PHYDYAS Workshop

Equalization for FBMC

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June 21, 2009

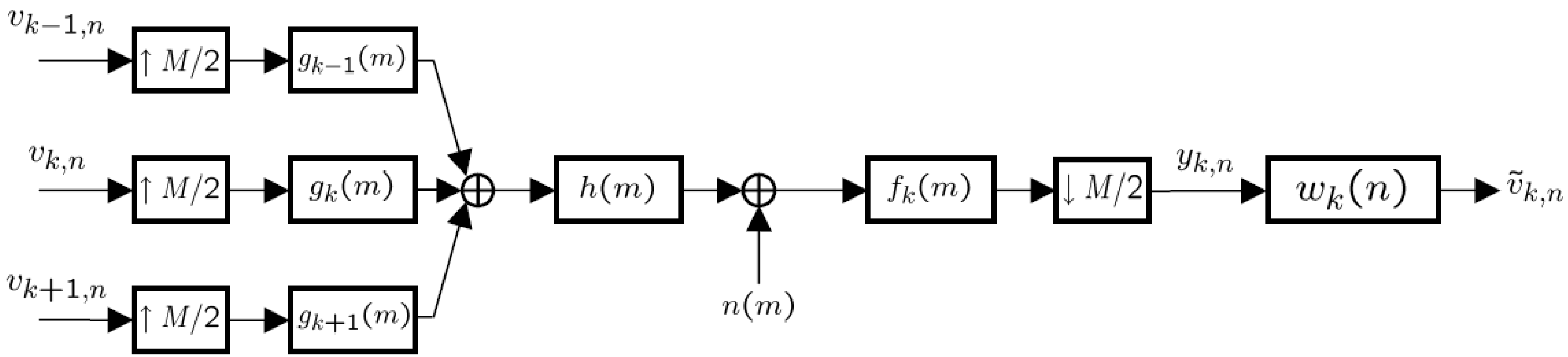
Outline

- **Model for equalization**
- **Different types of equalizers**
  - Frequency Sampling
  - MMSE
  - Two-stage interference cancelation
- **Performance comparison**

  (WiMAX-like scenario)

- **Linear precoding for FBMC**
  - Frequency diversity

General comments on equalization



- Per subcarrier → scalability
- Only adjacent subcarriers create interference
- Equalizer works at double the subcarrier rate
  - Compensate for channel selectivity
- Multiple taps → Ability to compensate for FTD
- Different criteria for computation

Different types

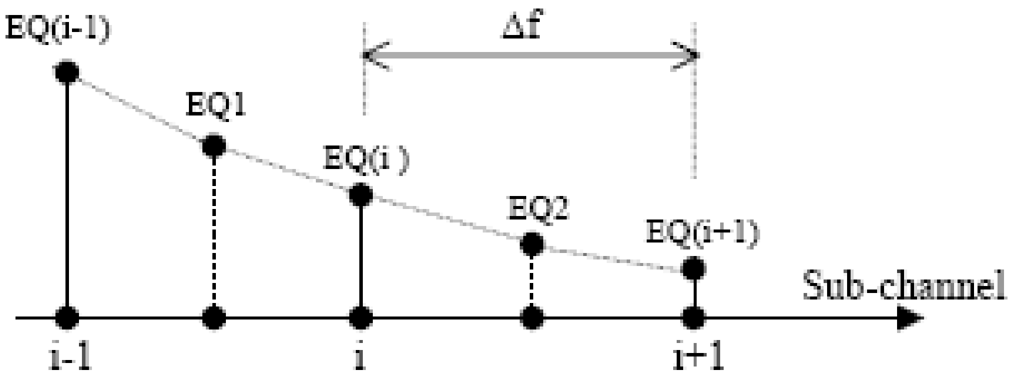
- 1-tap
- Frequency sampling
- MMSE
- DFE
- Two-stage interference cancelation

