IEEE 802.11be
TECHNOLOGY INTRODUCTION

White paper | Version 01.00 | Lisa Ward, Jörg Köpp

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CONTENTS

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- R&S®FSW signal and spectrum analyzer
- R&S®SMW200A vector signal generator
- R&S®SMM100A vector signal generator
- R&S®VSE vector signal explorer software
- R&S®TS8997 regulatory test system for wireless devices
- R&S®FSV3000 signal and spectrum analyzer
- R&S®SMBV100B vector signal generator
- R&S®DST200 RF diagnostic chamber
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- R&S®TS7124 RF shielded box

1 INTRODUCTION

The IEEE 802.11 working group develops the wireless local area network (WLAN) specifications behind the Wi-Fi technology. First, IEEE 802 created 11a/b/g to enable wireless communications for everyone. Since then, the IEEE 802.11 MAC and PHY layers have continuously been enhanced to improve user experience, increase throughput, utilize resources more efficiently and/or support new use cases. These enhancements are amendments to the base IEEE 802.11 standard and many have been published in the last 20+ years. See the IEEE 802.11 website [1] for a full list and description of all IEEE 802.11 amendments.

The most well-known amendments introduced major generational changes. For example, IEEE 802.11n (Wi-Fi 4) published in 2009 provided new features such as MIMO and frame aggregation to increase throughput, IEEE 802.11ac (Wi-Fi 5) published in 2013 offered wider bandwidths and MU-MIMO for even higher throughput and IEEE 802.11ax (Wi-Fi 6) added OFDMA and BSS Color (spatial reuse) in 2021 to use spectrum resources more efficiently. See the Rohde & Schwarz white paper IEEE 802.11ax technology introduction [11] for more information.

The IEEE 802.11 working group is currently developing the next generation of Wi-Fi, IEEE 802.11be (Wi-Fi 7), also known as Extremely High Throughput (EHT). The EHT goals defined in the IEEE 802.11be project authorization request [2] include at least one operating mode supporting 30 Gbps (measured at the MAC data services access point) and at least one operating mode to improve latency and jitter for time sensitive network support. EHT operates in the unlicensed bands between 1 GHz and 7.125 GHz.

EHT reuses many of the concepts and techniques used at the HE PHY layer but makes enhancements such as assigning multiple resource units to a single user, increasing bandwidths up to 320 MHz, supporting up to 16 spatial streams and adding 4096QAM modulation support. EHT introduces several significant features at the MAC layer such as multilink operation (MLO) to enable multiple links between a station (STA), an access point (AP) and restricted TWT. This allows an AP to save STA resources for more predictable traffic with lower latency and higher reliability.

For the last 20 years, IEEE 802.11/Wi-Fi networks have essentially been limited to the 2.4 GHz and 5 GHz unlicensed bands while at the same time Wi-Fi usage continued to grow. User applications require faster speeds, higher throughput and/or lower latency. Despite continuous IEEE 802.11 standard efficiency enhancements, it became clear that additional unlicensed spectra would benefit Wi-Fi users. Regulators around the globe are therefore allocating some or all of the 6 GHz band for unlicensed usage. Wi-Fi Alliance-certified Wi-Fi 6 (IEEE 802.11ax) products capable of 6 GHz operation are already available [3].

This white paper focuses on the IEEE 802.11be physical layer and contains five main parts:

- Chapter 2: IEEE 802.11be amendment development core documents
- Chapter 3: IEEE 802.11be goals and feature summary
- Chapter 4: Features to achieve extremely high throughput
- Chapter 5: EHT physical layer descriptions
- Chapter 6: Transmitter and receiver test requirements

2 IEEE 802.11be CORE DOCUMENTS

Much of the information in this paper comes from two key IEEE 802.11be core documents: The IEEE 802.11be draft amendment version 1.0 and the IEEE 802.11be Specification Framework Document (SFD) version 23.

The IEEE 802.11be Specification Framework Document [6] includes the IEEE 802.11be task group features and requirements and is used as the IEEE 802.11be amendment framework or outline. The latest version of the Specification Framework Document can be downloaded here: [4].

IEEE 802.11be draft text is based on the SFD agreements. It specifies changes to the base IEEE 802.11-2020 standard [7] necessary to meet IEEE 802.11be project goals by adding new PHY and MAC clauses and modifying existing IEEE 802.11 text as needed.

IEEE 802.11be draft v1.0 [8] was released in May, 2021. The final approved IEEE 802.11be amendment document is expected to be published by mid 2024. The IEEE 802.11 task groups provide public status updates of their work: [5].

3 IEEE 802.11be GOALS AND FEATURE SUMMARY

Wireless LAN (Wi-Fi) has been a key component of wireless data services in a wide array of environments. The recent surge of people working from home highlights how important Wi-Fi is for connectivity. Not only does it provide data and connections to office networks, it is increasingly used for video conferencing to connect remote workers and facilitate online meetings that are used as substitutes for face-to-face meetings and large conferences. The use of video traffic will continue to increase in the coming years as applications such as VR/AR become more widely used. In addition, WLAN users will expect reliable and near real-time gaming and cloud computing experience.

Figure 3-1: Wi-Fi 7 extreme high throughput use cases

IEEE 802.11be aims to specify MAC and PHY features that will meet the high throughput and low latency requirements for these applications. The IEEE 802.11be PHY is very similar to the PHY defined in the highly successful IEEE 802.11ax standard. For example, IEEE 802.11be will support MU-MIMO, OFDMA and longer symbol duration (smaller subcarrier spacing). Some key IEEE 802.11be PHY improvements and changes include the ability to assign multiple resource units to a single user in OFDMA transmissions as well as 320 MHz bandwidth and 4096QAM modulation support as listed in Table 3-1.

Table 3-1: PHY parameter values for IEEE 802.11n, IEEE 802.11ac, IEEE 802.11ax and IEEE 802.11be

	IEEE 802.11n (HT)	IEEE 802.11ac (VHT)	IEEE 802.11ax (HE)	IEEE 802.11be (EHT)
Supported bands	2.4 GHz, 5 GHz	5 GHz	2.4 GHz, 5 GHz, 6 GHz	2.4 GHz, 5 GHz, 6 GHz
Channel bandwidth (in MHz)	20, 40	20, 40, 80, 80 + 80, 160	20, 40, 80, 80 + 80, 160	20, 40, 80, 160, 320
Subcarrier spacing (in kHz)	312.5	312.5	78.125	78.125
Symbol time (in µs)	3.2	3.2	12.8	12.8
Cyclic prefix (in µs)	0.8	0.8, 0.4	0.8, 1.6, 3.2	0.8, 1.6, 3.2
MU-MIMO	no	downlink	uplink and downlink	uplink and downlink
Modulation	OFDM	OFDM	OFDM, OFDMA	OFDM, OFDMA
Data subcarrier modulation	▶ BPSK ▶ QPSK ▶ 16QAM ▶ 64QAM	▶ BPSK ▶ QPSK ▶ 16QAM ▶ 64QAM ▶ 256QAM	▶ BPSK ▶ QPSK ▶ 16QAM ▶ 64QAM ▶ 256QAM ▶ 1024QAM	▶ BPSK ▶ QPSK ▶ 16QAM ▶ 64QAM ▶ 256QAM ▶ 1024QAM ▶ 4096QAM
Coding	▶ BCC (mandatory) ▶ LDPC (optional)	▶ BCC (mandatory) ▶ LDPC (optional)	▶ BCC (mandatory) ▶ LDPC (optional)	▶ BCC (mandatory) ▶ LDPC (mandatory [1])

[1] Devices supporting only 20 MHz channel bandwidth are not required to support LDPC.

IEEE 802.11be also has an eye towards future compatibility. IEEE 802.11 PHY always considers backward compatibility with legacy IEEE 802.11 generations, but IEEE 802.11be introduces forward compatibility concepts. For example, IEEE 802.11be includes a new preamble field called the universal SIG (U-SIG) that will be used in IEEE 802.11be and all future IEEE 802.11 generations as well as more precise terms and rules for reserved bits.

The IEEE 802.11be MAC layer introduces significant changes and new features such as multilink operation, multi-AP support, restricted target wake time (TWT) and 1024-bit block acknowledgement (1K BA) to meet the targeted low latency applications.

Table 3-2 provides an overview of new and enhanced IEEE 802.11be features and their benefits compared to IEEE 802.11ax.

Table 3-2: Key benefits from new and enhanced IEEE 802.11be features

Feature	Support in IEEE 802.11ax	Support in IEEE 802.11be	Benefit
Bandwidth	20 MHz, 40 MHz, 80 MHz, 80+80 MHz and 160 MHz channels	adds 320 MHz and does not support noncontiguous bandwidth such as 80+80 MHz	increased data rate and lower complexity
Modulation	BPSK, QPSK, 16QAM, 64QAM, 256QAM, 1024QAM	adds 4096QAM option	increased throughput
Resource units	single resource unit (RU) per user	adds support for multiple RU (MRU) assignments to a single user and modifies the RU allocation plan for bandwidth ≥ 80 MHz	efficient spectrum utilization and more scheduling flexibility
MU-MIMO	UL and DL supported with up to 8 spatial streams (SS), 4 users with 1 or 2 SS	up to 16 spatial streams and an enhanced sounding protocol (MAC)	increased throughput
Compatibility	supports backward compatibility in the 2.4 GHz and 5 GHz band	enhanced preamble that adds a universal SIG field to indicate the PHY version	easier/better coexistence with future Wi-Fi generations
6 GHz band support	yes	yes	availability of more spectrum and a few 320 MHz channels
Preamble puncturing	yes	slight modifications to some spectral emission masks when puncturing is used	efficient spectrum utilization, better coexistence with other users in the band
Multilink operation	no	new to IEEE 802.11be	improved spectral efficiency, load balancing, higher data throughput, lower latency
Restricted target wake time (TWT)	no	new to IEEE 802.11be	enables dedicated service period for low latency traffic
1K block ack (BA)	yes	IEEE 802.11be extends the negotiated block ack buffer size to 1024 bits	more efficient MAC data unit aggregation and better support for MLO

4 ACHIEVE EXTREMELY HIGH THROUGHPUT AND MORE

The EHT physical layer supports wider bandwidth, more spatial streams and a higher modulation scheme to achieve extremely high throughput.

