Introduction to Wireless and Mobile Networking

Lecture 4: Wireless MAC and Random Access

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Wireless MAC

What's MAC

- Medium Access Control
  - Sharing the wireless medium
- The MAC protocol defines
  - a set of rules for the orderly access of a shared media wireless channel by multiple mobile devices
  - a set of services that support real-time voice and video, and reliable delivery of data
  - plays a crucial role in the efficient and fair sharing of scarce wireless bandwidth

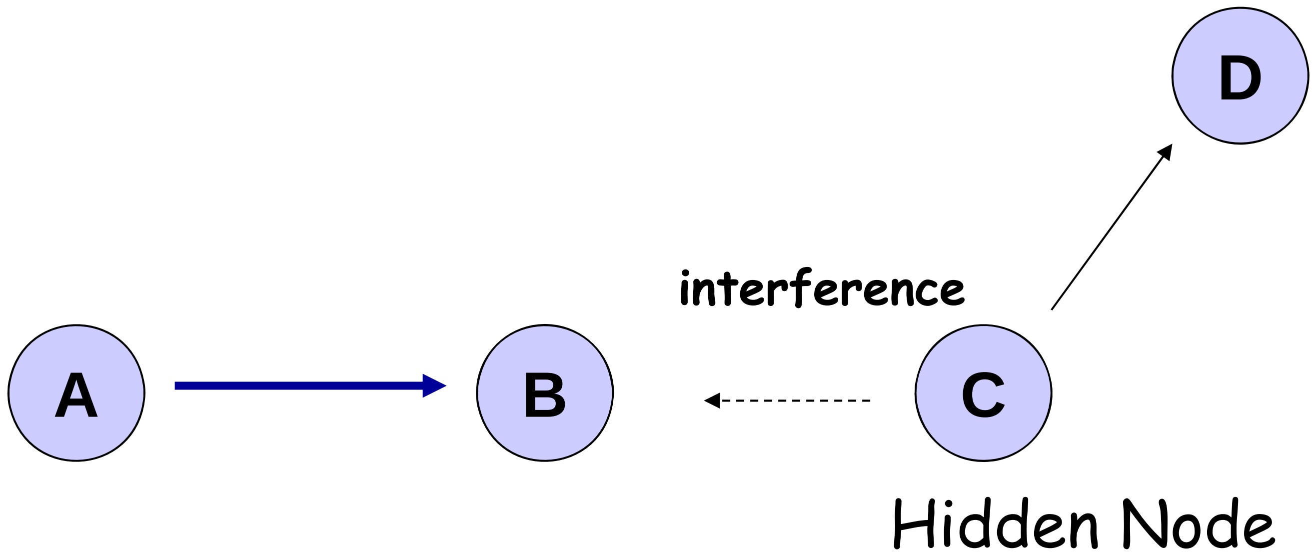
Issues in MAC

- Multiple devices need to share the "channel" efficiently
  - Problems: "interfere", contention, access control, channel quality varies over space and time
- Different service requirements
  - Voice (real-time, reservation-based)
  - Data (best effort, reliable deliver)
- Different approaches and trade-offs
  - "Centralized vs. Distributed"
- Other challenges
  - Mobility, power conservation, security considerations
- It's a difficult problem
  - Near-far, hidden terminals, time-varying channel, burst errors, etc.

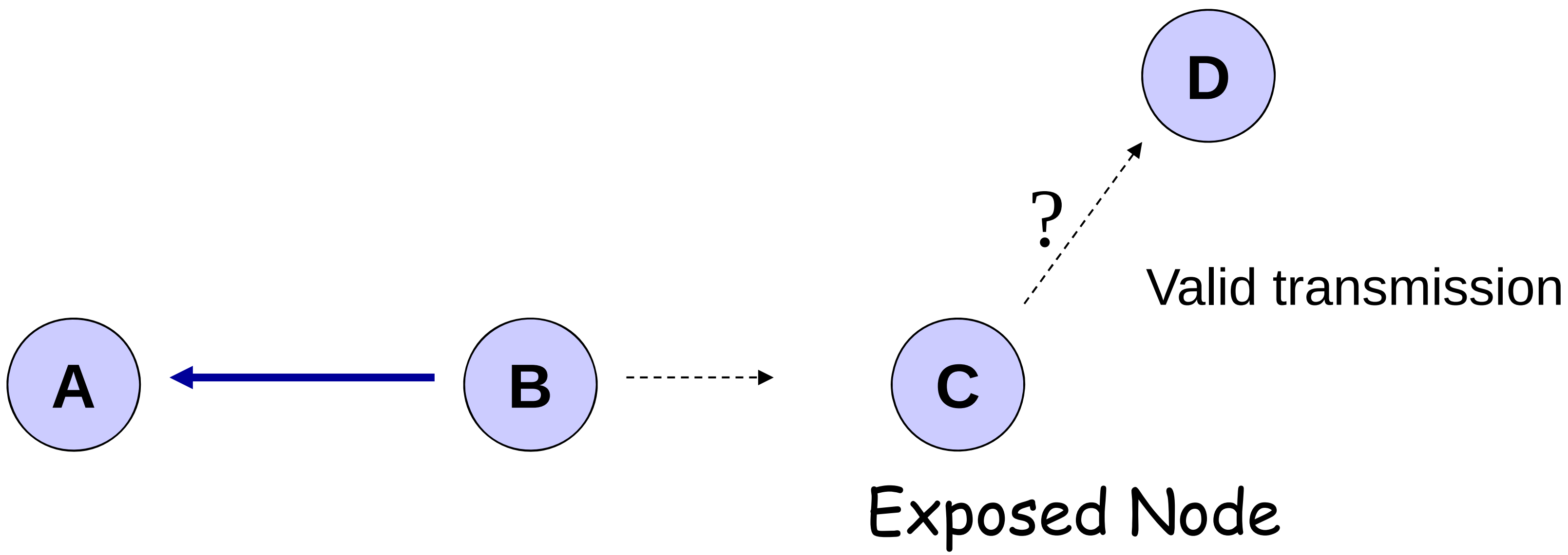
Could We Apply MAC From Wired Networks?

