer applications.

Qorvo's products have been used in radar, tactical radio, and electronic warfare systems for years. Now our products using gallium nitride (GaN), gallium arsenide (GaAs), silicon, bulk acoustic wave (BAW), and surface acoustic wave (SAW) technologies are being used in wireless infrastructure for emerging 5G networks.

We see the future of the Internet of Things (IoT), and we are accelerating its adoption with futureproof solutions like our multi-protocol communication controller (MPCC) chips. These ultra-low power, wireless data communication controller chips enable IoT and smart home applications today that will be compatible tomorrow.

Cees Links who leads Qorvo's Wireless Connectivity business was the founder and CEO of GreenPeak Technologies. Cees is a Wi-Fi industry visionary who led the development of the world's first wireless LANs and pioneered the development of access points, home networking routers, and hotspot base stations. He was involved in the establishment of the IEEE 802.11 standardization committee and the Wi-Fi Alliance® and was also instrumental in establishing the IEEE 802.15 standardization committee to become the basis for the Zigbee® sense and control networking.

At Qorvo, what we do matters. We see a future where you remotely control all aspects of your connected home, where medical conditions are proactively managed, where your car is self-driving, your reality is virtual, and new possibilities emerge. A future where our core technologies bring people closer to the stars.

Qorvo is all around you—making a better, more connected world possible.

Deep Roots in Core Technologies

For more than 30 years, Qorvo (NASDAQ:QRVO) has been all around you. We've been innovating, researching, developing, and acquiring cutting-edge technologies that shape the world as you know it.

Regardless of the route to becoming Qorvo, the mission has always remained the same: To drive connectivity, no matter the technology. From the start of RF Micro Devices® (RFMD®) in 1991, TriQuint in 1985, and dating back to roots in Tektronix®, Texas Instruments™, Raytheon®, and Watkins-Johnson, we've helped send rockets to Mars, connected you with your family and friends through cell phones, and brought satellite radio to your car.

Here are a few of the milestones that got us where we are today, and where Qorvo will help take you tomorrow.

1957

Mark of Our Beginning

Dean A. Watkins and H. Richard Johnson form Watkins-Johnson Company (WJ) a leader in semiconductor-manufacturing equipment and electronic products for the wireless-telecommunications and defense industries. TriQuint acquires WJ in 2008.

1985

TriQuint Forms as Tektronix Spinoff

A group of talented engineers founds TriQuint as a spinoff of Tektronix to research and develop the use of gallium arsenide (GaAs) for high-performance wireless applications.

1991

RFMD Is Formed

Visionaries in high-performance radio frequency (RF) founded RFMD to design and manufacture solutions for mobility, connectivity, and enhanced functionality for mobile devices.

1998

Texas Instruments and Raytheon Acquisitions

TriQuint acquires Texas Instruments' GaAs Monolithic Microwave Integrated Circuit (MMIC) business and Raytheon Defense Systems and Electronics Group.

2005

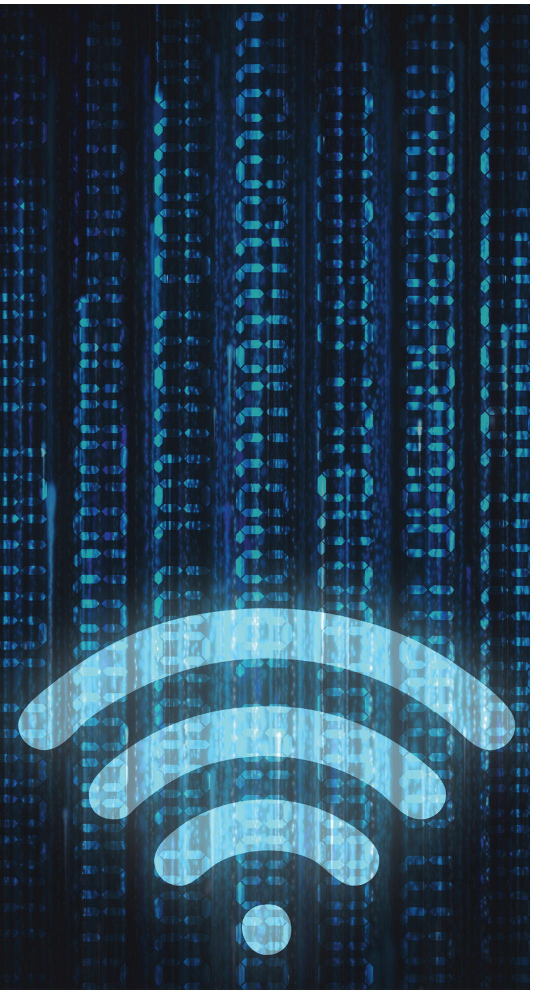
Communication Received from Huygens Probe on Saturn's Moon, Titan

TriQuint enabled communication included data and a photo of Titan's surface.

2012

Mission to Mars: Curiosity

The TriQuint-enabled Mars Curiosity rover lands safely on Mars, marking the beginning of NASA's most ambitious Mars mission.



2014

Agreement to Merge Under Name Qorvo

TriQuint and RFMD announce an agreement to merge and operate under a new name as Qorvo with a goal to deliver the core RF technologies and innovation that enable customers to accelerate their next-generation designs.

2015

First Day of Qorvo

Qorvo, Inc.'s doors open, bringing together all the critical RF building blocks needed to simplify design, reduce size, and conserve power for mobile, infrastructure, and aerospace/defense applications.

2017

Industry's First 5G RF Front End

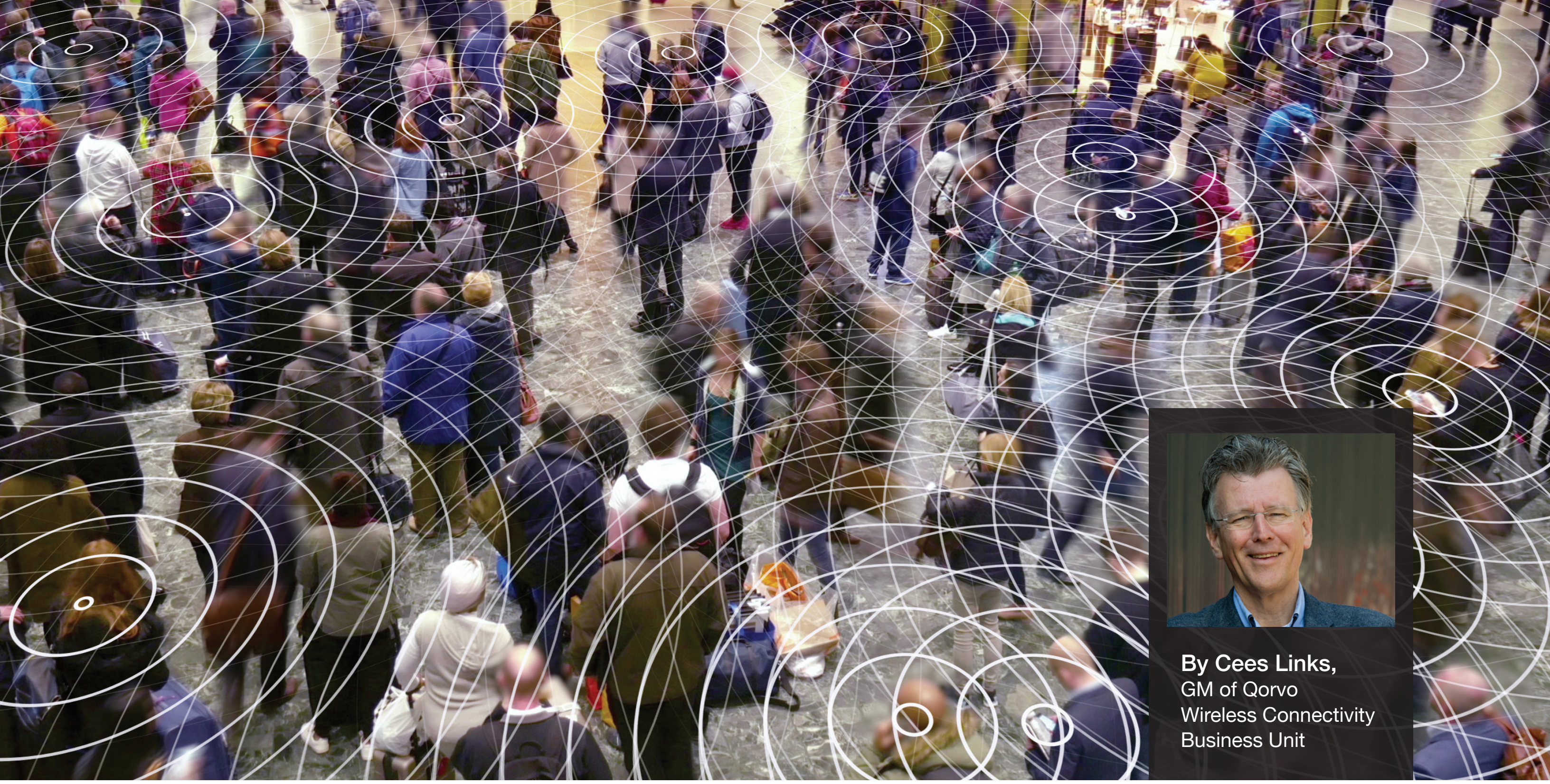
Qorvo announces a breakthrough 5G RF front end (FE) developed in close collaboration with a global chipset provider.

