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Robust Transmission over Fast Fading Channels on the Basis of OFDM-MFSK

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Outline

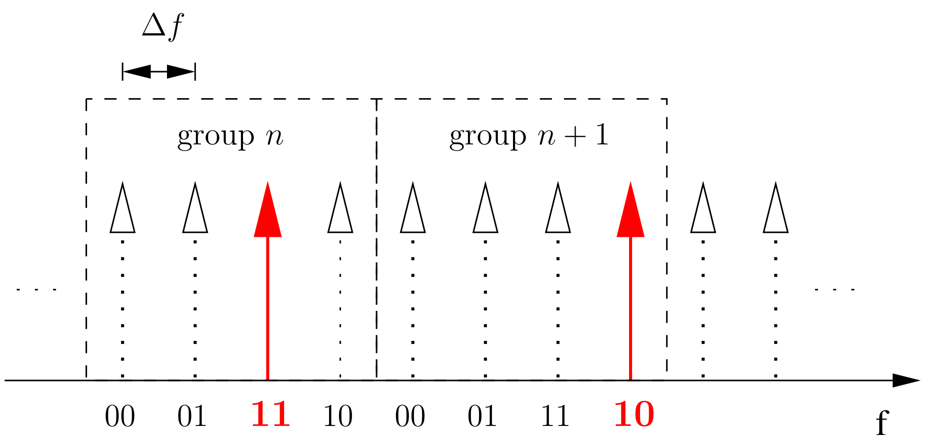
- Motivation
- A Robust Transmission Scheme – OFDM-MFSK
- Increasing the Bandwidth Efficiency using Hybrid Modulation
- BER Simulation Results
- The PAPR Problem
- PAPR Reduction Methods
- Conclusions

Motivation

- Scenario: Communication with high speed trains
- Speed up to 600 km/h causes fast changing channels
- Channel estimation is very difficult
- Security relevant control data requires robust transmission
- Additional services for passengers like internet access require high data rates
- FSK schemes are very robust and are currently in use

Goal: Robust transmission scheme based on OFDM with high data rate

A Robust Transmission Scheme – OFDM-MFSK



- Subcarriers are grouped into groups of M and MFSK modulation is applied to each group
- Alternative: Multitone FSK (N out of M subcarriers occupied)
- No CSI is needed for noncoherent detection
- Very robust against time variant channels
- Low bandwidth efficiency (uncoded OFDM-4FSK: 0.5 bit/subcarrier)

A Robust Transmission Scheme – OFDM-MFSK

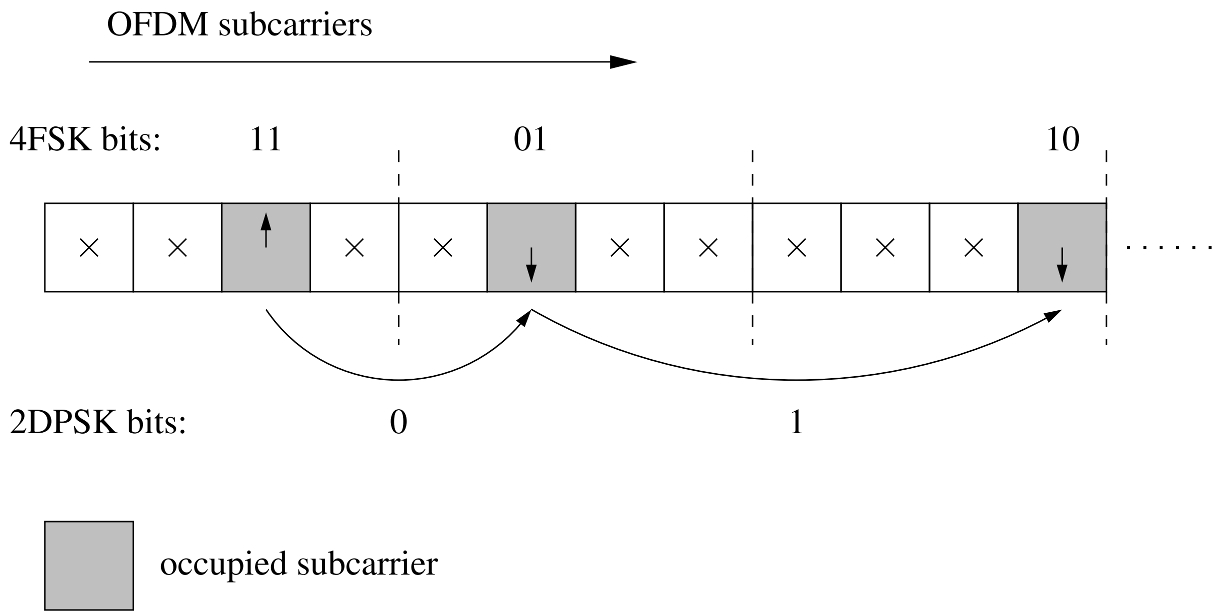
Noncoherent detection

- Subcarrier phase of transmit symbols is arbitrary

This degree of freedom can be exploited

- Use phases to increase bandwidth efficiency by transmitting additional data
- Phases can be used for PAPR reduction
- Noncoherent detection of OFDM-MFSK is not influenced

