Mobile Communications

Wireless Data Link

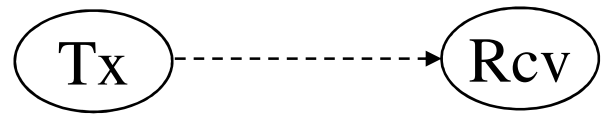
Manuel P. Ricardo

Faculdade de Engenharia da Universidade do Porto

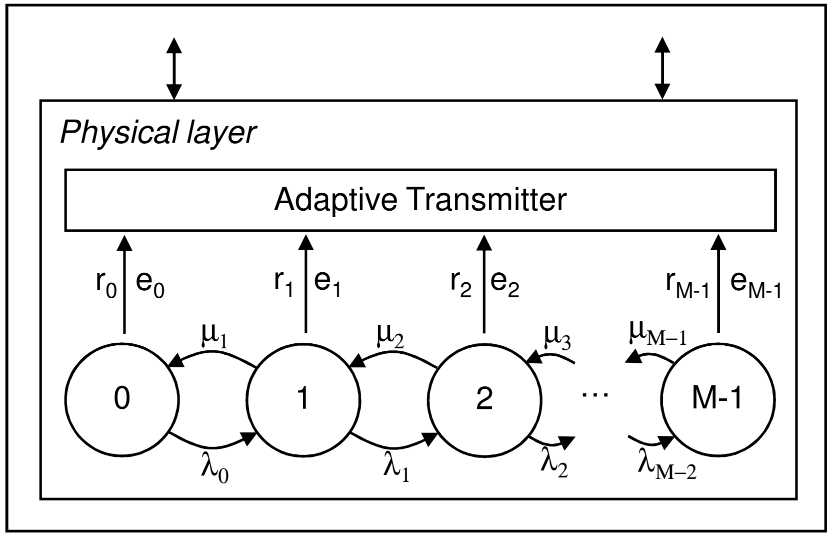
- *How to transmit signals in both directions simultaneously?*

- *How to enable multiple users to communicate simultaneously?*

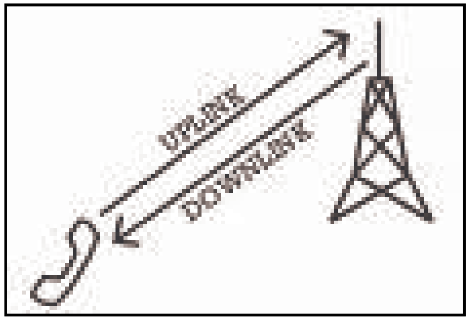
Radio Link Model



- Wireless physical layer
  - » provides virtual link of unreliable bits
  - » service described in terms of
    - Gross bit rate – R, r (bit/s)
    - Bit error ratio – BER, e
- In absence of link adaptation
  - » R constant
  - » BER *absorbs* channel variability
- Using link adaptation techniques
  - » BER usually kept bounded
  - » R changes



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

To Think About

- *How to place several sender-receiver pairs communicating in the same common space?*

Multi-Access Schemes

- Multi-access schemes
  - » Identify radio resources
  - » Assign resources to multiple users/terminals

- 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 codes
  - » Space-Division Multiple Access (SDMA)

