The Wi-Fi® 6 Revolution is a Wakeup Call for Your Test Strategy

White Paper

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Abstract:

The IEEE 802.11ax amendment (Wi-Fi 6) focusses on greater efficiency in wireless connectivity. While the key attributes of this improved efficiency directly improve traditional Wi-Fi applications, (homes and small offices), the attributes will largely affect higher-density applications: large offices, shopping malls, apartment complexes, airports, indoor arenas, outdoor stadiums. This white paper offers several ideas of how to make Wi-Fi 6 a reality.

White Paper

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ROHDE&SCHWARZ

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1 Introduction

The purveyors of 5G are promising faster data rates, wider bandwidths, lower latencies, and more. This might prompt you to ask, “If we have 5G, why do we still need Wi-Fi?”

Cisco may have a slightly biased view, but they offer a useful perspective: today, Wi-Fi carries a majority of internet traffic, and this is likely to continue in the future (Fig.1). By the numbers, Wi-Fi carried an estimated 55% of that traffic in 2017 and one forecast predicts 57% in 2022. In contrast, the same projection puts 4G LTE and 5G at a combined 22% in 2022.

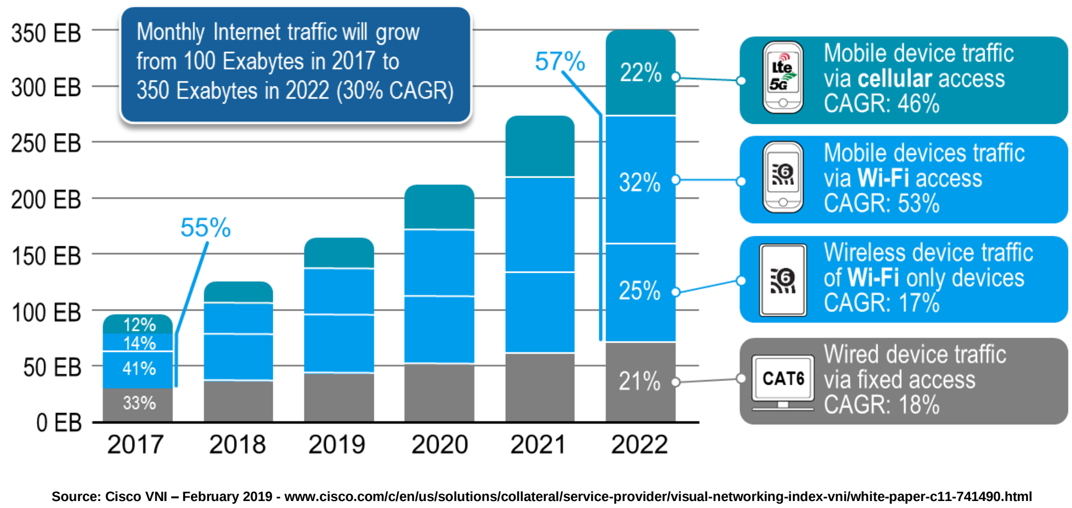


Figure 1: Wi-Fi will remain a vital conduit for internet traffic in the near future. [1]

Since the beginnings of Wi-Fi in the 1990s, demand for faster data rates and wider bandwidth has grown without pause. To stay relevant, the intention for Wi-Fi 6 is not evolution but rather revolution in the wireless space. Thus, with IEEE 802.11ax, higher data rates are part of the story, but the focus is on greater efficiency in wireless connectivity. Let us define “efficiency” as it relates to Wi-Fi 6: key attributes are average throughput per station, successful operation in dense environments, use of the 2.4 GHz and 5.0 GHz bands, and optimized power consumption in network stations.

While these enhanced efficiencies are useful in traditional Wi-Fi applications, namely homes and small offices, they become hugely important in higher-density applications: large offices, shopping malls, apartment complexes, airports, indoor arenas, outdoor stadiums. This also extends to the Internet of things (IoT) and a planet populated with billions of low-power devices.

1 Figure 22 from www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white-paper-c11-741490.html

How do we make Wi-Fi 6 a reality? This white paper offers several ideas organized into four parts. First, we look at the current strengths and limitations of Wi-Fi. In the second section, we examine the relevant dimensions of Wi-Fi technology. Third, we explore the best ways to gain greater efficiency with sixth-generation Wi-Fi. In the concluding section, we offer six good reasons to review and revise your testing strategy to ensure full validation of new designs versus the requirements of the 802.11ax standard.

2 Strengths and Limitations of Today's Wi-Fi

With present and future applications in mind, three dimensions capture the essence of Wi-Fi performance: bandwidth (BW), data bits per subcarrier (SC), and the number of spatial streams (SS). Figure 2 illustrates these in a simple x-y-z format, with callouts highlighting the advances achieved in 802.11g (c.2003), 802.11n (c.2009), and 802.11ac (c.2013 and 2016; also called Wi-Fi 5).

