Broadband OFDM-FDMA System for the Uplink of a Wireless LAN

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Overview

- Motivation
  - OFDM Transmission Technique
  - Multiple Access Schemes for OFDM
  - OFDM-FDMA Uplink
- Peak-to-average ratio in OFDM communications
- DFT-spreading
  - Types of spreading matrices
  - Mapping scheme
  - Single user case
  - OFDM-FDMA
  - User data rate adaptation
- Summary

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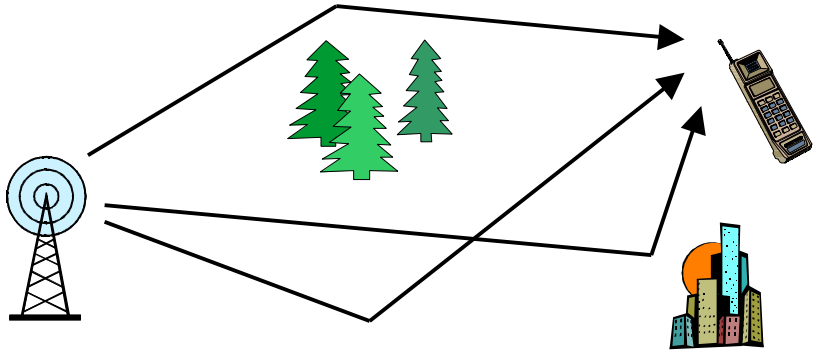
Properties of the OFDM Transmission Technique



Typical parameters of future WLANs

System bandwidth B	20 MHz
Sampling time T	50 ns
Max. multi-path delay τ_{max}	< 2 µs

Single Carrier:

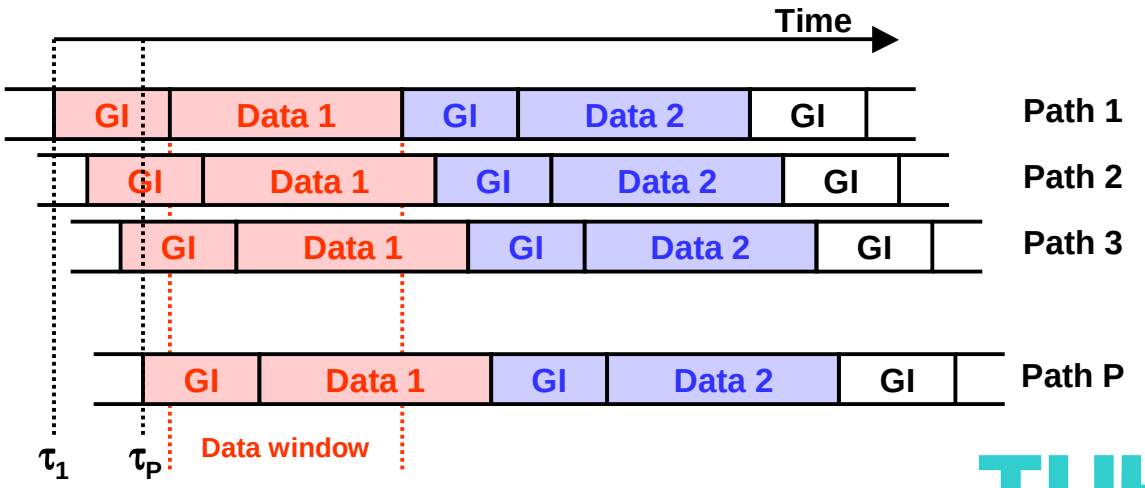
- Symbol duration mainly depends on data rate
- Symbol duration << Max. multi-path delay
- Inter symbol interferences (ISI) occur

High complexity equalizer required

Multi Carrier:

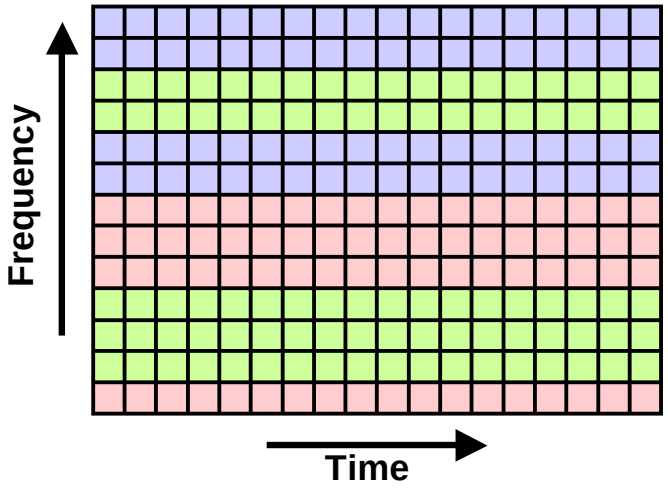
- Transmission on parallel, orthogonal subcarriers
- Symbol duration >> Max. multi-path delay
- No ISI and no ICI if guard interval is used

