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802.11ad WILL VASTLY ENHANCE Wi-Fi

The Importance of the 60 GHz Band to Wi-Fi's Continued Evolution

Wi-Fi continues to evolve in the 2.4 GHz and 5 GHz bands, but as those bands get more crowded, the industry will increasingly look to IEEE 802.11ad, also known as WiGig, in the unlicensed 60 GHz band. 802.11ad provides multiple Gigabit per second data rates and solves congestion issues by:

- Using **ultra-wideband channel widths** of 2.16 GHz
- Using the **60 GHz band** instead of the 2.4 GHz or 5 GHz band
- Using **beamforming** to form narrow beams in 60 GHz spectrum, allowing for other products to use even the same channel at the same time in many cases
- Being a part of the Wi-Fi ecosystem with **tri-band** solutions that can do **handoffs** between 60 GHz and the other Wi-Fi bands

The goal of 802.11ad is to address the congestion and capacity issues, resulting in an improved user experience.

Note that true tri-band Wi-Fi solutions use three bands: 2.4 GHz, 5 GHz, and 60 GHz. There are some Wi-Fi product vendors that labeled their products as tri-band. However, in reality, these are really dual-band products that can use two channels in 5 GHz simultaneously, in addition to 2.4 GHz for additional speed and capacity.

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802.11ad has been shipping for years in very low volumes in the PC market and will hit the ground running in 2016 with several chipset vendors—including Intel and Qualcomm—offering 802.11ad solutions across a range of product categories. Shipments will grow rapidly over the next five years, with smartphones as a key product type, and the 2020s will see an evolution to 802.11ay, sometimes referred to as WiGig 2, in the 60 GHz band that is backwards compatible with 802.11ad.

The evolution of Wi-Fi protocols is shown below with the progression within each band over approximate years:

SPECTRUM BAND	1999		2003		2008		2014		2019
2.4 GHz	11b	→	11g	→	11n	→	11n	→	11ax
5 GHz	11a	→	11a	→	11n	→	11ac	→	11ax
60 GHz							11ad	→	11ay

AN INTRODUCTION TO 802.11AD

The market for Wi-Fi-enabled products continues to ramp up as everything becomes connected to the Internet and wires disappear. End-user devices are untethered from routers because of Wi-Fi. Many PC peripherals, such as keyboards and mice, use Bluetooth or a proprietary wireless technology. Smartphones connect to wearable devices, head units in cars, headsets, speakers, input devices, smart toys, and more over Bluetooth. Power cords and video cables remain. Power cords are used to power or charge a mobile device or PC. Video cables are used to connect video sources like PCs and consumer electronics to TVs, PC monitors, and projectors. There are multiple types of video cables used for PCs, and HDMI cables are used for consumer electronics. These continue to whittle down with the introduction of USB-C, but they are still cumbersome, get lost, and are sometimes incompatible. These will also eventually disappear for the most part with the continued adoption of wireless charging/power and IEEE 802.11ad, also known as WiGig.

The goals of 802.11ad are to provide higher data throughput and lower latency solutions away from more crowded spectrum bands by operating in the 60 GHz millimeter wave band. The 60 GHz band is unlicensed, just like the 2.4 GHz and 5 GHz bands. This spectrum band accommodates ultra-wideband channels that enable multiple Gigabit-per-second data rates. 802.11ad is a Wi-Fi protocol with a very different technology than that used by other protocols, but will leverage the brand, ubiquity, and momentum of Wi-Fi with tri-band solutions. Generally the number of bands covers:

- Single-band: 2.4 GHz
- Dual-band: 2.4 GHz and 5 GHz
- Tri-band: 2.4 GHz, 5 GHz, and 60 GHz

There are four ultra-wideband channels in the 60 GHz band used for 802.11ad. Each of these channels is 2.16 GHz wide—much larger than the 20 MHz, 40 MHz, 80 MHz, and 160 MHz channel widths used by 802.11n and 802.11ac today. Beamforming is a critical RF technology that makes millimeter wave spectrum usable by focusing transmissions into narrow beams of energy. More antenna elements result in a more focused beam. Antenna elements can be placed on a chipset such that half are on one side and half on the other side, or by using two 802.11ad RF chipsets. This allows for more reliable connections from products placed on desks, for example, at various angles to whatever they are meant to connect to.

