MATLAB Example 4: Reproducing Table III in IEEE TCOM “Efficient PHY Layer Abstraction for Fast Simulations in Complex System Environments”

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Prerequisites: MATLAB 2020b (or later version), MATLAB WLAN toolbox in MATLAB 2020b (or later version)

Goal: Learn how to implement traditional EESM PHY layer abstraction shown in Fig. 1 of our IEEE TCOM paper, and observe the runtime scaling issue caused by traditional EESM PHY layer abstraction. The implementation flow of traditional EESM PHY layer abstraction is shown in Fig. 7 of our IEEE TCOM paper.

Folders:

MU code basic/1 Full PHY (no interferer)
MU code basic/2 EESM parameter optimization
MU code basic/5 Traditional EESM (no interferer)

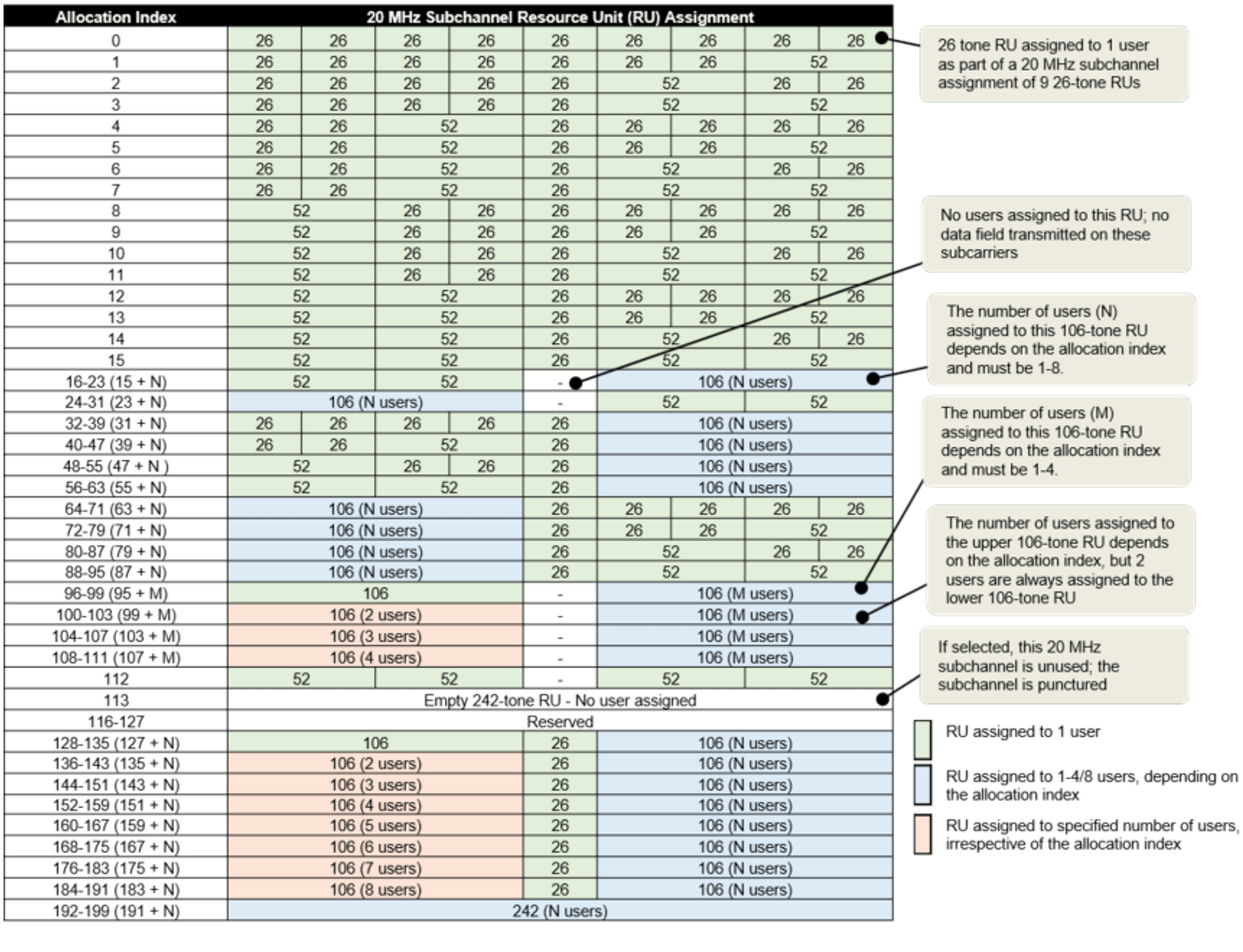
Step 1 (Full PHY simulation):

Goal: full PHY simulation shown in Fig. 7 of our IEEE TCOM paper.

