# *Mobile Communications*

## *Wireless Data Link,*
## *Wireless Medium Access Control*

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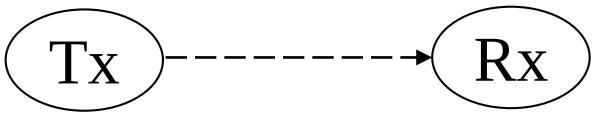
- *How to model an adaptive wireless data link layer?*
- *How to implement duplex communications in a wireless link?*
- *How to enable multiple access?*
- *What is a random access method?*
- *What is an hidden node? What is an exposed node?*
- *Why is collision avoidance important?*
- *How to avoid the hidden node?*
- *How does the CSMA/CA work?*
- *What is the minimum distance between nodes in CSMA/CA?*
- *What are the services possibly provided by RLC?*

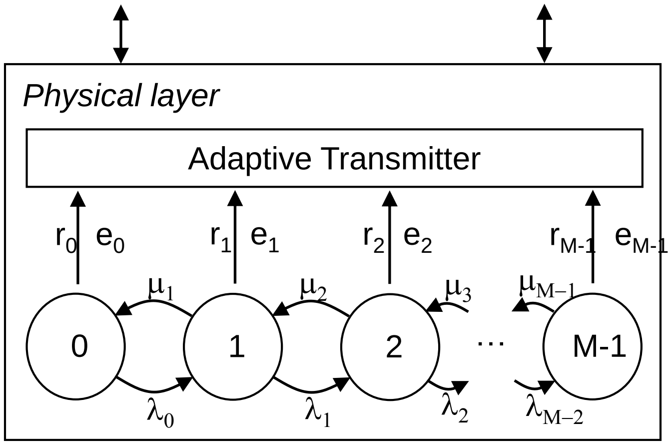
# *Radio Link*

- Radio link affected by $SNIR = \dfrac{P_r}{N + I} = \gamma$
- Modulation, coding, power
  used to overcome SNIR variation along the time



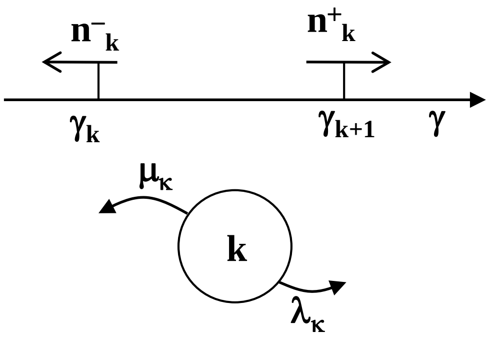

- Service offered by the (wireless) Physical layer to layer above
  - » characterized by data rate (bit/s) and bit error ratio
  - » modern technologies ➔ multiple operation modes
- Operation mode (also known as Modulation-Code Scheme)
  - » pair (modulation, code)
  - » High-Speed Downlink Packet Access (HSDPA/UMTS) ➔ 12 modes
  - » IEEE 802.11a ➔ 7 modes

# *Radio Link Model – Continuous Time Markov Chain*




- Radio link modeled as a Markov Chain
- Markov chain state
  - » Operation mode $S_i$ - pair (modulation, code)
  - » $\boldsymbol{S_i} \Leftrightarrow \gamma \in [\gamma_i, \gamma_{i+1}[$
  - » Characterized by transmit bit rate $\boldsymbol{r_i}$ and bit error ratio $\boldsymbol{e_i}$
- Markov chain transition rates
  - » Process moves only to neighbor states
  - » Estimating the transition rates

$$\lambda_k = n_k^+ / t_k \qquad \mu_k = n_k^- / t_k$$



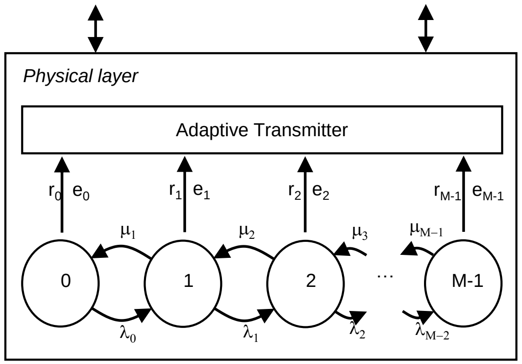

$$\pi_k \approx t_k / t$$

Probability of systems being in state k

Total amount of time the system remains in state k

# *Information Rate (Goodput)*

Mean Information rate ➔ $$\boxed{\overline{R_c} = \sum_{i=0}^{M-1} r_i \pi_i}$$




$$L_d = L_h + L_i \quad \rightarrow \quad \eta_h = L_i / L_d$$

$$L_p = L_d + L_o \quad \rightarrow \quad \eta_c = L_d / L_p$$

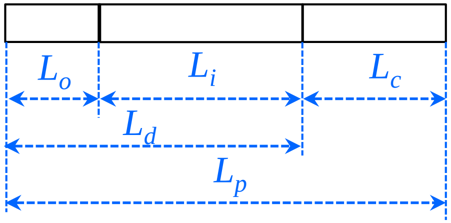
$$\eta_h \eta_c = L_i / L_p$$

$$\boxed{r_i = \frac{\eta_h \ \eta_c \ k_i}{T_s}}$$

number of bits/symbol

Symbol duration

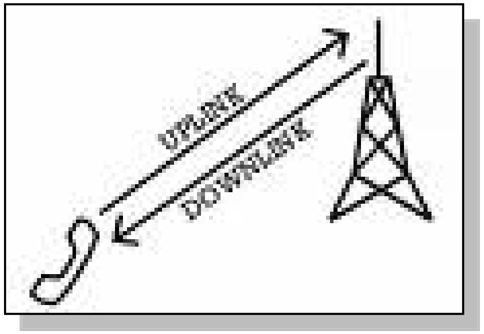
***Frame***




***$L_i$*** : number of information bits
***$L_o$*** : number of overhead bits
***$L_c$*** : number of redundant (code) bits

*How to transmit signals in both directions simultaneously?*

# *Duplex Transmission*




- Duplex – transference of data in both directions
  - **Uplink** and **Downlink** channels required

- Two methods for implementing *duplexing*
  - » Frequency-Division Duplexing (**FDD**)
    - wireless link split into frequency bands
    - bands assigned to uplink or downlink directions
    - peers communicate in both directions using different bands
  - » Time-Division Duplexing (**TDD**)
    - timeslots assigned to the transmitter of each direction
    - peers use the same frequency band but at different times

