MATLAB sample code for coded OTFS with detection

Orthogonal time frequency space is a novel modulation scheme where the information symbols are multiplexed in the delay-Doppler domain resulting in all the information symbols experiencing roughly the same channel. This code package implements the coded OTFS system with turbo maximal ratio combining (MRC) decoder proposed for ZP-OTFS in [R1,R2,R3] and extends it to other OTFS variants in the literature [R1].

➢ MATLAB functions

MATLAB functions	**Description**
OTFSvariants_coded_system.m	main file to run the LDPC coded OTFS system
select_LDPC_parity_matrix.m	Select the LDPC parity check matrix corrresponding to the LDPC rate and codeword length.
LDPC_system_objects.m	Generate LDPC encoder and decoder system objects using MATLAB inbuilt function
Generate_2D_data_grid.m	Generate MxN 2-D information symbols
Generate_delay_Doppler_channel_parameters.m	Generate the gain, delay and Doppler-shift of the P propagation path according to EPA, EVA or ETU channel models
Gen_time_domain_channel_OTFSvariants.m	Generate **G** matrix (time domain channel matrix) and the DT channel response $g^s[l,q]$ in [R1] (gs[l,q] in MATLAB code).
Gen_delay_time_channel_vectors_OTFSvariants.m	Generate the delay-time channel vectors $\tilde{\nu}_{m,l}$ in [R1] (nu_ml_tilda in the MATLAB code) from $g^s[l,q]$.
Generate_time_frequency_channel_OTFSvariants.m	Generate single tap time-frequency channel for low-complexity initial estimate
MRC_turbo_decoder_OTFSvariants.m	turbo MRC decoder for coded OTFS
turbo_decoder.m	LDPC decoder function to

Remarks

- Run OTFSvariants_coded_system.m for all coded OTFS variants by simply changing the ‘variant’ variable (see below in Figure 1) to the appropriate OTFS variant.

```
%% OTFS variant: (RZP / RCP / CP / ZP)
variant='RZP';
```

```
%% OTFS parameters%%%%%%%%%%
% N: number of symbols in time
N = 64;
% M: number of subcarriers in frequency
M = 64;
% M_mod: size of QAM constellation
M_mod = 64;
M_bits = log2(M_mod);
% average energy per data symbol
eng_sqrt = (M_mod==2)+(M_mod~=2)*sqrt((M_mod-1)/6*(2^2));
```

Figure 1: Piece of code in the main MATLAB file where the OTFS variant is selected.

Additional information

- The LDPC parameters (rate and codeword length) are set here (as shown in Figure 2). Choose between codeword lengths of 672 and 3840. The users can add more codeword lengths if the parity check matrix for those codeword lengths are available.

```
%% Error-correcting code parameters
% LDPC code parameters
LDPC_rate = 1/2;% can be changed to 3/4
LDPC_codeword_length = 3840; %(672 / 3840)
LDPC_info_length = LDPC_codeword_length*LDPC_rate;
% LDPC_trans_blocks: number of LDPC blocks transmitted in each frame
% we transmit zero's for the remaining bits in N_bits_perfram
LDPC_trans_blocks = floor(N_bits_perfram/LDPC_codeword_length);
trans_bits_length = LDPC_trans_blocks*LDPC_codeword_length;
trans_info_bits_length = LDPC_trans_blocks*LDPC_info_length;
trans_symbols_tot = trans_info_bits_length/M_bits;
[hEnc,hDec,hDec_coded_soft,hDec_coded_hard]=LDPC_system_objects(LDPC_rate,LDPC_codeword_length);
```

Figure 2: Piece of code in the main MATLAB file where the LDPC rate and codeword length are set.

- The damping factor variable ‘omega’ can be adjusted to improve the performance. The users may also consider optimizing ‘omega’ in each iteration to improve convergence or error performance.

```
%% MRC turbo detection in [R1,R2,R3]

n_ite_MRC=50; % maximum number of MRC detector iterations
%damping parameter - optimizing omega improves error performance
omega=1;
init_estimate=0;    %1-use the TF single tap estimate as the initial estimat
%(Note: it is recommended to set init_estimate to 0 for higher order modulat.
```

Figure 3: Piece of code in the main MATLAB file where the init_estimate flag is set.