Hybrid Modulation Scheme



- Additional differential encoding of phases of occupied subcarriers
- Encoding in frequency or time direction
- Noncoherent detection, no CSI needed

Channel Coding

- Separate encoding of MFSK and DPSK component
- Detection and decoding of MFSK component first to determine occupied subcarriers
- Afterwards detection and decoding of DPSK component

Advantages:

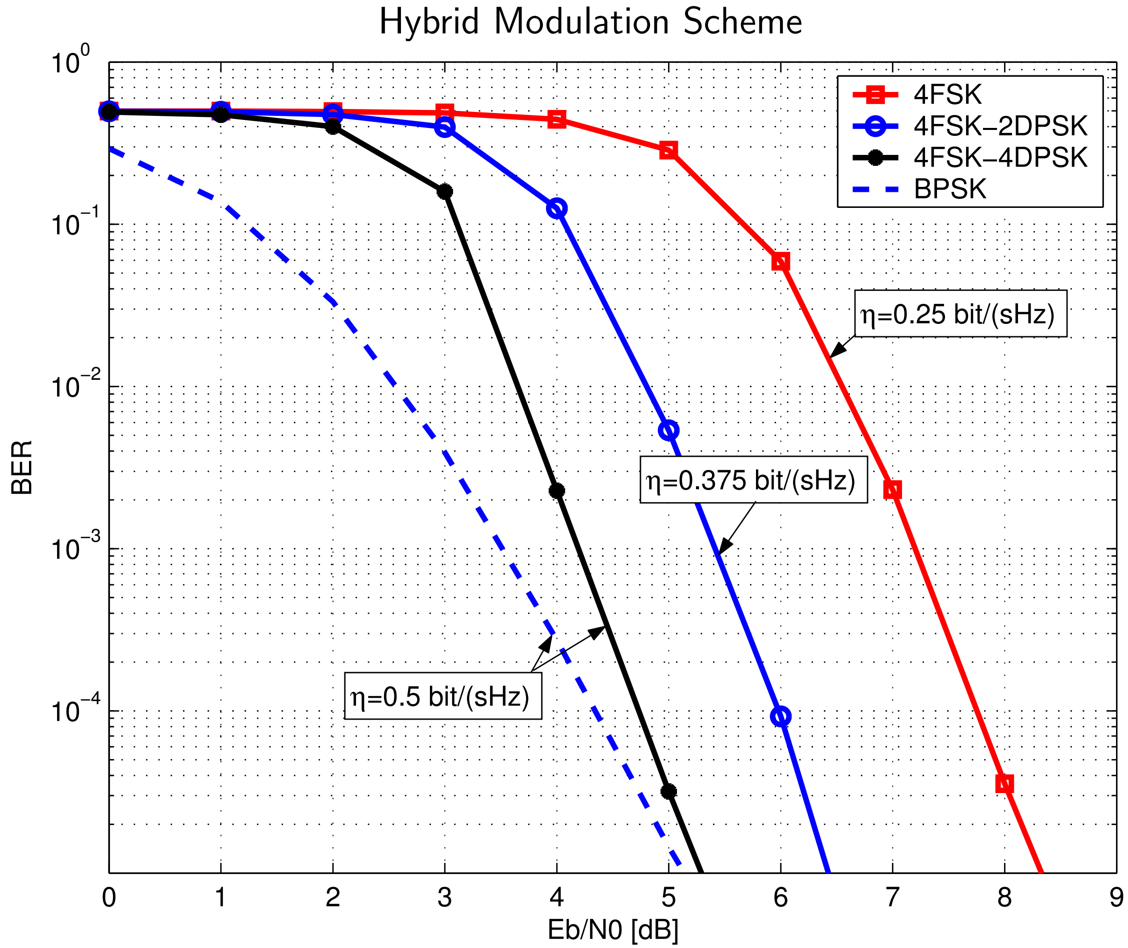
- Different level of protection for both components using different codes
- Coded OFDM-MFSK transmission is not affected by DPSK component

Convolutional code: rate 1/2, memory 6, generator polynomial [133,171],
soft decision detection

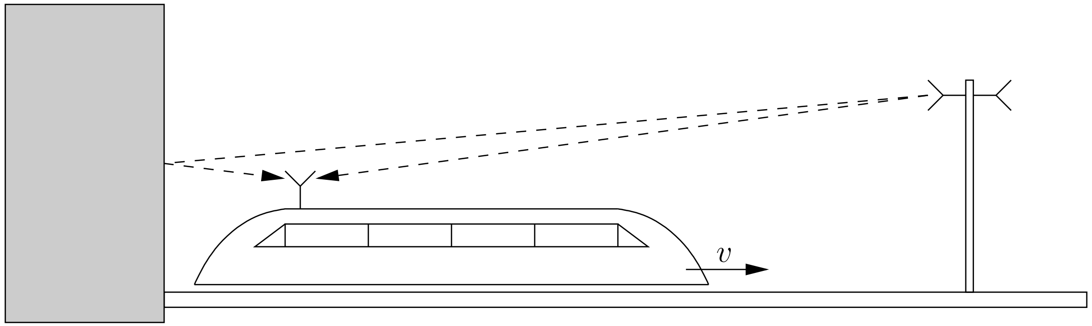
Simulation Results – AWGN

Overall BER for coded transmission:

- Separate coding for 4FSK and DPSK component using the same convolutional code
- BER is dominated by 4FSK errors for AWGN
- Codes can be adapted



Worst Case Channel Model



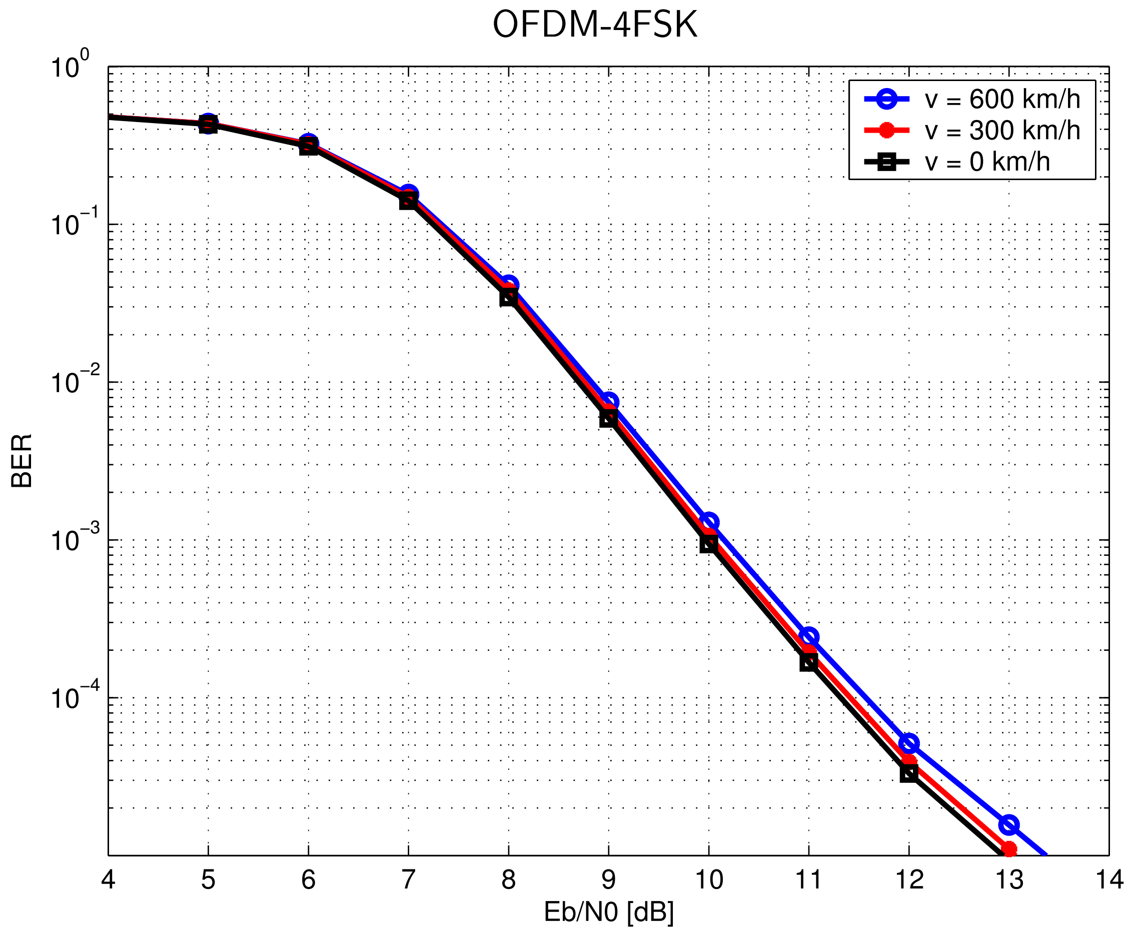
- Reflection at tunnel entrance or bridge
- Two paths with equal attenuation
- Maximum Doppler spread $2f_d = 2f_c\frac{v}{c}$ due to opposite direction of arrival

carrier frequency	$f_c = 38$ GHz	subcarrier separation	$\Delta f = 312.5$ kHz
FFT length	$N_f = 256$	cyclic extension	$T_g = N_g \Delta t = 0.8\,\mu$s
no. of used subcarriers	$N_{f\text{used}} = 160$	symbol duration	$T_s = (N_g + N_f)\,\Delta t = 4\,\mu$s

Simulation Results

BER for coded OFDM-4FSK:

