EP2210 – FEP3210
Performance analysis of Communication networks

Topic 2
Medium access control
(or multiple access protocols)

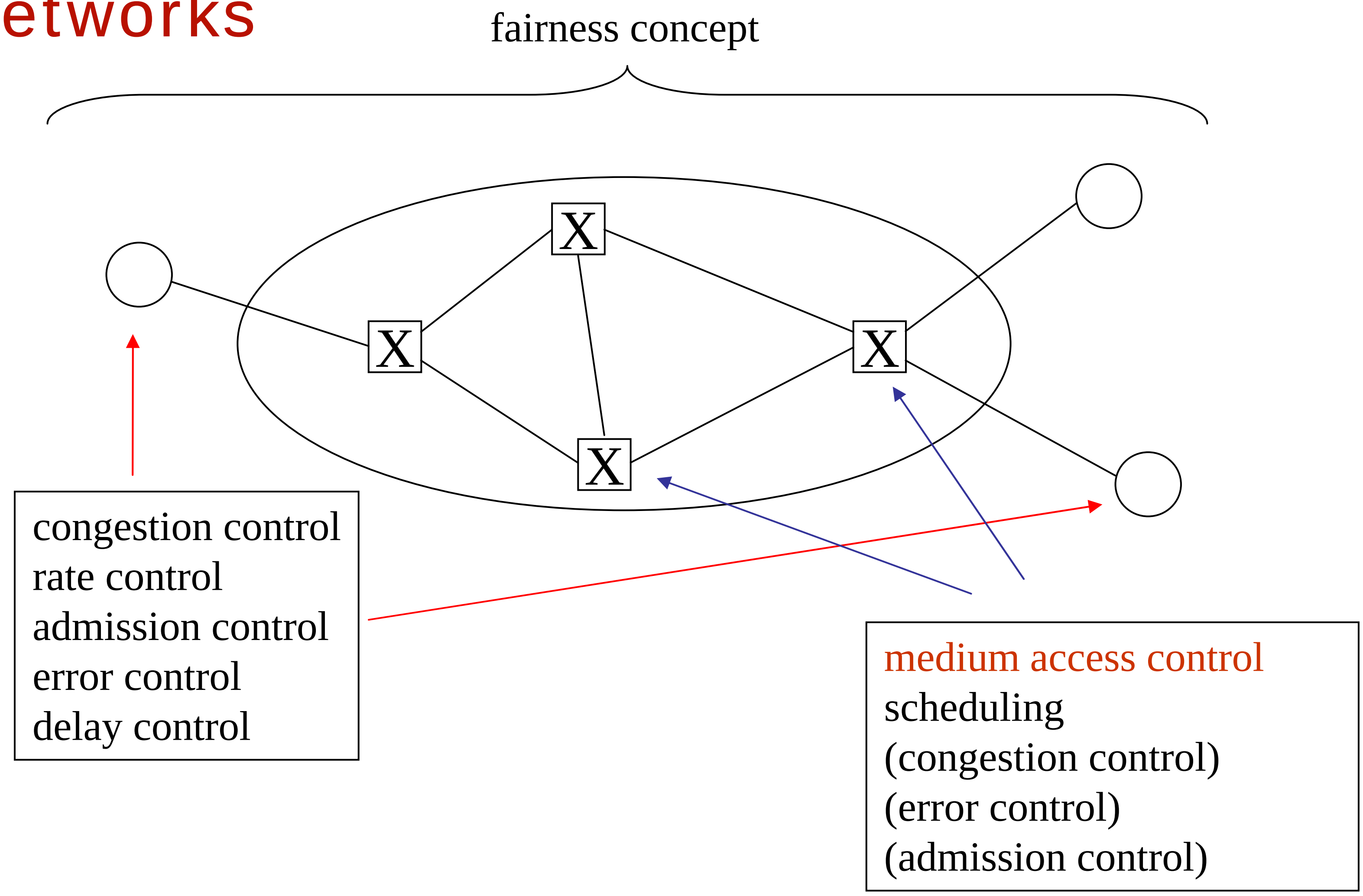
Medium access control

- Lecture material:
  - R. Rom, M. Sidi, Multiple access protocols, Ch. 2-4
  - TDMA, FDMA, Aloha
- Reading for next lecture:
  - R. Rom, M. Sidi, Multiple access protocols, Ch. 2-4
  - Slotted Aloha, CSMA, CSMA/CD main results

Control functions in communication networks

- Protocols or control functions?
- Control functions are selected to achieve given objectives (e.g., lossless transmission)
- Protocols are realizations of a set of control functions, where
- Control functions are coupled in some sensible way (e.g., loss and congestion control in TCP)

Control functions in communication networks



Group work

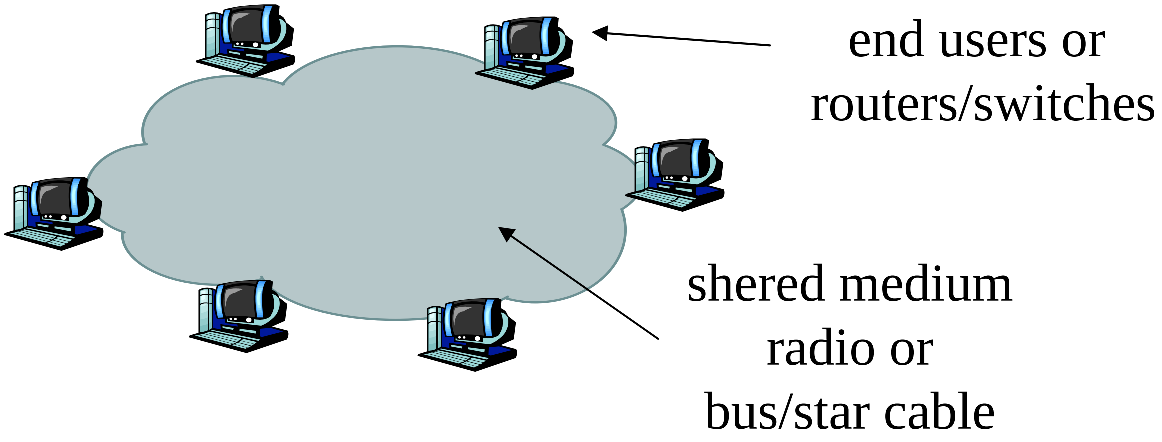
- Give examples of protocols/methods that realize the following control functions.
- Where are these protocols/methods implemented in the network?

