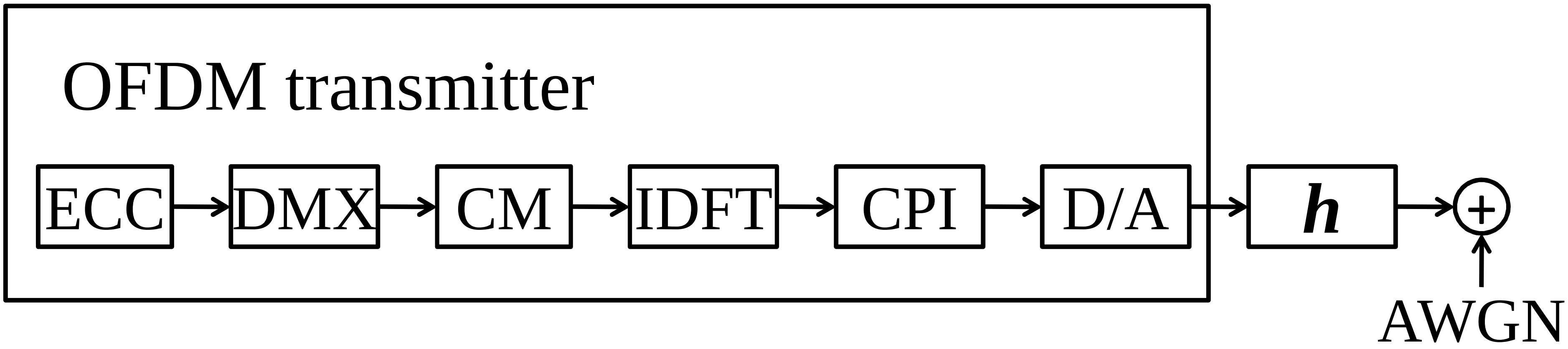
EXPLOITING CYCLIC PREFIX REDUNDANCY IN OFDM TO IMPROVE DECODING OF LDPC CODE

Tomas Palenik, Peter Farkas

Presentation Outline

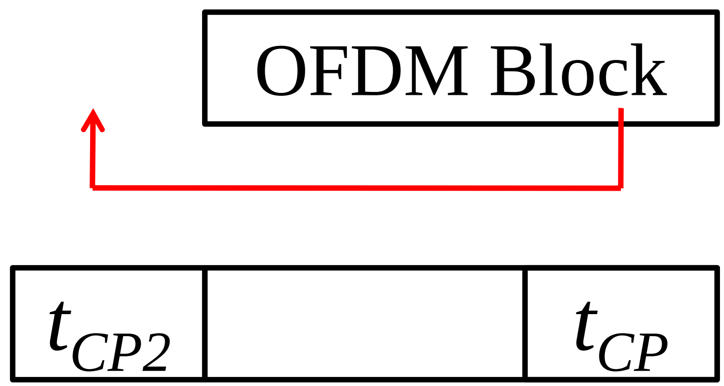
- OFDM and redundancy
- Redundancy extraction
- New modified OFDM SDR receiver
- Simulation results
- Practical consideration

Coded OFDM system review



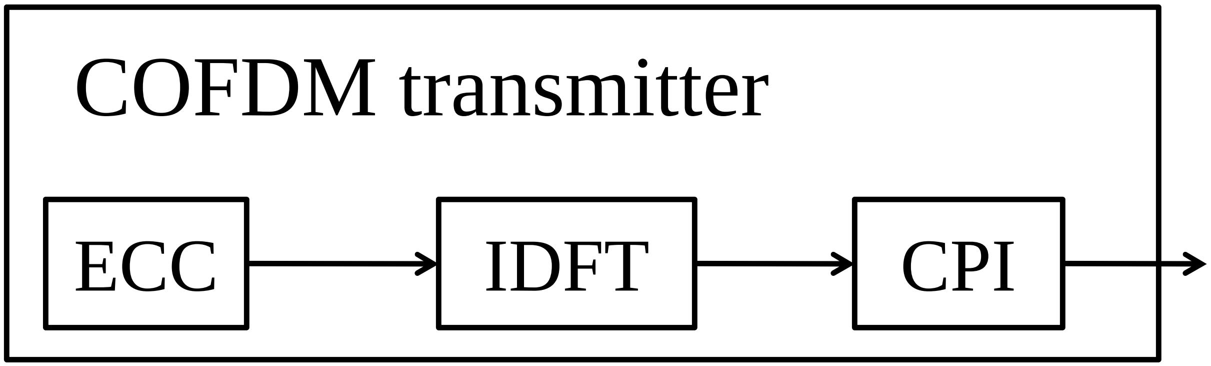
- ECC – Error Correcting Code
- DMX – Demultiplexor
- CM – Constellation Mapping (Modulation)
- IDFT – Inverse Discrete Fourier Transform
- CPI – Cyclic Prefix Insertion
- ***h*** – Channel impulse response
- AWGN – Additive White Gaussian Noise

