Drahtlose Breitbandkommunikation – Zusammenfassg.

Humboldt-Universität zu Berlin, Institut für Informatik,
IHP, Leibniz Institut für innovative Mikroelektronik, Frankfurt (Oder)

Vorlesung Drahtlose Breitbandkommunikationssysteme

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Termine

Prüfungstermine Informatik/BBK:

https://www.informatik.hu-berlin.de/de/studium/plan-muendliche-pruefungen.pdf

Institut für Informatik - Prüfungsplan Wintersemester 2017/18

Mündliche Prüfungen

Anmeldung: **- Die Frist für die Prüfungsanmeldung endet zwei Wochen vor dem Prüfungstermin.**
- Termine für die Anmeldung entnehmen Sie bitte der Tabelle.

Abmeldung: **Die Frist für die Rücknahme der Prüfungsanmeldung endet eine Woche vor dem Prüfungstermin.**

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Drahtlose Breitbandkommunikation

Prüfungsart	Prüfer/in	Termin/e	Ort	Anmeldung	Abmeldung
mündliche Prüfung	Prof. E. Grass	28.02.2018 09.03.2018 06.04.2018 11.04.2018	RUD 25, 4.323	- ab: 29.01.2018 - bis: siehe Hinweis oben - bei: Frau Schoch RUD 25, 3.302	- bis: siehe Hinweis oben - unter: schochsi@informatik.hu-berlin.de

Wesentliche Prüfungsthemen:

- **Shannons Kanalkapazitäts-Gleichung**
- **Friis Pfadverlust Gleichung**
- **Link-budget Berechnung**
- **Kanaleigenschaften und Kanalmodellierung**
  - Delayspread
  - Dopplerverschiebung
  - Frequenzoffset
- **Modulationsarten**
  - AM, FM, PSK, QAM
  - Spread Spectrum, CDMA
- **Struktur und Funktionsweise eines OFDM-Basisbandprozessors**
  - Modulation, Kanalkodierung
  - Synchronisation, Kanalschätzung / -Entzerrung
- **Entwurf eines OFDM-Systems**
  - Guardintervall / Cyclic Prefix
  - Unterträgerabstand
  - Anzahl der Unterträger
- **Prinzipien Beamforming / MIMO**

BMBF (D-National)

- „*Tactile Internet*“ (2016)
  -> minimum Latency
- Zuverlässige Drahtlose Kommunikation in der Industrie, Industrie 4.0 (2014)
  - Maschienensteuerung (***Sicherheit, Lokalisierung***,…)
  - Augmented Reality (***Datenrate, Lokalisierung***, …)
- Autonomes Fahren & Car-to-Car Kommunikation (2015, 2017)
  - Dynamische Systemlösungen für Funkanwendungen im Verkehrsumfeld
  - Unterstützung des autonomen Fahrens durch sichere Kommunikationssysteme

EU – Horizon 2020

1. Advanced ***5G Network*** Infrastructure for the Future Internet (ca. 500 Mio €) & ***beyond 5G***
   - Radio network architecture and technologies
   - Network ***virtualisation*** and Software Networks
   - Network slicing
2. ***Smart*** optical and wireless network technologies
   - dynamic control of wireless network resources through disruptive new "***femtocell***" like paradigms
3. Smart ***Cyber-Physical Systems***
   - embedded ICT systems that are interconnected and collaborating including through the ***Internet of things (IoT)***, and providing citizens and businesses with a wide range of innovative applications and services

EU – Horizon 2020

Big data, ***internet of things*** (IoT) are trends which will influence and impact the future development of ***cloud computing*** systems. Information gathering, processing and computing of massive amounts of data generated from and delivered to highly distributed devices (e.g. sensors and actuators) creates new challenges, especially for services and data hosted and executed across borders ….

These requirements will impact the underlying ***cloud infrastructure*** requiring efficient management of very large sets of globally distributed non-structured or semi-structured data that could be produced at very high rates (i.e. big data). A ***multi-cloud*** service platform supported by ***broadband networks*** needs to handle all these challenges and appear to the application environment as one uniform platform.

- “***offloading***” data from cellular networks to WLAN

Economical & Legal Issues

- Despite rapid exponential growth of data rate, the prices for a WLAN Terminal have to remain constant!
  – this is expected by the customers, i.e. ***us*** ☺!

- Due to growing complexity, the development effort is growing too

  Example: (IEEE802.11a : 40 Mio $; IEEE 802.15.3c: 100 Mio $; IEEE 802.11ad: ca. 150 Mio $)

  - IP-reuse becomes more and more important
  - Small specialized companies need to obtain licences for required IP
  - Very expensive design-tools are required (> 1 Mio $ per year)

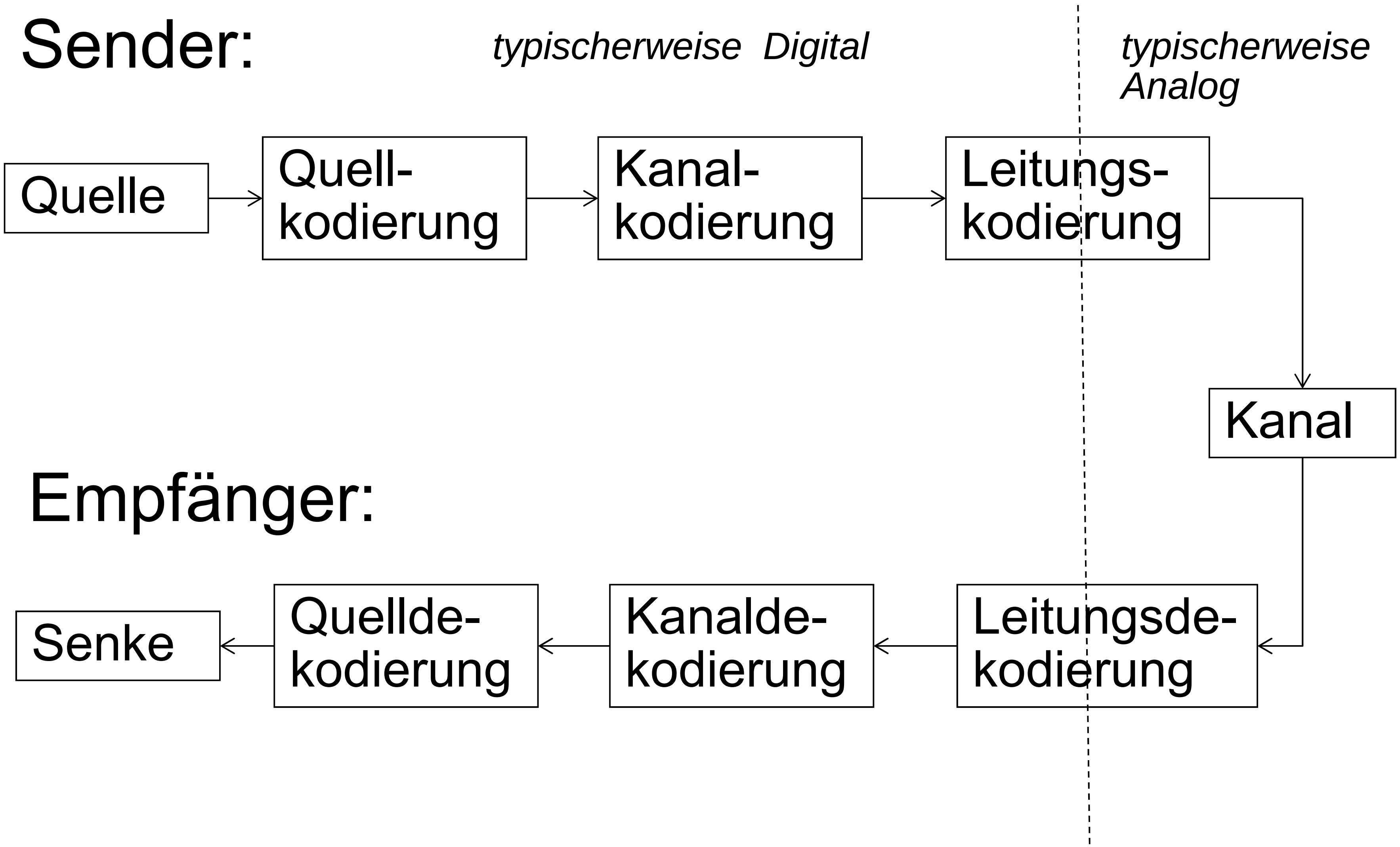
- A complex system contains a large amount of IP and the clearance of legal-, IP- and patent- issues becomes a major part of the business (IP-trade).

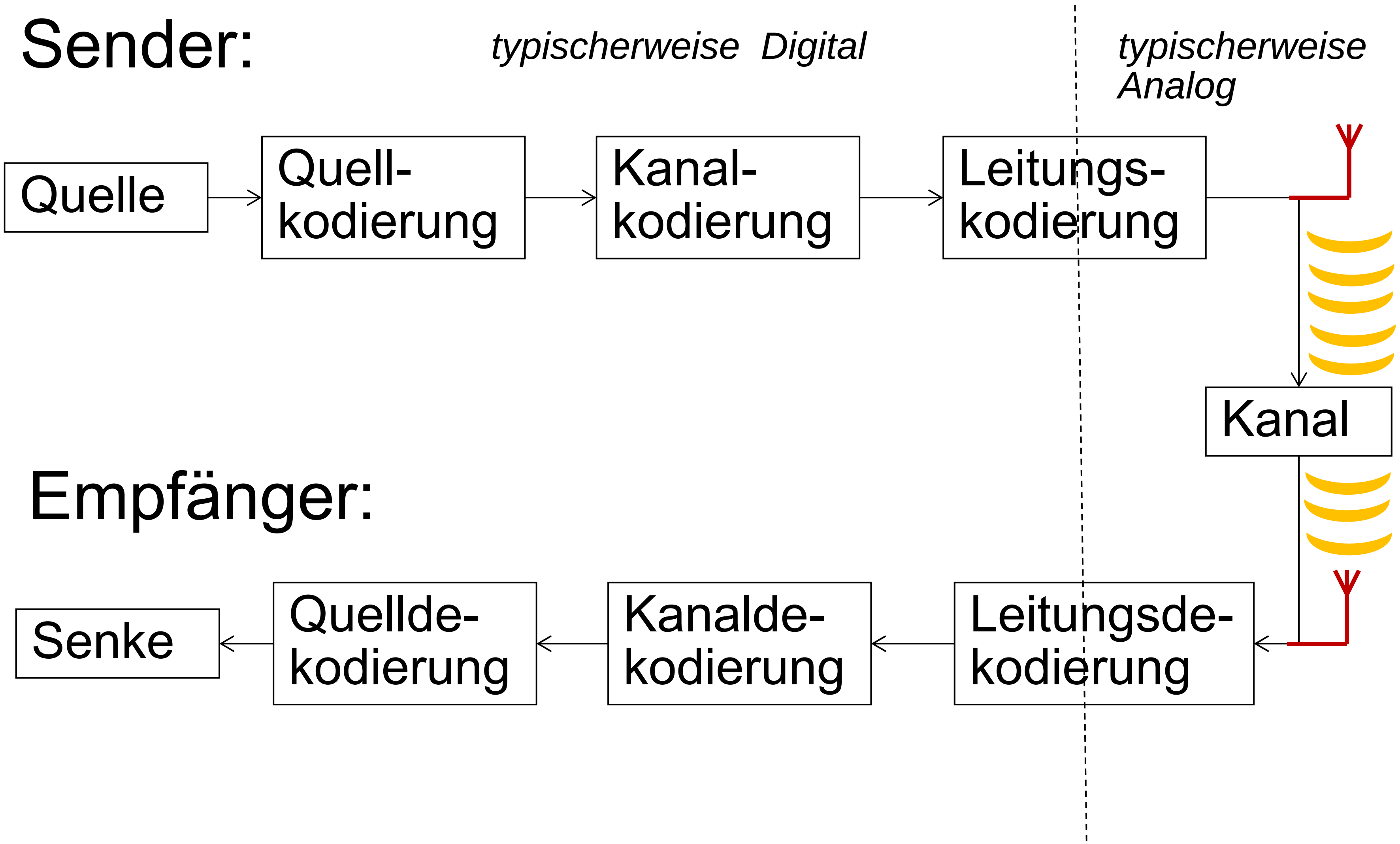
- Patenting good ideas and solutions becomes vital for a company (and for Research Institutes too)

