An Efficient Channel Estimation Scheme for Short Frame OTFS Using Impulse-Train Pilots

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Outline

- Motivations
- DT-Based CE
- Simulations

Orthogonal Time Frequency Space (OTFS)

- Properties [1]
  - *Symbols are modulated in the delay-Doppler (DD) domain*
  - *Exploits the time-frequency diversity to improve the error rate*
  - *With lower peak-to-average power ratio (PAPR) than OFDM*

- DD-based channel estimation (CE)
  - *To estimate the DD path parameters* ***as precisely as possible***
  - ***DD sparsity*** *assumption is usually introduced to exploit super-resolution algorithms*
  - *Tough to be achieved when* ***the number of Doppler samples is relatively small***

[1] R. Hadani, S. Radkib, M. Tsatsanis, A. Monk, A. J. Goldsmith, A. F. Molisch and R. Calderbank, "Orthogonal time frequency space modulation," *IEEE WCNC*, San Francisco, CA, USA, Mar. 2017

Orthogonal Time Frequency Space (OTFS)

- DD-based channel estimation (CE)

  - *To estimate the DD path parameters* ***as precisely as possible***

    No need in symbol demodulation since symbol **pulse is also bandwidth-limited**

  - ***DD sparsity*** *assumption is usually introduced to exploit super-resolution algorithms*

    DD channels are **not always sparse**, and the number of paths is also to be estimated

  - *Tough to be achieved when* ***the number of Doppler samples is relatively small (short frame OTFS)***

    Due to the requirement of **low-latency** and **no range migration phenomena**

Proposed Delay-Time (DT) Based CE for OTFS

- Main ideas

  - *Using **impulse-train pilot (ITP)** pattern*

    A **comb-type** pilot for time domain channel estimation

  - *Implemented in the DT domain, to achieve a **non-parametric** estimation*

    DD Sparsity assumption and **super-resolution** processing are **not need**

  - *Simple **extra-impulse (EI)** method to improve the estimation performance*

    To match the symbol duration and pilot duration

  - *Performs effectively in the **short frame** OTFS systems, **combined with the MRC-Rake detector** [1]*

    DT-based OTFS signal processing

[1] T. Thaj, and E. Viterbo, "Low complexity iterative rake decision feedback equalizer for zero-padded OTFS systems," *IEEE Trans. Veh. Technol.*, vol. 69, no. 12, pp. 15606-15622, Dec. 2020