- 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 → distributed
  - Signal strength decreases proportional to the square of the distance
  - The sender would apply CS and CD, but the collisions happen at the receiver
  - Sender might not "hear" the collision
    - CD does not work
  - CS might not work if
    - a terminal is "hidden"

Hidden Node

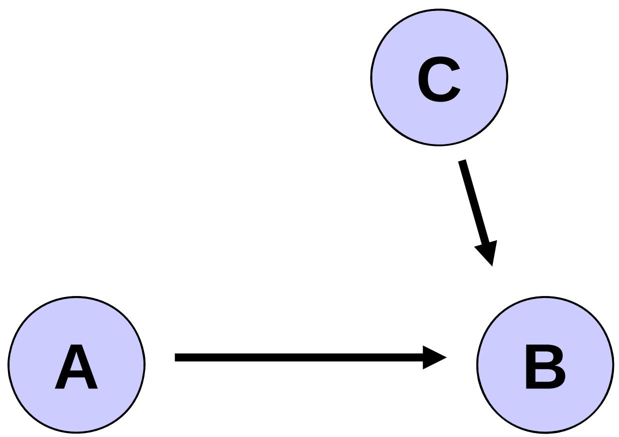


Exposed Node



Capture

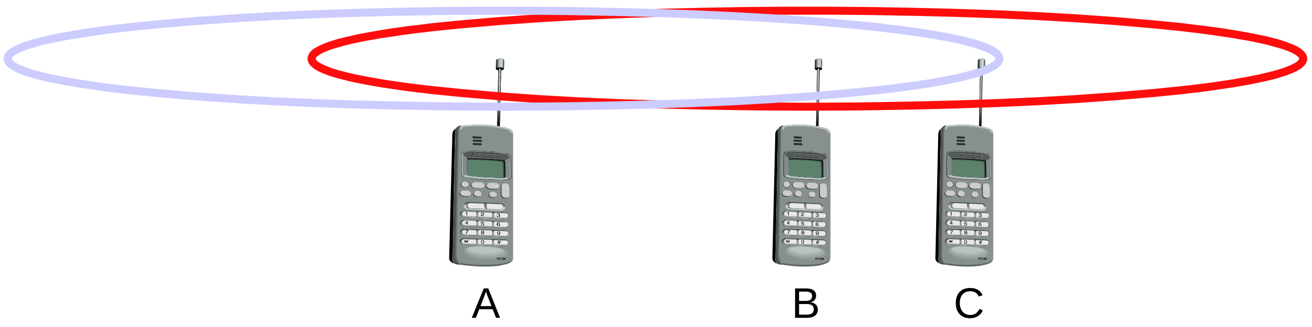
- Capture occurs when a receiver can cleanly receive a transmission from one of two simultaneous transmissions.
  - Improve performance
  - But, result in unfairness



$P_{CB} >> P_{AB}$

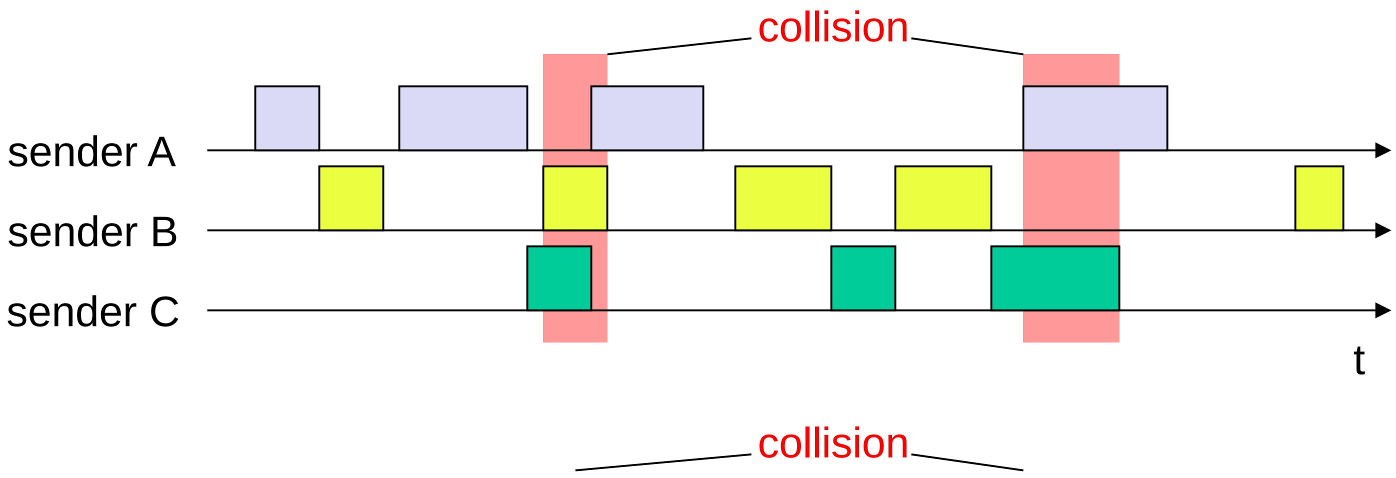
Near and far terminals

- 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



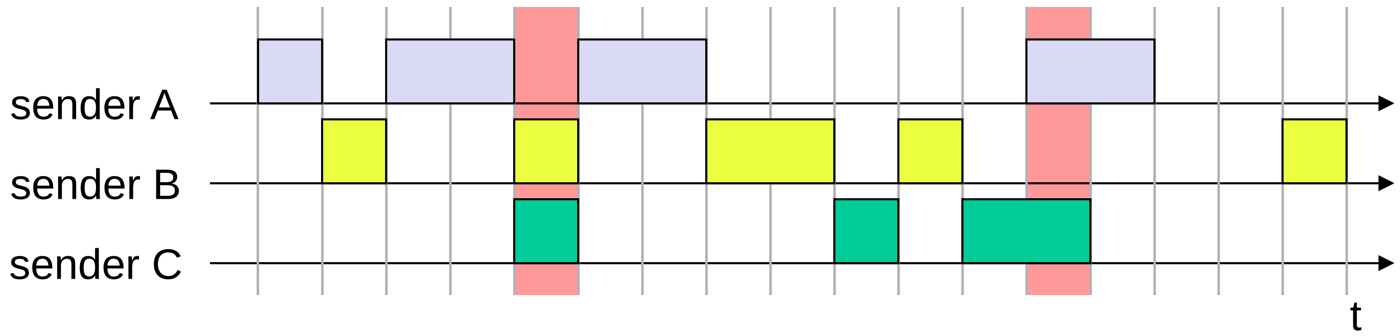
Aloha

- Mechanism
  - random, distributed (no central arbiter), time-multiplex
- The oldest random access protocol



Slotted Aloha

- Slotted Aloha
  - Time slots
    - Transmission at the beginning of slots
- Performance
  - Channel efficiency only 18% for Aloha
  - 36% for Slotted Aloha
  - assuming Poisson distribution for packet arrival and packet length
  - Room for improvement!