Data rates range from 385 Mbps (MCS 1) to 4.620 Gbps (MCS 12). All of the 802.11ad chipsets on the market and coming to market support MCS 12. Increasingly, more chipsets will also support up to 6.76 Gbps (MCS 24), which incorporates OFDM. Latency is close enough to zero to eliminate any delays or lag.

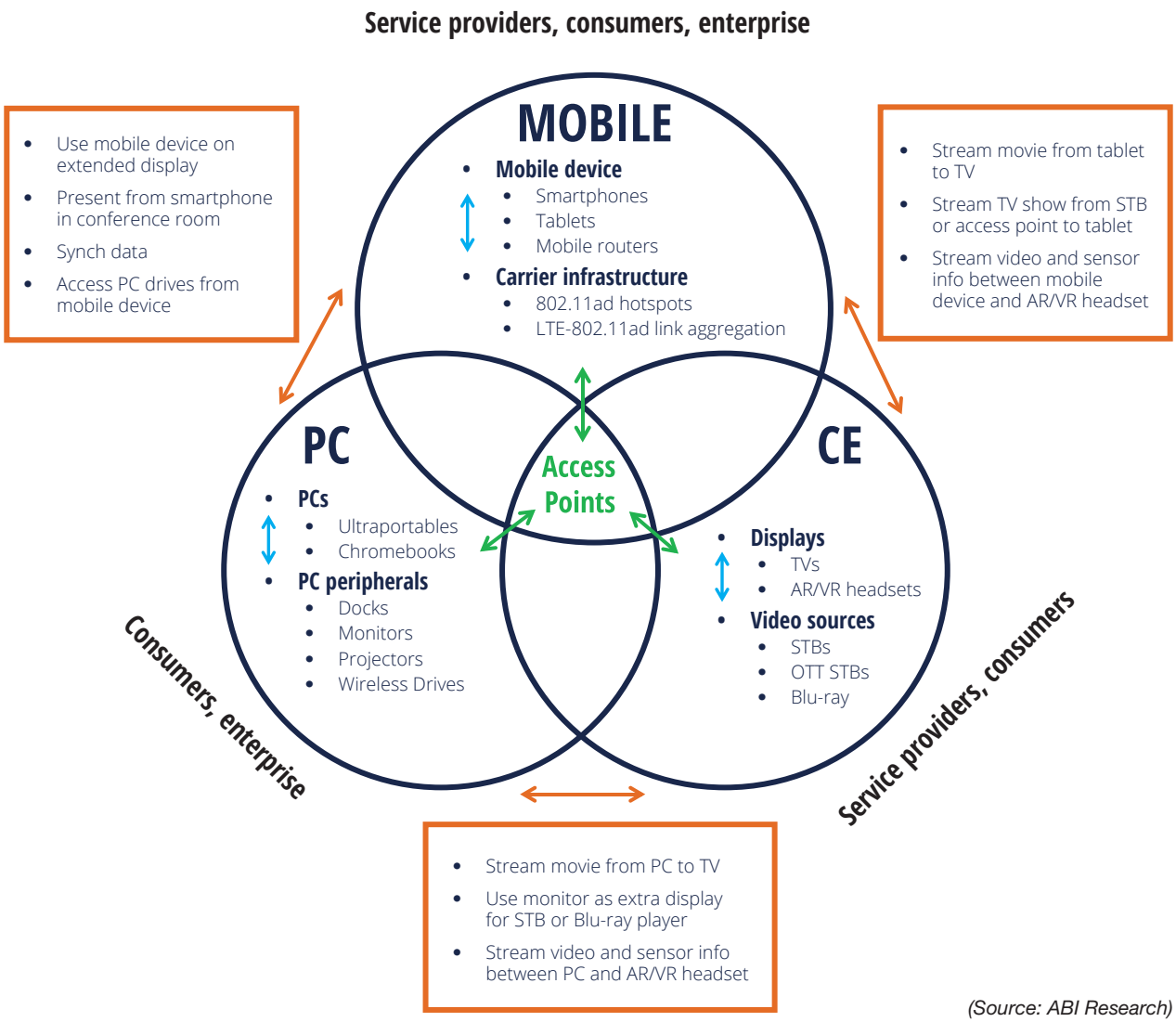
The 802.11ad standard was completed in 2012; chipsets are commercially available from a few companies, including Intel and Qualcomm, and Wi-Fi Alliance certification will start in late 2016. The Wi-Fi Alliance's certification will say "WiGig Certified by Wi-Fi Alliance." New networking, docking, PC, and mobile products with WiGig were announced and displayed at CES 2016 in January.

