0.1 Introduction

The medium access control (MAC) sublayer and the logical link control (LLC) sublayer together make up the data link layer.

The LLC sublayer provides multiplexing mechanisms that make it possible for several network protocols to coexist within a multipoint network and to be transported over the same network medium. It can also provide flow control and automatic repeat request (ARQ) error management mechanisms. The LLC sublayer acts as an interface between the media access control (MAC) sublayer and the network layer.

When sending data to another device on the network, the MAC block encapsulates higher-level frames into frames appropriate for the transmission medium, adds a frame check sequence to identify transmission errors, and then forwards the data to the physical layer as soon as the appropriate channel access method permits it. Controlling when data is sent and when to wait is necessary to avoid congestion and collisions. Additionally, the MAC is also responsible for compensating for congestion and collisions by initiating retransmission if a jam signal is detected, and/or negotiating a slower transmission rate if necessary.

0.2 Multiple Access Links

- **Point to Point** (single wire):
  - PPP for dial-up access;
  - Point-to-point link between Ethernet switch and host;
- **Broadcast** (shared medium, wired or wireless):
  - old-fashioned cabled Ethernet;
  - 802.11 wireless LAN;

0.2.1 Ideal Multiple Access Protocol

Used to coordinate the stations to use a common broadcast and shared channel of rate R bit/s.

- **one** station wants to transmit -> it uses the **R** bit/s;
- **m** stations want to transmit -> each station uses an average rate **R/m** bit/s
- **simple** and **decentralized** (no coordination, no synchronization of clocks).

0.2.2 MAC Model and Concepts

Independent Traffic: The model consists of N independent stations, each with a program or user that generates frames for transmission. The expected number of frames generated in an interval of length g is d*g, where d is a constant.Once a frame has been generated, the station is blocked and does nothing until the frame has been successfully transmitted. To analyze the protocols it uses Poisson Models.
Single Channel: A single channel is available for all communication. All stations can transmit on it and all can receive from it
Collision: Happens if two frames are transmitted simultaneously by different stations. A collided frame must be transmitted again later
Continuous Time: frame can be transmitted at any time.
Slotted Time: frame can be transmitted only at the beginning of a time slot.
Carrier Sense: station can know if medium (channel) is busy before using it.
No Carrier Sense: station cannot sense channel before using it.
Poisson models

0.3 MAC Protocols

The MAC Protocols can be separated into Three Classes: Channel Partitioning, Random Access and Taking turns.

0.4 Channel Partitioning

Divide channel into smaller "pieces"(time slots,frequency).
The communication resource is partitioned in N channels that are assigned to stations is a quasi-static way.
Poor efficiency on low loaded channels.
The principle protocols are:

- Time Division Multiplexing;
- Frequency Division Multiplexing.

0.5 Random access protocols

- Each station tries to access the full communication resource in a random, uncoordinated manner -> collisions occur;
- Poor efficiency on highly loaded channels;
- When station has packet to send a packet,transmits at channel data rate **R** bit/s.
- Random Access MAC protocol defines:
  - when to send data;

- how to detect collisions;
- how to recover from collisions.

0.5.1 Pure ALOHA

Aloha is a technique for coordinating the access of large numbers of intermittent transmitters in a single shared communication channel.

- In Aloha, whenever a station has data, it transmits it;
- If more than one frames are transmitted, they collide and are lost. The Sender finds out whether the transmission was successful or experienced a collision by listening to the broadcast from the destination station;
- If ACK (signal that data has been received successfully) not received within timeout, then a station picks random backoff algorithm to re-transmit;
- After the backoff time, the station re-transmits the frame.

