WLAN Tool Box for MATLAB Users: IEEE802.11ax

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Outline

- Brief Review on IEEE 802.11ax (High Efficiency WLAN)
- Intro to WLAN Tool Box for MATLAB Users

Wi-Fi is Emerging to 5G Wireless

- On 17 December 2019 the IEEE announced “IEEE P802.11ax meets or exceeds requirements specified by the International Telecommunications Union for the 5G *Indoor Hotspot and Dense Urban* test environments of the enhanced Mobile Broadband (eMBB) usage scenario. IEEE P802.11ax establishes a foundation for an advanced Wi-Fi technology capable of supporting 5G network performance.”

Carrier Wi-Fi

802.11ax is focused on improving performance in dense environments

- Existing 802.11 WLAN systems serve dense deployments: 2019 Super bowl: 24TB* of data carried on WLAN network
- 802.11ax aims to further improve performance of WLAN deployments in dense scenarios
  - Targeting at least 4x improvement in the per-STA throughput compared to 802.11n and 802.11ac.
  - Improved efficiency through spatial (MU MIMO) and frequency (OFDMA) multiplexing.
- Dense scenarios are characterized by large number of access points and large number of associated STAs deployed in geographical limited region
  - e.g. a stadium or an airport.

Access to Internet, latest airlines' announcements, and digital media such as movies and sport events

* https://www.extremenetworks.com/resources/slideshare/wi-fi-engagements-from-super-bowl-liii/

Source: IEEE 802.11 Public Doc [2]