# *Duplex Transmission*

| *Characteristics* | *FDD* | *TDD* |
|---|---|---|
| channel gain estimation | $\Downarrow$ requires separate estimation for uplink and downlink | $\Uparrow$ channel measurements in one direction are used in the opposite direction |
| interference between directions | $\Uparrow$ requires guard-bands | $\Downarrow$ requires guard-intervals and precise time synchronization |
| frequency planning | $\Downarrow$ demands frequency planning, normally using pairs of bands | $\Uparrow$ does not demand bands in pairs |
| asymmetric allocation of capacity | $\Downarrow$ difficult to provide asymmetric capacities in both directions | $\Uparrow$ easy to implement by changing the direction associated to time slots |

# *Multi-Access Schemes*

- Multi-access schemes
  - Identify radio resources
  - Assign radio resources to users/terminals using some criteria

- Types of multi-access schemes
  - Frequency-Division Multiple Access (FDMA)

    resources divided in portions of spectrum (channels)
  - Time-Division Multiple Access (TDMA)

    resources divided in time slots
  - Code-Division Multiple Access (CDMA)

    resources divided in orthogonal codes
  - Space-Division Multiple Access (SDMA)

    resources divided in areas

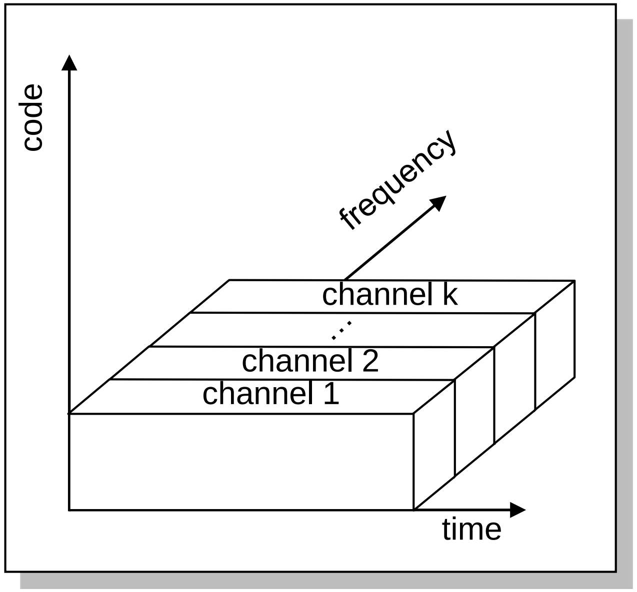
# *FDMA*

» Signal space divided along the frequency axis
  into non-overlapping channels

» Each user is assigned a different frequency channel

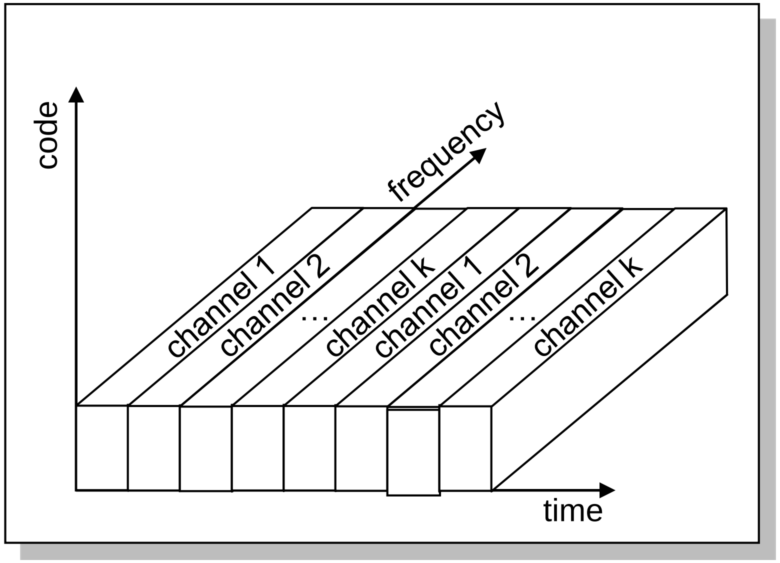
» The channels often have guard bands

» Transmission is continuous over time



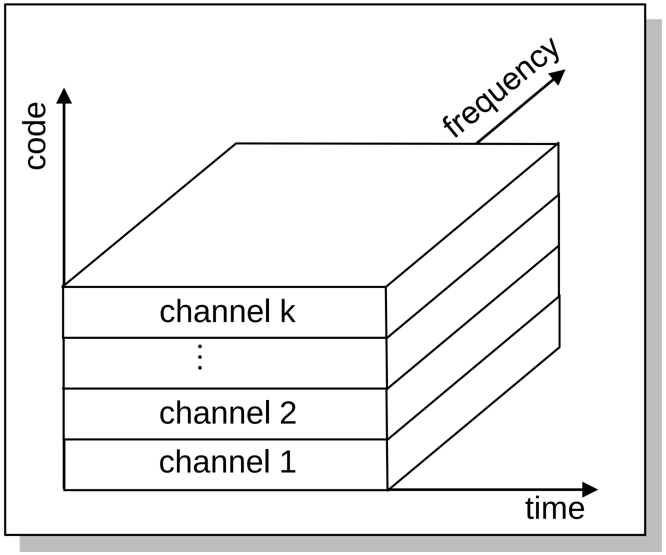
# *TDMA*

- Signal space divided along the time axis
  into non-overlapping channels
- Each user assigned a different cyclically-repeating timeslot
- Transmission not continuous for any user



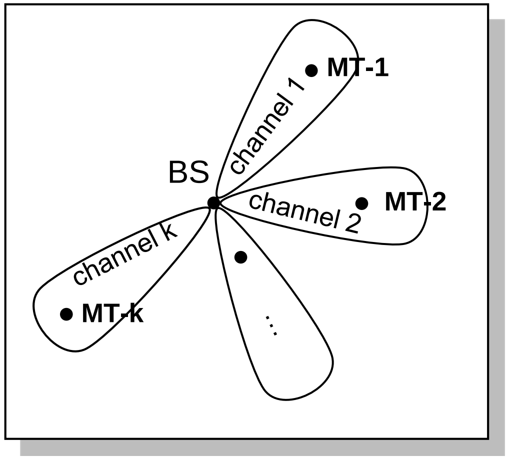
# *CDMA*

- Each user assigned a code to spread his information signal
  - Multi-user spread spectrum (e.g. Direct Sequence)
  - The resulting spread signal
    - occupy the same bandwidth
    - transmitted at the same time