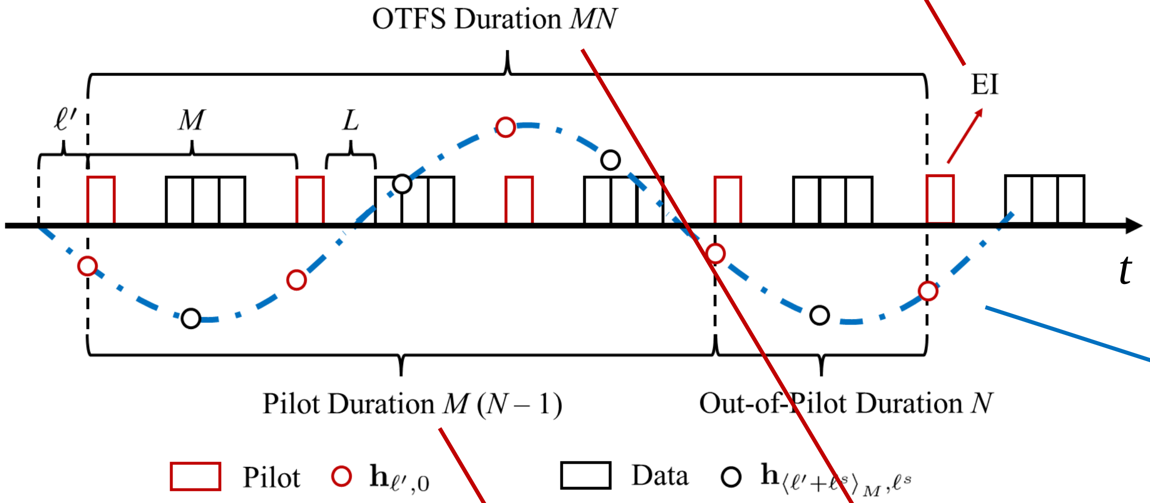
Outline

- Motivations
- **DT-Based CE**
- Simulations

Proposed Delay-Time (DT) Based CE for OTFS

- Impulse-Train-Pilot-OTFS

A pilot impulse of the next OTFS frame,
To match the pilot duration and OTFS duration



Mismatch between pilot duration and OTFS duration

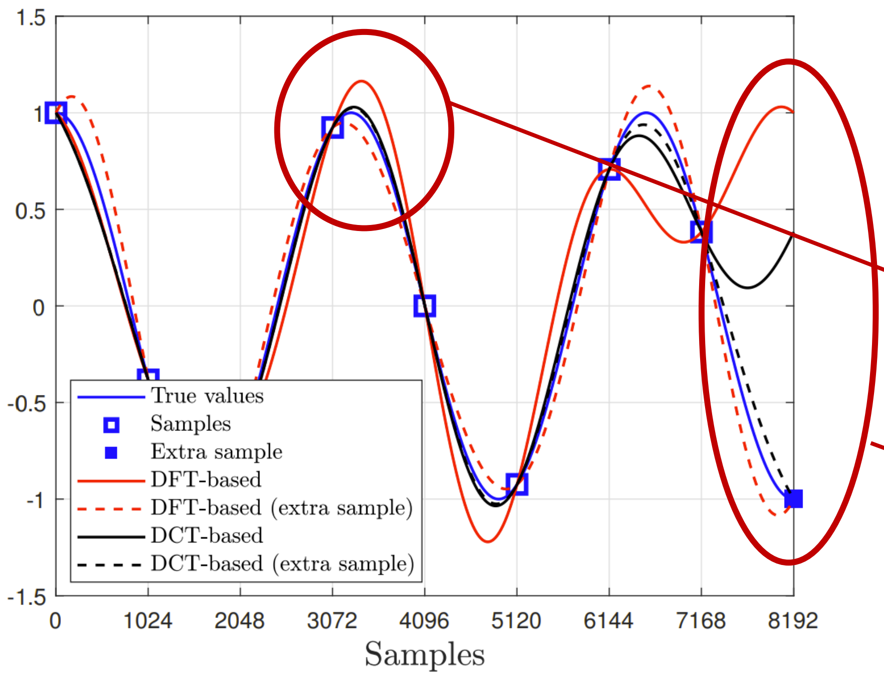
Pilot power Pilot sequence

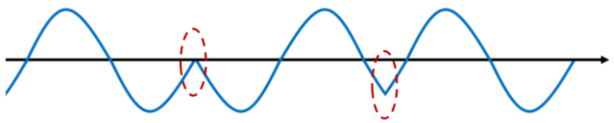
$$\mathbf{x}_{\ell,\mathrm{T}} = \begin{cases} \sqrt{P_\pi}\mathbf{s}_N &, \ \ell = 0 \\ \mathbf{0}_N &, \ 1 \le \ell \le L \text{ or } \ell \ge M-L \\ \mathbf{F}_N^{\mathrm{H}}\mathbf{x}_{\ell,\mathrm{D}} &, \ \text{otherwise} \end{cases}$$

Channel gain $\mathbf{h}_{\langle \ell'+\ell^s\rangle_M,\ell^s}$ at data position can be estimated via sample **interpolation** using $\mathbf{h}_{\ell',0}$ at pilot positions

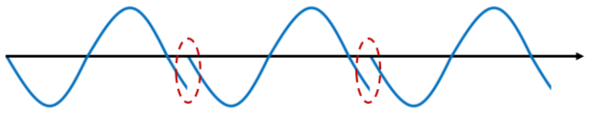
Proposed Delay-Time (DT) Based CE for OTFS

