ALOHA Class of Multiple Access Protocols

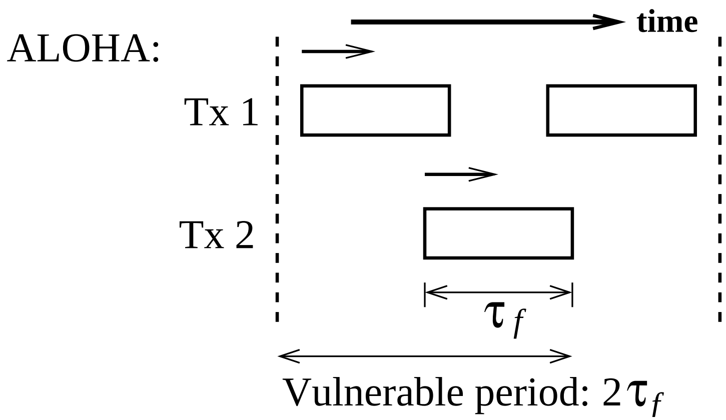
- **ALOHA**, also called pure ALOHA: Whenever a user has a frame to send, it simply transmits the frame. If collision occurs, it waits for a random period of time and re-sends it again
  - Sender can always find out if its frame was destroyed by listening to channel. For a LAN, feedback is immediate, while for a satellite there is a long delay of 270 ms before sender knows
  - If listening while transmitting is not possible, ACKs are needed, e.g. in packet radio, collision from simultaneous transmissions of multiple transmitters is detected by base station, who sends out ACK or NAK accordingly (via reverse channel)
- **Performance**: throughput S (frames/s) which defines average number of frames successfully transmitted per unit time, and average delay D (s) experienced by a frame
- Assuming average frame length τ_f (s) and fixed channel rate, frame transmission can be modelled by Poisson distribution with mean arrival rate λ (frames/s)

Normalised channel traffic or average number of old and new frames submitted per frame time is

$$G = \lambda\tau_f \quad \text{(unit in Erlang)}$$

The throughput is then given by

$$S = G \times \text{Prob(no collision)}$$



ALOHA Class (continue)

- **Slotted ALOHA**: time is divided into slots of equal length greater or equal to average frame duration τ_f, and frame transmission can only start at beginning of a time slot
- Probability that a frame does not suffer from a collision is given by

$$P_0 = \begin{cases} e^{-2G}, & \text{ALOHA} \\ e^{-G}, & \text{slotted ALOHA} \end{cases}$$

  The throughput/frame time is then

$$S = \begin{cases} G \cdot e^{-2G}, & \text{ALOHA} \\ G \cdot e^{-G}, & \text{slotted ALOHA} \end{cases}$$

- Maximum throughput of ALOHA:

$$\frac{dS}{dG} = e^{-2G} - 2Ge^{-2G} = 0 \Rightarrow G_{\max} = \frac{1}{2} \Rightarrow S_{\max} = \frac{1}{2}e^{-1} = 0.1839$$

  Maximum throughput of slotted ALOHA:

$$\frac{dS}{dG} = e^{-G} - Ge^{-G} = 0 \Rightarrow G_{\max} = 1 \Rightarrow S_{\max} = e^{-1} = 0.3679$$

- ALOHA class is simple to implement but efficiency is low. By listening before transmitting, lots of collisions can be avoided $\longrightarrow$ carrier sense multiple access (CSMA)

Carrier Sense Multiple Access

- A user wishing to transmit first listens to the medium to see if another transmission is in progress (carrier sense)

  If the channel is in use, it must wait. If the medium is idle, it may transmit

  - **1-persistent**: a user keeps listening to see if channel is free and, as soon as the channel is idle, it transmits
  - **Nonpersistent**: when the channel is busy, it waits for a random period of time before trying to listen again. This is less greedy
  - **p-persistent**: for slotted systems. When the channel is free during current slot, it may transmit with probability p or may defer until next slot with probability $1 - p$

- **Detection** or sensing **delay** is determined by receiver hardware: a small detection time means that a user can detect a free channel rapidly

