Current Mobile Radio Systems

- Development of Cellular Standards
- Mobility vs. Data Rate
- Current Standards
  - GSM
  - DECT
  - UMTS
  - HiperLAN/2
  - IEEE 802.11

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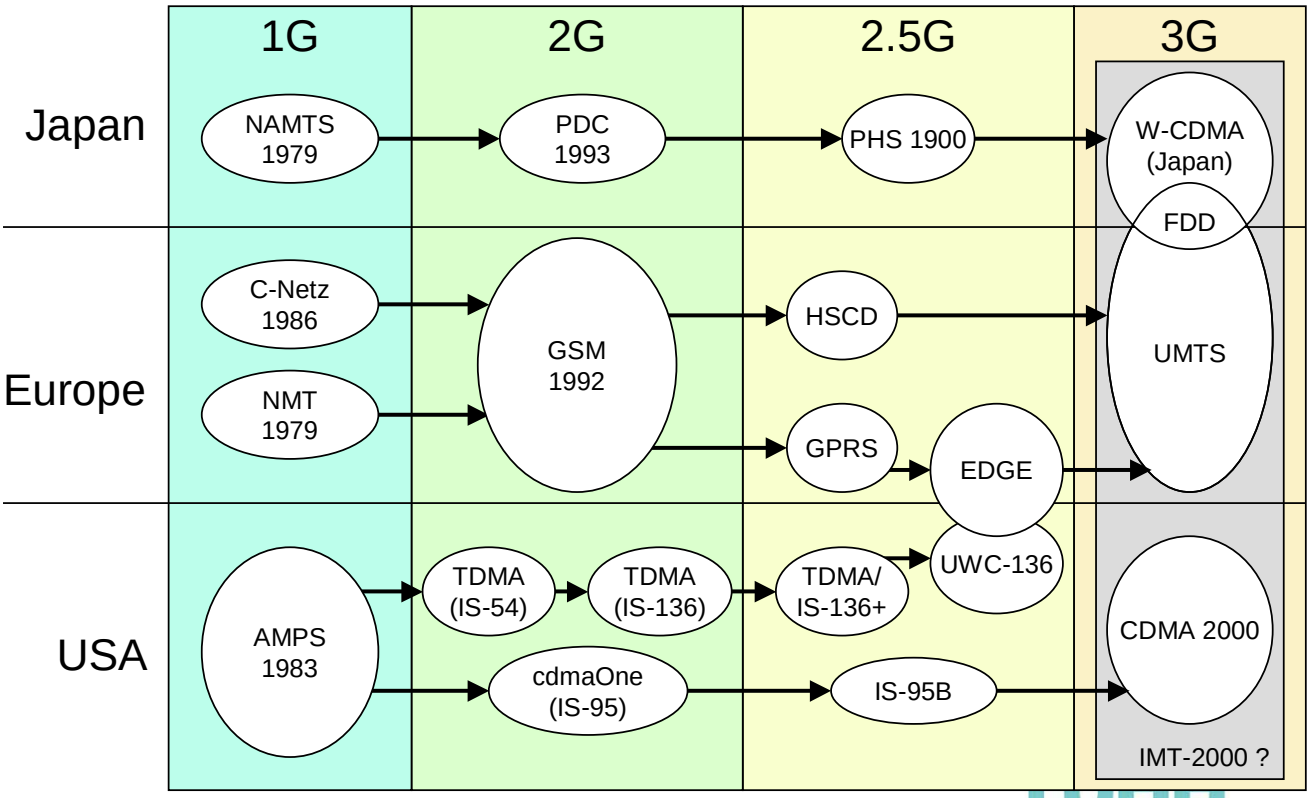
Development of Cellular Standards



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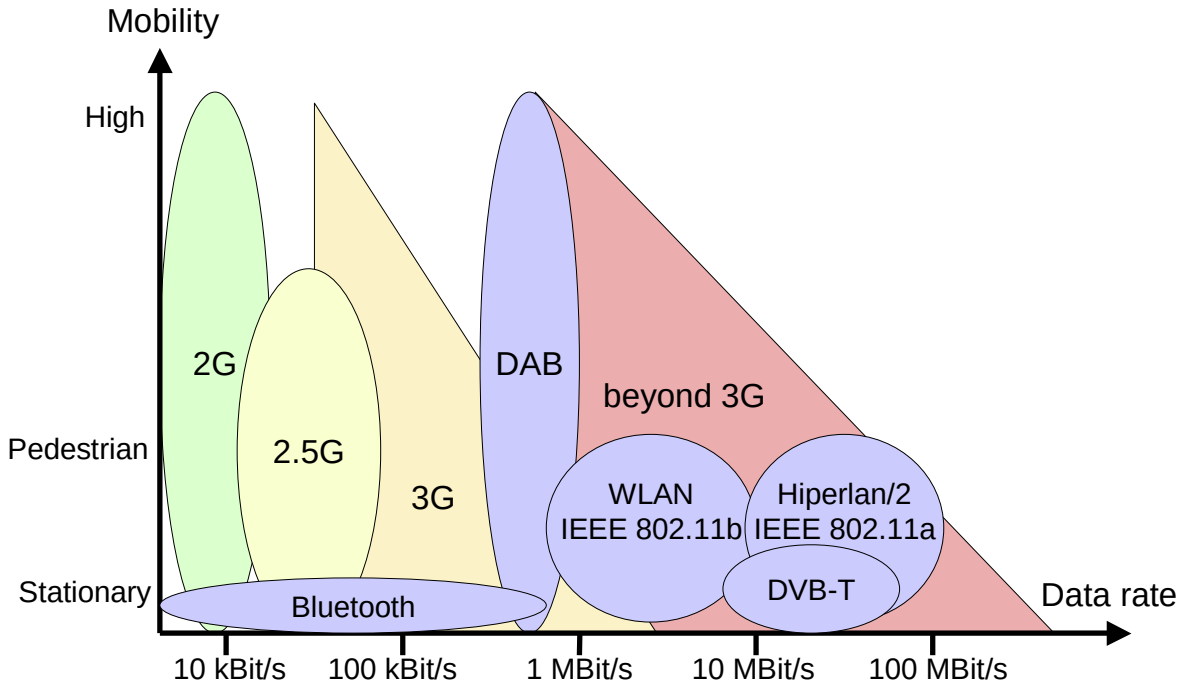
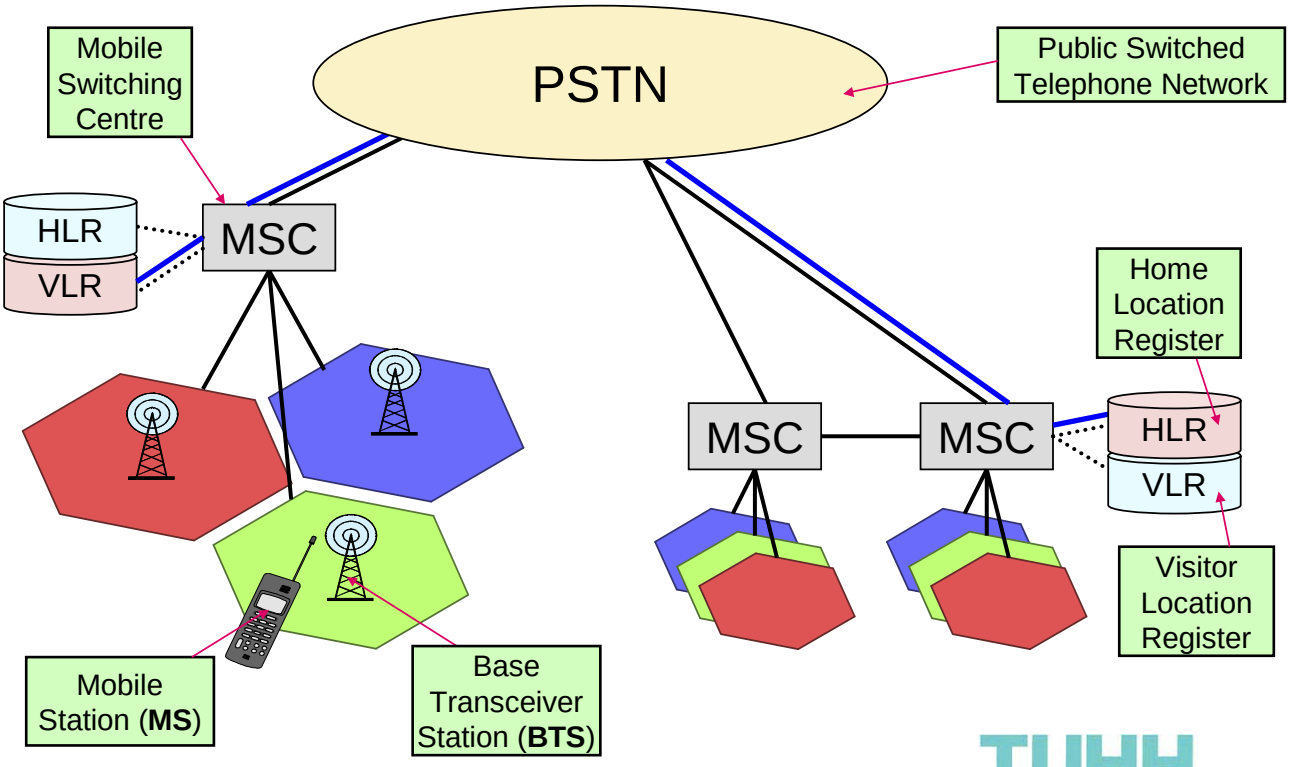
Mobility vs. Data Rate



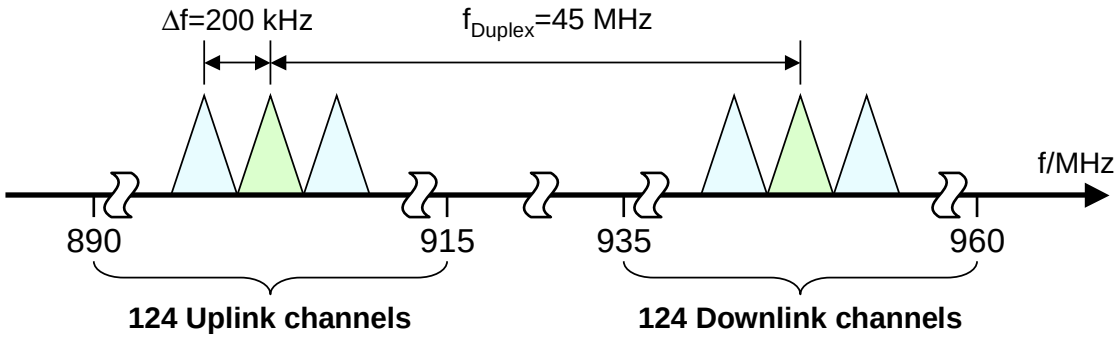
GSM History

1982	CEPT established the “Groupe Spéciale Mobile” (**GSM**) to develop a pan-European standard for mobile communications
1987	Decision for a **digital** system, first GSM specifications drafted
1989	• European Telecommunications Standards Institute (**ETSI**) defined GSM as digital cellular telephony standard • GSM renamed to Global System for Mobile Communications
1990	Phase 1 GSM 900 specifications are frozen
1992	• January - First GSM network operator in Finland • December - 13 networks on air in 7 areas (also start of “**D-Netz**” in Germany)
1994	• Phase 2 data/fax bearer services launched • Start of GSM 1800 (start of “**E-Netz**” in Germany)
today	Over 694 million customers worldwide, 70 percent of the total digital wireless market (status of May 2002)

