IEEE 802.11ax

Waveform Generation and Link-level Simulation in MATLAB with WLAN System Toolbox

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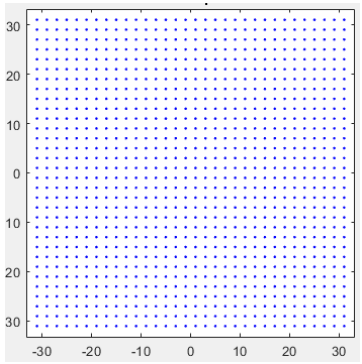
What is 802.11ax?

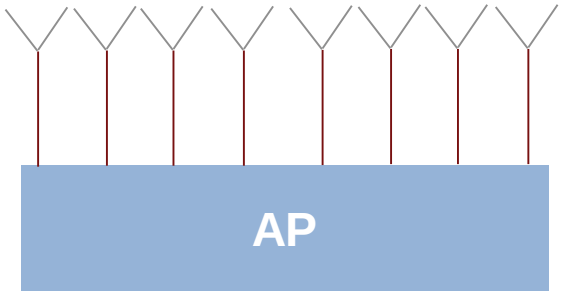
- IEEE 802.11ax is the latest member of the Wi-Fi standards
- Evolution of the popular 802.11ac
- HE = High Efficiency
- Goals:
  - More effectively use 2.4 and 5 GHz bands
  - Increase average throughput 4x per user in high-density scenarios
  - Scenarios: corporate offices, stadiums, outdoor hotspots, dense residential complexes
  - Improve outdoor performance
  - Improve power efficiency

- Backwards compatibility with 11a/b/g/n/ac

Key Features of 802.11ax

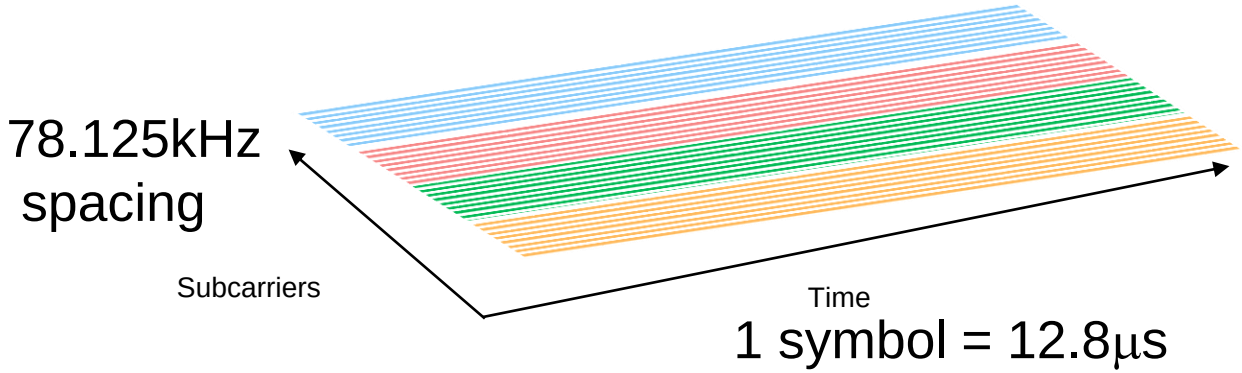
- Modulation order up to 1024-QAM
- 8x8 Access-Point MIMO





- Downlink OFDMA & MU-MIMO
- Uplink OFDMA & MU-MIMO

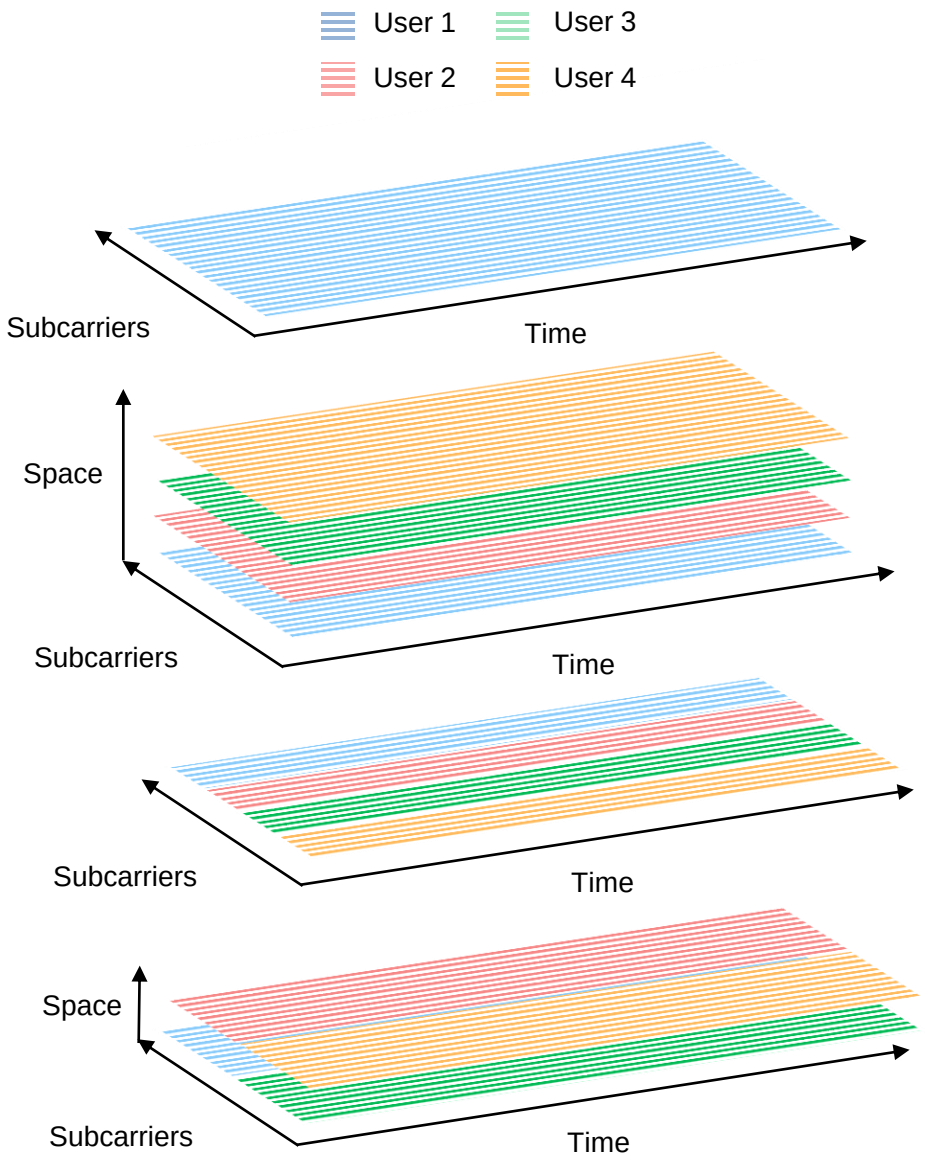
- 4x longer Symbol Duration
- Extended range preamble