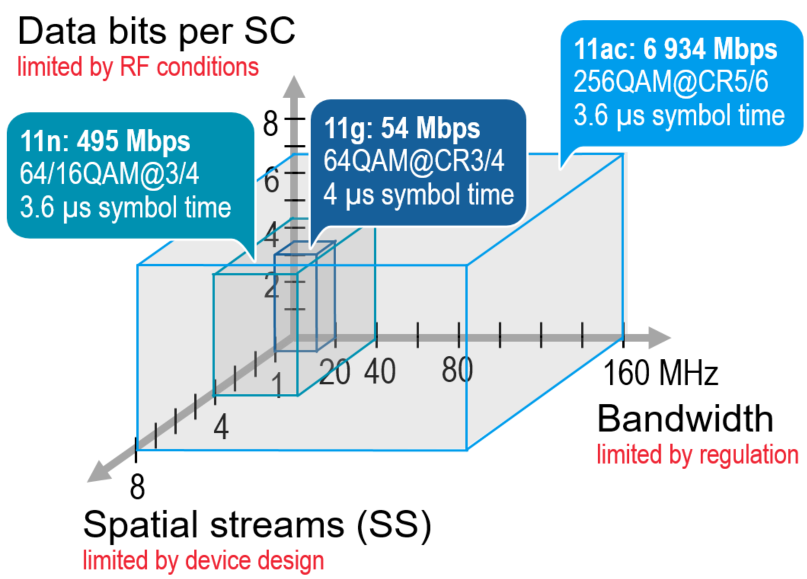


Figure 2: Wi-Fi standards continue to evolve along three crucial dimensions.

Taken together, these attributes determine the available maximum data rate:

$$data\ rate = \frac{(\#\ of\ data\ subcarriers) \times (data\ bits\ per\ symbol) \times (\#\ of\ spatial\ streams)}{(symbol\ time)}$$

In the numerator, bandwidth affects the number of data subcarriers, and the modulation and coding schemes affect the number of data bits per symbol. In the denominator, symbol time includes the guard interval.

On the plus side, these implementations provide very good performance in applications such as homes, small offices, coffee shops, and so on. Given a sufficient number of access points per installation, they can also be reasonably effective when deployed in hotels, airport terminals, medium-sized offices, and other moderate-scale applications.

On the negative side, as more households (or ISPs) deploy more access points (APs), channel crowding and interference become more problematic. Further, as more users connect more devices to any single network, the cries for a better user experience become louder.

We can’t solve these problems overnight, and Figure 2 calls out the limiting factors in each dimension. Bandwidth is, of course, limited by regulation and specified by the standards. The other two dimensions face technical limitations. For example, the ability to transmit and receive more data bits per subcarrier is limited by RF conditions in the operating environment. Further, the ability to utilize more spatial streams is limited by the physical limitations of compact devices: how many different antennas can you successfully integrate into handheld user equipment (UE) or an IoT device?

3 Relevant Dimensions of Wi-Fi Technology

Even with our simple three-dimensional model in mind, we could rightly ask, “OK, where do we start?” Do we add more antennas? Do we explore complex modulation schemes? Do we lobby for more bandwidth?

As with any technology, we can explore a variety of dimensions, techniques and tactics in the pursuit of better performance and greater efficiency. Our developer’s imagination will sift through myriad possibilities:

- New and different frequency bands
- Wider channel bandwidths
- Advanced modulation schemes
- Complex transmission methods
- Tighter subcarrier spacing
- New approaches to access control and scheduling
- Longer guard intervals
- Variations on multiple-input/multiple output (MIMO)

3.1 Five Areas Most Likely to Provide Greater Efficiency.

1. Consider: Increasingly complex modulation schemes

Currently, Wi-Fi uses an access scheme based on carrier-sense multiple access with collision avoidance (CSMA/CA). This works well with a limited number of clients on the network.

However, as the number of clients increases, and as packet length decreases (more common these days), performance falls due to increased wait times or back-off times as transmitters idle while looking and waiting because they detect seemingly constant traffic. Charting this effect, we can see how the average throughput of a Wi-Fi network depends on the number of active stations (Fig.3).

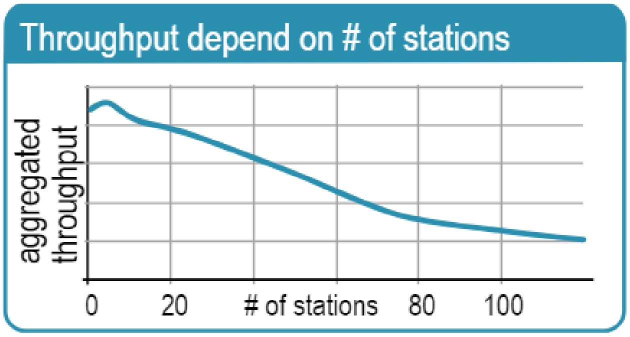


Figure 3: Throughput falls off rapidly when more than 20 stations share a current-generation Wi-Fi access point.