- Medium access cont.
- Error control
- Delay control
- Congestion control
- Admission control
- Rate control
- Scheduling

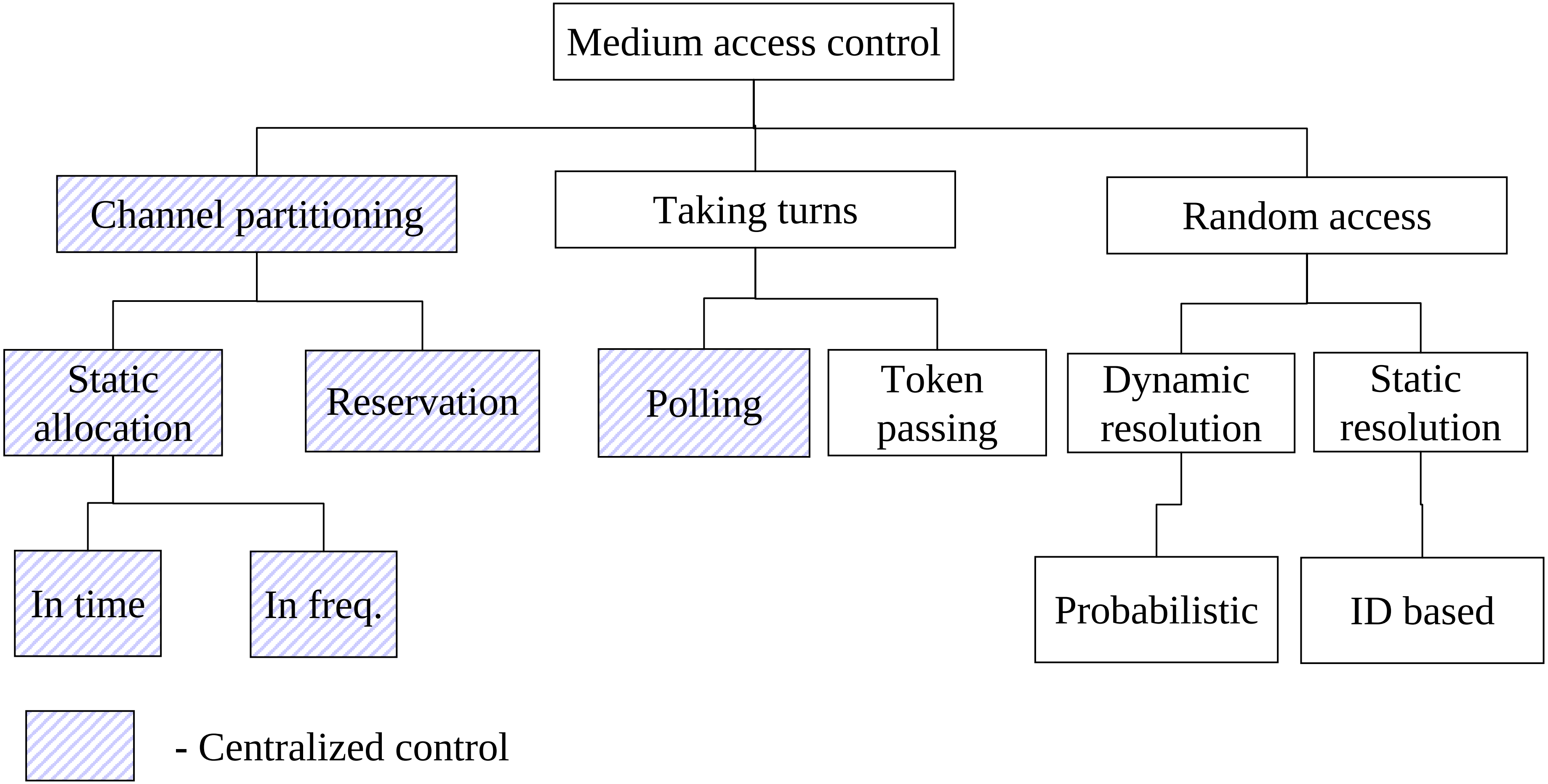
- IEEE 802.x

Medium access control

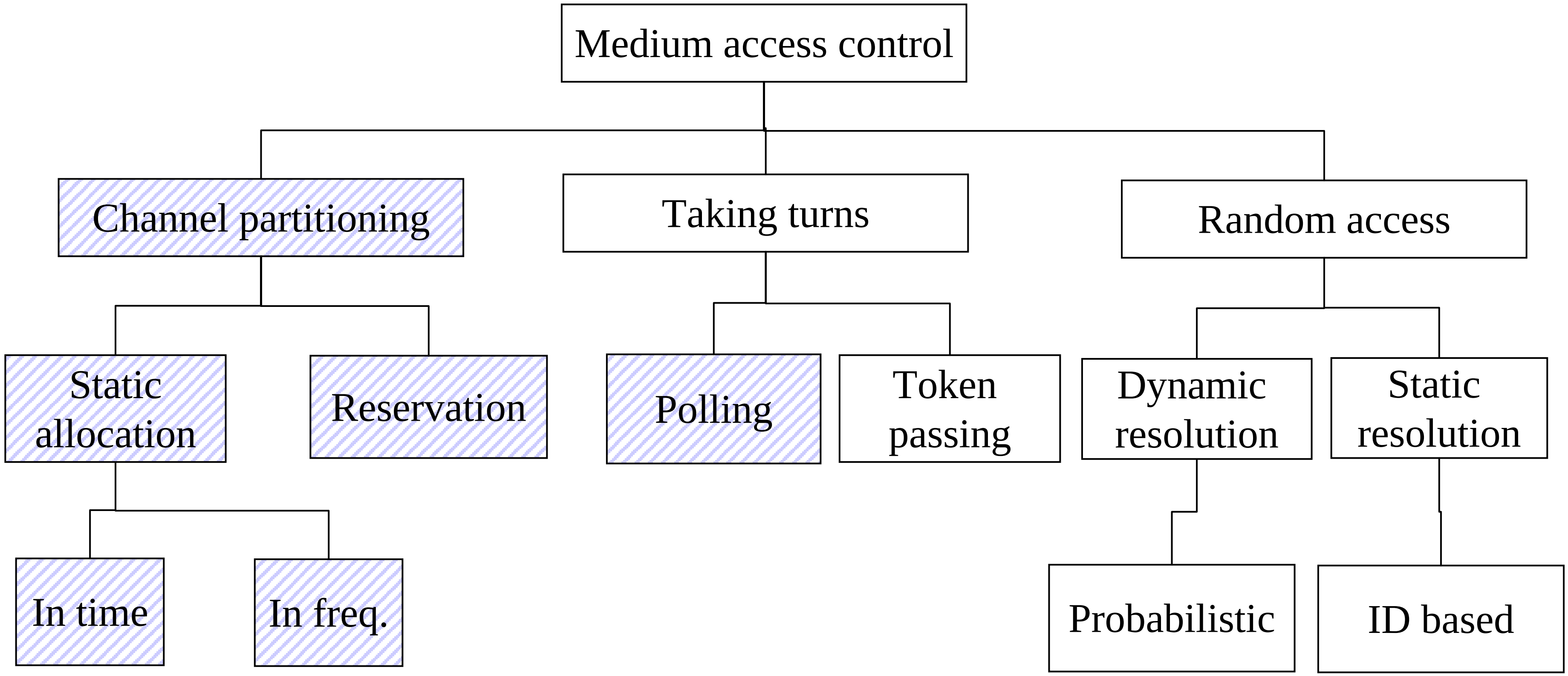
- Medium access control
  - to regulate the access to a shared medium (radio or cable)
  - the main objectives of medium access control
    - Simplicity – have to work at very high speed
    - Efficiency – have to utilize the resources well
    - Fairness – all users should get the similar chances to access the network



Classification



Group work

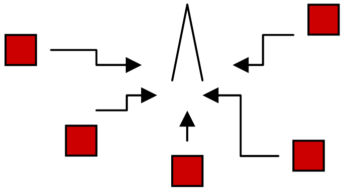


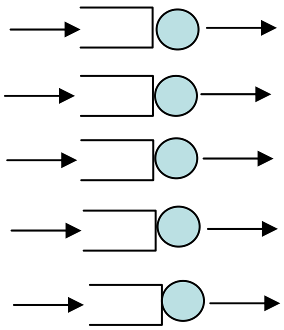
Classify the followings: FDMA, TDMA, CSMA/CD, Token-ring, Bluetooth, ZigBee, WirelessHART

FDMA performance analysis

- FDMA example:
  - In a cellular system each user (or session) receives a subband of the available spectrum.
  - Each user transmits at the same time, independently from each other.

- Networking scenario:
  - Users receive an equal share of the spectrum.
  - Each user transmits fixed size packets over the FDMA link.
  - The packets are generated according to a Poisson process, with the same intensity at each user.
  - Packet sizes are deterministic (and equal for all users.)
  - Queues are infinite