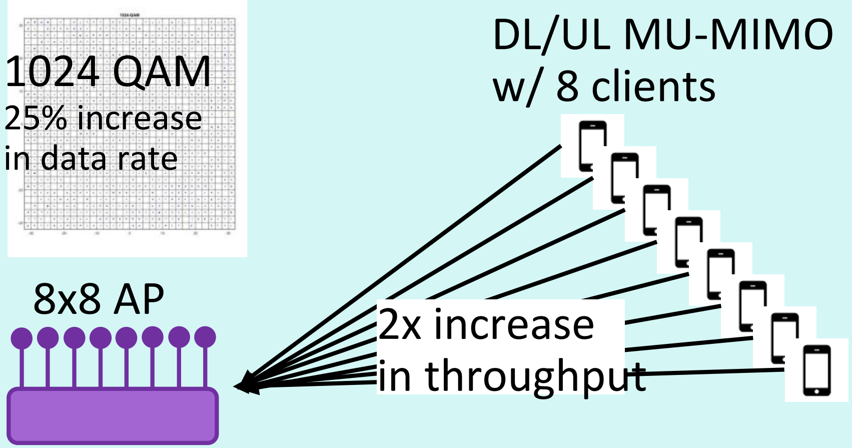
802.11ax Categories of Enhancements

Spectral Efficiency & Area Throughput

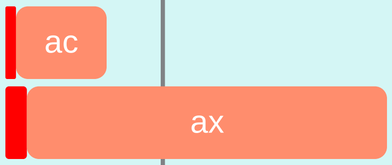
1024 QAM
25% increase in data rate

DL/UL MU-MIMO w/ 8 clients

8x8 AP



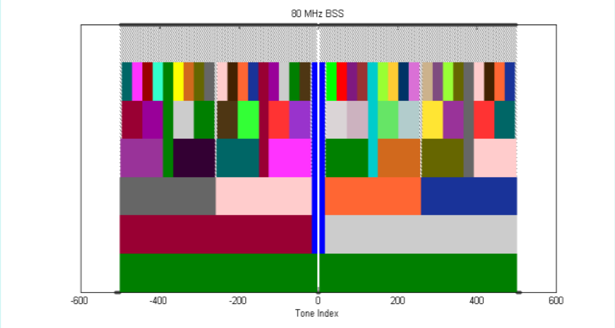
Long OFDM Symbol



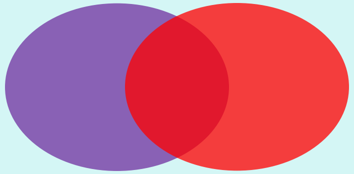
Up to 20% increase in data rate

High Density

OFDMA

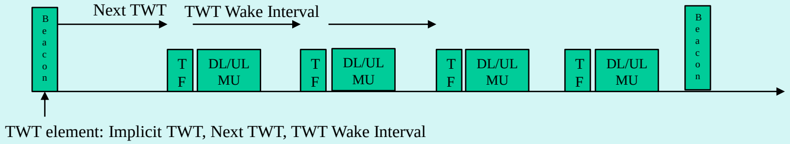


Spatial Reuse



Power Saving

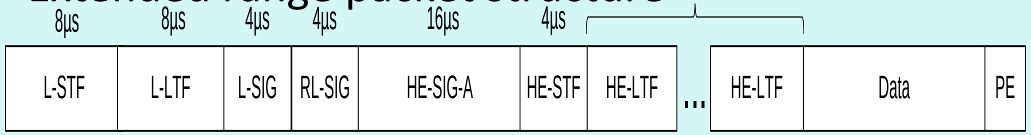
Scheduled sleep and wake times



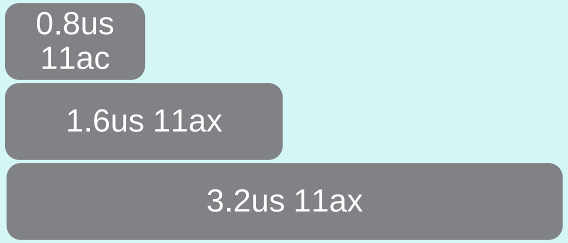
20 MHz-only clients

Outdoor / Longer range

Extended range packet structure

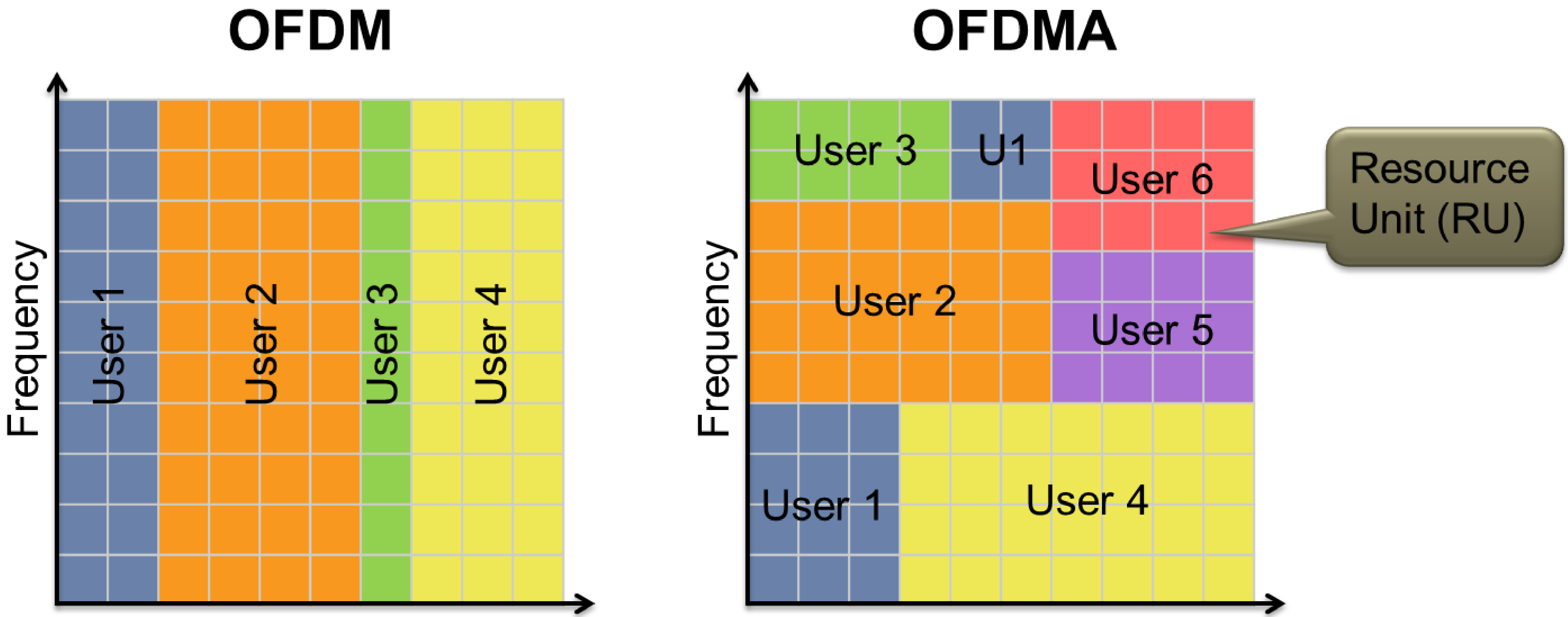


Enhanced delay spread protection- long guard interval



Source: IEEE 802.11 Public Doc [2]

OFDMA enables further AP customization of channel use to match client and traffic demands

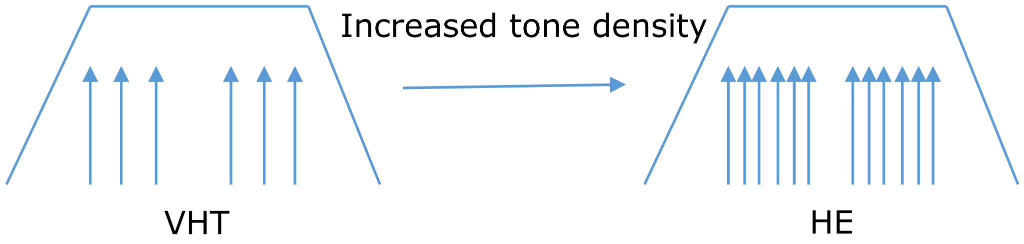


Increased efficiency for (high percentage of traffic) short data frames

Source: IEEE 802.11 Public Doc [2]

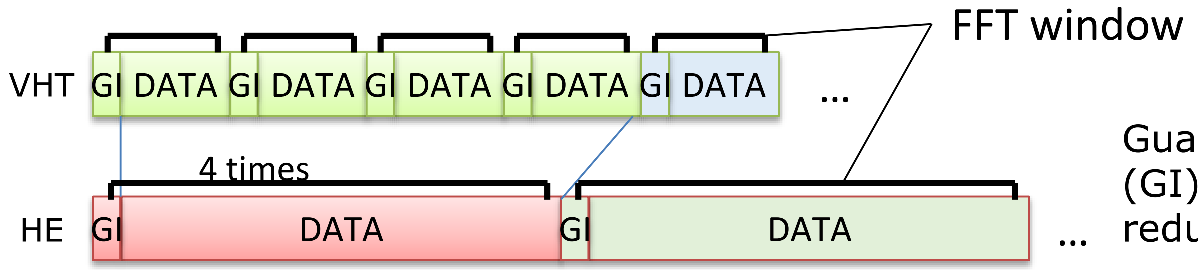
802.11ax Increases link efficiency

Frequency domain
(~5% gain)



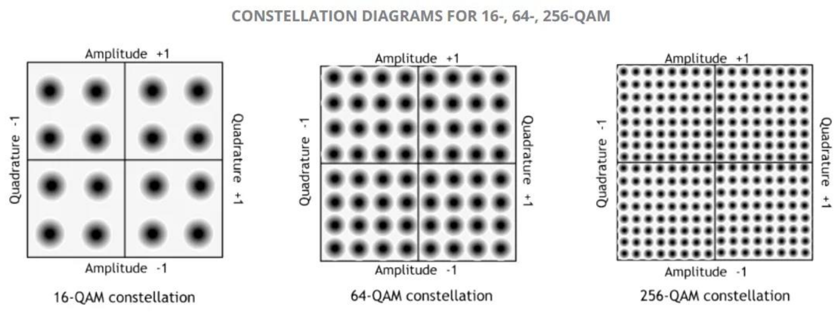
Squeeze more tones in around DC and edge

Time domain
(~15% gain)



Guard interval (GI) overhead reduced

Modulation
(~25% gain)



+ 1024-QAM

Source: IEEE 802.11 Public Doc [2]

UL OFDMA & UL MU-MIMO

