CDMA

2/17/06

CDMA

- Code division multiplexing: different users use different languages.
- CDMA: code division multiple access.

- How to find good codes?
- How to separate the signal from other signals and noise?

CDMA

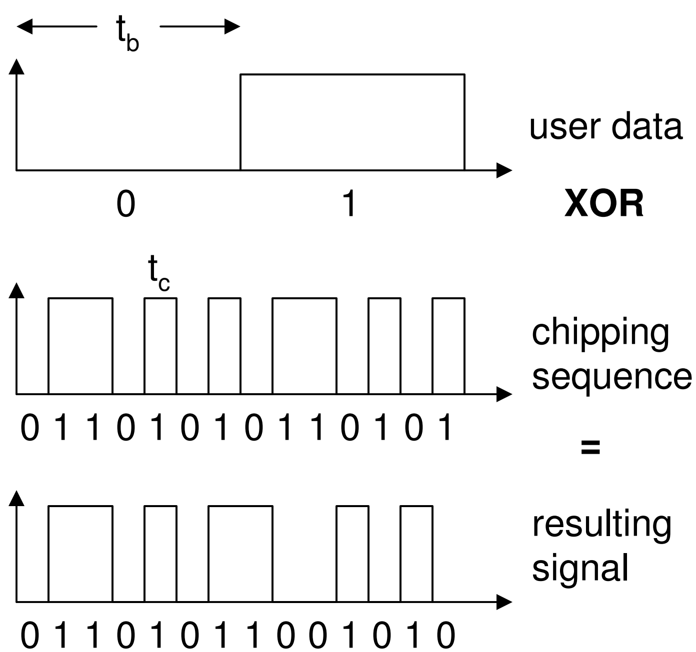
- CDMA (Code Division Multiple Access)
  - all terminals send on the same frequency probably at the same time and can use the whole bandwidth of the transmission channel
  - each sender has a unique random number, the sender XORs the signal with this random number
  - the receiver can “tune” into this signal if it knows the pseudo random number, tuning is done via a correlation function

CDMA

- Disadvantages:
  - higher complexity of a receiver (receiver cannot just listen into the medium and start receiving if there is a signal)
  - all signals should have the same strength at a receiver
- Advantages:
  - all terminals can use the same frequency, no planning needed
  - huge code space (e.g. 2^{32}) compared to frequency space
  - interferences (e.g. white noise) is not coded
  - forward error correction and encryption can be easily integrated

Example: DSSS

- DSSS (Direct Sequence Spread Spectrum)
- The code: chipping sequence.



t_b: bit period
t_c: chip period

What is a good code?

- A code is a vector, each bit is 1 or -1.
  - 10110111000 is (1,-1,1,1,-1,1,1,1,-1,-1,-1).
- Good autocorrelation
  - a·a is large.
- Orthogonal to other codes
  - a·b is zero.

- Why is this helpful?

An example

- Sender A
  - sends $A_d = 1$, key $A_k = 010011$ (assign: „0“= -1, „1“= +1)
  - sending signal $A_s = A_d * A_k = (-1, +1, -1, -1, +1, +1)$
- Sender B
  - sends $B_d = 0$, key $B_k = 110101$ (assign: „0“= -1, „1“= +1)
  - sending signal $B_s = B_d * B_k = (-1, -1, +1, -1, +1, -1)$

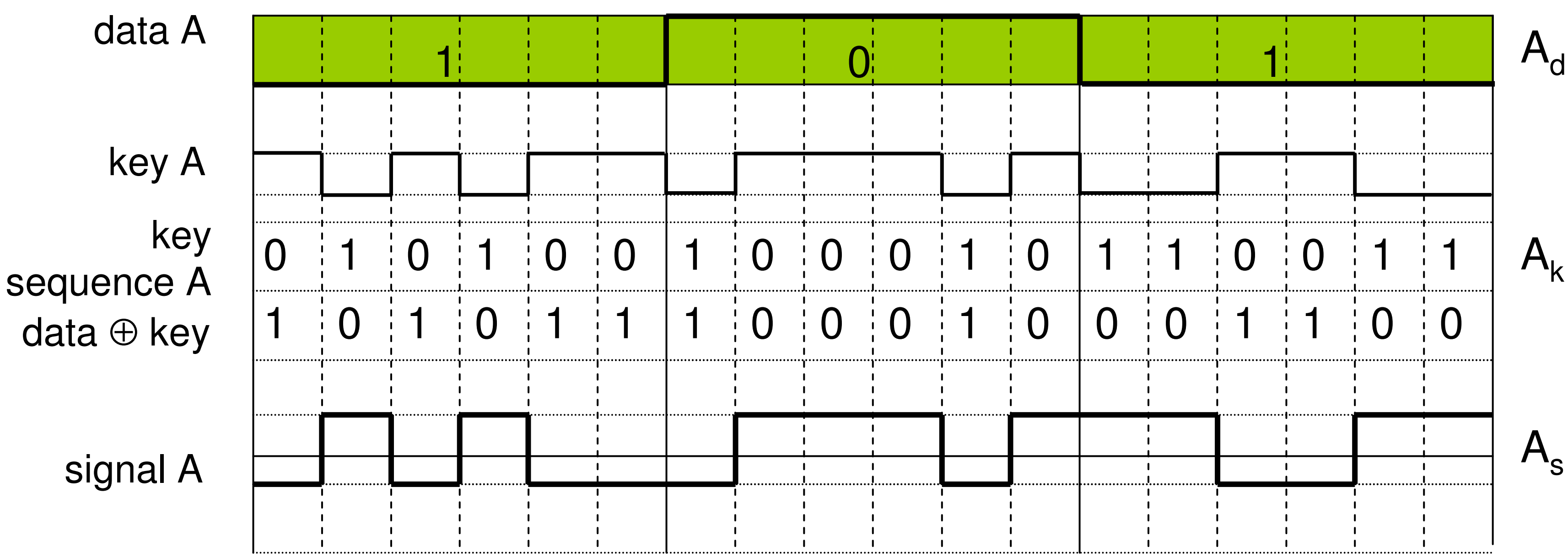
Receiver

- Both signals superimpose in space
  - interference neglected (noise etc.)
  - $A_s + B_s = (-2, 0, 0, -2, +2, 0)$
- Receiver wants to receive signal from sender A
  - apply key A_k bitwise (inner product)
    - $A_e = (-2, 0, 0, -2, +2, 0) \bullet A_k = 2 + 0 + 0 + 2 + 2 + 0 = 6$
    - result greater than 0, therefore, original bit was „1“
  - receiving B
    - $B_e = (-2, 0, 0, -2, +2, 0) \bullet B_k = -2 + 0 + 0 - 2 - 2 + 0 = -6$, i.e. „0“

