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WHAT YOU NEED TO KNOW ABOUT 802.11AC

DEMYSTIFYING THE BUSINESS AND TECHNICAL IMPLICATIONS OF THE NEXT GENERATION OF WLAN TECHNOLOGY

MOTOROLA SOLUTIONS

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INTRODUCTION: WLANs IN TRANSITION

The appetite for wireless bandwidth is seemingly insatiable. Fifteen years ago, the first standard wireless LANs emerged at 1Mbps and 2Mbps to serve niche applications such as warehouse picking, inventory scanning and, in office buildings where mobility wasn't a requirement, cordless PC connections aimed at lowering cabling costs. Fast forward through several WLAN generations to today, and the story has completely changed.

Fifth-generation WLANs are now nearing standardization, and they are poised to run at 1Gbps speeds and beyond to serve any number of mission-critical applications across all industries. Instead of wireless connectivity being reserved for specialized applications or occasional connections in conference rooms, most knowledge workers today use the WLAN as their primary access network, and mobility has become a primary requirement. Employees typically tote a combination of smartphones, tablet computers and laptops supporting both Wi-Fi (802.11) and cellular network connections to access many of their corporate applications.

As a result, greater wireless throughput and denser networks of wireless access points (APs) are needed to satisfy burgeoning bandwidth demands. Today's 802.11n Wi-Fi version, offering 300Mbps to 450Mbps maximum theoretical speeds per radio, has matured. Enterprises have been steadily installing it since 2009. But even its generous capacity is already being tested in some organizations and soon will be in others, driving the IEEE to develop a 1Gbps WLAN standard, called "802.11ac: Enhancements for Very High Throughput for Operation in Bands Below 6 GHz."

The 802.11ac standard now specifies WLANs running exclusively in the 5GHz band, so it will be backward-compatible with 802.11n devices running at 5GHz. The standard is expected to be finalized next year.

WHY DO WE NEED FASTER WI-FI?

A number of factors are fueling industry progress with 802.11ac standards. Among them:

- **More users.** Sheer traffic volume is exploding. Wi-Fi has more or less succeeded at displacing Ethernet in the access portion of the corporate network, so there are simply more Wi-Fi users creating traffic. In addition, guest traffic in certain verticals is adding to the loads. For example, retail customers often want to use their Wi-Fi-enabled devices in stores to comparison shop; in turn, retailers take advantage of customers' wireless connectivity by pushing in-store advertising to them over the airwaves.

- **More devices per user/BYOD.** In addition, users now tend to carry at least two devices; most carry a mobile phone and a laptop, and some carry a tablet computer, as well. This has created a dense population of devices with varying transmit power levels, generating more traffic and creating new Wi-Fi design considerations for the enterprise.

- **"Big" apps.** Users are running bandwidth-hungry apps such as Apple iCloud and Google Drive over-the-air synchronization services, high-def video, Web conferencing, social networking apps, Apple FaceTime videoconferencing and Pandora radio streaming, to name just a few. These consume far more capacity than the low-speed data transfers of yesterday.

- **Cellular offload.** A number of 3G/4G cellular carriers are growing anxious to offload mobile WAN traffic onto Wi-Fi wherever possible to prevent cellular traffic jams. This works because most popular mobile devices support both cellular and Wi-Fi connections, so cellular subscribers can hop onto Wi-Fi when they are in range.

802.11ac will help address and facilitate all of these situations. Final IEEE 802.11ac Working Group approval is expected in late 2013, though, as with most WLAN standards, the industry's Wi-Fi Alliance expects to certify "pre-standard" products six to 12 months earlier than that, most likely for the home/consumer market. 802.11ac products earning a pre-standard Wi-Fi certification by the alliance have been tested for interoperability by the alliance's labs with a number of other early products built to the 802.11ac standard in its near-final state.

Note that to be considered "standards-compliant," ratification of the final standard must take place, and products must be tested for conformity to all the mandatory components of that standard. Standards conformance/compliance still is not an assurance of product interoperability, as standard features might be interpreted and executed slightly differently. So interoperability testing and certification remains a good idea, whether products are "pre-standard" or built to the final, ratified standard.

