WHITE PAPER

Everything You Need to Know About Wi-Fi® 7

Wi-Fi 7 RF, and data throughput testing

KEYSIGHT

Introduction

Consumer demand for wireless data access and throughput has grown steadily since wireless local area networks (WLAN) first became popular with the adoption of the Institute of Electrical and Electronics Engineers (IEEE) 802.11 standard in 1997. Today, users expect widespread availability of high-speed WLAN to support data-intensive applications. WLAN-enabled devices sharing a network have also significantly increased as PCs, smartphones, tablets, cameras, TVs, and smart home devices increase at home.

Over the years, updates to the 802.11 standards have improved the maximum data rates for WLAN. The IEEE 802.11ax standard or High-Efficiency (HE) specification provided greater spectral efficiency, capacity, and coverage in dense deployment scenarios and outdoor environments. The 802.11ax aimed to improve the average throughput per station by at least 4x compared to 802.11ac. Most recently, the IEEE has been defining the Wi-Fi® standard for Wi-Fi 7, also known as IEEE 802.11be or Extremely High Throughput (EHT). This latest Wi-Fi generation will use spectrum resources working across all three bands (2.4 GHz, 5 GHz, and 6 GHz). While the goal of Wi-Fi 6 was to respond to the growing number of devices, Wi-Fi 7 aims to deliver astounding speeds for every device with greater efficiency.

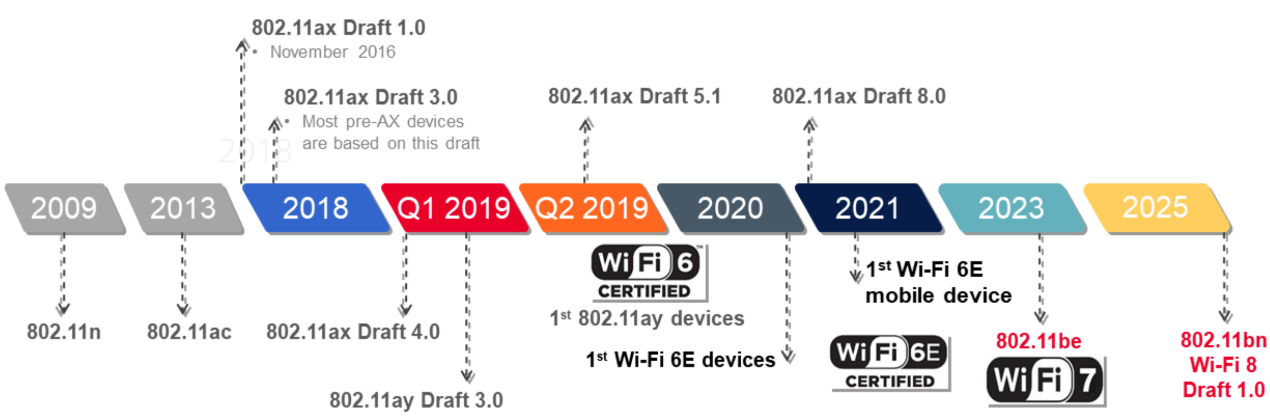

Figure 1. Wi-Fi technology evolution based on IEEE 802.11

While technical specifications are in progress, the new standard could provide nominal peak data rates of more than 40 Gbps, four times faster than Wi-Fi 6 and Wi-Fi 6E. In addition, the standard will employ new technologies to reduce latency, increase network capacity, and boost efficiency.

Wi-Fi 7 introduces 320 MHz ultra-wide bandwidth, 4096-quadrature amplitude modulation (QAM), multiple resource units (Multi-RUs), and multi-link operation (MLO) to provide faster speeds than Wi-Fi 6 and unlock more scenarios for a higher throughput generation. Wi-Fi 7 aims to continuously improve spectrum utilization, throughput, and user experience while ensuring the compatibility and coexistence of new WLAN devices with legacy IEEE 802.11 devices operating in the same band.

Key Features of Wi-Fi 7 (802.11be)

Updates to the 802.11 standard continue improving the maximum data rates for WLAN. For example, 802.11a/g increased the speed from the original 11 Mbps of 802.11b to 54 Mbps, while 802.11n (High Throughput or HT specification) increased the rate of one stream to 150 Mbps. Also, 802.11n introduced multiple-input, multiple-output (MIMO) antennas to transmit up to four streams for 600 Mbps maximum data throughput.