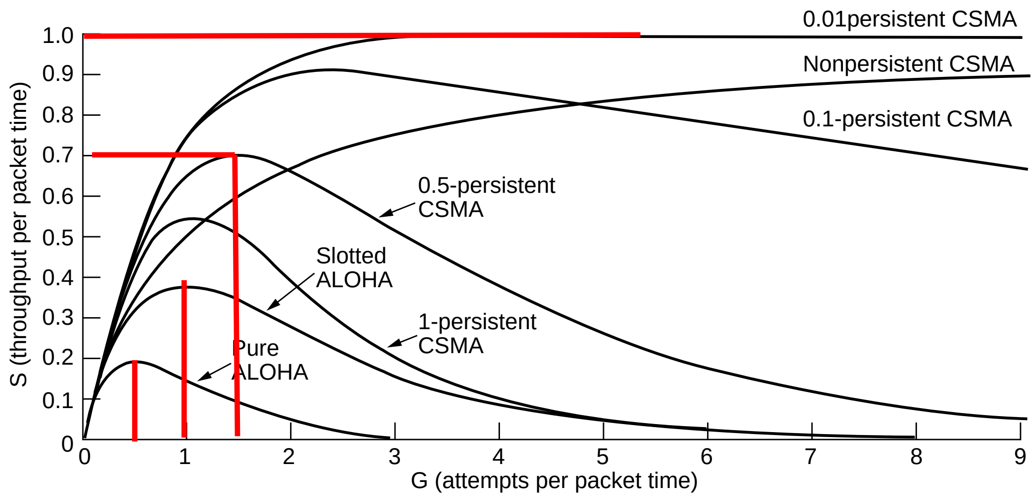
- **Propagation delay** is critical to performance: a small propagation delay means that as soon as a user launches a packet, others knows quickly and will defer to transmit, thus reducing collisions

- CSMA is effective for LANs, where propagation delay is usually very small compared with frame transmission, i.e. small link parameter a

- Performance of a random access scheme is specified by S versus G and D versus G

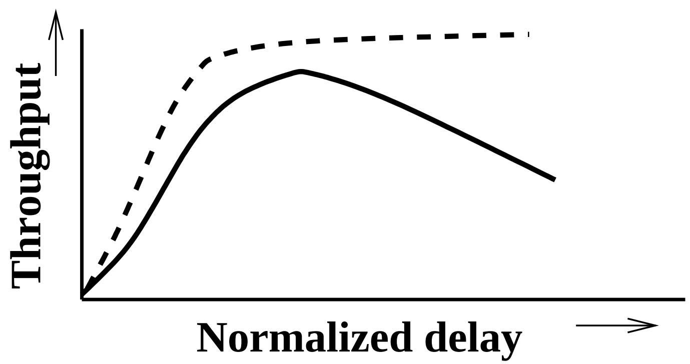
CSMA (continue)

- Throughput versus load:



  - For CSMA with small p, the method performs very well in terms of throughput at high load (almost 100%). However, for smaller p, users must wait longer (larger delay) to attempt transmission
  - In the extreme case: only single user wishes to transmit, expected number of deferring is $1/p$. If $p = 0.01$, at low load, a user will wait an average of 99 time slots before transmitting on an idle line
  - For low load, slotted ALOHA is preferred due to its low delay

- Trade-off **throughput** versus **delay**: multiple access protocol with the characteristics of dashed curve is preferred



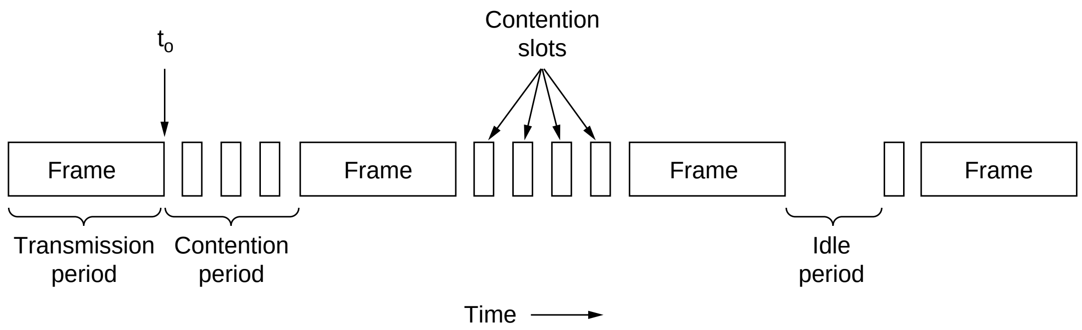
- Better performance can be achieved if user continues to listen to medium while transmitting and stops transmission immediately if collision is detected → CSMA with collision detection

