Computer networks
The Media Access Control sublayer

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Reminder

- **Defined in the physical layer**
  - **the mechanical interfaces;**
  - **electrical interfaces;**
  - **functional interfaces;**
  - **the procedural interfaces.**
- A **channel for transmitting** the **raw bitstream**.
- The **transmission** could be:
  - **baseband** (signal coding),
  - **broadband** (modulation)
- The **channel** can be:
  - **point by point,**
  - **broadcast**

Reminder

Error-free transmission of data units (frames) of a given size

3. Network		3. Network
2. Data connection		2. Data connection
1. Physical		1. Physical
	Physical medium	

Bitstream transmission

- **In the case of a broadcast channel** (e.g. on a LAN bus)
  - multiple access (multi-access), or
  - random access channel (random access channel)

Data link layer	⇒	**Logical Link Control sublayer** **LLC : Logical Link Control**
		Media Access Control Sublayer **MAC: Media Access Control**

The data link layer

Data link layer	⇒	Logical Link Control sublayer LLC : Logical Link Control
		Media Access Control Sublayer MAC: Media Access Control

- **For point-to-point connection (LLC only)**
  - **framing/delimitation;**
  - **fault protection;**
  - **data flow control;**
  - **connection control.**
- **In case of broadcast channel (LLC+MAC)**
- **MAC**
  - **sharing a single broadcast channel between multiple competing users (stations)**
  - "point-to-point" services to the LLC sublayer

MAC : Media Access Control sublayer

- **Your task**
  – sharing a single broadcast channel (channel sharing - channel allocation) between multiple competing users (stations)
- **Channel sharing methods**
  – Static channel sharing,
  – dynamic channel sharing:
    - Collision (competitive),
    - Collision-free (deterministic).
- **Analysis, comparison**
  – (e.g. throughput depending on load)

Tasks of the MAC sublayer

- **Sharing a single broadcast channel among multiple competing users (stations).**
- “point-to-point” services to the LLC sublayer
- “Channel Sharing” (“Channel Allocation”)

Considerations for examining channel sharing methods

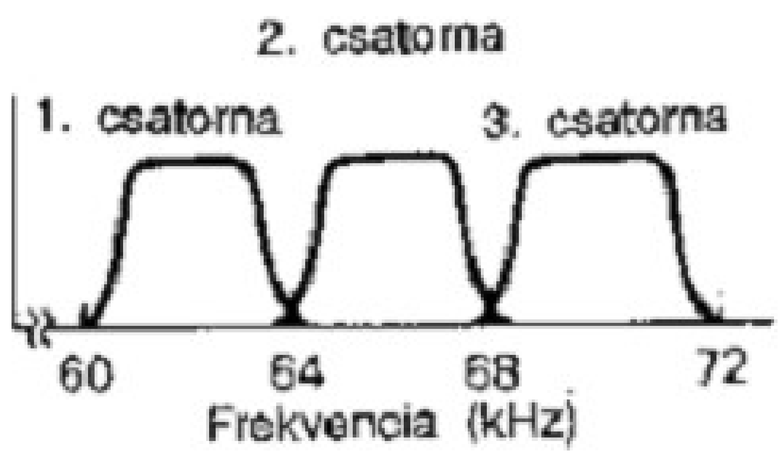
- **In case of different types and sizes of traffic**
  - **the average delay and the**
  - **channel utilization.**
- **The nature of the traffic may be**
  - **continuous transmission:**
    - **requiring a well-defined bandwidth over a long period of time,**
  - **burst transmission:**
    - **random, relatively short, burst-like demand.**
- **Characteristics related to the volume of traffic:**
  - **channel occupancy:**
    - **what % of the transmission capacity is occupied;**
  - **utilization:**
    - **the average portion of the transmission capacity used for "useful" data transmission;**
  - **average delay:**
    - **the average time from frame readiness to the flawless transmission.**

Channel sharing methods can be

- **Static**
  - **Fixed number of users, everyone benefits equally from the channel even if they don't actually need it at a given time.**
- **Dynamic**
  - **The channel is shared among those users who need it.**
  - **From a control perspective, it can be:**
    - **centralized:** a designated (possibly special) station has control over the channel allocation;
    - **distributed:** distributed algorithm decides (no designated station).
  - **The access procedure can be**
    - **competitive** (collision)
    - **deterministic** (collision-free)

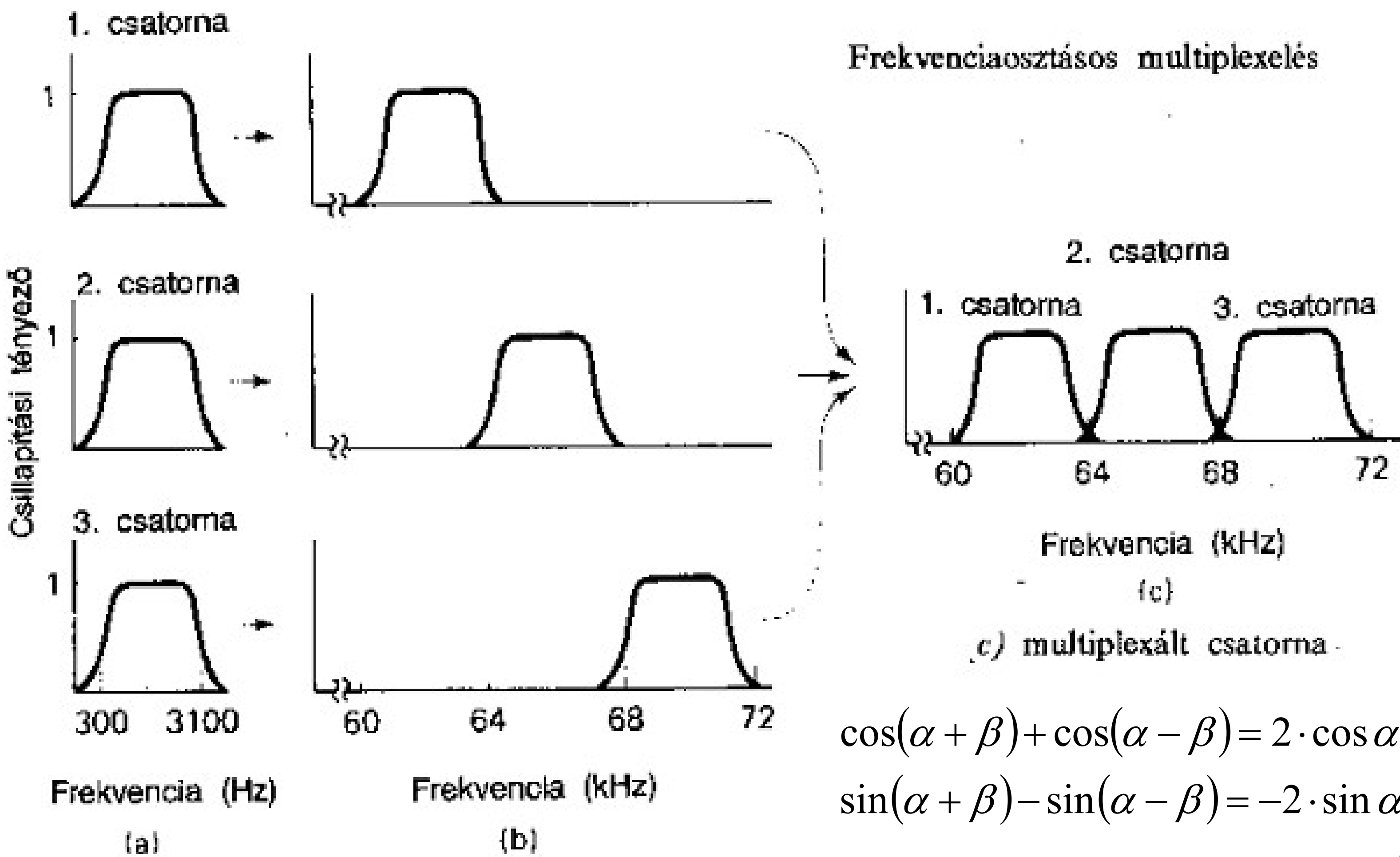
Static channel sharing methods

- **FDM (Frequency Division Multiplexing).**
- **Essence:**
  - **Fixed number of users n**
    ⇒ dividing the bandwidth into n equal parts,
    each user gets one part of the bandwidth.
  - **Everyone has their own frequency band**
    ⇒ no interference (users do not disturb each other)



“Guard bands” between the bands to reduce interference (crosstalk) (better separation).