GSM Functional Architecture



Frequency Allocation for GSM 900

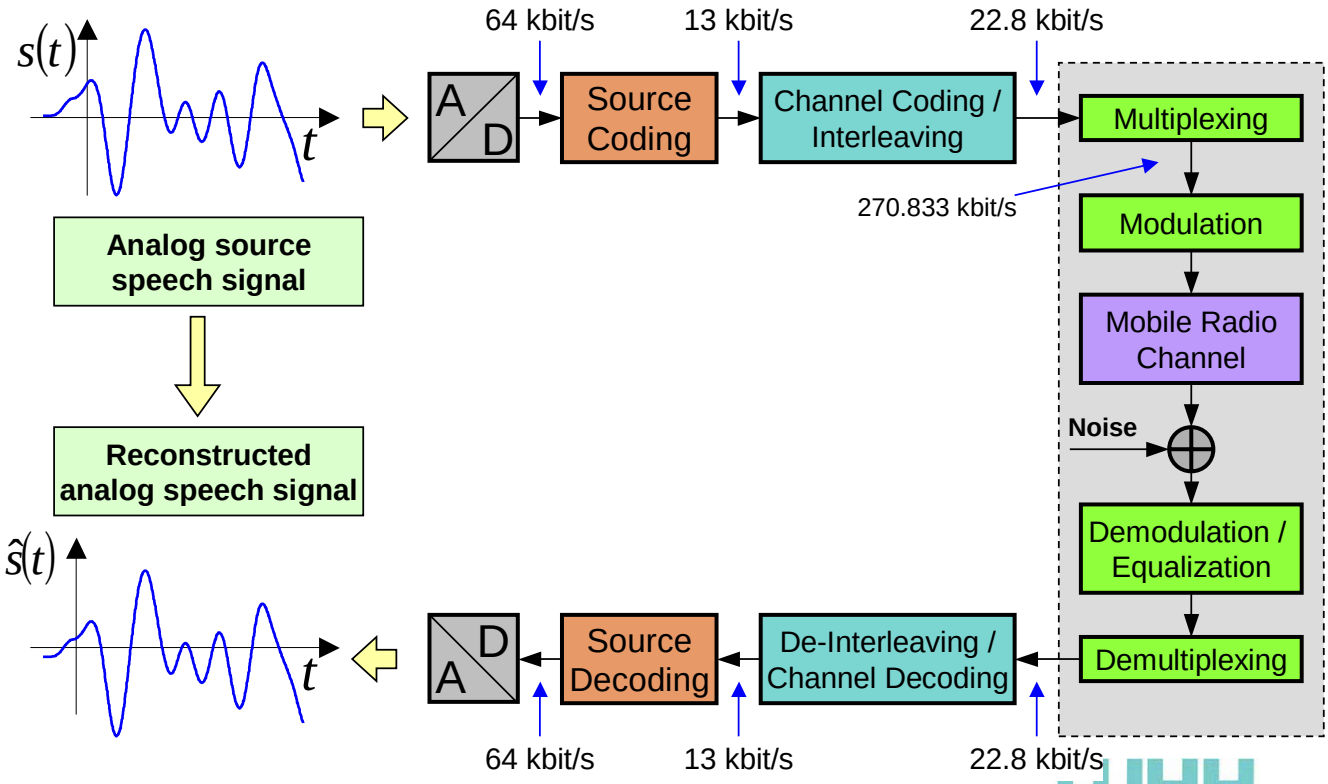


- Frequency Division Duplex (**FDD**)
- Frequency raster Δf=200 kHz
- Optional frequency hopping with $\Delta f_h = i * 200$ kHz
- Time Division Multiple Access with 8 user per channel

$$f_{\text{uplink}} = 890.2\,\text{MHz} + 0.2 \cdot (n-1)\,\text{MHz}\ , \quad (1 \le n \le 124)$$

$$f_{\text{downlink}} = 935.2\,\text{MHz} + 0.2 \cdot (n-1)\,\text{MHz}\ , \quad (1 \le n \le 124)$$

GSM Transmission Chain



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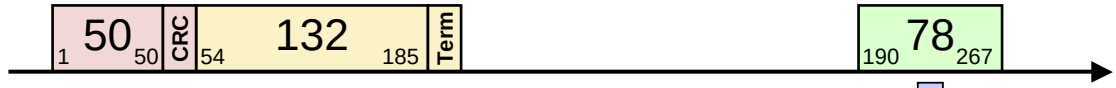
GSM Channel Coding

Error protection scheme for voice data in the GSM System

1. Sorting of 260 data bits according to bit importance

2. Generation of 3 parity bits for error detection (CRC), 4 bit Trellis termination (zeros)



3. Convolutional coder, code rate R=1/2, constraint length L=5

Input from source coding (RPE-LTP):	260 bit / 20 ms	= **13.0 kbit/s**
Output after channel coding:	456 bit / 20 ms	= **22.8 kbit/s**

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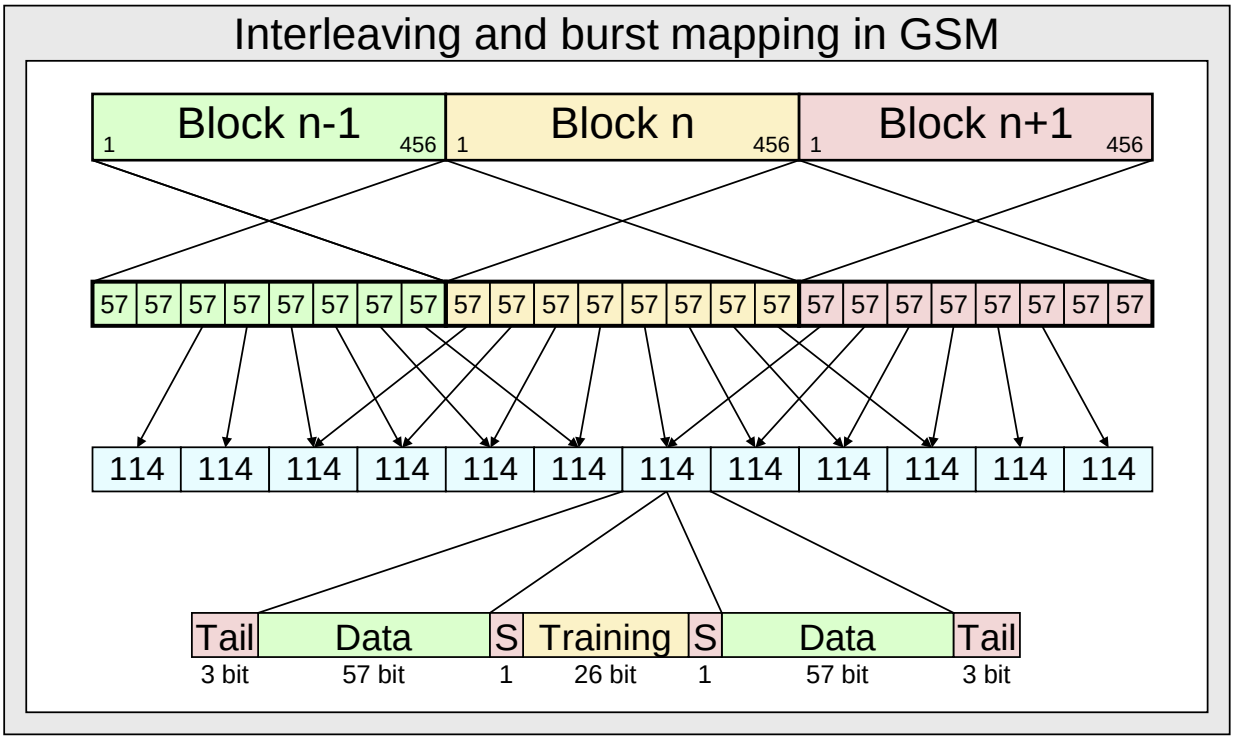
GSM Interleaving



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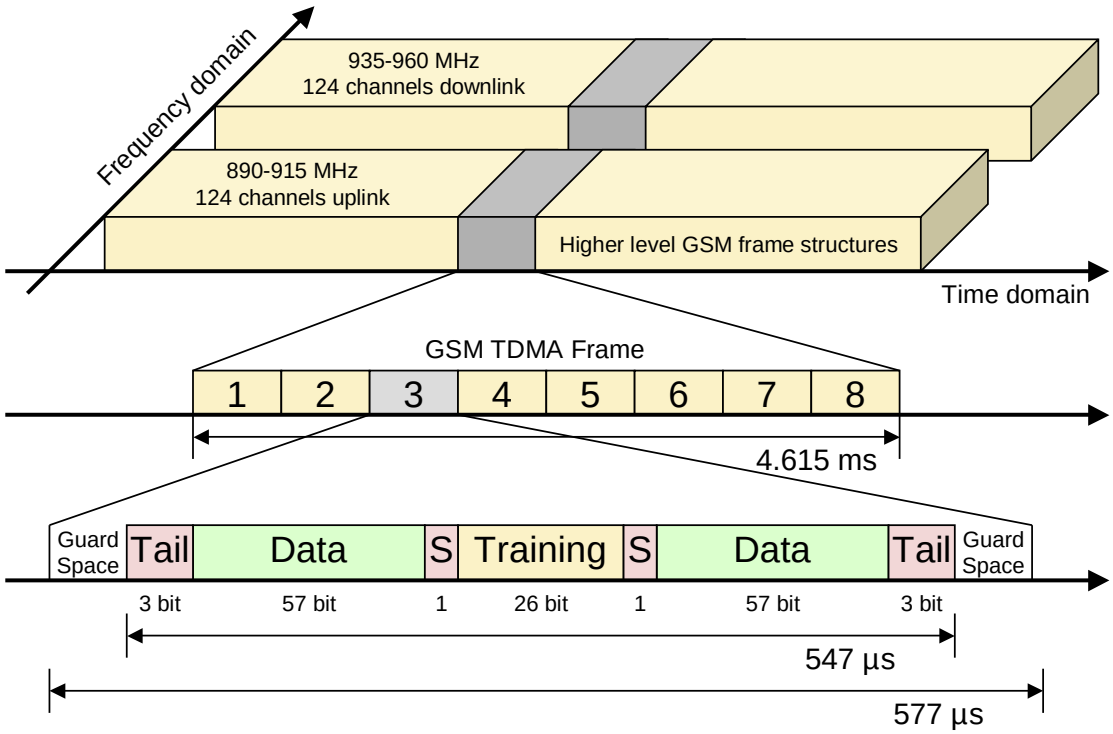
GSM Multiple Access



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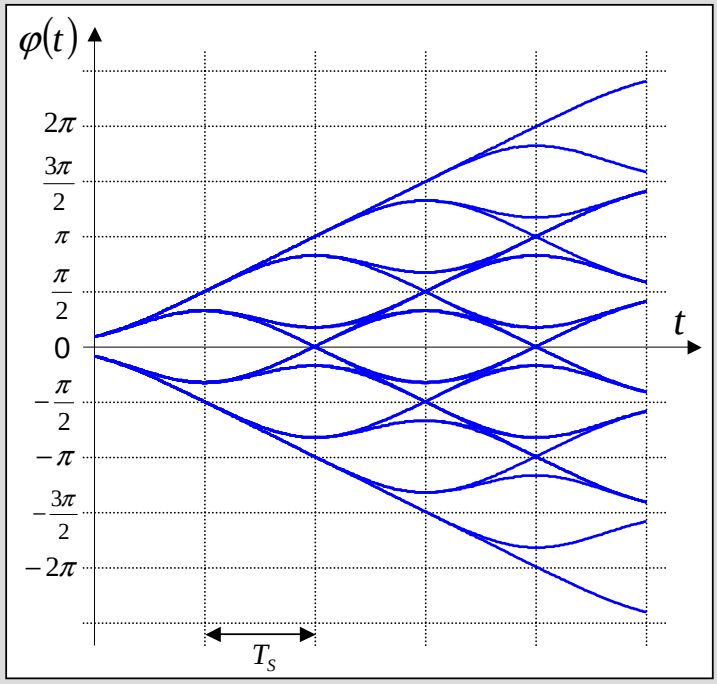
GSM Modulation

GMSK Phase diagram (B*T=0.3)

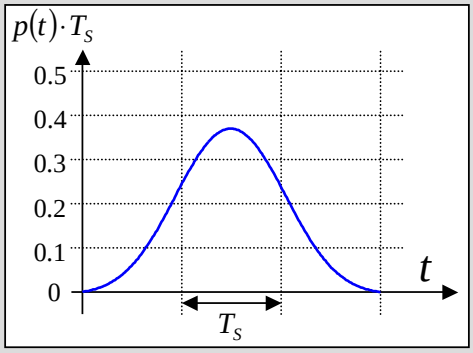


GMSK / B*T=0.3

$$h(t) = \frac{1}{\sqrt{2\pi}\sigma T_S} \exp\left[-\frac{1}{2\sigma^2}\left(\frac{t}{T_S}\right)^2\right]$$

$$\sigma = \frac{\sqrt{\ln 2}}{2\pi \cdot BT} \qquad p(t) = \frac{1}{2} h(t) * \mathrm{rect}\left(\frac{t}{T_S}\right)$$

