Quantenna

Dual-Band 11AX

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WHITEPAPER

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1. A Brief History of Wi-Fi

Wi-Fi has become a ubiquitous technology in today's world, providing connectivity for billions of devices. While it's generally just referred to as "Wi-Fi", the term really encompasses a number of different technologies and frequency bands. In spite of this, the industry has been quite successful in merging all of these different technologies into a single Wi-Fi experience for end-users.

The first Wi-Fi technology to be deployed circa 1997 was 802.11b, which operates in the 2.4 GHz ISM band and is based on spread-spectrum techniques. It was followed in 1999 by 802.11a, which operates exclusively in the 5GHz band and uses OFDM modulation instead. Later, around 2003, the technology that underlies 802.11a was adapted to operate in the 2.4 GHz band as well, which gave rise to 802.11g.

802.11n, published in 2009, was a major revamp of Wi-Fi, introducing new concepts like MIMO and several advanced features that are built on MIMO (such as beamforming, spatial multiplexing, …). 802.11n also was the first Wi-Fi technology to be defined for both the 2.4 GHz and the 5 GHz band. However, widespread adoption of the more advanced features of 11n did not happen until the introduction of the next-generation Wi-Fi, 802.11ac.

802.11ac was published in 2013. It pushed features like beamforming and MU-MIMO into the mainstream, but it is only defined for the 5GHz band.

This means that since publication of 802.11n in 2009, no single technology exists that covers both Wi-Fi bands and that has good support for advanced features to serve the demands of today's Wi-Fi. Partly in response to this, 802.11ax was started in May 2014. It is currently scheduled to become officially ratified as a standard by late 2019. In the interim, a well-developed draft of the standard is available for initial implementations and first-generation products are emerging.

In this paper, we'll discuss 11ax and how to make optimal use of the dual-band support and the set of features that it brings to the table. We'll argue that a home network is best served by simultaneous operation of 11ax in both the 2.4 GHz and 5 GHz bands, combined with a judicious partitioning of the devices between those bands. Different 11ax features can then further be used to address the conditions or services encountered in each of the bands. In addition, 11ax should also be considered as a technology for IoT devices, such that all or most in-home communications can be harmonized using a single underlying technology.

2. A Quick Look at 11ax Features

In this section, we'll provide a brief overview of the key features of 11ax. 11ax inherits all the advanced MIMO features of 11ac and adds many new features that are targeted at dense-deployment scenarios. The flagship features of 11ax are:

- New OFDM Symbol Duration
- Downlink OFDMA
- Uplink OFDMA
- Downlink MU-MIMO
- Uplink MU-MIMO
- Spatial Reuse
- Extended Range Operation
- Target Wake Time
- Modulation improvements (1024 QAM)
- 20 MHz -only operation

These features are described briefly below.

2.1 New OFDM Symbol duration

Like 11a, 11g, 11n and 11ac, 11ax uses OFDM modulation. With OFDM, data is transmitted in symbols using a large number of frequency subcarriers. Prior to 11ax, the symbol duration was 4 microseconds. The duration for 11ax symbols was chosen to be four times longer. This choice makes 11ax more robust in highly dispersive channels with lower overhead than these older technologies.

2.2 Downlink OFDMA (DL-OFDMA)

In DL-OFDMA, the AP sends data to several users simultaneously, by assigning different parts of the spectrum to different users. This does not increase the total resources of the channel, but it enables the sharing of the transmission overhead (such as preamble, inter-frame silent periods, …) over several users, rather than having to duplicate them for every user. This reduction in overhead translates in improved throughput. As this overhead can be significant for short data transmissions, one possible application of DL-OFDMA is aggregating many low-rate data streams.

2.3 Uplink OFDMA (UL-OFDMA)

UL-OFDMA uses the same principles as DL-OFDMA (assigning different users to different parts of the spectrum), but in this case the data originates from different client devices, all of which are then simultaneously received at the AP. The AP will control the timing of the UL transmissions by sending targeted clients a Trigger frame to invite them to transmit uplink data.

2.4 Downlink MU-MIMO (DL-MU-MIMO)

MU-MIMO uses the spatial diversity of the channel to send independent stream of data over the same bandwidth. Unlike OFDMA, all users use the full bandwidth, leading to potentially impressive multiplexing gains. In DL-MU-MIMO, the AP sends multiple simultaneous transmissions to a number of clients. The AP pre-codes the transmissions such that the mutual interference between the different streams is cancelled at the respective clients' locations.

