Mobile Networking

Mohammad Hossein Manshaei

manshaei@gmail.com

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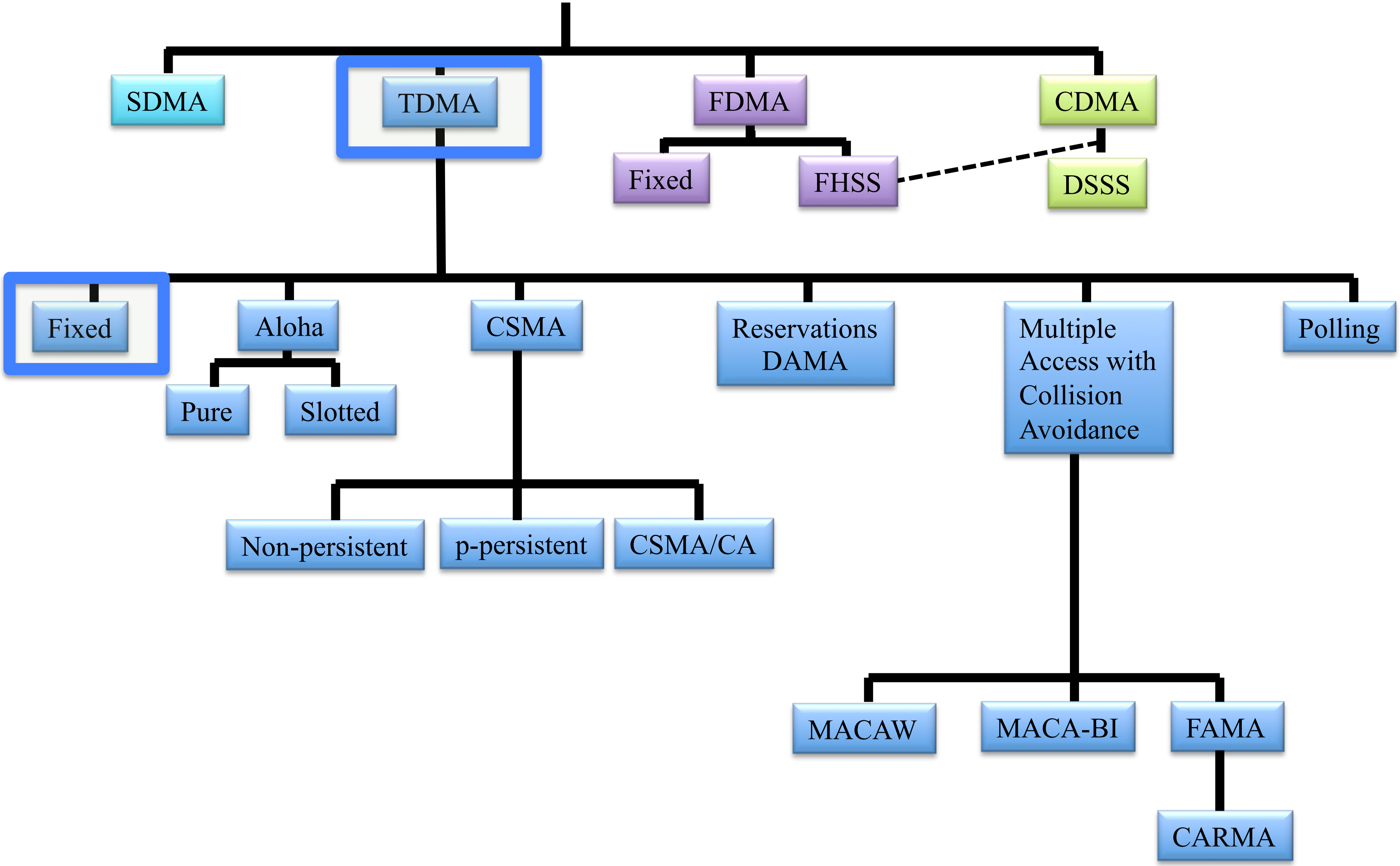
Contents

- Time Division Multiple Access
- Aloha
- Carrier Sense Multiple Access
  - Non-Persistent
  - Persistent
- Demand Assigned Multiple Access
- Multiple Access with Collision Avoidance

Medium Access Control Mechanisms for Wireless

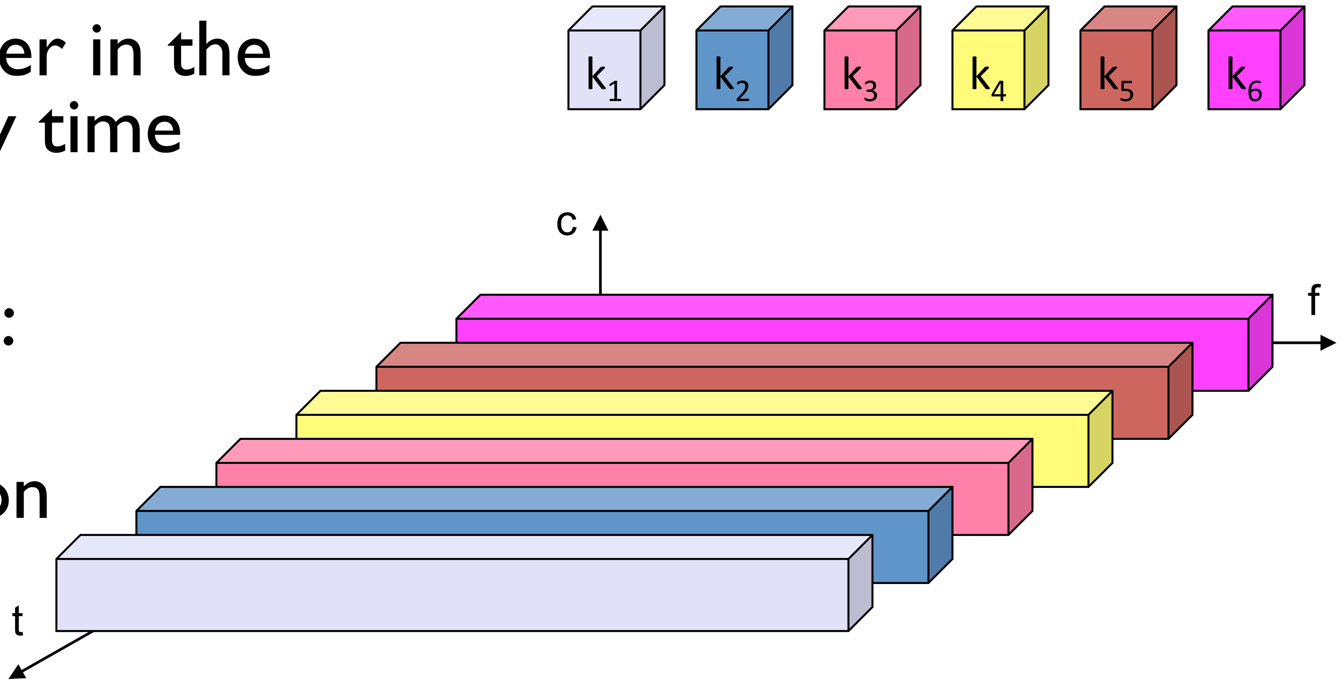


Time Multiplex

- A channel gets the whole spectrum for a certain amount of time.