➢ Objective: compare them

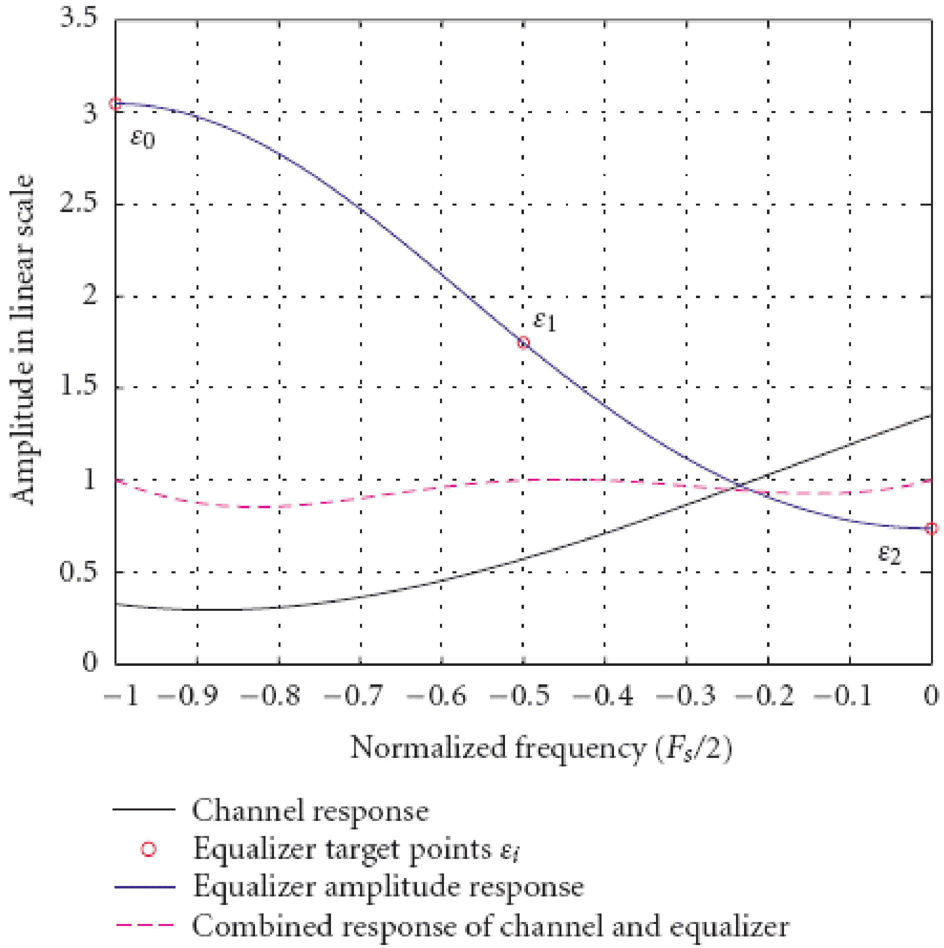
➢ When to use which equalizer?

Frequency sampling

- Use channel estimation at center frequency points
- Interpolate target equalizer value at several intermediate points
  - Geometric interpolation
- Compute multiple taps equalizers based on desired points

