

# IEEE 802.11ax

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



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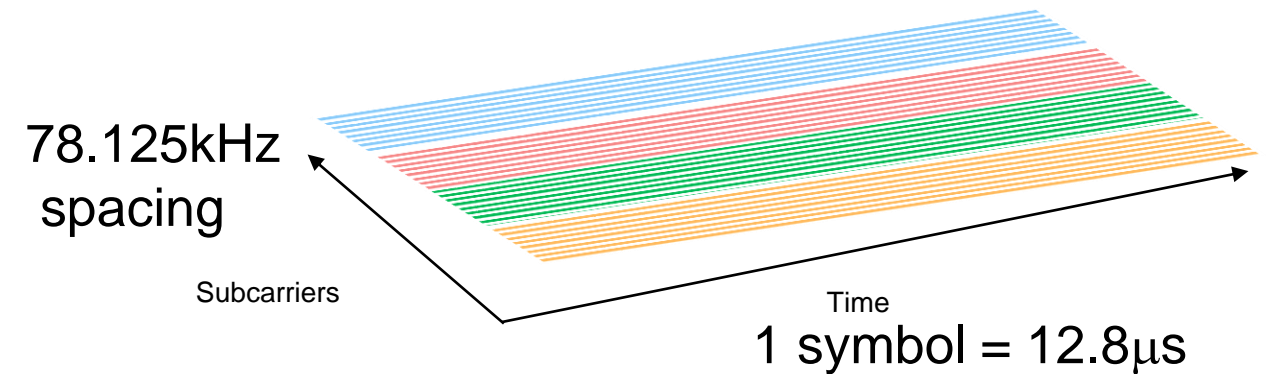
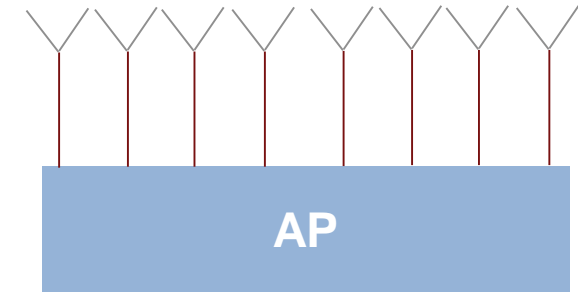
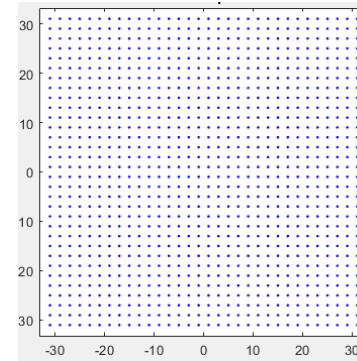
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# What is 802.11ax?

