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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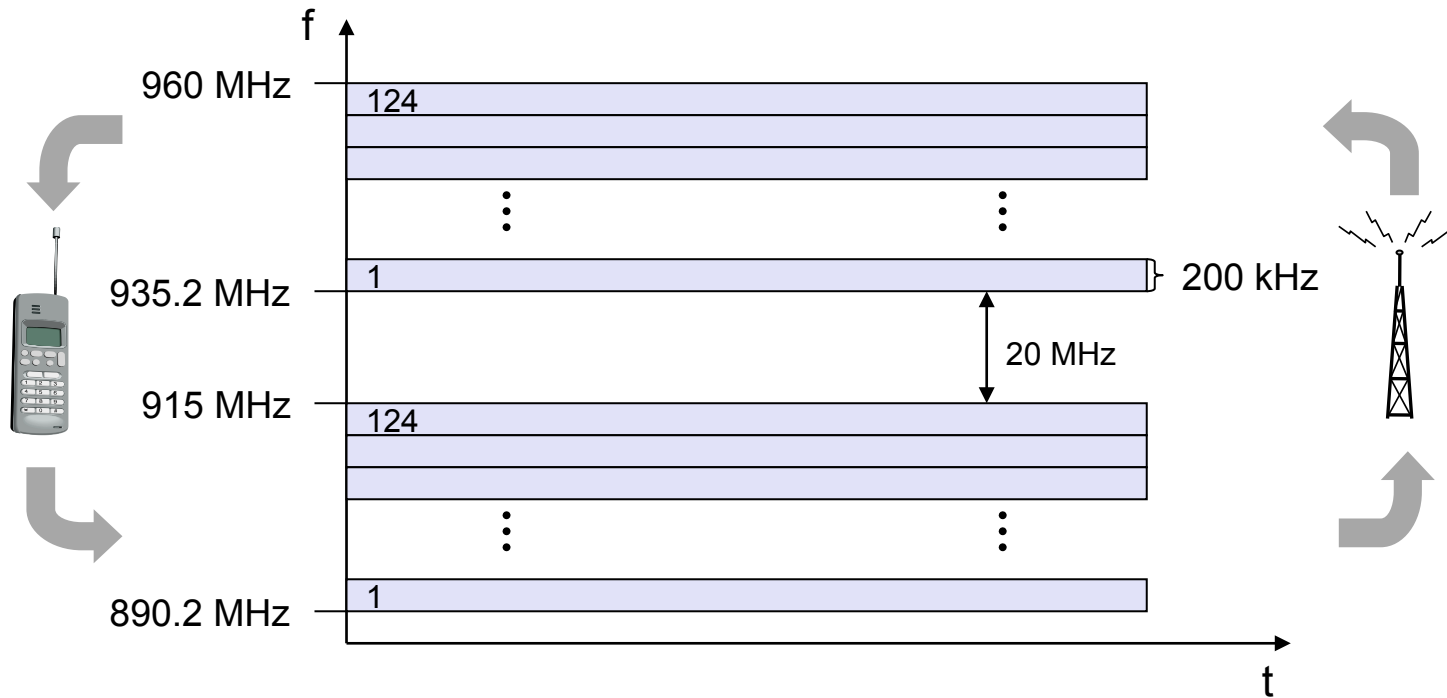# Access methods
SDMA/FDMA/TDMA

- 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!
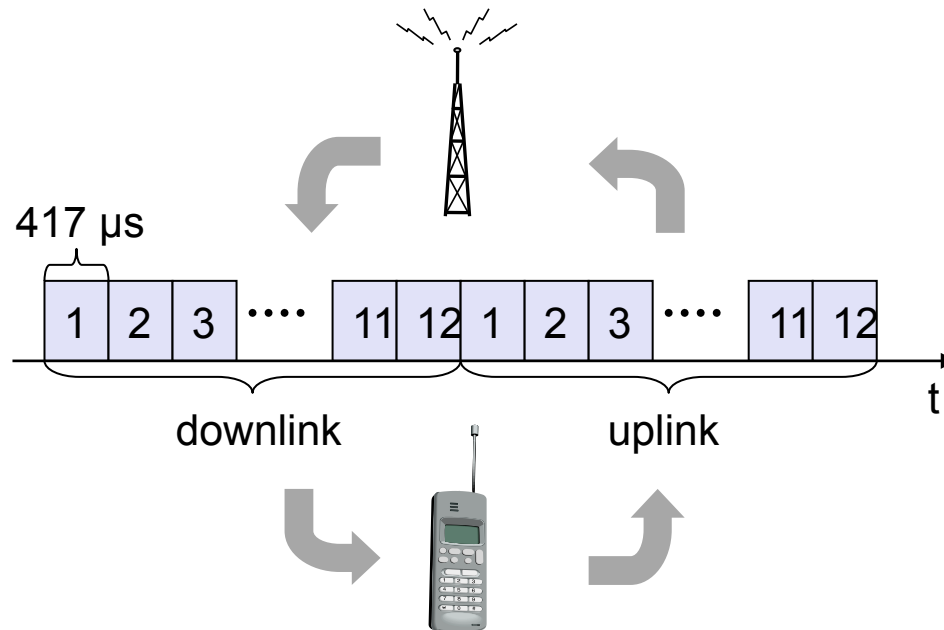
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FDM in GSM