- Channel bonding

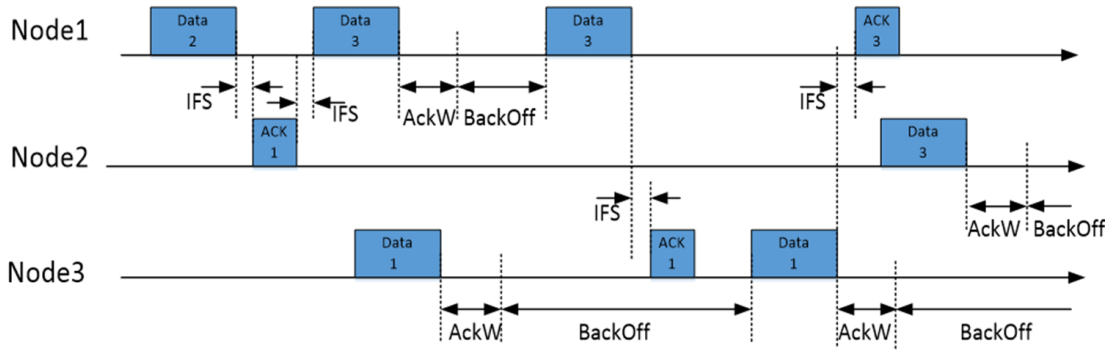
Enabling technologies: OFDMA and MU-MIMO

- **SU-MIMO** - all subcarriers (full-band) are used by one user
- **MU-MIMO** - all subcarriers (full-band) are used by multiple users
- **OFDMA** - subsets of subcarriers are used by individual users
- **MU-MIMO & OFDMA** - a subset of subcarriers are used by multiple users



Rationale: More efficiency

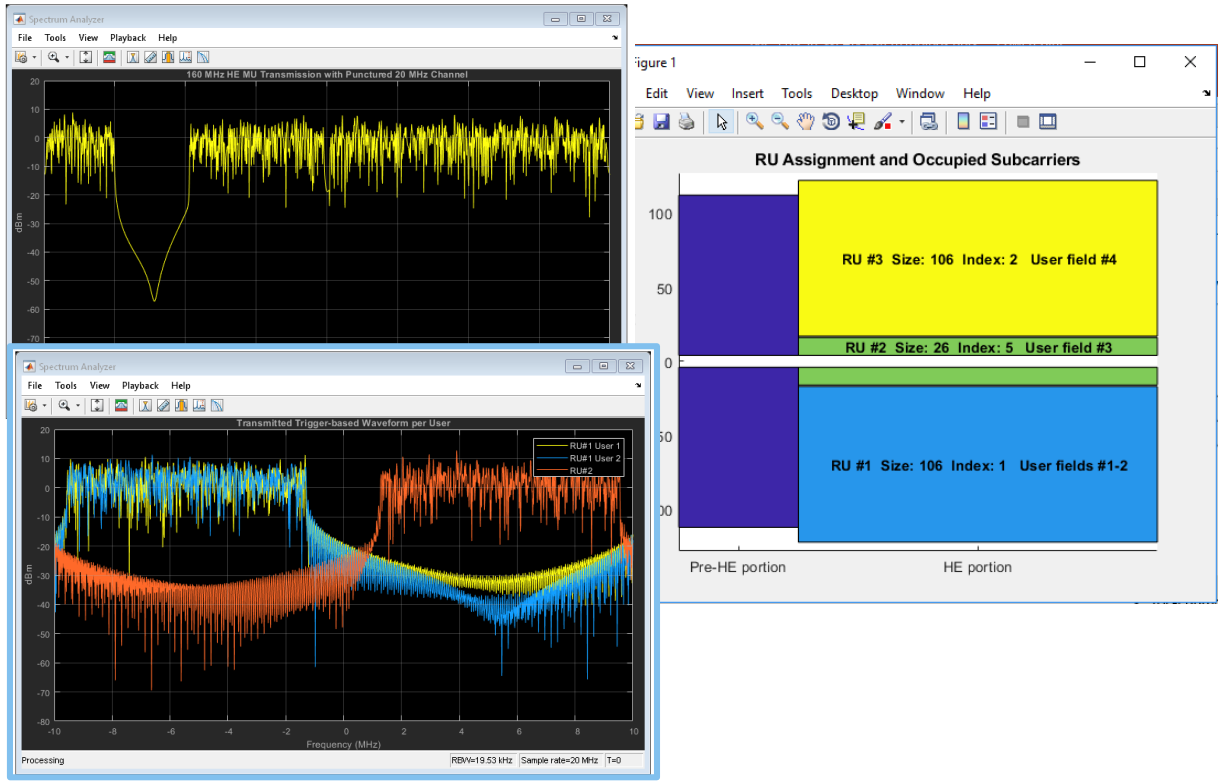
- WLAN MAC efficiency drops with increasing number of stations (users)
- Overhead (preamble, MAC headers, …) may consume more time that payload data