With a broad portfolio of innovative RF products covering frequencies ranging from 600 MHz to 80 GHz, Qorvo combines product and technology leadership, systems-level expertise, and global manufacturing scale to solve our customers' most complex technical challenges quickly. Qorvo serves diverse high-growth segments of large global markets, including advanced wireless devices, wired and wireless networks, and defense radar and communications. We also leverage our unique competitive strengths to advance 5G networks, cloud computing, Internet of Things (IoT), and other emerging applications that expand the global framework interconnecting people, places, and things.

Summary

Qorvo is ready today with next-generation RF smarts and solutions to connect people, places, and things faster, further, and more reliably. Qorvo partners with leading companies to create tomorrow's connected world using core RF products and engineering expertise. Qorvo provides higher performance in more power-efficient networks and devices, to connect and protect mission critical defense systems and emerging commercial and consumer applications. Qorvo is all around you—making a better, more connected world possible.

Visit mouser.com to learn more about our newest products and how Qorvo connects the world.



By Cees Links,
GM of Qorvo
Wireless Connectivity
Business Unit

Where Is Wi-Fi Heading?

What Matters to Customers?

There are three things that customers care most about when it comes to using Wi-Fi:

1. **High Capacity**
2. **High Data Rates**
3. **Good Range**

Of course, there are other considerations, like easy to connect and easy to install. There has been great progress on the first, and ease of installation is getting better with distributed Wi-Fi in a box (which also indirectly addresses the range issue). There is also the murkier issue of avoiding interference from neighbors, which may or may not contribute to a slow Wi-Fi issue.

Capacity

While higher data rate may seem to be the most important issue, let's first look at capacity—multiple users using Wi-Fi at the same time. Most people today have a router, and everyone connecting to that router is using the same Wi-Fi channel. Which also means that those users are sharing the same bandwidth and the same raw data rate. When people are using a repeater, that bandwidth gets shared even more – you talk with your repeater on the same channel as your repeater talks with your router, effectively doubling the traffic on that same channel.

Here is where distributed Wi-Fi comes in and makes dramatic improvement. Every node on the network can talk on its own frequency band with the end user, while simultaneously communicating on other frequency bands with the main router connecting to the Internet.

To put this in perspective, consider that the first Wi-Fi effectively used 3 channels (in the 2.4GHz band) to stay away from using the same channel as the neighbors. Today, "modern Wi-Fi" uses 40 MHz-wide channels and effectively supports 10 of those channels in the 2.4 and 5GHz bands, making it not only easier to stay away from the neighbors, but also to optimize usage in a home by enabling different users using different channels and also allowing a wireless infrastructure in the home for distributed Wi-Fi with multiple access points.

Distributed Wi-Fi—Not as Simple as It Sounds

If talking about different channels in Wi-Fi makes it sound as simple as digital radio and changing channels with a push of a button, the reality is a little harsher. Cheap Wi-Fi radio technology causes easy bleeding from one channel into another, particularly when using high or maximum output power. This bleeding effectively kills the neighboring channels, drastically reducing overall capacity. The real name of the game in Wi-Fi today is making sure that channels are well-separated, to stop the bleeding. Suddenly, building a Wi-Fi product is not only about the Wi-Fi chip. Now it's also about the "front-ends"—the amplifiers and filters between the Wi-Fi chip and the antenna that make or break the capacity of the distributed Wi-Fi system.

Higher Data Rates Do Count

So back to raw data rates. Our appetite for ever higher data rates seems insatiable. So, let's take a look at where we came from and where are we going, as shown in the following table:

Raw Data Rates by Protocol

Protocol	Year	Frequency (GHz)	Number of Channels	Max Data Rate (Mb/s)	Max Channel Width (MHz)
802.11	1997	2.4	3	2	22
802.11a	1999	5	19	54	20
802.11b	1999	2.4	3	11	22
802.11g	2003	2.4	4	54	20
802.11n	2009	2.4 or 5	2/9	600	40
802.11ac	2014	5	5	6,900	160
802.11ax	2019	2.4 or 5	5	9,600	160

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It's important to note that this table focuses on raw data rate. But of course, we all know that in real life usage, there is often a significant difference between raw data rate and actual throughput, which can be half or even less of the raw data rate. In light of that, it's good to know that while IEEE 802.11ax (planned for 2019) does include a modest increase in raw data rate, its main intention is to increase the actual throughput by a factor of 4 as compared to IEEE 802.11ac. This capacity improvement will result through splitting up multiple input/multiple output (MIMO) communication streams and assigning them to different users for throughput optimization.

Bluetooth® on Steroids?

Another example of the race for more bandwidth is the 60GHz family of IEEE 802.11 standards (originally under WiGig™, but now back in the Wi-Fi Alliance™). The first one (IEEE 802.11ad) has been available for several years but has not yet been widely adopted—and the next generation is already in the works, as shown here:

Raw Data Rates for 60 GHz Protocols

Protocol	Year	Frequency (GHz)	Number of Channels (*)	Max Data Rate (Mb/s)	Max Channel Width (MHz)
802.11ad	2016	60	3/4	7,000	2,160
802.11ay	2020	60	3/4	44,000	2,160

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Unfortunately, there is a problem with 60GHz—it cannot penetrate walls, and therefore it "stays" in the room. But wait, is this really a problem? If it stays in the room, that means it does not interfere with the usage of the same channel/frequency in the other rooms, much less the neighbors. Sounds kind of ideal, doesn't it? One may really wonder: If 60GHz 8011.ad has existed for years, why hasn't the market jumped on it yet?

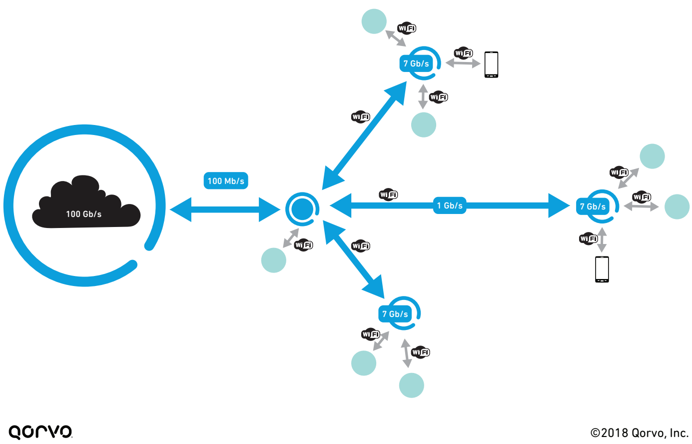
Something Is Wrong

To understand this, let's compare it to our road system. We have freeways connecting cities, big through-roads connecting neighborhoods, and the small streets in the neighborhoods. There is a hierarchy. And this hierarchy makes sense. You don't have freeways in neighborhoods or small streets connecting large cities. But for Internet in our homes, the situation is different.

The Internet, or the cloud, has very high-speed interconnects (100Gbps or more), comparable with large freeways. But the exit lane, the pipe to our home called the “local loop” (or the “small cell” in wireless lingo), is usually 100Mbps at best, although 1Gbps fiber and 10Gbps Data Over Cable Service Interface Specification (DOCSIS®) 3.1 are starting to emerge. Then we have the option of a distributed Wi-Fi network in our house or building, for instance 802.11ac at 1Gbps or even a wired 10Gbps Ethernet cable. And finally, with the connection with the end node (the TV, game station, tablet, smart phone), we’re again at something like 1Gbps, although this could even be 7Gbps if we use IEEE 802.11d (WiGig).

Something is wrong with this. Where’s the hierarchy? The high speed in the home is not served by the access to the home. We have freeways inside the house, but only a small street provides access to the house. And even inside the house, there is no real hierarchy. Take a look at this visual representation:

Out-of-Balance (100 Mb/s – 1 Gb/s – 7 Gb/s)



WiGig Doesn’t Help in This Scenario

It’s no surprise, then, that WiGig (IEEE 802.11ad) hasn’t really taken off yet. Why build a higher multi-Gbps highway in your room, if it connects via a 1Gbps pipe to a 100 Mbps local loop, single lane road? It’s also no surprise that in this context, the expectations for the tens of Gbps (IEEE 802.11ay) should not be too high. Higher data rates to the end nodes are great, but if the infrastructure does not support it, then what’s the point?