2. Consider: Access control and scheduling

A CSMA/CA-style listen-before-talk approach works only when every element in a system is aware of every other element. This is known as the hidden-node problem. Envision a scenario with three nodes: A and B can see each other and the AP; node C is hidden and, similarly, can see the AP without any awareness of either A or B (Fig.4).

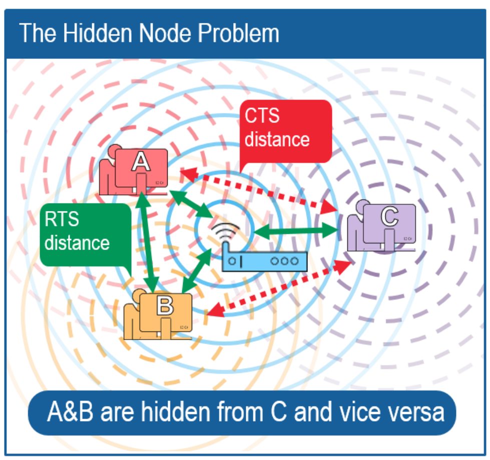


Figure 4: Without a coordination function, the hidden-node problem creates interference and packet loss at the AP.

The solution is called the distributed coordination function (DCF). In this scheme, the system uses a two-part handshake: any station can use a request-to-send (RTS) message to indicate its intent; on the other side, the AP can broadcast its availability by sending a clear-to-send (CTS) message (Fig.5). This solves the hidden-node problem; however, it does not necessarily improve the overall efficiency of the network because the control functions consume resources and add delays.

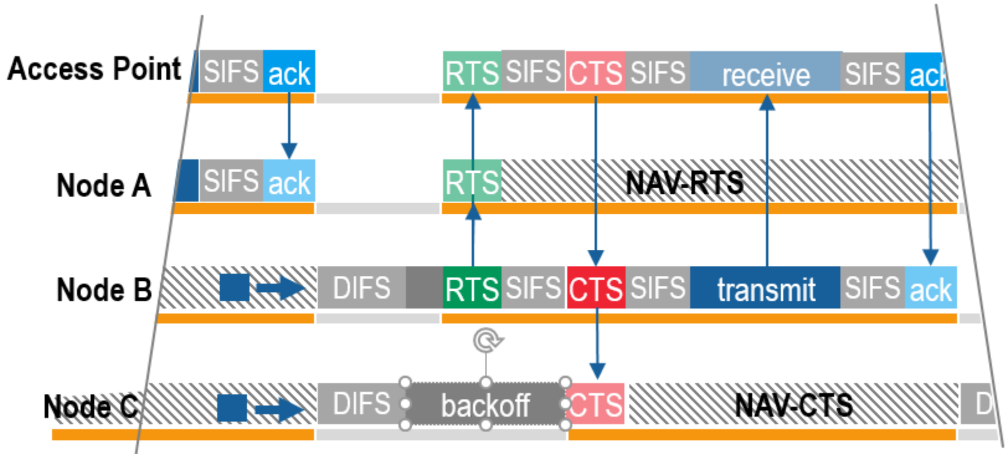


Figure 5: Using DCS with the RTS/CTS handshake improves coordination between nodes and the AP.

3. Consider: Guard intervals

At present, Wi-Fi guard intervals are too short to deal with the inter-symbol interference (ISI) that occurs all too often in multi-path environments that have large delay spreads. While indoor systems typically see delays of less than 0.5 µs, outdoor deployments experience delay spreads of up to 3.0 µs, long enough to encroach on the 3.2 µs symbol time and thereby cause ISI (Fig.6). One possible solution, then, is to use wider guard intervals that account for outdoor use cases with inherently longer delays.

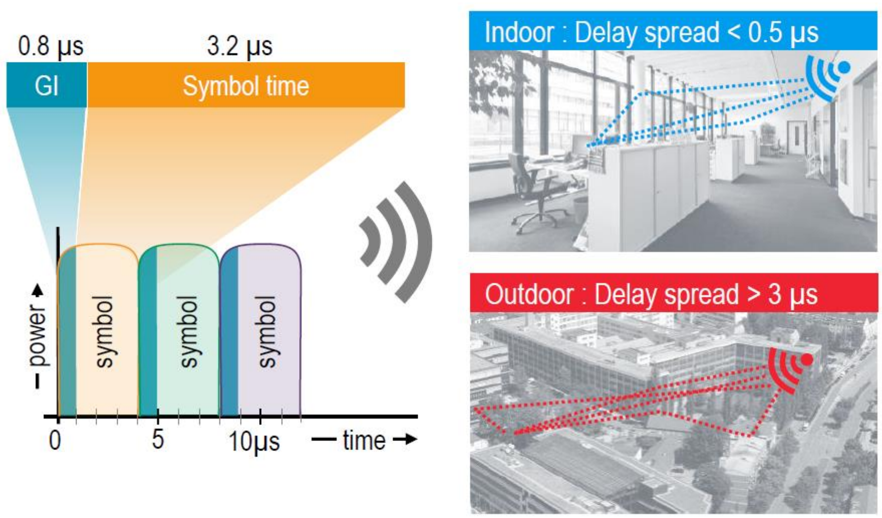


Figure 6: The use of wider guard intervals will help eliminate ISI in outdoor applications that are susceptible to multi-path interference.