The maximum throughput of a single physical link can be calculated by the simple formula below.

$$Maximum\ physical\ data\ rate = \frac{N_{SD} \cdot N_{CBPS} \cdot R \cdot N_{SS}}{T_{SYM}}$$

N_{SD}: Number of data subcarrier dependent on channel bandwidth (CBW)

	20 MHz	40 MHz	80 MHz	160 MHz	320 MHz
N_{SD}	234	468	936	1960	3920

N_{CBPS}: Number of coded bits per OFDM symbol

	BPSK	QPSK	16QAM	64QAM	256QAM	1024QAM	4096QAM
N_{SD}	1 bit	2 bit	4 bit	6 bit	8 bit	10 bit	12 bit

R: Code rate; 1/2, 2/3, 3/4 or 5/6
N_{SS}: Number of spatial streams; 2, 4, 8 or 16
T_{SYM}: OFDM symbol duration incl. guard time; 12.8 µs + GI, where GI can be 0.8 µs, 1.6 µs or 3.2 µs

A link using a 320 MHz channel, 16x16 MIMO, short guard interval of 0.8 µs, 4096QAM modulation with 5/6 coding can reach a theoretical data rate of 46 Gbps. A more typical example is a 160 MHz channel with 2x2 MIMO,1024QAM with 3/4 coding for example, achieving up to 2.1 Gbps.

Multilink operation (MLO) increases throughput by using several physical links in parallel (see section 4.2 for more information).

4.1 Up to 320 MHz channel bandwidth

EHT supports 20 MHz, 40 MHz, 80 MHz, 160 MHz and 320 MHz channel bandwidths. 320 MHz bandwidth is new to IEEE 802.11be and is made possible thanks to updated regulatory rules in many countries that now allow unlicensed device operation (subject to regional restrictions) in the 6 GHz band. In the US and Canada for example, the full spectrum from 5925 MHz to 7125 MHz is available while in Europe only the lower part from 5945 MHz to 6425 MHz is available. Spectrum regulations classify the following three device categories:

- Low power indoor (LPI) devices with a power (EIRP) limit of around 250 mW
- Very low power devices (VLP) with a power (EIRP) limit of around 25 mW
- Standard power devices for indoor and outdoor with an AP applying automatic frequency coordination (AFC)

The Wi-Fi Alliance provides a global spectrum tracker of the current status for unlicensed 6 GHz band usage via the following page:
https://www.wi-fi.org/countries-enabling-wi-fi-6e

Because IEEE 802.11 wants to make full use of the newly allocated spectrum, EHT seeks to encourage high throughput and low latency applications in the 6 GHz band. Additional EHT device bandwidth requirements for the three operating bands are listed below:

- An IEEE 802.11be AP must support:
  - 160 MHz operating channel width in 6 GHz band
  - 80 MHz operating channel width in 5 GHz band
  - 20 MHz operating channel width in 2.4 GHz band
- IEEE 802.11be non-AP STA must support 80 MHz channel in 5/6 GHz (unless it is a 20 MHz only device)
- 20 MHz only devices can operate in the 2.4 GHz and 5 GHz band

Figure 4-1 shows sample channelization based on US FCC regulations. Because of an odd number of 160 MHz channels, EHT defines a set of overlapping 320 MHz channels. This provides a way to efficiently use the spectrum since each 160 MHz can be part of a 320 MHz channel. To facilitate signaling and make it easier for a STA to identify overlapping 320 MHz channels, IEEE 802.11be defines two types of 320 MHz channelization: 320 MHz-1 and 320 MHz-2.

The center frequencies are determined using the IEEE 802.11 standard equation:

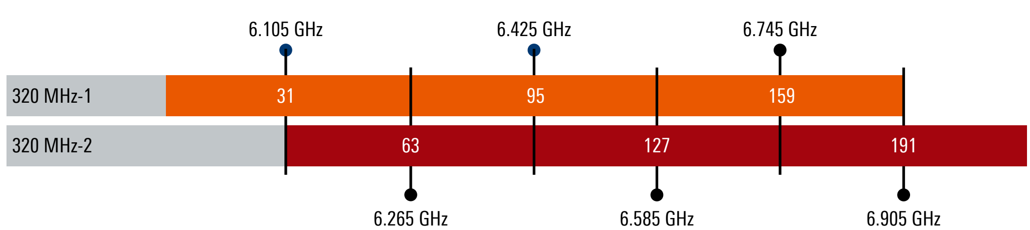
$$\mathit{Channel\ center\ frequency} = \mathit{Channel\ starting\ frequency} + 5 \cdot n_{ch}\ (\text{in MHz})$$

where

n_{ch}: channel center frequency number;
31, 95, and 159 for 320 MHz-1 or
63, 127, and 191 for 320 MHz-2 channels

$\mathit{Channel\ starting\ frequency}$ = 5.950 GHz

Figure 4-1: 320 MHz channel allocation in the 6 GHz band in line with FCC



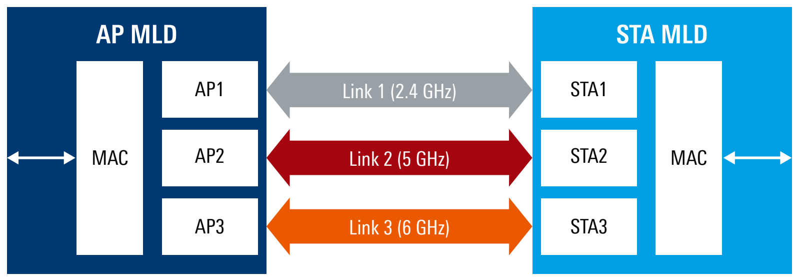
IEEE 802.11be noncontiguous (e.g. 80+80 MHz) operation is not used because in part it was found that the 80+80 MHz noncontiguous channelization defined in IEEE 802.11ax is not commonly used [9]. In addition, the IEEE 802.11be MLO MAC feature can be used to achieve the same results as the noncontiguous PHY channels.

To achieve extremely high throughput, IEEE 802.11be will also support up to 8 spatial streams (SS) across all scheduled stations for DL/UL MU-MIMO and SU-MIMO. For EHT MU-MIMO transmissions, the maximum number of spatial streams per STA is four up to a maximum of eight users.

4.2 Multilink operation (MLO)

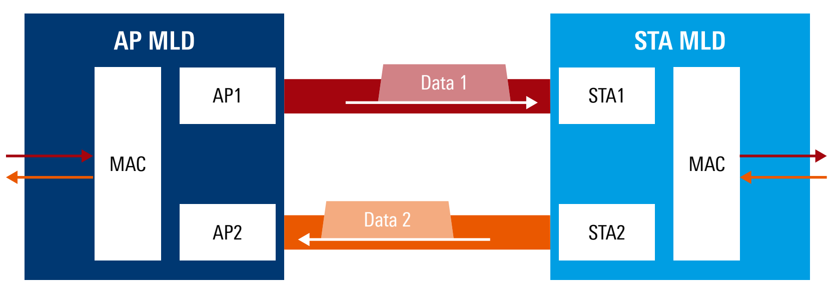
EHT introduces a new MAC feature called multilink operation (MLO). An MLO device (MLD) can establish multiple links on different channels with other MLDs as shown in Figure 4-2. Two example use cases – higher throughput using link aggregation and load balancing – benefit from this feature. Aggregation uses two or more links for data transmission, achieving higher throughput than if only one link was used. In load balancing, MLO can be used to quickly switch to a channel link with fewer users. Fewer users on the medium means the latency due to channel access contention/retries is reduced. Although MLO uses multiple links, setup/association between the AP and non-AP is done via a single link, reducing the amount of overhead compared to legacy operation.

Figure 4-2: EHT multilink operation (MLO) of AP and non-AP multilink devices (MLD)



MLO devices with two or more radios can transmit and receive on different links at the same time, called simultaneous transmit and receive (STR). Figure 4-3 shows a link pair with one link at a channel in the 5 GHz band and another link at a channel in the 6 GHz band. In this example, AP1 in the 5 GHz band is transmitting data to STA1 in the 5 GHz band while STA2 simultaneously sends data to AP2.