So, the fact that the step from IEEE 802.11ac to IEEE 802.11ax is a very moderate step in terms of data rate, and a step more focused on higher capacity in the home (multiple users at the same time) makes a lot of sense. But the real hurdle is getting more data to (and from) the home.

Streaming and Bursting Affect Data Rates

To complicate matters further, there are effects to consider from streaming and bursting. There is another factor also, that makes this all even more convoluted. There is a difference between streaming and bursting. To stream a movie, you typically need a lot of continuing bandwidth for quite some time, say a continuous 20Mbps for high quality. That sounds quite doable with a 100Mbps pipe to your home. However, this 100Mbps has a somewhat statistical character. If everyone on the street is watching a movie, then the 100Mbps to your house quickly drops to significantly lower rates. Streaming a movie on a Saturday evening can be a challenging experience, as you are not the only one on the street (or in your small cell). It is no different than everyone in the house taking a shower at the same time, causing the pressure of the water system to drop.

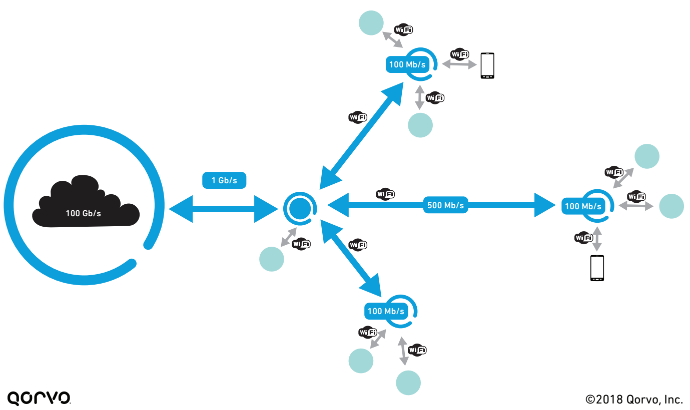
Burst is another statistical effect. You can compare it to someone opening all the taps in the home to get as much water flowing as possible. If someone tries to download a movie as fast as possible (to watch it later, for example), it causes a real burst of data consumption as the system tries to get as close as possible to the 100Mbps to one house, instantaneously. For a short time, this should be no problem. But of course, it is not sustainable, as the rest of the neighborhood would degrade quickly. From a statistical perspective, the chance that everyone on the street would try to download a movie at the same time is probably not that high, but the fact that bursts have an effect on the available bandwidth is clear.

What Needs to Happen?

With all this in mind, let's circle back to the problem of the disrupted hierarchy. What needs to be done to restore balance? Because until this problem is solved, it will be very hard to justify advancements on in-home data rates. So, let's give this a closer look, because now the usage pattern in the home becomes relevant: how many people are living in the home, how many rooms (floors) does your home have, how many devices are used simultaneously per user, etc.

Let's take an example of a family of four. Internet radio is playing in one room, mom is having a video conference in another room, dad is downloading a large report on his computer, the son is playing a video game, and the daughter is watching YouTube on her phone while a movie streams on the TV. This family would be very happy with 1Gbps to the home, a 500Mbps distribution system in the home, and 100Mbps speed access from the end device to the access point, as shown below:

Practical Solution (1 Gb/s – 500 Mb/s – 100 Mb/s)

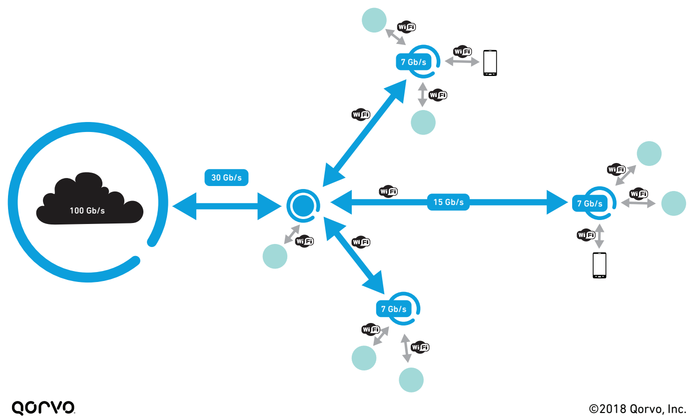


As we've discussed, it's getting access to the home with 1Gbps that is the current challenge. Although the first rollout of 10Gbps DOCSIS 3.1 has started, most people are still working with 100Mbps or less. This means that at this moment there is clearly overcapacity with all the infrastructure inside the building and the end nodes raw data rates today exceeding 1Gbps.

Approaching This from The Other Side

We can also ask the reverse question: When does 7Gbps with 802.11ad in the phone or in a tablet start making sense? Well probably if the in-home infrastructure can handle 15-20Gbps and the access to the home is 30-50Gbps. Well… that probably is going to take a while, unfortunately….

The Future? (30 Gb/s – 15 Gb/s – 7 Gb/s)

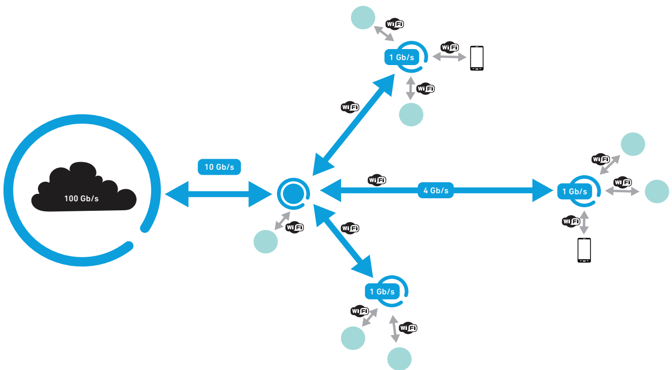


Currently fiber to the home (FTTH) is advertised at 1Gbps for DOCSIS 3.0. The next-generation DOCSIS 3.1 full duplex (FD) promises 10Gbps (in 2020?), so—we are getting up there, but there are no plans yet beyond this. Also, for distributed Wi-Fi in the home the plans with IEEE 802.11ax are not reaching beyond the 4Gbps for in-building distribution—but as can be found in many installations in the home or in an office: 10-100Gbps Ethernet may come to the rescue if needed.

So, What Can We Realistically Expect?

In the near future, we probably have to settle with end nodes using 1Gbps IEEE 802.11ac, the home infrastructure will use 4Gbps IEEE 802.11ax, and probably with something like DOCSIS 3.1 FD at 10Gbps. This will give a balanced picture that can be the next stabilizing point for the industry for Internet access at home and in buildings. In this scenario, all the resources are effectively balanced and put in a proper hierarchy.

The Practical Next Step? (10 Gb/s – 4 Gb/s – 1 Gb/s)



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Cloud vs. Edge

Interestingly, there is another solution for the broken hierarchy. But it would not be a simple one.

The concept of the solution goes something like this. Instead of doing everything “in the cloud,” this is about building a layer in between the cloud and the end-user. This layer, sometimes referred to as “edge computing,” is essentially a smart solution to pre-distribute information from the cloud to a local “super” edge-router with an integrated server.

Let’s look at an example. Someone interested in the news has a subscription that downloads all the news articles and video clips at 6 AM to her local router/server. She can browse during breakfast at 8 AM, going through the news and watching clips at incredibly high speeds and without delays. The bottleneck of getting information from the Internet has been removed. The router/server has become a traditional mailbox, in essence, and the news is kept up-to-date in her mailbox (router/server) all during the day.

From the other direction, “edge computing” is also helpful. Instead of sending a complete voice command, chat, or conversation to the cloud for processing, the processing already takes place in the router, reducing the amount of data to be transmitted.

It is clear that such an architecture overhaul would be a tremendous undertaking, but it may nevertheless be a cheaper solution than rewiring all the exits from the high-speed Internet freeway. Certainly cheaper for the network providers, because in this situation the consumer will pick up the tab – either by paying for the more sophisticated edge-router and/or paying for the subscription for “edge routing” services.

What Does This All Mean?

There are several interesting consequences and conclusions to be drawn:

1. IEEE 802.11ax, the emerging new Wi-Fi standard, will first appear in distributed Wi-Fi systems, as this is the first place for traffic aggregation and would benefit from higher data rates the most.
2. IEEE 802.11ax for end nodes will stay more of a marketing game for a while, because the infrastructure to support the higher data rates will not be there.
3. It looks like for end nodes IEEE 802.11ac will be the right choice for quite some time, avoiding the .11ax complexity and relatively small benefit. Even for lower performing end nodes, 802.11n will be a good solution for a while.
4. We need a successor for IEEE 802.11ax for increasing the bandwidth of the indoor distributed Wi-Fi infrastructure. 15-25Gbps would be a good target. The goal should be to make 60GHz IEEE 802.11ad relevant; maybe by defining that role for IEEE 802.11ay.
5. The near future for IEEE 802.11ad and 802.11ay still looks quite bleak. Longer term, if the infrastructure is in place, then these standards will become relevant.
6. The DOCSIS 3.1 Full-Duplex local loop coming to our homes providing higher speed access will make tremendous improvements to what at this moment is the real bottleneck.
7. Finally, there are opportunities to solve the problem in a smarter way than brute force raw data rates. An edge router functionality between the cloud and the end nodes can take away the pressure from the on-ramps and off-ramps of the Internet highway.

