Verify WLAN RF Performance

Uncover issues with the Keysight E7515W UXM wireless connectivity test platform

KEYSIGHT

Test WLAN Designs with Confidence

For Wi-Fi® design, both access point (AP) and client, the correct test approach is to focus on the radio frequency (RF) level first and work up the protocol stack. Issues with RF performance affect all testing at the higher layers, so it is vital to understand the particularities of that operation before determining whether high-level tests are consistent. RF testing enables isolation of the RF layer transmit (Tx) and receive (Rx) operation.

Testing RF performance with signaling emulates how a device under test (DUT) behaves in the real world. A focus on Tx and Rx performance is vital to ensure expected end-user behavior.

Keysight has solutions for analyzing Wi-Fi Tx and Rx operation with signaling:

- A platform and software solutions dedicated to Wi-Fi RF testing with signaling.
- Full coverage of Institute of Electrical and Electronics Engineers (IEEE) Wi-Fi technology, including 802.11be (Wi-Fi 7).
- Measurement of rate versus range (RvR), throughput, transmitted power, spectral quality, modulation quality, and receiver sensitivity.
- An easy-to-use automation tool based on IEEE measurement definitions.

Figure 1 shows the Keysight E7515W UXM wireless connectivity test platform using the Keysight S8714A UXM 5G RF application.

Figure 1. Keysight E7515W UXM wireless connectivity test platform using the Keysight S8714A RF application for Wi-Fi RF analysis

Analyze Transmitter RF Performance

Understanding the transmissions of an AP or client is essential to Wi-Fi design. Good RF performance during transmission minimizes errors when decoding the received signal. Building on good RF transmit performance is the RvR test, which measures the correct operation and efficiency of the rate adaptation algorithm.

Several measurements are useful for analyzing transmitter RF performance. Power level and flatness over time, spectral quality, and modulation quality are typical. Characterizing transmitter performance overall power levels and frequency bands is necessary and often requires repetitive testing, best implemented with automation.

Transmitter power measurements

Transmitted power is a key specification for wireless devices. Defining limits on the maximum transmitted power and the power envelope of a transmitted signal minimizes interference with other transmissions — for example, in a shared frequency band.

The transmit spectrum mask measurement helps characterize the shape of the power in each transmitted signal. Limits placed at several parts of the signal define the required envelope. AP or clients that transmit outside the mask may cause interference, so finding and resolving transmission issues is essential.

To characterize transmitted power performance, the engineer configures the AP or client to transmit at the desired power. This level depends upon the type of testing and troubleshooting required. A common configuration has the DUT transmitting at maximum or minimum power at the peak of the burst, as these levels often stress the DUT's performance and identify potential issues.

The DUT connects directly to the test equipment in-cable to minimize loss and error during the measurement. Over-the-air (OTA) transmissions introduce complicating RF channel characteristics.

Stability during burst or frequency transitions can cause the peak of the mask to slope or have an initial narrow burst of power after the switch from off to on. Another typical failure occurs when a narrow burst of power happens during the off period, possibly caused by poor grounding that leads to leakage during device transmission or by images created during frequency conversion.

Figure 2 shows an example of transmit spectrum mask results. The mask and limits, outlined on the graph, appear in the table. This Wi-Fi 6E client transmits within the mask and passes the test.

Figure 2. Example of spectrum emission mask measurement results for a Wi-Fi 6E client

Transmitter modulation quality measurements

Modulation quality is another essential measure of transmitter performance. Ensuring precise transmission with different orders of modulation minimizes errors during signal reception. Correctly decoding a Wi-Fi signal at the receiver is difficult when modulation quality is poor.

Several measurements characterize modulation quality. Error vector magnitude and its constellation diagram are especially important with Wi-Fi 6 using up to 1024 QAM and Wi-Fi 7 using up to 4,096 QAM. A constellation diagram with imprecisely located signals makes decoding the transmitted signal at the receiver difficult. The cause may be noise floor or phase noise issues with the design. Frequency conversions in the design may cause excessive errors in the center or symbol clock frequency.

Figure 3 shows an example constellation diagram and important results from a transmitter modulation quality measurement.

