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microelectronics



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

Vorlesung Drahtlose Breitbandkommunikationssysteme

Prof. Dr. Eckhard Grass grass@ihp-microelectronics.com
grass@informatik.hu-berlin.de

<http://www.informatik.hu-berlin.de/~grass/bbk>

Prüfungsthemen (u.a.):

- **Shannons Kanalkapazitäts-Gleichung**
- **Friis Pfadverlust Gleichung**
- **Link-budget Berechnung**

- **Kanaleigenschaften und Kanalmodellierung**
 - Delayspread
 - Dopplerverschiebung
 - Frequenzoffset

- **Struktur und Funktionsweise eines OFDM-Basisbandprozessors**
 - Modulation
 - Kanalkodierung

- **Entwurf eines OFDM-Systems**
 - Guardintervall / Cyclic Prefix
 - Unterträgerabstand
 - Anzahl der Unterträger

Termine

Prüfungstermine Informatik/BBK:

http://www.informatik.hu-berlin.de/studium/Prf_term/muendlich

Institut für Informatik - Prüfungsplan Wintersemester 2013/14

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 - in Abhängigkeit von der jeweils zutreffenden Prüfungsordnung - 2 Arbeitstage bzw. eine Woche vor dem Prüfungstermin.

...

Drahtlose Breitbandkommunikation

Prüfungsart	Prüfer/in	Termin/e	Ort	Anmeldung	Abmeldung
mündliche Prüfung	Prof. E. Grass	04.03.2014 07.03.2014 08.04.2014	RUD 25, 4.323	- ab: 10.02.2014 - bis: siehe Hinweis oben - bei Frau Schoch, RUD 25, 3.302	- bis: siehe Hinweis oben - unter: schochsi@informatik.hu-berlin.de

Aktuelle Forschungsziele und „Calls“

BMBF (D-National)

„Tactile Internet“

-> minimum Latency

1. Zuverlässige Drahtlose Kommunikation in der Industrie (2013)
 - Maschineneinstellung (**Sicherheit, Lokalisierung, ...**)
 - Augmented Reality (**Datenrate, Lokalisierung, ...**)
2. Kognitive Radio (2012)
 - Dynamische Systemlösungen für Funkanwendungen im heterogenen Kommunikationsumfeld
 - Neuartige Spektrumsnutzung sowie dynamisches Spektrumsmanagement

Aktuelle Forschungsziele und „Calls“

EU – Horizon 2020

1. Advanced **5G Network** Infrastructure for the Future Internet
 - Radio network architecture and technologies
 - convergence beyond last mile
 - Network **virtualisation** and Software Networks
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**, and providing citizens and businesses with a wide range of innovative applications and services

Aktuelle Forschungsziele und „Calls“

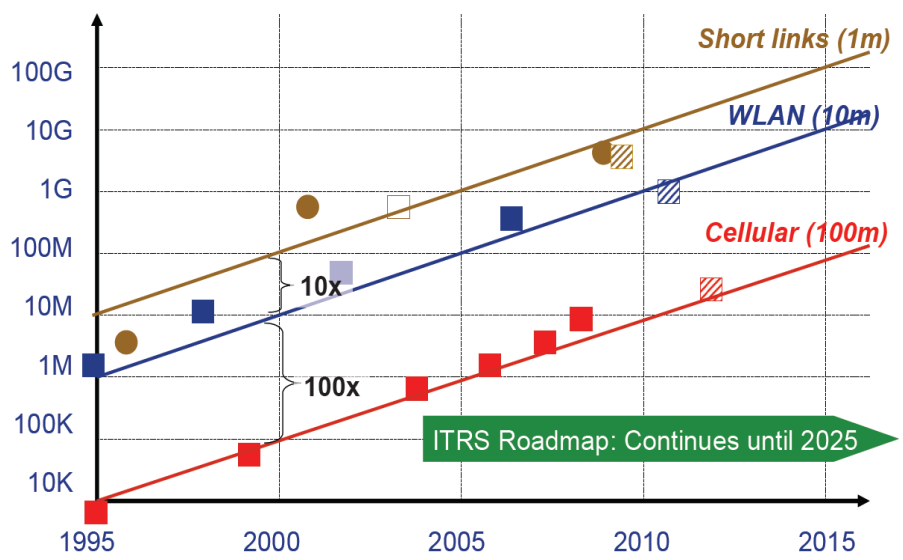
EU – Horizon 2020

Big data, internet of things 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

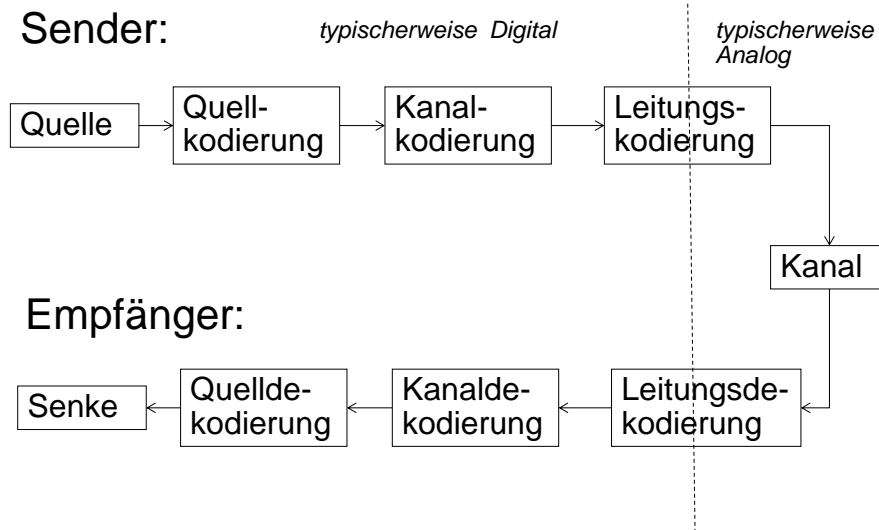
Wireless Systems Roadmap (Source G. Fettweis)