The 2.4 GHz and 5 GHz bands are becoming increasingly crowded by existing protocols and other technologies, and this negatively affects the user experience. By using the 60 GHz band, Wi-Fi has an option to avoid interference from other Wi-Fi bands, while also not adding to that interference. Since beamforming is required to form the more concentrated transmissions that make the 60 GHz band usable, 802.11ad has the added benefit of spatial separation. The same channel could be used by separate transmission from separate pairs of products at the same time as long as they are not too close together. 802.11ad has a speed and capacity advantage gained from the use of a different spectrum band, ultra-wideband channels, and the resulting spatially separated transmissions that result from beamforming required to make millimeter wave spectrum usable.

VARIED ECOSYSTEM AND USE CASES

There are three main pillars for 802.11ad products—mobile, PC, and consumer electronics (CE). 802.11ad can be used within these three pillars as well as between them. The figure below illustrates example use cases within and between these pillars. The multi-Gbps data rates WiGig provides will enhance Wi-Fi services and use cases, and allow for new ones where other Wi-Fi protocols have been insufficient.

Figure 1: 802.11ad Product Ecosystem and Use Cases



(Source: ABI Research)

These pillars cross three areas—consumer, enterprise, and mobile networks. These areas all have a common need for greater network capacity and more interference-free wireless data transmissions. The problem is most pronounced in the dense networking environment in the enterprise space and strained mobile networks in urban and suburban areas. Still, the consumer space is also seeing a larger number of Wi-Fi-enabled devices in the home while increasingly streaming content wirelessly. This content is shifting from 720p to 1080p, and now 4k as well. In the near future, 8k content will arise. This shift is also occurring in the mobile space. With the exception of some product types, most 802.11ad-enabled devices would be able to connect to tri-band access points that cover 802.11n in 2.4 GHz, 802.11ac in 5 GHz, and 802.11ad in 60 GHz. There will also be content-related kiosks that mobile devices and PCs can connect to, where the user could download a movie to watch on a plane right before boarding, for example, and do so in several seconds instead of several minutes or more.

802.11ad will bring benefits to both operators and OEMS and will be driven by a number of motivations depending on the device type:

Mobile

- Big push for 802.11ad by Qualcomm in 2016 as part of its Snapdragon 820 platform;
- The first smartphone with 802.11ad, the LeTV Le Max Pro, has a Q2 2016 release time frame. This will fuel competitive pressure among major device OEMs to include the technology in their own products later in 2016 and 2017;
- Differentiation of products with the latest technologies, especially in flagship products;
- Desire to improve brand image;
- Desire to better support increasingly streamed video content to various displays;
- Offering mobile Wi-Fi routers that use 802.11ad in addition to 802.11n and 802.11ac for use in dense environments like press announcements and trade shows where the venues' Wi-Fi access and users' own mobile Wi-Fi routers face a lot of interference;
- Need to add densely deployed Internet access, such as airports, train stations, building lobbies, shopping malls, conferences, and trade shows;
- Desire by content vendors to allow very fast downloads of video content at airports and train stations;
- Need for mobile operators to use unlicensed spectrum, and to do so with minimal interference with other users of unlicensed spectrum.

