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802.11ax:
Not just another higher data rate

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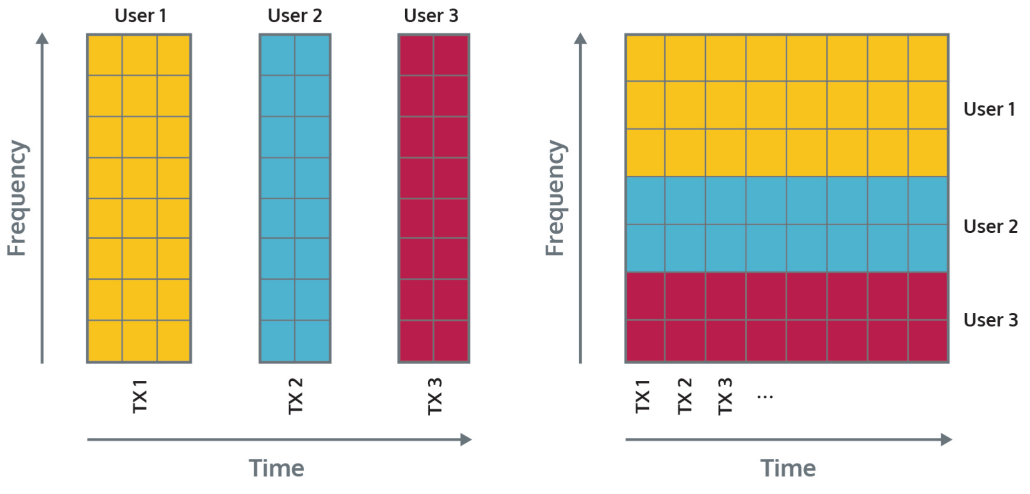
802.11ax, the next-generation WLAN standard, promises greater capacity and more robust data transmission than previous Wi-Fi standards. It represents the most fundamental change in Wi-Fi operation since 802.11n, which first emerged in products in 2004 with the promise of 100 Mbits/s data speeds. 802.11ax is first and foremost designed to tackle the problem of network capacity, which has become a larger issue in dense environments such as airports, sporting events, and campuses.

802.11ax borrows heavily from LTE, utilizing technology proven in cellular networks to increase system capacity by as much as ten times more users for the same spectrum. Thus, there are many new system aspects in 802.11ax requiring validation that have been unknown in the Wi-Fi community.

OFDM EVOLVES TO OFDMA

The biggest change with 802.11ax over earlier WLAN systems is the adoption of orthogonal frequency division multiple access (OFDMA). OFDMA systems allocate blocks of time and frequency—called resource units (RUs)—based on a central resource (the access point). In OFDM systems, the user occupies the entire channel. As more users are added, each user's requests for data competes for media access via carrier sense multiple access with collision detection (CSMA/CA). Too many users can create a bottleneck, resulting in poor quality of service (QoS) as these users request data, especially in high bandwidth applications such as streaming video.

Figure 1 compares OFDM to OFDMA spectrum usage. In OFDM, the users occupy all the subcarriers (RF spectrum) all the time for a given data request, whereas in OFDMA the users occupy only a subset of subcarriers for a prescribed amount of time. OFDMA requires that all users transmit at the same time, so each user is required to buffer its packets to a defined number of bits so that all users stay aligned in time regardless of the amount of data to transmit. Additionally, an OFDMA access point (AP) can dynamically change the amount of spectrum a user occupies based on how much bandwidth that user needs. For example, a streaming video user would need more subcarriers (spectrum) as opposed to an e-mail transmission that doesn't need real time performance.



ODFM (802.11ac)

ODFMA (802.11ax)

Figure 1. With ODFM, a user occupies an entire channel, but not in OFDMA.

The dynamic allocation of spectrum required to support OFDMA adds considerably Wi-Fi's spectrum complexity and stresses the radio hardware in ways not previously seen. Timing synchronization, frequency alignment, and response time characteristics matter. New test methods are needed to ensure the system performs correctly. Poor or mediocre response timing may not result in total system failure, but could lead to reduced system capacity impairing the key performance advancement in 802.11ax, and leading to poor product reviews.

POWER CONTROL

OFDM systems allocate an entire portion of spectrum (all subcarriers) for an amount of time for one user (left side of Fig.1). Subsequent users then get all the subcarriers for the next amount of time based on CSMA/CA. OFDMA systems share the spectrum with multiple users at the same time (right side of Fig. 1).

