Cellular systems

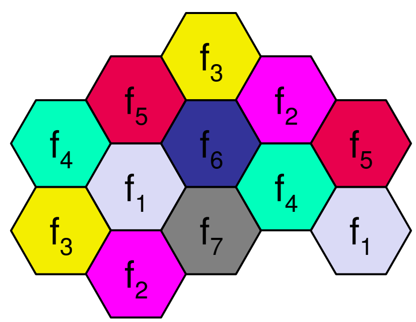
02/10/06

Cellular systems

- Implements space division multiplex: base station covers a certain transmission area (cell)
- Mobile stations communicate only via the base station
- Cell sizes from some 100 m in cities to, e.g., 35 km on the country side (GSM) - even less for higher frequencies

Cell structure and SDM

- Space division multiplexing.
- Frequency reuse only with a certain distance between the base stations
- Users inside a cell use FDM or CDM.
- Standard model using 7 frequencies:



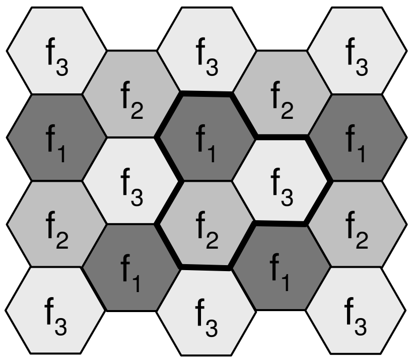
Cellular systems

- Advantages of cell structures:
  - Frequency reuse, higher capacity, higher number of users
  - less transmission power needed
  - more robust, decentralized
  - base station deals with interference, transmission area etc. locally
- Problems:
  - fixed network needed for the base stations
  - handover (changing from one cell to another) necessary
  - Frequency planning

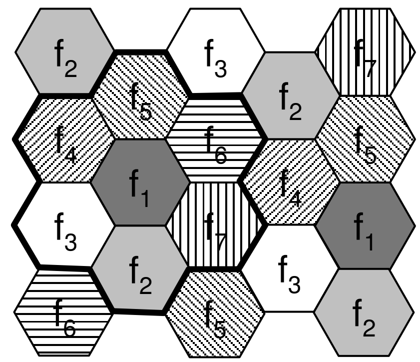
Frequency planning

- Fixed frequency assignment:
  - certain frequencies are assigned to a certain cell
  - problem: different traffic load in different cells
- Dynamic frequency assignment:
  - base station chooses frequencies depending on the frequencies already used in neighbor cells
  - more capacity in cells with more traffic
  - assignment can also be based on interference measurements

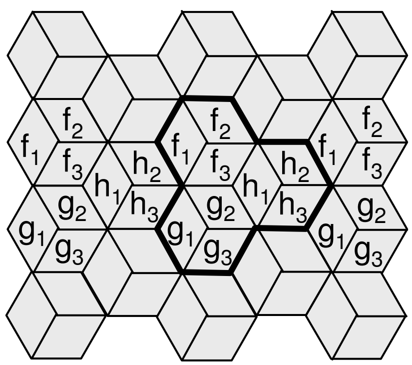
Cell systems



3 cell cluster



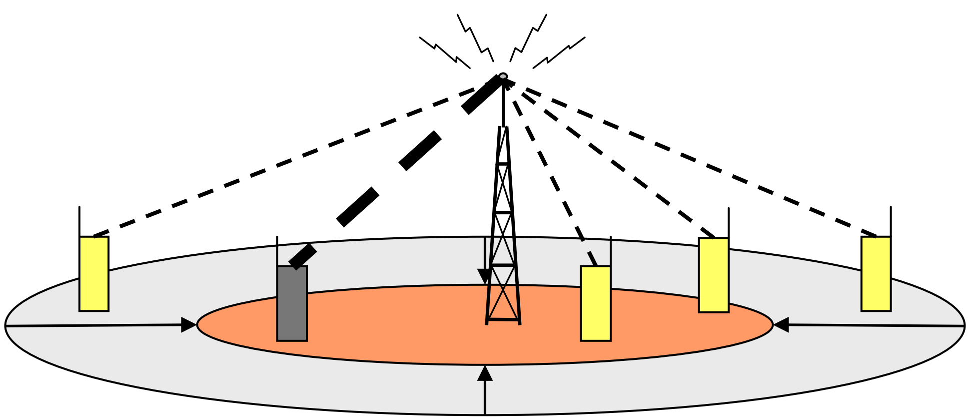
7 cell cluster



3 cell cluster
with 3 sector antennas

Cell breathing

- CDM systems: cell size depends on current load.
- Additional traffic appears as noise to other users
- If the noise level is too high users drop out of cells