PC

- Big push for 802.11ad by Intel in the portable PC space as part of its "No Wires Initiative" alongside wireless charging/power;
- A dozen PC vendors offer 802.11ad as an option. This will ramp up the technology into peripherals that can then be leveraged by mobile devices and consumer electronics, making it easier to justify the inclusion of 802.11ad in those devices;
- Dell's history of including 802.11ad as an option in some portable PCs for a few years;
- Lenovo including 802.11ad as an option in all higher-end portable PCs and plans to include this option in all mid-tier portable PCs;
- Provide dense network access in enterprise settings to more efficiently serve the needs of workers carrying multiple devices with reliably high data rates;
- Provide easy access to peripherals for mobile workers and enterprise hoteling. Workers using any empty cubicle can instantly connect to multiple monitors and peripherals just by setting the portable PC, tablets, or smartphone down near the dock or the monitor used as a dock;
- Simplify connecting to overhead projectors without the need to have the right cable or connector, the need to remember to bring a cable, or the need to sit near the connector or take time connecting the device to the projector;
- Provide support for home network caching;
- Enable fast backup of PC drives.

Consumer Electronics

- Provide better streaming video from video sources (*e.g.,* set-top boxes, Blu-ray players, mobile devices, *etc.*) free of interference and capacity issues;
- Allow for the streaming of multiple 4k videos from an access point to multiple devices;
- Reduce cable clutter to zero by eliminating HDMI cables to TVs and between home theater components;
- Enable more reliable connections from PCs and mobile devices to AR (augmented reality) and VR (virtual reality) accessories;
- Untether VR (virtual reality) headsets to remove the limitation of cord length and risk of tripping on cords;
- Make home theater installations easier by eliminating HDMI cables to connect between components, and make it easier to install a TV on a wall mount.

Many of these use cases are now covered by wired solutions such as PCIe, HDMI, DisplayPort, and USB. Even before the IEEE had adopted WiGig as the technology for 802.11ad and the Wi-Fi Alliance absorbed the WiGig Alliance, the WiGig Alliance had created three Protocol Adaption Layers (PALs). These allow existing designs to use 802.11ad to carry these common standard connection types: Wireless Bus Extension (WBE) supports PCIe; Wireless Display Extension (WDE) supports HDMI and DisplayPort; and Wireless Serial Extension (WSE) supports USB 3.0.

While 802.11ad was originally intended to be a peer-to-peer technology, it will also be an access technology to reach the network or Internet. 802.11ad will be included in tri-band access points and potentially separate 802.11ad-only access points, which could be placed in conference rooms and other crowded enterprise settings, as well as in homes in specific rooms where video is watched. Tri-band access points will be able to hand off traffic from one band to another using Fast Secure Transfer (FST).

Additionally, there will be an opportunity for 802.11ad to play a strong role in hardware and software resource sharing between devices. Hardware and software resource sharing allows one product to use the hardware or software from another. This could be labeled many ways, but the phrase "hardware cloud" could fit, and it could also be seen as a form of local fog computing. Some of the hardware components that could be shared are the camera, microphone, GPU, and main processor. For some of these applications, using 802.11ad versus 802.11ac or 802.11n would allow for more interference-free and lower power applications. Certain applications like sharing a GPU would require a certain minimum, stable data rate that would be enabled by 802.11ad among devices within close proximity.

The announcement of 802.11ad-enabled products at CES 2016 also points to a strong start for the technology in 2016. This includes the first smartphone (LeEco / LeTV) and consumer Wi-Fi router (TP-Link) with 802.11ad, which are both key tri-band Wi-Fi product types. There were more portable PC products announced with 802.11ad. Others were on display but not announced at CES since some PC vendors previously announced their plans to include tri-band Wi-Fi with 802.11ad and consider this to be business as usual now.

It is absolutely critical that the market has multiple sources for the enabling technology. The number of 802.11ad vendors selling chipsets now or within a year from now is fairly large.