FDD/FDMA - general scheme, example GSM

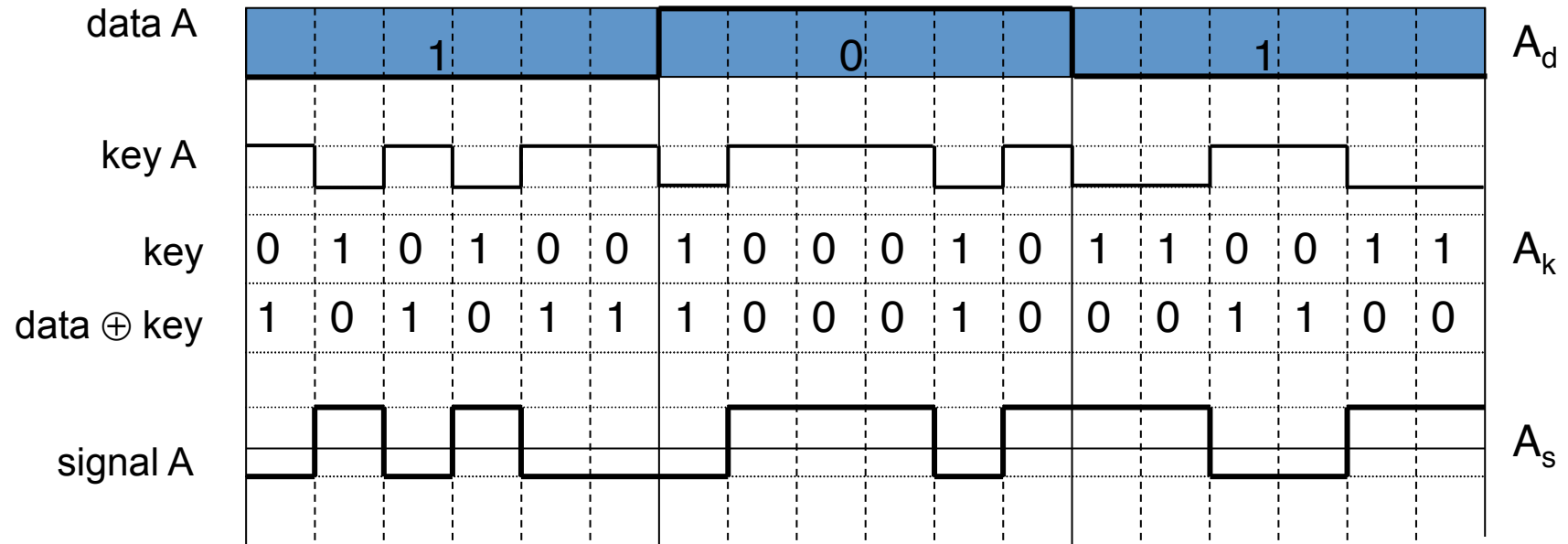# TDMA in DECT

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
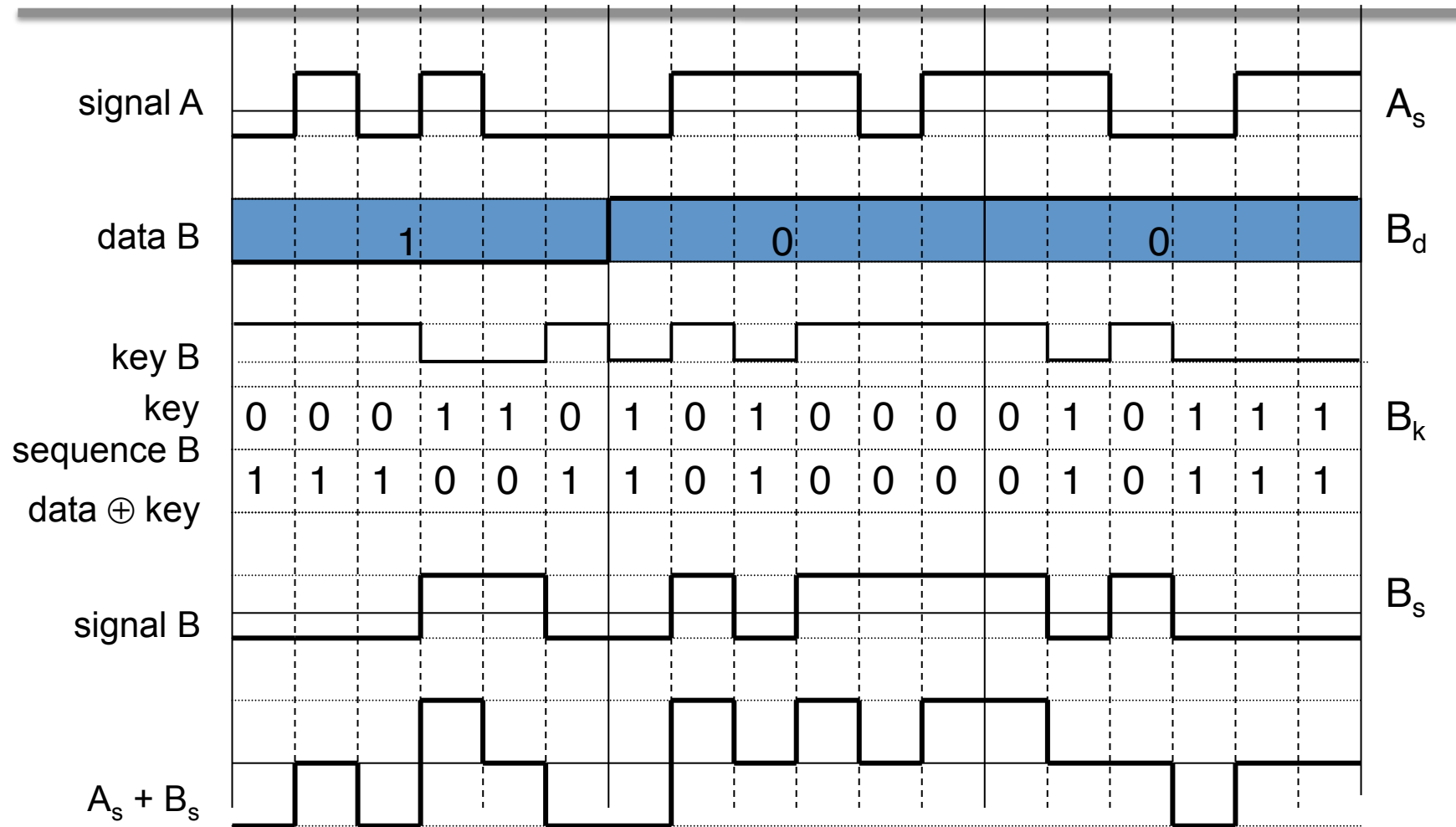
CDMA in theory

- 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"