802.11AC UNDER THE HOOD

Also known as "Gigabit Wi-Fi," 802.11ac represents more of an evolutionary than revolutionary step up from 802.11n, because the newer standard relies substantially on algorithms already ironed out during the development of 802.11n.

Among the technologies that 802.11n and 802.11ac have in common:

- **Channel bonding** for wider channels and greater throughput
- **Multiple input, multiple output (MIMO)** antenna technology to avoid multipath interference problems and improve data throughput
- **Beamforming,** or concentrating signal strength from an antenna toward one or more client devices
- **Air time fairness** to prevent overall network performance from "falling back" to the transmission speed of the slowest device on the network. In other words, just as an 802.11a client joining a 5GHz 802.11n network no longer degrades an 802.11n client's performance in the 5GHz band, a 5GHz-band 802.11n client is not expected to degrade the performance of an 802.11ac client.

802.11ac will operate in the 5GHz band, where there are more non-overlapping channels available for design flexibility than have been available in the 2.4GHz range occupied by 802.11b and its successor, 802.11g. 802.11n can run in either band. Representing a "fifth-generation" of Wi-Fi (timeline, page 9), 802.11ac will make use of 80MHz- and, eventually, 160MHz-wide channels using the channel bonding technique, which aggregates 20MHz channels together for a larger wireless "pipe" within the spectrum. Channel bonding in Wi-Fi was introduced with 802.11n, which allowed for aggregating two 20MHz channels for a maximum 40MHz channel width. 802.11ac pushes the technology even farther.

Figure 1 shows the number of available non-overlapping channels in the 5GHz band using various bonding algorithms.

Like all flavors of 802.11 WLANs, throughput and coverage depend on network design, environmental conditions, vendor implementation, the size of the user population at any given moment and other factors. However, 802.11ac can eventually be used with up to eight antennas and associated spatial streams (compared with a maximum of four in 802.11n), so it is rated from 433Mbps up to nearly 7Gbps theoretical maximum speeds.

The higher end of the throughput range is targeted at outdoor applications, where there will be less device density compared with indoors. In addition, the eight-spatial-stream support and 160MHz-wide channels are not likely to be supported in the first group of commercially available, pre-standard products expected late this year for the consumer market.

Attributes and Benefits

As with most generations of new networking technology, getting a boost in throughput and, presumably, resulting application performance is the main benefit expected from 802.11ac.

As noted, there is flexibility in how 802.11ac is deployed in terms of number of antennas and spatial streams and the width of the channels used, which all affect performance and number of devices supported. For example, if 10 clients today each use 30Mbps from an 802.11n AP that delivers 300Mbps throughput using three spatial streams, at least twice as many (20 clients) could easily share an 11ac AP that delivers 600Mbps.

This is particularly beneficial in very dense deployments, such as universities, business offices and manufacturing floors, where a number of devices are collocated closely together.

In addition to enabling the support of wider channels and double the number of spatial streams than 802.11n, 802.11ac also achieves performance improvements from enhanced coding. Quadrature amplitude modulation (QAM) jumps from 64 QAM in 802.11n to 256 QAM in 802.11ac. The greater the QAM number, the more bits per symbol that can be transmitted and the faster the data rate of the wireless

Figure 1. 5GHZ NON-OVERLAPPING CHANNEL AVAILABILITY AT VARIOUS CHANNEL WIDTHS

CHANNEL WIDTH	NO. OF CHANNELS (U.S)	NO. OF CHANNELS (EUROPEAN UNION)
20MHz	21	16
40MHz	9	7
80MHz	4	3
160MHz	2	2

link. The 802.11ac standard also specifies more aggressive error correction codes that have fewer redundant bits and is expected to improve rate-versus-range performance and link reliability when operating at a distance.