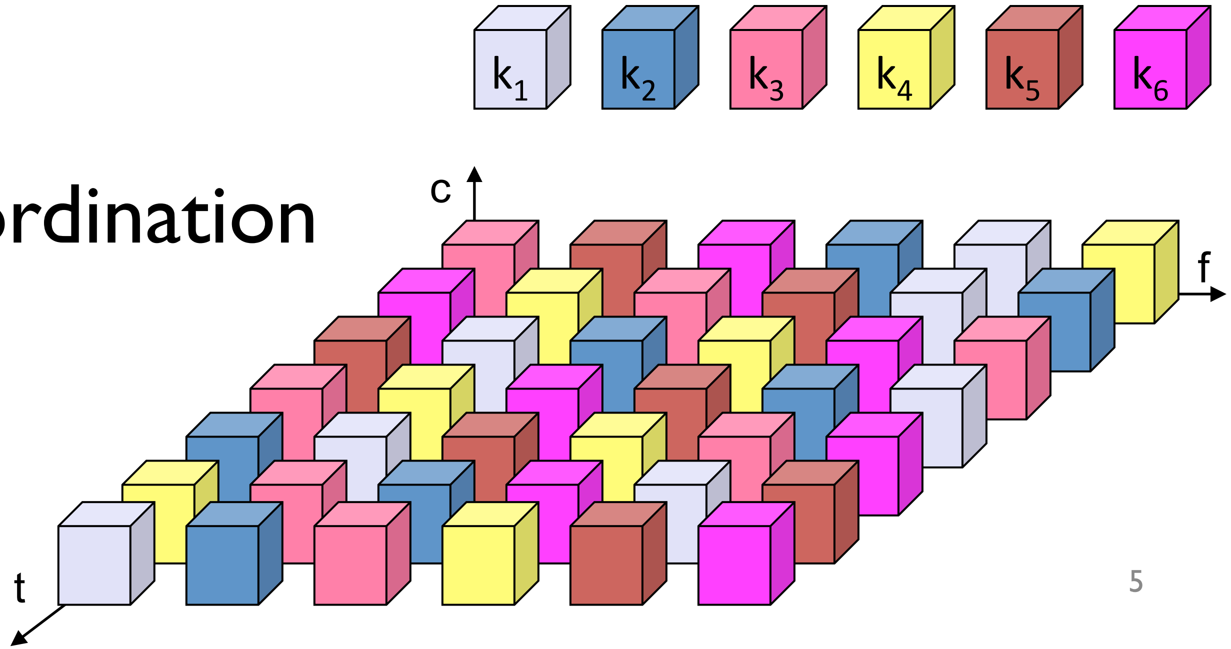
- Advantages:
  - ❑ only one carrier in the medium at any time

- Disadvantages:
  - ❑ precise synchronization required

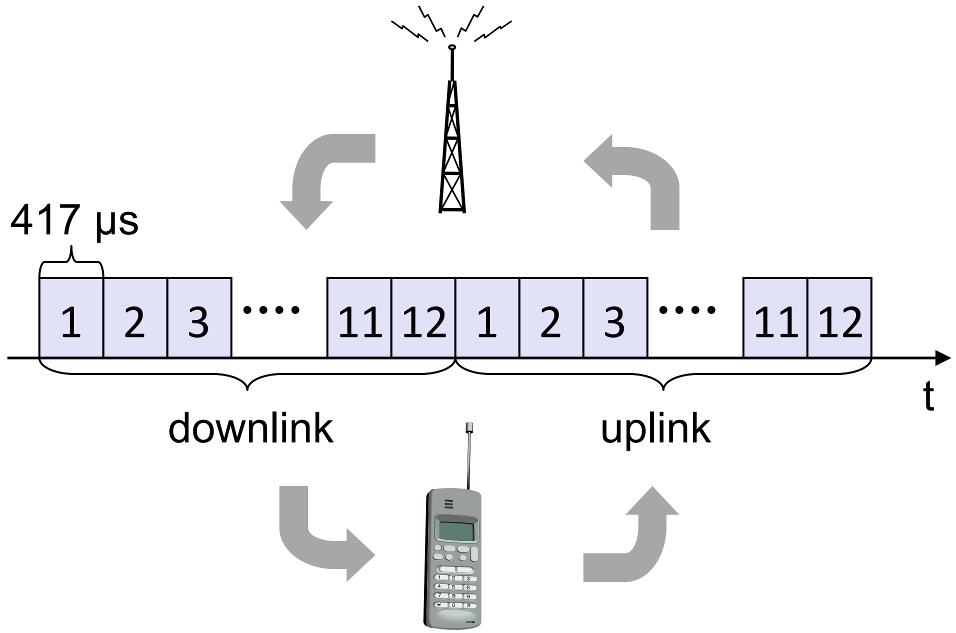


Time and Frequency Multiplex

- Combination of both methods.
- A channel gets a certain frequency band for a certain amount of time.
- Example: GSM
- Advantages:
  - more flexibility
- But: precise coordination required