Scheduled UL access for increased capacity and efficiency

Contention based resource allocation (11ac)

- Un coordinated resource management
- Devices all compete and try to get resource till they succeed
- Works well in single AP scenario

Scheduling based resource allocation (11ax)

- Up link resource allocation managed by AP
- A must for dense scenarios
- Increased capacity and better user experience

Source: Qualcomm marketing [3]

Key PHY Features/Capabilities

- 8x8 MU-MIMO & OFDMA both UL/DL
- More Spatial Streams
- BSS Color to enable additional channel reuse
- Uplink resource scheduling (via Trigger Based PPDU)
- Higher order modulation for higher throughput (1024 QAM)
- Enhanced cyclic length for outdoor (longer range) applications
- Midamble for mobility

WLAN Tool Box or Work Bench

- Standard based waveform generation and receiver processing
  - ✓ All preamble, signaling bits, modulation/coding, and the PPDU format are compliant with the standard
- Applications may include
  - ✓ To employ the generated 11ax waveform to assist the signal processing algorithm design and development taking into account of random arrival and CCA detection, frequency drift, and various channel models, etc.
  - ✓ To feed the generated 11ax waveform to assist receiver hardware (FPGA/ASIC) design and optimization
  - ✓ To measure the signal integrity of an 11ax waveform generated from any transmitting hardware such as FPGA