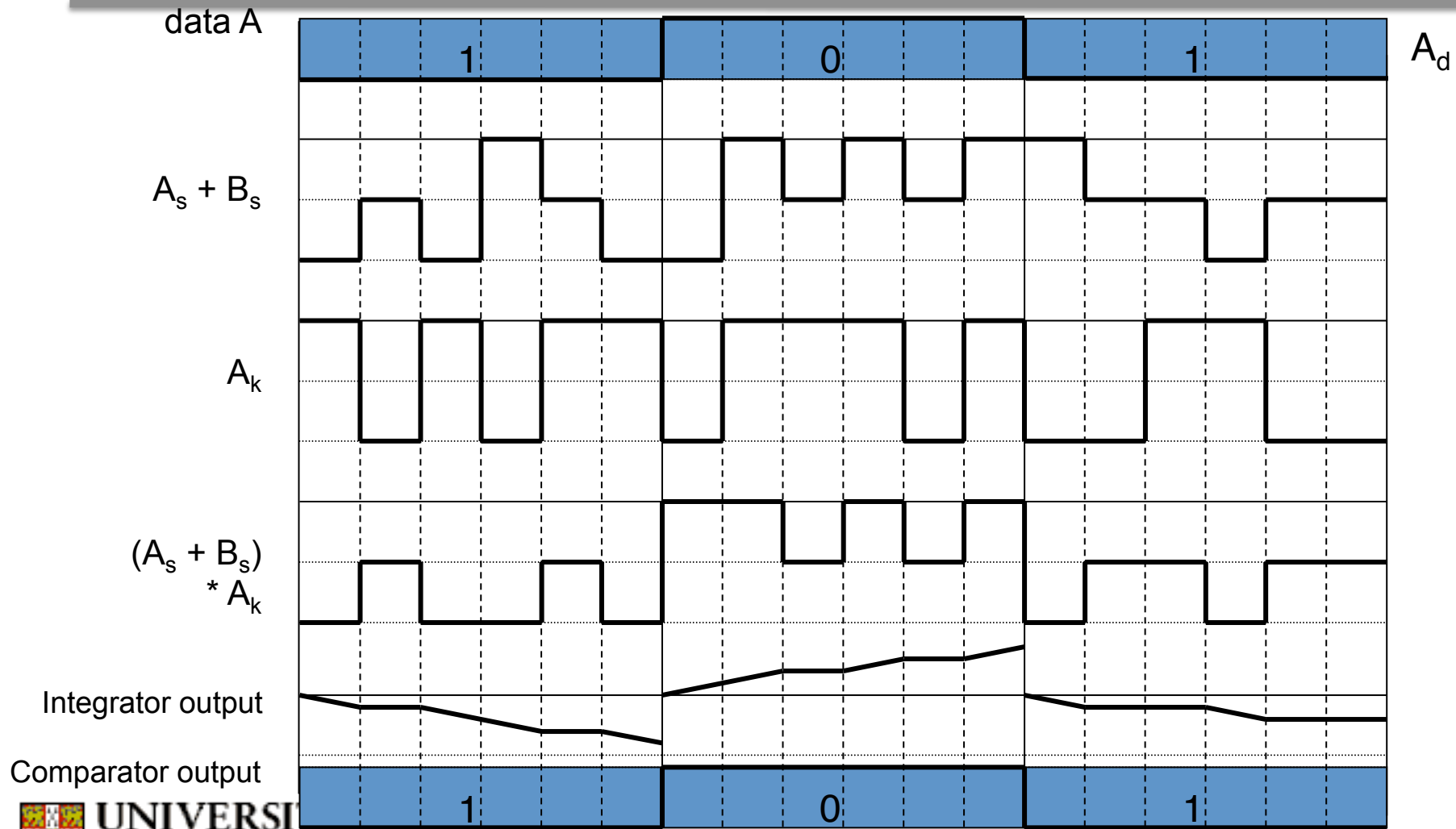**UNIVERSITY OF CAMBRIDGE**

CDMA on signal level I

data A			1					0					1				A_d
key A																	
key	0	1	0	1	0	0	1	0	0	0	1	0	1	1	0	0	1	1	A_k
data ⊕ key	1	0	1	0	1	1	1	0	0	0	1	0	0	0	1	1	0	0	
signal A																			A_s

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

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CDMA on signal level II

| signal A | | | | | | | | | | | | | | | | | A_s |

| data B | 1 | | | | | 0 | | | | | | 0 | | | | | B_d |

| key B | | | | | | | | | | | | | | | | | |

| key sequence B | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | B_k |
| data ⊕ key | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | |

| signal B | | | | | | | | | | | | | | | | | B_s |

| $A_s + B_s$ | | | | | | | | | | | | | | | | | |

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CDMA on signal level III

data A: A_d — 1, 0, 1

$A_s + B_s$

A_k

$(A_s + B_s) * A_k$

Integrator output

Comparator output: 1, 0, 1

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CDMA on signal level IV

CDMA on signal level V

$A_s + B_s$

wrong key K

$(A_s + B_s) * K$

integrator output

comparator output

(0)   (0)   ?