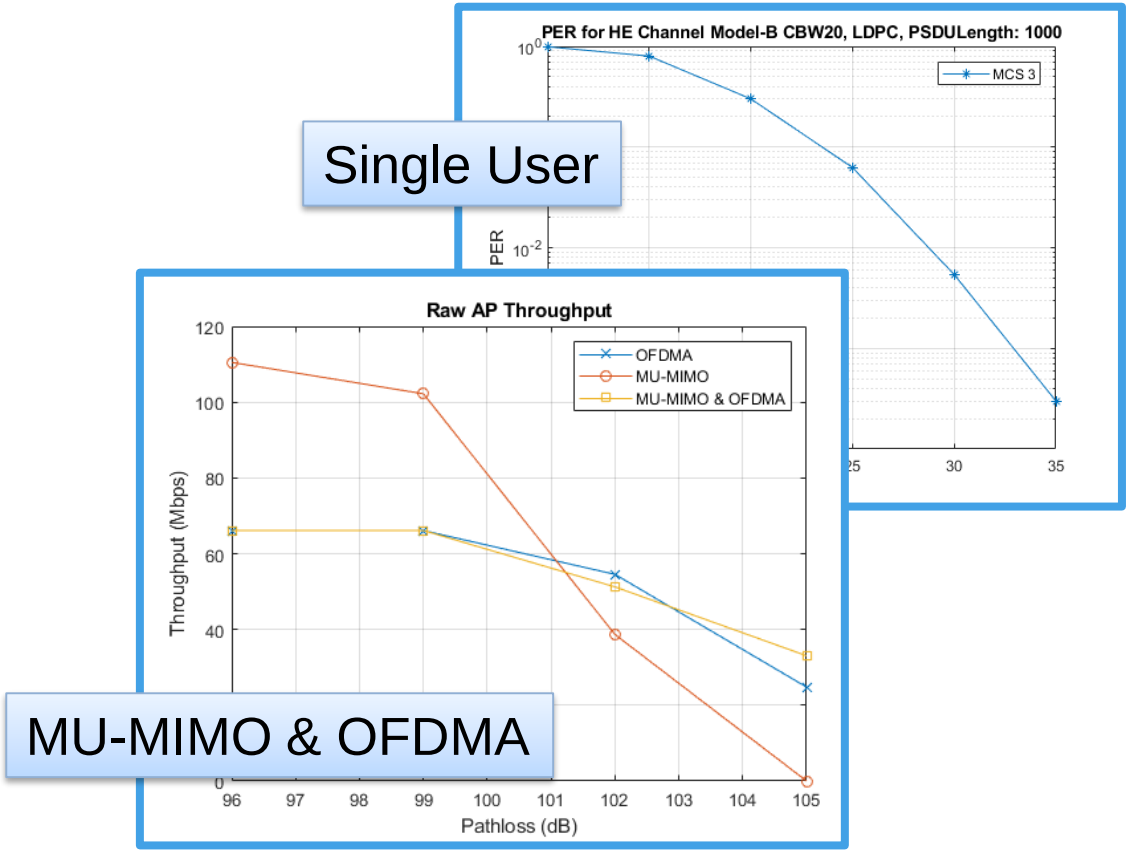
- **802.11n** – introduced Aggregation
  - Combines short packets in time
- **802.11ac** – introduced MU-MIMO
  - Combines multiple users in space
- **802.11ax** - introduced OFDMA
  - Combines multiple users in frequency dimension

