ALBERT-LUDWIGS-
UNIVERSITÄT FREIBURG

Algorithms for Radio Networks

Orthogonal Frequency Division Multiplexing

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Repetition

- **Multiplexed**
  - Spatial Multiplexing
  - Frequency division multiplexing
  - Time division multiplexing
  - Code division multiplexing
  - Multiple-input multiple-output (next lecture)
- **Modulation**
  - Amplitude modulation
  - Phase modulation
  - Frequency modulation

Principle of OFDM

- **OFDM (Orthogonal Frequency Division Multiplex)**
  - Signals are divided into parallel signal streams
  - Parallel signals are modulated on carrier waves of different frequencies, phase / amplitude
  - e.g. 16-QAM
  - The carrier signals are combined and transmitted simultaneously
- **Special form of frequency-division multiplexing**
- **The carrier waves using orthogonal frequency:**
  - frequencies f, 2f, 3f, 4f, 5f, ...

Repitition: Complex Numbers

- **i: imaginary number with**
  - $i^2 = -1$
- **A complex number is a linear combination of a real part a and imaginary b**
  - $z = a + bi$
- **Calculation rules:**
  - $(a+bi)+(c+di) = (a+c) + (b+d)\, i$
  - $(a+bi)\,(c+di) = (ac - bd) + (ad + bc)\, i$
  - $1/\,(a+b\, i) = (a-bi)/(a^2+b^2)$
- **Complex conjugate**
  - $(a+bi)^* = (a - bi)$

Exponentiation of Complex Numbers

- **Important equation**
  - $e^{i\pi} = -1$
  - $e^{i\varphi} = \cos \varphi + i \sin \varphi$
- **Exponentiation of a complex number**
  - $e^{a+bi} = e^a e^{bi} = e^a (\cos b + i \sin b)$
- **Therfore**
  - real part $e^{i\varphi}$: $Re(e^{i\varphi}) = \cos \varphi$
  - imaginary of $e^{i\varphi}$: $Im(e^{i\varphi}) = \sin \varphi$

Equivalent Representations of the FFT

- **Real number representation**
  - Sine and cosine functions of different frequencies

$$g(x) = \sum_{k=0}^{N-1} a_k cos\frac{2\pi kt}{T} + b_k sin\frac{2\pi kt}{T}$$

- **Computation of the inverse by cosine/sine integral product**

$$a_k = \frac{2}{T}\int_0^T g(t)\cos(2\pi nft)dt$$

$$b_k = \frac{2}{T}\int_0^T g(t)\sin(2\pi nft)dt$$

- **Complex representation**
  - real part of the exponential function of differnent frequencies

$$f(x) = \sum_{k=0}^{N-1} z_k \; e^{i2\pi kt/T}$$

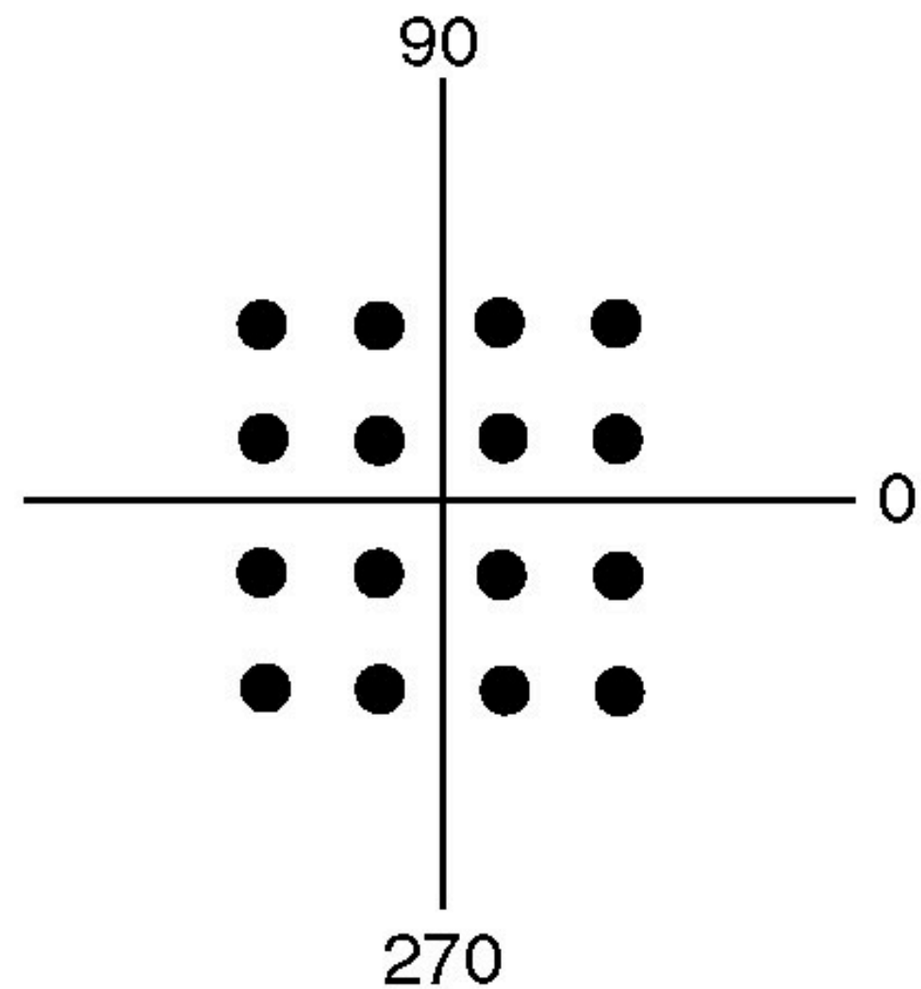
- **Computation of the inverse by the integral over the product with the complex conjugated carrier wave**

$$z_k = \frac{1}{T}\int_0^T \left(e^{i2\pi kt/T}\right)^* f(x)dt$$

Advantage of the Complex Representation

- **Each of the QAM symbols can be represented directly as a complex number**

$$f(x) = \sum_{k=0}^{N-1} z_k \; e^{i2\pi kt/T}$$



Application OFDM

- **Wired**
  - Broadband Internet (ADSL, VDSL)
  - Powerline communications networks (power line communication)
- **Wireless**
  - WLAN: 802.11 a,g,n
  - Terrestrial digital television DVB-T
  - Mobile communication
    - 802.16 WiMAX (Worldwide Interoperability for Microwave Access)
  - WPAN 802.15.3a

Pros and Cons

- **Pro**
  - High bandwidth at low SINR
  - Simple and efficient method
  - proven technology
  - Robust to Multiple Path Fading
  - Efficient use of frequency bands
- **Contra**
  - Susceptible to Doppler effect
  - High power consumption
  - Synchronization reduces efficiency

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