Redundancy in OFDM - Cyclic Prefix



- Cyclic prefix insertion
  - Prepend part of samples (1/8 default in WiMax)
  - Eliminate Inter Block Interference
  - Frequency Domain Equalization
- CP is discarded in the receiver

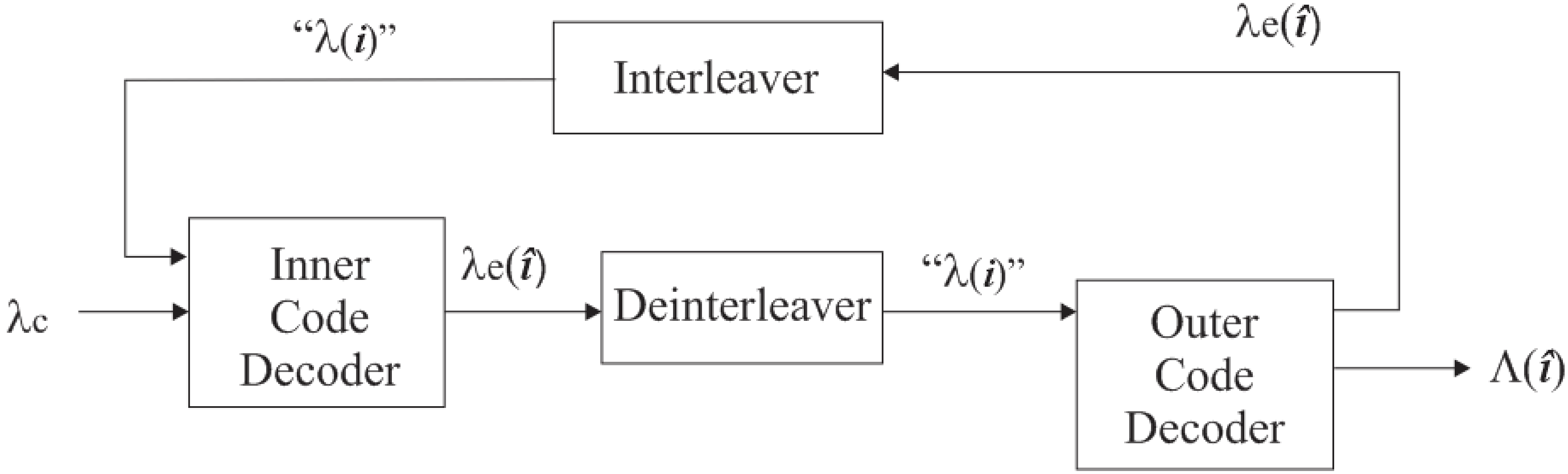
Key observations



- CP insertion is a partial repetition code
- IDFT is an Interleaver
- COFDM transmitter is a serially encoded system