HE PPDU FORMATS [1]

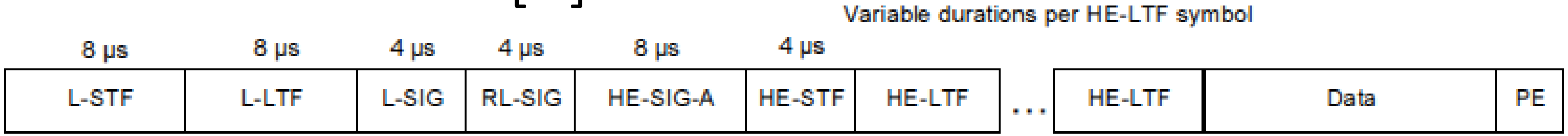


Figure 27-8—HE SU PPDU format

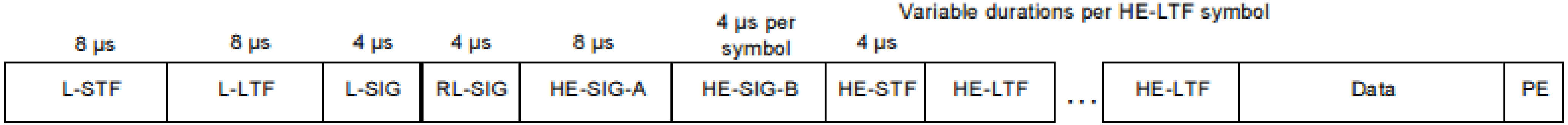


Figure 27-9—HE MU PPDU format

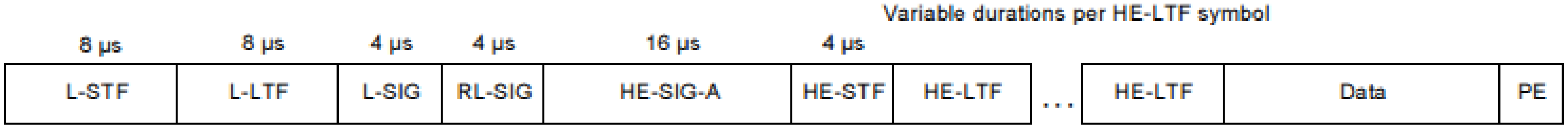


Figure 27-10—HE ER SU PPDU format

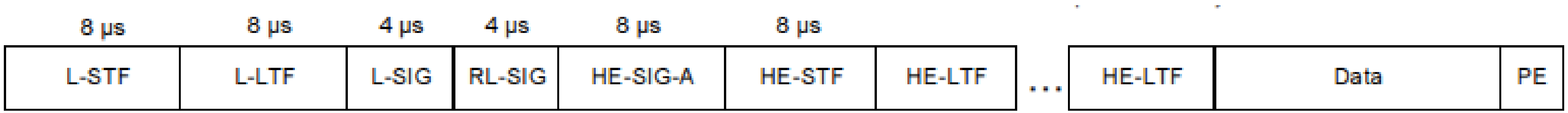


Figure 27-11—HE TB PPDU format

Example 1 from Annex Z [1]

An example of the HE-SIG-B field with resource allocation signaling for an 80 MHz HE MU PPDU is shown in Table Z-1.

Table Z-1—Resource allocation signaling example 1

RU	484-tone RU 1	26-tone RU 19 (center 26-tone RU)	242-tone RU 3	242-tone RU 4
SS0	STA-ID 1441, HE-MCS 10, LDPC	STA-ID 1443, HE-MCS 3, BCC, 1SS, no beam-forming, no DCM	STA-ID 1444, HE-MCS 4, BCC, 2SS, Tx beam-forming	STA-ID 1445, HE-MCS 8, BCC
SS1				STA-ID 1446, HE-MCS 7, BCC
SS2	STA-ID 1442, HE-MCS 9, LDPC		N/A	STA-ID 1447, HE-MCS 6, BCC
SS3				STA-ID 1448, HE-MCS 5, BCC

Example from Annex Z (HE-SIG-B Content) [1]

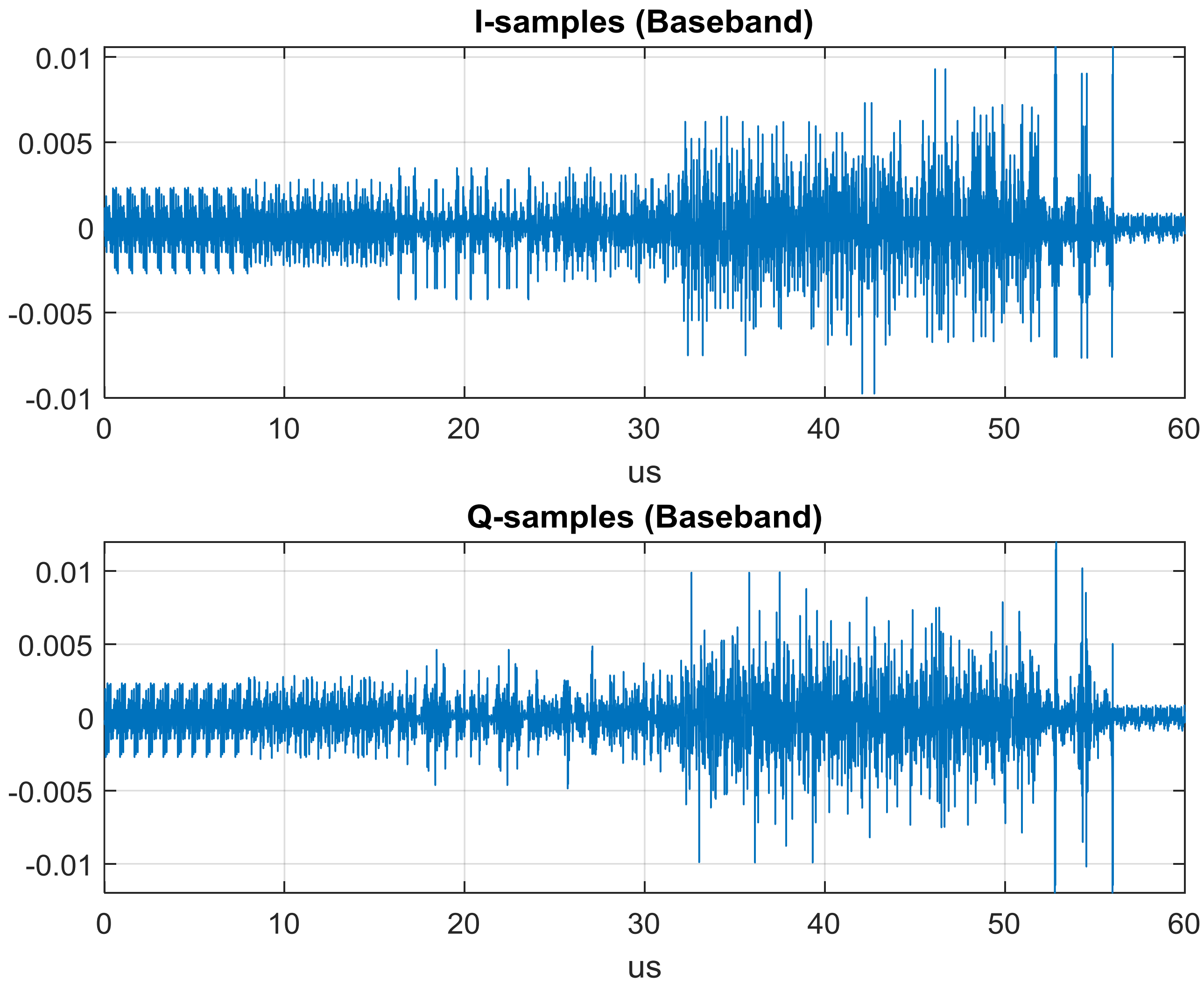
Table Z-2—HE-SIG-B content for example 1

