Orthogonal Frequency Division Multiplexing

Postgraduate Course in Radio Communications
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Outline

- OFDM
  - Subchannels
  - Pilots
- System overview
  - Coding / Interleaving
  - Mapping
  - IFFT / FFT
  - Guard time / Cyclic prefix
- System planning example
- References
- Homework

OFDM

- Multi-carrier modulation/multiplexing technique
- Available bandwidth is divided into several subchannels
- Data is serial-to-parallel converted
- Symbols are transmitted on different subcarriers

OFDM

- Signal processing made digitally in the frequency domain
  - IFFT/FFT –pair
- Guard time is added to reduce effects caused by multipath propagation
- Tolerant to frequency-selective fading
  - Information lost in deep fades can be recovered using FEC
- Flexible data rates (IEEE 802.11a/g 6 – 54 Mbit/s)
  - Different code rates
    - Puncturing
  - Different modulation methods (mapping)

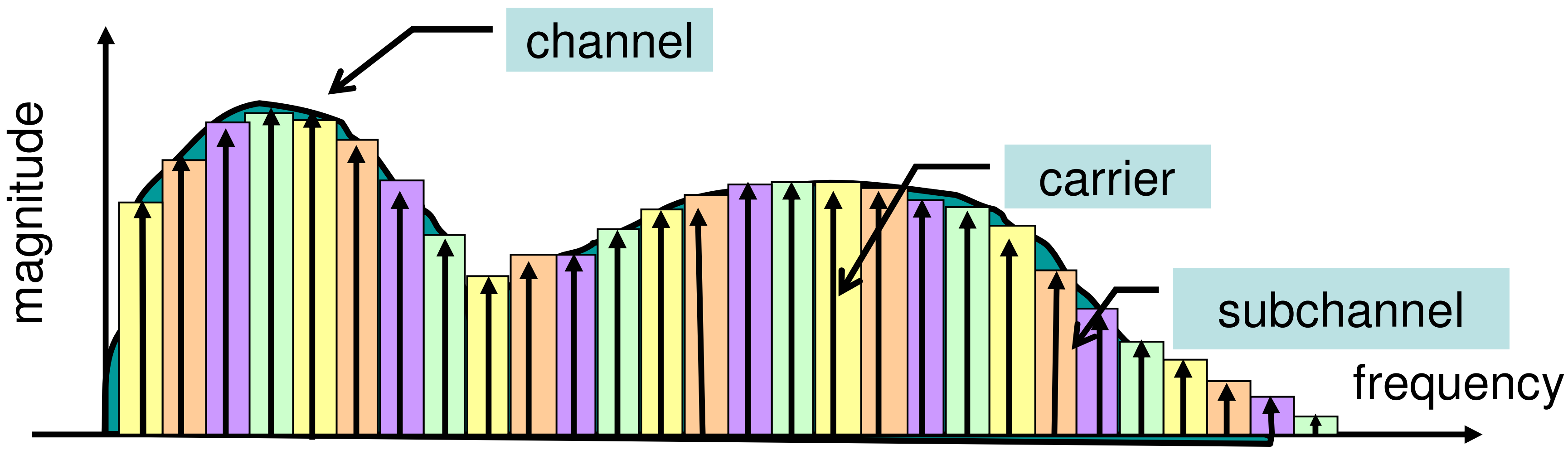
OFDM

- Advantages
  - Spectral efficiency
  - Simple implementation
  - Tolerant to ISI

- Disadvantages
  - BW loss due guard time
  - Prone to frequency and phase offset errors
  - Peak to average power - problem