- Modify the receiver to turbo-like design
- Don’t modify the protocol/standard

Turbo-like OFDM receiver

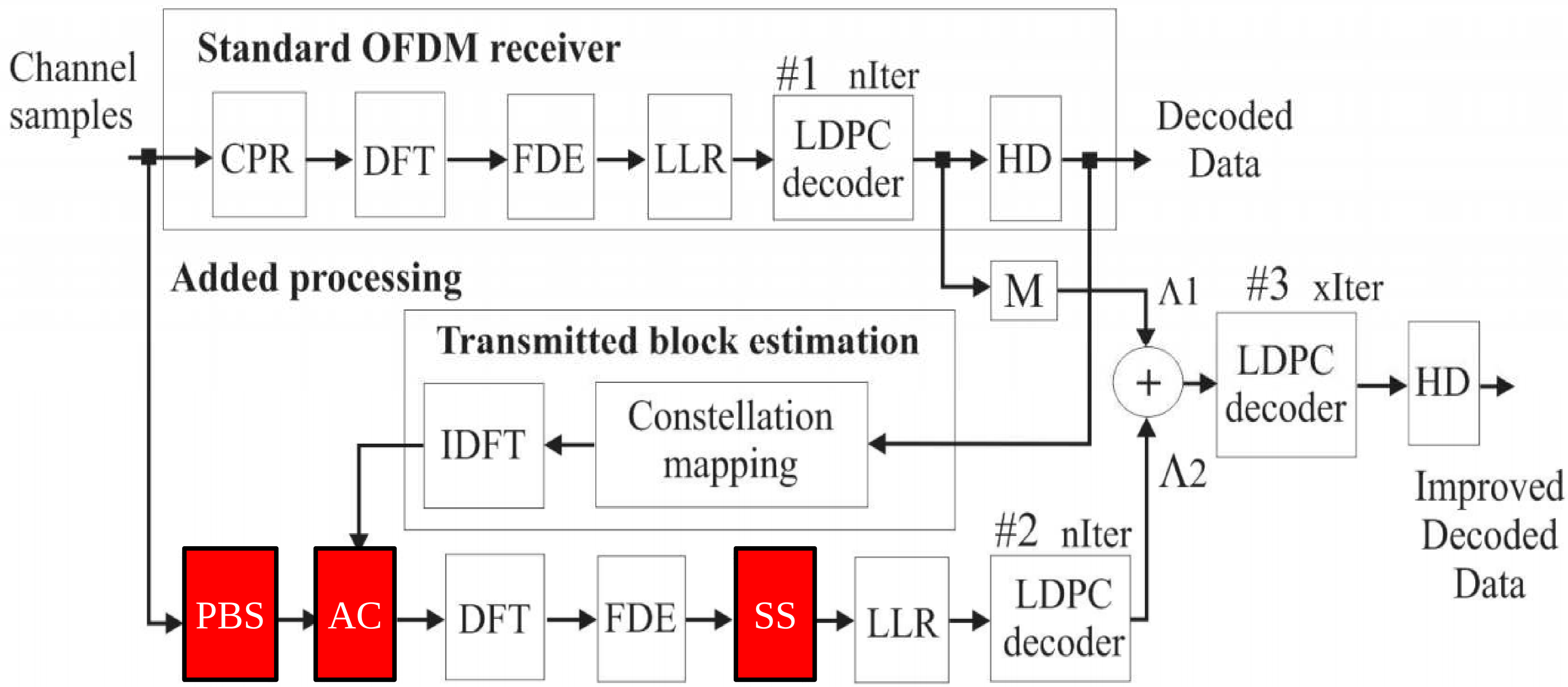


- Iterative design for decoding turbo-codes
- SISO decoders exchange extrinsic information
- LLR based decoding

Problems and Solutions

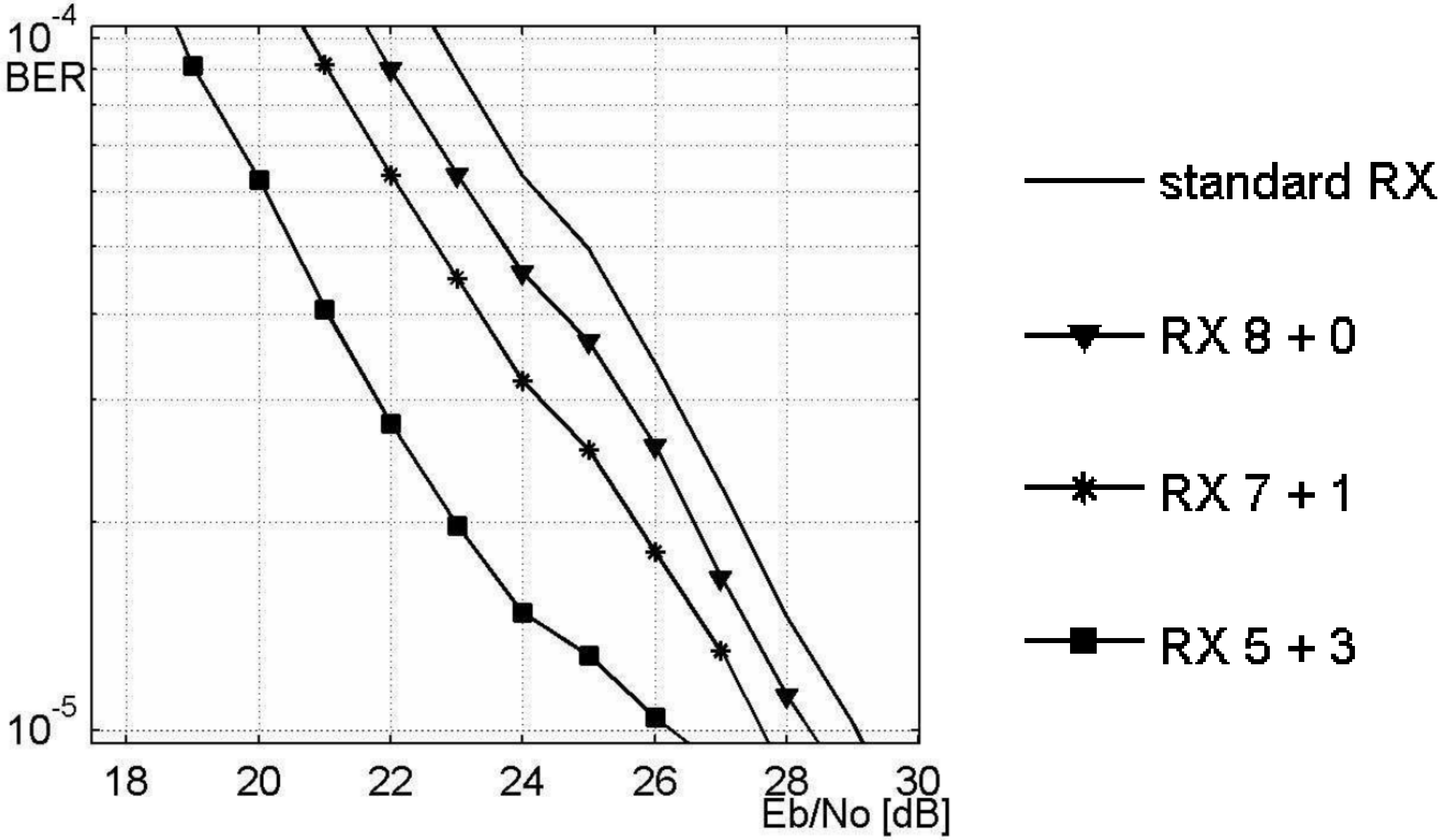
- CP samples corrupted by IBI
  - Interference cancellation by additive correction
  - Reconstruction of transmitted OFDM block in RX
- IDFT is not interleaver
  - For large N can approximate interleaver function
- Time-domain decoding cannot use LLR metric
  - Decoder reordering – move to frequency-domain
- Repetition code very weak
  - Simplify iterative scheme