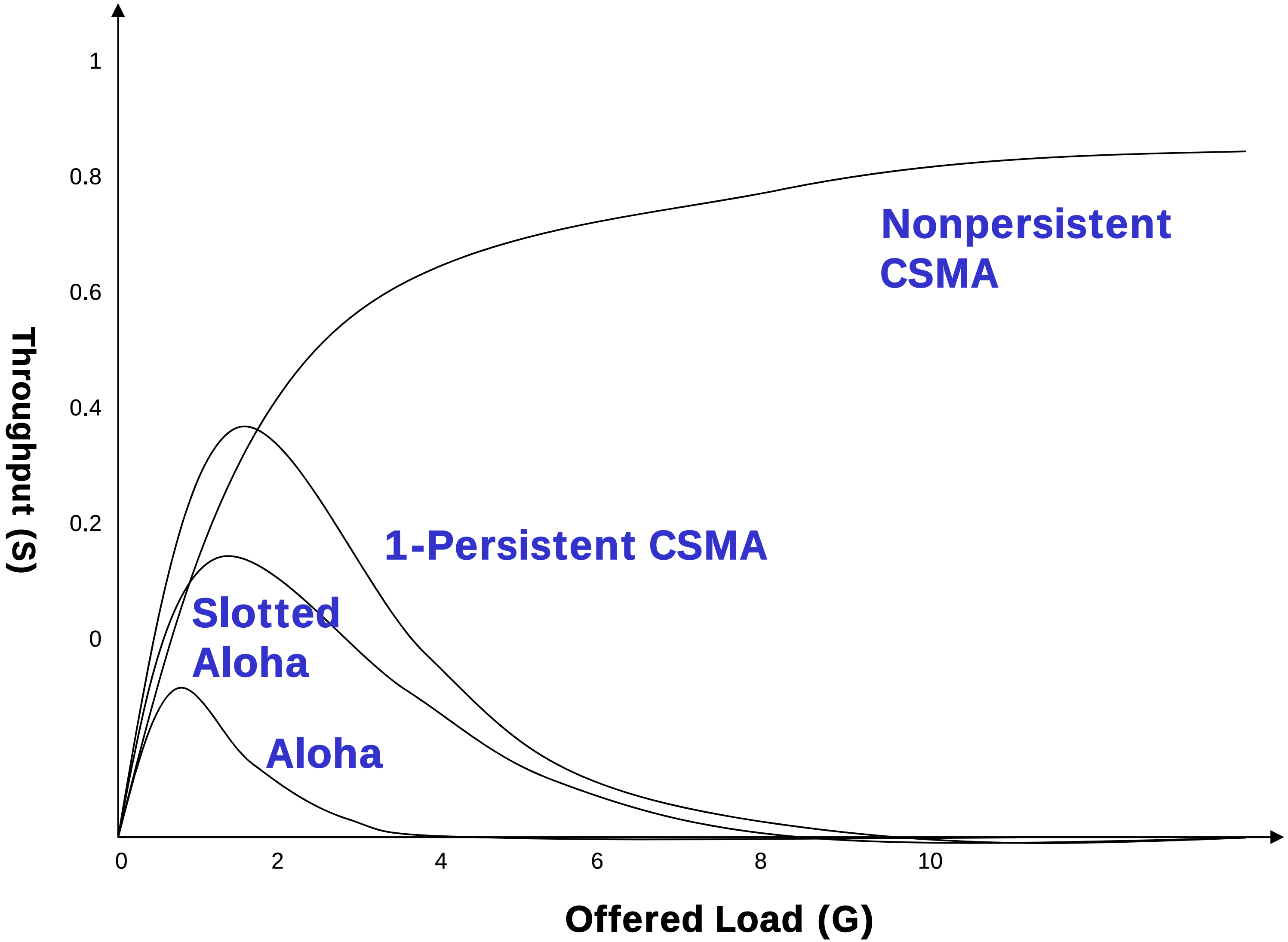
CSMA

- Carrier Sense Multiple Access (CSMA)
- Carrier Sense
  - Listen (sense carrier) before transmission
  - Improvement over Aloha
    - Aloha doesn't consider what other users are doing
- Collision still occurs
  - Backoff when carrier is busy
  - Backoff when collision occurs
- CSMA/CD
  - Collision Detection (CD)
    - Listen for a collision with another node's transmission
    - Nodes are able to detect collision and stop transmissionl
  - IEEE 802.3 standard
    - Ethernet

Different types of backoff

- 1-persistence
  - After channel becomes idle, a node transmits its packet immediately
- p-persistence
  - After channel become idle, a node transmits its packet with probability p.
- Non-persistence
  - A node does not sense the channel until waiting for a random waiting period

Random MAC



1
0.8
0.6
0.4
0.2
0
Throughput (S)
Nonpersistent
CSMA
1-Persistent CSMA
Slotted
Aloha
Aloha
0
2
4
6
8
10
Offered Load (G)