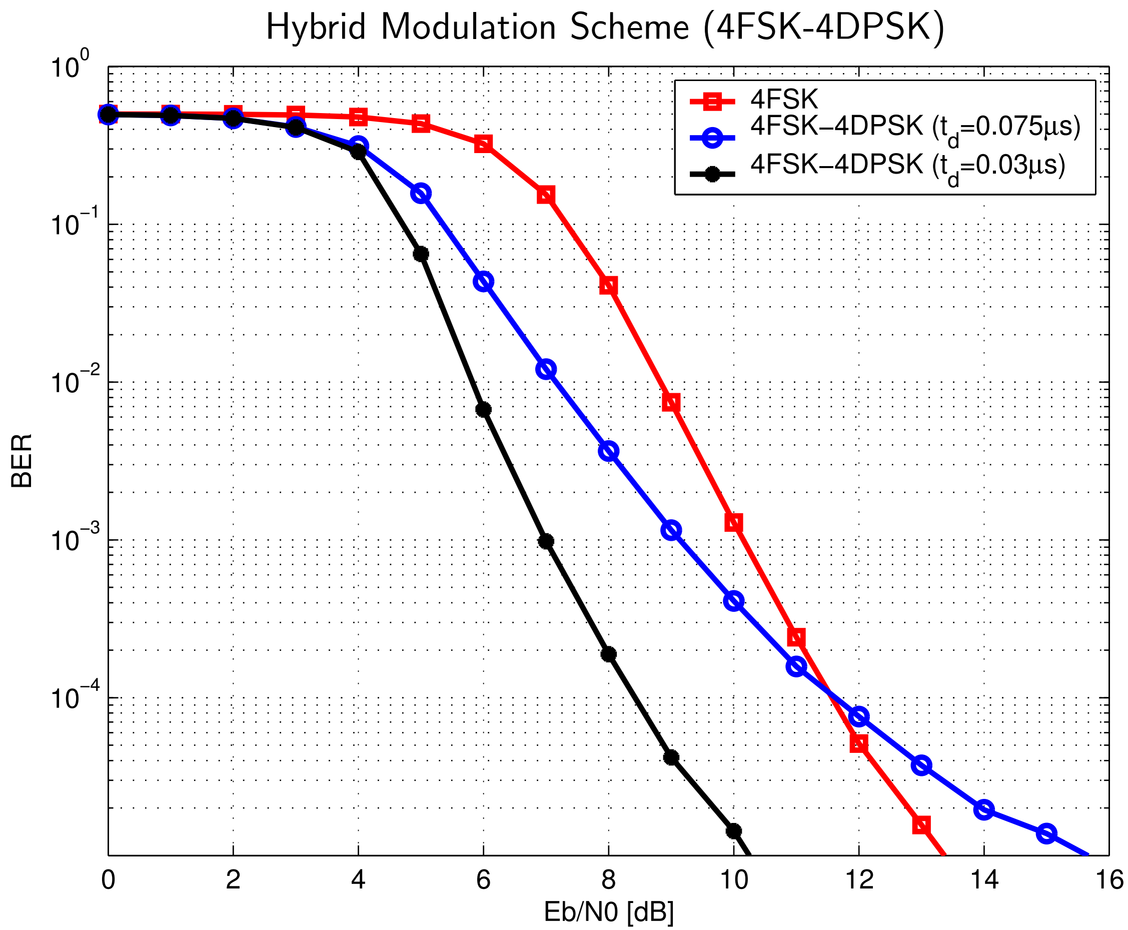
- Path delay $t_d = 0.75\,\mu s$
- Strong frequency selectivity
- Very robust against frequency selectivity
- Very robust against high velocity



Simulation Results

Overall BER for coded transmission:

- DPSK component encoded in frequency direction
- Speed $v = 600\,km/h$
- Very robust against high velocity
- DPSK component very sensitive against frequency selectivity (large distance between used subcarriers)



The PAPR Problem

Definition of the PAPR:

$$PAPR = \frac{\left(\max_t |s(t)|\right)^2}{\frac{1}{T_S}\int_0^{T_s} |s(t)|^2 dt}$$

- Unfavourable superposition of subcarriers in OFDM may lead to high PAPR
- Problem: Transmit amplifier has saturation limit
  - ✘ Nonlinear distortion (out of band radiation)
  - ✘ High backoff necessary (amplifier inefficient)
- Noncoherently detected OFDM-MFSK:
  - ✘ Subcarrier phases can be chosen arbitrarily so that PAPR is reduced
  - ✘ No side information necessary

The PAPR Problem

Goal: Find optimum subcarrier phases for each OFDM symbol, so that PAPR is minimum

Problem: $N = 256$ and OFDM-4FSK:

- 2^{128} possible OFDM symbols
- 2^{64} possibilities to assign the phase if only two phases for each subcarrier are considered