New modified SDR receiver



- SDR - Only three new blocks to implement

Simulation results



- Rayleigh fading quasi-static multipath channel
- $T_{CP} = 1/8 \times T_u$,LDPC code with R = 1/2
- Improvement up to 4dB

Practical considerations (WiMax)

- Method is ***suboptimal***
- Prefix size adaptive
  - $T_{CP} = \{1/2, 1/4, \mathbf{1/8,}\ 1/16, 1/32\} \times T_u$
- Target data BER = 10^{-6}
  - best improvement for BER 10^{-4} – 10^{-5}
- Increased RX processing + 65%
- SDR receiver necessary
- Whole OFDM symbol to one Subscriber
  - Trouble in cellular network with many MS

Possible use scenario (with WiMax)

- Video transfer
- Remote subscriber site
  - Large prefix size
- Fixed installation point
  - Extra processing no problem
  - Bandwidth dedicated to one subscriber station

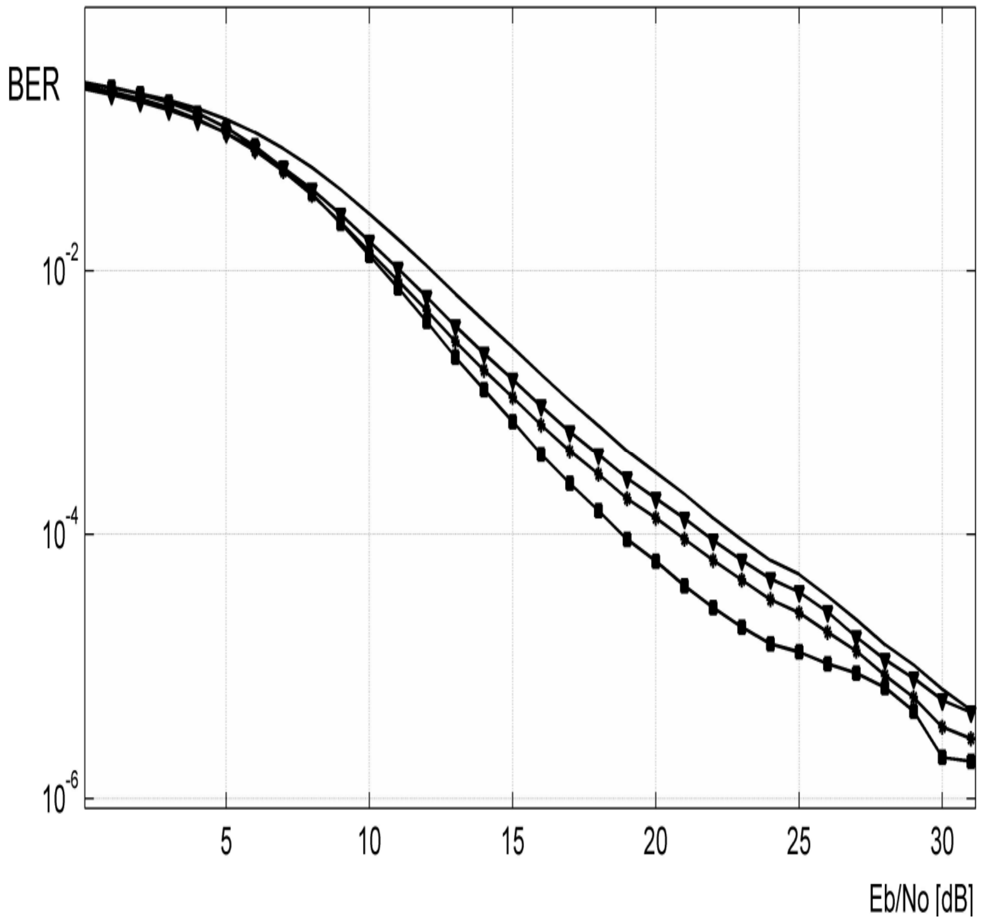
References

1. MOQVIST, P. *Serially concatenated systems: An iterative decoding approach with application to continuous phase modulation*. Chalmers University of Technology, Goteborg, Sweden, Dec. 1999
2. DEBBAH, M. *Short introduction to OFDM*. 2002 Available: www.supelec.fr/d2ri/ flexibleradio/cours/ofdmtutorial.pdf
3. Hagenauer, Offer, Papke: *Iterative decoding of Binary Block and Convolutional Codes,* . In *IEEE Transactions on Information Theory*, Mar. 1996.
4. HÄRING, J., VINCK, A. J. H. Iterative decoding of Codes over Complex Numbers for Impulsive Noise Channels. In *IEEE Transactions on Information Theory*, May 2003.