802.11ax in WLAN System Toolbox

Signal Generation



End-to-End Simulations

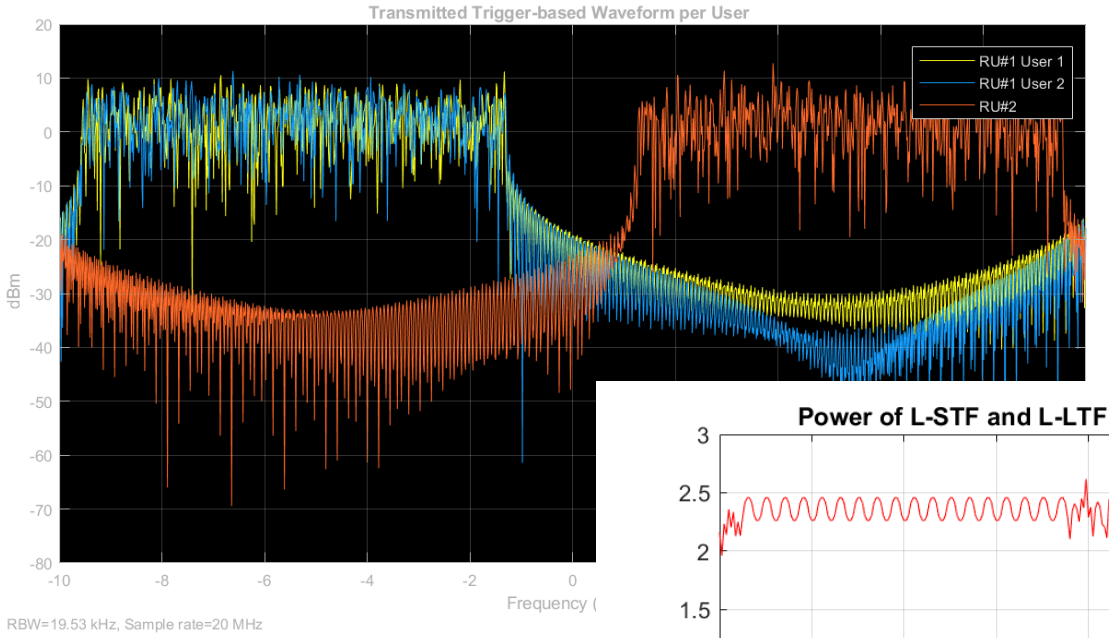


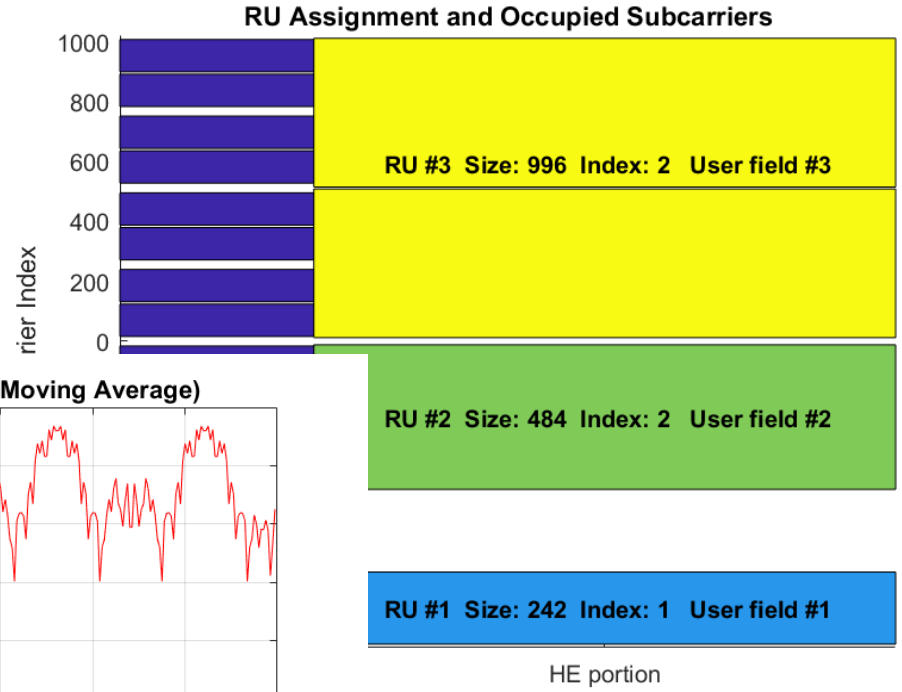
Single User

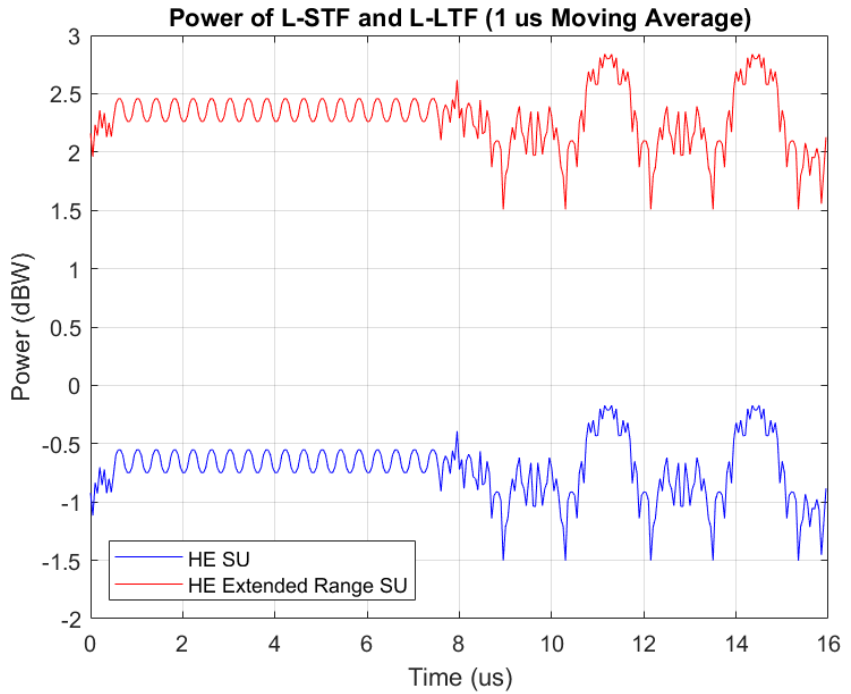
MU-MIMO & OFDMA

- Based on IEEE P802.11ax/D1.1

Waveform Generation Example in MATLAB







Generating 802.11ax PPDU Formats

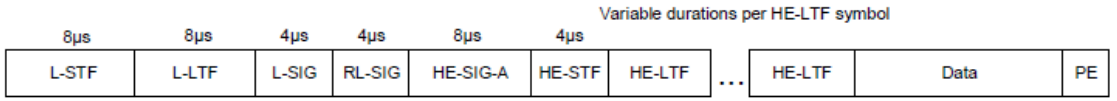


Figure 28-5—HE SU PPDU format

```
cfg = heSUConfig;
```

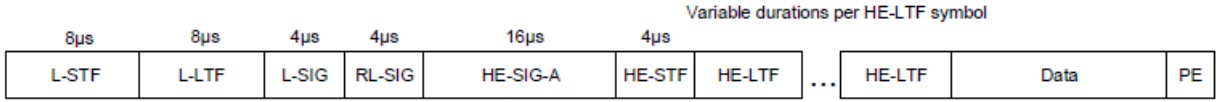


Figure 28-7—HE extended range SU PPDU format

```
cfg = heSUConfig;
cfg.ExtendedRange = true;
```