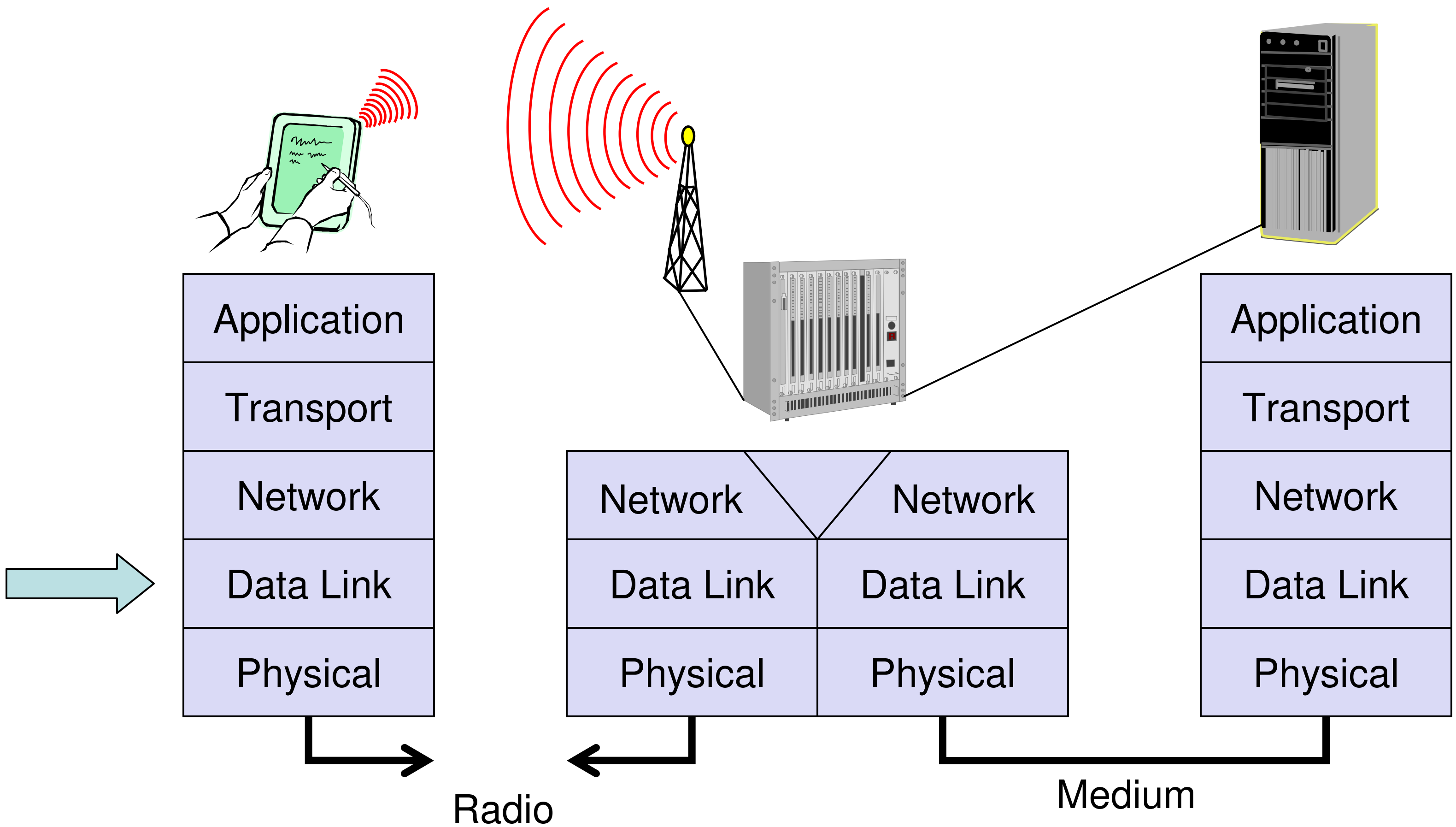


Medium access control

MAC

- Multiple users share the same medium
- Medium Access Control specifies how this is implemented.
- General mechanisms:
  - Space division multiplexing
  - Time division multiplexing
  - Frequency division multiplexing
  - Code division multiplexing
- It is a distributed environment. A user does not know what the others want to do.

