# Mobile and Sensor Systems

## Lecture 2: Mobile Medium Access Control Layer

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## In this Lecture

- In this lecture we will discuss aspects related to the MAC Layer of wireless networks
  - In comparison with wired networks
  - In terms of how multiplexing in applied
  - In terms of carrier sensing

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# 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 presented in the previous lecture are now used to control medium access!

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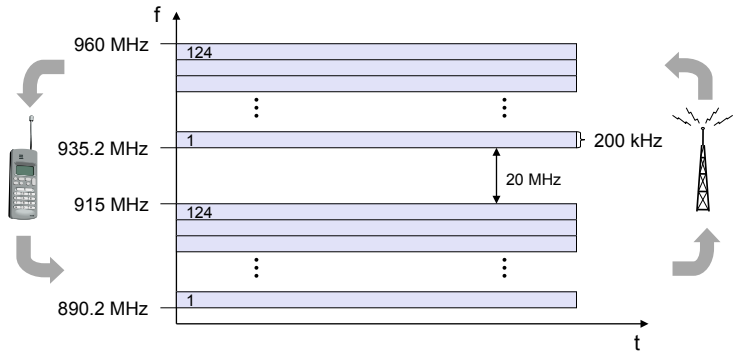
# FDM in GSM

FDD/FDMA - general scheme, example GSM

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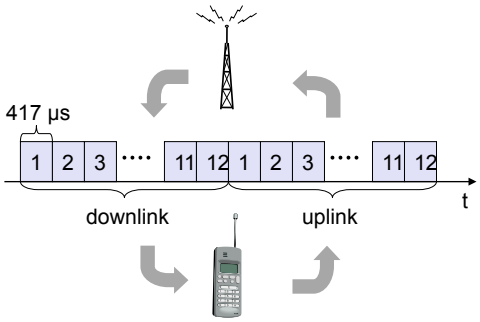
# TDMA in DECT

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# Access method CDMA

- CDMA (Code Division Multiple Access)
  - all terminals send on the same frequency roughly 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 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
- Advantages:
  - all terminals can use the same frequency, no planning needed
  - huge code space (e.g. $2^{32}$) compared to frequency space

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# 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) • $A_k$ = 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) • $B_k$ = -2 + 0 + 0 - 2 - 2 + 0 = -6, i.e. "0"

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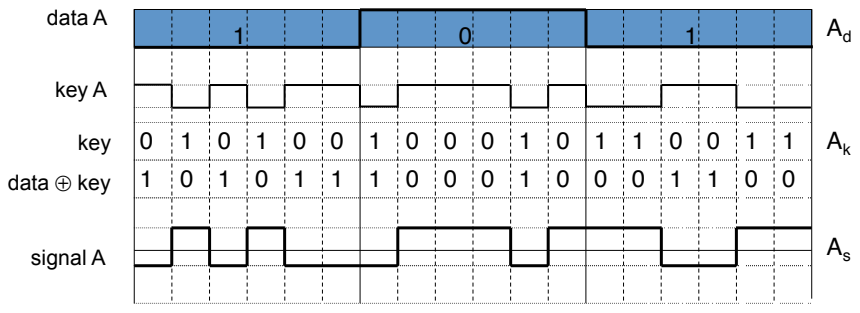
# CDMA on signal level I




0 is a positive signal and 1 is a negative signal in these examples

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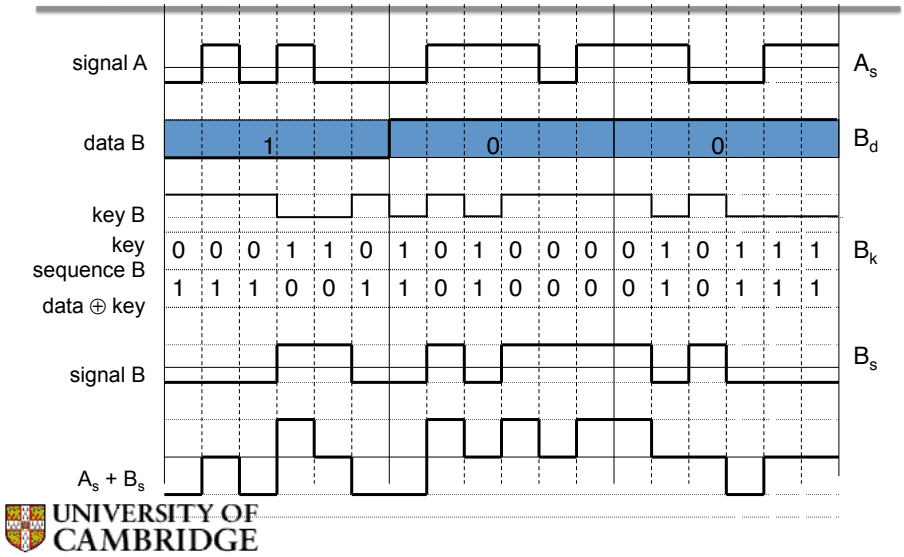
# CDMA on signal level II