    resources divided in areas

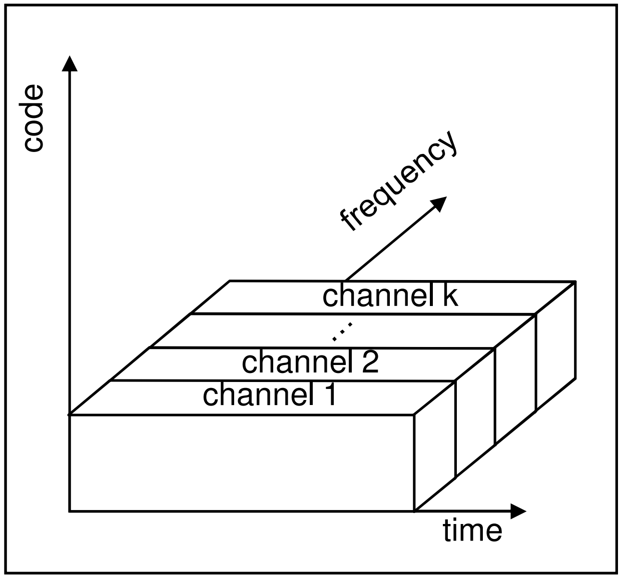
FDMA

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

» Each user assigned a different frequency channel

» The channels often have guard bands

» Transmission is continuous over time



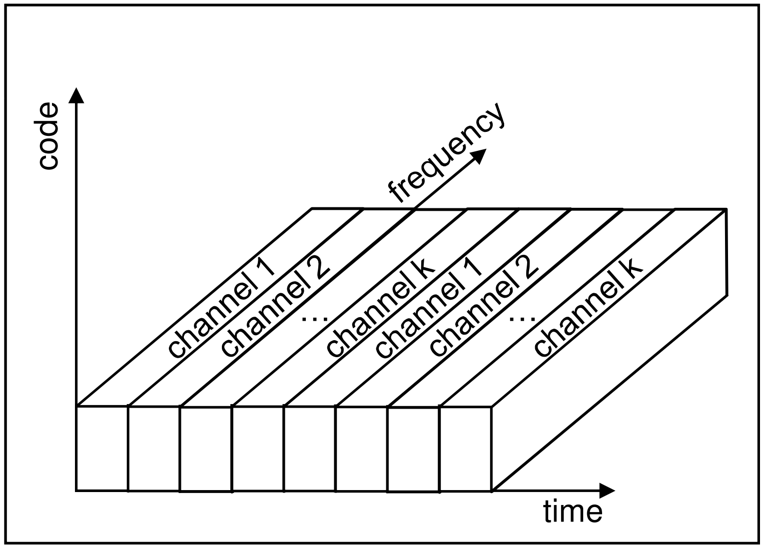
TDMA

» 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



» Major problem

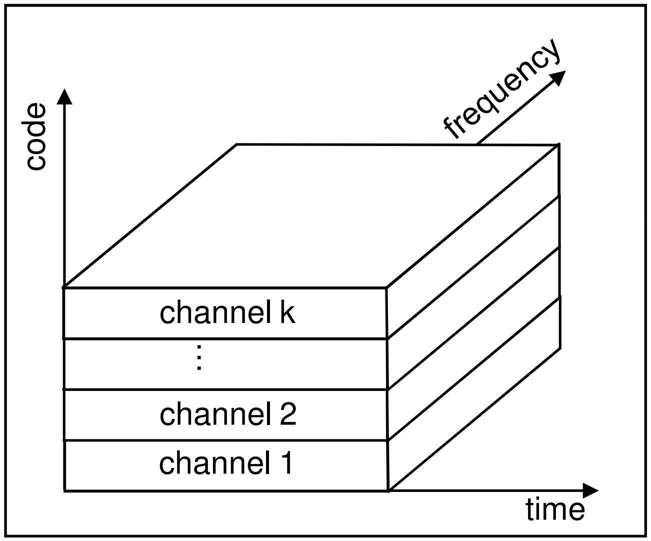
synchronization among the users in the uplink channels

users transmit over channels having different delays

uplink transmitters must synchronize

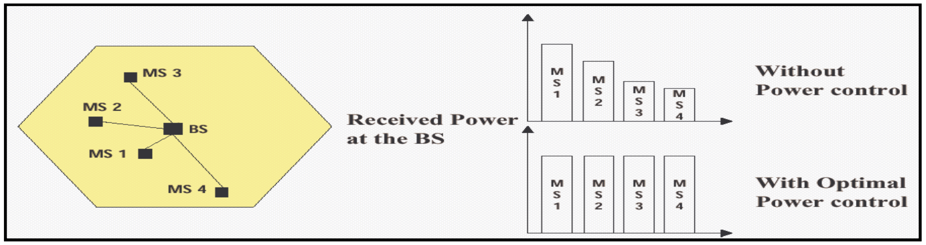
CDMA

- Each user assigned a code to spread his information signal
  - » Multi-user spread spectrum (Direct Sequence, Frequency Hopping)
  - » The resulting spread signal
    - – occupy the same bandwidth
    - – transmitted at the same time