Open: MU code basic/1 Full PHY (no interferer)/fullPHY.m

PHY layer configuration:

- OFDMA allocation with 106 subcarriers
- 2-user 8×2 MU-MIMO with 2 streams
- TGax channel model-D
- Payload length = 1000 Byte
- MCS4, LDPC coding



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	26
9	52		26	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 + N)	52		52		-	106 (N users)			
24-31 (23 + N)	106 (N users)				-	52		52	
32-39 (31 + N)	26	26	26	26	26	106 (N users)			
40-47 (39 + N)	26	26	52		26	106 (N users)			
48-55 (47 + N)	52		26	26	26	106 (N users)			
56-63 (55 + N)	52		52		26	106 (N users)			
64-71 (63 + N)	106 (N users)				26	26	26	26	26
72-79 (71 + N)	106 (N users)				26	26	26	52	
80-87 (79 + N)	106 (N users)				26	52		26	26
88-95 (87 + N)	106 (N users)				26	52		52	
96-99 (95 + M)	106				-	106 (M users)			
100-103 (99 + M)	106 (2 users)				-	106 (M users)			
104-107 (103 + M)	106 (3 users)				-	106 (M users)			
108-111 (107 + M)	106 (4 users)				-	106 (M users)			
112	52		52		-	52		52	
113	Empty 242-tone RU - No user assigned								
116-127	Reserved								
128-135 (127 + N)	106				26	106 (N users)			
136-143 (135 + N)	106 (2 users)				26	106 (N users)			
144-151 (143 + N)	106 (3 users)				26	106 (N users)			
152-159 (151 + N)	106 (4 users)				26	106 (N users)			
160-167 (159 + N)	106 (5 users)				26	106 (N users)			
168-175 (167 + N)	106 (6 users)				26	106 (N users)			
176-183 (175 + N)	106 (7 users)				26	106 (N users)			
184-191 (183 + N)	106 (8 users)				26	106 (N users)			
192-199 (191 + N)	242 (N users)								

26 tone RU assigned to 1 user as part of a 20 MHz subchannel assignment of 9 26-tone RUs

No users assigned to this RU; no data field transmitted on these subcarriers

The number of users (N) assigned to this 106-tone RU depends on the allocation index and must be 1-8.

The number of users (M) assigned to this 106-tone RU depends on the allocation index and must be 1-4.

The number of users assigned to the upper 106-tone RU depends on the allocation index, but 2 users are always assigned to the lower 106-tone RU

If selected, this 20 MHz subchannel is unused; the subchannel is punctured

🟩 RU assigned to 1 user

🟦 RU assigned to 1-4/8 users, depending on the allocation index

🟧 RU assigned to specified number of users, irrespective of the allocation index

In this example, we set the 11ax allocation index to be 97.

Checking the above RU assignment figure, for allocation index 97, the 2nd RU contains 106 subcarriers, and the 2 users occupies this RU. We focus on the 2nd user. So, we set userIdx = 2, and ruIdx = 2.

8×2 MIMO dimension with 2 streams corresponds to numTxRx = [8 2] and Nsts = 2.
MCS4 corresponds to mcs = [4].
TGax channel model-D corresponds to chan = “Model-D”.
Payload length = 1000 Byte corresponds to cfgHE.User{userIdxIter}.APEPLength = 1000.
LDPC coding is the default coding for 11ax. There is no need to setup LDPC. Please check cfgHE.User for the LDPC configuration.

The configuration code is shown as follows:

```
%% Full PHY simulation setup
clear all
tStart = tic;
mcs = [4]; % Vector of MCS to simulate between 0 and 11
numTxRx = [8 2]; % Matrix of MIMO schemes, each row is [numTx numRx]
chan = "Model-D"; % String array of delay profiles to simulate
userIdx = 2; % User of investigation
ruIdx = 2; % RU of investigation
Nsts = 2; % Number of space-time streams
maxnumberrors = 40*1e3;  % The maximum number of packet errors at an SNR
point
maxNumPackets = 40*1e3; % The maximum number of packets at an SNR point
% maxnumberrors = 5*1e1;  % The maximum number of packet errors at an SNR
point
% maxNumPackets = 5*1e2; % The maximum number of packets at an SNR point

% Fixed PHY configuration for all simulations
cfgHE = wlanHEMUConfig(97); % Input 11ax allocation index
% The full RU assignment and allocation index lookup table is shown
% in the quick start guide
% Example: when allocation index = 24,
% then 1st RU has size 106, 2nd/3rd RU size = 52
for userIdxIter = 1:numel(cfgHE.User)
    cfgHE.User{userIdxIter}.APEPLength = 1000; % Payload length in bytes
end
```

Open: MU code basic/1 Full PHY (no interferer)/getBox0SimParams.m

Consider simulating the PHY layer under RX SNR = 15, 18, 20, 21 dBs.
In the variable snr: Model-D, 8x2, MCS4 part, set the snr to be [15,18,20,21] (notice the bold part in the following code):