TDMA/TDD – Example: DECT



DECT: Digital Enhanced Cordless Telecommunications
TDD: Time Division Duplex

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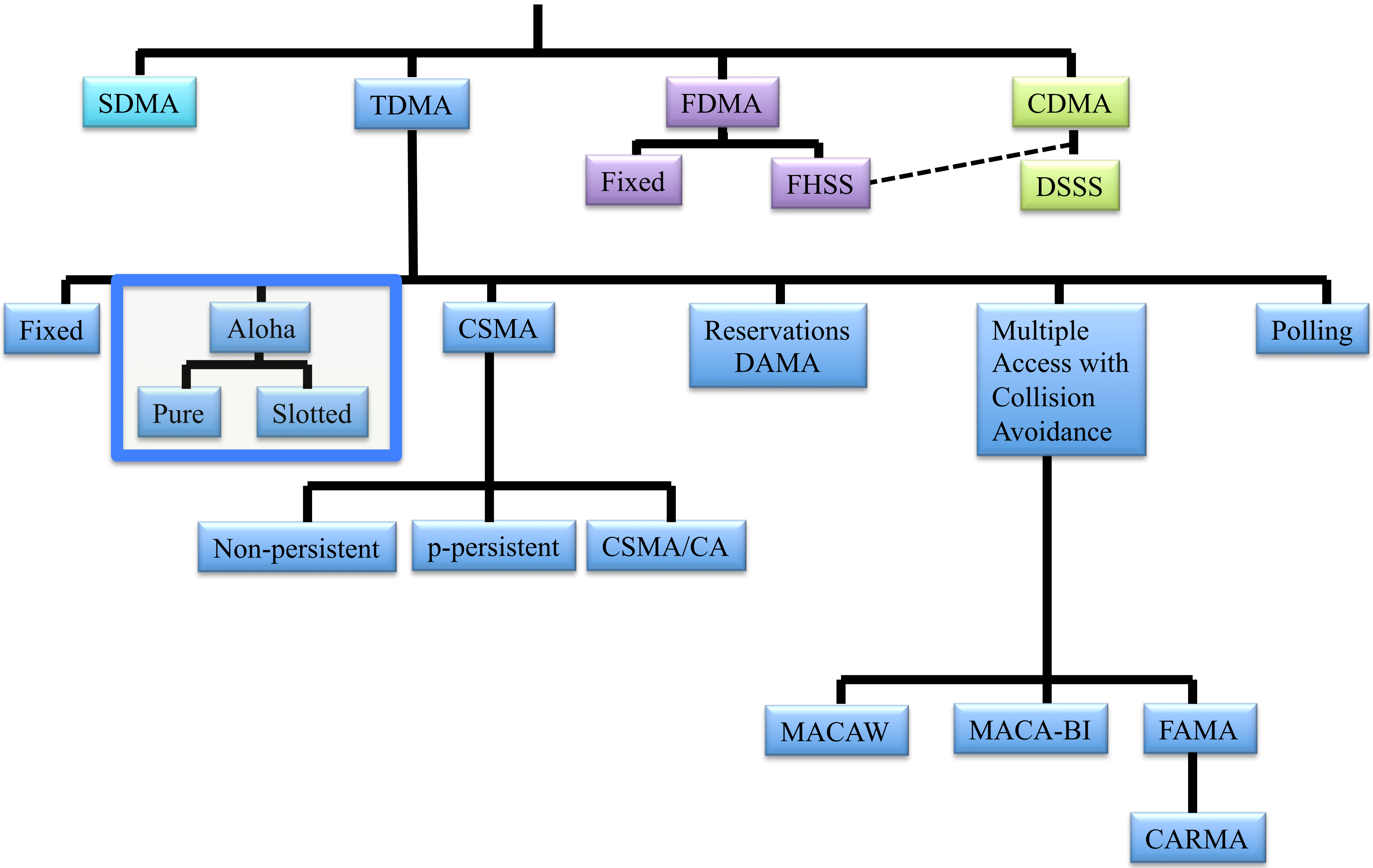
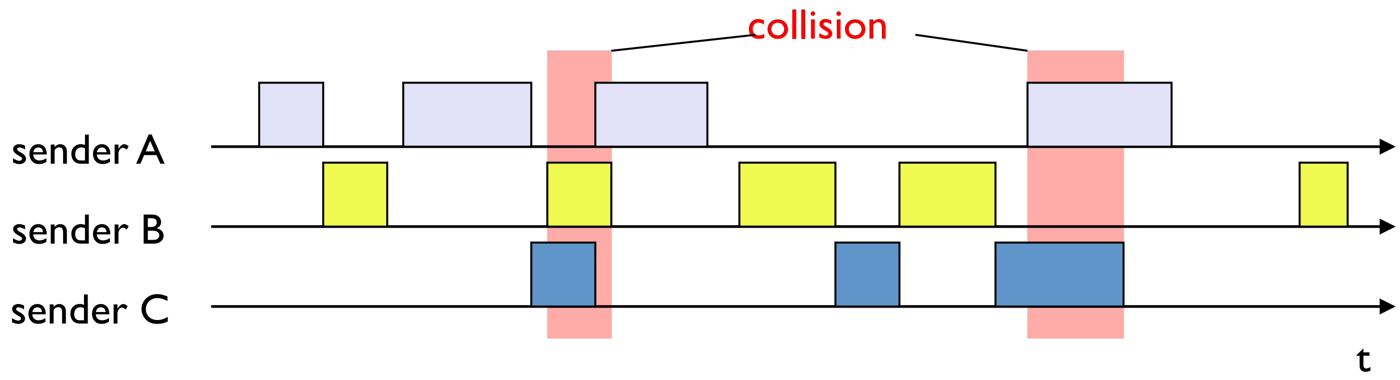
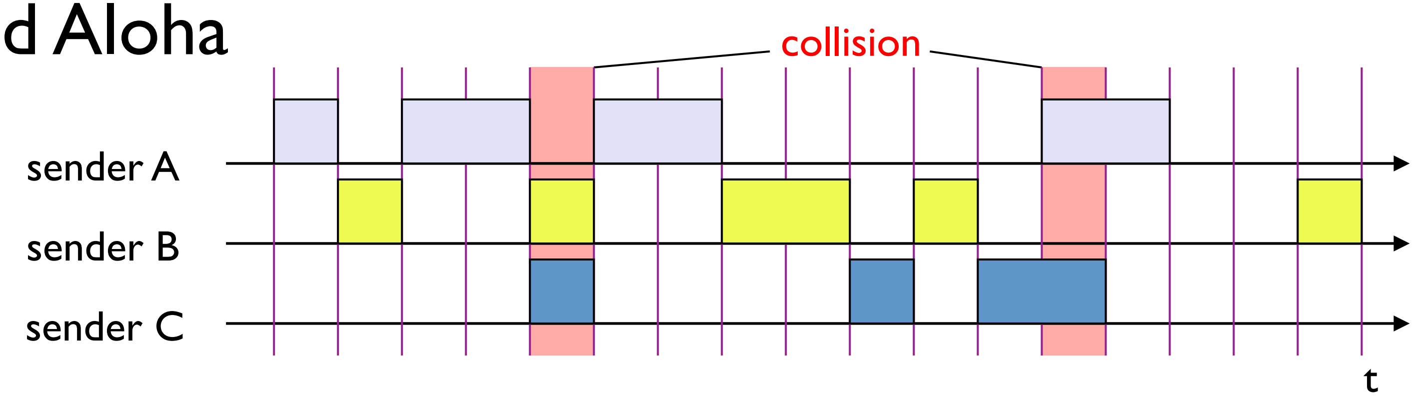


Aloha/Slotted Aloha

- Mechanism
  - random, distributed (no central arbiter), time-multiplex
  - Slotted Aloha additionally uses time-slots, sending must always start at slot boundaries
- Aloha



- Slotted Aloha



Slotted ALOHA

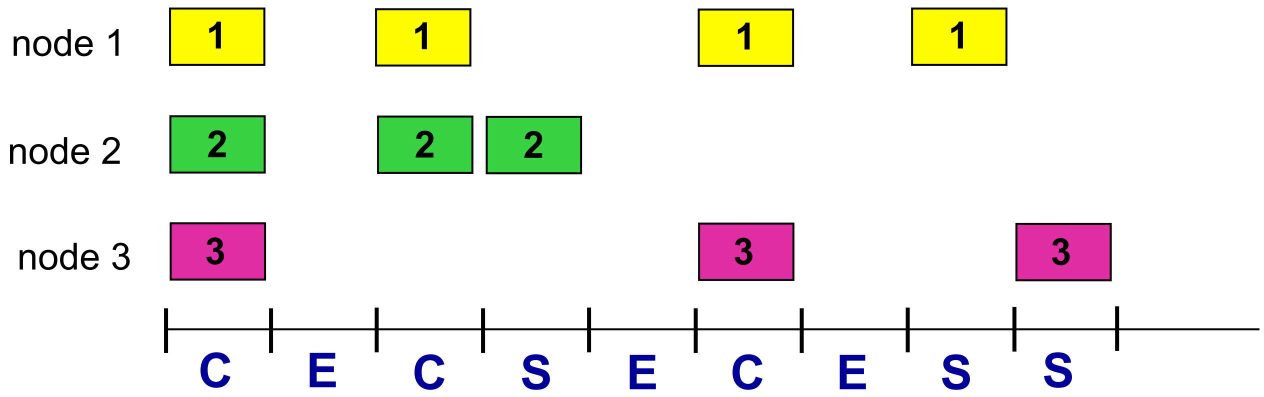
assumptions:

- all frames same size
- time divided into equal size slots (time to transmit 1 frame)
- nodes start to transmit only slot beginning
- nodes are synchronized
- if 2 or more nodes transmit in slot, all nodes detect collision

operation:

- when node obtains fresh frame, transmits in next slot
  – *if no collision:* node can send new frame in next slot
  – *if collision:* node retransmits frame in each subsequent slot with prob. p until success

Slotted ALOHA



Pros:

- single active node can continuously transmit at full rate of channel
- highly decentralized: only slots in nodes need to be in sync
- simple

Cons:

- collisions, wasting slots
- idle slots
- nodes may be able to detect collision in less than time to transmit packet
- clock synchronization

Slotted ALOHA: Efficiency

efficiency: long-run fraction of successful slots (many nodes, all with many frames to send)

- *suppose: N* nodes with many frames to send, each transmits in slot with probability *p*
- prob that given node has success in a slot = $p(1-p)^{N-1}$
- prob that *any* node has a success = $Np(1-p)^{N-1}$

- max efficiency: find p* that maximizes $Np(1-p)^{N-1}$
- for many nodes, take limit of $Np^*(1-p^*)^{N-1}$ as N goes to infinity, gives:

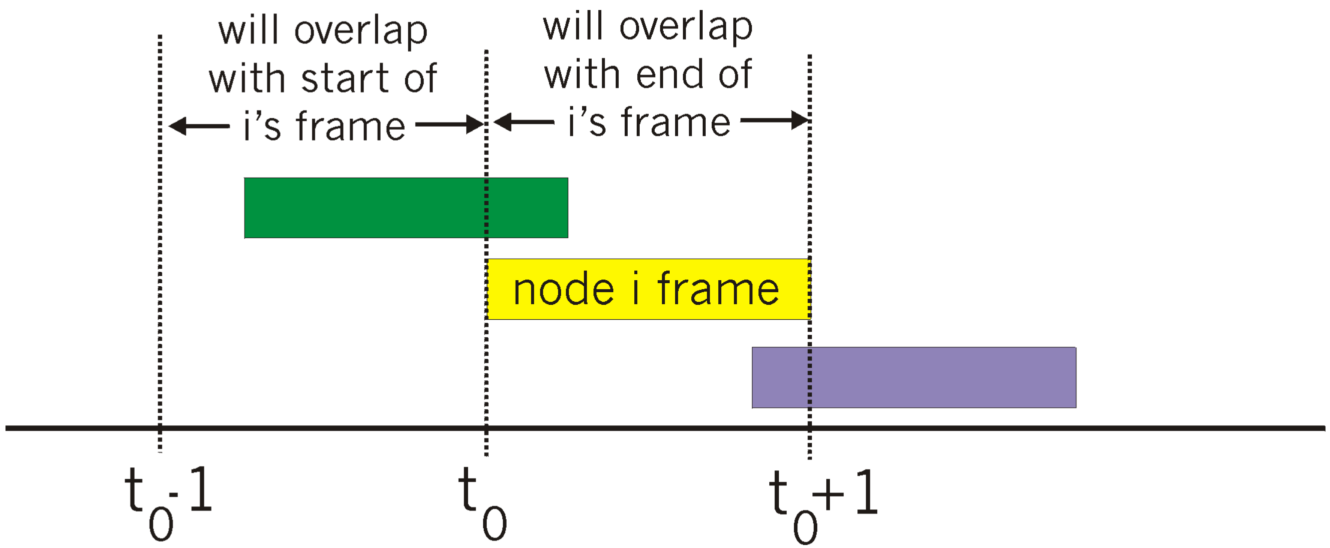
max efficiency = 1/e = .37

at best: channel used for useful transmissions 37% of time!

!

Pure (unslotted) ALOHA

- Unslotted Aloha: simpler, no synchronization
- When frame first arrives
  - transmit immediately
- Collision probability increases:
  - frame sent at t_0 collides with other frames sent in $[t_0-1, t_0+1]$



Pure ALOHA Efficiency

P(success by given node) = P(node transmits) $\cdot$

P(no other node transmits in $[t_0\text{-}1, t_0]$ $\cdot$

P(no other node transmits in $[t_0, t_0+1]$

$$= p \cdot (1-p)^{N-1} \cdot (1-p)^{N-1}$$

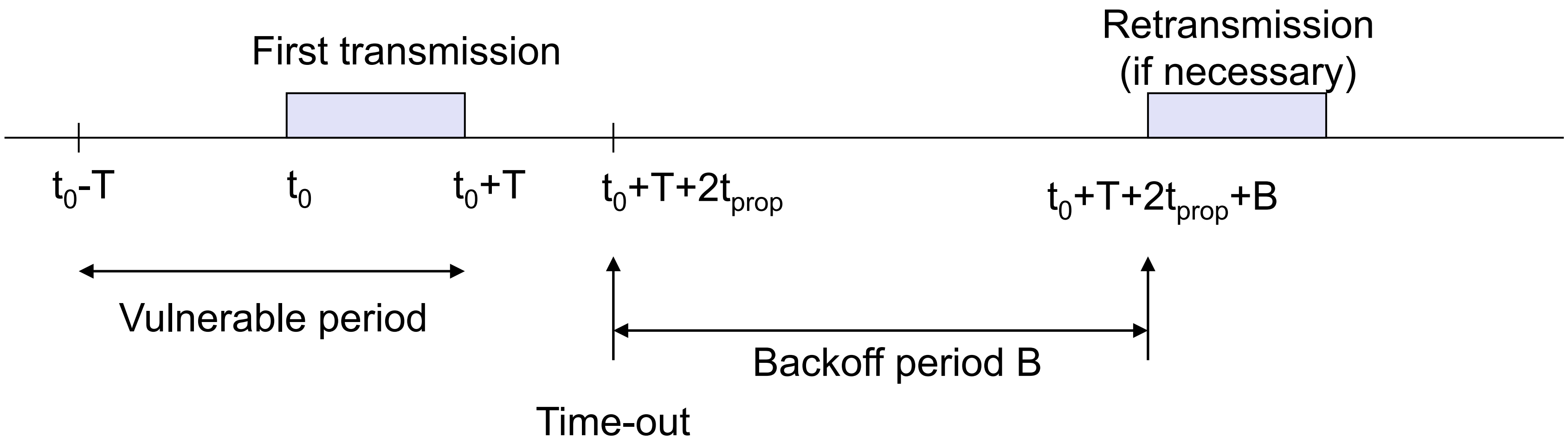
$$= p \cdot (1-p)^{2(N-1)}$$

… choosing optimum p and then letting $n \longrightarrow \infty$

$$= 1/(2e) = .18$$

even *worse* than slotted Aloha!

Performance of Pure Aloha



- t_{prop} : maximum one-way propagation time between 2 stations
- Information about the outcome of the transmission is obtained after the reaction time 2 t_{prop}
- B: backoff time

Pure Aloha Performance

- Users generate packets with a **Poisson process arrival rate λ**
- All packets have the same **fixed length** T
- **Rate of scheduling is** g: Offered load to the channel g is bigger than λ, because some packets are transmitted more than once
- ***Approximation***: The scheduling process is also assumed to be Poisson process with arrival rate g
- **Probability of successful transmission** (in period $2T$) :

$$\begin{aligned} P_s &= P\text{ (no collision)} \\ &= P\text{(no transmission in two packets time)} \\ &= e^{-2gT}. \end{aligned}$$