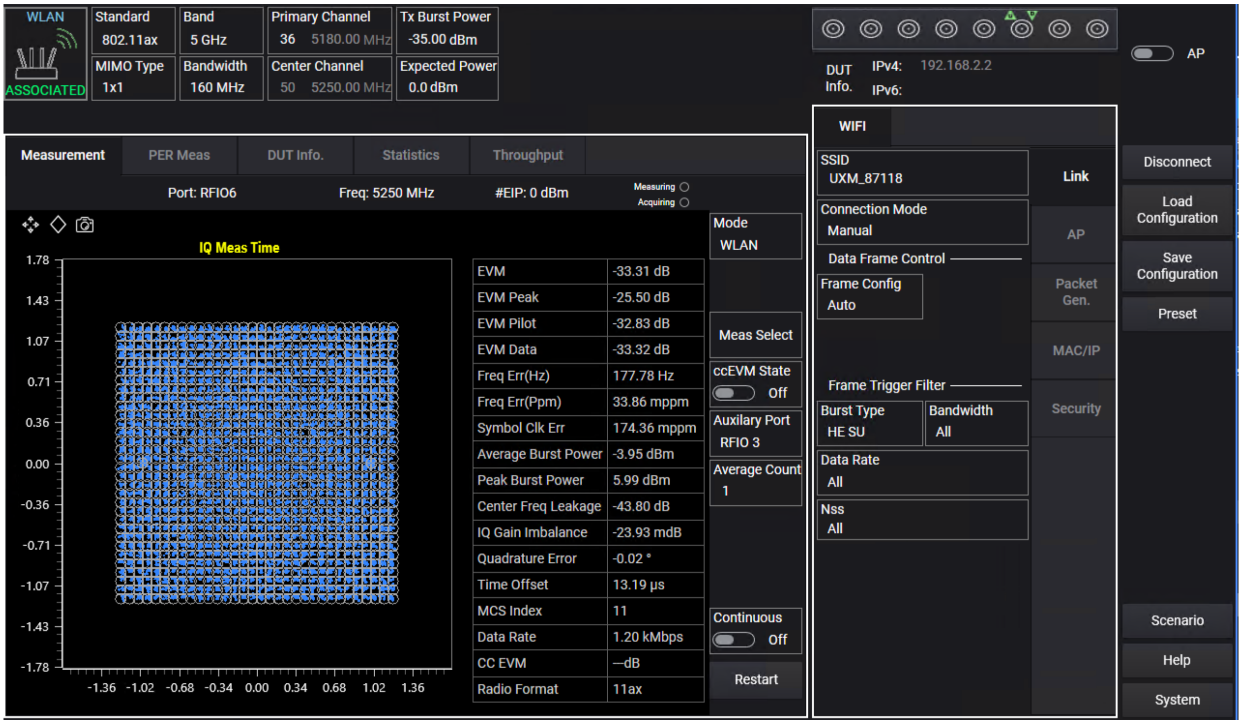

Figure 3. Example transmitter modulation quality results from a client using 1024 QAM

Transmitter spectral quality measurements

Characterizing a Wi-Fi design's performance over frequency is essential to ensuring efficient operation and minimizing interference. Wi-Fi designs typically use the spectral flatness measurement, although occupied bandwidth (OBW) results are sometimes useful.

Poor spectral performance causes signal leakage that could interfere with other transmissions. Inefficient spectral behavior, with transmissions outside expected frequencies, can also cause issues with the burst timing and envelope of a Wi-Fi design.

Typical failures are spurs, images, or harmonics caused by poor grounding, poor noise suppression, or errors during frequency conversion in the design.

Figures 4 and 5 show examples of spectral flatness and OBW results for a Wi-Fi client.

Figure 4. Example 802.11ax spectral flatness results

Figure 5. Example Wi-Fi 7 OBW results

RvR measurement for an AP

RvR is a test of a DUT — a Wi-Fi client or AP — run in a lab environment that shows rate (transmitted data User Datagram Protocol throughput) versus range (over distance). This testing occurs with the DUT connected to a reference client or AP through a variable attenuator. For each increasing decibel (dB) step of the attenuator (increasing path loss), traffic runs from the DUT to the reference device, and the rate gets recorded. Path loss in decibels is preferred rather than distance (m) because the relationship between path loss and range is complex in practice and dictated by a variety of environmental factors.

RvR, often misunderstood as a test of Tx RF quality, best serves to isolate and allow assessment of transmit rate adaptation. As the simulated distance increases, the device will have to reduce the rate to adapt the modulation coding scheme (MCS), allowing data transmission with higher path loss / lower signal-to-noise ratio at the reference device receiver. This rate adaptation could be suboptimal, with MCS rates being too low or too high or showing excessive MCS switching. Each distance will have an optimal MCS choice of transmission. In practice, rate adaptation inefficiency will cause lower throughput, higher latencies, and degradation of application quality of experience.