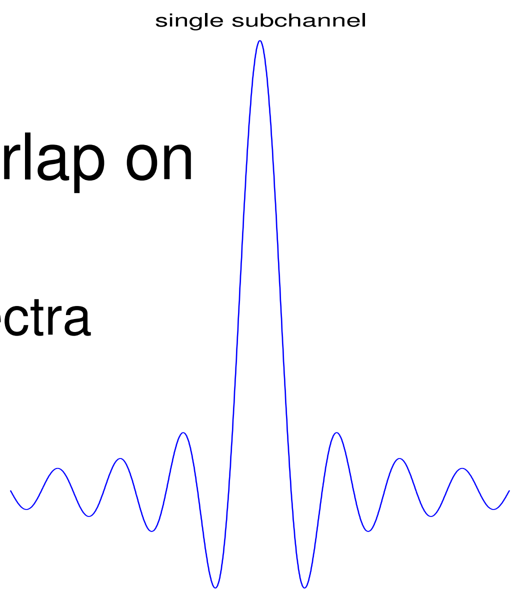
Subchannels

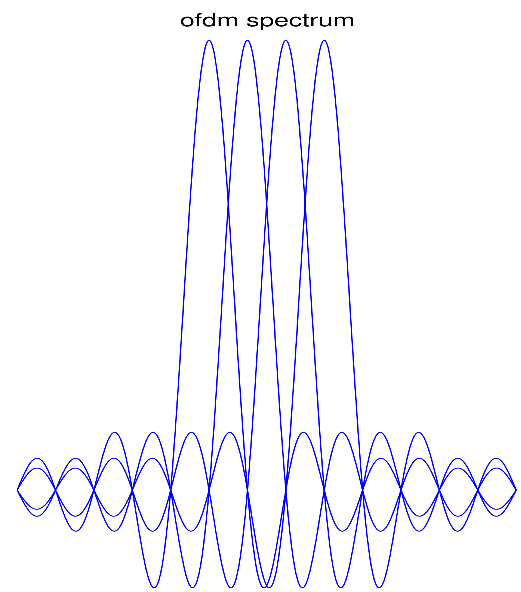
- Frequency-selective channel is divided into flat fading subchannels
- Fast serial data stream is transformed into slow parallel data streams
  - Longer symbol durations



Subchannels

- Subchannel spacings are selected so, that they are mathematically orthogonal to each other
  - FDM ⟶ OFDM
- Subchannels overlap on each other
  - Sinc -shaped spectra

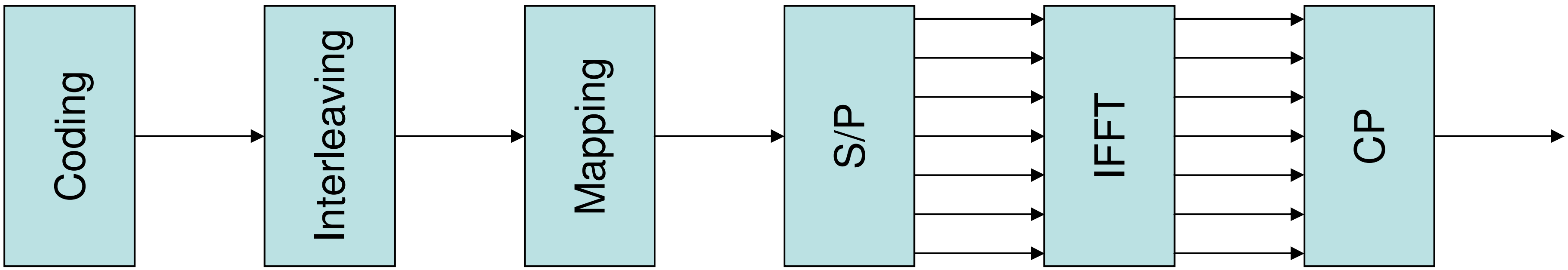




Pilots

- Pilots are transmitted first in each burst
  - 802.11a/g uses 4 subchannels as pilots
  - Some ’timeslots’ can be used as pilots
- Data can be normalized by pilot components
- Pilots are designed for easy detection
- Pilots are used for channel estimation
  - Frequency and phase offsets
  - Can be used for synchronization