Mobile communication OSI-layer model

<ul style="list-style-type: none"> • Application layer 	<ul style="list-style-type: none"> • service location • new applications, multimedia • adaptive applications 	<ul style="list-style-type: none"> • Application Layer • Presentation Layer • Session Layer
<ul style="list-style-type: none"> • Transport layer 	<ul style="list-style-type: none"> • congestion and flow control • quality of service 	<ul style="list-style-type: none"> TCP UDP
<ul style="list-style-type: none"> • Network layer 	<ul style="list-style-type: none"> • addressing, routing, device location • hand-over 	<ul style="list-style-type: none"> IP IPsec
<ul style="list-style-type: none"> • Data link layer 	<ul style="list-style-type: none"> • authentication • media access • multiplexing • media access control (MAC) 	
<ul style="list-style-type: none"> • Physical layer 	<ul style="list-style-type: none"> • encryption • modulation • Interference • attenuation • frequency 	

Breitbandkommunikation – Einführung (PHY-Modell)

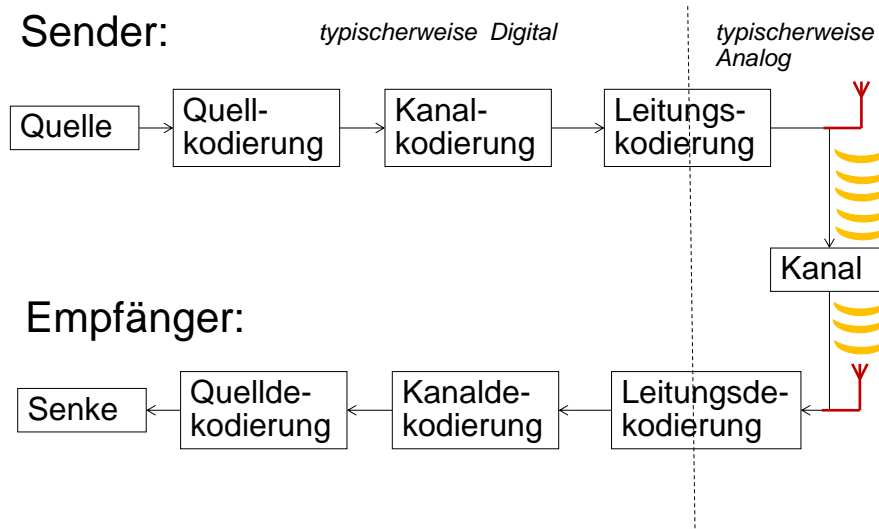


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Drahtlose Breitbandkommunikation (BBK)

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Breitbandkommunikation – Einführung (PHY-Modell)



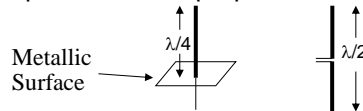
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Drahtlose Breitbandkommunikation (BBK)

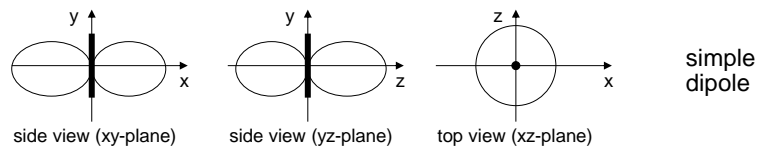
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Antennas: simple dipoles

- 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



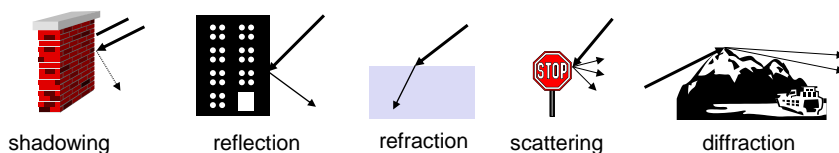
- Example: Radiation pattern of a simple Hertzian dipole



- 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 ($10 \cdot \log_{10} P_i / P_{\max}$)

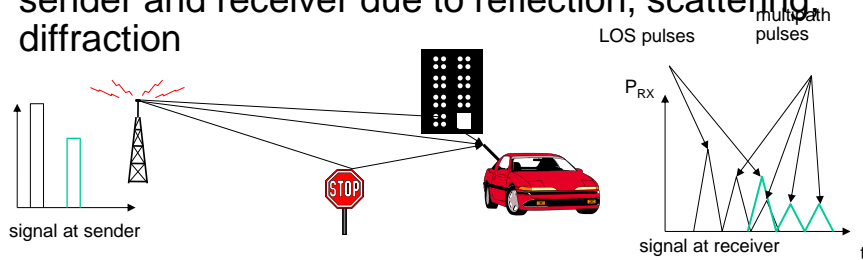
Signal propagation

- Propagation in free space always like light (straight line)
- Receiving power proportional to $1/d^2$
 (d = distance between sender and receiver)
- Receiving power additionally influenced by
- fading (frequency dependent; H₂O resonance at 2.5 GHz; O₂ Resonance at 60 GHz)
- shadowing
- reflection at large obstacles
- refraction depending on the density of a medium
- scattering at small obstacles
- diffraction at edges



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

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Drahtlose Breitbandkommunikation (BBK)

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Digital modulation

- Modulation of digital signals known as “Shift Keying”

- Amplitude Shift Keying (ASK):