MAC stays in link layer



SDMA

- SDMA (Space Division Multiple Access)
  - segment space into sectors, use directed antennas
  - cell structure
- Cellular system
  - A cellphone is assigned the optimal base station, although it receives signals from multiple base stations.
  - Criteria: available resources such as frequencies (FDM), time slots (TDM) or code (CDM).
- SDMA is never used in isolation.

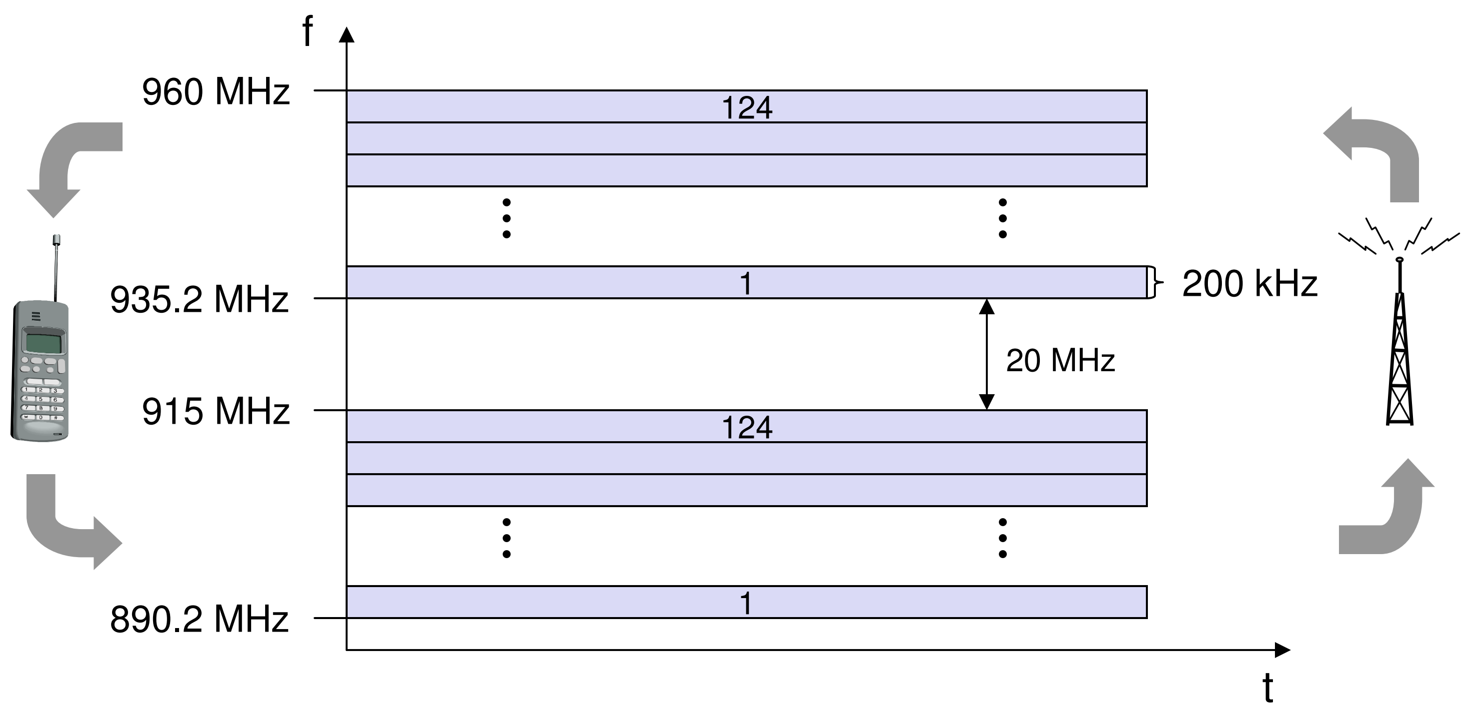
FDMA

- FDMA (Frequency Division Multiple Access)
  - assign a certain frequency to a transmission channel between a sender and a receiver
  - permanent (e.g., radio broadcast), or dynamic (demand driven).
  - Pure FDMA (the same frequency is used at all times) or FDMA combined with TDMA (to alleviate narrowband interference).
  - slow hopping (e.g., GSM), fast hopping (FHSS, Frequency Hopping Spread Spectrum)
  - Senders and receivers agree on a fixed hopping pattern.

FDMA

- Mobile users and base stations in cellular networks.
- They establish a duplex channel for simultaneous transmission in both directions.
- The two way transmissions are separated by different frequencies --- frequency division duplex (FDD).
- They agree on the frequencies in advance.