The best for Wi-Fi is yet to come, but it is important to look at the broader context to understand the relevance and the timing of all its new varieties.

By Wayne Polonio,
Qorvo® Senior Product Marketing Manager

Resolving Interference in a Crowded Wi-Fi Environment Using Bulk Acoustic Wave Filters

There are any number of strategies that consumers can try to fix interference problems with Wi-Fi in their homes—moving the router, reconnecting the device to their Wi-Fi network, power cycling the modem … and calling their service provider when nothing works and they don't know what else to try. But as an radio frequency (RF) engineer, how can you design a Wi-Fi access point that addresses the biggest interference issues from the outset?

This article examines the following factors that can impact Wi-Fi interference:

- The need to support multiple wireless standards
- Different types of interference
- Why band edges matter
- The importance of high-performance bandedge and coexistence bulk acoustic wave (BAW) filters

One Access Point, Many Standards

When developing Wi-Fi access points, designers must consider many wireless technology standards:

- Standards that operate at short and mid coverage ranges, such as Bluetooth®, Zigbee®, and Z-Wave®
- Standards that operate at higher power levels and short and long ranges, including Wi-Fi, 3G/4G Long Term Evolution (LTE), and 5G

Many of these standards can interfere with each other, leading to connectivity problems for users.

And then there's unlicensed spectrum to contend with. Licensed and unlicensed networks are becoming more important factors as constrained wireless communications offload data to continually expand capacity. Also, the new Internet of Things (IoT) realm draws heavily on this unlicensed spectrum.

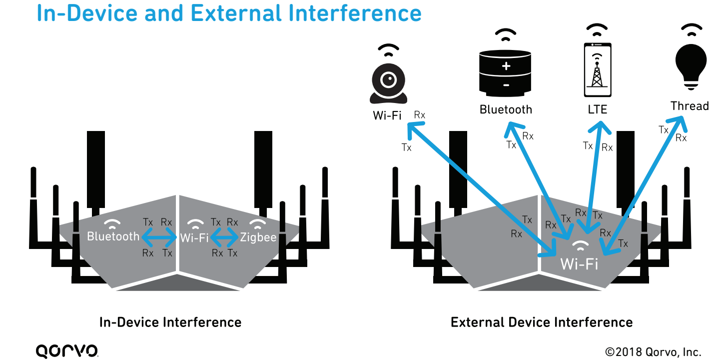
The challenge is to keep all these licensed and unlicensed bands and multiple protocols working in conjunction with each other without interference difficulties.

Not only about the Wi-Fi chip. Now it's also about the "front-ends"—the amplifiers and filters between the Wi-Fi chip and the antenna that make or break the capacity of the distributed Wi-Fi system.

Different Types of Interference: From In-Device to LTE and Bluetooth

Interference can occur within a device or between devices, including between wireless carrier signals or between wireless standards. The most common interference scenario is Bluetooth and LTE with Wi-Fi because these technologies are so widespread. Let's look at some of these in more detail.

In-Device and External Interference



In-device coexistence: For in-device coexistence, the system's multiple antenna architectures can interfere with each other. As a result, the coupling between the affected antennas (antenna isolation) is compromised. The foreign transmit (Tx) signal increases the noise power at the affected receiver, which has a negative impact on the signal-to-noise ratio. The receive (Rx) sensitivity decreases, which causes what engineers call "desensitization."

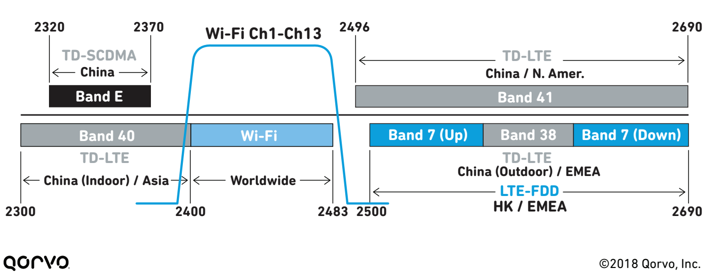
Desensitization is a degradation of the sensitivity of the receiver due to external noise sources, and results in dropped or interrupted wireless connections. It isn't a new problem—early radios encountered receiver sensitivity when other components became active—but now it's particularly troublesome for today's wireless technologies, including smartphones, Wi-Fi routers, Bluetooth speakers, and other devices.

The primary "desense" scenarios are:

- Two radio systems occupy bordering frequencies, and carrier leakage occurs.
- The harmonics of one transmitter fall on the carrier frequencies used by another system.
- Two radio systems share the same frequencies.

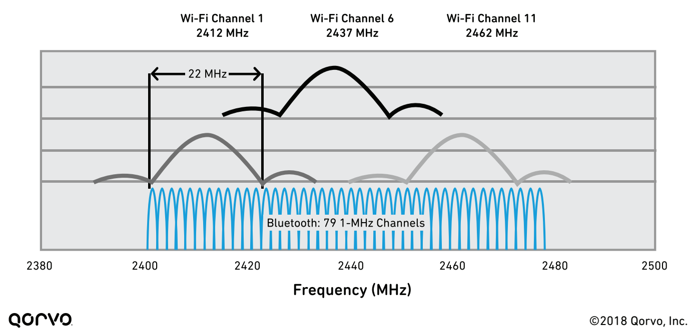
LTE and Wi-Fi: As shown in the below figure, several LTE bands—Bands 40, 7, and 41—are very close to the Wi-Fi band channels. Leakage into the adjacent Wi-Fi radio band is very probable at both the high and low end of the 2.4 GHz band. Without proper system design, the cellular and Wi-Fi channels 1 and 11 can interfere with each other's transmissions and receive capability.

Spectrum Example of Asia and EMEA



Bluetooth and Wi-Fi: Bluetooth and Wi-Fi transmit in different ways using differing protocols, but they operate in the same frequency ranges, as shown in the following figure. As a result, when Wi-Fi operates in the 2.4 GHz band, Wi-Fi and Bluetooth transmissions can interfere with each other. Because Bluetooth and Wi-Fi radios often operate in the same physical area (such as inside an access point), interference between these two standards can impact the performance and reliability of both wireless interfaces.

ISM, Wi-Fi & Bluetooth Channel Frequencies



Why Band Edges Matter for Wi-Fi Coexistence

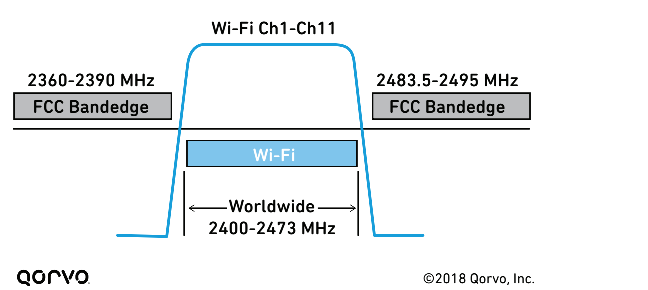
One way federal governments have tried to help consumers is by regulating the emissions and spectrum of many electronic devices and requiring consumer products to undergo compliance testing.

In the United States, the Federal Communications Commission (FCC) requires that most RF devices undergo testing to demonstrate compliance to FCC rules. They enforce strict band edges by requiring steep skirts on the lower and upper Wi-Fi frequencies, to help with coexistence with neighboring spectrum.

There are two ways for Wi-Fi access points to meet this FCC requirement:

1. Back off the power level on Wi-Fi channel 1 and 11, because they're at the edge of the Wi-Fi spectrum.
2. Use filters with very steep band edges.

Spectrum Example of Wi-Fi and Bandedge



Design Tips to Overcome Interference Challenges: Use High-Q BAW Filters

Our approach is to use high-performance coexistence and bandedge filters, to allow Wi-Fi transmitters to operate close to the upper and lower FCC band edges.

Customers have had success using high-Q bulk acoustic wave (BAW) bandpass filters, which offer many advantages:

- **Extremely steep skirts** that simultaneously exhibit low loss in the Wi-Fi band and high rejection in the band edge and adjacent LTE/Time-Division Long-Term Evolution (TD-LTE) bands
- **Significant size reductions,** which aid designers in creating smaller, more attractive end-user devices for homes and office environments
- **Resolves coexistence of Wi-Fi and LTE signals** within the same device or near one another
- **Unique power handling capabilities,** allowing for implementation into high-performance, high-power access points and small cell base stations

These filters address the stringent thermal challenges of multi-user multiple input/multiple output (MU-MIMO) systems, without compromising harmonic compliance and emissions performance. This is critical to achieving reliable coverage across the full allocated spectrum.