⇒Exhaustive search is impossible

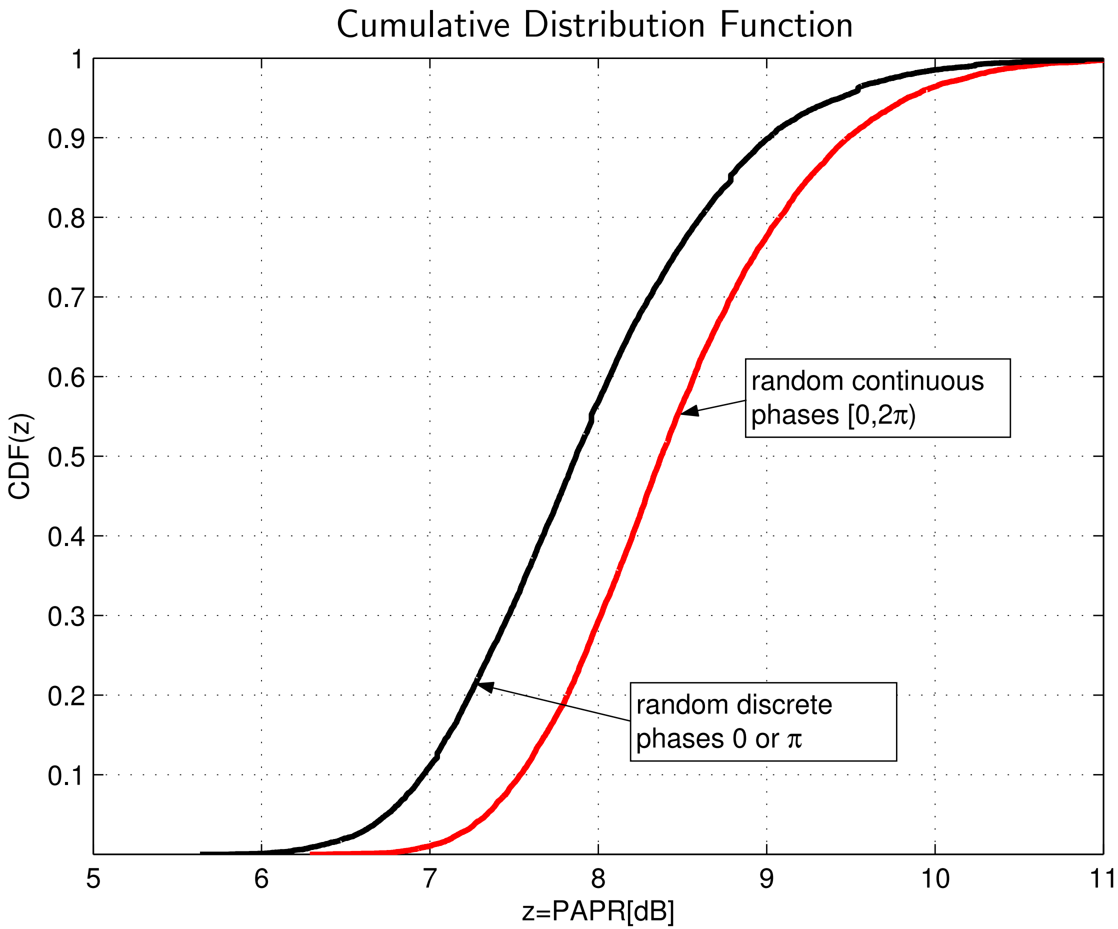
Worst case: All subcarrier phases are the same

- Subcarriers add coherently
- PAPR $= \frac{N}{M} = \frac{256}{4} = 18\,$dB

PAPR Distribution – Random Phases

First Approach:

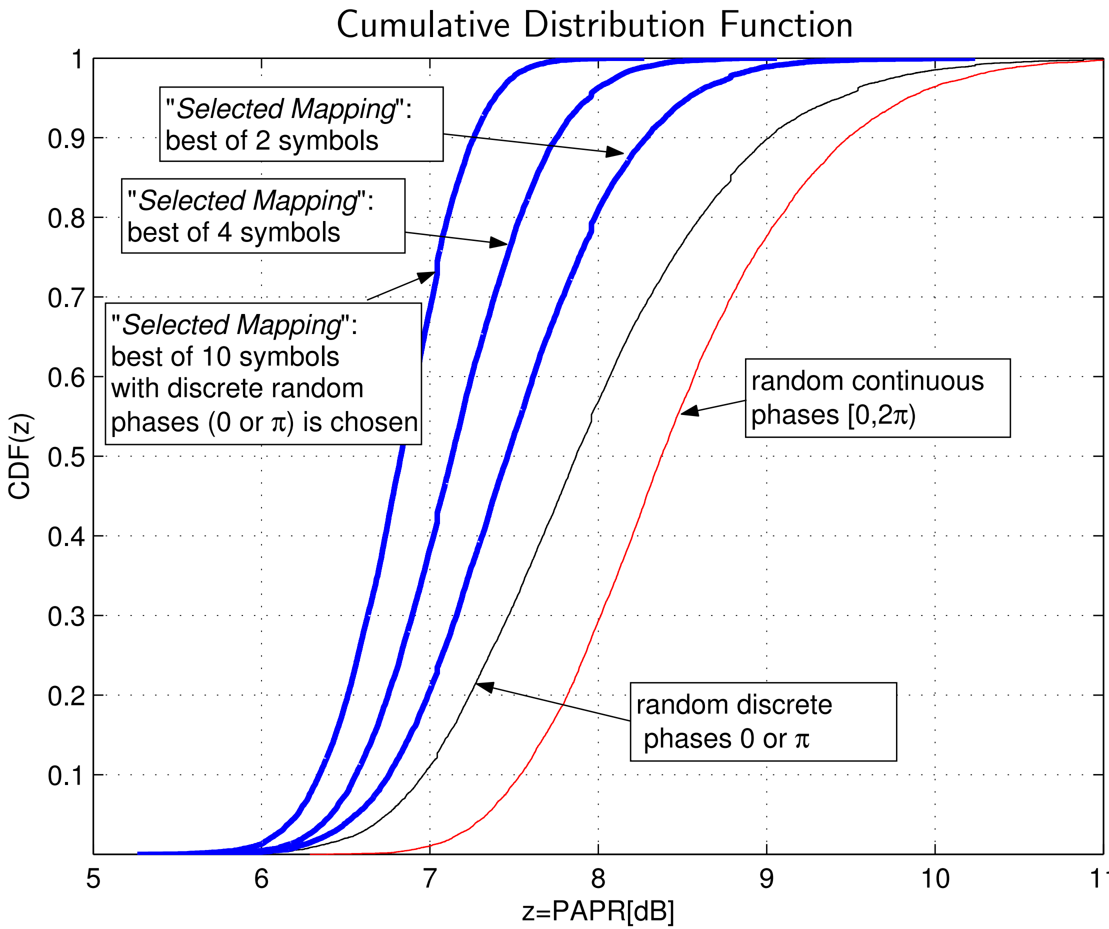
- Use random phases
- Allow only binary phases
- No additional complexity