FDD/FDMA - general scheme, example GSM



TDMA

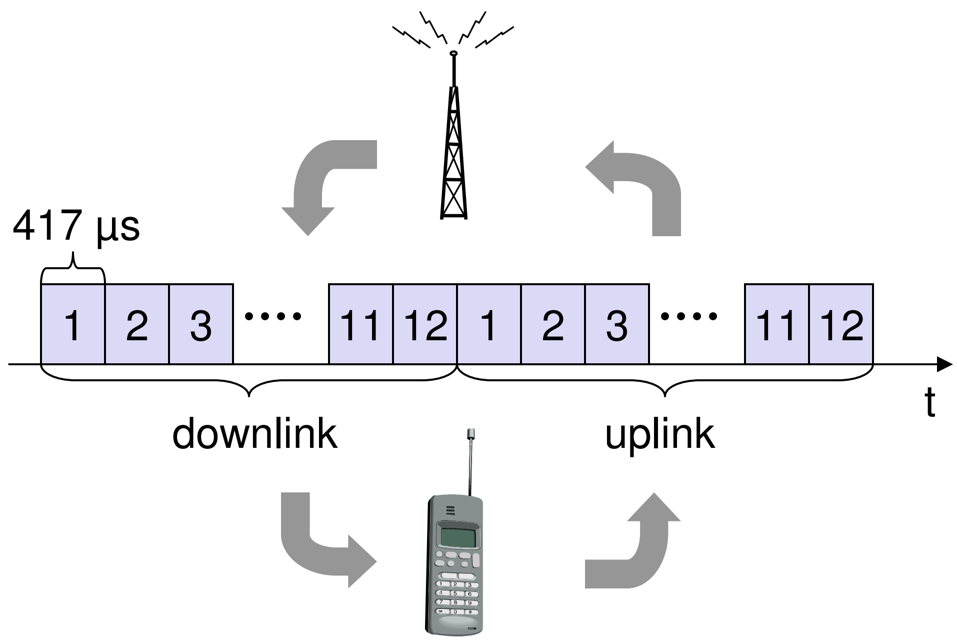
- TDMA (Time Division Multiple Access)
  - assign the fixed sending frequency to a transmission channel between a sender and a receiver for a certain amount of time
- No need to tune to a certain frequency.
- Simple transmitters and receivers.
- Almost all MAC schemes for wired network use TDMA, e.g., ethernet, Token ring, ATM.
- Fixed allocation v.s. dynamic allocation.

Fixed TDM

- Allocate time slots in a fixed pattern.
  - Fixed bandwidth for each user.
  - Simple, each mobile phone knows its turn, which is assigned by the base station.
  - Fixed delay.
  - Used in a number of phone systems.
  - Good for connections with a fixed rate, e.g., voice.
  - Inefficient for busty data or asymmetric transmissions.

TDD/TDMA - general scheme, example DECT

- DECT: each user is guaranteed access every 10 ms.



Aloha

- Time division multiple access without control.
- Invented by U. of Hawaii
- Used in ALOHANET between Hawaii islands.
- Random access scheme.
- Aloha does not coordinate nor resolve contention.
- If multiple stations access the medium at the same time, a collision happens, data is destroyed.
- Resolving packet loss is left to upper layers.