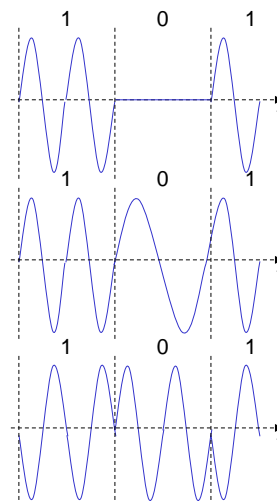
- very simple
- low bandwidth requirements
- very susceptible to interference

- Frequency Shift Keying (FSK):

- needs larger bandwidth

- Phase Shift Keying (PSK):

- more complex
- robust against interference



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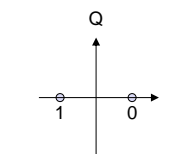
Drahtlose Breitbandkommunikation (BBK)

WS2013/14

Advanced Phase Shift Keying

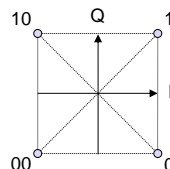
- **BPSK (Binary Phase Shift Keying):**

- bit value 0: sine wave
- bit value 1: inverted sine wave
- very simple PSK
- low spectral efficiency
- robust, used e.g. in satellite systems

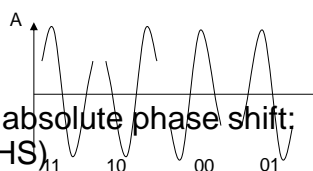


- **QPSK (Quadrature Phase Shift Keying):**

- 2 bits coded as one symbol
- symbol determines shift of sine wave
- needs less bandwidth compared to BPSK
- more complex

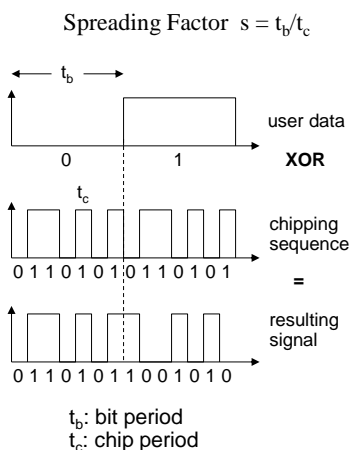


- Often also transmission of relative, not absolute phase shift:
DQPSK - Differential QPSK (IS-136, PHS)

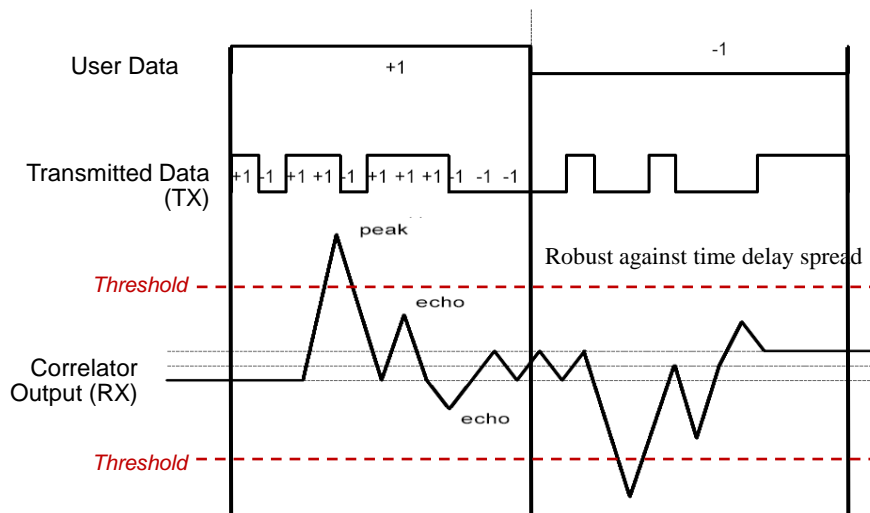


DSSS (Direct Sequence Spread Spectrum) I

- 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



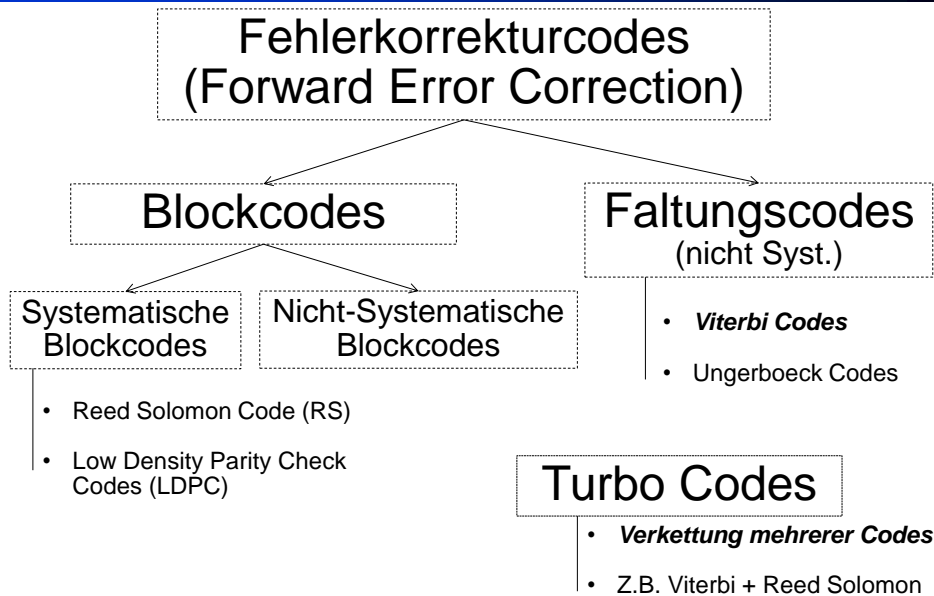
Example Barker Code



Kanalcodierung

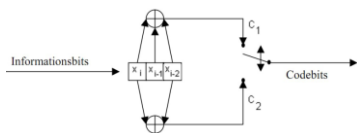
- Einfügen von Redundanz vor der eigentlichen Datenübertragung im Sender
- Übertragung über gestörten Kanal (Bitfehler)
- Fehlerkorrektur und Entfernen der Redundanz im Empfänger