	HE-SIG-B content channel 1		HE-SIG-B content channel 2	
Common field	10010011 00000011 1 1111 000000		01001110 11000011 1 1100 000000	
User fields	STA 1441	10000101101 0010 0101 0 1	STA 1445	10100101101 0000 0001 0 0
	STA 1442	01000101101 0010 1001 0 1	STA 1446	01100101101 0000 1110 0 0
	CRC & tail	0011 000000	CRC & tail	1101 000000
	STA 1444	00100101101 100 1 0010 0 0	STA 1447	11100101101 0000 0110 0 0
	STA 1443	11000101101 000 0 1100 0 0	STA 1448	00010101101 0000 1010 0 0
	CRC & tail	1000 000000	CRC & tail	1001 000000
	Padding	0	Padding	0
HE-SIG-B field content in hexa-decimal	0x9303F810B49545A529804B648C5A18400		0x4EC3E014B40465A1C681CB41815A14480	

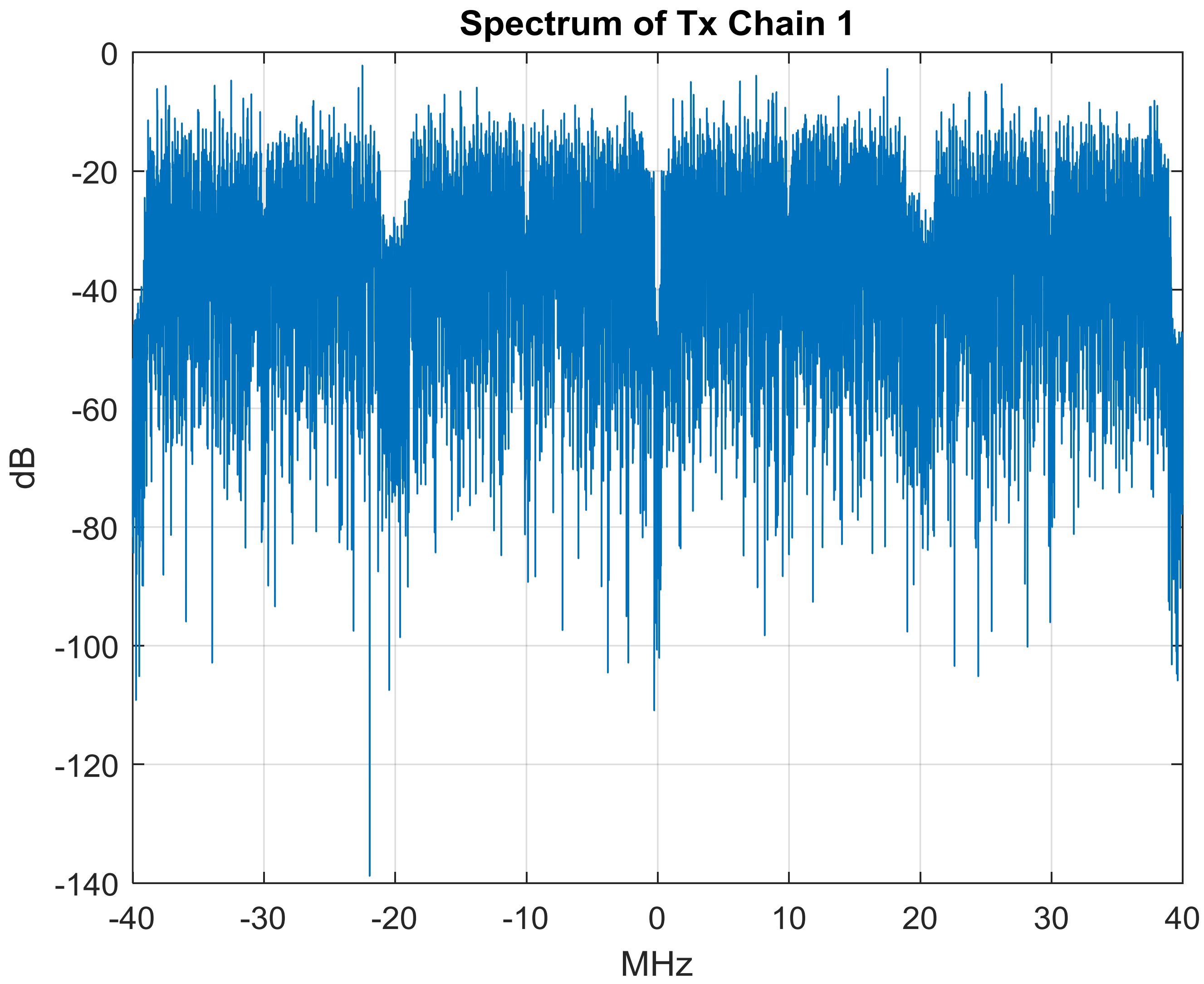
MAC Provided TXVECTOR as the PHY Input

Read Me: When HE_SU or HE_ER_SU is specified, RU is ignored.												
FORMAT_HE	1		0=SU, 1=MU, 2=ER_SU, 3 =TB									
CHBW	80		MHz									
N_TX	NO_SIG_EXTN	STBC	GI_TYPE	TXPW_LEVEL_INDEX	TXOP_DURATION	SPATIAL_REUSE	DOPPLER	HE_LTF_TYPE	BEAM_CHANGE	BSS_COLOR	UPLINK_FLAG	MIDAMBLE_PERIODICITY
1	1	0	1	0	0	0	0	1	1	1	1	0
0	0	0	1	4	MU parameters: A) SIG_B_COMPRESSION_MODE, B) MCS_SIGB, C) DCM_SIGB, D) CENTER_26_TONE_RU, E) NUM_HE_LTF							
201	192	114	195					RU Allocations (up to 8 RUs)				
0	0	0	0	0	0	0	0	INACTIVE SUBCHANNELS from the lowest to the highest 20 MHZ (0=active, 1=inactive)				
STA_ID	FEC	MCS	APEP_LENGTH	NUM_STS	DCM	DELTA_SNR	BEAM-FORMED	NORMAL_PACKET_PADDING	EXPANSION_MAT	YorN_MU_MIMO	Space-config	
1441	1	10	96	2	0	0	0	0	0	1	4	
1442	1	9	96	2	0	0	0	0	0	1	4	
1444	0	4	1024	2	0	0	1	0	0	0	0	
1443	0	3	100	1	0	0	0	0	0	0	0	
1445	0	8	600	1	0	0	0	0	0	1	0	
1446	0	7	1024	1	0	0	0	0	0	1	0	
1447	0	6	600	1	0	0	0	0	0	1	0	
1448	0	5	1024	1	0	0	0	0	0	1	0	

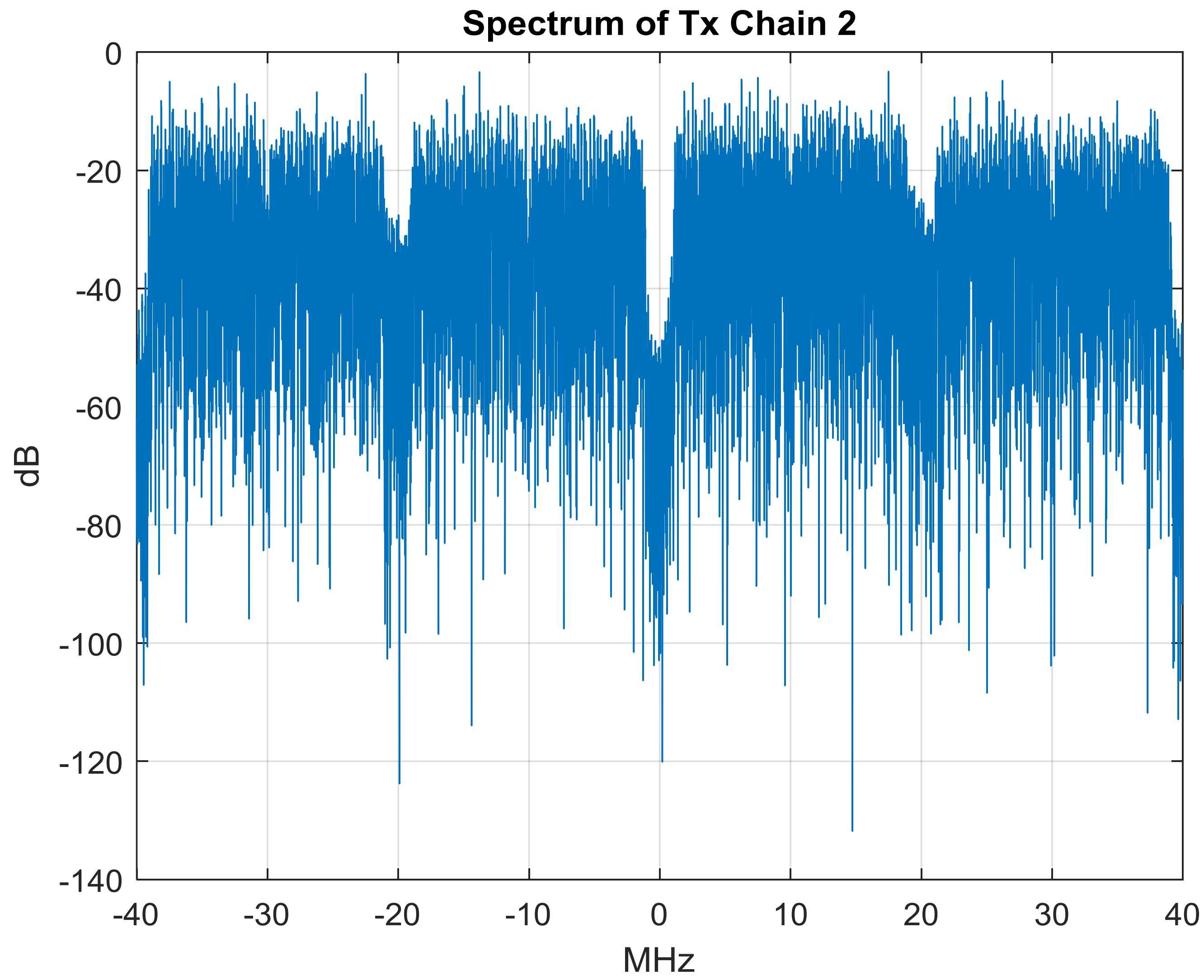
Generated I/Q Samples (Baseband)



Transmitted Spectrum (Tx 1)



Transmitted Spectrum (Tx 2)



TXVECTOR Input Display

The selected file name is User_Data_Input_80Ex1.csv
TXVECTOR input:
PPDU FORMAT= HE PPDU MU, Channel Bandwidth= 80
N_TX= 1, NO_SIG_EXTN= 1, STBC= 0, GI_TYPE= 1, TXPW_LEVEL_INDEX= 0
TXOP_DURATION= 0, SPATIAL_REUSE= 0, DOPPLER= 0, HE_LTF_TYPE= 1
BEAM_CHANGE= 1, BSS_COLOR= 1, UPLINK_FLAG= 1, MIDAMBLE_PERIODICITY= 0
SIG-B Compression= 0, SIGB-MCS= 0, SIGB-DCM= 0, NUM_HE_LTF= 4
Center_26_Tone_RU= 1
******* MU-MIMO User Info from TxVECTOR *******

```
1441 1 10     96 2 0 0 0 0 0 1 4
1442 1  9     96 2 0 0 0 0 0 1 4
1444 0  4   1024 2 0 0 1 0 0 0 0
1443 0  3    100 1 0 0 0 0 0 0 0
1445 0  8    600 1 0 0 0 0 0 1 0
1446 0  7   1024 1 0 0 0 0 0 1 0
1447 0  6    600 1 0 0 0 0 0 1 0
1448 0  5   1024 1 0 0 0 0 0 1 0
```