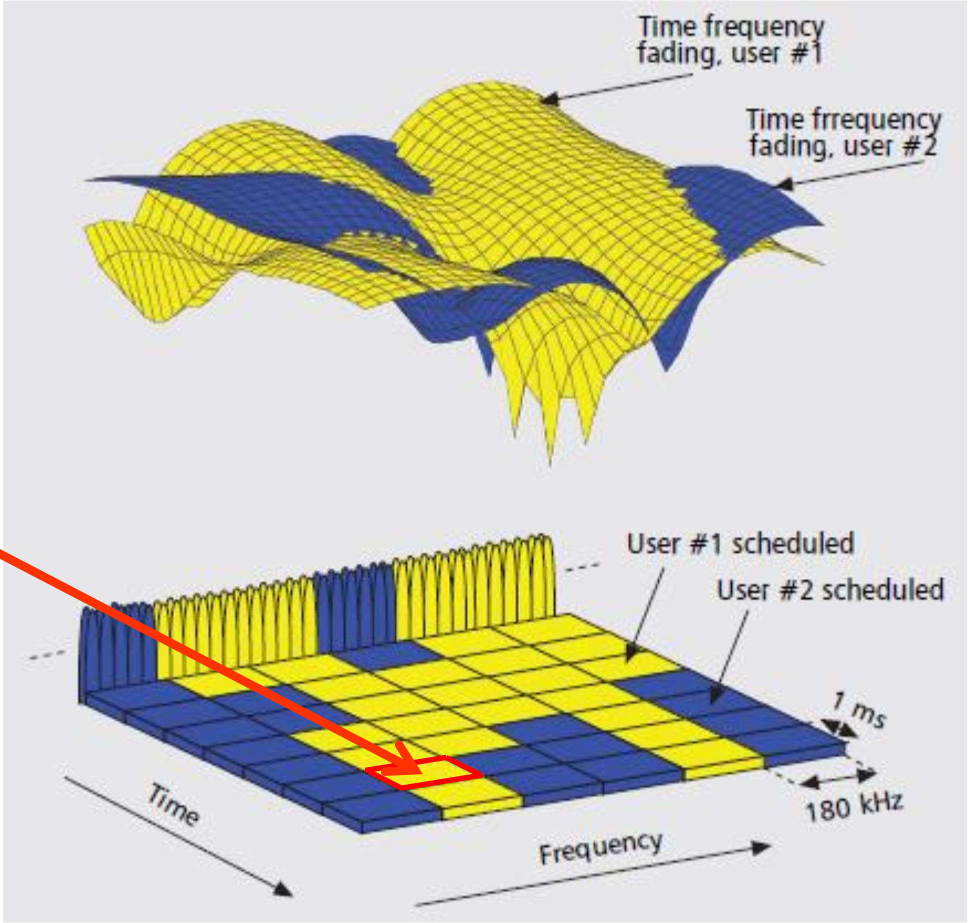
# *SDMA*

- SDMA uses direction (space angle) to assign channels to  users
- Implemented using sectorized antenna arrays
  - » the 360° angular range divided in N sectors
  - » TDMA or FDMA then required to channelize users in each sector



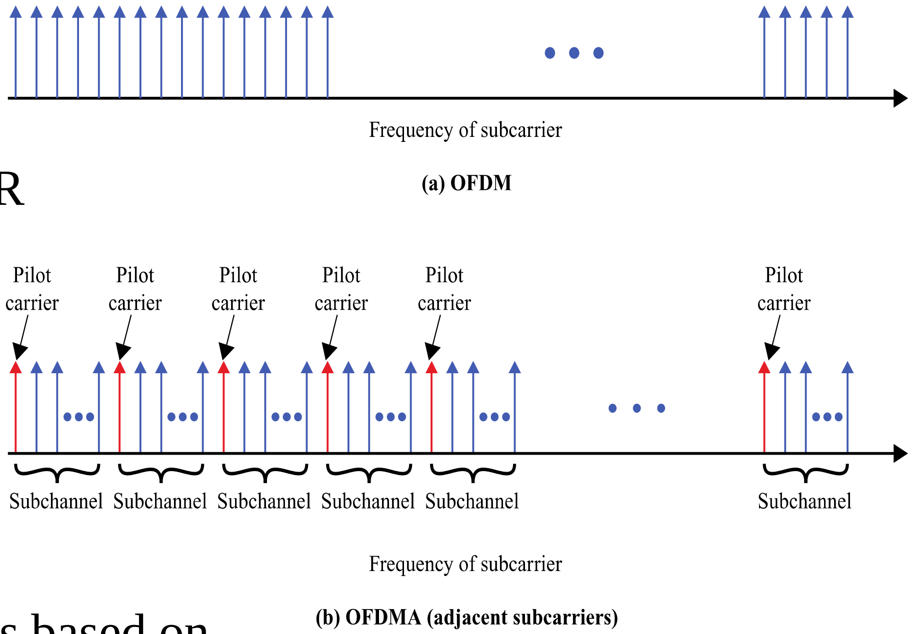
# *OFDMA* – *Orthogonal Frequency Division Multiple Access*

- Based on OFDM
- Time x Frequency space
- Radio Block ***RB***
  - » E.g. $T_{RB} \times B_{RB} = 1\,ms \times 180\,kHz$
- Blocks are allocated to users by a central entity



# OFDMA

- OFDMA
  - Subcarriers allocated in groups
  - Adjacent subcarriers have similar SINR
  - Group of subcarriers → subchannel




- Opportunistic scheduling
  - Schedule subchannels and power levels based on
    Channel conditions (SNR) or Data requirements
  - Use channel variations as an opportunity to schedule the best choice
    - System efficiency: select users with best throughput (e.g. best SNR)
    - Fairness: maintain throughput fairness between users
    - Requirements: audio, video (e.g. delay)

# *Wireless Medium Access Control*

- Medium Access Control (MAC)

  assigns radio resources to terminals along the time (time division)

- 3 type of resource allocation methods
  - » dedicated assignment (contention free)

    resources assigned in a predetermined, fixed, mode (e.g. static TDMA)

  - » random access (contention based)