Pulse shaping (B*T=0.3)



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GSM Channel Estimation

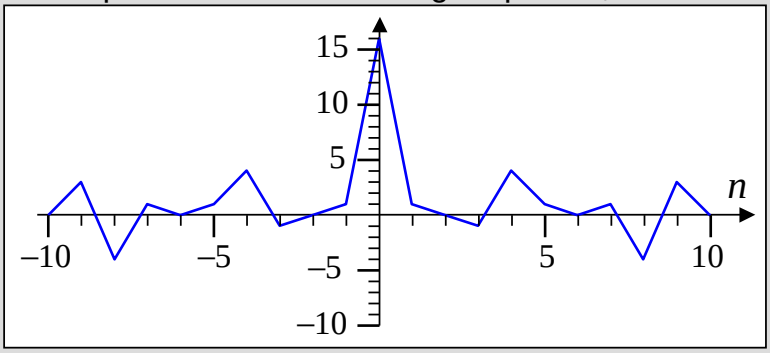
GSM Training sequences:

$$\text{Length} = 16 + 2 \cdot 5 = 26$$

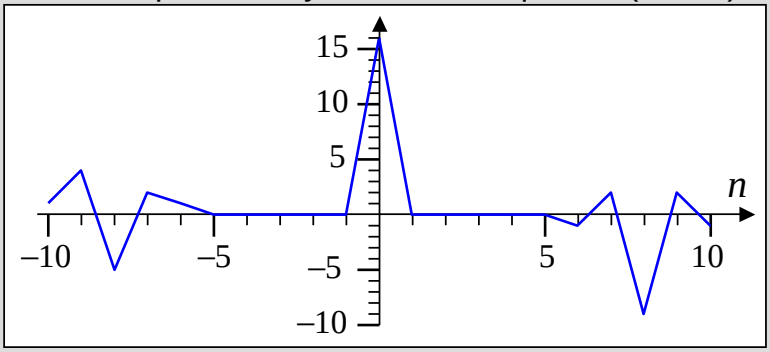
Bit pattern of training sequences

Nr	Bit Sequence
0	00100 **1011100001000100** 10111
1	00101 **1011101111000101** 10111
2	01000 **0111011101001000** 01110
3	01000 **1111011010001000** 11110
4	00011 **0101110010000011** 01011
5	01001 **1101011000001001** 11010
6	10100 **1111101100010100** 11111
7	11101 **1110001001011101** 11100

Aperiodic ACF of training sequence, N=16



ACF of periodically extended sequence (PACF)



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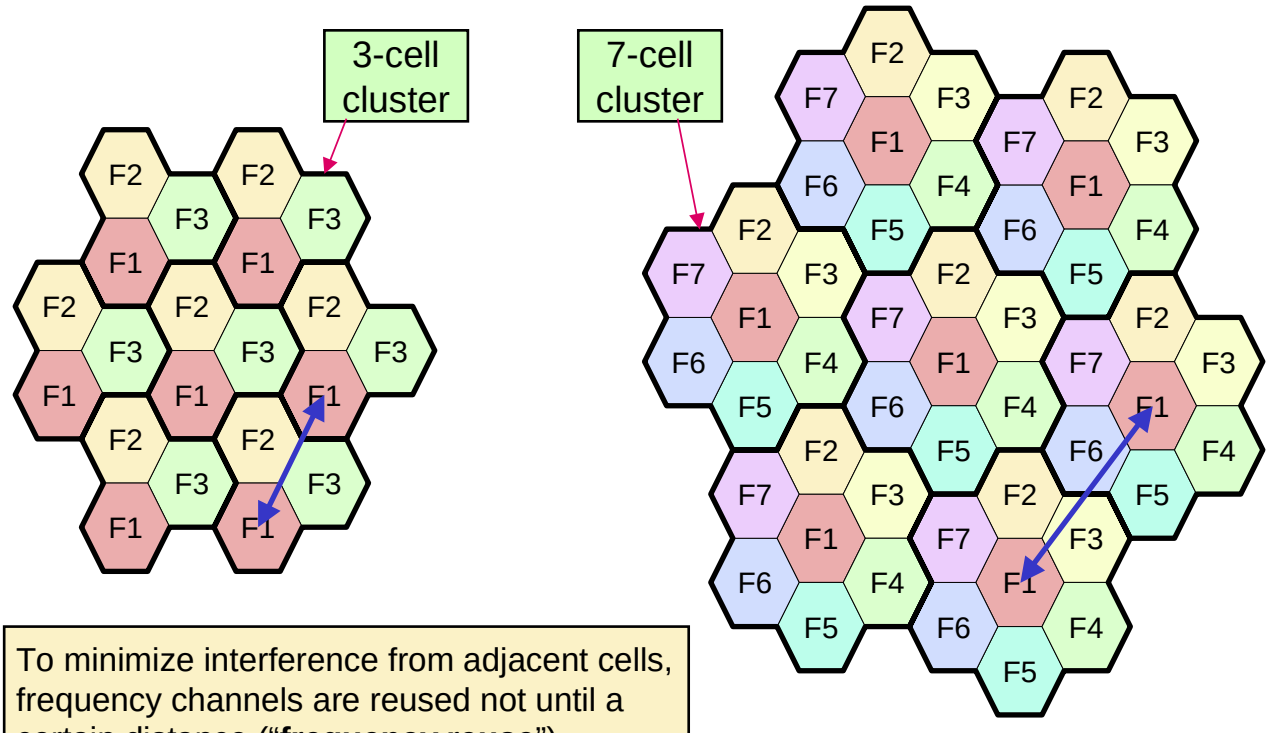
GSM 900 System Parameters

Frequency range	890-915 MHz (Uplink) / 935-960 MHz (Downlink)
Number of channels	124
Channel spacing	200 kHz
Multiple access	FDMA / TDMA
Duplex	FDD
Data rate	270.833 kbit/s per channel (8 user)
Channel coding	Convolutional code, rate R=1/2, constraint length L=5
Equalization	MLSE, Viterbi equalizer
Modulation	Gaussian Minimum Shift Keying (GMSK), B*T=0.3
Transmission power	• Downlink : 10 W (typical) to 50 W (maximum) • Uplink : 2 W (maximum)

Frequency Reuse



To minimize interference from adjacent cells, frequency channels are reused not until a certain distance ("**frequency reuse**")

GSM Data Services

HSCSD

- "High Speed Circuit Switched Data"
- Circuit switched
- Fixed number of timeslots (up to 4) per frame for one user

Time Slots	9.6 kbit/s per TS	14.4 kbit/s per TS
1	9.6	14.4
2	19.2	28.8
3	28.8	43.2
4	38.4	57.6

Applications:

- File Transfer
- Streaming services
- Real-time applications

GPRS

- "General Packet Radio Service"
- Packet switched
- Variable number of timeslots (up to 8) per frame for one user
- Requires major changes in GSM network infrastructure
- **Up to 115.2 kbit/s**

Applications:

- Internet
- Mobile Office
- Remote control
- Monitoring

EDGE

- "Enhanced Data Rates for GSM Evolution"
- Packet switched
- Uses the same infrastructure as GPRS
- New methods on physical layer (8-PSK, different FEC, etc.) to increase data rates
- **Up to 384 kbit/s**

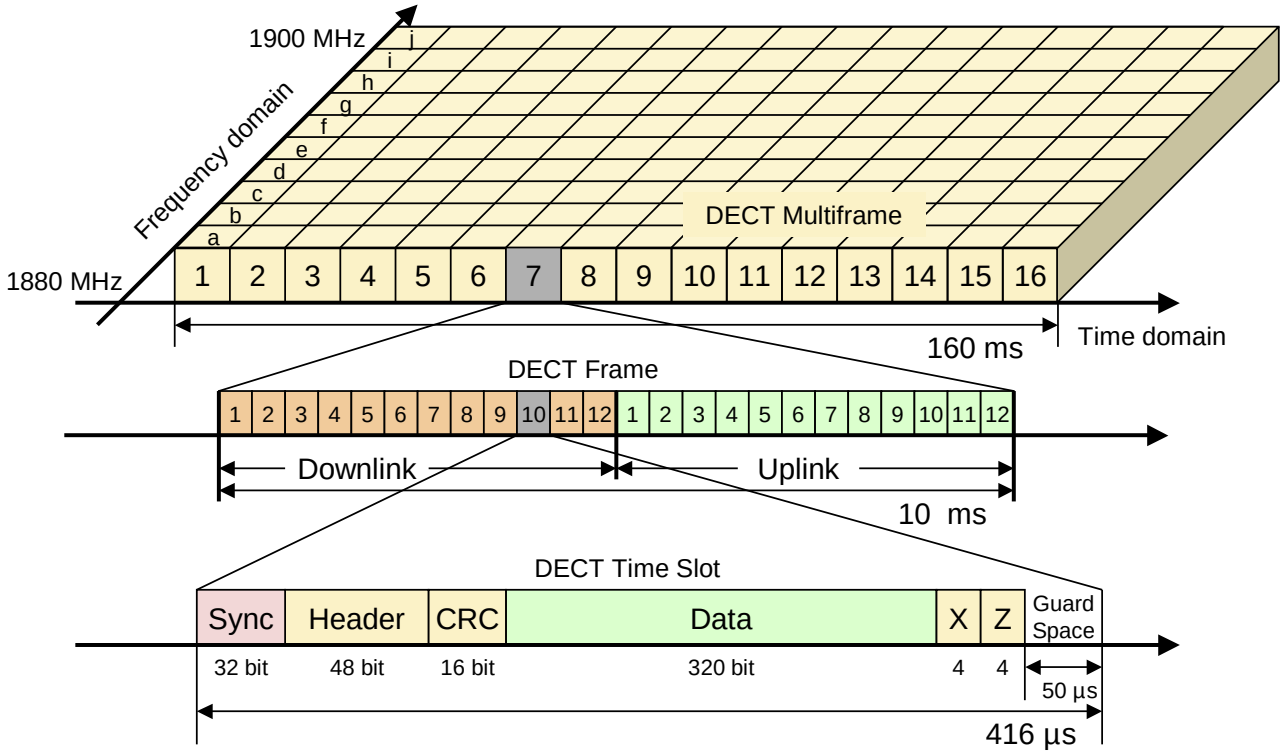
Applications:

- High speed Internet
- Like GPRS

DECT System Parameters

Frequency range	1880-1900 MHz
Number of channels	10
Channel spacing	1728 kHz
Multiple access	TDMA
Duplex	TDD
Data rate	1.152 Mbit/s
Channel coding	Only error detection (CRC)
Equalization	None
Modulation	Gaussian Minimum Shift Keying (GMSK), B*T=0.5
Admissible BER	10^{-3}
Transmission power	<250 mW
Cell radius	30 – 300 m