Data Processing Validating TXVECTOR

------- RU Allocations -------
CHBW= 80 MHz, Number of RUs = 5
RU tones: 484 242 26 484 242
RU index: 1 1 19 1 1
Number of Users per RU: 2 1 1 0 4
RU power scaler: 1.000 1.000 1.000 0.000 1.000
++++++++++++++++++++++++++++++++++++
N_TX is updated to N_STS_Qk= 4 from 1

Internal checking

N_SYM=18, a_factor=1, LDPC_EXTRA_SYMBOL=0
L_preamble=20 us, HE_preamble=72 us
SIGB_CC1
9303F810B49545A529804B648C5A18400
SIGB_CC2
4EC3E014B40465A1C681CB41815A14480

Parsed L-SIG and SIG-A at Rx End

... Start processing Rx...
Receiving PPDU format: MU_MIMO....... Channel Bandwidth: 80 MHz
The Rx chain under examination = 1
Rx_wave power=4.20e-04, pwr_L-STF=9.07e-04, pwr_L-LTF1=9.07e-04, pwr_L-LTF2=9.07e-04
L-SIG: Rate mode= 6, LENGTH (from TXTime)= 245
++
SIGA of MU PPDU:
UPLINK_FLAG=1, HE_SIGB_MCS=0, HE_SIGB_DCM=0, BSS_Color=1, Spatial_Reuse=0
N_HE_SIGB_or_MU_MIMO=6, HE_SIGB_Compression=0, GI+LTF_TYPE=2, Doppler=0, TXOP=0
N_HE_LTF_SYM=4, Midamble=0, LDPC_EXTRA_SYMBOL=0, STBC=0, a_factor=1, PE_Disambiguity=0

Parsed SIG-B Content Channels at Rx End

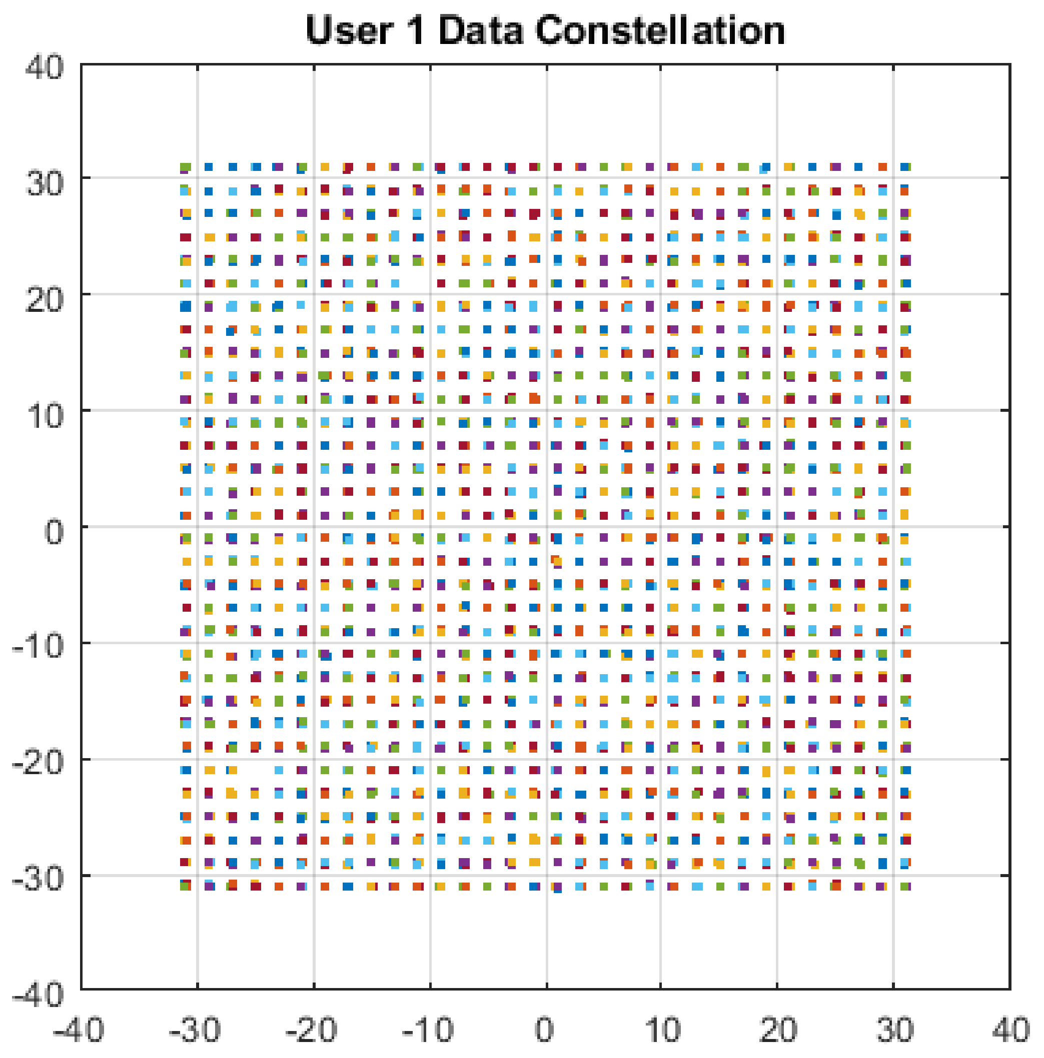
Decoded SIGB on CC 1
9303F810B49545A529804B648C5A184000000000
SIGB decoded user info on Content Channel 1
STA_ID, N_SS, Beamformed, HE-MCS, DCM, Coding, SpatialConfig, MU-MIMO or not, RUtone_user, RU index, CCn, not used

1441	0	0	10	0	1	4	1	484	1	1	0
1442	0	0	9	0	1	4	1	484	1	1	0
1444	2	1	4	0	0	0	0	242	1	3	0
1443	1	0	3	0	0	0	0	26	5	1	0

Decoded SIGB on CC 2
4EC3E014B40465A1C681CB41815A144800000000
SIGB decoded user info on Content Channel 2
STA_ID, N_SS, Beamformed, HE-MCS, DCM, Coding, SpatialConfig, MU-MIMO or not, RUtone_user, RU index, CCn, not used

1445	0	0	8	0	0	0	1	242	1	4	0
1446	0	0	7	0	0	0	1	242	1	4	0
1447	0	0	6	0	0	0	1	242	1	4	0
1448	0	0	5	0	0	0	1	242	1	4	0

Demodulated Output (1024 QAM)