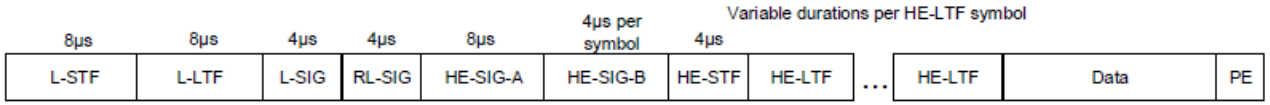


Figure 28-6—HE MU PPDU format

```
cfg = heMUConfig(allocation);
```

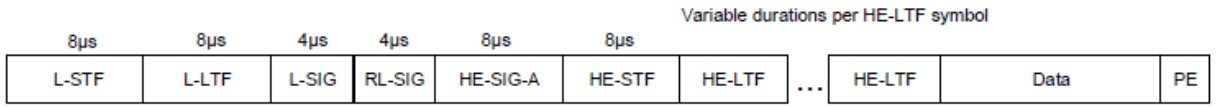


Figure 28-8—HE trigger-based PPDU format

```
cfg = heTriggerBasedConfig();
```

```
tx = heWaveformGenerator(psdu,cfg);
```

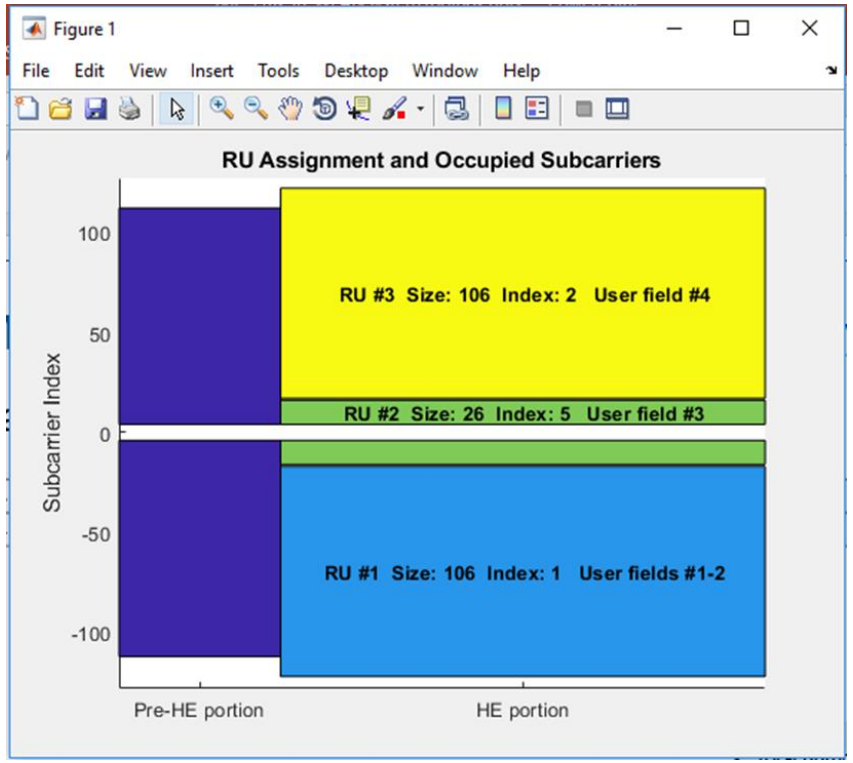
Resource Units in 802.11ax

- OFDMA in 11ax is facilitated by **resource units** (RUs)
- An RU is a group of 26, 52, 106, 242, 484, 996 or 1992 subcarriers
- ≤ 8 users can share an RU (MU-MIMO)
- A user can only be assigned to one RU
- The number, size, and location of RUs is defined by an **allocation index**

Allocation Index	20 MHz Subchannel Resource Unit (RU) Assignment
0	26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26
1	26 | 26 | 26 | 26 | 26 | 26 | 26 | 52
2	26 | 26 | 26 | 26 | 26 | 52 | 26 | 26
3	26 | 26 | 26 | 26 | 26 | 52 | 52
4	26 | 26 | 52 | 26 | 26 | 26 | 26 | 26
5	26 | 26 | 52 | 26 | 26 | 26 | 52
6	26 | 26 | 52 | 26 | 52 | 26 | 26
7	26 | 26 | 52 | 26 | 52 | 52
8	52 | 26 | 26 | 26 | 26 | 26 | 26
9	52 | 26 | 26 | 26 | 26 | 52
10	52 | 26 | 26 | 26 | 52 | 26 | 26
11	52 | 26 | 26 | 26 | 52 | 52
12	52 | 52 | 26 | 26 | 26 | 26 | 26
13	52 | 52 | 26 | 26 | 26 | 52
14	52 | 52 | 26 | 52 | 26 | 26
15	52 | 52 | 26 | 52 | 52
16-23 (15 + NumUsers)	52 | 52 | - | 106 (1-8 users)
24-31 (23 + NumUsers)	106 (1-8 users) | - | 52 | 52
32-39 (31 + NumUsers)	26 | 26 | 26 | 26 | 26 | 106 (1-8 users)
40-47 (39 + NumUsers)	26 | 26 | 52 | 26 | 106 (1-8 users)
48-55 (47 + NumUsers)	52 | 26 | 26 | 26 | 106 (1-8 users)
56-63 (55 + NumUsers)	52 | 52 | 26 | 106 (1-8 users)
64-71 (63 + NumUsers)	106 (1-8 users) | 26 | 26 | 26 | 26 | 26
72-79 (71 + NumUsers)	106 (1-8 users) | 26 | 26 | 26 | 52
80-87 (79+ NumUsers)	106 (1-8 users) | 26 | 52 | 26 | 26
88-95 (87 + NumUsers)	106 (1-8 users) | 26 | 52 | 52
96-103 (95 + NumUsers)	106 | - | 106 (1-8 users)
104-112 (103 + NumUsers)	106 (1-8 users) | - | 106
112	52 | 52 | - | 52 | 52
113	Empty 242-tone RU - No user assigned
116-127	Reserved
128-135 (127 + NumUsers)	106 | 26 | 106 (1-8 users)
136-143 (135 + NumUsers)	106 (2 users) | 26 | 106 (1-8 users)
44-151 (143 + NumUsers)	106 (3 users) | 26 | 106 (1-8 users)
152-158 (151 + NumUsers)	106 (4 users) | 26 | 106 (1-8 users)
160-166 (158 + NumUsers)	106 (5 users) | 26 | 106 (1-8 users)
168-175 (166 + NumUsers)	106 (6 users) | 26 | 106 (1-8 users)
176-183 (175 + NumUsers)	106 (7 users) | 26 | 106 (1-8 users)
184-191 (183 + NumUsers)	106 (8 users) | 26 | 106 (1-8 users)
192-199 (191 + NumUsers)	242 (1-8 users)