As a result, power control is needed to ensure that a user very close to the access point (AP) does not drown out another user farther from the AP. Widely different power levels between users at the AP will result in increased inter-carrier interference (ICI), receiver compression, leakage, and carrier frequency offset (CFO) due to timing misalignments between Wi-Fi user/station (STA) devices. In 802.11ax, the AP commands the STAs to adjust their power up or down based on the target received signal strength indicator (RSSI) at the AP side. The STA first estimates path loss by subtracting measured RSSI (at STA) from AP transmit power (encoded inside the packet). The STA then transmits a signal with power equal to the target RSSI plus estimated path loss. Devices closer to the AP transmit less power while devices farther away transmit more power to overcome the greater path loss. **Figure 2** illustrates the process.

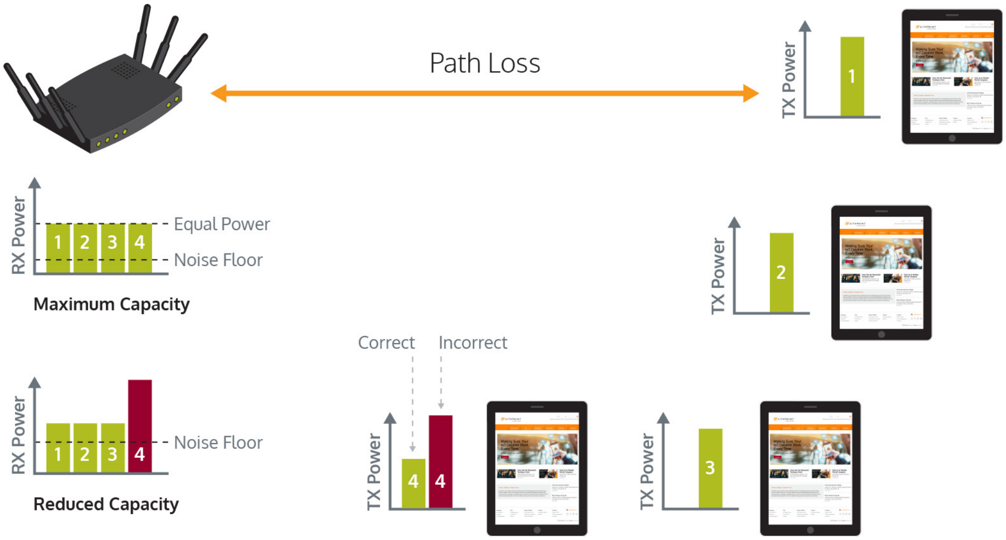


Figure 2. With multiple users sharing the same spectrum gives rise to a need for power control.

he 802.11ax standard defines device classes based on how accurately they control their power. Class "A" devices control their transmit power within ±3 dB while Class "B" devices control their power within ±9 dB. In earlier 802.11 systems (pre-802.11ax), STA devices simply transmitted their maximum designed/allowed power. Of course, a class A device will help improve system capacity and have a higher selling price, so manufacturers will have an incentive to ensure class A performance, which requires more stringent testing and calibration. The new requirements of dynamic power control in 802.11ax require testing to verify that the system operates correctly and capacity isn't degraded due to one STA improperly controlling its transmit power.

To test the power control functionality of a STA device, the test system needs to mimic an AP's real-time responses (**Figure 3**). In a power-control test, the device under test (DUT) will adjust its transmit power based on information encoded in the downlink signal from the tester (acting like an access point). The DUT (STA) will transmit the corresponding power back to the tester, where the tester measures the transmitted power from the DUT, and then sends back a corresponding command to increase or decrease the power. This entire process requires real-time behavior with latencies on the order of a few hundred microseconds. The diagram below shows how this process takes place.

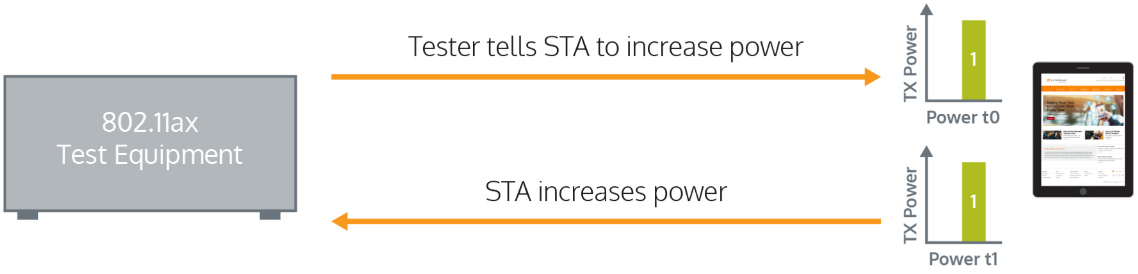


Figure 3. In a power-control test, an 802.11AX tester emulates an access point, adjusting the power of the DUT.