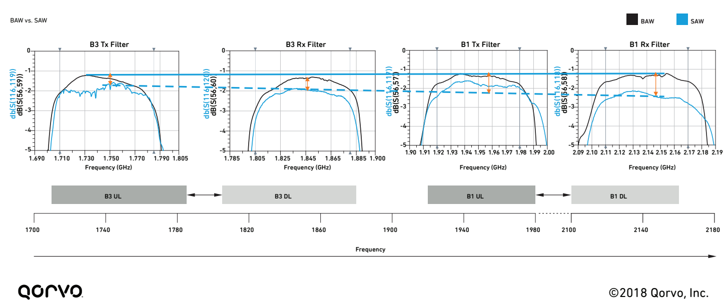
But why do high-Q BAW filters make such a difference for FCC band edges?

#1: BAW devices have lower insertion loss, steeper band edges, and better temperature stability than SAW technology at Wi-Fi frequencies

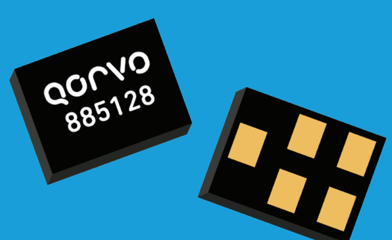
As you move into higher bandwidths like Wi-Fi, surface acoustic wave (SAW) devices can suffer from higher insertion losses than BAW due to radiation of acoustic energy into the bulk of the substrate. As shown in the following figure, as you move up (to the right) in frequency, you can see high-Q BAW is a better option for filter designs due to this bulk radiation loss effect. Also, BAW maintains the steep skirts required for FCC band edges; SAW can't meet the performance requirements at these higher frequencies.

BAW also has better temperature stability than other technologies, which gives it an advantage during FCC certification tests. Most Wi-Fi designs are created at room temperature (20-25°C) on a bench, but the system in its application environment can actually operate around 60-80°C. Insertion loss increases as temperature increases, and failing to estimate for this can cause issues during product certification. Using BAW reduces the shifts in insertion loss and makes certification test results more predictable.

BAW Versus SAW Technology



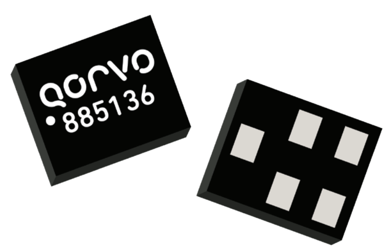
Qorvo 885128 2.4GHz Wi-Fi/BT LTE Co-Existence Filter



- Low loss in Wi-Fi band with extended upper corner for inclusion of Bluetooth
- High rejections in LTE bands B7 / B41 / B38 / B40
- Performance over -40 to +95ºC

Learn More

Qorvo 885136 2.4GHz RF BAW Filter Wi-Fi Band Edge



- Industry leading size - 1.1 x 0.9 x 0.50mm
- Performance over -40 to +95ºC
- High rejection at 2390MHz, 2483.5MHz, B38/ B40/B7/B41

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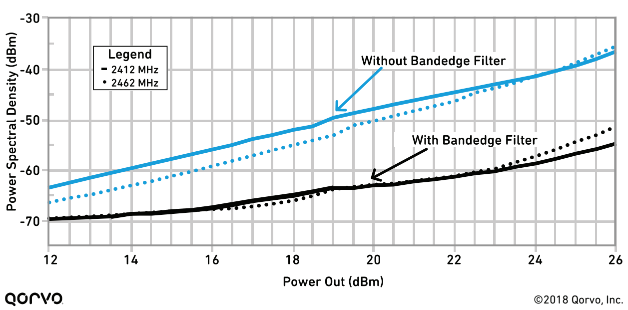
#2: BAW filtering can help engineers provide seamless transitioning between interfering bands

As shown in the following figure, the bandedge response is better using a filter than without it, and it allows designers to push the limit on RF front-end output power while meeting the FCC requirement for power spectral density. This means bandedge BAW filtering allows operators and manufacturers to deliver high-speed data and greater bandwidth by using spectrum that might be lost with no filtering.

FCC Restricted Bandedge With and Without BAW Filter



#3: High-Q BAW bandedge filters can extend the range in channel 1 and 11 by 2-3 times

Wi-Fi designers normally must set the entire unit power to whatever the lowest bandedge-compliant power is for all channels. So, if the compliant channel at channel 1 is 15dBm but channel 6 can achieve 23dBm, the designer settles the entire power control scheme to 15dBm. Using bandedge filtering allows designers to set the power scheme to much higher powers, thus making it possible to use fewer RF chains to achieve their goals.

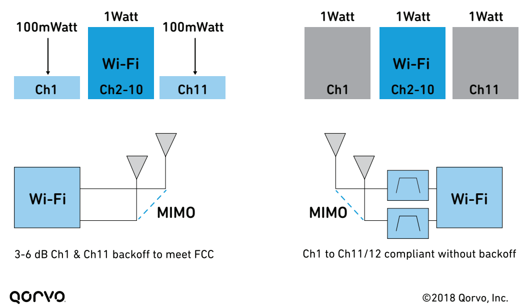
BAW bandedge filters can also exhibit power handling capabilities for transmitting up to 28dBm. This can improve system performance by greater than 15 percent and enable 5G multi-MIMO with less co-channel interference.

Customer premises equipment (CPE) developers who don't use bandedge filtering have difficulty meeting FCC requirements on Wi-Fi band channels 1 and 11. In contrast, when high-Q BAW bandedge filters are used, it allows the CPE designer to keep the power level the same throughout all the channels (1 – 11).

To paint the picture, here's the difference in user experience with and without bandedge filters:

Without bandedge filters: Let's assume you're in a house with several individuals using Wi-Fi and mobile phones. You're on Wi-Fi using channel 5, streaming a football game and experiencing no buffering or interruption. But then new mobile users arrive in the house and begin to take over your channel 5 Wi-Fi space. The CPE unit adjusts and bounces you to channel 1 to free up more space on channel 5. If the Wi-Fi unit doesn't have bandedge filters (as in the block diagram on the left), your Wi-Fi strength and streaming degrade to the point where buffering occurs. Why? Because to meet the FCC requirement, the CPE unit must back off its power in channel 1 so it doesn't interfere with adjacent cellular bands.

Wi-Fi/LTE System Models
(With/Without Bandedge Filters)



With bandedge filters: However, if the CPE unit had been designed with bandedge filters (as shown in the block diagram on the right), channel 1 and 11 would not be compromised and the power level would not require backoff. You can watch your streamed football game without any buffering.

Go In Depth: How Qorvo Wi-Fi Solutions Can Help Solve Interference Challenges

In a connected world with more and more devices and wireless standards, coexistence and interference issues will not go away. To make use of every bit of spectrum available, Wi-Fi designs with high-Q BAW filters can improve the performance of Wi-Fi access points.

By
Steven
Keeping,
for Mouser
Electronics

Wi-Fi Updates for Efficiency and Range

What's new about the amendments to IEEE 802.11 (the standard for Wi-Fi) and what applications do they target are the two questions we will discuss in this article.

Since the first Wi-Fi® protocol—based on the IEEE 802.11 standard—was introduced in 1997, Wi-Fi has become a globally established wireless technology for consumer and industrial applications because it offers good tradeoffs between throughput, range, and power consumption. The protocol originally targeted wireless local area network (WLAN) applications and has now become the dominant standard in this sector.

IEEE 802.11 has continually evolved to meet the demands of new Wi-Fi applications. For example, the introduction of more efficient modulation techniques and additional spatial streams has boosted throughput, and Wi-Fi's coexistence with other wireless technologies has improved by using industrial, scientific, and medical (ISM) spectrum allocations and by introducing newer versions of this technology, which operate in the less congested 5 and 60GHz bands.

However, further throughput gains do not solve the key problem facing today's Wi-Fi users. The problem stems from the fact that Wi-Fi is now being used in ways that were not envisaged when the standard was first drawn up. At that time, engineers thought that relatively few users would demand a high-throughput service, which meant that Wi-Fi service was contention based; bandwidth was shared between users; access points covered overlapping areas; and end users could be shifted between access points. Moreover, traffic monitoring was not a priority, so every user was treated the same, and there was no facility to track and manage performance to optimize network efficiency. These drawbacks were not critical when there were relatively few users, but with today's high demands and dense deployments, the spectral inefficiency of contention-based Wi-Fi is beginning to limit the quality of service.

Elsewhere, engineers are also looking to expand Wi-Fi technology to sub-1GHz spectrum allocations to boost range up to 1km for relatively low-throughput applications, which involve the burgeoning Internet of Things (IoT), and to use TV-white-space spectrum allocations effectively.

Four amendments to the IEEE 802.11 standard, dubbed IEEE 802.11ax, ay, af, and ah, now exist to remove these challenges.