Kanalcodierung



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

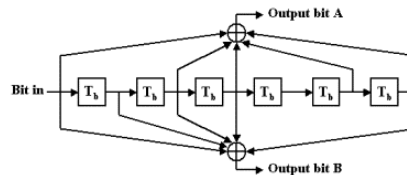


Constraint length (K) = 3

$$c_1 = X_i + X_{i-1} + X_{i-2}$$

$$c_2 = X_i + X_{i-2}$$

Convolutional Code ($7_8, 5_8$)



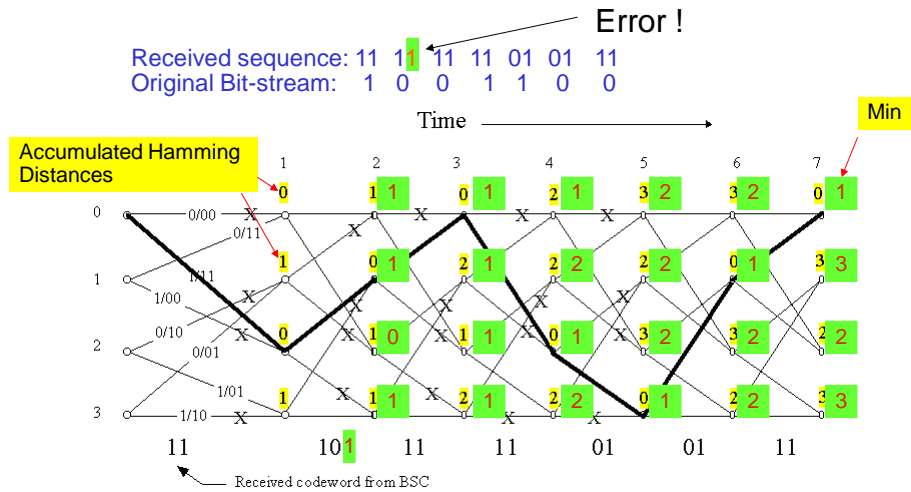
Constraint length (K) = 7, $R=1/2$

$$\text{Out_A} = g_1(z) = 1 + z^2 + z^3 + z^5 + z^6$$

$$\text{Out_B} = g_2(z) = 1 + z + z^2 + z^3 + z^6$$

Convolutional Code (133,171)

Viterbi Decoder - Principle Operation



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, ...)

MCM Model for Transmission

N = number of subcarriers

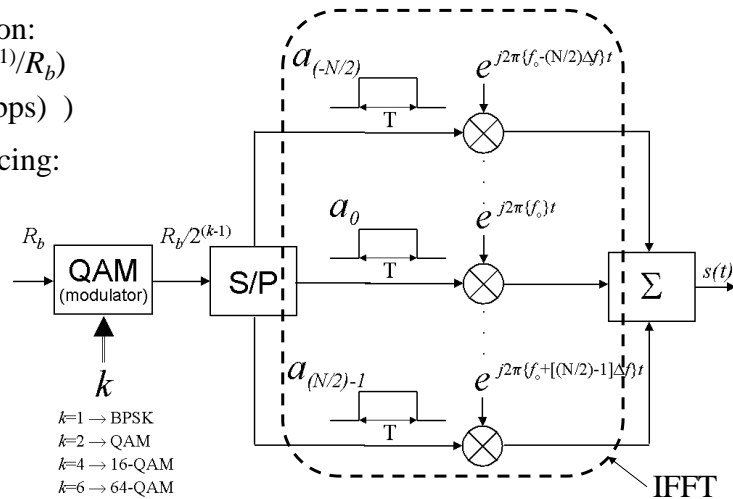
Symbol duration:

$$T_s = T = N(2^{(k-1)}/R_b)$$

($R_b \equiv$ bit rate (bps))

Subcarrier spacing:

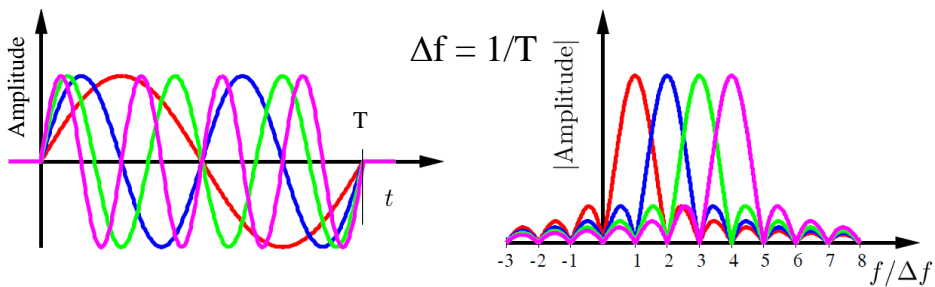
$$\Delta f = 1/T$$



Orthogonality in Time Domain

Example: WLAN IEEE 802.11a

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



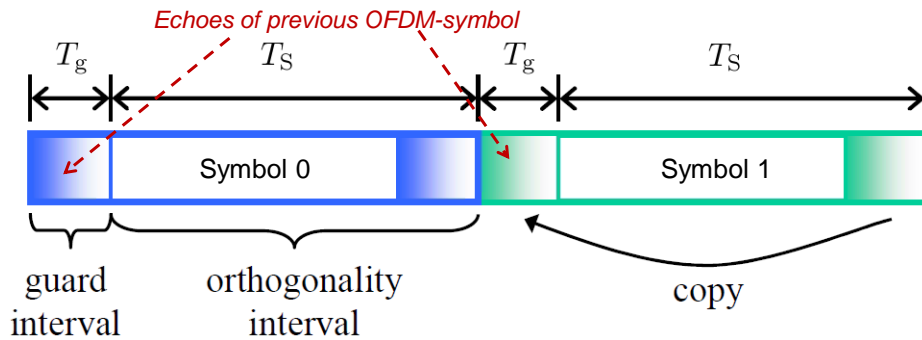
Source: L. Häring (Uni Duisburg, 2011)