FDM



a) eredeti sávszélességek; b) frekvenciatartományban eltolt sávszélességek;

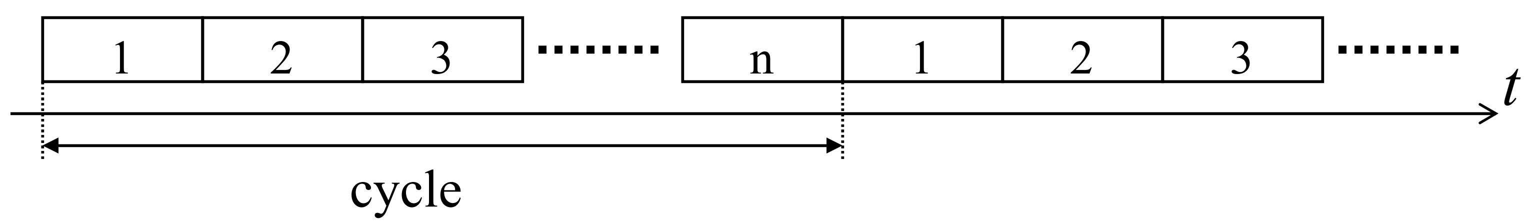
$$\cos(\alpha+\beta)+\cos(\alpha-\beta)=2\cdot\cos\alpha\cdot\cos\beta$$

$$\sin(\alpha+\beta)-\sin(\alpha-\beta)=-2\cdot\sin\alpha\cdot\sin\beta$$

$$\alpha=\varpi\cdot t=\frac{2\cdot\Pi}{T}\cdot t$$

Static channel sharing methods

- **TDM (Time Division Multiplexing)**
- **Essence:**
  - **Fixed number of users n**
    ⇒ divides cycle time into n equal time slots
    statically assigns 1 time slot to each user.
    (In the i. slot, the i. user can use the entire bandwidth)



Generation of cycles and gaps requires central synchronization (usually marking the beginning of the gaps)

Static channel sharing methods

- **Their characteristics:**
  - **the user number is fixed;**
  - **average frame delay is n times that of if the entire channel belonged to one user;**
    - **FDM: smaller (n-th part) bandwidth,**
    - **TDM: there is a higher waiting time in (has the n^{th} part of the cycle time only).**
  - **the frame delay is constant;**
  - **channel utilization**
    - **bad in case of small and uneven traffic**
      (if a busy channel is empty, no one else can take it),
    - **good for continuous, even load**
      (e.g. old inter-telephone exchange trunk – small fixed number of users, high even load).

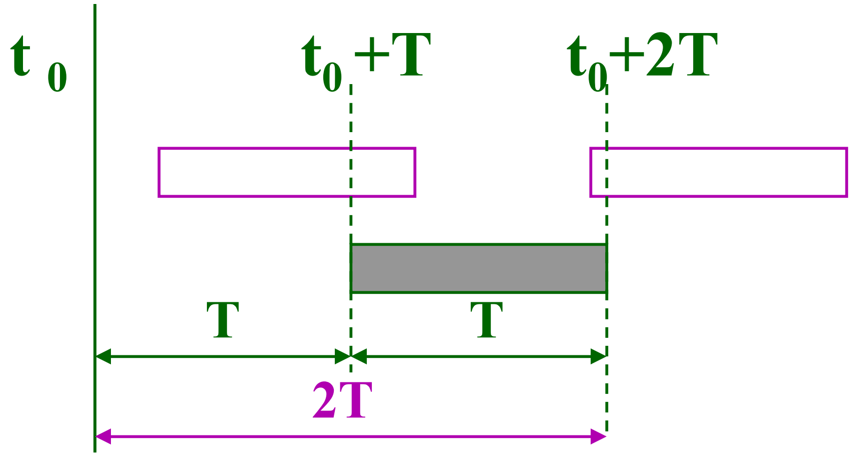
Dynamic channel sharing methods

- **The channel is shared among those users who need it.**
- **From a control perspective, it can be:**
  - **centralized:** a designated (possibly special) station has control over the channel allocation;
  - **distributed:** distributed algorithm decides (no designated station).
- **The access procedure can be**
  - **competitive** (collision)
  - **deterministic** (collision-free)
- **Prerequisites for subsequent tests:**
  - **A station only sends 1 frame at a time.**
  - **The frames are limited in size.**
  - **Only one channel is available.**
  - **Even a 1-bit collision is devastating.**

The ALOHA protocol *

- **University of Hawaii, circa 1970, UHF radio network**
- **Basic idea:**
  - **Fixed, equal-length frames**
    (not just limited sizes);
  - **Stations can transmit at any time**
    (as soon as a frame is ready);
  - **After transmission, they wait for an acknowledgement**
    (positive acknowledgement, or the lack of a response as a negative acknowledgement);
  - **If the station detects that its frame has collided** (no acknowledgement),
    it waits for a random amount of time and then retransmits.
- **Multiple access without channel monitoring.**
- * **“Simple” ALOHA protocol**

ALOHA throughput



T: the "frame time"
(fixed)
(transmission time of one frame)

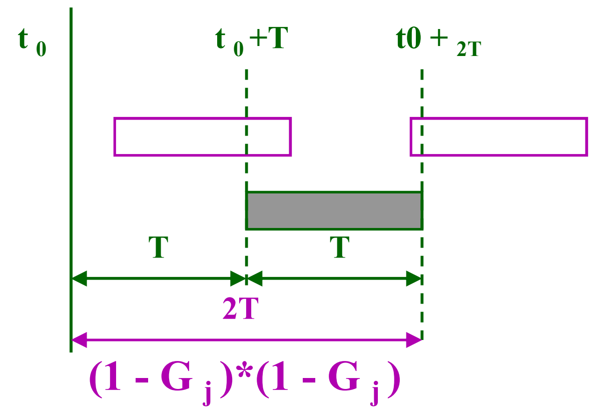
- **From the perspective of the "dark" frame, the "collision-prone" period extends from t_0 to (t_0+2T).**
  - **Another frame that started in the time range $t_0 \rightarrow (t_{0+T})$ may collide with the "beginning" of it;**
  - **(t_0+T) → (t_0+2T) may collide with the "end".**
- **2T collision hazard**
  (the "critical section" is 2T in length)

ALOHA throughput

- **What percentage of sent frames arrive successfully (survive collisions)?**
- **Let's assume**
  - N **: the station number** (population);
  - **T: the frame time** (frame length/bit rate);
  - S_i *is* **the probability that the frame sent by station i will be successfully delivered within the frame time;**
  - G_i **is the probability that station i transmits in the time slot.**
- **In the case of N equal (identical) stations**
  - $S_i = S/N$; **where**
    S **: the number of frames successfully transmitted in one frame time ≡ throughput [frame/frame time]**
  - $G_i = G/N$; **where**
    G**: total number of frames to be sent in a frame time ≡ this is the load [frame/frame time] – the offered traffic**
    $S \leq G$ allways

ALOHA throughput

- **When does the frame sent by station i arrive successfully in the frame time $S_i = ?$**
- **If no one else tries to send during the critical period of length 2T** (if anyone else tried, it would certainly collide).
- The probability that **station j transmits in a time slot is: G_j**
  $\rightarrow$ it does not send is $(1 - G_j)$
  $\rightarrow$ it does not send in two time frames is $(1 - G_j)*(1 - G_j) = (1 - G_j)^2$



- The probability that **neither station broadcasts in two time slots**
  (they are independent of each other) **:**

$$\prod_{\forall j} (1 - G_j)^2$$

- The probability that
  i. sends one and the others
  do not send for two time frames is:

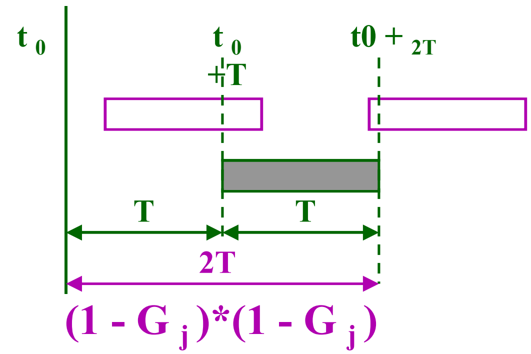
$$S_i = G_i \cdot \prod_{\forall j, j \neq i} (1 - G_j)^2$$

ALOHA throughput

- **The probability that a frame sent by station i will successfully arrive within the frame time is:**

$$S_i = G_i \cdot \prod_{\forall j, j \neq i} \left(1 - G_j\right)^2$$

$$S_i = \frac{S}{N}, \quad G_i = \frac{G}{N}$$



$$S = G \cdot \left(1 - \frac{G}{N}\right)^{2\cdot(N-1)}$$

- **For all the stations, if $N \to \infty$:**

Comment:

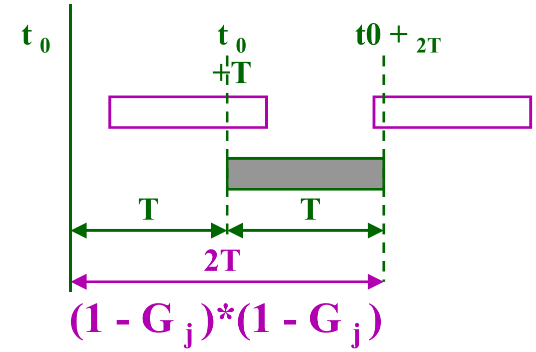
$$\lim_{k \to \infty} \left(1 + \frac{x}{k}\right)^k = e^x$$

$$S = G \cdot e^{-2\cdot G}$$

The ALOHA throughput as a function of the load

ALOHA throughput

- **The throughput of ALOHA is S as a function of the load G ($N \to \infty$):**



$$S = G \cdot e^{-2 \cdot G}$$

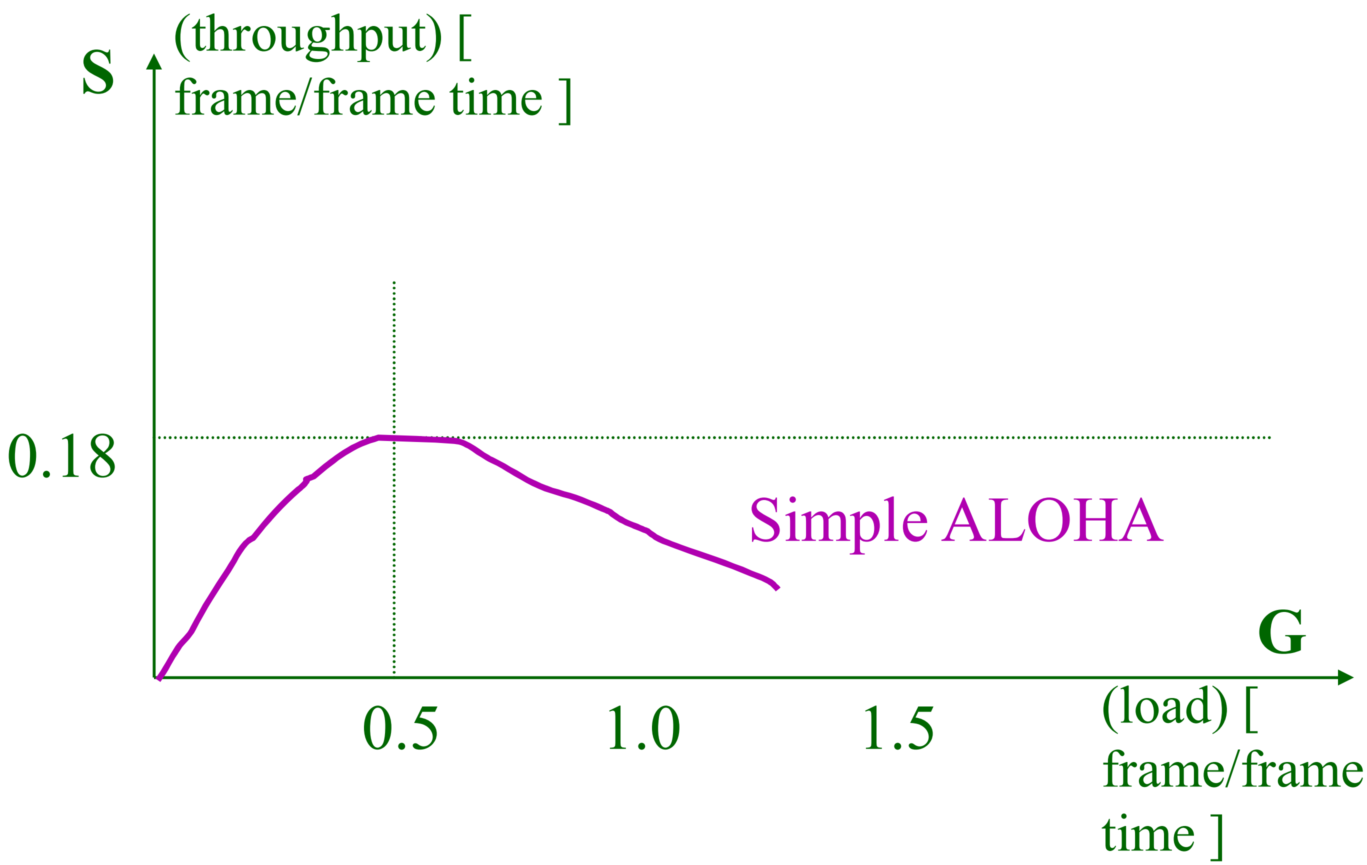
- **The maximum throughput S_{max} ($N \to \infty$):**

$$dS/dG = 1 \cdot e^{-2 \cdot G} + G \cdot e^{-2 \cdot G} \cdot (-2) = 0 \quad \Rightarrow \quad G = 0.5$$

$$S_{\max} = 0.5 \cdot e^{-1} = 0.5 \cdot \frac{1}{2,71828...} \cong 0,18$$

- **Channel utilization is maximum 18% if $N \to \infty$**

Throughput as a function of load



The channel utilization of simple ALOHA is max 18%!
(N → ∞)

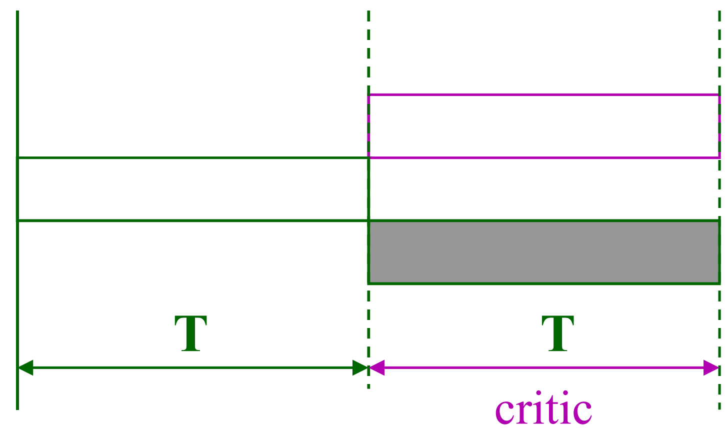
They may be beneficial for many stations with relatively low traffic.

Slotted ALOHA

- 1972 amendment: slotted ALOHA
- Time is divided into time slots
  - The synchronization of the stations must be solved separately, e.g. a separate station sends a special signal at the beginning of each slot.
- Sending can only start at the beginning of the time slot!
- The collision-prone critical period decreases from 2T to T!

From this, the throughput is:

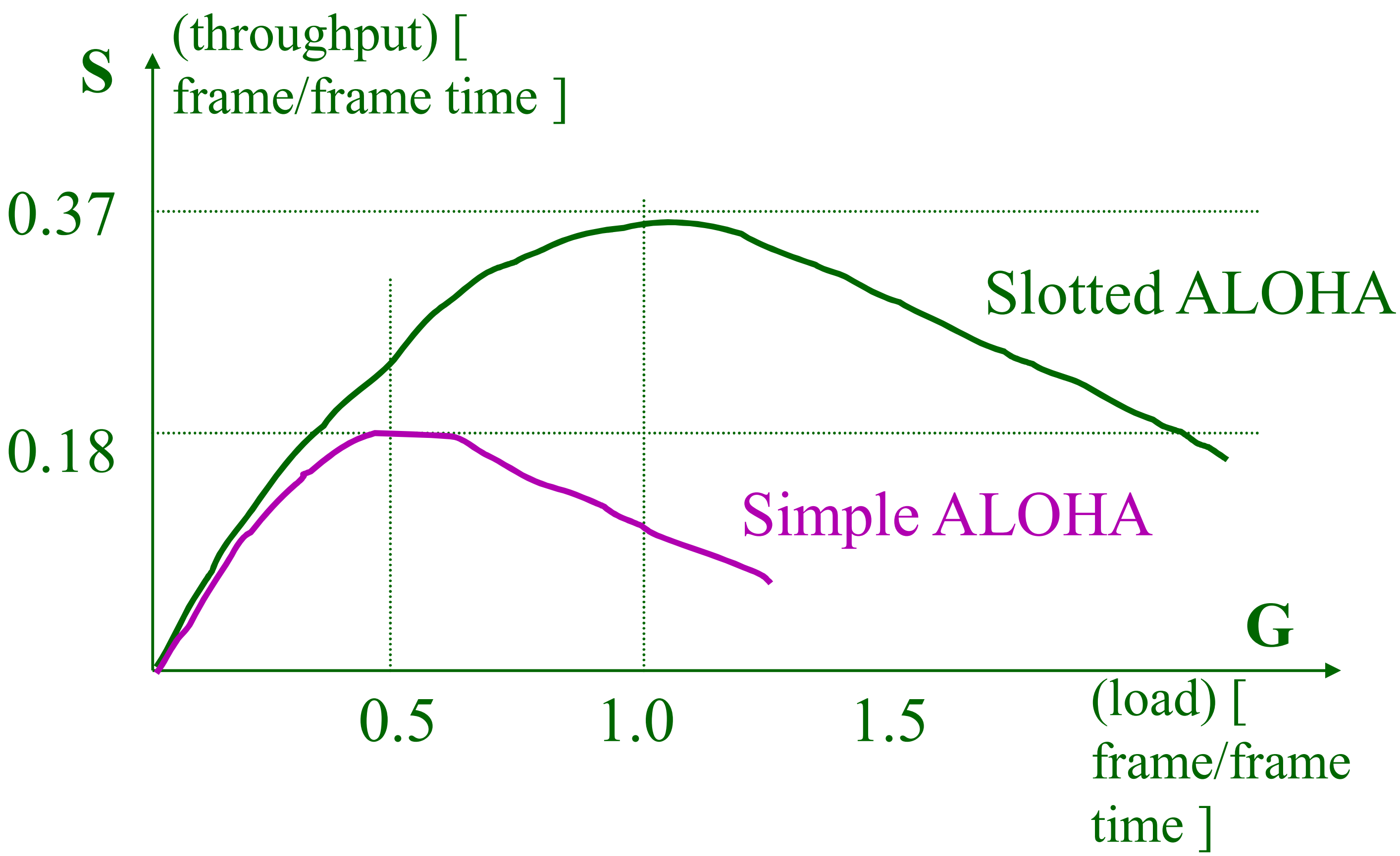
$$S = G \cdot e^{-G}$$



Channel utilization is at most 37%.

$$(N \to \infty, G = 1)$$

Throughput as a function of the load



The channel utilization of simple ALOHA is max 18%!
(N → ∞)

They may be beneficial for many stations with relatively low traffic.