2.5 Uplink MU-MIMO (UL-MU-MIMO)

UL-MU-MIMO uses the same principles of DL-MU-MIMO, but transmissions originate at different clients and are simultaneously received by the AP. Each transmission uses the full bandwidth but using different independent streams. The AP's receiver is responsible for canceling the interference between the different received data streams.

2.6 Spatial reuse (SR)

Wi-Fi systems operate on a shared medium. In order to avoid packets from colliding, 802.11 uses a collision avoidance mechanism known as CSMA/CA. This involves transmitters assessing the medium for a specified amount of time to determine whether other transmissions are in progress. If another transmission is detected, the transmitter refrains from transmitting. While this is an effective way to avoid collisions, the method is overly conservative. It does not recognize opportunities where multiple transmitters could be active without affecting the signal at the respective receivers. One instance would be the case where the receivers are well separated in space. Spatial reuse is a collective name for methods that improve on basic CSMA/CA by allowing more simultaneous transmissions. One specific implementation (OBSS-PD) balances transmit power versus detection levels.

2.7 Extended Range (ER) operation

11ax defines a special Single-User (SU) mode of operation that is designed to be more robust in adverse channel conditions (specifically long distances). This mode does not achieve the same data rates as typical SU transmissions, but it allows communication over larger distances.

2.8 Target Wake Time (TWT)

Many client devices are battery-operated and benefit from power-saving strategies. 11ax further builds on power-saving schemes that were defined previously by introducing TWT. TWT is a highly-customizable way of negotiating the times at which clients will be available for accessing the medium. This means devices don't have to wake up as frequently for instance to monitor beacons sent by the AP.

2.9 Modulation improvements

In addition to the modulation sizes that were supported in 11ac, 11ax adds a new 1024 QAM modulation, which increases the number of bits per tone from a maximum of 8 (256 QAM) to a maximum of 10, leading to a potential 25% increase in raw throughput. Note that the ability to successfully use 1024 QAM depends on channel conditions and the channel quality requirements are higher than for other modulation types.

2.10 20 MHz only operation

In the 5 GHz band, 11ac mandates support of 80 MHz bandwidth for all devices. Unlike 11ac however, 11ax allows a new class of devices that operate in 20 MHz only, to support those applications that don’t have a need for the highest throughputs, but that put a premium on simplicity and power saving.

3. Concurrent Dual-Band Operation for Home Networks

As discussed, 11ax is defined to operate in both the 2.4 GHz and 5 GHz ISM bands. All features listed above are available in each of those bands. When deploying a Wi-Fi network, the AP or network administrator has to make a choice to operate in either 2.4 GHz, 5 GHz or both. With the advent of 11ax as a true dual-band technology with a rich set of features across the bands, we believe that the right approach is for the AP to support a dual-band network. Operation in a single band, be it 2.4 GHz or 5 GHz, comes with a number of drawbacks.

3.1 Single band 2.4 GHz operation

The 2.4GHz has the advantage of penetrating further due to the physics of being a lower frequency compared to 5GHz. However, given that the 2.4 GHz band is historically the oldest Wi-Fi band it has gotten very congested in most places. Devices based on legacy Wi-Fi protocols like 802.11b and 802.11g can only operate in this band, further contributing to the congestion. The bandwidth of the 2.4 GHz band is limited to 70 MHz, comprising only three non-overlapping 20 MHz Wi-Fi channels. Moreover, the 2.4 GHz band needs to be shared with non-Wi-Fi technologies that operate or radiate on the same frequencies, such as Bluetooth, cordless phones or household devices like microwaves. All these sources of interference combine to create a noisy environment, especially in dense deployments such as apartment complexes, stadiums, shopping malls and public hotspots.

The main drawbacks of single-band 2.4 GHz operation are the quality of the band and the limited availability of spectrum.

3.2 Single-band operation in 5 GHz

The 5 GHz band on the other hand has significantly more available bandwidth – 25 non-overlapping 20 MHz Wi-Fi channels, which can be further combined into 40 MHz, 80 MHz or even 160 MHz Wi-Fi channels. This makes the 5 GHz band especially well-suited for applications that require higher bandwidth, such as high-definition streaming video services and gaming applications. However, using it as the only band within a home network has its own set of issues. Not all devices in the network may even be able to operate in the 5 GHz channels. The reach of 5 GHz Wi-Fi signals is lower than in the 2.4 GHz band, so it may be less suitable for devices that require long-range connection. With the exception of 802.11a, all 5 GHz-capable Wi-Fi technologies typically operate in bandwidths wider than 20 MHz. Specialized light-weight Wi-Fi devices will not be able to use the wider bandwidth efficiently, resulting in wasted resources for the network.