4. Consider: MIMO

MIMO has proven to be useful because the respective numbers of transmit and receive antennas have a direct effect on data rates: a 4x4 system can provide a fourfold increase compared to a single stream. However, as a practical matter, it can be difficult to integrate four antennas into a smartphone or an IoT device—and this is why many have just two.

This opens the door to multi-user MIMO (MU-MIMO) systems in which a transmitter with four antennas can establish 2x2 connections with UE devices equipped with two antennas (Fig.7). Making this work depends on clear separation of downlink (DL) and uplink (UL) signals between the transmitter and the receivers. The key is a high level of directivity, and this is now commonly implemented using beamforming via electronically steered phased-array antennas.

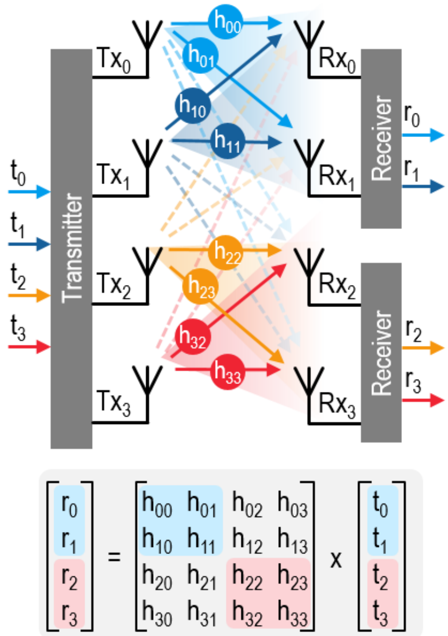


Figure 7: In this configuration, MU-MIMO with beamforming can double the effective data rate.

5. Consider: IoT-focused capabilities

The IEEE 802.11ah standard offers three features that could be useful in Wi-Fi 6. One is dual-carrier modulation: each symbol is mapped to a pair of subcarriers, and these are widely separated in frequency. The net effect is a multi-decibel increase in receiver sensitivity, and this will be useful in outdoor applications.

Another is target wait time (TWT), a form of scheduling in which a station conveys its available communication windows to the AP. This reduces contention and, perhaps more significant, helps minimize power consumption in the remote device because it need not be listening continuously for communication (Fig.8).

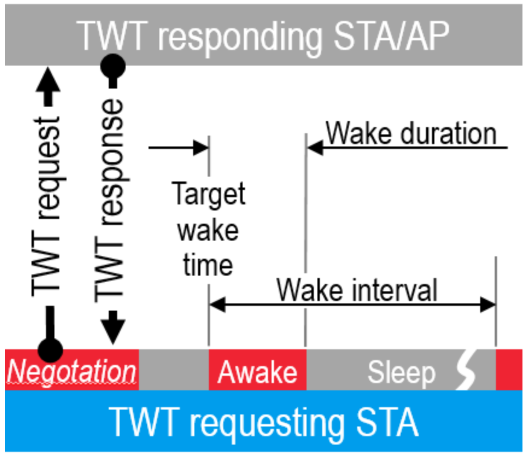


Figure 8: The use of TWT allows optimization of power consumption and can minimize network contention.

Because these devices may operate in dense signal environments, they need the ability to clearly differentiate any basic service sets (BSS) that are within range. One solution is called spatial reuse, and the "BSS coloring" technique enables differentiation of frames from a specific BSS versus any overlapping BSS. By assigning each AP a specific color, individual stations can ignore signals carrying any other color code.

4 The Building Blocks of Greater Efficiency

Leveraging the concepts covered so far, the current definition of Wi-Fi 6 incorporates eight core elements aimed at creating a high-efficiency wireless (HEW) physical layer (PHY). These are summarized in Table 1: frequency bands, channel bandwidths, subcarrier spacing, symbol times, guard-interval durations, transmission schemes, and spatial streams per user. Items highlighted in bold are new developments that go beyond earlier versions of Wi-Fi.