The 802.11ac standard (Very High Throughput or VHT specification) increased the data rate for one stream to 866.7 Mbps and allowed up to eight streams for a theoretical maximum data rate of 6.93 Gbps. However, the reality is that in exceptionally crowded environments, users commonly experience far slower data rates. The 802.11ax standard (High Efficiency or HE specification) provided better spectral efficiency, capacity, and coverage in dense deployment scenarios and outdoor environments. It aimed to improve the average throughput per station by at least 4x compared to 802.11ac.

The IEEE 802.11be standard, or Wi-Fi 7, builds on the foundation laid by its predecessor, Wi-Fi 6 / 6E, to deliver even faster and more reliable connectivity. With Wi-Fi 7, users can expect enhanced performance, increased capacity, and reduced latency. The groundbreaking technology that enables Wi-Fi 7 provides a seamless experience for various applications, from basic browsing to bandwidth-intensive activities such as virtual reality gaming and 8K video streaming.

The new capacity Wi-Fi 7 delivers introduces new capabilities, features, and technologies. The following table compares the critical physical layer (PHY) technologies of IEEE 802.11ax (Wi-Fi 6 / 6E) with those of IEEE 802.11be (Wi-Fi7).

Table 1. The key technologies of Wi-Fi 6 / 6E in comparison with Wi-Fi 7

Parameter	**Wi-Fi 6 / 6E (IEEE 802.11ax)**	**Wi-Fi 7 (IEEE 802.11be)**
Frequency band / channel BW	• 2.4 GHz / 20, 40 MHz • 5 GHz / 20, 40, 80, 160 MHz • 6 GHz / 80, 160 MHz	• 2.4 GHz / 20, 40 MHz • 5 GHz / 20, 40, 80, 160MHz • 6 GHz / 80, 160, 320 MHz • 7.125 GHz / 80, 160, 320 MHz
Modulation	Orthogonal frequency-division multiple access (OFDMA)	OFDMA with enhancements
Highest modulation order	1024 QAM	4096 QAM
Max data rate	~9.6 Gbps	~46.1 Gbps
MU-MIMO	Downlink MU-MIMO	Uplink / downlink MU-MIMO
Spatial streams	Up to 8	Up to 16
Enhanced OFDMA		Preamble puncturing, Multi-RUs
Multi-Link Operation (MLO)		Yes
Key features	• Greater scalability • Reduced interference • Improved security • Faster performance • Lower latency	• Improved user-experienced data rate • Extremely High Throughput (EHT) • Improved spectrum efficiency • Improved network energy efficiency • Better connection density • More cost-effective • Improved area capacity • Ultra-low latency
Applications	Indoor, outdoor, and IoT	• 4K and 8K streaming • Virtual and augmented reality applications • Mission-critical and industrial applications • Data-hungry use cases

Wi-Fi 7's 320 MHz bandwidth enables more data transmission

Wi-Fi 7 provides faster data transfer speeds – higher throughput - than Wi-Fi 6 and supports the increasing demand for high-bandwidth applications. The 320 MHz channel bandwidth of Wi-Fi 7 in the 6 GHz band provides a wider channel to transmit more data.

With the wider channel, interference likely means that sections of the channel might be unusable. Wi-Fi 7 uses puncturing to partition the spectrum into usable portions. While channel puncturing existed in Wi-Fi 6 as an optional feature, it will likely become a standard feature with Wi-Fi 7. To further improve data throughput, the challenge for device makers is to consider interference and power consumption when designing and developing their products.