Thank you for your attention.

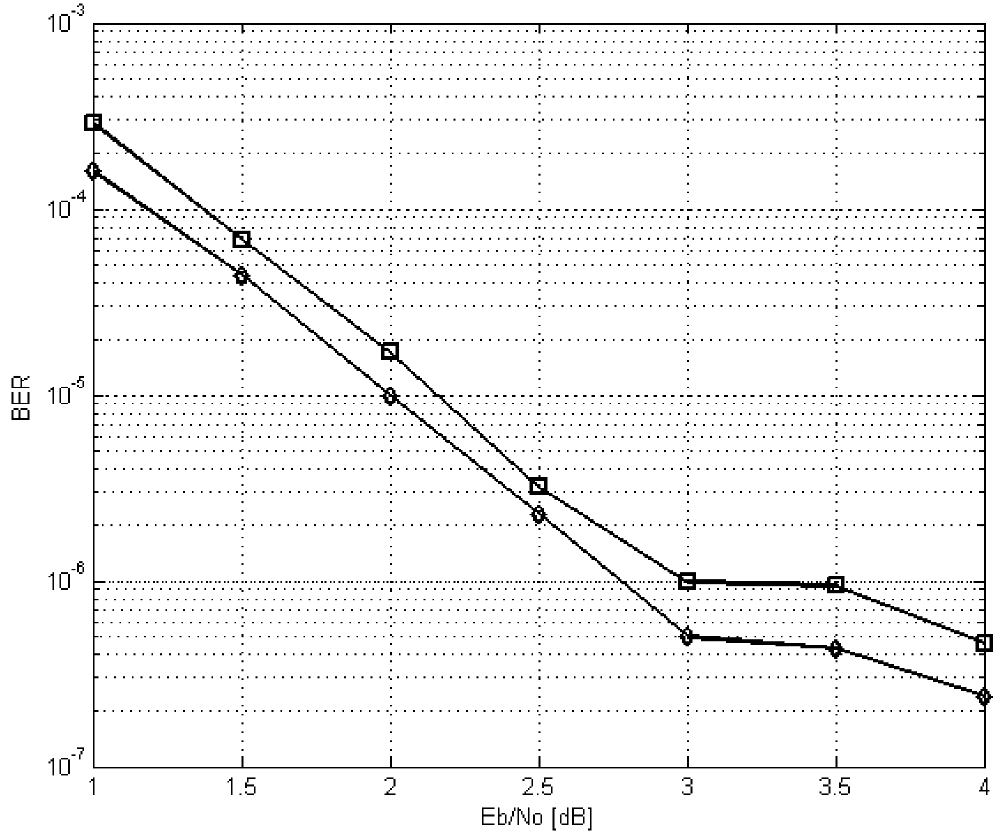
Questions ?

Full simulation results



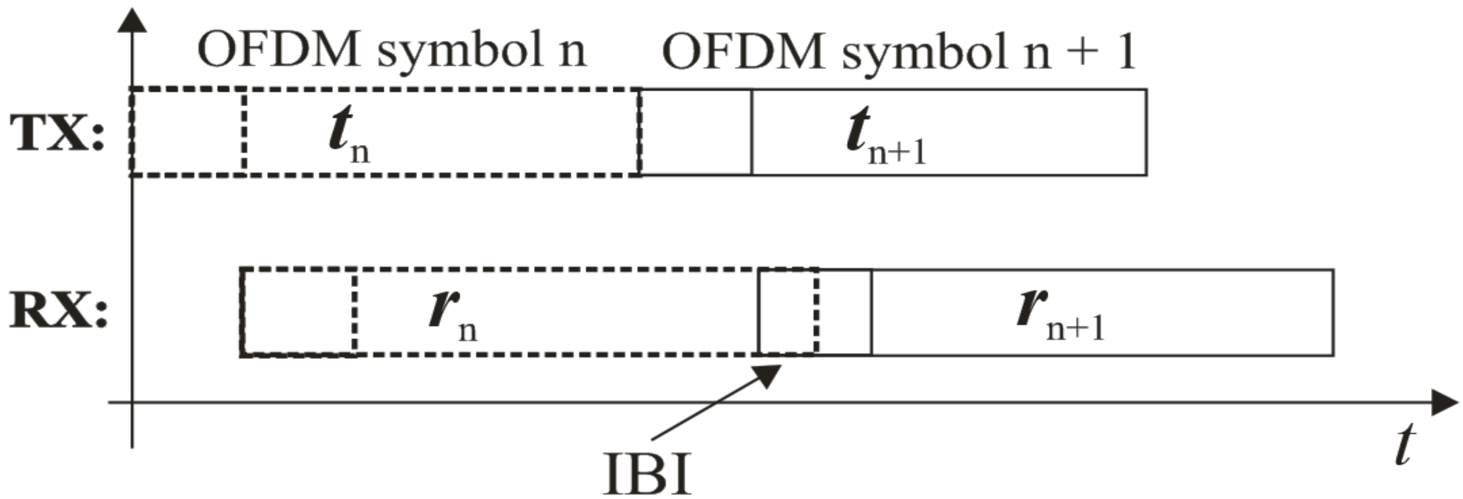
- OFDM
  - N = 1152 carriers
  - $T_g = 1/8\ T_u$
- LDPC
  - R = ½
  - n = 1152
- Channel
  - Rayleigh fading
  - No Doppler shift
  - ITU-T model