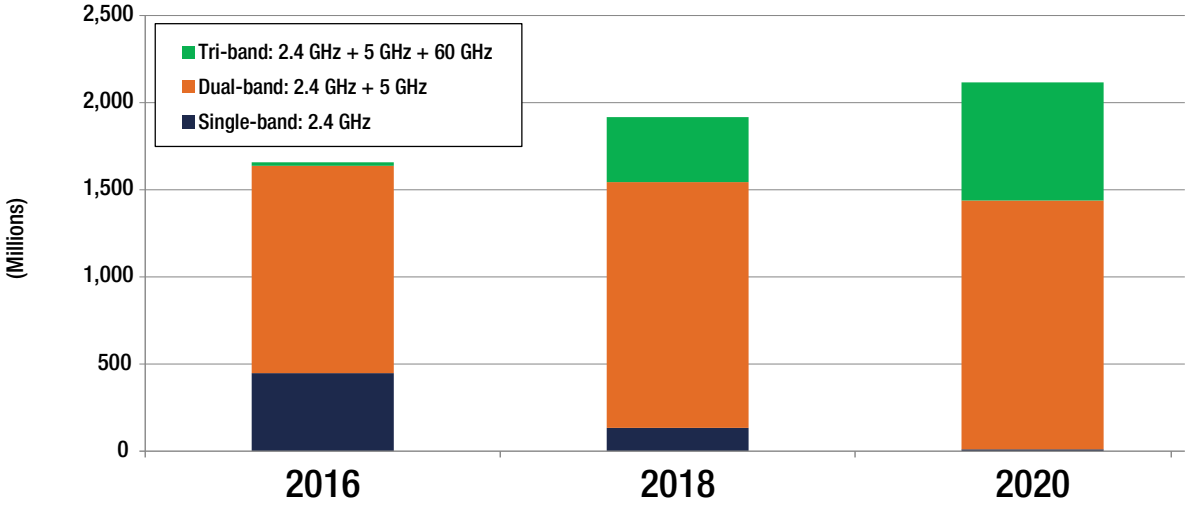
Semiconductor Vendors Offering and Planning to Offer 802.11ad Chipsets

Half of the 12 companies highlighted in the table above either have solutions available now or will very shortly. Qualcomm and Intel are shipping today in notable volumes. Most of these companies will have solutions by the end of 2016. These various chipset vendors will have different solutions, generally ranging from 1 to 32 antenna elements, depending on the vendor and application. This will provide a diverse set of solutions targeting different applications, products, quality, and cost.

While WiGig certification by the Wi-Fi Alliance will come later in 2016, chipset vendors have hinted at or announced interoperability testing done privately in preparation for official certification. Qualcomm mentioned SiBeam and Peraso in a CES 2016 press release. In February 2016, Intel and Qualcomm Atheros announced in a joint blog that they successfully achieved interoperability of their chipsets at data rates of multiple Gigabits per second. The two companies also demonstrated their interoperability at Mobile World Congress 2016 in February. ABI Research mentioned in the past how important it is that Intel and Qualcomm are behind the same standard, in addition to 802.11ad being another protocol in the Wi-Fi family. Intel's chips are very important in the PC industry, including portable PCs and docks, while Qualcomm's chips are important to the mobile device industry. They do not and will not exclusively cater to these areas, respectively, but they do demonstrate that the ecosystem for 802.11ad is backed by some of the largest companies in these major markets. On top of this, there is a diverse set of 802.11ad chipset suppliers.

In the context of the overall Wi-Fi market, products with 802.11ad barely register on the chart below in 2016, since its inclusion into smartphones will significantly affect volumes in 2017 and 2018. The ramp-up of smartphones and portable PCs with 802.11ad will provide the foundation needed for access point, kiosk, and peripheral vendors to confidently move forward with 802.11ad-enabled product plans.