Mobile communication OSI-layer model

• Application layer	• service location • new applications, multimedia • adaptive applications	• Application Layer • Presentation Layer • Session Layer
• Transport layer	• congestion and flow control • quality of service	TCP UDP
• Network layer	• addressing, routing, device location • hand-over	IP IPsec
• Data link layer	• authentication • media access • multiplexing • media access control (MAC)	
• Physical layer	• encryption • modulation • Interference • attenuation • frequency	

Channel & Antenna


Sender:
typischerweise Digital
typischerweise Analog
Quelle
Quell-kodierung
Kanal-kodierung
Leitungs-kodierung
Kanal
Empfänger:
Senke
Quellde-kodierung
Kanalde-kodierung
Leitungsde-kodierung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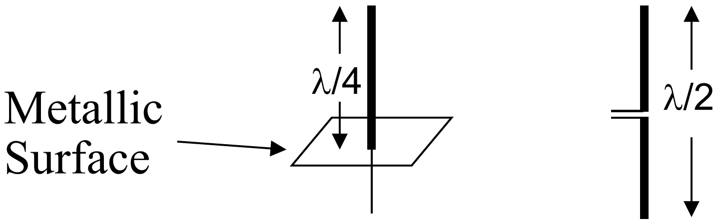
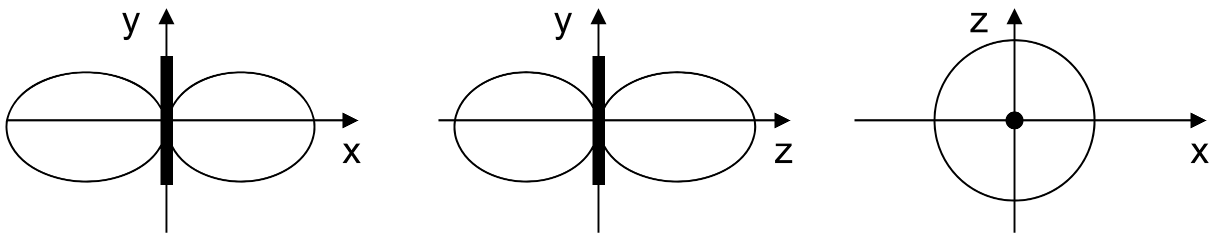
Leitungs-kodierung
Kanal
Empfänger:
Senke
Quellde-kodierung
Kanalde-kodierung
Leitungsde-kodierung

- Real antennas are not isotropic radiators but, e.g., dipoles with lengths $\lambda/4$ on car roofs or $\lambda/2$ as Hertzian dipole
  ➔ shape of antenna proportional to wavelength



- Example: Radiation pattern of a simple Hertzian dipole



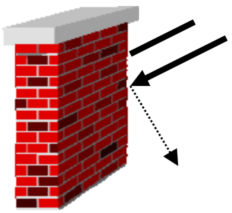
side view (xy-plane) side view (yz-plane) top view (xz-plane)

simple dipole

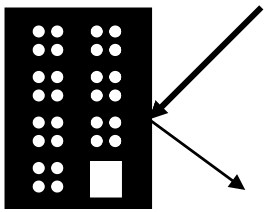
- Gain: maximum power in the direction of the main lobe compared to the power of an isotropic radiator (with the same average power)
- Gain measure in dBi ($10*\log_{10}P_i/P_{max}$)

Signal propagation

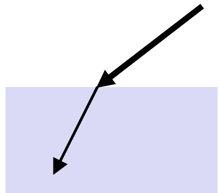
- Propagation in free space always like light (straight line)
- Receiving power proportional to 1/d²
  (d = distance between sender and receiver)
- Receiving power additionally influenced by
- fading (frequency dependent; H_2O resonance at 2.5 GHz; O_2 Resonance at 60 GHz)
- shadowing
- reflection at large obstacles
- refraction depending on the density of a medium
- scattering at small obstacles
- diffraction at edges



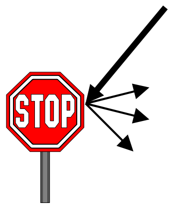
shadowing



reflection



refraction

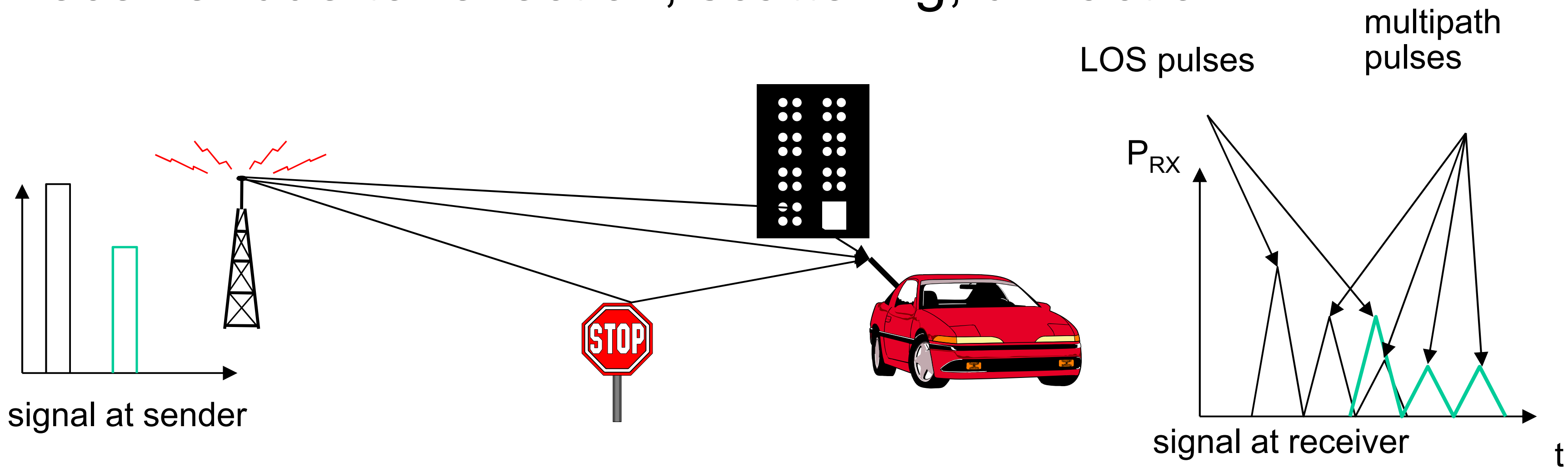


scattering

diffraction

Multipath propagation

- Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction



- Time dispersion: signal is dispersed over time (delay spread)
  - ➔ interference with “neighbor” symbols, Inter Symbol Interference (ISI)
- The signal reaches a receiver directly and phase shifted
  - ➔ distorted signal depending on the phases of the different parts

Modulationsverfahren

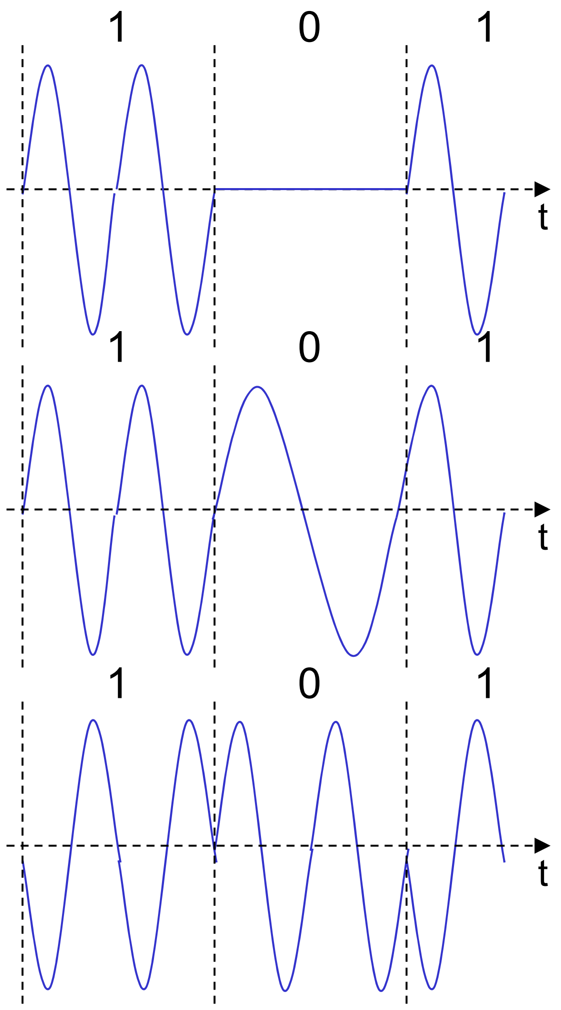
Digital modulation

- Modulation of digital signals known as “Shift Keying”

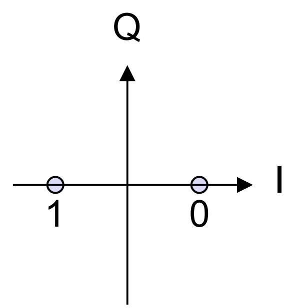
- Amplitude Shift Keying (ASK):
  - very simple
  - low bandwidth requirements
  - very susceptible to interference

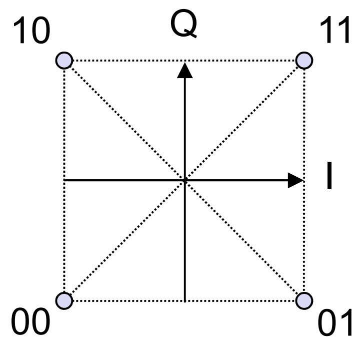
- Frequency Shift Keying (FSK):
  - needs larger bandwidth

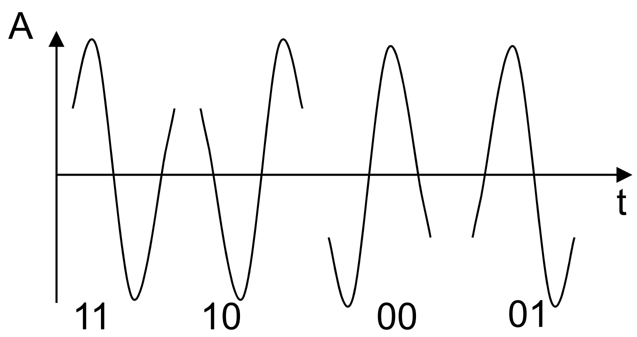
- Phase Shift Keying (PSK):
  - more complex
  - robust against interference



- BPSK (Binary Phase Shift Keying):
  - bit value 0: sine wave
  - bit value 1: inverted sine wave
  - very simple PSK
  - low spectral efficiency
  - robust, used e.g. in satellite systems
- QPSK (Quadrature Phase Shift Keying):
  - 2 bits coded as one symbol
  - symbol determines shift of sine wave
  - needs less bandwidth compared to BPSK
  - more complex





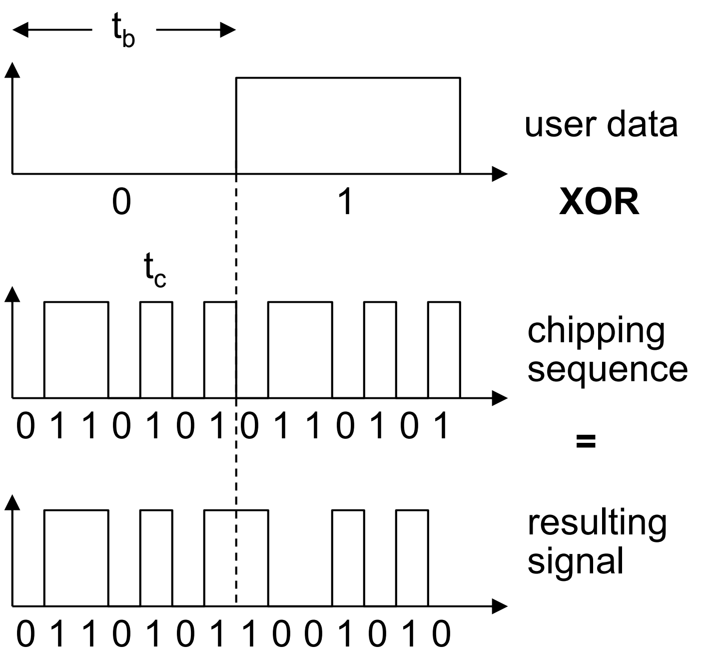


- Often also transmission of relative, not absolute phase shift: DQPSK - Differential QPSK (IS-136, PHS)

