FRACTIONAL COSINE TRANSFORM (FRCT)-TURBO BASED OFDM FOR UNDERWATER ACOUSTIC COMMUNICATION

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1. Project objective

A hybrid Discrete Fractional Cosine Transform (DFrCT) with Tikhonov regularization based Turbo Minimum mean square error (MMSE) equalization (DFrCT-Turbo) is presented to suppress inter-carrier interference (ICI) over underwater acoustic channels (UWA). The scheme is based on Orthogonal Frequency Division Multiplex (OFDM) scenario. In addition, an optimal order selecting method for DFrCT is developed by maximizing carrier to interference ratio (CIR) to UWA channel character.

2. Background

- Underwater Acoustic Channel suffers from doubly selective fading, caused by multipath as well as Doppler spread attributed to relative motion between transmitter and receiver.
- DFrCT[2] transforms a function of time into an intermediate domain between time and frequency [2].
- The search of optimal order of DFrCT is based on exploiting carrier–to-interference ratio (CIR).
- Block turbo equalizer exchange soft extrinsic information [most often log-likelihood ratios (LLRs) between MMSE equalization, and maximum a posteriori probability (MAP) decoder [1].
- Tikhonov regularization based MMSE algorithm is proposed to replace the inverse of Signal to noise (SNR^{-1}) ratio, avoiding the ill-condition of doubly selective channel.

