WLAN 802.11ax speeds up communications in multi-user scenarios

The upcoming 802.11ax standard introduces new techniques to more efficiently utilize the unlicensed 2.4 GHz and 5 GHz bands. Public WLAN networks will especially benefit from the standard.

Background

The number of WLAN-capable devices has risen drastically in the past few years, and the growth rate is expected to increase. This is because, in addition to laptops, smartphones and tables, an ever greater number of televisions, game consoles, cameras, smart home devices and IoT devices are connecting to WLANs. This will increase the density of users in networks, leading to a noticeable reduction in the data throughput due to packet collisions and shorter "free" time periods during which a subscriber can transmit. WLAN routers (access points, AP) in apartment buildings have the same effect because they are very close to each other and act as interferers.

To alleviate these problems, the IEEE is currently working on a new WLAN standard: 802.11ax. Previous standards (802.11g/n/ac) increased data throughput primarily by enhancing physical parameters such as bandwidth and modulation factor or by introducing new transmission methods such as multiple input multiple output (MIMO). 802.11ax will not introduce any essential changes in this area. Instead, the new standard focuses on making networks more efficient and on better utilizing existing transmission capacities.

802.11ax

The standard is currently in the planning phase and is projected for completion by the end of 2018. The key players in the WLAN market already started developing 802.11ax-capable chipsets in 2016. Although draft version 1.0 of the standard did not receive a majority vote by the IEEE working group in early 2017, the first devices are expected on the market even before the standard receives final approval.

802.11ax aims to increase the performance of intensively used networks, especially those for:

- I Airports and train stations
- I Local and long-distance public transportation
- I Stadiums and concert halls
- Apartment buildings

This article presents the changes that 802.11ax will make to the physical layer (Fig. 1) (for changes to the MAC layer, refer to the draft of the standard [1] and to the specification framework document [2]). The focus is increasingly on outdoor applications. Outdoor transmission channels exhibit stronger multipath propagation and longer echo times. To prevent intersymbol interference in this scenario, an optional transmission scheme will be introduced in which the guard interval and symbol duration are lengthened by a factor of four while the subcarrier offset is reduced by one fourth, keeping the transmission rate the same but improving resistance to fading. Under optimal conditions, 802.11ax can achieve a maximum data rate of 1200 Mbit/s on a single channel by using the newly introduced 1024QAM modulation and a shorter guard interval. With 8 × 8 MIMO, 9.6 Gbit/s is theoretically possible. Even in its optimal configuration, 802.11ac achieves "only" 6.9 Gbit/s.

OFDMA

The most significant change is the introduction of orthogonal frequency division multiple access (OFDMA) in the uplink and downlink, where multiple users transmit simultaneously and share the available bandwidth of a channel. Previous standards use OFDM and time division multiplexing, i.e. only one user transmits over the full bandwidth.

In the case of OFDMA, each user is allotted a portion of the available spectrum by assigning the user a contiguous subset of subcarriers (minimum 26, maximum 996). This subset of subcarriers is called a resource unit (RU). Both the spectral width of an RU and the modulation mode can vary from subscriber to subscriber. This makes it possible for an access point to satisfy the data rate requirements of each individual user. Unlike the frequency domain's dynamic structure, the

Feature	Benefit
OFDMA in the uplink and downlink	Overhead reduction, channel can be used by multiple users in parallel
Multi-user MIMO (uplink)	Higher throughput in the uplink through space divi- sion multiplexing
1024QAM	Higher maximum data rate
Quadruple symbol duration	Robustness for outdoor use
Extended range preamble	Specialized packet format for outdoor applications

Fig. 1: The most important changes in 802.11ax.

time axis has a uniform structure: to prevent interference, the data packets in all RUs have the same length and are transmitted synchronously. Users that have less data to transmit than permitted by the packet length must pad the packet with padding bits.

Fig. 2 shows the possible resource unit configurations for a 20 MHz channel. The smallest RU size of RU26 allows up to nine users to transmit simultaneously (see the top row in the figure). The maximum bandwidth is 160 MHz, permitting up to 74 simultaneous users.

A single active user is a special scenario in OFDMA in which a resource unit is allocated the entire bandwidth (RU 242 in the figure).

802.11ax operating modes

Previous WLAN standards typically use only one packet type and do not distinguish between the uplink and the downlink. 802.11ax introduces four new, uplink and downlink specific packet types (Fig. 3). Uplink still refers to the transmission from a mobile device (station, STA) to the WLAN router (access point, AP), while a downlink is the transmission from the access point to the station. Every packet type (high-efficiency PLCP protocol data unit, HE-PPDU; physical layer convergence procedure, PLCP) has a different preamble for the signaling information, followed by the payload.