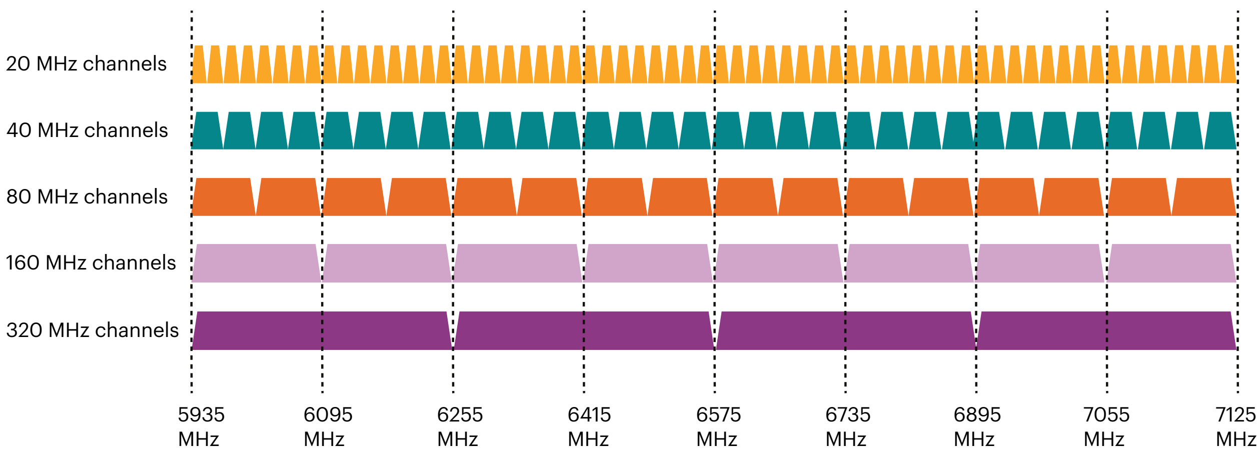

Figure 2. Channel allocations in the 6 GHz band

Achieve faster data throughput with higher-order modulation

QAM transmits data over radio waves using discrete points in the constellation diagram. Each discrete point represents a certain number of data bits: the more discrete points allowed, the more data can be transmitted. Wi-Fi 7 allows a maximum of 4096 QAM, also known as 4K QAM, with 12 data bits per symbol. With its higher data transmission rate, 4096 QAM is crucial for consistently serving many clients and ensuring fast and reliable Wi-Fi coverage in high-density deployment scenarios. The impact of channel noise is the main challenge with this high-order modulation. Therefore, 4096 QAM requires a high signal-to-noise ratio (SNR) to achieve high data throughput.

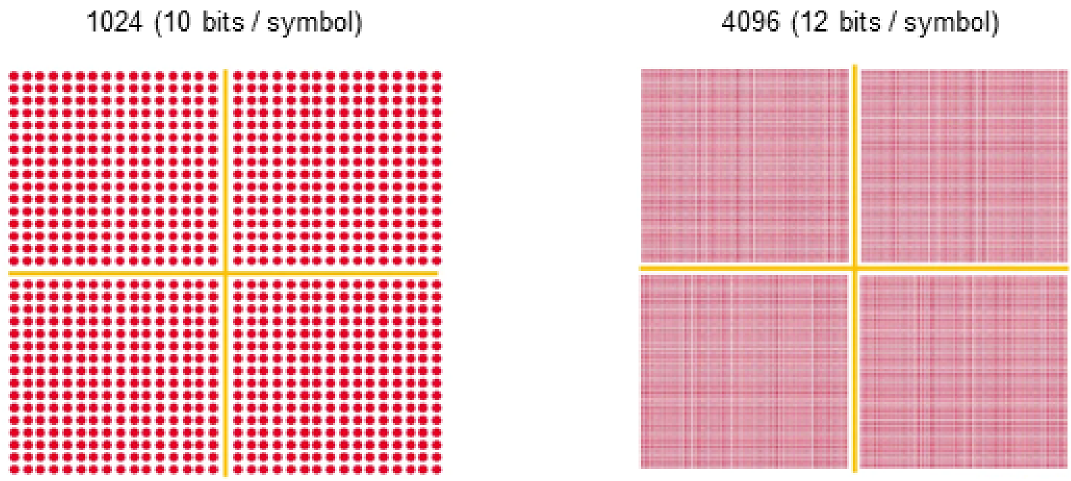

Figure 3. 1024 QAM compared with 4096 QAM

In Figure 3, with 4096 QAM, the constellation points are much closer together, so correct demodulation requires better error vector magnitude (EVM) performance in the transmitter and receiver. The IEEE standard requires < 38 dB EVM for 4096 QAM, compared to < 32 dB for 256 QAM. Device manufacturers frequently design for 5 to 10 dB performance better than the requirement and need an additional margin in the test equipment to verify this performance.