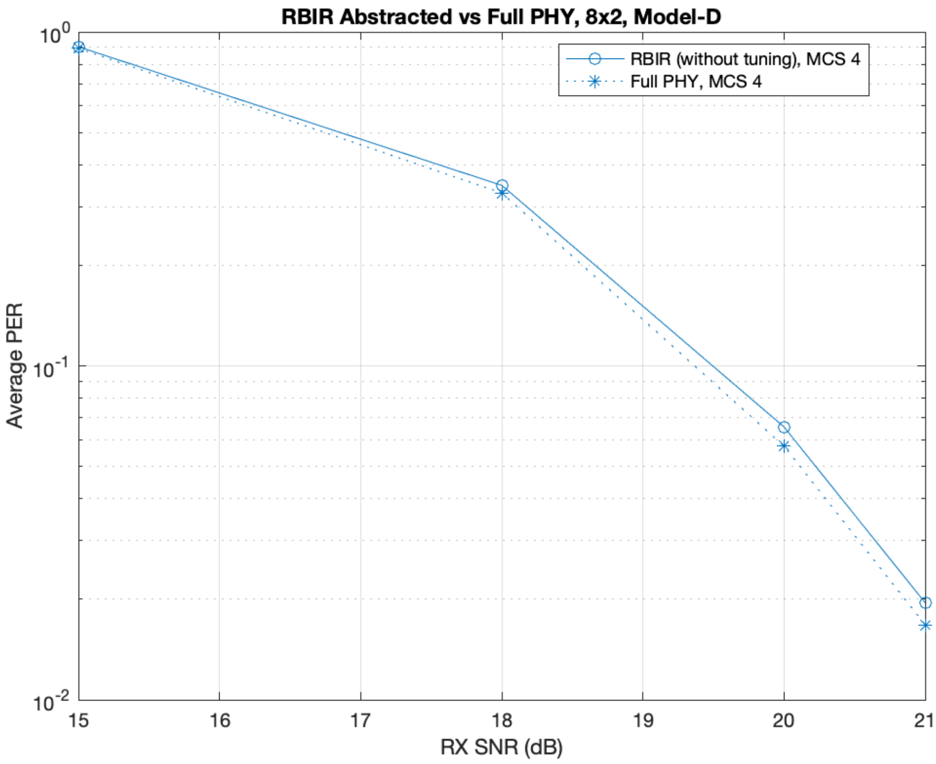
```
snr = {
    % Model-B
    [ ...
        {... % 1x1
    [-3:4:9,11], ...   % MCS 0
    [1:4:13], ...     % MCS 1
    [2:4:18], ...     % MCS 2
    [7:4:19,21], ...     % MCS 3
    [9:4:25], ...     % MCS 4
    [13:4:29], ...    % MCS 5
    [14:4:30], ...    % MCS 6
    [16:4:32,34], ...    % MCS 7
    [18:4:34,36] ... % MCS 8
    [18:4:38] ...     % MCS 9
    21.5:4:37.5 ... % MCS 10
    22:4:38 ...     % MCS 11
    }; ...
        {... % 4x1
    1:3:17, ...  % MCS 0
    5:3:23, ...  % MCS 1
    9:4:30, ...  % MCS 2
    12:4:36, ... % MCS 3
    16:4:40, ... % MCS 4
    20:4:43, ... % MCS 5
    22:4:46, ... % MCS 6
    24:4:48, ... % MCS 7
    26:4:50 ...  % MCS 8
    29:4:54 ...  % MCS 9
    21.5:4:37.5 ... % MCS 10
    22:4:38 ...     % MCS 11
    }; ...
        {... % 4x2
    1:3:17, ...  % MCS 0
    5:3:23, ...  % MCS 1
    9:4:30, ...  % MCS 2
    12:4:36, ... % MCS 3
    16:4:40, ... % MCS 4
    20:4:43, ... % MCS 5
    22:4:46, ... % MCS 6
    24:4:48, ... % MCS 7
    26:4:50 ...  % MCS 8
    29:4:54 ...  % MCS 9
    21.5:4:37.5 ... % MCS 10
    22:4:38 ...     % MCS 11
    }; ...
         {... % 8x2
    1:3:17, ...  % MCS 0
    5:3:23, ...  % MCS 1
    9:4:30, ...  % MCS 2
    12:4:36, ... % MCS 3
    16:4:40, ... % MCS 4
    20:4:43, ... % MCS 5
    22:4:46, ... % MCS 6
    24:4:48, ... % MCS 7
    26:4:50 ...  % MCS 8
    29:4:54 ...  % MCS 9
    21.5:4:37.5 ... % MCS 10
    22:4:38 ...     % MCS 11
    }; ...
    ];
```

```
% Model-D
    [ ...
        {... % 1x1
    -3:3:9, ...     % MCS 0
    0:4:12, ...     % MCS 1
    2:4:18, ...     % MCS 2
    8:4:20, ...     % MCS 3
    11:4:23, ...    % MCS 4
    [14:4:26,28], ...    % MCS 5
    16:4:28, ...    % MCS 6
    18:4:30, ...    % MCS 7
    21.5:4:37.5 ... % MCS 8
    20:4:36 ...     % MCS 9
    21.5:4:37.5 ... % MCS 10
    22:4:38 ...     % MCS 11
    }; ...
        {... % 4x1
    -4:2:2, ...   % MCS 0
    5:2:15, ...   % MCS 1
    9:2:21, ...   % MCS 2
    12:2:24, ...  % MCS 3
    12:2:16, ...  % MCS 4
    20:3:32, ...  % MCS 5
    22:3:34, ...  % MCS 6
    24:3:39, ...  % MCS 7
    27:3:40 ...   % MCS 8
    29:3:44 ...   % MCS 9
    21.5:4:37.5 ... % MCS 10
    22:4:38 ...     % MCS 11
    }; ...
        {... % 4x2
    [11,13,14,15], ...   % MCS 0
    5:2:15, ...   % MCS 1
    9:2:21, ...   % MCS 2
    12:2:24, ...  % MCS 3
    [13 16 18 20], ...  % MCS 4
    20:3:32, ...  % MCS 5
    22:3:34, ...  % MCS 6
    24:3:39, ...  % MCS 7
    27:3:40 ...   % MCS 8
    29:3:44 ...   % MCS 9
    21.5:4:37.5 ... % MCS 10
    22:4:38 ...     % MCS 11
    }; ...
        {... % 8x2
    1:2:10, ...   % MCS 0
    5:2:15, ...   % MCS 1
    9:2:21, ...   % MCS 2
    12:2:24, ...  % MCS 3
    [15,18,20,21], ...  % MCS 4
    20:2:30, ...  % MCS 5
    22:3:34, ...  % MCS 6
    24:3:39, ...  % MCS 7
    27:3:40 ...   % MCS 8
29:3:44 ...    % MCS 9
21.5:4:37.5 ... % MCS 10
22:4:38 ...     % MCS 11
}; ...
] ...
};
```