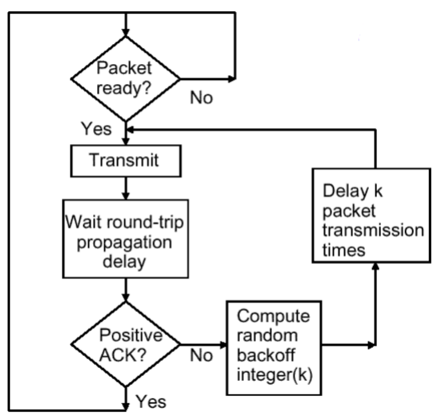


Figura 1: Station behaviour

0.5.2 Slotted ALOHA

In the Slotted ALOHA, the time is divided into time slots and each slot corresponds to one frame.
A station is not permitted to send whenever the user types a line. Instead, it is required to wait for the beginning of the next slot and the stations transmit frames only at the beginning of a time slot.
This method causes a reduction on the collision probability.

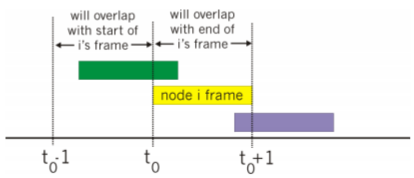


Figura 2- Pure ALOHA

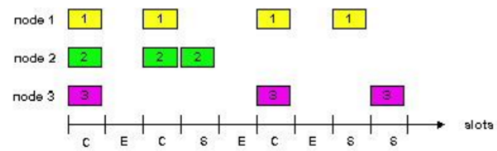


Figura 3- Slotted ALOHA

ALOHA Efficiency:

- Traffic model
  - » Poisson arrival, large number N of stations
  - » Constant frame length, $T_{frame}=1$
  - » S – Received traffic

    λ_{rx} – rate of received frames (transmitted with success)

    $S=\lambda_{rx} * T_{frame} < 1$; **S = efficiency**
  - » G – Generated traffic (new packets and retransmissions)

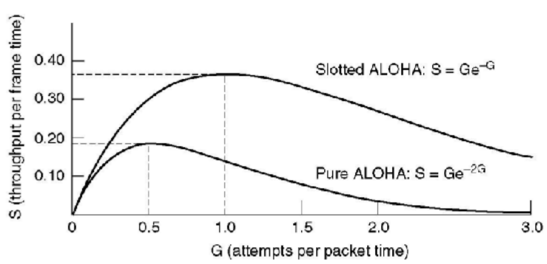
    λ – rate of generated packets

    $G=\lambda * T_{frame}$
  - » p – probability of **one station** generating a packet (new or retransmission) in T_{frame}

    N*p=G

- Slotted Aloha
  - » $S = P(Success) = N\left(p(1-p)^{N-1}\right) \approx Npe^{-p(N-1)} \approx Npe^{-pN} = Ge^{-G} = Gp_0(T_{frame}) = Ge^{-G}$
  - » $S_{\max} \Rightarrow \dfrac{\partial S}{\partial G} = 0; \quad G = 1; \quad S_{\max} = \dfrac{1}{e} = 36{,}8\%$

- Pure Aloha
  - » $S = Gp_0(2 \times T_{frame}) = Ge^{-2G}$
  - » $S_{\max} \Rightarrow \dfrac{\partial S}{\partial G} = 0; \quad G = \dfrac{1}{2}; \quad S_{\max} = \dfrac{1}{2e} = 18{,}4\%$



0.5.3 CSMA (Carrier Sense Multiple Access)

Carrier-sense multiple access (CSMA) is a media access control (MAC) protocol in which a node verifies the absence of other traffic before transmitting on a shared transmission medium.
A transmitter attempts to determine whether another transmission is in progress before initiating a transmission using a carrier-sense mechanism. If a carrier is sensed, the node waits for the transmission in progress to end before initiating its own transmission.
Persistency - what to do after the medium is found busy

CSMA collisions:

- Collisions can still occur due to a propagation delay or because stations may not hear other transmissions;
- When a collision happens the station waits random time and repeats algorithm;
- Collision vulnerability time = 2*Tprop;
- Collision probability = a = Tprop/Tframe;

CSMA Variants:

- CSMA **1-persistent:** If the channel is idle (free), the stations sends its data. Otherwise, if the channel is busy, the station just waits until it becomes idle. Then the station transmits a frame.
- CSMA **Non-persistent:** If the channel is idle, the stations sends its data. Otherwise, if the channel is busy, the station waits a random time and repeats algorithm
- CSMA **p-persistent:** If the channel is idle, it transmits with a probability p. With a probability $q = 1 - p$, it defers until the next slot. If that slot is also idle, it either transmits or defers again, ith probabilities p and q. This process is repeated until either the frame has been transmitted or another station has begun transmitting. In the latter case, the unlucky station acts as if there had been a collision. If the station initially senses that the channel is busy, it waits until the next slot and applies the algorithm above.

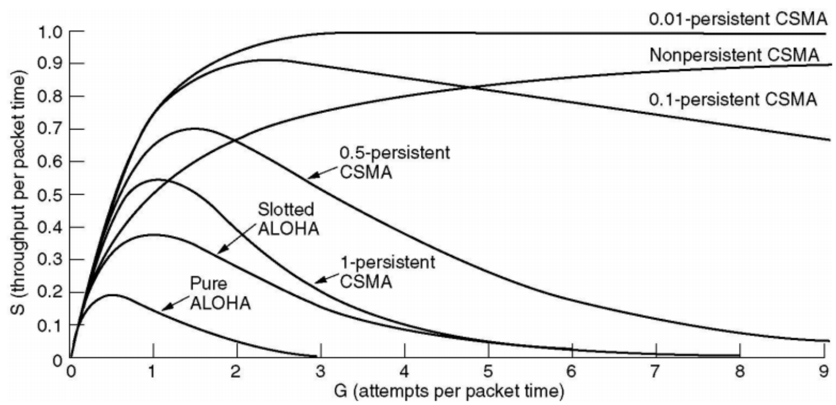


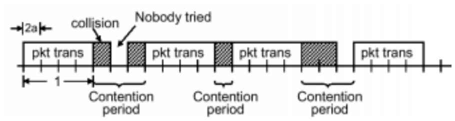
Figura 2: Efficiencies

0.5.4 CSMA with Collision Detection (CSMA/CD)

CSMA/CD operates by detecting the occurrence of a collision. Once a collision is detected, CSMA/CD immediately terminates the transmission thus shortening the time required before a retry can be attempted. The last information can be re-transmitted.
CSMA/CD is used by Ethernet.

- **Carrier Sense:** Station senses medium before transmitting. If free, station starts transmission. If busy, waits until its free and then transmits (= 1-persistent)
- **Collision Detection:** If collision is detected,the transmission is aborted and the re-transmission is delayed using a Binary Exponential Back-off algorithm.
- **Binary Exponential Back-off algorithm:**
  - Time is modeled in time slots and each Tslot= 2*Tprop;
  - After the i consecutive collision -> waits a random number of slots uniformly distributed in [0, 2i-1] and attemps to re-transmit.
- **Doesn't use ACK**.
- To detected a collision,**Tframe>2*Tprop**.

CSMA/CD - Efficiency



- Let's assume $T_{slot} = 2 \times T_{prop}$, $T_{frame} = 1$
- Number slots $\boldsymbol{n_{tx}}$ required to transmit a frame $n_{tx} = \frac{T_{frame}}{T_{slot}} = \frac{T_{frame}}{2 \times T_{prop}} = \frac{1}{2a}$
- Efficiency $S = \frac{n_{tx}}{n_{tx} + E[n_{cont}]}$
- Let's define
  - » p – probability that one station transmits in a slot
  - » A – probability that exactly one station transmits in a slot and gets the medium