Figure 4-3: Simultaneous transmit/receive (STR) example

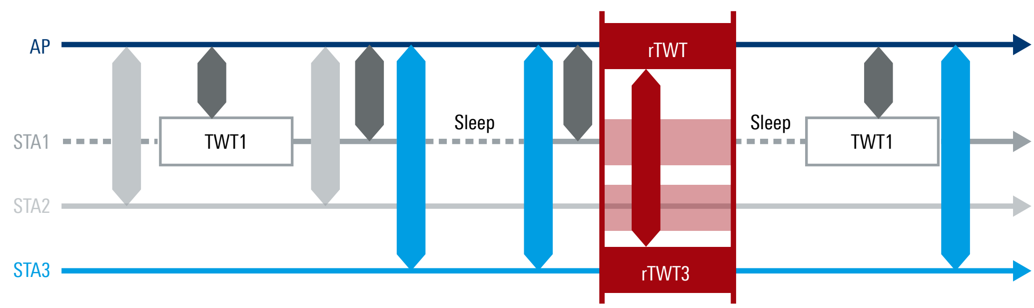


Not all MLDs are STR-capable at any time. The MLD must be able to receive on one of the links in the presence of transmissions on the other link. If the frequency of the two channels is too close, the device may not be able to meet the IEEE 802.11be receiver requirements in case of transmissions on the other link (see section 6.2 for more information on IEEE 802.11be receiver requirements). With an established multilink, the STA indicates via an MLD capability field how much frequency separation it needs to be able to operate as an STR link.

4.3 Restricted target wake time

The target wake time (TWT) feature was introduced in IEEE 802.11ah to support low power IoT applications by allowing STAs to go into sleep mode outside wake time periods after AP negotiation. It also allows the AP to distribute STA wake periods over time to minimize contention. IEEE 802.11be extends TWT capabilities and provides predictable latency to support time sensitive application requirements. STAs must ensure that any transmission ends before the start of a restricted TWT service period so that the channel can be exclusively used by STAs with established membership to the restricted TWT schedule as shown in Figure 4-4, with STA3 as member of a restricted TWT (rTWT3) and STA1 using TWT (TWT1) for power saving.

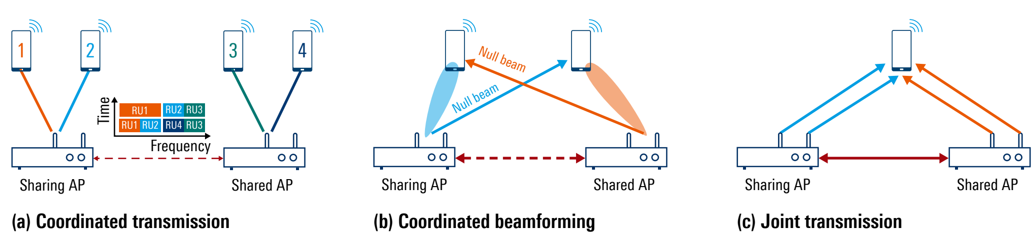
Figure 4-4: Restricted target wake time principle



4.4 Multi-AP operation

IEEE 802.11be also discusses features for improving the operating efficiency of adjacent access points. This makes it possible to use spectrum resources more efficiently and improve the throughput. For example, the coordinated transmission (a) allows spectrum resources sharing in the time or frequency domain between a sharing AP and one or more shared APs.

Figure 4-5: Multi-AP coordination feature principles



It might also be worthwhile to coordinate beamforming between adjacent APs by forming spatial radiation nulls (null beams) to non-associated STAs in the neighborhood, which allows simultaneous transmission at the same frequency resource. The probably most complex feature under discussion is the joined transmission (c) where multiple APs transmit/receive to/from one or multiple stations using the same frequency in a distributed MIMO scheme.

5 IEEE 802.11be PHYSICAL LAYER

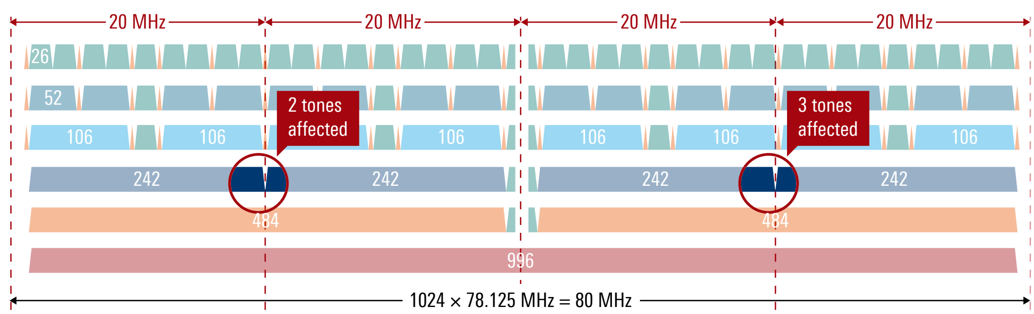
5.1 New resource units and tone plans

IEEE 802.11ax (HE) introduced OFDMA to IEEE 802.11, and users were allocated resource units (RU) with 26, 52, 106, 242, 484 or 996 tones in size.

The EHT tone plan and resource unit (RU) locations for a 20 MHz and 40 MHz PPDU are the same as for the IEEE 802.11ax 20 MHz and 40 MHz PPDU. The EHT 80 MHz PPDU RU and tone locations, however, are slightly different from HE. When HE developed the tone plan, the focus was to use the spectrum as efficiently as possible. As many subcarriers as possible are used for data transmission. For example, a middle RU was defined for straddling DC, and no null carrier was used between two 242-tone RUs.

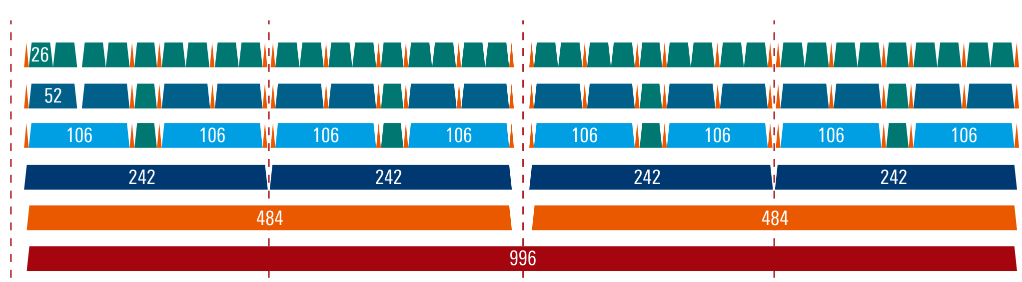
As a design consequence, 242-tone RUs do not align with 20 MHz subchannel boundaries and the middle 26-tone RU falls into two 20 MHz subbands. This causes problems in case of preamble puncturing, for example where a punctured 20 MHz subchannel punctures tones from an adjacent RU causing adjacent channel RU degradation. Figure 5-1 shows the misalignment of the 20 MHz boundaries and the 242-tone RU. Figure 5-1 shows two examples where a punctured 20 MHz subchannel impacts subcarriers from adjacent resource units [10].

Figure 5-1: HE 80 MHz tone plan



The EHT 80 MHz plan solves this issue with a minimal change to the HE 80 MHz plan as shown in Figure 5-2. This small change means that the same RU sizes can be used in EHT as in HE, but eliminates the middle 26-tone RU and aligns the 242-tone RU with 20 MHz channel boundaries.

Figure 5-2: EHT 80 MHz tone plan

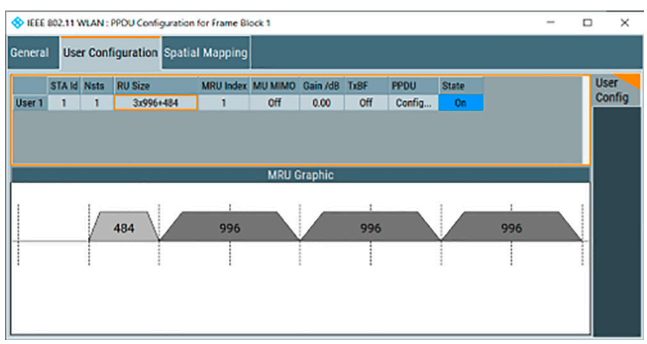


5.2 Multiple resource units per user

While much of the IEEE 802.11be PHY is the same or very similar to IEEE 802.11ax, a key differentiator for IEEE 802.11be is the capability to allocate more than one resource unit to a single user. Assigning multiple RUs per user provides scheduling flexibility to take advantage of frequency diversity and to efficiently allocate resources within the spectrum. The drawback of this additional flexibility is an increased overhead needed to describe all possible RU combinations. EHT avoids this by defining rules to limit which RUs may be combined by focusing on those combinations that provide the most benefit. The rules are based on the EHT RU classification as small or large size RU. Small size RUs are less than 20 MHz, i.e. 26, 52, 106-tone RUs. Large size RUs are 20 MHz or larger, i.e. 242-tone (20 MHz), 484-tone (40 MHz), 996-tone (80 MHz) RUs. Small and large size RUs are not used together in an MRU. So, a multiple resource unit (MRU) contains either two small RUs or two large RUs.

Small RUs in an MRU are contiguous and lie within a 20 MHz channel boundary. In addition, 26+26-tone MRU, 52+52-tone MRU and 106+106-tone MRU are not allowed since the AP should schedule a single 52-tone RU, 106-tone RU or 242-tone RU, respectively.