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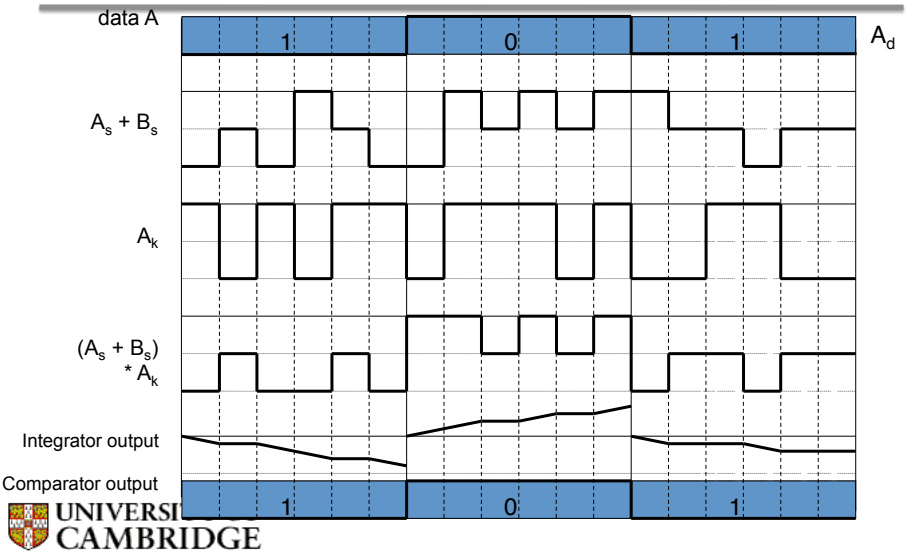
# CDMA on signal level III

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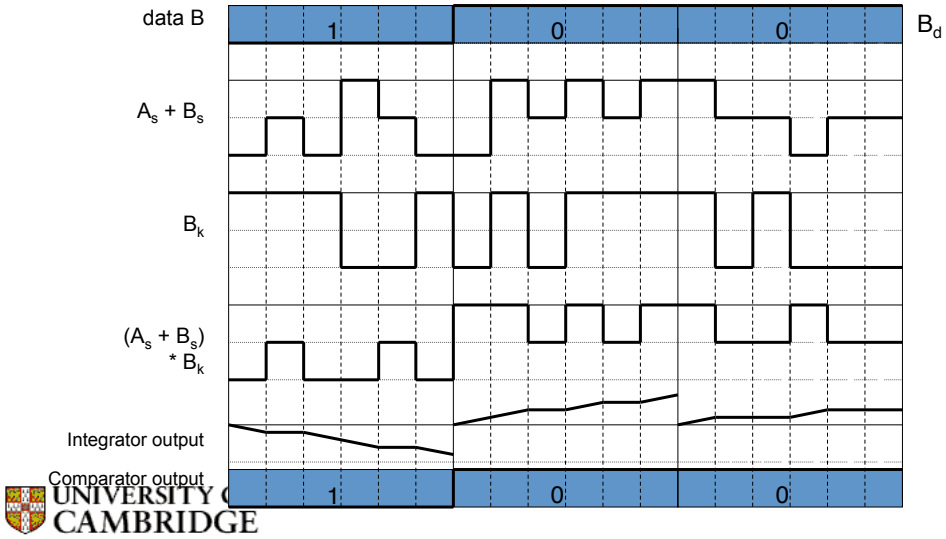
# CDMA on signal level IV

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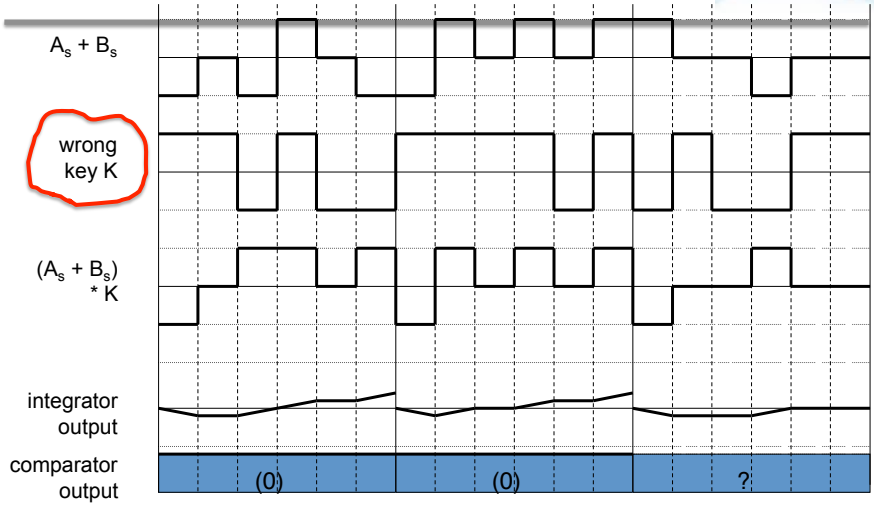
# CDMA on signal level V