DECT Multiple Access



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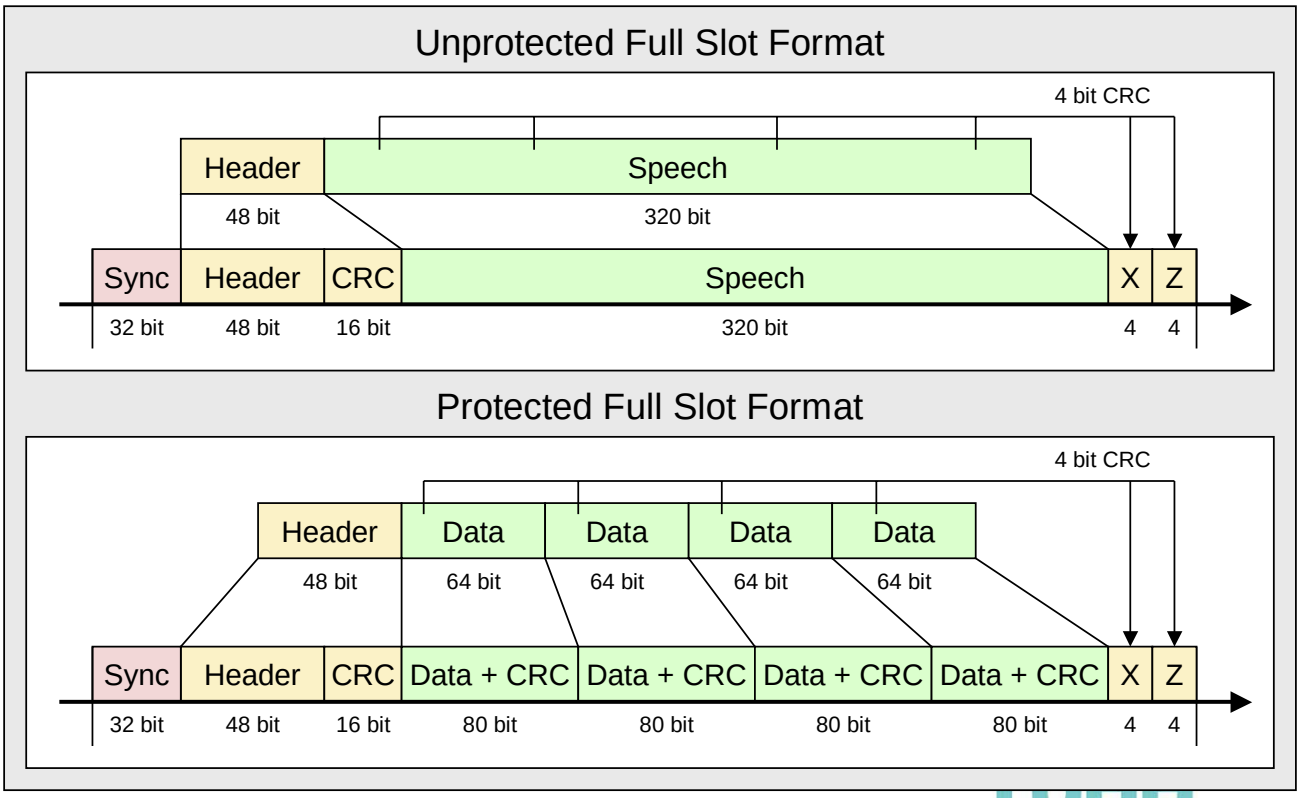
DECT Frame Structure & Coding



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UMTS Key Features

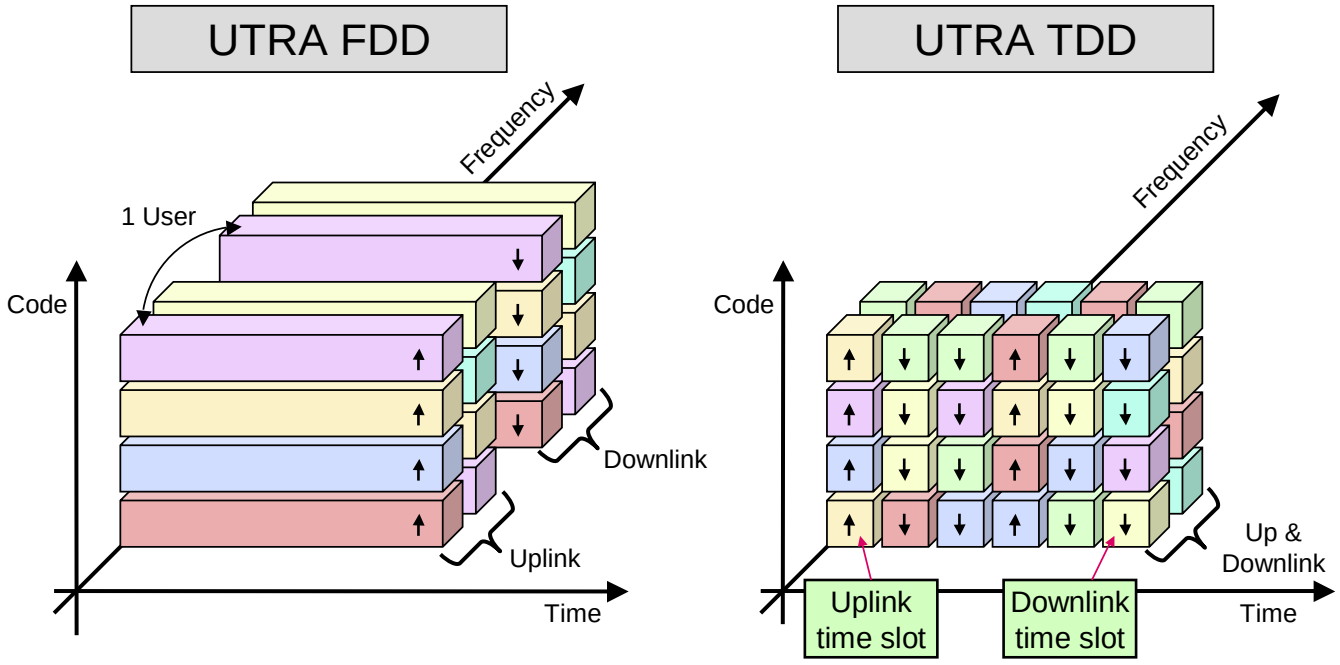
- "**Universal Mobile Telecommunications System**"
- Support of different services (speech, data) *anytime*, *anywhere* with data rates of up to 2 Mbit/s
- Roaming between sub-networks
- Virtual home environment (identical user interface, independent of access)
- Open interfaces for service providers
- Adaption of bandwith, depending on service

UMTS Concepts

Concept group	Description	Proposals
α	Wideband CDMA	FRAMES Mode 2, Fujitsu WB-CDMA, NEC WB-CDMA
β	OFDM	Sony-BDMA, TELIA-OFDMA, Lucent-OFDMA
γ	Wideband TDMA	FRAMES Mode 1 without spreading
δ	Wideband TD/CDMA	FRAMES Mode 1 with spreading, Swiss PTT CTDMA
ε	ODMA	Vodafone ODMA

In January 1998, ETSI adopted the proposals from α– and δ–groups as standards for UTRA (UMTS Terrestrial Radio Access)

UMTS Duplex Schemes



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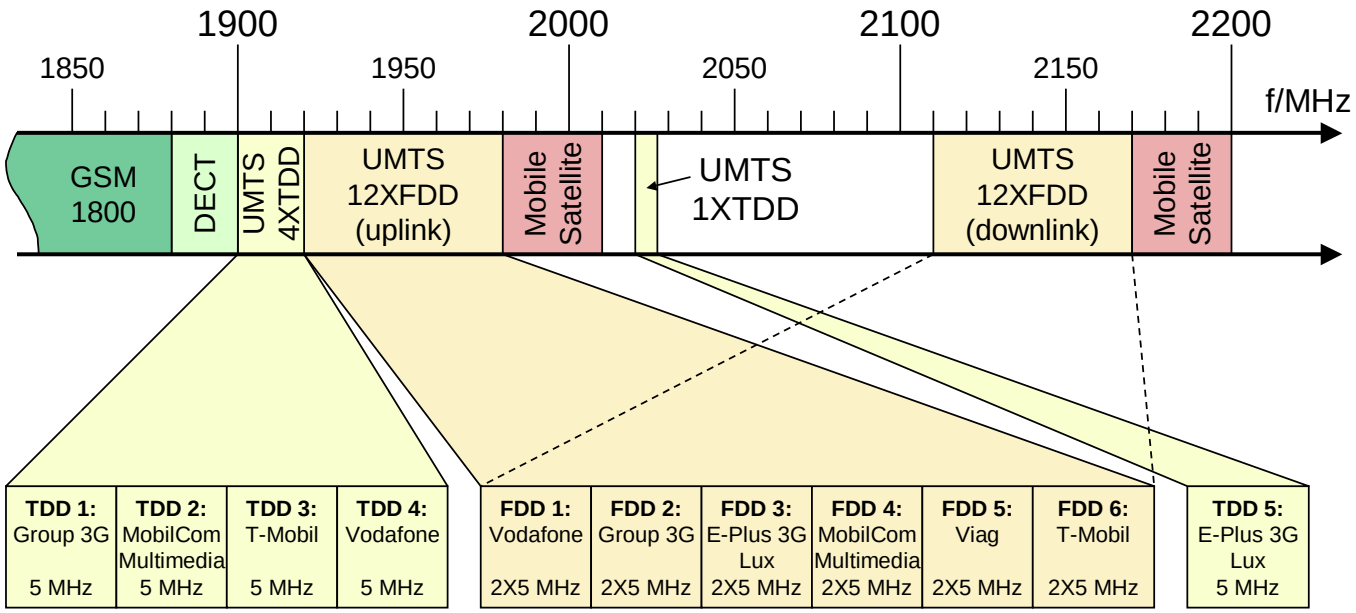
UMTS Spectrum in Germany



Source: RegTP (June, 2002)

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UMTS System Parameters

	UTRA FDD	UTRA TDD
Duplex	Frequency Division Duplex	Time Division Duplex
Multiple access method	W-CDMA	TD/CDMA
Chip rate	3.84 Mcps	
Pulse shaping	root raised cosine (roll-off 0.22)	
Carrier spacing	5 MHz	
Frame length	10 ms (38400 chips)	
Time slot	667 µs (2560 chips) / 15 slots per frame	
Modulation	QPSK	
Spreading	Q=2,4,8,…,256	Q=1,2,4,8,16
Channel coding	Conv. Codes (rates 1/2 and 1/3), Turbo codes (rate 1/3)	

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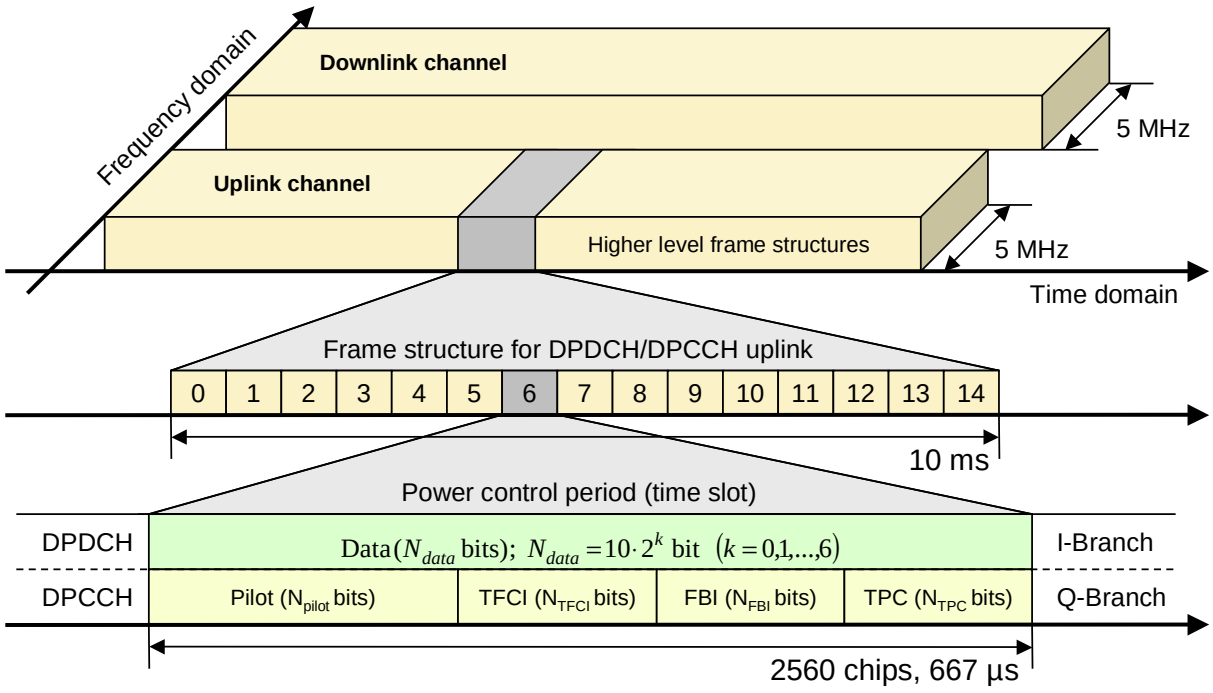
UTRA FDD Multiple Access (Uplink)



