Wireless Networks: Medium Access Control

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Slides adapted from "Mobile Communications" by J. Schiller

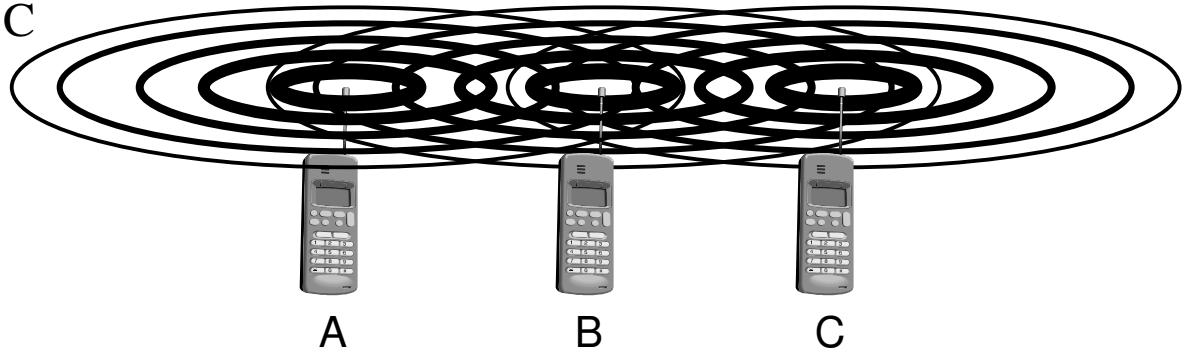
Motivation

- Can we apply media access methods from fixed networks?

- Example CSMA/CD
  - **C**arrier **S**ense **M**ultiple **A**ccess with **C**ollision **D**etection
  - send as soon as the medium is free, listen into the medium if a collision occurs (original method in IEEE 802.3)
- Problems in wireless networks
  - signal strength decreases proportional to the square of the distance
  - the sender would apply CS and CD, but the collisions happen at the receiver
  - it might be the case that a sender cannot “hear” the collision, i.e., CD does not work
  - furthermore, CS might not work if, e.g., a terminal is “hidden”

Motivation - hidden and exposed terminals

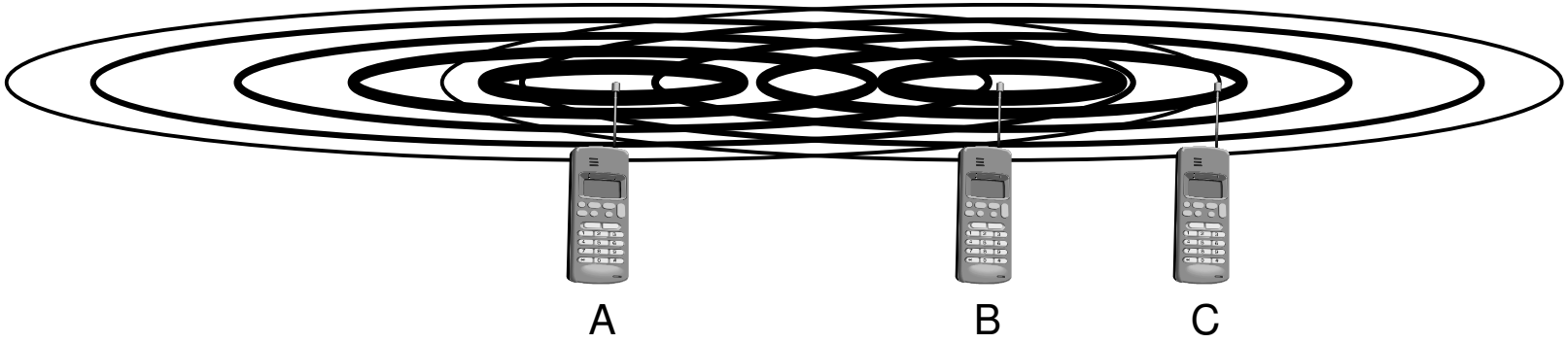
- Hidden terminals
  - A sends to B, C cannot receive A
  - C wants to send to B, C senses a “free” medium (CS fails)
  - collision at B, A cannot receive the collision (CD fails)
  - A is “hidden” for C



- Exposed terminals
  - B sends to A, C wants to send to another terminal (not A or B)
  - C has to wait, CS signals a medium in use
  - but A is outside the radio range of C, therefore waiting is not necessary
  - C is “exposed” to B

Motivation - near and far terminals

- Terminals A and B send, C receives
  - signal strength decreases proportional to the square of the distance
  - the signal of terminal B therefore drowns out A's signal
  - C cannot receive A



