Non-Linear Receivers for Unique Word OFDM

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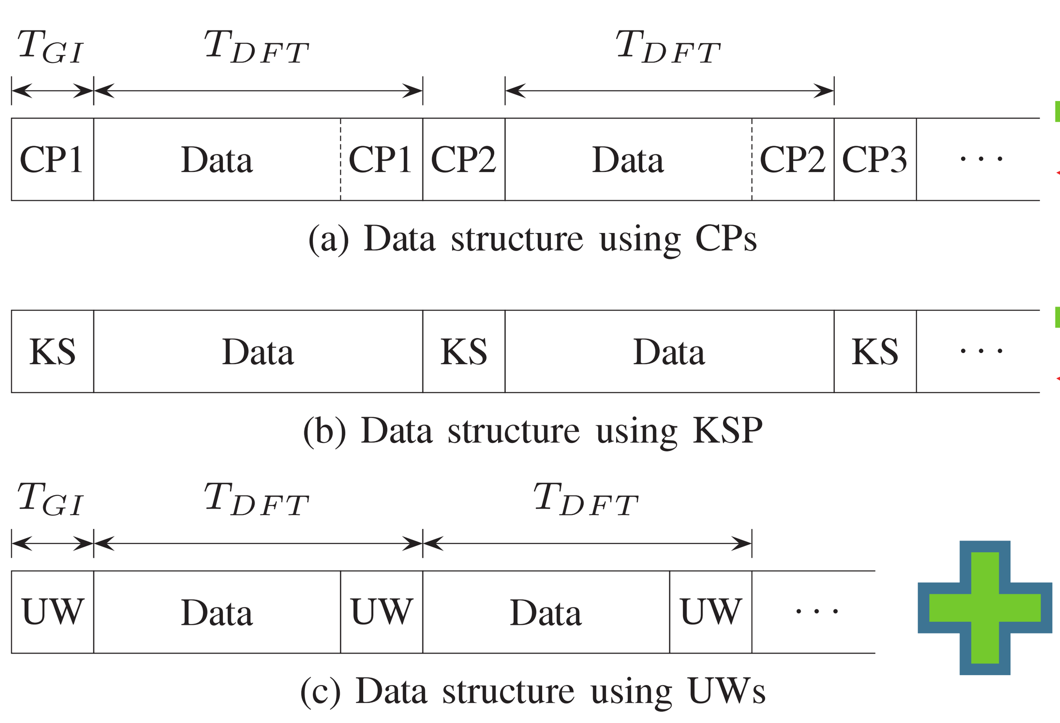
Principles of Unique Word OFDM



(a) Data structure using CPs

(b) Data structure using KSP

(c) Data structure using UWs

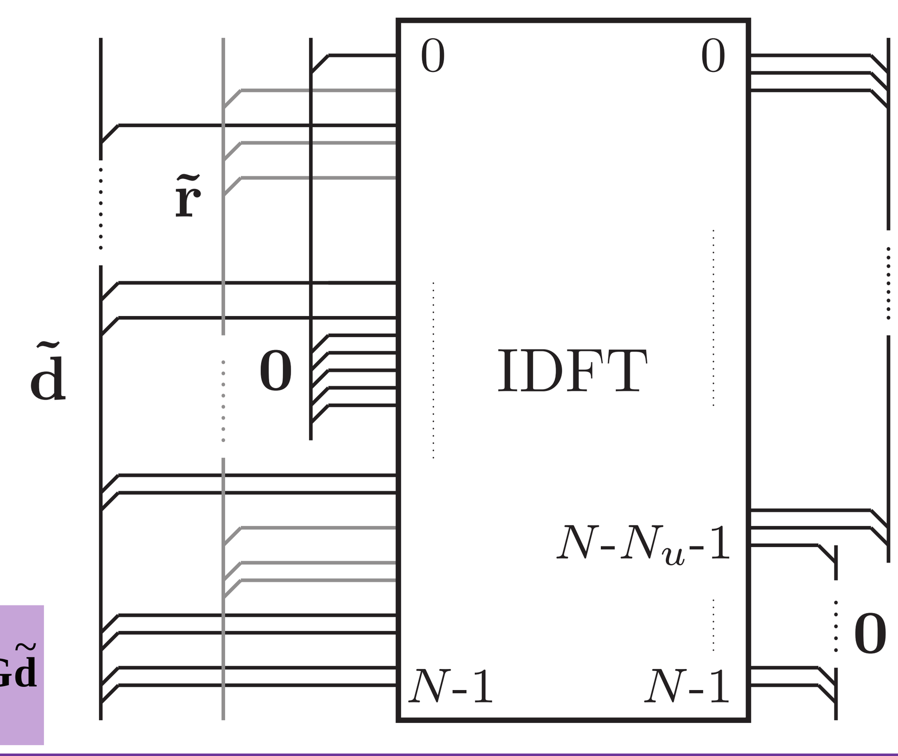
- Cyclicity within T_DFT
- CP is random
- KS is deterministic
- No cyclicity
- UW is deterministic
- Cyclicity within T_DFT
- Coding gain