End-to-end processing per Intended User

```
The STA ID LIST in this received PPDU is as follows:
1441 1442 1444 1443 1445 1446 1447 1448
Enter your STA ID to receive data: 1441
----------
Selected STA-ID= 1441 -> iU= 1, iTx= 1, iRU=1, RU size = 484, N_STS_total_r= 4
HE-MCS= 10, MU-MIMO or non-MU-MIMO= 1 (1=yes)
Kr= 484, Kr_HE_STF= 30, N_STS_total_r= 4
GI+HE_LTF_TYPE= 2 (from SIGA), GI_time=   1.6us, HE_LTF_SYM_time (including GI)=   8.0us
N_SYM= 18, LDPC_EXTRA_SYMBOL= 0
--> Demodulating  & plotting...
Data Tones for iUser=1, from kTx=1, iRU=1, kpn=10:
Data subcarriers from -500 to -17 with size 468
HE-MCS= 10, # bits/carrier =10, DCM= 0, STBC= 0, FEC= 1, CodeRate= 0.75
The rms Vector Error Measurement of the received subcarrier samples (data field) = 0.071 or  -22.9 dB
pw_scale_LLTF1= 0.030, pw_scale_DataSymbols = 0.264, pw_HE_STF = 0.254
--> Decoding ...
Calling decoding_LDPC_11ax:
LDPC_EXTRA_SYMBOL=0, N_pld=121140, N_avbits=161520
LDPC decoding: Npld= 121140, N_avbits= 161520
  L_LDPC= 1944, N_CW= 84, N_shrt= 1332, N_pucn= 444, N_rep= 0, CodeRate_Data=0.750
```

Fine AGC

End-to-end processing to decoded bits (BCC or LDPC)

--> Decoding ...

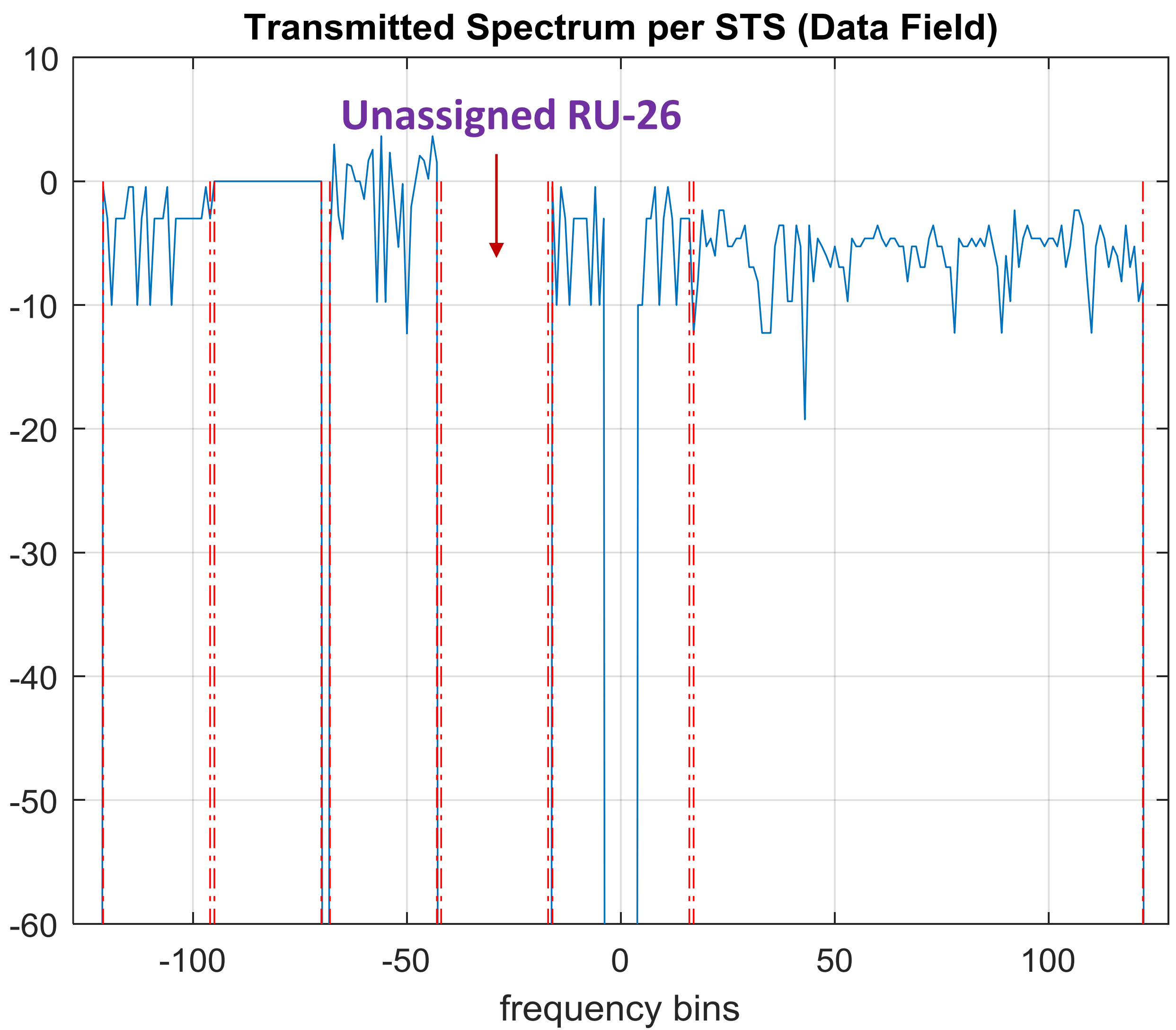
The first 64-bit display of the decoded (1st row) and the input PSDU (2nd row):

0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 1 1 1 1 0 0 0 1 0 1 1 0 0 1 0 1 0 0 1 1 0 1 0 1 1 1 0 0 0 1 1 1 0 1 1 1 0 0 0 0 1 0 0 1