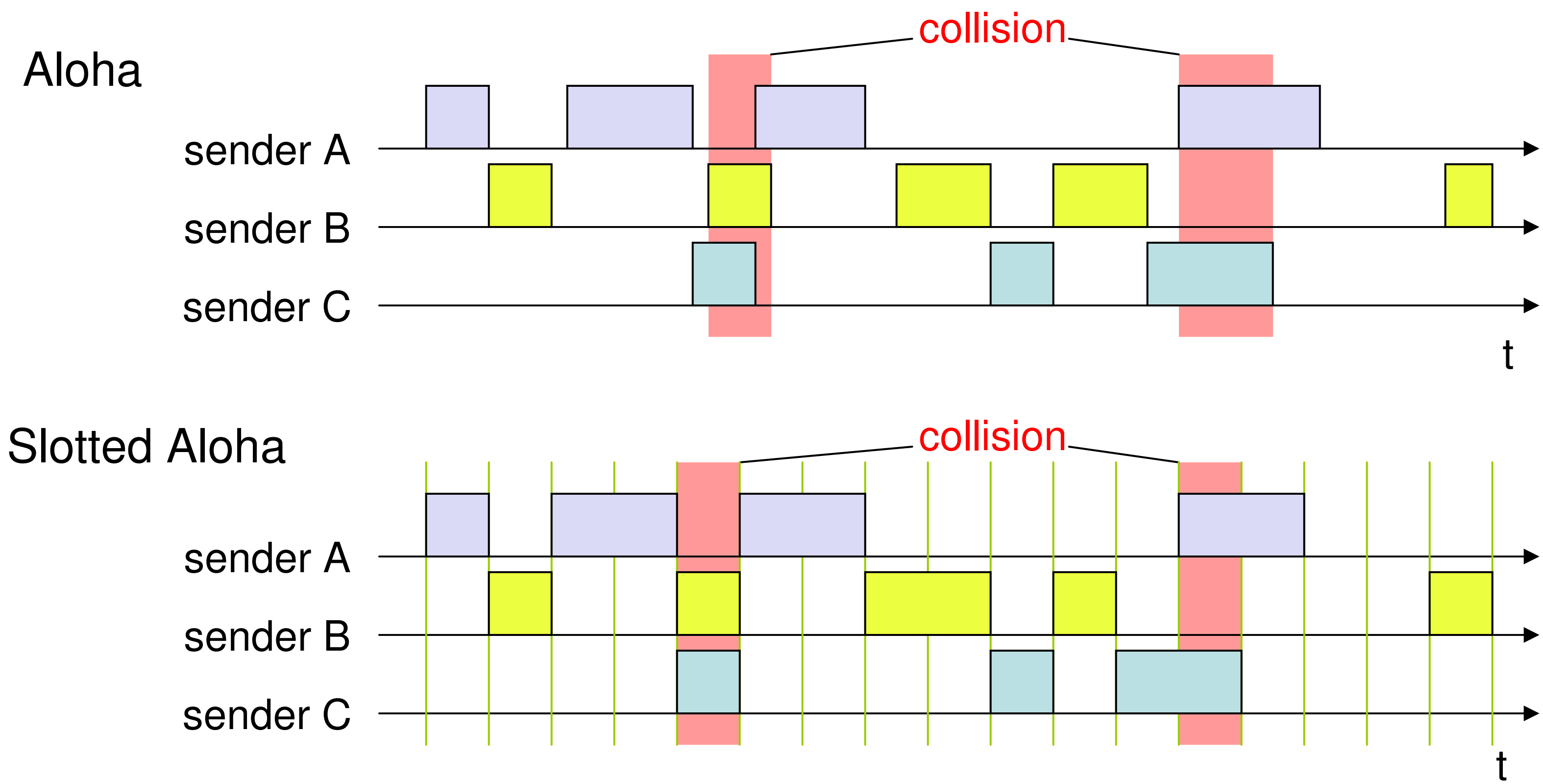
Aloha

- Random access, no central control.
- Very simple.
- Works fine for a light load.
- No delay guarantee

- Protocol:
  - Whenever a station has data, it transmits immediately
  - Receivers ACK all packets
  - No ACK = collision. Wait a random time and retransmit

Aloha and slotted aloha

- Slotted aloha: transmissions are synchronized and only start at the beginning of a time slot.



Fixed assignment v.s. random access

- Voice and data have different characteristics
  - Voice: continuous, steady rate.
  - Data: bursty, assymetric.
- Fixed assignment: resource is assigned at the beginning of the connection and is held throughout the lifetime.
  - Suitable for voice
  - Examples: TDMA, FDMA, CDMA
  - High throughput in high load, uniform traffic.

Fixed assignment v.s. random access

- Random access: resource is assigned per packet.
  - Contention: compete for resources.
  - Assignment is done in a distributed, random fashion.
  - Collision can happen, delay is not guaranteed.
  - Suitable for data.
  - Throughput is low compared with fixed assignment, especially at high load. ➔ lots of collisions
  - Handles non-uniform data traffic much better.