Dynamic power control can introduce settling time issues in an 802.11ax system. As the power changes, delays in power settling due to power amplifier response times or power control loops may become an issue. This behavior needs to be checked to ensure settling is fast enough and there are not undesirable overshoot conditions (**Figure 4**).

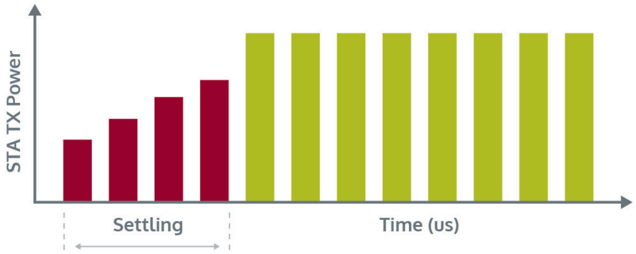


Figure 4: Power control settling response time is one of several measurements needed for testing 802.11ax STA devices.

To perform these tests, you need to measure power on a packet-by-packet basis and accurately report the power per packet as a function of time to validate proper response of the STA to power control commands. Because these measurements are made as part of the power control testing, no additional test time is incurred.

TIMING MATTERS

802.11ax users share the spectrum at the same time. Thus, interference between simultaneous users must be minimized to achieve the highest system capacity. Accurate timing across users is required to minimize interference and maximize system capacity.

The 802.11ax standard requires that all STA devices transmit within 400 ns of each other. The synchronization in the 802.11ax system is provided by the trigger frame sent by the AP. All the STA devices are synchronized to the AP, which acts as the “master” in an 802.11ax system. The trigger frame contains information sent by the AP about which stations can transmit during the specified time and which subsets of OFDMA sub-carriers resource units to use. A simple analogy for the trigger frame is to think of the coxswain on a rowing team controlling the direction of the boat and the pace of the crew.

In 802.11ax, this precise user-to-user timing is important because larger timing errors with residual CFO and sampling frequency offset (SFO) generate inter-carrier interference (ICI), and intersymbol interference (ISI), all of which reduce system capacity. Even in 802.11ac systems (OFDM), the frequency error was an important parameter to control. Because one user gets all the sub-carriers at a moment in time, there is only one user’s frequency error that matters. When multiple STA devices transmit at once, the frequency error of each user matters. **Figure 5** illustrates how CFO and timing errors in the time domain lead to interference in the frequency domain, and degrade the receiver’s ability to correctly decode the information.