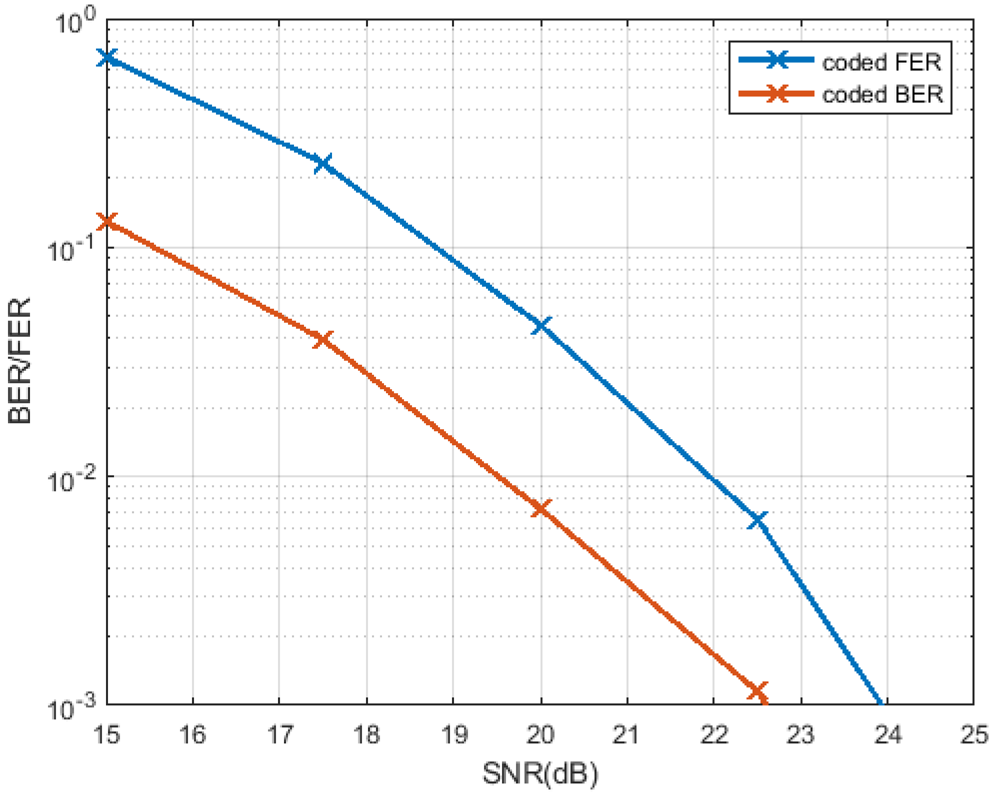
- A single tap TF equalizer is used to provide a low-complexity initial estimate for the MRC detection. For higher order modulation schemes like 64-QAM and 256-QAM, the initial estimate may not be reliable and the MRC detection works better without the initial estimate. Therefore, it is recommended to set the 'init_estimate' flag (shown in the code snippet in Figure 3) to 0.

➢ Sample simulation plots

Below we provide sample BER/FER plots for coded OTFS with turbo MRC detection using the following parameters