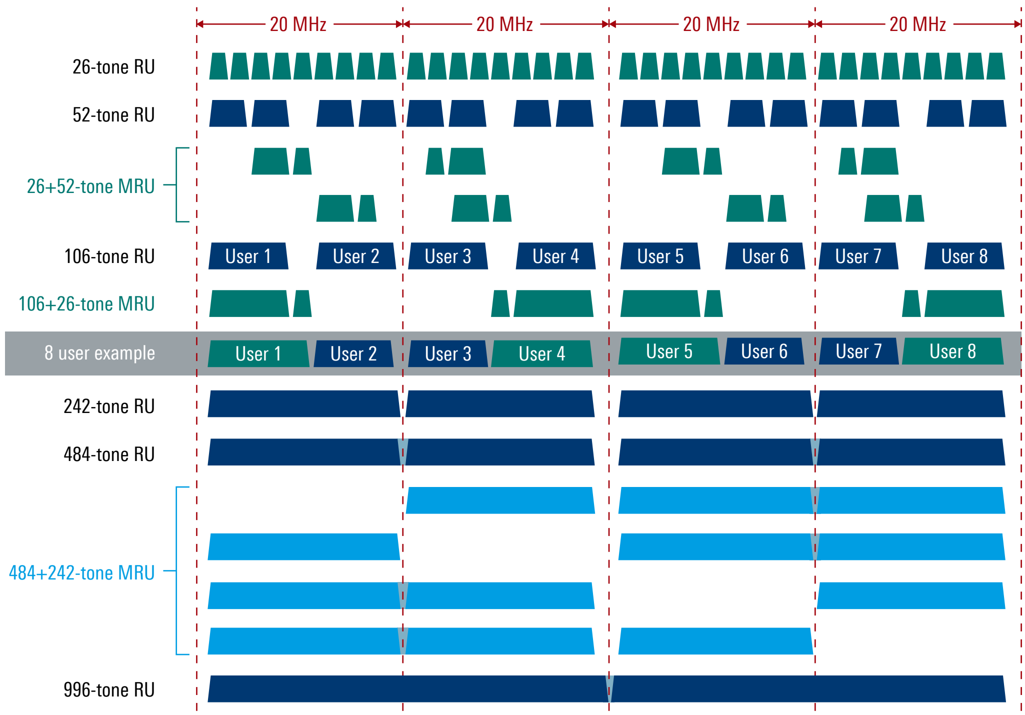
Figure 5-3: PPDU configuration example of large multi-user RUs on the R&S®SMM100A vector signal generator



The permitted large size RU combinations are used to achieve an aggregated bandwidth that would not be possible with a single RU. For example, using 484+242-tone MRU in an 80 MHz channel would yield a 60 MHz aggregated bandwidth, but supporting 484+484-tone MRU in an 80 MHz would result in 80 MHz aggregated bandwidth, which could be obtained using a single 996-tone RU instead. Unlike small size RUs, large size RUs need not be contiguous and the exact RU locations that are supported are chosen to support the puncture patterns defined by EHT.

Figure 5-4 shows the 52+26-tone, 106+26-tone and 484+242-tone MRU combinations in green. Note that only one 106+26-tone MRU is introduced in each 20 MHz segment providing a spectrally efficient way to utilize the spectrum for eight users so that users 1, 4, 5 and 8 are assigned 106+26-tone MRU and users 2, 3, 6 and 7 are assigned a single 106-tone RU. The figure also shows the large size RU combination 484+242-tone MRU with four possible permutations that can be used to support a punctured 20 MHz subchannel.

Figure 5-4: Allowed multiple resource unit (MRU) example



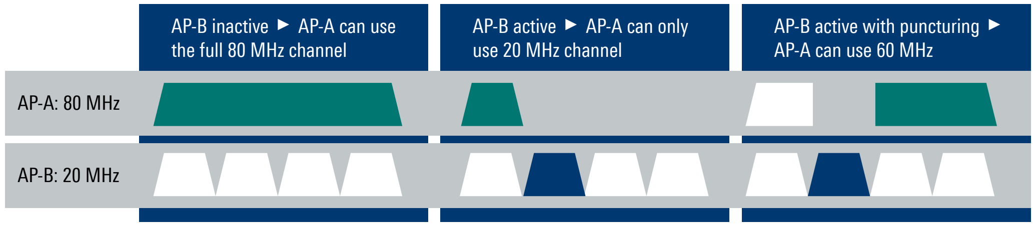
5.3 Preamble/subchannel puncturing

IEEE 802.11 operates in unlicensed bands that can be utilized by other networks and technologies. In addition, incumbent users are present in the newly allocated 6 GHz band. It is crucial that IEEE 802.11 networks behave as good neighbors and limit any interference to already occupied channels. At the same time, however, it is important to use the spectrum as efficiently as possible and make use of the wider channel bandwidths defined for IEEE 802.11be (and IEEE 802.11ax). IEEE 802.11be (and IEEE 802.11ax) therefore can utilize a wide bandwidth channel (for example 160 MHz) for transmission but puncture (not transmit) in a subchannel that is already in use. This is called preamble puncturing.

The size of the punctured subchannel is a multiple of 20 MHz. The 20 MHz resolution matches the legacy 20 MHz preamble bandwidth and makes coexistence with legacy PHYs more straightforward. Moreover, 20 MHz is the minimum IEEE 802.11be clear channel assessment (CCA) bandwidth.

Figure 5-5 illustrates three example scenarios of an 80 MHz PPDU transmission (AP-A). First, the full 80 MHz can be used for transmission because the other AP is inactive. Second, if the AP-B becomes active on the second 20 MHz channel, AP-A can only use the primary 20 MHz of the 80 MHz channel. In the third case, AP-A detects the second 20 MHz subchannel is busy. The AP signals to the STA that it is puncturing the second subchannel and will transmit on the first, third and fourth subchannels, allowing it to fully utilize the available spectrum (60 MHz).

Figure 5-5: Example of an 80 MHz PPDU transmission (AP-A) in three different scenarios



A finite number of puncturing patterns are defined to reduce signaling and implementation complexity. For OFDMA, the patterns X212, 1X12, 12X2, 121X, XX12, 12XX and 1XX2 are defined per 80 MHz subblock. Each pattern value represents a 20 MHz subchannel, "X" stands for a punctured subchannel and 1, 2 are the content channel numbers (which is similar to the IEEE 802.11ax content channel). Note that if two subchannels are punctured, they must be adjacent.

In the case of non-OFDMA, the puncturing patterns are defined depending on transmission bandwidth as shown in Table 5-1 and Table 5-2 with the punctured subchannel identified with "X". The puncturing granularity for 80 MHz and 160 MHz PPDU bandwidth is 20 MHz, and the puncturing granularity for 320 MHz PPDU bandwidth is 40 MHz. The last column in the table is the field value used to provide the puncture pattern to the device(s).

Table 5-1: Non-OFDMA puncture patterns for 80 MHz and 160 MHz PPDUs

PPDU bandwidth	Case	Pattern	RU/MRU index	Field value punctured channel indication
80 MHz	**no puncturing**	[1 1 1 1]	996-tone RU 1	0
	20 MHz puncturing	[X 1 1 1]	484+242-tone MRU 1	1
		[1 X 1 1]	484+242-tone MRU 2	2
		[1 1 X 1]	484+242-tone MRU 3	3
		[1 1 1 X]	484+242-tone MRU 4	4
160 MHz	**no puncturing**	[1 1 1 1 1 1 1 1]	2×996-tone RU 1	0
	20 MHz puncturing	[X 1 1 1 1 1 1 1]	996+484+242-tone MRU 1	1
		[1 X 1 1 1 1 1 1]	996+484+242-tone MRU 2	2
		[1 1 X 1 1 1 1 1]	996+484+242-tone MRU 3	3
		[1 1 1 X 1 1 1 1]	996+484+242-tone MRU 4	4
		[1 1 1 1 X 1 1 1]	996+484+242-tone MRU 5	5
		[1 1 1 1 1 X 1 1]	996+484+242-tone MRU 6	6
		[1 1 1 1 1 1 X 1]	996+484+242-tone MRU 7	7
		[1 1 1 1 1 1 1 X]	996+484+242-tone MRU 8	8
	40 MHz puncturing	[X X 1 1 1 1 1 1]	996+484-tone MRU 1	9
		[1 1 X X 1 1 1 1]	996+484-tone MRU 2	10
		[1 1 1 1 X X 1 1]	996+484-tone MRU 3	11
		[1 1 1 1 1 1 X X]	996+484-tone MRU 4	12

Table 5-2: Non-OFDMA puncture patterns for 320 MHz PPDUs

PPDU bandwidth	Case	Pattern	RU/MRU index	Field value punctured channel indication
320 MHz	**no puncturing**	[1 1 1 1 1 1 1 1]	4 × 996-tone RU 1	0
	40 MHz puncturing	[X 1 1 1 1 1 1 1]	3 × 996+484-tone MRU 1	1
		[1 X 1 1 1 1 1 1]	3 × 996+484-tone MRU 2	2
		[1 1 X 1 1 1 1 1]	3 × 996+484-tone MRU 3	3
		[1 1 1 X 1 1 1 1]	3 × 996+484-tone MRU 4	4
		[1 1 1 1 X 1 1 1]	3 × 996+484-tone MRU 5	5
		[1 1 1 1 1 X 1 1]	3 × 996+484-tone MRU 6	6
		[1 1 1 1 1 1 X 1]	3 × 996+484-tone MRU 7	7
		[1 1 1 1 1 1 1 X]	3 × 996+484-tone MRU 8	8
	80 MHz puncturing	[X X 1 1 1 1 1 1]	3 × 996-tone MRU 1	9
		[1 1 X X 1 1 1 1]	3 × 996-tone MRU 2	10
		[1 1 1 1 X X 1 1]	3 × 996-tone MRU 3	11
		[1 1 1 1 1 1 X X]	3 × 996-tone MRU 4	12
	80 MHz + 40 MHz puncturing	[X X X 1 1 1 1 1]	2 × 996+484-tone MRU 7	13
		[X X 1 X 1 1 1 1]	2 × 996+484-tone MRU 8	14
		[X X 1 1 X 1 1 1]	2 × 996+484-tone MRU 9	15
		[X X 1 1 1 X 1 1]	2 × 996+484-tone MRU 10	16
		[X X 1 1 1 1 X 1]	2 × 996+484-tone MRU 11	17
		[X X 1 1 1 1 1 X]	2 × 996+484-tone MRU 12	18
		[X 1 1 1 1 1 X X]	2 × 996+484-tone MRU 1	19
		[1 X 1 1 1 1 X X]	2 × 996+484-tone MRU 2	20
		[1 1 X 1 1 1 X X]	2 × 996+484-tone MRU 3	21
		[1 1 1 X 1 1 X X]	2 × 996+484-tone MRU 4	22
		[1 1 1 1 X 1 X X]	2 × 996+484-tone MRU 5	23
		[1 1 1 1 1 X X X]	2 × 996+484-tone MRU 6	24

5.4 PPDU formats

IEEE 802.11 transmits data over PHY layer protocol data units (PPDU). PPDUs contain the data to be transmitted in the frame along with a preamble prepended to the data that will be sent. The preamble consists of several fields which are used as reception aid (e.g. automatic gain control and timing synchronization) and provide information that the receiver needs to demodulate the packet. The field names are listed in Table 5-3.