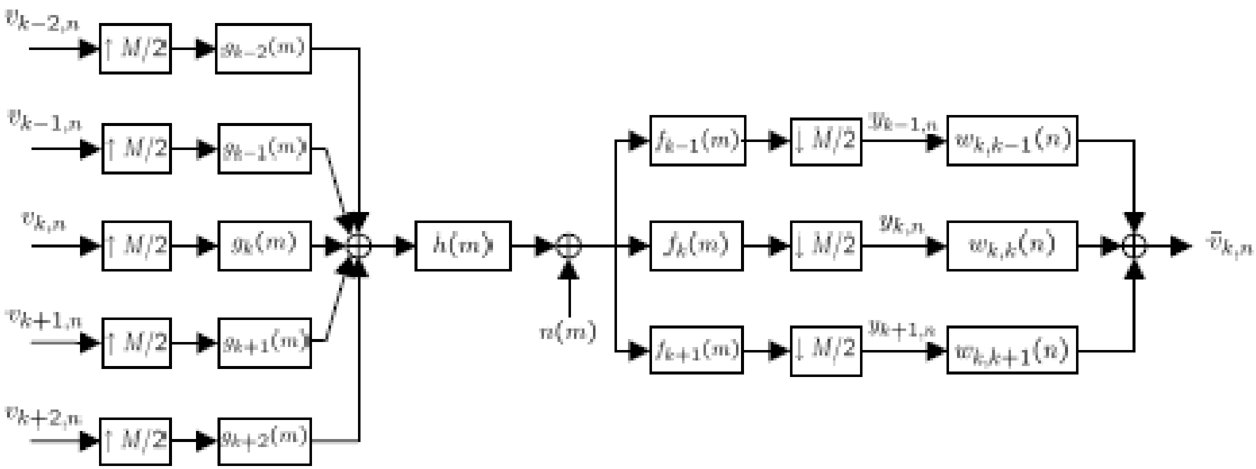


Frequency sampling



MMSE Criterion

- **Derivation of MMSE equalizer**
  - Assumes perfect channel knowledge
  - Takes into account interference from adjacent subcarriers
  - Variations:
    - ➢ Simplified model with current subcarrier only
    - ➢ Multiple branches:

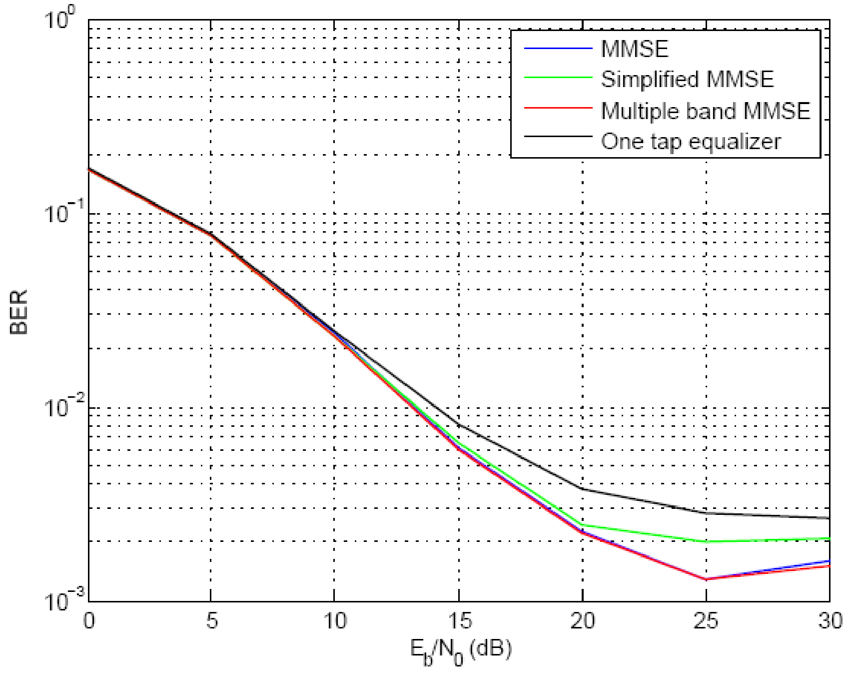


MMSE performance

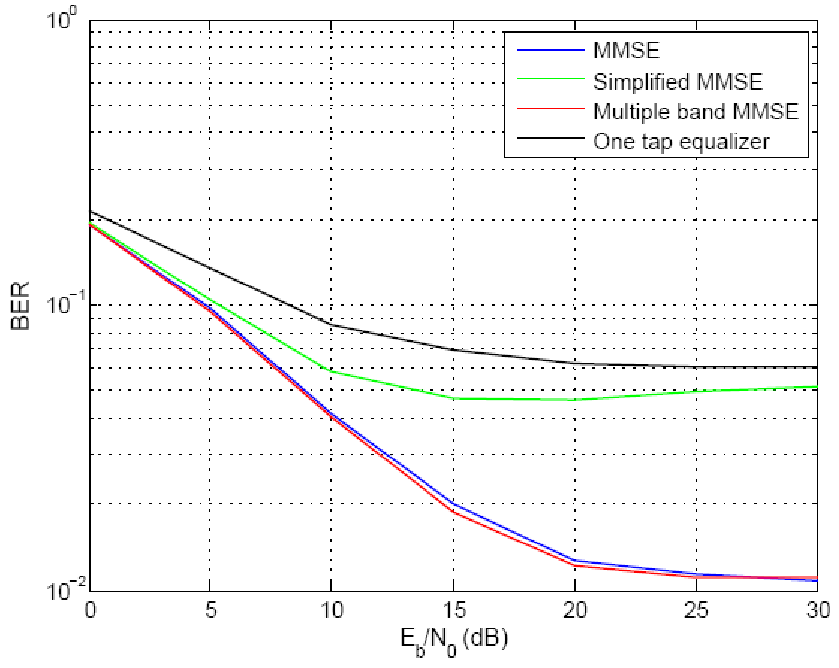
Performance comparison: depends on channel selectivity

