Helping Define IEEE 802.11 and other Wireless LAN Standards

IEEE 802.11 wireless local area networks

Intel is a longtime contributor to the IEEE 802.11 standard, a group of specifications developed by the Institute of Electrical and Electronics Engineers (IEEE) for wireless local area networks (WLANs). Much of the current work on IEEE 802.11 centers on increasing transmission speeds and range, improving Quality of Service (QoS), and adding new capabilities.

Now that IEEE 802.11n, the latest version of IEEE 802.11, is shipping in volume, the focus is on even faster solutions, specifically IEEE 802.11ac and IEEE 802.11ad. These amendments aim to provide gigabit speed WLAN. The difference is their frequencies. IEEE 802.11ac will deliver its throughput over the 5 GHz band, affording easy migration from IEEE 802.11n, which also uses 5 GHz band (as well as the 2.4 band). IEEE 802.11ad, targeting shorter range transmissions, will use the unlicensed 60 GHz band.

Quality of Service (QoS)
In computer networking, QoS doesn't refer to achieved service quality — though it plays an important role in it. Instead, QoS is about using resource reservation control mechanisms to give different priority to different applications, users, or data flows to ensure a certain level of performance. For example, a particular bit rate, along with limits on delay, jitter, and packet dropping probability and/or bit error rate, may be guaranteed for a real-time streaming multimedia application such as an online game or video. For such delay-sensitive applications, QoS guarantees are important, when network capacity is insufficient for all the concurrent data flow (i.e., the video and other less sensitive applications such as email and web browsing).

Through range improvements and faster wireless transmissions, IEEE 802.11ac and ad will:

- Improve the performance of high definition TV (HDTV) and digital video streams in the home and advanced applications in enterprise networks
- Help businesses reduce capital expenditures by freeing them from the cost of laying and maintaining Ethernet cabling
- Increase the reach and performance of hotspots
- Allow connections to handle more clients
- Improve overall user experience where and whenever people are connected

The IEEE 802.11 Working Group (WG) consists of individuals who are experts in wireless technology and includes a number of Intel employees. Intel sees IEEE 802.11 as vital to continuing to improve and expand the wireless experience of many devices using its products. This case study takes a brief look at the history of IEEE 802.11, current efforts to improve the standard, and potential improvements in the future.

A short history of IEEE 802.11

802.11, or “Wi-Fi” as it is popularly known, sprang into existence as a result of a decision in 1985 by the United States Federal Communications Commission (FCC) to open several bands of the wireless spectrum for use without a government license. These so-called "garbage bands" were allocated to equipment such as microwave ovens which use radio waves to heat food. To operate in

Did you know?
The term "Wi-Fi" was invented by the organization now known as the Wi-Fi Alliance. The term "IEEE 802.11b-compliant" was considered too long and hard for consumers to remember for consumers. "Wi-Fi" meant nothing at the time, but sounded like "hi-fi," a familiar electronics term. Later, the meaning "wireless fidelity" was attached to Wi-Fi.

these bands though, devices were required to use "spread spectrum" technology. This technology spreads a radio signal out over a wide range of frequencies, making the signal less susceptible to interference and difficult to intercept.

Wireless LAN Throughput by IEEE Standard		
IEEE WLAN Standard	**Over-the-Air (OTA) Estimates**	**Media Access Control Layer, Service Access Point (MAC SAP) Estimates**
IEEE 802.11b	11 Mbps	5 Mbps
IEEE 802.11g	54 Mbps	25 Mbps (when .11b is not present)
IEEE 802.11a	54 Mbps	25 Mbps
IEEE 802.11n	Up to 600 Mbps	Up to 400 Mbps
IEEE 802.11ac	Up to 867 Mbps with 2 antennas and 80 MHz; Up to 1.3 Gbps with 3 antennas and 80 MHz	Up to 600 Mbps with 2 antennas and 80 MHz; Up to 900 Mbps with 3 antennas and 80 MHz
IEEE 802.11ad	At least 1.1 Gbps (up to 4.6 Gbps in some first generation products)	Up to 700 Mbps for 1.1 Gbps OTA (up to 3 Gbps for 4.6 Gbps OTA)

In 1990, a new IEEE committee called IEEE 802.11 was set up to look into getting an open standard started. Demand for wireless devices was so high that by the time the standard was published in 1997, devices adhering to the new standard were already shipping.