Guard Interval

$T_g \sim \text{max. delay spread of channel } (T_{\text{rms}})$

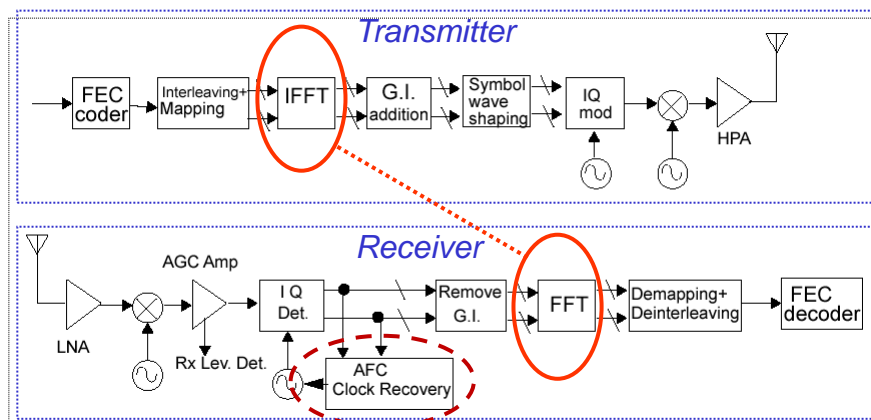
-> Reflections (echos) of previous symbol fall into the guard interval of the actual symbol

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



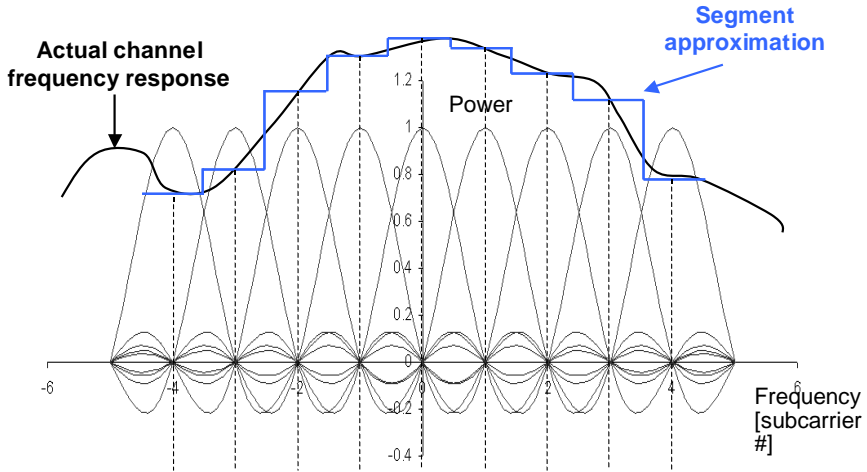
Source: L. Häring (Uni Duisburg, 2011)