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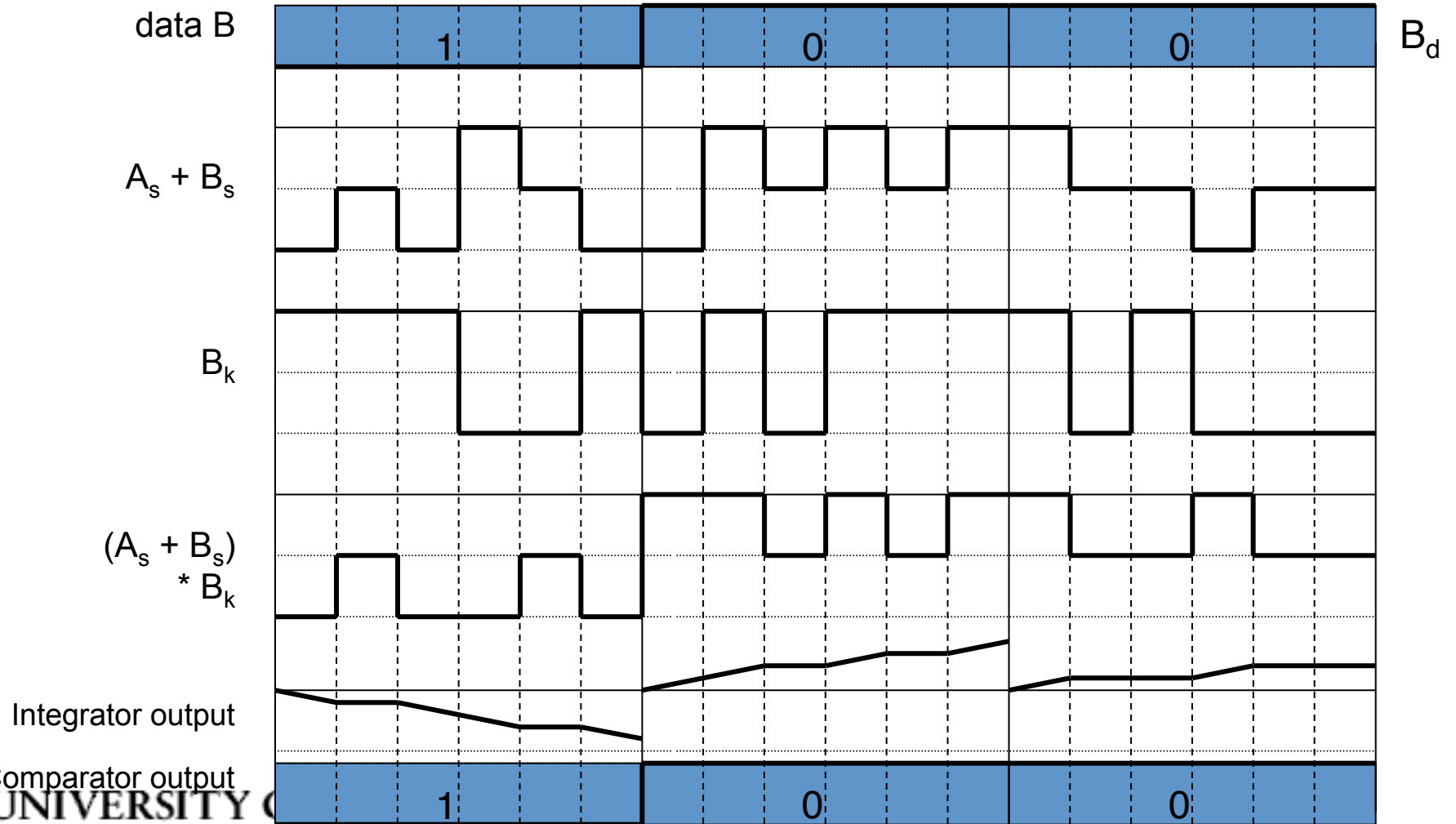