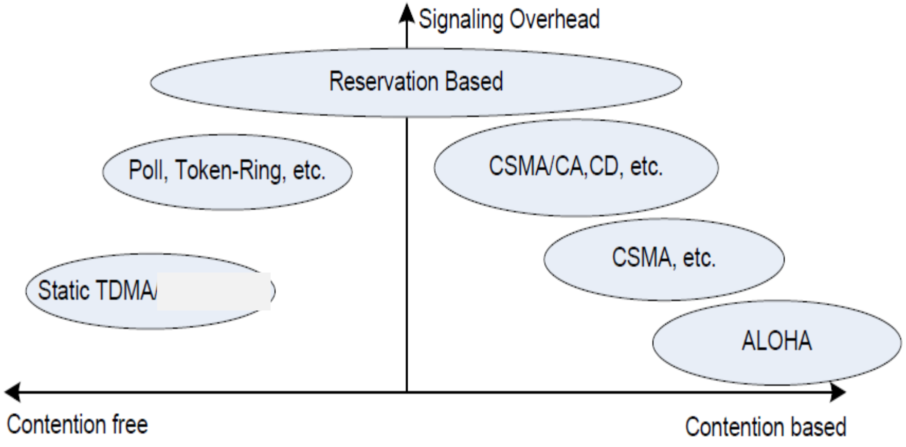
    terminals auto-regulate channel access

  - » reservation-based

    terminals ask for reservations

    using

    dedicated or random access channels



# *Random MAC Protocols - Aloha, S-Aloha, CSMA*

- Aloha ← Efficiency of 18 %

  if station has a packet to transmit
    - transmits the packet
    - waits confirmation from receiver (ACK)
    - if confirmation does not arrive in round trip time, the station computes random backofftime → then retransmits packet

- Slotted Aloha ← Efficiency of 37 %

  works as Aloha, but stations transmit only at the beginning of timeslots

- Carrier Sense Multiple Access (CSMA) ← Efficiency of 54 %
  - station listens the carrier before it sends the packet
  - If medium busy → station defers its transmission

- ACK required for Aloha, S-Aloha and CSMA

# *CSMA/CD – Not Used in Wireless*

- CSMA/Collision Detection ← Efficiency < 80%
  - station monitors de medium (carrier sense)
    - medium free → transmits the packet
    - medium busy → waits until medium is free → then, transmits packet
    - if, during a round trip time, detects a collision

      → station aborts transmission, stresses collision, waits random delay, retransmits

      (no ACK packet)