Detailed Structure of OFDM Transceiver

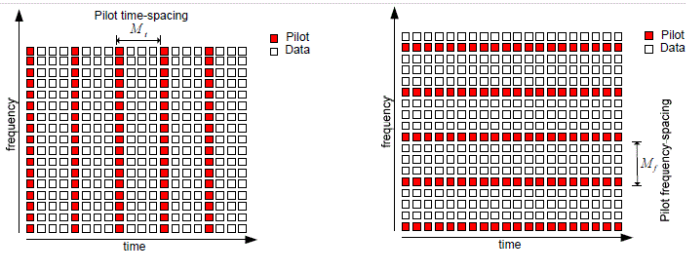


OFDM: Effects of fading channels

• CHANNEL'S PIECEWISE APPROXIMATION

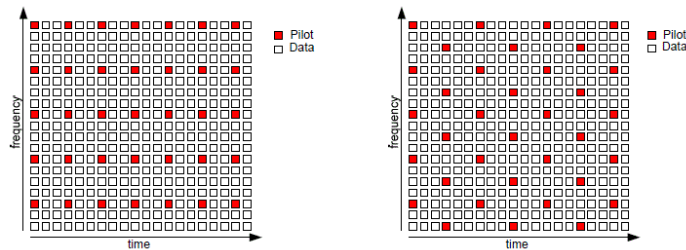


OFDM Channel Estimation using „Pilot Carriers“



(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

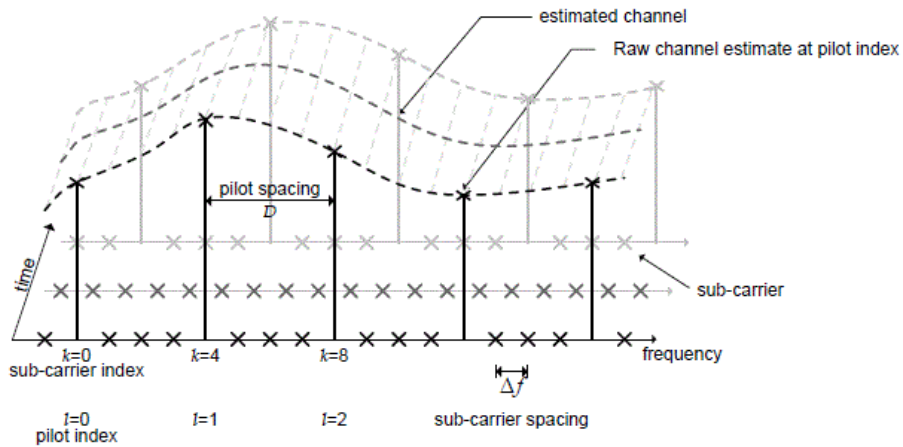


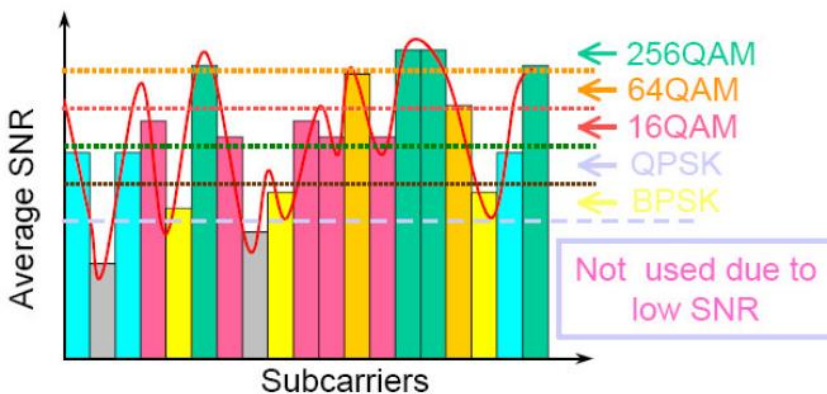
Figure 4-6. Channel estimation in time-frequency domain

[From Akram (Nokia)]

OFDM-Nachlese: Adaptive Modulation („Water filling“)

Adaptive Modulation:

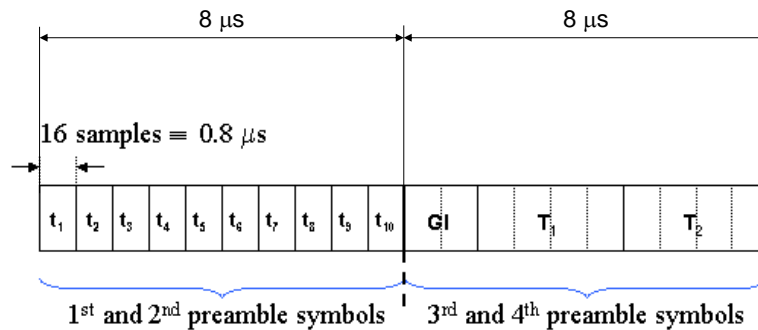
1. Special version of OFDM where, depending on the SNR-level, the modulation scheme for every subcarrier is adapted optimally
2. High SNR -> High modulation scheme (i.e. 64 QAM)
3. Low SNR -> low modulation scheme (i.e. BPSK) or subcarrier not used
4. Advantage: Optimal use of channel
5. Disadvantage: Signaling overhead
(Receiver needs to know modulation scheme for each subcarrier.)



Source: M. Essam Khedr, "Adaptive Modulation in OFDM", Fall 2007

Timing Synchronisation using Preamble

IEEE802.11a Preamble structure:

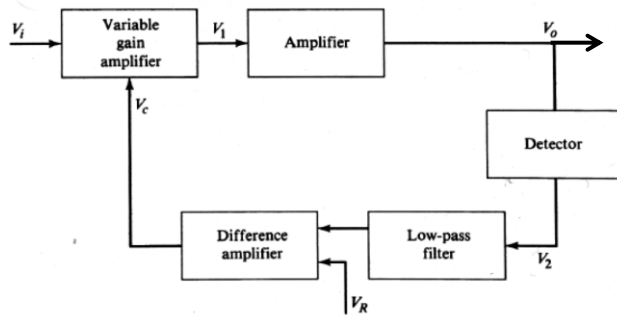


Main Synchronisation Steps

- 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

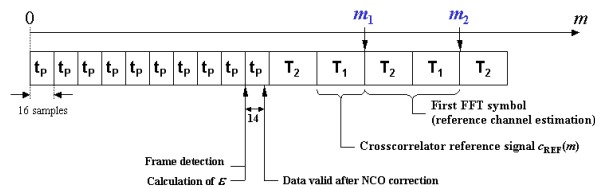


V_i – Input signal
 V_o – Output signal
 V_c – Control signal
 V_R – Reference signal

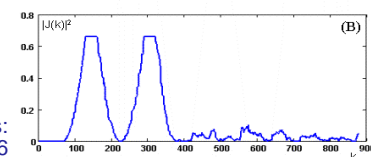
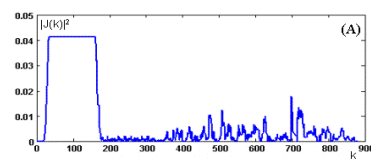
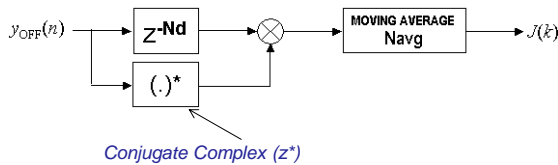
Source: Iulian Rosu, <http://www.qsl.net/va3iul/>

Timing Synchronisation using Preamble

IEEE802.11a Preamble structure:



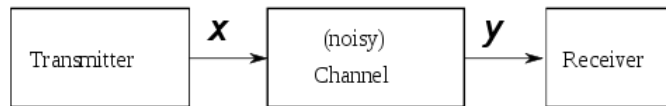
General autocorrelator architecture:



Autocorrelation applied to the IEEE 802.11a preambles:
 (A) $N_d=16$, $N_{avg}=16$
 (B) $N_d=64$, $N_{avg}=64$

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 .