$$\mathbf{F}_N^{-1}\mathbf{B}\mathbf{P}\begin{pmatrix}\tilde{\mathbf{d}}\\ \tilde{\mathbf{r}}\end{pmatrix}=\begin{pmatrix}\mathbf{x}_d\\ \mathbf{0}\end{pmatrix}$$

$$\begin{pmatrix}\mathbf{M}_{11} & \mathbf{M}_{12}\\ \mathbf{M}_{21} & \mathbf{M}_{22}\end{pmatrix}\begin{pmatrix}\tilde{\mathbf{d}}\\ \tilde{\mathbf{r}}\end{pmatrix}=\begin{pmatrix}\mathbf{x}_d\\ \mathbf{0}\end{pmatrix}$$

$$\tilde{\mathbf{r}}=-\mathbf{M}_{22}^{-1}\mathbf{M}_{21}\tilde{\mathbf{d}}=\mathbf{T}\tilde{\mathbf{d}}$$

$$\tilde{\mathbf{c}}=\mathbf{P}\begin{pmatrix}\tilde{\mathbf{d}}\\ \tilde{\mathbf{r}}\end{pmatrix}=\mathbf{P}\begin{pmatrix}\tilde{\mathbf{d}}\\ \mathbf{T}\tilde{\mathbf{d}}\end{pmatrix}=\mathbf{P}\begin{pmatrix}\mathbf{I}\\ \mathbf{T}\end{pmatrix}\tilde{\mathbf{d}}=\mathbf{G}\tilde{\mathbf{d}}$$