DSSS (Direct Sequence Spread Spectrum) I

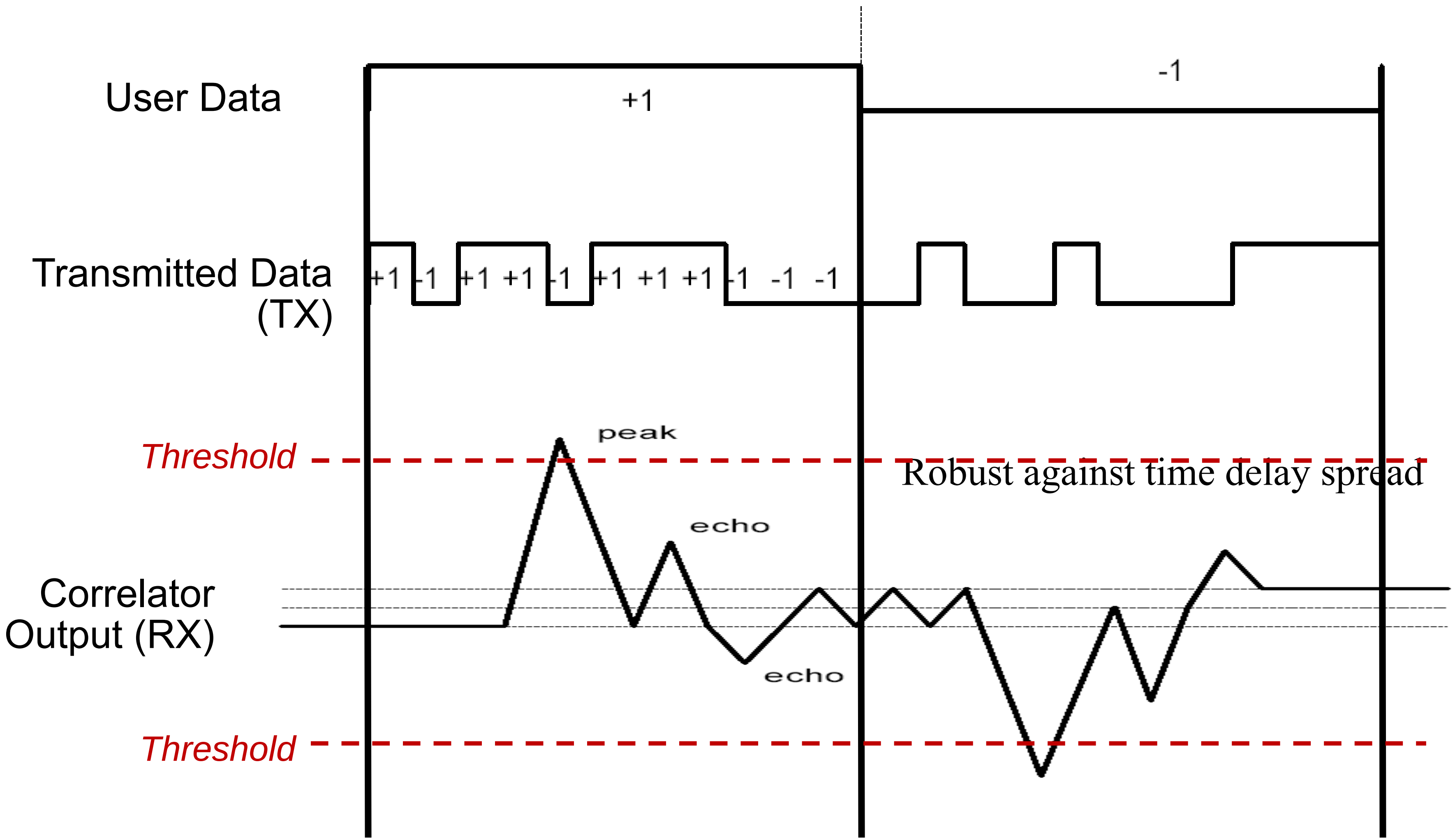
- XOR of the signal with pseudo-random number (chipping sequence)
  - many chips per bit (e.g., 128, best known 11) result in higher bandwidth of the signal
- Advantages
  - reduces frequency selective fading
  - in cellular networks
    - base stations can use the same frequency range
    - several base stations can detect and recover the signal
    - soft handover
- Disadvantages
  - precise power control necessary
  - Precise synchronization necessary (multi correlators can take advantage from multi-path propagation (Rake-receiver)
  - Cell breathing in cellular systems

Spreading Factor $s = t_b/t_c$



t_b: bit period
t_c: chip period

Example Barker Code



Kanalcodierung

- Einfügen von Redundanz vor der eigentlichen Datenübertragung im Sender
- Übertragung über gestörten Kanal (Bitfehler)
- Fehlerkorrektur und Entfernen der Redundanz im Empfänger

Fehlerkorrekturcodes (Forward Error Correction)

Blockcodes

Systematische Blockcodes

- Reed Solomon Code (RS)
- Low Density Parity Check Codes (LDPC)

Nicht-Systematische Blockcodes

Faltungscodes (nicht Syst.)

- ***Viterbi Codes***
- Ungerboeck Codes

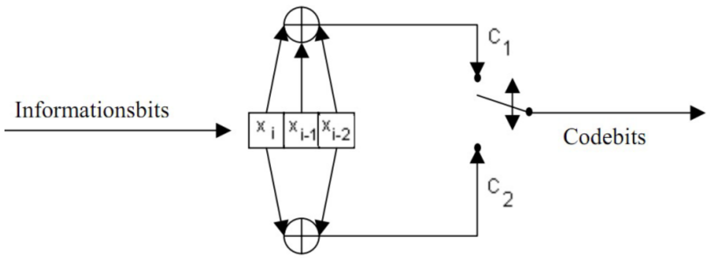
Concatenated Codes

Verkettung mehrerer Codes

- z.B. Viterbi + Reed Solomon
- Turbo Codes, e.g.:
  Serial Concatenated Convolutional Codes

Faltungskodierer

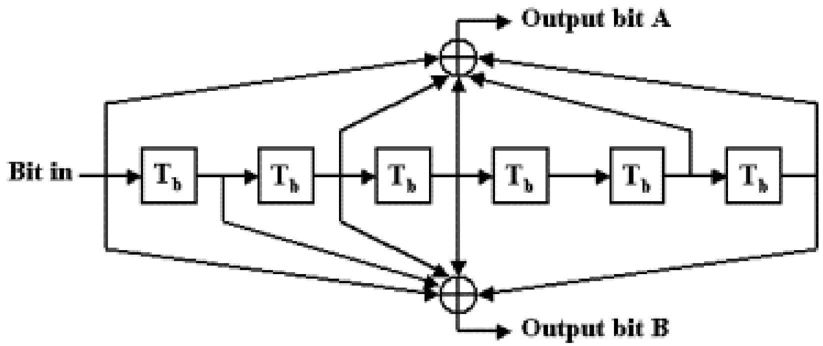
- Bietet Vorwärtsfehlerkorrektur
- In Praxis fast ausschließlich nicht-systematische Codes
- Rekursiv (mit Rückkopplung) und nicht-rekursiv möglich
- Informationsgehalt wird über mehrere Nutzdatenstellen „verschmiert“
- Entspricht der Faltung in der digitalen Signalverarbeitung
- Leistungsfähiger als Blockcodes
- Kann mit Punktierung kombiniert werden um beliebige Code-Rate zu erreichen



Constraint length (K) = 3

$c_1 = x_i + x_{i-1} + x_{i-2}$
$c_2 = x_i + x_{i-2}$

Convolutional Code (7_8, 5_8)



Constraint length (K) = 7, R=1/2

Out_A = g1(z) = $1+z^2+z^3+z^5+z^6$
Out_B = g2(z) = $1+z+z^2+z^3+z^6$

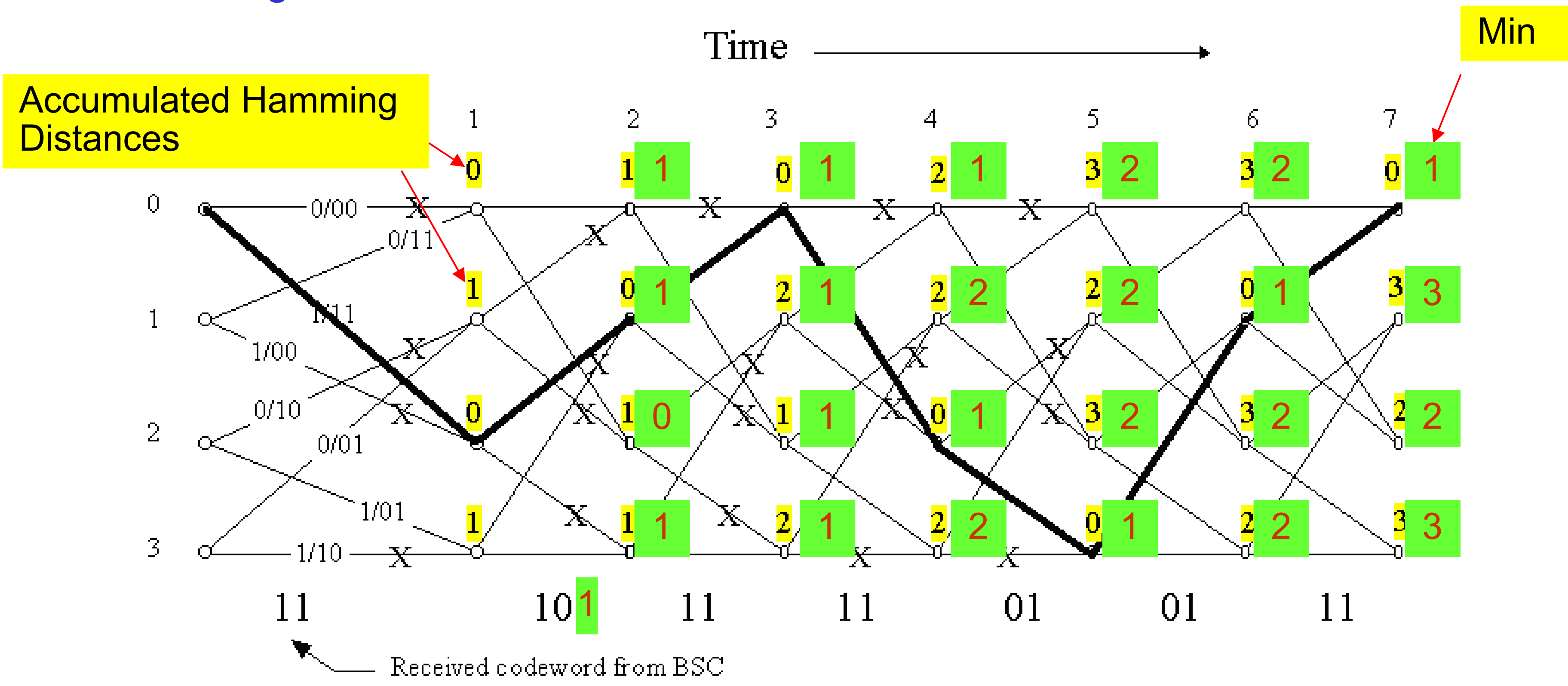
Convolutional Code (133,171)

Viterbi Decoder - Principle Operation

Error !