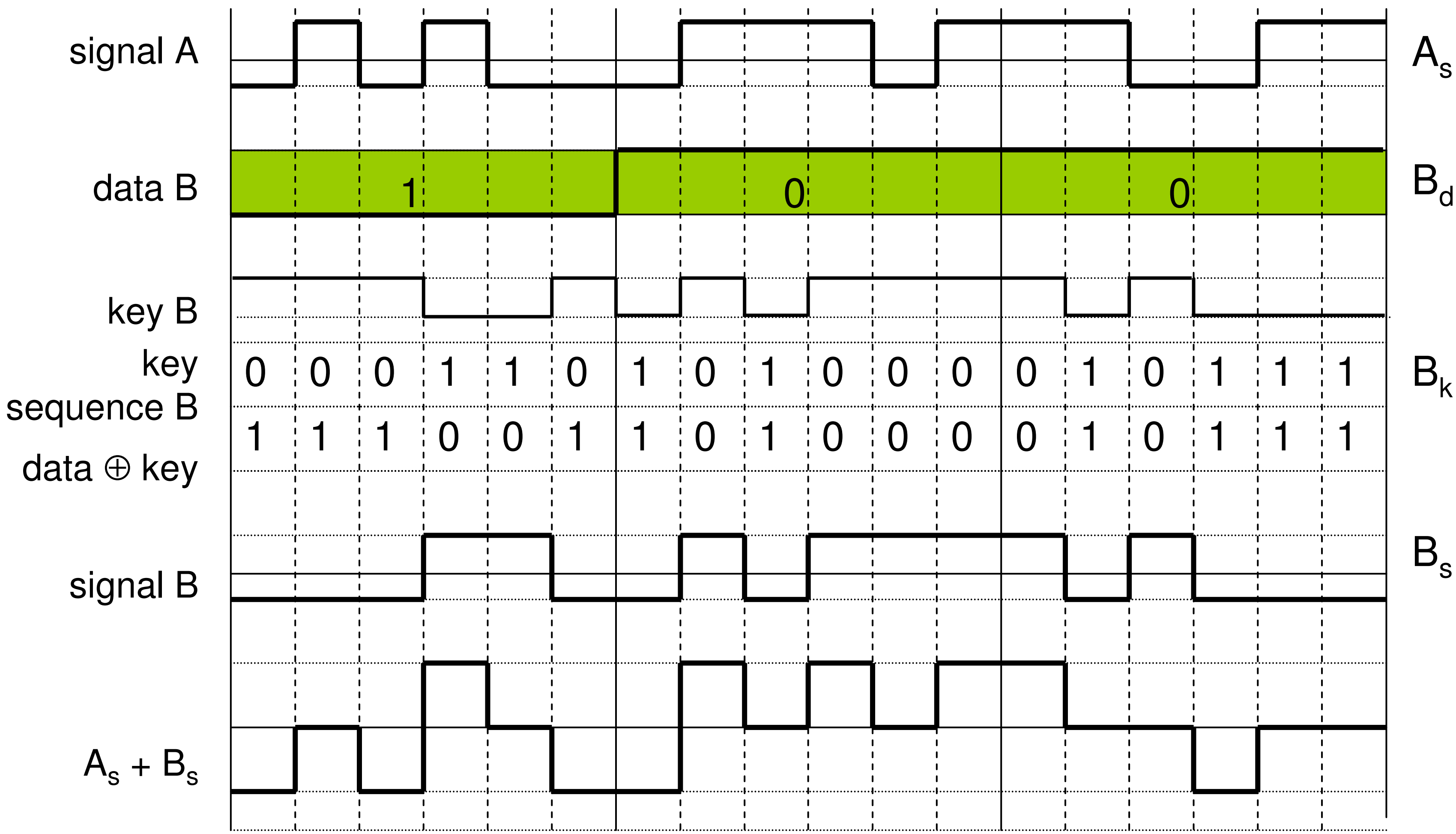
Receiver

- We did several simplifications:
  - No noise.
  - Signal strength are the same.
  - Perfectly superimpose.
- Assume B's signal strength is 5 times larger.
  - $A_s + 5B_s = (-6, -4, 4, -6, +6, -4)$
- Receiver wants to receive signal from sender A
  - apply key A_k bitwise (inner product)
    - $A_e = (-6, -4, 4, -6, +6, -4) \bullet A_k = 6$
  - receiving B
    - $B_e = (-6, -4, 4, -6, +6, -4) \bullet B_k = -30$