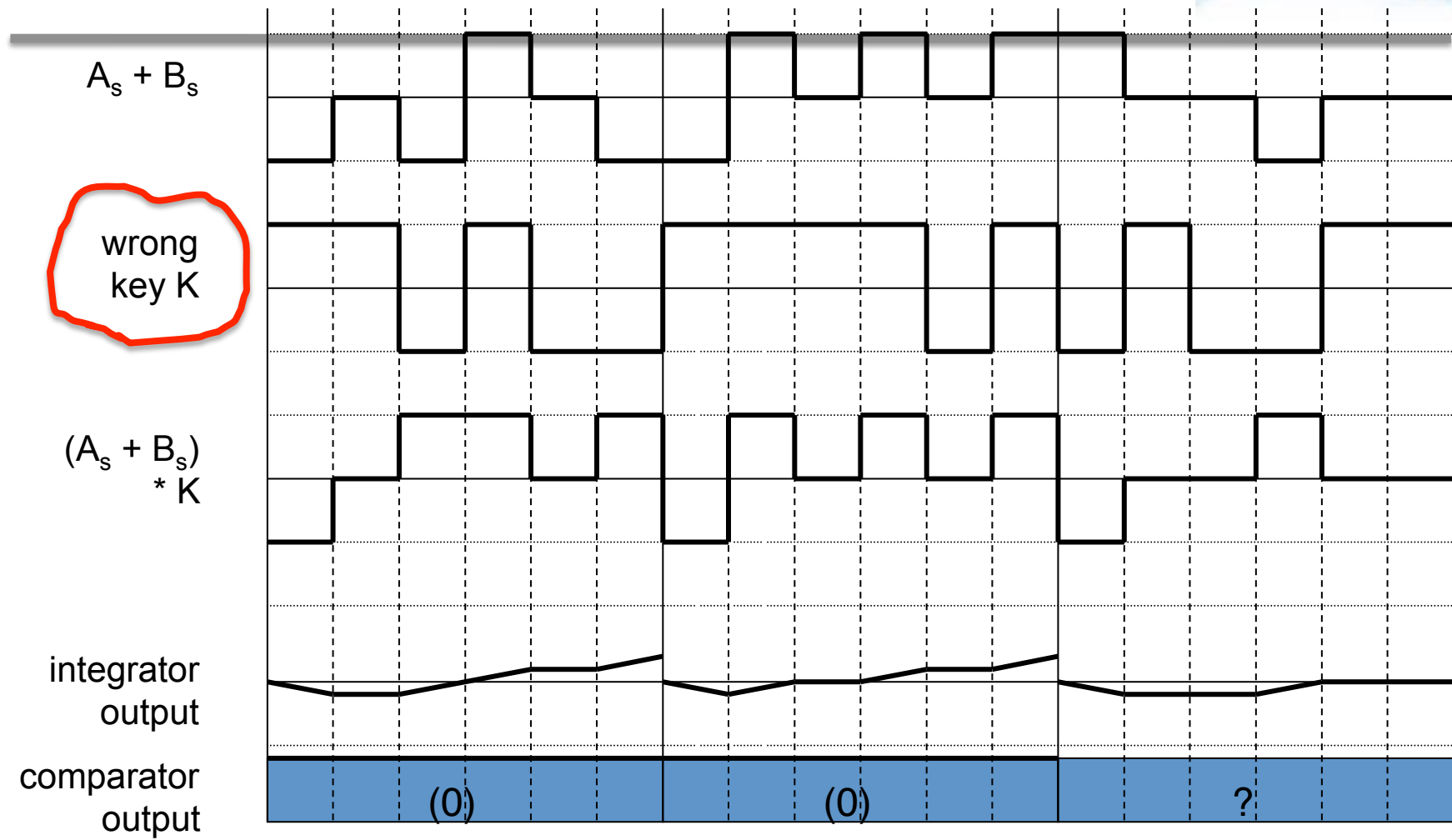
Comparisons