- 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

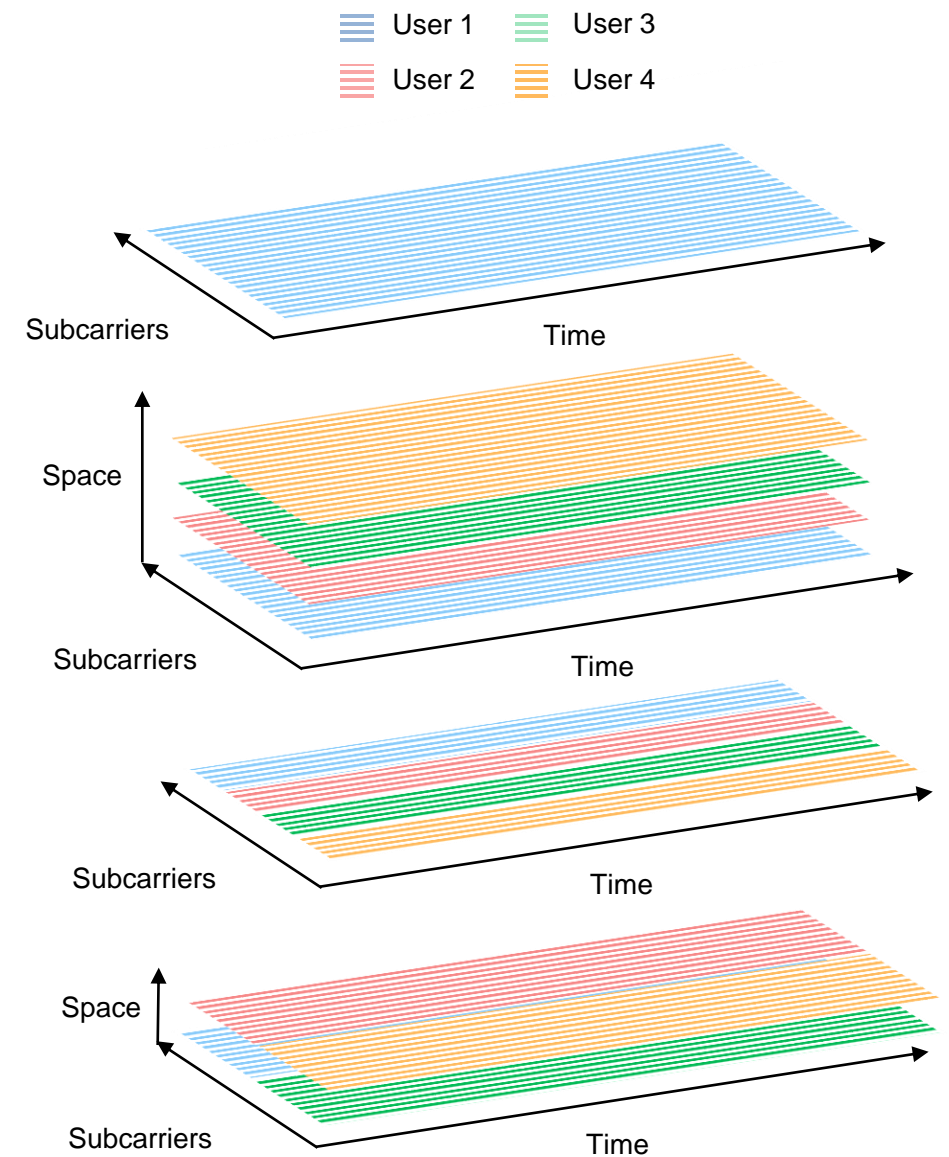
# Key Features of 802.11ax

- 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



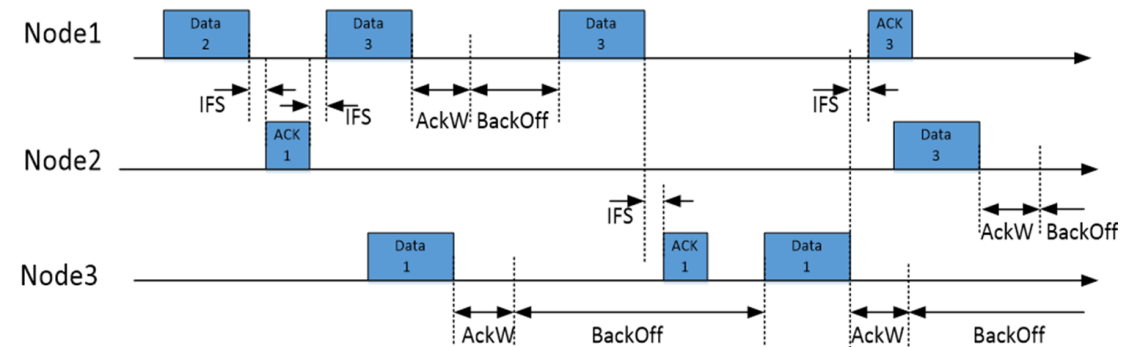
# Enabling technologies: OFDMA and MU-MIMO