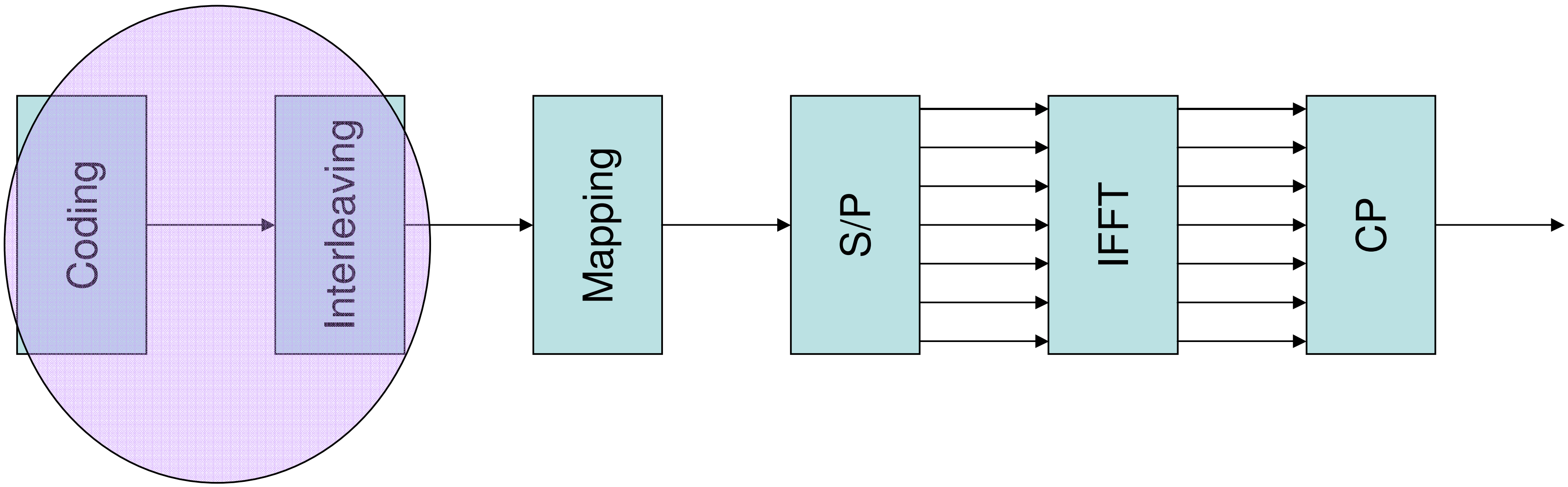
Typical OFDM transmitter



- IEEE 802.11 a/g WLAN
- IEEE 802.16 WiMAX
- DAB
- DVB-T
- ADSL (DMT)
- PLC (DMT

- DMT uses bit loading – algorithms
  - High SNR subchannels carry more bits
- DVB-T can use > 6800 subchannels
- WiMAX can divide subchannels to different users

Coding / Interleaving

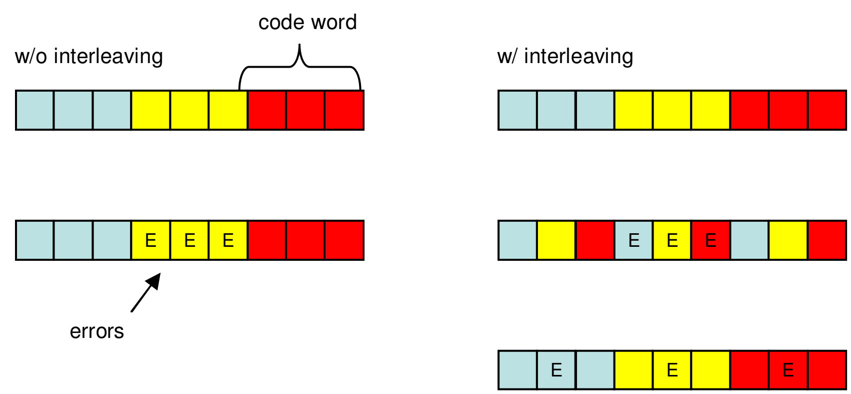


Coding / Interleaving

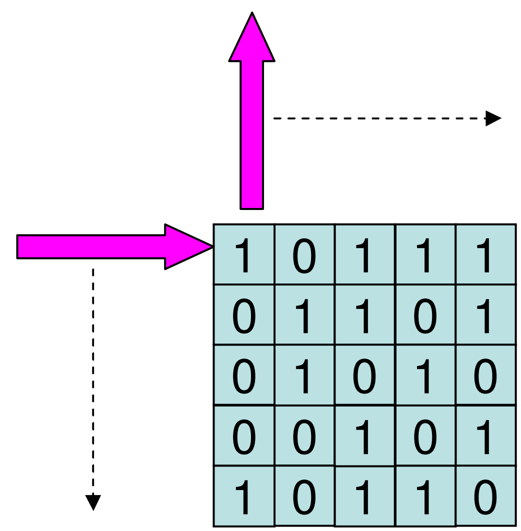
- Convolutional and/or Reed-Solomon coding
  - Adds redundancy to the information
  - Convolutional coding operates on bit streams
  - Reed-Solomon coding is block coding
  - Low implementation cost
  - OFDM → COFDM (Coded OFDM)
    - DVB-T uses inner/outer coding and interleaving
- Convolutional coding studied in earlier presentations