Single-user mode (HE_SU)

This mode is used to communicate with a single user. Uplink and downlink signals use the same packet format. The user is allocated the entire spectrum via a resource unit with the maximum size. This mode eliminates the unavoidable communications overhead found in multi-user mode.

Multi-user downlink (HE_MU)

Packet type HE_MU is used for OFDMA mode in the downlink. The access point transmits the packets for all users simultaneously, the usual 802.11ax case. The preamble contains the HE_SIG_B field, which contains information about the organization of the spectrum into resource units and their allocation to users.

Multi-user uplink (HE_TRIG)

In OFDMA uplink, the stations simultaneously transmit their data packets to the access point when triggered by the access point. To ensure that this process takes place without collisions, it must be defined in advance which RU is allocated to which user, how much data will be transmitted and at what level each user must transmit. This information is essential because signals from the station must arrive at the access point simultaneously and at the same level to prevent any interference. To achieve this, the AP first sends

Resource units





b) Example of different RU sizes in multi-user downlink mode. The DC subcarriers in the channel center are excluded to prevent interference due to LO leakage.



Fig. 3: 802.11ax distinguishes between four different packet formats.

a trigger frame to all users (Fig. 4). This frame contains the configuration parameters, including payload length, band-width, RU allocation and modulation mode. Users must start transmitting the uplink PPDUs after a predefined time interval known as short interframe space (SIFS).

Extended range PPDU (HE_EXT_SU)

This packet type is intended specifically for outdoor use over large distances where a poor signal-to-noise ratio is typical. The bandwidth is limited to 20 MHz, and only the robust BPSK and QPSK modulations are used. Portions of the preamble are transmitted at 3 dB more power to ensure robust channel estimation.



Fig. 4: Multi-user communications in the uplink with three users at a channel bandwidth of 20 MHz.



Fig. 5: Scenario showing the benefit of BSS color. STA2 lies in the coverage area of two networks, but can ignore the external network thanks to BSS color.



Fig. 6: In 802.11ax, multi-user MIMO supplies up to eight stations simultaneously.

BSS color

A basic service set (BSS) is a network that consists of an access point and the stations associated with it. Each station is assigned to one and only one BSS. Multiple BSS networks can exist in close proximity to one another. Fig. 5 shows a typical scenario often found in apartment buildings. A station (STA2) not only receives the signals from its own access point (AP1), but also from the adjacent AP2. Because AP1 and AP2 do not recognize one another, they transmit independently of each other and often simultaneously, leading to packet collisions and interference at STA2. As a consequence, incorrectly received packets from the local AP must be retransmitted, resulting in an additional load on the network. On the other hand, stations themselves can only transmit when the path is free, i.e. only if no other device (AP or STA) is transmitting. However, STA2 has the opportunity to do so less often because of the additional signals it receives from AP2. Both situations can significantly reduce the throughput for the affected station. 802.11ax therefore introduces BSS color to improve the reutilization of frequencies. The 802.11ax preamble assigns a BSS color to each AP so that STA2 can distinguish between packets from its own BSS (intra-BSS) and those from an adjacent BSS (inter-BSS). As a result, STA2 can ignore inter-BSS packets up to a certain receive level and can transmit its own packets despite simultaneous activity on AP2.

Multi-user MIMO

Single-user MIMO was introduced in 802.11n. The intent was to increase the data rate by simultaneously transmitting multiple data streams from the access point to an individual subscriber over multiple antennas. This is done sequentially in the case of multiple subscribers. 802.11ac further improves performance with multi-user MIMO (MU-MIMO, Fig. 6), where multiple users are supplied simultaneously via additional antennas, increasing the effective data rate in the network.

Downlink MU-MIMO uses beamforming (Fig. 7). Antenna array beamforming is designed to direct a beam toward each individual user so that each station receives only the signals intended for it. 802.11ax includes this feature and extends the number of possible parallel data streams from four to eight. It also introduces MU-MIMO in the uplink for the first time. This makes it possible for multiple stations to transmit simultaneously (Fig. 7). However, they do not use beamforming so the signals are jumbled together on the path to the access point. But with its antenna array, the access point is able to separate the overlapping signals and allocate them to the individual users.

TX/RX specifications

The requirements placed on stations' digital and RF components increase further with 802.11ax. The smaller subcarrier offset makes signals more vulnerable to phase noise due to interference from adjacent carriers. As a result, the local oscillator (LO) phase noise must be better than was necessary for 802.11ac. Because the spacing between the constellation points in 1024QAM is smaller than in lower-order constellations, the system noise must also be reduced in order to ensure error-free transmission. This requires a larger signal-tonoise ratio for the D/A and A/D converters. Amplifiers must also operate with minimal distortion. The standard defines a number of requirements for physical parameters in the transmit (TX) and receive (RX) mode, all of which must be validated using appropriate test equipment. Most of the values have not changed from those defined for 802.11ac. Therefore, only the modified or new requirements are described below.