Keysight has a unique RvR test mechanism that provides objective Tx rate adaptation in one test. This occurs without a variable attenuator. Keysight simulates increasing attenuation by increasing the packet error rate (PER) and not returning acknowledgment signals (ACKs), matching a preprogrammed table. As the PER increases, the DUT will adapt to altering its throughput. This process is graphed for that decibel point, and then the next step is taken.

The strength of this approach is that engineers can compare the RvR results against the optimal theoretical data throughput achievable under the Wi-Fi configuration in the preprogrammed table. This is an upper limit. For example, in 802.11ax 4x4 MIMO 80 MHz (996-tone) MCS 11, 0.8 us GI with 100% ACK rate, the maximum theoretical PHY rate from the specification is 2401.9 Mbps. However, what is of interest is the maximum achievable data rate. This rate is lower than the specification provided PHY rate because of uncounted packet headers that may vary in size, short interframe spacing / distributed interframe spacing intervals, ACK transmissions, suboptimal a single MAC protocol data unit / an aggregated MAC protocol data unit settings, and other factors. Keysight is unique in providing this objective information, with calculations performed at each step for each MCS as the ACK rate decreases.

The Keysight RvR test provides an objective assessment of the isolated DUT Tx rate adaptation operation. It enables debugging of DUT problems (for example, hysteresis and rate adaptation logic) through unexpected spikes or dips in the rate adaptation results.

Characterize Receiver Performance

Understanding how well the receiver of a Wi-Fi AP or client decodes a signal is essential to Wi-Fi design. To receive the correct information, capturing and decoding the signals accurately is crucial.

Several measurements are useful for analyzing receiver performance. Sensitivity of the receiver to varying power levels, signal throughput with maximum received power, received PER, and RvR are typical. Characterizing receiver performance over all power levels and frequency bands is necessary and often requires repetitive testing, best implemented with automation.

Receiver PER measurements

Analyzing the accuracy of the packets received is another measure of a receiver’s performance. The PER measurement provides a ratio of correctly received packets to all received packets.

Errors in reception and signal decoding lead to incorrect information provided to the end user and possible connection failure. Poor PER performance may result from poor Rx sensitivity or decoding errors.

Receiver sensitivity measurements

Characterizing the ability of a receiver to correctly detect and decode a signal transmitted at all power levels and MCS rates is vital to understanding the receiver's performance. Rx sensitivity measures this and determines at which power level a receiver can no longer detect the signal.

Reception and signal decoding flaws lead to frame errors, causing retransmission, reduced throughput, and possible connection failure.

To measure Rx sensitivity, the network emulator transmits Wi-Fi signals starting at the maximum power level and continuing until the receiver can no longer detect the signal. Usually, graphing the results is the best way to show where the receiver's sensitivity begins to worsen. These results come from automation of the PER versus power results across all MCS rates and system configurations. See Figure 6.

Poor dynamic range or noise floor in the Wi-Fi design may cause poor Rx sensitivity.