  - We re interested in the delay from packet generation to completed transmission



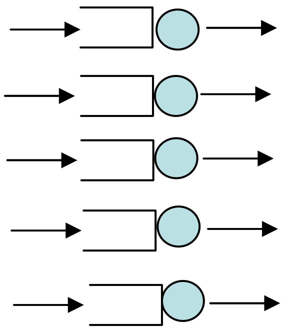


FDMA performance analysis

- Each user served independently: M independent M/D/1 queues
- Average delay as a function of the throughput

R: channel bitrate
M: number of users
$\rightarrow$ R/M bitrate per user
λ: packet arrival rate from a single user, Poisson
P: packet size, constant
ρ: per channel load ($\rho=\lambda T<1$)

T: transmission time $T=P/(R/M)$
S: per channel and system throughput, defined by the fraction of time the server is busy transmitting useful data, max throughput=1
$S=\rho$: since no losses or unsuccessful transmissions happen
D: average delay including waiting + transmission
*D**: and delay normalized by *P/R*



FDMA performance analysis

- Each user served independently: M independent M/D/1 queues
- Average delay as a function of the throughput

  R: channel bitrate

  M: number of users

  λ: packet arrival rate from a single user, Poisson

  P: packet size, constant

  T: transmission time

  ρ=*S*: per channel and system throughputs are equal

  *D, D**: average waiting + transmission delay and delay normalized by *P/R*.

$$T = P/(R/M)$$

$$\rho = \lambda T = S$$

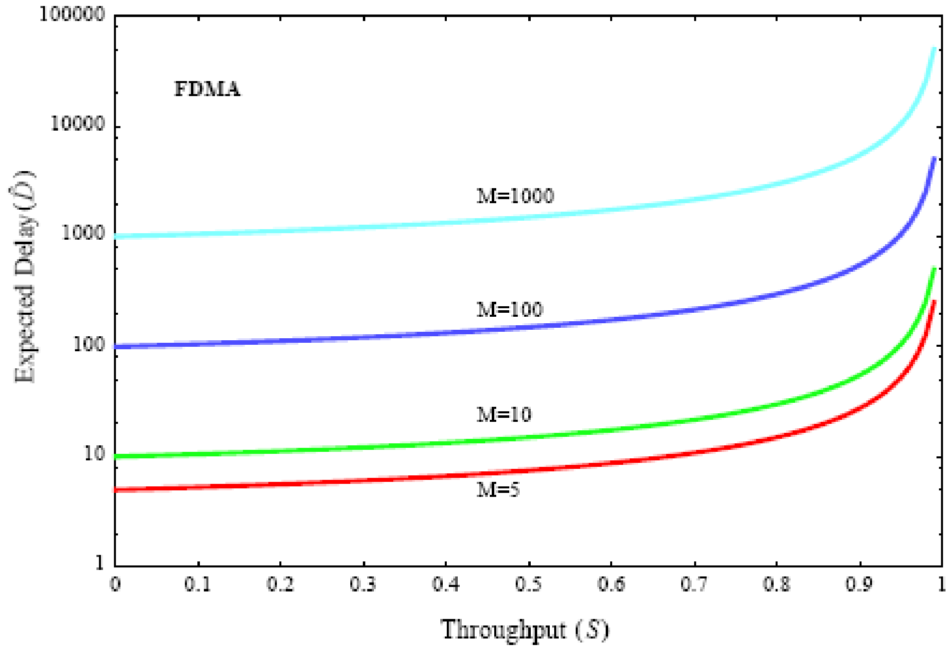
This depends on the channel bitrate and the packet size. Normalize!