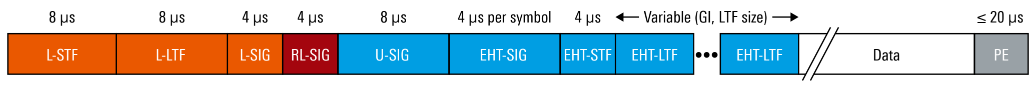
Table 5-3: PPDU field descriptions

Field	Description
L-STF	legacy short training field
L-LTF	legacy long training field
L-SIG	legacy signal field
RL-SIG	repeated legacy signal field
U-SIG	universal signal field
EHT-SIG	EHT signal field
EHT-STF	EHT short training field
EHT-LTF	EHT long training field
Data	data
PE	packet extension field

Two PPDU formats are defined in EHT:
- ▶ Multi-user PHY protocol data unit (EHT MU PPDU)
- ▶ Trigger based PHY protocol data unit (EHT TB PPDU).

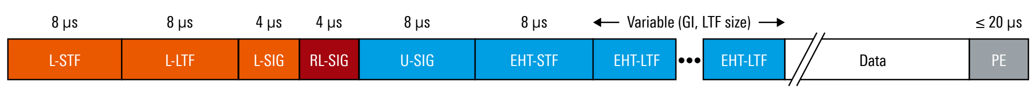
The EHT MU PPDU can be sent to a single user or to multiple users. The related EHT-SIG field, along with the U-SIG, provides RU/MRU allocations and other information the STAs need to understand the EHT MU packet. When the MU PPDU is sent to multiple users, the transmission can be OFDMA or MU-MIMO. An RU that is 242 tones or larger in an OFDMA transmission may use MU-MIMO to send the RU to up to eight users. The MU PPDU format is shown in Figure 5-6.

Figure 5-6: EHT MU PPDU format



An AP uses a control frame called a trigger frame to assign resources and solicit a response from one or more STAs. The STAs use the EHT TB PPDU to respond to the trigger from the AP. The EHT TB frame format (see Figure 5-7) is very similar to the EHT MU PPDU. However, the TB PPDU does not contain the EHT-SIG preamble field. In addition, the EHT-STF field is two times longer than in the EHT MU PPDU in order to improve performance and reliability for uplink transmissions.

Figure 5-7: EHT TB PPDU format

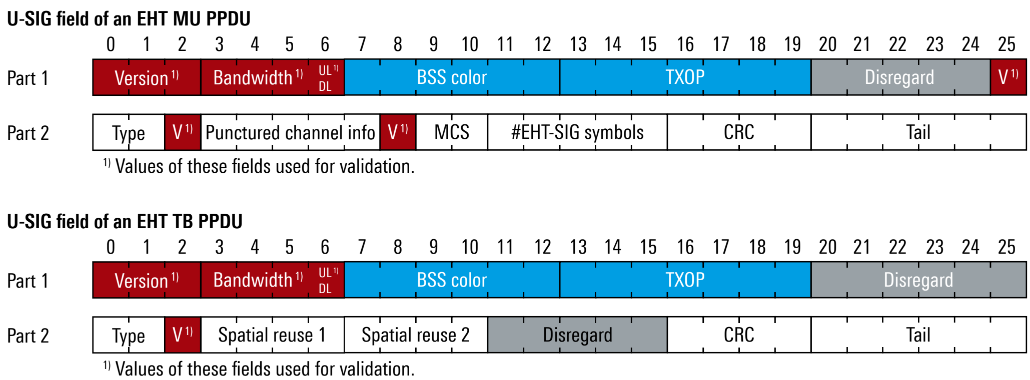


5.5 EHT preamble: designed for the future

Over the years, IEEE 802.11 has evolved the PHY layer from IEEE 802.11a published in 1999 to IEEE 802.11ax in 2021. The preamble is a crucial design component used to provide information such as MCS relevant for the receiver to decode the transmitted data. It is also used to provide backward compatibility with previous PHY versions. However, the preamble never directly conveyed the PHY version of the packet. Auto detection/spoofing mechanisms were defined for the receiver to implicitly determine the PHY version. As the number of PHYs has increased in IEEE 802.11, the auto detection algorithms have become more complex.

EHT will solve this problem by introducing the universal signal field (U-SIG). The U-SIG comes right after the RL-SIG and is 2 OFDM symbols in length. The U-SIG will be present in EHT and all future IEEE 802.11 PHYs and contains version independent and version dependent bits. The version independent bits are the first 20 bits of the U-SIG and will have the same location and definition for EHT and all future PHYs. Table 5-4 lists the contents of the independent portion of the U-SIG: The first 3 bits (bits 0 to 2) are used to identify the PHY version, which will greatly simplify auto detection for EHT and future IEEE 802.11 generations. The next 3 bits (bits 3 to 5) indicate the spectrum occupancy of the PPDU (e.g. 80 MHz bandwidth). The 7th bit (bit 6) signals the link direction (i.e. uplink or downlink). The next 6 bits (bits 7 to 12) identify the basic service set (BSS) in use via the BSS color and the 7 TXOP bits (bits 13 to 19) provide information on how long the PPDU uses the medium. The U-SIG bits/fields remainder (not described in the table) depends on the PHY version and PPDU type.

Figure 5-8: U-SIG filed content for EHT MU PPDU and EHT TB PPDU



To provide flexibility and prepare for possible new capabilities, EHT classifies the reserved bits in the EHT preamble as "disregard" or "validate". This classification helps a receiver determine the appropriate action if it comes across a bit value that is not used in a PHY it supports. Disregard means ignore this bit and continue reception. Validate means check if the bit matches a known value and if not, terminate reception. As an example, values 1 to 7 in the PHY version identifier field will correspond to a future IEEE 802.11 PHY version not recognized by a device supporting the current EHT version. If a baseline EHT device receives a value other than 0 (0 indicates EHT PHY), the device should stop reception.

Table 5-4: Content of the U-SIG version independent fields

Bit	Field	Number of bits	Description
B0 to B2	PHY version identifier	3	set to 0 for EHT, other values are validated
B3 to B5	bandwidth (BW)	3	set to 0 for 20 MHz, set to 1 for 40 MHz, set to 2 for 80 MHz, set to 3 for 160 MHz, set to 4 for 320 MHz (1), set to 5 for 320 MHz (2), values 6 and 7 are validated
B6	UL/DL	1	indicates whether the PPDU is uplink (UL) or downlink (DL), set to 1 if the PPDU is addressed to an AP (UL), set to 0 otherwise (DL)
B7 to B12	BSS color	6	BSS identifier
B13 to B19	TXOP	7	based on TXVECTOR parameter TXOP_DURATION (provides information on how long the medium is used)

6 PHY LAYER TEST REQUIREMENTS

6.1 Transmitter requirements

6.1.1 Transmit spectral mask

The spectrum mask requirements for the IEEE 802.11be 20/40/80/160 MHz bandwidth transmissions are the same as in IEEE 802.11ax. The spectrum mask for the IEEE 802.11be 320 MHz bandwidth is a scaled version of the IEEE 802.11ax mask and is shown in Figure 6-1. Table 6-1 summarizes the mask values for the five different bandwidths. Measurements are made using RBW = 100 kHz and VBW = 7.5 kHz; no other analyzer settings are specified.