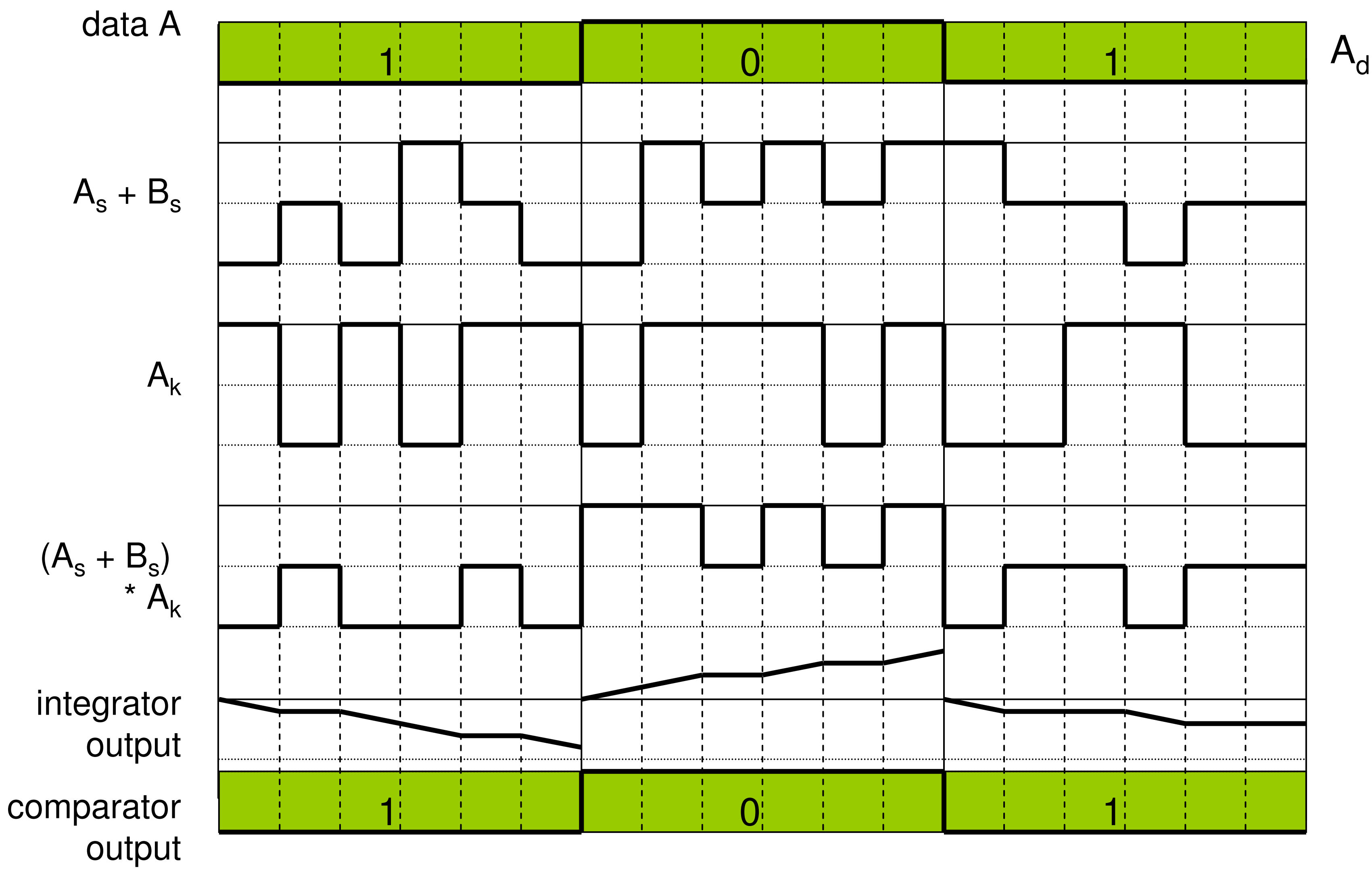
CDMA on signal A



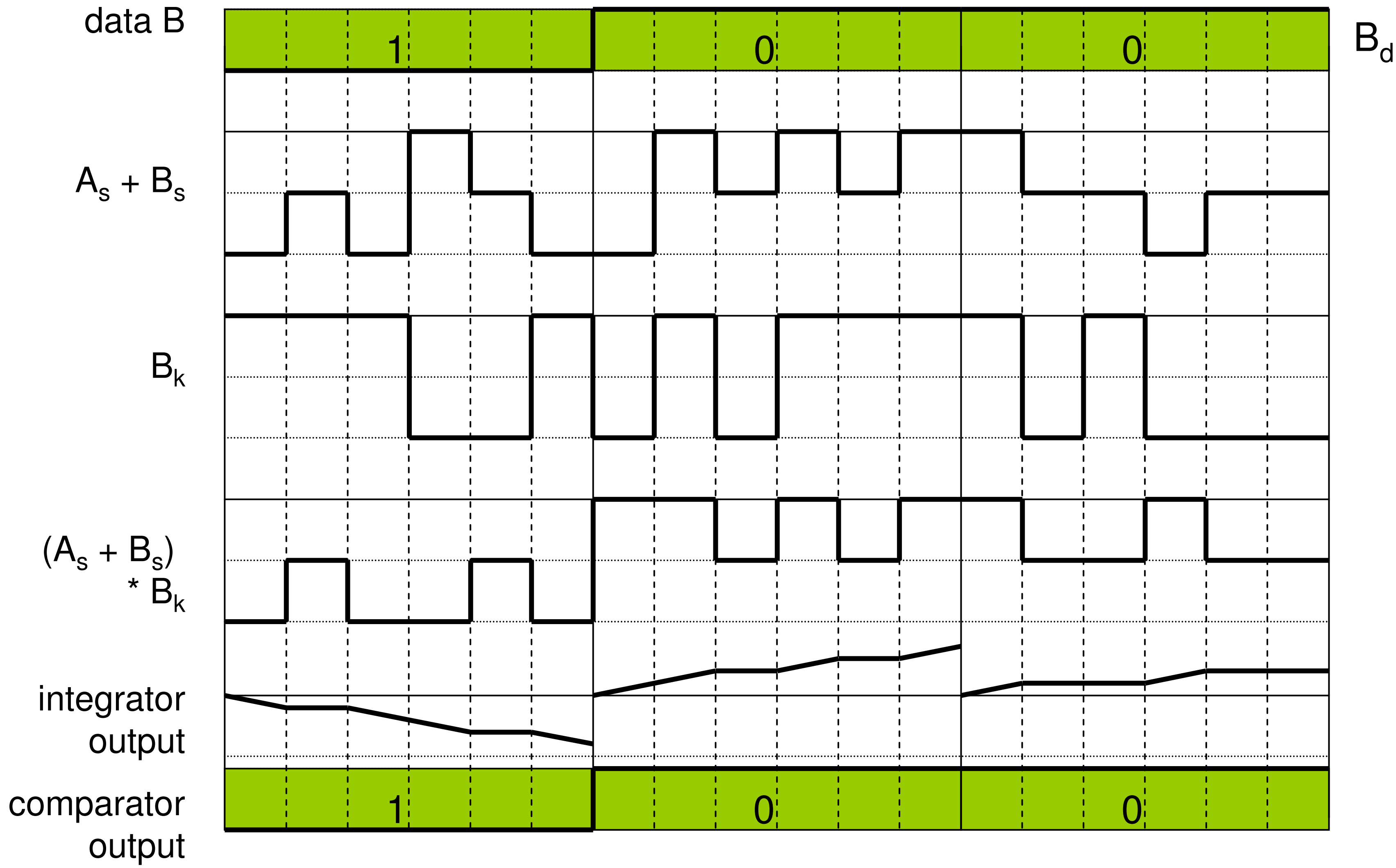
CDMA on signal B



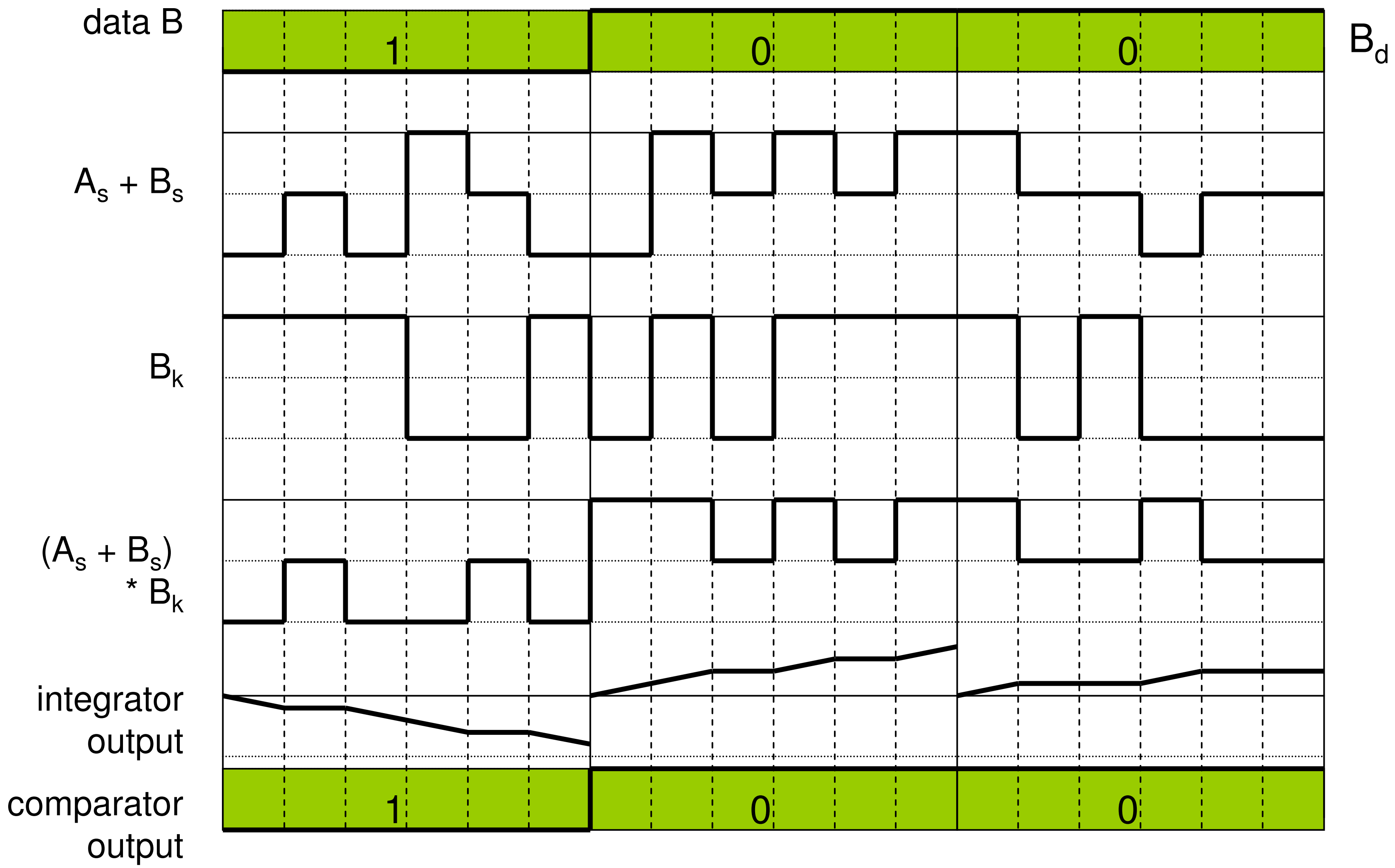
Recover A


data A
1
0
1
A_d
$A_s + B_s$
A_k
$(A_s + B_s) * A_k$
integrator output
comparator output
1
0
1

Recover B


data B
1
0
0
B_d
$A_s + B_s$
B_k
$(A_s + B_s)$