Coding / Interleaving

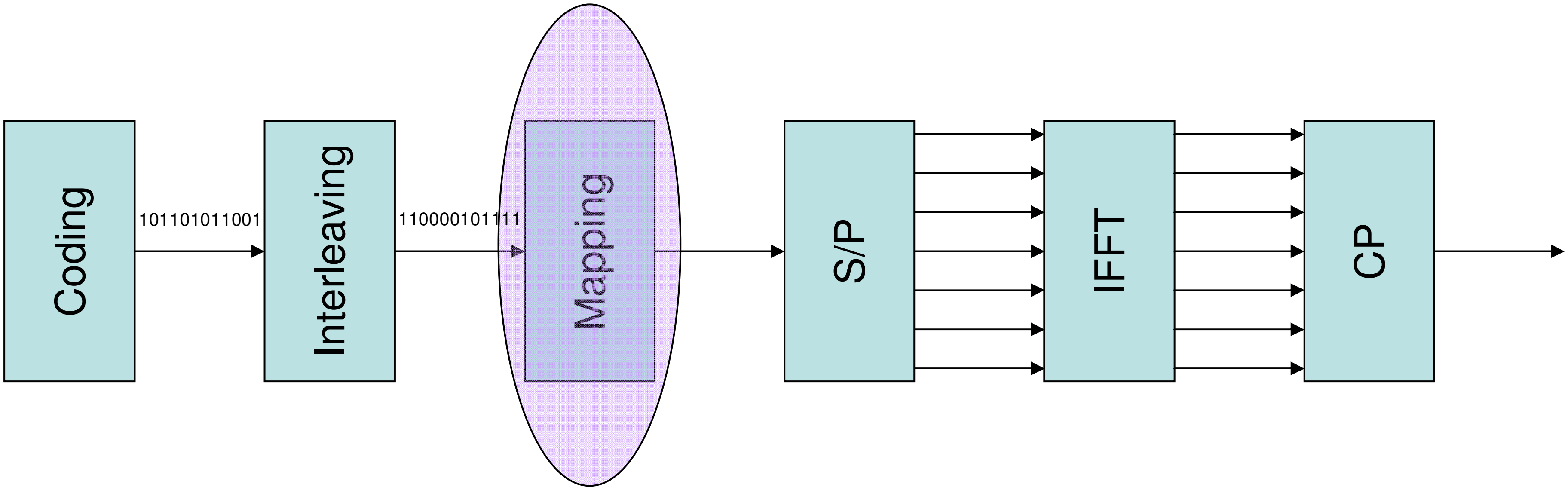
- Interleaving
  - Scatters error bursts
  - Can be done in time or in frequency domain



- One of the simplest form is block interleaving
  - Write row-by-row
  - Read column-by-column (or another way around)
  - Additional matrix permutation is possible