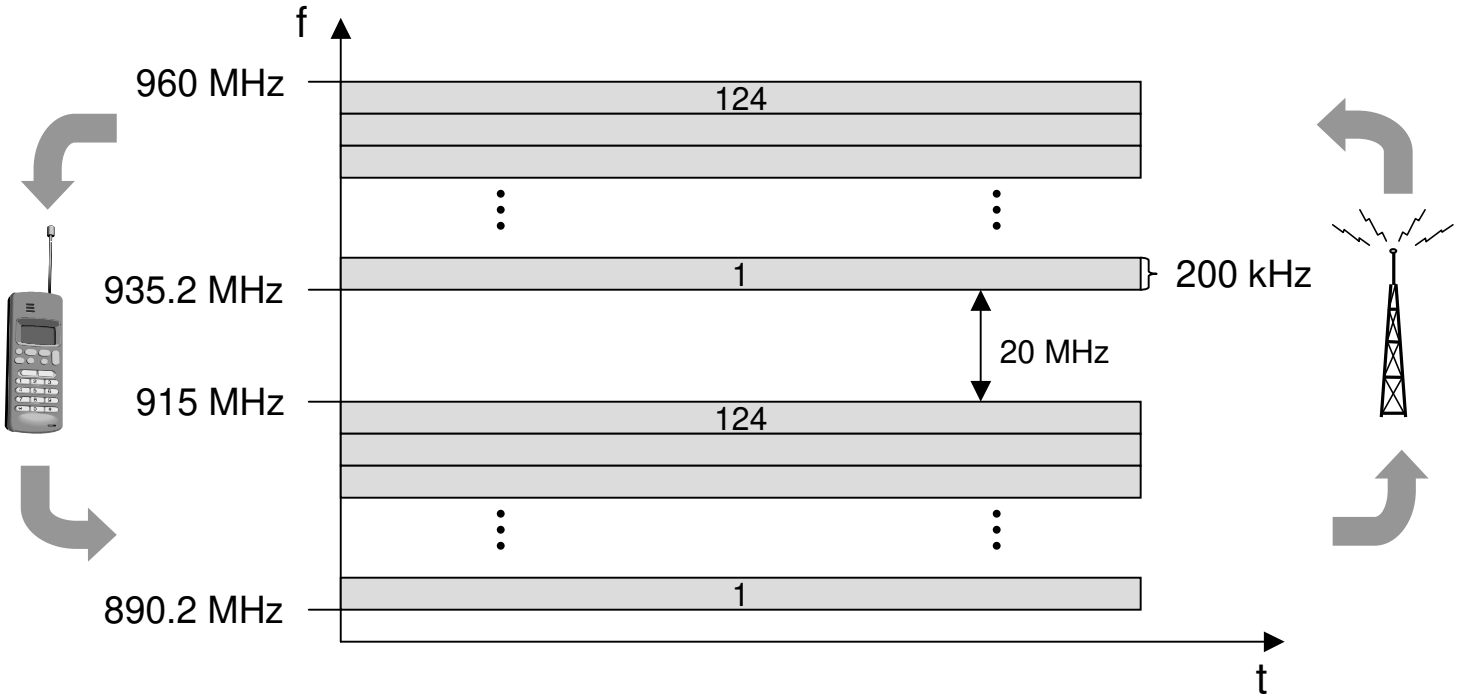
- If C for example was an arbiter for sending rights, terminal B would drown out terminal A already on the physical layer
- Also severe problem for CDMA-networks - precise power control needed!