- Interpolation methods





DCT – mirror-extension



DFT – periodic extension

Less Gibbs' effect using **DCT-based interpolation** [1]

Improved using an **extra-impulse (EI)**

[1] Y.-H. Yeh, and S.-G. Chen, "Efficient channel estimation based on discrete cosine transform," *IEEE ICASSP*, Hong Kong, China, Apr. 2003

Proposed Delay-Time (DT) Based CE for OTFS

- Proposed DT-based CE method for OTFS

DT pilot samples with an extra-impulse

$$\mathbf{y}^{\pi}_{\ell',\mathrm{T}} = \begin{cases} \sqrt{P_\pi}\mathbf{h}_{\ell',0} \odot \mathbf{s}_N + \mathbf{w}_{\ell',\mathrm{T}} & , \ \ell' \in \mathcal{L} \\ \mathbf{w}_{\ell',\mathrm{T}} & , \ \text{otherwise} \end{cases}$$

***Least-square**-based estimation*

$$\widehat{\mathbf{h}}_{\ell',0} = \frac{1}{\sqrt{P_\pi}}\mathbf{y}^{\pi}_{\ell',\mathrm{T}} \oslash \mathbf{s}_N \qquad \widehat{\mathbf{h}}^{\mathrm{EI}\ (\kappa)}_{\ell',0} = \begin{bmatrix} \widehat{\mathbf{h}}^{(\kappa)}_{\ell',0} \\ \left[\widehat{\mathbf{h}}^{(\kappa+1)}_{\ell',0}\right]_0 \end{bmatrix}$$

Discrete cosine transforming

$$\left[\widehat{\mathbf{c}}^{\mathrm{EI}\ (\kappa)}_{\ell',0}\right]_k = \lambda_k \sum_{n=0}^{N} \left[\widehat{\mathbf{h}}^{\mathrm{EI}\ (\kappa)}_{\ell',0}\right]_n \cos\frac{\pi\left(2n+1\right)k}{2\left(N+1\right)}$$

*Threshold **denoising** in DCT domain*

$$\left[\widetilde{\mathbf{c}}^{\mathrm{EI}\ (\kappa)}_{\ell',0}\right]_k = \begin{cases} \left[\widehat{\mathbf{c}}^{\mathrm{EI}\ (\kappa)}_{\ell',0}\right]_k & , \ \left|\left[\widehat{\mathbf{c}}^{\mathrm{EI}\ (\kappa)}_{\ell',0}\right]_k\right| > \gamma \\ 0 & , \ \text{otherwise} \end{cases}$$

***Interpolation** using DCT [1]*

$$\left[\widetilde{\mathbf{h}}^{\mathrm{EI}\ (\kappa)}_{\langle\ell'+\ell^s\rangle_M,\ell^s}\right]_n = \sum_{k=0}^{N} \lambda_k \left[\widetilde{\mathbf{c}}^{\mathrm{EI}\ (\kappa)}_{\ell',0}\right]_k \cos\frac{\pi\left(2\left(\ell^s+Mn\right)+M\right)k}{2M\left(N+1\right)}$$

[1] Y.-H. Yeh, and S.-G. Chen, “Efficient channel estimation based on discrete cosine transform,” *IEEE ICASSP*, Hong Kong, China, Apr. 2003

Outline

- Motivations
- DT-Based CE
- **Simulations**

Numerical Results

- Simulation conditions

Num. of subcarriers	1024
Subcarrier spacing	30KHz
Carrier frequency	5GHz
Denoising threshold	$3\tilde{\sigma}$
Channel model	EVA
Doppler model	Jakes
Num. of Doppler samples	**8/16/32**
Num. of Doppler taps each delay tap	**200**