Basic Components in Random MAC

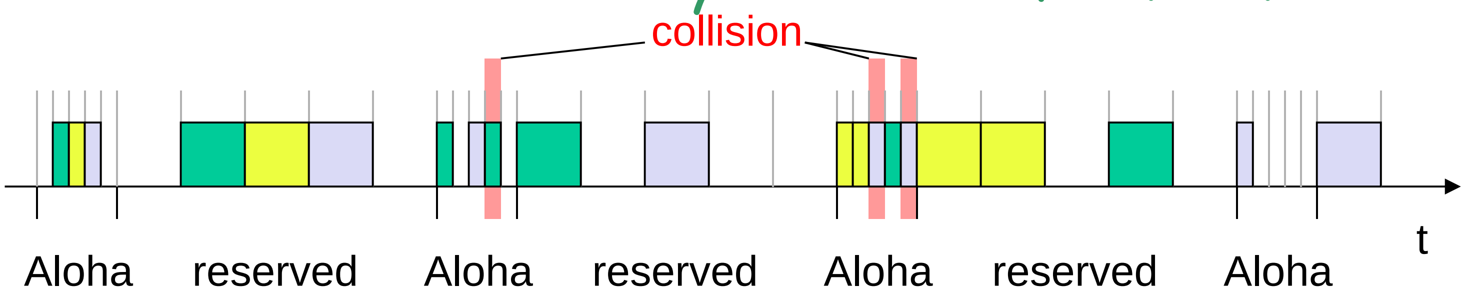
- Some components
  - Contention
    - Basic for random access
    - Show your interest in
  - Reservation
  - Data transmission
- Design principle
  - Reduce the cost of contention
    - Avoid unnecessary contention
    - Reduce the cost of each contention trial

DAMA(Demand Assigned Multiple Access)

- Reservation can increase efficiency to 80%
  - a sender *reserves* a future time-slot
  - sending within this reserved time-slot is possible without collision
  - reservation also causes higher delays
  - typical scheme for satellite links
- Examples for reservation algorithms:
  - *Explicit Reservation*
  - *(Reservation-ALOHA)*
  - *Implicit Reservation (PRMA)*
  - *Reservation-TDMA*

Explicit Reservation

- Reservation Aloha
  - two modes:
    - *ALOHA mode* for reservation: competition for small reservation slots, collisions possible
    - *reserved mode* for data transmission within successful reserved slots (no collisions possible)
  - Limitations
    - all stations to keep the reservation list consistent
    - all stations have to synchronize from time to time

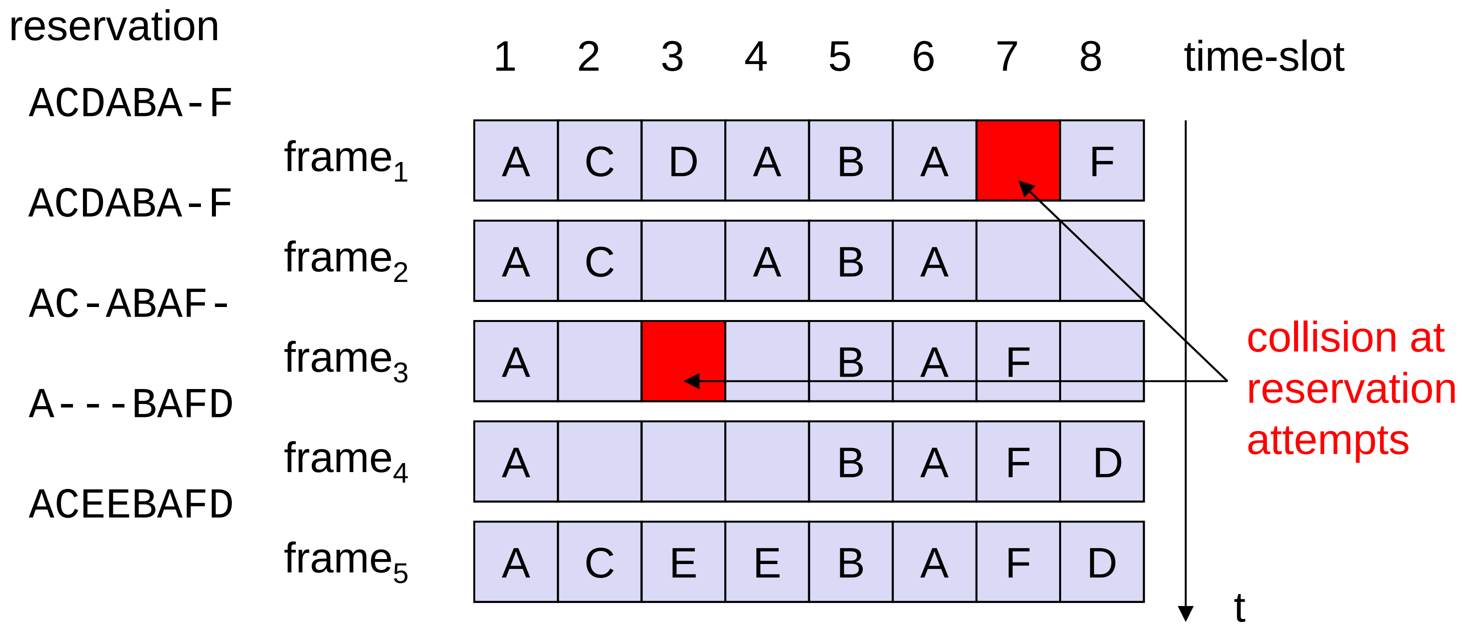


PRMA - Packet Reservation MA

- Implicit reservation
  - Several slots form a frame
  - Slots are either reserved or empty
  - Stations compete for empty slots according to the slotted aloha principle
  - Once a station reserves a slot successfully, this slot is automatically assigned to this station in all following frames as long as the station has packets to send
  - Competition for this slots starts again as soon as the slot was empty in the last frame
- Suitable for voice/video real-time reservation
  - Might treat voice and data traffic differently