Figure 6-1: IEEE 802.11be 320 MHz transmit spectral mask

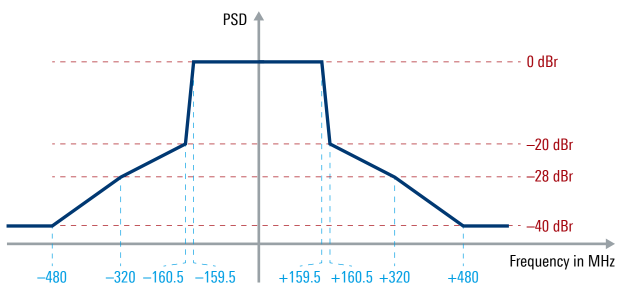


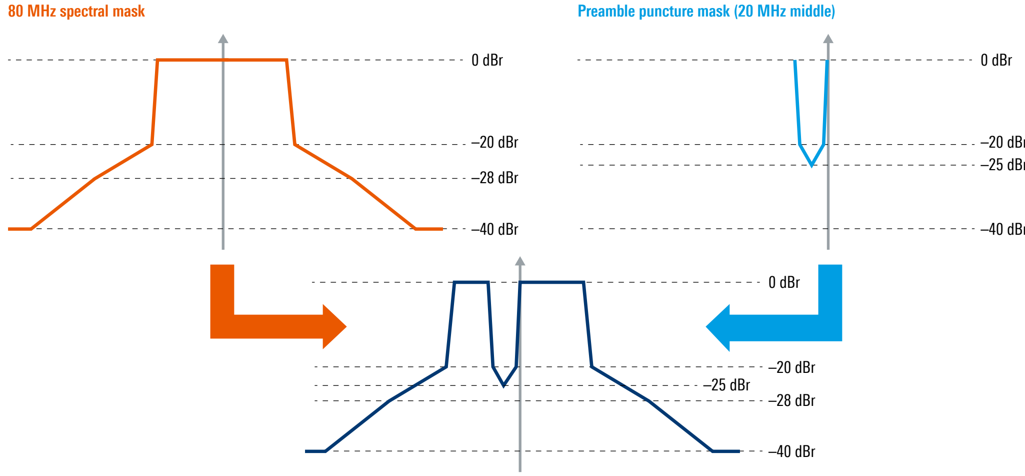
Table 6-1: Transmit mask values all channel bandwidths

Bandwidth	0 dBr	–20 dBr	–28 dBr	–40 dBr
20 MHz	±9.75 MHz	±10.5 MHz	±20 MHz	±30 MHz
40 MHz	±19.5 MHz	±20.5 MHz	±40 MHz	±60 MHz
80 MHz	±39.5 MHz	±40.5 MHz	±80 MHz	±120 MHz
160 MHz	±79.5 MHz	±80.5 MHz	±160 MHz	±240 MHz
320 MHz	±159.5 MHz	±160.5 MHz	±320 MHz	±480 MHz

6.1.1.1 PPDU spectrum mask with punctured channel(s)

Punctured subchannels are used in EHT (and HE) to avoid transmission on subchannels that are not available or are occupied by other/incumbent users. Make sure that the leakage from the occupied subchannel(s) into the punctured subchannel(s) is low enough to avoid interference. EHT applies an additional mask for the punctured subchannel(s) so that an overall spectrum mask for a PPDU containing punctured channel(s) is formed. This is done by combining the transmit spectral mask defined in the previous section with a puncture mask. The puncture masks are based on those defined in the ETSI BRAN EN 301 893 standard. Figure 6-2 illustrates the spectral mask formation for an 80 MHz PPDU with a punctured middle 20 MHz subchannel.

Figure 6-2: Spectrum mask for an 80 MHz PPDU with a punctured middle subchannel



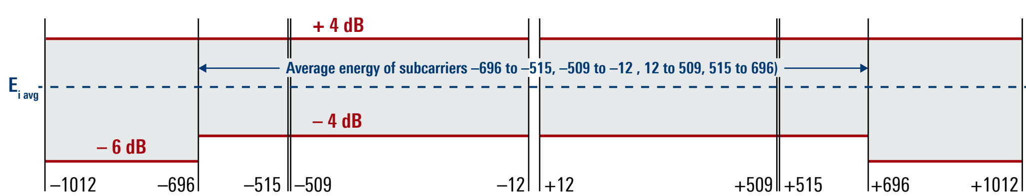
6.1.2 Spectral flatness

Spectral flatness helps measure whether the subcarriers have a similar amount of power. This is done by determining the average energy of a range of subcarriers and by verifying that no individual subcarrier's energy in that range deviates by more than the specified value.

EHT spectral flatness requirements for 20 MHz, 40 MHz and 80 MHz non-punctured PPDU are the same as in HE (see section 5.2.1 of Rohde & Schwarz white paper "IEEE 802.11ax technology introduction" [11]).

The EHT 160 MHz flatness specification differs from HE because HE requirements are based on 80+80 MHz noncontiguous transmissions that relax the acceptable deviation for the inner subcarriers. Because EHT does not use noncontiguous transmission modes, this relaxation is not needed. Figure 6-3 shows the flatness requirements for a non-punctured EHT 160 MHz PPDU.

Figure 6-3: EHT non-punctured 160 MHz spectral flatness mask



EHT includes two additional HE modifications. One is an addition of 320 MHz PPDU requirements that did not exist in HE. The other is relaxed deviation requirements for punctured PPDUs so that all occupied subcarriers are within +4/–6 dB of the inner subcarriers' average energy. Table 6-2 summarizes the EHT spectral flatness requirements for all transmission bandwidths as well as for punctured and non-punctured cases.

Table 6-2: EHT PPDU spectral flatness specification

Bandwidth	Averaging subcarrier indices (inclusive)	Tested subcarrier indices (inclusive)	Maximum deviation (in dB) without preamble puncturing	Maximum deviation (in dB) with preamble puncturing
20 MHz				
	–84 to –2, +2 to +84	–84 to –2, +2 to +84	+4/–4	–
		–122 to –85, +85 to +122	+4/–6	–
40 MHz				
	–168 to –3, +3 to +168	–168 to –3, +3 to +168	+4/–4	–
		–244 to –169, +169 to +244	+4/–6	–
80 MHz				
	–344 to –3, +3 to +344	–344 to –3, +3 to +344	+4/–4	+4/–6
		–500 to –345, +345 to +500	+4/–6	+4/–6
160 MHz				
	–696 to –515, –509 to –12, +12 to +509, +515 to +696	–696 to –515, –509 to –12, +12 to +509, +515 to +696	+4/–4	+4/–6
		–1012 to –697, +697 to +1012	+4/–6	+4/–6
320 MHz				
	–1400 to –1036, –1012 to –515, –509 to –12, +12 to +509, +515 to +1012, +1036 to +1400	–1400 to –1036, –1012 to –515, –509 to –12, +12 to +509, +515 to +1012, +1036 to +1400	+4/–4	+4/–6
		–2036 to –1539, –1533 to –1401, +1401 to +1533, +1539 to +2036	+4/–6	+4/–6

Spectral flatness is measured using BPSK modulated OFDM subcarriers. The test signal should contain at least 20 PPDUs with each PPDU including at least 16 data symbols. Non-occupied subcarriers are to be ignored during testing and averaging. In addition, resource unit power boosting and beamforming should not be used during this test.

6.1.3 Transmitter modulation accuracy

6.1.3.1 Transmit center frequency leakage

Transmit center frequency leakage measures the amount of energy that "leaks" through and appears at the RF LO frequency. This measurement is needed because too much power leakage at this frequency may lead to poor demodulator performance, depending on the receiver type used. A too high power level can cause false triggering on the signal.

The IEEE 802.11be draft standard requires that the power is measured at the RF LO location using bandwidth 78.125 kHz resolution, and the measured power should not exceed –20 dBm or the transmit power per antenna in dBm minus 32 dB.

6.1.3.2 Transmitter constellation error

The transmitter constellation error also called error vector magnitude (EVM) is an important figure of merit for transmitters in digital modulation systems. EVM helps measure how close to an ideal constellation point the device is able to transmit.

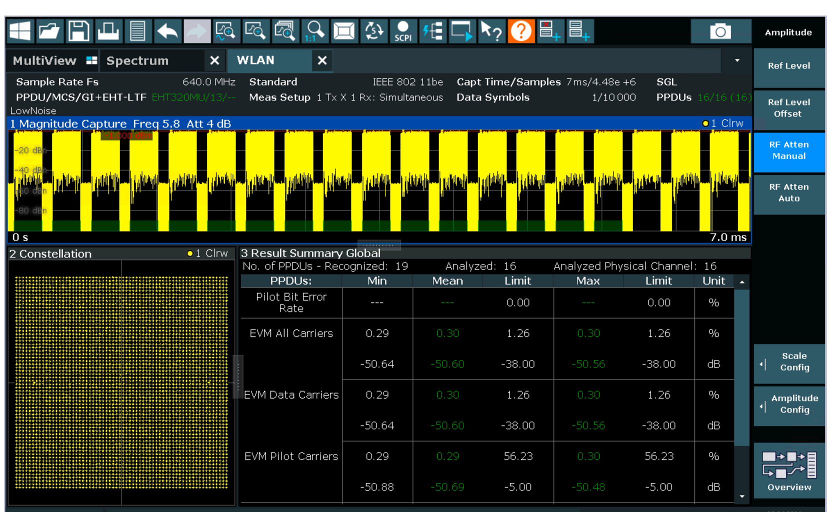
Table 6-3: ETH transmitter constellation error

MCS	Modulation	Coding	EVM of EHT MU PPDU	EVM of EHT TB PPDU transmit power larger than MCS 7 maximum power	EVM of EHT TB PPDU transmit power equal or less than MCS 7 maximum power
0	BPSK	1/2	–5 dB	–13 dB	–27 dB
1	QPSK	1/2	–10 dB	–13 dB	–27 dB
2	QPSK	3/4	–13 dB	–13 dB	–27 dB
3	16QAM	1/2	–16 dB	–16 dB	–27 dB
4	16QAM	3/4	–19 dB	–19 dB	–27 dB
5	64QAM	2/3	–22 dB	–22 dB	–27 dB
6	64QAM	3/4	–25 dB	–25 dB	–27 dB
7	64QAM	5/6	–27 dB	–27 dB	–27 dB
8	256QAM	3/4	–30 dB	–30 dB	–30 dB
9	256QAM	5/6	–32 dB	–32 dB	–32 dB
10	1024QAM	3/4	–35 dB	–35 dB	–35 dB
11	1024QAM	5/6	–35 dB	–35 dB	–35 dB
12	4096QAM	3/4	–38 dB	–38 dB	–38 dB
13	4096QAM	5/6	–38 dB	–38 dB	–38 dB
14	BPSK-DCM-DUP	1/2	–5 dB	–	–
15	BPSK-DCM	1/2	–5 dB	–13 dB	–27 dB

The IEEE 802.11be EVM measurement is very similar to IEEE 802.11ax. The test is performed using a minimum of 20 PPDUs with at least 32 data symbols containing random data if the occupied RU has 26 tones. If the occupied RU has more than 26 tones, the PPDUs must be at least 16 data symbols long. The EVM is calculated using compensation of both estimated frequency offset and sampling offset drift. The result is determined by averaging over the subcarriers, frequency segments, EHT PPDUs and spatial streams.