Access methods SDMA/FDMA/TDMA

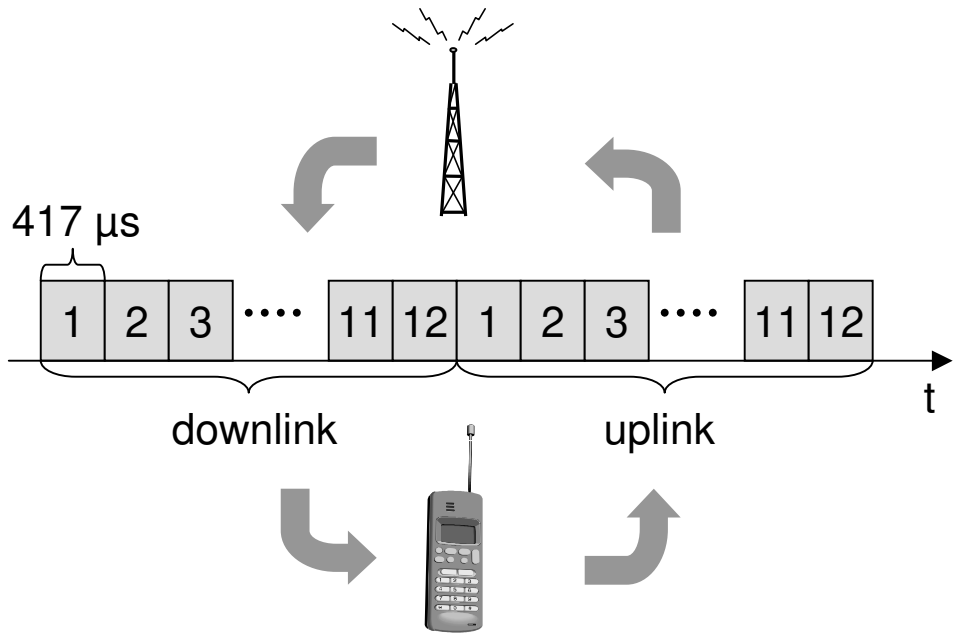
- SDMA (Space Division Multiple Access)
  - segment space into sectors, use directed antennas
  - cell structure
- FDMA (Frequency Division Multiple Access)
  - assign a certain frequency to a transmission channel between a sender and a receiver
  - permanent (e.g., radio broadcast), slow hopping (e.g., GSM), fast hopping (FHSS, Frequency Hopping Spread Spectrum)
- TDMA (Time Division Multiple Access)
  - assign the fixed sending frequency to a transmission channel between a sender and a receiver for a certain amount of time

- The multiplexing schemes are now used to control medium access!

FDD/FDMA - general scheme, example GSM



TDD/TDMA - general scheme, example DECT



Frequency Division Multiple Access

- Concept:
  - assign different frequency bands to different users
  - no sharing of a frequency band between two users
  - user separation using band-pass filters
  - continuous flow
  - two-way: two frequency bands or Time Division Duplex (TDD)
- Advantages: simple receivers
  - longer symbol duration: no-need for equalization
    - low inter-symbol interference
    - e.g., 50kb/s QPSK =>40 μs >> 1-10μs delay spread
- Drawbacks:
  - frequency guard bands, costly tight RF band-filters,
  - long fading duration: need slow frequency hopping
  - may need spatial diversity (multiple antennas/beam forming) Rx/Tx

Frequency Selection

- Frequency management:
  - Fixed (cellular phones-base stations): reuse factor
  - On demand (cellular phones-mobile terminals)
  - Dynamic (cordless/WLAN): based on sensing interference levels
  - Problems: congestion management, dynamic load, …

- Antenna implications:
  - High antennas (e.g., 50m): higher coverage but higher interference between base stations (need for synchronization)
  - Low antennas: higher attenuation, lower coverage, better reuse

- Conclusion:
  - Pure FDMA is only interesting for simple cordless systems (CT-2)

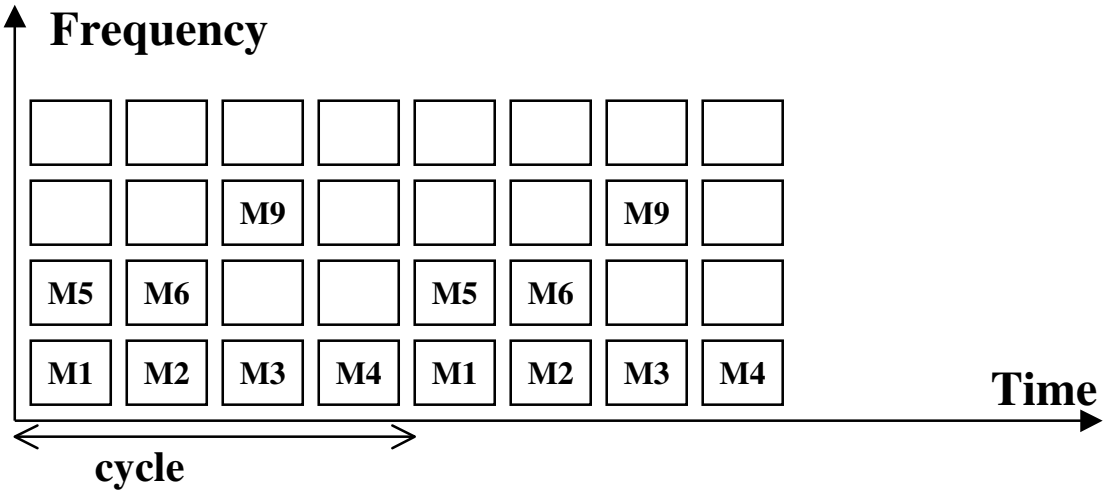
Time Division Multiple Access

- Concept:
  - use the same frequency over non-overlapping periods of time
- Advantages:
  - simple filters (window)
  - transmit and receive over the same frequency channel
- Drawbacks:
  - users must be synchronized with BS (master clock over a BCH)
  - guard times: common 30-50μs, may be less in recent systems
  - short symbol duration: need for equalization, training sequences...
    - high inter-symbol interference
    - e.g., 50Kbps, QPSK, 8 users:
      - 5 μs symbol duration
      - delay spread: 1μs (cordless), upto 20μs for cellular