Gain greater spectral efficiency with multi-RUs

Previous Wi-Fi standards, such as Wi-Fi 6 (802.11ax), introduced multiple-user, multiple-input, multiple-output (MU-MIMO) with the ability to allocate multiple RUs to different devices concurrently, improving overall network efficiency by allowing multiple users to transmit and receive data simultaneously. Enhancing spectral efficiency and improving the operation of multiple devices in crowded environments are common goals for each new Wi-Fi standard. Orthogonal frequency-division multiple access (OFDMA) improves performance by allowing simultaneous transmissions between numerous clients. With Wi-Fi 6, a channel divides into RUs as frequency groupings. Each device is allocated one RU. Wi-Fi 7 allows the allocation of multiple RUs to each device, providing better efficiency by utilizing a spectrum that may otherwise be wasted.

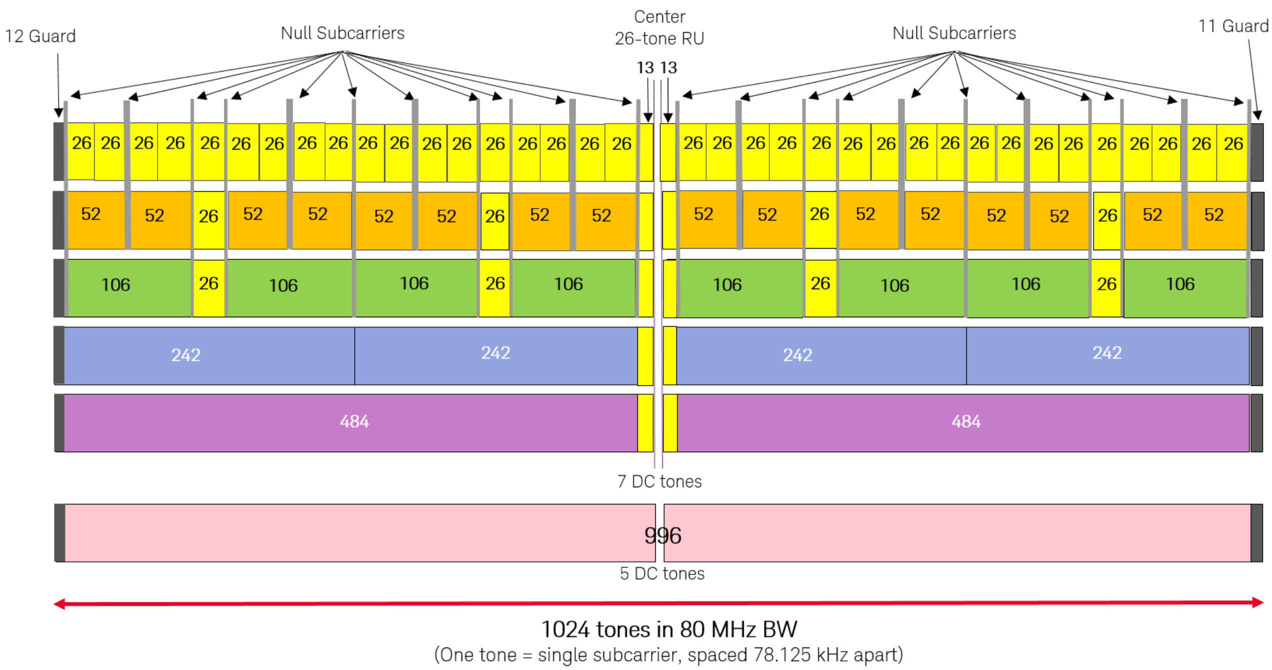

Figure 4. Location of RUs

The complexity of using multiple RUs with one device increases the importance of testing each device under conditions emulating real-world usage to verify parameters such as unused tone error, optimal transmit power levels and timing error.

MU-MIMO is another feature that provides enhanced performance in complex and crowded wireless environments such as sports arenas. Wi-Fi 6 allows eight spatial streams for simultaneous data transmission and reception between access points (APs) and client devices. With up to sixteen spatial streams allowed in Wi-Fi 7, device performance in the presence of interference (such as crowded environments with many devices) and network efficiency are greatly improved.