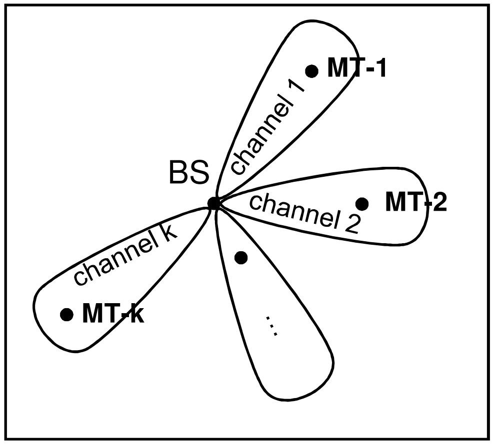
- Different bitrates to users
  - Ł control length of codes

- Power control required in uplink
  - » to compensate near-far effect
  - » If not Ł interference from close user swamps signal from far user



SDMA

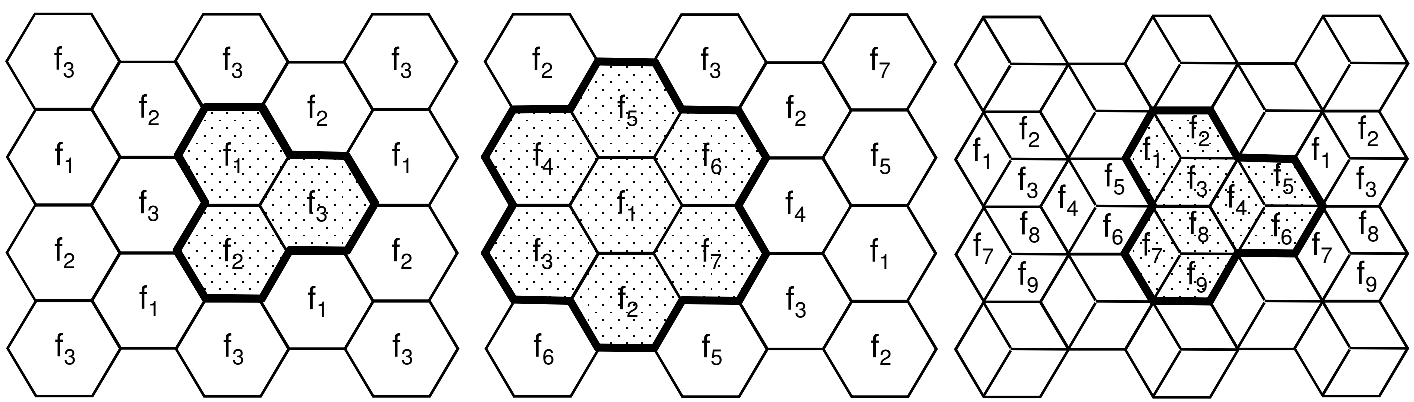
- SDMA uses direction (angle) to assign channels to users
- Implemented using sectorized antenna arrays
  - the 360º angular range divided in N sectors
  - TDMA or FDMA then required to channelize users



- Cellular division of the space
  - is also SDMA

Combined Multi-access Techniques

- Current technologies Ł combinations of multi-access techniques
  - » GSM: FDMA and then TDMA to assign slots to users
- The cell concept Ł combined multi-access technique
  - » SDMA + FDMA
- Cellular planning



a) Group of 3 cells b) Group of 7 cells c) Group of 3 cells, each having 3 sectors

Wireless Medium Access Control Issues

- Medium Access Control (MAC)
  - » Assign radio resources to terminals along the time