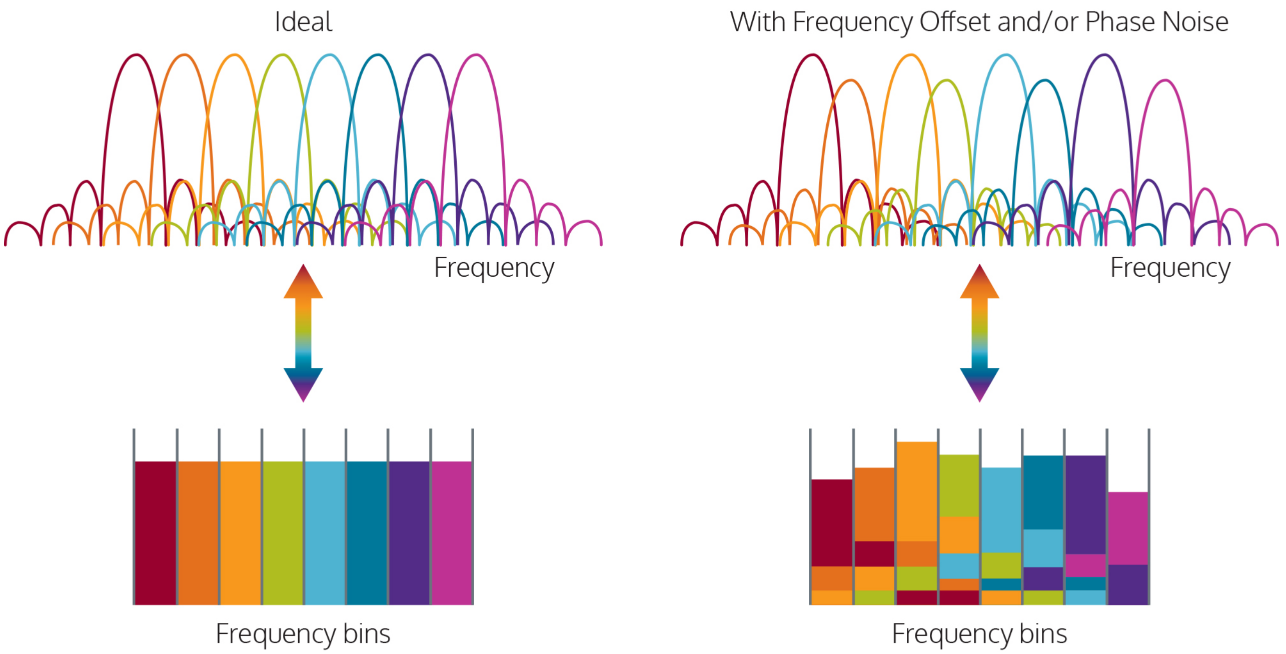


Figure 5. Timing offsets produce the frequency degradation shown in the spectrum plots on the right.

Testing this key behavior requires that the tester can act like an access point and generate the trigger frames to the STA devices while measuring the time from the sending of the trigger packet to the reception of the DUT (STA) packet within tens of nanoseconds. **Figure 6** illustrates just such a test sequence.

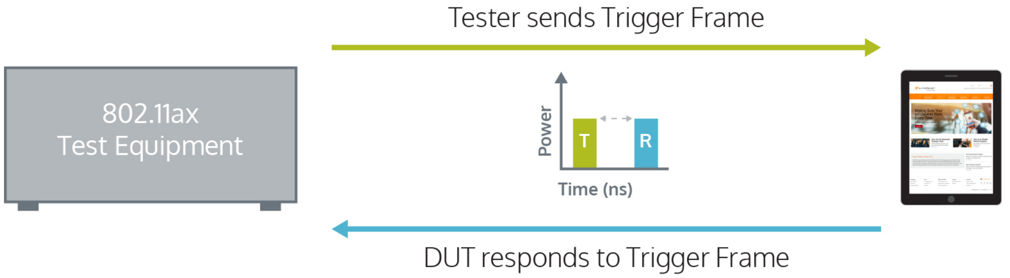


Figure 6. an 802.11ax timing test requires that the DUT properly respond to a trigger frame.

In this test, you need to send the trigger frame with encoded information. The DUT then receives the trigger frame, decodes the information, and responds with a packet. You must then measure the time from when the trigger frame packet left the tester to when the DUT packet was received. This time needs to be the short interframe space (SIFS) time ±400 ns (16,000 ns ±400 ns).

CFO is another parameter that you must validate in 802.11ax systems. The CFO is the remaining frequency error in the station device after it has synchronized to the trigger packet from the AP. An increase in CFO leads to more ICI in the 802.11ax system and data decoding errors increase. The 802.11ax standard requires that CFO be less than 350 Hz.

Measurement of CFO uses the same process as the timing-error test. You must send a trigger-frame packet, which the DUT (STA) decodes. The DUT aligns its clock to the information within the trigger frame and responds with a packet to the tester. You'll then need to decode this information and calculate the residual CFO.

CONCLUSION

802.11ax utilizing OFDMA employs several characteristics to dramatically increase system capacity over past Wi-Fi systems. The addition of timing synchronization, central coordination of users with the AP, and power control adds complexity never-before seen in Wi-Fi systems. Thus, new tests are required to ensure these systems will operate as expected.

Many of these parameters could fail in a way that would only be visible as part of a larger, multi-user system, as opposed to a hard failure of any one device. Depending on the final behavior of a system, these offending devices may be assigned to a low-quality selection of subcarriers, refused connections, or dropped from the network entirely due to their poor performance. You could imagine a cell phone being dropped from the network if it begins to harm network performance.

By employing test approaches described in this article, makers of 802.11ax systems can ensure they will have products that work seamlessly on 802.11ax networks and deliver the highest performance while maximizing network capacity.

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