Non-sparse and fractional in Doppler domain

Short frame OTFS system

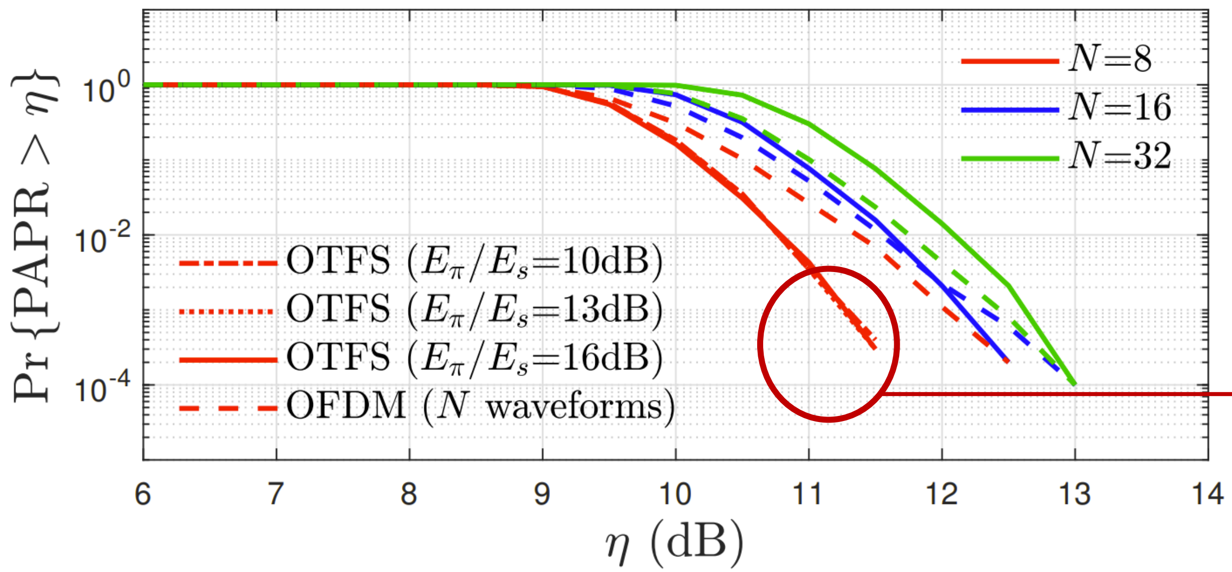
Numerical Results

- PAPRs of ITP-OTFS waveform under E_π / E_s or N

Number of Doppler samples

Single symbol energy

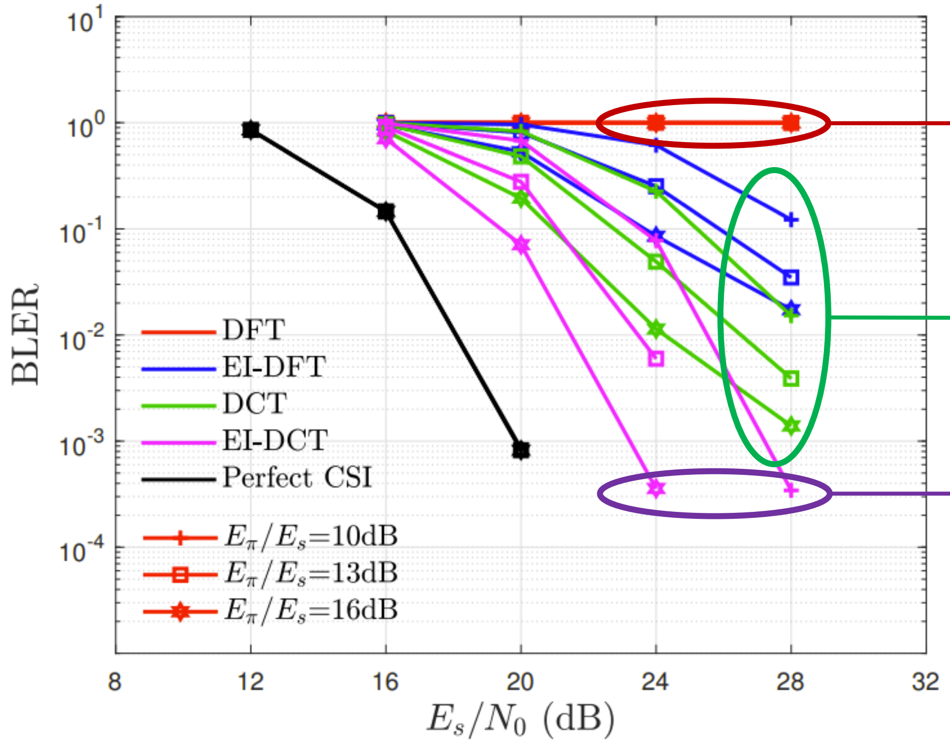
Total pilot energy



Lower PAPR than OFDM waveform when **short frame** ITP-OTFS waveform is adopted

Numerical Results

- BLERs vs. E_s/N_0 under different E_π/E_s (16-QAM, N=8, $v_{\max}$=500kmh)