CSMA with Collision Detection

- A user wishes to transmit:
  1. Listens to see if the channel is free. If the channel is idle, it transmits. If the channel is busy, it keeps listening until the channel is free, then transmits immediately (1-persistent)
  2. During the transmission, it keeps listening to detect collision. If a collision is detected, it stops transmitting immediately, and waits a random period of time before goes back to step **1**.
- States of CSMA/CD:

  transmission period, contention period and idle period

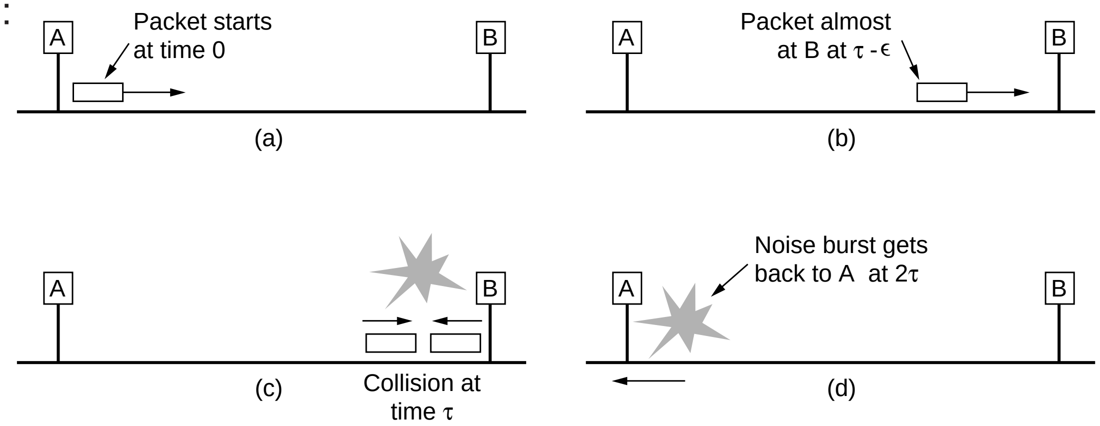
  Let τ be **end-to-end** (two farthest users) **propagation time**



- Worst case time to detect collision is 2τ:

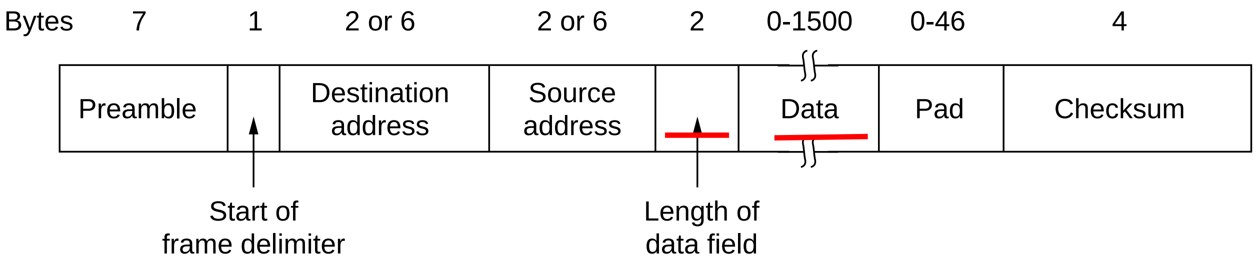
  Frames should be **long** enough to allow collision detection prior to the end of transmission, otherwise CSMA/CD degrades to CSMA

  Binary exponential backoff is used: when repeatedly facing collisions, mean value of random delay is doubled



MAC for IEEE 802.3 Ethernet

- IEEE 802.3 Ethernet uses 1-persistent CSMA with CD and the frame format is:



  - **Preamble**: seven 10101010 for receiver and sender clock synchronisation
  - **Start of frame delimiter**: 10101011, 1-byte frame flag
  - **Address**: 48 bits, the 1st bit is 0/1 for ordinary/group address and the 2nd bit is 0/1 for global/local address, and address consisting of all 1 bits is for broadcast
  - Frame $\geq$ worst-case time to detect collision. For 10-Mbps Ethernet specification with maximum cable length 2.5 km and 4 repeaters, minimum frame time is 51.2 μs $\longrightarrow$ minimum 64 bytes
  - **Data length** and **pad**: If length of data is less than 46 bytes, pad field is filled out to achieve minimum frame size of 64 bytes. This in turn requires to indicate actual data length
- MAC frame does not have control field and hence no sequence number $\longrightarrow$ it alone can only offer unacknowledged connectionless datagram services
- For connection-oriented services or for error and flow control $\longrightarrow$ LLC protocol "frames" are inserted in data fields of MAC frames
- LLC is very similar to HDLC, with address, control and data fields but no frame flag and checksum: completed layer-2 frame is MAC frame, which already has frame flag and frame checksum

