Introducing Wireless Standards of the Future: IEEE 802.11ac and LTE-Advanced

Microwaves and RF
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It's no secret that wireless communications standards continue to evolve to provide ever-increasing data throughput capabilities. The boost in data rates is largely accomplished through enhancements in the physical layers of the protocols. These enhancements often take years to develop—allowing us to envision both the communications systems of tomorrow and the changes in RF test needs. Today, two of the hottest wireless standards are IEEE 802.11ac in wireless-local-area-network (WLAN) products and 3GPP LTE-Advanced in cellular communications.

IEEE 802.11ac is a new standard that is currently in pre-draft mode—with a formal draft expected by late 2011. Designed for higher-throughput wireless connectivity, it features more MIMO channels, wider bandwidths, and higher-order modulation types than today's generation Wi-Fi products based on IEEE 802.11a/g/n. Some key IEEE 802.11ac specifications we'll investigate are the use of 8x8 multiple-input, multiple-output (MIMO) antenna techniques, 160-MHz channel bandwidth, and 256-state quadrature amplitude modulation (256QAM).

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Similarly, LTE-Advanced is an evolution of the 3GPP LTE specifications—with a range of enhancements that also include more spatial streams and carrier aggregation. While today's newly designed LTE networks are based on the 3GPP release 8 specifications, LTE-Advanced is based on the 3GPP release 10 specification—and its enhancements will likely come as future upgrades to existing LTE networks. Key LTE-Advanced details include its use of 8x8 MIMO technology and carrier aggregation to use as much as 100 MHz of channel bandwidth.

In this article, we'll take a look the physical layer characteristics of both standards and explain how higher data rates are achieved. More specifically, we'll look at how features such as more spatial streams, carrier aggregation, and higher-order modulation schemes directly correspond to higher data throughput. Finally, we'll look at how evolutions in the physical layer for each standard create new test challenges for today's RF engineer.

Increasing Spatial Streams

It has been over half a decade since the first wireless communications standards introduced MIMO antenna technology as a mechanism to increase data rates. Until MIMO, the Shannon-Hartley theorem was generally regarded as the model of theoretical data throughput for a given digital communications channel:

$$\text{Capacity} = \text{Bandwidth} \times \log_2(1+\text{SNR})$$

Classical Shannon-Hartley Theorem Model of Channel Throughput

According to the theorem, data rates through a particular channel can be increased by affecting either channel bandwidth or signal-to-noise ratio (SNR). However, the design of MIMO systems with multiple spatial streams allowed a departure from the Shannon-Hartley theorem. In a 2x2 MIMO system, the use of two independent spatial streams in the same physical channel effectively doubles the data rates over what one might expect from a traditional single-input, single-output (SISO) system. Accordingly, a 4x4 MIMO channel would enable 4x data rates, and an 8x8 MIMO channel would enable 8x data rates.

Today, next-generation wireless communications standards such as IEEE 802.11ac and LTE-Advanced continue to use more spatial streams as a mechanism to increase data throughput. For example, while the previous incarnation of Wi-Fi, IEEE 802.11n, uses MIMO configurations as complex as 4 x 4, next-generation 802.11ac uses MIMO configurations to 8x8. The evolution in cellular communications from LTE to LTE-Advanced brings a similar change. While today's LTE specifications allow for a 4X4 MIMO downlink channel, LTE-Advanced allows as large as 8x8 MIMO in the downlink. Beyond IEEE 802.11ac and LTE-Advanced, it's possible that we'll see this trend continue. Research is already being done on 16x16 MIMO systems and—depending on the outcome—it's possible we'll see 16x16 systems one day.

For engineers testing next-generation MIMO-based communications systems, synchronization requirements for multi-port, MIMO measurements were historically difficult, if not impossible, to meet with traditional instrumentation. Today, the modularity and software-defined architecture of PXI instrumentation provides engineers with the flexibility needed to test next-generation wireless standards. For example, in a typical PXI system, a 4-channel RF signal analyzer can be upgraded to an 8-channel RF signal analyzer simply by adding more PXI downconverters and digitizers to the same mainframe.

Wider Channel Bandwidth

As the Shannon-Hartley theorem might suggest, increasing the bandwidth of a digital communications channel is a second mechanism to increase channel bandwidth. Historically, in the cellular world, when GSM/EDGE progressed to UMTS, channel bandwidth was increased simply by increasing the symbol rate of a digitally modulated signal. However, it's widely recognized that using wideband signals in a single-carrier communications system introduces inherent physical hardware challenges. In addition, because systems with higher symbol rates yield shorter symbol periods, other common wireless challenges such as multipath fading become increasingly problematic in wideband single-carrier communications systems.