Additional protocol improvement option: channel monitoring (Carrier Sense)

- **Channel monitoring before transmission: busy - not busy**
- **The station won't broadcast if the channel is busy!**
- **CSMA - Carrier Sense Multiple Access**
- **Its essence: if the station ready to send**
  - **(1): Monitors the channel (listens in);**
    - **if there is no transmission: starts transmitting and (2)**
    - **if there is a transmission: waits for the end, then starts transmitting and (2)**
  - **(2): It transmits the frame until it is finished. <u>If there was a collision</u> : it waits for a random amount of time and then retransmits the frame (1).**
- **Problem: high probability of collision when retransmitting** (synchronizes the end of the transmission, others may be waiting for it)
- **This is 1 persistent CSMA !**

Nonpersistent CSMA

- **If a station ready to send**
  - **(1): Monitors the channel (listens in);**
    - **If there is no transmission (the channel is idle), it starts transmitting and (2).**
    - **If there is a transmission (the channel is busy), it does not continuously monitor the channel, but waits for a random amount of time, then (1).**
  - **(2): Sends the frame all the way through.**
    <u>If there was a collision</u> :
    waits for a random amount of time, then (1).
- **Less "greedy":**
  - **There is no “sync point” at the end of sending.**
- **However, it is also “sluggish” because of this.**

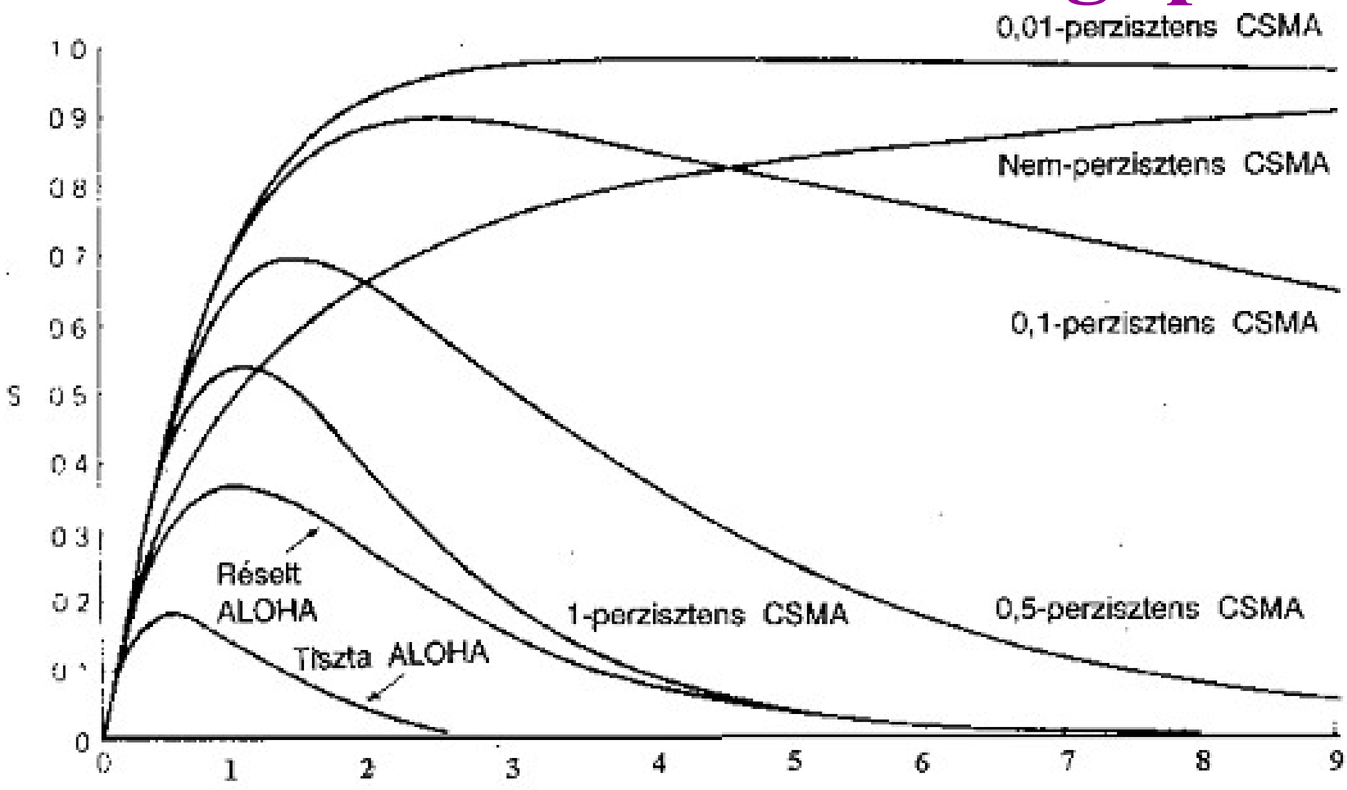
p-persistent CSMA

- **It uses a "slotted" channel**
  (it counts time in time slots (time durations)).
- **If the station ready to send**
  - **(1): Monitors the channel (listens in);**
  - **(2): if the channel is idle:**
    - **starts to give with probability p and (3);**
    - **(1-p) with probability not to send, but waits for the next time slot and (1);**
  - **If the channel is busy, it waits until it is free (2);**
  - **(3): Sends the frame all the way through.**
    <u>If there was a collision</u> :
    waits for a random amount of time, then (1).
  - **Note: for p = 1 ≡ 1-persistent**
- **Configurable persistence**

Characteristics of channel monitoring protocols

- **Their performance is greatly affected by propagation delay!**
  (time it takes for the signal to travel through the channel)
- **The bigger this is, the worse the situation is!**
  - **They don't sense each other's transmissions in time.**
- **Delay:**
  - **small in case of low traffic,**
  - **increases in case of high traffic.**
- **Their maximum throughput is limited, usually well below the ideal value** ($S_{max}=1$) .

ALOHA – CSMA throughput



Véletlen hozzáférésű protokollok összehasonlítása a terhelés függvényében mért csatorna kihasználtság alapján

ALOHA 18% of max

Slotted ALOHA 37% of max

1p CSMA 50 – 60 %

0.5 p CSMA between 60-70%

Non P CSMA 90% almost

0.01 p CSMA 95% almost

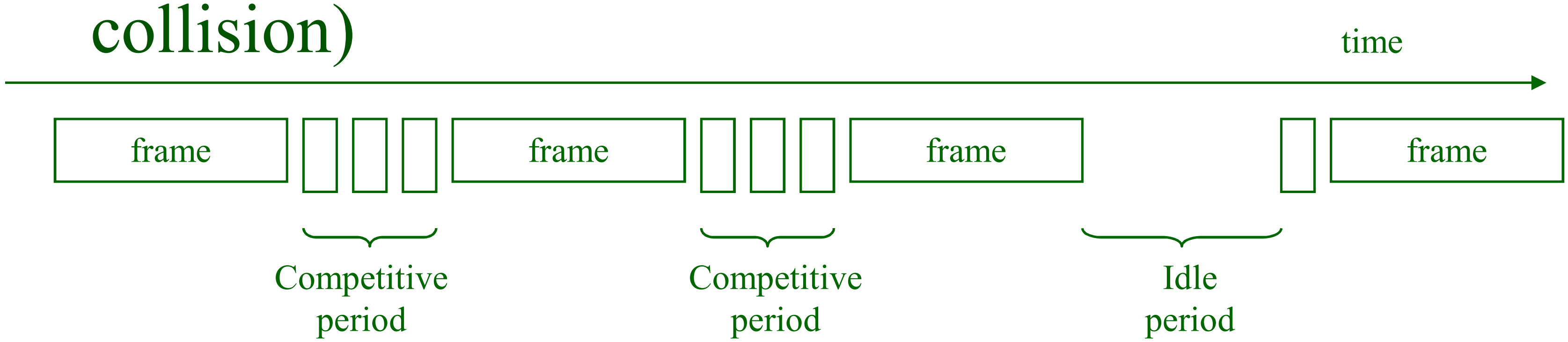
1 persistent "greedy" – p persistent parameterizable – non-persistent "lazy"

Additional improvement: collision detection

- **Collision detection during transmission** (not always possible).
- **When a collision is detected, the collided stations stop sending the frame.**
  (They do not send the entire frame → they gain time.)
- **This is CSMA/CD: CSMA with Collision Detection (channel sense multiple access with collision detection)**
- **1-persistent CSMA/CD**
  – **1-persistent CSMA+**
  – **stops transmitting in case of collision.**
  (Waits for a random amount of time and continues like 1-persistent CSMA).