After the above setup, go back to MU code basic/1 Full PHY (no interferer)/fullPHY.m
This is the main script of full PHY simulation. click on ‘Run’ in MATLAB.
The main script will call MU code basic/1 Full PHY (no interferer)/box0Simulation.m, the key function to realize full PHY simulation. This key function assumes ZF MIMO precoding and MMSE MIMO decoding. Users can comment out the ZF MMO precoding calculation part in box0Simulation.m to enable the default Fourier MIMO precoding.

After running the above full PHY simulation (takes about 6~7 hours), a file named “sinrPer_Config97_Model-D_8-by-2_MCS4.mat” will be created.

A figure named “RBIR Abstracted vs Full PHY, 8x2, Model-D” will also pop up.
This figure shows the average PER vs RX SNR(dB) of the full PHY simulation and RBIR prediction (without tuning). If the two curves approximately match, then we can move on the next step.



Step 2 (EESM parameter estimation):

Goal: optimizing EESM parameter (beta) using 40000 {post-MIMO processing SINR matrix, packet error state} pairs generated from full PHY simulation. This step is shown in Fig. 7 of our IEEE TCOM paper.

Copy “sinrPer_Config97_Model-D_8-by-2_MCS4.mat” generated in Step 1 into MU code basic/2 EESM parameter optimization.

Open: MU code basic/2 EESM parameter optimization/eesmAbstractionPerVsEffSinr.m
This is the main script in MU code basic/2 EESM parameter optimization.

Load “sinrPer_Config97_Model-D_8-by-2_MCS4.mat”:

```
load('sinrPer_Config97_Model-D_8-by-2_MCS4.mat');
```

For different MCS, set different initial EESM parameter for optimization.

The suggestions for choosing initial EESM parameter are shown in the following code.

```
% Tuning parameter in this function: EESM parameter - beta
% Suggestion: the higher MCS, the larger initialized beta
% Initial values for reference:
%   MCS: 0  -> beta : 1
%   MCS: 1  -> beta : 2
%   MCS: 2  -> beta : 1.5
%   MCS: 3  -> beta : 5
%   MCS: 4  -> beta : 7
%   MCS: 5  -> beta : 26
%   MCS: 6  -> beta : 33
%   MCS: 7  -> beta : 43
%   MCS: 8  -> beta : 111
%   MCS: 9  -> beta : 170
%   MCS: 10  -> beta : 410
%   MCS: 11  -> beta : 650
beta = 7;
```

As we use MCS4, set the initial EESM parameter value to be 7 according the above suggestion.

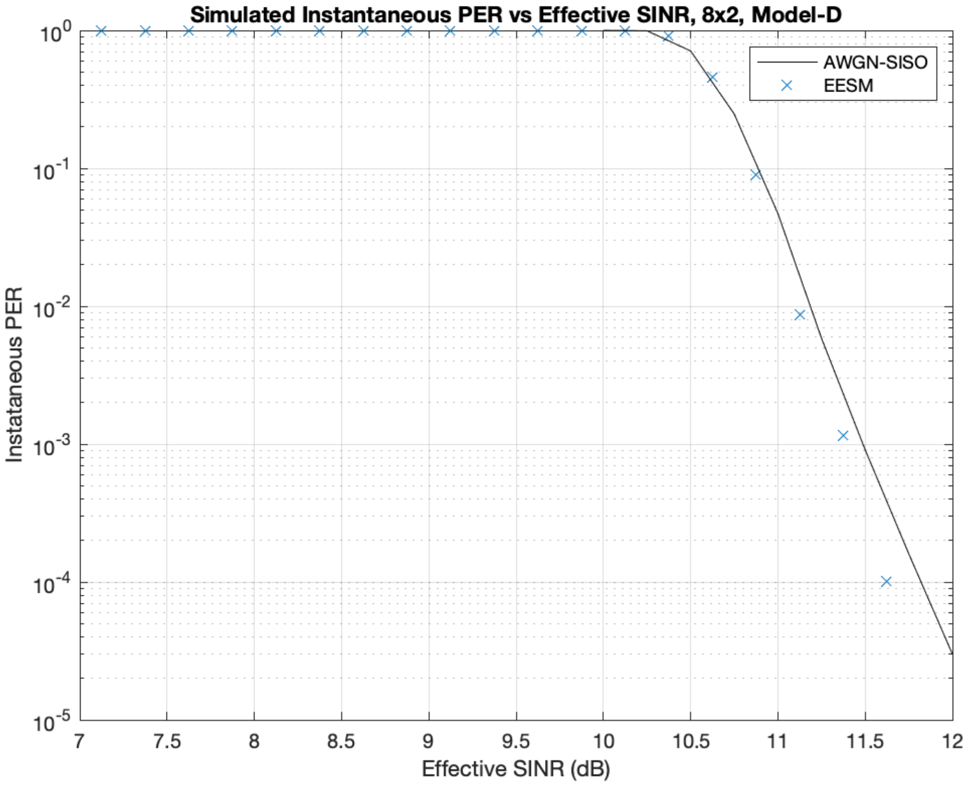
Opening eesmAbstractionPerVsEffSinr.m, click on ‘Run’ in MATLAB.
This main script minimizes MSE between 1) instantaneous PER VS EESM based effective SNR under the PHY layer configuration in step 1, and 2) instantaneous PER VS SNR under AWGN-SISO channel. The output is the optimized EESM parameter (beta): betaOpt. This is realized in the awgnPerSnrFittingMse.m function and MATLAB fminsearch function.
After running eesmAbstractionPerVsEffSinr.m (takes about a few mins), a file named “eesmEffSinr_Config97_Model-D_8-by-2_MCS4.mat” will be created.
This file includes the optimized beta value stored in betaOpt.