IEEE 802.11ax

IEEE 802.11ax, or "high-efficiency Wi-Fi (HEW)," was designed to meet the growing demand for dense deployments of connected devices and services in offices, schools, and public hotspots.

IEEE 802.11ax increases the data rate capability from the legacy standard. It also vastly increases 2.4GHz data rates, as 2.4GHz was not addressed in the 802.11ac standard officially (only 5GHz).

IEEE 802.11ax promises a marked improvement to the user experience found in today's common use cases, boosting the data rate around 30 percent in comparison to IEEE 802.11ac and multiplying the capacity of each access point up to fourfold, for a faster, more reliable user experience. In addition, because it brings significant efficiency enhancements, IEEE 802.11ax will assist in situations where cellular network coverage is poor or in handling some of the wireless traffic load when a network is congested.

Technical Enhancements

IEEE 802.11ax takes advantage of both the 2.4 and 5GHz channels. (Previously, IEEE 802.11n was the only dual-band version of Wi-Fi.) Like other Wi-Fi amendments, IEEE 802.11ax is backward compatible with legacy Wi-Fi devices operating in the same band. The technology supports 20, 40, 80, 80 + 80, and 160MHz-channel widths and introduces a sub-channel width of 78.125kHz (compared to 312.5kHz for previous versions).

IEEE 802.11ax gains much of its spectral efficiency increase by combining a higher single-stream data rate with more spatial streams, multiple channels, and an increased number of sub-channels. The amendment also takes advantage of multi-user multiple input/multiple output (MU-MIMO), orthogonal frequency-division multiple access (OFDMA) (borrowed from Long Term Evolution (LTE) cellular technology), and higher-rate quadrature amplitude modulation (1024-QAM) to ensure the most efficient use of the available spectrum.

IEEE 802.11ax also provides an increase in symbol duration from the 3.2µs for legacy versions to 12.8µs and includes the option for a longer guard interval (GI) of 3.2µs.

Technical Benefits

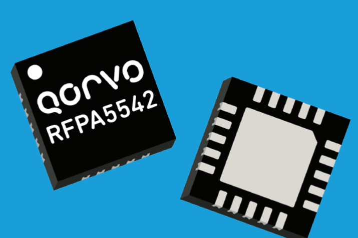
IEEE 802.11ax's dual-band capability allows users to choose between the 2.4GHz allocation's longer propagation range or the lower congestion of the 5GHz allocation. Support for a full range of channel widths and narrower sub-channels divides the available spectrum, ensuring good service to users in dense deployments.

IEEE 802.11ax supports up to 8 x 8 MU-MIMO connections for both downlink and uplink, which allows an access point to simultaneously transmit and receive data from up to eight users. Previously MU-MIMO was limited to downlink connections only. The new amendment combines MU-MIMO with an uplink resource scheduler to ensure that uploads from different users don't clash. Previously, legacy versions required that devices wait for an "all-clear" signal before transmission. In the event of interference, devices reverted to a back-off procedure and again listened for the all-clear signal before transmitting. In dense deployments, collision avoidance limited the quality of service. The new "managed" approach addresses this problem while improving resource allocations and aiding efficiency.

The introduction of OFDMA allows the OFDM sub-channels used in previous amendments to be further split into four, increasing the number of multiple users who receive service simultaneously, despite their varying bandwidth needs. The 1024-QAM modulation allows each packet to carry more information and is available with 3/4 and 5/6 coding rates, which results in about a 30 percent throughput gain compared to IEEE 802.11ax alone.

The data rate of a single stream that uses an 80MHz channel (the highest modulation rate of 1024-QAM) along with a 5/6 coding rate and guard interval of 0.8µs is around 600Mbps. Taking advantage of the technology's eight streams and 160MHz channel bumps the data rate to 9.6Gbps.

Qorvo RFPA5542 5GHz Wi-Fi Power Amplifier Module 802.11a/n/ac



- Pout = 23dBm, 5V, .11ac 80MHz MCS9 @ 1.8% EVM
- Gain = 33dB
- 50Ω input and output matched

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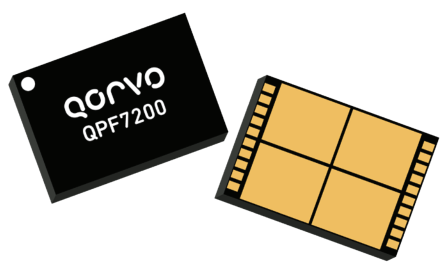
Qorvo QPF7200 2.4GHz Wi-Fi Front End Module



- Fully integrated FEM includes highly selective BAW filters achieving FCC bandedge and coexistence attenuation over operating conditions
- 37dB Tx gain
- Pout = +25dBm, 802.11n, MCS7 -30dB EVM (bandedge compliant Ch1-11)

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The increase in symbol duration helps to ensure reliable service for a technology that promises an ambitious 8 x 8 MU-MIMO scheme. The additional guard band interval of 3.2μs adds robustness in demanding, outdoor, and dense deployment situations **(Table 1)**.

Feature	IEEE 802.11ac	IEEE 802.11ax
Operating frequency (GHz)	5	2.4, 5
Channel bandwidths (MHz)	20, 40, 80, 160	20, 40, 80, 160
Highest modulation rate	256-QAM	1024-QAM
Data rate (Mbps), required channel (MHz)	433, 80MHz channel 6933, 160MHz channel	600, 80MHz channel 9607, 160MHz channel
Capacity increase vs previous version	2X	4X
BSS coloring	No	Yes
MU-MIMO	Downlink only	Uplink and downlink
OFDMA	No	Yes
TWT	No	Yes
Range (ft.)	About 800	800+

Table 1: This table compares IEEE 802.11ac and IEEE 802.11ax. (Source: Mouser Electronics)

IEEE 802.11ax also introduces a feature that aims to reduce the power consumption of battery-powered devices. Called target wake time (TWT), this feature supports resource scheduling by enabling devices to negotiate when and how often they will wake up to send or receive data. Because their communication is scheduled via the TWT rather than by an ad hoc time, devices can safely spend non-scheduled communication time in a low power, sleep mode.

Target Applications

HEW was designed to succeed IEEE 802.11ac as the mainstay of Wi-Fi communication. With the significant advantages of greater throughput and more robust service, HEW will support the ubiquitous Wi-Fi to which mobile-device consumers have become accustomed in both domestic and commercial environments. After adoption of the amendment, it's likely that consumer-electronics firms and domestic and commercial access-point makers will quickly integrate the new technology into their products.

Security

Wi-Fi Protected Access II (WPA2), which was introduced in 2004 and based on the IEEE 802.11i specification, currently protects Wi-Fi from malicious attacks. The WPA2 protection operates under the Counter Mode with Cipher Block Chaining Message Authentication Code Protocol (CCMP), which is based on Advanced Encryption Standard (AES) processing and uses a 128-bit block size and a 128-bit key.

IEEE 802.11ax could be the first amendment to take advantage of Wi-Fi Protected Access "III" (WPA3), the replacement for WPA2, announced by the Wi-Fi Alliance™ in January 2018. The new security standard uses a 192-bit key encryption and encryption individualization for each user. Supposedly, WPA3 also simplifies the process of setting up devices with no display interface, which is an essential requirement for units such as wireless sensors that connect to IoT.

Availability

Uncertified Wi-Fi technology and associated development tools typically hit the market before the formal adoption of a new amendment to allow engineers to start on new projects. If the amendment specification changes after uncertified products have been introduced, then firmware updates are usually permissible to bring deployed units into full compliance.

With IEEE 802.11ax slated for adoption in 2019, silicon vendors have already started introducing chipsets. For example, Qorvo, a radio frequency (RF) systems company, has launched the QPL7210 2.4GHz Wi-Fi LNA Receive Module, a front-end module (FEM) for Wi-Fi 802.11ax as well as "n" and "ac" applications. The QPL7210 integrates a 2.4GHz low noise amplifier (LNA), an LNA bypass, and a high-selectivity receiving bulk acoustic wave (BAW) filter for wireless coexistence. By integrating this functionality into a single module (measuring 3.0 x 3.5 x 1.0mm), the QPL7210 addresses some of the design complexity that IEEE 802.11ax introduces.

Design Challenges

IEEE 802.11-based RF design requires a high level of expertise even when leveraging proven technology, firmware, and operating systems from leading vendors. This is because IEEE 802.11ax, for example, introduces modulation techniques from LTE cellular technology, brings extra complexity, and adds to the design challenges. However, with a knowledgeable silicon and firmware vendor and previous experience (particularly with IEEE 802.11ac), developing with IEEE 802.11ax can certainly fall within the scope of capability for most competent engineers.