- **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



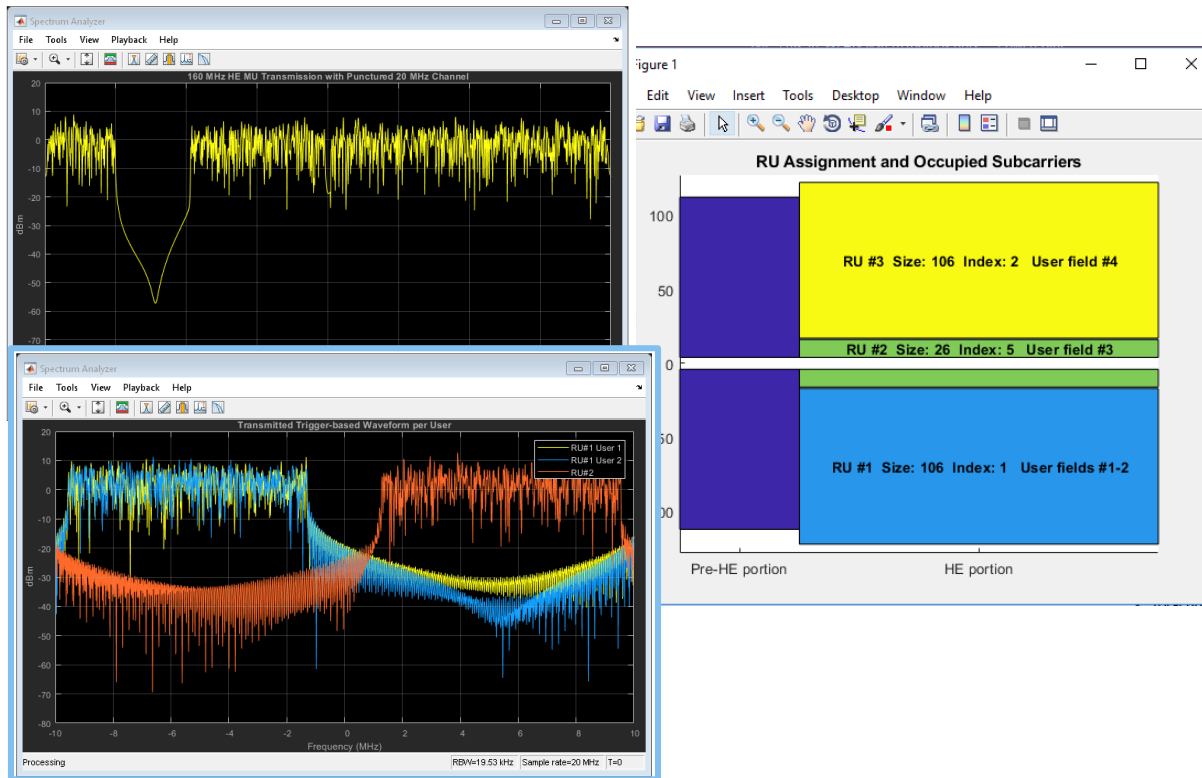
## Rationale: More efficiency

- WLAN MAC efficiency drops with increasing number of stations (users)
- Overhead (preamble, MAC headers, ...) may consume more time than 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