Test equipment used for this measurement should have a residual EVM of 10 dB or less. This means that the analyzer should be capable of measuring lower than –48 dB for the 4096QAM test case. Figure 6-4 shows a screenshot from the R&S®FSW signal and spectrum analyzer with –50 dB EVM for an EHT PPDU measuring a signal generated by an R&S®SMW200A vector signal generator using 4096QAM modulation in a 320 MHz channel.

Figure 6-4: 4096QAM WLAN constellation on 320 MHz channel and EVM measurements

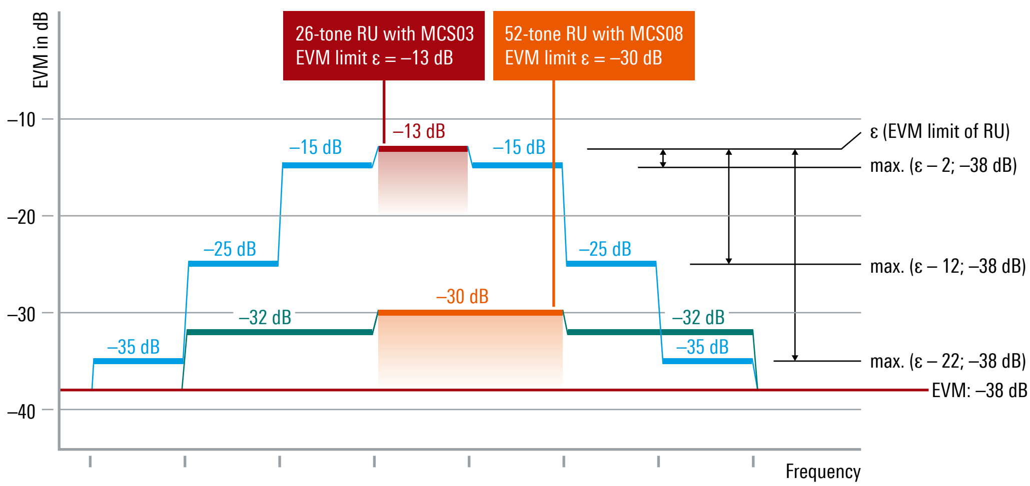


6.1.3.3 Unused tone error

For EHT TB PPDU, the EVM requirements need to account for multiple STAs transmitting at the same time. The AP sees noise from multiple sources as total cumulative noise, and network performance deteriorates if this noise becomes too large. In addition, a STA transmitting power unintentionally outside of its allocated RU negatively affects the EVM of other STAs. Therefore, EHT TB PPDUs must also meet the EVM unused tones requirement for measuring if a STA causes interference to adjacent RUs.

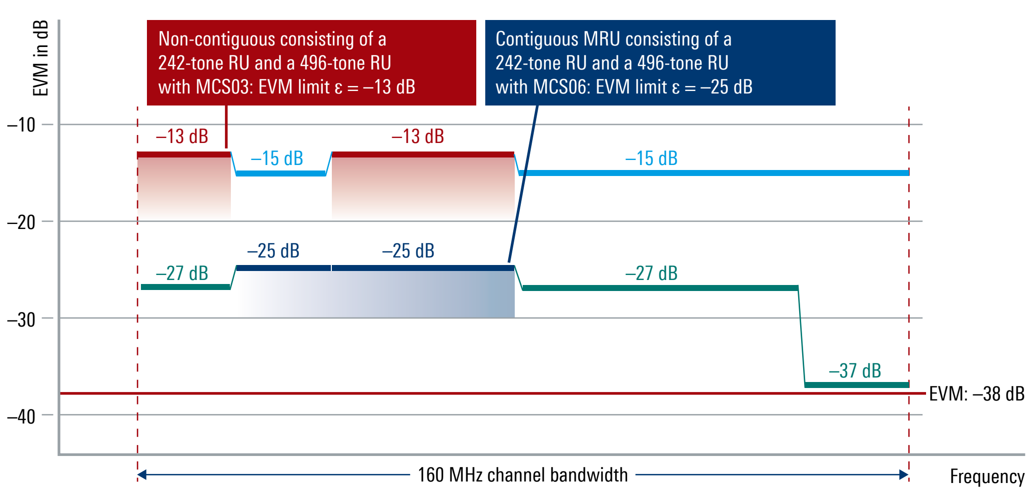
The unused tone error is measured and averaged in 26-tone RU blocks to avoid frequency-dependent variations. Unused tone error limits are specified as staircase masks defined at three points depending on the RU size and the EVM limit (ε) of the used RU. Figure 6-5 shows the unused tone error mask for a 26-tone RU (in blue) and for a 52-tone RU (in green). The mask includes a noise floor of –38 dB as shown with the green mask. An MRU mask containing contiguous RUs is formed using the same method.

Figure 6-5: Unused tone error for single user RUs



Noncontiguous MRUs are first treated as large RUs/MRUs which do not have an unmodulated portion. For example, a 242+484 tone MRU with its second 20 MHz unused is treated as 992-tone RU in order to determine the EVM mask value. The limit for the unused portion (i.e. the second 20 MHz) is max. (ε – 2; –38 dB). Figure 6-6 shows a 242+496 tone MRU using MCS03.

Figure 6-6: Unused tone error for contiguous and noncontiguous MRUs



6.2 EHT receiver requirements

The IEEE 802.11be receiver testing requirements and limits described in this section are similar to those defined in the IEEE 802.11ax specification. For information and details on how to generate IEEE 802.11ax receiver test signals, see Rohde & Schwarz application note "Generating WLAN IEEE 802.11ax Signals". This paper also covers additional receiver test features such as adding fading and imperfections to generated signals. It can be downloaded from www.rohde-schwarz.com/appnote/1GP115.

6.2.1 Receiver minimum input sensitivity

The minimum input sensitivity test verifies that a receiver is able to successfully demodulate a signal at a given minimum input level. Successful demodulation is determined by a packet error rate (PER) of less than 10 %. For IEEE 802.11be, the minimum input sensitivity level depends on the modulation, coding rate and bandwidth as shown in Table 6-4. The IEEE 802.11be packets used for this test should be 4096 byte in length.

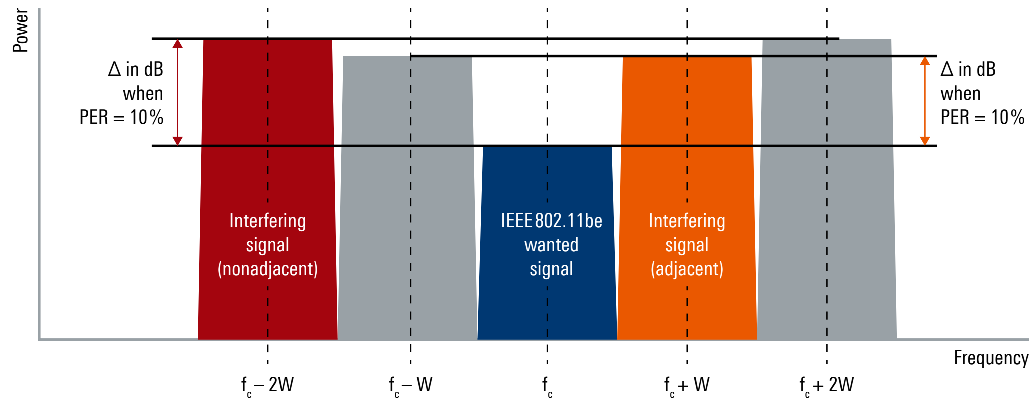
Table 6-4: Minimum sensitivity limits

MCS	Modulation	Coding rate (R)	Minimum sensitivity (20 MHz PPDU, in dBm)	Minimum sensitivity (40 Hz PPDU, in dBm)	Minimum sensitivity (80 MHz PPDU, in dBm)	Minimum sensitivity (160 MHz PPDU, in dBm)	Minimum sensitivity (320 MHz PPDU, in dBm)
0	BPSK	1/2	–82	–79	–76	–73	–70
1	QPSK	1/2	–79	–76	–73	–70	–67
2	QPSK	3/4	–77	–74	–71	–68	–65
3	16QAM	1/2	–74	–71	–68	–65	–62
4	16QAM	3/4	–70	–67	–64	–61	–58
5	64QAM	2/3	–66	–63	–60	–57	–54
6	64QAM	3/4	–65	–62	–59	–56	–53
7	64QAM	5/6	–64	–61	–58	–55	–52
8	256QAM	3/4	–59	–56	–53	–50	–47
9	256QAM	5/6	–57	–54	–51	–48	–45
10	1024QAM	3/4	–54	–51	–48	–45	–42
11	1024QAM	5/6	–52	–49	–46	–43	–40
12	4096QAM	3/4	–49	–46	–43	–40	–37
13	4096QAM	5/6	–46	–43	–40	–37	–34
14	BPSK-DCM-DUP	1/2	N/A	N/A	–78	–75	–72
15	BPSK-DCM	1/2	–82	–79	–76	–73	–70

6.2.2 Adjacent and nonadjacent channel rejection

Adjacent channel rejection tests are used to measure the ability of an IEEE 802.11be receiver to detect and demodulate a signal in the presence of stronger signals in a nearby channel. Figure 6-1 illustrates the concept. The receiver demodulates the wanted IEEE 802.11be signal at f_0 with a bandwidth of W MHz (W = 20, 40, 80, 160 or 320) and power set 3 dB higher than the value of the minimum sensitivity level given in Table 6-4. An interfering EHT-compliant signal with a duty cycle (on/off ratio) greater than 50 % and the same bandwidth as the wanted signal is centered W MHz from the wanted signal (f_c + W MHz). The packet error rate is measured as the interferer signal power is increased. When the packet error rate reaches 10 %, the delta between the interferer power and the wanted signal power is measured. This delta is called adjacent channel rejection. It must be greater than the value provided in Table 6-5. (If a 160 MHz or 320 MHz receiver is being tested but the regulatory domain does not allow an adjacent 160 MHz or 320 MHz channel, the adjacent channel rejection test can be skipped.)