PRMA

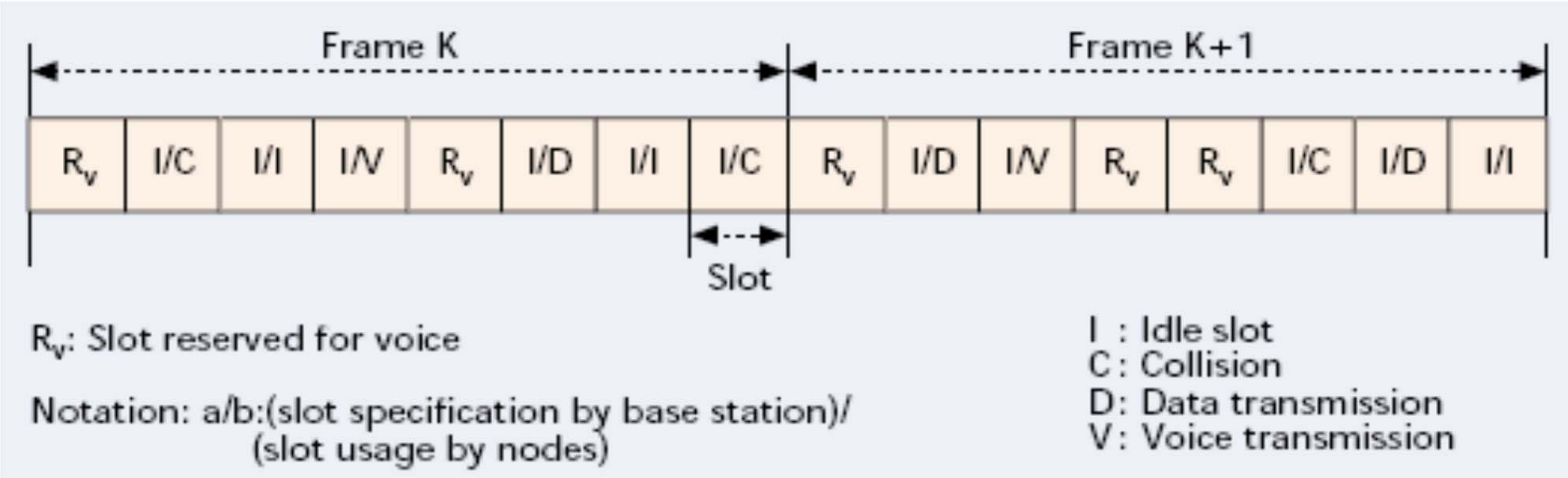
BS notification (DL)



Slot usage (UL transmission)

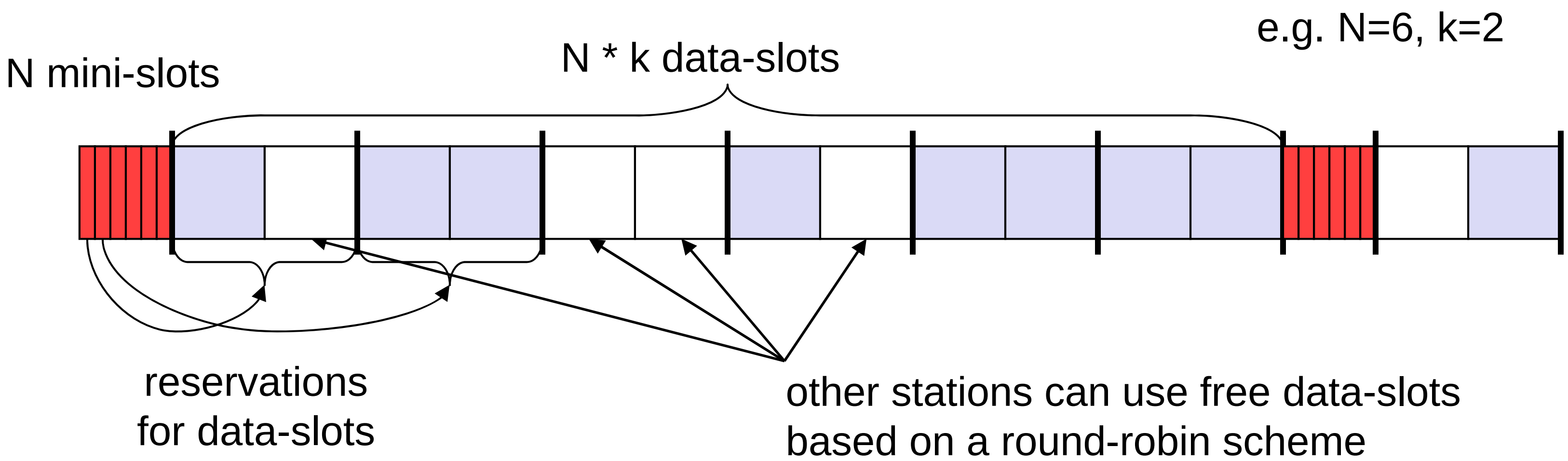
PRMA: voice+data

- Voice (reservation)
  - Implicitly reservation for the future slots
- Data (random access)
  - Random access to idle slots for data transmission



Reservation-TDMA

- Reservation Time Division Multiple Access
  - every frame consists of N mini-slots and x data-slots
  - every station has its own mini-slot and can reserve up to k data-slots using this mini-slot (i.e. $x = N * k$).
  - other stations can send data in unused data-slots according to a round-robin sending scheme (best-effort traffic)

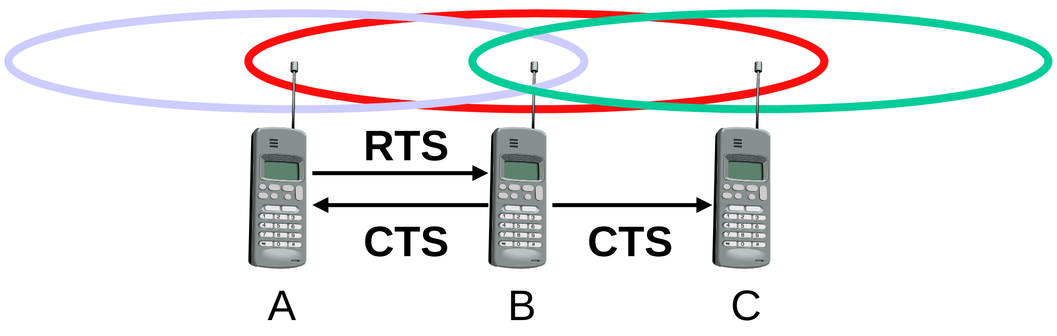


MACA (Multiple Access with Collision Avoidance)