$* B_k$
integrator
output
comparator
output
1
0
0

Wrong key


data B
1
0
0
B_d
$A_s + B_s$
B_k
$(A_s + B_s)$
$* B_k$
integrator
output
comparator
output
1
0
0

CDMA

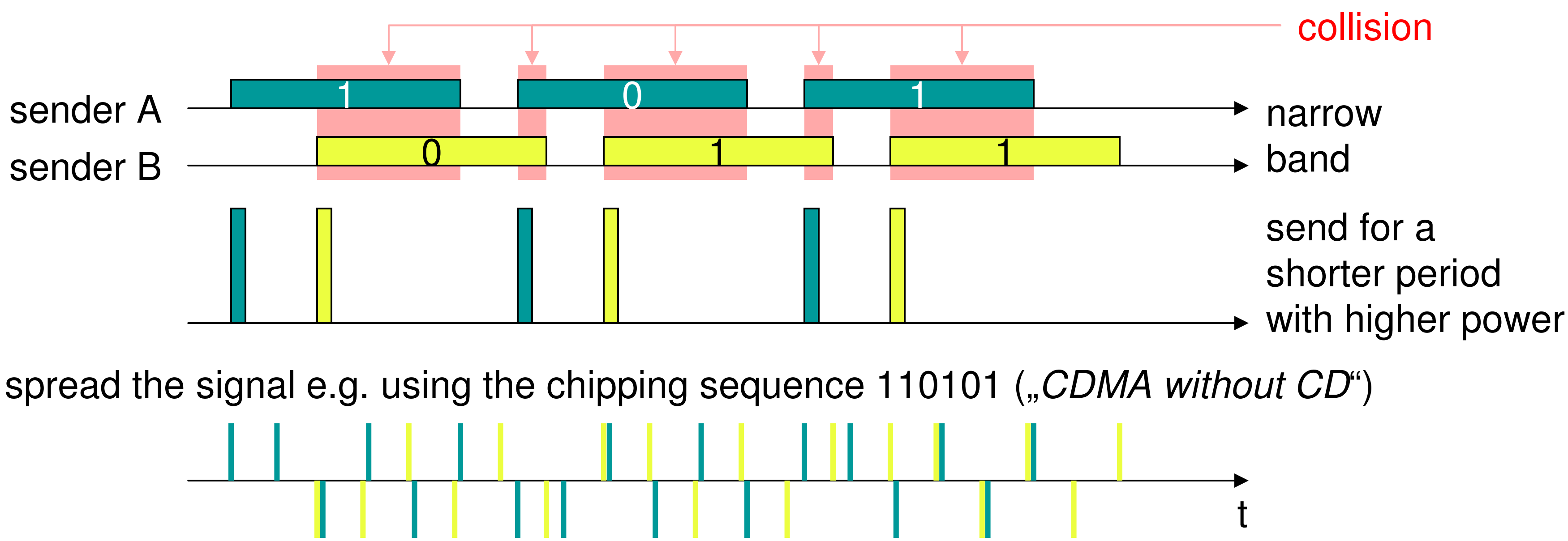
- Good against tapping: the adversary does not know the chipping sequence.
- Why the chipping sequence is also called a key.