DPDCH: Dedicated Physical Data Channel
DPCCH: Dedicated Physical Control Channel

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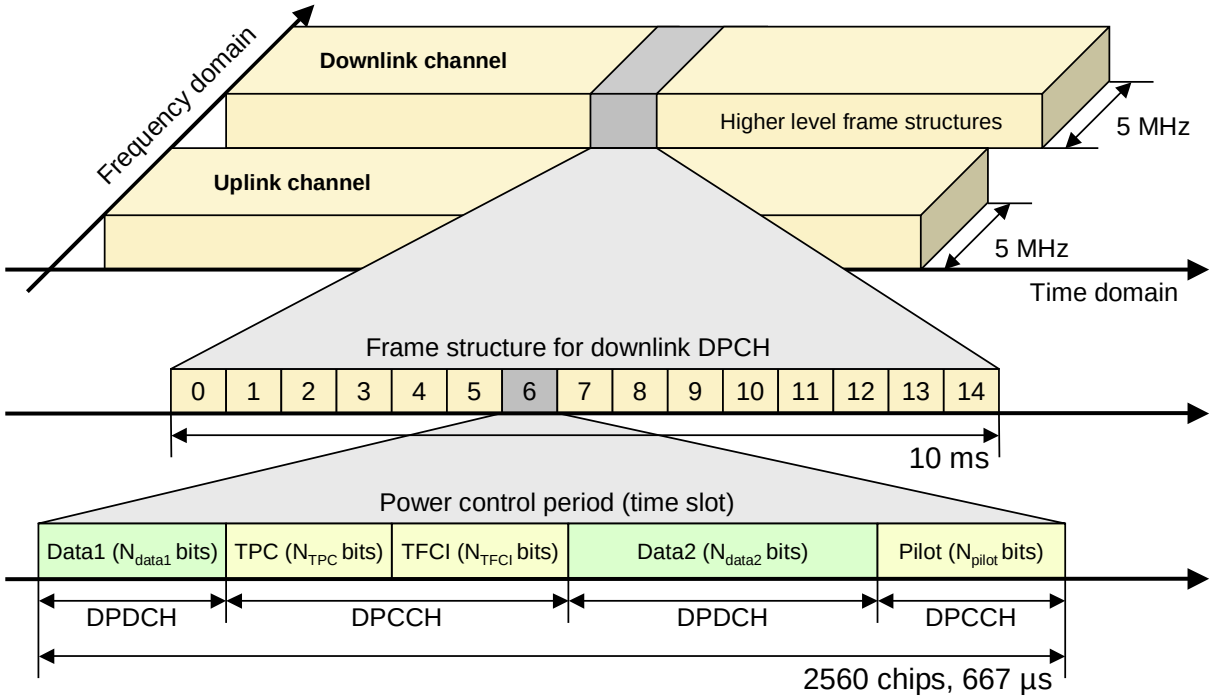
UTRA FDD Multiple Access (Downlink)



DPDCH: Dedicated Physical Data Channel
DPCCH: Dedicated Physical Control Channel

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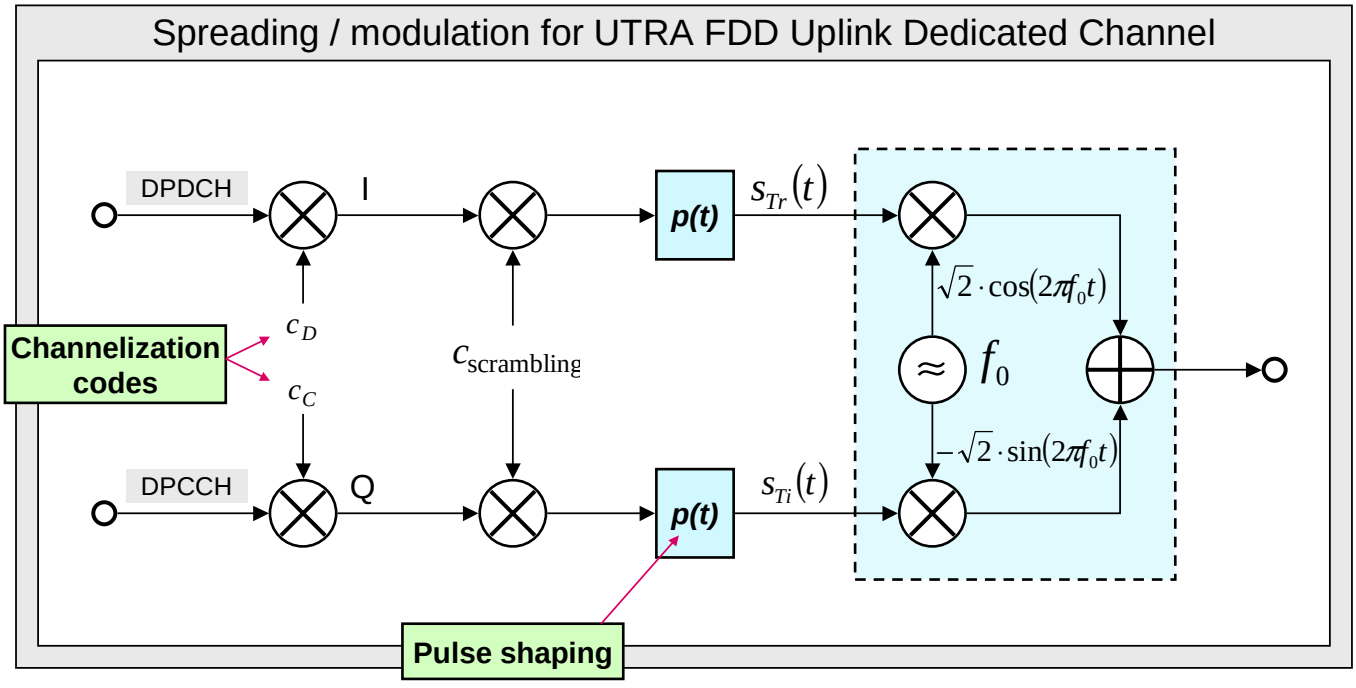
UTRA FDD Transmission (Uplink)



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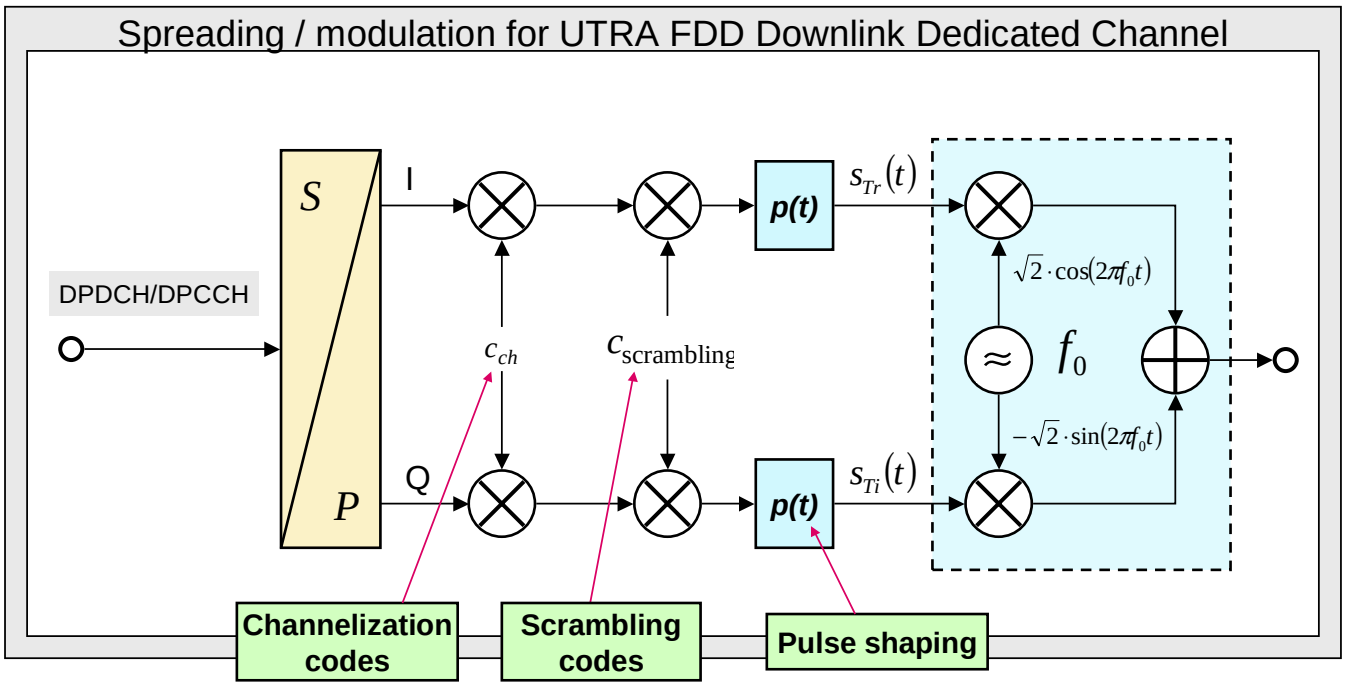
UTRA FDD Transmission (Downlink)



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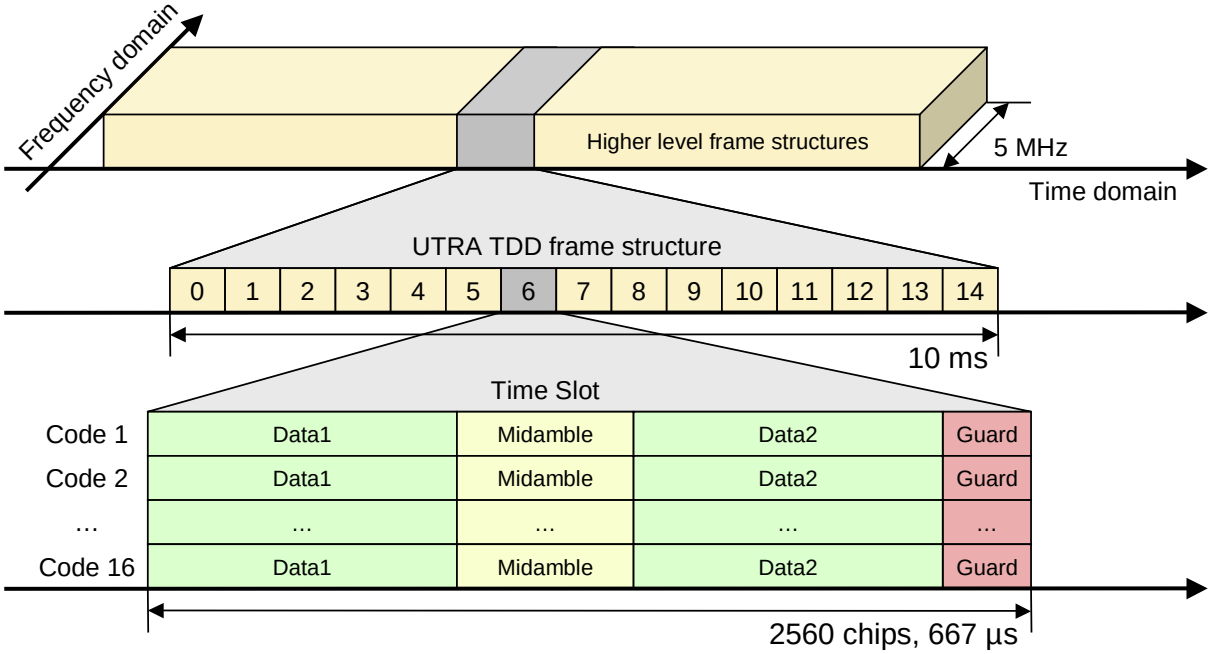
UTRA TDD Multiple Access



Each time slot can be assigned to either uplink or downlink, individually

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HiperLAN/2 Key Features

- **“High Performance Local Area Network”**
- Providing communication between portable devices (with limited mobility)
- Data rates up to 54 Mbit/s to support future multimedia applications
- Standardized in the ETSI project BRAN (“Broadband Radio Access Networks”)

