DL OFDMA (HE MU PPDU) bit-by-bit

Gjermund Raaen

Mail: gjermund1506@gmail.com
Twitter: @gjermundraaen
Web: gjermundraaen.com

Constructive feedback are welcome

Draft v4

Background

- The 802.11ax standard consist of several new technologies
- This powerpoint-serie is the first in a series where I will try to explain ODFMA at a deep level
- My main reference guide is the IEEE 802.11 ax draft version 4.0, amendment 1: Enhancements for High Efficiency WLAN
- Other good references
  - Cleartosend's podcast series about 802.11ax
  - David Colemans presentation at WLPC_US Feb 2019

Intention

- This presentation are about the frame that sends data down to associated stations (STAs) that need data, during a MU-OFDMA transmission
- The frame that sends this DL MU-OFDMA is called a HE MU PPDU. This is one of the four different PPDU formats in 802.11ax
- To fullfill this transmission there have to be a acknowledgment frame and optionally a MU-RTS and a CTS frame too. It will be covered in later presentations
- UL MU-OFDMA will also be covered later

The figure show an example of a DL MU-OFDMA transmission. This presentation will only cover the HE MU PPDU

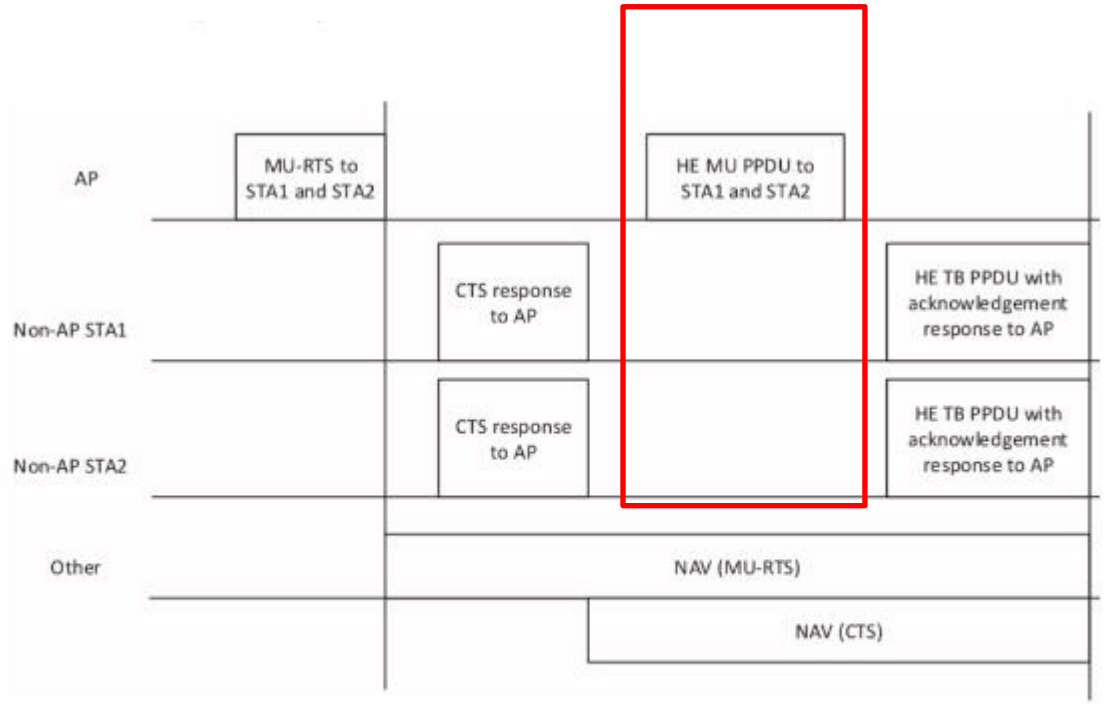


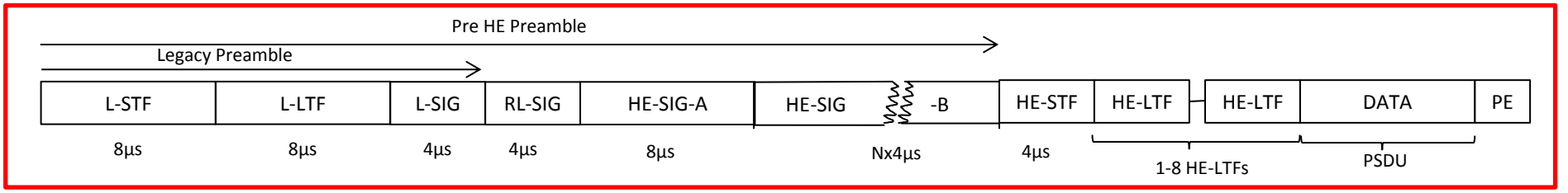
Figure 26-1—Example of MU-RTS/CTS/DL MU PPDU/Acknowledgment Response and NAV setting

Remarks

- All technologies all called Legacy ODFM, HT, VHT or HE instead of 802.11a/n/ac/ax
- The transmission is based of using a 20MHz channel on the 5GHz band
- All figures are selfproduced or from the IEEE802.11ax draft 4.0, unless particulary described
- Many slides have a page notation to the IEEE draft

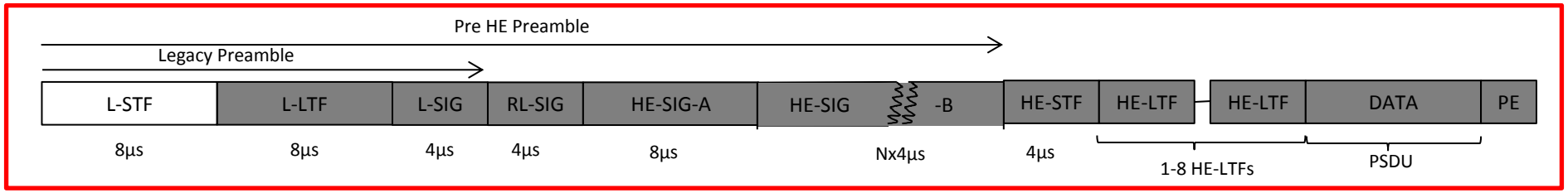
The HE MU PPDU

The frame (PPDU) format that are used when the AP is downloading OFDMA-data to the stations (STAs) that need data lookes like this
Is's name is High Efficiency Multi User Physical Layer Protocol Data Unit (HE MU PPDU)



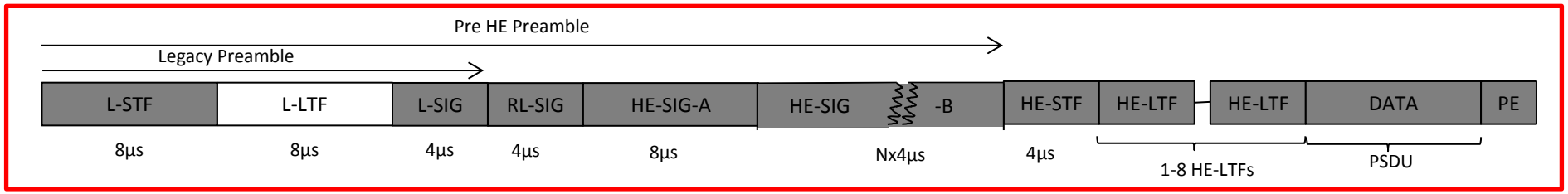
The slides in this serie will cover each field in this PPDU and show examples when the AP sends data in four different RUs (52-tone) to four STAs