MLO provides increased link efficiency

Wi-Fi 7 will introduce multi-link operation (MLO) technology, which allows devices to send and receive data over multiple frequency bands simultaneously using a single aggregated connection. The aggregated connection can include signals from any of the three bands: 2.4 GHz, 5 GHz, and 6 GHz. The technology enables faster throughput performance, helps reduce latency, and permits data to flow unimpeded by network traffic or interference. Sending duplicated data on multiple links increases reliability, and assigning traffic to appropriate links enhances the quality of service (QoS). MLO enables intelligent load balancing mechanisms, where devices intelligently distribute their data traffic across multiple links to optimize network utilization.

As a result, users experience increased data rates and improved reliability, and devices can better balance the load in scenarios where multiple APs are available.

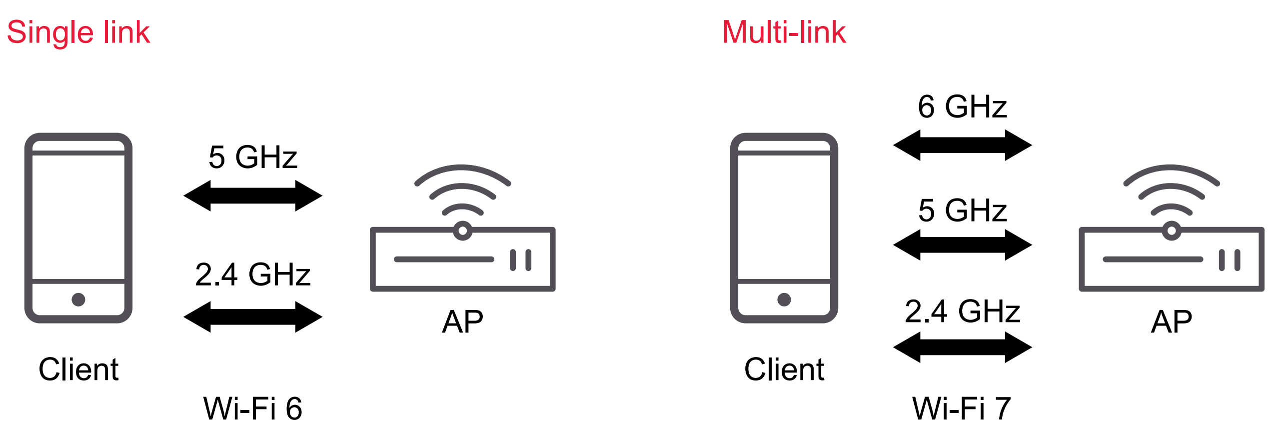

Figure 5. Wi-Fi 6 single-link operation compared with Wi-Fi 7 MLO

5 New Testing Challenges for Wi-Fi 7

Wi-Fi 7 enhancements bring new challenges for verifying designs across the workflow from device development to device acceptance and deployment. Test engineers must focus on a few categories of tests to ensure the performance of Wi-Fi 7 devices:

- **Compliance and regulatory testing:** Compatibility testing with existing Wi-Fi networks and devices, signal quality testing, and data transfer rates.
- **Coexistence testing:** Device connectivity, communication, and interaction with other IoT devices.
- **Security test:** Correct encryption for data protection and secure communication.
- **Energy efficiency:** Power consumption for devices connected to Wi-Fi 7 networks.
- **Reliability testing:** Link stability and reliability over time and different environmental conditions and use cases.

Engineers will require exhaustive and predictive testing to cover the many test cases the features of Wi-Fi 7 introduce. An ideal test solution validates the expected behavior of Wi-Fi 7 client, and AP designs operating with the latest capabilities under real-world conditions. It must:

- Evaluate interference when using wider 320 MHz bandwidth channels.
- Measure critical EVM and SNR performance with 4096QAM transmissions.
- Characterize modulation and timing accuracy with multiple RU allocated to one device.
- Verify full data throughput rates with MLO in all three bands, especially while using 4096 QAM.
- Test load balancing with MLO under real-world conditions.
- Ensure compatibility, mobility, and interworking with legacy Wi-Fi and cellular.
- Validate typical performance not new to Wi-Fi 7, such as power consumption, connectivity, security with encryption, link stability, and connection reliability.

Testing Wi-Fi 7 Designs

RF performance and data throughput testing are critical for Wi-Fi 7, considering the standard aims to improve speed, capacity, and efficiency over previous Wi-Fi generations. RF performance testing characterizes critical specifications such as EVM, SNR, receive (Rx) sensitivity and interference. While RF testing can be done without signaling, testing while using new Wi-Fi 7 signaling capabilities emulates behavior seen by the end user.