Pure Aloha Performance

- Rate of successful transmission: gP_s
- **Throughput of the pure ALOHA:**

$$S_{\text{th}} = gTe^{-2gT}$$

- **Normalized offer load:** $G = gT$

$$S_{\text{th}} = Ge^{-2G}$$

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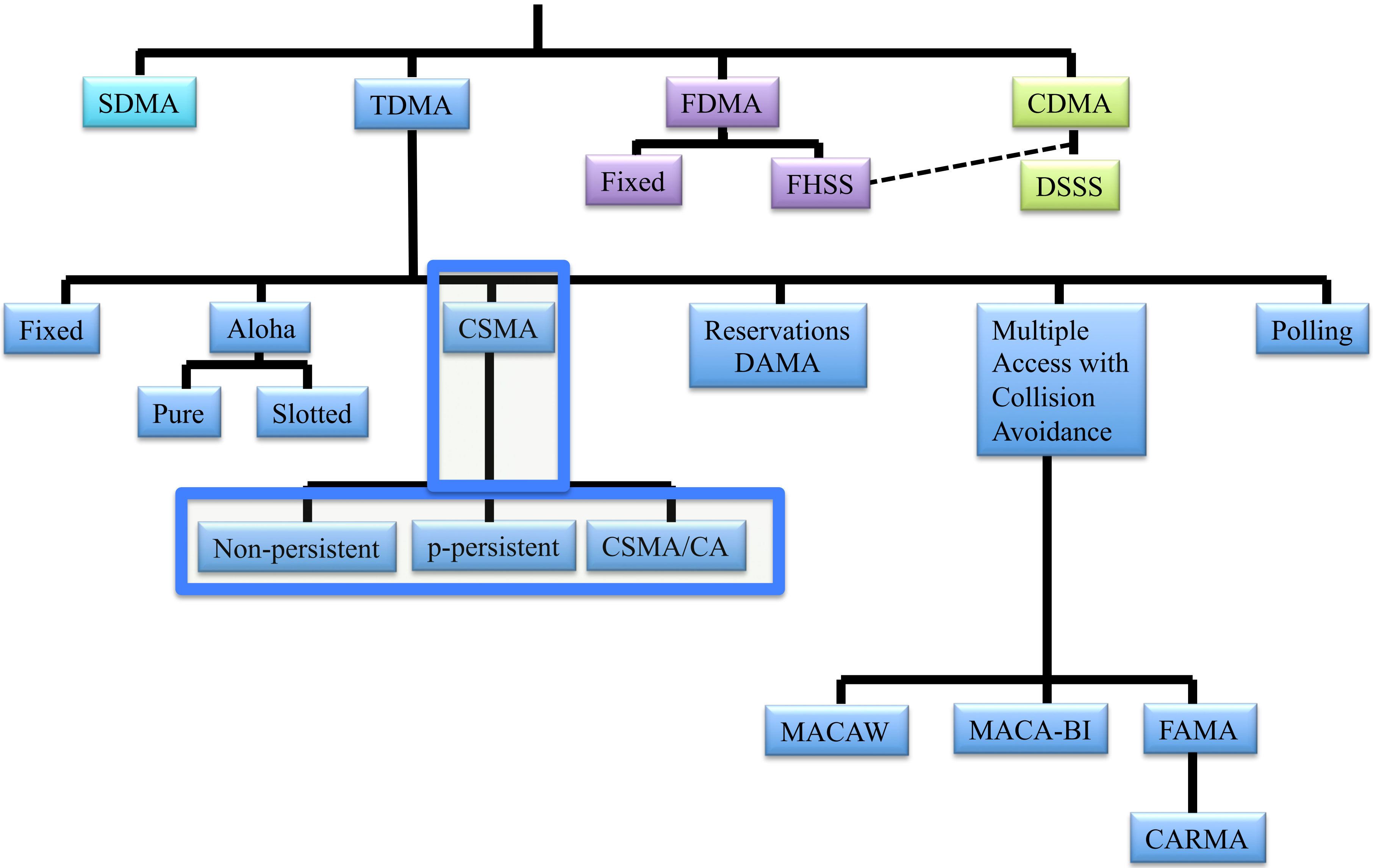


Carrier Sense Multiple Access (CSMA)

- **Goal**: reduce the wastage of bandwidth due to packet collisions
- **Principle**: sensing the channel before transmitting (never transmit when the channel is busy)
- **Many variants:**
  - Collision detection (CSMA/CD) or collision avoidance(CSMA/CA)
  - Persistency (in sensing and transmitting)

Station A begins transmission at t=0

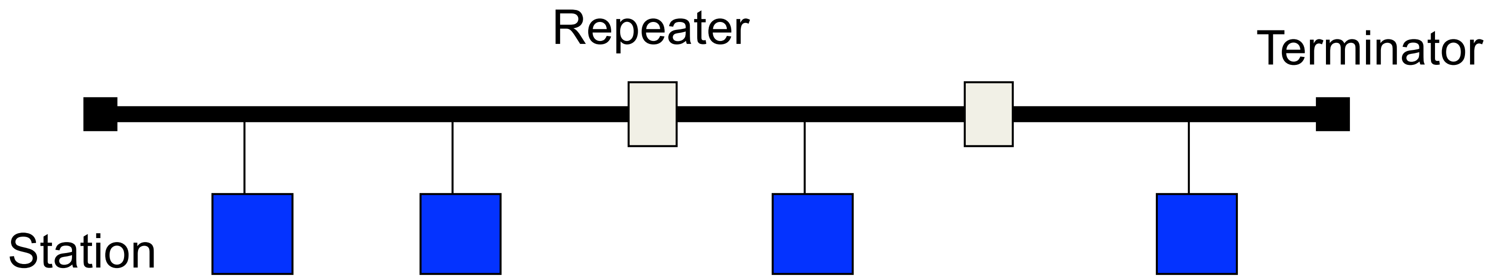
Station A *captures* the channel at $t=t_{prop}$

About CSMA/CD

- Can we borrow media access methods from fixed networks?

- **Example of 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)

CSMA/CD (reminder)



CS: Carrier Sense *(Is someone already talking ?)*

MA: Multiple Access *(I hear what you hear !)*

CD: Collision Detection *(We are both talking !!)*

Three states for the channel : contention, transmission, idle

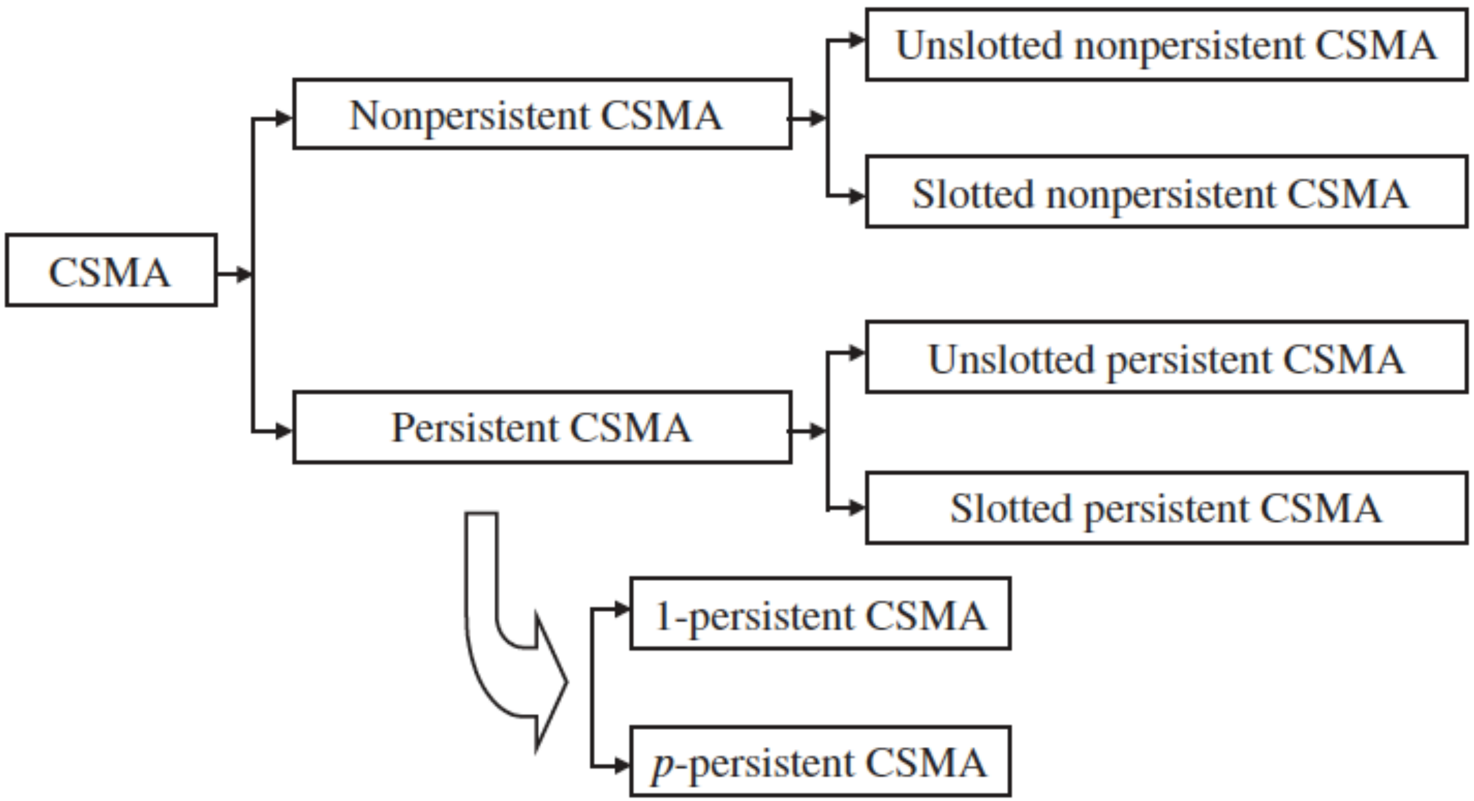
- Operating principle

- ❑ Check whether the channel is idle before transmitting
- ❑ Listen while transmitting, stop transmission when collision
- ❑ If collision, one of the 3 schemes above (1-persistent, non-persistent or p-persistent)

Why CSMA/CD is unfit for WLANs?