- Precise power control – waste a lot of energy.
- It requires the mutual agreement on a key.
- Cellular phone system: base stations take charge of key establishment.
- For spontaneous communication, the key establishment is too much overhead.

SAMA - Spread Aloha Multiple Access

- Aloha + CDMA
- Use the same code, but compete for the medium.
- Aloha has only a very low efficiency, CDMA needs complex receivers to be able to receive different senders with individual codes at the same time
- Idea: use spread spectrum with only one single code (chipping sequence) for spreading for all senders accessing according to aloha

SAMA - Spread Aloha Multiple Access



Problem: find a chipping sequence with good characteristics

Comparison SDMA/TDMA/FDMA/CDMA

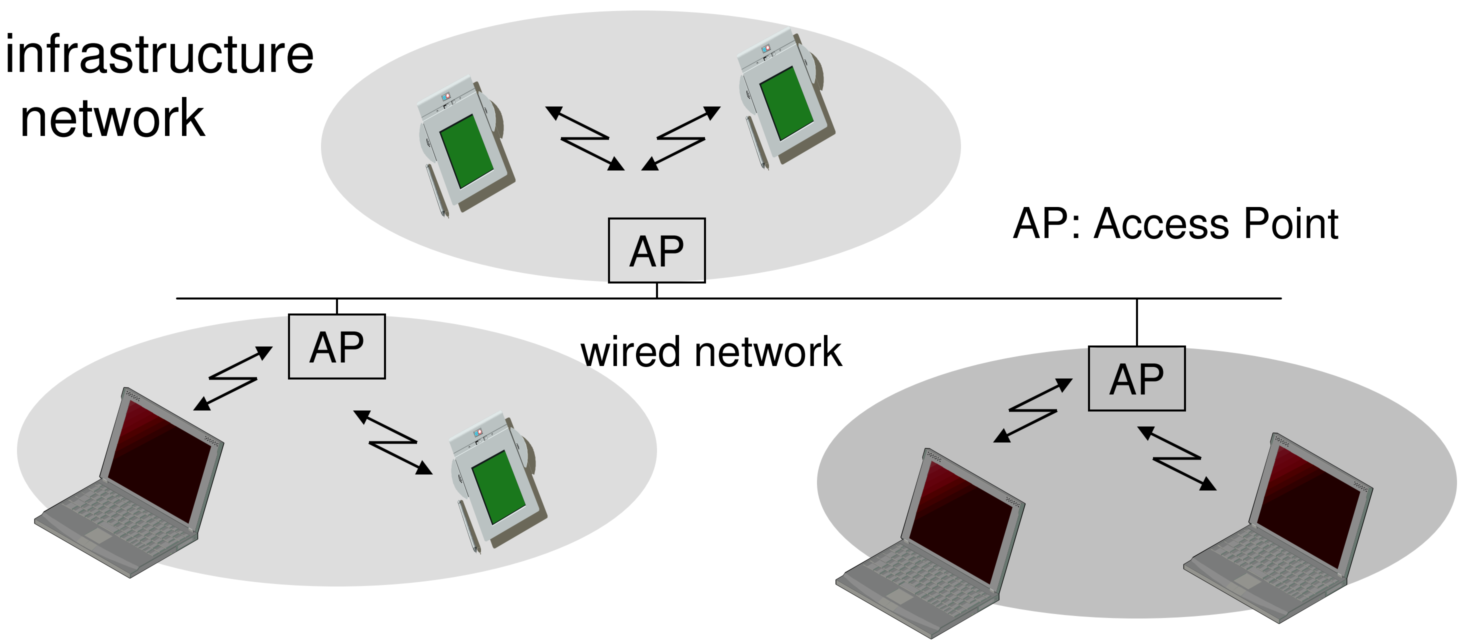
Approach	SDMA	TDMA	FDMA	CDMA
Idea	segment space into cells/sectors	segment sending time into disjoint time-slots, demand driven or fixed patterns	segment the frequency band into disjoint sub-bands	spread the spectrum using orthogonal codes
Terminals	only one terminal can be active in one cell/one sector	all terminals are active for short periods of time on the same frequency	every terminal has its own frequency, uninterrupted	all terminals can be active at the same place at the same moment, uninterrupted
Signal separation	cell structure, directed antennas	synchronization in the time domain	filtering in the frequency domain	code plus special receivers
Advantages	very simple, increases capacity per km^2	established, fully digital, flexible	simple, established, robust	flexible, less frequency planning needed, soft handover
Dis-advantages	inflexible, antennas typically fixed	guard space needed (multipath propagation), synchronization difficult	inflexible, frequencies are a scarce resource	complex receivers, needs more complicated power control for senders
Comment	only in combination with TDMA, FDMA or CDMA useful	standard in fixed networks, together with FDMA/SDMA used in many mobile networks	typically combined with TDMA (frequency hopping patterns) and SDMA (frequency reuse)	still faces some problems, higher complexity, lowered expectations; will be integrated with TDMA/FDMA

Wireless LAN

This chapter

- We’ve covered how to communicate between each pair of users.
- Now we have many users and put them together in a system.
- Architecture: how to organize them?