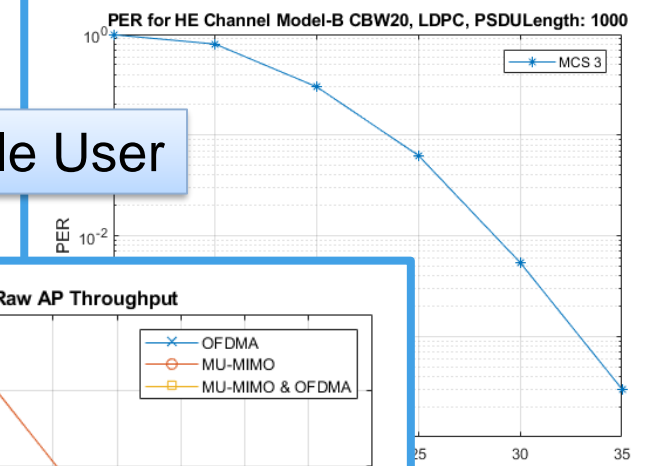
# 802.11ax in WLAN System Toolbox

## Signal Generation

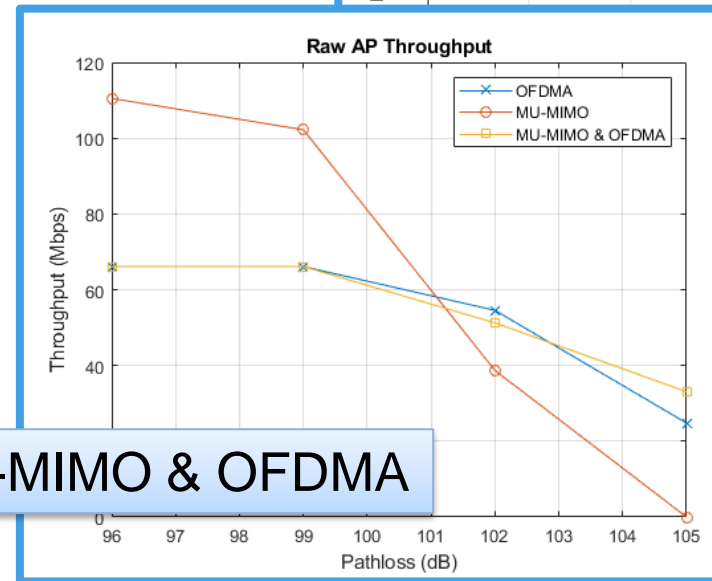


## End-to-End Simulations

### Single User

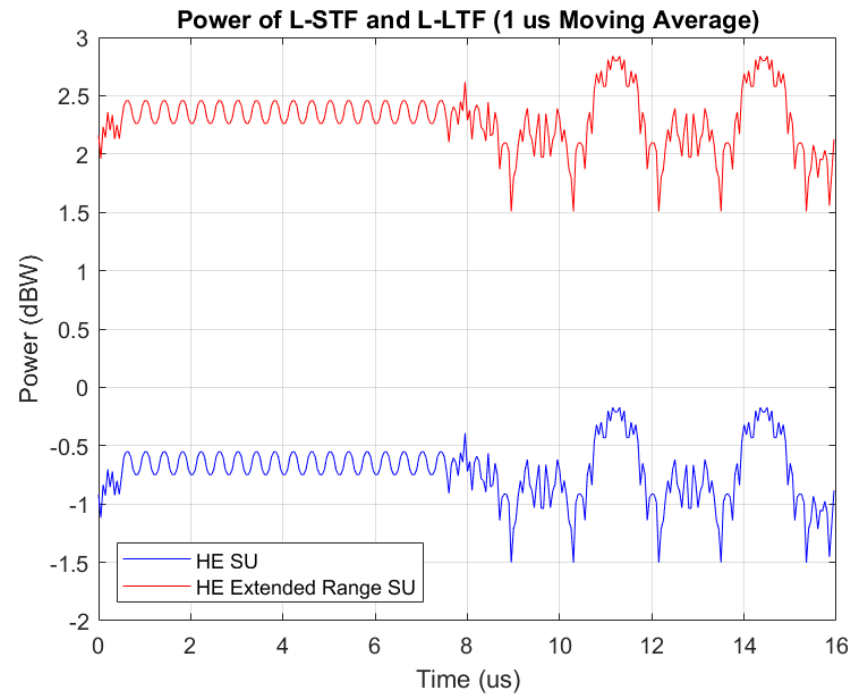
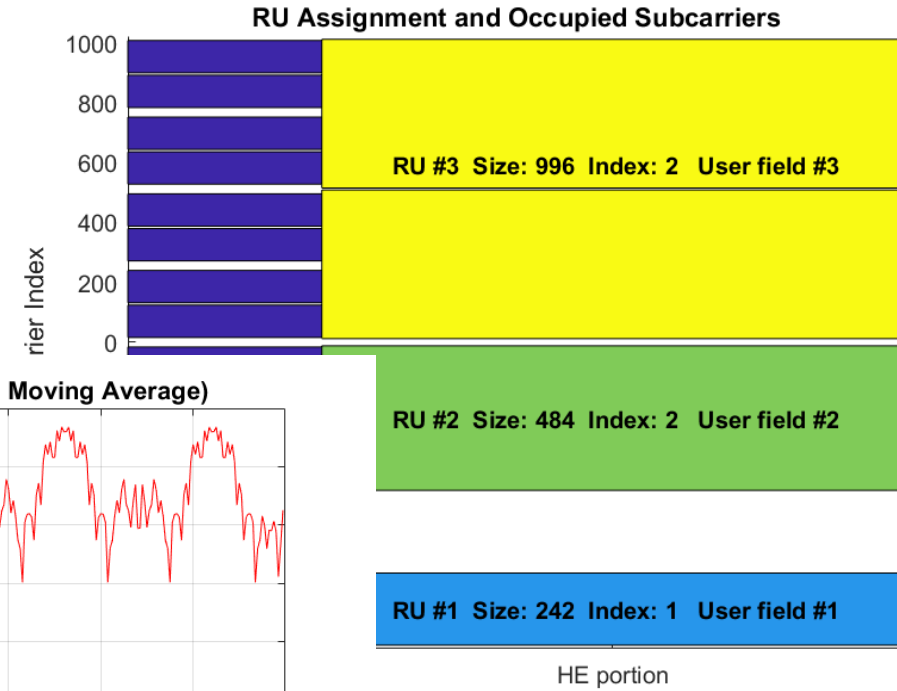
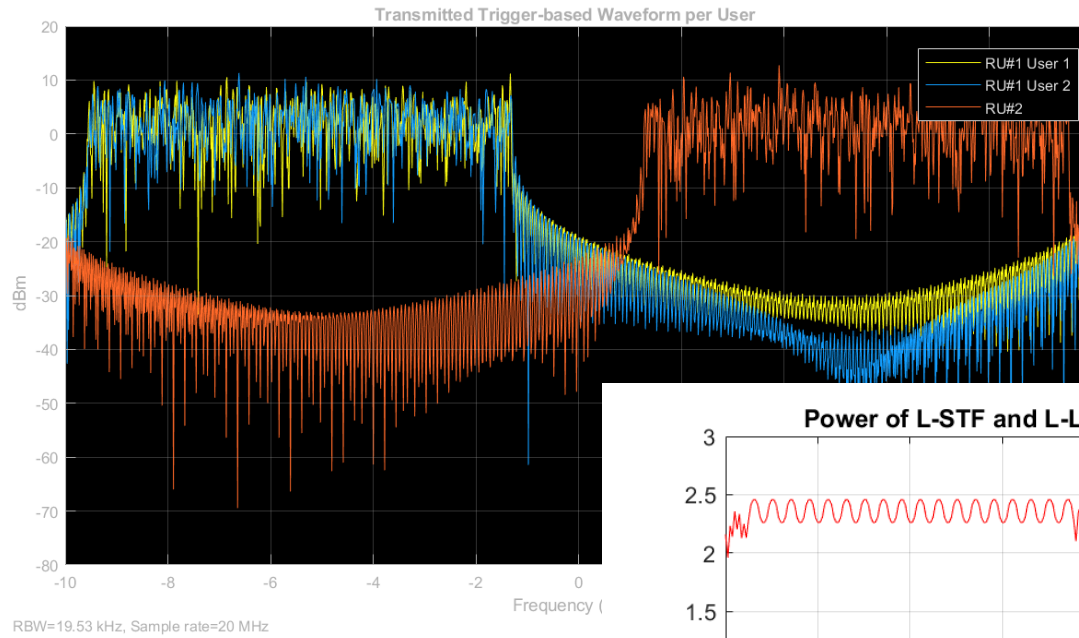