Simple one tap equalizer for each subcarrier



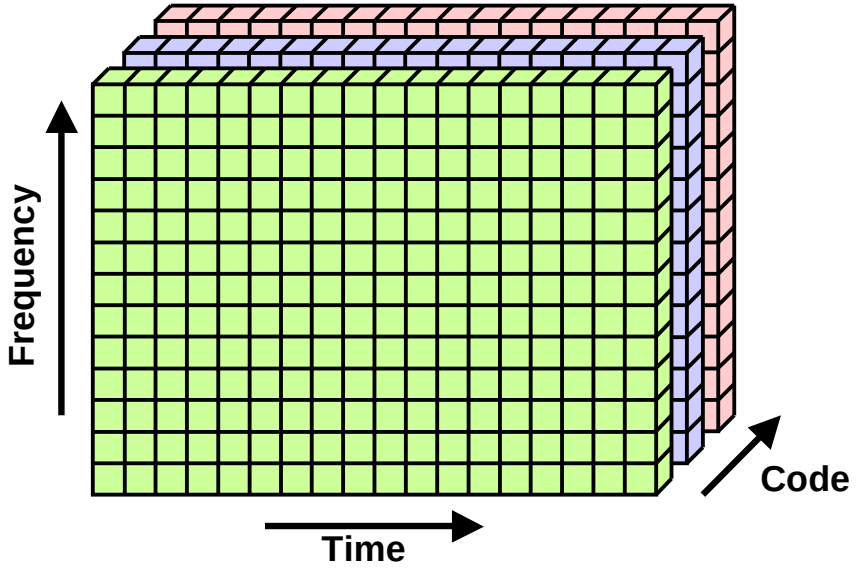
Advantages of OFDM Multiple Access Schemes

OFDM-FDMA



- No multiple access interferences
- Flexible resource allocation
- Channel adaptive