Infrastructure-based networks



Ad hoc networks

Infrastructure v.s. ad hoc

- Infrastructure-based
  - Communication only between access points and wireless nodes.
  - Access point decide on MAC, and forwarding.
  - Easy to organize.
  - Most functionalities lies within the access point.
  - Clients are simple.
  - Less flexible, not in disaster relief.
  - Cellular networks, satellite based networks.
  - 802.11 Wireless LAN

Infrastructure v.s. ad hoc

- Ad hoc networks
  - Flexible, suitable for emergent situation.
  - Nodes self-organize into a network.
  - The complexity of each node is higher.
  - Each node handles MAC, hidden/exposed terminal problems.
  - Bluetooth.
- Hybrid networks

Mobile Communication Technology according to IEEE

Local wireless networks
WLAN 802.11

WiFi

802.11a → 802.11h
802.11i/e/…/w
802.11b → 802.11g

Personal wireless nw
WPAN 802.15

ZigBee

802.15.4 → 802.15.4a/b
802.15.5
802.15.3 → 802.15.3a/b
802.15.2
802.15.1

Bluetooth

Wireless distribution networks
WMAN 802.16 (Broadband Wireless Access)

WiMAX

+ Mobility

802.20 (Mobile Broadband Wireless Access)

Characteristics of wireless LANs

- Advantages
  - very flexible within the reception area
  - Ad-hoc networks without previous planning possible
  - (almost) no wiring difficulties (e.g. historic buildings, firewalls)
  - more robust against disasters like, e.g., earthquakes, fire - or users pulling a plug...
- Disadvantages
  - typically very low bandwidth compared to wired networks (1-10 Mbit/s) due to shared medium
  - many proprietary solutions, especially for higher bit-rates, standards take their time (e.g. IEEE 802.11)
  - products have to follow many national restrictions if working wireless, it takes a vary long time to establish global solutions like, e.g., IMT-2000

Design goals for wireless LANs

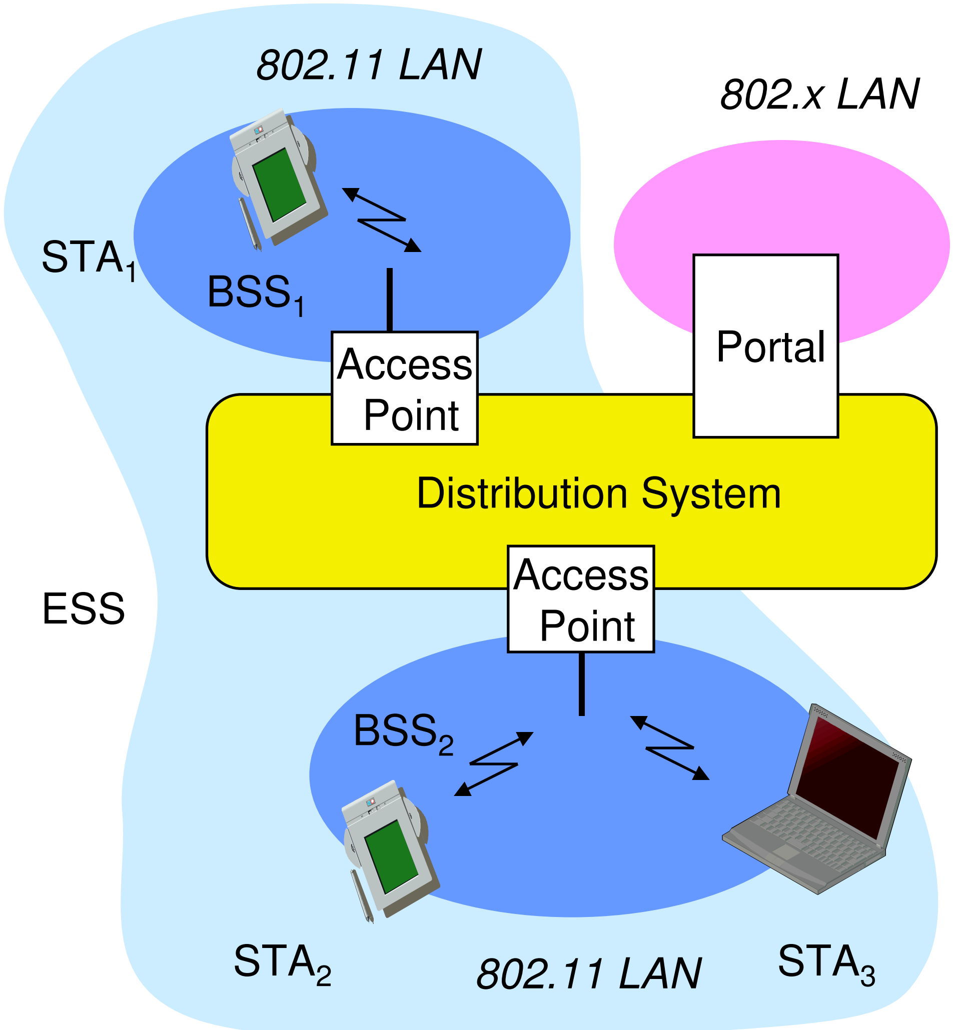
- global, seamless operation
- low power for battery use
- no special permissions or licenses needed to use the LAN
- robust transmission technology
- simplified spontaneous cooperation at meetings
- easy to use for everyone, simple management
- protection of investment in wired networks
- security (no one should be able to read my data), privacy (no one should be able to collect user profiles), safety (low radiation)
- transparency concerning applications and higher layer protocols, but also location awareness if necessary

Comparison: infrared vs. radio transmission

- Infrared
  - uses IR diodes, diffuse light, multiple reflections (walls, furniture etc.)
- Advantages
  - simple, cheap, available in many mobile devices
  - no licenses needed
  - simple shielding possible
- Disadvantages
  - interference by sunlight, heat sources etc.
  - many things shield or absorb IR light
  - low bandwidth
- Example
  - IrDA (Infrared Data Association) interface available everywhere

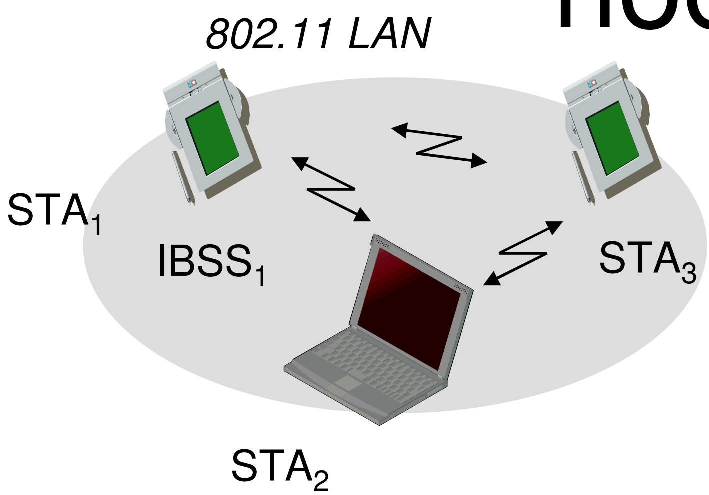
- Radio
  - typically using the license free ISM band at 2.4 GHz
- Advantages
  - experience from wireless WAN and mobile phones can be used
  - coverage of larger areas possible (radio can penetrate walls, furniture etc.)
- Disadvantages
  - very limited license free frequency bands
  - shielding more difficult, interference with other electrical devices
- Example
  - Many different products