L-STF, page 519



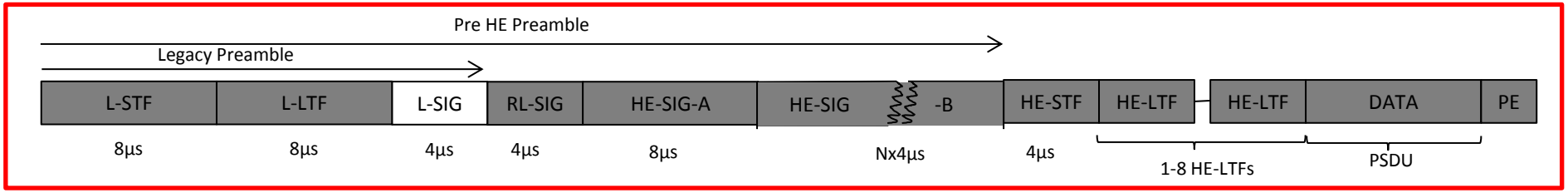
- Legacy Short Training Field
- 10 repetitions of a 0,8µs symbol
- Start-of-packet detection
- Automatic gain control
- Initial frequency offset estimation
- Initial time synchronization
- Using 12 of 52 subcarriers [-/+24, -/+20, -/+16, -/+12, -/+8, -/+4]
- Duration 8µs

L-LTF, p 521



- Legacy Long Training Field
- Two 3,2µs long training symbols prepended by a 1,6µs cyclic prefix
- 52 subcarriers [-26 to +26, except 0]
- Channel estimation
- More accurate frequency offset estimation and time synchronization
- Duration 8µs

L-SIG, p522

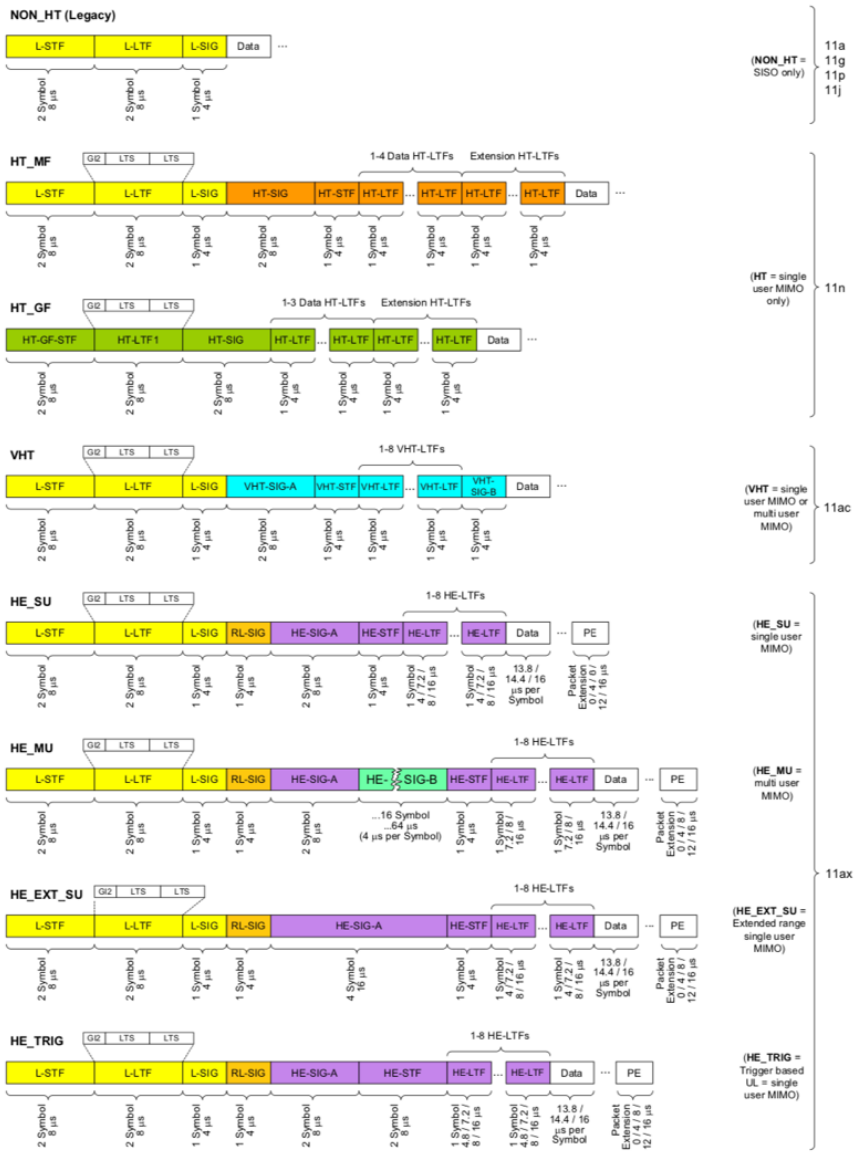


- Legacy Signal Field
- 24 bit
  - Rate, 4 bit, 8 levels
    - 6, 9, 12, 18, 24, 36, 48, 54 mbs
    - Set to 6mbs for all PPDU-types newer than legacy OFDM
  - Reserved, 1 bit
  - Length, 12 bit. Amount of data in octets
    - Dependent of HE PPDU-types there are minor differerences on how the length-field is calculated
  - Parity, 1 bit. To give even parity over the first 17 bit
  - Tail, 6 bit. All zeros, used to flush the encoder/decoder
- Duration 4µs
- One symbol
  - 24 bit
  - BCC encoded
  - Code Rate ½
  - Interleaved and mapped to BPSK-constellation over 48 subcarriers, aka legacy 6mbs
  - Pilots inserted
  - Cyclic prefix (guard interval) 0.8µs and Data Symbol Time 3,2µs

Key moment, what comes next

- The L-STF, L-LTF and L-SIG are called legacy preamble. Those three field are common for all types of PPDU-format, except HT Greenfield
- Every station in the BSS, and other stations using the same channel, can understand the legacy preamble
- If any station don´t understand the next part of the transmission, they still have enough information to interpret how long it should defer from the channel
- But what comes in the next symbol: Is it legacy OFDM, is it mixed-HT, is it VHT or is it HE
- Each of those protocols have their own PPDU-frame formats
- What does the station do to differentiate between PPDU-formats
- Next slide shows all available PPDU-formats