Data throughput testing assesses real-world data transfer capabilities under various conditions. Maximum data rates are often used to advertise new technologies, so optimizing and characterizing a design's data throughput is essential. Tests such as rate vs. range (RvR) provide more detailed analysis and help troubleshoot issues when measured data rates are lower than expected.

Wi-Fi 7 RF testing with signaling

As Wi-Fi technology evolves, RF signaling tests become even more critical to validate the advancements and improvements introduced in each new standard. RF signaling tests ensure the technology performs optimally in real-world environments and meets the growing demand for faster and more reliable wireless communication. RF testing also measures the performance of the design’s transmit (Tx) and Rx operation.

Testing RF performance with signaling involves emulating how a device under test (DUT) behaves in the real world. It includes testing per the IEEE standards or, more generally, analyzing transmitter and receiver RF performance.

Now, let’s look deeper at transmitter and receiver RF performance analysis.

Transmitter RF performance analysis

Minimizing errors during AP and client transmissions requires robust RF performance. Test engineers need several measurements to analyze that performance, including power level and flatness over time, spectral quality, and modulation quality. Automation is often necessary to ensure the repeatability and reliability of all power levels and frequency bands.

1. Power

Power transmission is one of the critical specifications for wireless devices. Limits on the maximum transmitted power and the power envelope of a transmitted signal must be defined to minimize interference with other transmissions.

Transmit spectrum mask measurements characterize the shape of the power in each transmitted signal and compare it to limits defining the required envelope. AP or clients that transmit outside the mask may cause interference, so finding and resolving transmission issues is essential.

The AP or client configuration must transmit at the desired power to characterize transmitted power performance. A standard configuration has the DUT transmitting at maximum or minimum power at the peak of the burst since these levels often stress the DUT performance and identify potential issues to resolve. The DUT connects directly to the test equipment to minimize loss and error during the measurement.

2. 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 a receiver is easier when modulation quality is better.

As Wi-Fi 7 uses 4096 QAM, EVM and its constellation diagram are crucial. Frequency errors at the center frequency of the transmitted signal and its symbol clock frequency must also be considered when analyzing the modulation quality of a transmitter. Other common modulation quality results for Wi-Fi are timing errors and unused tone errors.