Received sequence: 11 11 11 11 01 01 11

Original Bit-stream: 1 0 0 1 1 0 0



OFDM

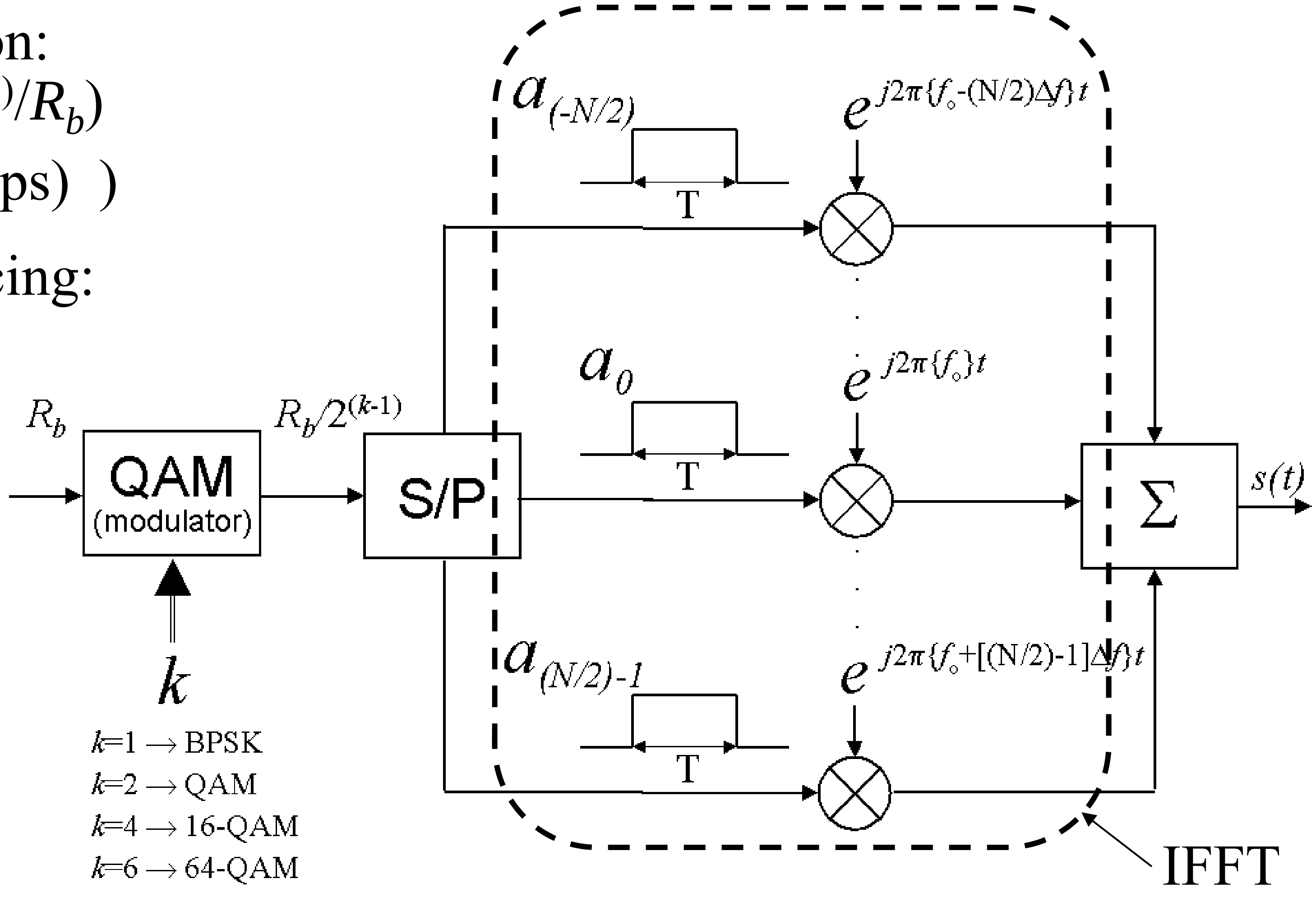
Why OFDM

- In order to cope with inter-symbol interference (ISI), we should increase the symbol duration
- If we increase the symbol duration the data rate goes down
- In order to limit the reduction in data rate, several carriers can be used (Multi Carrier Transmission)
- → One OFDM symbol consists of several subcarriers
- In order to reduce the interference between subcarriers, their frequencies are chosen such that they are orthogonal
- In order to efficiently use the digital hardware the number of subcarriers is usually a power of 2 (i.e. 64, 256, 1024, …)

N = number of subcarriers

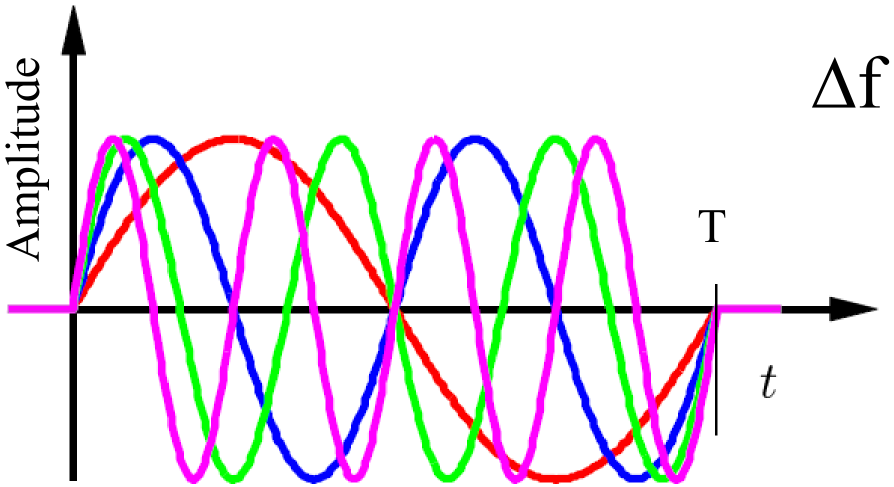
Symbol duration:
$T_s = T = N(2^{(k-1)}/R_b)$
($R_b \equiv$ bit rate (bps))

Subcarrier spacing:
$\Delta f = 1/T$

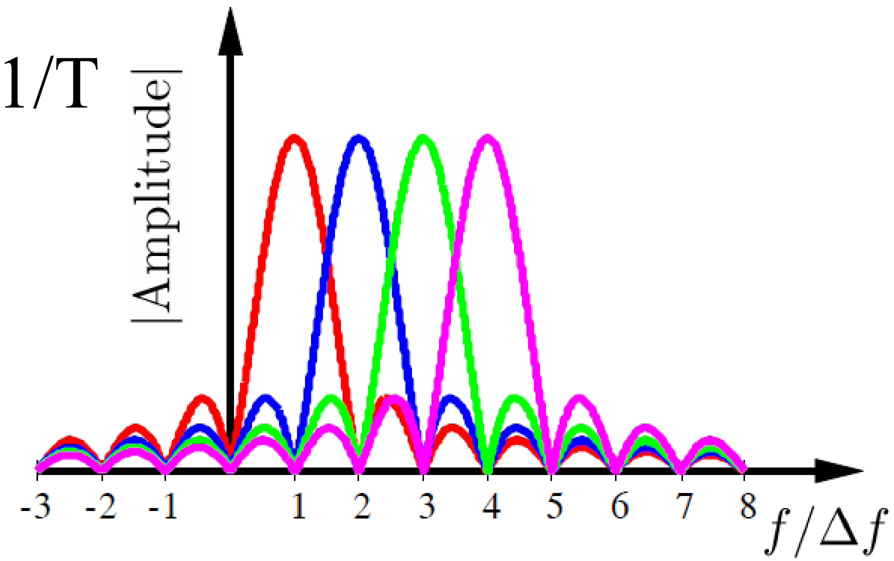


Example: WLAN IEEE 802.11a

OFDM Symbol Duration:	3.2 + 0.8µs (Guard Interval, Cyclic Prefix)
Number of subcarriers:	64 (52 used)
Subcarrier Spacing:	312.5 kHz
Signal Bandwidth:	16.66 MHz
Channel Spacing:	20 MHz



$\Delta f = 1/T$



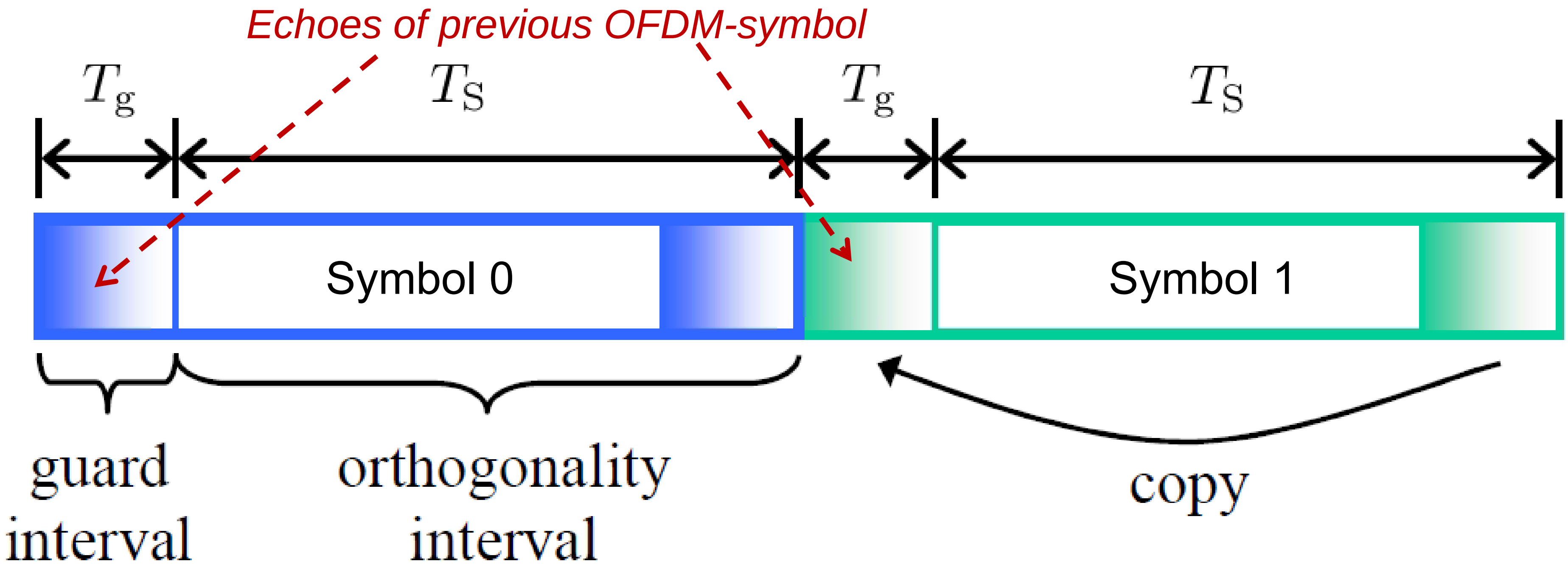
Source: L. Häring (Uni Duisburg, 2011)

Guard Interval

T_g ~ max. delay spread of channel (T_{rms})