- 3 type of resource allocation methods
  - » dedicated assignment

    resources assigned in a predetermined, fixed, mode

  - » random access

    terminals contend for the channel

  - » demand-based

    terminals ask for reservations

    using dedicated/random access channels

Hidden, Exposed and Capture Nodes

- Signal strength decays with the path length

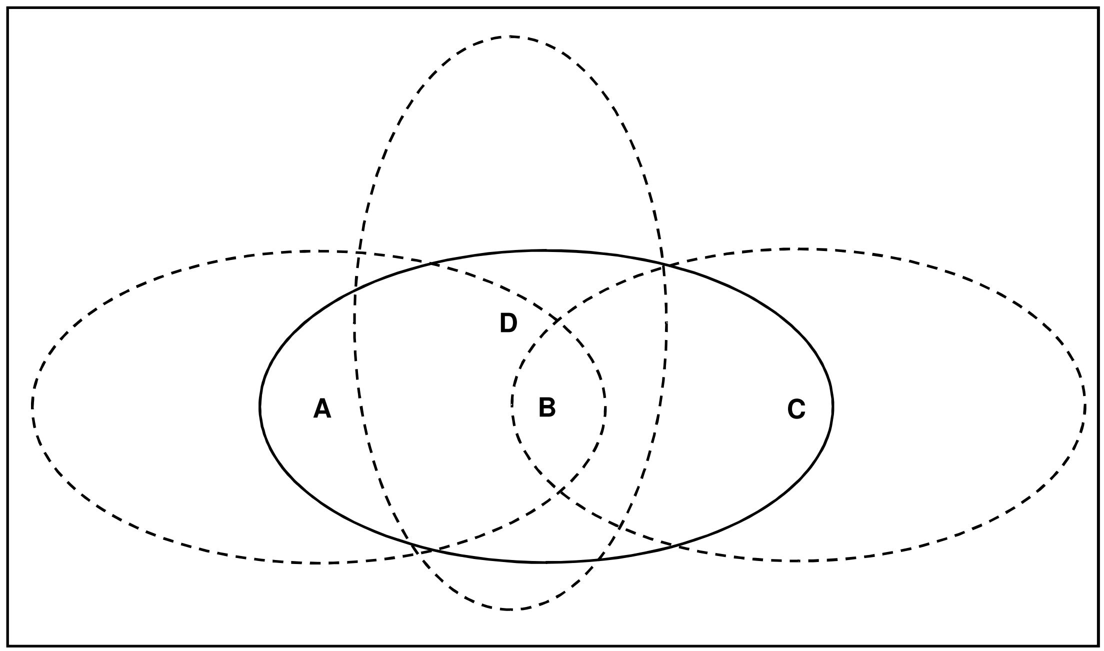
$$P_{r_{dBm}} = P_{s_{dBm}} + K_{dB} - 10\,\gamma\,log\left[\frac{d}{d_0}\right]$$

- Carrier sensing depends on the position of the receiver
- MAC protocols using carrier sensing Ł 3 type of nodes