In this example,

```
betaOpt =

   8.3891
```

A figure named “Simulated Instantaneous PER vs Effective SINR, 8x2, Model-D” will also pop up. This figure shows 1) instantaneous PER VS EESM based effective SNR under the PHY



layer configuration in step 1, and 2) instantaneous PER VS SNR under AWGN-SISO channel. If the two curves approximately match, then the traditional EESM L2S mapping works well and we can move on the next step.

Step 3 (Traditional EESM PHY layer abstraction):

Goal: implement traditional EESM PHY layer abstraction shown in Fig. 1 of our IEEE TCOM paper, and observe the runtime scaling issue caused by traditional EESM PHY layer abstraction. The principle of traditional EESM PHY layer abstraction is shown in Fig. 1 of our IEEE TCOM paper.

Open MU code basic/5 Traditional EESM (no interferer)/eesmAbstraction.m. This is the main script in MU code basic/5 Traditional EESM (no interferer).

First, input betaOpt obtained in Step 2.

```
betaOpt = 8.3891; % EESM tuning parameter
```

The other PHY layer configurations are the same as the PHY layer configurations in Step 1:

```
%% Full PHY simulation setup
clear all
tStart = tic;
mcs = [4]; % Vector of MCS to simulate between 0 and 11
numTxRx = [8 2]; % Matrix of MIMO schemes, each row is [numTx numRx]
chan = "Model-D"; % String array of delay profiles to simulate
```

```
userIdx = 2; % User of investigation
ruIdx = 2; % RU of investigation
Nsts = 2; % Number of space-time streams
betaOpt = 8.3891; % EESM tuning parameter
maxnumberrors = 40*1e3;  % The maximum number of packet errors at an SNR
point
maxNumPackets = 40*1e3; % The maximum number of packets at an SNR point
% maxnumberrors = 5*1e1;  % The maximum number of packet errors at an SNR
point
% maxNumPackets = 5*1e2; % The maximum number of packets at an SNR point

% Fixed PHY configuration for all simulations
cfgHE = wlanHEMUConfig(97); % Input 11ax allocation index
for userIdxIter = 1:numel(cfgHE.User)
    cfgHE.User{userIdxIter}.APEPLength = 1000; % Payload length in bytes
end
```

Open: MU code basic/5 Traditional EESM (no interferer)/getBox0SimParams.m

Consider simulating the PHY layer under RX SNR = 15, 18, 20, 21 dBs as Step 1.
In the variable snr: Model-D, 8x2, MCS4 part, set the snr to be [15,18,20,21] (notice the bold part in the following code):