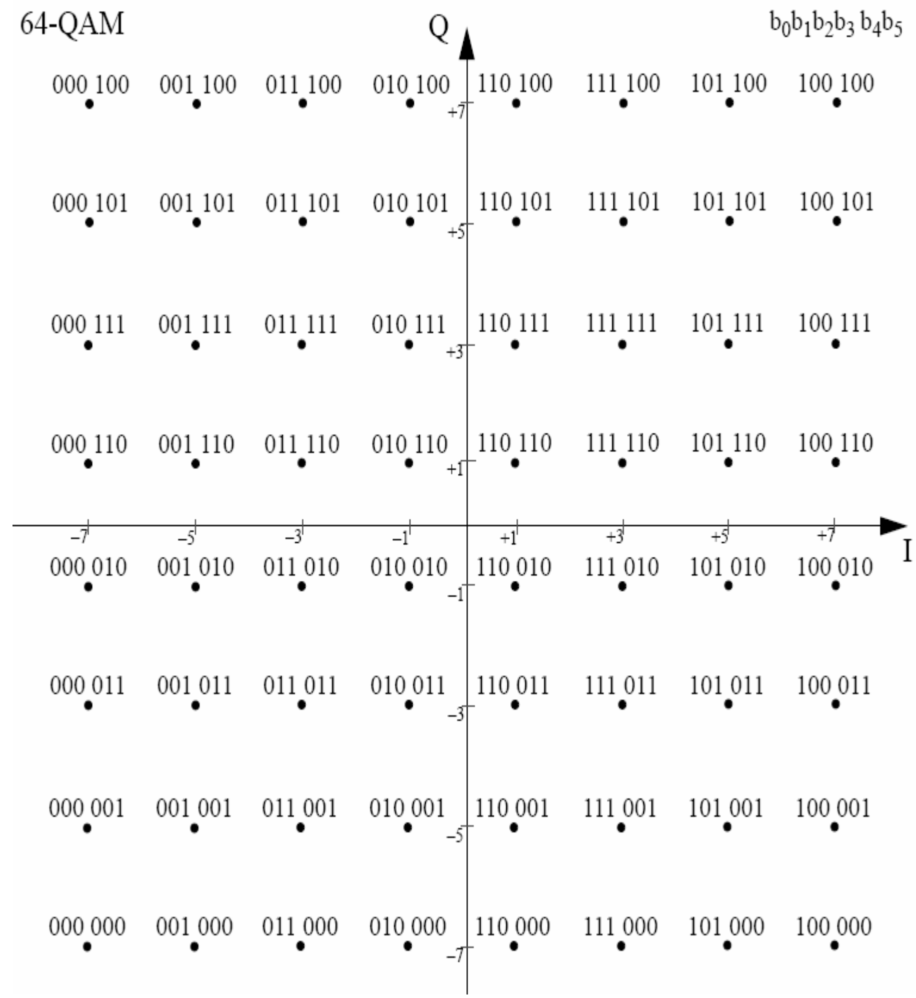
Mapping



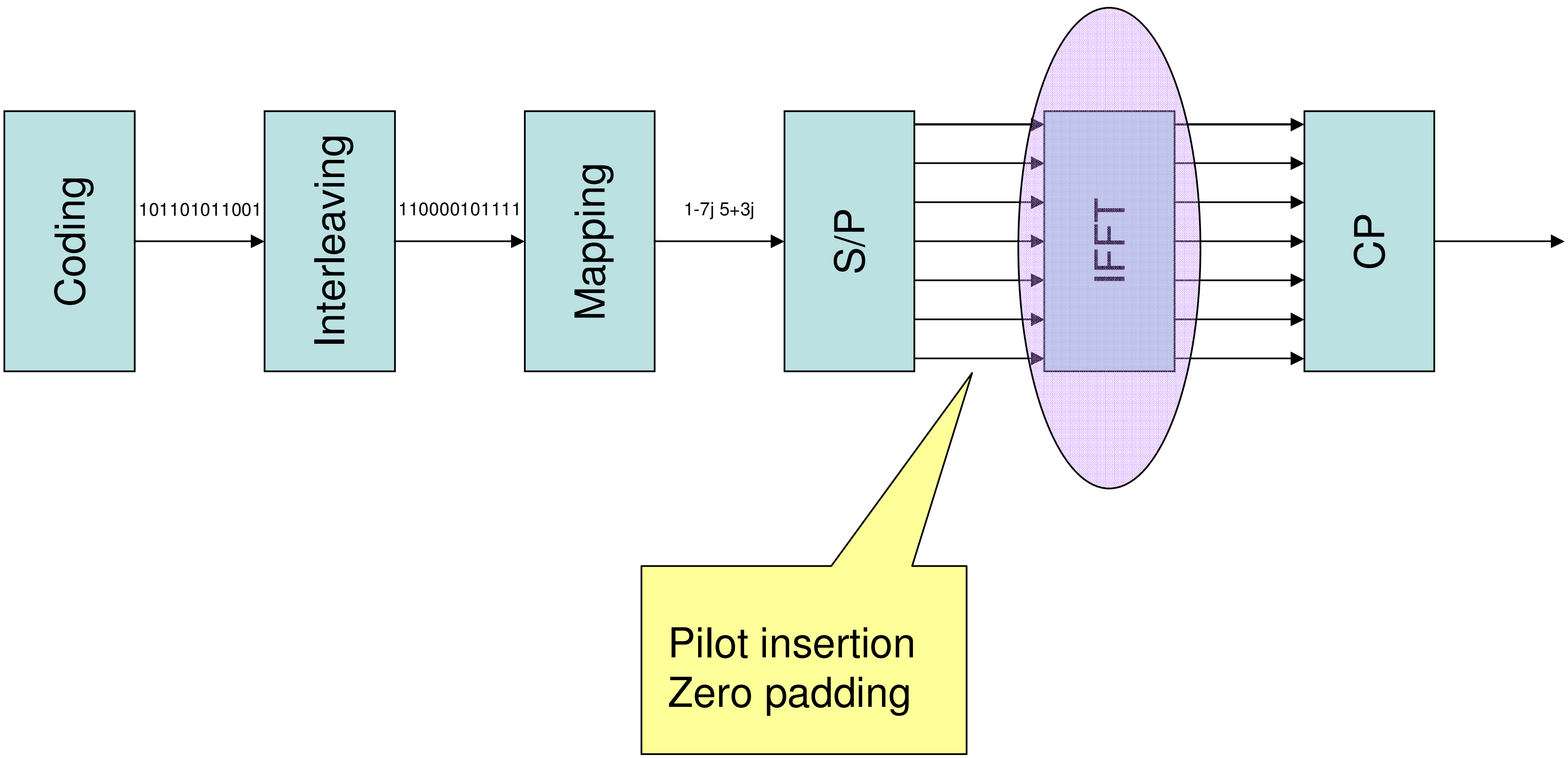
Coding
101101011001
Interleaving
110000101111
Mapping
S/P
IFFT
CP