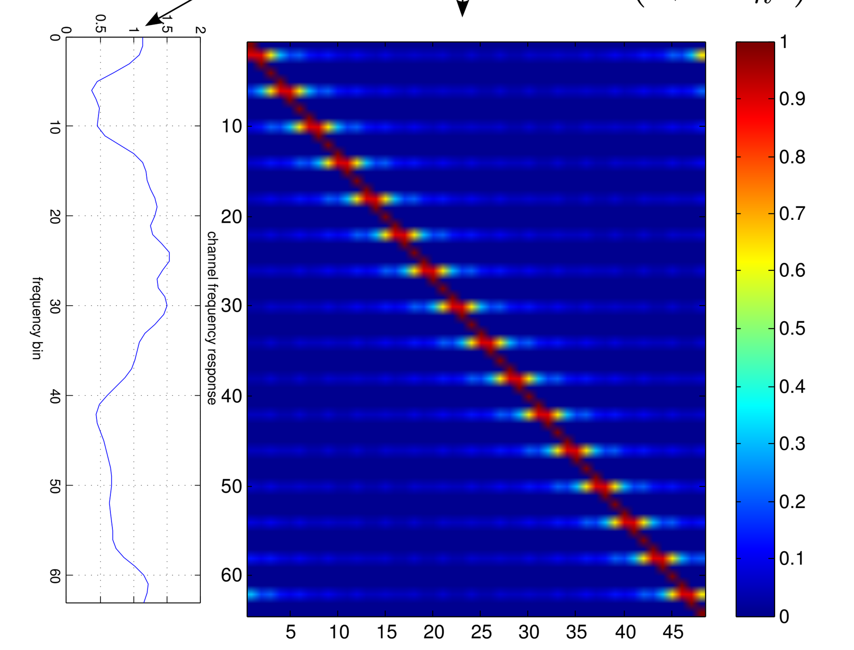


Procedure as follows
- assemble UW-OFDM symbol
- transmit over multi-path channel
- transform into frequency domain
- remove zero subcarriers and UW influence

=> linear model

$$\tilde{\mathbf{y}}=\tilde{\mathbf{H}}\mathbf{G}\tilde{\mathbf{d}}+\tilde{\mathbf{n}}$$

$\mathcal{N}(\mathbf{0};N\sigma_n^2\mathbf{I})$



Apply sophisticated linear and non-linear data detection methods

... from estimation theory, MIMO channel models, etc.

LMMSE estimation

$$\hat{\mathbf{d}}=\left(\mathbf{G}^H\tilde{\mathbf{H}}^H\tilde{\mathbf{H}}\mathbf{G}+\frac{N\sigma_n^2}{\sigma_d^2}\mathbf{I}\right)^{-1}\mathbf{G}^H\tilde{\mathbf{H}}^H\tilde{\mathbf{y}}$$

$$\mathbf{C}_{ee}=N\sigma_n^2\left(\mathbf{G}^H\tilde{\mathbf{H}}^H\tilde{\mathbf{H}}\mathbf{G}+\frac{N\sigma_n^2}{\sigma_d^2}\mathbf{I}\right)^{-1}$$

Sphere Decoding

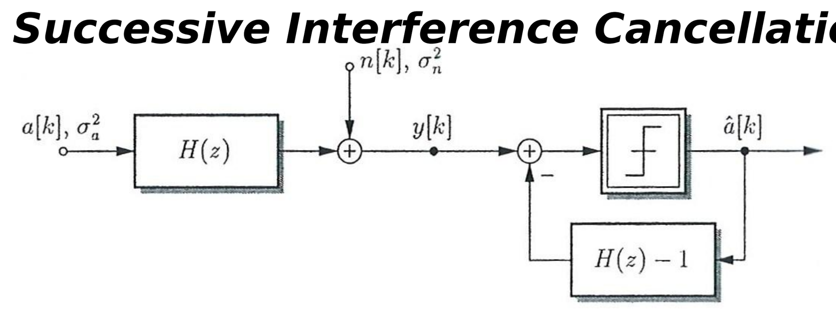
QR decomposition

$$\mathbf{d}^{ML}=\arg\min_{\tilde{\mathbf{d}}\in\mathcal{A}^{N_d}}\left\|\tilde{\mathbf{H}}\mathbf{G}\,\tilde{\mathbf{d}}-\tilde{\mathbf{y}}\right\|_2^2$$

$$=\arg\min_{\tilde{\mathbf{d}}\in\mathcal{A}^{N_d}}\left\|\mathbf{R}\tilde{\mathbf{d}}-\tilde{\mathbf{y}}'\right\|_2^2$$

upper triangular

Successive Interference Cancellation



Noise Interpolation

Use LMMSE estimate and error statistics to interpolate picked error values

$$\mathbf{e}^{\mathrm{LMMSE}}=\tilde{\mathbf{d}}^{\mathrm{LMMSE}}-\left\lfloor\tilde{\mathbf{d}}^{\mathrm{LMMSE}}\right\rceil$$

$$e_k^{\mathrm{NI}}=\boldsymbol{\theta}_k^T\mathbf{e}^{\mathrm{LMMSE}}$$

$$\tilde{\mathbf{d}}^{\mathrm{NI}}=\tilde{\mathbf{d}}^{\mathrm{LMMSE}}-\mathbf{e}^{\mathrm{NI}}$$

$$\mathbf{C}_{ee}^{\mathrm{NI}}=\mathbf{C}_{ee}^{\mathrm{LMMSE}}-\boldsymbol{\Theta}^T\left(\mathbf{C}_{ee}^{\mathrm{LMMSE}}\right)^H$$

NI

Choice of samples to interpolate and from which to interpolate is crucial for the performance.