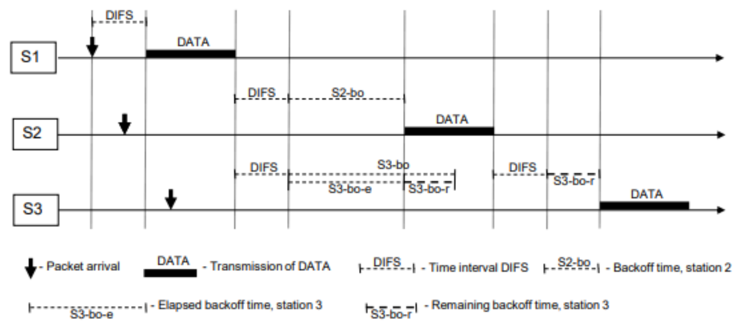
$$A = \binom{N}{1} p^1 (1-p)^{N-1} = Np(1-p)^{N-1}$$

- $E[n_{cont}] = \sum_{i=1}^{+\infty} i(1-A)^i A = \frac{1-A}{A} \quad \Rightarrow S = \frac{1/2a}{1/2a + (1-A)/A} = \frac{1}{1+2a(1-A)/A}$
- p=1/N ➔ $A_{MAX} = \left(1 - \frac{1}{N}\right)^{N-1} \quad \lim_{N\to\infty} A_{\max} = \lim_{N\to\infty}\left(1-\frac{1}{N}\right)^{N-1} = \frac{1}{e} \quad \Rightarrow \lim_{N\to\infty} S = \frac{1}{1+3.44a}$

0.5.5 CSMA with Collision Avoidance (CSMA/CA)

Carrier-sense multiple access with collision avoidance (CSMA/CA) is a network multiple access method in which carrier sensing is used, but nodes attempt to avoid collisions by beginning transmission only after the channel is sensed to be idle. When they do transmit, nodes transmit their packet data in its entirety. It is an unreliable method

- if medium free, transmits frame
- if medium busy:
  - Random backoff interval is selected which will be decremented as long as the channel is sensed idle;
  - Stopped when a transmission is detected on the channel;
  - Re-activated when the channel is sensed idle again for more than a DIFS;
  - The station transmits when the backoff time reaches 0.
- To avoid channel capture, station waits random backoff time between two consecutive frame transmissions, even if the medium is sensed idle in the DIFS time.
- **It uses ACKs**.



0.5.6 Taking-turns protocols

Tightly coordinate shared access to avoid collisions.
Usage of the communication resource is disciplined by some turning mechanisms.

- Each station has its own turn;
- Stations with more information to send, might have bigger turns;
- **Polling:**
  - Controlled by a master station which invites slave stations to transmit in turn.
  - **concerns**: polling overhead; latency; single point of failure (master).
- **Token passing:**
  - The stations will pass the control token from one station to next sequentially, warning which is able to transmit.
  - **concerns**: token overhead; latency; single point of failure (token).

0.6 MAC

The standard for wireless LANs is called IEEE 802.11, aka WiFi.
The most common type of wired LANs is called IEEE 803.2, aka Ethernet.

- 48 bit address
- Unique for each adaptor
- Broadcast address FF-FF-FF-FF-FF-FF

0.7 Ethernet

- Bus Topology :

  Popular in the mid 90s

  Stations in same collision domain

- Star Topology :

  Current Topology

  Active switch in center

  Each station runs individual Ethernet protocols

  Stations do not collide with each other

- **Full-Duplex**: The stations don't have to wait for each other and there is no collision. The CSMA/CD algorithm is not needed.