### MU-MIMO & OFDMA



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

# Waveform Generation Example in MATLAB





# Generating 802.11ax PPDU Formats

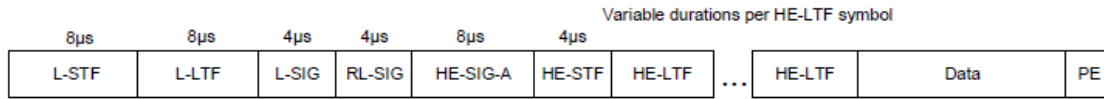


Figure 28-5—HE SU PPDU format

```
cfg = heSUConfig;
```

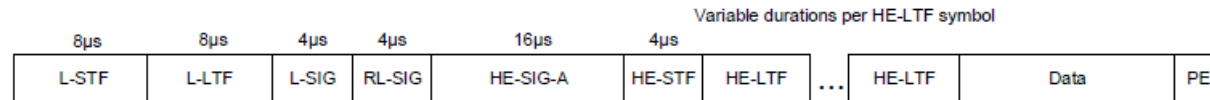


Figure 28-7—HE extended range SU PPDU format

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

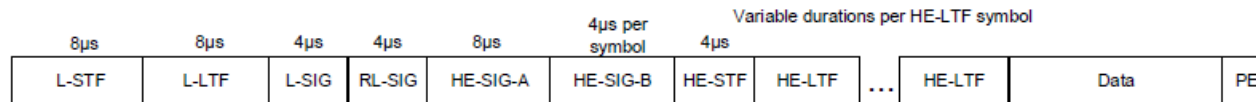


Figure 28-6—HE MU PPDU format

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

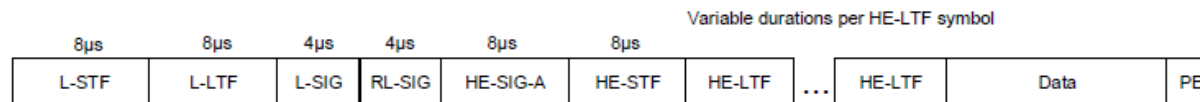


Figure 28-8—HE trigger-based PPDU format

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

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



# Resource Units in 802.11ax

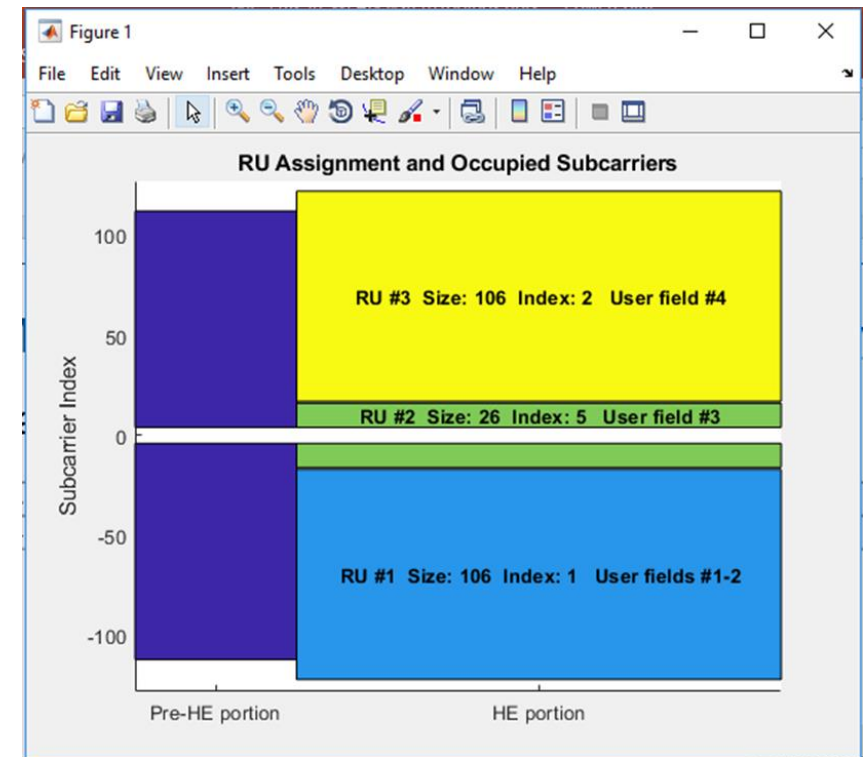
- OFDMA in 11ax is facilitated by **resource units (RUs)**
- An RU is a group of 26, 52, 106, 242, 484, 996 or 1992 subcarriers
- $\leq 8$  users can share an RU (MU-MIMO)
- A user can only be assigned to one RU
- The number, size, and location of RUs is defined by an **allocation index**