- Problem of CSMA/CD in wireless networks

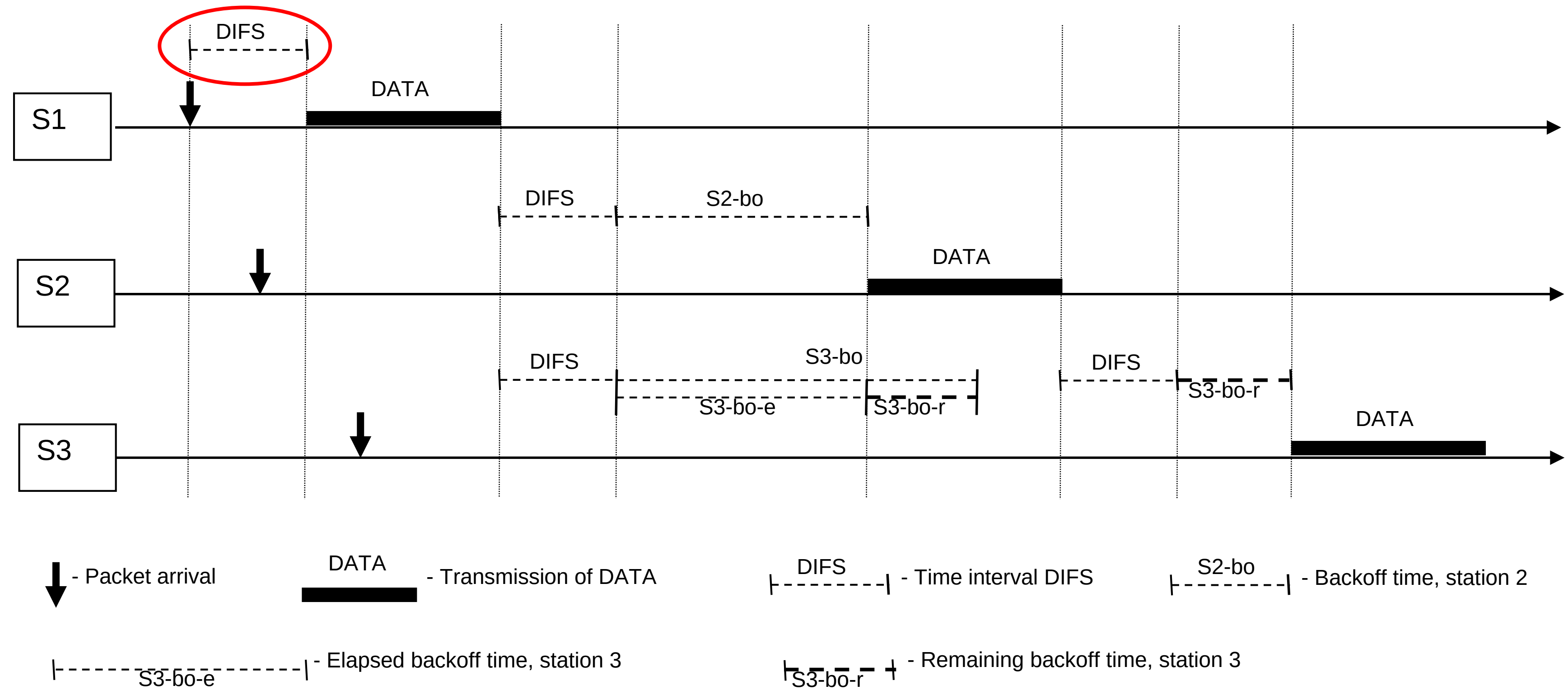
***Collision detection***

near-end interference

makes simultaneous transmission and reception

very difficult to implement

# CSMA with Collision Avoidance (CSMA/CA)



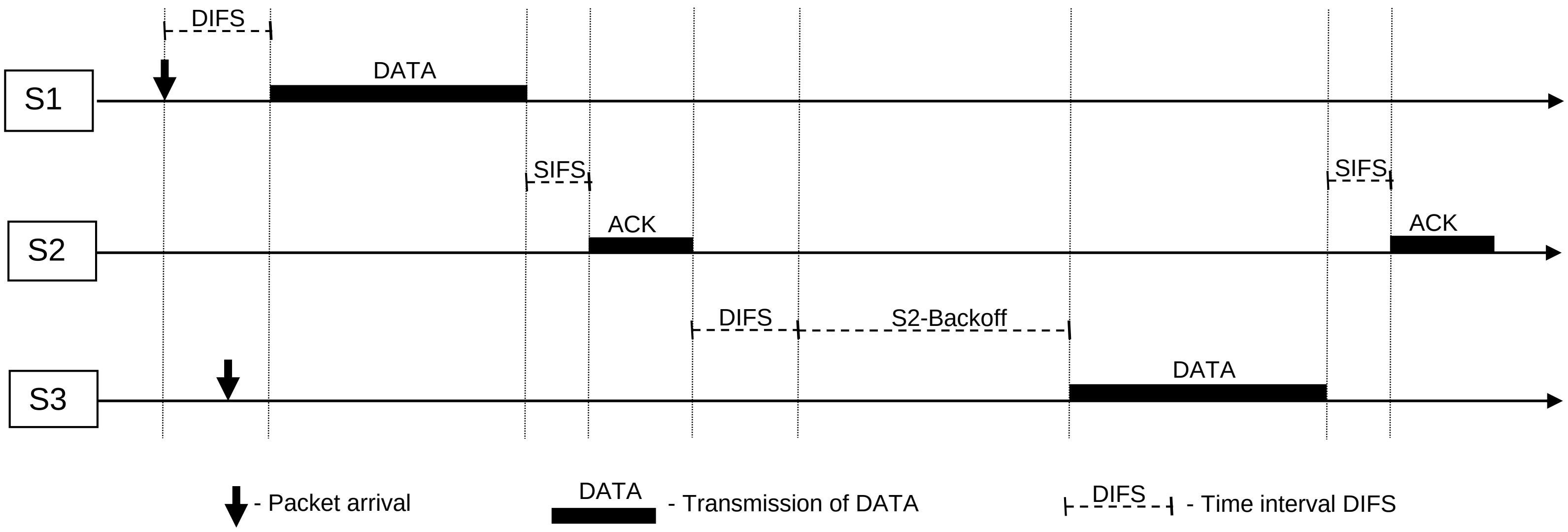
# *CSMA with Collision Avoidance (CSMA/CA)*

- Station with a packet to transmit monitors the channel activity until an idle period equal to a Distributed Inter-Frame Space (DIFS) is observed

- If the medium is sensed busy, a random backoff interval is selected. The backoff time counter is decremented as long as the channel is sensed idle, stopped when a transmission is detected on the channel, and reactivated when the channel is sensed idle again for more than a DIFS. The station transmits when the backoff time reaches 0

- To avoid channel capture, a station must wait a random backoff time between two consecutive packet transmissions, even if the medium is sensed idle in the DIFS time

# *CSMA/CA – ACK Required*



# *CSMA/CA – ACK Required*

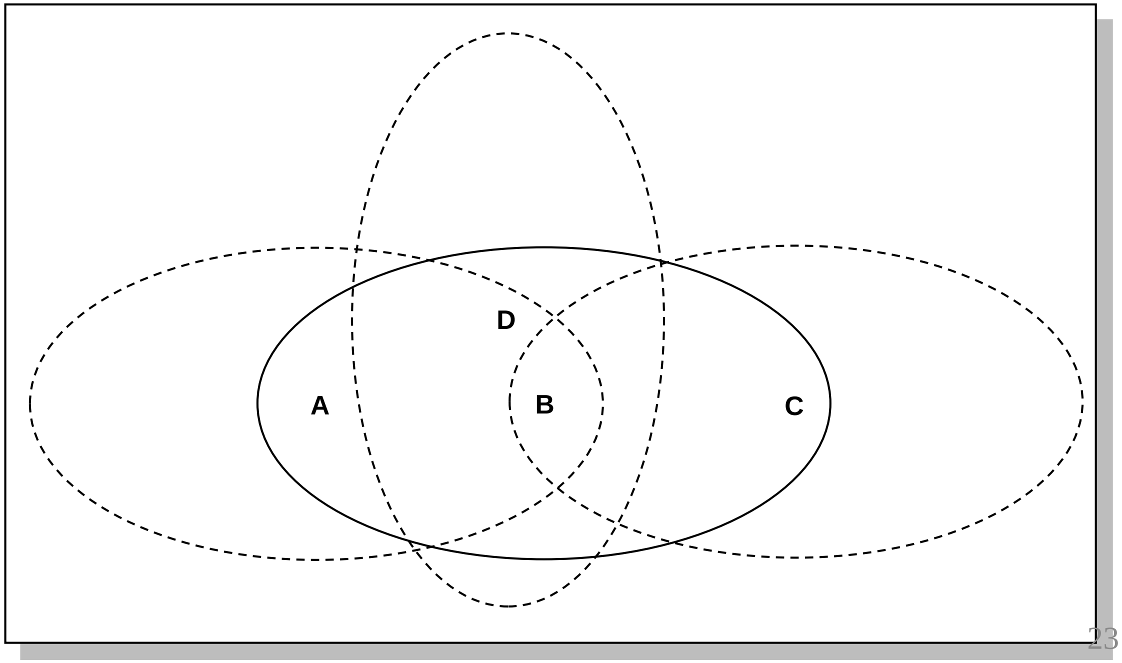
- CSMA/CA does not rely on the capability of the stations to detect a collision by hearing their own transmission
- A positive acknowledgement is transmitted by the destination station to signal the successful packet reception
- In order to allow an immediate response, the acknowledgement is transmitted following the received packet, after a Short Inter-Frame Space (SIFS)
- If the transmitting station does not receive the acknowledge within a specified ACK timeout, or it detects the transmission of a different packet on the channel, the station reschedules the packet for transmission
- The efficiency of CSMA/CA depends on the number of competing stations. But it also depends also on the hidden stations, which compromise the communications

# *Hidden, Exposed and Capture Nodes*

- Received signal power decays with the transmitter-receiver distance

$$P_{r_{dBm}} = P_{s_{dBm}} + K_{dB} - 10\ \gamma\ log\left[\frac{d}{d_0}\right]$$