FDMA/TDMA

- First channel allocation:
  - random access channel (RACH) to send short requests
  - ALOHA type protocol over the RACH

- One can use both FDMA and TDMA
  - examples: GSM system, D-AMPS



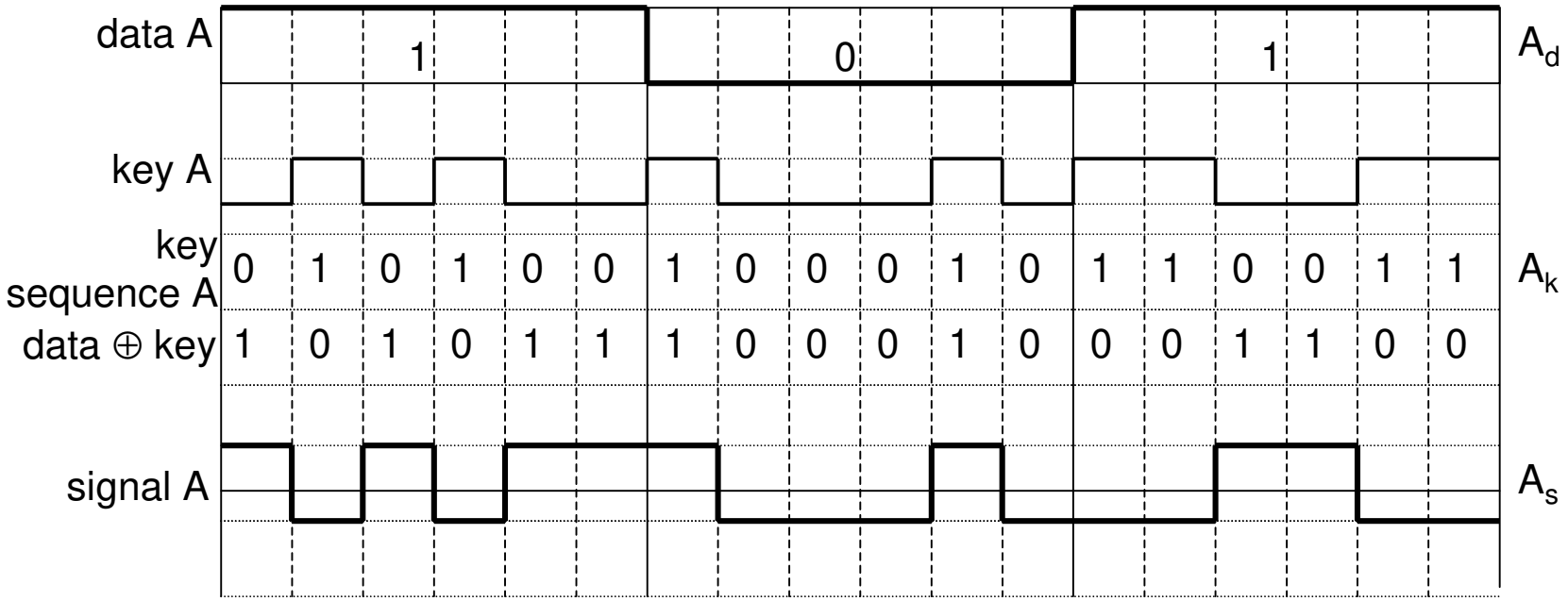
Access method CDMA

- 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
  - codes generate signals with "good-correlation" properties
  - signals from another user appear as "noise" (use spread spectrum technology)
  - signals are spread over a wideband using pseudo-noise sequences (e.g., 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
- 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 (near-far effect)
- Advantages:
  - all terminals can use the same frequency => no planning needed; macrodiversity
  - 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