Today, next-generation wireless communications channels use a combination of orthogonal-frequency-division-multiplex (OFDM) techniques and carrier aggregation to increase the effective symbol rate—all while avoiding the classic challenges of wideband single-carrier communications systems. OFDM is one such common technique used today in IEEE 802.11a/g/n and LTE to divide a channel into orthogonal and lower symbol rate subcarriers, enabling higher effective symbol rates while mitigating the multipath problem. For next-generation standards such as IEEE 802.11ac and LTE-Advanced, the increase in data rates via an increase in channel bandwidth comes through their use of two mechanisms: more subcarriers and carrier aggregation.

While the IEEE 802.11g standard was designed for a single 20-MHz OFDM channel, IEEE 802.11n added carrier aggregation by allowing devices as much as two 20-MHz channels for 40-MHz total bandwidth. By contrast, IEEE 802.11ac supports 20- , 40- , 80- , and 160-MHz channel bandwidth options. In the 40- and 80-MHz modes of IEEE 802.11ac, wider bandwidth is achieved through the use of more subcarriers. Thus, while the 20-MHz mode uses 64 subcarriers, the 40-MHz mode employs 128 subcarriers, the 80-MHz mode uses 256 subcarriers, and the 160 mode operates with 512 subcarriers. By contrast, the 80 + 80 MHz mode of IEEE 802.11ac will use a slightly different scheme. In this mode, a carrier aggregation scheme will employ two unique 80-MHz OFDM channels (256 subcarriers each) simultaneously by means of an access point. In the table below, we compare and contrast the various modulation types, MIMO schemes, and channel bandwidths of various common IEEE 802.11 standards.

	802.11a/g	802.11n	802.11ac
Antenna Configuration	1x1 SISO	Up to 4x4 MIMO	Up to 8x8 MIMO
Highest Order Modulation	BPSK to 64-QAM	BPSK to 64-QAM	BPSK to 256-QAM
Channel Bandwidth	20 MHz	20 MHz & 20+20 MHz	20, 40, 80, 80+80, and 160 MHz
Year Introduced	1999 (802.11a) 2003 (802.11g)	2009 (draft)	2012 (estimated)

Physical Layer Characteristics of Various WLAN Standards

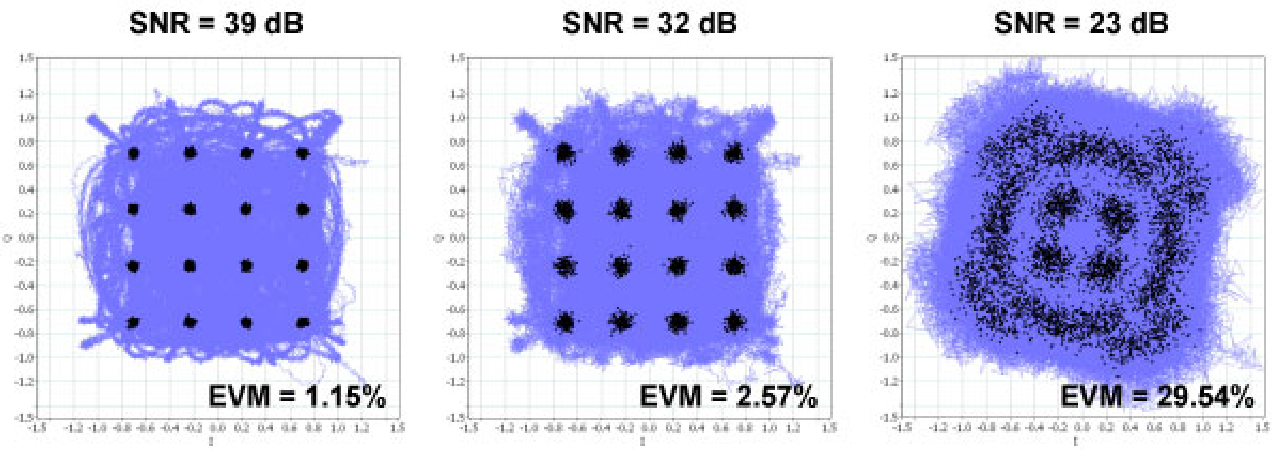
Similar to IEEE 802.11ac, LTE-Advanced also employs a carrier aggregation scheme to increase data throughput. While the original LTE specifications from 3GPP release 8 allowed for a scalable bandwidth from 1.4 to 20 MHz, LTE-Advanced expands channel bandwidth through carrier aggregation as well. In the next-generation specification, LTE-Advanced allows for the use of up to five contiguous 20-MHz carriers for as much as 100 MHz total channel bandwidth. Today, many questions remain regarding exactly how much bandwidth tomorrow's LTE-Advanced devices will actually use. With the astronomical cost of wireless spectrum, it's likely that few devices will actually use the full 100-MHz of available channel bandwidth.