PAPR Distribution - Selected Mapping

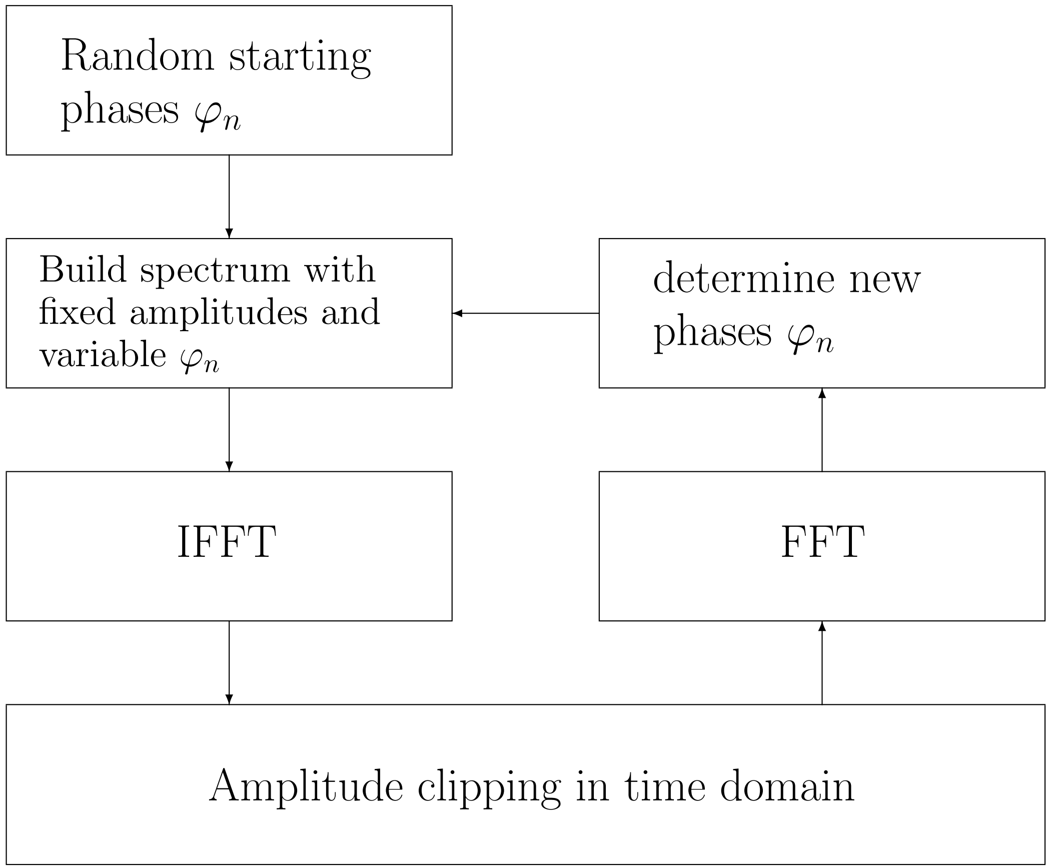
Selected Mapping:

- Introduced by Bäuml, Huber and Fischer ('96)
- Assign random phases to each symbol several times
- Select OFDM symbol with lowest PAPR for transmission
- For noncoherently detected OFDM-MFSK no side information is needed