The main drawbacks of single-band 5 GHz operation is that not all devices can operate there and that it is mostly geared towards high-bandwidth high-quality types of traffic.

3.3 Organized dual-band operation for the home network

Since each band has its own merits and drawbacks, dual-band operation looks like the natural approach.

An important caveat is that dual-band should be understood as "fully concurrent". This means that transmissions and receptions in one band can take place entirely independently from transmissions and receptions in the other band. In contrast, some solutions that are positioned as dual-band are either "selectable dual-band" or "virtual concurrent dual band". "Selectable dual band" means that, while the device supports both 2.4 GHz and 5 GHz bands, in actual operation it is limited to using one of the bands. "Virtual Concurrent dual band" means that the device is capable of operating in the two bands, but it essentially time-shares its operations between the two. This means that any inefficiencies in one of the bands will affect the other band. Moreover, such time-shared operation leaves the AP and all other devices temporarily blind in the band it is not operating in. Only a fully concurrent dual-band device aggregates the resources of both bands efficiently.

While dual-band operation provides access to more spectrum than operating in one band, there is more to it than just extending the total available spectrum. Within a typical home network, there exists a diverse mix of device types. There are handheld devices (phones, tablets) with relatively limited bandwidth requirements, applications that require only simple web-browsing, set-top boxes that offer video streaming, gaming applications with strict latency requirements, IoT connected devices of all types (doorbells, sensors, …), and so on …

In such an environment, an almost natural arrangement offers itself if the network is truly dual-band (i.e. dual band concurrent).

The 2.4 GHz band can be assigned for:

- Devices that require only basic connectivity
- Legacy Wi-Fi products (802.11b, 802.11g)
- Connected devices that benefit from greater reach, albeit at lower rates
- IoT devices

The 5 GHz can be assigned for:

- High-rate streaming video services
- High bit-rate internet connections
- High-end gaming solutions

This dual-band arrangement provides connections that serve the needs of the devices in each of the bands. In 2.4 GHz, the network serves devices that have only limited performance or QoS requirements that can be met within the constraints of the band (limited bandwidth, higher levels of interference). In 5 GHz, the network serves devices that have high-bandwidth requirements. Interference between the two bands and hence the two types of services is entirely avoided.

In this context, it is also worth noting that the Wi-Fi Alliance recently (i.e. September 2017) announced the availability of their “Agile multi-band” certification program. This program offers a protocol to explicitly steer capable devices to one of the two available bands. It adds another layer to the dual band network and facilitates setting up and managing the network in accordance with the split described above.

4. The Importance of 11ax in Dual-Band Home Networks

While dual-band operation as such is not entirely new, the entrance of 11ax in the Wi-Fi space makes the concept even more compelling. Conversely, any dual-band network can make good use of the feature set offered by the 11ax standard.

As mentioned before, 11ax is the only Wi-Fi technology that is both dual-band and has its advanced features available in both bands. Different features benefit different services that may be deployed in either of the bands.

4.1 Benefits of 11ax in 5 GHz

Assuming the 5GHz band is mostly used for high-rate services with stringent Quality of Service requirements, a subset of 11ax features can be used to optimize the performance of devices delivering those services.

- DL MU-MIMO can be used to deliver concurrent data from the AP to multiple client devices using the full bandwidth. MU-MIMO enables full use of the channel's spatial diversity. Without it, the network throughput may be limited by the MIMO configuration supported by the least-capable clients (which is typically lower than the MIMO configuration supported by the AP).
- Similarly, for client devices that generate a lot of traffic that needs to be sent to the AP, UL MU-MIMO can be used to aggregate this traffic in the most efficient way.
- The higher constellation size (1024 QAM) supported by 11ax increases the peak throughput rate when channel conditions are good. In those cases, theoretical throughput can be increased by 25 percent.
- DL-OFDMA may not significantly increase the throughput for high-rate traffic, but it can help reduce the latency for latency-sensitive services. Packets with strict latency requirements can now be sent in parallel over different parts of the spectrum, rather than be sent sequentially.