Elements of the Wi-Fi 6 HEW PHY		How it enhances efficiency
Supported bands	2.4 GHz, 5 GHz (6 or 7 GHz)	Provides flexibility in crowded spectrum
Channel bandwidths	20, 40, 80, 80+80, 160 MHz	Improves data throughput
Transmission schemes (encoding)	OFDMA, OFDM	Reduces delays for individual users Increases efficiency for large number of users
Subcarrier spacing	78.125 kHz	Reduces GI overhead
Symbol times	3.2 µs, 6.4 µs, 12.8 µs	Provides adaptability to multi-path environments
Guard-interval duration	0.8 µs, 1.6 µs, 3.2 µs	Provides adaptability to multi-path environments
Modulation schemes	BPSK, QPSK, 16QAM, 64QMA, 256QAM, 1024QAM	Improves data throughput
Spatial streams per user	SU-MIMO: ≤ 8 MU-MIMO: ≤ 4	Supports and manages complex DL and UL activity of resource units

Table 1: Eight core elements contribute to greater efficiency in Wi-Fi 6.

4.1 Four sources of efficiency

Starting with transmission schemes, let's take a closer look at how these enhancements contribute to greater efficiency in Wi-Fi 6.

1. Transmission Schemes

OFDMA enhances efficiency by using both time and frequency to manage resources, power and synchronization (e.g., of stations and users). While this does not increase the maximum PHY data rate, it efficiently interleaves communication from a large number of simultaneous users while also reducing the delays experienced by each individual user.

2. Subcarrier Spacing, Symbol Times and GI Duration

By increasing the density of subcarriers, Wi-Fi 6 reduces GI overhead to 6% from 20%. Further, the use of multiple, and longer, symbol times and guard intervals enhances efficiency by enabling dynamic adaptation to suit indoor applications as well as outdoor environments that suffer from multi-path and fading.

3. Modulation Schemes

Using 1024QAM improves data throughput by as much as 25%. However, achieving that level of performance requires excellent radio conditions and exceptional modulation accuracy on the order of –35 dBm error-vector magnitude (EVM) in the transmitter.

4. Spatial Streams per User

The multi-user case is the most complex, and MU-MIMO coupled with OFDMA enables efficient management of highly complex DL and UL activity using what the 802.11ax standard calls a resource unit (RU). This fundamental concept, borrowed from 4G LTE, is the key to understanding not only the operation of Wi-Fi 6 but also the testing and validation of new devices that support this standard.

4.2 The RU Concept and Wi-Fi 6

Table 2 shows the possible ways to manage RUs in terms of the number that can occupy a specific bandwidth. At the low end, simple communications may need just 1.9 MHz of bandwidth carrying 26 tones and two pilots. At the other extreme, a high-performance connection may consume the maximum bandwidth of 153.2 MHz and utilize 996 tones and 32 pilots.

tones	pilots	BW (data)	20 MHz	40 MHz	80 MHz	160 MHz	80+80 MHz
26	2	1.9 MHz	9	18	37	74	74
52	4	3.8 MHz	4	8	16	32	32
106	4	8.0 MHz	2	4	8	16	16
242	8	18.3 MHz	1	2	4	8	8
484	16	36.6 MHz	n/a	1	2	4	4
996	16	76.6 MHz	n/a	n/a	1	2	2
996	32	153.2 MHz	n/a	n/a	n/a	1	1

Table 2: In Wi-Fi 6, each channel can carry a flexible number of RUs to suit a variety of communication needs.

In Wi-Fi 6, OFDMA uses RUs to allocate subcarriers, and the AP assigns RUs to fixed locations within each channel (e.g., 20, 40, 80, 80+80 or 160 MHz). Each RU can use a different modulation scheme, coding rate and power level. Fig.9 shows four possible mappings of RUs onto a 20 MHz bandwidth within the Wi-Fi 6 spectrum. In this scheme, APs manage per-user UL and DL communication by assigning a range of RUs to specific OFDMA timeslots.

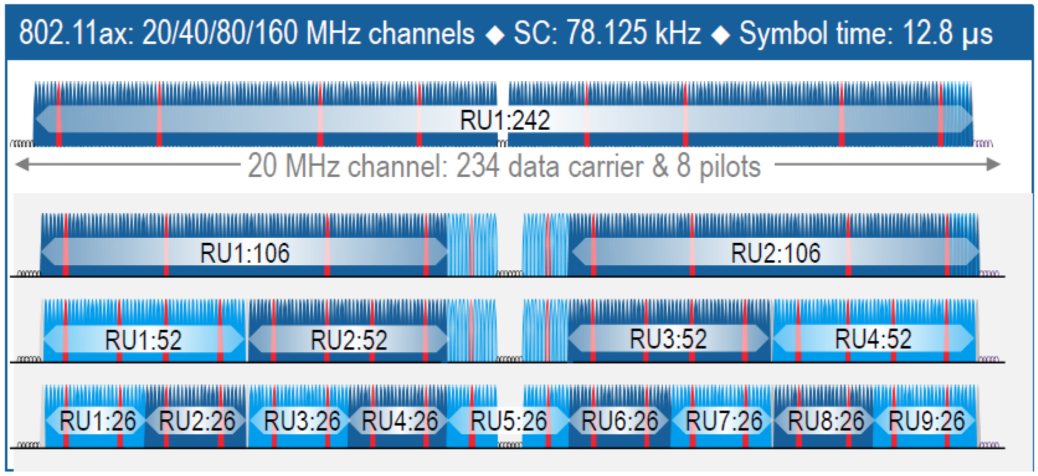


Figure 9: This mapping of RUs onto the Wi-Fi 6 frequency spectrum illustrates the 20 MHz column of Table 2.