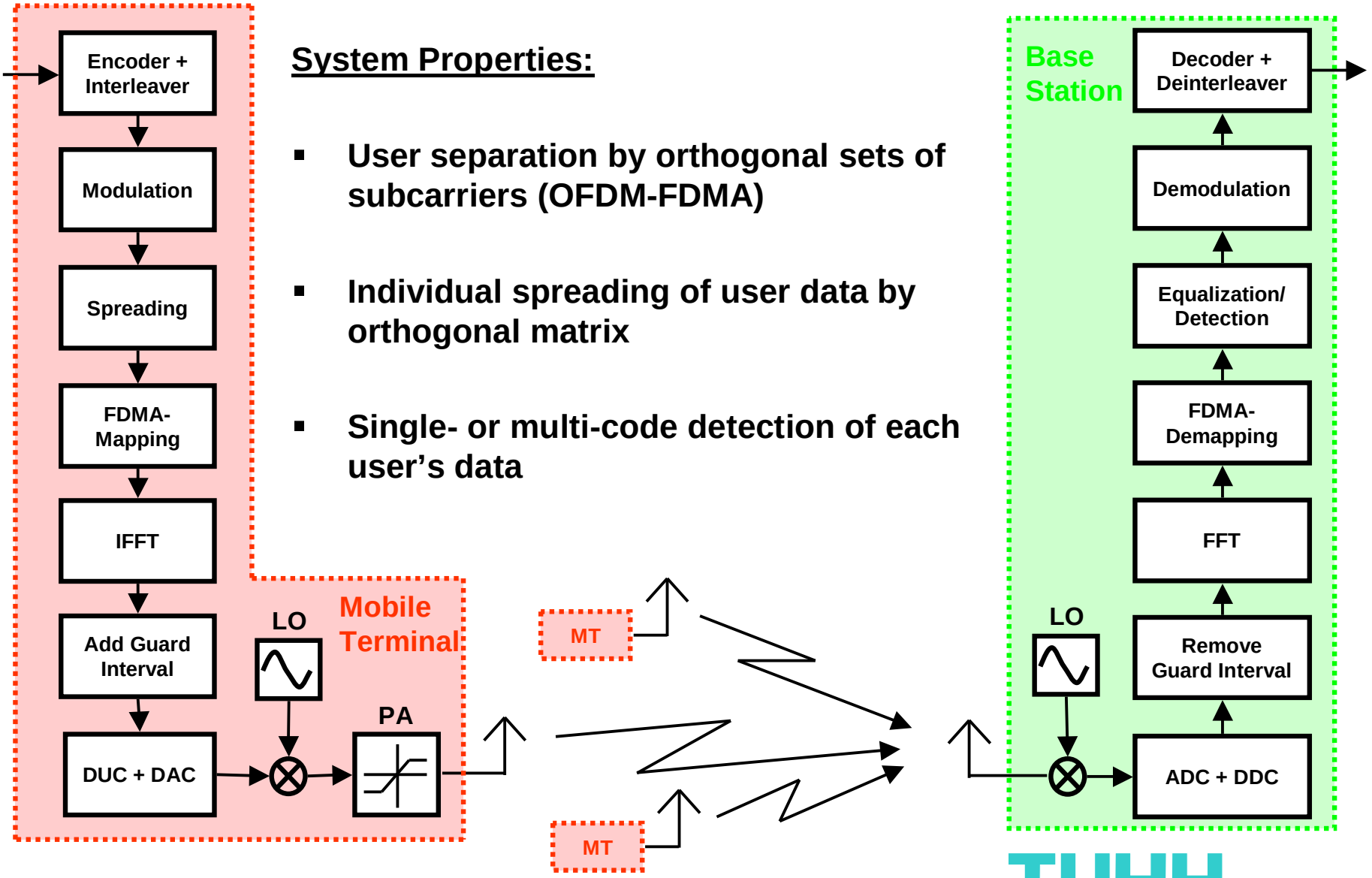
OFDM-CDMA



- Exploit frequency diversity
- Robust against interferences

Combine OFDM-FDMA with individual spreading of user data to profit from advantages of both concepts !

OFDM-FDMA Uplink System Structure

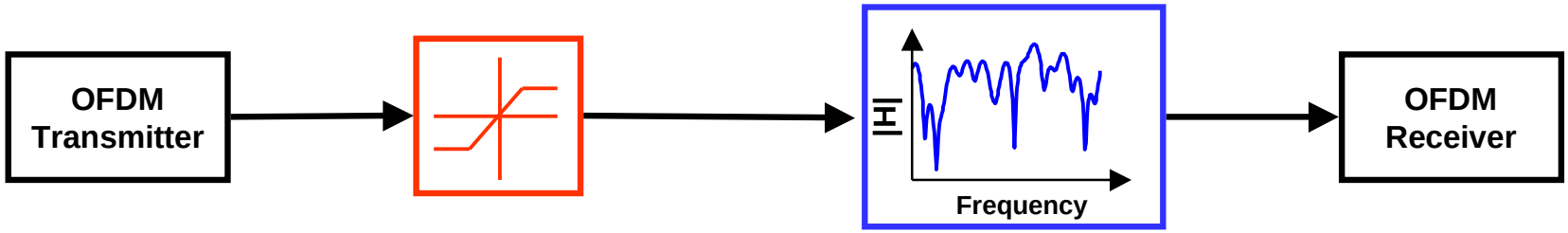


System Properties:

- User separation by orthogonal sets of subcarriers (OFDM-FDMA)
- Individual spreading of user data by orthogonal matrix
- Single- or multi-code detection of each user's data

Fundamental Questions in OFDM Systems

Two major questions in OFDM system design …



High power amplifier

Problem:

Non-linearity of the PA causes in- and out-of-band distortions

Possible solutions:

- Amplifier input backoff (IBO)
- Correction functions
- Adaptive mapping
- Optimised Coding

Frequency selective channel

Problem:

Large attenuation of a number of subcarriers causes flat fading BER

Possible solutions:

- Interleaving + Coding
- Spreading + Coding

… can be solved jointly by spreading with DFT matrices.