$$D = T + \frac{\lambda T^2}{2(1-\lambda T)} = T\left[1+\frac{S}{2(1-S)}\right] = \frac{MP}{R}\left[1+\frac{S}{2(1-S)}\right]$$

$$D^* = \frac{D}{P/R} = M\left[1+\frac{S}{2(1-S)}\right] = \frac{M}{2}\left[2+\frac{S}{1-S}\right] = \frac{M}{2}\left[1+\frac{1-S+S}{1-S}\right] = \frac{M}{2}\left[1+\frac{1}{1-S}\right]$$

FDMA performance analysis

$$D^* = \frac{M}{2}\left[1 + \frac{1}{1-S}\right]$$



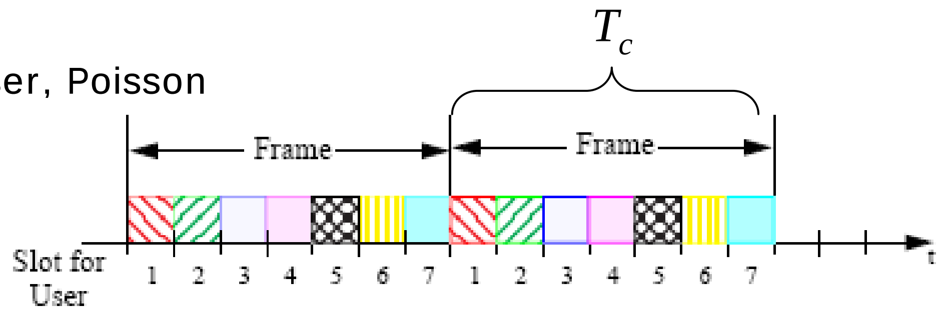
- At small load the average delay is determined by the packet transmission time, that is, the number of users: D*~M.
- This means, the system uses the resources in an inefficient way if the load is small.
- Simple, fair, but not efficient.

TDMA performance analysis

- Average delay as a function of the throughput

  R: channel bitrate
  M: number of users
  λ: packet arrival rate from a single user, Poisson
  P: packet size, constant

  $T=P/R$: packet transmission time
  $T_c=MT$: frame duration
  $S=\rho=\lambda T_c= \lambda MT= \lambda P/(R/M)$:
  for the same λ, *R* and *M* the same as for FDMA.



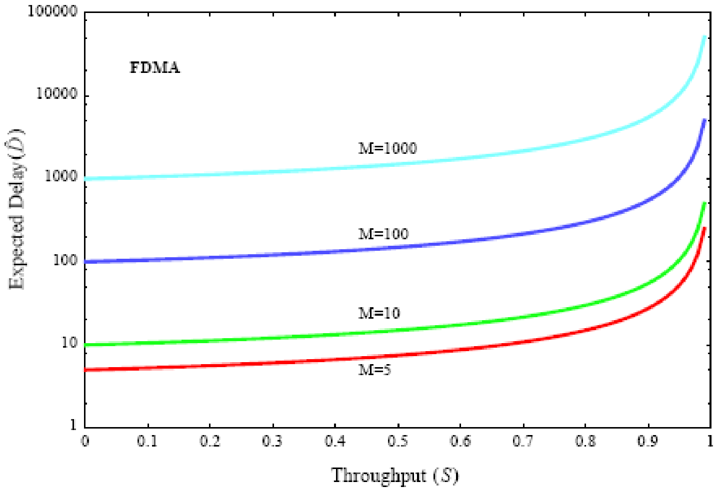
  Average delay of a packet:
  – packet transmission time: *T*
  – queuing time, 1 packet per frame transmitted: like queuing time in M/D/1 with T_c
  – average time until the beginning of a new frame: $0.5T_c$

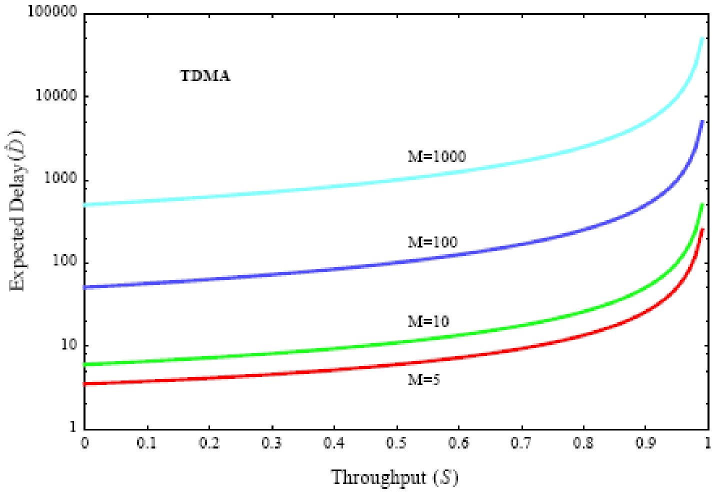
$$D = T + \frac{\lambda T_c^2}{2(1-\lambda T_c)} + 0.5T_c = T + \frac{SMT}{2(1-S)} + 0.5MT = T + \frac{S+1-S}{2(1-S)}MT$$

$$D = T\left[1+\frac{M}{2(1-S)}\right] = \frac{R}{P}\left[1+\frac{M}{2(1-S)}\right]$$