Mapping

- Data on OFDM subcarriers is mapped (modulated) using common digital modulation schemes
  - IEEE 802.11a/g WLANs uses BPSK, QPSK, 16-QAM, 64-QAM
- Serial binary data is converted into complex numbers representing constellation points
  - Constellation mappings usually Gray-coded



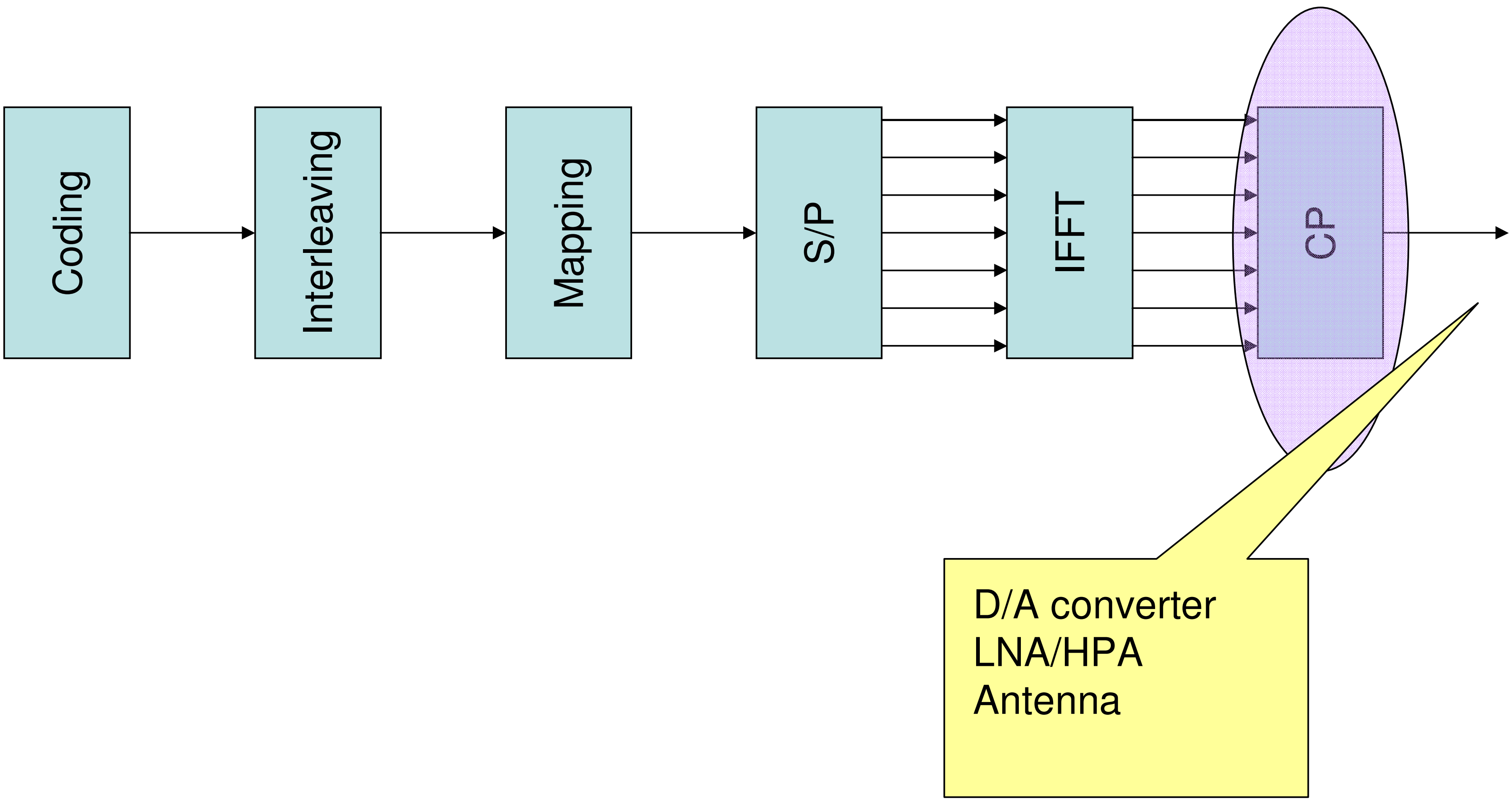
IFFT / FFT


Coding
101101011001
Interleaving
110000101111
Mapping
1-7j 5+3j
S/P
IFFT
CP
Pilot insertion
Zero padding