Figure 6-7: Adjacent and nonadjacent channel rejection



Nonadjacent channel rejection is similar, but the interfering signal is 2W MHz from the wanted signal as shown in Figure 6-7.

Table 6-5: Minimum adjacent and nonadjacent channel rejection requirements for 20/40/80/160/320 MHz channel

MCS	Modulation	Coding rate (R)	Adjacent channel rejection (in dB)	Nonadjacent channel rejection (in dB)
0	BPSK	1/2	16	32
1	QPSK	1/2	13	29
2	QPSK	3/4	11	27
3	16QAM	1/2	8	24
4	16QAM	3/4	4	20
5	64QAM	2/3	0	16
6	64QAM	3/4	–1	15
7	64QAM	5/6	–2	14
8	256QAM	3/4	–7	9
9	256QAM	5/6	–9	7
10	1024QAM	3/4	–12	4
11	1024QAM	5/6	–14	2
12	4096QAM	3/4	–17	–1
13	4096QAM	5/6	–20	–4
14	BPSK-DCM-DUP	1/2	16	32
15	BPSK-DCM	1/2	16	32

6.2.3 Receiver maximum input level

The receiver maximum input level tests the ability of a receiver to demodulate an IEEE 802.11be signal with an input level of –30 dBm operating in the 5 GHz and 6 GHz bands and –20 dBm operating in the 2.4 GHz band. The packet error rate (PER) is measured at each physical antenna port and must be below 10 %. The measurement uses a PSDU length of 2048 octets for BPSK modulation with DCM or 4096 octets for all other modulations.

6.3 Trigger based PPDU precorrection specifications

When an AP solicits simultaneous TB PPDUs from multiple STAs, it is necessary that packets from the different STAs arrive at the AP with similar power, frequency and time to ensure the packets are synchronized and do not cause interference. IEEE 802.11be (similar to IEEE 802.11ax) defines TB PPDU precorrection tests to ensure proper precorrection of STA transmissions to meet this goal.

6.3.1 Transmit power accuracy and RSSI measurement

Transmit power and RSSI measurement inaccuracies can result in excessive interference during uplink multi-user transmissions. Table 6-6 provides the transmit power and RSSI requirements for EHT trigger based PPDUs. The absolute transmit power accuracy is applicable for the entire STA transmit power range. The RSSI is measured on the non-EHT portion of the EHT PPDU preamble to meet RSSI accuracy requirements. In the 2.4 GHz band, this is applicable for receive signals from –82 dBm to –20 dBm, and in the 5 GHz and 6 GHz band for receive signals from –82 dBm to –30 dBm. Note that there are different requirements for high capability devices (device class A) and low-cost devices (device class B).

Table 6-6: Transmit power and RSSI measurement requirements

Parameter	IEEE 802.11be minimum requirements		Comments
	Class A devices	Class B devices	
Absolute transmit power accuracy	±3 dB	±9 dB	Accuracy of achieving a specified transmit power level
Relative transmit power accuracy	not applicable	±3 dB	Accuracy of the change in transmit power for consecutive EHT TB PPDU
RSSI measurement accuracy	±3 dB	±5 dB	Difference between the measured RSSI and the received power

6.3.2 Carrier frequency offset (CFO) error and timing drift

A STA has to compensate CFO error compensation relative to the trigger frame frequency in order to reduce the amount of residual CFO at the AP during UL MU transmission.

For the CFO requirement, the CFO error statistics are measured. At the 10 % point of the CCDF curve, the CFO error must be less than 350 Hz. The measurement is made in the primary 20 MHz channel at –60 dBm received power. The CFO is measured after the U-SIG field on an EHT TB PPDU.

In order for the AP to decode packets from multiple users, the UL OFDMA and MU-MIMO transmissions need to be synchronized when the AP receives them. After the users receive information from the AP to trigger the uplink transmissions, they transmit the HE_TB PPDU at a specified time. At the STA antenna connector, the accuracy of this time is required to be ±0.4 μs + 16 μs from the end of the last OFDM symbol of the triggering PPDU sent by the AP to trigger the UL transmissions.

7 ABBREVIATIONS

Term	Explanation
AFC	Automated frequency coordination
AP	Access point
BCC	Binary convolutional coding
BPSK	Binary phase shift keying
BSS	Basic service set
BW	Bandwidth
CCA	Clear channel assessment
CCDF	Complementary cumulative distribution function
CFO	Carrier frequency offset
CRC	Cyclic redundancy check
CSMA	Carrier sense multiple access
DCM	Dual carrier modulation
DL	Downlink
DUP	Duplicated transmission
EHT	Extremely high throughput
EIRP	Equivalent isotopically radiated power
EVM	Error vector magnitude
GI	Guard interval
HE	High efficiency
IEEE	Institute of Electrical and Electronics Engineers
LDPC	Low density parity check
L-LTF	Legacy long training field
L-STF	Legacy short training field
LO	Local oscillator
LPI	Low power indoor
LTF	Long training field
MAC	Medium access control layer
MIMO	Multiple input multiple output
MLD	Multilink device
MLO	Multilink operation
MRU	Multiple resource unit
MU	Multi-user
MU-MIMO	Multi-user MIMO
OFDM	Orthogonal frequency division multiplexing
OFDMA	Orthogonal frequency division multiplexing access
PA	Power amplifier
PE	Packet extension
PER	Packet error rate
PHY	Physical layer
PLCP	Physical layer convergence procedure
PPDU	PLCP protocol data unit
PSDU	Physical service data unit
PPM	Parts per million
PS	Power save (mode)
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase shift keying
RBW	Resolution bandwidth
RSSI	Receive signal strength indicator
RU	Resource unit
SFD	Specification framework document
SIG	Signal field
STA	Station

Term	Explanation
STBC	Space time block coding
STF	Short training field
STR	Simultaneous transmit and receive
SU	Single user
TBD	To be determined
TG	Task group
TWT	Target wait time
TXOP	Transmission opportunity
UL	Uplink
U-SIG	Universal signal field
VBW	Video bandwidth
VHT	Very high throughput
VLP	Very low power
WLAN	Wireless local area network

8 REFERENCES

[1] IEEE 802.11 amendments on IEEE 802.11 website. [Online].
Available: www.ieee802.org/11/QuickGuide_IEEE_802_WG_and_Activities.htm

[2] IEEE 802.11be project authorization request (PAR). [Online].
Available: www.ieee802.org/11/PARs/P802_11be_PAR_Detail.pdf

[3] List of Wi-Fi 6e certified products. [Online].
Available: www.wi-fi.org/product-finder-results?sort_by=certified&sort_order=desc&capabilities=189&certifications=1275

[4] IEEE 802.11be Specification Framework Document, latest version. [Online].
Available: https://mentor.ieee.org/802.11/documents?is_dcn=1935&is_group=00be

[5] IEEE 802.11 task groups, public status updates. [Online].
Available: www.ieee802.org/11/Reports/tgbe_update.htm

[6] E. Au, „IEEE 802.11 Documents," 17 January 2021. [Online].
Available: https://mentor.ieee.org/802.11/dcn/19/11-19-1262-23-00be-specification-framework-for-tgbe.docx

[7] „IEEE 802.11-2020: Wireless LAN Medium Access Control and Physical Layer (PHY) Specifications," in Amendment IEEE 802.11ax Enhancements for High-Efficiency WLAN, 2021

[8] „IEEE P802.11be™/D1.0," in Amendment 8: Enhancements for extremely high, 2021

[9] R. Cao, „IEEE 802.11 Documents," 27 October 2020. [Online].
Available: https://mentor.ieee.org/802.11/dcn/20/11-20-1100-01-00be-discussions-on-eht-non-contigeous-ppdu.pptx

[10] R. Porat, „IEEE 802.11 Documents," 01 May 2020. [Online].
Available: https://mentor.ieee.org/802.11/dcn/20/11-20-0666-01-00be-80mhz-ofdma-tone-plan.pptx

[11] L. Ward, „IEEE 802.11ax technology introduction 2020," Rohde & Schwarz white paper, [Online]. Available: www.rohde-schwarz.com/solutions/test-and-measurement/wireless-communication/wireless-connectivity/wlan-wifi/wlan-ieee-802.11ax-testing/white-paper-ieee-802.11ax-technology-introduction_253050.html

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