- Using short signaling packets for collision avoidance
  - RTS (request to send): a sender request the right to send from a receiver with a short RTS packet before it sends a data packet
  - CTS (clear to send): the receiver grants the right to send as soon as it is ready to receive
- Signaling packets contain
  - sender address
  - receiver address
  - packet size
- Variants of this method can be found in IEEE802.11

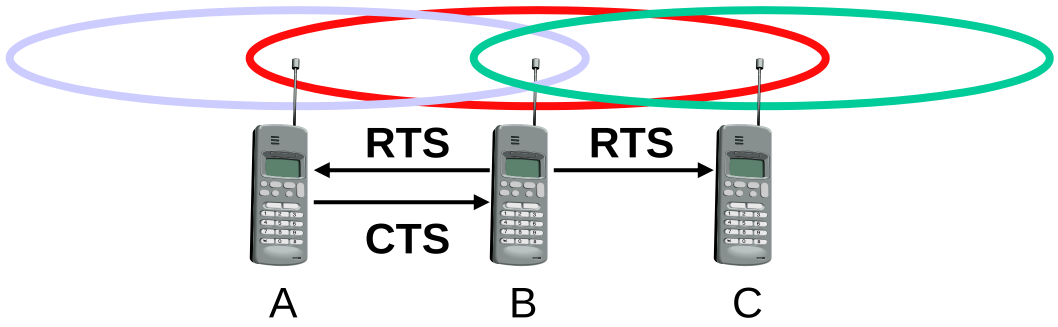
MACA examples

- MACA avoids the problem of hidden terminals
  - A and C want to send to B
  - A sends RTS first
  - C waits after receiving CTS from B

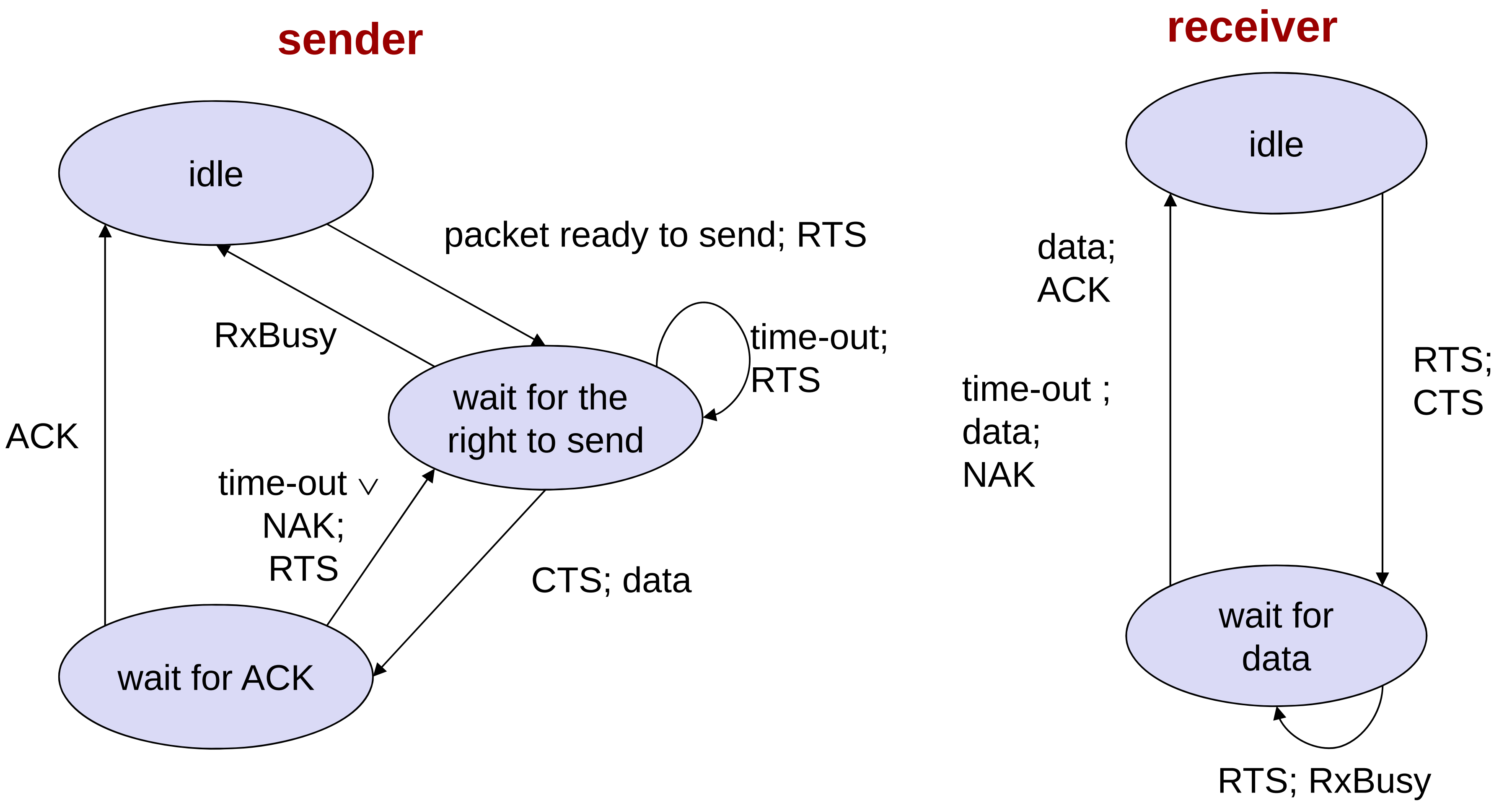


MACA example

- MACA avoids the problem of exposed terminals (in some cases)
  - B wants to send to A, C to another terminal
  - now C does not have to wait for it cannot receive CTS from A
- In some MACA variant
  - It creates exposed terminal problem!