Developed under the rules of the IEEE (commonly pronounced as “I triple e”), the IEEE 802.11 standard defines an over-the-air interface between a wireless client and a base station (or access point), or between two or more wireless clients. As capabilities are added to the IEEE 802.11, some become known by the name of the amendment. For example, many people recognize IEEE 802.11b, IEEE 802.11g and IEEE 802.11n as popular wireless solutions for connecting to networks. Each of these amendments defines a maximum speed of operation, the radio frequency band of operation, how data is encoded for transmission, and the characteristics of the transmitter and receiver.

The first two variants were IEEE 802.11b (which operates in the industrial, medical and scientific — ISM — band of 2.4 GHz), and IEEE 802.11a, which operates in the available 5 GHz bands (5.15-5.35 GHz, 5.47-5.725 GHz, and 5.725-5.825 GHz). A third variant, IEEE 802.11g, was ratified in June 2003. Both IEEE 802.11a and IEEE 802.11g use a more advanced form of modulation called orthogonal frequency-division multiplexing (OFDM). Using OFDM in the 2.4 GHz band, IEEE 802.11g achieves speeds of up to 54 Mbps.

The advent of IEEE 802.11n

In the constant quest for greater transmission speed, a High Throughput standardization effort was launched, and IEEE 802.11n, ratified in October 2009, became the fourth IEEE 802.11 variant. Intel product groups and Intel research and development employees contributed to the development of the IEEE 802.11n standard from its beginning to completion, playing major roles in the IEEE 802.11n Task Group and providing technical assistance. IEEE 802.11n leveraged many important specifications of its predecessors, but also introduced significant advancements in wireless technology. Some of Intel's contributions included the development of channel models, usage models, functional requirements, and comparison criteria. Intel employees also helped define key modifications to the Physical Layer and Media Access Control Layer (PHY/MAC) and develop performance measurement methodologies and simulation methodologies.

IEEE 802.11n approximately quadruples WLAN throughput performance compared to IEEE 802.11a/g networks. Its support for multiple antennas provides better range at given throughputs and improved, more uniform service within the coverage of a basic service set (BSS). Using multiple antenna systems for both the transmitter and the receiver is referred to as multiple-input multiple-output (MIMO) or a "smart antenna" system (see Figure 1). Intel contributed much research to MIMO. By employing multiple diverse antennas tuned to the same channel, each transmitting with different spatial characteristics, MIMO uses spectrum more efficiently without sacrificing reliability. Every receiver listens for signals from every transmitter, enabling path diversity where multi-path reflections (normally disruptive to signal recovery) may be recombined to enhance the desired signals.

Basic Service Set (BBS)
A BBS is the basic building block of an IEEE 802.11 WLAN. A BSS consists of a single access point (AP), together with all associated devices, such as a laptop, smart phone and HDTV. This is not to be confused with the coverage of an access point, which is called basic service area (BSA).

MIMO technology also uses Spatial Division Multiplexing (SDM). SDM spatially multiplexes multiple independent data streams (essentially virtual channels) simultaneously within one spectral channel of bandwidth. Having multiple antennas simultaneously send different flows of individually encoded signals (spatial streams) over the air shoves more data through a given channel. At the receiving end, each antenna sees a different mix of the signal streams and the device "demultiplexes" them to use them. MIMO SDM can significantly increase data throughput as the number of resolved spatial data streams is increased. Each spatial stream requires its own transmit/receive (TX/RX) antenna pair at each end of the transmission.