DFT based scheme [1] doesn't work

DCT based scheme performs even better than EI-DFT based scheme

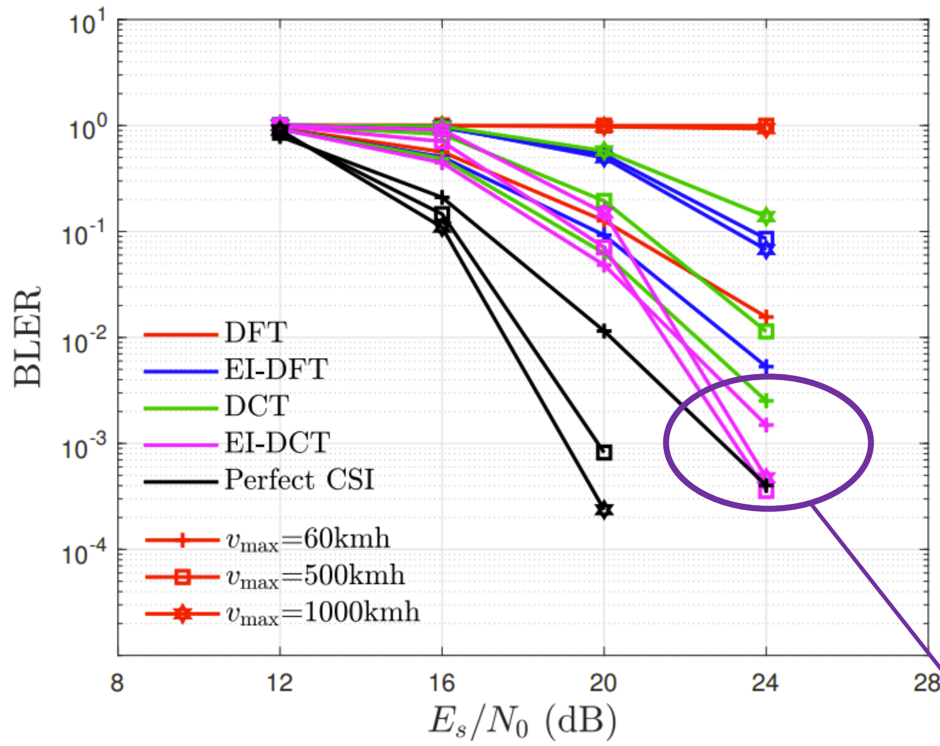
EI-DCT* based scheme performs well

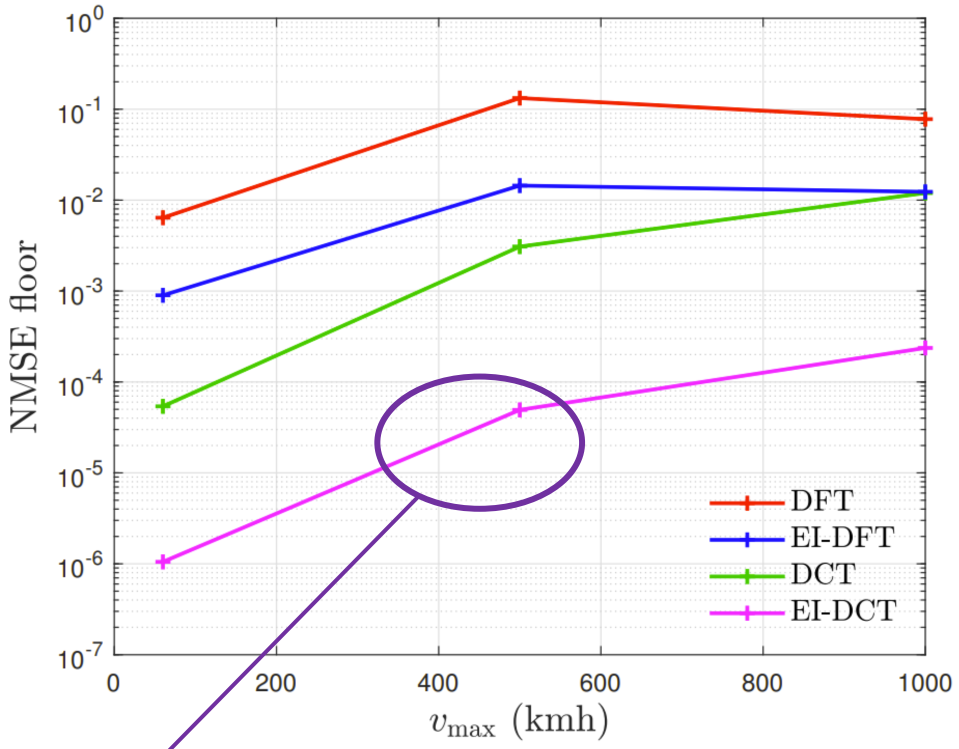
**Note: EI-DCT in these slides refers to the DCT approach with the extra-impulse, rather than the extendible inverse DCT.*

[1]. Raviteja, K. T. Phan, and Y. Hong, "Embedded pilot-aided channel estimation for OTFS in delay–Doppler channels," *IEEE Trans. Veh. Technol.*, vol. 68, no. 5, pp. 4906-4917, May. 2019

Numerical Results

- BLERs vs. E_s/N_0 under different $v_{\max}$ (16-QAM, E_π/E_s=16dB, N=8)