All PPDU-formats

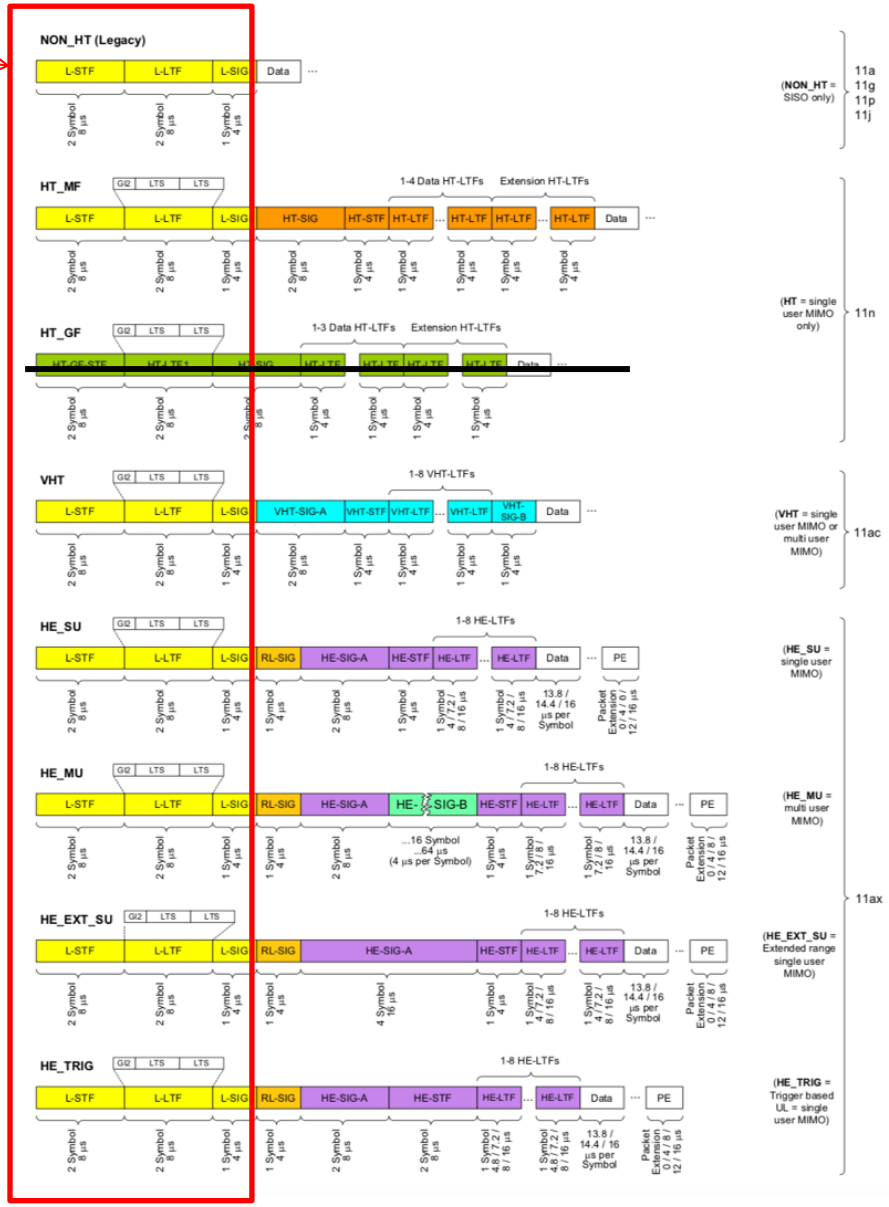


From Rohde-Schwarz, IEEE 802.11ax Technology Introduction

Draft v4

Common for all PPDU formats

Legacy preamble



After the legacy preamble

- newer technologies understand older technologies
- but not vice versa

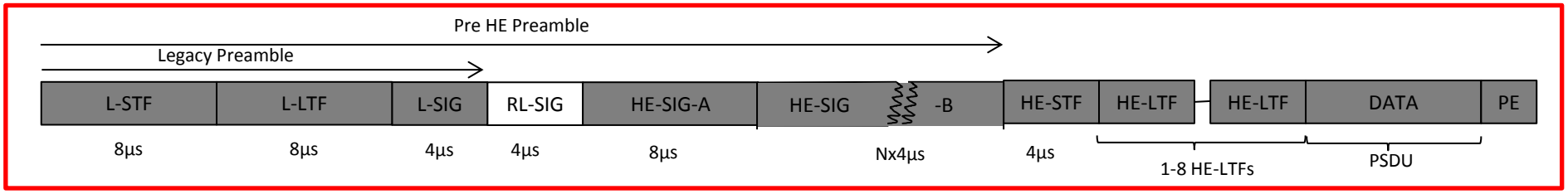
From Rohde-Schwarz, IEEE 802.11ax Technology Introduction

How to differentiate after legacy Preamble

- For legacy OFDM, HT and VHT there is the general rule: Compute a metric based of power on the real part of subcarriers averaged over the 48 subcarriers minus the power of the imaginary part over the same subcarriers
- Legacy OFDM at 6mbs: Gives a large positive number
- HT: First symbol is HT-SIG1 and it´s rotated 90°(QBPSK). Will give a large negative number
- VHT: first symbol is VHT-SIG-A1 and is BPSK-modulated, next symbol is VHT-SIG-A2 and is QBPSK-modulated

- HE repeat the L-SIG in the next symbol as Repeated Legacy Signal, RL-SIG. HE stations checks if this symbol and the previous symbol are equal or not. Equal is HE. If they are not equal, check for legacy OFDM, HT or VHT

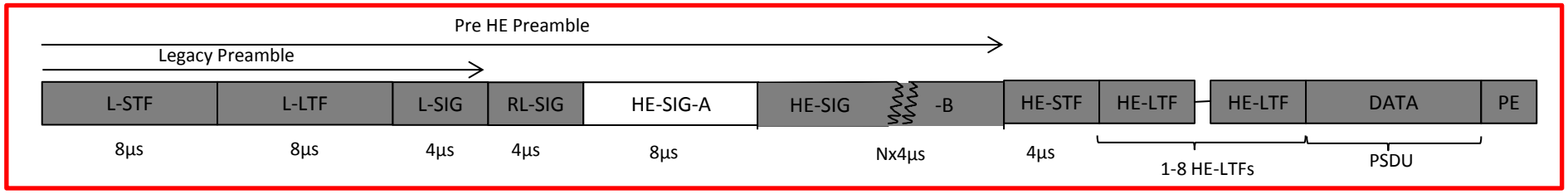
RL-SIG, p524



- Repeated Legacy SIG
- Duration 4µs
- Each symbol
  - 24 bit
  - BCC encoded
  - Code Rate ½
  - Interleaved and mapped to BPSK-constellation over 48 subcarriers (-26,+26)
  - Pilots inserted
  - Cyclic prefix (guard interval) 0.8µs and Data Symbol Time 3,2µs