» hidden nodes
  - C is hidden to A

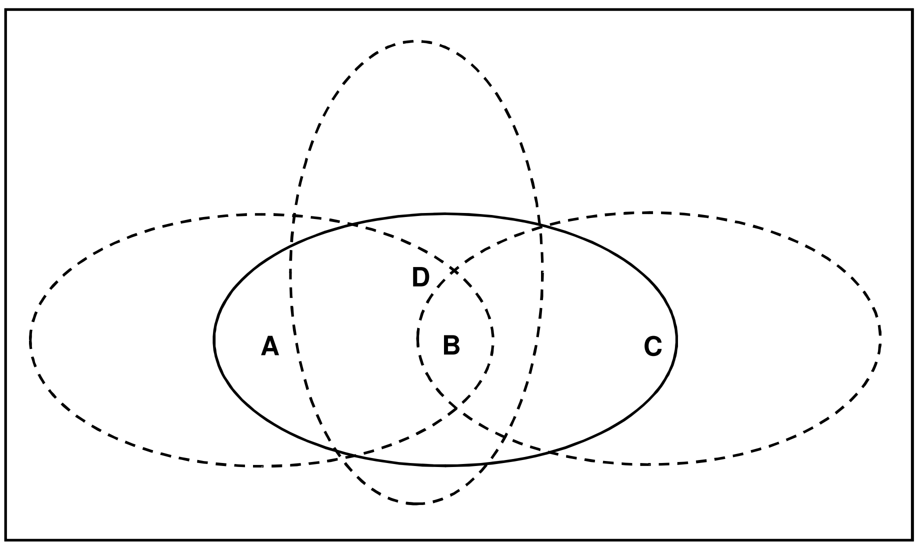
» exposed nodes
  - C is exposed to B

» 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 Ł interferes with data reception at B
  - *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
  - receiver can receive from two senders
  - A and D transmit simultaneously to B; but signal from D much higher than that from A



Alhoa, S-Alhoa, CSMA

- Alhoa 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 retransmits packet

- Slotted Alhoa Efficiency of 37 %

  stations transmit just at the beginning of each time slot

- 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 Alhoa, S-Alhoa and CSMA

CSMA/CD – Not Used in Wireless

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

      station aborts transmission and stresses collision

      (no ACK packet)