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

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?

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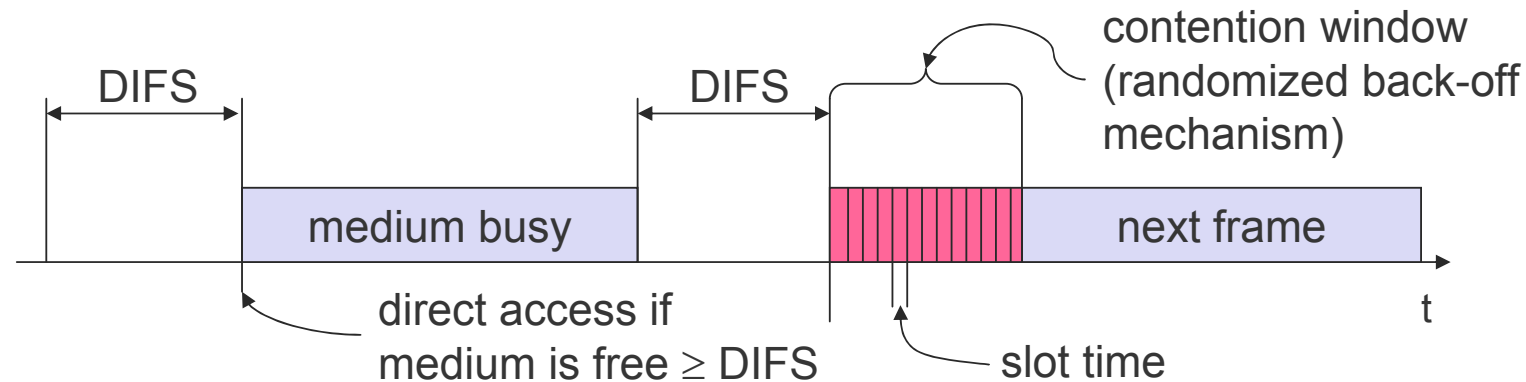
• CSMA/CA: sense medium. If free transmit (although this might generate collision at the receiver). If not, wait with a back off strategy. Transmit when medium is sensed free.