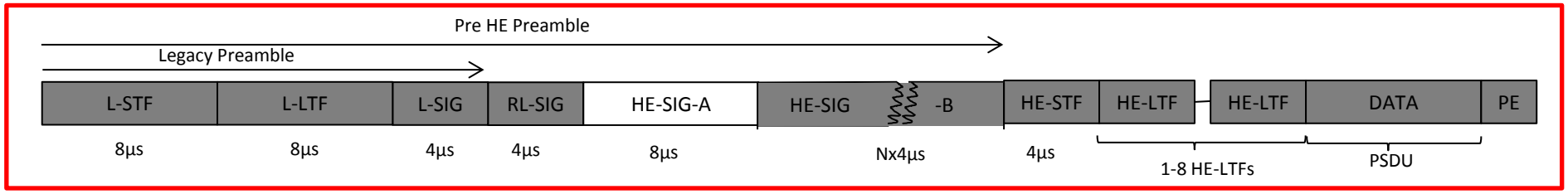
- A HE transmission also do a BPSK modulation on subcarrier [-28, -27, +27, +28]
- The Length field is calculated in a unique manner. For HE MU PPDU and HE ER SU PPDU the length fild is withdrawn by a factor of 1. For the two other PPDU-formats (HE SU PPDU and HE TB PPDU) with a factor of 2
- By doing a MOD 3 calculation at the receiver it can determine between HE MU PPDU and HE ER SU PPDU and the two other PPDU formats, HE SU PPDU and HE TB PPDU
- Differentiating between HE MU PPDU and HE ER SU PPDU are been done during in the next symbol, HE-SIG-A

HE-SIG-A for HE MU PPDU, p525



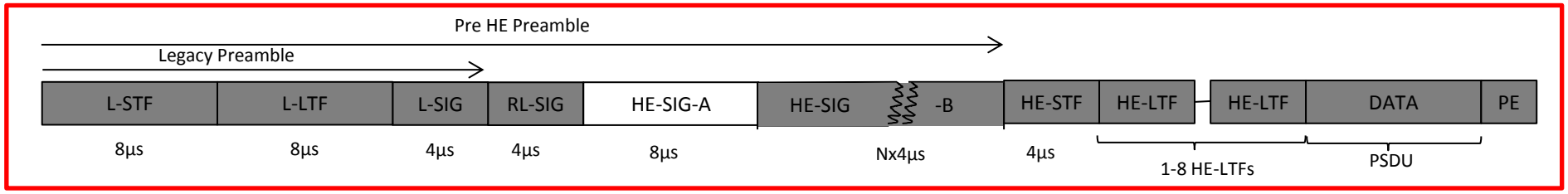
- Information necessary to interpret HE PPDUs
- HE-SIG-A have different content depended of type of HE-PPDU
- HE-SIG-A field consist of two symbol, HE-SIG-A1 and HE-SIG-A2.
- Total duration 8µs (4µs for HE-SIG-A1 and 4µs for HE-SIG-A2)
- Each symbol
  - 26 bit
  - BCC encoded
  - Code Rate ½
  - Interleaved and mapped to BPSK-constellation over 52 subcarriers (first time with 52 subcarriers), aka mcs0
  - Pilots inserted
  - Cyclic prefix (guard interval) 0.8µs and Data Symbol Time 3,2µs
- HE ER SU PPDU are QBPSK in symbol HE-SIG-A2 to differentiate between HE MU PPDU and HE ER SU PPDU

HE-SIG-A1 for HE MU PPDU, p529



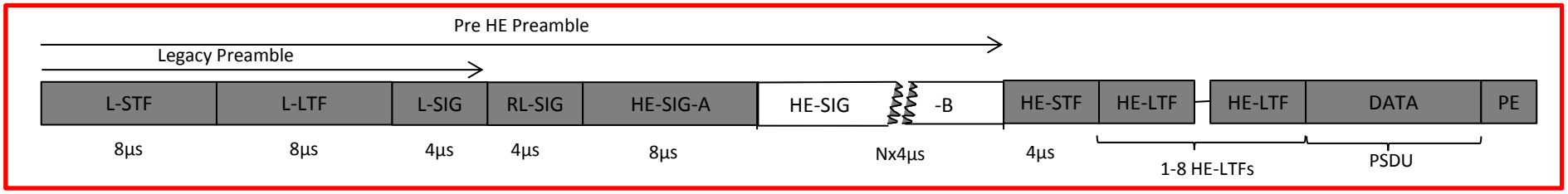
- Each bit explained relative to a HE MU PPDU-transmission
- B0: UL/DL
  - Whether the transmission is uplink or downlink
- B1-3: SIGB MCS
  - The MCS-rate of HE-SIG-B, 0=mcs0, 1=mcs1, ……., 5=mcs5. Values 6 and 7 are reserved
- B4: SIGB DCM
  - Indicate that the HE-SIG-B is modulated with Dual Carrier Modulation (DCM). 0=not DCM, 1=DCM
- B5-10: BSS Color
  - The indentifier (color) of the BSS
- B11-14: Spatial Reuse
  - Indicate whether spatial reuse is allowed during transmission
- B15-17: Bandwidth
  - 0=20MHz, 1=40MHz, 2=80MHz, 3=160 or 80+80MHz. Values 4-7 is used if SIGB Compression is set to 0
- B18-21: Number of HE-SIG-B Symbols or MU-MIMO users
  - If SIGB Compression=0; number of OFDM-symbols in the HE-SIG-B minus 1 if it's less than 16. More than 16, see draft
  - If SIGB Compression=1; the number of MU-MIMO users minus 1
- B22: SIGB Compression
  - Set to 0 if HE-SIG-B is present, set to 1 if HE-SIG-B is not present
- B23-24: GI + LTF Size
  - The size of the HE-LTF and the duration of the guard interval in the Data field. 0=4xHE-LTF and 0,8µs GI, 1=2xHE-LTF and 0,8µs GI, 2=2xHE-LTF and 1,6µs GI, 3=4xHE-LTF and 3,2µs GI
- B25: Doppler
  - Used in conjuction with Midamble on fast varying channels. Set to 0 without Midamble

HE-SIG-A2 for HE MU PPDU, p531

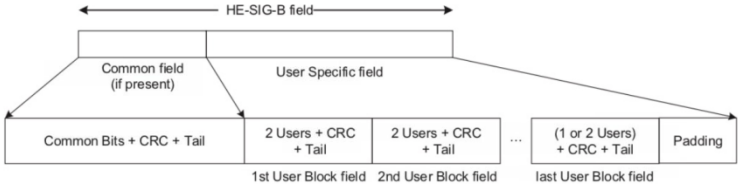


- Each bit explained relative to a HE MU PPDU-transmission
- B0-6: TXOP
  - Used to indicate duration information for NAV setting and protection of the TXOP
- B7: Reserved
  - Reserved and set to 1
- B8-10: Number of HE-LTF Symbols or Midamble Periodicity
  - If Doppler=0; indicate the number of HE-LFT Symbols. 1, 2, 4, 6 or 8 HE-LTF
  - If Doppler=1; b8-9 indicate the number of HE-LTF (1,2 or 4), b10 indicate midamble periodicity (0=10,1=20)
- B11: LDPC Extra Symbol Segment
  - Indicate of the precence of extra OFDM symbol segment for LDPC, 1=extra symbol segment
- B12: STBC
  - In OFDMA only transmission. Set to 1 if all RUs are STBC
- B13-14: Pre FEC Padding Factor
  - Indicate the pre-FEC padding factor. 0=factor of 4, 1=factor of 1, 2=factor of 2, 3=factor of 3
- B15: PE Disambiguity
  - Indicate PE disambiguity (Packet extension)
- B16-19: CRC
  - CRC for bits 0-41 of HE-SIG-A, bits 0-25 of HE-SIG-A1 and bits 0-15 of HE-SIG-A2
- B20-25: Tail
  - Used to terminate the trellis of the convolutional decoder. Set to 0