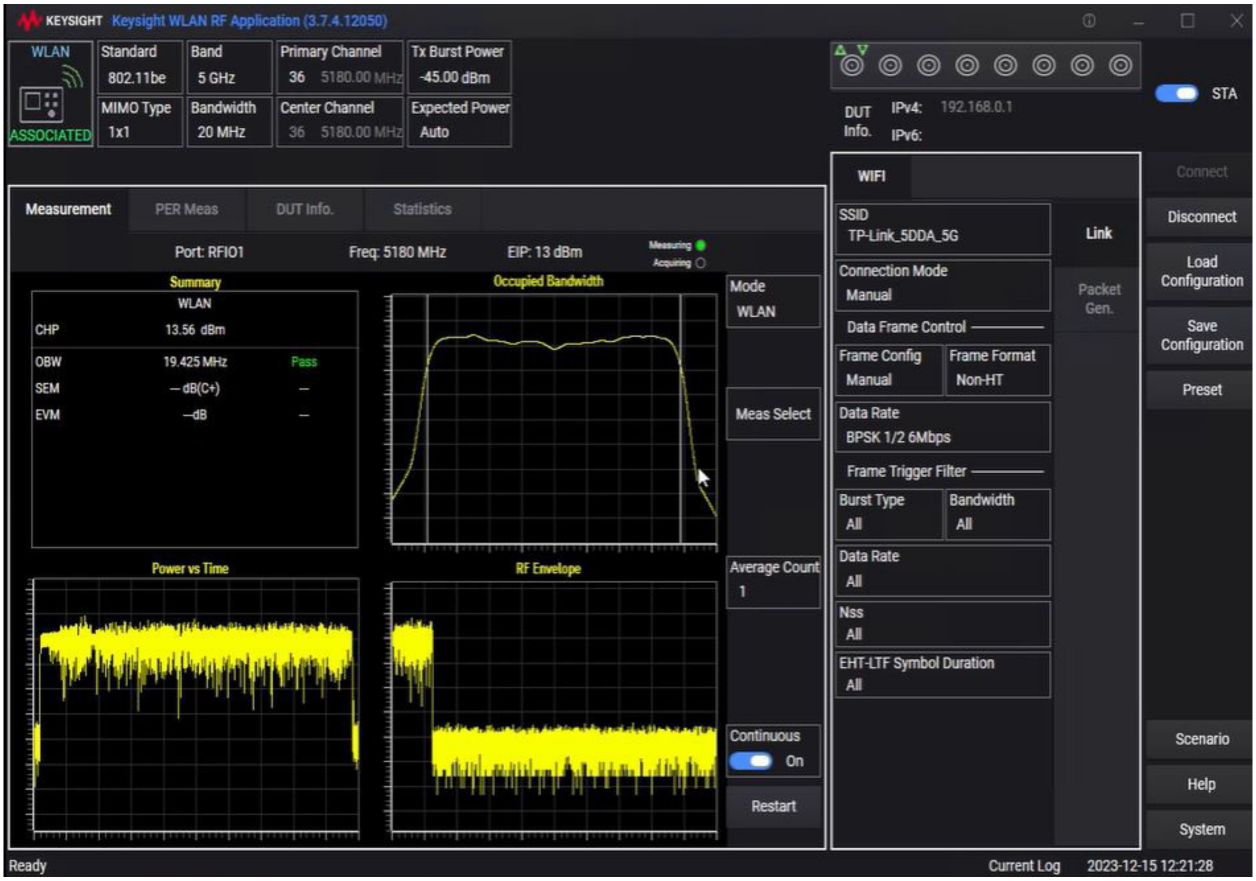

Figure 6. Example of Wi-Fi 7 (IEEE 802.11be) RF transmitter measurements with the E7515W UXM wireless connectivity test platform

3. Spectral quality measurements

Characterizing a Wi-Fi design's performance over frequency is essential to ensure efficient operation and minimize interference.

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

Receiver RF performance characterization

Understanding how well the receiver of a Wi-Fi AP or client decodes a signal is essential to Wi-Fi designs. Accurate signal capture and decoding ensure the reception of the correct information. To analyze the receiver performance, test engineers need to perform a selection of measurements. The most crucial ones are the receiver's sensitivity to varying power levels, signal throughput under various conditions, and received packet error rate (PER).

1. Receiver sensitivity measurements

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

Measuring Rx sensitivity requires a specific network emulator configuration to transmit Wi-Fi signals starting at its maximum power level and continuing to the power level where the receiver can no longer detect the signal.

2. Receiver PER measurements

Analyzing the accuracy of the packets received is another measure of a receiver's performance. The packet error ratio (PER) measurement provides a ratio of correctly received packets to all received packets.

Wi-Fi 7 throughput testing

Wi-Fi 7 data throughput testing is critical as it impacts the user experience and the effectiveness of a wireless network. Throughput represents the measure of information transmission and reception. It is also 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, poor signal quality, and many other reasons can cause low throughput. So, it is crucial to characterize throughput across all power levels, frequencies, and modulation types to ensure optimal performance. Automated testing is the most efficient method to cover all these test scenarios and identify the corner cases where designs are most likely to fail.

Throughput measurements typically happen at the receiver by transmitting signals with a network emulator. As the signal transmits, a graph shows throughput over time. The signal characteristics vary while observing the throughput results, as shown in Figure 7.

Figure 7. Wi-Fi throughput testing with the E7515W UXM wireless connectivity test platform

Testing Wi-Fi 7 throughput is fundamental for assessing its performance, optimizing network efficiency, and ensuring a positive user experience. Test engineers must use throughput testing as a critical metric to validate the capabilities of Wi-Fi 7 and make decisions during deployment and optimization.

Another useful and more detailed measurement using throughput is RvR. A rate versus range test measures the uplink and downlink throughput for varying ranges (distances) between the client device and router. As the distance between the router and the device increases, the magnitude (signal strength) of the uplink and downlink Wi-Fi signals are reduced. Testing RvR over varying conditions can pinpoint the cause of data throughput issues.