CSMA with CD Performance

- Let R be data rate (bps), d be end-to-end link distance (m), V be propagation velocity (m/s), and L average frame length (bits). The **link parameter** is defined as:

$$a = \frac{\text{propagation time}}{\text{frame time}} = \frac{R\,d}{L\,V}$$

- Maximum possible **utilisation** of the channel is expressed as the **ratio of throughput to capacity**
- View time in "slots", with slot length 2τ and $\tau = \frac{d}{V}$ being end-to-end propagation time
- Recall CSMA/CD model: transmission, contention and idle periods. Under heavy load assumption $\longrightarrow$ no idle time
- Let T_t be average transmission interval and T_c be average contention interval. The maximum utilisation or efficiency is given by

$$U = \frac{T_t}{T_t + T_c}$$

- Since $T_t = \frac{1}{2a} \times 2\tau$ and it can be shown $T_c = e \times 2\tau$,

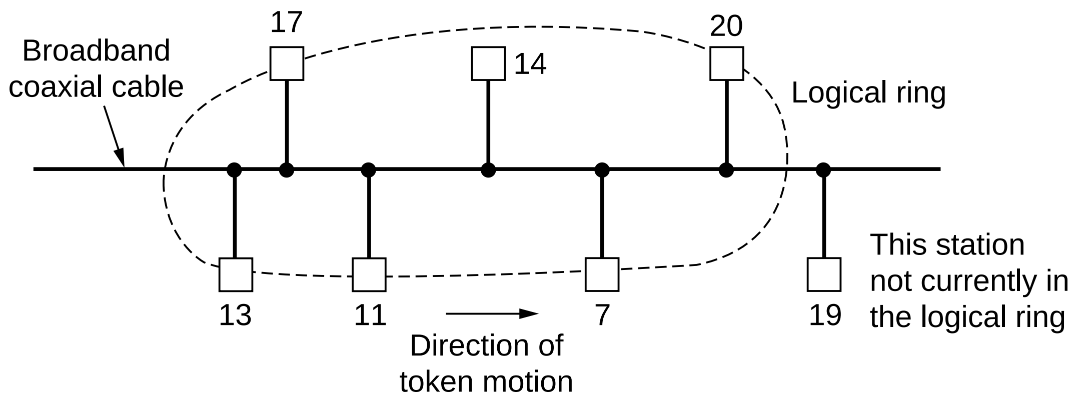
$$U = \frac{1}{1 + 5.44a}$$

- **Example**. Guided media $V = 2 \times 10^8$ (m/s), 10 Mbps LANs (Ethernet) with $\tau = 25.6$ μs: Frame length 64 bytes $\Rightarrow U = 0.27$, and frame length 1024 bytes $\Rightarrow U = 0.85$

IEEE 802.4 Token Bus

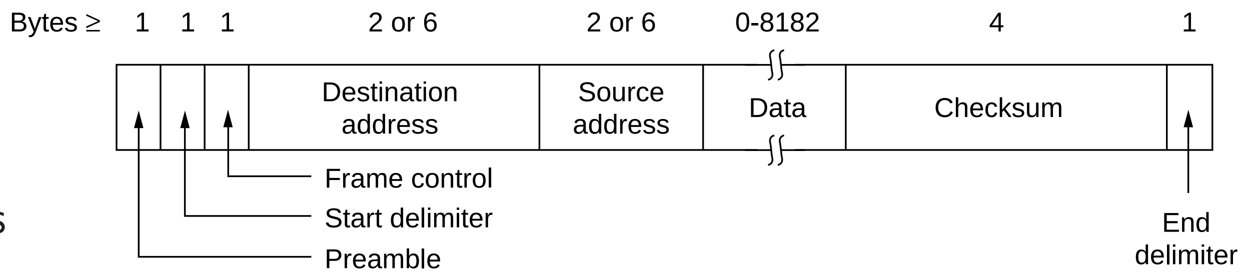
- Contention protocol in IEEE 802.3 Ethernet is stochastic, i.e. worst case waiting may be unbounded. Some applications prefer known or fixed worst case waiting $\longrightarrow$ round-robin