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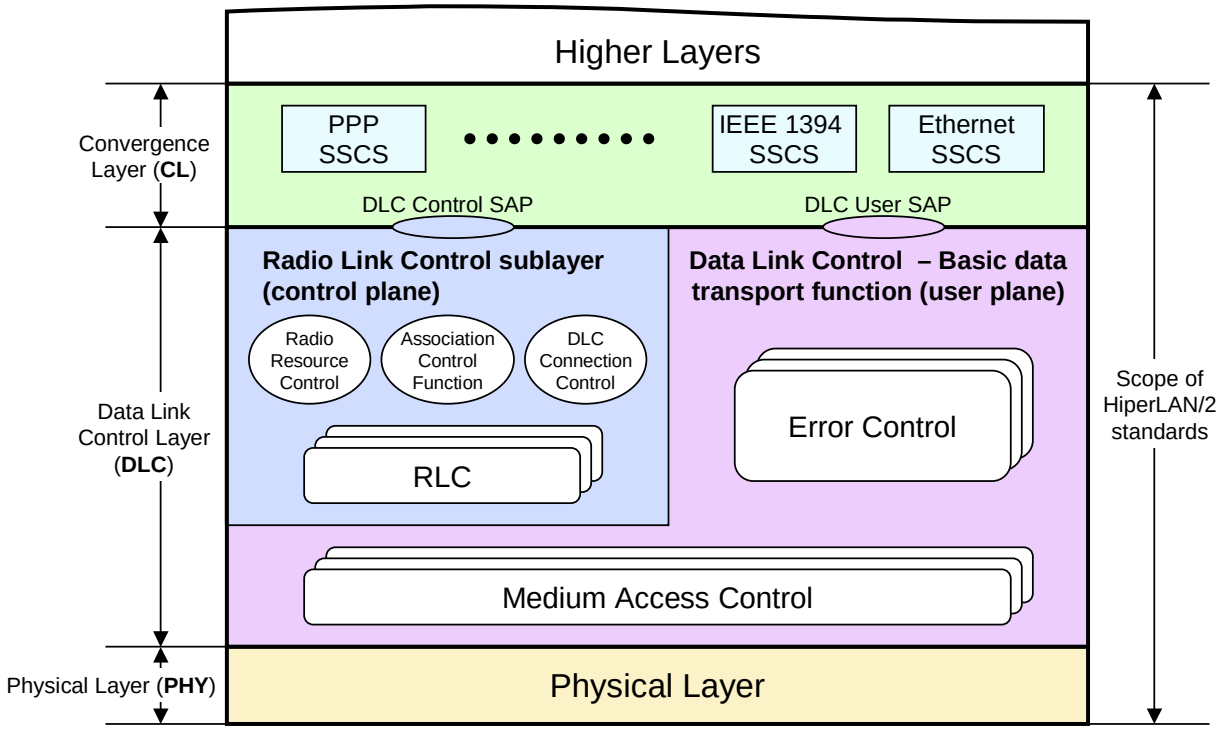
HiperLAN/2 Protocol Architecture



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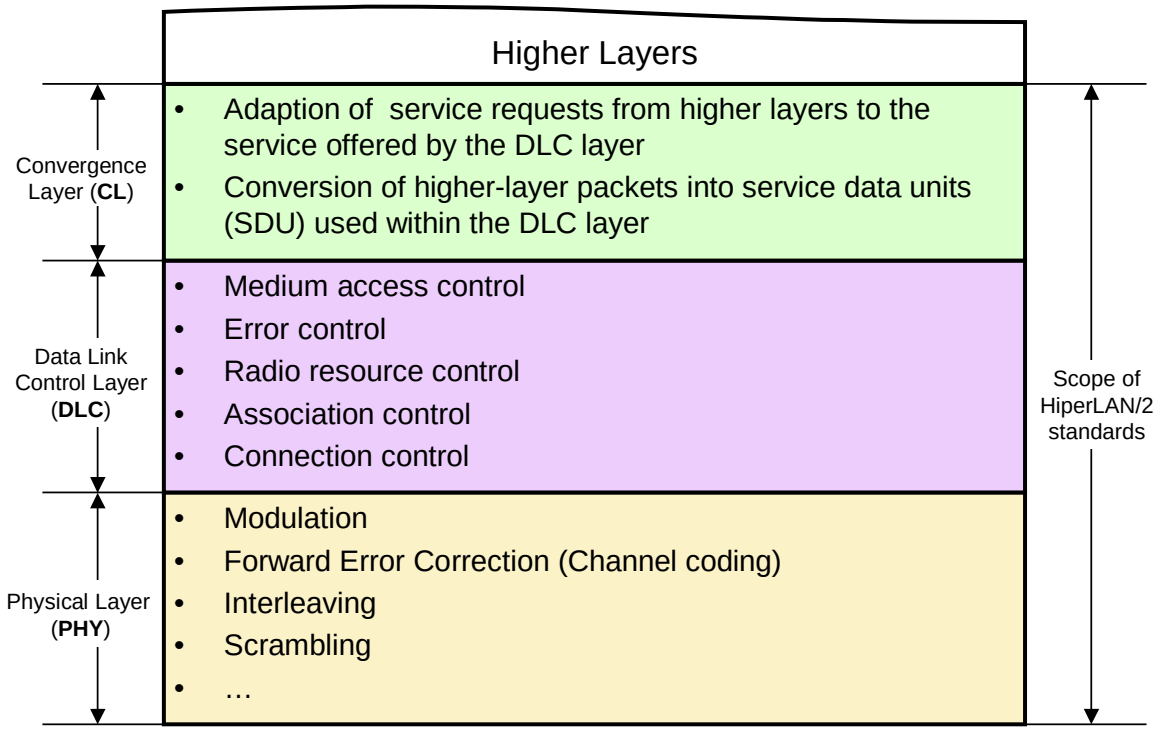
HiperLAN/2 Functional Architecture



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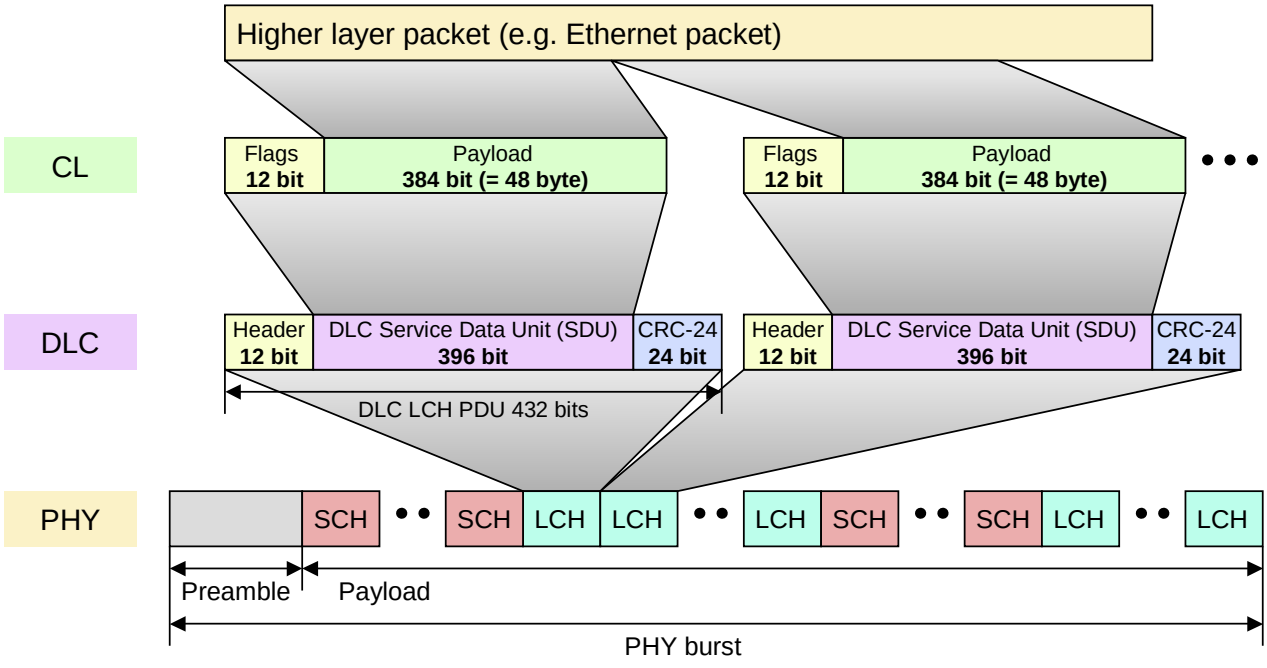
HiperLAN/2 Data Mapping Example



SCH: Short Transport Channel
LCH: Long Transport Channel

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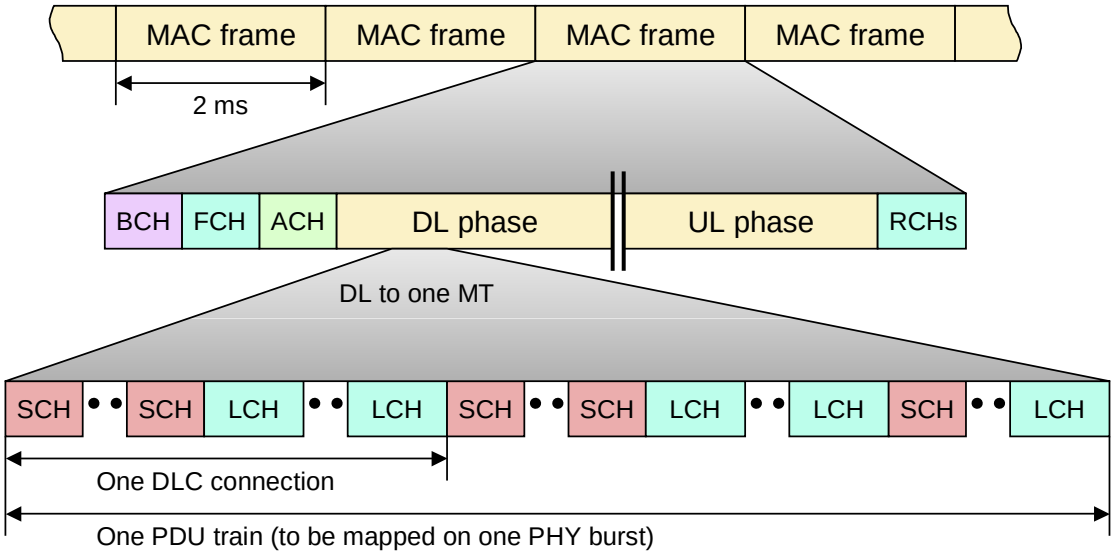
HiperLAN/2 Basic Frame Structure



BCH: Broadcast Channel	FCH: Frame Channel
ACH: Access Feedback Channel	RCH: Random Access Channel
LCH: Long Transport Channel	SCH: Short Transport Channel

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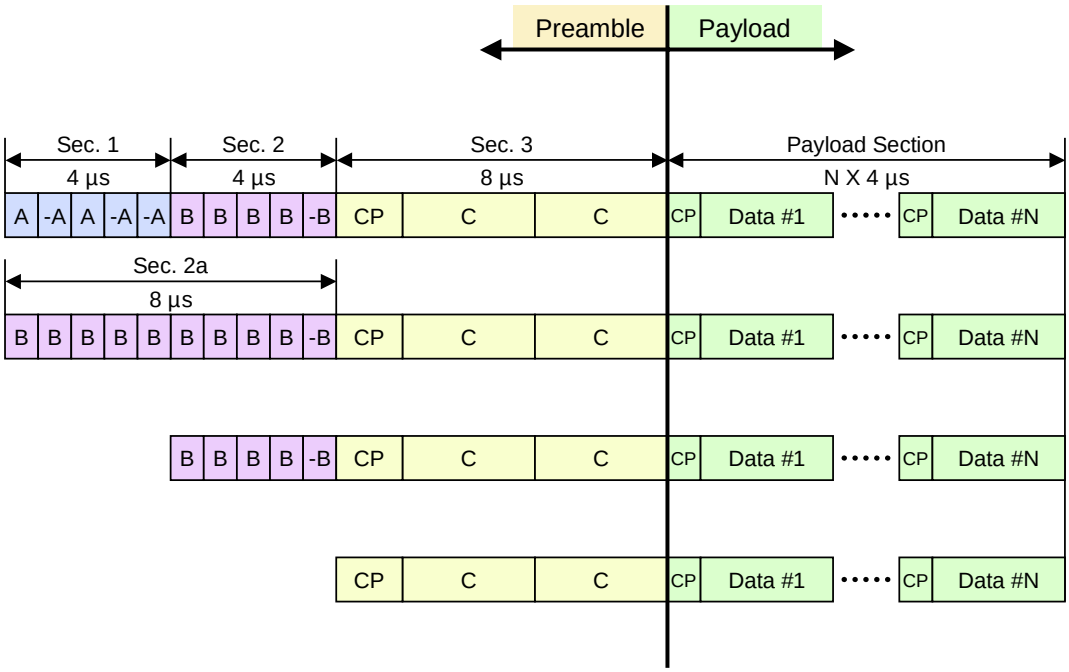
HiperLAN/2 PHY Bursts