- Carrier sensing depends on the position of the receiver
- Carrier sensing based protocols have 3 type of problematic nodes



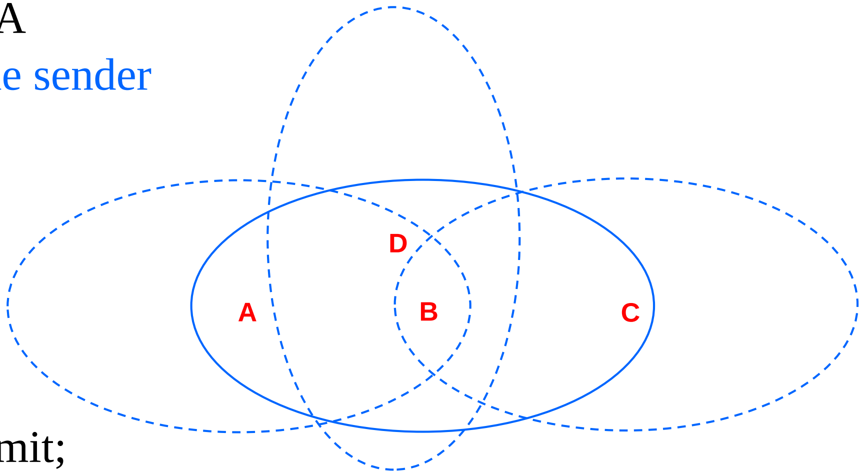

» hidden nodes
  – C is hidden to A

» exposed nodes
  – C is exposed to B

» capture nodes
  – D captures A

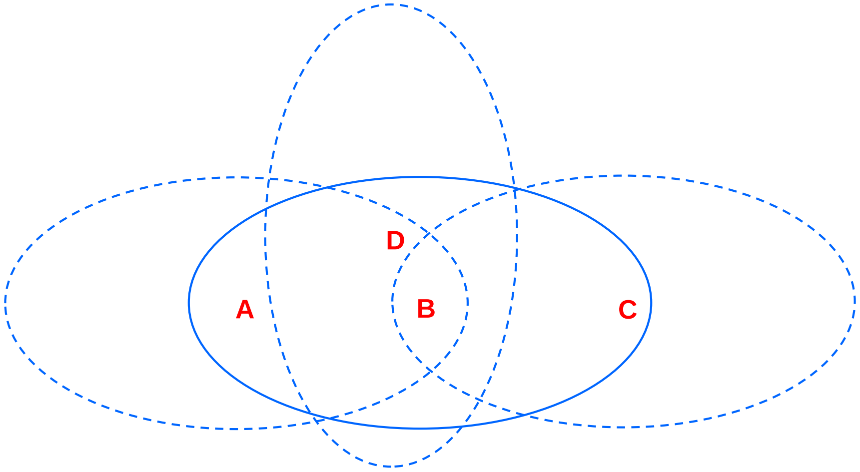
# *Hidden, Exposed and Capture Nodes*

- Hidden node → C is hidden to A
  - » A transmits to B; C cannot hear A
  - » If C hears the channel it thinks channel is idle; C starts transmitting
    → interferes with data reception at B from A
  - » In the range of receiver; out of the range of the sender



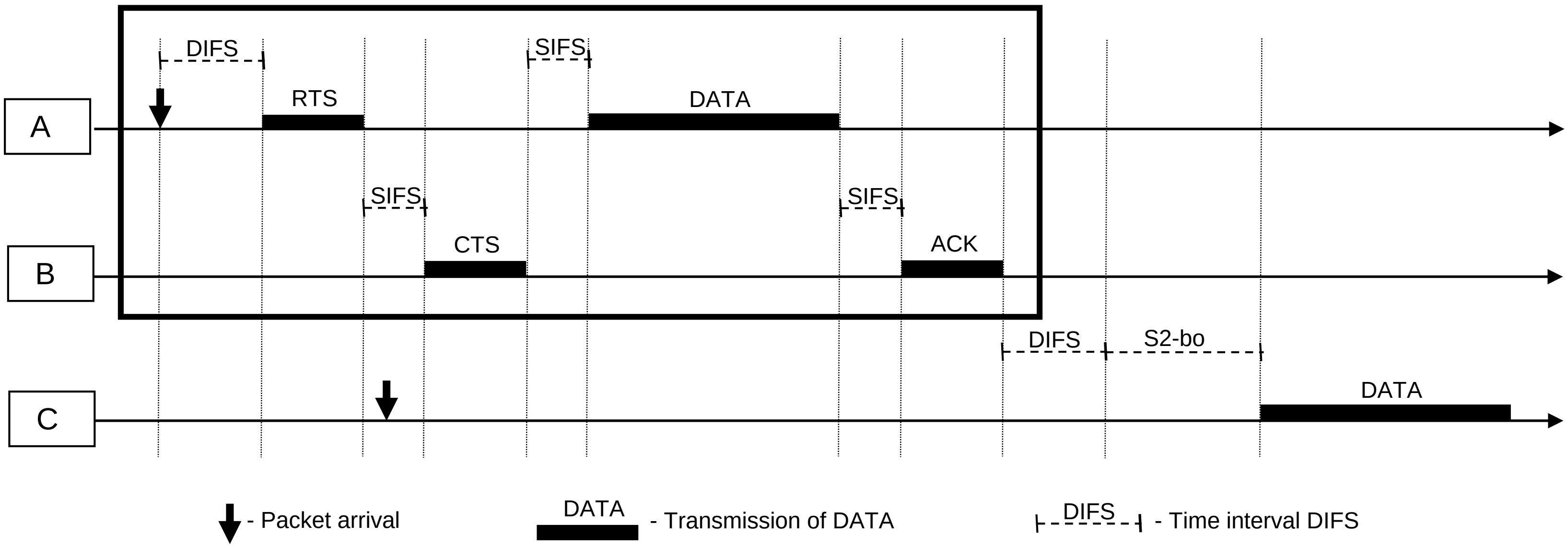

- Exposed node → C is exposed to B
  - » B transmits to A; C hears B; C does not transmit;
  - » but C transmission would not interfere with A reception
  - » In the range of the sender; out of the range of the receiver
- Capture → D captures A
  - » A and D transmit simultaneously to B; but signal power received by B from D is much higher than that from A