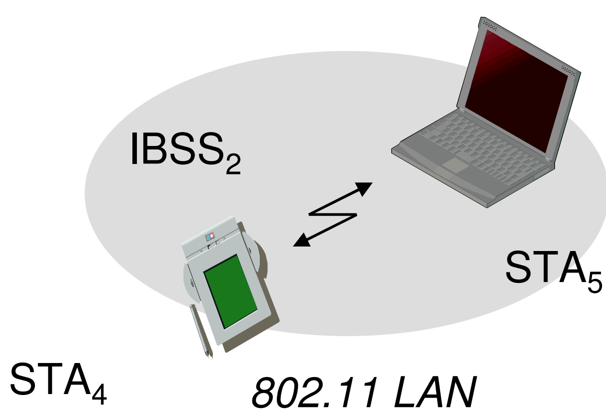
802.11 - Architecture of an infrastructure network



- Station (STA)
  - terminal with access mechanisms to the wireless medium and radio contact to the access point
- Basic Service Set (BSS)
  - group of stations using the same radio frequency
- Access Point
  - station integrated into the wireless LAN and the distribution system
- Portal
  - bridge to other (wired) networks
- Distribution System
  - interconnection network to form one logical network (EES: Extended Service Set) based on several BSS

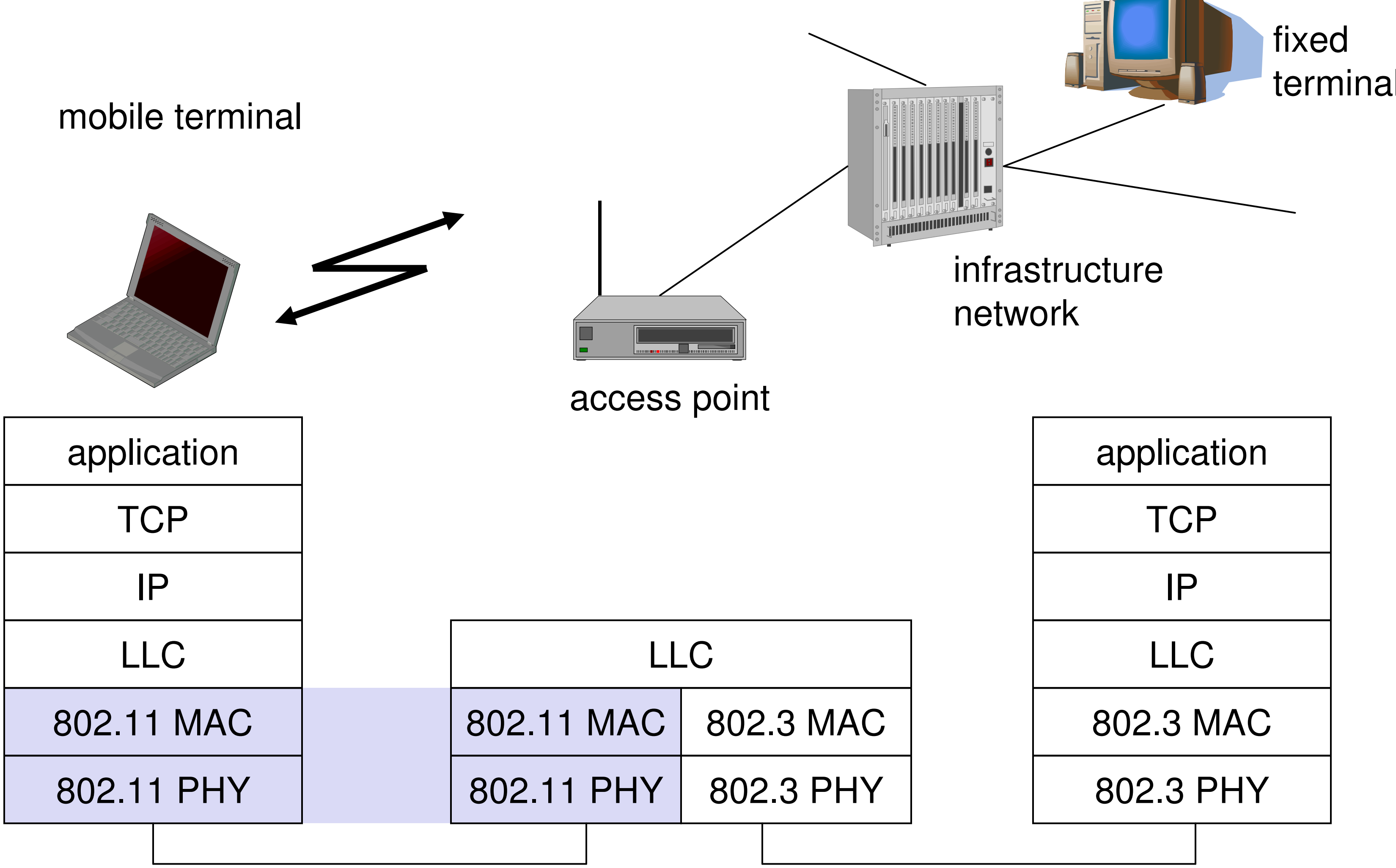
802.11 - Architecture of an ad-hoc network