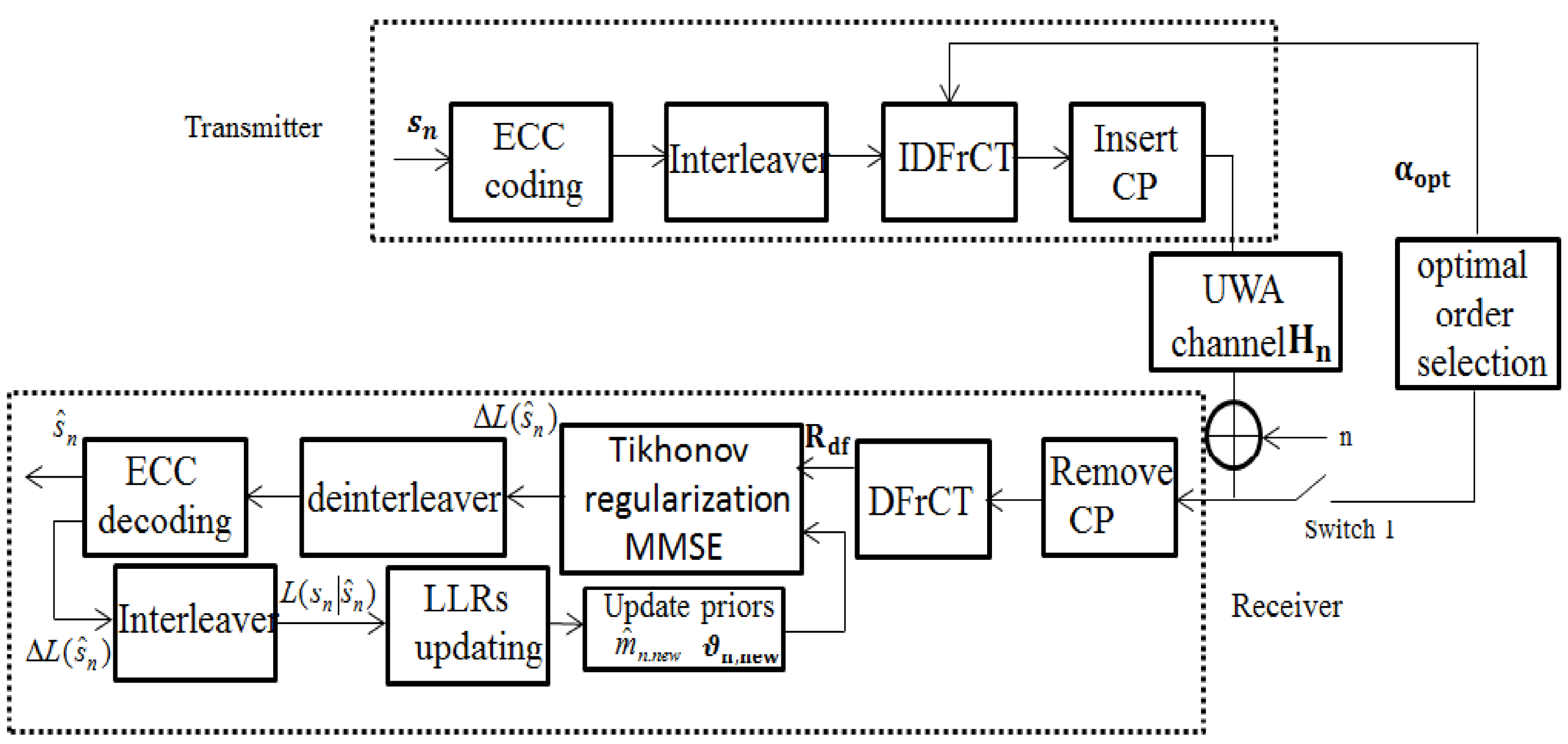

Figure1: Diagram of DFrCT-Turbo Transceiver

Algorithm

a). Selection of optimal order

The search of optimal order α_{opt} is based on exploiting carrier–to-interference ratio (CIR), defined as follows

$$CIR = \frac{\sum_{n=1}^{N} \|B(n,n)\|^2}{\sum_{k=1 k\neq n}^{N} \|B(n,k) - B(n,n)\|^2}$$

Where H_{df} is replaced by the masked channel matrix B_k. Subsequently, the optimal order can be estimated as a maximum CIR problem, as follows

$$\alpha_{opt} = arg\{ \min_{\alpha\in[-1,1]} [CIR] \}$$

b). Tikhonov regularization based turbo MMSE equalization

The doubly selective channels could be highly ill-conditioned, which means that the ratio between the larg-est eigenvalue and the smallest eigenvalue of the channel matrix become very large. Therefore, at high SNR, the inverse matrix contained in the MMSE formula is subject to significant numerical errors, contributing to less stable of equalization. In order to solve this problem, a Tikhonov regularization based MMSE algorithm is proposed to replace the inverse of Signal to noise (SNR^{-1}) ratio by inversed modified signal to interference (SINR) ratio, which is described as follows

$$SINR = \frac{1-Po}{Po+\gamma}$$

Where **Po** represents the out of band power, defined as

$$Po = \frac{\|H_{df} - B_k\|^2}{N_a}$$

Where N_a represents the uncompensated ICI that falls in a specific data subcarrier.

Reference

[1] K. Fang, L. Rugini, and G. Leus, "Low-complexity block turbo equalization for OFDM systems in time-varying channels," *IEEE Trans. Signal Process.*, vol.56, no. 11, pp. 5555-5566, Nov. 2008.

[2] P. Soo-Chang and D. Jian-Jiun, "Fractional cosine, sine, and Hartley transforms," *Signal Processing, IEEE Transactions on*, vol. 50, pp. 1661-1680, 2002.

3. Simulation

The number of subcarriers is N=128, of which 96 are active and the length of cyclic prefix is L=8. The UWA channel is modeled as Rayleigh fading channel with exponential multipath intensity profile of [-7.2, -4.2, -6.2, -10.5, -12.2, -14.0]dB and time delay profile of [0, 0.02, 0.05, 0.16, 0.23, 0.5] ms. The normalized Doppler frequency is $f_d T_d = 0.0014$. The signal to noise ratio (SNR) ranges from 0 to 80dB. In addition, the low complexity equalizer is set at U=6 and the number of Monte Carlo runs is 10000. The error coding is a rate 1/2 convolution code with generator matrix [1 0 1,1 1 1] and random interleaving.