HE-SIG-B for HE MU PPDU, p542

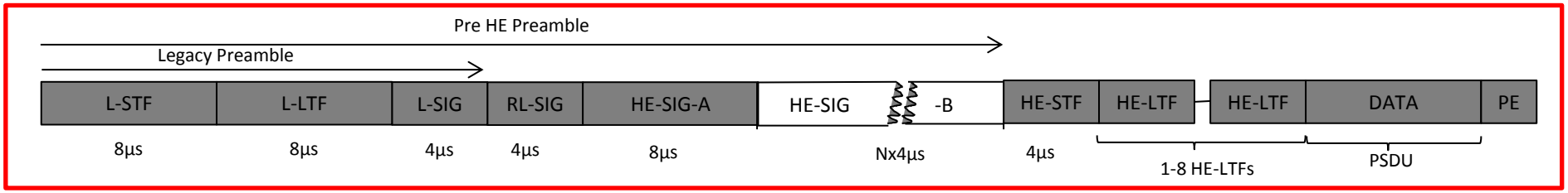


- Provides OFDMA and MU-MIMO resource allocation
- Present only in HE MU PPDUs, aka a OFDMA or MU-MIMO transmission
- HE-SIG-B have different amount of bits depended of resouce allocation and can therefor have different amount of symbols
- HE-SIG-B consist of a Common field, if present, followed by a User Specific field which together are referred to as HE-SIG-B content channel



- Each symbol
  - BCC encoded
  - Code Rate ½
    - If the MCS indicate a coding other than ½, each field is concatenated and then punctured
  - Interleaved and mapped to MCS specified in HE-SIG-A
  - Each symbol shall have 52 data tones (data subcarriers)
  - Pilots inserted
  - Cyclic prefix (guard interval) 0.8µs and Data Symbol Time 3,2µs

HE-SIG-B common field, p549



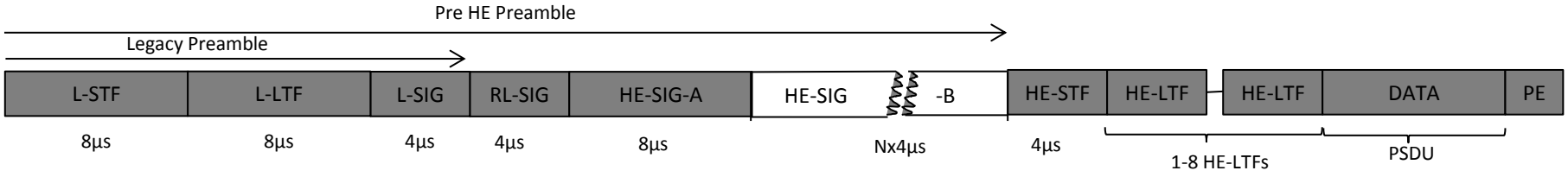
- The Common field in the HE-SIG-B field carries the RU Allocation subfields.

Subfield	Number of bits	Description
RU Allocation	Nx8	Indicates the RU allocation. Can also indicate the number of users in each RU for MU-MIMO. N=1 for 20 and 40MHz, N=2 for 80MHz, N=3 for 160 or 80+80MHz
Center 26-tone RU	1	Is present if Bandwidth is set to greater than 1, >=80MHz Is not present for 20 or 40MHz
CRC	4	CRC
Tail	6	Used to terminate the trellis of the convolutional decoder. Set to 0

- The 8 bit in the RU allocation subfield indicates the sizes of the RUs and their placement in the frequency domain. The figure shows a example of two different RU allocations

8 bits indices (B7 B6 B5 B4 B3 B2 B1 B0)	#1	#2	#3	#4	#5	#6	#7	#8	#9	Number of entries
00001110	52		52		26	52		26	26	1
00001111	52		52		26	52		52		1

HE-SIG-B per User content field, p553



- The User Block field is defined

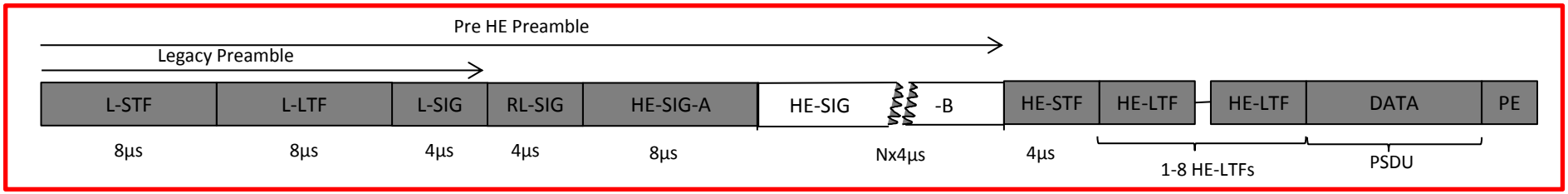
Subfield	Number of bits	Description
User field	Nx21	User field format for either MU-MIMO or non-MU-MIMO N=1 if it is the last User Block field and if there is only one user in the last User Block field. N=2 otherwise
CRC	4	CRC is calculated over bits 0-20 for a User Block field that contains one User field, and bits 0-41 for a User Block field that contains two User field
Tail	6	Used to terminate the trellis of the convolutional decoder. Set to 0

- User field for a non-MU-MIMO allocation, aka OFDMA-transmission

Bit	Subfield	Number of bits	Description
B0-B10	STA-ID	11	STA-ID (association ID) for the station allocated to this RU
B11-B13	NSTS	3	Number of space-time streams minus 1
B14	Beamformed	1	Use of transmit beamforming. Set to 1 if a beamforming matrix is applied to the waveform in an SU transmission
B15-B18	MCS	4	Modulation and coding scheme. MCS0-11. Values 12-15 is reserved
B19	DCM	1	Indicates whether or not DCM(dual carrier modulation) is used
B20	Coding	1	Indicates whether BCC or LDPC is user. 0=BCC, 1=LDPC

- RUs not allocated to any user can be indicated with the value 2046 for the STA-ID subfield in the User field

HE-SIG-B example



- 4 clients; STA-1 , STA-2 and STA-3 with mcs 9, STA-4 with mcs 7, single stream for all stations, 20MHz, BCC
- Assume that the AP/WLC have decided to give each station a 52 RU-tone. The standard says nothing about how the AP decide to allocate the RUs