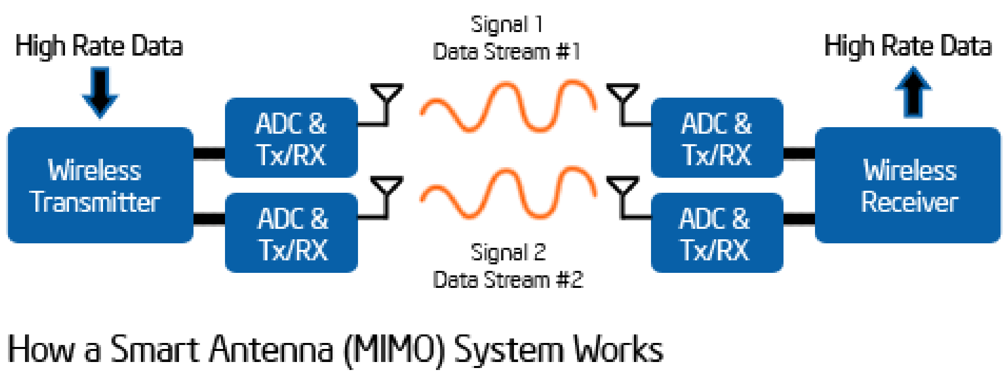

Figure 1. Diagram showing how a smart antenna system enables multiple input/multiple output (MIMO).

An important tool in IEEE 802.11n for increasing the physical transfer rate is wider bandwidth spectral channels, also known as channel bonding. Using a wider channel bandwidth, in combination with OFDM, offers significant advantages in maximizing performance. Wider bandwidth channels are cost-effective and easily accomplished with moderate increases in digital signal processing (DSP). If properly implemented, doubling the legacy bandwidth of IEEE 802.11 channels from 20 MHz to 40 MHz can provide greater than two times the usable channel bandwidth. Coupling MIMO architecture with wider bandwidth channels offers the opportunity of very powerful, yet cost effective approaches for increasing the physical transfer rate.

The use of these technologies in IEEE 802.11n enables a WLAN to achieve up to 300 Mbps. Designs employing four antennas tuned to the same channel — each transmitting a different spatial stream at a channel width of 40 MHz — are capable of even delivering up to 600 Mbps.

The development of 802ac and IEEE 802.11ad

In a world hungry for mobile devices capable of simultaneously handling high definition (HD) streaming video, voice over IP (VoIP) calls, web page delivery, and fast data transfers, IEEE 802.11n is fast, but still not fast enough to keep up with people's desire for higher performance, particularly in video streaming and game play, and for handling the growing number of devices connecting to an AP. What's more, the enormous popularity and success of Wi-Fi continues to create new challenges, many of which could be attributed to the need to cope with the technology's overwhelming its success. In addition to speed, these challenges include providing greater bandwidth and better handling of channel contention.

According to In-Stat, mobile devices with Wi-Fi will account for around 800 million units by 2015. It's expected that 100 percent of mobile hotspot shipments by that date will support IEEE 802.11ac.

Foreseeing these challenges, the IEEE 802.11 WG in 2007 formed the Very High Throughput (VHT) study group to work on the next generation IEEE 802.11. One goal was to increase throughput to at least 1 Gbps to be shared by devices connected to an AP in the under 6 GHz band, with the capability for a single link to operate at 500 Mbps. The second goal was single-link performance of at least 1 Gbps in the 60 GHz band. IEEE 802.11ac and IEEE 802.11ad were the two interfaces targeted for development for VHT operation.

All WLAN standards depend on access to radio spectrum. IEEE 802.11b and IEEE 802.11g share the 2.4 GHz spectrum with cordless phones, noise from microwave ovens, and various other nuisances. IEEE 802.11n can use a combination of 2.4 GHz and 5 GHz bands. To avoid contention, all IEEE 802.11 variants divide their targeted bands into channels, similar to how radio and TV broadcast bands are subdivided. This enables devices to share the same spectrum with neighboring devices on other channels in the same band. The ability to use different channels also enables IEEE 802.11 to be more easily adapted internationally since channel use can be configured for each country.

IEEE 802.11ac is designed to use the 5 GHz spectrum, which is clearer and faces less interference than the 2.4 GHz spectrum. The 2.4 GHz spectrum is congested with current Wi-Fi and Bluetooth wireless communication, the growing popularity of smart-grid wireless home-area networks, and the "Internet-of-things." What's more, only one non-overlapping 40MHz channel is available in 2.4 GHz. In comparison, the 5 GHz band provides 11 non-overlapping

40MHz channels. For all these reasons, the IEEE 802.11ac Task Group sees the 5 GHz band as the solution for high-bandwidth, high QoS Wi-Fi communications.

IEEE 802.11ad, on the other hand, uses the much higher 60 GHz spectrum. This spectrum has even more room to pack different communication channels side by side. Consequently, it can deliver up 7 Gbps — but only for short distances. It's easily obstructed by air, water and walls, and other limitations.