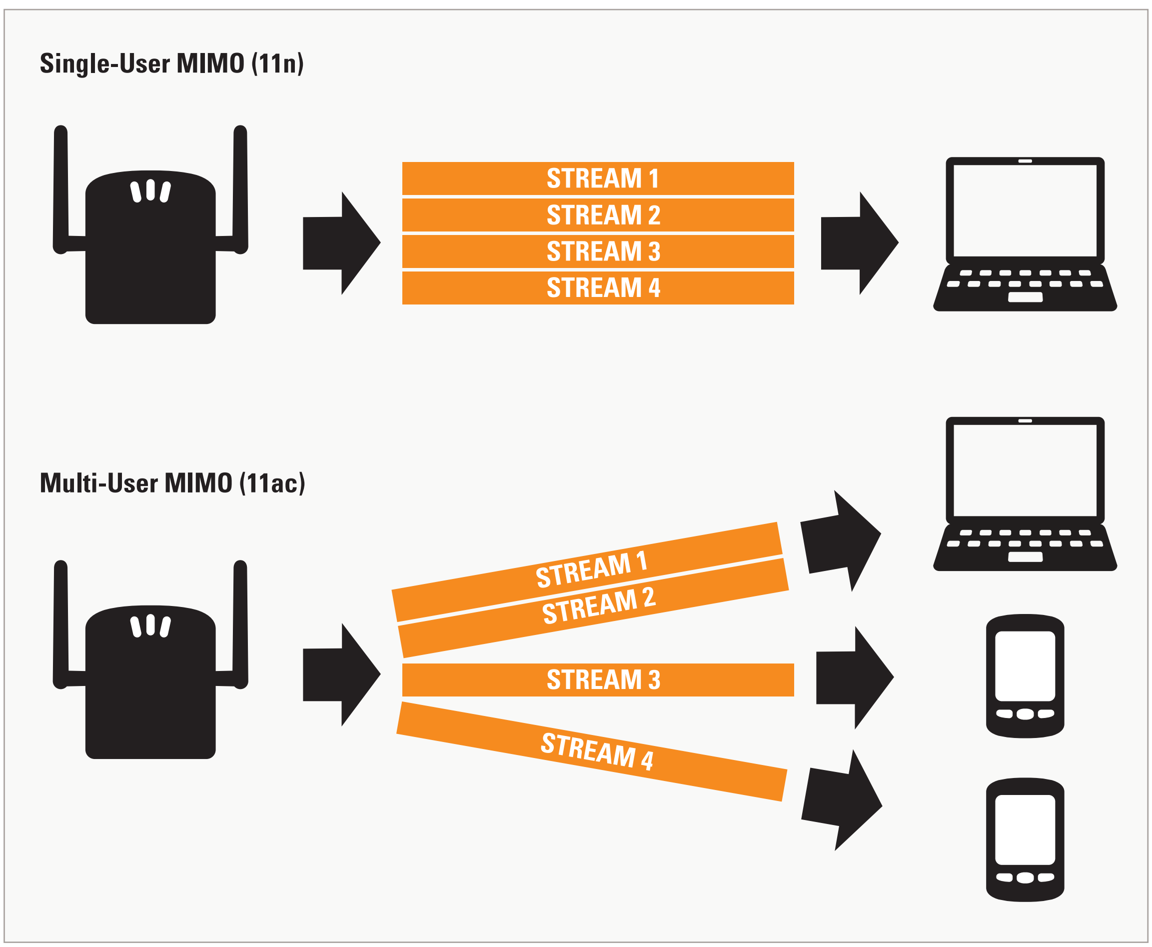
New Component: Multi-User MIMO

MIMO capabilities were introduced in 802.11n. Radios spread a user's data into multiple spatial streams, and they are transmitted through multiple antennas, propagating over the air along different paths. When all streams reach the client, the data are recombined.

Multi-User MIMO, or MU-MIMO, to be introduced in the second or third wave of 802.11ac products, supercharges the MIMO capabilities by increasing the number of bits moved per megahertz of spectrum. While 802.11n's "single-user" MIMO will only benefit a single device at a time, 802.11ac MU-MIMO allows multiple streams to be assigned to different clients, increasing the total bandwidth that can be transmitted simultaneously. In the example (see Figure 2), an 802.11ac AP with 4 antennas could transmit a 2x2:2 stream to a 2x2:2 client, while using the other two antennas to transmit 1x1:1 streams to 2 mobile devices simultaneously. (see **Figure 2**).

In addition, MU-MIMO builds upon the transmit beamforming (TxBF) option in the 802.11n standard, a technique used to focus RF energy in a given direction to improve signal strength and, thus, throughput of individual client devices. This feature will be a boon to supporting high-density networks but, again, will not likely be supported in the very first 802.11ac products on the market.