- **Token bus**: physically all users are connected to a bus (as in Ethernet) but they are logically organised in a ring



- Special control frame, token, is handed from user to user in turn. User currently holding token may transmit

- **Token bus MAC**:
  Frame control: indicates whether a frame is data or control

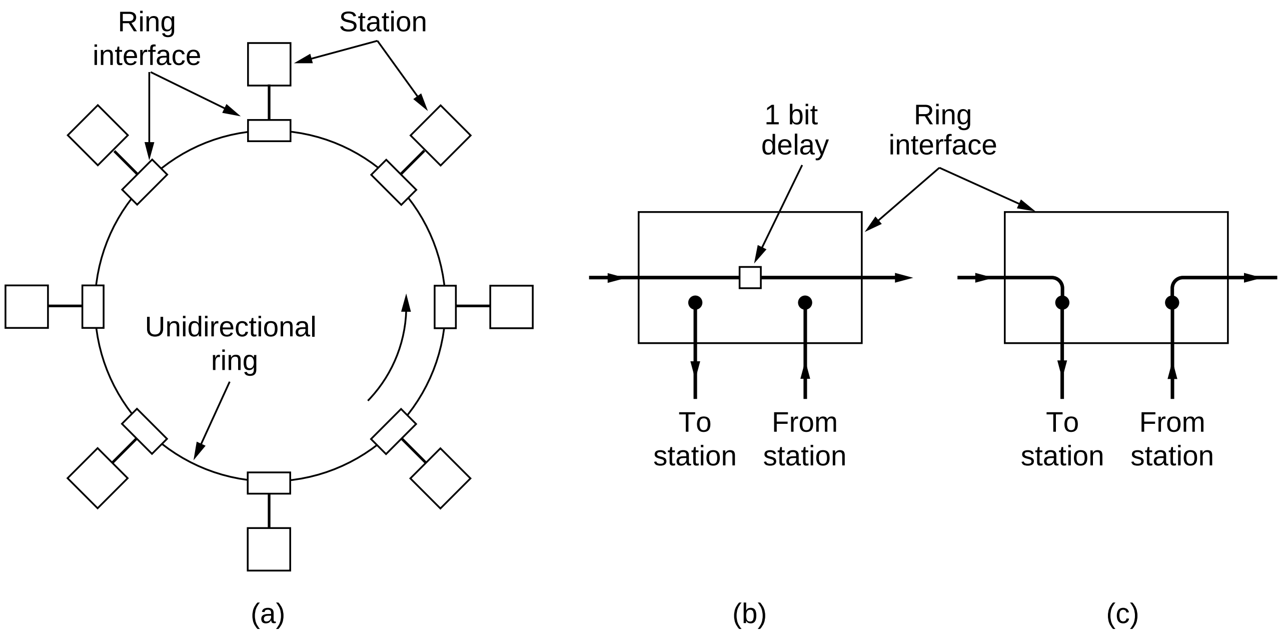


  – For data, frame control contains the frame's priority and a frame status indicator for destination to acknowledge correct or incorrect receipt of the frame. Otherwise destination would not be allowed to do anything since it does not have token
  – For control, it indicates type of control frame, such as claim token during initialisation, allow new stations to enter, recover from token loss, resolve contending stations for position, actual token, allow stations to leave

IEEE 802.5 Token Ring

- Token bus has very high complexity, much to do with converting a physical bus into a logical ring
- **Token ring**: Why make thing difficult? $\longrightarrow$ Just physically connect stations into a ring
- **Bit physical length**: Let the data rate be R Mbps and propagation speed 200 m/μs $\longrightarrow$ A bit lasts $1/R$ μs or has a length $200/R$ m