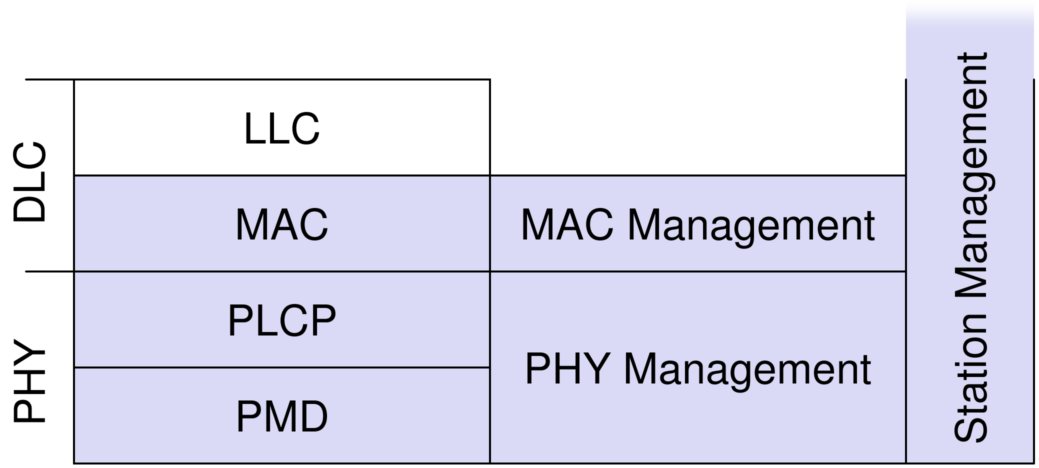
- Direct communication within a limited range
  - Station (STA): terminal with access mechanisms to the wireless medium
  - Independent Basic Service Set (IBSS): group of stations using the same radio frequency

IEEE standard 802.11



802.11 - Layers and functions

- MAC
  - access mechanisms, fragmentation, encryption
- MAC Management
  - synchronization, roaming, MIB, power management



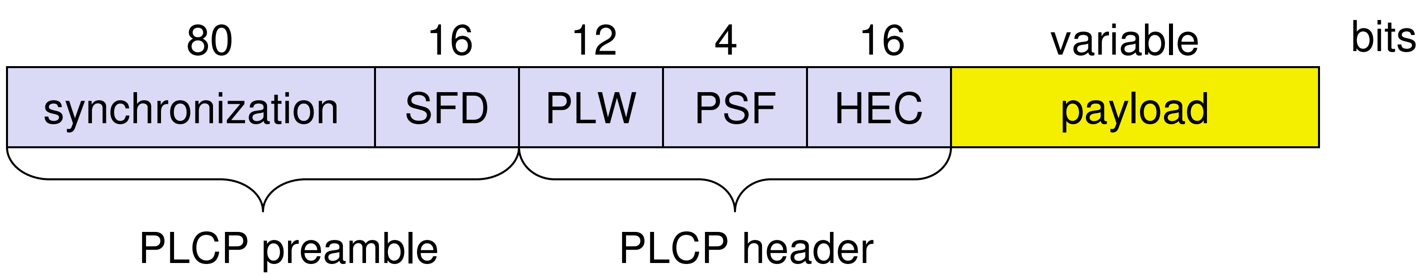
- PLCP Physical Layer Convergence Protocol
  - clear channel assessment signal (carrier sense)
- PMD Physical Medium Dependent
  - modulation, coding
- PHY Management
  - channel selection, MIB
- Station Management
  - coordination of all management functions

802.11 - Physical layer (classical)

- 3 versions: 2 radio (typ. 2.4 GHz), 1 IR
  - data rates 1 or 2 Mbit/s
- FHSS (Frequency Hopping Spread Spectrum)
  - spreading, despreading, signal strength, typ. 1 Mbit/s
  - min. 2.5 frequency hops/s (USA), two-level GFSK modulation
- DSSS (Direct Sequence Spread Spectrum)
  - DBPSK modulation for 1 Mbit/s (Differential Binary Phase Shift Keying), DQPSK for 2 Mbit/s (Differential Quadrature PSK)
  - preamble and header of a frame is always transmitted with 1 Mbit/s, rest of transmission 1 or 2 Mbit/s
  - chipping sequence: +1, -1, +1, +1, -1, +1, +1, +1, -1, -1, -1 (Barker code)
  - max. radiated power 1 W (USA), 100 mW (EU), min. 1mW
- Infrared
  - 850-950 nm, diffuse light, typ. 10 m range
  - carrier detection, energy detection, synchronization

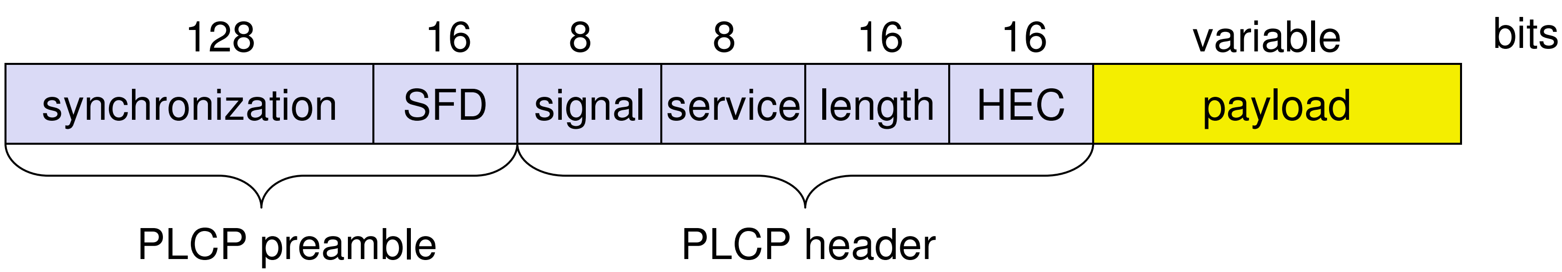
FHSS PHY packet format

- Synchronization
  - synch with 010101... pattern
- SFD (Start Frame Delimiter)
  - 0000110010111101 start pattern
- PLW (PLCP_PDU Length Word)
  - length of payload incl. 32 bit CRC of payload, PLW < 4096
- PSF (PLCP Signaling Field)
  - data of payload (1 or 2 Mbit/s)
- HEC (Header Error Check)
  - CRC with $x^{16}+x^{12}+x^5+1$



DSSS PHY packet format

- Synchronization
  - synch., gain setting, energy detection, frequency offset compensation
- SFD (Start Frame Delimiter)
  - 1111001110100000
- Signal
  - data rate of the payload (0A: 1 Mbit/s DBPSK; 14: 2 Mbit/s DQPSK)
- Service
  - future use, 00: 802.11 compliant
- Length
  - length of the payload
- HEC (Header Error Check)
  - protection of signal, service and length, $x^{16}+x^{12}+x^5+1$



Summary

- CDMA
- Infrastructure v.s. ad hoc
- Wireless LAN
- 802.11 standard
  – Physical layer