IFFT / FFT

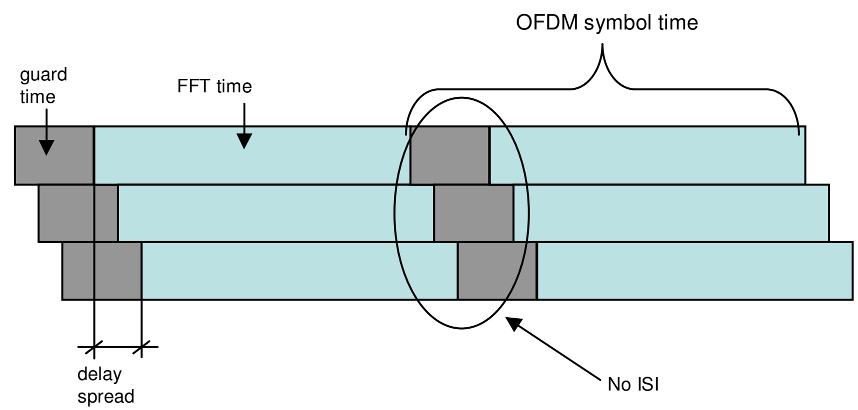
- IFFT / FFT pair is the key factor in OFDM
  - IFFT: From frequency domain to time domain
  - FFT: Vice versa
- All signal processing is made in frequency domain
- IFFT / FFT low implementation cost

Guard time / Cyclic prefix



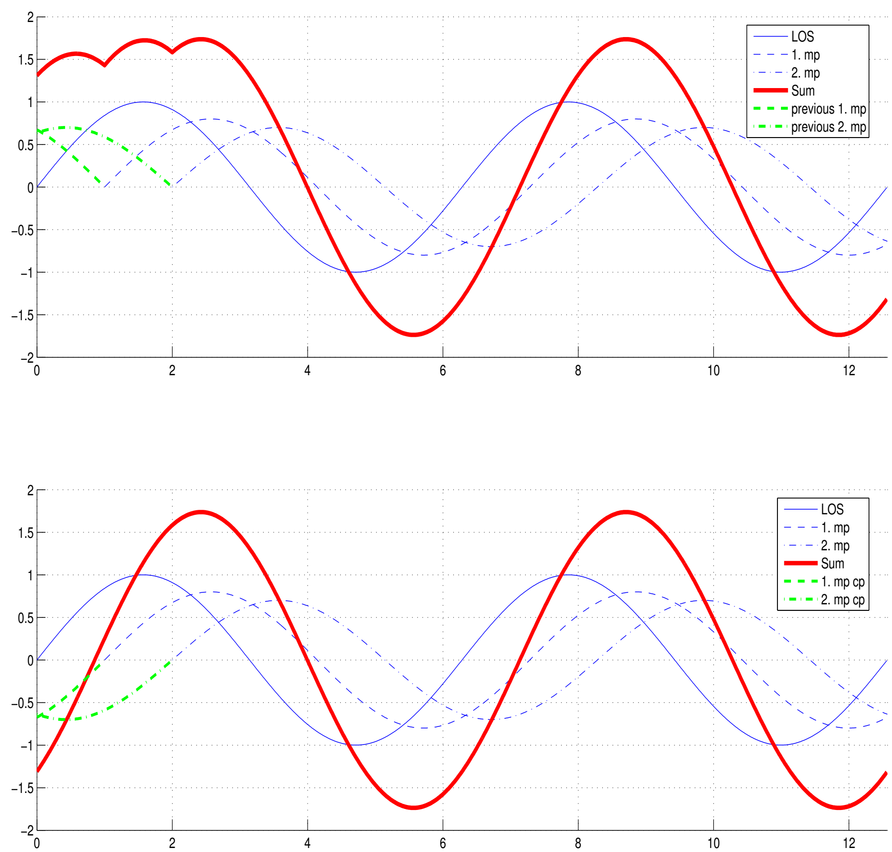
Guard time / Cyclic prefix

- Guard time is inserted between consecutive OFDM symbols
  - Helps to combat against ISI
  - Guard time is larger than delay spread
  - Multipath components fade away before information extraction
- Reduces BW effiency

