MATLAB sample code for OTFS variants

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 OTFS system with maximal ratio combining method proposed for ZP-OTFS in [R1,R2,R3] and extends it to other OTFS variants in the literature [R1]. See Chapter 6, [R1] for full details of the MRC algorithm.

➢ MATLAB functions

MATLAB functions	**Description**
OTFSvariants_uncoded_system.m	main file to run all OTFS variants
RZP_OTFS_uncoded_system.m	main file for RZP-OTFS systems
RCP_OTFS_uncoded_system.m	main file for RCP-OTFS systems
CP_OTFS_uncoded_system.m	main file for CP-OTFS systems
ZP_OTFS_uncoded_system.m	main file for ZP-OTFS systems
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_delay_time_detector_RZP.m	MRC detection for RZP-OTFS
MRC_delay_time_detector_RCP.m	MRC detection for RCP-OTFS
MRC_delay_time_detector_CP.m	MRC detection for CP-OTFS
MRC_delay_time_detector_ZP.m	MRC detection for ZP-OTFS

Remarks

- Run OTFSvariants_uncoded_system.m for all 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.

- Alternatively, the sample code for each variant (RZP, RCP, CP and ZP) - OTFS can be run individually using from RZP_OTFS_uncoded_system.m, RCP_OTFS_uncoded_system.m , CP_OTFS_uncoded_system.m and ZP_OTFS_uncoded_system.m, respectively.

➢ Additional information

- The damping factor variable 'omega' can be adjusted to improve the performance. It is recommended to use smaller values for higher order modulation schemes like 64-QAM and 256-QAM to improve convergence. The users may also consider optimizing 'omega' in each iteration to improve convergence or error performance.

```
%damping parameter - reducing omega improves error performance at the cost of increased detector it
omega=1;
if(M_mod>=64)
    omega=0.25;     % set omega to a smaller value (for example: 0.05) for modulation orders greate
end
decision=1; %1-hard decision, 0-soft decision
init_estimate=1; %1-use the TF single tap estimate as the initial estimate for MRC detection, 0-ini
%(Note: it is recommended to set init_estimate to 0 for higher order modulation schemes like 64-QAM
```

Figure 2: Piece of code in the main MATLAB file where the decision and init_estimate flag is set.

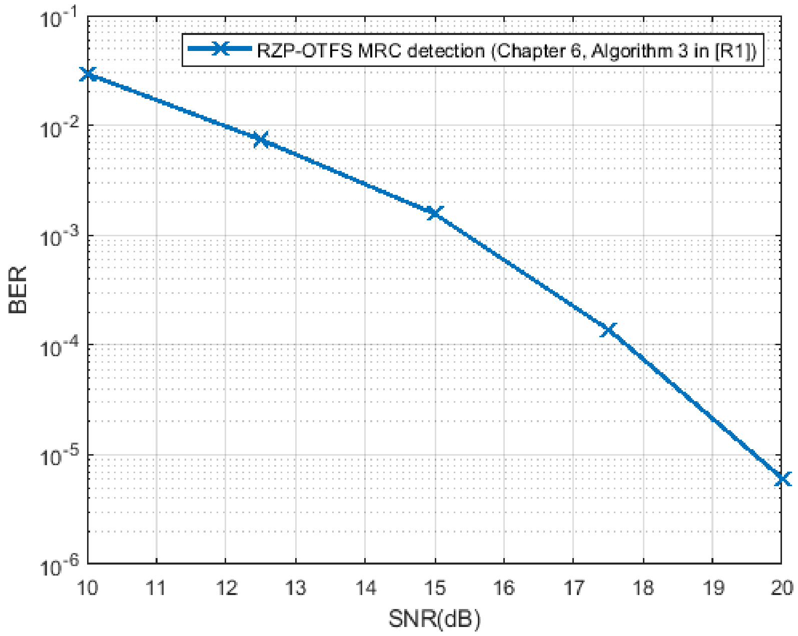
- A single tap TF equalizer is used to provide a low-complexity initial estimate for the MRC detection. For higher order modulation schemes like 64-QAM and 256-QAM, the initial estimate may not be reliable and the MRC detection works better without the initial estimate. Therefore, it is recommended to set the 'init_estimate' flag (shown in the code snippet in Figure 2) to 0.

➢ Sample simulation plots

Below we provide sample BER/FER plots for coded OTFS with turbo MRC detection using the following parameters. *init_estimate* (shown in Figure 2) is set to zero in the sample plots.