5 Six Reasons to Revisit Your Test Strategy

Whether your focus is on product development or device manufacturing, the complex operation of Wi-Fi 6 offers at least six reasons to step back and revisit your test strategy for WLAN devices. To provide context, let us consider the management of UL and DL communication in an OFDMA system that has multiple users.

Figure 10 shows a wireless network with one access point and four stations (i.e., multiple users). When the AP is ready to send downlink data, it issues an MU RTS notice to all stations. As shown, three have incoming traffic and these separately confirm their readiness with a CTS message. The AP then sends all data simultaneously using MU-DL PHY-layer protocol data unit (PPDU) within the predetermined RU configuration. To conclude the session, the AP sends a block acknowledgement request (BAR) and the stations reply with individual block acknowledgements (BACK).

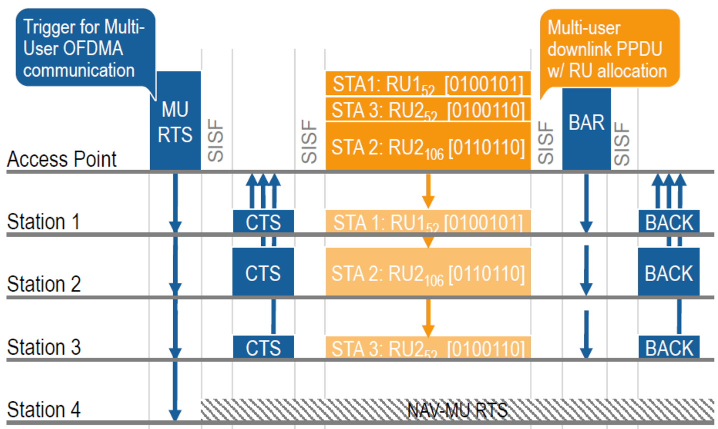


Figure 10: Precise coordination is needed to ensure successful parallel transmissions from the AP.

UL communication is a bit more complicated (Fig.11). In the background, the AP is continuously collecting buffer-status information from all stations. Using that data, the AP first calculates the best RU configurations for parallel communication from all stations, and it then sends an MU RTS. Each station replies with a CTS and then waits for the AP to send the trigger frame that provides synchronization and control of UL communication. All stations then respond within their assigned RU using AP-defined modulation, coding, power level and duration. The process concludes with an MU block acknowledgement from the AP.

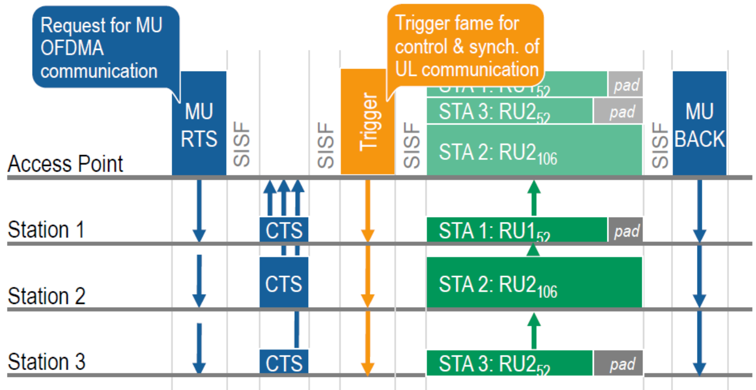


Figure 11: During UL, all frames should reach the AP at the same time with the expected power and duration (including a pad, as shown, if needed).

Reasons 1, 2 & 3: Timing, Power Control, and RU Spectrum

Within this operational scheme, developers will face three design challenges: accurate timing (i.e., triggers), accurate power levels, and a clean RU spectrum.

5.1 Timing

Figure 12 highlights the timing problem: UL transmissions from all stations must occur within 16 µs ±400 ns. This level of precision can be difficult to achieve and equally difficult to measure across multiple simultaneous signals.

5.2 Power Control

Moving to Figure 13, each station is expected to deliver roughly the same power level to the AP. To do this, the AP sends its own known transmit power level and the expected incoming power level as part of the control information encoded with the trigger signal. Each station makes its own received signal strength indicator (RSSI) measurement and then, using the AP-provided info, determines the necessary transmit power. The standard defines expected accuracy levels for transmit power and RSSI measurements, and designers must verify device performance versus these requirements.