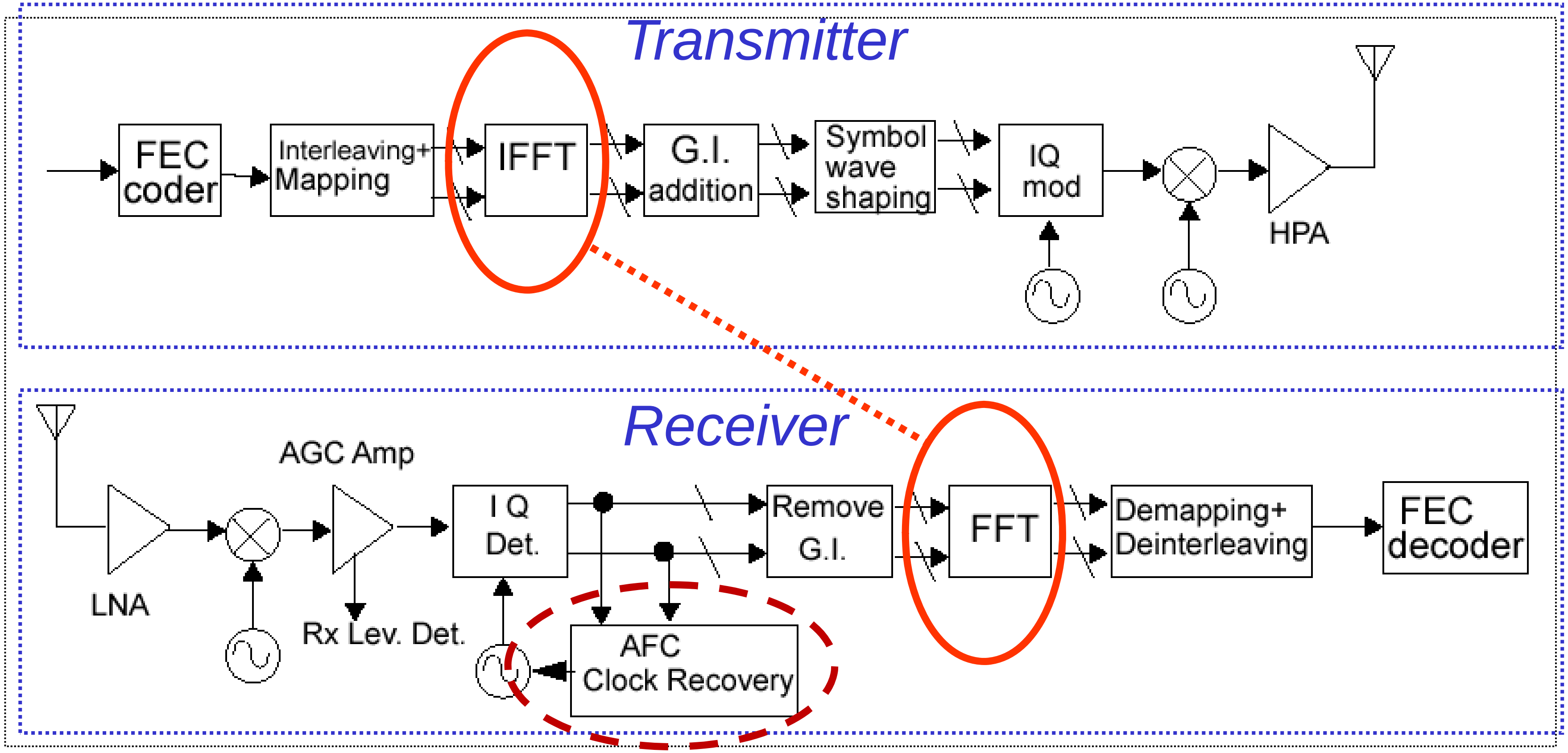
-> Reflections (echos) of previous symbol fall into the guard interval of the actual symbol

-> The actual FFT-Window (orthogonality interval) is not affected



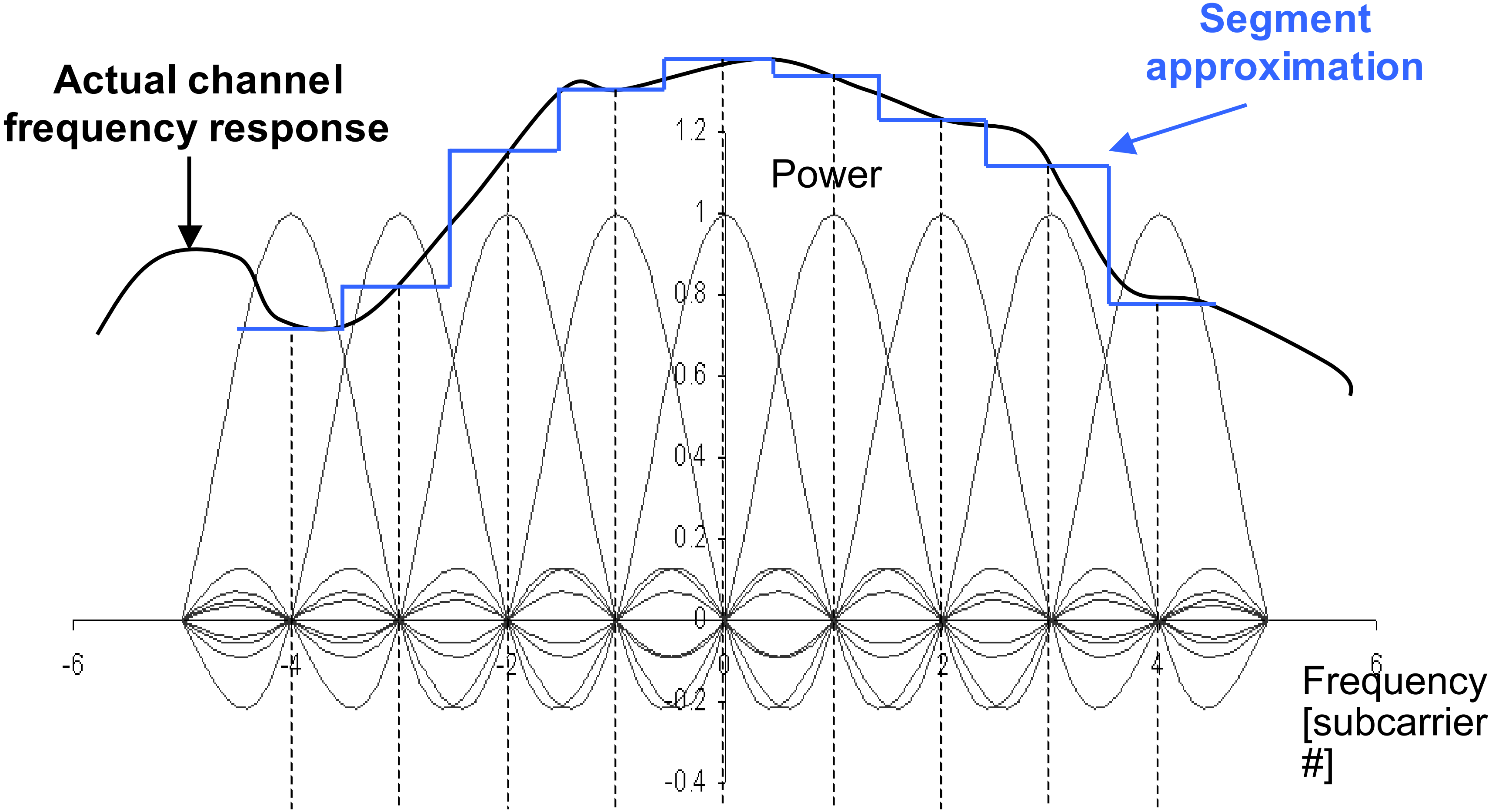
Source: L. Häring (Uni Duisburg, 2011)

Detailed Structure of OFDM Transceiver

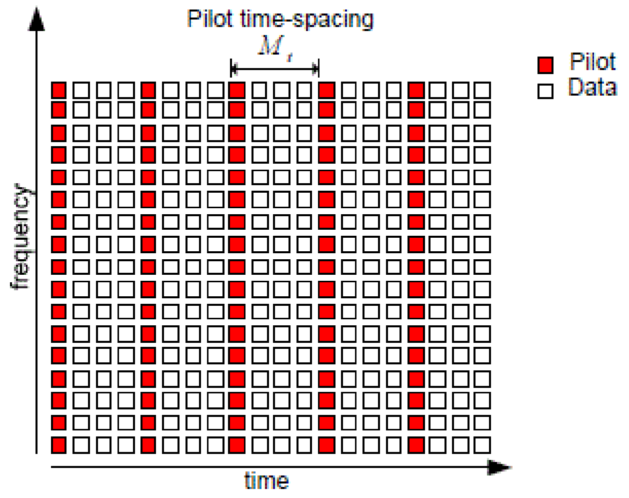


OFDM: Effects of fading channels

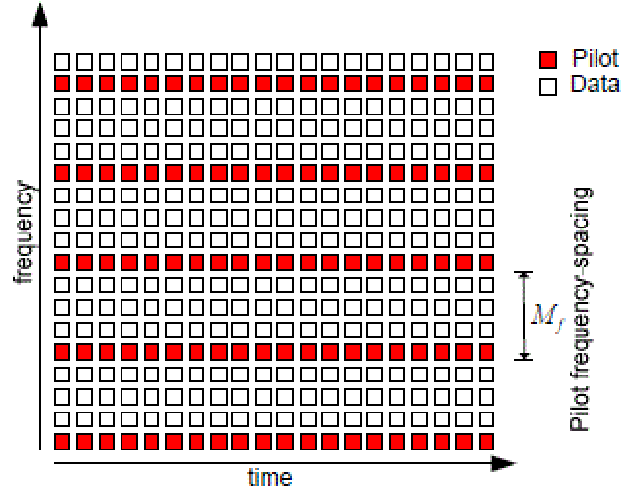
- **CHANNEL'S PIECEWISE APPROXIMATION**



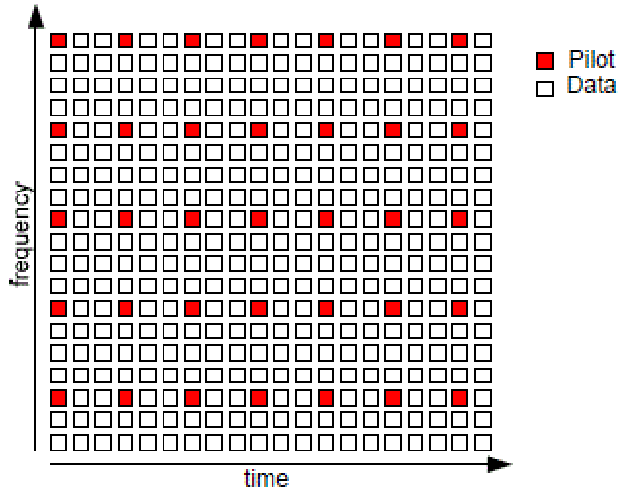
OFDM Channel Estimation using „Pilot Carriers“



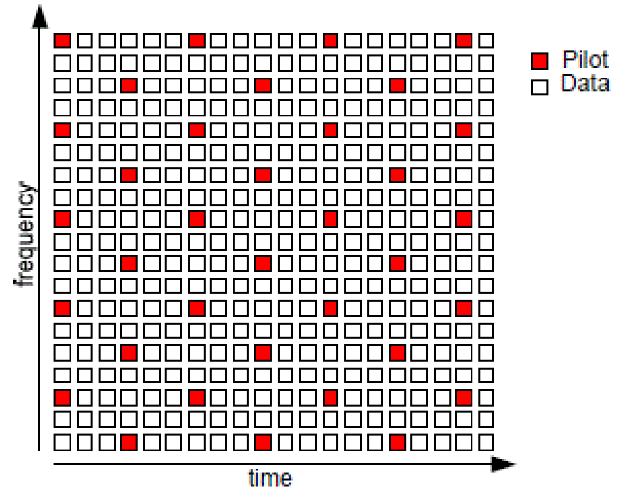
(a) All frequency-time spaced pilot allocation



(b) Frequency spaced - all time pilot allocation



(c) Frequency spaced - time spaced pilot allocation



(d) Frequency spaced - time spaced pilot allocation

[From Akram (Nokia)]