HE-MU Format: OFDMA and MU-MIMO Allocations

- An **allocation index** is required when creating an HE-MU configuration
- For each 20MHz sub-band an allocation index specifies:
  - The number, size and location of RUs
  - How many users are assigned to each RU
  - Which HE-SIG-B content channel users are signaled on, for RUs >242-tones



- You can easily visualize user allocations

```
>> plotAllocation(cfg);
```

OFDMA and MU-MIMO Allocation in WLAN System Toolbox

- Use allocation index to define an 802.11ax configuration

128-135 (127 + NumUsers)	106	26	106 (1-8 users)
136-143 (135 + NumUsers)	106 (2 users)	26	106 (1-8 users)

```
allocationIndex = 136;
cfg = heMUConfig(allocationIndex);
ruInfo(cfg)
```

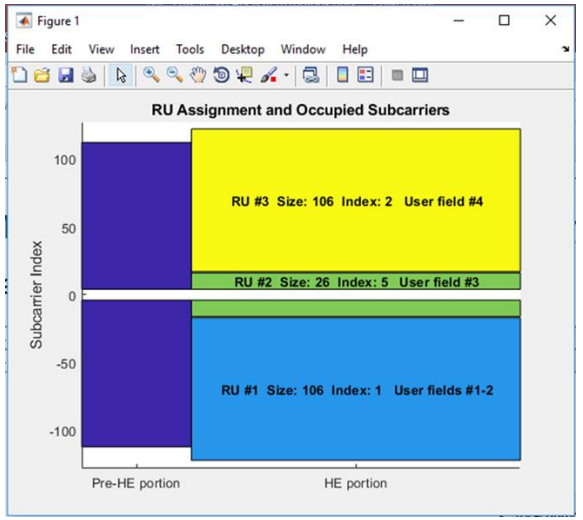
136 specifies 3 RUs, 2x106-tone and 1x26 tone

```
ans =

  struct with fields:

                NumUsers: 4
                  NumRUs: 3
               RUIndices: [1 5 2]
                 RUSizes: [106 26 106]
            NumUsersPerRU: [2 1 1]
  NumSpaceTimeStreamsPerRU: [2 1 1]
     PowerBoostFactorPerRU: [1 1 1]
```

Total number of users in this allocation

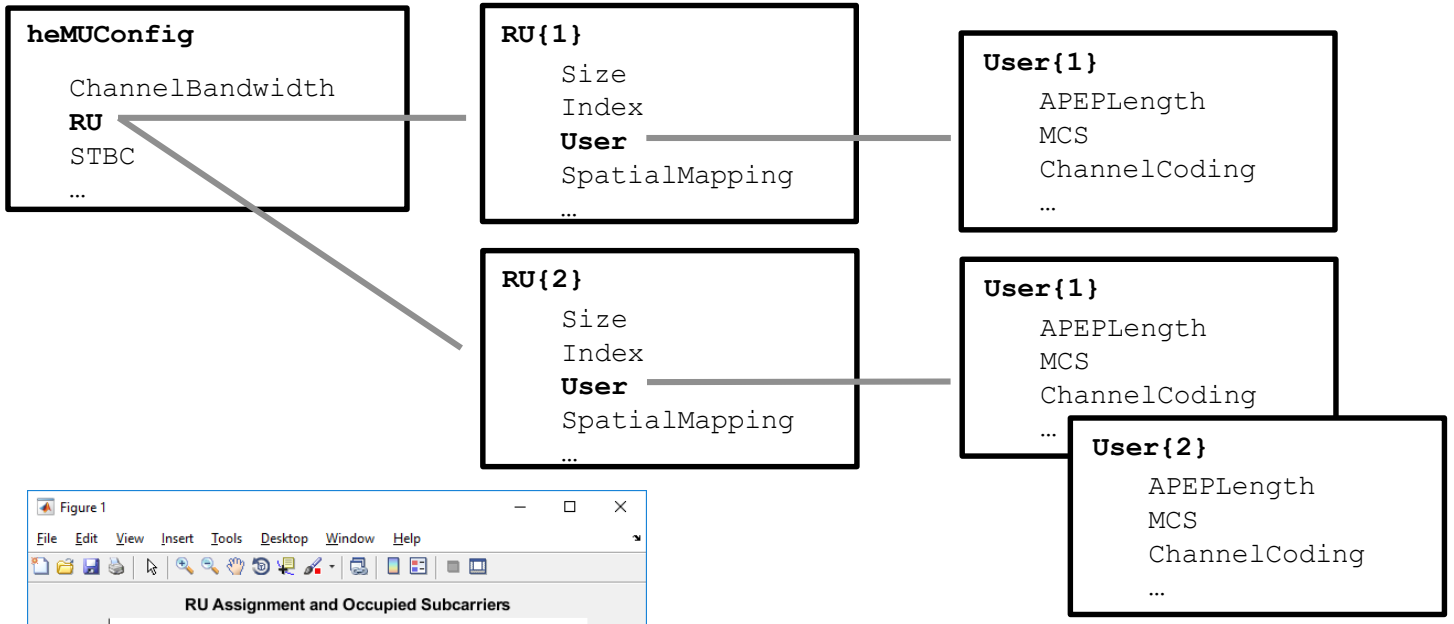
Number of resource units (RUs) in this allocation