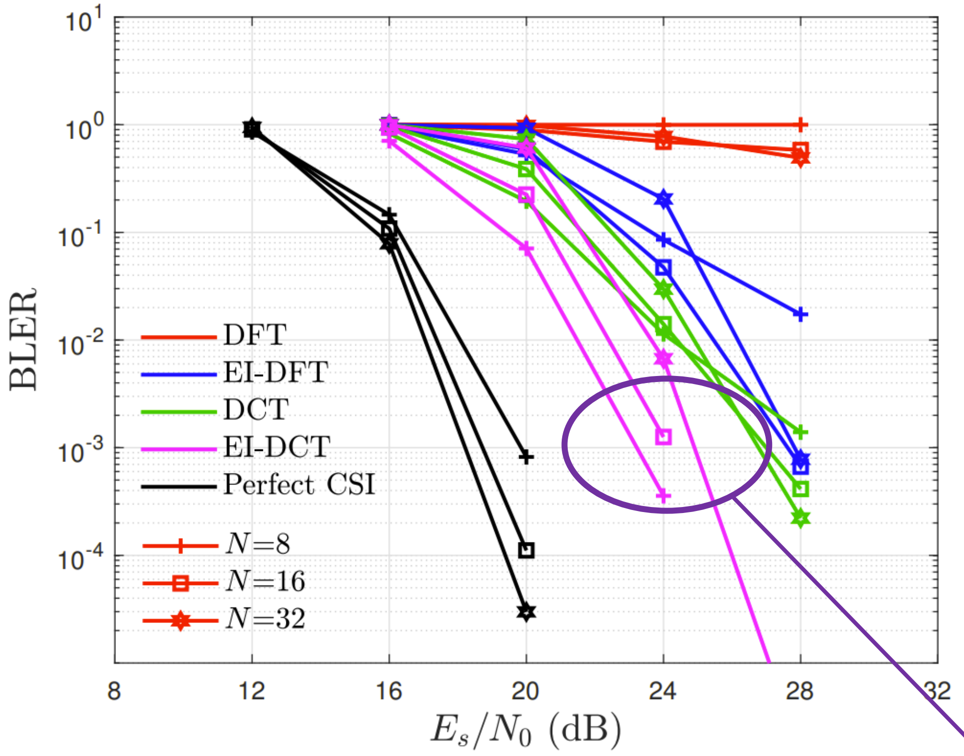


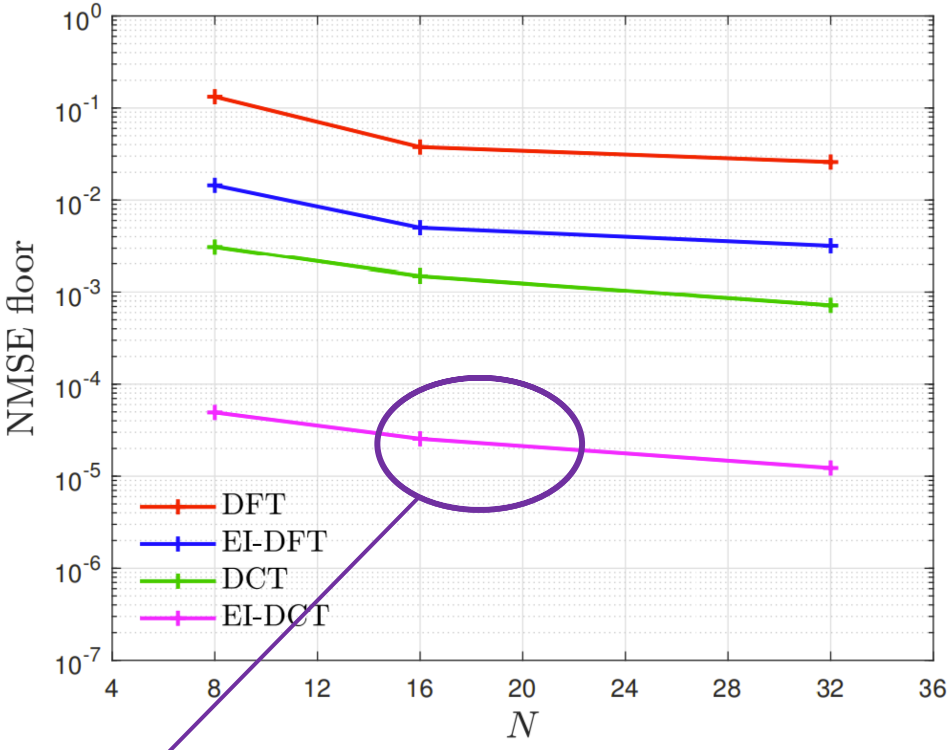


EI-DCT based scheme has the **lowest error rate** and **lowest NMSE floor**

Numerical Results

- BLERs vs. E_s/N_0 under different N (16-QAM, E_π/E_s=16dB, $v_{\max}$=500kmh)