5.3 RU Spectrum

A clean spectrum will help minimize interference between RUs that are transmitting at the same time. Each RU must operate with its specified band (e.g., 20, 40, 80, 80+80 or 160 MHz) without spilling over into any adjacent bands. As usual, EVM is the essential metric for modulation accuracy, and Figure 14 shows the expected performance levels. In Wi-Fi

6, the other metric for modulation accuracy is unused tone error, and it provides a benchmark for the unoccupied subcarriers in each PPDU.

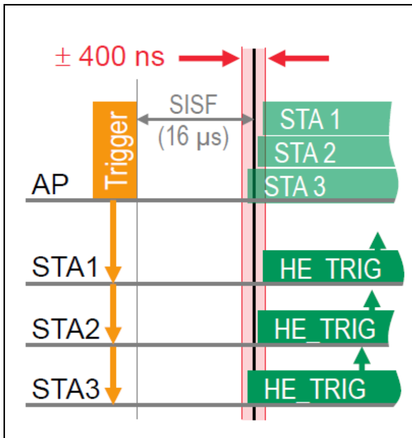


Figure 12: Accurate timing of all UL transmissions is necessary to ensure simultaneous arrival at the AP.

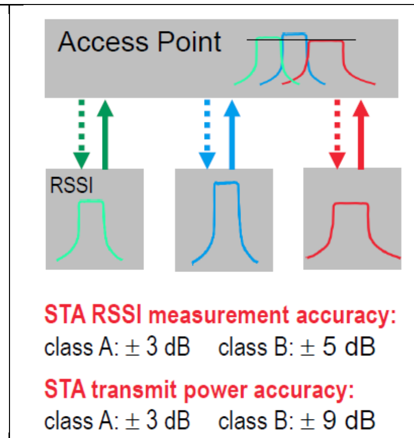


Figure 13: Each station must make an accurate RSSI measurement and then calculate the required transmit power level.

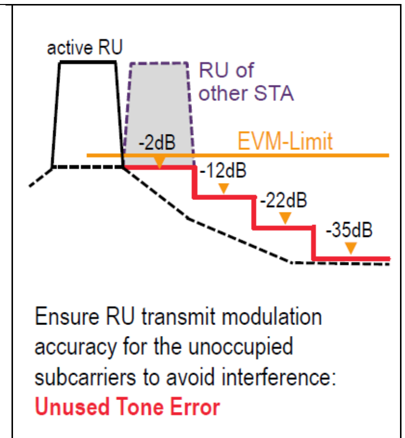


Figure 14: Each RU spectrum must be very clean in part because dynamic operation precludes use of static filters.

Reasons 4, 5 & 6: Clean Signals, New Use Cases, and Signaling Test

In R&D and production, three more challenges suggest further rethinking of your test strategy: wideband test signals with low distortion, multi-path use cases, and the need for signaling test.

5.4 Clean Signals

Testing 1024QAM requires signal-generation capabilities with very low distortion over the full 160 MHz bandwidth. Your existing equipment may not be capable of producing such signals.

5.5 New Use Cases

Wi-Fi 6 includes use cases for multi-path environments, and these also specify testing under fading conditions. Satisfying these requirements depends on a signal-generation solution capable of emulating the full slate of RU configurations along with multi-path and fading.

5.6 Signaling Test

Efficient testing of new media-access control (MAC) functionalities related to OFDMA and MU-MIMO require solutions that support signaling test. Here, it's worth comparing non-signaling and signaling scenarios. As shown in Fig.15, non-signaling test can be performed with a signal generator, a signal analyzer, and a direct interface to control the device-under-test (e.g., put the DUT into test mode). This allows very fast testing of specific characteristics such as the RF performance of transmitters and receivers.

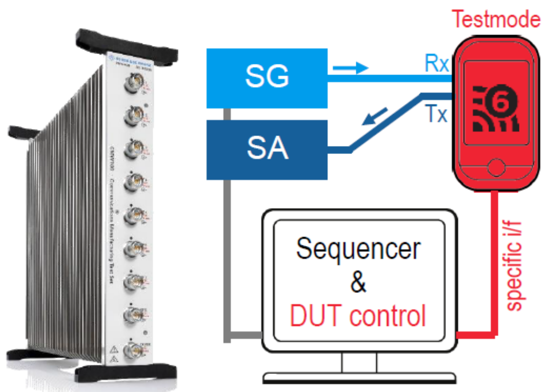


Figure 15: In non-signaling test, the use of a specific test interface to control the DUT enables very fast measurements (e.g., in production).