Figure 2. **SINGLE- AND MULTI-USER MIMO OPERATIONS**



HOW MANY SPATIAL STREAMS?

MIMO and spatial stream numbers work together to indicate throughput potential at given ranges. Generally, the greater the number of receive antennas, the greater the distance that a particular data rate can be sustained. But as noted in "802.11ac Under the Hood," page 4, the actual throughput and coverage range users experience depends on the environment – the floor plan, building and window construction materials, configuration of the client devices involved in the transmission, how saturated the network is at a given time and other factors.

MIMO (and, eventually, MU-MIMO) is just one part of the equation. It refers to the number of transmit (Tx) and receive (Rx) antennas involved in exchanging wireless signals across a propagation channel, which is the wireless path that signals take through the air. 2x2 MIMO, for example, indicates two Tx antennas and two Rx antennas. 2x3 MIMO indicates two transmitting antennas and three receiving antennas, and so forth. Spatial multiplexing is a mandatory component of the 802.11n and 802.11ac standards, and MIMO is required in order for spatial multiplexing to take place. So the two work together.

As indicated, spatial multiplexing is a technique whereby multiple antennas separately send different flows of individually encoded signals (called spatial streams) over the air in parallel; in essence, reusing the wireless medium or "multiplexing" the signals to squeeze more data through a given channel. At the receiving end, each antenna sees a different mix of the signal streams. In order to decode them accurately, the receiving device needs to separate the signals back out, or "demultiplex" them (see **Figure 3**).

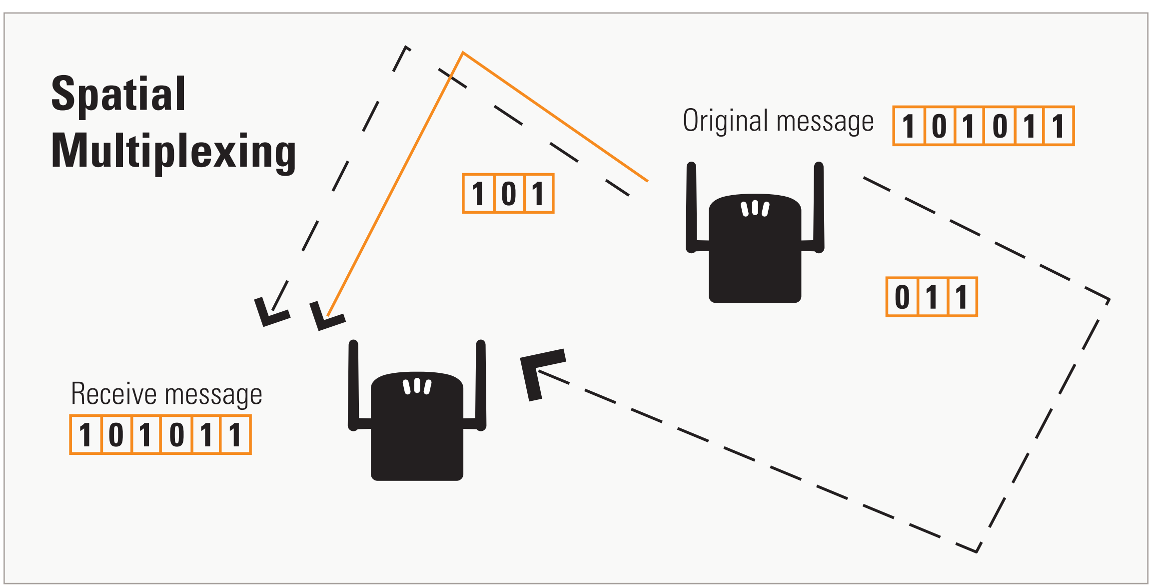
Note that the number of spatial streams that can be multiplexed over the air is dependent on the number of transmitting antennas. So while 2x3 MIMO has an additional receive antenna compared to 2x2 MIMO, only two spatial streams can be supported in both configurations. Often, to express the number of Tx and Rx antennas as well as the number of spatial streams supported, products are described with the number of spatial streams following the MIMO designation: for example, 3x3:2 indicates support for three Tx antennas and three Rx antennas but two spatial streams, while 3x3:3 indicates three Tx antennas, three Rx antennas and three spatial streams.