From a test point of view, the wider bandwidths of next-generation wireless standards such as IEEE 802.11ac and LTE-Advanced will introduce significant challenges. For example, while IEEE 802.11ac will support a mode that uses as much as 160 MHz, today's RF signal analyzers generally have instantaneous bandwidth of only 100 MHz or less. When testing devices that use wideband carrier aggregation, the bandwidth requirements alone will require engineers to assembly test systems based on multiple RF signal generators and analyzers. In these scenarios, the modularity of PXI produces significant benefits, since multiple signal generators and analyzers can be configured and software-controlled in a single PXI system.

Higher-Order Modulation Types

A third mechanism that wireless communications system designers use to increase data rates is higher-order modulation types. As suggested by the Shannon-Hartley theorem, an increase in SNR corresponds to an increase in data throughput. For digital communications systems, higher data rates can be accomplished through use of higher-order modulation types. For systems using quadrature amplitude modulation (QAM), the throughput of the physical channel is directly related to the QAM "order." For example, a 4-QAM channel is capable of 2 bits per symbol, since two is the maximum number of bits that can be represented by four unique symbols [$\log_2(4) = 2$] . Similarly, a 16-QAM channel yields 4 bits per symbol and a 64-QAM channel yields 6 bits per symbol.

The new IEEE 802.11ac specification is one of the first consumer wireless standards to allow to 256-QAM. The 256-QAM format yields 8 b per symbol and [$\log_2(256) = 8$], thus enabling a 33% higher throughput than a system using only 64-QAM. Of course, the capability of a digital communications channel to use a higher-order modulation type such as 256-QAM requires that a sufficiently high SNR can be sustained. For years, wireless communications systems have used adaptive modulation types—enabling the use of more robust schemes such as QPSK in low SNR environments. As an example, consider the below figure, which illustrates the constellation diagram of a 16-QAM signal under varying SNR conditions.



As we observe in the constellation diagrams, an SNR of 44 dB is sufficiently large to demodulate a 16-QAM signal without bit errors. By contrast, an environment with an SNR of 30 dB or less, using a 16-QAM modulation type, would result in significant bit errors. In this scenario, a lower-order modulation type such as QPSK would be more appropriate. Given these considerations, one might correctly assume that IEEE 802.11ac will only use the 256-QAM modulation type in scenarios where SNR is reasonably high.

From an instrumentation perspective, the addition of new modulation types almost purely a software change. In modular, software-defined platforms such as PXI, each new wireless standard or modulation type is merely a new waveform, allowing engineers to evolve their test equipment along with the evolution in communications standards. As a result, adding support for the 256-QAM modulation type in IEEE 802.11ac—and possibly future standards as well—will likely come through simple software updates.

Summary

As we look at next-generation wireless communications standards, we see continued trends of using more spatial streams, wider channel bandwidths, and higher-order modulation types to increase data throughput. With IEEE 802.11ac, this trend results in the use of 8x8 MIMO, as much as 160 MHz bandwidth, and 256QAM. With LTE-Advanced, we also see support for 8x8 MIMO configurations and the implementation of carrier aggregation to support for as much as 100 MHz channel bandwidth. As such, it should also be noted that existing 2G and 3G cellular standards continue to evolve and add these features as well. For example, even the next evolution of today's "2.5G" EDGE standard will make use of carrier aggregation as well. Moreover, in UMTS, HSPA+ is a somewhat recent addition that adds 64-QAM to the downlink. Going forward, HSPA+ Advanced will add two- and four-carrier aggregation to increase throughput in existing 3G cellular communications networks.

While next-generation wireless standards produce obvious benefits to consumers in the form of higher data rates, design and test of IEEE 802.11ac and LTE-Advanced radios produce significant challenges. From building transceivers capable of handling wider bandwidth to packing more antennas on a single mobile device, next-generation standards come with substantially more difficult hardware requirements. As a result, the measurements and instrumentation required for next-generation wireless standards are more challenging as well. Fortunately, the modularity and software-defined architecture of PXI test equipment makes it a compelling alternative to traditional instrumentation for testing emerging standards such as IEEE 802.11ac and LTE-Advanced.

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