➢

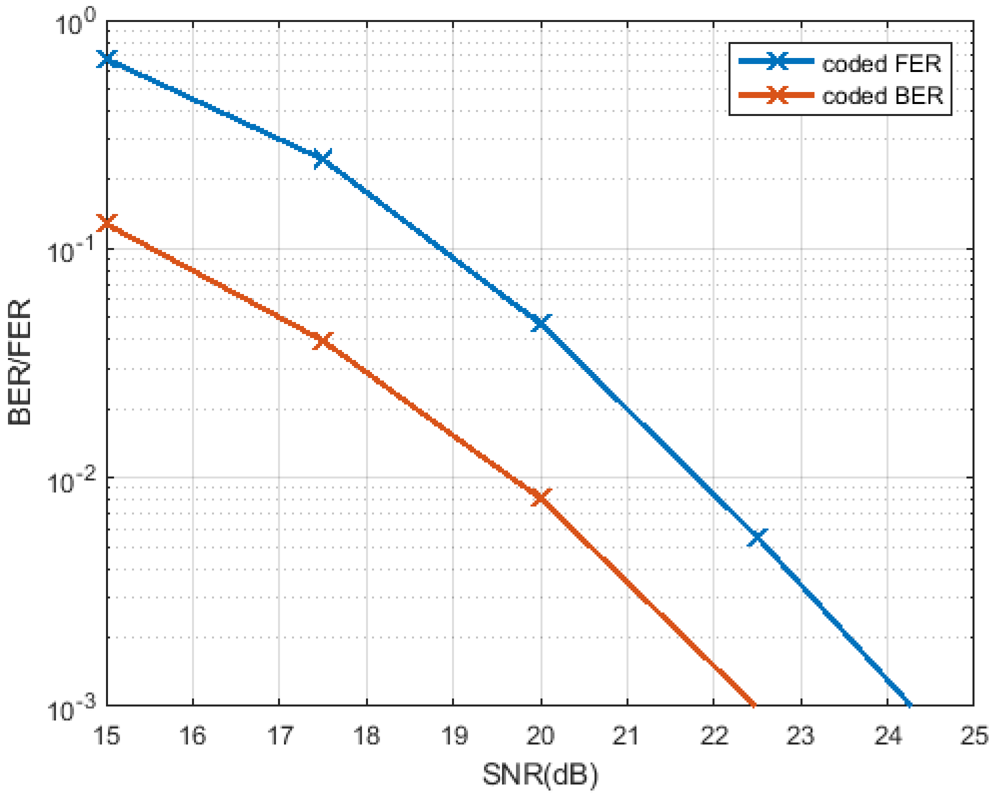
OTFS variant	RCP-OTFS
Frame size	N=M=64
Channel model	Extended Vehicular – A (EVA)
Maximum UE speed	500 km/hr
QAM size	64-QAM
LDPC rate	½ rate
LDPC codeword length	672



➢

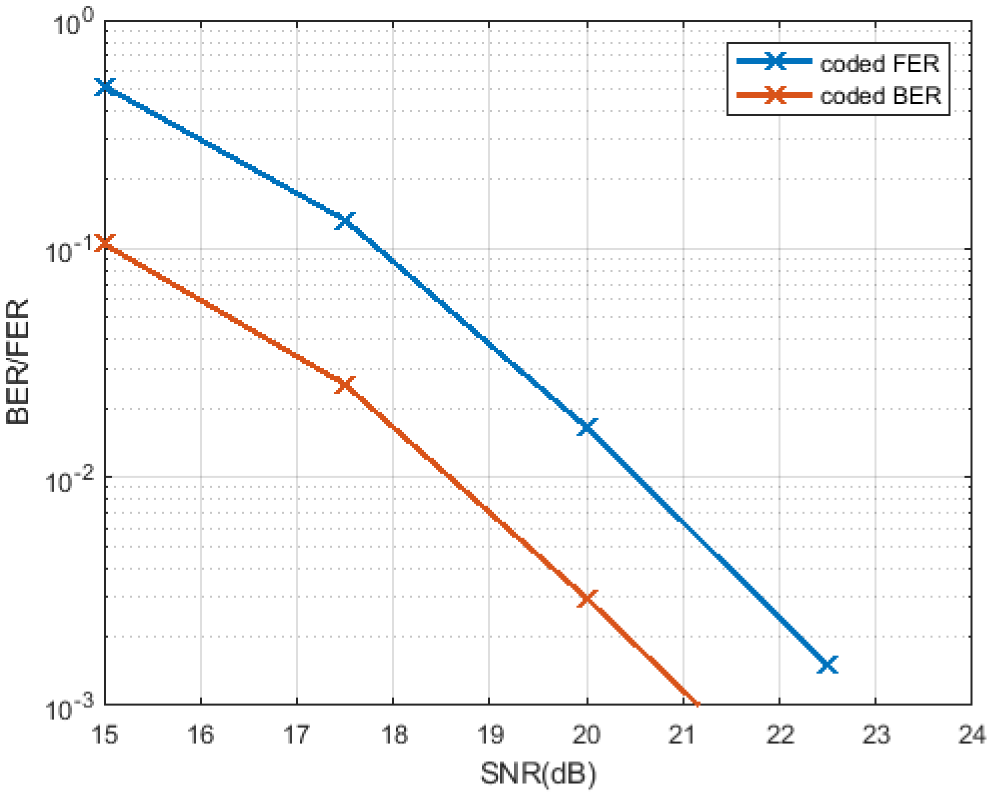
OTFS variant	ZP-OTFS
Frame size	N=M=64
Channel model	Extended Vehicular – A (EVA)