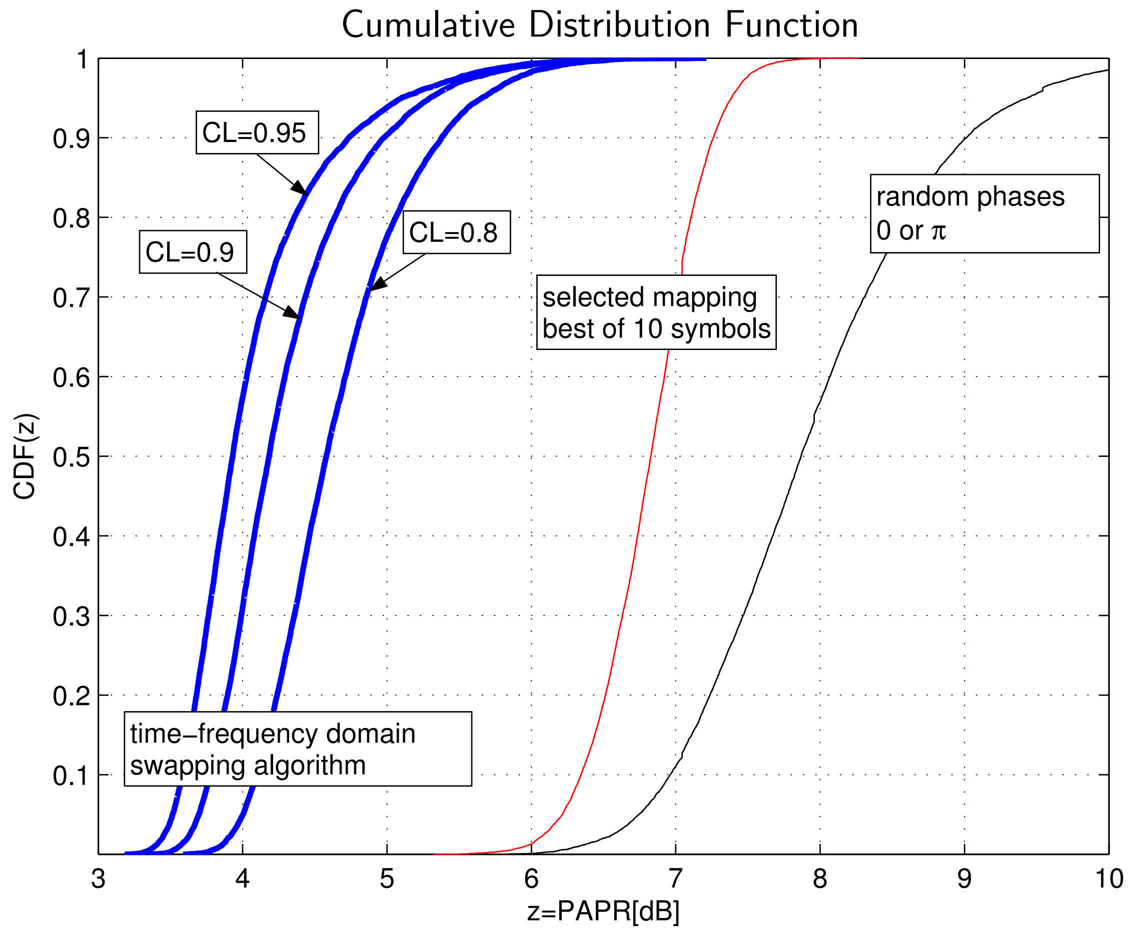
Time-Frequency Domain Swapping

- Introduced by Ouderaa et al. ('88)
- Swapping between time and frequency domain
- Iterative reduction of PAPR
- Stop when PAPR is not decreasing any more
- Parameter: time domain clipping level CL



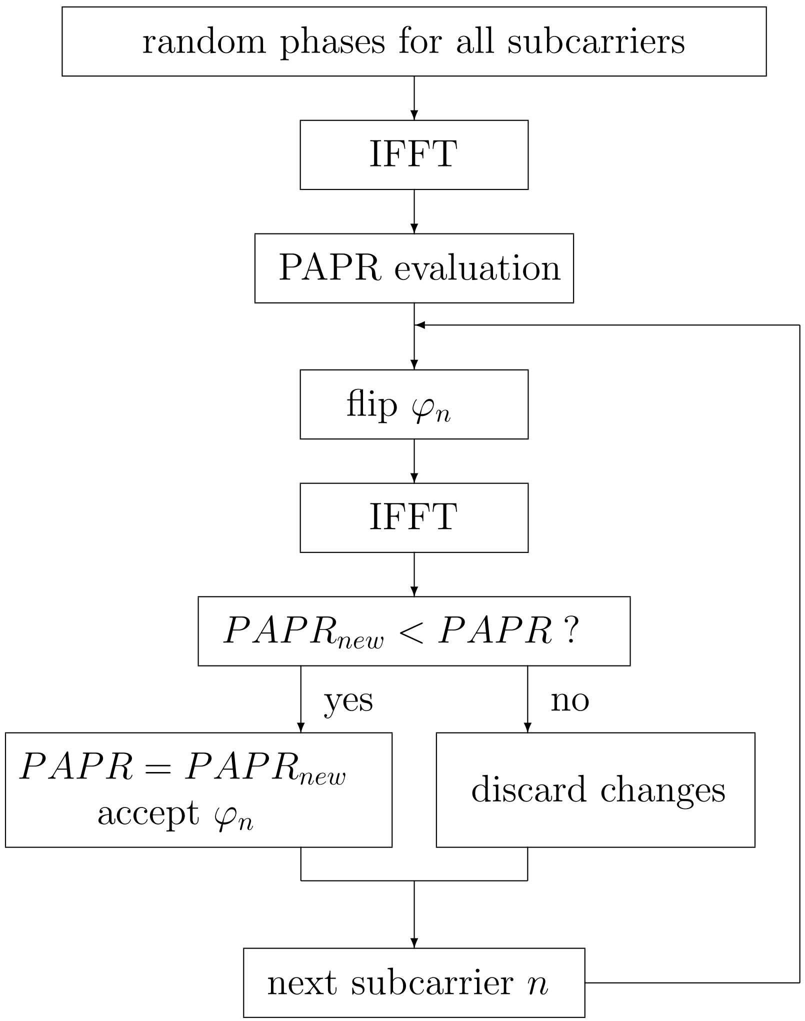
PAPR Distribution - Swapping Algorithm

- Good performance
- Very high complexity: up to several hundred iterations per symbol