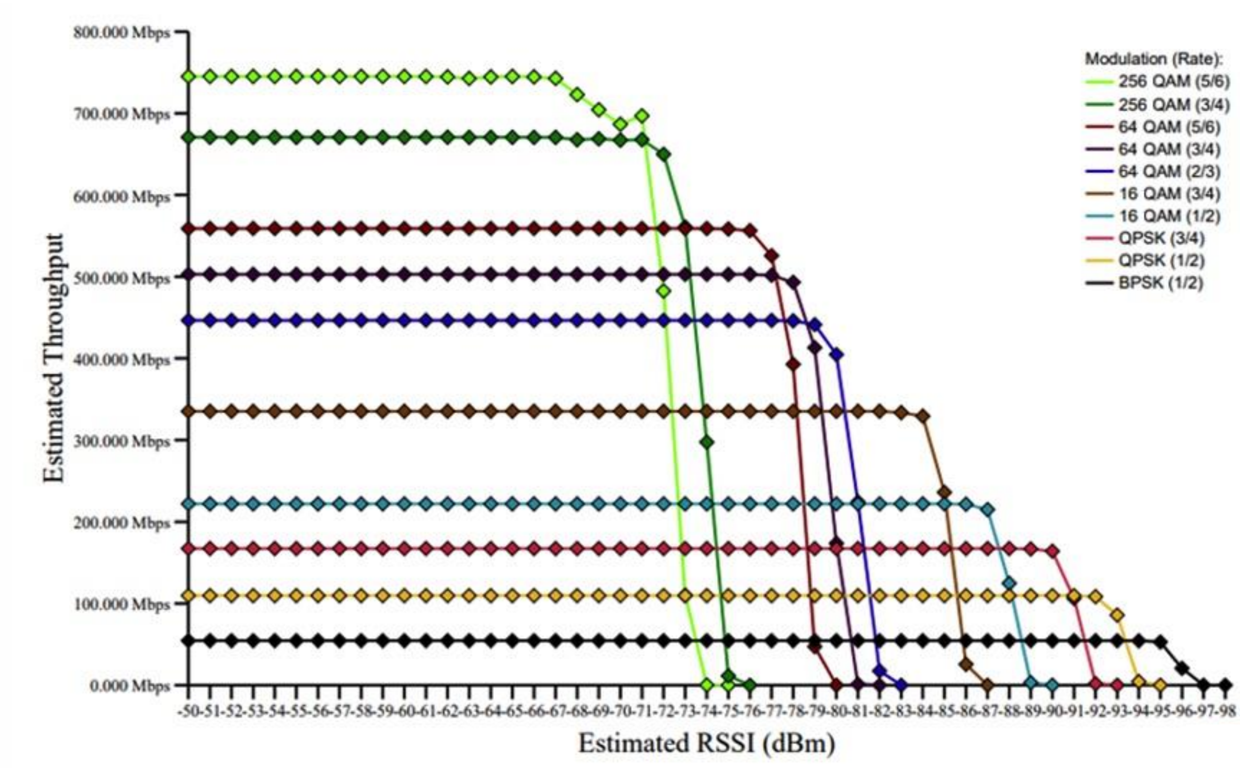

Figure 6. Graphed receiver sensitivity overall modulations versus throughput

Characterize receiver performance with automation

Automated receiver testing is quick and easy with the Keysight E7515W UXM wireless connectivity platform, S8714A RF application, and S8703A functional key performance index (KPI) toolset. Users can evaluate Rx sensitivity, RvR, and data throughput and troubleshoot issues early in the design workflow.

Figure 7 lists the functional KPI WLAN performance test cases.

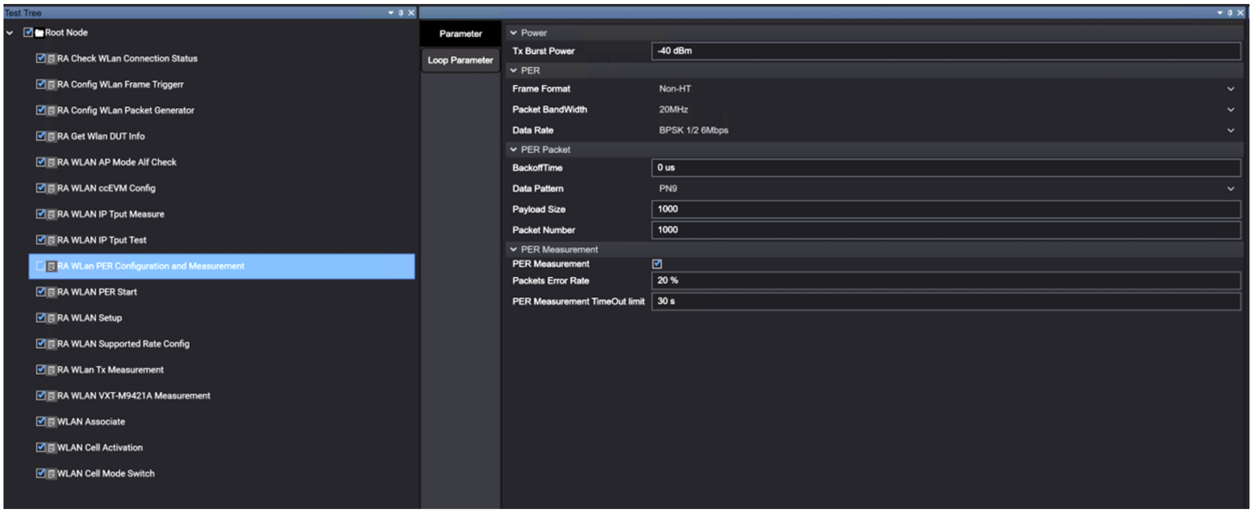

Figure 7. Receiver test cases and example PER result using functional KPI toolset

Evaluate Throughput Performance

Throughput is a measure of how much information a system can transmit and receive. It is an essential specification for all types of wireless devices and is frequently used to promote network performance.