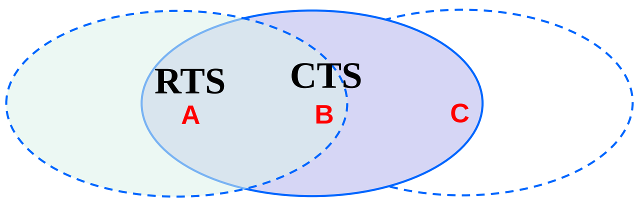
*How to enable hidden terminals to sense the carrier?*




***Hidden node: C is hidden to A***

# RTS-CTS Mechanism



# *RTS-CTS Mechanism*

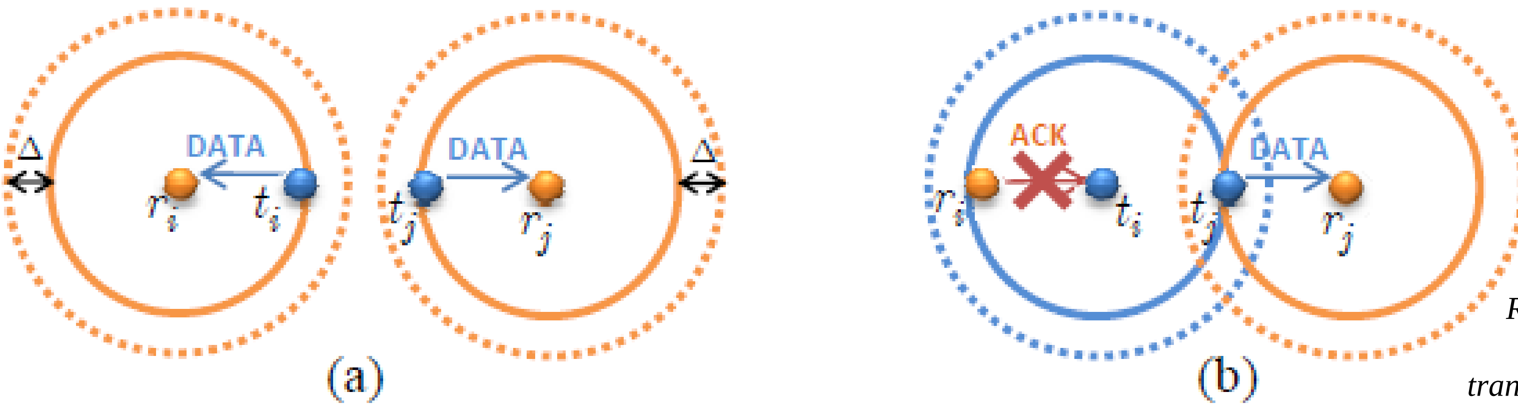
- For some scenarios where long packets are used or the probability of hidden terminals is not irrelevant, the efficiency of CSMA/CA can be further improved with a Request To Send (RTS) - Clear to Send (CTS) mechanism

- The idea is that a sender station sends a short RTS message to the receiver station. When the receiver gets a RTS from the sender, it polls the sender by sending a short CTS message. The sender then sends its packet to the receiver. After correctly receiving the packet, the receiver sends a positive acknowledgement (ACK) to the sender

- This mechanism is particularly useful to transmit large packets. The listening of the RTS or the CTS messages enable the stations in range respectively of the sender and receiver to be informed that a big data packet is about to be transmitted. Usually both the RTS and the CTS contain information about the number of slots required to transmit the 4 packets (RTS, CTS, DATA, ACK). Using this information, the other stations refrain themselves to transmit packets, thus avoiding collisions and increasing the system efficiency.

- SIFS are used before the transmission of CTS, Data, and ACK

# *Interfering Links*




(a) (b)

*Reception of ACK by $t_i$ will be interfered by transmission of DATA from $t_j$*

- ***$t_i$* , *$r_i$*** – physical coordinates of transmitter, receiver of link ***i***
- If the effect of ACK is also considered (but no RTS+CTS)

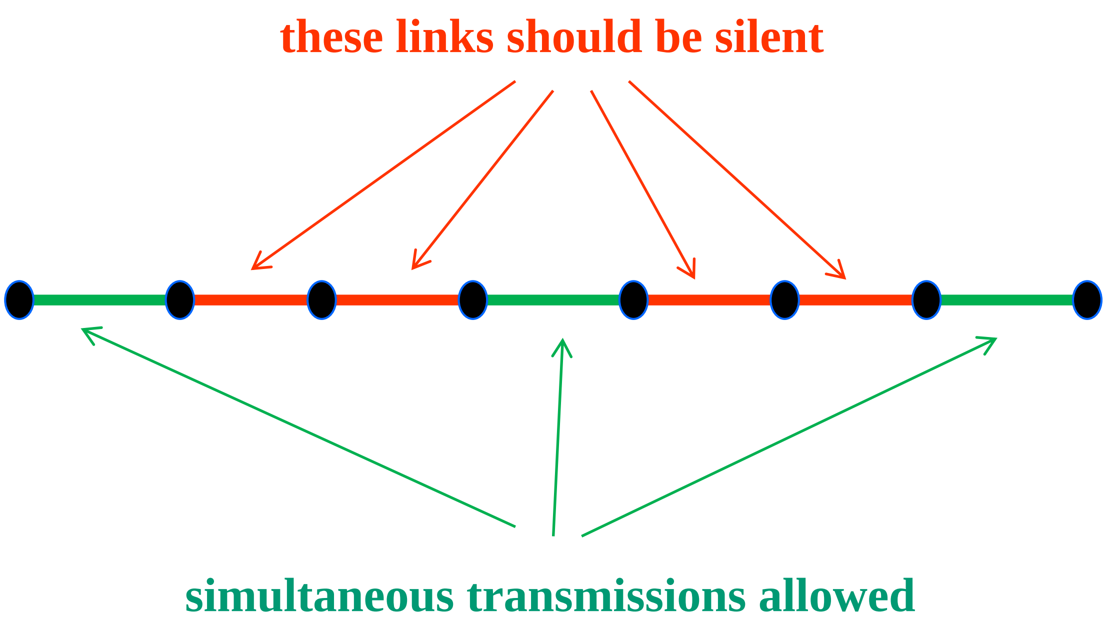
  links ***i*** and ***j*** may transmit simultaneously with success only if

$$\text{dist}(i,j) \geq (1+\Delta)|t_i - r_i|$$

where, $\text{dist}(i,j) \triangleq \min(|t_j - r_i|, |r_j - t_i|, |r_j - r_i|, |t_j - t_i|)$