- Problems of CSMA/CD in wireless networks

Collision Detection

near-end interference makes simultaneous transmission and reception difficult

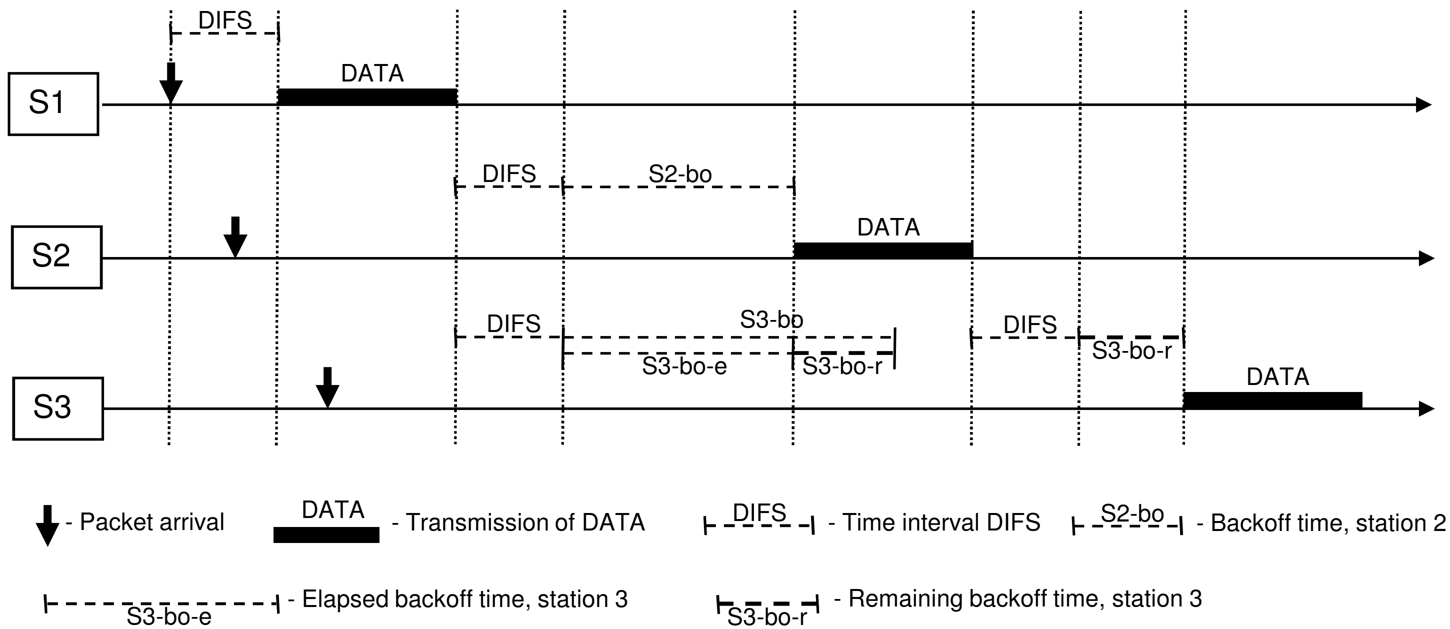
Carrier Sensing

carrier sensing difficult for hidden terminal

To think about

- *How to minimize collision in a wireless medium?*

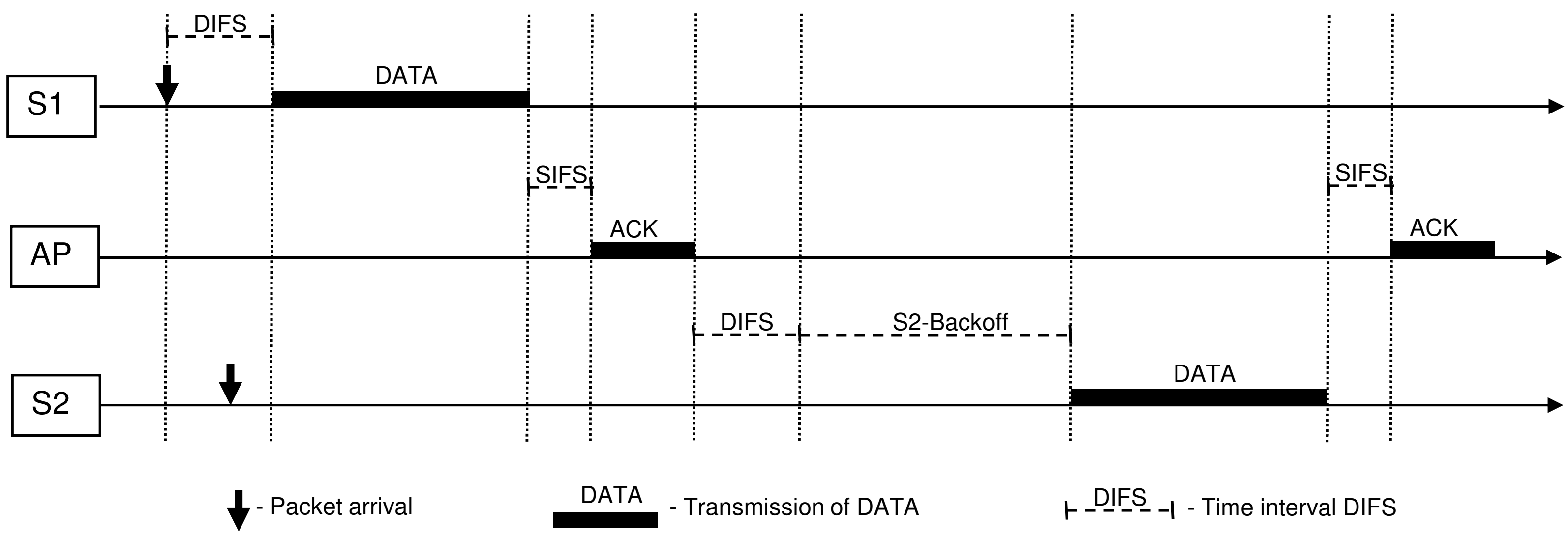
CSMA with Collision Avoidance (CSMA/CA)



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) has been 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