Poor throughput leads to dissatisfied end users and, eventually, connection failures. Poor Rx sensitivity, low transmitted power, and poor signal quality are some causes of low throughput.

Therefore, it is important to characterize throughput overall power levels, frequencies, and modulation types to ensure optimal performance. Automated testing is the most efficient method to cover these test scenarios and identify the corner cases where designs are most likely to fail, such as at band edges or low power levels.

Throughput measurement typically occurs at the receiver by transmitting signals with a network emulator. As the signal transmits, a graph shows throughput over time. The signal characteristics are varied while observing the throughput results. Once both downlink and uplink throughput meet requirements, engineers can test bidirectional throughput using uplink and downlink at the same time. This process can expose MAC scheduling issues that occur when one side is dominant.

Figure 8 shows an example of throughput results.

Figure 8. Example throughput graph for IEEE 802.11ax

Verify Performance of WLAN Designs to IEEE Standards

IEEE defines tests for Wi-Fi designs. The test cases are similar to those described previously and cover the full range of Wi-Fi technologies. Keysight solutions using the E7515W UXM wireless connectivity platform, the S8714A RF application, and the S8702A RF automation toolset make it easy to automate RF test cases based on IEEE definitions and provide flexibility for more in-depth testing.

Table 1. Solution test coverage

Test case	Description
IEEE 802.11a measurements	
17.3.9.2	Transmit power levels
17.3.9.3	Transmit spectrum mask
17.3.9.5	Transmit center frequency tolerance
17.3.9.6	Symbol clock frequency tolerance
17.3.9.7.2	Transmitter center frequency leakage
17.3.9.7.3	Transmitter spectral flatness
17.3.9.7.4	Transmitter constellation error
17.3.10.2	Receiver maximum input sensitivity
17.3.10.5	Receiver maximum input level
IEEE 802.11b measurements	
15.4.5.2	Transmit power levels
15.4.5.5	Transmit spectrum mask
15.4.5.6	Transmit center frequency tolerance
15.4.5.7	Chip clock frequency tolerance
15.4.5.10	Transmit modulation accuracy
15.4.6.2	Receiver maximum input sensitivity
15.4.6.3	Receiver maximum input level
IEEE 802.11g measurements	
18.4.7.2	Transmit power levels
18.4.7.3	Transmit spectrum mask
18.4.7.4	Transmit center frequency tolerance
18.4.7.5	Symbol clock frequency tolerance
17.3.9.7.2	Transmitter center frequency leakage
17.3.9.7.4	Transmitter constellation error
18.4.8.2	Receiver maximum input sensitivity
17.3.10.5	Receiver maximum input level

IEEE 802.11n measurements	
19.3.18.1	Transmit spectrum mask
19.3.18.2	Spectral flatness
19.3.18.3	Transmit power
19.3.18.4	Transmit center frequency leakage
19.3.18.6	Symbol clock frequency tolerance
19.3.18.7.2	Transmitter spectral flatness
19.3.18.7.3	Transmitter constellation error
19.3.19.1	Receiver maximum input sensitivity
19.3.19.4	Receiver maximum input level
IEEE 802.11ac measurements	
21.3.17.1	Transmit spectrum mask
21.3.17.2	Spectral flatness
21.3.17.3	Transmit center frequency and symbol clock frequency tolerance
21.3.17.4.2	Transmit center frequency leakage
21.3.17.4.3	Transmitter constellation error
21.3.18.1	Receiver maximum input sensitivity
21.3.18.4	Receiver maximum input level
IEEE 802.11ax measurements	
27.3.19.1	Transmit spectrum mask
27.3.19.2	Spectral flatness
27.3.19.3	Transmit center frequency and symbol clock frequency tolerance
27.3.19.4.2	Transmit center frequency leakage
27.3.19.4.3	Transmitter constellation error
27.3.20.2	Receiver maximum input sensitivity
27.3.20.5	Receiver maximum input level
General-purpose measurements	
AP and client	Receiver minimum input sensitivity search
AP and client	Throughput
AP	RvR

Figure 9 shows an example of automated results for a Wi-Fi design.