Allocation Index	20 MHz Subchannel Resource Unit (RU) Assignment							
0	26	26	26	26	26	26	26	26
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	26
7	26	26	52	26	52	52	52	
8	52	26	26	26	26	26	26	26
9	52	26	26	26	26	26	52	
10	52	26	26	26	52	26	26	26
11	52	26	26	26	52	52	52	
12	52	52	26	26	26	26	26	26
13	52	52	26	26	26	52	52	
14	52	52	26	52	26	26	26	26
15	52	52	26	52	52	52	52	
16-23 (15 + NumUsers)	52	52	-	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	
24-31 (23 + NumUsers)	106 (1-8 users)	-	52	52	52	52	52	
32-39 (31 + NumUsers)	26	26	26	26	26	106 (1-8 users)	106 (1-8 users)	
40-47 (39 + NumUsers)	26	26	52	26	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	
48-55 (47 + NumUsers)	52	26	26	26	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	
56-63 (55 + NumUsers)	52	52	26	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	
64-71 (63 + NumUsers)	106 (1-8 users)	26	26	26	26	26	26	26
72-79 (71 + NumUsers)	106 (1-8 users)	26	26	26	52	52	52	
80-87 (79 + NumUsers)	106 (1-8 users)	26	52	26	26	26	26	26
88-95 (87 + NumUsers)	106 (1-8 users)	26	52	52	52	52	52	
96-103 (95 + NumUsers)	106	-	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	
104-112 (103 + NumUsers)	106 (1-8 users)	-	106	106	106	106	106	
112	52	52	-	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)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	
136-143 (135 + NumUsers)	106 (2 users)	26	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	
144-151 (143 + NumUsers)	106 (3 users)	26	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	
152-158 (151 + NumUsers)	106 (4 users)	26	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	
160-166 (158 + NumUsers)	106 (5 users)	26	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	
168-175 (166 + NumUsers)	106 (6 users)	26	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	
176-183 (175 + NumUsers)	106 (7 users)	26	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	
184-191 (183 + NumUsers)	106 (8 users)	26	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	106 (1-8 users)	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