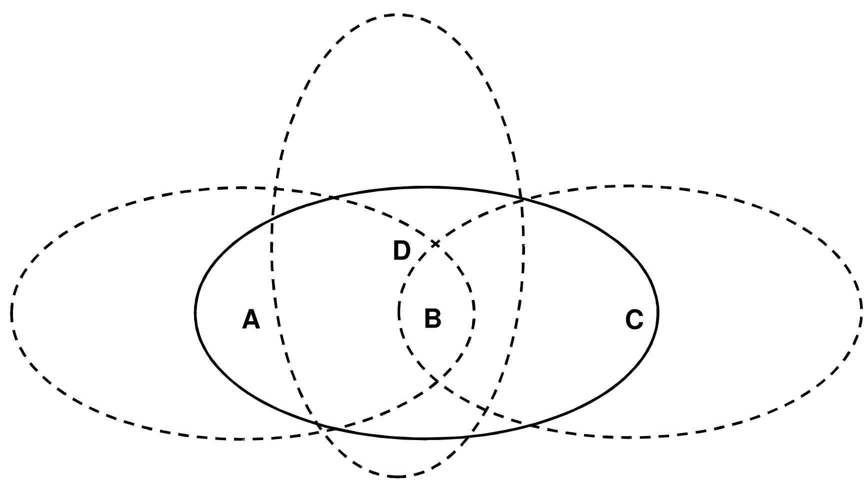


CSMA/CA – ACK Required

- 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 transmission
- 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, it re-schedules the packet transmission according to the previous backoff rules.
- Efficiency of CSMA/CA depends strongly of the number of competing stations. An efficiency of 60% is commonly found