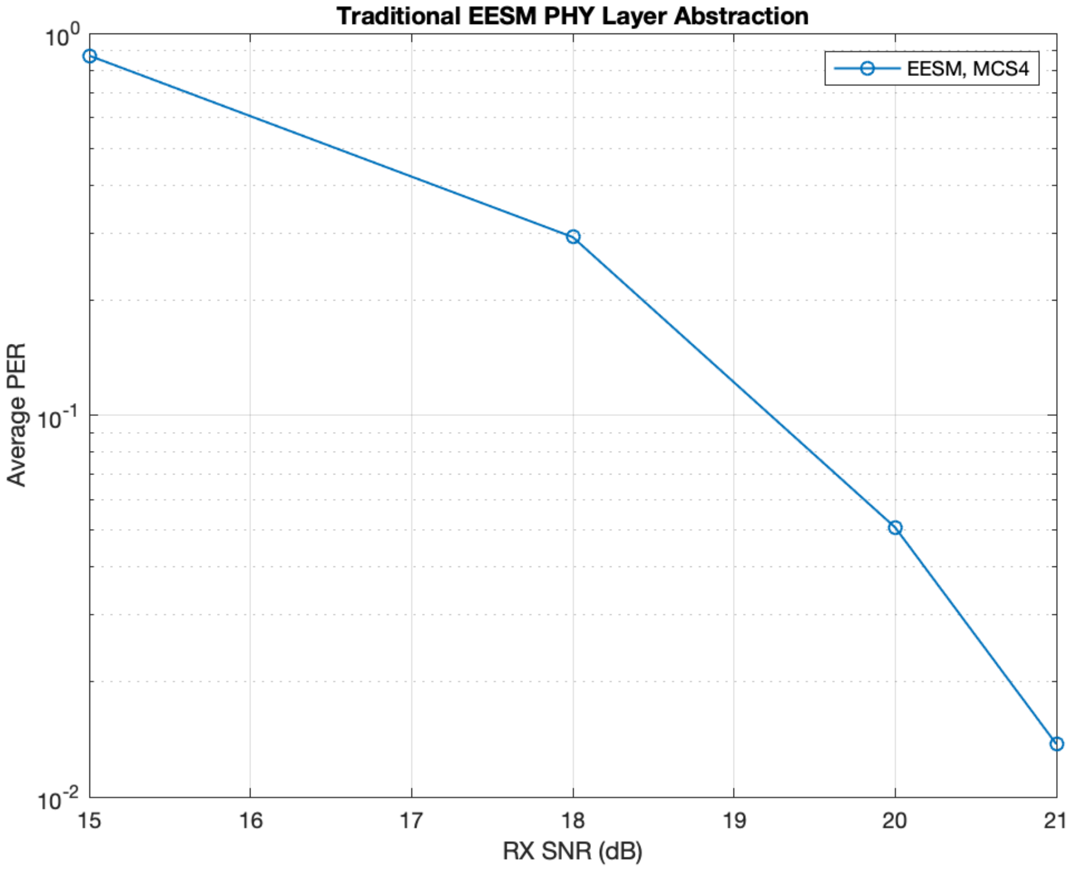
```
snr = {
    % Model-B
    [ ...
        {... % 1x1
    [-3:4:9,11], ...   % MCS 0
    [1:4:13], ...     % MCS 1
    [2:4:18], ...     % MCS 2
    [7:4:19,21], ...     % MCS 3
    [9:4:25], ...     % MCS 4
    [13:4:29], ...    % MCS 5
    [14:4:30], ...    % MCS 6
    [16:4:32,34], ...    % MCS 7
    [18:4:34,36] ... % MCS 8
    [18:4:38] ...     % MCS 9
    21.5:4:37.5 ... % MCS 10
    22:4:38 ...     % MCS 11
    }; ...
        {... % 4x1
    1:3:17, ...  % MCS 0
    5:3:23, ...  % MCS 1
    9:4:30, ...  % MCS 2
    12:4:36, ... % MCS 3
    16:4:40, ... % MCS 4
    20:4:43, ... % MCS 5
    22:4:46, ... % MCS 6
    24:4:48, ... % MCS 7
    26:4:50 ...  % MCS 8
    29:4:54 ...  % MCS 9
    21.5:4:37.5 ... % MCS 10
    22:4:38 ...     % MCS 11
    }; ...
        {... % 4x2
    1:3:17, ...  % MCS 0
    5:3:23, ...  % MCS 1
    9:4:30, ...  % MCS 2
    12:4:36, ... % MCS 3
    16:4:40, ... % MCS 4
    20:4:43, ... % MCS 5
    22:4:46, ... % MCS 6
    24:4:48, ... % MCS 7
    26:4:50 ...  % MCS 8
    29:4:54 ...  % MCS 9
    21.5:4:37.5 ... % MCS 10
    22:4:38 ...     % MCS 11
    }; ...
         {... % 8x2
    1:3:17, ...  % MCS 0
    5:3:23, ...  % MCS 1
    9:4:30, ...  % MCS 2
    12:4:36, ... % MCS 3
    16:4:40, ... % MCS 4
    20:4:43, ... % MCS 5
    22:4:46, ... % MCS 6
    24:4:48, ... % MCS 7
    26:4:50 ...  % MCS 8
    29:4:54 ...  % MCS 9
    21.5:4:37.5 ... % MCS 10
    22:4:38 ...     % MCS 11
    }; ...
    ];

% Model-D
    [ ...
        {... % 1x1
    -3:3:9, ...     % MCS 0
    0:4:12, ...     % MCS 1
    2:4:18, ...     % MCS 2
    8:4:20, ...     % MCS 3
    11:4:23, ...    % MCS 4
    [14:4:26,28], ...    % MCS 5
    16:4:28, ...    % MCS 6
    18:4:30, ...    % MCS 7
    21.5:4:37.5 ... % MCS 8
    20:4:36 ...     % MCS 9
    21.5:4:37.5 ... % MCS 10
    22:4:38 ...     % MCS 11
    }; ...
        {... % 4x1
    -4:2:2, ...   % MCS 0
    5:2:15, ...   % MCS 1
    9:2:21, ...   % MCS 2
    12:2:24, ...  % MCS 3
    12:2:16, ...  % MCS 4
    20:3:32, ...  % MCS 5
    22:3:34, ...  % MCS 6
    24:3:39, ...  % MCS 7
    27:3:40 ...   % MCS 8
    29:3:44 ...   % MCS 9
    21.5:4:37.5 ... % MCS 10
    22:4:38 ...     % MCS 11
    }; ...
        {... % 4x2
    [11,13,14,15], ...    % MCS 0
    5:2:15, ...   % MCS 1
    9:2:21, ...   % MCS 2
    12:2:24, ...  % MCS 3
    [13 16 18 20], ...  % MCS 4
    20:3:32, ...  % MCS 5
    22:3:34, ...  % MCS 6
    24:3:39, ...  % MCS 7
    27:3:40 ...   % MCS 8
    29:3:44 ...   % MCS 9
    21.5:4:37.5 ... % MCS 10
    22:4:38 ...     % MCS 11
    }; ...
        {... % 8x2
    1:2:10, ...   % MCS 0
    5:2:15, ...   % MCS 1
    9:2:21, ...   % MCS 2
    12:2:24, ...  % MCS 3
    [15,18,20,21], ...  % MCS 4
    20:2:30, ...  % MCS 5
    22:3:34, ...  % MCS 6
    24:3:39, ...  % MCS 7
    27:3:40 ...   % MCS 8
    29:3:44 ...   % MCS 9
    21.5:4:37.5 ... % MCS 10
    22:4:38 ...     % MCS 11
    }; ...
    ] ...
    };
```