CDMA in theory

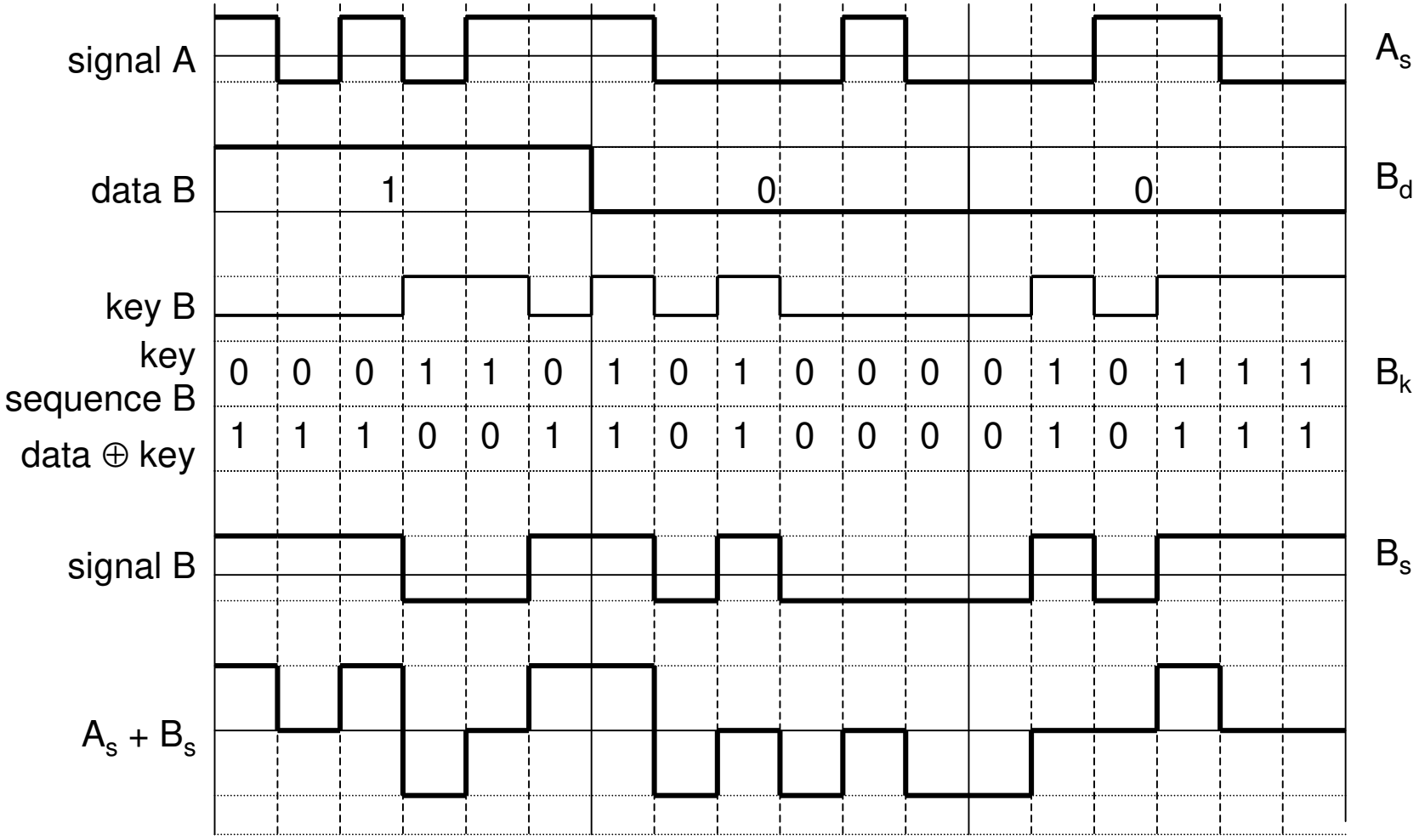
- Sender A
  - sends $A_d = 1$, key $A_k = 010011$ (assign: „0“= -1, „1“= +1)
  - sending signal $A_s = A_d * A_k = (-1, +1, -1, -1, +1, +1)$
- Sender B
  - sends $B_d = 0$, key $B_k = 110101$ (assign: „0“= -1, „1“= +1)
  - sending signal $B_s = B_d * B_k = (-1, -1, +1, -1, +1, -1)$
- Both signals superimpose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