0.8 WiFi

- Bus Topology :

  Popular in the mid 90s

  Stations in same collision domain

- Star Topology :

  Current Topology

  Active switch in center

  Each station runs individual Ethernet protocols

  Stations do not collide with each other

0.9 Switch

- Link-layer device
- Forwards Ethernet frames
- Transparent to hosts
- Does not need to be configured
- Has forwarding table

0.9.1 When the Switch receives a frame:

- Records link associated with sending host
- index forwarding tabel using MAC destination address
- if entry is found in table

    if destination is on segment from which frame arrived,

    drop the frame

    else

    forward the frame on interface indicated else flood (forward on all but the interface on which the frame arrived)

0.10 Virtual LANs

- One bridge/switch simulates multiple LANs/broadcast domains
- One LAN may be extended to other bridges

0.11 Previous Exams Questions:

Dos protocolo de acesso aleatório ao meio estudados

Selecione uma opção de resposta:

- a. CSMA, o CSMA/CD e o CSMA/CA usam a trama de confirmação ACK.
- b. o Aloha, o CSMA e o CSMA/CD usam a trama de confirmação ACK.
- c. o Aloha, o CSMA e o CSMA/CA usam a trama de confirmação ACK. ✓

6. No protocolo de acesso ao meio **CSMA/CD**, quando uma estação emissora deteta uma colisão, esta estação

a) Continua a transmitir a trama até ao fim e retransmite a trama após espera de um número aleatório de *timeslots*.
b) Continua a transmitir a trama até ao fim e retransmite a trama de forma persistente no *timeslot* seguinte.
c) Aborta a transmissão da trama e retransmite a trama após espera de um número aleatório de *timeslots*.
d) Aborta a transmissão da trama e retransmite a trama de forma persistente no *timeslot* seguinte.

5. Assuma que 8 estações competem para aceder a um meio partilhado, que cada estação gera em média 1 pacote/s e que o meio é capaz de transportar 10 pacote/s. Neste cenário, sob o ponto de vista do atraso,

a) Um mecanismo de acesso aleatório (ex. CSMA/CD) é preferível a um mecanismo de TDMA.
b) Um mecanismo TDMA é preferível a um mecanismo de acesso aleatório.
c) Os dois tipos de mecanismos são equivalentes.
d) Nenhum dos dois tipos de mecanismos consegue comutar a quantidade de tráfego indicada.

5. Considere um meio partilhado por um conjunto de computadores. Assuma que a maior distância entre dois computadores é L [m] e que a informação se propaga no meio com uma velocidade S [m/s]. Assuma ainda que os computadores acedem ao meio usando o protocolo CSMA/CD (*Collision Detection*). Nesta situação, o tempo de transmissão T [s] de uma trama deve satisfazer a seguinte condição

a) $T < L/S$
b) $L/S < T < 2L/S$
c) $T > 2L/S$
d) Nenhuma das anteriores.

5. Considere a tecnologia de acesso ao meio *Carrier Sense Multiple Access* (CSMA), o tempo de transmissão de uma trama T_{frame} e o tempo de propagação de uma trama no meio partilhado T_{prop}. O CSMA usa-se em situações em que

a) $T_{frame} >> T_{prop}$.
b) T_{frame} é aproximadamente igual a T_{prop}.
c) $T_{frame} << T_{prop}$.
d) A sua utilização é independente da relação entre T_{frame} e T_{prop}.

6. Assuma um cenário composto por 2 computadores A e B implementando o protocolo de acesso ao meio CSMA/CD (*Collision Detection*), e interligados entre si através de um comutador Ethernet (switch igual ao do laboratório). As portas de rede dos computadores e do comutador funcionam em modo **full-duplex**. Se o computador A estiver a transmitir uma trama e o computador B também tiver uma trama para transmitir, o computador B

a) Escuta até ao fim da transmissão de A e só depois transmite a sua trama.
b) Transmite de imediato a sua trama causando uma colisão.
c) Transmite de imediato a trama mas só haverá colisão se a trama enviada por A tiver como destino B.
d) Transmite de imediato e não haverá colisão.

Quando uma trama é recebida por um switch Ethernet e a tabela de encaminhamento do switch não contém uma entrada para o endereço de destino da trama, o switch

Selecione uma opção de resposta:

- a. lança um pedido na rede para que o computador de destino da trama anuncie a sua presença.
- b. envia a trama para todas as portas excepto a porta através da qual a trama foi recebida. ✓
- c. elimina a trama.