HE SIG B format

Common field 18 bits	User Block field 1 52 bits	User Block field 2 52 bits	User Block field 3 31 bits	Padding ?? bits

Common field

52+52+26+52+52 RU tone allocation 00001111+CRC(4)+Tail(6)

Use Block field 1

STA-ID 1, 21 bits STA-ID 1+NSTS+Beamformed+MCS+DCM+Coding STA-1 0 0 9. 0. 0	STA-ID 2, 21 bits STA-ID 2+NSTS+Beamformed+MCS+DCM+Coding STA-2 0 0 9. 0. 0	CRC and Tail CRC (4) + Tail (6)

Use Block field 2

Unallocated RU, 21 bits Unnal+NSTS+Beamformed+MCS+DCM+Coding 2046 0 0 9. 0. 0	STA-ID 3, 21 bits STA-ID 3+NSTS+Beamformed+MCS+DCM+Coding STA-3 0 0 9. 0. 0	CRC and Tail CRC (4) + Tail (6)

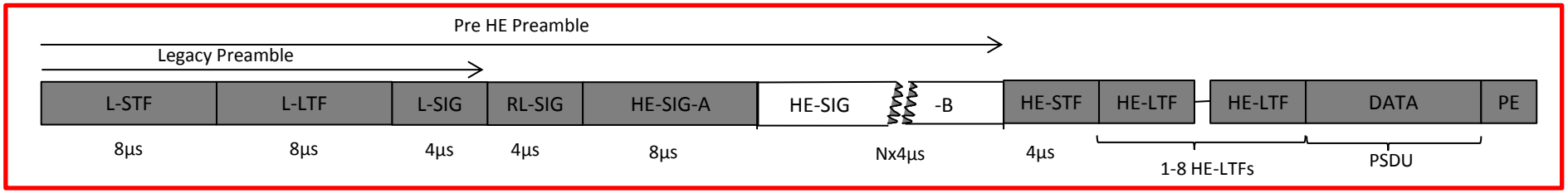
Use Block field 3

STA-ID 4, 21 bits STA-ID 4+NSTS+Beamformed+MCS+DCM+Coding STA-4 0 0 7. 0. 0	CRC and Tail CRC (4) + Tail (6)

Padding

Padding ?? bits

Padding to HE-SIG-B



- Summation of bits
  - Common field : 18 bits
  - User Block field 1: 52 bits
  - User Block field 2: 52 bits
  - User Block field 3 : 31 bits
  - **Total: 153 bits**

- If SIGB MCS in HE-SIG-A1 is set to mcs0 then HE-SIG-B is modulated with BPSK and coding rate ½ and use of 52 subcarriers
- Then we can modulate 26 bit on each symbol
- 6 symbols consist of 6 times 26 bits -> 156 bit
- The padding will be with 3 bits

- The ”Number of HE-SIG-B Symbols or MU-MIMO users” in the HE-SIG-A1 must then be set to 5. (6 symbols minus 1)
- The ”SIGB Compression” in the HE-SIG-A1 must be set to 0 (HE-SIG-B is present)

- If the mcs-rate for the HE-SIG-B were set to mcs1, aka QPSK and coding rate ½, then we would only need 3 symbols for the HE-SIG-B in this example

- Example 9 stations allocated to 9 26-tone RUs
  - Common field: 18 bit
  - User block field of 52 bits each to STA1+2, STA3+4, STA5+6, STA7+8. 4 User Block field = 208 bit
  - User block field for STA9, 31 bits
  - Total: 257 bit
  - With mcs0 for HE-SIG-B (26 bit pr symbol) we need 10 symbols (260 bits). And 3 padding bits

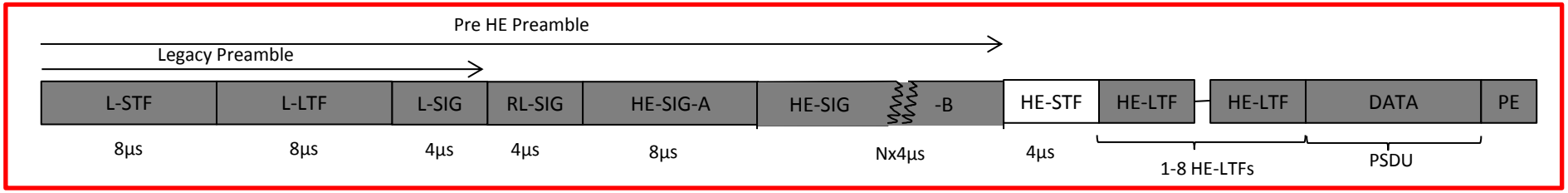
End of Pre HE PPDU

- When HE-SIG-B ends the pre HE PPDU also ends
- As documented, all symbols until now have used legacy subcarriers setup (except L-STF and L-LTF)
  - either 48 or 52 subcarriers with 312,5kHz spacing
  - BPSK modulated, HE-SIG-B can be modulated with QPSK, 16-QAM or 64-QAM
  - Coding rate of ½. HE-SIG-B can be coded with QPSK ¾, 16-QAM ¾, 64-QAM 2/3
  - Time for data symbol 3,2us
  - Guard interval (cyclic prefix) 0,8us
- So in principle it is a legacy 6mbs ODFM in the legacy preamble for L-STF, L-LTF and L-SIG, and a ODFM-transmission at mcs0 with long Guard Interval for the rest of the symbols (HE-SIG-B can have other mcs-rates)
  - RL-SIG uses legacy ODFM, but the extra subcarriers for mcs0 is modulated

- Next symbols are the HE-STF and HE-LTFs. Those prepare the reciever for the new HE PPDU format
  - 256 subcarriers with 78,125kHz spacing
  - Time of data symbol 12,8us
  - Guard interval (cyclic prefix) of either 0,8us, 1,6us or 3,2us
  - RU-allocation according to HE-SIG-B
  - Pilot subcarriers
  - Guard subcarriers
  - Null subcarriers

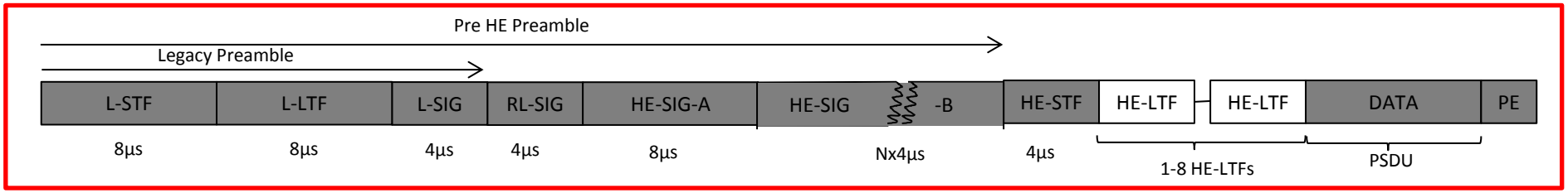
- All STAs that will recieve data (MSDU) have all necessary to interpret which subcarriers they will receive it's data on
  - The Color of the BSS the STA is associated to
  - The RU allocation
  - It's STA-ID (association ID) allocated to one of the RUs