The size and index of each RU in the allocation



Configuring Users and RUs

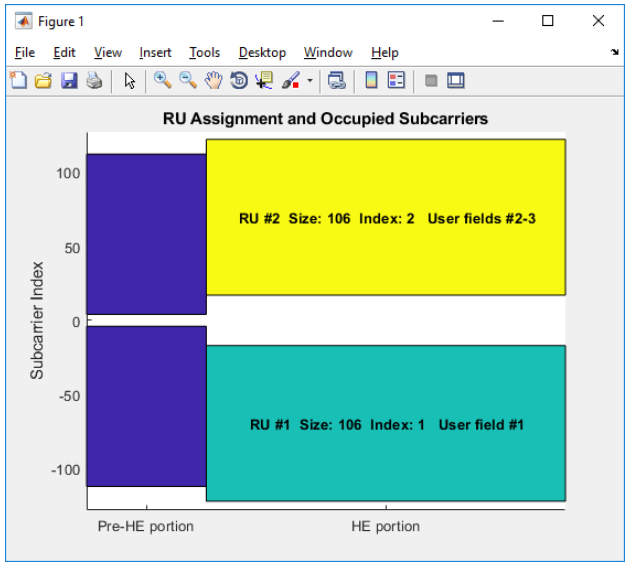
- The hierarchy within heMUConfig allows RUs to be configured:



A cell array `cfg.RU` contains the configuration for RUs

```
cfg = heMUConfig(97);

% Configure RU 1 and the user
cfg.RU{1}.User{1}.APEPLength = 1500;
cfg.RU{1}.User{1}.MCS = 2;
cfg.RU{1}.User{1}.NumSpaceTimeStreams = 4;
cfg.RU{1}.User{1}.ChannelCoding = 'LDPC';
cfg.RU{1}.SpatialMapping = 'Direct';

% Configure RU 2, user 1
cfg.RU{2}.User{1}.APEPLength = 1000;
cfg.RU{2}.User{1}.MCS = 3;
cfg.RU{2}.User{1}.NumSpaceTimeStreams = 2;
cfg.RU{2}.User{1}.ChannelCoding = 'BCC';

% Configure RU 2, user 2
cfg.RU{2}.User{2}.APEPLength = 2000;
cfg.RU{2}.User{2}.MCS = 6;
cfg.RU{2}.User{2}.NumSpaceTimeStreams = 2;
cfg.RU{2}.User{2}.ChannelCoding = 'LDPC';

% Configure RU 2 common properties
cfg.RU{2}.SpatialMapping = 'Custom';
cfg.RU{2}.SpatialMappingMatrix = Q;
```

A cell array `RU{x}.User` contains the configuration for users within a RU x



Full-band MU-MIMO Allocations

- A full-band MU-MIMO allocation is specified with index 192-223

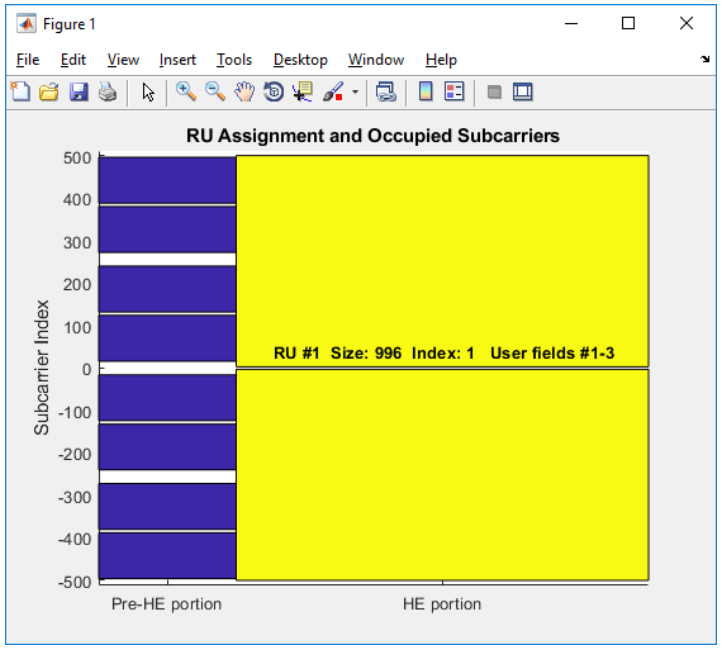
Allocation Index	20 MHz Subchannel Resource Unit Assignment
192-199 (191 + NumUsers)	**Full band 20 MHz** (1-8 users)
200-207 (199 + NumUsers)	**Full band 40 MHz (1-8 users)**, or 448-tone RU with 1-8 users signaled in the corresponding HE-SIG-B content channel
208-215 (207 + NumUsers)	**Full band 80 MHz (1-8 users)**, or 996-tone RU with 1-8 users signaled in the corresponding HE-SIG-B content channel
216-223 (215 + NumUsers)	**Full band 160 MHz (1-8 users)**

```
cfg = heMUConfig(210);
ruInfo(cfg)

ans =

  struct with fields:

                NumUsers: 3
                  NumRUs: 1
               RUIndices: 1
                 RUSizes: 996
           NumUsersPerRU: 3
  NumSpaceTimeStreamsPerRU: 3
     PowerBoostFactorPerRU: 1
```

210 specifies 3 users, full band 80 MHz

3 users

All users on single RU



OFDMA and MU-MIMO Allocations greater than 20 MHz

- An allocation index is required for each 20 MHz subchannel

192-199 (191 + NumUsers)	242 (1-8 users)