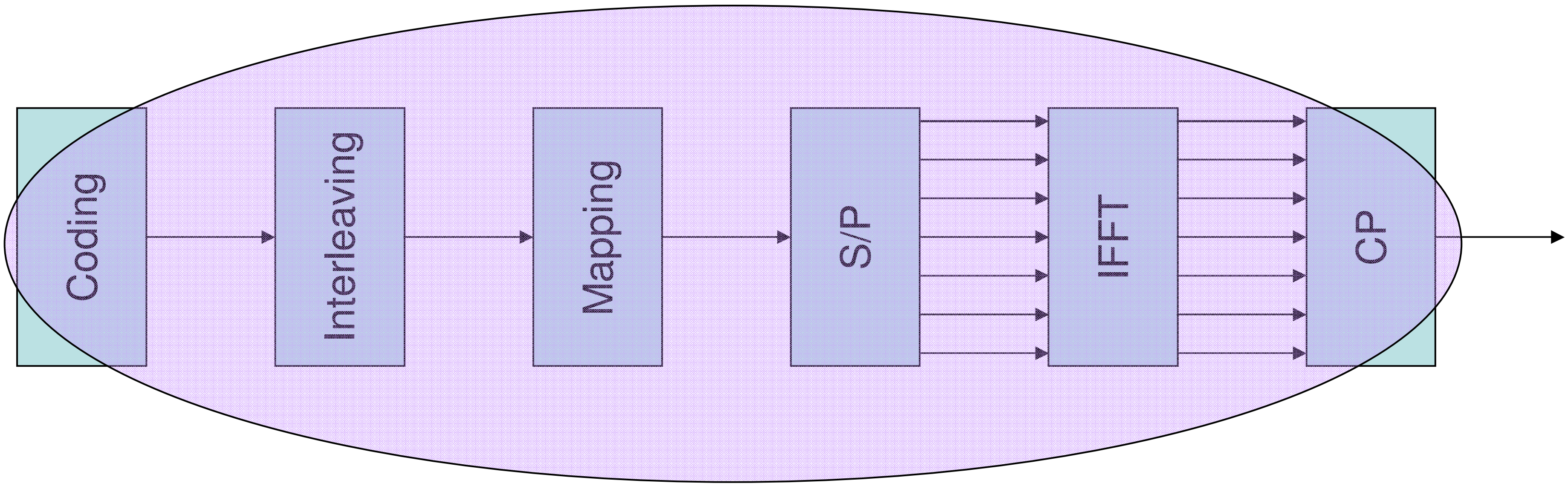


Guard time / Cyclic prefix

- Implemented with cyclic extension
  - Part of the signal is copied to the front of the signal
  - Orthogonality is maintained
- Every copy of the signal has an integer number of cycles in the FFT window
  - Same phase signals sums up
- Phase correction still needed



System planning example



System planning example

- Delay spread 200 ns
- Doppler spread 250 Hz (120 km/h)
- Assigned BW 15 MHz

- FFT time 4 µs
- Guard time 1 µs
- OFDM symbol 5 µs (Guard time + FFT)

- Subchannel BW 1/T=200kHz
- Nrof subchannels 75
  - FFT limitation >>>> nrof subch. 64 (2^N)
  - 11 subchannels unused

System planning example

- Subchannels are flat fading
  - Symbol period >> delay spread
  - Subch. BW << Coherence BW

- Data rates
  - BPSK (1 bit / symbol)   12,8 Mbit/s
  - QPSK (2 bits / symbol)   25,6 Mbit/s
  - Coding reduces data rates

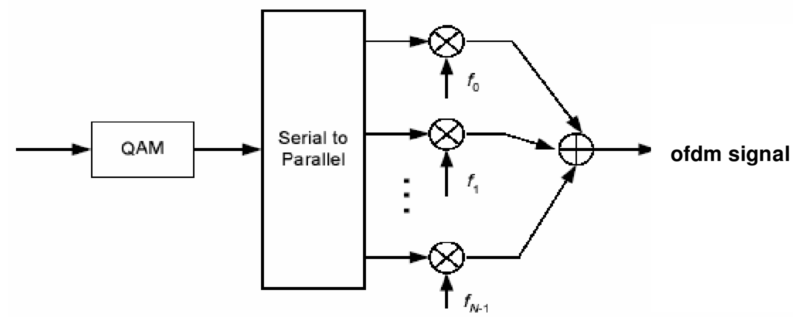
- 20% BW loss because of guard time

References

- Richard van Nee, Ramjee Prasad, *OFDM for Wireless Multimedia Communications*. Artech House Publishing, U.S.A., 2000
- Juha Heiskala, John Terry, *OFDM Wireless LANs: A Theoretical and Practical Guide*, Sams Publishing, U.S.A., 2002
- IEEE 802.11a Std, "*Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications*", ISO/IEC 8802-11, IEEE, 1999

Homework

- Derive expression for OFDM-signal
- Use 4 subchannels and 4QAM



OFDM transmitter

- Input data sequence:
  11 01 00 10
- Subcarrier frequencies are:
  $-2f_c$ $-1f_c$ $1f_c$ $2f_c$

4QAM