CDMA on signal level I

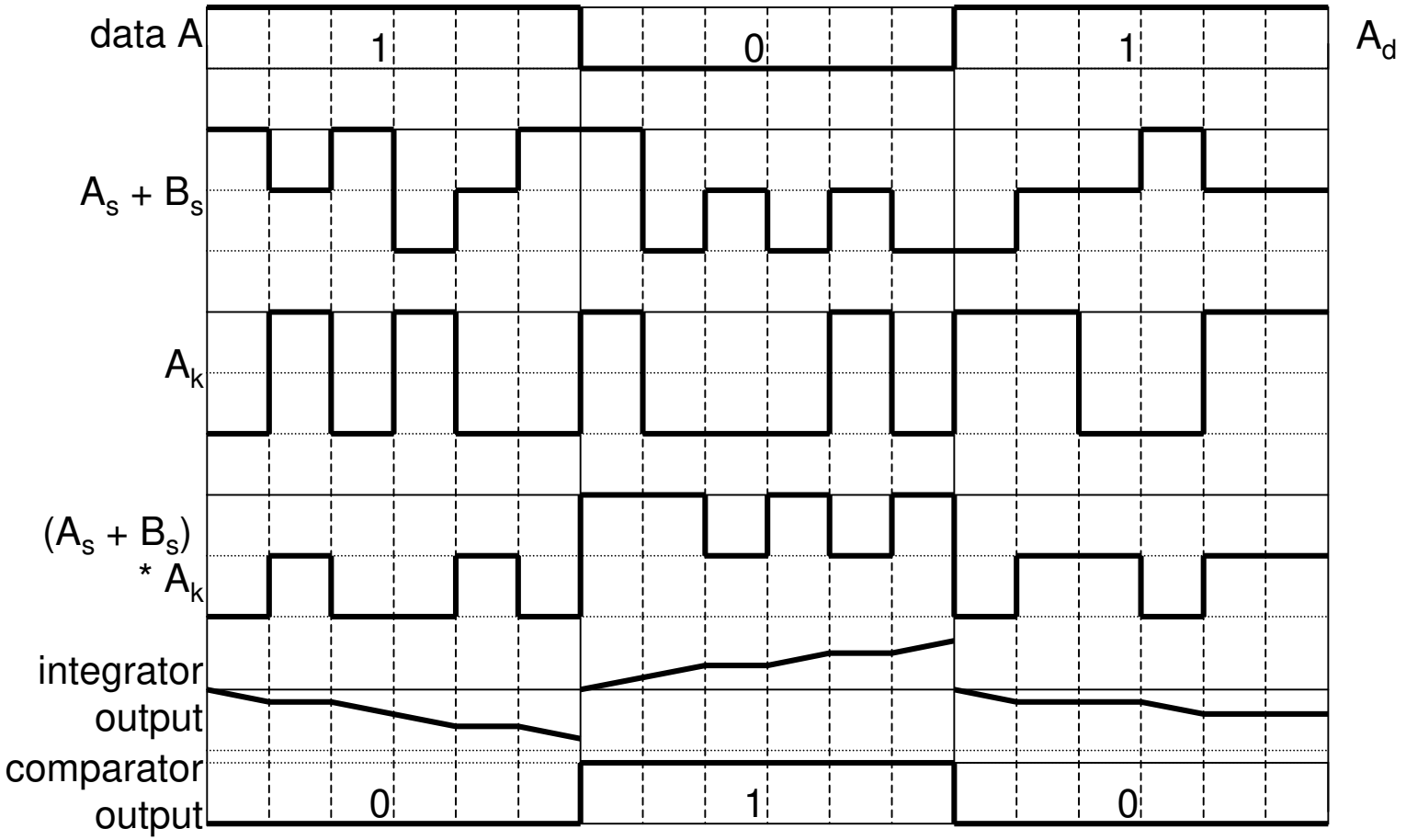


Real systems use much longer keys resulting in a larger distance between single code words in code space.