Veh A, 16-QAM, 1 or 3-tap eq.

256 subc



64 subc

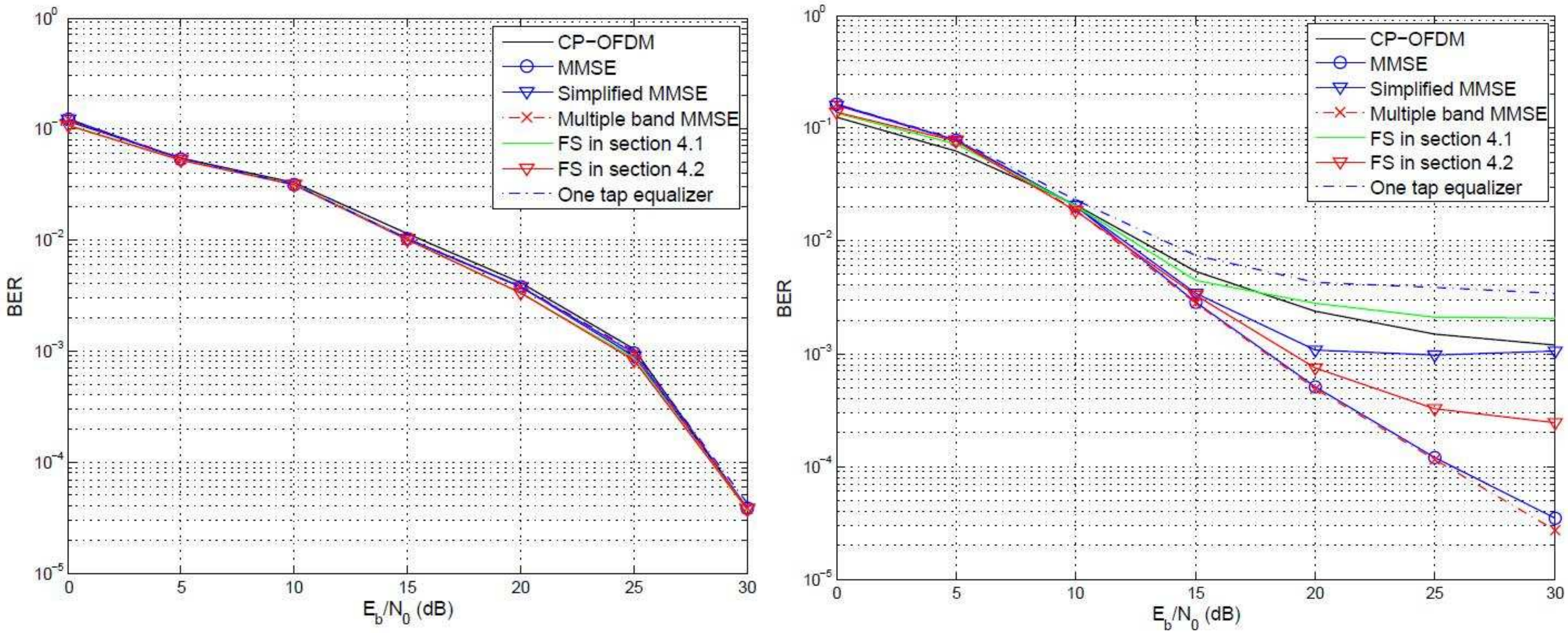


Performance comparison

Channel selectivity influences the choice of equalizer structure:

3 tap eq, 1024 subc, 16-QAM, CP length=128

Veh A Veh B



Two-stage Interference cancelation

1. MMSE equalizer

$$\overline{\mathbf{w}}_{k-MMSE} = \left[\sum_{i=k-1}^{k+1} \overline{\overline{\mathbf{Q}}}_i \overline{\overline{\mathbf{Q}}}_i^T + \mathbf{R}_{\mathbf{n},k} \right]^{-1} \overline{\overline{\mathbf{Q}}}_k \mathbf{e}_\delta$$

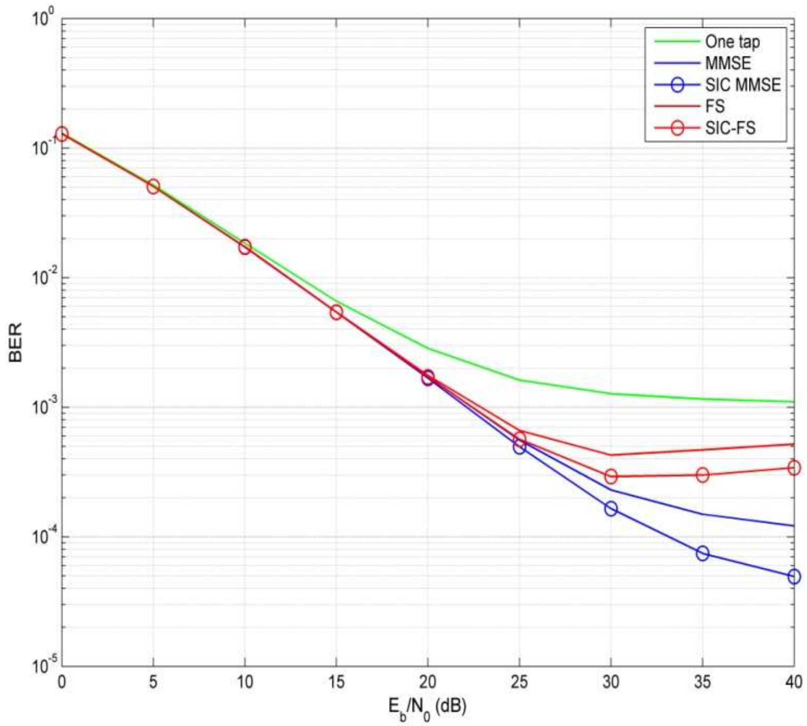
2. Enhanced (two-stage) MMSE equalizer

- **Stage 1:** Compute the MMSE equalizer
- **Stage 2:** Subtract the interference coming from the adjacent subcarrier using the result from stage 1.
- **Stage 3:** Compute a simplified MMSE equalizer, ignoring adjacent subcarriers

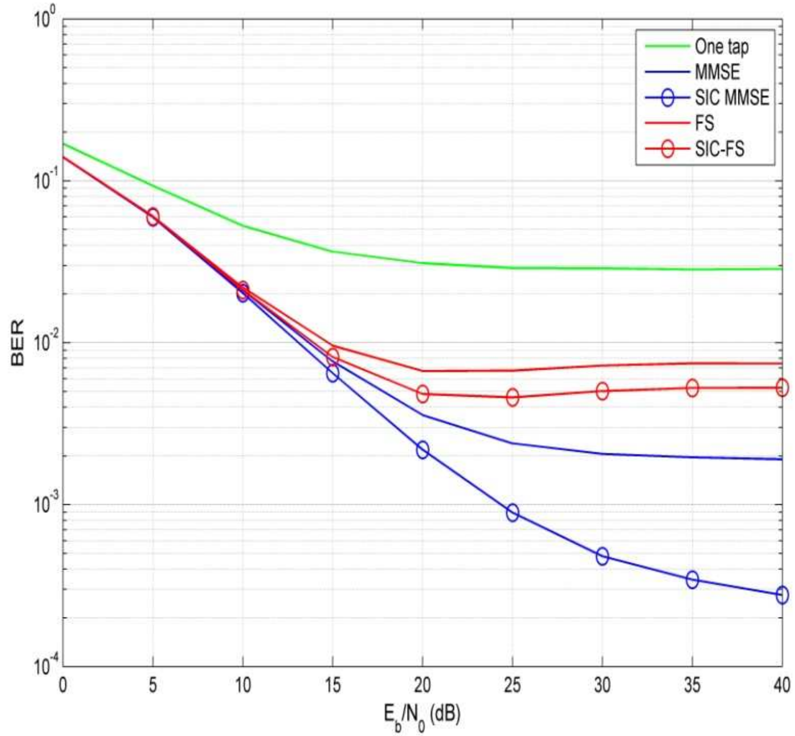
$$\overline{\mathbf{w}}_{k-MMSE} = \left[\overline{\overline{\mathbf{Q}}}_k \overline{\overline{\mathbf{Q}}}_k^T + \mathbf{R}_{\mathbf{n},k} \right]^{-1} \overline{\overline{\mathbf{Q}}}_k \mathbf{e}_\delta$$