1. A radio can usually not transmit and receive at the same time
2. Signal strength decreases proportionally to the square of the distance or even more
3. The sender would apply CS and CD, but the collisions happen at the receiver
4. It might be the case that a sender cannot "hear" the collision, i.e., CD does not work
5. Furthermore, CS might not work if, e.g., a terminal is "hidden"

Type of CSMA Protocols



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Non-Persistent CSMA

- Attempts to reduce the incidence of collisions
- Stations with a packet to transmit sense the channel
- If the channel is busy, the station immediately runs the back-off algorithm and reschedules a future sensing time
- If the channel is idle, then the station transmits

Consequence : channel may be free even though some users have packets to transmit.

Non-Persistent CSMA: Throughput

Pure $$S_{\text{th}} = \frac{Ge^{-\alpha G}}{G(1+2\alpha)+e^{-\alpha G}}$$

Slotted $$S_{\text{th}} = \frac{\alpha Ge^{-\alpha G}}{(1-e^{-\alpha G})+\alpha}$$

τ : Propagation Delay through the air

$\alpha = \tau/T$: Normalized time unit

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1-Persistent CSMA

- Stations having a packet to send sense the channel continuously, waiting until the channel becomes idle.
- As soon as the channel is sensed idle, they transmit their packet.
- If more than one station is waiting, a collision occurs.
- Stations involved in a collision perform a backoff algorithm to schedule a future time for re-sensing the channel
- Optional backoff algorithm may be used in addition for fairness

Consequence : The channel is highly used (greedy algorithm).

1-Persistent CSMA: Throughput

Pure

$$S_{\text{th}} = \frac{G\left[1 + G + \alpha G(1 + G + \frac{\alpha G}{2})\right] e^{-G(1+2\alpha)}}{G(1 + 2\alpha) - (1 - e^{-\alpha G}) + (1 + \alpha G)e^{-G(1+\alpha)}}$$

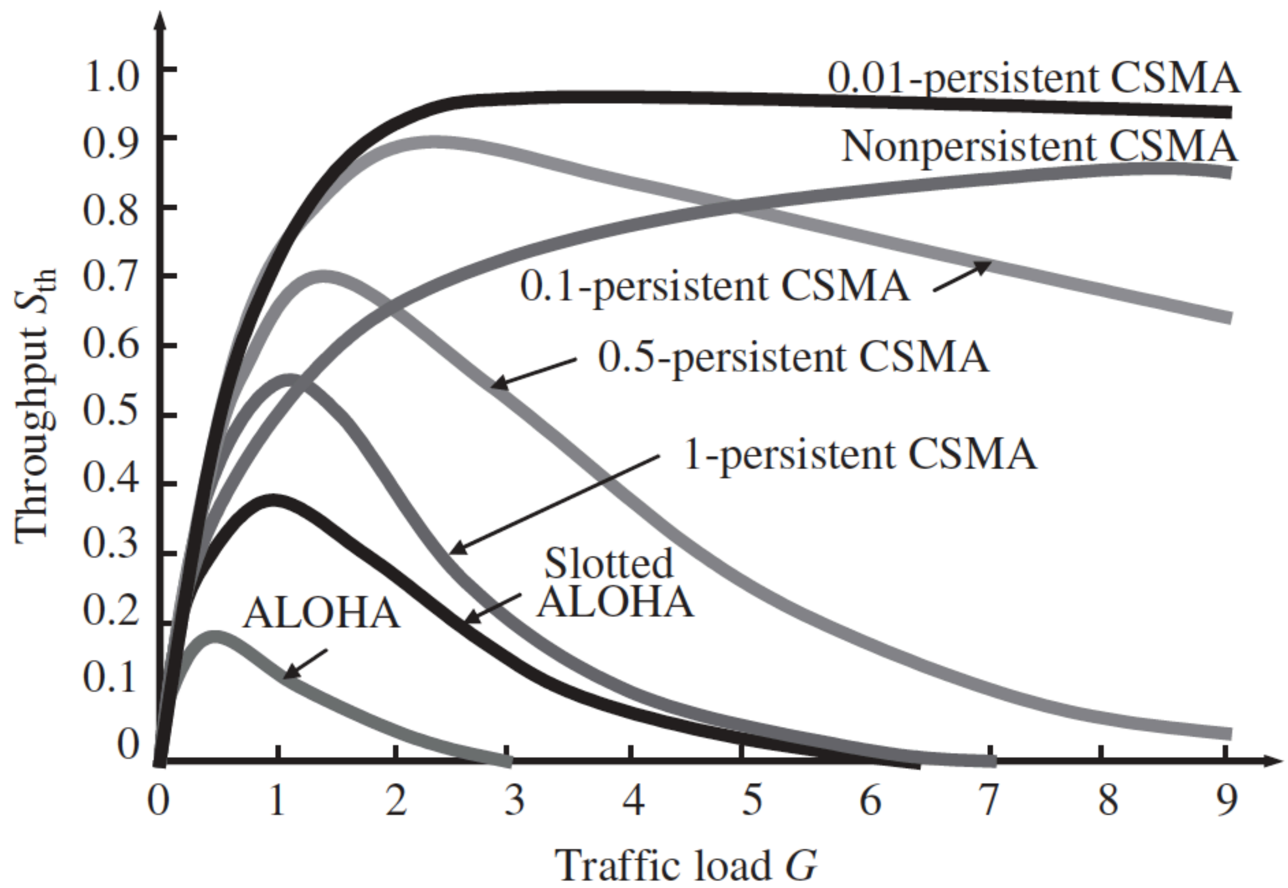
Slotted

$$S_{\text{th}} = \frac{G(1 + \alpha - e^{-\alpha G})e^{-G(1+\alpha)}}{(1 + \alpha)(1 - e^{-\alpha G}) + \alpha e^{-G(1+\alpha)}}$$

p-Persistent CSMA

- Combines elements of the above two schemes
- Stations with a packet to transmit sense the channel
- If it is busy, they persist with sensing until the channel becomes idle
- If it is idle:
  - With probability *p*, the station transmits its packet
  - With probability *1-p*, the station waits for a random time and senses again

Throughput Plot



CSMA/CA

- Will be described in IEEE 802-11 standard

[We will see more details in the following sessions]