Sequential Algorithm

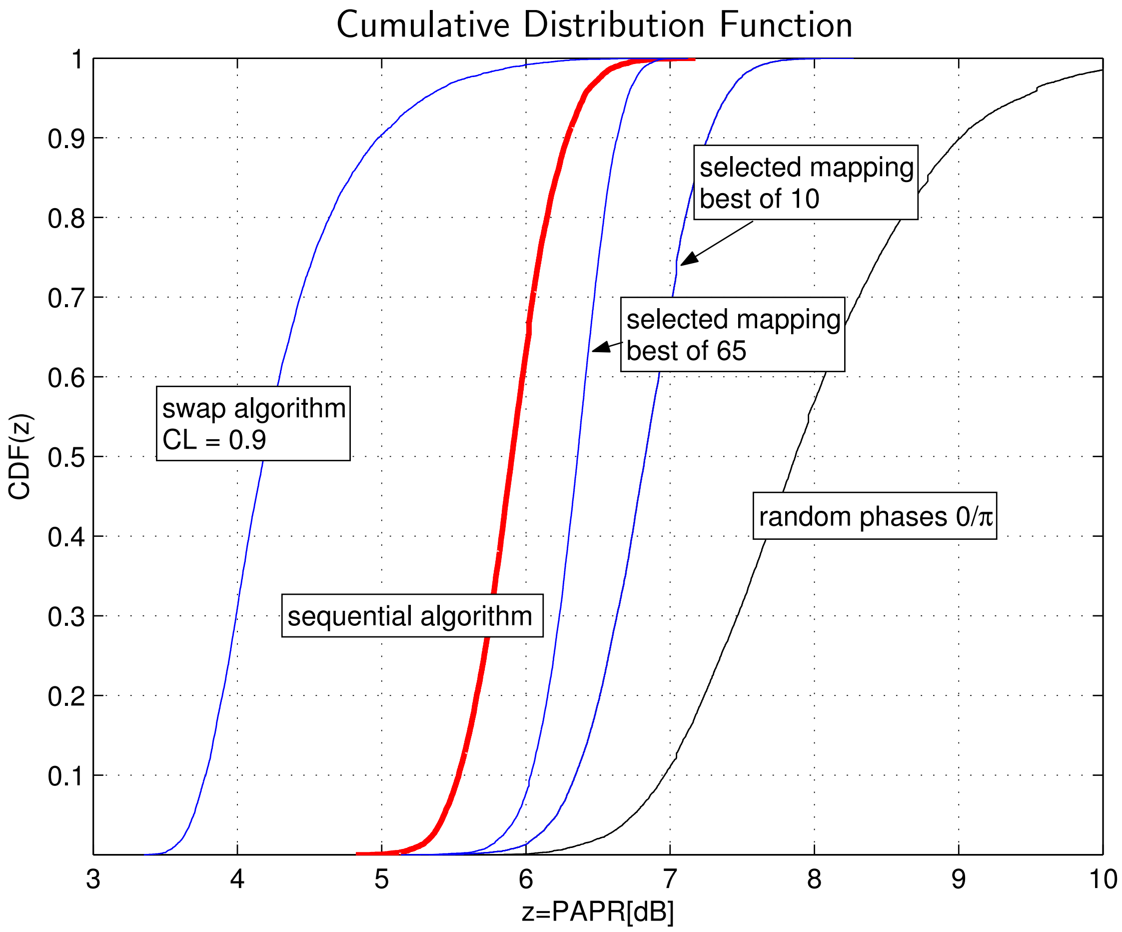
- Subcarrier phases are systematically changed to reduce PAPR
- Subcarrier phases are flipped sequentially
- Complexity: one extra IFFT per occupied subcarrier
- Complexity can be reduced by exploiting linearity of DFT



PAPR Distribution - Sequential Algorithm

- Better performance than selected mapping
- Lower complexity than swapping algorithm

Good complexity/performance tradeoff



Conclusions

- Noncoherently detected OFDM-MFSK is a robust transmission scheme in fast fading environments
- Subcarrier phases can be used for PAPR reduction or transmission of additional data
- Hybrid modulation does not affect the underlying MFSK transmission but offers additional data rate for moderate channels
- no CSI necessary
- PAPR reduction methods do not affect the noncoherent MFSK detection but reduce the PAPR
- In general: the better the performance of PAPR reduction methods the higher the complexity

CDF - QPSK vs. BPSK

Assumption:
all subcarriers occupied, QPSK modulation (or random phases $\varphi_n \in [0, 2\pi)$), no oversampling

All N_f time domain samples are Gaussian distributed and uncorrelated:

$$P(\mathrm{PAPR} \leq z) = CDF(z) = (1 - e^{-z})^{N_f} \quad (1)$$

On the other hand, if we allow only $\varphi_n \in \{0, \pi\}$, i.e. the OFDM symbols in the frequency domain are real-valued, some of the time domain samples will be correlated:

$$P(\mathrm{PAPR} \leq z) = (1 - \mathrm{erfc}\left(\sqrt{z/2}\right))^2 (1 - e^{-z})^{\frac{N_f - 2}{2}} \quad (2)$$