HE-STF for HE MU PPDU, page 557



- HE- Short Training Field
- Improve automatic gain control estimation in a MIMO transmission
- Periodicity of 0,8µs with 5 periods
- New subcarrier spacing of 78,125kHz and a total of 242 subcarriers
- The HE-STF field is constructed by mapping the HE-STF signal to each 242-tone RU
- The HE-STF signal is a sequence multiplied by a imaginary number, page 557
- Duration 4µs
-

HE-LTF for HE MU PPDU, page 561



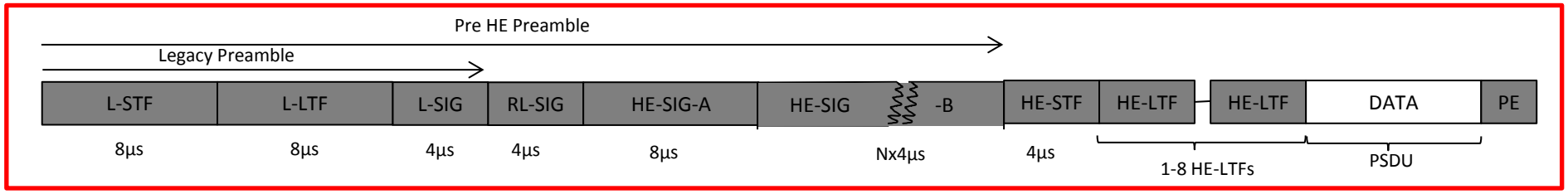
- HE Long Training Field
- The HE LTF Field provides a means for the receiver to estimate the MIMO channel between the set of constellation mapper output and the receive chains
- Data tones of each HE LTF is multiplied by entries belonging to a matrix P_{HE_LTF}
- Pilot tones are multiplied to matrix R_{HE_LTF} that allowes receivers to phase track and frequency offset during MIMO channel estimation
- For HE MU PPDUs the HE LTF have those mandatory values
  - 2xHE LTF + 0,8µs Guard Interval
  - 2xHE LTF + 1,6µs Guard Interval
  - 4xHE LTF + 3,2µs Guard Interval
- HE LTF have this optionally value
  - 4xHE LTF + 0,8µs Guard Interval

- Timings
  - Duration of each 2xHE LTF ODFM Symbol without GI: 6,4µs
  - Duration of each 4xHE LTF ODFM Symbol without GI: 12,8µs

End of HE MU Preamble and start of Data field

- At this moment in the transmisson the HE preamble ends. All symbols until now is used to setup the receiver so it it able to receive the actual data, the PSDU (MPDU), for each RUs
- All symbols until now has been common information for the PHY-layer and it has used the hole bandwith of the channel. First data modulated om 48 subcarriers (legacy preamble), then data modulated on 52 subcarriers, and at last the change from legacy subcarriers setup to HE subcarriers setup with 242 subcarriers
- When we start to send the Data field each STAs PSDU will be modulated on the subcarriers that are allocated to the STAs RU

Data Field for HE MU PPDU, page 578



- We will not cover so much about what happens during the Data field transmission. But this are some of the key points
  - Each data time symbol is 12,8µs and subcarrier spacing of 78,125kHz
  - The guard interval duration of 0,8µs, 1,6µs or 3,2µs as described in the HE-SIG-A field
  - The RU allocation for each receiving STA is described during HE-SIG-B, both the RU allocation and which STA is allocated to which RU
  - BCC or LDPC encoding can be used. LDPC is the only FEC coding scheme for HE MCSs 10 and 11
    - If BCC encoding is used the Data field consist of the Service field, the PSDU, the pre-FEC PHY padding bits, the tail bits and the post-FEC padding bits
    - If LDPC encoding is used the Data field shall consist of the Service field, the PSDU, the pre-FEC padding bits, and the post-FEC padding bits
  - STBC encoding can be applied with 1 spatial stream
  - Padding is used for
    - Fill up the last symbol for the STA with the largest amount of symbols in the MSDU
    - Fill up the other STAs data field so that all ends at the same symbol/time
  - Depended on how the AP has allocated it's RUs we can have different RU locations The next slide shows RU location on a 20MHz channel

RU locations in a 20 MHz HE PPDU

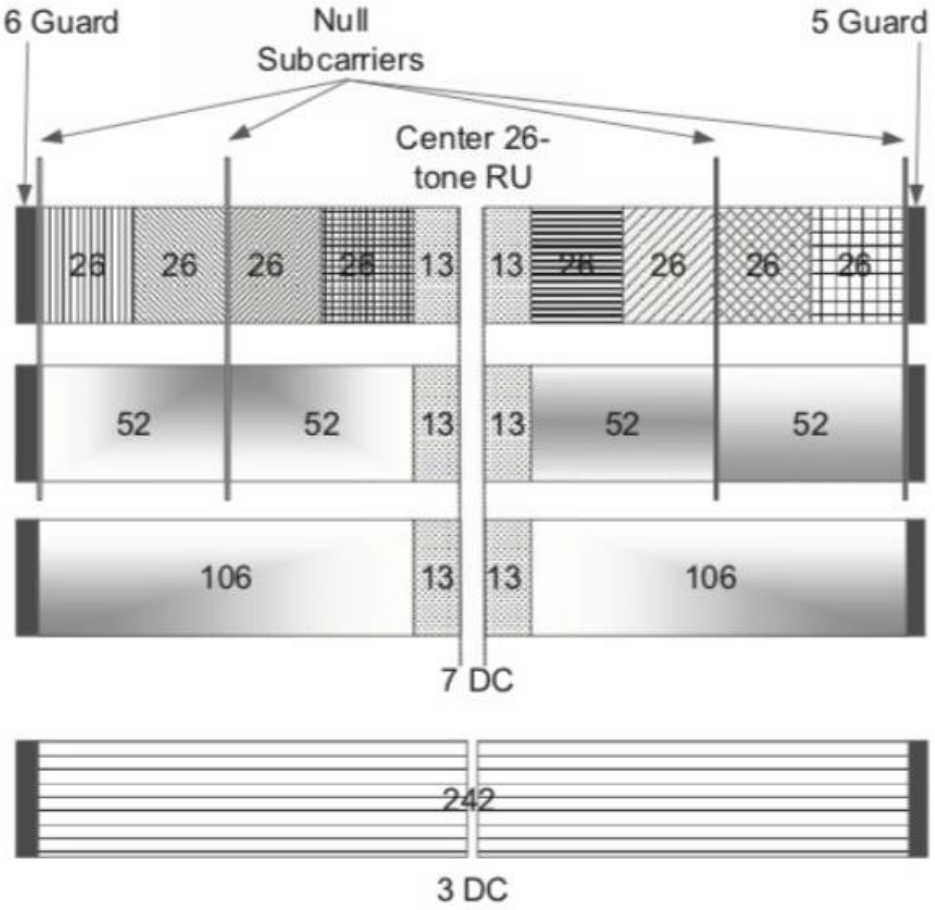
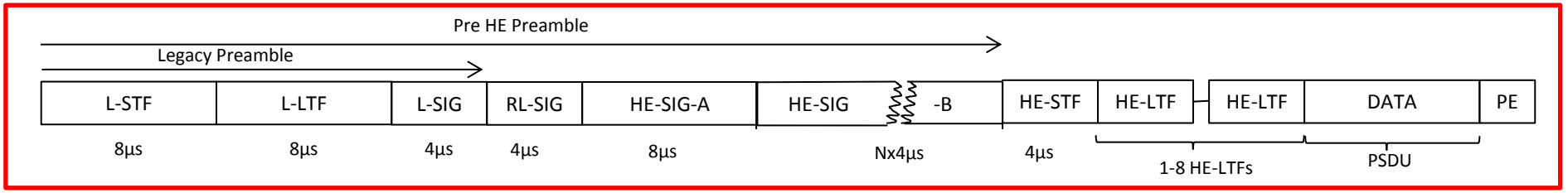