Broadcast burst

Uplink burst, long preamble

Uplink burst, short preamble

Downlink burst

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HiperLAN/2 PHY Modes

Mode	Modulation	Code rate	Physical layer bit rate
1	BPSK	1/2	6 Mbit/s
2	BPSK	3/4	9 Mbit/s
3	QPSK	1/2	12 Mbit/s
4	QPSK	3/4	18 Mbit/s
5	16QAM	9/16	27 Mbit/s
6	16QAM	3/4	36 Mbit/s
7	64QAM	3/4	54 Mbit/s

The quality of the radio link, which is dependant on the radio environment, changes over time and in accordance with traffic in surrounding radio cells
⇒ **Link adaptation** of the physical mode is applied

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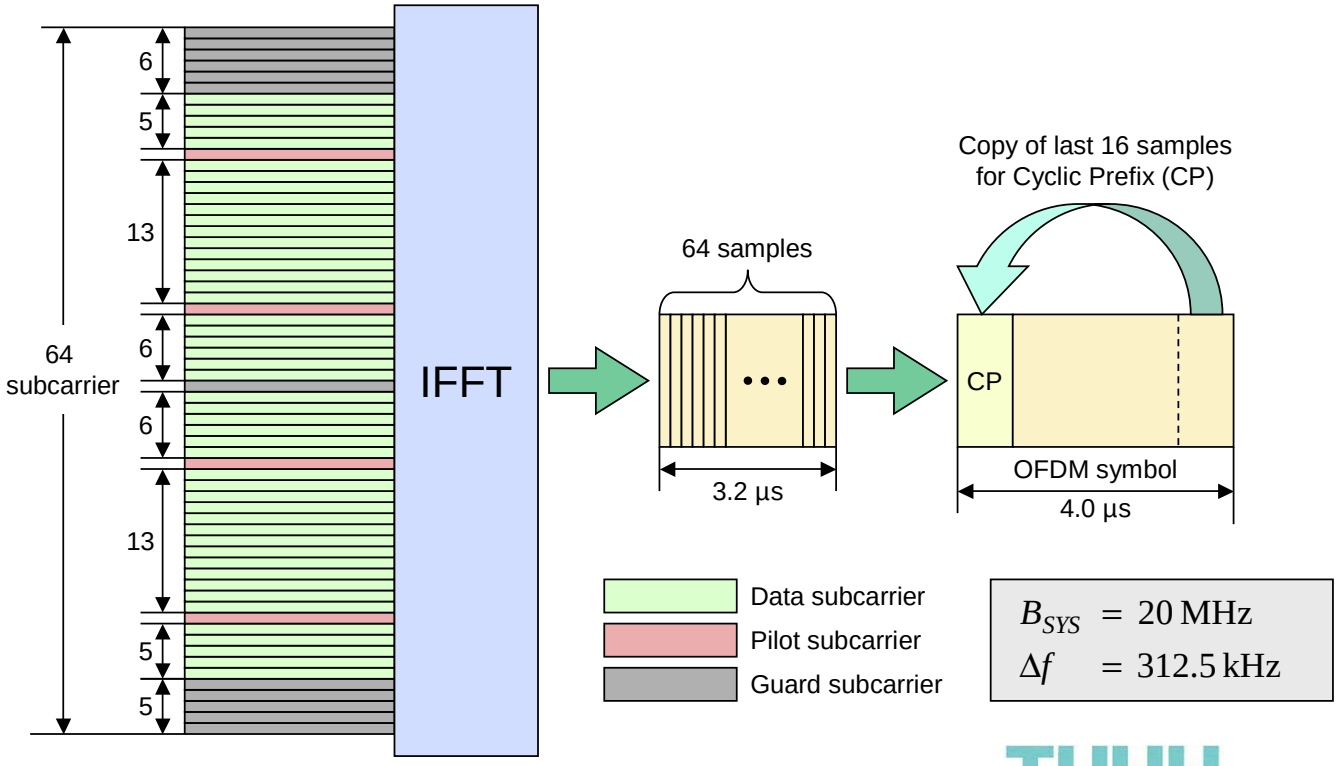
HiperLAN/2 Signal Generation



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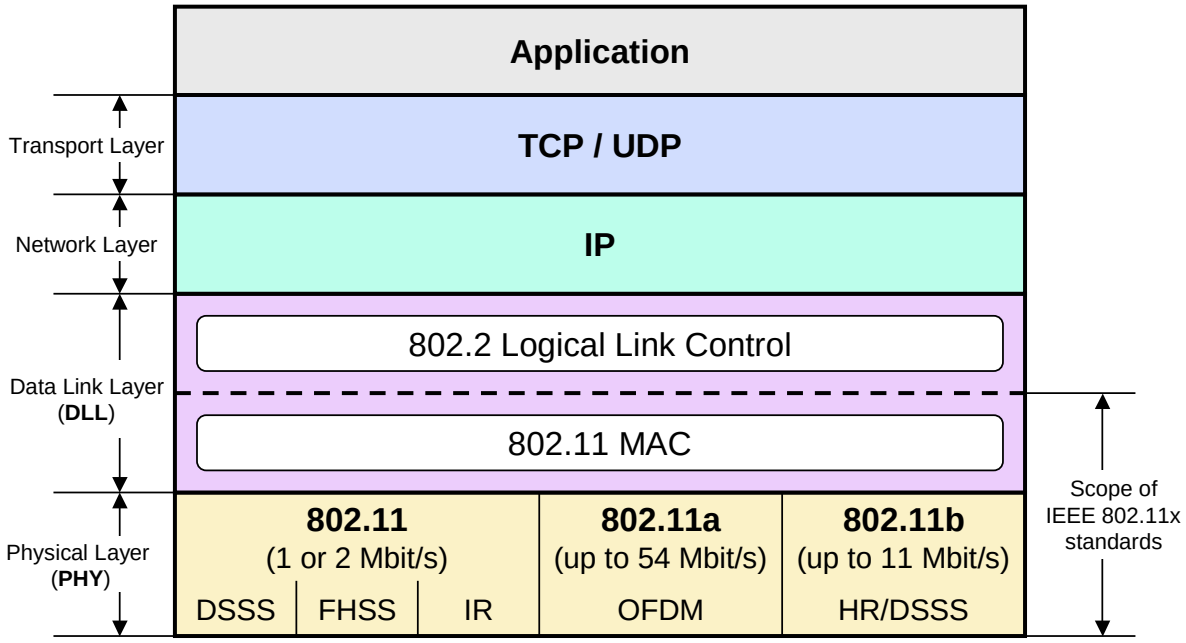
HiperLAN/2 System Parameters

Parameter	Value	
Carrier Frequency	5.150 GHz – 5.350 GHz / 5.470 GHz – 5.725 GHz	
Duplex	Time Division Duplex (TDD)	
Multiple access method	TDMA	
Sampling rate f_s=1/T	20 MHz	
Useful symbol part duration T_U	64 X T = 3.2 µs	
Cyclic prefix duration T_{CP}	16 X T = 0.8 µs (mandatory)	8 X T = 0.4 µs (optional)
Symbol interval	80 X T = 4.0 µs (T_U+T_{CP})	72 X T = 3.6 µs (T_U+T_{CP})
Number of data subcarriers N_{SD}	48	
Number of pilot subcarriers N_{SP}	4	
Total number of subcarriers N_{ST}	52 (N_{SD} +N_{SP})	
Subcarrier spacing Δf	312.5 kHz ($1/T_U$)	
FFT size	64	

IEEE 802.11 Key Features

- Purpose (according to 802.11 Specification):
  - "The purpose of this standard is to provide wireless connectivity to automatic machinery, equipment, or stations that require rapid deployment, which may be portable or hand-held, or which may be mounted on moving vehicles within a local area."
- Scope
  - Medium Access Control (MAC)
  - Physical Layer (PHY), different PHYs defined (FHSS, DSSS, IR, …)
- Local area communication with high data rates
- Support of Ad Hoc networking groups
- Developed to work in the *Industrial, Scientific and Medical* (**ISM**) Bands

IEEE 802.11 Protocol Architecture



DSSS:	Direct Sequence Spread Spectrum	IR: Infrared
FHSS:	Frequency Hopping Spread Spectrum	HR: High Rate

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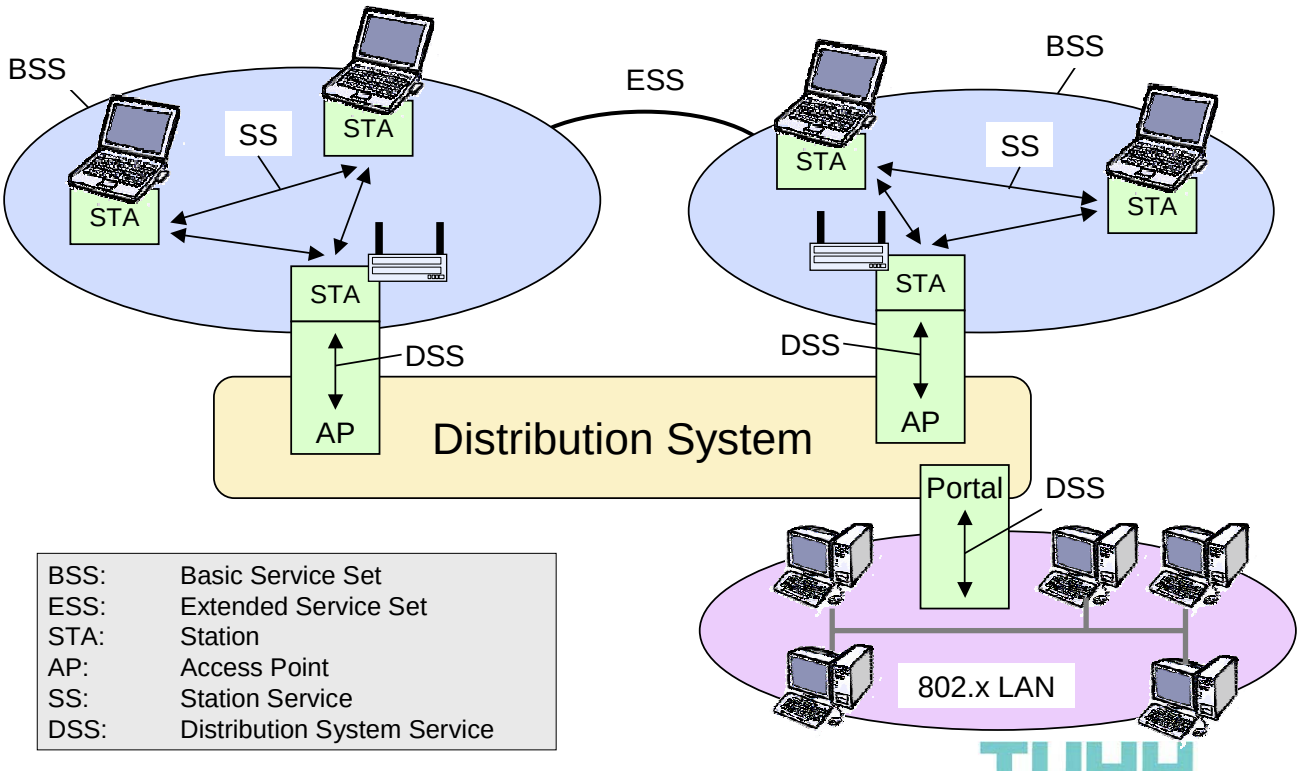
IEEE 802.11 Infrastructure



BSS:	Basic Service Set
ESS:	Extended Service Set
STA:	Station
AP:	Access Point
SS:	Station Service
DSS:	Distribution System Service

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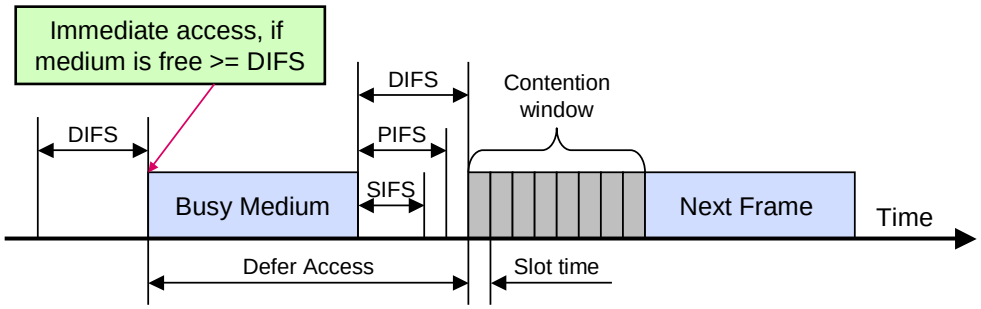
IEEE 802.11 MAC (1)