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

A   B   C

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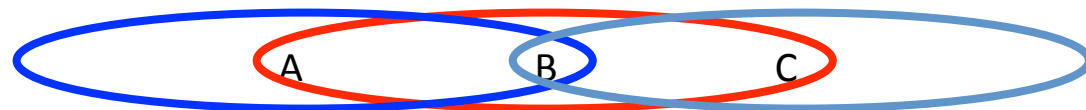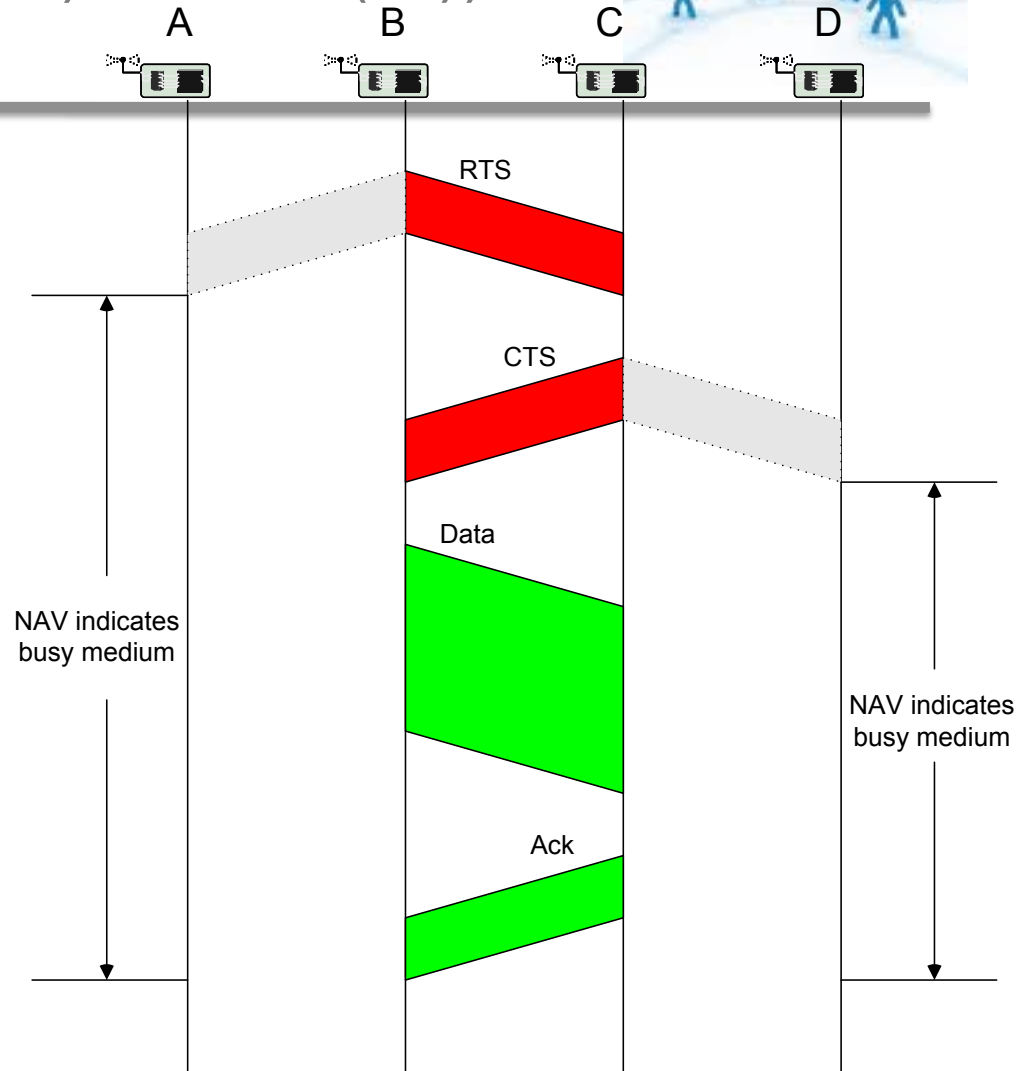
Exposed Terminal