Previous work –results for turbo code



- UMTS turbo code
- Improvement minimal – 0.1 dB

IBI corruption of CP samples



- Formal segmentation of channel matrix

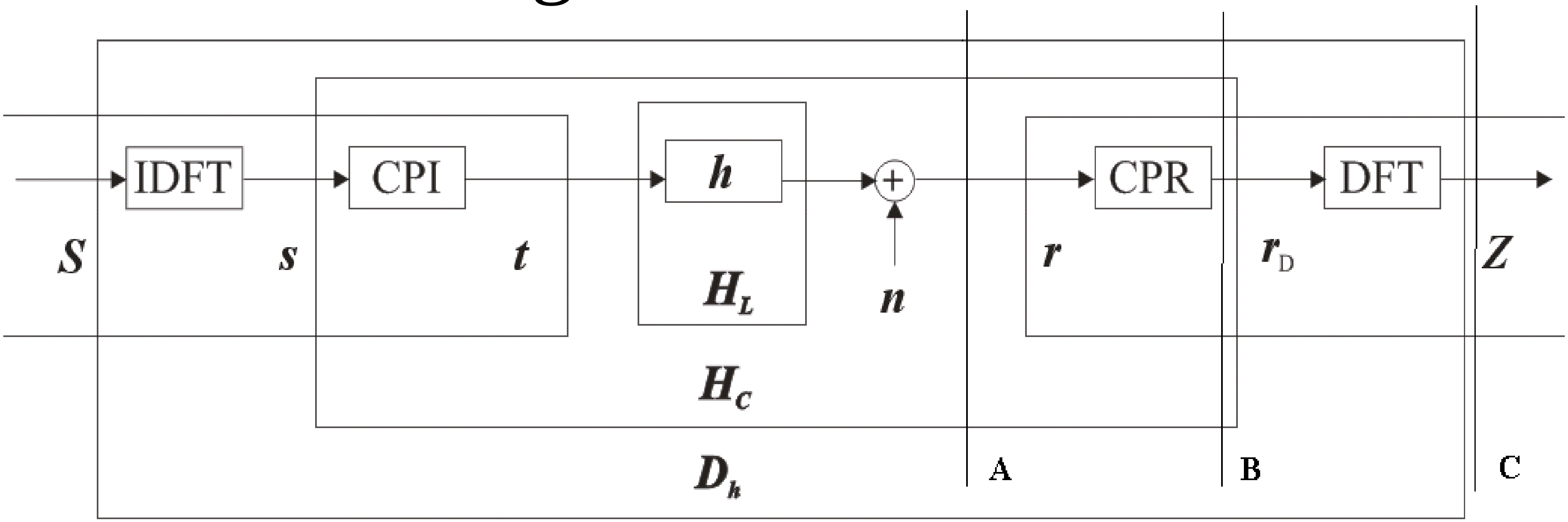
$$\boldsymbol{r}_{IBI(\mathrm{n})} = \boldsymbol{r}_{CP(\mathrm{n})} + \boldsymbol{r}_{T(\mathrm{n}-1)} = \boldsymbol{H}_{\boldsymbol{11}(\mathrm{n})} \times \boldsymbol{t}_{CP2(\mathrm{n})} + \boldsymbol{H}_{\boldsymbol{43}(\mathrm{n}-1)} \times \boldsymbol{t}_{CP(\mathrm{n}-1)}$$

- Assuming perfect CSI in RX:

$$\boldsymbol{r}_{cor1(n-1)} = \boldsymbol{r}_{T(\mathrm{n}-1)} = \boldsymbol{H}_{\boldsymbol{43}(\mathrm{n}-1)} \times \boldsymbol{t}_{CP(n-1)}$$