Shannon-Hartley Theoreme (for AWGN)

$$C = B \log_2 \left(1 + \frac{S}{N} \right)$$

- C : Channel capacity in bits per second;
- B : Bandwidth of the channel in hertz;
- S : Total received signal power over the bandwidth (in case of a modulated signal, often denoted C , i.e. modulated carrier), measured in watt or volt²;
- N : Total noise or interference power over the bandwidth, measured in watt or volt²; and
- S/N : Signal-to-noise ratio (SNR) or the carrier-to-noise ratio (CNR) of the communication signal to the Gaussian noise interference expressed as a linear power ratio (not as logarithmic decibels).

AWGN Channel Capacity

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

- 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:

$$PL(a) = (4 \cdot \pi \cdot d \cdot f / c)^2 \quad \text{(direct form)}$$

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

(logarithmic form)

- 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 | |

Received Power:

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

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): $T_{\text{CP}} \sim 2 \dots 4 \times T_{\text{RMS}}$
 - $T_{\text{OFDM}} \sim > 5 \times T_{\text{CP}} \quad \rightarrow (T_{\text{sym}} = T_{\text{CP}} + T_{\text{FFT}})$
 - $T_{\text{FFT}} \sim > 4 \times T_{\text{CP}}$
- Number of subcarriers:
 - $N_{\text{sub}} = B \times T_{\text{FFT}}$
 - $N_{\text{sub}} = \text{target bitrate} / (\text{bitrate/subcarrier}) \quad (-> \text{modulation scheme})$
- Channel Coherence Time T_{C} determines:
 - Pilot scheme (time axis)
- Channel Coherence Bandwidth B_{C}
 - Pilot scheme (frequency axis)

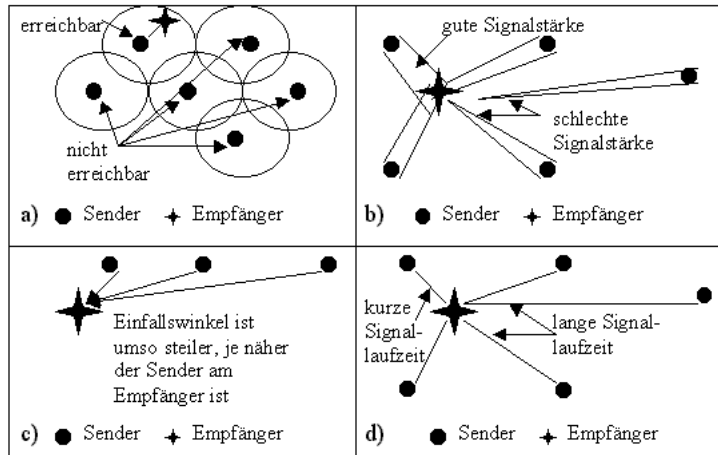
OFDM System Parameter Choice II

Example Parameters for OFDM-parameter choice (@ board)

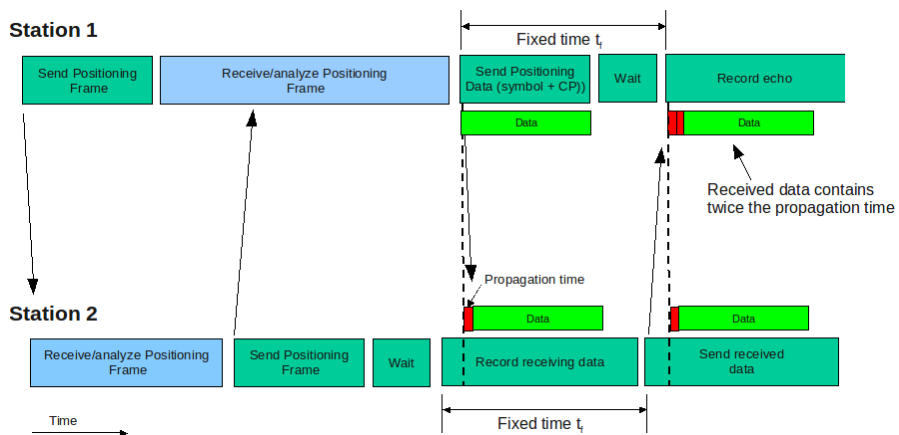
Channel properties / target parameters:

- Application scenario:
Large office; metal coated windows
- Delay spread of channel: $T_{\text{RMS}} = 200 \text{ ns}$
- Available bandwidth: $B = 20 \text{ MHz}$
- Target data rate: $R = 50 \text{ Mb/s}$
- Coherence time of channel: $T_{\text{C}} = 5 \text{ } \mu\text{s}$
- Coherence bandwidth of channel: $B_{\text{C}} = 5 \text{ MHz}$