Potential Benefits of More Rx Antennas

Whether there's a benefit of having additional Rx antennas is a matter of much debate and independent vendor implementation and testing. The extra receive antenna might increase the range at which a given throughput is maintained. This factor is less likely to be relevant in high-density WLANs in which spectrum is frequently reused with large numbers of APs installed to create smaller "cells" of coverage. However, the additional Rx antenna might also increase throughput at a given range. When you have more receive antennas, the system might experience something called "combining gain," in that more copies of the same transmitted signal will deliver greater signal-to-noise ratio, which strengthens the signals and improves throughput.

The 802.11n standard allows for up to four pairs of antennas and four spatial streams, and the 802.11ac standard allows for double that.

Figure 3. **BASIC SPATIAL MULTIPLEXING OPERATION**



Spatial Streams vs. Channel Widths

All this said, increasingly, many of the devices connecting to Wi-Fi networks are smartphones, which typically have supported just a single stream across a single (unbonded) 20MHz channel. So what good are more antennas, more streams and fatter (bonded) channels?

When MU-MIMO becomes available, the antennas should be more relevant. While a single client with one or two antennas would not be able to fully utilize eight spatial streams offered by an 8x8:8 11ac AP, it's possible for several Wi-Fi clients to share a larger pool of streams and antennas, so that overall aggregate throughput improves for the client population. Early demonstrations of a single-stream 11ac radio, mounted in smartphone prototypes, have delivered approximately 220Mbps in a fairly challenging environment. The faster the handset can transmit its loads, the better its battery life, because faster devices spend less time transmitting and more time "sleeping."

INTEROPERABILITY AND MIGRATION CONSIDERATIONS

802.11ac will be backward-compatible with 802.11n but only with 802.11n clients operating in the matching 5GHz range. The 2.4GHz range, which has been home to 802.11b, 802.11g, much of 802.11n and a variety of non-Wi-Fi devices, has been deemed impractical for enhancing WLAN throughput going forward.

This is a potential sticking point for some of today's mobile devices. Though a number of handsets and tablets built specifically for enterprise applications operate in the 5GHz band, most consumer-class handsets growing popular within the enterprise operate in the 2.4GHz band only. As such, they will not be compatible with 802.11ac per se. Two things will likely happen here:

1) Many organizations will continue to support 802.11n as they introduce 802.11ac, and the 2.4GHz radios in their 802.11n infrastructures will continue to serve the 2.4GHz clients.

2) Newer devices will have multiple radios, including both 2.4GHz and 5GHz Wi-Fi radios. For example, the most current version of the Apple iPhone (the iPhone 4S) supports 2.4GHz Wi-Fi only; however, the latest version of the Apple iPad tablet computer, the iPad 3, supports both Wi-Fi frequencies.

While 802.11ac will not be available in many such devices for a while, support for 5GHz suffices for backward compatibility. And air time fairness algorithms, described earlier, will make sure that each device transmits only for the length of time allotted by the standard it supports so as not to degrade performance of 802.11ac clients running on 802.11ac backbones.

As mentioned, many of the technology concepts that were created for and used by 802.11n were expanded upon and applied to 802.11ac, which bodes well for interoperability testing, as well as initial price points.

The most difficult decision in migrating, perhaps, will be in determining channel plans that take advantage of 802.11ac's fatter channels while maintaining performance for single-stream mobile devices. Otherwise, depending what the range and throughput requirement is for the new installation, it is likely that an 802.11ac AP can be dropped directly into a legacy AP location, one for one.

While 802.11n is specified to support up to four spatial streams, most products on the market today currently support two or three. Early 802.11ac products are likely to support just two or three, as well. Determining whether to invest in early 802.11ac products or mature 802.11n products in the near-term, then, is likely to depend on how product costs fall out and each organization's philosophy over whether to continue investments in "legacy" technology if it continues to do the job needed. 802.11n was so long in coming and brought such dramatic advances to the Wi-Fi industry, it is hard to imagine it as a "legacy" technology. However, in about a two- to three-year time frame, that's exactly what it will be.