4.2 Benefits of 11ax in 2.4 GHz

With the 2.4 GHz band containing mostly low-rate, best-effort services and miscellaneous types of IoT-type connected devices, a different set of 11ax features comes into play.

- In this case, DL-OFDMA can be used to aggregate multiple low-rate data streams. Doing so would increase the MAC efficiency of the transmissions, since the overhead per packet can be reduced, in some cases even significantly.

- UL-OFDMA can likewise be used to aggregate low-rate data streams in uplink. It also offers the advantage that it allows the AP tighter control over the scheduling of uplink client traffic, since UL-OFDMA is always initiated by a trigger frame from the AP. This reduced contention in the uplink, which benefits overall network operation.
- Using OFDMA, the bandwidth used by or towards a single client device can be as low as 2 MHz. This reduces the HW requirements for IoT-type devices and allows them to concentrate the transmit power in a smaller bandwidth. This in turn makes it possible to close the link to the AP with reduced power.
- OFDMA can also be used to select the best spectrum to use towards a certain device and to avoid parts of the spectrum that are polluted by interference from other sources.
- IoT devices can benefit from the improved power-saving modes that are available to 11ax devices, such as Target Wake Time (TWT)
- Devices that require longer-range connectivity can use the 11ax Extended-Range format. The same format could also be used to transmit at lower powers for shorter distances.
- Peak throughputs are increased relative to 11n (remember that 11ac is not defined in 2.4 GHz)
- 20 MHz-only operation for devices with limited bandwidth requirements

4.3 2.4 GHz remains important

Although 2.4 GHz is sometimes considered as a “lost band” for high-quality wireless communication, it is important in the context of a dual-band home network. By using it as an essential pillar in the partitioning of home network services, it helps both the services that are allocated to the 2.4 GHz band and the services that are allocated to the 5 GHz band.

Additionally, note that the 2.4 GHz band essentially lost out on a generation of Wi-Fi since 11ac was only defined for 5 GHz. With the introduction of 11ax, 2.4 GHz is getting a major upgrade that will make the band a useful and essential part of home networking.

5. 802.11ax for IoT Devices

IoT devices currently use a wide array of different technologies, such as several Bluetooth variants, 3GPP-based NB-IoT, 802.11ah, Zigbee, Z-Wave, … See Figure 1 for a summary of existing IoT technologies.

Bluetooth Classic	Bluetooth LOW ENERGY (4.0) / SMART	Bluetooth 5	NB-IoT	THREAD	WiFi HaLow	ZigBee	Z WAVE
Bluetooth SIG	Bluetooth SIG	Bluetooth SIG	3GPP	Thread Group	WFA Alliance	IEEE 802.15.4	Z-Wave Alliance
2.4GHz	2.4GHz	2.4GHz	Cellular Bands	Same as Zigbee but IPv6 based stack	900MHz	2.4GHz, 900MHz, 800MHz	900MHz
1 – 3Mbps	125Kbps to 2Mbps	500Kbps to 50Mbps	250Kbps		650Kbps to 234Mbps	250Kbps	40Kbps
1MHz	1MHz	1MHz	180KHz		2, 4, 8, 16MHz	2MHz	300-400KHz
1x1	1x1	1x1	1x1		Up to 3x3	1x1	1x1

Figure 1. Selected available IoT technologies

Ideally, some or all of those devices could be replaced with 11ax-based appliances operating in the 2.4 GHz band. Features that benefit IoT-type devices are:

- the lower bandwidths supported by 11ax (down to 2 MHz)
- Improved sleep modes, reducing power consumption of devices
- 20 MHz-only operation

Being able to use 11ax for IoT would lead to even further integration of connectivity within the home. A dual-band 11ax-based network would then be able to provide pretty much every type of connectivity required in the home, from very basic signaling to high-end video streaming.

6. Conclusion

In a typical home network, fully concurrent dual-band operation provides the best way to manage the network and the unique service and performance requirements of the various devices found in the home. Low-rate and basic-connectivity devices can be concentrated in the 2.4 GHz band, while high-rate, high-QoS types of traffic may be assigned to the 5 GHz band. In such a network, 11ax is a technology that unifies operation in both the 2.4 GHz and 5 GHz band, while offering a set of features that matches the requirements of applications in each of the bands. In addition, 11ax may also be a suitable candidate to replace current IoT technologies, providing the prospect of a purely Wi-Fi-enabled connected home.