TS-IC: Results

Simulation parameters: M=64 carriers, overlapping factor K=4, 16-QAM modulation. Random channels with flat PDP. 200 independent realizations. 3-tap equalizers.



channel length ν+1=5



channel length ν+1=20

TS-SIC: comments

- Can be based on any equalizer (ex TS-FS or TS-MMSE)
- Requires two equalizer computations instead of one
- Requires computation of interference coefficients
  - Based on channel estimation
- Shows MMSE cannot remove all interference (for 3-tap equalizer)

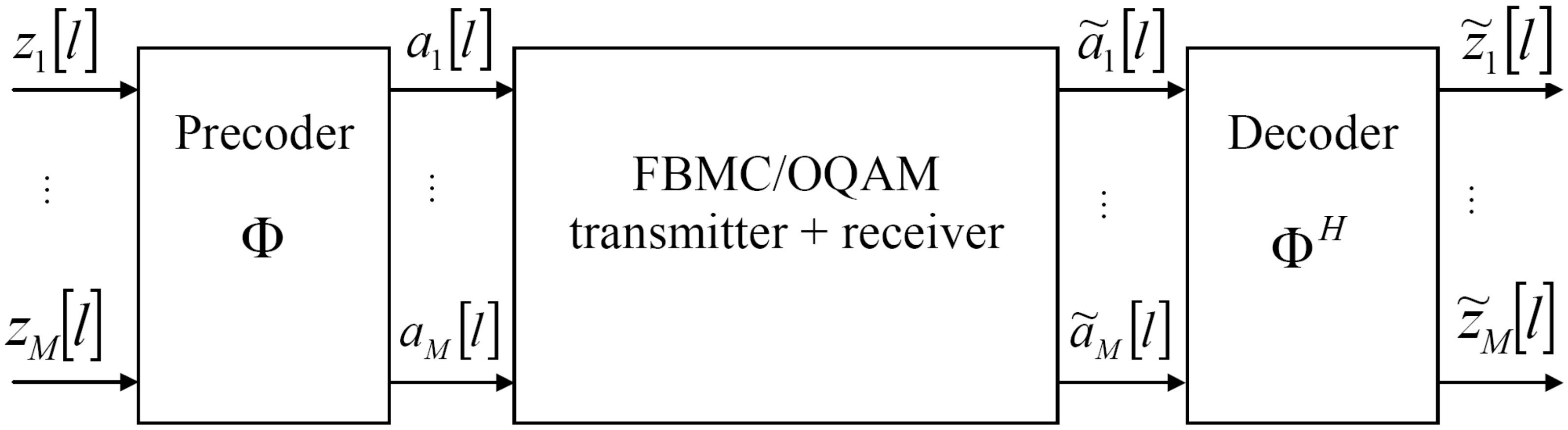
Comparison of equalizers

- 1-tap sufficient for short channels and low SNR
  - Assuming large number of subcarriers
- Frequency sampling provides efficient multiple-taps equalization
  - Allows correction of timing
  - Useful in mildly frequency selective environment
- MMSE
  - For more selective channels
  - To reach higher SNRs
- Other methods exist for even harder environments

Transmitter optimization: precoding

- Precoding across frequencies
- Benefits from frequency diversity
- Replaces use of frequency coding, without adding redundancy
- NOT useful if Bit/Power allocation is used
- Simple to implement
- Similarity with CP-Single carrier