192 specifies 1 user in a 242-tone RU

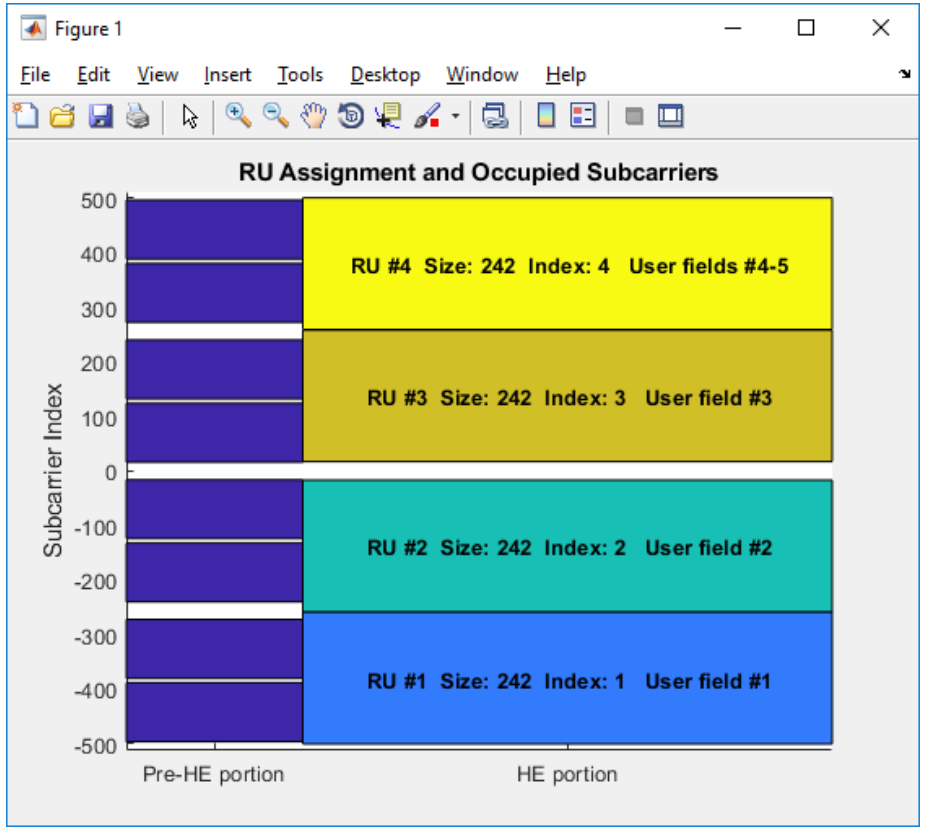
193 specifies 2 users in a 242-tone RU

```
cfg = heMUConfig([192 192 192 193]);
ruInfo(cfg)

ans =

  struct with fields:

                 NumUsers: 5
                   NumRUs: 4
                RUIndices: [1 2 3 4]
                  RUSizes: [242 242 242 242]
            NumUsersPerRU: [1 1 1 2]
  NumSpaceTimeStreamsPerRU: [1 1 1 2]
     PowerBoostFactorPerRU: [1 1 1 1]
```

Four allocation indices defines an 80 MHz allocation. Each element specifies the allocation for a 20MHz subchannel

The total number of users is 1+1+1+2 = 5

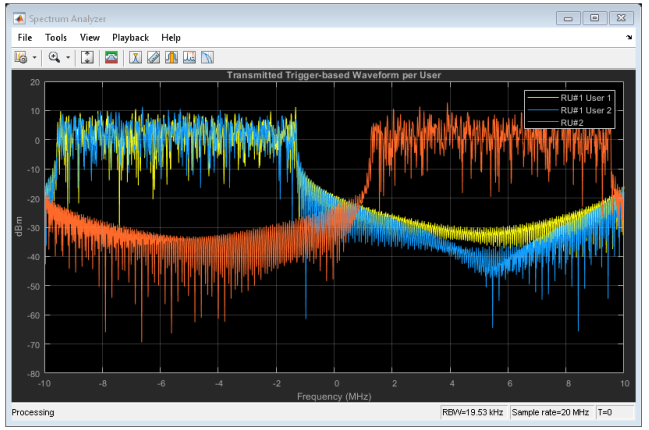
The 4th RU contains 2 users, as the allocation index is 193.



WLAN Examples

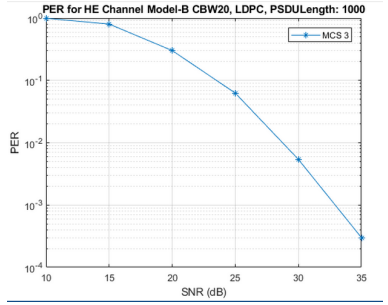
802.11ax Parameterization for Waveform Generation and Simulation

Generation of different types of IEEE 802.11ax high efficiency (HE) formats.



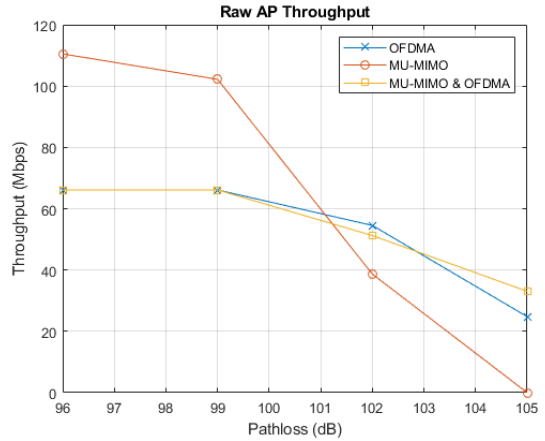
802.11ax Packet Error Rate Simulation for Single User Format

Packet error rate of an 802.11ax single user format link.



802.11ax OFDMA and Multi-User MIMO Throughput Simulation

Throughput of OFDMA, MU-MIMO, and a combination of OFDMA and MU-MIMO over TGax indoor channel.



For which aspects of 802.11ax do you want more support?

- HE-MU uplink transmission with a single 106-tone RU
- Demodulation and decoding of HE trigger-based format transmissions
- 80+80 channel bandwidth
- Outdoor TGax channel model
- Code generation support

Summary

- Support of single-user, MU-MIMO and OFDMA
  - Waveform generation
  - End-to-end simulation
- Open environment
  - MATLAB source code included
  - Link to test and measurement instruments, RF, SDRs
- Easy configuration and visualization
  - Allocation index
  - Resource visualization