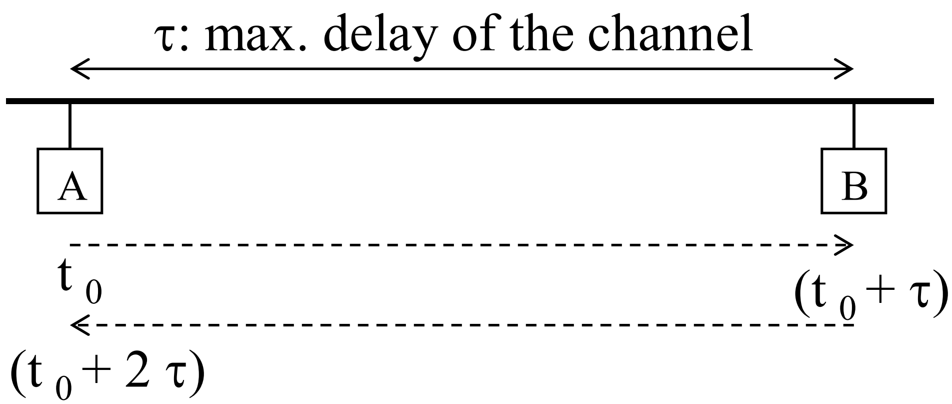
CSMA/CD

- **The sending of frames may be preceded by periods of contention.**
- **The size of the contention slots is determined by the maximum propagation delay of the channel!**
  (Even the most distant stations must recognize the collision)



CSMA/CD

- Even the most distant stations must recognize the collision



- **"A"** can only be sure that it has "acquired the channel" if **it can transmit for at least 2τ without collision.** (it would only notice at t_0+2τ if "B" started transmitting at t_0+τ).
- **The minimum frame time is 2τ** (from this the minimum frame size can be calculated).
- The "contention" period can be modeled as if it were a slotted ALOHA with a slot length of 2 τ (since there is no CD)!
- E.g. Ethernet, max 2.5 km diameter, 51.2 μsec is the max. round trip time (2 τ).

Collision detection

- **Requires analog devices**
  (recieving while transmitting)
- **Appropriate bit encoding is required**
  (e.g. Manchester – e.g. “voltage window” check)
- **Not all physical media are suitable for it**
  (or it is too complicated, or expensive to solve)

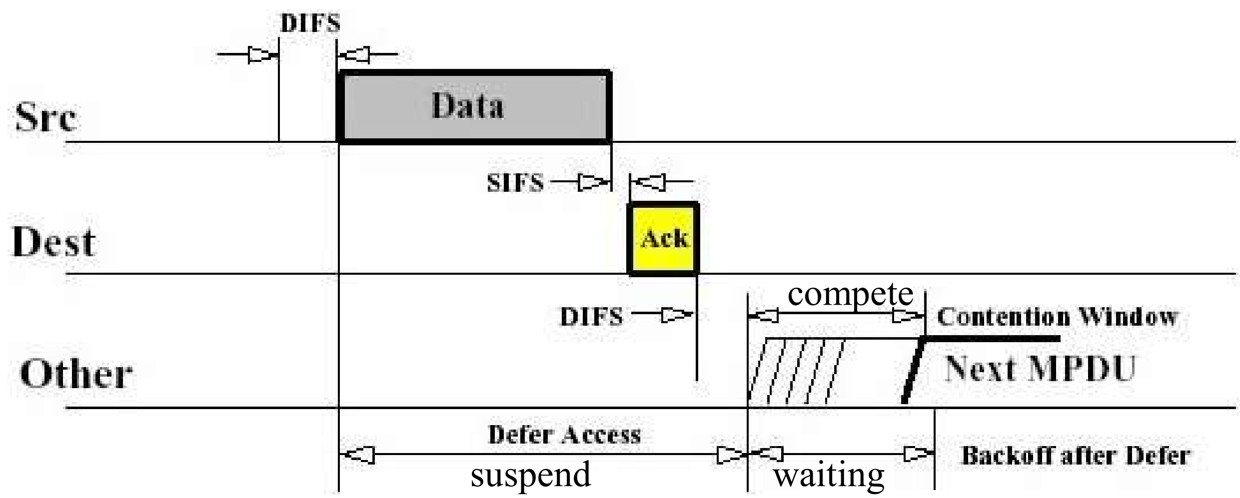
If there is no possibility of collision detection – collision avoidance

- **E.g. radio networks – IEEE 802.11**
  “While speaking, it is deaf”
- **but also via cable – Apple Macintosh LocalTalk:**
  - simple HW: reception capabilities are definitely needed, but there is no need to implement collision detection
  - via interface connected to printer port, 230 Kbps

Collision avoidance: CSMA/CA (Collision Avoidance)

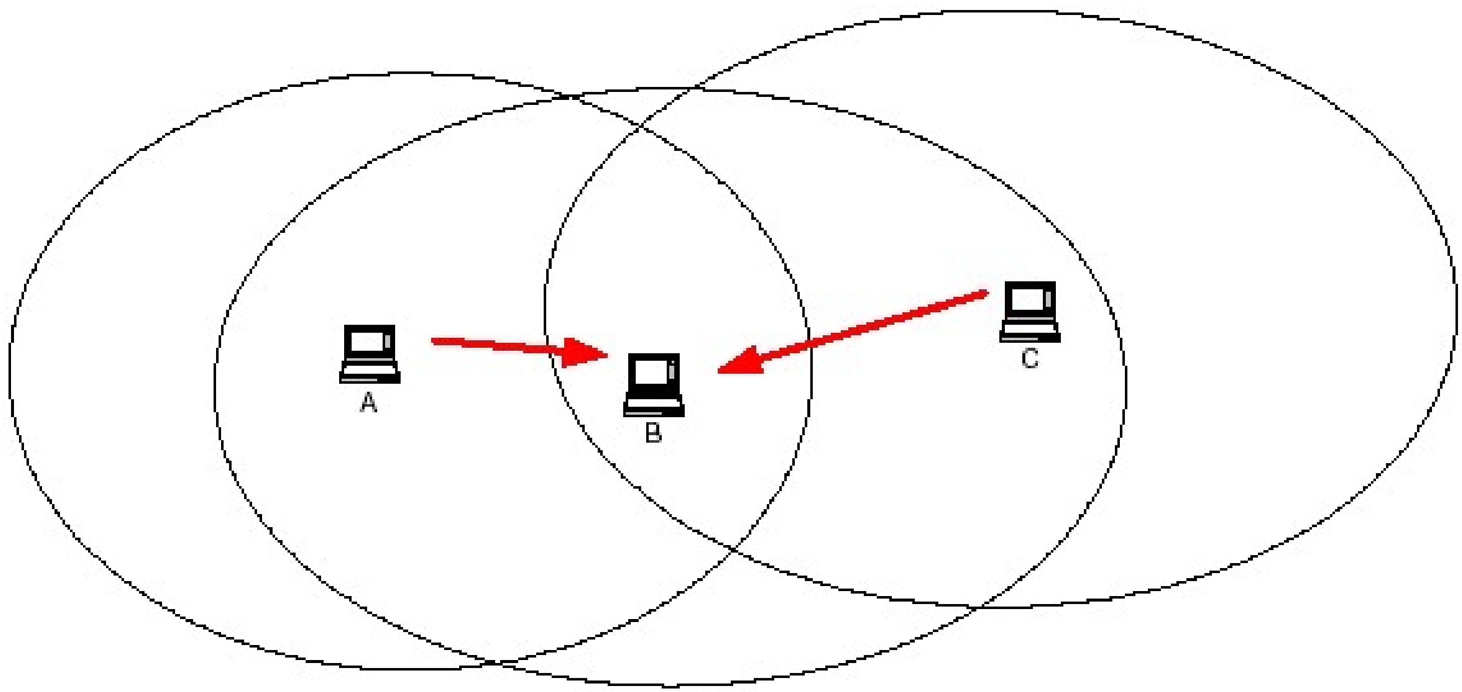
Solution :

- **Before transmitting, it listens to the channel (CSMA)**
- **If it is empty for an Interframe Spacing (IFS) period, it starts transmitting.**
- **If it is busy, it waits for a random amount of time (backoff) and then tries again.**
- **In case of a collision (lack of ACK), it waits for a random amount of time (backoff) and then tries again (as if the channel was busy).**



Radio networks – additional problems

- **A fundamental problem is that in a radio network, not all stations can hear each other:**
- **Hidden Node Problem**
- B hears A, C ; A does not hear C
  (this cannot practically happen on cable)