Precoding scheme



- Unitary precoders
  - No effect on PSD
  - No correlation introduced
- Fixed matrix (no channel knowledge)
- Computation of per-subcarrier equalizers remains unchanged

Precoding computation

- ✓ Precoding

$$\mathbf{a}[l] = \mathbf{\Phi}\,\mathbf{z}[l]$$

- ✓ Example of precoders
  - Hadamard precoder

$$\Phi_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \quad \Phi_M[n] = \begin{bmatrix} \Phi_{M/2} & \Phi_{M/2} \\ \Phi_{M/2} & -\Phi_{M/2} \end{bmatrix}$$

  - Vandermonde precoder

$$\Phi = \frac{1}{\kappa}\begin{bmatrix} 1 & \beta_1 & \cdots & \beta_1^{M-1} \\ 1 & \beta_2 & \cdots & \beta_2^{M-1} \\ \vdots & \vdots & \vdots & \vdots \\ 1 & \beta_M & \cdots & \beta_M^{M-1} \end{bmatrix}$$

for $\beta_i = \exp(-j2\pi i / M)$

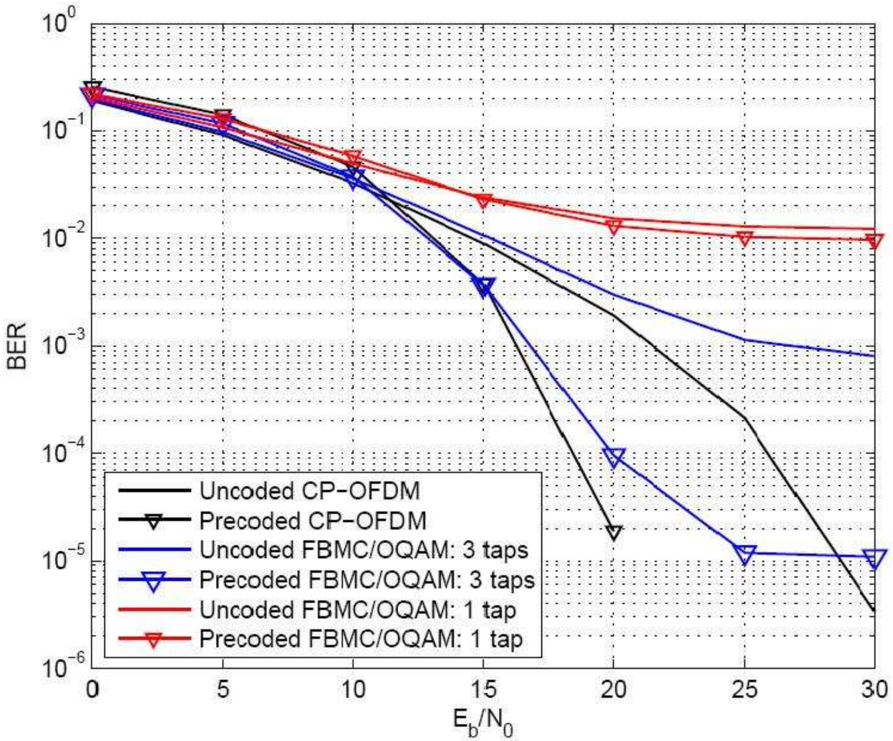
Φ is Fourier matrix

- ✓ Decoding

$$\tilde{\mathbf{z}}[l] = \mathbf{\Phi}^H\,\tilde{\mathbf{a}}[l]$$

Precoding Results

Simulation parameters: M=64 carriers, overlapping factor K=4, 16-QAM modulation. Random channels with flat PDP. 500 independent realizations. 3-tap equalizers.



channel length $\nu+1=8$

Precoding: comments/conclusion

- Efficient for 3-tap equalizers
  - Interference limited with 1-tap equalizer
  - Similar gains to OFDM
- Effect of averaging the SINR on different subcarriers
- Interesting to avoid design of frequency coding
- Prevents per-subcarrier DD schemes
- Can be done on subset of subcarriers