# *Interfering Links*

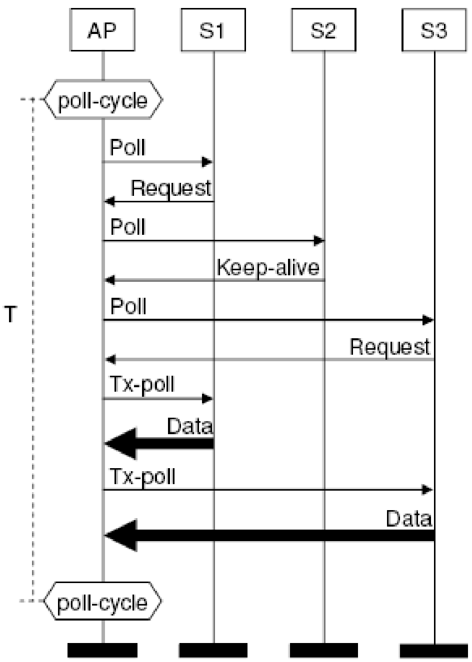
- If $\Delta$=0 and there is a chain of nodes



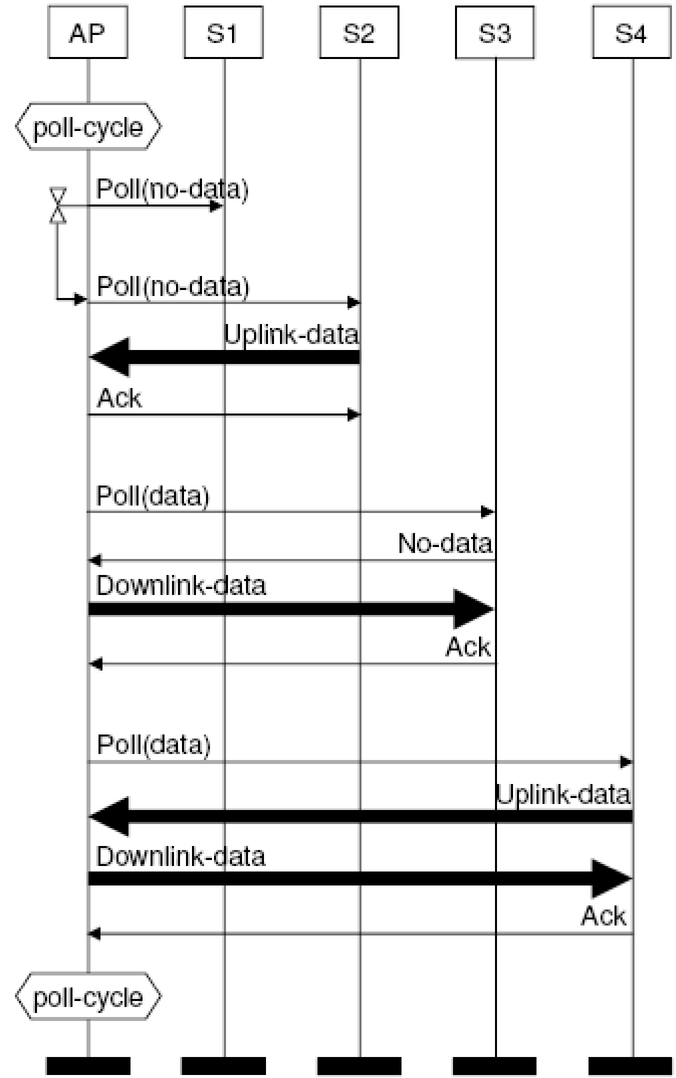

**Why?**

# *Guaranteed Access Control*

- Polling
  - » AP manages stations access to the medium
  - » Channel tested first, using a control handshake




***a) poll-request-poll-data***




***b) poll-data***

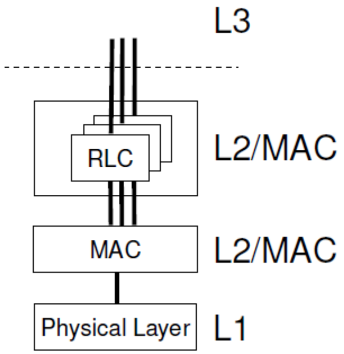
# *Wireless Radio Link Control*

- MAC layer may not always provide acknowledged delivery

  e.g., MAC working over dedicated resources (time slot, code)

- Radio Link Control (RLC) sub layer is used in some technologies
  - » e.g. cellular technologies

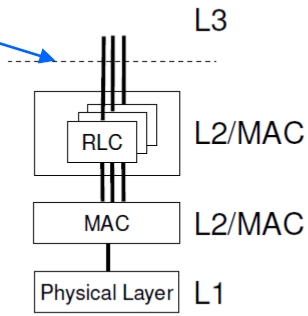
- Example
  - » 3 virtual links, represented by 3 RLC instances
  - » RLC uses service provided the MAC sub-layer



# *Possible Services Provided by RLC to Upper Layer*

- Transparent data transfer
  - » no addition of information

- Unacknowledged data transfer
  - » frames are not acknowledged by the RLC receiver
  - » frame arriving with errors at RLC receiver is discarded
  - » frame sent by the RLC transmitter has a sequence number
  - » upper layer, at the receiver, knows which frames were discarded




- Acknowledged data transfer
  - » guarantees error-free and unique delivery
  - » upper layer receiver gets frames by the correct order
  - » Selective Repeat ARQ or Hybrid ARQ are used

- Short frames should be used, in order to have low FER ➔ $FER = 1 - (1 - BER)^L$

# *Hybrid ARQ*

- Hybrid Automatic Repeat Request (HARQ)
  - » HARQ uses combination of FEC (Forward Error Correction codes) and ARQ
  - » Chase combining
    - – information from a previous frame not corrected by FEC (frame with errors) is used and combined with retransmissions of the same frame
    - – Original and retransmitted frames are equal
  - » Incremental redundancy
    - – Different, maybe more, coding (redundant bits) used in each retransmission
    - – Uses less overhead (coding bits) in the first transmissions

# *Homework*

1. Review slides
   » use them to guide you through the recommended books

2. Read from Schiller
   » Chap. 3 - Medium access control

3. Read from Vijay Garg
   » Cap. 6 - Multiple Access Techniques

4. Answer questions at moodle