Good choice: Iterative approach
1) pick value k to interpolate, with highest noise variance (diag of C_ee)
2) interpolate noise value k from other noise values
3) update noise statistics C_ee
4) return to 1

Non-systematic Symbol Generation

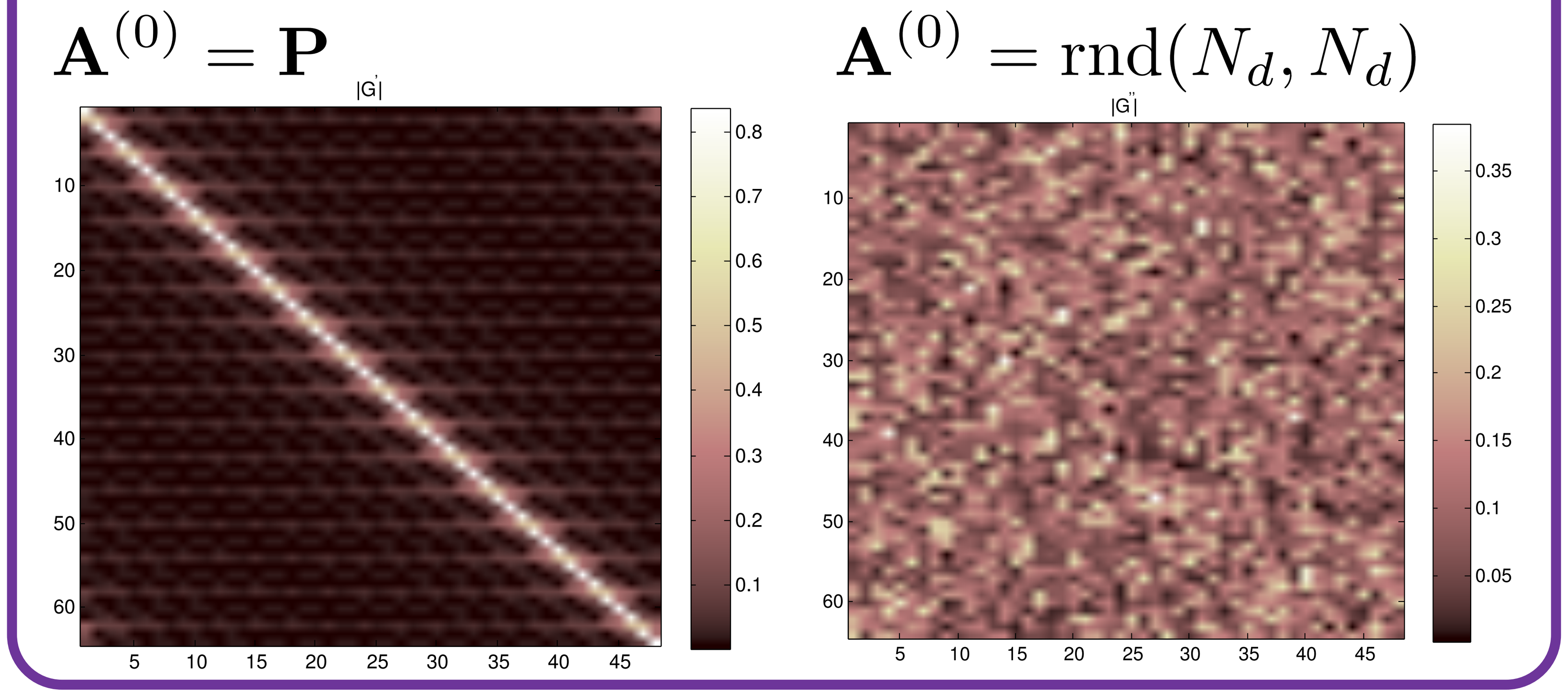
$$\mathbf{F}_N^{-1}\mathbf{B}\mathbf{A}\begin{bmatrix}\mathbf{I}\\ \breve{\mathbf{T}}\end{bmatrix}=\begin{bmatrix}\mathbf{x}_d\\ \mathbf{0}\end{bmatrix}$$