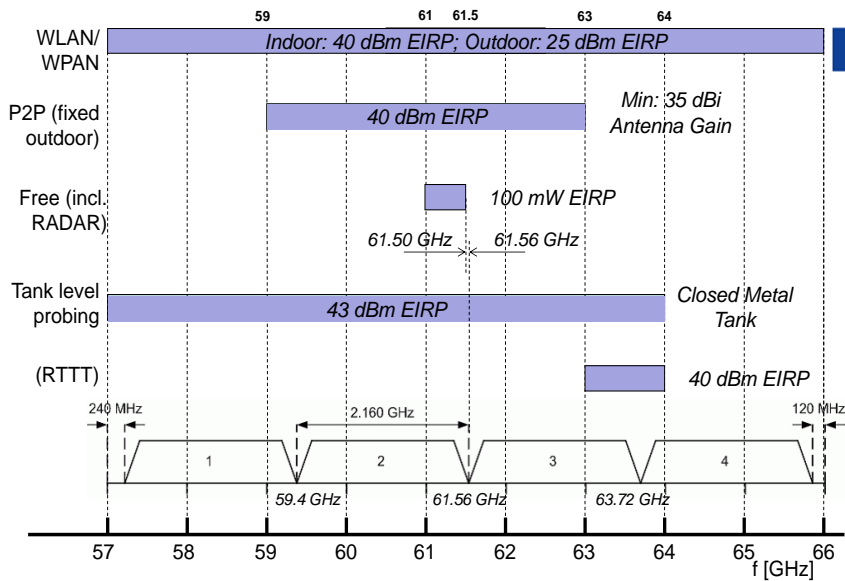
Breitbandkommunikation - Lokalisierung



Breitbandkommunikation - Lokalisierung



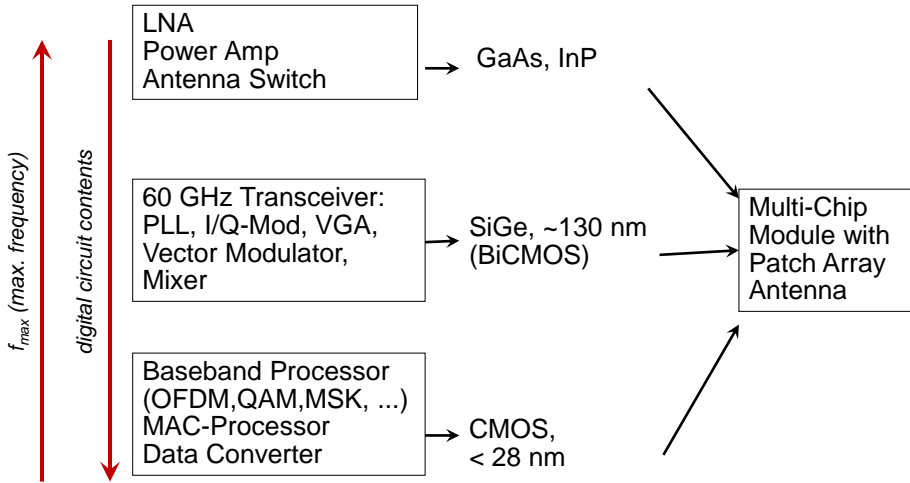
Frequency Regulation in EU + Channel Plan



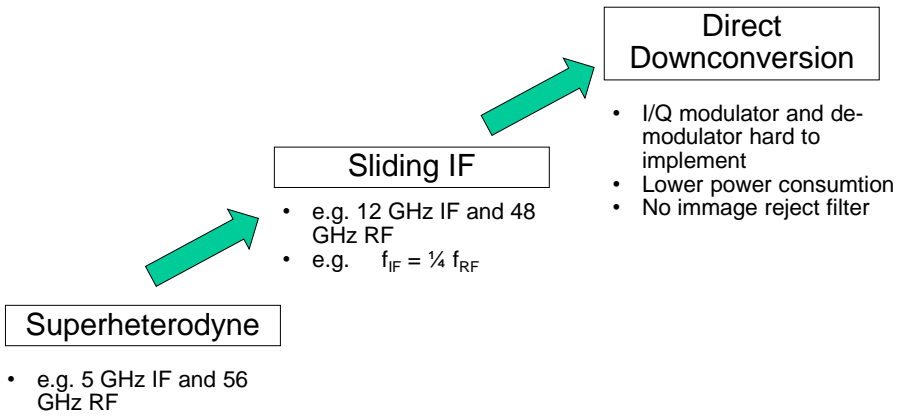
Main PHY Parameters for ECMA & IEEE Standards

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

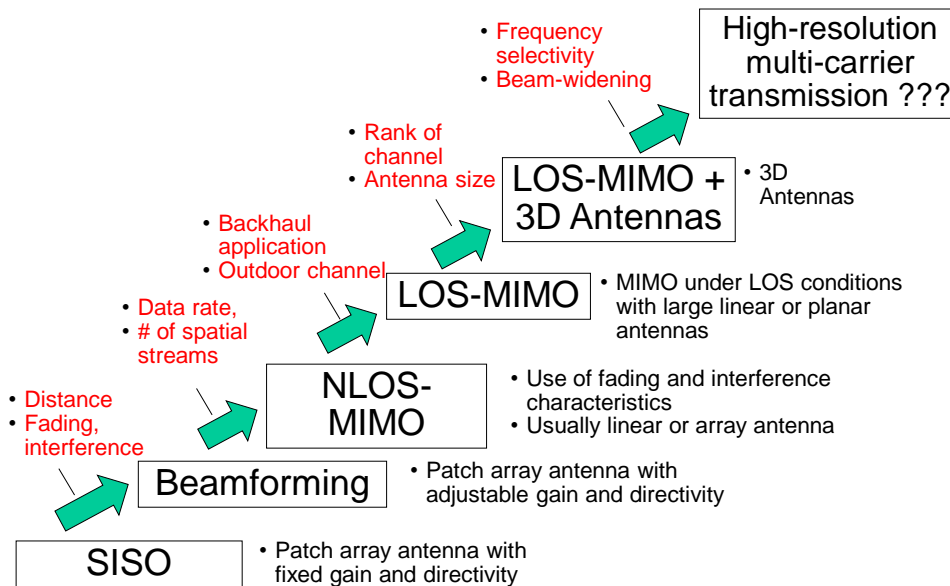
Implementation: Technology Trends



Trends: Transceiver Architecture



Trends: Transmission Schemes



Economical & Legal Issues

- Despite rapid exponential growth of data rate, the prices for a WLAN Terminal have to remain constant !
- Due to growing complexity, the development effort is growing too
 - Example: (IEEE802.11a : 40 Mio \$; IEEE 802.15.3c: 100 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)

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)
- Free-space optics systems
- ...

Optimisation and Implementation

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

Conclusions

- 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 WLANs are very heterogeneous and incorporate legacy devices
 - A number of technologies operating in different frequency bands have to seamlessly work together (Cognitive Radio)

Broadband Wireless Communications is a hot research topic!



Anmeldung zur Pruefung nicht vergessen!!!