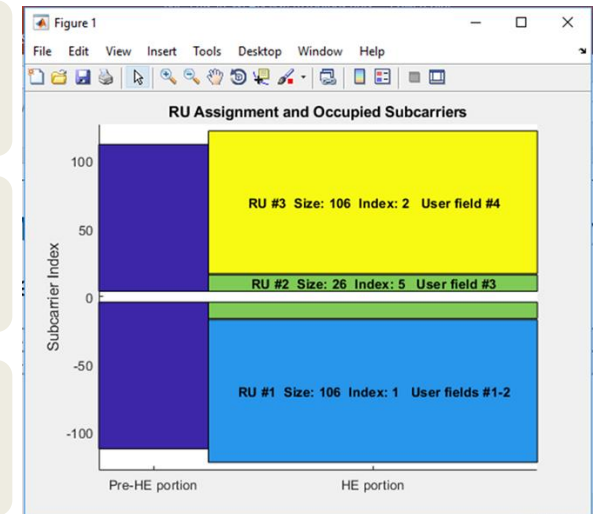
```
ans =
struct with fields:
```

```
    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

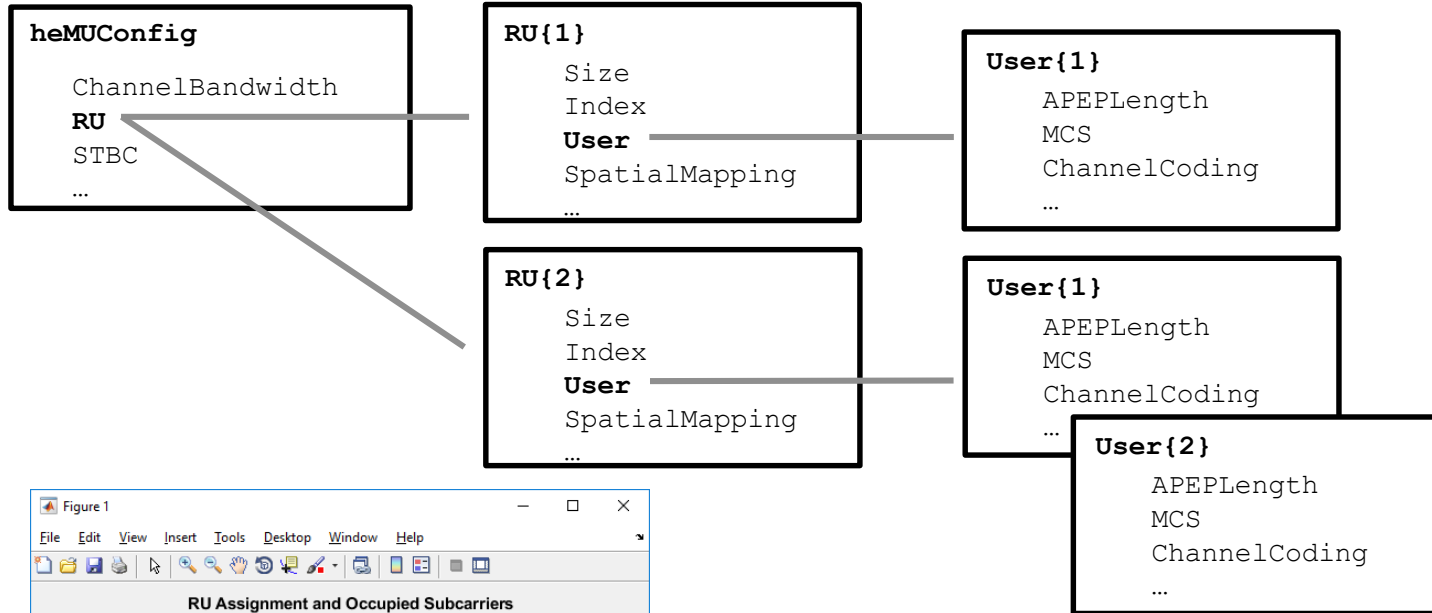
Number of resource units (RUs) in this allocation

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';

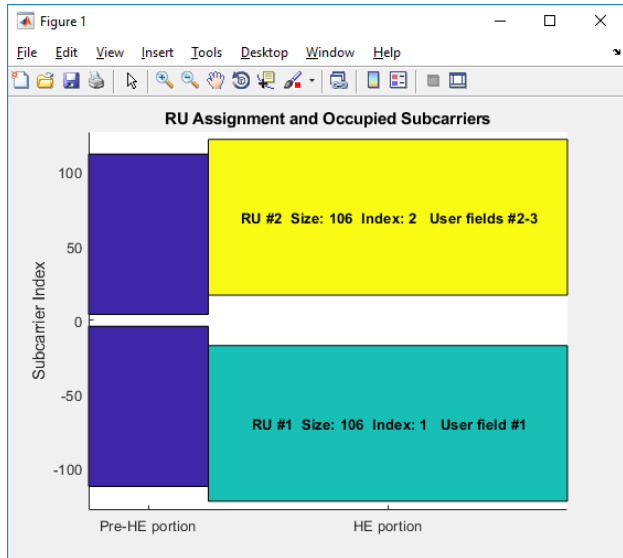
% Configure RU 2, user 1
cfg.RU{2}.User{1}.APEPLength = 1000;
cfg.RU{2}.User{1}.MCS = 3;
cfg.RU{2}.User{1}.NumSpaceTimeStreams = 2;
cfg.RU{2}.User{1}.ChannelCoding = 'BCC';

% 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)
```

210 specifies 3 users,  
full band 80 MHz

```
ans =
```

```
struct with fields:
```

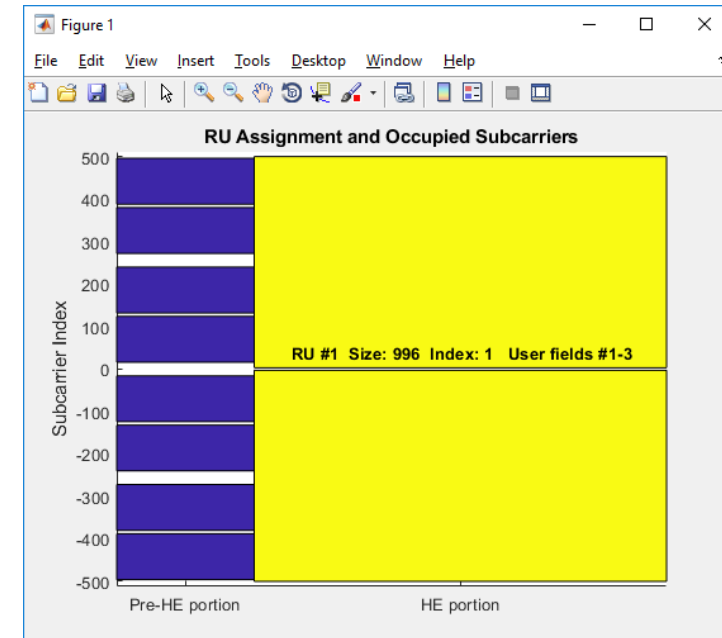
```

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

```

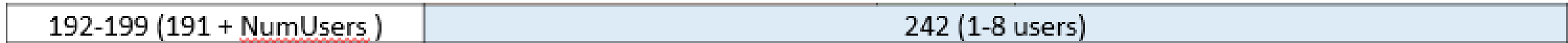
3 users

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 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 =