IEEE 802.11ac, the successor to mainstream Wi-Fi

The goal for IEEE 802.11ac is for it to become the mainstream networking access point technology that people use in homes, businesses, and public Wi-Fi hot spots. According to Kelly Davis-Felner, marketing director for the Wi-Fi alliance, with a raw data rate of 1 Gbps and the ability to stream up to three lightly compressed HD videos at one time, IEEE 802.11ac will be a big enabler for the digital home.

To achieve this performance level, devices will be required to support channel bonding. First introduced with IEEE 802.11n, channel bonding improves bandwidth both by using larger channels and by combining channels. IEEE 802.11ac takes even greater advantage of channel bonding by supporting 20, 40 and 80 MHz channels. In fact, IEEE 802.11ac supports as an option the use of 160 MHz channels. However, there are a few isolated issues with some of these channels depending on geographic locations. In China, for instance, 160 MHz channels are not available because of the limited available bandwidth. Nonetheless, with its multiple channel choices, the future is bright for global adoption of 802.11ac.

To enhance performance, IEEE 802.11ac will use an advanced form of MIMO technology known as Downlink multi-user MIMO (MU-MIMO). Downlink MU-MIMO exploits the availability of multiple independent radio terminals to improve network capacity when transmitting to multiple terminals. The primary use of Downlink MU-MIMO is to aggregate low data-rate devices to enable higher network capacity. Consider that in IEEE 802.11n half the devices are single antenna and limited to 150 Mbps at the physical layer (PHY). This means when an access point is transmitting to such a device, the network is limited to 150 Mbps. With Downlink MU-MIMO, an access point can transmit to up to four users simultaneously resulting in considerable network capacity improvement. For example, a 4+ antenna AP could transmit a single stream to each of four physically separated single antenna stations at once, achieving up to four times the capacity from a single 40 (or 80 or 160) MHz-wide channel.

While much of the work on an amendment is done in a committee, Intel employees have played major roles in IEEE 802.11ac development from the very start. This involvement began with an Intel employee holding the chair of the VHT Study Group which gave birth to IEEE 802.11ac. Intel also contributed technology to the enhancement of the IEEE 802.11n channel model that became crucial to the development of 802.11ac. As work progressed, Intel employees in the IEEE 802.11 Working

> In July 2011 at an event called Wireless Technology Park in Yokohama City, NTT, Japan's telecommunications in Japan, Nippon Telegraph and Telephone (NTT) Corporation demonstrated a prototype setup using the next generation IEEE 802.11ac standard The system can wirelessly transmit data to three users at the same time with an effective throughput of 120Mbps. The NTT system used six antennas for transmission and three for reception. NTT also showcased a transceiver module using IEEE 802.11ad.

Group led the development of the specification framework document and participated in drafting the IEEE 802.11ac amendment. Now that the amendment is finished, an Intel employee is co-chair of the IEEE 802.11ac Coexistence Ad Hoc to help with the transition to IEEE 802.11ac.

801.11ad: The perfect complement to IEEE 802.11ac

For applications requiring just a few meters of transmission, IEEE 802.11ad, provides a very viable solution delivering blazing 7 Gbps speeds. Since IEEE 802.11ad-compatible APs will be able to cover not much more than a room, a primary target for IEEE 802.11ad is streaming HD video. The goal is for it to enable wireless docking between devices in a room. For instance, a person could bring a laptop into a room and have it automatically link wirelessly to a large display, digital projector and/or storage system to stream video or data at astonishing speeds. Such fast data transfers will enable incredibly fast wireless “sync and go” between devices such as a laptop and smart phone.

801.11ad is being supported by a consortium, the Wireless Gigabit Alliance. Intel is a key board member, along with other prominent hardware and software companies, such as Broadcom, Cisco, Dell, Marvell, Mediatek, Microsoft, NEC, Nokia, Nvidia, Panasonic, Qualcomm, Samsung, Toshiba, and Wilocity.

The reason IEEE 802.11ad is capable of such high data rates is the breadth of frequencies that it can use. In the 60 GHz range, there is around 7 GHz of free spectrum — this is over 83 times more free space than the 83.5 MHz of free space available in the unlicensed 2.4 GHz range most Wi-Fi networks use.