- TX block estimate necessary in RX

Modeling OFDM Transmission



- Simple transmission model:

$$Z(k) = H(k) \cdot S(k) \ , \ k = 0, \ldots, N-1$$

- Simple frequency-domain equalization in RX:

$$S(k) = H^{-1}(k) \cdot Z(k) \ , \ k = 0, \ldots, N-1$$

Channel Matrix Segmentation

$$\boldsymbol{H}_{\boldsymbol{L}} = \begin{bmatrix} \boldsymbol{H}_{11}^{(O\times O)} & \boldsymbol{H}_{12}^{(O\times(N-O))} & \boldsymbol{H}_{13}^{(O\times O)} \\ \boldsymbol{H}_{21}^{((N-O)\times O)} & \boldsymbol{H}_{22}^{((N-O)\times(N-O))} & \boldsymbol{H}_{23}^{((N-O)\times O)} \\ \boldsymbol{H}_{31}^{(O\times O)} & \boldsymbol{H}_{32}^{(O\times(N-O))} & \boldsymbol{H}_{33}^{(O\times O)} \\ \boldsymbol{H}_{41}^{((\nu-1)\times O)} & \boldsymbol{H}_{42}^{((\nu-1)\times(N-O))} & \boldsymbol{H}_{43}^{((\nu-1)\times O)} \end{bmatrix}$$

- $\boldsymbol{H}_{\boldsymbol{L}}$ models channel convolution
- TX block segmentation:

$$\boldsymbol{t}^{((N+O)\times 1)} = \left[\boldsymbol{t}_{CP2}^{(O\times 1)} \parallel \boldsymbol{t}_{NP}^{((N-O)\times 1)} \parallel \boldsymbol{t}_{CP}^{(O\times 1)} \right]$$

- RX block segmentation:

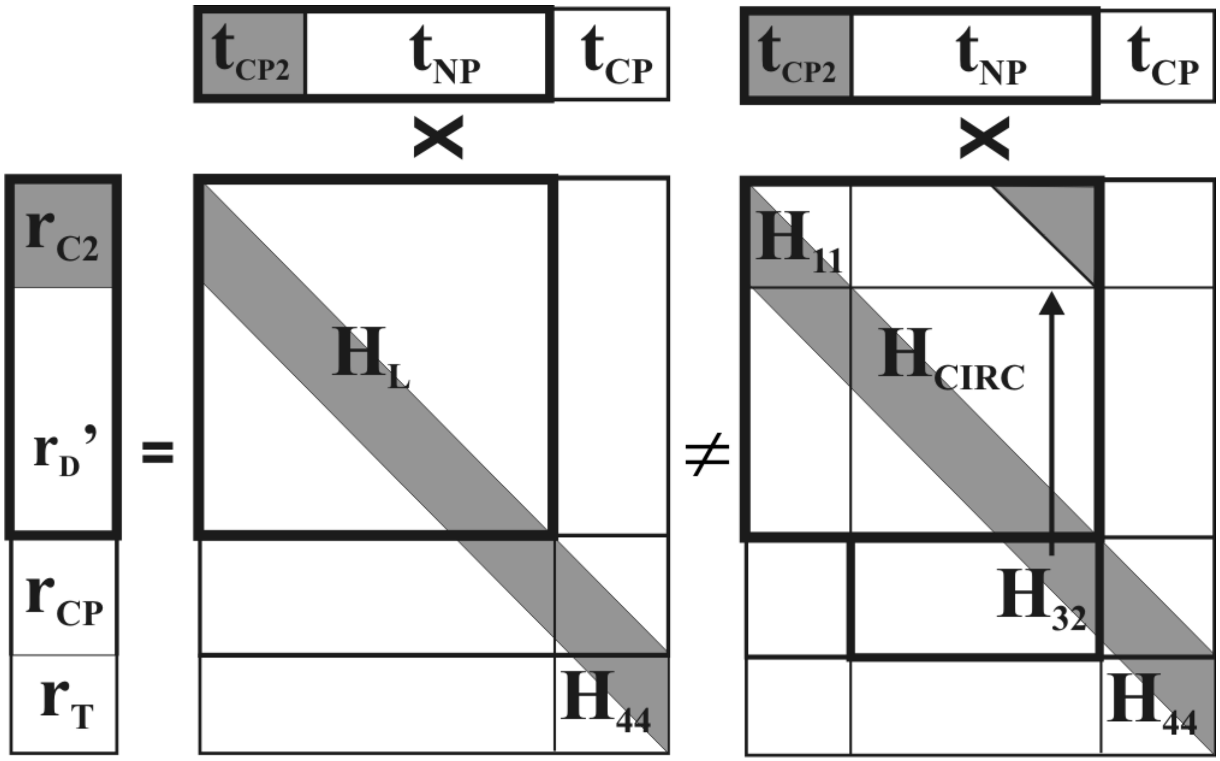
$$\boldsymbol{r} = \left[\boldsymbol{r}_{CP}^{(O\times 1)} \parallel \boldsymbol{r}_{D}'^{((N-O)\times 1)} \parallel \boldsymbol{r}_{D}''^{(O\times 1)} \parallel \boldsymbol{r}_{T}^{((\nu-1)\times 1)} \right]$$