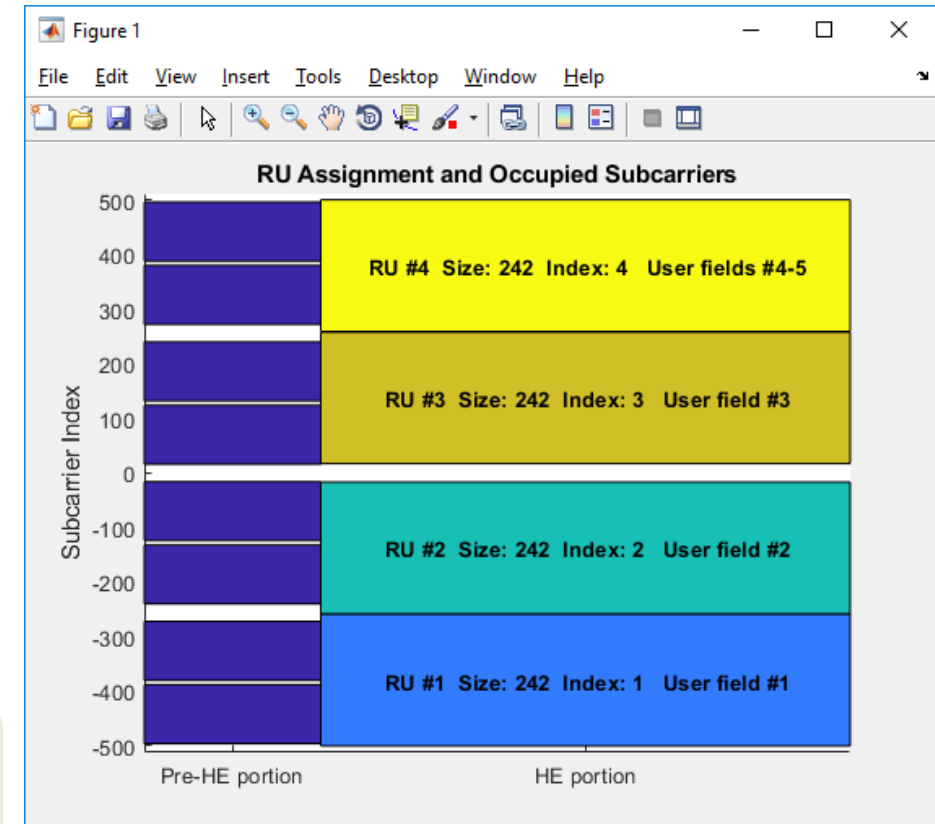
struct with fields:

```
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

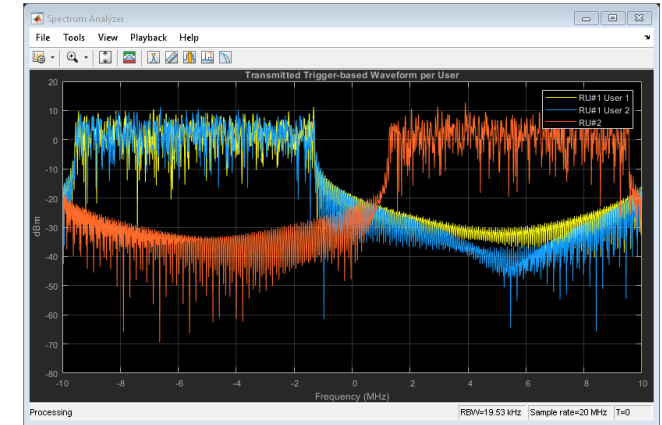
The 4<sup>th</sup> RU contains 2 users, as the allocation index is 193.



# WLAN Examples

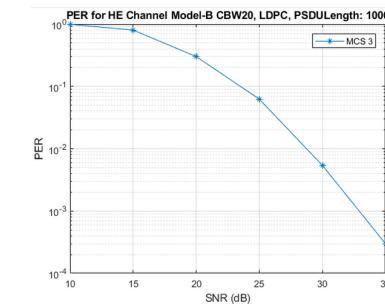
## 802.11ax Parameterization for Waveform Generation and Simulation

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



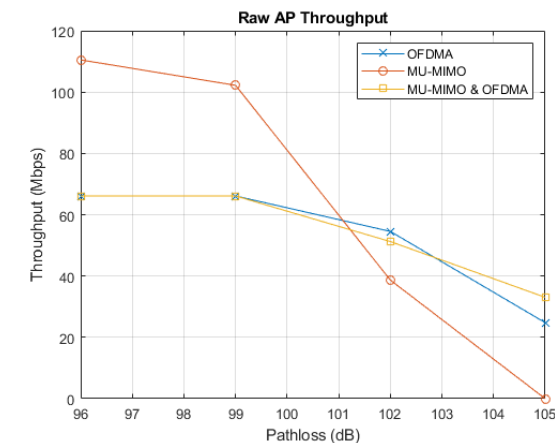
## 802.11ax Packet Error Rate Simulation for Single User Format

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