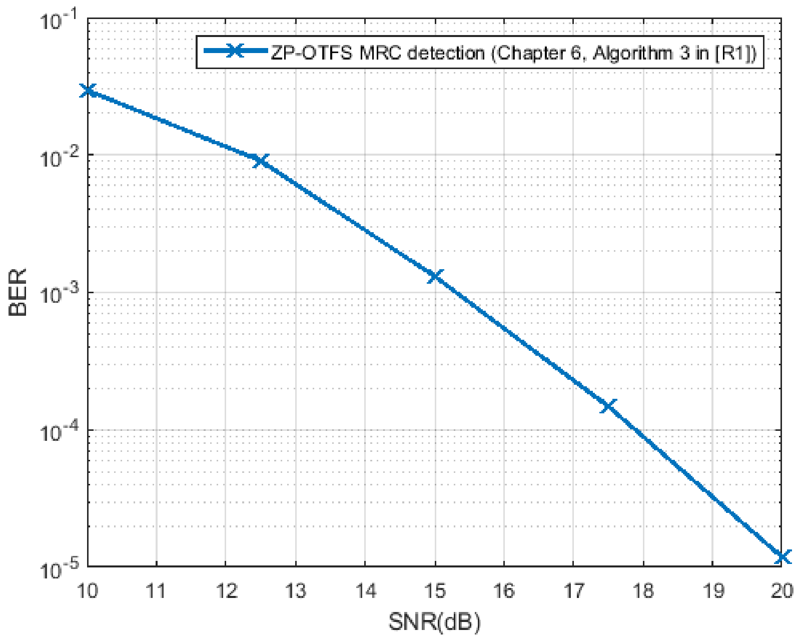
➢

OTFS variant	RZP-OTFS
Frame size	N=M=64
Channel model	Extended Vehicular – A (EVA)
Maximum UE speed	500 km/hr
QAM size	4-QAM



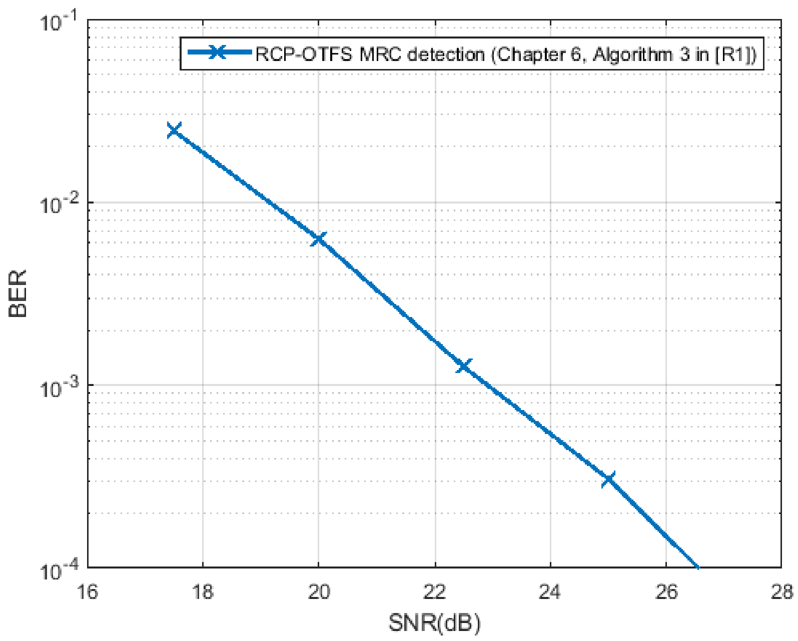
➢

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



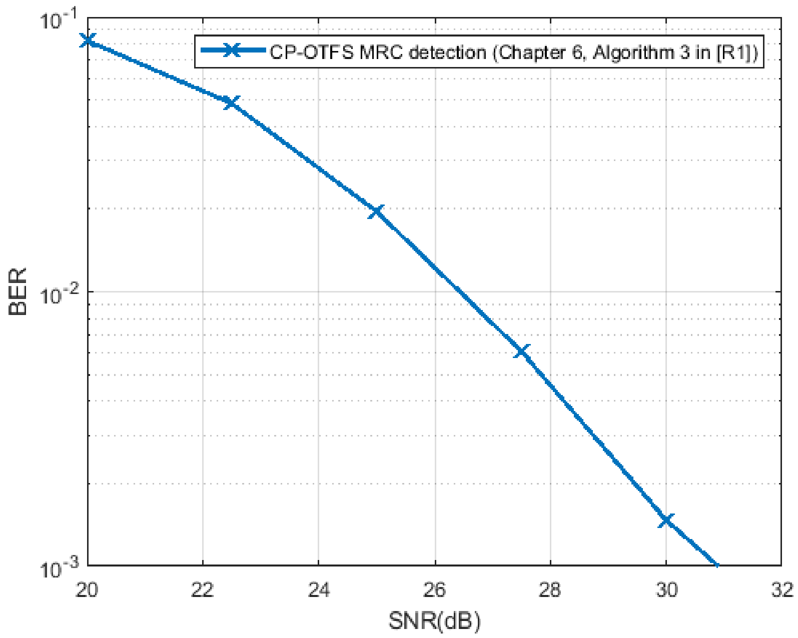
➢

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



➢

OTFS variant	CP-OTFS
Frame size	N=M=64
Channel model	Extended Vehicular – A (EVA)
Maximum UE speed	500 km/hr
QAM size	64-QAM



➢ 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.