Channel Matrix Segmentation Example

t s s_2 r_{D2} r_D

r		s7	s8	s9	s10	s1	s2	s3	s4	*s5*	*s6*	s7	s8	*s9*	*s10*
r1	r_{CP}	h1													
r2		h2	h1												
r3		h3	h2	h1											
r4			h3	h2	h1										
r5	r_D'			h3	h2	h1									
r6					h3	h2	h1								
r7						h3	h2	h1							
r8							h3	h2	h1						
r9								h3	h2	h1					
r10									h3	h2	h1				
r11	r_D''									h3	h2	h1			
r12											h3	h2	h1		
r13												h3	h2	h1	
r14													h3	h2	h1
r15	r_T													h3	h2
r16															h3

Second Circulant Submatrix in $\boldsymbol{H_L}$



- Additive correction necessary:

$$\boldsymbol{r}_{cor\,2} = \boldsymbol{H_{32}} \times \boldsymbol{t}_{NP}$$

LLR decoding of repetition code

- Parity equation in binary coding:

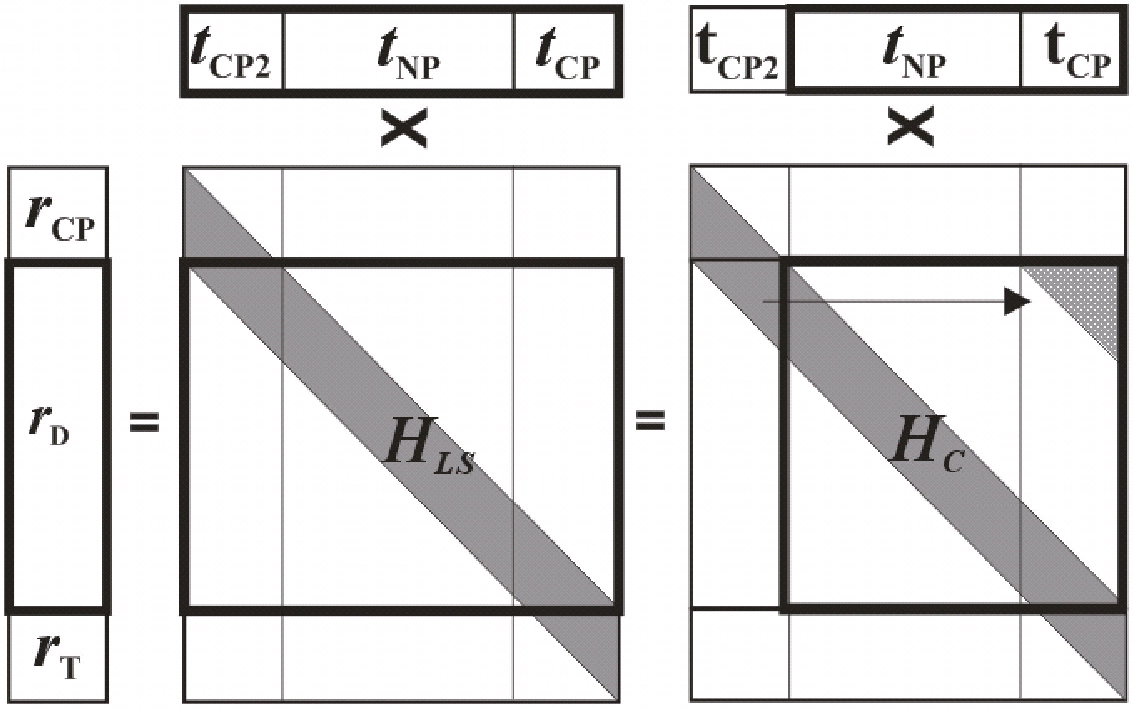
$$b_1 + b_2 + ... + b_i + ... + b_m = 0$$

- Soft decision LLR equivalent:

$$\lambda_e(b_i) = 2\,\mathrm{arctan\,h}\left(\prod_{j \in \{1,...,m\} \setminus \{i\}} \tanh\left(\frac{\lambda(b_j)}{2} \right) \right)$$

- In repetition b_j is a copy of b_i
- Equation simplifies to: $\lambda_e(b_i) = \lambda(b_j)$
- Decoding: $\lambda_{app}(b_i) = \lambda(b_i) + \lambda(b_j)$

FDE – Circulant submatrix in channel matrix



- $\boldsymbol{\Omega}$ - Cyclic Prefix Insertion matrix
- $\boldsymbol{\Psi}$ - Cyclic Prefix Remove matrix

$$\boldsymbol{H}_{\boldsymbol{c}}^{(N \times N)} = \boldsymbol{\Psi} \times \boldsymbol{H}_{\boldsymbol{L}}^{((N+O+\nu-1)\times(N+O))} \times \boldsymbol{\Omega}$$