$$D^* = \frac{D}{P/R} = 1+\frac{M}{2(1-S)}$$

TDMA-FDMA performance analysis





$$D^*_{FDMA} = \frac{M}{2} + \frac{M}{2(1-S)}$$

$$D^*_{TDMA} = 1 + \frac{M}{2(1-S)}$$

$$D^*_{FDMA} - D^*_{TDMA} = \frac{M}{2} - 1$$

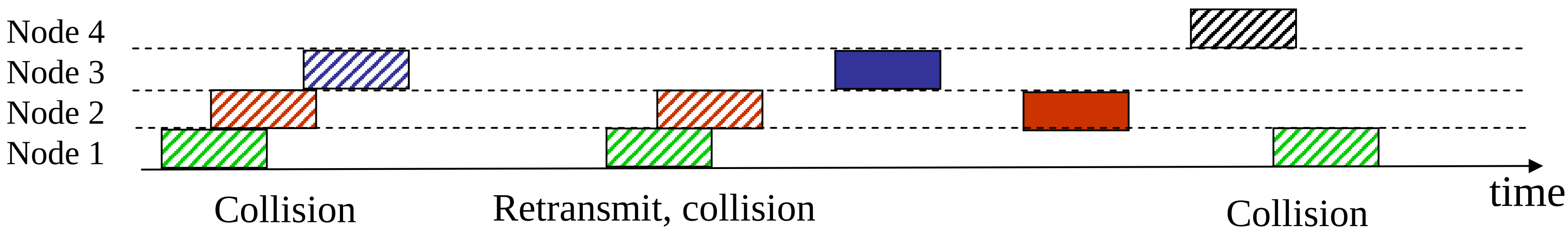
- TDMA is more efficient than FDMA, independently of the load
- However, TDMA is more complex to implement (slot synchronization)

Random access – or contention based protocols

- (Pure) Aloha
- The first contention based medium access protocol
- The naïve approach
  - If you have data $\rightarrow$ send
  - If the transmission is not successful $\rightarrow$ wait random amount of time then try again (back-off)
- 1971, Hawaii, communication between islands

Aloha protocol description

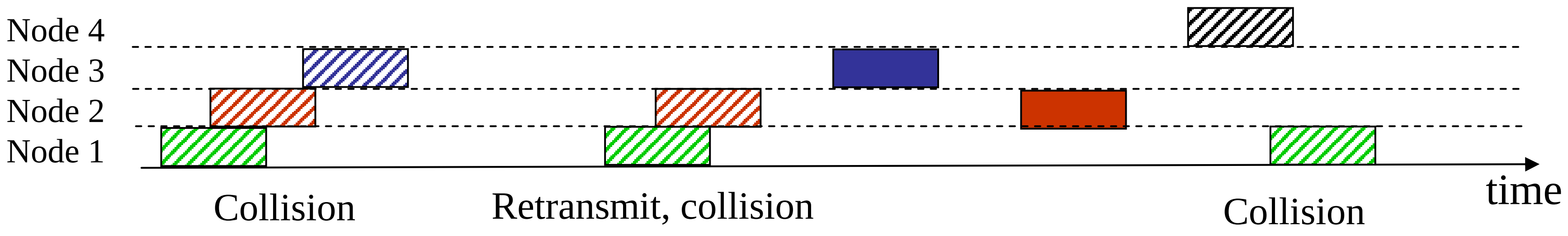
- All nodes share the common transmission medium (radio, bus, star)
- Nodes transmit newly generated packets immediately
- Colliding packets are lost, no bits can be recovered
- If no acknowledgement arrives, nodes retransmit with random delay



Aloha – maximum throughput

- Model assumptions and notation:
  - infinite population
  - transmitted and retransmitted packets from all users form a Poisson arrival process ($g > \lambda$)
  - constant packet transmission time (T)
  - offered load: G=gT
  - throughput (collision free): S

- Vulnerable period: packet is lost if other packets arrive within this time interval: 2T