One approach that eases design complexity is to select a module that incorporates the designer's selected technology. Modules offer good RF performance directly out of the box and are typically verified and certified solutions. Modules come with tested Wi-Fi and Transmission Control Protocol/Internet Protocol (TCP/IP) firmware stacks, leaving the designer to focus on differentiating his or her product via the application software. Module downsides include a higher bill of materials (BOM) and a larger space requirement compared to the requirement of a discrete solution.

In addition to the overall complexity of IEEE 802.11ax, certain design challenges exist of which engineers should be aware. First, the technology is more prone to narrowband interference than previous versions; overcoming such interference may require the engineer to employ schemes such as notch filtering and dual sub-channel modulation. Second, the technology's narrower sub-channel space (78.125kHz) makes it more prone to frequency and phase errors and unwanted residual-center frequency offsets. Third, 1024-QAM presents design challenges such as non-linearity during power amplification, and 8 x 8 MU-MIMO connections demand more signal generations and analysis channels for testing. Finally, IEEE 802.11ax's complexity can cause quantization errors during analog-to-digital conversions and phase noise increases in local oscillators.

IEEE 802.11ay

While IEEE 802.11ax focuses on spectral efficiency, elsewhere IEEE 802.11 technical committees are considering amendments to the technology's physical and media access-control layers that dramatically increase the throughput of Wi-Fi for specialist applications. The latest of these amendments, IEEE 802.11ay, builds on IEEE 802.11ad and promises to boost throughput while helping to extend range.

Technology

IEEE 802.11ay was designed to operate in the unlicensed 60GHz spectrum allocation and is backward compatible with IEEE 802.11ad equipment. The allocation offers a frequency band of around 14GHz in width, which the amendment proposes dividing into 2.16, 4.32, 6.48, and 8.64GHz channels.

IEEE 802.11ay brings MIMO operation to 60GHz Wi-Fi for the first time. The technology will offer "single-user" multiple input/multiple output (SU-MIMO) connections, downlink MU-MIMO (up to eight users), and up to four spatial streams.

While exact details are yet to be released, it's likely that IEEE 802.11ay will use OFDM modulation; up to 256-QAM; and 5/8, 3/4, and 13/16 coding rates. Maximum throughput will be 20Gbps for a single stream.

Enhancements

IEEE 802.11ay was specifically designed to build on the established technology of IEEE 802.11ad. It offers enhancements to the previous amendment by introducing channel bonding and aggregation along with MIMO. Also, the new amendment offers a greater variety of beamforming techniques, which leads to a boost in maximum throughput of 80Gbps (when employing four spatial streams), compared to IEEE 802.11ad's 6.7Gbps (in a single stream), and an indoor/outdoor range of 10/100m, compared to 3/30m.

Target Applications

IEEE 802.11ay was designed to provide ultra-high-speed wireless connectivity between devices within reasonably close proximity (for example, 5 to 10m) and in the absence of obstacles such as walls. One such application is downloading high-definition (HD) movies to a smart TV. Early IEEE 802.11ay implementations that offer a data rate of 10Gbps can download a 4K movie (60GB) in just over a minute compared to more than 11 minutes for an IEEE 802.11ad installation.

Other applications include virtual and augmented reality (VR and AR). For example, a gaming application and content on a managing device, such as a smartphone, could wirelessly transfer to a VR headset using an ultra-high-speed IEEE 802.11ay wireless link, all with no cellular or Internet link requirements **(Figure 1).**

Figure 1: IEEE 802.11ay meets the high-bandwidth demands of mobile VR applications. Source: (Getty Images)

Another application that IEEE 802.11ay targets is the wireless backhaul that supplements cellular networks across short distances—for example, for wirelessly linking two adjacent office buildings on a commercial campus.

Availability

The IEEE 802.11ay technical committee estimates that the amendment's adoption will occur in late 2019. To date, commercial technology and development tools are not available for this amendment.

Design Challenges

While high-frequency Wi-Fi provides the inherent advantage of greater throughput, range limitations are present forcing engineers to turn to complex beamforming transmitters and multiple antennas to achieve satisfactory performance.

Such complexity compounded with the challenges of high RF circuitry and printed circuit board (PCB) layouts pushes the so-called "gigabit" Wi-Fi a step above the more "routine" 2.4 and 5GHz technology. Signal analysis and testing of 60GHz Wi-Fi is also correspondingly more complex.

Wi-Fi for IoT

While much of the focus of the IEEE's working groups has been on improving Wi-Fi's throughput and spectral efficiency, complementary efforts have been in process to introduce amendments that make the technology applicable as a connectivity option for IoT.

The demands of IoT are far removed from those of Wi-Fi's traditional target markets, such as wireless Ethernet where throughput is more important than range or power consumption. In contrast, an IoT application sensor data upload to the cloud demands a relatively infrequent transfer of low volumes of information. Low-power consumption is important because sensors typically operate from batteries for long periods, yet long-range capacity is an advantage because sensor deployment might span over a wide outdoor area in applications like traffic or security monitoring **(Figure 2).**

Figure 2: Sub-1GHz Wi-Fi offers the long range essential for external, wireless monitoring deployments. Source: (Getty Images)

Wi-Fi also provides a key advantage over many competing IoT wireless technologies, such as Bluetooth® Low Energy (BLE) and Zigbee, because its firmware typically incorporates TCP/IP upper layers that enables a connection to the Internet without the recourse of expensive and complex gateways.

IEEE 802.11af

IEEE 802.11af is sometimes referred to as a "White-Fi" and was designed to employ licensed very high frequency (VHF) and ultrahigh frequency (UHF) TV channels from 54 to 790MHz—enabling more efficient use of that part of the electromagnetic spectrum. Because Wi-Fi access power transmits at relatively low power, minimal interference should affect other devices, like analog/digital TV and wireless microphones, that use the spectrum allocation. However, to ensure that these primary users don't suffer from interference, IEEE 802.11af includes measures such as cognitive radio technology, which allows a system to detect transmissions and move to alternative channels when it detects these signals.

IEEE 802.11af borrows much from IEEE 802.11ac, including OFDM modulation and 256-QAM, and because of its lower operating frequency, IEEE 802.11af experiences a much lower attenuation from obstacles such as walls and ceilings. Its indoor range can exceed 100m (compared to IEEE 802.11ac's 35m), and its outdoor range can exceed several kilometers, which makes it a good candidate for IoT applications such as smart lighting or security.

IEEE 802.11af offers 6, 7, and 8MHz channels, of which four can be bonded into one or two contiguous blocks. The technology also supports MIMO (with up to four spatial streams). Its throughput ranges from 1.8Mbps for a single-stream-6MHz channel to 570Mbps for four-bonded-8MHz channels with four spatial streams, 256-QAM modulation, and a 5/6 coding rate.

IEEE 802.11af was designed to operate like a traditional WLAN while avoiding the congested 2.4GHz spectrum allocation and the range limitations of the 5GHz allocation. Throughput on an IEEE 802.11af single channel has more limitations than IEEE 802.11ac, but by bonding channels and employing MIMO, satisfactory Wi-Fi WLAN performance is achievable.

IEEE 802.11af was adopted in February 2014. While some chipsets with this technology began to appear in early 2016, broad use of the technology has been slow, and this is primarily because spectrum allocations vary not only from country-to-country but even from region-to-region, making it tough for chip makers to introduce chipsets that cater to all applications.

IEEE 802.11ah

IEEE 802.11ah (dubbed "HaLow") complements the "af" amendment by introducing IoT-targeted capabilities, such as sensor-traffic priority and low-power consumption. Employing a low duty cycle operation restricts power consumption, allowing a sensor to spend long periods in sleep mode. Claims suggest that the technology's power consumption is around one percent of a conventional Wi-Fi chip's consumption. The technology also employs TWT and other power saving techniques such as restricted access windows.

IEEE 802.11ah operates in the 900MHz ISM band in the US and in other sub-1GHz bands elsewhere in the world, supporting up to a 1km range. The technology's channel widths are 1, 2, 4, 8, and 16MHz, and it supports MIMO, OFDM modulation, and up to 256-QAM. With a single spatial stream, 1/2 coding rate, and a 2MHz channel width, throughput is 650kbps. At the top end, using three spatial streams, 256-QAM modulation, a 3/4 coding rate, and an 8MHz channel width, throughput is 234Mbps.

The amendment supports mesh networking and includes IP support at the node, which is crucial for IoT-targeted technologies.

IEEE 802.11ah was adopted at the end of 2016, and while the introduction of commercial products that embody this new standard has been slow, some chipsets, firmware, and development tools are now starting to trickle into the market. Qorvo has a family of <1GHz FEMs to mate across multiple chipset solutions on the market.

Conclusion

The IEEE 802.11 amendments underpinning Wi-Fi have continued to evolve since the adoption of the original standard over two decades ago. Amendments such as IEEE 802.11ay progressively address consumer demands for greater throughput for applications such as high-definition video streaming, and other amendments such as IEEE 802.11ax address the challenge of creating the best use for increasingly congested RF spectrum allocations while also continuing to enhance the IEEE 802.11's overall performance standard.