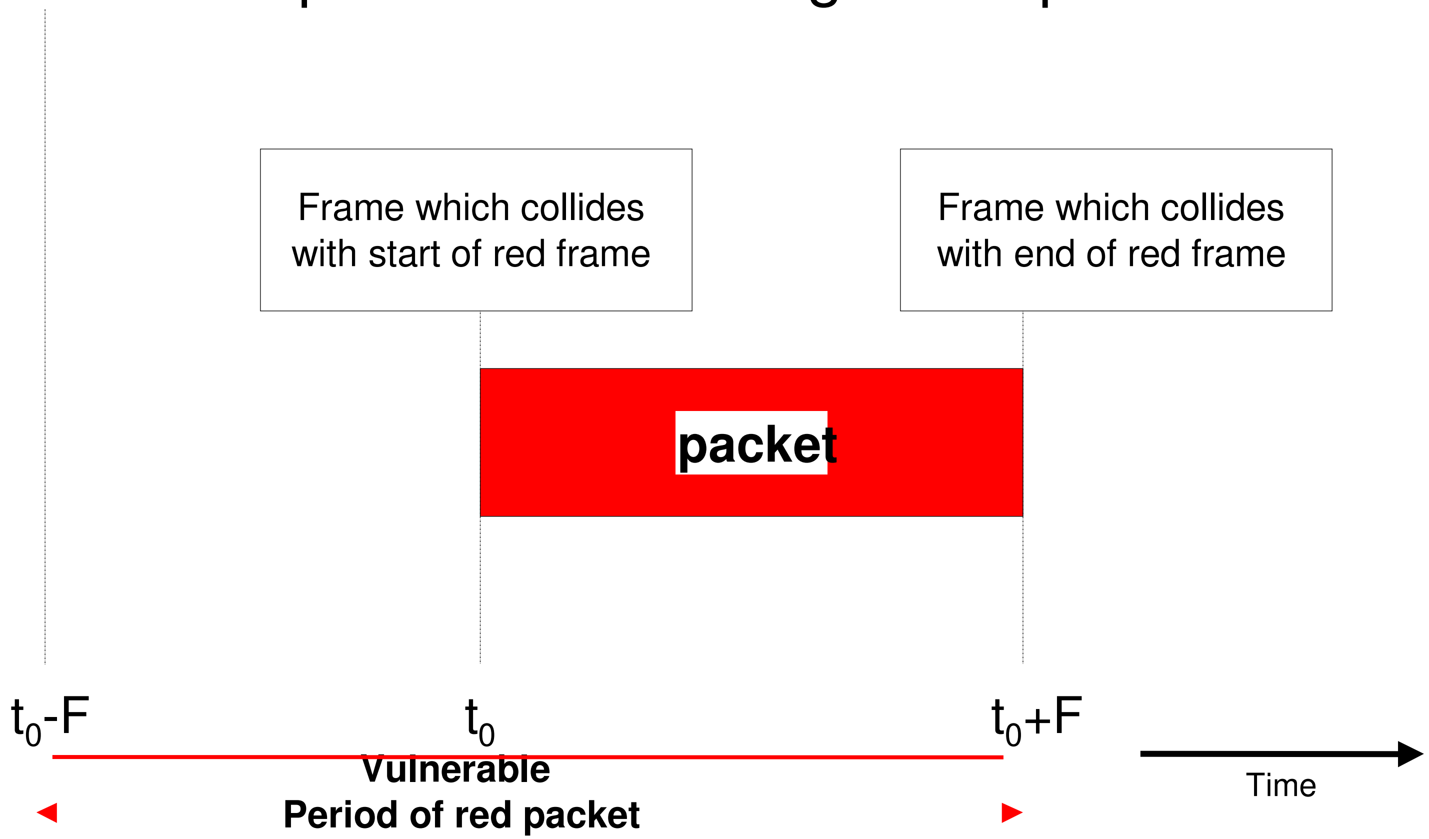
Aloha

- How well does it work?
- What is the throughput?

- Throughput = # packets transmitted/ total # packets allowed.
- Throughput (Aloha) = 18%.
- Throughput (Slotted aloha) = 36%.
  - Packets either collide completely or do not collide at all.

Analysis of pure Aloha

- A packet will be in a collision if and only if another transmission begins in the vulnerable period
- Vulnerable period has the length of 2 packet times



Analysis of pure Aloha

- Assume that there are a large number (N) of users in the network
- All users transmit packets with a fixed (average) length of T seconds
- Each user transmits with a fixed probability (p) in the time period (T)
- Thus, the average number of packets transmitted in the system in the time period T will be R=Np.