11ac in Numbers

Research firm NPD In-Stat expects the 802.11ac standard to trigger an explosion in Wi-Fi-enabled cellular devices, with shipments exceeding 650 million by 2015. In the same year, 802.11ac is also projected to be on one of every four notebooks.

Use Cases for 802.11ac

The general growth in consumption of WLAN bandwidth is one driver behind 802.11ac. Wi-Fi has simply become the default access network in many organizations. That, coupled with users carrying multiple Wi-Fi-enabled devices and carriers wanting to offload cellular traffic onto Wi-Fi, will soon be pushing the limits of 802.11n. In addition, specific applications and use cases for Wi-Fi are adding to the flood of Wi-Fi traffic and requiring more dense deployments:

- HD outdoor surveillance cameras
- Various healthcare apps, including electronic medical charts on physician tablets and real-time remote "bedside" videoconference patient consults
- Automatic over-the-air backup and synchronization applications
- Backhaul applications; aggregating traffic from lower-speed Wi-Fi networks

"Wi-Fi Chipset Revenue to Reach $6.1 Billion in 2015, Says NPD In-Stat," January 2012 <http://www.prweb.com/releases/In-Stat/NPDGroup/prweb9151164.htm>

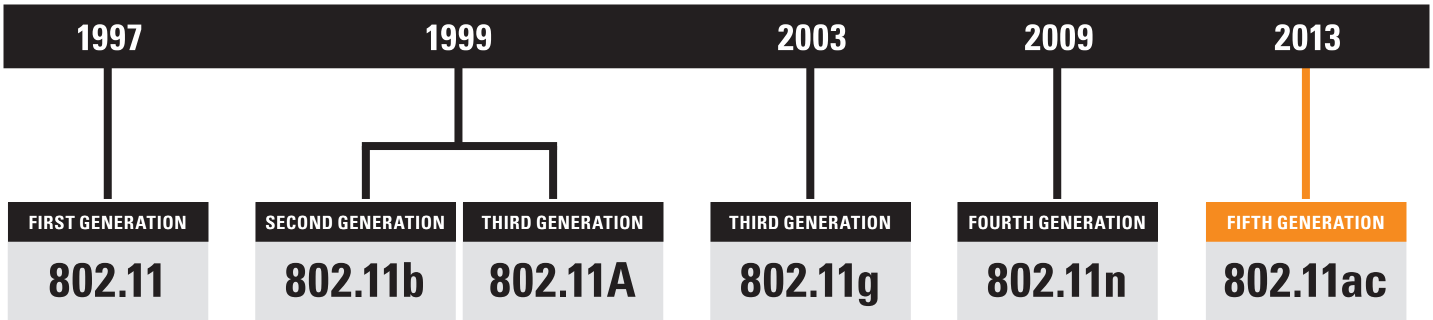
CONCLUSION AND SUMMARY

802.11ac represents the fifth generation of IEEE 802.11 WLAN standards and is expected to deliver a data rate connection of at least three times that of 802.11n. Many of the algorithms of 802.11n are being reused, but enhanced, with 802.11ac, which should make the technology easy to fold into existing networks.

802.11ac will be backward-compatible with 802.11n networks operating in the 5GHz range and is expected to offer dramatic improvements in Wi-Fi reliability, throughput and range. 801.11ac is expected to be ratified by IEEE late 2013. The earliest, pre-ratified products are expected late 2012 and will likely ship for the home/consumer market. From there, it's expected that the rollout of new IEEE 802.11ac devices will take between one and three years. By 2015, according to experts, all new Wi-Fi products coming to market are expected to be based on 802.11ac technology.

Enterprise-class products will ship with variations on the number of antennas, spatial streams and channel widths, and the most important education for enterprises to seek at this time is how wider channels, but fewer of them, will affect the organization's channel plan. This is particularly relevant for early enterprise adopters, who will likely be supporting large volumes of single-stream handset clients for a couple of years, as well as clients that use the 2.4GHz band, which will be obsolete in 802.11ac. There's a fine balance between accommodating the high density of these devices with enough channels to avoid co-channel interference and reaping the aggregate throughput benefits of the greater channel widths of 80MHz and, eventually, 160MHz, that have been specified by 802.11ac standards.

802.11 TIMELINE



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