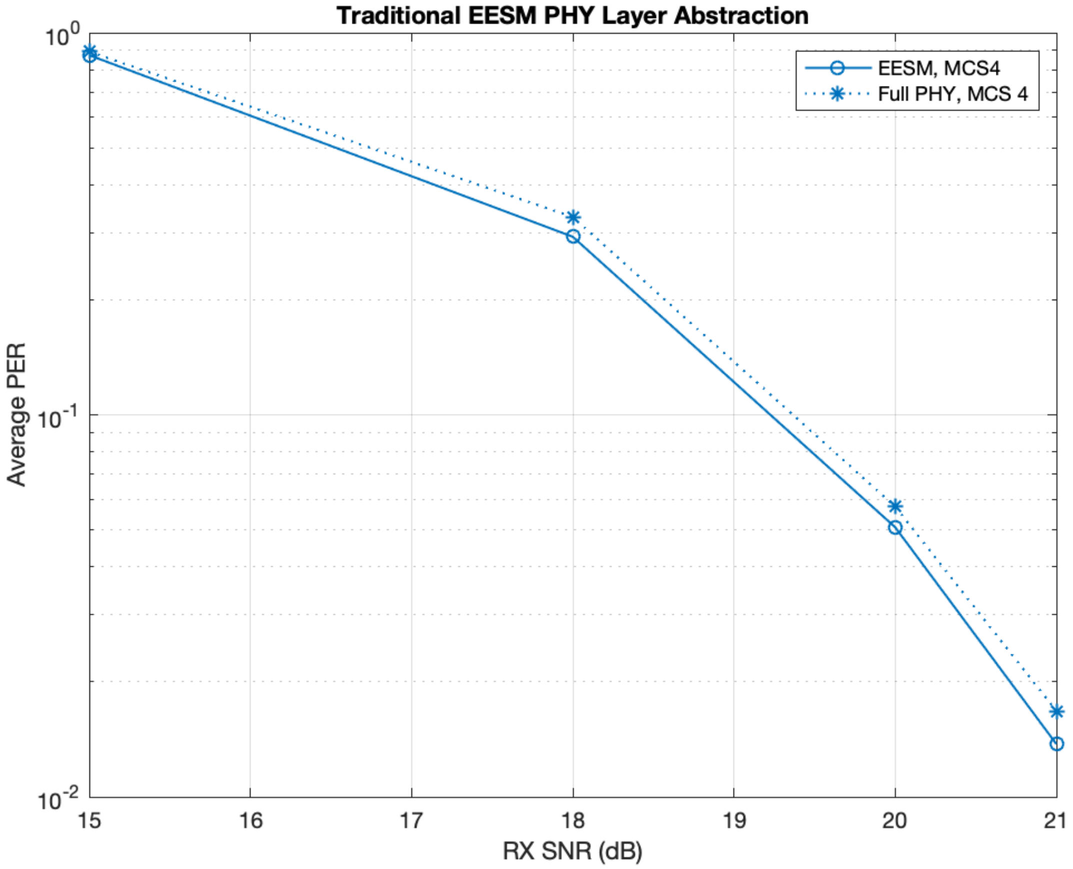
After the above setup, go back to MU code basic/5 Traditional EESM (no interferer)/eesmAbstraction.m
This is the main script of traditional EESM PHY layer abstraction. click on ‘Run’ in MATLAB. The main script will call MU code basic/5 Traditional EESM (no interferer)/box0Simulation.m, the key function to realize traditional EESM PHY layer abstraction. This key function assumes ZF MIMO precoding and MMSE MIMO decoding. Users can comment out the ZF MMO precoding calculation part in box0Simulation.m to enable the default Fourier MIMO precoding. Different from the full PHY simulation, traditional EESM PHY layer abstraction does not contain symbol-level encoding and decoding. The principle of traditional EESM PHY layer abstraction follows the flow in Fig. 1 of our IEEE TCOM paper.

After running the above full PHY simulation (takes about 2~3 hours, you can click on tEndEesmAbs in the workspace to see the runtime in seconds), a file named “eesmAvgPer_Config97_Model-D_8-by-2_MCS4.mat” will be created. This file stores the effective SINR vector in the variable named results.

A figure named “Traditional EESM PHY Layer Abstraction” will also pop up.



This figure shows the average PER vs RX SNR(dB) of the EESM PHY layer abstraction. If we copy the full PHY simulation result in Step 1 to this figure, we will see the two curves match very well.



In this example, the runtime of traditional EESM PHY layer abstraction is still very large. We can observe the runtime by checking tEndEesmAbs, which shows the runtime in seconds.

```
tEndEesmAbs =

   9.2684e+03
```

This corresponds to 154.47min, close to the average runtime of 156 min in Table III for the considered setup. If we conduct above Step 3 multiple times, we can calculate the average runtime of the traditional EESM PHY layer abstraction.