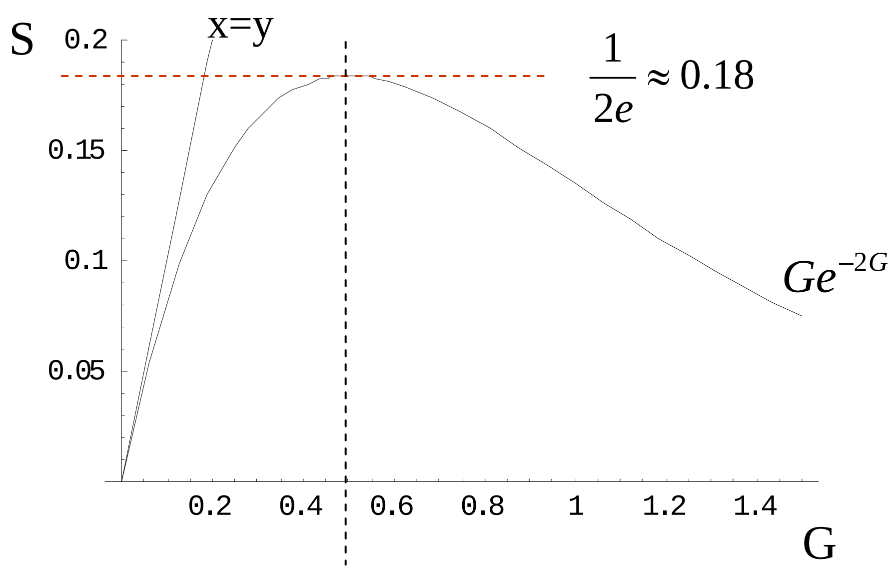
Aloha – maximum throughput

$$p(k) = P\{\text{k arrivals in 2T period}\} = \frac{(g2T)^k}{k!}e^{-g2T}$$

$$P_{succ} = P\{\text{no other arrivals in 2T period}\} = e^{-2gT}$$

$$S = P_{succ}\,gT = gTe^{-2gT}$$

$$S = Ge^{-2G}, \qquad S' = (1-2G)e^{-2G}$$



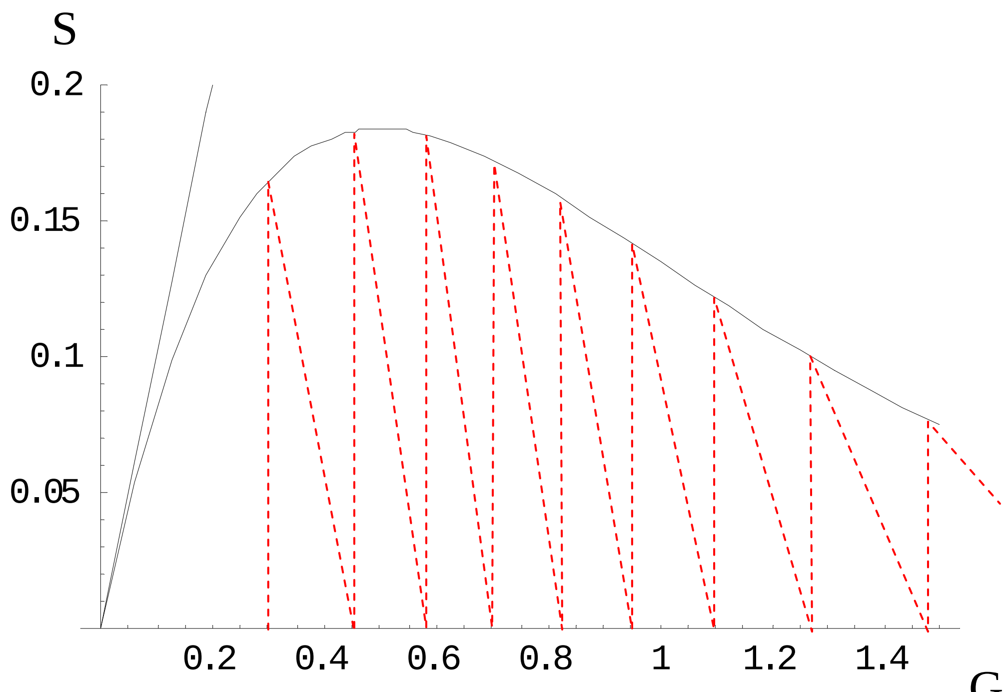
- Poisson arrival with g
- S: throughput defined as useful load (<1)
- G=gT: offered load

- Max throughput of 0.18
- At offered load (first and retransmissions) of 0.5

Aloha instability

- Pure Aloha throughput converges to 0 under Poisson load
  - simple, fair, not efficient
  - Poisson load is not realistic (off hours), so Aloha could work in practice

- It is not a perfect solution – let's look at the modifications



Instability

Aloha improvements – home reading

- Slotted version to decrease contention interval
  - home reading, including throughput analysis (R-S 3.2)
- Listen before talk: carrier sense multiple access, CSMA
  - home reading, basic ideas and results, discussed next lecture (R-S 4.3)
- Listen while talking: CSMA with collision detection, CSMA/CD
  - home reading, basic ideas and results (R-S 4.4)

- IEEE 802.11 Markovian model
  - maybe discussed next lecture

Carrier sense multiple access - CSMA

- Pure Aloha throughput converges to 0 under Poisson load
- It is not a good solution – let's look at the modifications

- Idea: Listen before you transmit – carrier sense
- If channel is idle $\rightarrow$ send data
- If channel is busy $\rightarrow$ back off
  - nonpersisten: packet rescheduled with a random delay
  - 1-persistent: packet transmitted immediately as the channel becomes idle
  - p-persistent one of the two with probability p and 1-p
- If no acknowledgement received transmit again

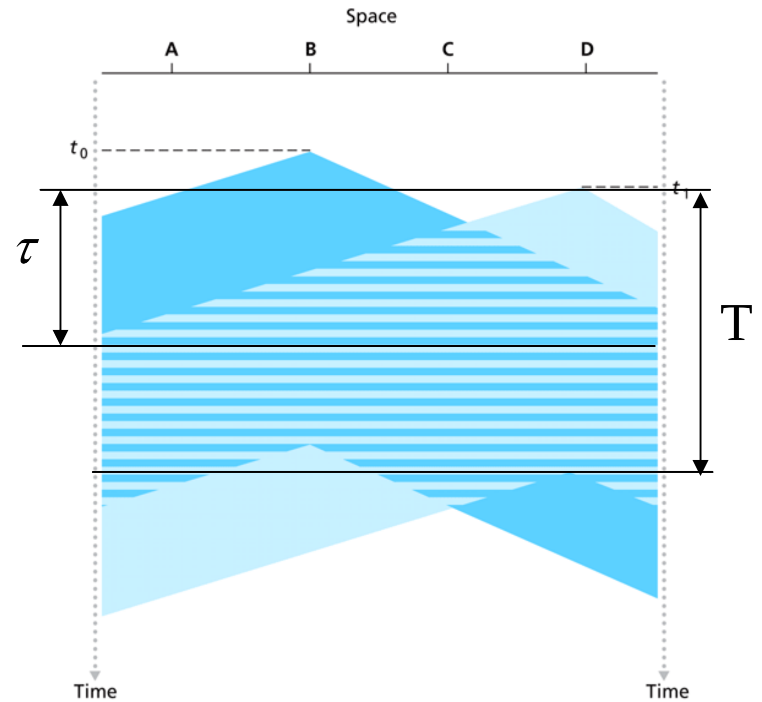
- If all nodes listen before transmit, and all nodes see the channel, is there collision in CSMA?