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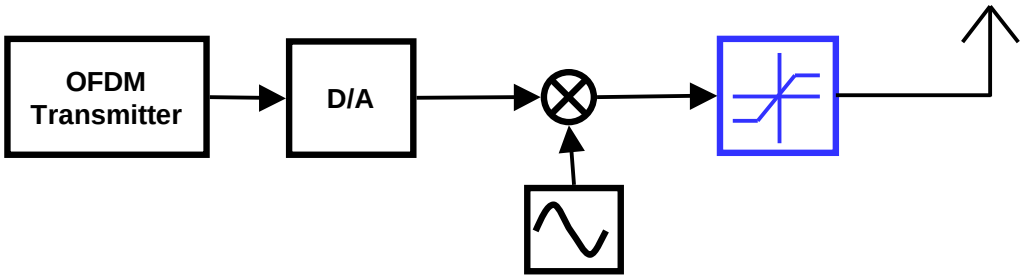
The Peak-to-Average Problem

Limited linear range of the power amplifier causes clipping



Input backoff:

$$IBO = 10 \cdot \log_{10} \frac{A_0^2}{P_S} [dB]$$

A_0 – **Maximum amplitude of amplifier**

P_S – **Input signal power**

Effects of clipping:

- **In-band distortion of the signal**

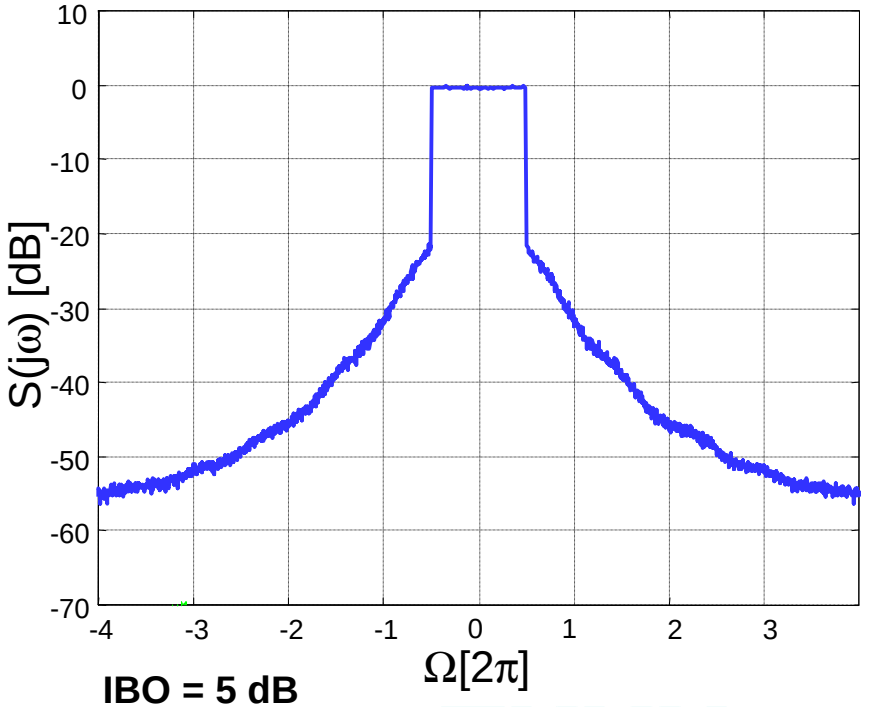
  Increased BER is a quality of service aspect and a selling argument

  Nobody will buy such a system !

- **Out-of-band emissions**

  Other services will be disturbed by the system

  Nobody will allow such a system !



IBO = 5 dB

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Selection of Spreading Matrices

Requirements on spreading matrices:

- **Orthogonal:**
  Separate data symbols of different users without interference

- **Orthonormal:**
  Spread symbol energy equally over the frequency band since the channel transfer function is unknown

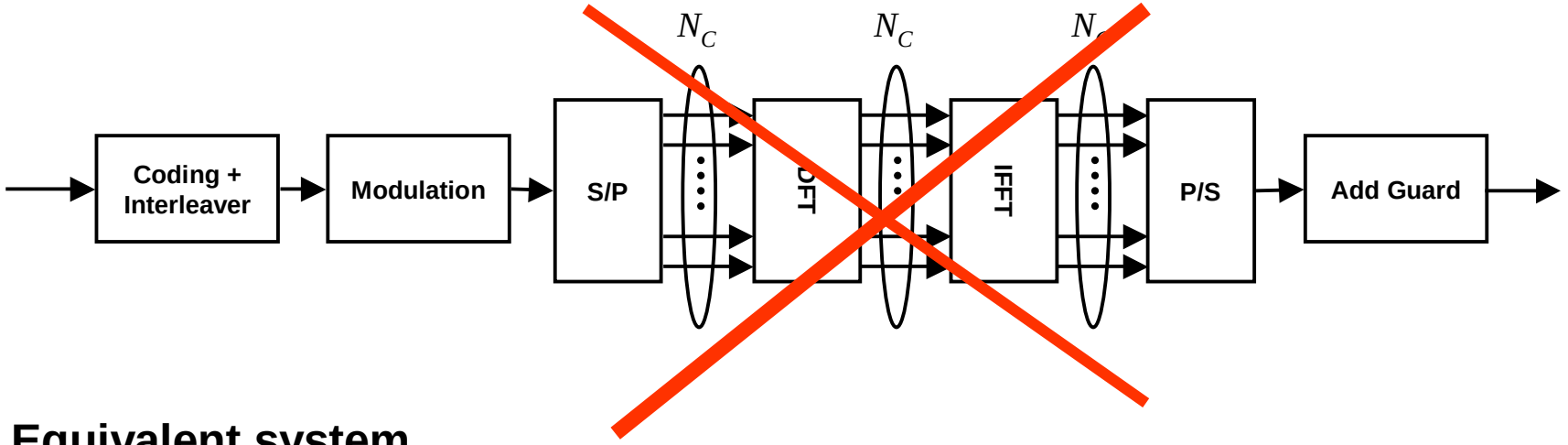
- **Unitary:**
  Preserve distance of code symbols after spreading