Fig. 7: In the downlink, beamforming ensures targeted station coverage. In the uplink, the data streams can be separated without beamforming.



Fig. 8: Modulation analysis of a 160 MHz 802.11ax signal using the R&S°FSW-K91ax option. In the case of a 1024QAM signal, the R&S°FSW achieves an EVM of < -53 dB when transmitting at 5 GHz.

Error vector magnitude (EVM)

Due to the denser constellation, stricter EVM limits apply for 1024QAM. Whereas in 802.11ac a DUT must achieve an EVM of -32 dB or less for 256QAM, the 802.11ax limit for 1024QAM is -35 dB. The T&M equipment requirements



Fig. 9: Spectrum of an 80 MHz uplink signal (HE_TRIG) on an active resource unit with a size of 242 (18.9 MHz).



Fig. 10: Unused tone error limit value for RU26. For other RU sizes, different limits values and step widths apply.

Fig. 11: Setup for measurements on uplink signals.

increase accordingly. To minimize measurement errors, the intrinsic EVM for the signal analyzer must lie significantly below the specification limits. A reserve of 10 dB is often required, which leads to a measurement error of about 0.5 dB. The R&S®FSW spectrum and signal analyzer with its excellent signal-to-noise ratio achieves an internal EVM of less than –53 dB, reducing the measurement error to 0.07 dB (Fig. 8). In this example, the test signal was generated by the R&S®SMW200A vector signal generator which has a similarly good EVM value.

Uplink requirements (stations) Unused tone error

In the uplink, each station transmits only on the resource unit assigned to it by the access point (Fig. 9). Spurious emissions into adjacent spectrums, which are of course used by other stations, must be minimized. 802.11ax introduces the unused tone error for this purpose. The power for the subcarriers that remain unused by a station (in RU26 blocks) is calculated and set proportionate to the power of the active RU, similar to an adjacent channel leakage ratio (ACLR) measurement. The limits the power must maintain are defined relative to the EVM limits of the active RU (Fig. 10). Subcarriers in close proximity to an active RU26 must lie 2 dB under the EVM limit, for example. For more distant subcarriers, the value is reduced in 10 dB steps down to –35 dB.

Frequency offset and timing offset

To ensure that stations do not interfere with one another when transmitting in parallel, the transmissions must be started virtually simultaneously. Otherwise, a timing offset between the frames will lead to intersymbol interference. In addition, all stations must adjust their transmit frequency to very closely match that of the access point. A frequency offset in one station disrupts the subcarriers of the adjacent stations. Stations synchronize their frequencies using the trigger frame previously received from the access point (Fig. 4).

The 802.11ax standard defines two new measurements for the uplink. First a trigger frame is sent to the DUT, which responds with an HE_TRIG frame (the frames for the uplink and downlink have different names). The relative frequency error (center frequency offset, tolerance ± 350 Hz) of the response signal as well as the delay between the end of the trigger frame and the start of the response frame (timing accuracy, tolerance $\pm 0.4 \,\mu$ s) are measured. Fig. 11 shows the test setup. In its role as the access point, the R&S°SGT100A vector signal generator generates the trigger frame and simultaneously starts the measurement by sending a trigger signal to the R&S°FSW. The RF must be extremely precise in order to measure the very small permissible frequency offset. The R&S°SGT100A and R&S°FSW are therefore coupled via the 10 MHz reference.

Receiver tests

Various sensitivity tests must be performed on the receiver. For example, it must be ensured that at low input power (-43 dBm in the case of 1024QAM), only 10 % of the received packets contain faulty bits. 802.11ax extends the 802.11ac test cases to include additional requirements for the new 1024QAM modulation. For these tests, a high-quality reference signal is needed to ensure that the measurement results are not influenced by the signal source. The R&S[®]SMW200A vector signal generator with the R&S[®]SMW-K142 WLAN option offers sufficient capacity for this purpose. Fig. 12 shows the settings for a measurement at 5 GHz. The R&S[®]SMW-K142 option makes it possible to generate both uplink and downlink signals. When combined with multiple R&S[®]SGT100A instruments and the realtime fading option for the R&S[®]SMW200A, the setup can also generate MIMO signals with up to eight antennas (Fig. 13).

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Fig. 12: The R&S[®]SMW-K142 option's configuration menu for downlink signals (HE_MU).

Fig. 13: Compact MIMO system for creating eight TX or eight RX signals using an R&S[®]SMW200A vector signal generator and six R&S[®]SGT100A extension units, optionally with real-time fading simulation.



References

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