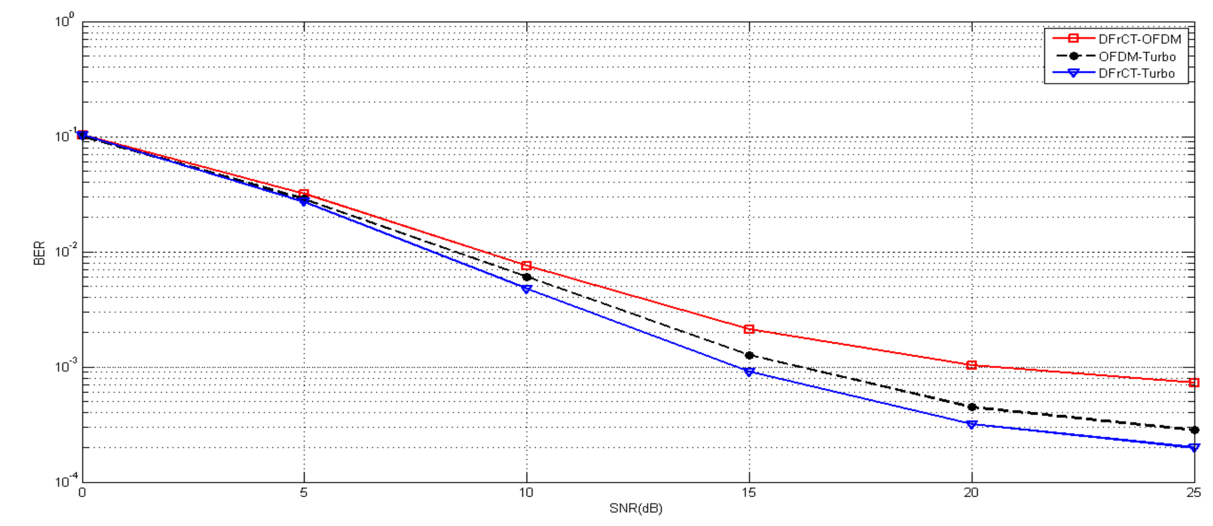

Figure2: BER of DFrCT-Turbo and OFDM-Turbo, and DFrCT-OFDM

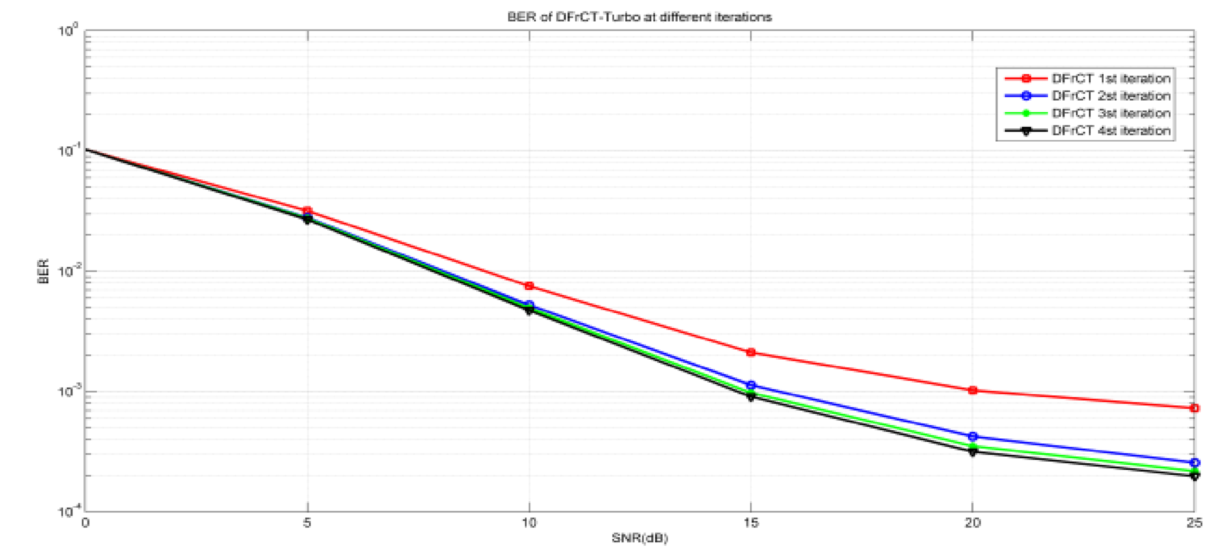

Figure3: BER of DFrCT-Turbo from iteration 1 to 4

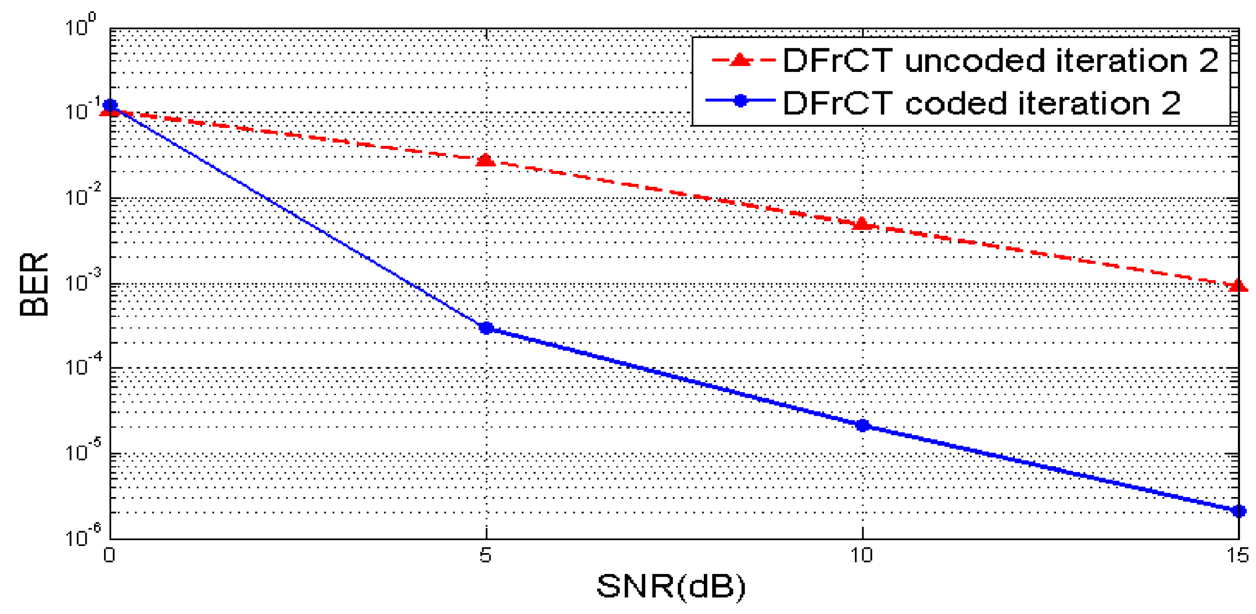

Figure4: Comparison of BER of DFrCT with or without convolution coding

In Figure 2, the optimal order obtained is 0.95. It can be seen that performance of DFrCT-Turbo is superior to that of conventional OFDM with a BER improvement of 1dB. The DFrCT-Turbo is superior to DFrCT-OFDM by approximately up to 5dB, attributed to the iterative performance of Tikhonov regularization based turbo MMSE equalization. In Figure 3, it can be seen that the BER improves as the number of iteration increases converging to the optimum at the 4th iteration. In Figure 4, The iteration number is set at 2. It is obvious that the system with ECC code outperforms with significant BER improvement of 30dB.

4. Conclusion

A novel DFrCT-Turbo system based on the hybrid use of the Discrete Fractional Cosine Transform (DFrCT), Tikhonov regularization based turbo MMSE equalization and low complexity banded MMSE equalization, and has been presented. The simulation results demonstrate that ICI is significantly mitigated under doubly selective channel compared to the conventional OFDM at moderate complexity providing an improvement in the overall Bit Error Rate.

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