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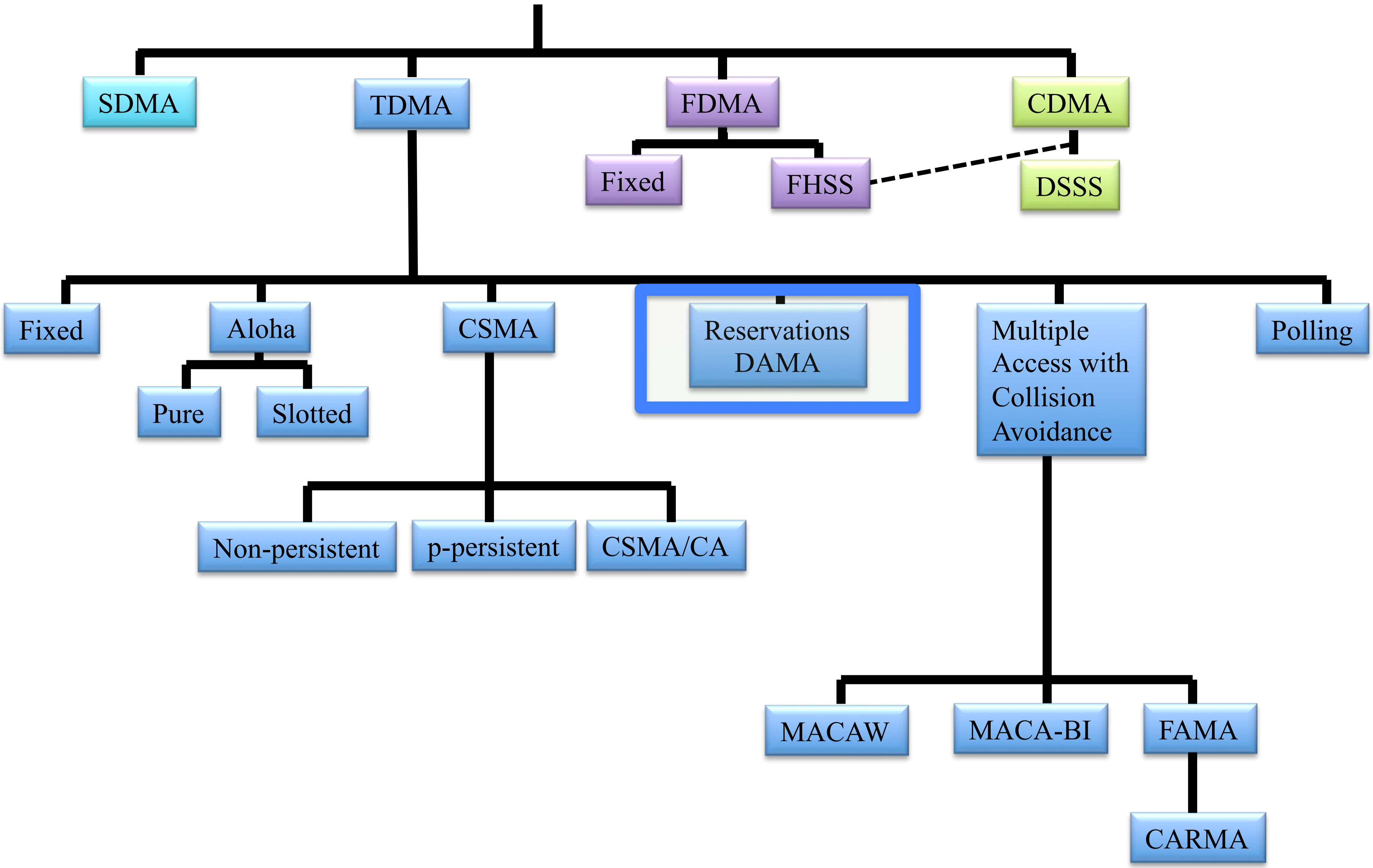
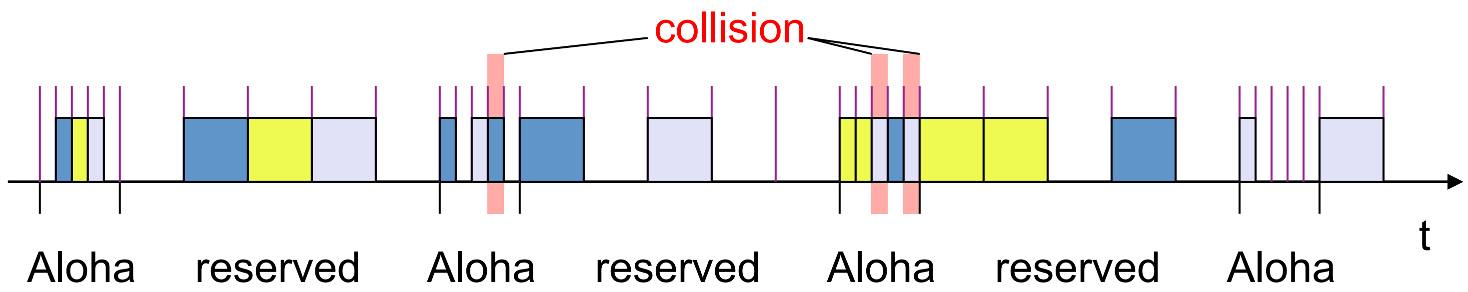


DAMA - Demand Assigned Multiple Access

- Channel efficiency only 18% for Aloha, 36% for Slotted Aloha
- 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*

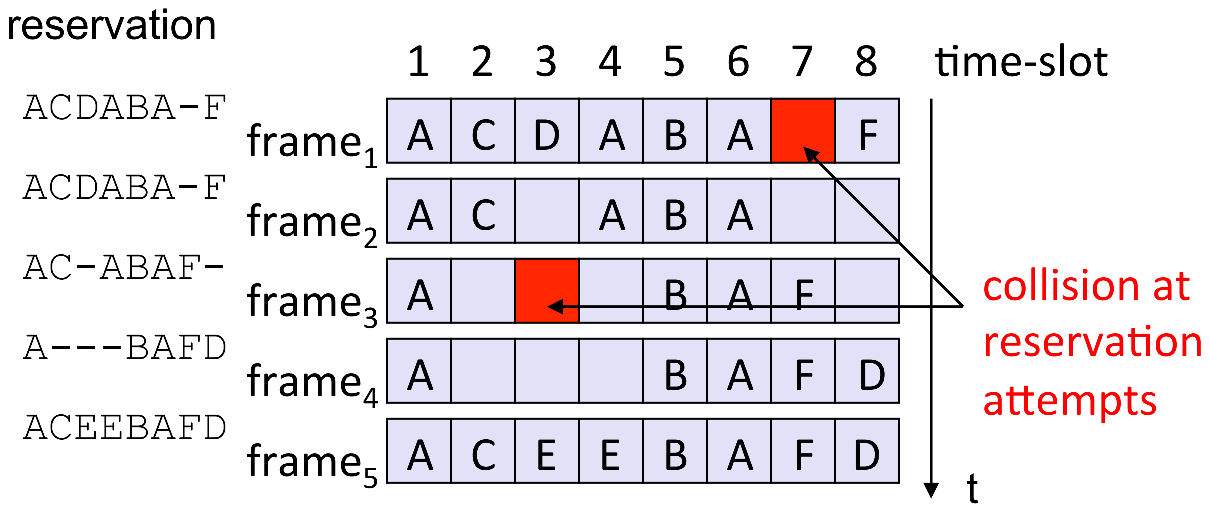
DAMA / Explicit Reservation

- **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)
  - it is important for all stations to keep the reservation list consistent at any point in time and, therefore, all stations have to synchronize from time to time