OFDM Channel Estimation

Interpolation in Time- and Frequency Domain

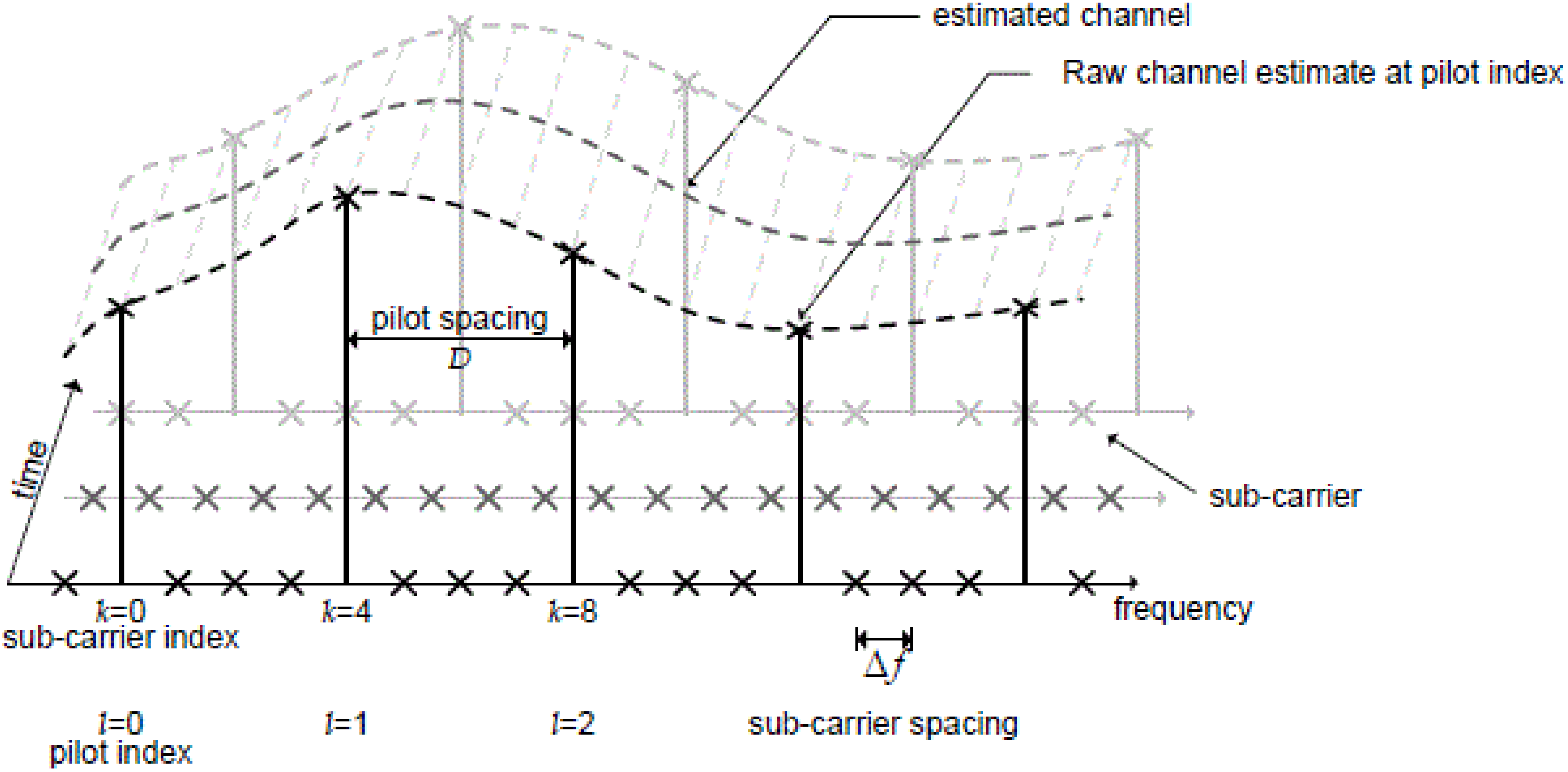
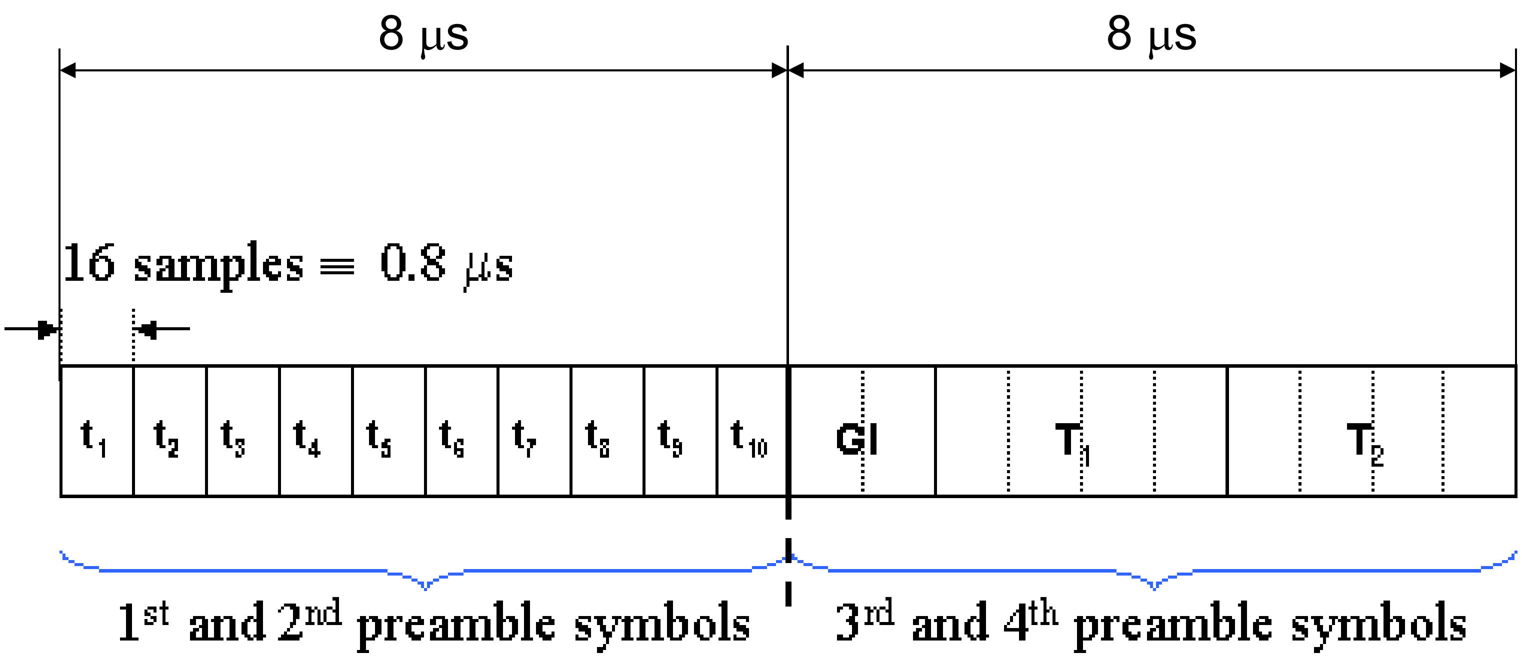


Figure 4-6. Channel estimation in time-frequency domain

[From Akram (Nokia)]

Timing Synchronisation using Preamble

IEEE802.11a Preamble structure:

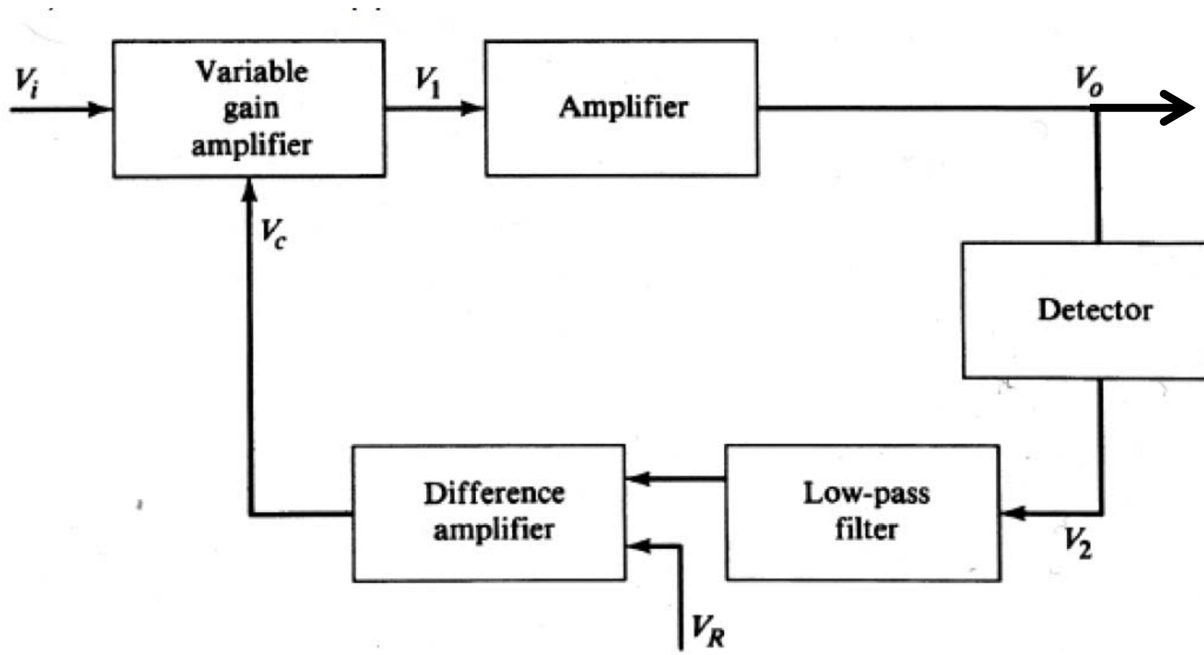


Main Synchronisation Steps

1) Frame detection (coarse timing estimation).
   - Settling of Automatic Gain Control (AGC)
   - Auto-correlation (short preamble symbols)
2) Carrier frequency offset estimation and correction.
3) Determination of the symbol timing (fine timing estimation).
   - Cross-correlation (long preamble symbols)
4) Extraction of the reference channel estimation.
5) Data reordering -> Signal Field decoding -> Data decoding

Automatic Gain Control (AGC)-Operation

- An AGC is used in the receive path of the analog frontend to normalize the signal level
- The AGC control signal (V_c) should settle (stabilize) during the short preamble



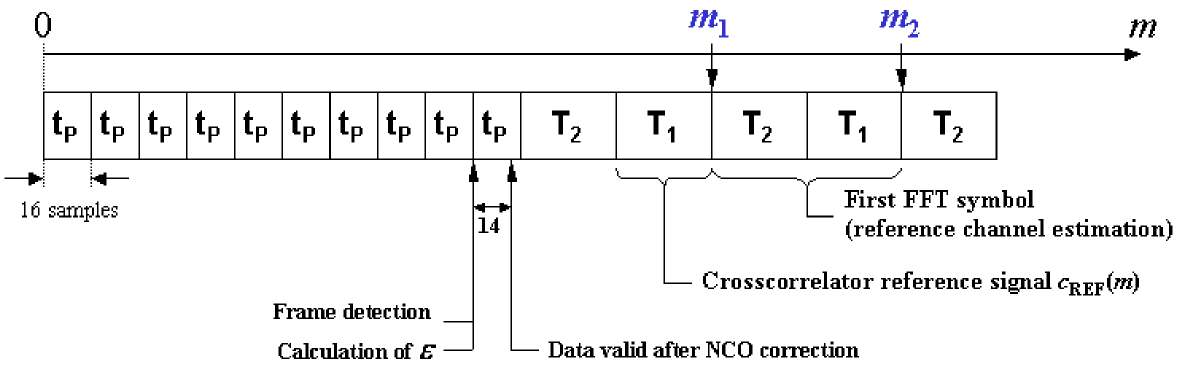
AGC Block Diagram

V_i – Input signal
V_o – Output signal
V_c – Control signal
V_R – Reference signal

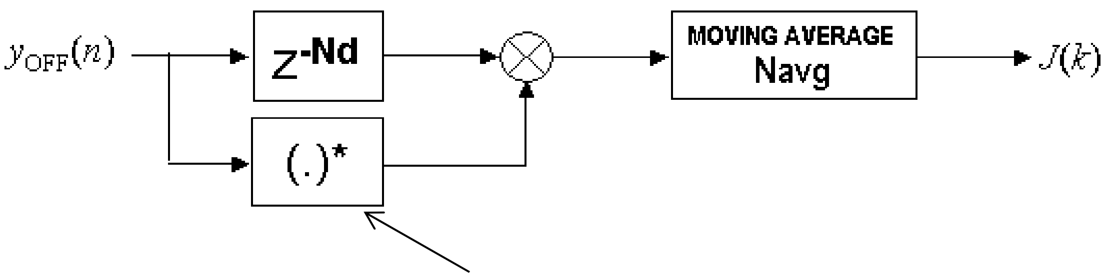
Source: Iulian Rosu, http://www.qsl.net/va3iul/