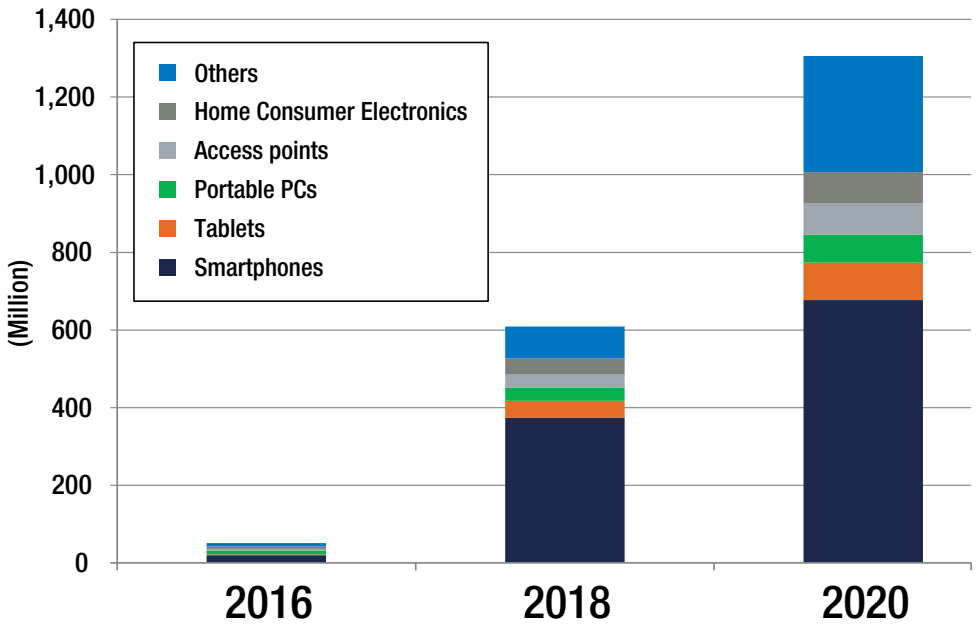
Chart 1: *Wi-Fi Chipset Shipments by Number of Bands*
World Market, Forecast: 2016, 2018, and 2020



(Source: ABI Research)

The Wi-Fi chipset market already transitioned away from a single-band market. High volumes of smartphones, tablets, PCs, consumer electronics devices, access points, and other products are dual-band Wi-Fi enabled products using 802.11n (dual-band) or 802.11n/ac. More than half of all products certified by the Wi-Fi Alliance are dual-band, and more than half of Wi-Fi enabled products are dual-band. Tri-band Wi-Fi-enabled products with 802.11ad will become increasingly significant over the forecast period.

Chart 2: *Total Single-band and Multi-band 802.11ad Chipset Shipments by Product Category*
World Market, Forecast: 2016, 2018, and 2020



(Source: ABI Research)

Smartphones will be a primary driving force for 802.11ad, comprising over half of all 802.11ad shipments over the forecast period. 802.11ad doesn't have a place everywhere, but it most certainly will be found in smartphones, tablets, consumer electronics, portable PCs, access points, monitors, VR headsets, and certain product types in the IoT space such as security cameras and kiosks.

802.11AD IN THE CONTEXT OF 802.11AC AND 802.11AX

It is easy to ask why the industry even needs 802.11ad, since existing Wi-Fi protocols can do a decent job transmitting video. The performance of 802.11ac is now improving with the addition of MU-MIMO (see ABI Research's white paper on MU-MIMO in Wi-Fi), and 802.11ax will have further improvements. If one looks merely at the latest Wi-Fi protocols, data rates, and capabilities, it is easy to think 802.11ad is not needed. However, 802.11ad is very complimentary to 802.11ac:

- There is much more spectrum available in 60 GHz than in 5 GHz;
- 5 GHz Wi-Fi will eventually suffer from a capacity problem in some scenarios—in homes with many data-intensive Wi-Fi enabled products being used, in dense enterprise settings, and on mobile networks in dense urban areas. By using 60 GHz spectrum, 802.11ad will avoid interference and network congestion in the 2.4 GHz and 5 GHz spectrum bands;
- 802.11ad transmissions will not interfere with each other as much as competing Wi-Fi networks do because of the inherent spatial division that occurs through the use of beamforming;
- 802.11ad has a better power-per-bit performance relative to 802.11ac, and a similar impact on battery life as 802.11ac.

802.11n in 2.4 GHz, 802.11ac in 5 GHz, and 802.11ad in 60 GHz span the gamut from backwards compatibility to forward compatibility and from range to performance.