The 60 GHz range hasn’t been commercially tapped until now because such high frequency transmissions are fragile. Low frequencies can bend around hills and penetrate walls, but high frequency transmissions can’t. To overcome this deficiency, 60 GHz transmissions must be highly targeted and line of sight. While this isn’t good for home networking, it’s fine for within a room. In fact, with adaptive beamforming (a signal processing technique), distances of more than 10 meters are possible. With a combination of physical antennas on the devices and algorithms to tune the signal, IEEE 802.11ad devices will effectively shoot their signals back and forth at each other in a narrow, targeted beam. Antennas in devices, like a router, will each have a broad reception area to see devices. When a device that wants to use the 60 GHz connection is brought into range, it will begin communicating with the antennas to fine tune the signals to maximize connection speed. (The antennas do this by adjusting both the amplitudes and the phase shifts of their broadcasted waves.) Should the high-speed connection be lost for any reason, devices will fall back on 2.4 GHz and 5 GHz signals to continue communications.

With IEEE 802.11ad, there’s even the possibility of a unified data and audiovisual (A/V) network. Through the use of protocol adaption layers (PAL), IEEE 802.11ad will allow the concurrent transmission of data and A/V signals. These PALs will operate at the MAC and PHY, below the IP data layer, allowing the wireless interfaces of HDMI and DisplayPort to be implemented, along with relevant digital rights management (DRM) technologies like HDCP.

This compliance means a user could plug a special dongle that can participate in all of the signal optimization processes into a TV's HDMI port, connect a computer to the TV over the 801.11ad Wi-Fi, and stream HD video. This assumes that the computer, router and dongle are IEEE 802.11ad-capable and within range of each other. These PALs can be extended to USB and PCIe, meaning a TV might be able to communicate directly with the system bus of a home theater PC or perhaps directly with an external USB hard drive caddy.

As in the development of 802.11ac, Intel employees have been involved in IEEE 802.11ad from the start. They were the main contributors to the channel model development and provided exhaustive measurements and Matlab* modeling. (Matlab is a numerical computing environment developed by MathWorks that facilitates analyzing and visualizing data, as well as publishing results.) An Intel employee led the development of the functional requirements document and the evaluation methodology document. Intel employees also played major roles in the development of such key IEEE 802.11ad technologies as the OFDM PHY, beamforming scheme, network architecture, channel access, and fast session transfer. In fact, an Intel employee is the editor of the amendment.

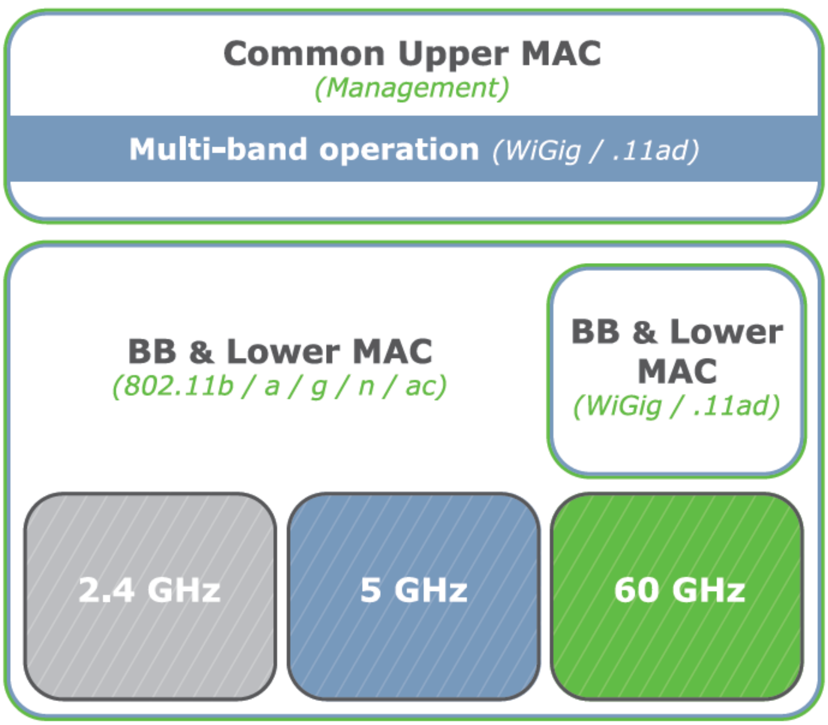

Figure 2. An IEEE 802.11 ac/ad device will be capable of tri-band communications. (Diagram courtesy WiGig Alliance.)