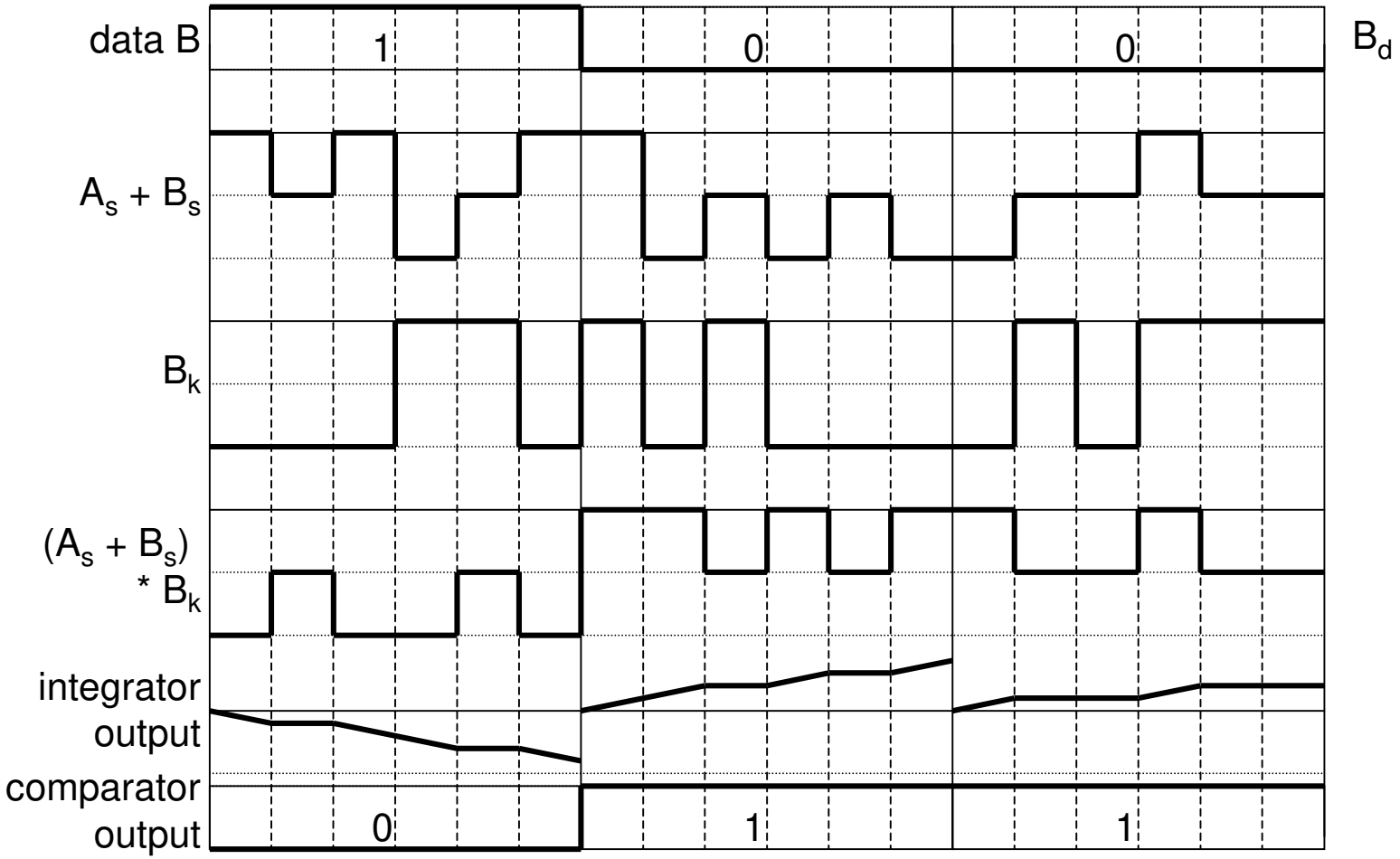
CDMA on signal level II



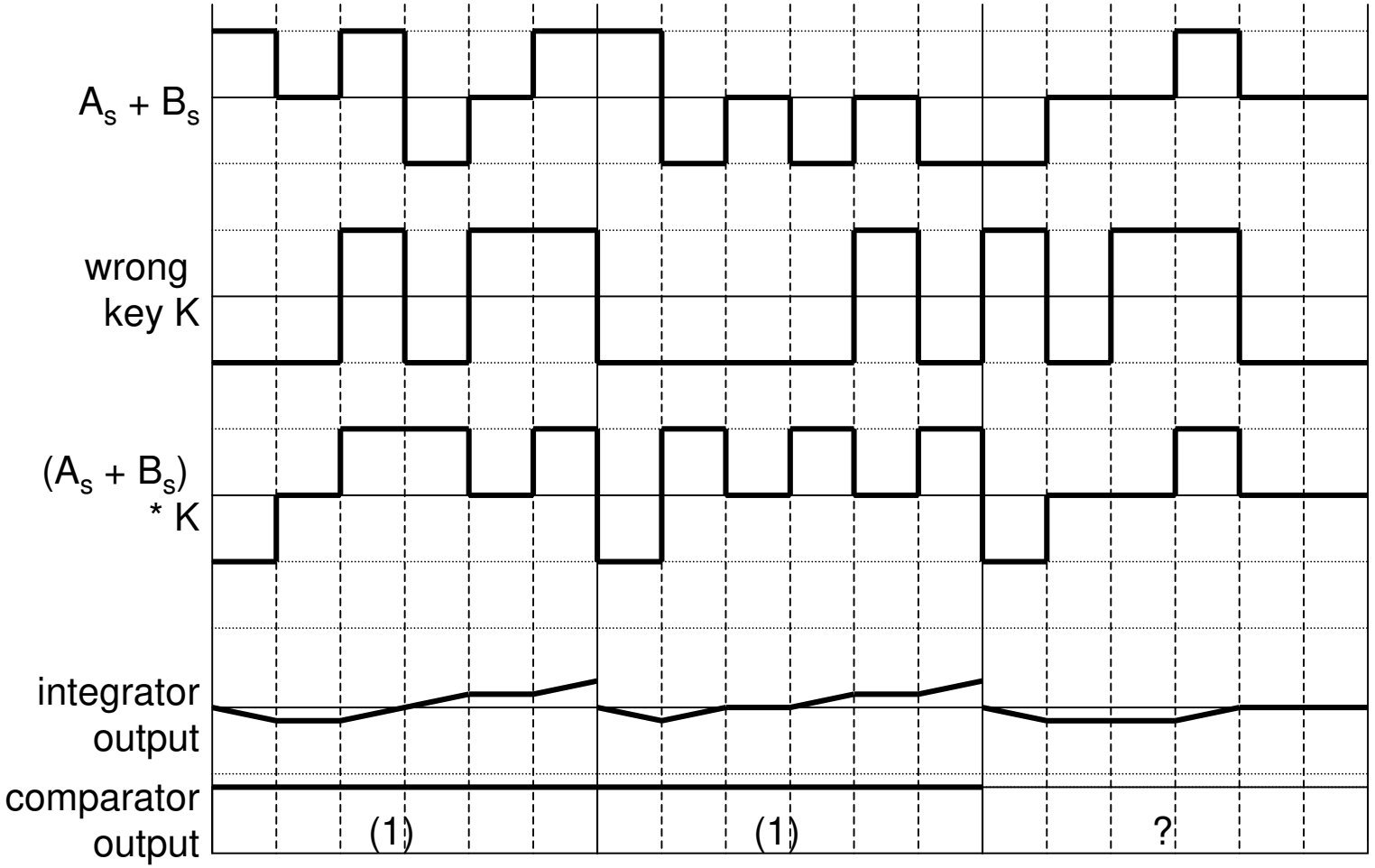
CDMA on signal level III



CDMA on signal level IV

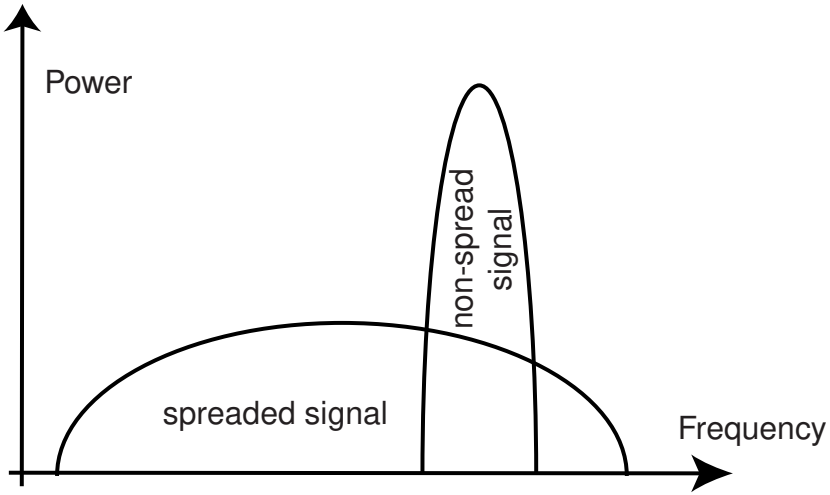
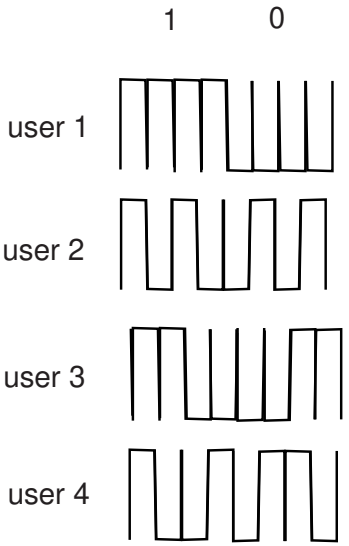


CDMA on signal level V



CDMA: Direct Sequence

- Each mobile is allocated a PN sequence:
- The elements of the PN-sequence are called chips
- To transmit one bit 1/0 send the PN-Seq/inv-PN-Seq
- Example Hadamard Matrix:
  - Each mobile uses one row
  - The rows are orthogonal



$$H_4 = \begin{bmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{bmatrix}$$