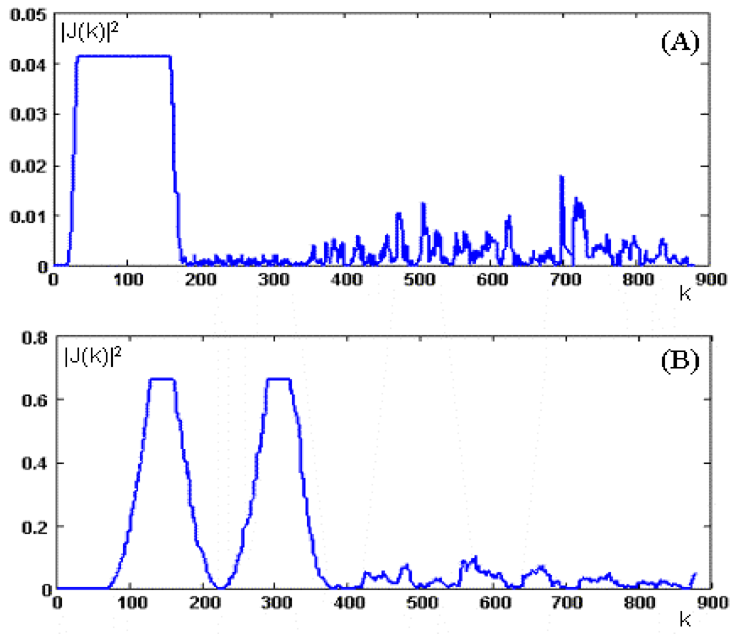
Timing Synchronisation using Preamble

IEEE802.11a Preamble structure:



General autocorrelator architecture:

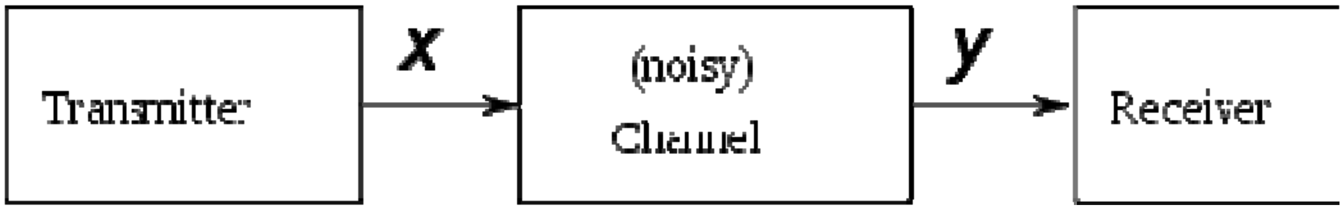




Autocorrelation applied to the IEEE 802.11a preambles:
(A) Nd=16, Navg=16
(B) Nd=64, Navg=64

Source: Alfonso Troya Ph.D.

Channel Capacity: Shannon Theorem [Wikipedia]



- The **Shannon limit** or **Shannon capacity** of a communications channel is the theoretical maximum information transfer rate of the channel, for a particular noise level.
- Stated by Claude Shannon in 1948 (with sketchy proof)
- The first rigorous proof by Amiel Feinstein in 1954.
- The Shannon theorem states that given a noisy channel with channel capacity *C* and information transmitted at a rate *R*, then if R<C there exist codes that allow the probability of error at the receiver to be made arbitrarily small.
  - ➢ This means that, theoretically, it is possible to transmit information nearly without error at any rate below a limiting rate, *C*.

AWGN Channel Capacity

$$C_{awgn} = W \log_2 \left(1 + \frac{\bar{P}}{N_0 W} \right) \quad \text{[bits/s]}$$

- If the average received power is $\bar{P}$ ***[W]*** and the noise power spectral density is N_0 ***[W/Hz]***, the AWGN channel capacity is C_{awgn}
- ***W*** is the used bandwidth
- $\bar{P}/(N_0 * W)$ is the signal-to-noise-ratio (SNR) at the receiver

Example II (WLAN)

- Example II:
  - Consider the operation of a WLAN modem IEEE802.11a. The channel spacing is 20 MHz and the used bandwidth is approximately 16 MHz. The SNR for a good channel and low distance can be about 100 (= 20 dB).
  - Therefore:

$$C = 16*10^6 \text{ MHz} \times \log_2(1 + 100) \text{ bits}$$
$$= (16*10^6 \text{ MHz})*(6.7) \text{ bits}$$
$$\approx 106.5 \text{ Mb/s}$$

Friis free-space path-loss equation

Received Power:

- $P_{rcvd}(d) = P_{tx} + G_t + G_r - PL$ [all in dB]

Path loss (PL) in free space:

$PL(a) = (4*\pi*d*f/c)^2$ (direct form)

$PL(log) = 10*\log_{10}(4*\pi*d*f/c)^2 = 20*\log_{10}(f) + 20*\log_{10}(d) + 20*\log_{10}(4\pi/c)$

(logarithmic form)

d_0

- d: Distance between Sender and Receiver
- f: Carrier Frequency
- c: Speed of light (300000km/s)

Link Budget Calculation

- TX-Power	P_{TX}	
- Friis equation (path loss)	L_{FS}	(=PL)
- Antenna gain TX	G_{TX}	
- Antenna gain RX	G_{RX}	
- RX Losses (cables, connectors, …)	L_{RX}	
- Miscellaneous losses (Implementation losses)	L_M	
- RX-Noise Figure	NF	
- Shannon channel capacity	C	

d_0

Received Power:

$$P_{RX}\,(dB) = P_{TX} + G_{TX} + G_{RX} - L_{FS} - L_{RX} - L_M$$

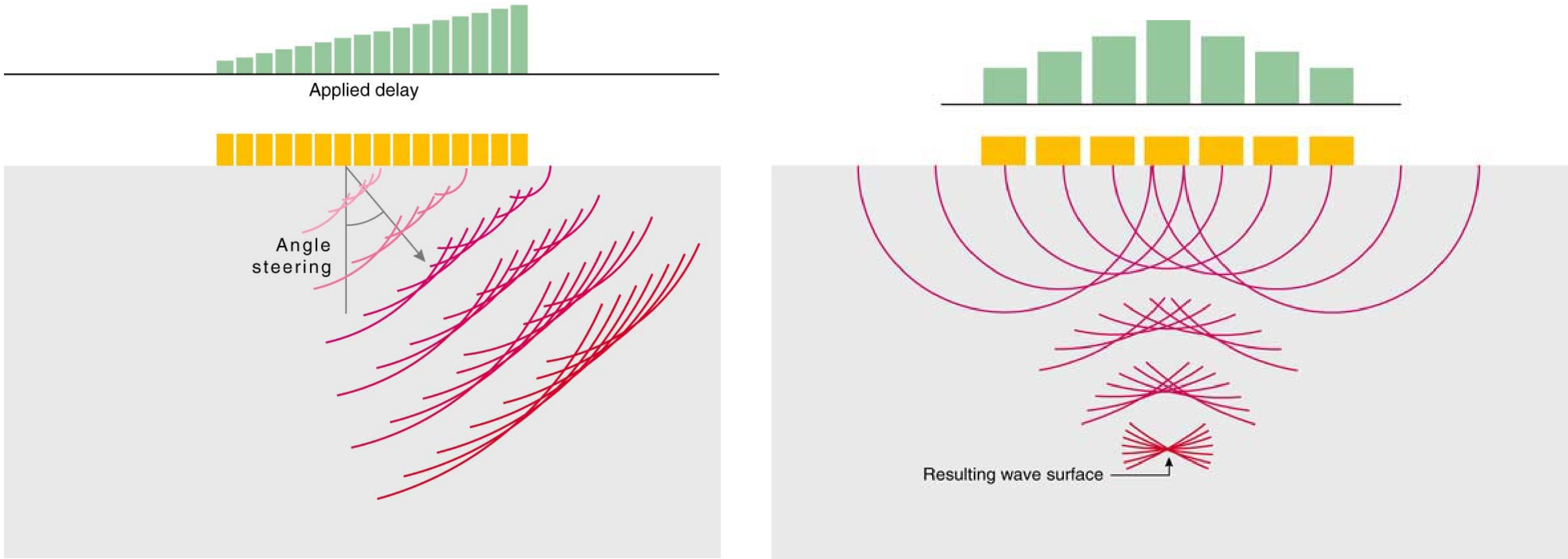
OFDM System Parameter Choice

Channel Parameters (T_{RMS}, Mobility, …)

- Strong multipath propagation and high bit rate
  - ➢ OFDM (otherwise single carrier scheme sufficient)
- Delay spread of channel T_{RMS} determines :
  - ➢ guard time (cyclic prefix): $T_{CP} \sim 2\ldots 4 \times T_{RMS}$
  - ➢ $T_{OFDM} \sim > 5 \times T_{CP}$ -> ($T_{sym} = T_{CP} + T_{FFT}$)
  - ➢ $T_{FFT} \sim > 4 \times T_{CP}$
- Number of subcarriers:
  - ➢ $N_{sub} = B \times T_{FFT}$
  - ➢ N_{sub} = target bitrate / (bitrate/subcarrier) (-> modulation scheme)
- Channel Coherence Time T_C determines:
  - ➢ Pliot scheme (time axis)
- Channel Coherence Bandwidth B_C
  - ➢ Pilot scheme (frequency axis)