State Diagram: generalized MACA



ACK: positive acknowledgement
NAK: negative acknowledgement

RxBusy: receiver busy

MAC: Polling

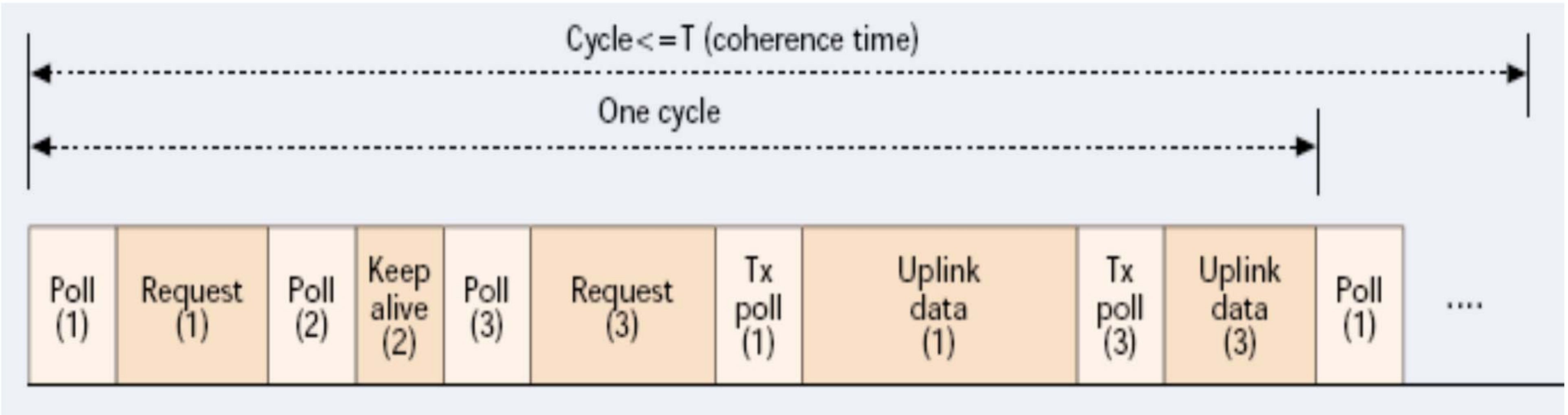
- MAC between TDMA and random access
- Master-slave architecture
  - E.g. BS (or AP) is the master
- BS sends a "poll" to MS
  - "Poll" frame indicates MS's MAC address
  - Uplink transmission is controlled by AP's polling
- 3 essential elements in polling
  - Request: MS request for uplink transmission
  - Poll: BS allocate bandwidth through polling
  - Data: Uplink data transmission

Polling Protocol Design

- Many polling mechanisms
- Design Space
  - Acknowledgement?
  - Combine uplink and downlink transmission?
  - Separate polling messages for
    - Bandwidth request
    - Actual data transmission
- 2 examples
  - Example 1:
    - Separate polling for bandwidth request and data transmission
  - Example 2:
    - Integrated design for both uplink and downlink data transmission

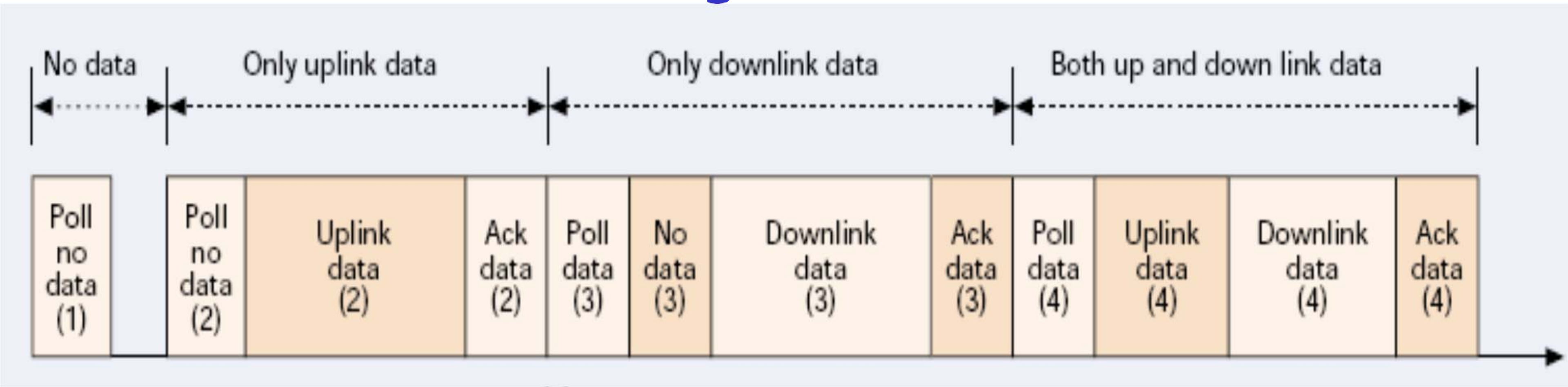
Example 1: Polling

- Poll: BS polls MS to transmit bandwidth request
- Request: MS tells BS if MS has uplink data to send (Request) or not (Keep Alive)
- Tx Poll: BS tells MS to transmit uplink data
  - Response to the previous Request message
- Uplink Data: MS transmits data to BS



Example 2: Polling

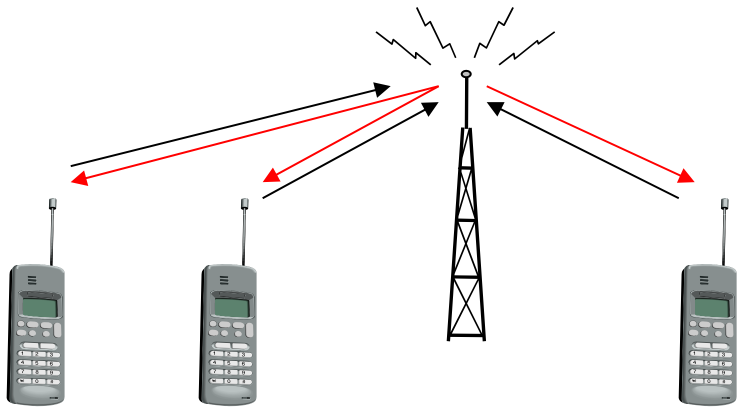
- Poll no data
  - BS polls MS
  - BS has no downlink data to send
- Poll data
  - BS polls MS
  - BS has downlink data to send
- Uplink data: MS sends data to BS
- Downlink data: BS sends data to MS
- Ack data: Acknowledgement of received data



ISMA (Inhibit Sense Multiple Access)