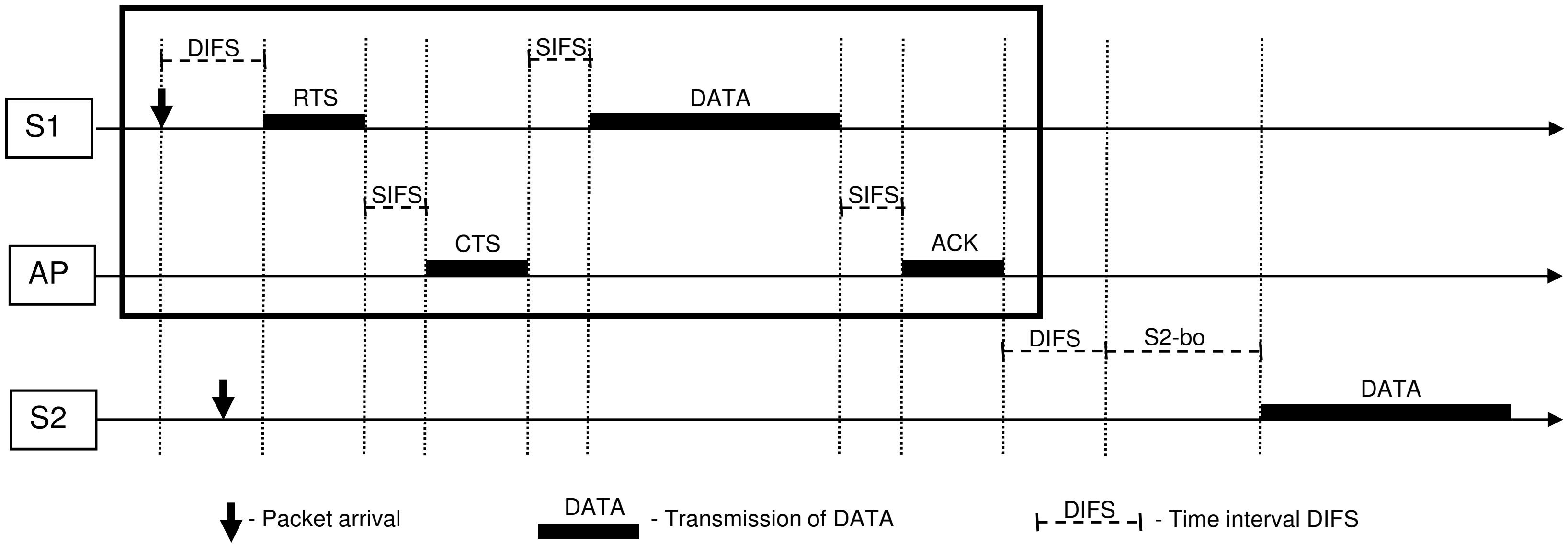
To Think About

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



Hidden node   C is hidden to A

RTS-CTS Mechanism

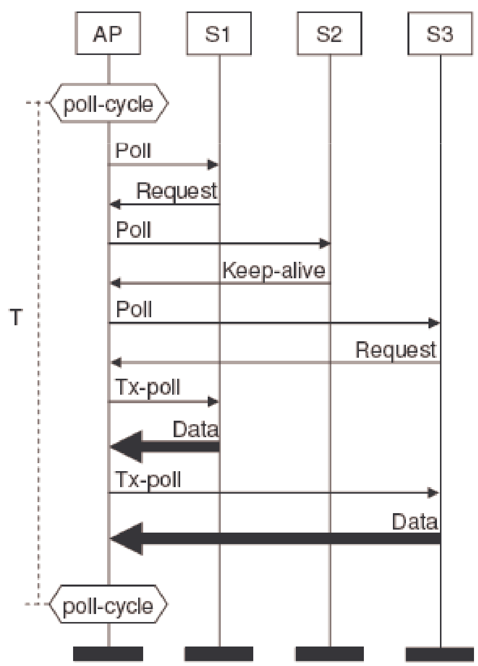


RTS-CTS Mechanism

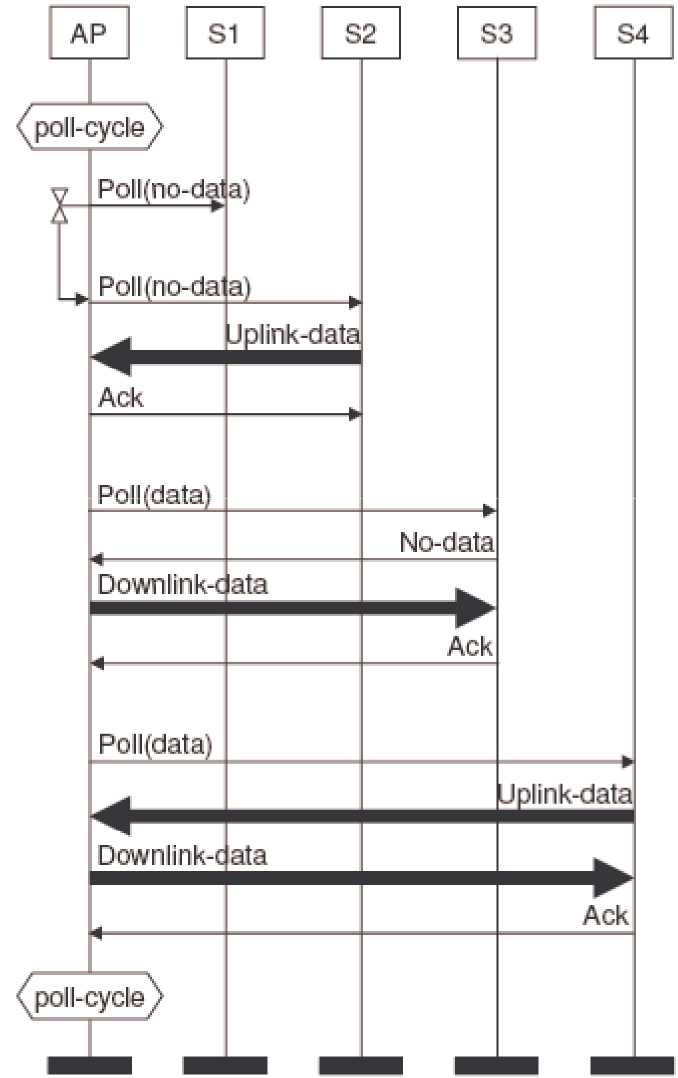
- For some scenarios where long packets are used or the probability of hidden terminals is not irrelevant, the efficiency of CSMA/CA can be further improved with a Request To Send (RTS) - Clear to Send (CTS) mechanism
- The basic concept is that a sender station sends a short RTS message to the receiver 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 or receiver that a big 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. 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
- In optimum conditions the RTS-CTS mechanism may add an efficiency gain of about 15%

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