"Hidden node" problem

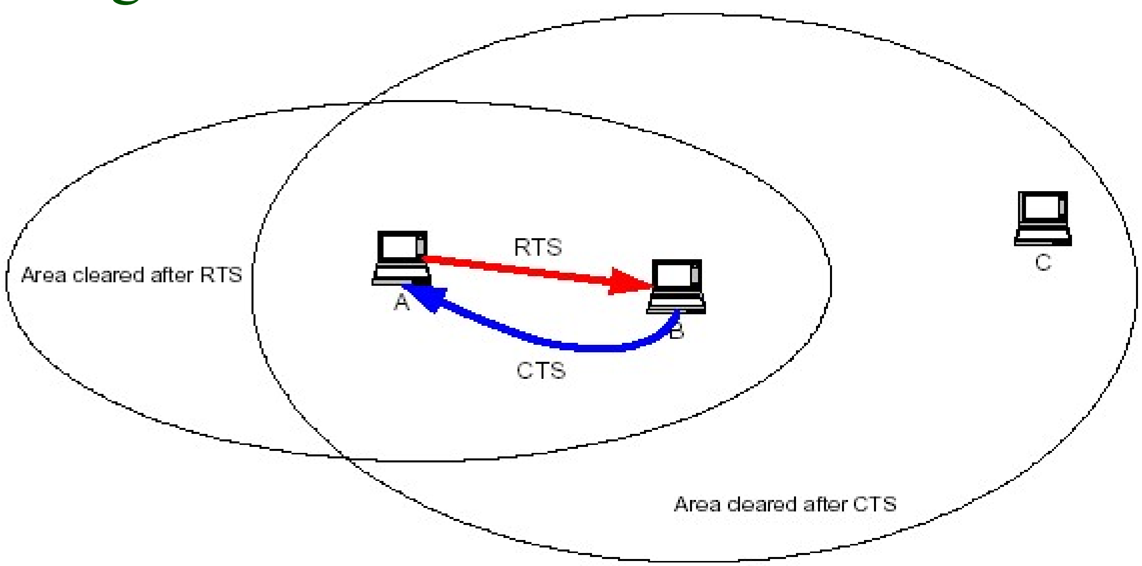
Solution (802.11): "Virtual" carrier sensing

- **The station wishing to transmit indicates its intention to transmit with a short** (Request To Send - **RTS**) **frame in which it specifies the duration of the frame to be sent (Duration field).**
- **The receiver acknowledges this with a short** (Clear To Send - **CTS**) **frame that repeats the duration indicated in the RTS.**
- Each station has a **Network Allocation Vector (NAV)** .
- **NAV always indicates the time remaining until the channel is free**
  – during this time, stations consider the channel busy even if no transmission is physically detected.
  "Virtual" carrier monitoring
- **Stations that receive either RTS or CTS update their NAV based on the Duration in it.**

“Virtual” carrier sensing

802.11: Virtual + real carrier sensing

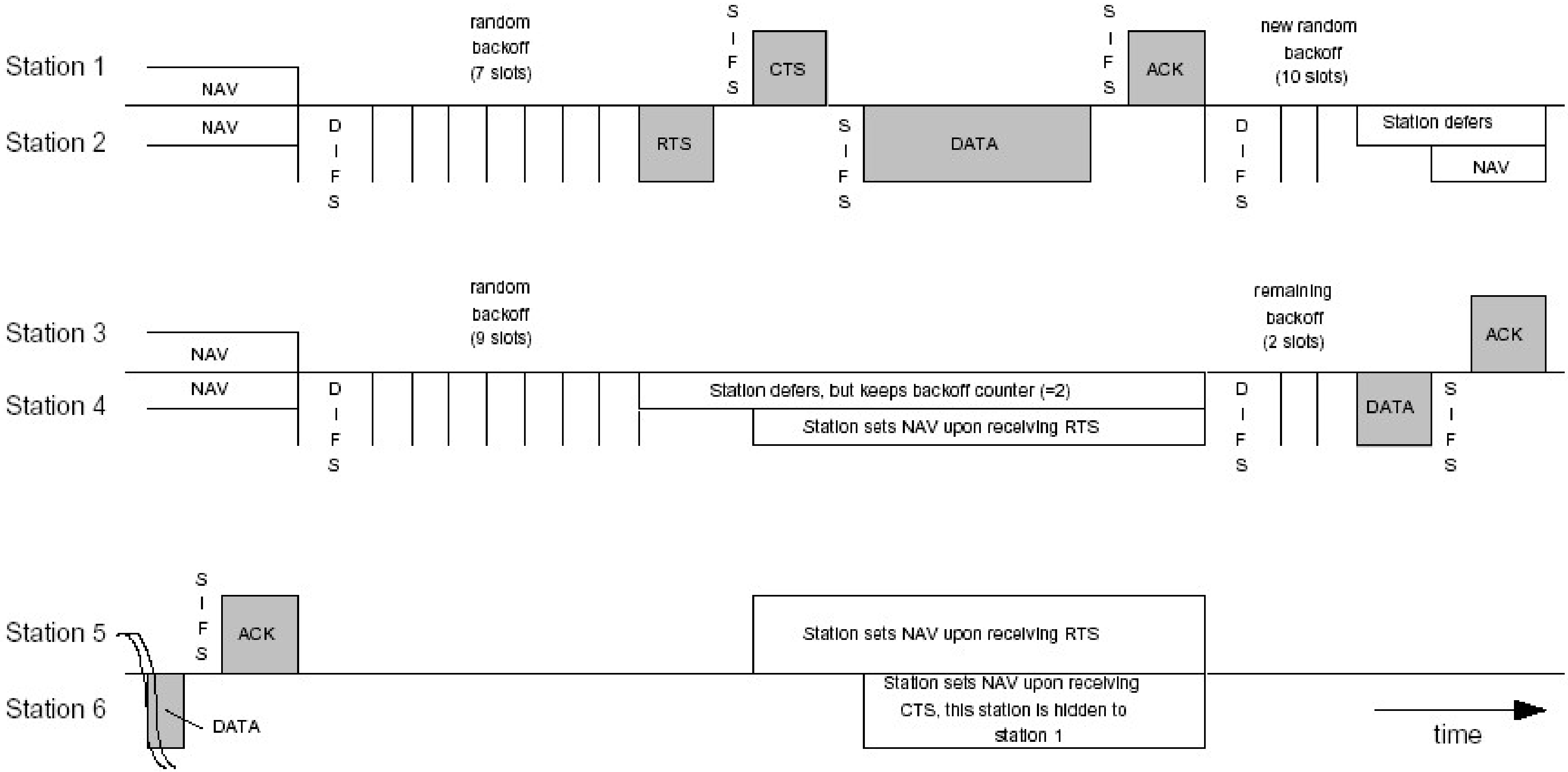
- **If the transmitting station is not heard (RTS),**
  - no real carrier sensing
- **The NAV (Network Allocation Vector) can still be set based on the receiver's CTS .**
  - virtual carrier sensing



“Virtual” carrier sensing

- **The RTS/CTS mechanism can be disabled.**
- **It is possible to define the minimum frame size below which the RTS/CTS mechanism is not needed** (unnecessary overhead in the case of short frames)
- **It is not needed if:**
  - **There is little bandwidth requirement and there is not much competition for the channel** (low traffic or few stations – low collision probability) and
  - **in a place where every station can hear everyone.**

“Virtual” carrier sensing



- 6 does not hear RTS from station 2, only CTS from station 1. (Ex: IEEE 802.11)

Collision based protocols

- **Minimal latency in low traffic conditions**
- **Congestion in case of high traffic,**
  limited channel capacity well below ideal
  (e.g. IEEE 802.3 Ethernet standard CSMA/CD)

- **To avoid congestions:**
  collision-free protocols

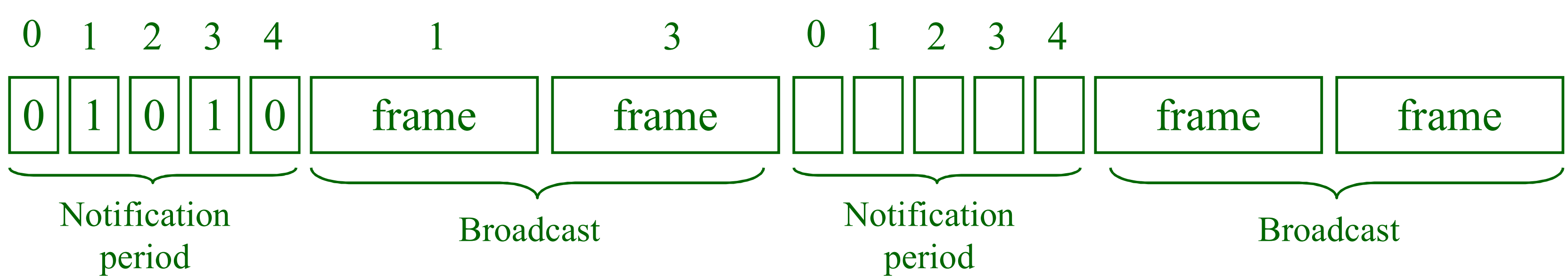
Collision-free protocols

- **Assumptions:**
  - **There are N stations and**
  - **each has a unique address**
    e.g. 0 - (N-1)
    (each one knows their own address “hardwired”).
- **We are discussing the**
  - **“basic bitmap” method,**
  - **“broadcast recognition with alternating priority” method and**
  - **the “token” based procedures:**
    - **Token bus,**
    - **Token ring.**

Basic Bit Map Method

- **Basic bitmap method**
- **Registration period:**
  - **exactly N** (number of stations) **slots,**
  - **we assign a 1-bit slot to each station.**
  - **Stations ready to transmit**
    set their own bit to 1 during the announcement period (they have a frame to send).
- **After the registration period, the checked-in stations send their frames in order.**
- Based on the previous registration period, everyone knows who is next and when the next reporting period will be.