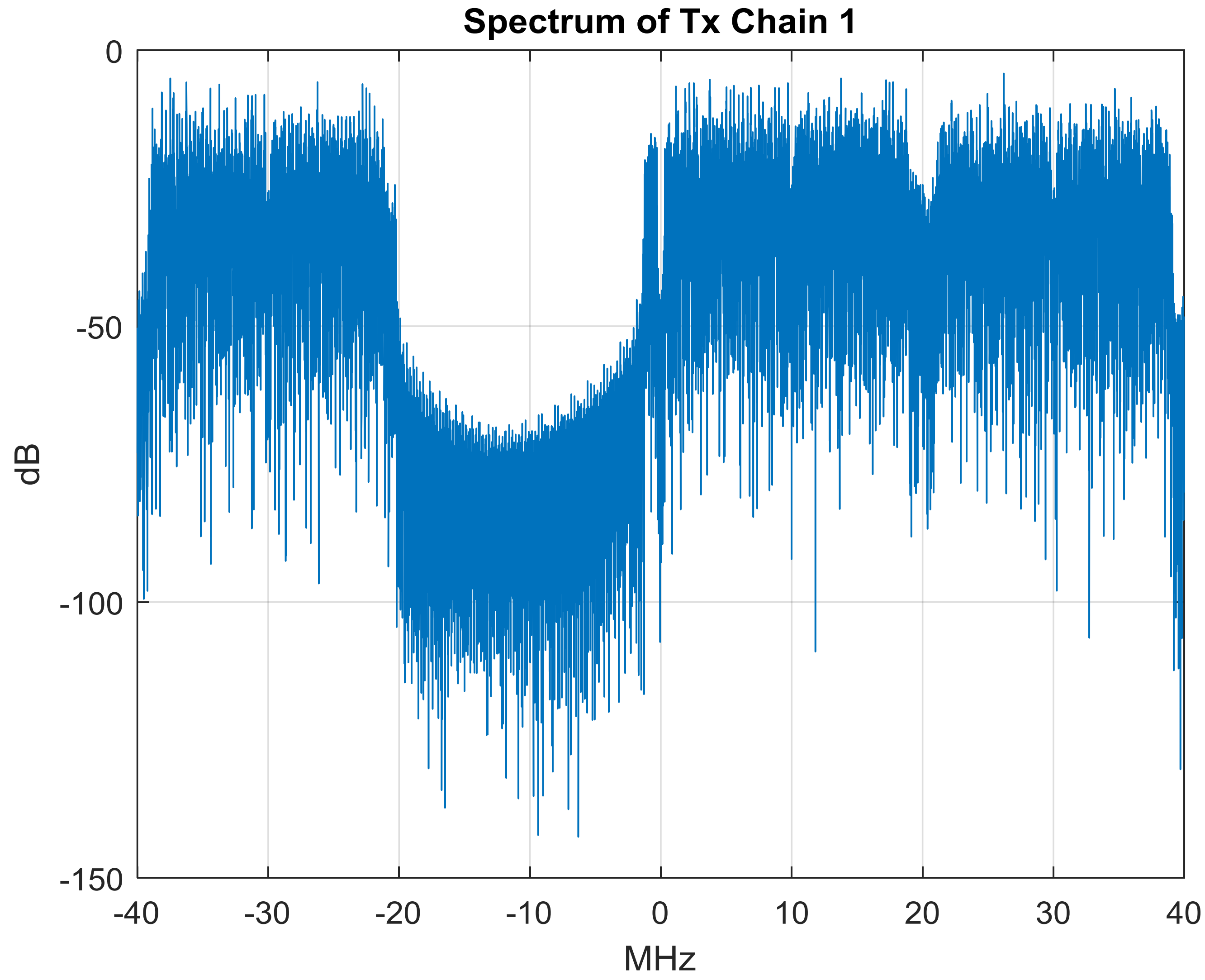
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 1 1 1 1 0 0 0 1 0 1 1 0 0 1 0 1 0 0 1 1 0 1 0 1 1 1 0 0 0 1 1 1 0 1 1 1 0 0 0 0 1 0 0 1

Congratulation! The whole decoding procedure is correct.

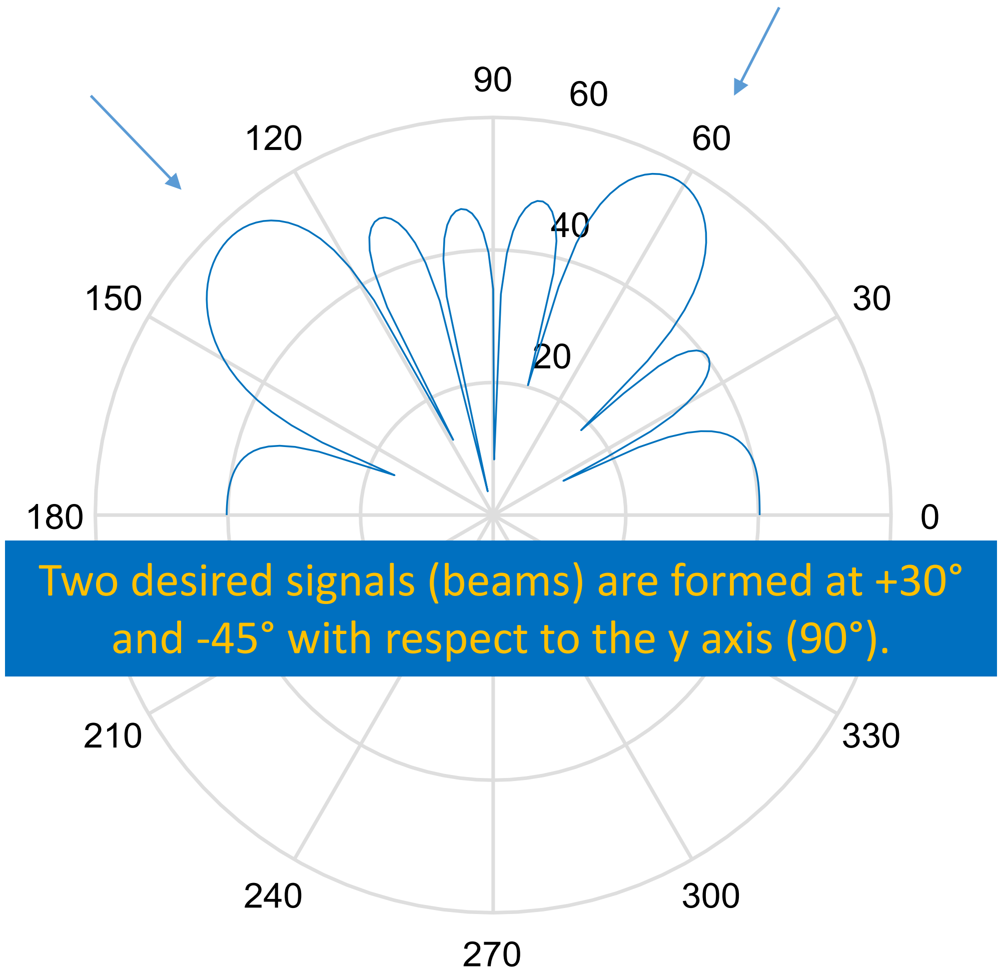
Example of Unassigned RU in a 20 MHz Width



Example of Punctured 20 MHz in 80 MHz Width



Antenna Beam Formed in an 8-element Linear Antenna



Two desired signals (beams) are formed at +30° and -45° with respect to the y axis (90°).

References

1) IEEE P802.11ax™/D6.0, January 2020
2) IEEE 802-11-Overview-and-Amendments-Under-Development, October 2019
3) 802-11ax-transforming-wi-fi-to-bring-unprecedented-capacity-efficiency, Qualcomm download

Thank You for your attention!

- Please send an email to howard@commaccess.com should you have any question or inquiry.

Thank You!