CSMA modeling – slotted case

- Collision due to propagation delay

- Efficient only if the packet transmission time (T) is much larger than the propagation time (τ)

- Slotted CSMA
  - time divided into minislots = propagation delay (τ)
  - packets wait until the beginning of next minislot, and sense the channel
    - if idle: transmit
    - if busy: retries according to being persistent or non-persistent

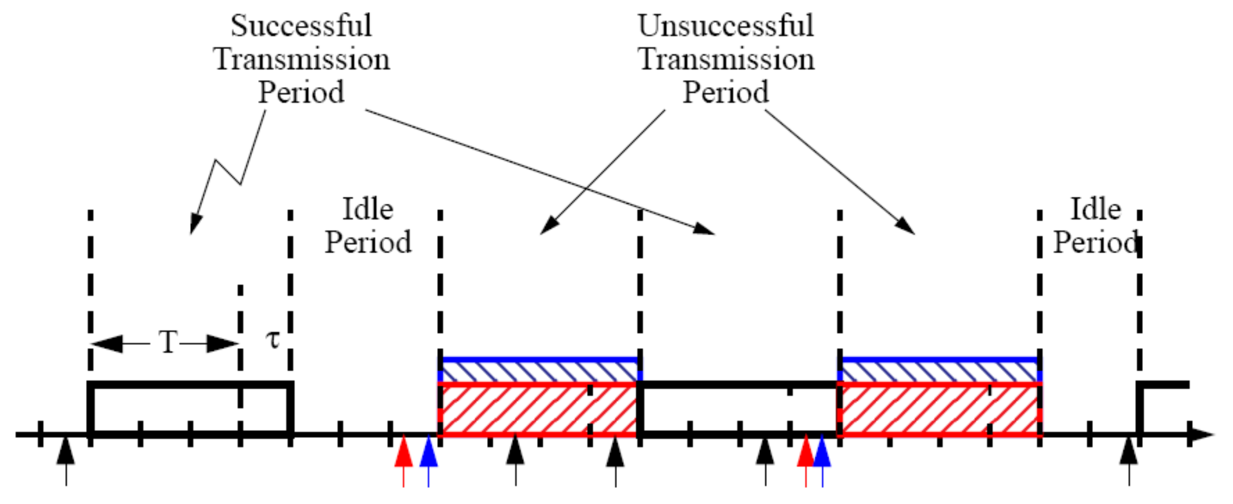


CSMA modeling – slotted case

- Modeling:
  - Poisson packet arrival, λ
  - fixed packet size, T
  - Throughput=(useful periods)/(idle+busy periods)   busy period=useful or collision

  - slotted, nonpersistent (if busy, tries again with random back-off)
  - minislot: propagation time (equal for all pair of nodes), τ
  - normalized diameter, a= τ /T <<1 (Packet transmission time >> propagation time)
  - assume 1/a is integer, packets occupy "a" minislots.

  - average idle period, I
  - average busy period (successful transmission or collision), B
  - average useful period (successful transmission), U



CSMA modeling – slotted case

$$\text{Idle period}: P\left[\hat{I} = k\tau\right] = \left(e^{-g\tau}\right)^{k-1}\left(1-e^{-g\tau}\right) \quad \text{(geometric distr.)}$$

$$I = \frac{\tau}{1-e^{-g\tau}}$$

No arrival in k-1 slots, at least one in slot k

$$\text{Transmission periods in busy period}: P\left[\hat{L} = l\right] = \left(1-e^{-g\tau}\right)^{l-1} e^{-g\tau}, \quad L = \frac{1}{e^{-g\tau}}$$

At least one arrival in l-1 slots, no arrival in the l-th slot

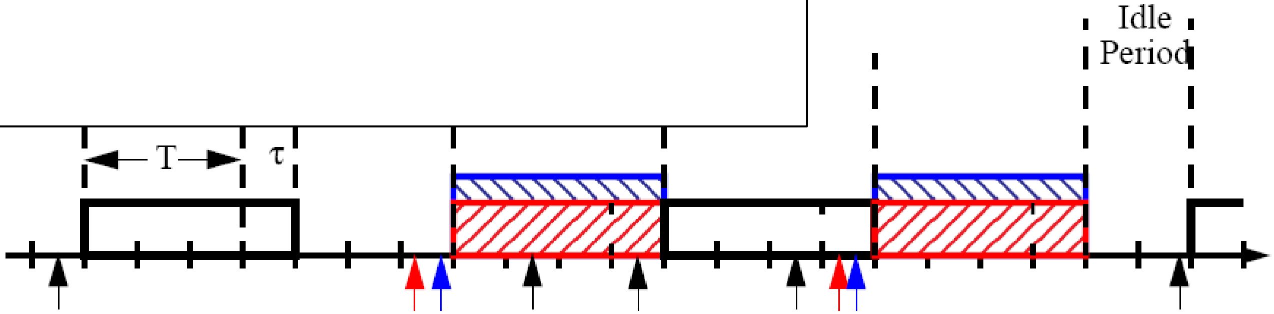
$$\text{Busy period}: B = (T+\tau)L = \frac{T+\tau}{e^{-g\tau}}$$

$$P_{succ} = P\left[\text{single arrival} \mid \text{some arrivals}\right] = \frac{P\left[\text{single arrival}\right]}{P\left[\text{some arrivals}\right]} = \frac{g\tau e^{-g\tau}}{1-e^{-g\tau}}$$

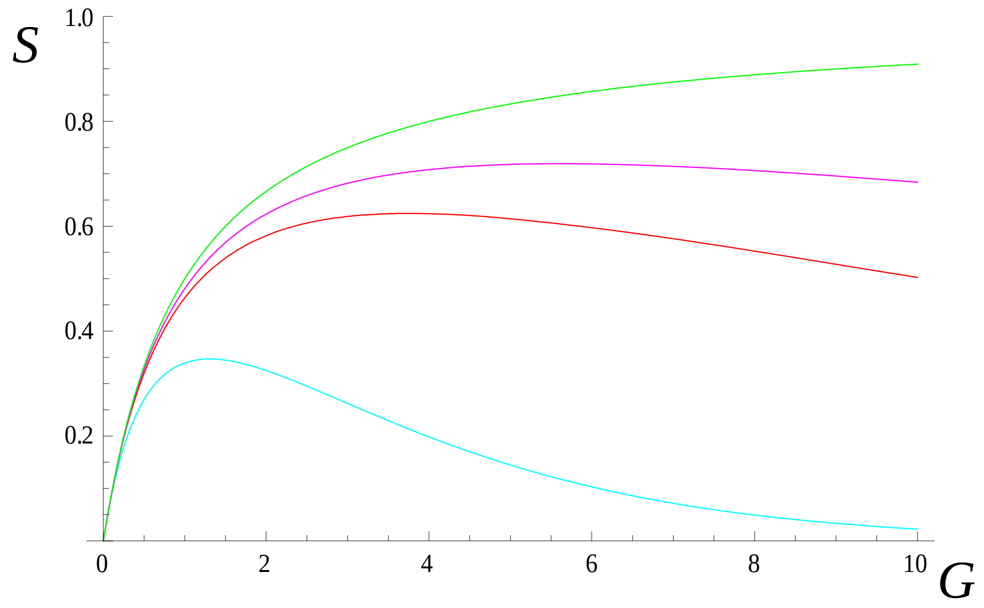
$$\text{Useful periods within a busy period}: U = \frac{T}{T+\tau} \cdot BP_{succ} = LTP_{succ} = \frac{T}{e^{-g\tau}} P_{succ}$$