Possible spreading matrices with these properties:

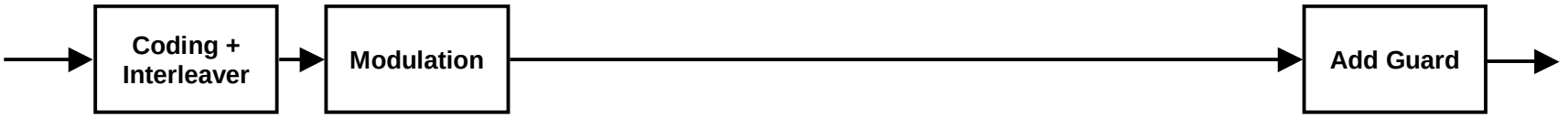
- **Walsh-Hadamard matrix (WH)**
- **Discrete Fourier transform matrix (DFT)**
- **…**

DFT-Spreading Single User Case

OFDM system with DFT spreading over all subcarriers



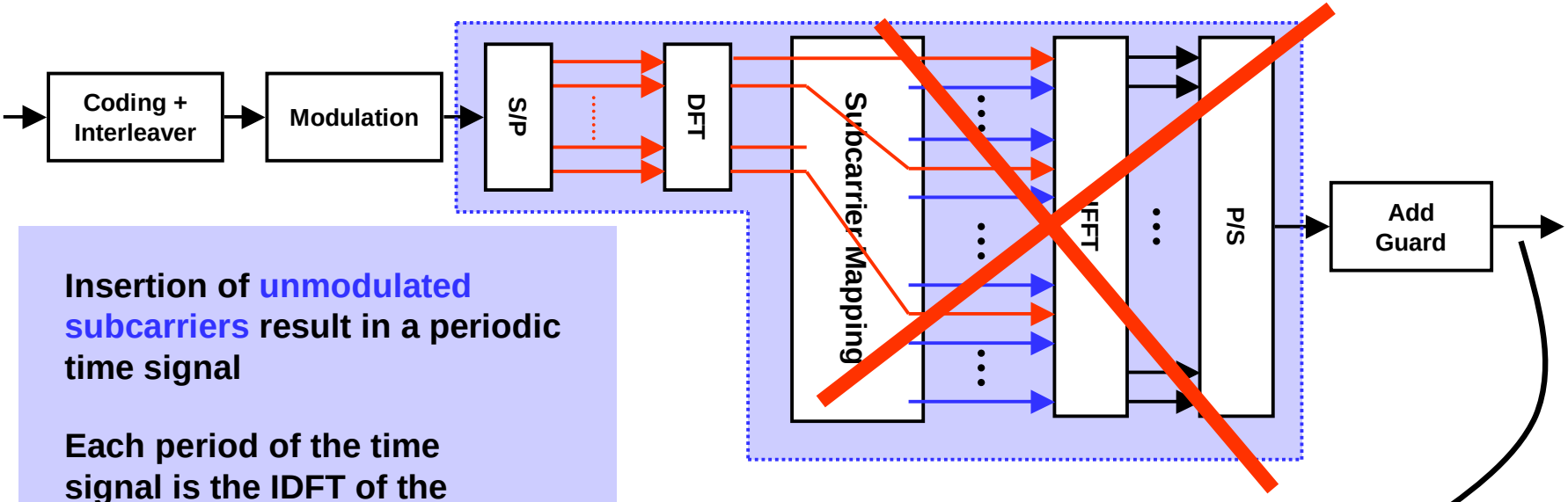
Equivalent system



An OFDM system with DFT spreading is equivalent to a single-carrier system with guard interval