802.11 MAC is based on the CSMA/CA protocol:

- Station willing to transmit senses the medium (carrier sensing)
- If medium is idle for a duration longer than the priority-dependant *Interframe Space* (**IFS**), the station accesses the medium
- Otherwise, the station waits for the next idle **IFS** and additionally defers its access by a random backoff time
- If the medium is accessed during the backoff phase by other stations, the backoff-counter is stopped

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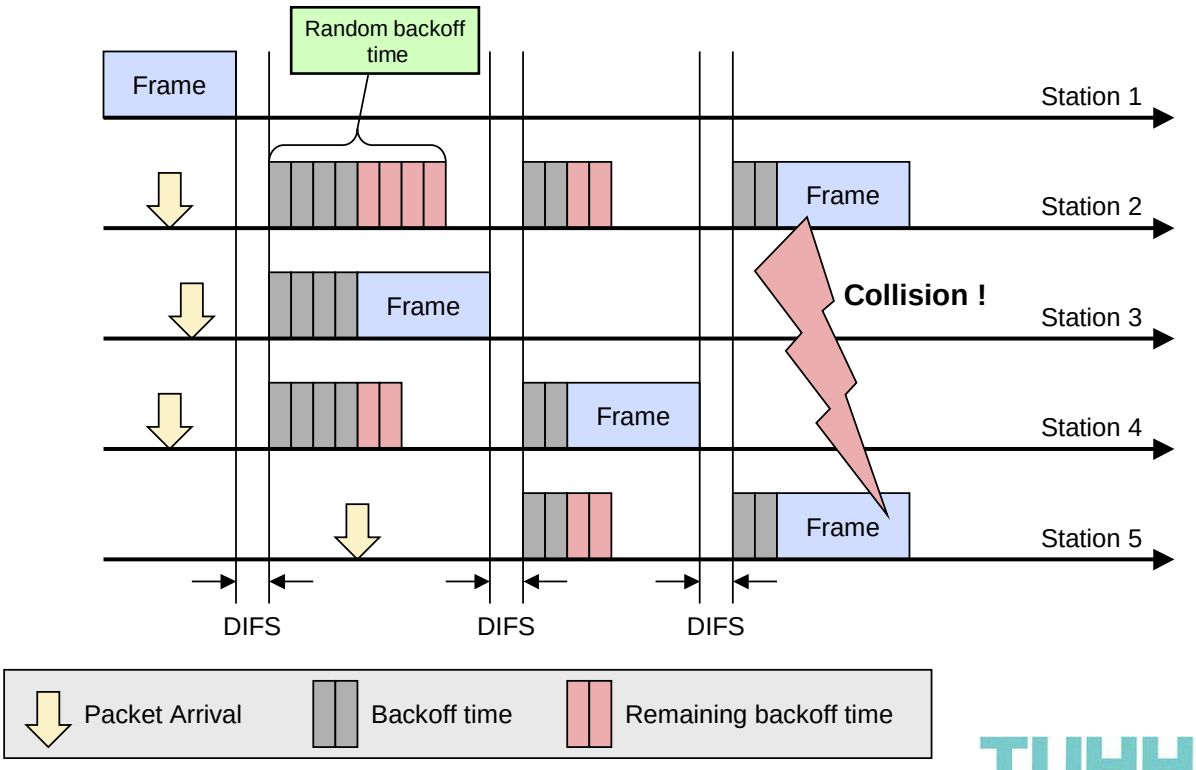
IEEE 802.11 MAC (2)



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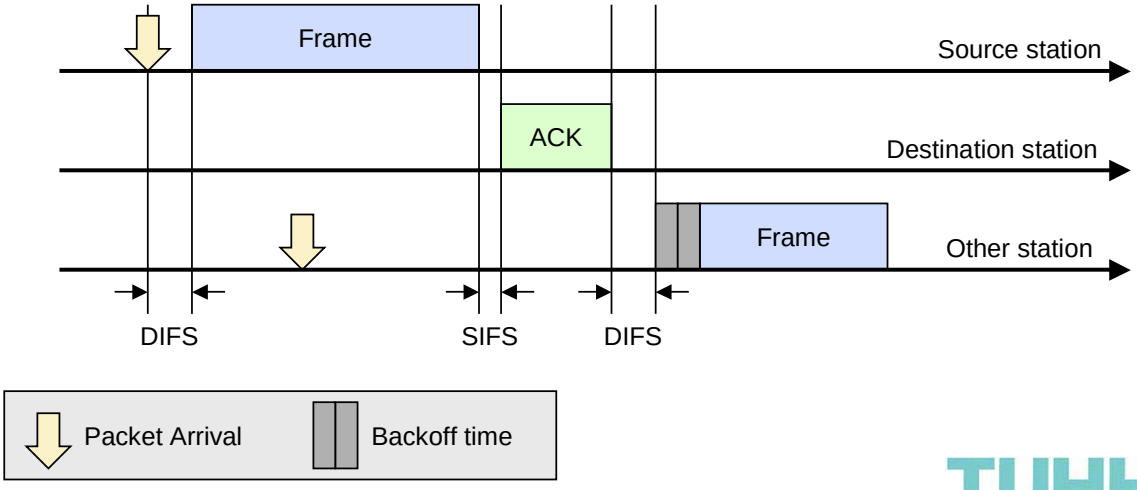
IEEE 802.11 MAC (3)

- In case of unicast transmissions:
  - Normal data packets are deferred using the **DIFS**
  - Correctly received packets are acknowledged after the **SIFS** period
  - If no acknowledgement is received, the packet is retransmitted



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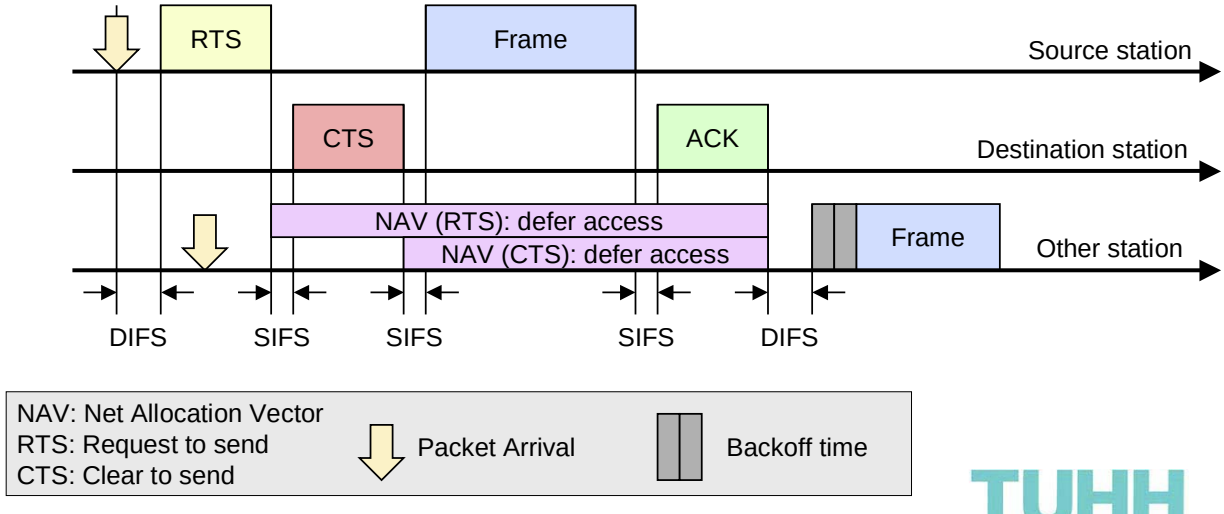
IEEE 802.11 MAC (RTS/CTS)

- A **RTS** packet indicating the intended transmission period is transmitted after the **DIFS** period
- The destination transmits a CTS after the **SIFS** period
- Transmission of source station after SIFS period
- Other stations defer transmissions using the Net Allocation Vector (**NAV**)



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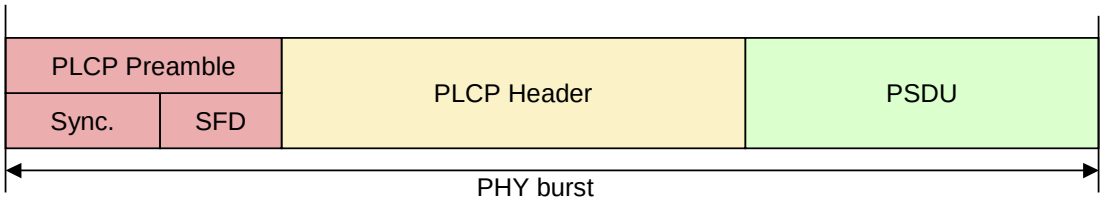
IEEE 802.11 PHY Frame Format

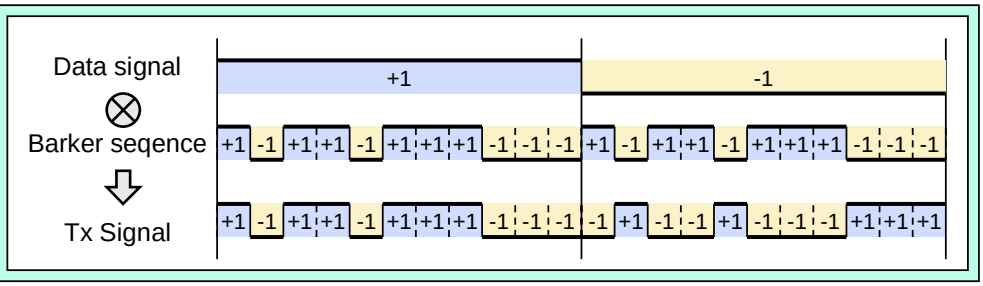


Sync.	Signal detection, time- and frequency-synchronization
SFD	*Start Frame Delimiter*, for frame synchronization
PLCP Header	Physical Layer Convergence Protocol Header (determines data rate, etc.)
PSDU	Physical Layer Service Data Unit (**PSDU**) of variable length

IEEE 802.11 PHY

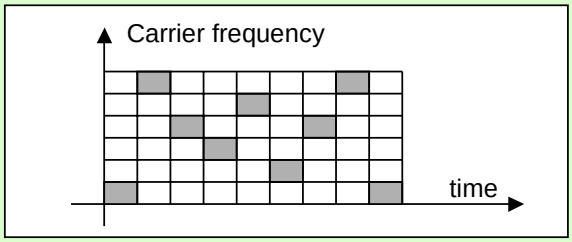
DSSS

- DBPSK for 1 Mbit/s
- DQPSK for 2 Mbit/s
- 11 Mcps chip rate
- 2,412 … 2,472 MHz



FHSS

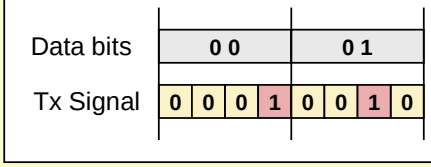
- GMSK with B*T=0.5 for 1 Mbit/s mode
- 4-GFSK for optional 2 Mbits/s mode
- Different frequency hopping tables defined
- 2,402 … 2,480 MHz



IR

- 16-PPM (Pulse Position Modulation) for 1 Mbit/s
- 4-PPM for 2 Mbits/s
- 850-950 nm diffuse light

Data bits	4-PPM symbol
0 0	0 0 0 1
0 1	0 0 1 0
1 0	0 1 0 0
1 1	1 0 0 0



IEEE 802.11 Extensions

- IEEE 802.11a
  - 6 Mbit/s – 54 Mbit/s
  - OFDM Physical Layer @5GHz (almost identical to HiperLAN/2 PHY)
- IEEE 802.11b
  - 5.5 Mbit/s – 11 Mbit/s
  - High Rate DSSS @2.4 GHz (Complementary Code Keying, CCK)
- IEEE 802.11e
  - MAC enhancements for Quality of Service (QoS)
- IEEE 802.11f
  - Inter-Access point protocol
- IEEE 802.11g
  - Higher data rate extensions (>20 Mbit/s) in the 2.4 Ghz band