Figure 27-5—RU locations in a 20 MHz HE PPDU

Our Data Field Transmission

- Subcarriers range for 4 times 52-tone RUs and a center 26 RU-tone
  - RU1, for STA1, [-121:-70]
  - RU2, for STA2, [-68:-17]
  - RU for the unallocated 26-tone RU in center, [-16:-4, 4:16]
  - RU3, for STA3, [17:68]
  - RU4 for STA4, [70:121]
- Pilot subcarriers: +/-10, -/+22, -/+36, -/+48, -/+62, -/+76, -/+90, -/+102, -/+116. The 52-tone RU get four pilot subcarriers each and the the center 26 RU-tone get two pilot subcarriers
- Null subcarrier: -/+ 69, -/+122
- Guard subcarriers: 6 at buttom [-128:-123], 5 at top[123:127]
- DC subcarriers: 7 in center [-3:3]

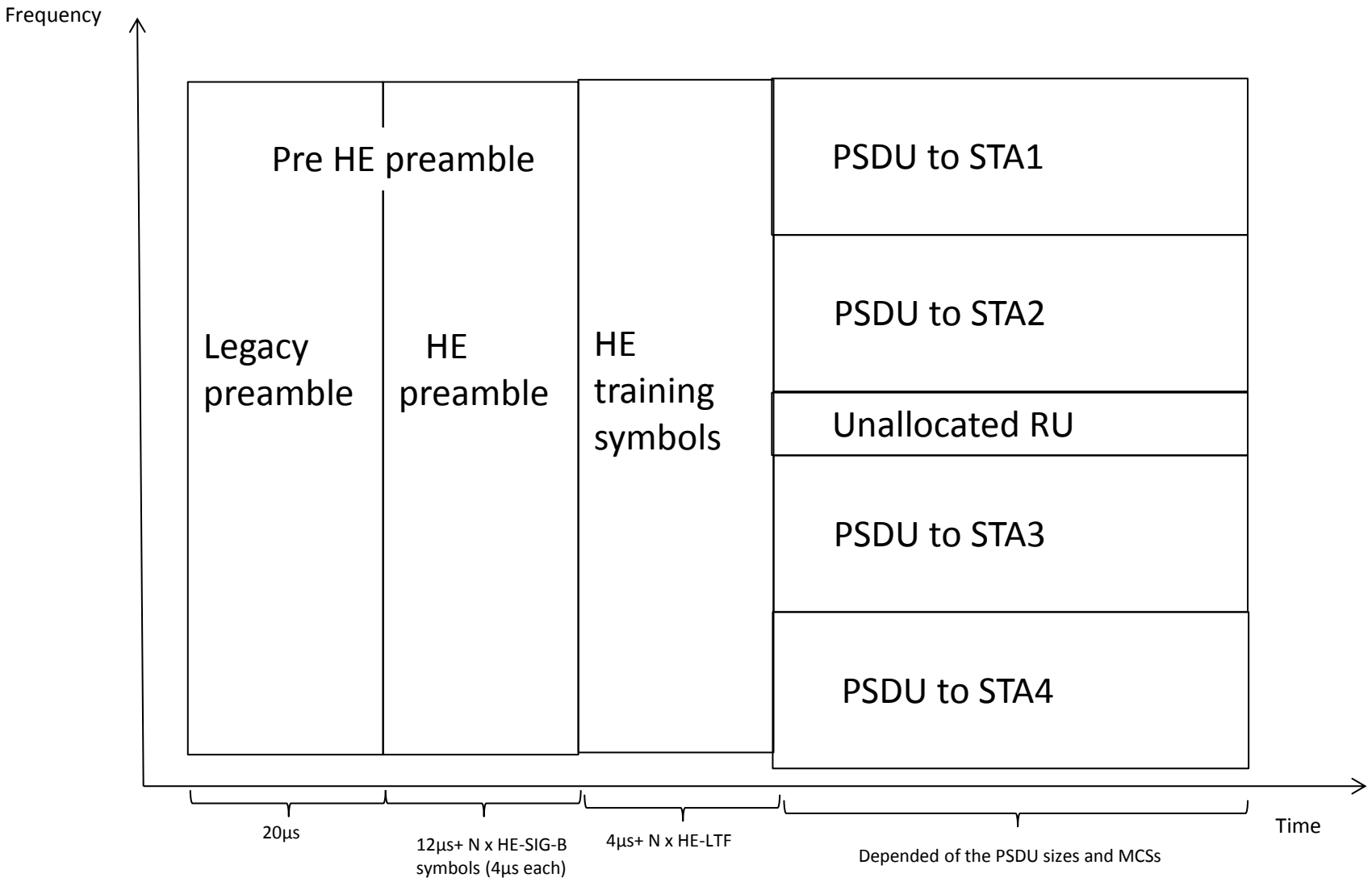
Summarize of a DL OFDM transmission



- We have now gone through all stages in the download ODFM transmisson to four STAs
- Remark: This is only for the frame that carries data download to the STAs, the HE MU PPDU
- We have four phases in this transmission

1. Legacy Preamble
    1. Understandable for all STAs on the channel, undepended of PHY-capabilities
    2. The Rate and Length information gives all STAs enough information to defer own transmission
2. Pre HE Preamble
    1. Not understandable for legacy STAs (OFDM, HT, VHT)
    2. Information necessary to interpret HE PPDUs
    3. Give information of RU allocation and STA id (which STA is using which RU)
3. HE training symbols
    1. Prepare the receivers for the new HE PPDU format
4. The Data transmission
    1. Each allocated STA receives it’s PSDU on theirs allocated RU (subcarriers)

Overview of a HE MU PPDU transmission



End

I hopes it has been useful
Constructive feedback are welcome
Mail: gjermund1506@gmail.com
Twitter: @gjermundraaen