Analysis of pure Aloha

- "Danger" period for a user's transmission starts T seconds before it initiates its transmission and ends T seconds after it completes its packet
- During this time period of 2T, the average number of packets transmitted will be E=2Np=2R
- A Poisson probability distribution indicates the probability of k events occurring in a "unit time".

$$p(k) = \frac{E^k e^{-E}}{k!}$$

Analysis of pure Aloha

- For transmission to be successful, no other user should transmit during the unit time of interest (2T). Thus the probability of a successful transmission will be

$$p(k=0)=e^{-E}=e^{-2R}$$

- Therefore, the system throughput for the time period T will be

  S=# transmission attempts in time period T x probability of successful transmission, or

$$S=Re^{-2R}$$

Analysis of pure Aloha

- Optimum Throughput occurs at R=0.5 or when

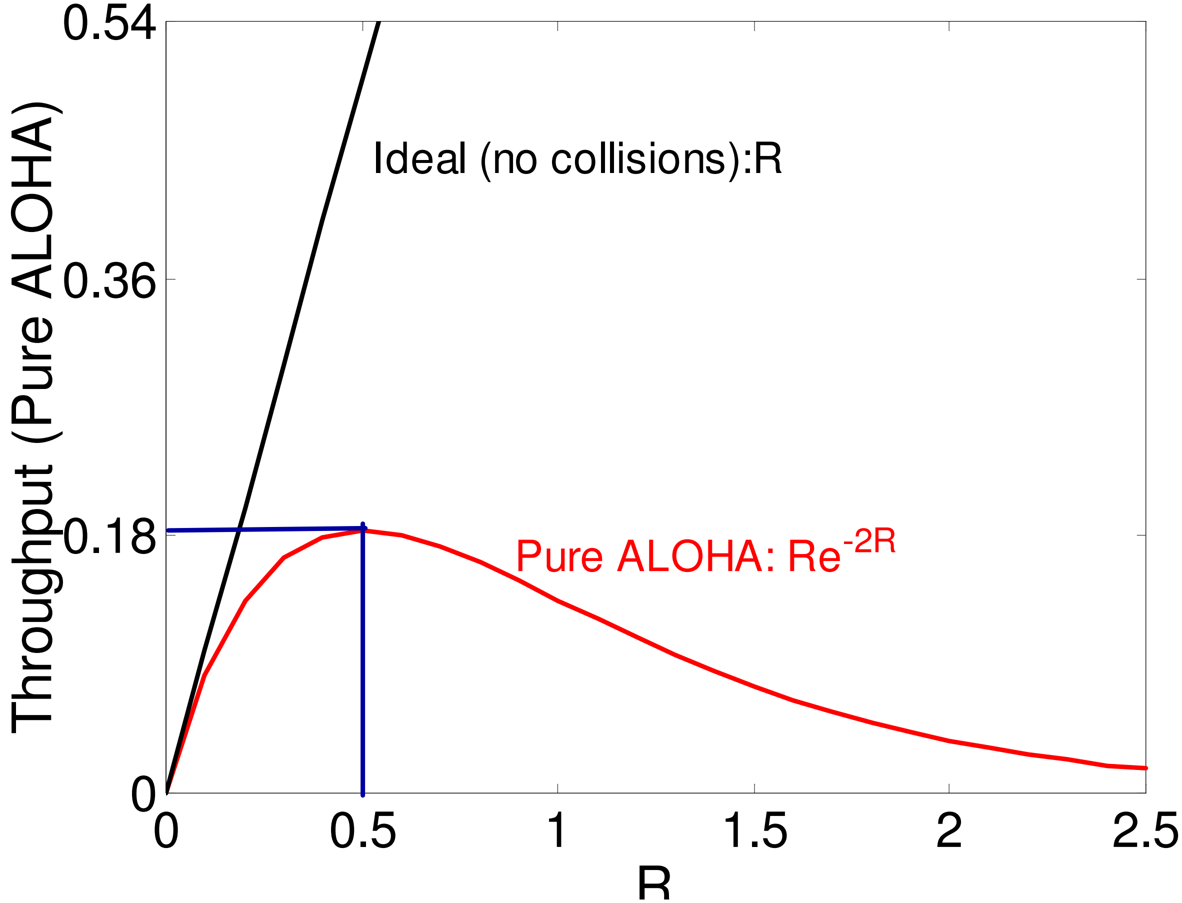
$$N = \frac{1}{2p}$$

- Average number of attempts to ensure successful transmission is

$$N_{av} = \sum_{i=1}^{\infty} n(1-e^{-2G})^{n-1} e^{-2G} = e^{2G}$$