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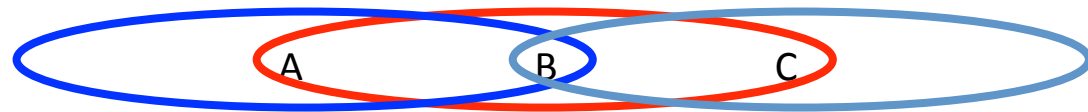
Multiple Access with Collision Avoidance (for Wireless): MACA(W))

- 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*)

A   B   C   D

RTS

CTS

Data

Ack

NAV indicates busy medium

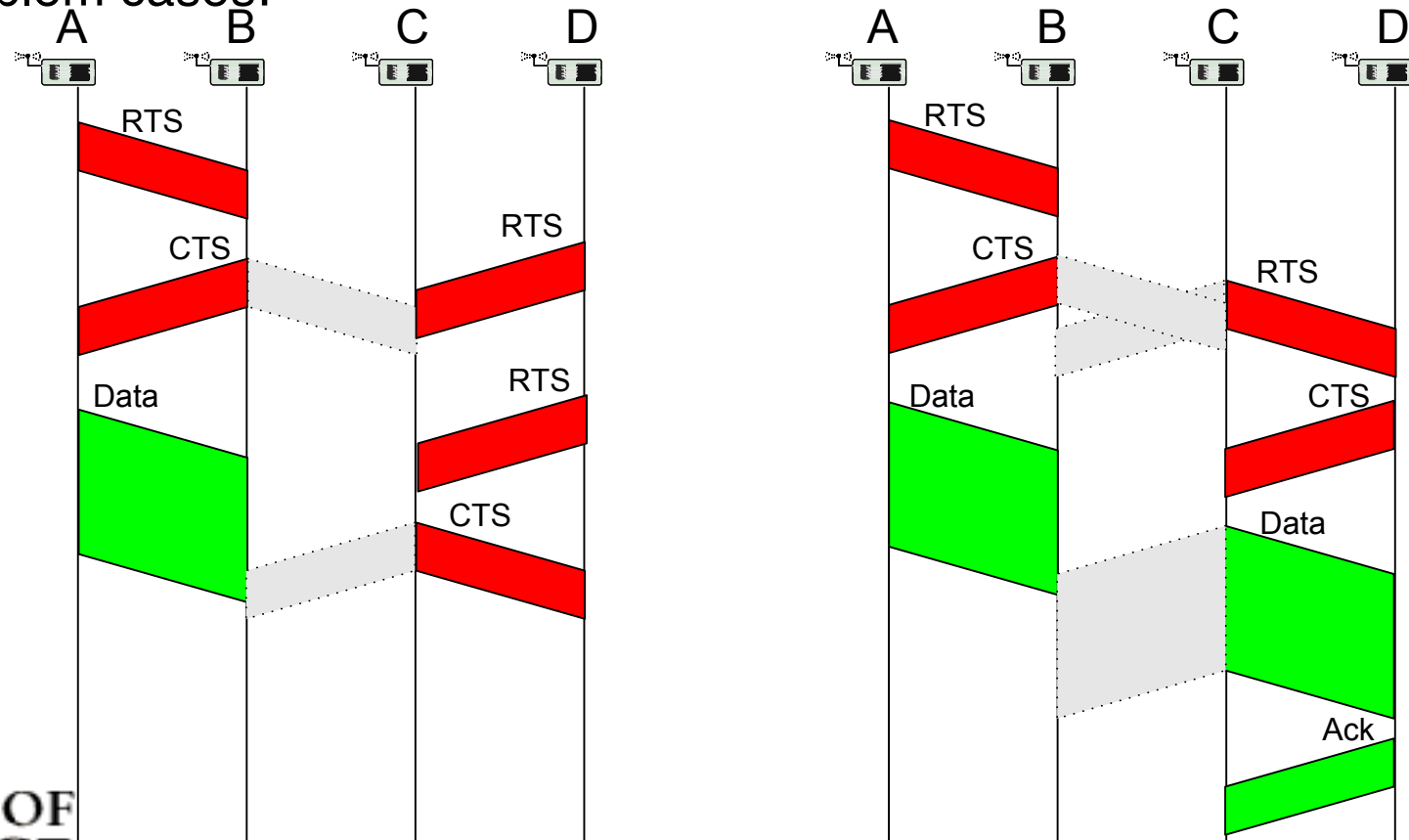NAV indicates busy medium

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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?**

RTS/CTS

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

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.

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