E.g. N=5; addresses=0-4

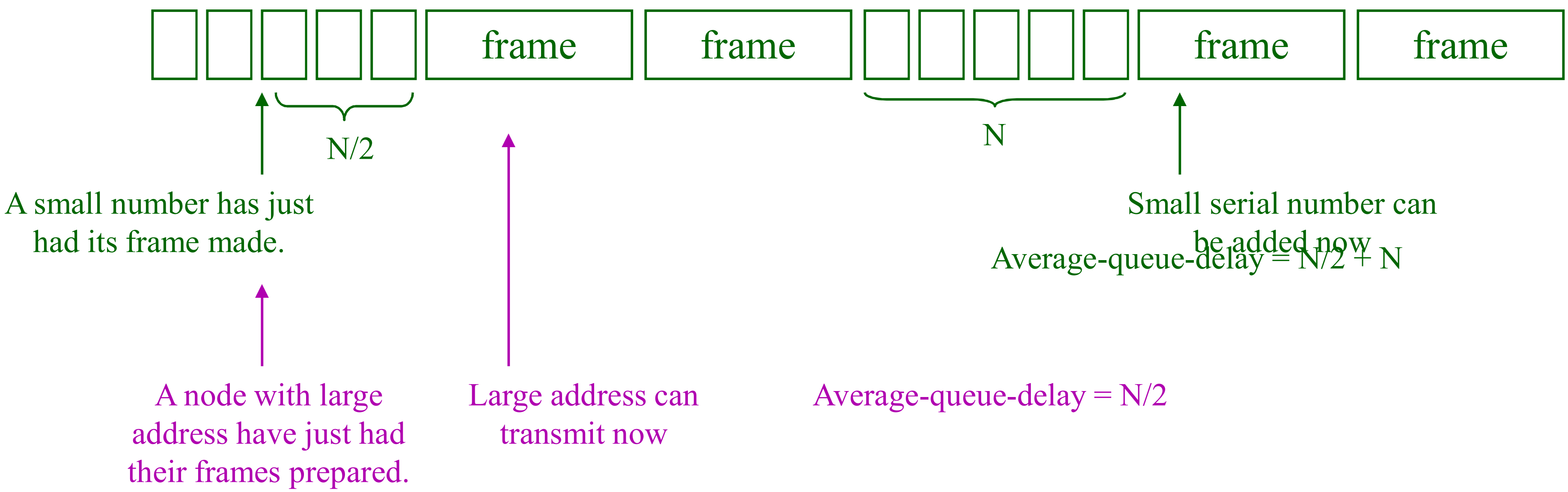


Basic Bit Map Method

- **Features**
  - **Relatively high latency in case of low traffic** (there is always a registration period with N slots, although these are short).
  - **If we are transmitting d data bits, then the utilization is: d/(d+N).** (It is better if d is large compared to N.)
  - **Stations with lower numbers are at a disadvantage!** They must register at the beginning of the registration period.
    - Even on an empty channel, those with low sequence numbers have to wait on average for the first (N/2)+N login slots before they can transmit.
    - Those with high sequence numbers only have to wait for the last N/2 slots on average.
  - **High traffic** (everyone would transmit)**, the overhead is small:** the N-bit registration period is divided between N pcs d_K frames: **the utilization: $d_K/(d_K+1) \approx 1$, if $d_K >> 1$ (TDM-like)**

Basic Bit Map Method

The disadvantages of small numbers are obvious:



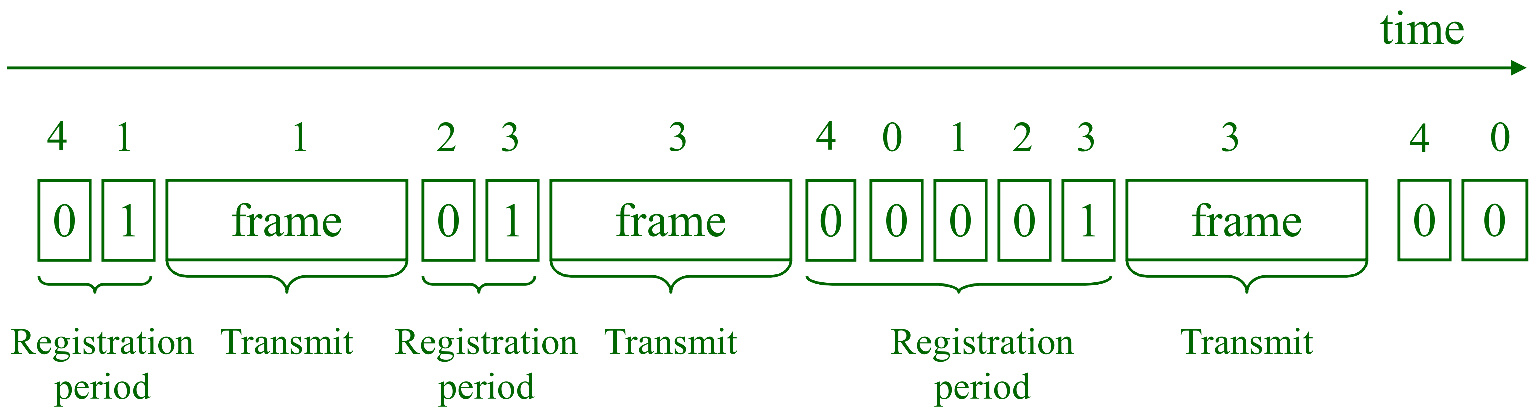
In the case of high traffic, if everyone gives: $d = d_k * N$

$$d/(d+N) = (N*d_K)/(N*d_K+N) = d_K/(d_K+1) \approx 1, \text{ if } d_K>>1$$

Broadcast Recognition with Alternating Priorities (BRAP)

- **Broadcast detection with variable priority**
- **Modified bitmap so that**
  - **we compensate for the advantage of those with higher addresses,**
  - **but the large overhead of the small load remains.**
- **How it works:**
  - **If a station announces its intention to transmit, the registration period is suspended and the station can transmit immediately.**
  - **When the transmission ends, the registration continues with the next station.**
- There is always 1 at the end of the registration period (intention to transmit)

BRAP



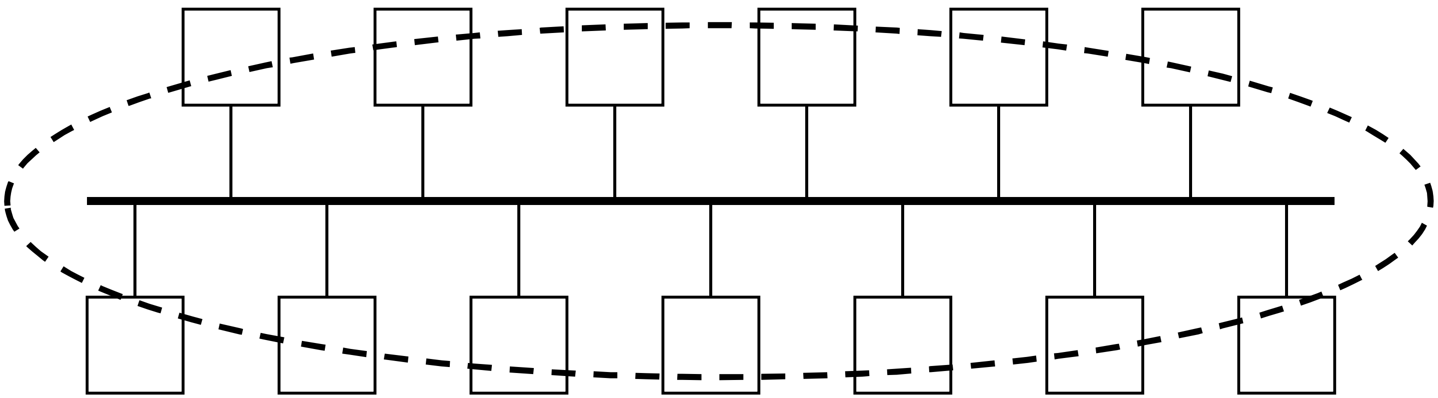
- **Characteristics:**
  like bit-map, but address independent, the medium access is balanced.
  (A station has to wait for N/2 slots on average.)