The Wi-Fi Alliance created Miracast to standardize the application layer to carry video over 802.11n and 802.11ac. Mobile operating system vendors put the right hooks into their operating systems, making it easier for developers to create applications that use it, and applications made it easy to operate. Miracast works over Wi-Fi Direct, which forms a peer-to-peer connection between two Wi-Fi products. This does not mean that this usage of Wi-Fi cannot benefit from 802.11ad. Indeed, 802.11ad is likely to become the ***de facto*** technology used to stream video for a few reasons:

- Miracast will soon work over 802.11ad, in addition to 802.11n and 802.11ac.
- Video requires steady reliable data rates, but can be disrupted by interference and network congestion issues. Existing Wi-Fi spectrum bands are getting congested in homes where many devices and other products are using the Wi-Fi network, including to stream video. Using Miracast over 802.11ad would avoid this congestion.
- Shifting as much video traffic as possible to 802.11ad will offload a considerable amount of traffic from 2.4 GHz and 5 GHz based Wi-Fi networks, which will result in an improved user experience over all three spectrum bands.

802.11ad is just the first Wi-Fi standard to come for the 60 GHz band. 802.11ay is a follow-on standard for Wi-Fi in 60 GHz, which will achieve well into the tens of Gigabits per second by adding OFDM and using multiple 60 GHz channels at once. This opens up many new use cases for the technology, including even higher capacity access points and backhaul solutions, and more applications of cross-device resource sharing. 802.11ay could fundamentally change the way products are designed by allowing computing resources—hardware and software—from one product to be leveraged by another. For example, a low cost tablet may leverage the GPU of another device nearby. Or the 4k front-facing camera in a TV could be used by a person setting up a video call on a smartphone. In this case, 802.11ad would essentially be used to form a wireless bus between separate products, to enable the resources of one to benefit the other.

802.11ad in no way is meant to replace 2.4 GHz and 5 GHz Wi-Fi; it is meant to augment it. Transmitting video over 802.11ad whenever possible would reduce the load on existing Wi-Fi networks.

SUMMING IT ALL UP

IEEE 802.11ad will be a very important addition to Wi-Fi. It will leverage the 60 GHz band in a complimentary way to existing Wi-Fi protocols and bands. 802.11ad uses beamforming to make use of a spectrum band that has been historically difficult to use. The very nature of this beamforming means that the same spectrum can be reused multiple times in different parts of the room. This allows for not only an increase in wireless capacity, but also makes these wireless connections more robust. 802.11ad can better avoid interference with other 802.11ad connections nearby, and is also completely avoiding any interference with the more omnidirectional Wi-Fi protocols in the 2.4 GHz and 5 GHz bands. 802.11ad will also evolve alongside 802.11ac and 802.11ax. WiGig 2 (802.11ay) will improve upon 60 GHz Wi-Fi and still be backwards compatible with 802.11ad. 802.11ad is not a dead-end protocol.

802.11ad will not be a niche technology, but will be used across a wide swath of the product landscape, supported by a large ecosystem of companies in multiple industries, including mobile devices and accessories, PCs and accessories, consumer electronics, and various applications across vertical markets. 802.11ad-enabled PCs will quickly ship in the tens of millions of devices while 802.11ad-enabled mobile devices will ship in the hundreds of millions of devices within a few years. Adding to that will be TVs, PC monitors, projectors, virtual reality headsets, kiosks, surveillance cameras, small cells, and more. Connections will be made across these categories—from PCs or mobile devices to TVs, from any 802.11ad-enabled product to Wi-Fi access points with 802.11ad, *etc.* The chipset side is not limited to just a few suppliers. Over a dozen companies ranging from small startups to wireless connectivity giants currently offer or are planning to offer 802.11ad chipsets or intellectual property.

802.11ad is a Wi-Fi protocol that has tapped into the latest wireless technological advances, such as millimeter wave transceivers, ultra-wideband channel sizes, and beamforming. It is being productized in the form of small, low-cost chipsets today. In previous years, the market for 802.11ad-en-

abled products started slowly with some portable PCs, but 2016 is shaping up to be an exciting year that brings tri-band Wi-Fi with 802.11ad to smartphones, more PCs, access points, docks, consumer electronics, and more.

Published April 2016

Post Office Box 452 • 249 South Street
Oyster Bay, New York 11771 USA
Tel: +1 516-624-2500 | Fax: +1 516-624-2501
www.abiresearch.com

Philip Solis: Research Director, Strategic Technology
Malik Saadi: VP, Strategic Technology