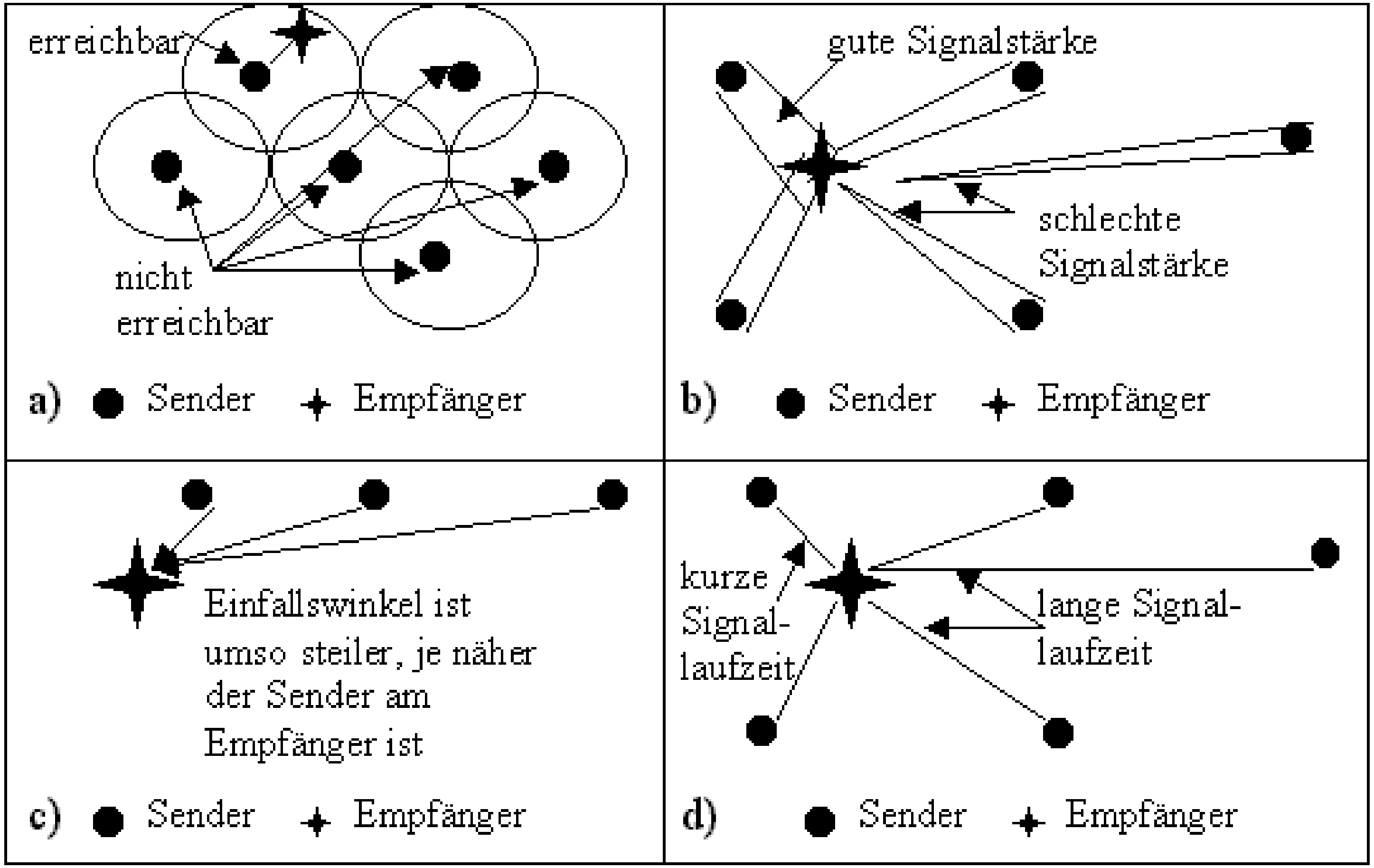
Beamforming -prinziple

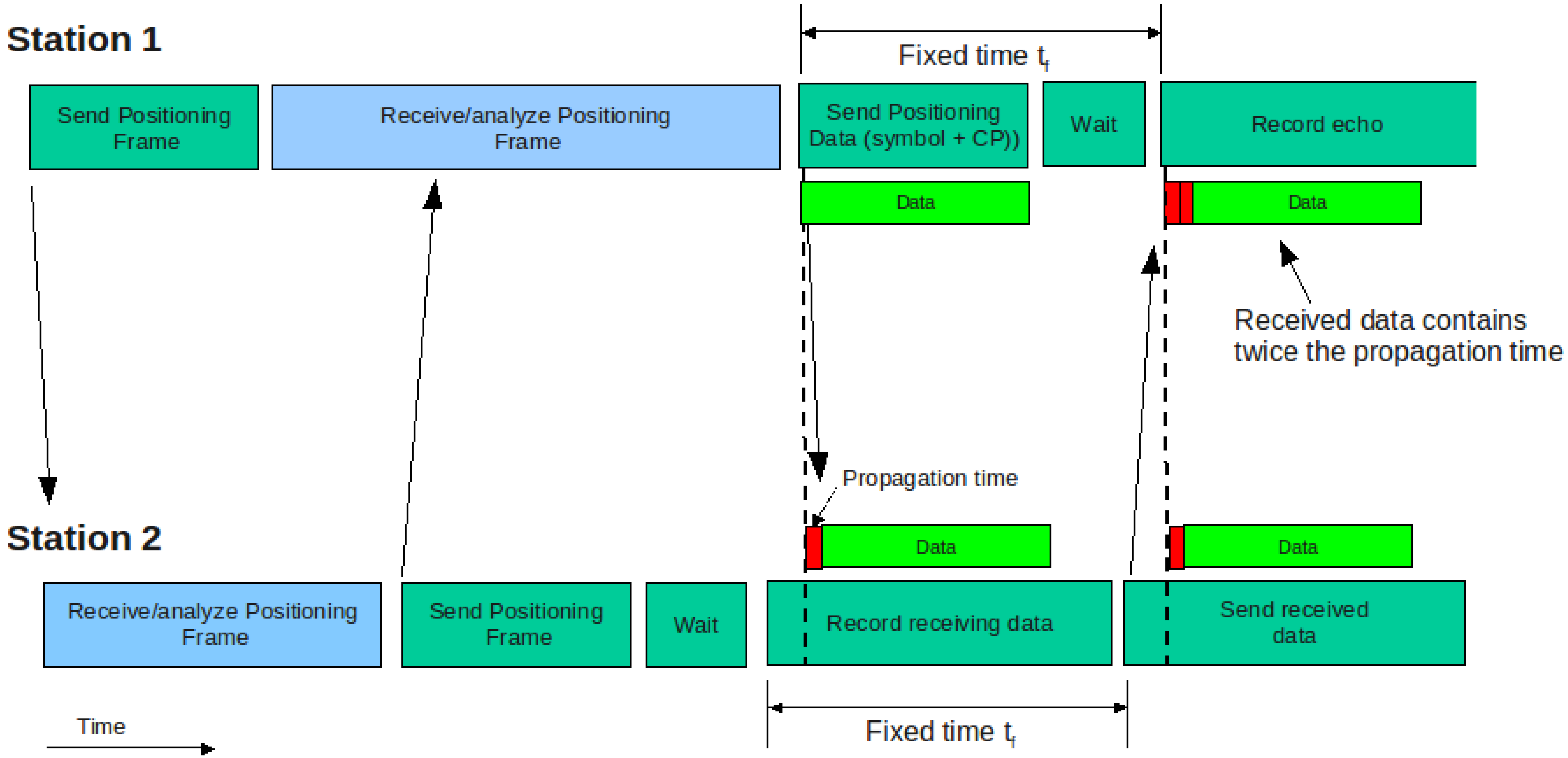
- Beamsteering and Beamfocussing



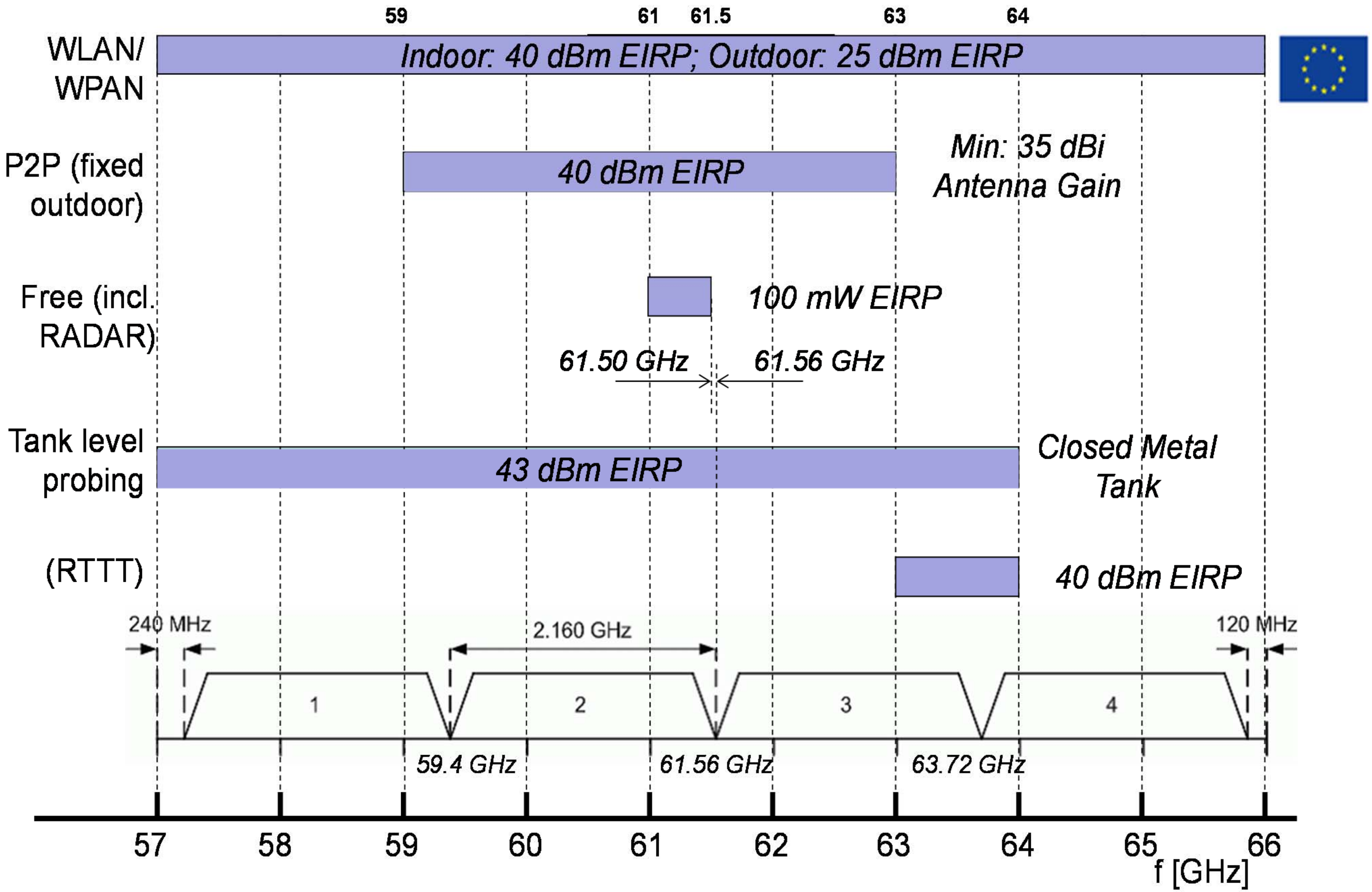
Source: http://www.detectunit.co.za/phased_arry.pdf

Breitbandkommunikation - Lokalisierung




Station 1
Fixed time t_f
Send Positioning Frame
Receive/analyze Positioning Frame
Send Positioning Data (symbol + CP))
Wait
Record echo
Data
Data
Received data contains twice the propagation time
Propagation time
Station 2
Data
Data
Receive/analyze Positioning Frame
Send Positioning Frame
Wait
Record receiving data
Send received data
Time
Fixed time t_f

Frequency Regulation in EU + Channel Plan



Main PHY Parameters for ECMA & IEEE Standards

Property or Parameter	ECMA 387 (Type 1)	IEEE802.15.3c (HSI-OFDM)	IEEE802.11ad (Draft 1.0)
Number of OFDM subcarriers	512	512	512
OFDM Sampling rate	2592 MHz	2640 MHz	2640 MHz
SC-Chip rate; Symbol rate	1728 MHz	1760 MHz	1760 MHz
OFDM Symbol duration	222.23 ns	218.18 ns	242 ns
OFDM Data rate	1.008 to 4.032 Gb/s	1.540 to 5.775 Gb/s	0.693 to 6.757 Gb/s
SC Data rate	0.397 to 6.350 Gb/s	0.361 to 5.280 Gb/s	0.385 to 4.620 Gb/s
Support of Beamforming	Yes	Yes	Yes
Support of unequal error protection (UEP)	Yes	Yes	No
Duplex mode	TDD	TDD	TDD
Channel Access in Command Exchange Period	CSMA/CA	CSMA/CA	CSMA/CA
Address space for Terminals	16 bit	8 bit	48 bit
Support of Channel-Bonding	Yes (1, 2, 3 and 4)	No	No

Open Issues and Future Work

General Work on Communication Systems

- Combination of data transmission with localization and RADAR
- Beamforming allows higher data rates and distance
- Polarisation diversity allows higher data rates (up to 2x)
- Cooperative algorithms in large networks
- Higher frequency and higher bandwidth & data rate
- Multi frequency systems (cognitive radio)
- Massive MIMO, Line-of-Sight MIMO, Multi-User MIMO, Orbital Angular Momentum (OAM)
- Combination of radio- with free-space optics systems
- ...

Optimisation and Implementation

- New optimized algorithms e.g. for error correction etc.
- Reducing power consumption
- Miniaturization
- Reduced cost
- ...

… Final Remarks

- The required data rate for wired and wireless communication systems is growing exponentially – the growth rate for wireless systems is significantly higher
- The license-free bandwidth at 60 GHz is enormous
  - This enables very high data rates for wireless communication
- Due to small wave length (5 mm), beamforming techniques can be easily implemented
  - This reduces interference and increases the data rate further
- A combination of data transmission with ranging and localization can be implemented with little additional effort
  - Localization enables many additional applications
- Future cellular networks (5G) work very closely together with WLANs, are very heterogeneous and have to incorporate legacy devices
  - A number of technologies operating in different frequency bands have to seamlessly work together (3G, 4G, 5G, WLAN,)

Broadband Wireless Communications is a hot research topic!

Anmeldung zur Pruefung nicht vergessen!!!