  e.g. for $R = 4$ Mbps, bit physical length is 50 m



- **Ring physical length** in bits must be large enough to contain token

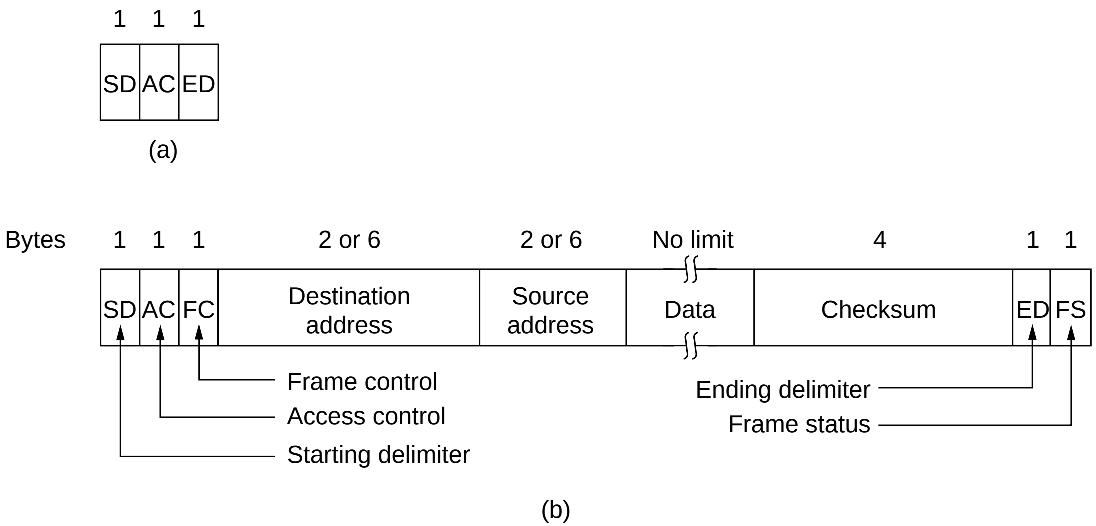
  e.g. 1 km ring with $R = 4$ Mbps, ring physical length is 20 bits, not enough for a 24-bit token

  If ring physical length is too small $\rightarrow$ insert artificial delay to increase it

- Characteristics: for 802.3 Ethernet bus, a minimum frame length is required; for 802.5 token ring, a minimum ring physical length is required

802.5 Token Ring (continue)

- **MAC for token ring**: with token/frame format as follows, 3-byte token circulates around the ring
  - User wishing to transmit must wait for token to arrive and captures it (turns token into 3 bytes of a normal frame)
  - It can then transmit and, when transmitted frame bits circulate back to sender, it removes them
  - After user has finished Tx, it regenerates and releases token



- **Access control**: contains token bit (0 for token, 1 for frame), monitor, priority and reservation bits
- **Frame control**: indicate data or control frame, latter for ring maintenance/fault management
- **Token holding time**: a user is allowed to hold token for THT, default value 10 ms
- **Frame Status**: contains A (address recognised) and C (frame copied) bits, both are reset to logic 0 at sender
  - When receiver recognises destination address as its own, it sets A to logic 1, and if receiver is able to copy frame, it sets C to logic 1 $\longrightarrow$ This provides automatic ACK for each frame, otherwise receiver cannot do anything as it does not have token

Token Bus and Ring MAC Performance

- Assume n active users and recall the definition of link parameter a
- Maximum utilisation or efficiency is

$$U = \begin{cases} \frac{1}{1+a/n}, & a < 1 \\ \frac{1}{a(1+1/n)}, & a > 1 \end{cases}$$

- Under a heavy load assumption, $n \to \infty$,

$$U = \begin{cases} 1, & a < 1 \\ \frac{1}{a}, & a > 1 \end{cases}$$

- Comparison of three LANs
  - 802.3, 802.4 and 802.5 use roughly similar technology and get roughly similar performance
  - Under most circumstances, all three perform well
  - 802.3 Ethernet is most popular
  - Three standards have three different frame formats $\rightarrow$ Bridging them can have serious difficulties

Issue	802.3	802.4	802.5
Performance	OK	OK	OK
Simplicity	yes	no	yes
deterministic	no	yes	yes
Priorities	no	yes	yes
Heavy-load Perf	bad	good	good
Reliability	OK	very good	good
User base	large	small	large

Summary

- For broadcast networks, data link layer is divided into medium access control and logical link control sublayers: LLC deals with point-to-point connection issues, and MAC deals with how to access shared medium
- Three medium access strategies are: contention (random access); round-robin and reservation (scheduled access)
- Contention methods: ALOHA, slotted ALOHA, CSMA, CSMA with CD
- Ethernet: CSMA with CD, frame time must be no less than $2\times$ end-to-end propagation delay $\rightarrow$ minimum frame length
- Token bus and ring standards (round-robin based): bit has a physical length and therefore minimum ring length is needed
- Comparison of three LANs, how their MACs operate, frame formats, special features