Token procedures

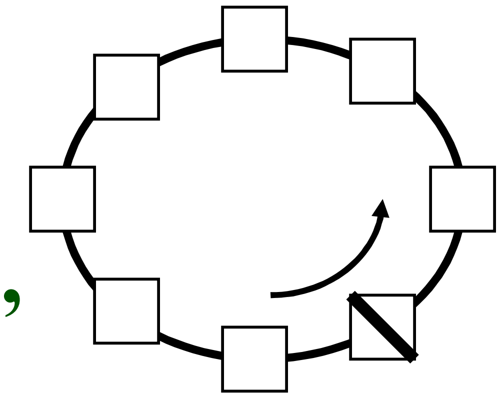
- **Their characteristics:**
  - **The stations form a (logical) ring,**
  - **A special control frame (token) circulates, carrying the right to transmit.**
- **Give**
  - **The station that owns the token can transmit.**
  - **The frame size is not limited, but**
  - **token holding time yes!**
    (if there is time - you can send multiple frames)
  - **Once the transmission is complete, it passes the token on to its logical neighbor in the ring.**
  - There is only 1 token in the ring $\Rightarrow$ only 1 station can transmit at a time!

Token Bus

- The stations are connected to a broadcast bus.
- They form a logical ring: they know who follows whom.



Token Ring



- **Physical ring**
- **When a station receives a token,**
  - **"cuts" the ring and**
  - **transmits (possibly more frames),**
  - **"takes off" its own frame after it has reached back,**
  - **forward the token if**
    - **you have nothing more to send, or if**
    - **the token holding time has expired.**
- **If a station does not have a token,**
    - **repeats (forwards the received frames);**
    - **monitors traffic addressed to it.**

Characteristics of the token based procedures

- **In case of low traffic, the delay is significant** (you have to wait for the token).
- **The overhead depends on the number of stations.**
- **Similar to TDM for high traffic.**
  Capacity is distributed proportionally to the number of stations, equally among all stations.

Comparison of media access procedures

Traffic	Collision-based	Collision-free
Small	small delay	greater delay
Large	sub-ideal limited utilization	similar to TDM ($S \approx 1$)
For max delay	no upper limit	there is an upper limit

Traffic	Static FDM	Static TDM
Small, bursty	low bandwidth	long waiting time
Large, even	good	good

It may be an exam question.

- **What is the difference between 1-persistent CSMA and 1-persistent CSMA/CD methods?**
  - **The first: If there is no transmission. It transmits the frame and then checks for a possible collision (e.g. acknowledgement).**
  - **The second: it detects a collision while transmitting a frame and immediately stops transmitting. (Due to propagation delay, a contention period may occur.)**
- **List some collision-free MAC protocols.**
  - **BBMM (basic bit-map method);**
  - **BRAP (broadcast recognition with alternating priority);**
  - **Token bus;**
  - **Token ring.**
- **What kind of competiting (collision based) MAC protocols do you know?**
  - **Simple ALOHA;**
  - **Slotted ALOHA;**
  - **CSMA (Channel Sense Multiple Access)**
    - **1-persistent; p-persistent; non-persistent.**
  - **CSMA/CD (channel sense + collision detection)**
  - **CSMA/CA (channel sense + collision avoidance (real+virtual CS))**

Exercise

- **Task 1: ALOHA**
  - **A group of N stations shares a single pure ALOHA channel with a transmission rate of 56 Kbps. The stations send their 1000-bit frames every 100 ms (including retransmissions).**
  - **At what value of N will the channel throughput be maximum?**
  - **Data:**
    - **$f = 10^{3}$ bits;**
    - **v = 56 Kbps;**
    - **$a = 100 * 10^{-3}$ sec.**

    - **From this, the frame time is: $T = f/v = 10^{3}/(56 * 10^{3}) = 1/56$ [sec] ;**

Exercise

- **Solution to Task 1:**
  - **Frame number per frame time for the *i* -th station (this is also the channel load of station**

$$G_i = \frac{T}{a} = \frac{\frac{1}{56}}{100 \cdot 10^{-3}} = \frac{10}{56} \quad \text{[frame/frame\_time]}$$

  - **Since there are N identical stations, the total channel load is:**

$$G = \mathrm{N} \cdot G_i = \mathrm{N} \cdot \frac{10}{56}$$

  - **And the throughput (pure ALOHA):**

$$S = G \cdot \left(1 - \frac{G}{\mathrm{N}}\right)^{2 \cdot (\mathrm{N}-1)} = \mathrm{N} \cdot \frac{10}{56} \cdot \left(1 - \frac{10}{56}\right)^{2 \cdot (\mathrm{N}-1)} = \mathrm{N} \cdot \frac{10}{56} \cdot \left(\frac{46}{56}\right)^{2 \cdot (\mathrm{N}-1)} \quad \text{[frame/frame\_time]}$$

  - **Question: What kind of N is this maximal for? We derive it with respect to N:**

$$\frac{dS}{d\mathrm{N}} = \frac{10}{56} \cdot \left(\frac{46}{56}\right)^{2 \cdot (\mathrm{N}-1)} + \mathrm{N} \cdot \frac{10}{56} \cdot \left(\frac{46}{56}\right)^{2 \cdot (\mathrm{N}-1)} \cdot \ln\left(\frac{46}{56}\right) \cdot 2 = 0$$

$$(a^x)' = a^x \cdot \ln a; \qquad (f \cdot g)' = f' \cdot g + f \cdot g'$$

  - **Of which:**

$$0 = 1 - \mathrm{N} \cdot 0{,}394$$

  - That is, N = 2.54. N can only be an integer, so N = 2; or N = 3.
  - If we want to know , let 's calculate the S's for the possible N's!
  - N=1, S=0.178; N=2, S=0.241; **N=3, S=0.244 (This is the maximum!);** N=4, S=0.219 .

Exercise

- **Task 2: Slotted ALOHA**
  - **Ten thousand airline reservation stations compete for use of a single slotted ALOHA channel.**
  - **A station transmits 18 requests (frames) per hour.**
  - **One slot is 125μsec.**
    (This is the frame time: [μsec/slot] = [μsec/frame time]).
  - **What is the approximate channel load?**
  - **Data:**
    - **$N = 10^4$; Slotted ALOHA**
    - **18 requests/hour = 18/(60*60) = 1/200 [requests/sec], or [frames/sec]**
    - **One slot (frame time) $125 \cdot 10^{-6}$ sec.**

Exercise

- **Solution to task 2:**
  - **The required throughput:**
  - **actually we are looking for *G* !**
  - **We know the throughput of slotted ALOHA:**
  - **replacing the value of *S with* this value :**

$$S_i = \frac{125}{200} \cdot 10^{-6} = 62{,}5 \cdot 10^{-8} \quad \text{[frame/slot]}$$

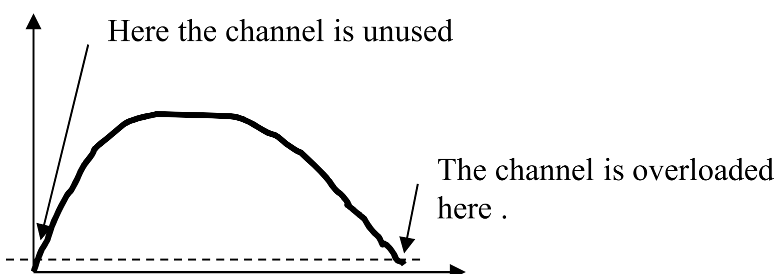
$$S = N \cdot S_i = 62{,}5 \cdot 10^{-4} \quad \text{[frame/slot]}$$

$$S = G \cdot \left(1 - \frac{G}{N}\right)^{N-1}$$

$$62{,}5 \cdot 10^{-4} = G \cdot \underbrace{\left(1 - \frac{G}{10^4}\right)^{10^4}}_{\cong 1 \text{, if } G \ll 1}$$

  - **Of which: G ≅ 62.5 10^{-4}**

  - **The S=62.5 10 $^{-4}$ throughput can include two *G* loads :**



Exercise

- **Task 3: Slotted ALOHA**
  - **Measurements of a slotted ALOHA system with an infinite population show that 10% of the slots are idle.**
    - **a) What is the channel load G?**
    - **b) What is the throughput S?**
    - **c) Is the channel underutilized or overloaded?**

Exercise

- **Solution to task 3:**
  - What we know: if $N \to \propto$, then $S = G * e^{-G}$
  - Note that in fact
    the throughput = channel load * probability of passage (p_0)
    formally: $S = G * p_0$
  - At the same time, this transition probability (p_0) is also the probability that the channel is idle (empty, since only in this case there are no collisions)
  - $S = G * e^{-G}$, $S = G * p_0 \Rightarrow p_0 = e^{-G}$.
  - That is, if the channel is 10% idle, then 0.1 = e^{-G}; and from this
  - a., $G = - \ln 0.1 = 2.3$
  - b., $S = G*p_0 = 2.3*0.1 = 0.23$
  - c., $G > 1$, so the channel is **overloaded**
    ($S_{\max}$ =0.368 , $G = 1$, if $N \to \propto$)