To perform signaling testing, it is necessary to emulate an AP or station and make measurements under realistic network conditions (Fig.16). Essential measurements include those characteristics mentioned above—timing error, unused tone error, power control—and more. Thus, a signaling tester covers much more than basic receiver or transmitter specifications:

- End-to-end performance
- Application performance
- WLAN/LTE aggregation and offloading
- Interference analysis
- IP security testing
- Message logging

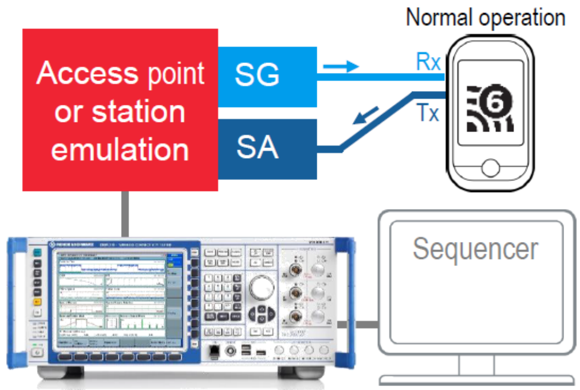


Figure 16: In signaling test, emulating a variety of realistic network conditions enables testing of end-to-end performance and more.

6 Rohde & Schwarz: Your Partner in Testing All Generations of Wi-Fi

Rohde & Schwarz has long been a pioneer in the development of T&M solutions for the wireless communications market. The examples presented here are designed to help you test all generations of Wi-Fi, including Wi-Fi 6.

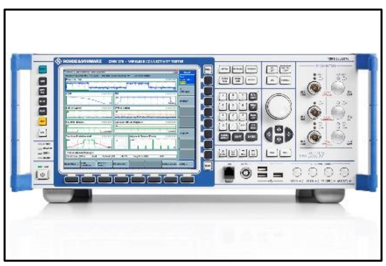
R&S®SMBV100B Vector Signal Generator

The state-of-the-art R&S SMBV100B vector signal generator sets new standards in its class, providing modulation bandwidth of up to 500 MHz and excellent EVM performance at high output power levels. Ultra-high output power, fully calibrated wideband signal generation and intuitive touchscreen operation make the R&S SMBV100B ideal for Wi-Fi 6.

R&S®FSV3000 Signal and Spectrum Analyzer

The R&S FSV3000 is the right choice for 802.11ax signal analysis: 200 MHz analysis bandwidth, 10 Hz to 7.5 GHz frequency range (FSV3007), and excellent EVM performance. It also accelerates measurement set-up: configure measurements at the push of a button, capture rare events with event-based actions, and create script programming with the SCPI recorder. Fast measurement speed provides high throughout in production applications.

R&S CMW270 Wireless Connectivity Tester

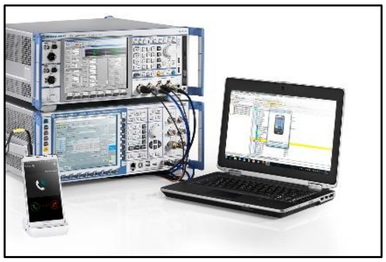


This is the non-cellular expert, covering 802.11ax and the testing of APs and stations in signaling and non-signaling modes. The R&S CMW270 is a cost-effective alternative for the development and production of Wi-Fi 6, Bluetooth® and GNSS designs, and it is especially attuned to the test requirements of IoT devices.

R&S®CMW100 Communications Manufacturing Test Set

The R&S CMW100 is a trendsetting product for cost-effective calibration and verification of various kinds of communications devices in non-signaling mode (analyzer/generator). A flexible RF interface enables simultaneous testing of up to eight RF ports, making the R&S CMW100 ideal for production test of 802.11ax MIMO.

R&S®CMWrun Sequencer Software Tool



This production-ready sequencer is the automation tool for R&S CMW models, supporting parallel testing of multiple DUTs through integrated chipset control. The software meets all requirements for executing remote-control test sequences in R&D, quality assurance, production and service for present and future wireless equipment.

7 Conclusion

To stay relevant in the age of 5G, the intention for Wi-Fi 6 is to create a wireless revolution. Higher data rates are part of the story, but the focus is on greater efficiency in wireless connectivity. Utilizing eight core building blocks, Wi-Fi 6 will ensure greater overall efficiency for large numbers of simultaneous users while also reducing the delays experienced by each individual user.

To make this revolution a reality, product developers and manufacturing test engineers alike will want to step back and rethink their respective test strategies. One of the key changes will be a shift to signaling test that validates device performance under realistic network conditions.

Rohde & Schwarz

The Rohde & Schwarz electronics group offers innovative solutions in the following business fields: test and measurement, broadcast and media, secure communications, cybersecurity, radiomonitoring and radiolocation. Founded more than 80 years ago, this independent company has an extensive sales and service network and is present in more than 70 countries.

The electronics group is among the world market leaders in its established business fields. The company is headquartered in Munich, Germany. It also has regional headquarters in Singapore and Columbia, Maryland, USA, to manage its operations in these regions.

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