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# Comparisons

| 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 km² | 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 |

# Limitations of multiplexing

- Multiplexing is one way to allow a basic share of medium to be shared more efficiently through the definition of “channels”
- Once channels are established packets will be sent through that
  - Might be a bit rigid as a method
  - For example, frequency division multiplexing would have issues with large numbers of users.
  - Also depending on traffic and time some users might want to send more or less
- More ad hoc approaches exist which allow channels to be shared in a “statistical” way

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# Review: Ethernet Medium Access Control (MAC)

- In Ethernet based fixed networks where you have wires between computers:
- CS (Carrier Sense): listen for others' transmissions before transmitting; defer to others you hear
- CD (Collision Detection): as you transmit, listen and verify you hear exactly what you send; if not, back off random interval, within exponentially longer range each time you transmit unsuccessfully

**Can CD be applied on wireless networks?**

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# Can we apply the same MAC protocols in wireless?

- Problems in wireless networks
  - signal strength decreases proportionally to the square of the distance
  - the sender would apply CS and CD, but 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"

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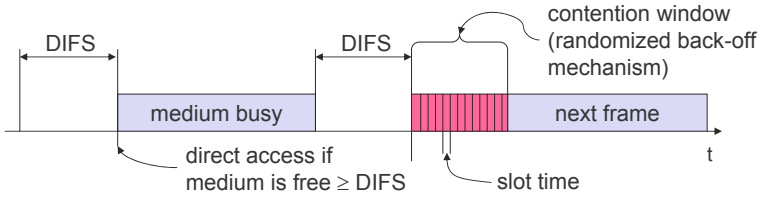
# CSMA/CA: Carrier Sensing Multiple Access Protocol with Collision Avoidance




• CSMA/CA: sense medium. If free transmit (although this might generate collision at the receiver). If not, wait with a back off strategy. Transmit when medium is sensed free.

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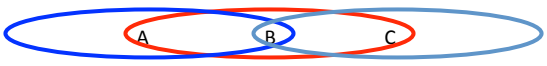
# Hidden Terminal

- Hidden terminals
  - A sends to B, C cannot receive from 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

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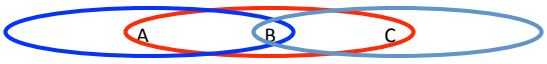
# Exposed Terminal

- 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

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# Multiple Access with Collision Avoidance (for Wireless): MACA(W))

- Sender B asks receiver C whether C is able to receive a transmission ***Request to Send (RTS)***
- Receiver C agrees, sends out a ***Clear to Send*** (***CTS***)
- Potential interferers overhear either RTS or CTS and know about impending transmission and for how long it will last
  - Store this information in a ***Network Allocation Vector***
- B sends, C acks

! ***MACA(W) protocol*** (used e.g. in ***IEEE 802.11***)




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# MACA(W)

- Absent CTS, sender backs off exponentially before retrying
- RTS and CTS can still themselves collide at their receivers; less chance as they're short;

- **What's the effect on exposed terminal problem?**

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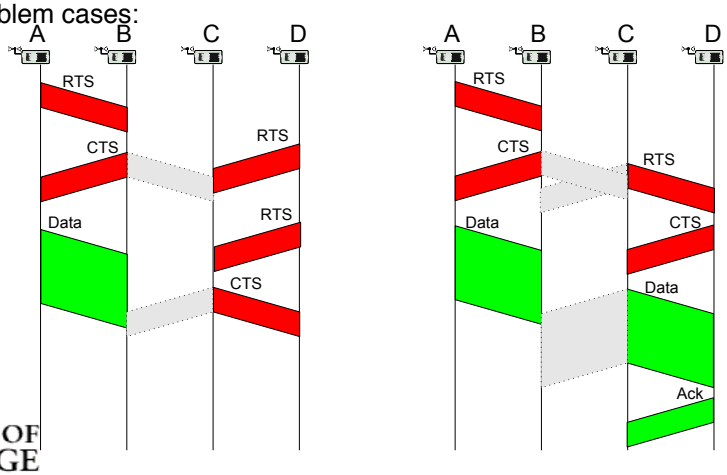
# RTS/CTS

- RTS/CTS ameliorate, but do not solve hidden/exposed terminal problems
- Example problem cases:

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# The 802.11 Protocol

- 802.11 uses 2 modes of operation: a basic CSMA/CA (in base station mode) and the RTS/CTS mode.
- Generally 802.11 drivers leave the RTS/CTS off by default.
- Also tests in practice show that hidden terminal might not be a problem in most cases as interference range is more than double communication range. Consider A->B<-C when A transmits it is very likely C can sense A's carrier directly.

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# Summary

- We have shown how multiplexing can be used at the MAC layer
- We have explained the limits of carrier sensing
- We have described the problems related to "hidden and exposed" terminals

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