$$N_{av}^{Optimum} = 2.72 \; attempts$$

Pure Aloha

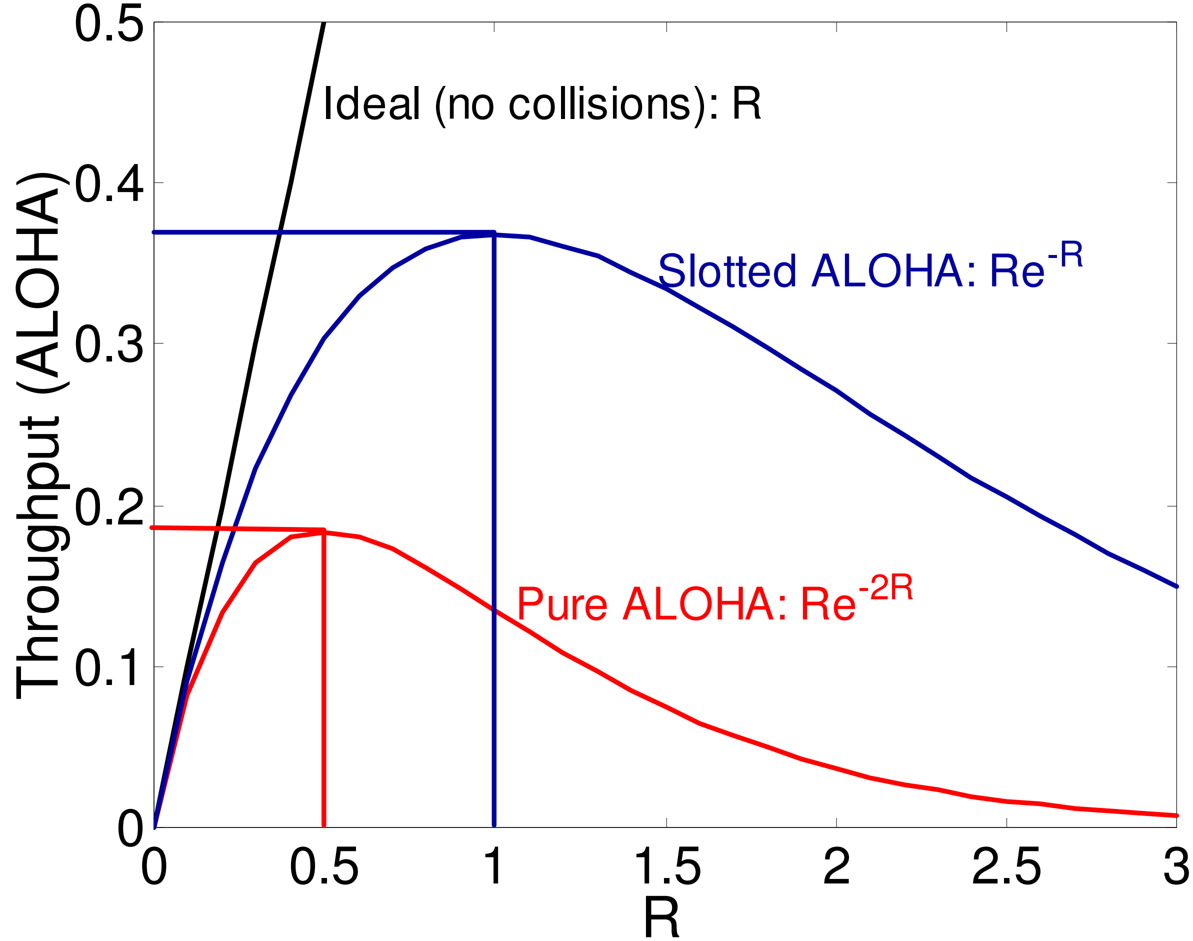


0.54
0.36
0.18
0
Throughput (Pure ALOHA)
Ideal (no collisions):R
Pure ALOHA: Re^{-2R}
0
0.5
1
1.5
2
2.5
R

Slotted Aloha

- Enhancement of pure ALOHA in that users can only start to transmit so that it arrives at the beginning of defined time slots of duration T
- "Danger" period for this system is only the T seconds prior to the start of the user's frame and thus $E=Np$ and $S=Re^{-R}$
- For this system, optimum throughput occurs if $R=1$.

Aloha, slotted aloha



Efficiency of slotted Aloha

- Successful throughput S read from graph (e.g. $S_{optimum}$=0.368 or 36.8% of timeslot contain successful transmissions)
- Number of frames with no transmissions can be found from Poisson distribution p(k=0)=0.368 or 36.8% slots
- Remaining time slots must contain collisions

Summary

- Cellular systems
- Medium Access Control
- SDMA
- FDMA
- CDMA
- Random Access, Aloha, Slotted Aloha
- Analysis of throughput of Aloha, slotted Aloha