$$S = \frac{U}{B+I} = \cdots = \frac{aGe^{-aG}}{1+a-e^{-aG}}$$

$$S_{a\to 0} = \frac{G}{1+G}$$



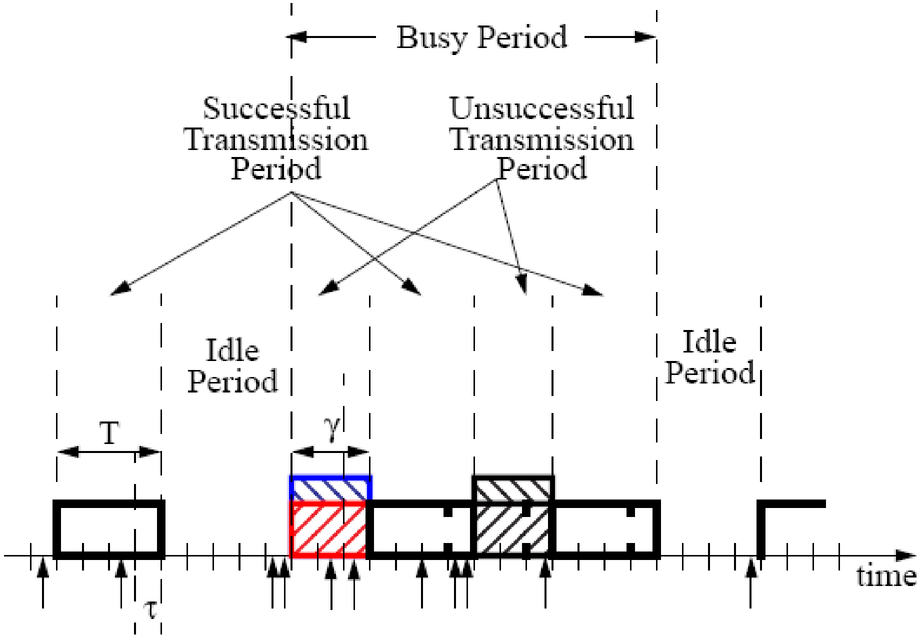
Aloha and CSMA comparison



- Group work: find the corresponding curve:
  - slotted Aloha
  - slotted CSMA with a=0.5 (packet length = 2*propagation time)
  - slotted CSMA with a=0.1
  - slotted CSMA with a=0.05
  - slotted CSMA with a=0 (packet length >> propagation time)

CSMA/CD – slotted case

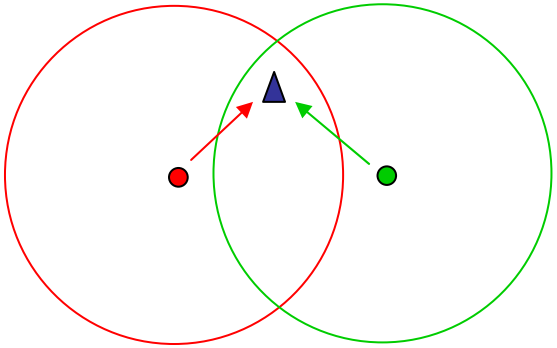
- To increase utilization: shorten busy periods -> shorten unsuccessful periods
- Listen while transmit
  - if collision is detected transmit jamming signal and stop transmission
  - γ: the length of the unsuccessful transmission, $\tau < \gamma < T$



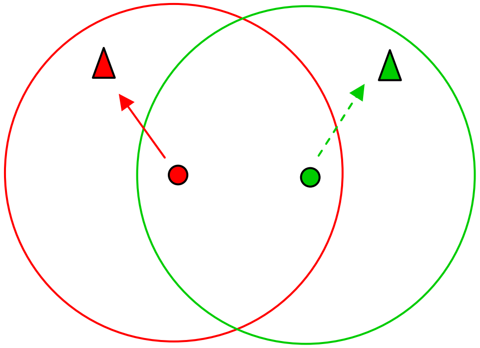
- Modeling:
  - length of idle period
  - transmission periods in busy period
  - probability of success
  - length of busy periods
  - throughput
- Home reading!

CSMA in wireless networks

- Does CSMA/CD work fine in wireless networks?
- Problem 0: Can not sense while transmit -> CSMA/CA
- Problem 1: Hidden terminal problem
  - the two terminals can not hear each others transmission
  - carrier sense does not work
- Solution: CSMA/CA with RTS/CTS
  - request to send (RTS)
  - clear to send (CTS)
  - both terminals can hear the CTS



- Problem 2: Exposed terminal problem
  - B could transmit, but backs off, as it assumes that the channel to its receiver is busy



Summary

- Medium access control protocols
  - Static allocation: TDMA, FDMA
  - Random access: Aloha, CSMA, CSMA/CD

- Simple models for general conclusions and comparison
  - Packet level models
  - Poisson arrival
  - Simplified network (e.g., equal distances, no hidden terminals)

- Reading assignment:
  - Rom, Sidi, Multiple Access Protocols, excerpts
    - Ch.2: page 9 to top of 15 (FDMA, TDMA)
    - Ch.3: page 47 to 52 (ALOHA)
    - Ch 4: page 79 to 83, 89 to top of 92, 94 to 98 (CSMA variations)