OFDM-FDMA System with DFT-Spreading

DFT spreading can be used in the uplink of an OFDM-FDMA system

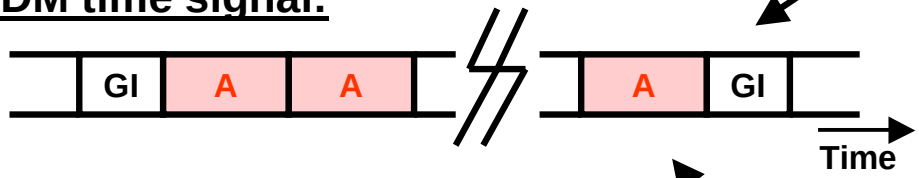


Insertion of unmodulated subcarriers result in a periodic time signal

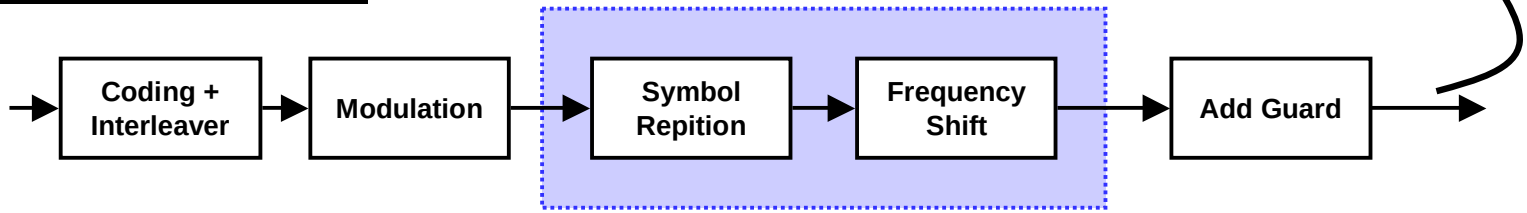
Each period of the time signal is the IDFT of the used subcarriers

The time signal is a repetition of the DFT spreading matrix input

OFDM time signal:

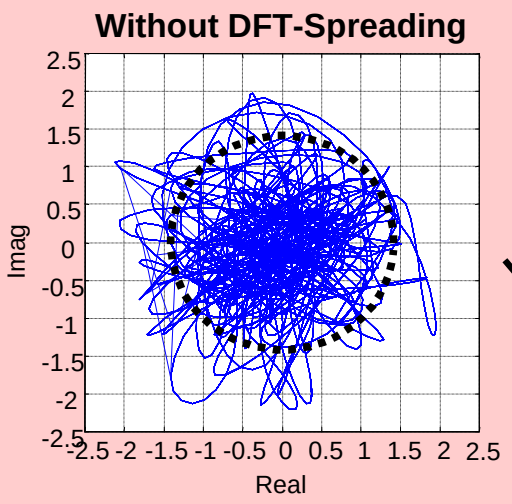


Equivalent system:



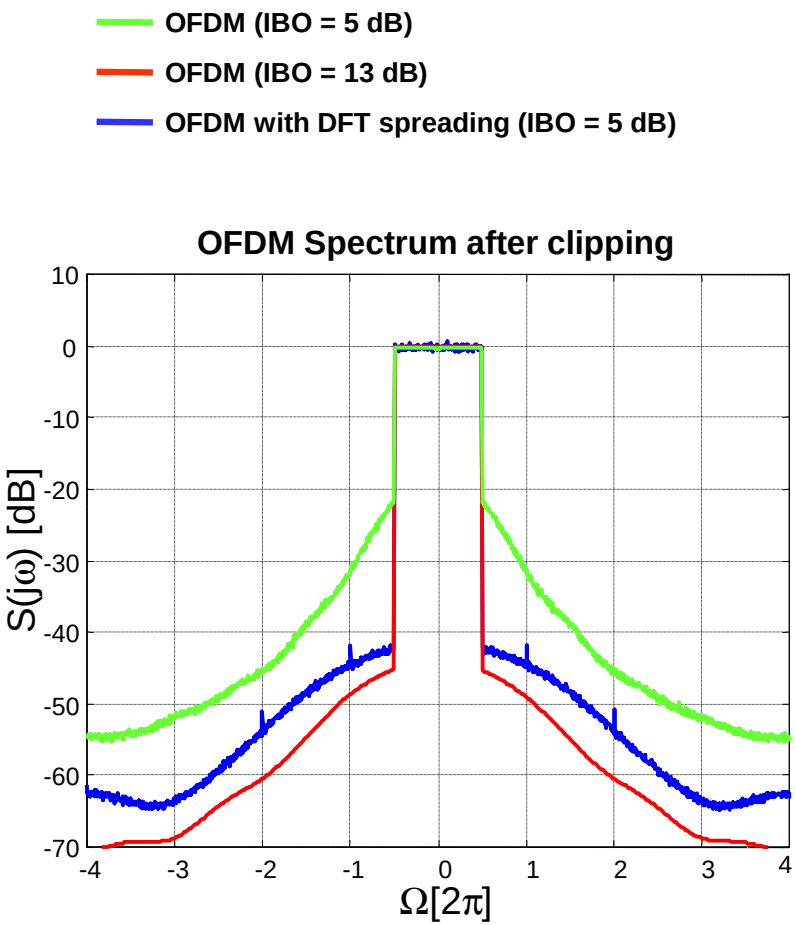
OFDM Spectrum

Signal envelope:



..... 3 dB level

PA



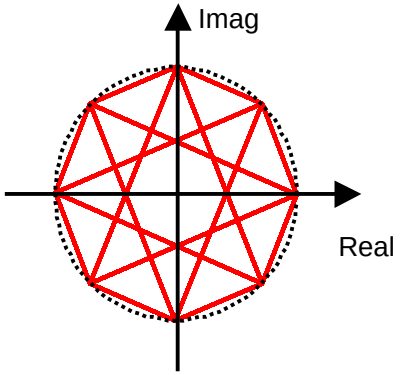
Result:

IBO can be reduced when DFT spreading is employed !

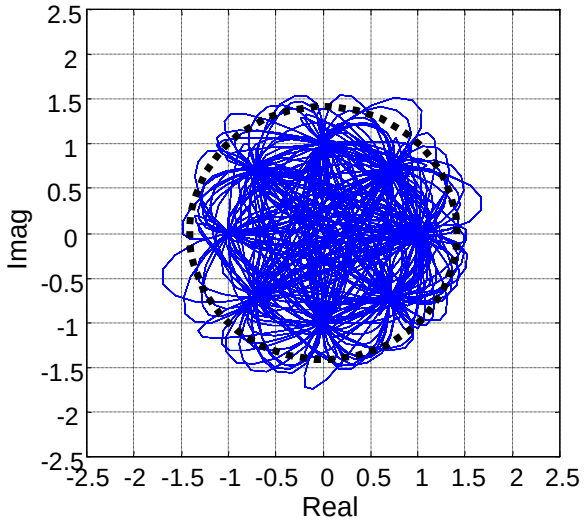
Use of π/4-QPSK for Subcarrier Modulation

Single carrier technique for PAR reduction:

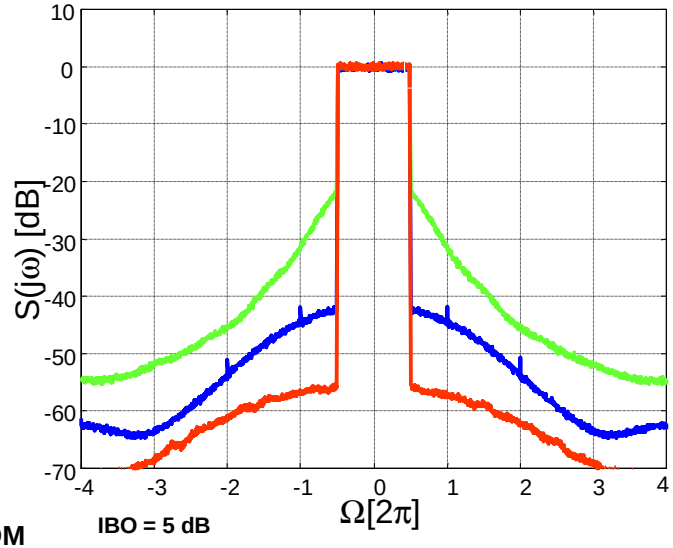
$$S_n = S_{n-1} \cdot e^{j\phi_n} \quad \phi_n \in \{\pm\frac{\pi}{4}, \pm\frac{3\pi}{4}\}$$



OFDM with DFT spreading and π/4-QPSK subcarrier modulation:



PA



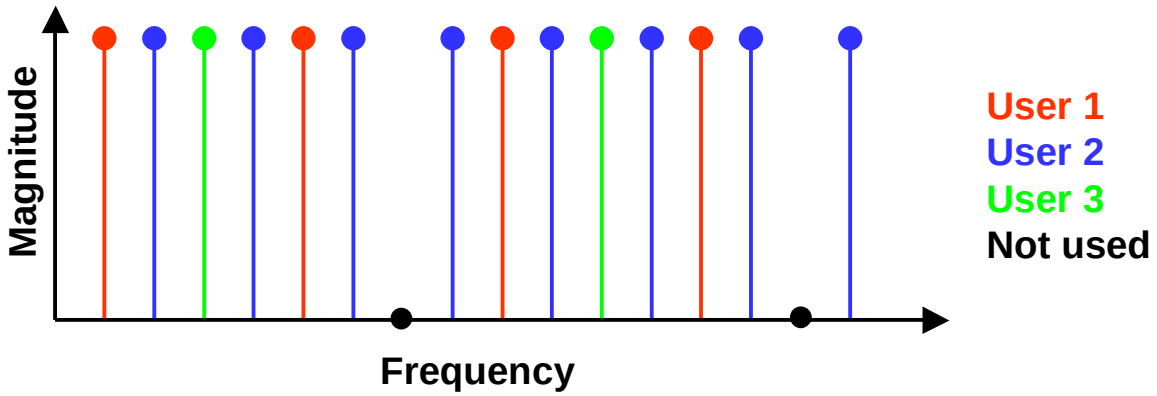
IBO = 5 dB

OFDM
OFDM (DFT)
OFDM (DFT,π/4-QPSK)

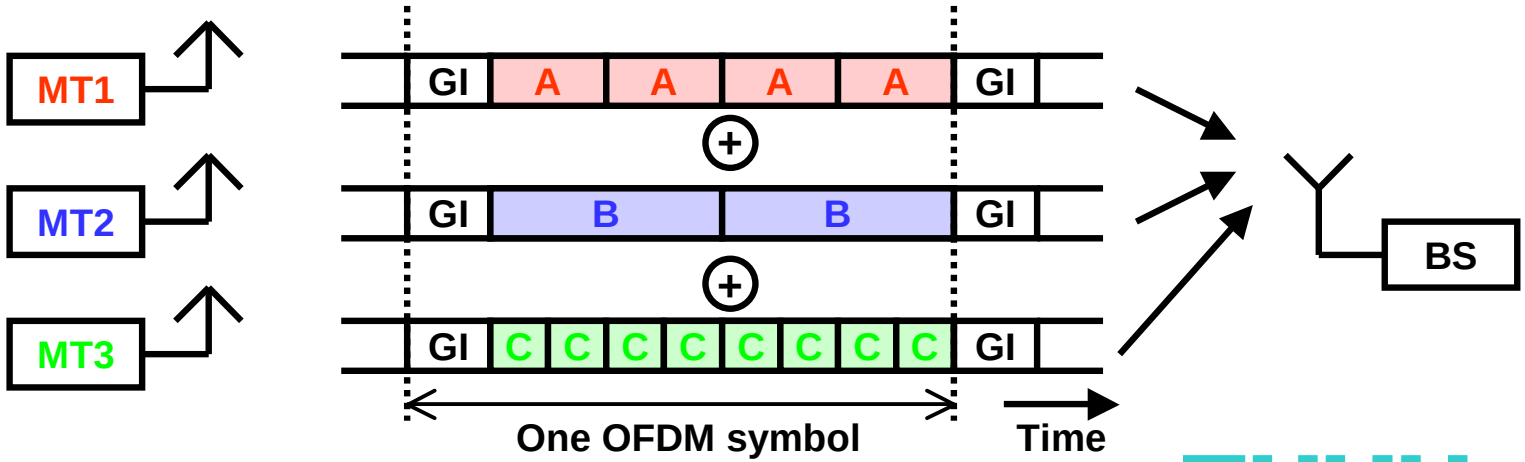
3 dB level

User Rate Adaptation

DFT-Spreading can be used with different user data rates …



Subcarrier spacing ⟺ Number of periods per OFDM symbol



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- Spreading can be used as a technique to modify the transmit signal
- A DFT spreading matrix can reduce the peak-to-average ratio of and OFDM-FDMA uplink system without a performance loss compared to spreading with Walsh-Hadamard matrices
- An OFDM-FDMA system with DFT spreading can be implemented as a single-carrier transmitter and a conventional OFDM-FDMA receiver
- Single-carrier techniques can be employed to further reduce the peak-to-average ratio
- Different user data rates can be realized by modifying the spacing of equidistant subcarriers (number of periods)