The full average runtime records at different PHY layer setup is shown in Table III of our IEEE TCOM paper:

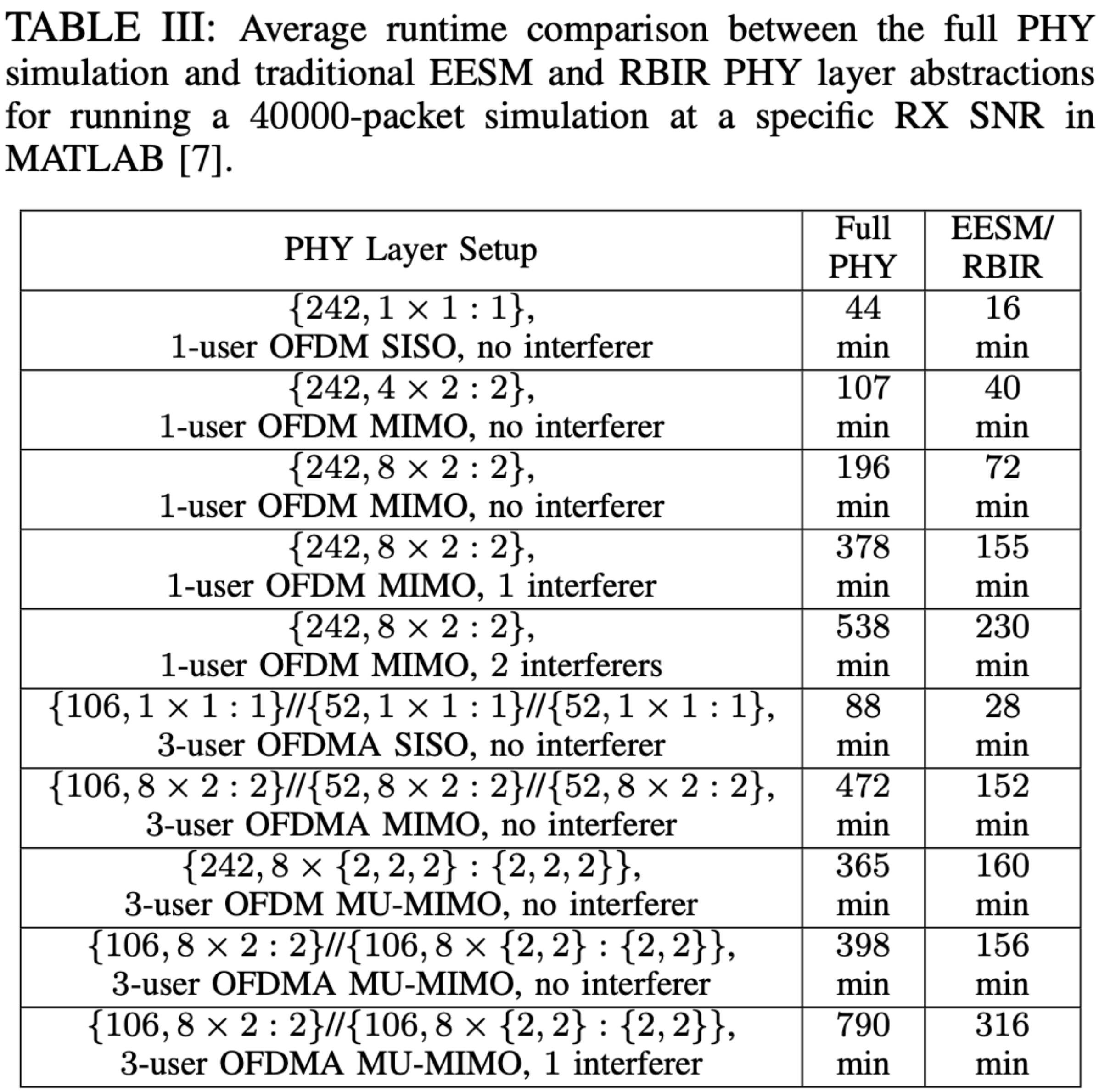


TABLE III: Average runtime comparison between the full PHY simulation and traditional EESM and RBIR PHY layer abstractions for running a 40000-packet simulation at a specific RX SNR in MATLAB [7].

PHY Layer Setup	Full PHY	EESM/ RBIR
$\{242, 1 \times 1 : 1\}$, 1-user OFDM SISO, no interferer	44 min	16 min
$\{242, 4 \times 2 : 2\}$, 1-user OFDM MIMO, no interferer	107 min	40 min
$\{242, 8 \times 2 : 2\}$, 1-user OFDM MIMO, no interferer	196 min	72 min
$\{242, 8 \times 2 : 2\}$, 1-user OFDM MIMO, 1 interferer	378 min	155 min
$\{242, 8 \times 2 : 2\}$, 1-user OFDM MIMO, 2 interferers	538 min	230 min
$\{106, 1 \times 1 : 1\}$//$\{52, 1 \times 1 : 1\}$//$\{52, 1 \times 1 : 1\}$, 3-user OFDMA SISO, no interferer	88 min	28 min
$\{106, 8 \times 2 : 2\}$//$\{52, 8 \times 2 : 2\}$//$\{52, 8 \times 2 : 2\}$, 3-user OFDMA MIMO, no interferer	472 min	152 min
$\{242, 8 \times \{2,2,2\} : \{2,2,2\}\}$, 3-user OFDM MU-MIMO, no interferer	365 min	160 min
$\{106, 8 \times 2 : 2\}$//$\{106, 8 \times \{2,2\} : \{2,2\}\}$, 3-user OFDMA MU-MIMO, no interferer	398 min	156 min
$\{106, 8 \times 2 : 2\}$//$\{106, 8 \times \{2,2\} : \{2,2\}\}$, 3-user OFDMA MU-MIMO, 1 interferer	790 min	316 min