Compatibility with the past

An important component of the work in the IEEE 802.11ac Task Group is to design backward-compatibility mechanisms that enable peaceful coexistence with existing networks. It's important that future Wi-Fi adapters support IEEE 802.11g's 2.4 GHz both for backwards compatibility and range. It’s also important they support IEEE 802.11n and IEEE 802.11ac’s 5 GHz for performance, and IEEE 802.11ad/WiGig’s 60 GHz for short-range, HD video data transfers. Thus, an IEEE 802.11n/ac/ad device will need to operate in all three IEEE 802.11 frequency ranges: 2.4 GHz, 5 GHz, and 60 GHz (see Figure 2). This multi-frequency performance is being achieved by mechanisms for automatic detection of legacy networks and continuing to comply with the technological requirements for supporting these earlier amendments.

Enabling next generation digital media through QoS

While data and audio communications have long been the primary attractions for most Wi-Fi users, streaming video is increasingly popular as a networked application. QoS issues with early Wi-Fi products degraded the user experience, particularly when wireless devices are in motion. Wi-Fi roaming improvements have enabled new secure and QoS-enhanced Voice-over-WLAN usages in the enterprise and public hotspots. The IEEE 802.11r (Fast BSS Transition) amendment published in July 2008 allows a roaming user device to procure QoS parameters at a new access point before making a transition away from the original access points. This enables handover without lost connections and stream disruption.

Intel employees worked closely with Cisco employees and other members of the IEEE 802.11 community to develop IEEE 802.11r, the secure, QoS-enhanced inter-access point roaming protocol amendment in IEEE 802.11. The IEEE 802.11r amendment, ratified in July 2008, builds upon the IEEE 802.11i security by providing faster (sub-50 millisecond) and secure key hierarchy-based handoffs when a user roams between access points. IEEE 802.11r enables user-undetectable inter-access point roaming for Multimedia-over-Wi-Fi applications, access point load balancing, and salt-and-pepper (dual-grid) usages in enterprises, healthcare, and operator deployments. IEEE 802.11r is fully compatible with IEEE 802.11a/b/g/n.

What lies ahead

As the number of computers and other devices using Wi-Fi continues to grow exponentially, proliferating all over the planet, the vision of freedom from wired Internet connections is becoming a reality. This wireless connectivity is spreading to non-mobile products like televisions, automobiles, thermostats, video surveillance cameras, medical equipment, and even toys, bathroom scales, exercise equipment, and home appliances. Being a player in a wide range of consumer and industrial electronic devices today requires offering Wi-Fi-enabled solutions.

> Over the past 15 years, IEEE 802.11 has evolved with the Internet to provide a five times increase in throughput every four or so years. Wireless innovation and Moore’s Law make it possible to achieve this throughput increase at the same cost and power consumption.

Behind this success is a well-established standard: IEEE 802.11. This standard is as crucial as ever to industry innovation and acceptance of IEEE 802.11 products. Because of IEEE 802.11, customers enjoy the ability to buy Wi-Fi devices with assurance of their interoperability. Because of IEEE 802.11, the Wi-Fi industry continues to profit from fast growth.

Intel’s contributions have been important to the evolution of Wi-Fi and continue to help drive ongoing improvements, such as IEEE 802.11ac and IEEE 802.11ad. As with previous IEEE 802.11 enhancements, both these new enhancements will also support compatibility with existing IEEE

802.11 services, access points and base stations as well as its management features such as association, authentication and security.

Intel is committed to IEEE 802.11 in all its "flavors" and will continue to support IEEE 802.11, the expansion of its ecosystem, and the end-user awareness necessary for the broad proliferation of broadband wireless. The innovation that has led to IEEE 802.11's success will continue in organizations such as IEEE as wireless networking is adapted to touch every facet of our lives, from homes and cars to office buildings, factories, and health care institutions.

Learn more
Visit the IEEE 802.11 Working Group (http://www.ieee802.org/11/) and the Wi-Fi Alliance (http://www.wi-fi.org/). Note: The links on this page will take you from the Intel Web site. Intel does not control the content on these Web sites.