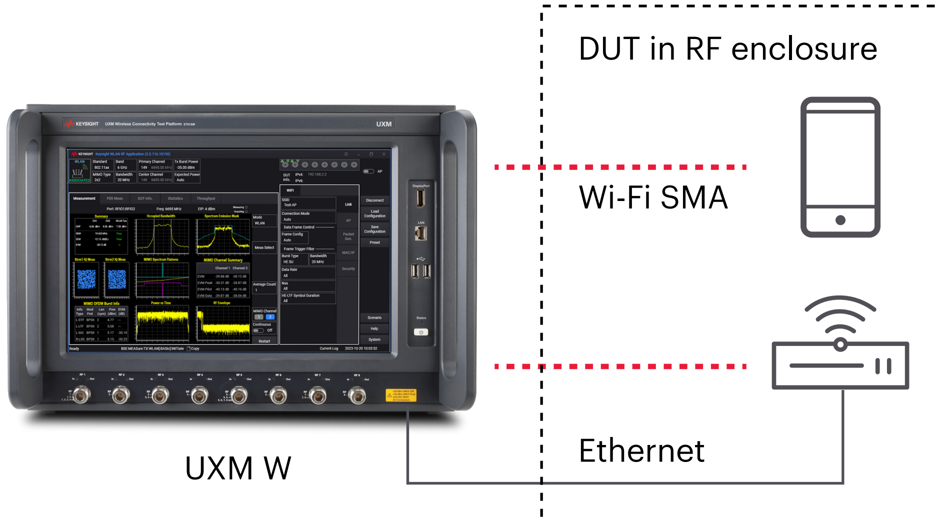

Figure 8. Configuration for Keysight RvR testing with the E7515W wireless connectivity test platform

Test Wi-Fi 7 Designs with Keysight's Solution

The new Keysight E7515W UXM Wireless Connectivity Test Platform extends Keysight's network emulation solutions portfolio to support extensive Wi-Fi testing. The system verifies the RF and functional performance of Wi-Fi clients (stations (STAs)) and APs and characterizes Wi-Fi to cellular interworking.

The standalone E7515W simplifies the testing by offering industry-leading capabilities with powerful automation, extensive yet easy-to-use configuration, and repeatable results. Wi-Fi and cellular software applications are embedded and controlled using the front panel graphical user interface (GUI) or standard commands for programmable instruments (SCPI). Simultaneous Wi-Fi client emulation and cellular backhaul simplify testing fixed-wireless access (FWA) devices such as CPE (customer-premises equipment). The E7515W is the only one-box solution available for testing FWA CPE with signaling.

Figure 9. The Keysight E7515W UXM wireless connectivity test platform

To meet the Wi-Fi 7 test challenges, the wireless test platform must:

- Emulate Wi-Fi 7 clients or APs with signaling to characterize connectivity, encryption of data, link stability, and link reliability over time.
- Perform extensive RF parametric tests, including interference, EVM, timing error, unused tone error, and enhanced Rx sensitivity while using wider 320 MHz bandwidth channels, 4096 QAM, and multiple Rus.
- Run unique rate vs. range and full data throughput tests to verify data rates with MLO in all three bands under varying conditions.
- Analyze behavior with OFDMA by sweeping through every possible RU allocation to validate designs under all defined configurations.
- Load hundreds of Wi-Fi clients on an AP to benchmark performance, load balancing, and quality of experience (QoE) with MLO using integrated VeriWave technology.
- Ensure Wi-Fi and cellular interworking by testing Wi-Fi offload and voice-over Wi-Fi calling, emulating cellular and Wi-Fi simultaneously.
- Run IEEE performance tests to ensure designs meet published specifications.

Conclusion

The IEEE 802.11be standard introduces several new features for improving WLAN efficiency, capacity, and coverage. Features such as MLO and multi-RUs increase the number of configurations and test scenarios to validate a device thoroughly. In addition to physical-layer testing, test engineers need to emulate signaling to verify interactions between APs and STAs and the performance of new features of Wi-Fi 7 under real-world conditions.

Keysight leads the market in testing WLAN designs across the product life cycle. Our solutions enable testing in device development, device acceptance, and deployment.

Rely on Keysight to provide the industry-leading performance, accuracy, and functionality required to validate the wireless networks of today and tomorrow.

Learn more

For more insights on how to accelerate Wi-Fi 7 testing, review the following content:

- Datasheet: E7515W UXM Wireless Connectivity Test Platform
- Webpage: E7515W UXM Wireless Connectivity Platform
- Webpage: WLAN Testing Solutions