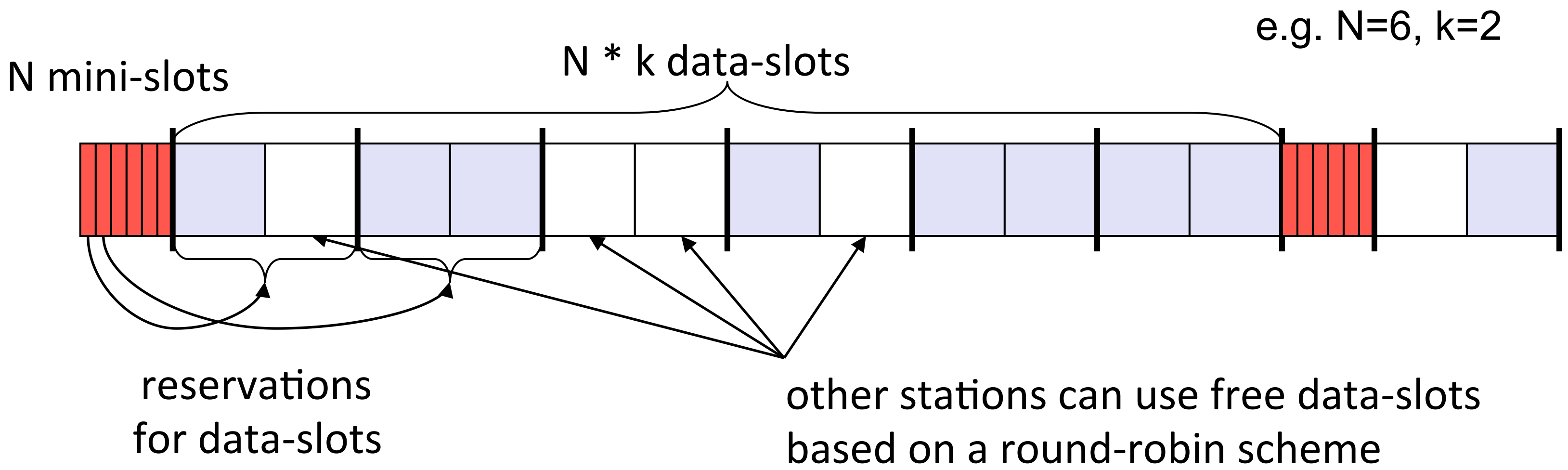
DAMA / Packet Reservation (PRMA)

- **Implicit reservation**
  - based on slotted Aloha
  - a certain number of slots form a frame, frames are repeated
  - 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 data to send
  - competition for a slot starts again as soon as the slot was empty in the last frame



DAMA / 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)



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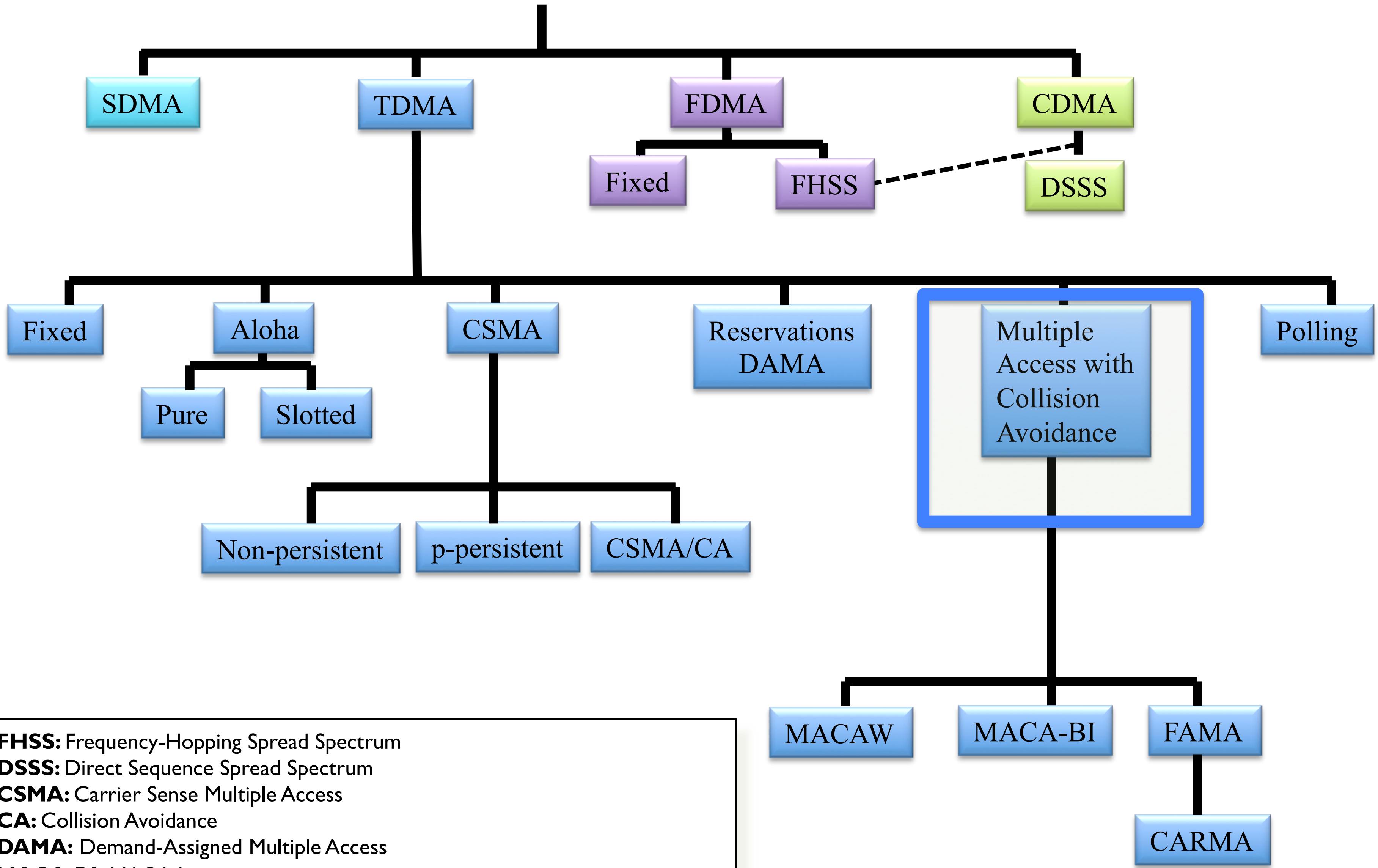


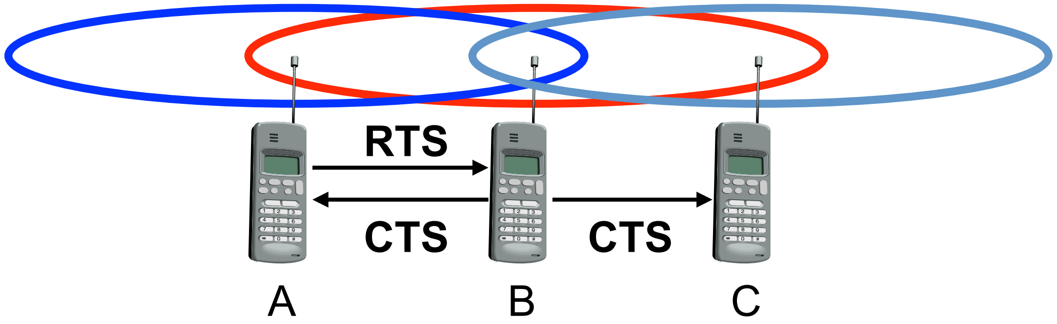
FHSS: Frequency-Hopping Spread Spectrum
DSSS: Direct Sequence Spread Spectrum
CSMA: Carrier Sense Multiple Access
CA: Collision Avoidance
DAMA: Demand-Assigned Multiple Access
MACA-BI: MACA by invitation
FAMA: Floor Acquisition Multiple Access
CARMA: Collision Avoidance and Resolution Multiple Access

MACA - Collision Avoidance

- MACA (Multiple Access with Collision Avoidance) uses short signaling packets for collision avoidance
  - Designed especially for packet radio networks (Phil Karn, 1990)
  - Principle:
    - 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 as DFWMAC (Distributed Foundation Wireless MAC)

MACA principle

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



- The hidden terminal problem might still arise, especially in case of mobility of the nodes

Comparison SDMA/TDMA/FDMA/CDMA

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 km^2	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	used in all cellular systems	standard in fixed networks, together with FDMA/SDMA used in many mobile networks	typically combined with TDMA (frequency hopping patterns) and SDMA (frequency reuse)	higher complexity

In practice, several access methods are used in combination
Example :SDMA/TDMA/FDMA for GSM