By Jeff Jones,
Qorvo Senior Manager,
Applications Engineering

Designing for 802.11ax Wi-Fi: Common Challenges and Tips to Overcome Them

In a previous article, we covered five key things to know about 802.11ax, the next big standard for Wi-Fi. Let's examine some of the challenges that radio frequency (RF) engineers will face when designing for 802.11ax and some tips on how to overcome them.

Some Background: 5 OFDMA PPDU Formats for 802.11ax

But first, let's look at the foundational signal structure for 802.11ax—the physical layer protocol data units that Wi-Fi clients and devices use to communicate.

802.11ax uses five formats for its OFDMA PPDU:

- **Single User (HE-SU).** For transmitting data from a single user.
- **Multi User (HE-MU).** For transmitting data to one or more users that isn't in response to a trigger frame.
- **Outdoor (HE-xSU).** For outdoor transmission for a single user. This format is new in 802.11ax.
- **Trigger Response (HE-TRIG).** For transmitting data in response to a trigger frame. Used to coordinate uplink MU-MIMO or uplink OFDMA transmissions with the access point.
- **Downlink Channel Sounding (HE-NDP).** For beamforming and downlink channel sounding.

See the image at the end of this article for details of the frame packets and fields within each PPDU format.

Glossary of Terms:

Evm: Error Vector Magnitude

He: High Efficiency

Hew: High-Efficiency Wlan (Or High-Efficiency Wireless)

Mu-Mimo: Multi-User Multiple Input/Multiple Output

Npd: Null Data Packet

Ofdma: Orthogonal Frequency-Division Multiple Access

Plcp: Physical Layer Convergence Procedure

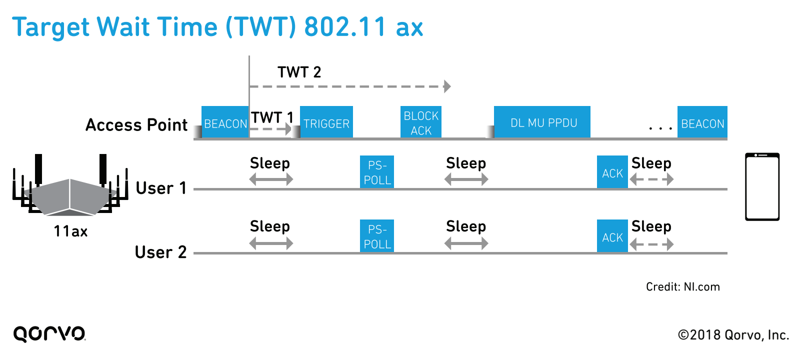
Ppdu: Plcp Protocol Data Unit

Qam: Quadrature Amplitude Modulation

Twt: Target Wait Time

Wait or Sleep Times: What Are the Challenges for the RF Front End?

One thing 802.11ax adds is target wait time (TWT)—also known as sleep times—which allows a device to stay in a sleep state longer before transmitting data. This resource scheduling improves battery life and means a better experience for a consumer.



However, latency in turn-on mode could be an underlying challenge. TWT also brings the following:

- **High susceptibility to frequency and clock offsets in OFDMA.** Unlike LTE base station technologies, 802.11ax doesn't have a synchronized clock signal. As a result, devices will rely on the access point to keep all the devices on the network synchronized. Additionally, 11ax uses longer orthogonal frequency-division multiplexing (OFDM) symbols than 11ac, which means more data comes through. In short, the access point will have to work harder—and be more accurate—than in the past.

- **Flatness maintained over a longer time period.** The specs we've received from some of our chipset partners show that the initial power amplifier (PA) turn-on time has not changed in 802.11ax; it's still 200-400 nanoseconds. However, the gain flatness has been extended, guaranteeing the front-end module (FEM) has no gain expansion or gain droop for the duration of the packet.

Indoor vs. Outdoor Wi-Fi: What Are the Similarities and Differences?

For 802.11ax to work across all environments, both indoor Wi-Fi and outdoor base stations or small cells will be required.

The front-end development is very similar for indoor and outdoor environments. The coexistence strategy—out-of-band rejection, harmonic filtering, and frequency range—is similar.

The main differences between indoor and outdoor environments include:

- **A new data packet structure for outdoor.** As we mentioned earlier, 802.11ax adds an entirely new data packet format for outdoor Wi-Fi, the HE-xSU PPDU format (shown in the PPDU figure at the end of this article). The extended range of the outdoor PPDU format allows the Wi-Fi signal to travel longer distances, as is typical for an outdoor Wi-Fi environment.

- **Power levels and the resulting thermal considerations.** Although some customer premises equipment (CPE) applications have similar power targets as mobile, there is also a high-power category, which means thermal management is even more important.

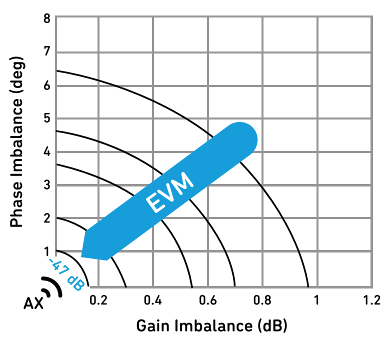
Designing for Tighter System Requirements in 802.11ax

The modulation scheme used in 802.11ax, 1024-QAM, quadruples the wireless speeds. But it also means the system becomes more sensitive to internal and external impairments.

Here are some of the design challenges that engineers should be aware of:

- **Tighter linearity specs for the PA.** The tighter constellation density in 1024-QAM drives the PA linearity requirement to approximately 47dB EVM in 802.11ax. (However, there are efforts to relax the system EVM requirement per IEEE doc 11-17-1350.) Also, don't forget to assess the test systems required to measure these EVM levels for FEMs/iFEMs.

802.11ax FEM/iFEM vs. System Requirements



- **LNAs must have a lower NF.** Earlier reference designs required low noise amplifiers (LNAs) to have a noise figure (NF) target range of 2.5-3dB. In 802.11ax, system sensitivity targets drive new LNA targets of 1.5-1.8dB NF.
- **Gain expansion/droop.** Ten years ago, the gain imbalance target was 1dB. Now it has decreased to 0.3-0.5dB. As shown in the following figure, gain and phase imbalance are being pushed to the lower left to attain -47dB EVM.
- **The overall system margin**. From a design perspective, the target PA specification is -47dB EVM, but the actual system spec is 35dB EVM. Chipset partners will typically drive for system margin.

To address all these design challenges, engineers and marketing can consider the following:

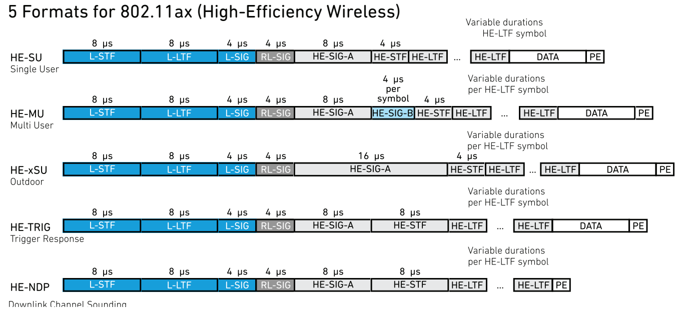
- **Increase current consumption to meet EVM targets.** A system will typically achieve better EVM if you increase circuit current (Icc), but it will also lower the power-added efficiency (PAE). To achieve a decent PAE and linearity tradeoff, you need to optimize these major focus areas:
    - Load line
    - Interstage matching
    - Bias circuit design
    - Digital predistortion (DPD)
    - Envelope tracking (ET)
- **Design assumptions: Ask if the device needs to be best-in-class for the premium tier or serve mass tier.** The answer really depends on the market, because requirements vary by customer and application. Early adopters and flagship premium products may push for best-in-class performance (47dB EVM). In contrast, if the product is for mass tier or the low-cost market, devices probably won't be required to support 802.11ax for another year or two after initial adoption in the premium tier.

A Final Thought: Designing for a Standard That's Still in Flux

Above all, remember that the 802.11ax spec is still being defined, and you should work with your applications team to maximize your product designs for the emerging standard. Qorvo is committed to helping customers and providing design expertise as this Wi-Fi standard takes shape.

OFDMA PPDU Formats

5 Formats for 802.11ax (High-Efficiency Wireless)



Field	Description
L-STF	Legacy Short Training Field
L-LTF	Legacy Long Training Field
L-SIG	Legacy Signal Field
RL-SIG	Repeated Legacy Signal Field
HE-SIG-A	HE Signal A Field
HE-SIG-B	HE Signal B Field
HE-STF	HE Short Training Field
HE-LTF	HE Long Training Field
DATA	Data
PE	Packet Extension Field
GI	Guard Interval
LTS	Legacy Training Sequence

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