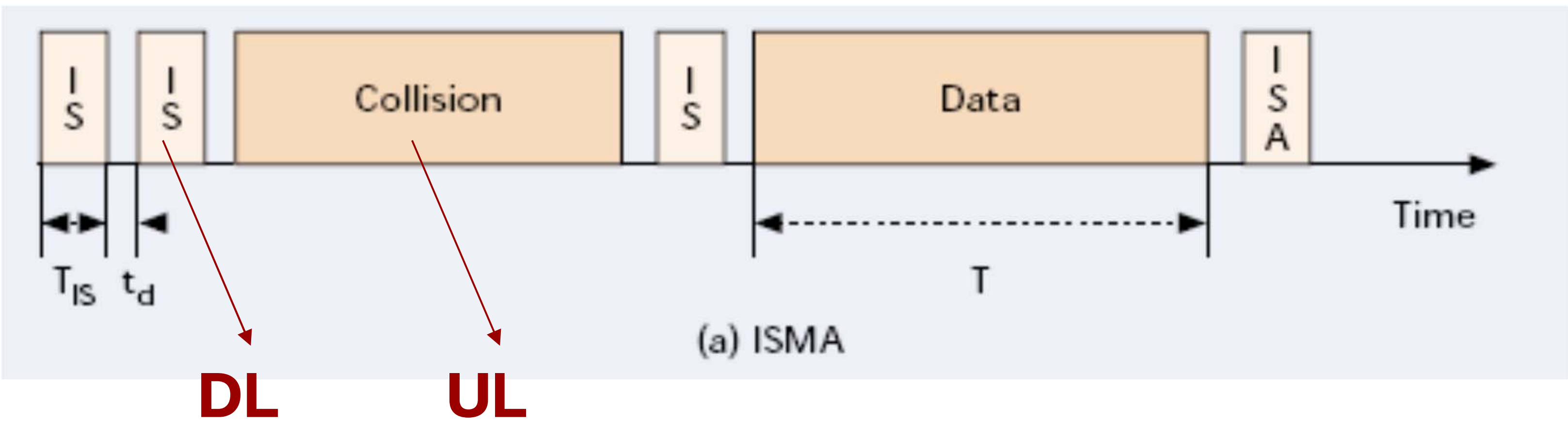
- Current state of the medium is signaled via a "busy tone"
  - BS signals on the downlink (BS→MS) if the medium is free or not
  - MS cannot send if the medium is busy
  - MS can access the medium as soon as the busy tone stops
  - BS signals collisions via busy tone
  - BS signals successful transmissions via ACK acknowledgements
- Used in CDPD
- Busy tone is used

  in some other systems



ISMA

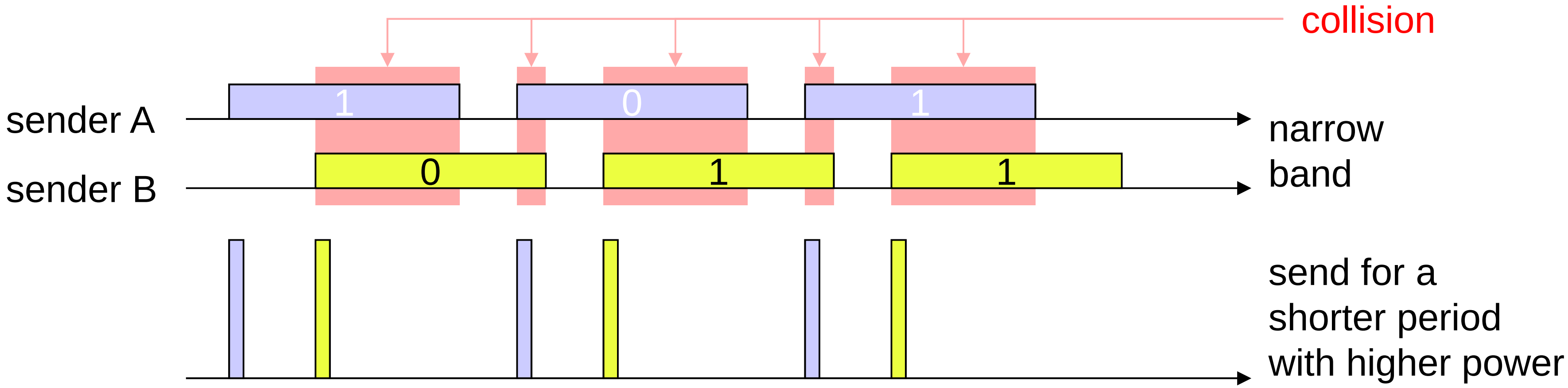
- IS: Idle signal
- ISA: Idle signal with acknowledgment



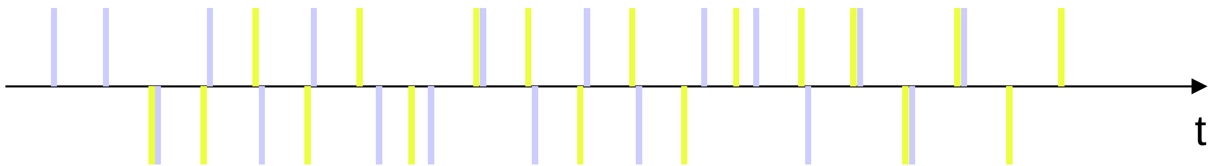
SAMA :Spread Aloha Multiple Access

- Aloha has only a very low efficiency, CDMA needs complex receivers to be able to receive different senders with individual codes at the same time
- Idea: use spread spectrum with only one single code (chipping sequence) for spreading for all senders accessing according to aloha
  - Code design
    - high autocorrelation
    - Low correlation with delay-shift

SAMA :Spread Aloha Multiple Access



spread the signal e.g. using the chipping sequence 110101 („*CDMA without CD*“)



Problem: find a chipping sequence with good characteristics

Summary: Types of wireless MAC

- (1) Centralized allocation
  - TDMA, CDMA, FDMA
    - Cellular downlink
    - Cellular uplink (dedicate allocation)
- (2) Request/Allocation
  - Polling
    - Cellular uplink
- (3) Random Access
  - CSMA, Aloha, 802.11