Goal: Find A to minimize trace of Cee after LMMSE estimation in an AWGN channel
For fixed c, the cost function reads

$$J=\sigma_d^2\mathrm{tr}\left\{\left(\frac{cN_d}{\mathrm{tr}\{\breve{\mathbf{G}}^H\breve{\mathbf{G}}\}}\breve{\mathbf{G}}^H\breve{\mathbf{G}}+\mathbf{I}\right)\right\}\Rightarrow\breve{\mathbf{G}}=\arg\min(J)$$

Different initializations:

$\mathbf{A}^{(0)}=\mathbf{P}$ $\qquad$ $\mathbf{A}^{(0)}=\mathrm{rnd}(N_d,N_d)$

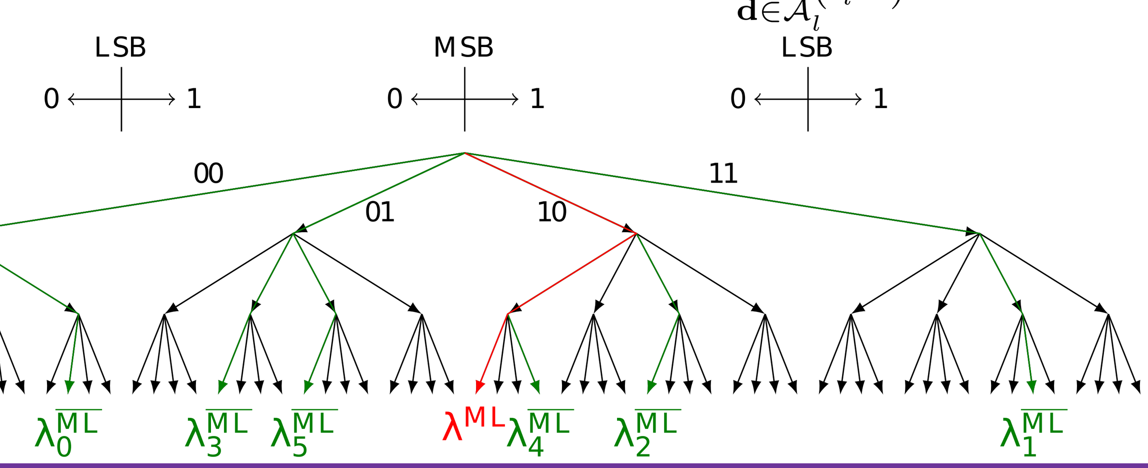


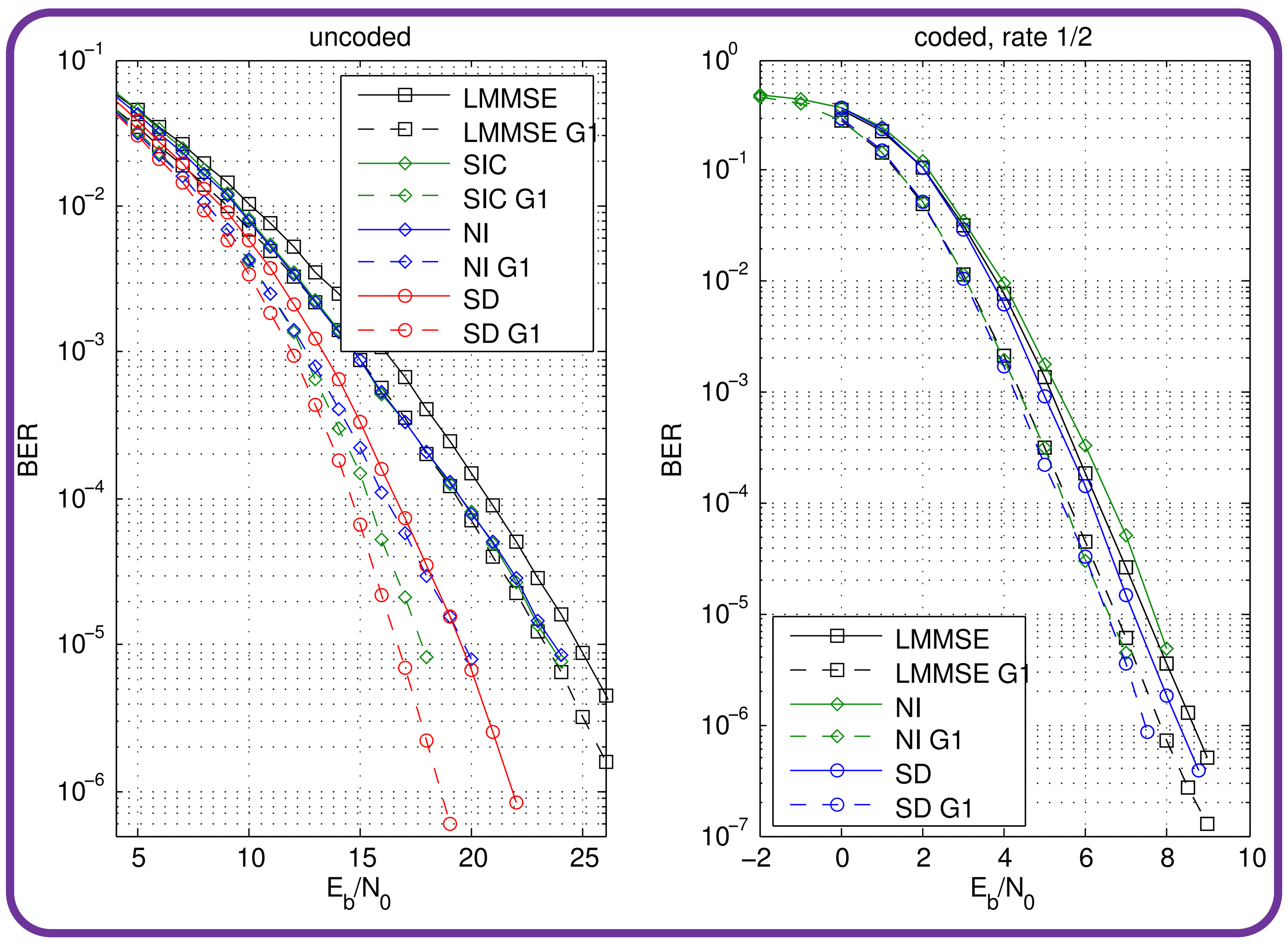
SD

Soft information by LLRs using the max-log approximation

$$L_l=\begin{cases}\lambda^{\mathrm{ML}}-\lambda_l^{\overline{\mathrm{ML}}} & \text{if } b_l^{\mathrm{ML}}=0,\\ \lambda_l^{\overline{\mathrm{ML}}}-\lambda^{\mathrm{ML}} & \text{if } b_l^{\mathrm{ML}}=1,\end{cases}$$

$$\text{with } \lambda_l^{\overline{\mathrm{ML}}}=\min_{\tilde{\mathbf{d}}\in\mathcal{A}_l^{(\overline{b_l^{\mathrm{ML}}})}}\left\|\tilde{\mathbf{H}}\mathbf{G}\tilde{\mathbf{d}}-\tilde{\mathbf{y}}\right\|^2$$





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