Maximum UE speed	500 km/hr
QAM size	64-QAM
LDPC rate	½ rate
LDPC codeword length	672



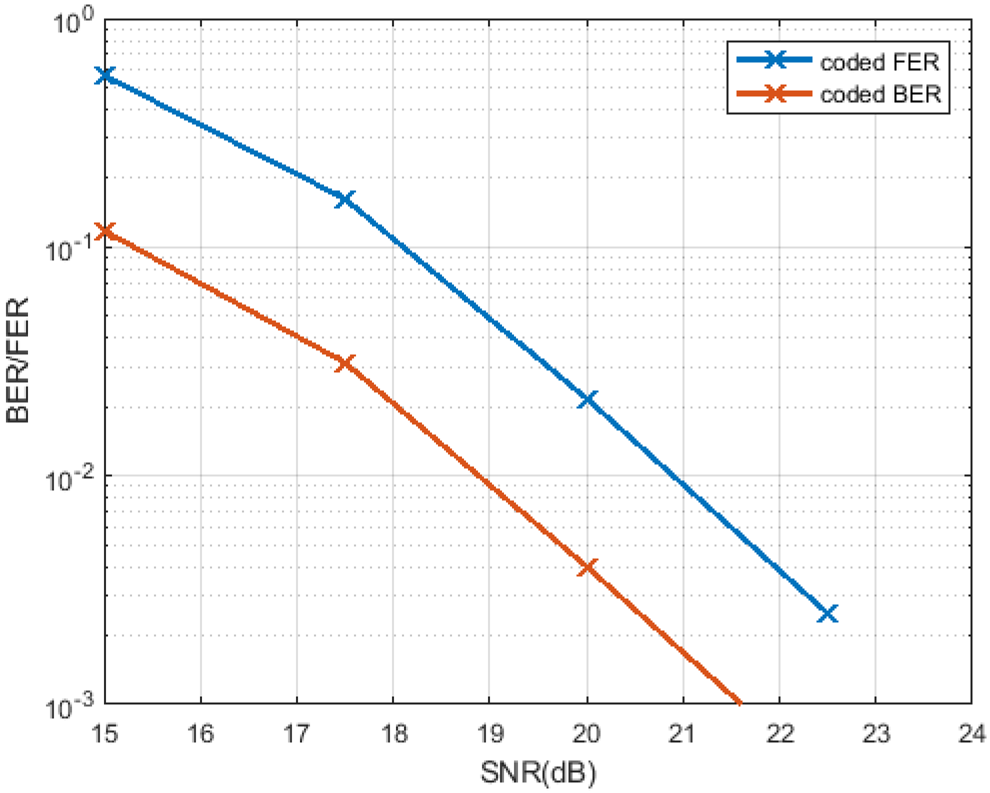
➢

OTFS variant	**RCP-OTFS**
Frame size	N=M=64
Channel model	Extended Vehicular – A (EVA)
Maximum UE speed	500 km/hr
QAM size	64-QAM
LDPC rate	½ rate
LDPC codeword length	3840



➢

OTFS variant	ZP-OTFS
Frame size	N=M=64
Channel model	Extended Vehicular – A (EVA)
Maximum UE speed	500 km/hr
QAM size	64-QAM
LDPC rate	½ rate
LDPC codeword length	3840



➢ References

[R1]. Y. Hong, T. Thaj, E. Viterbo, ``Delay-Doppler Communications: Principles and Applications'', Academic Press, 2022, ISBN:9780323850285

[R2]. T. Thaj and E. Viterbo,``Low Complexity Iterative Rake Decision Feedback Equalizer for Zero-Padded OTFS Systems'', in IEEE Transactions on Vehicular Technology, vol. 69, no. 12, pp. 15606-15622, Dec. 2020, doi: 10.1109/TVT.2020.3044276.

[R3]. T. Thaj and E. Viterbo,``Low Complexity Iterative Rake Detector for Orthogonal Time Frequency Space Modulation'' *2020 IEEE Wireless Communications and Networking Conference (WCNC)*, 2020, pp. 1-6, doi: 10.1109/WCNC45663.2020.9120526.