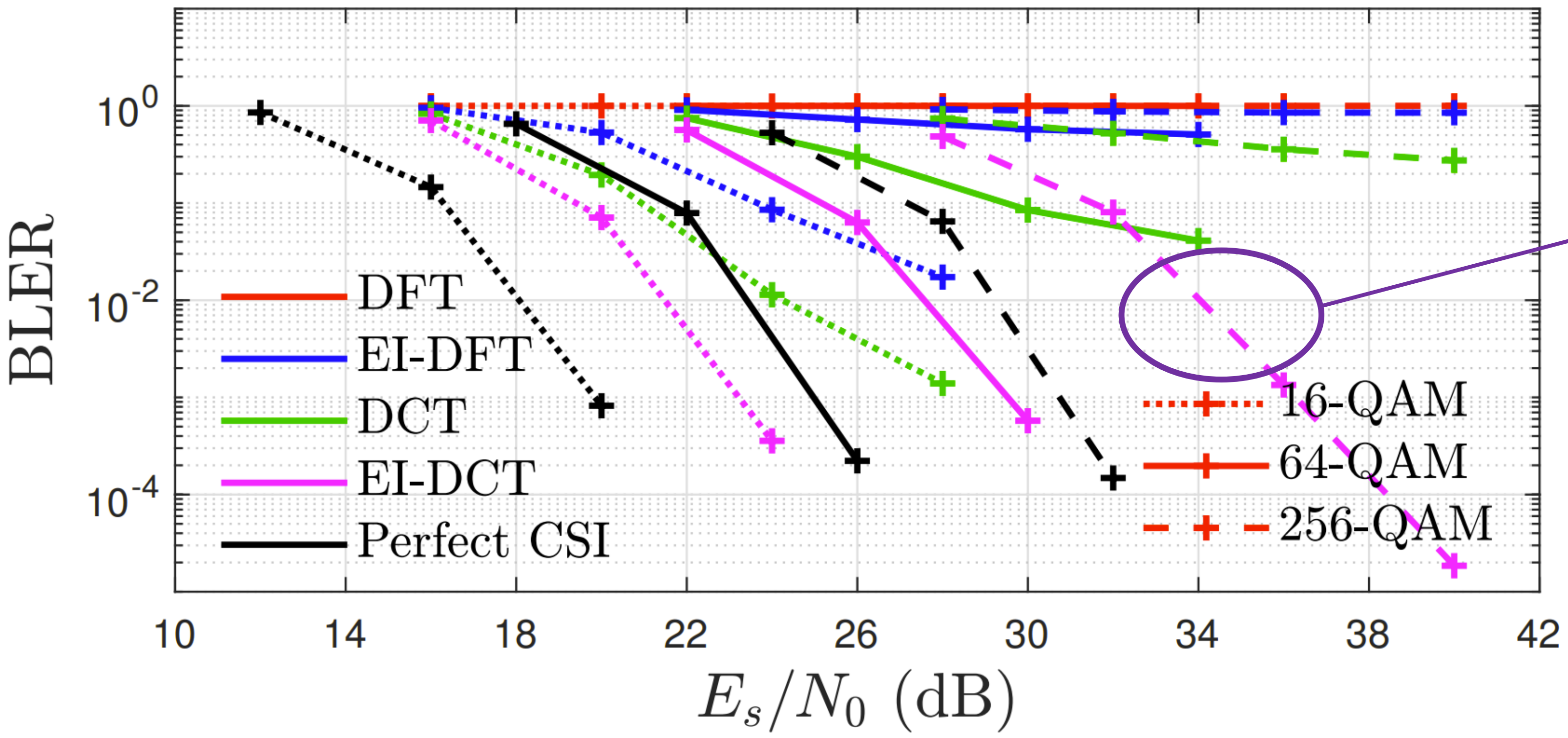




EI-DCT based scheme has the **lowest error rate** and **lowest NMSE floor**

Numerical Results

- BLERs vs. E_s/N_0 under different QAMs (E_π/E_s=16dB, N=8, $v_{\max}$=500kmh)



EI-DCT based scheme is effective when **high-order QAM** is adopted

Thanks for your attention !

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