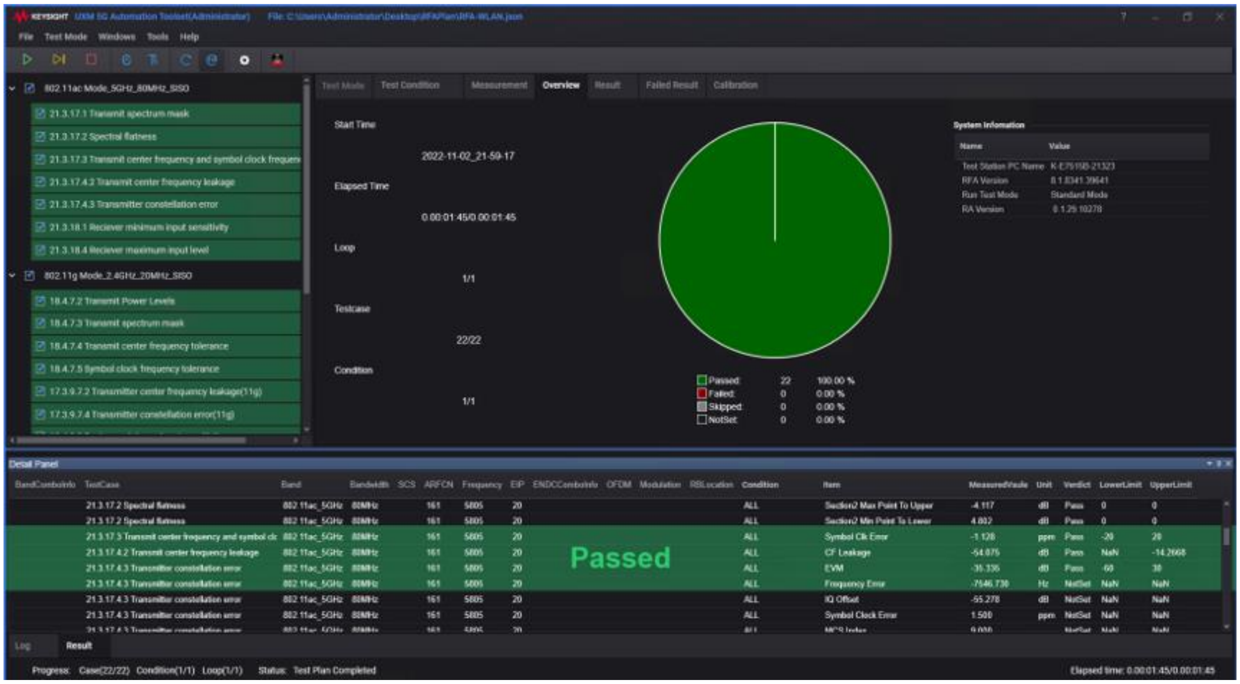

Figure 9. Example results with S8702A RFA

Lab environment

All testing described above must occur using cable in a controlled lab environment. Performing this test OTA outside of a lab is not feasible because of varying channel conditions and measurement imprecision, leading to gross unexpected outcomes that could well result from environmental factors.

Having a lab environment that produces controlled, automated, repeatable results is key. The lab needs an RF chamber to shield the DUT from unwanted RF interference. Testing should establish a baseline result to compare with future results. For example, assess DUT Tx RF quality first before moving on to RvR.

Ensure the RF Performance of WLAN Designs

The Keysight solution enables you to test the performance of Wi-Fi AP and clients with confidence. With the E7515W UXM 5G, S8714A RA, S8702A RFA, and S8703A functional KPI, optimizing performance is simple. Our solutions provide the following:

- A platform and software dedicated to WLAN testing with signaling.
- Full coverage of IEEE 802.11a through 802.11be.
- Throughput and RvR measurements.
- Easy-to-use automation based on IEEE definitions.

A simple software upgrade provides Wi-Fi 6E, 6, and previous technology performance testing when using existing E7515B UXM 5G hardware.

Verify Performance Across the Workflow

Keysight solutions for WLAN provide comprehensive testing during all phases of the design workflow to accelerate time to market and reduce failures seen by end users.

For more information, visit these Keysight websites:

- WLAN Testing
- E7515W UXM Wireless Connectivity Test Platform
- S8702A RF Automation Toolset
- S8703A Functional KPI Toolset
- S8714A RF Application
- Everything You Need to Know About Wi-Fi 7

KEYSIGHT