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  3. multiple access protocols, and
  4. examples implementations

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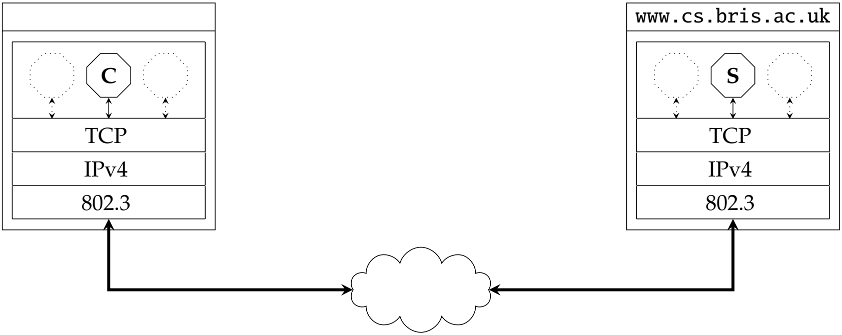

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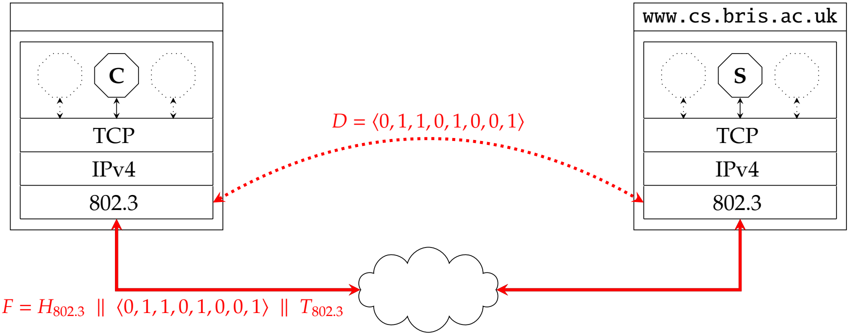

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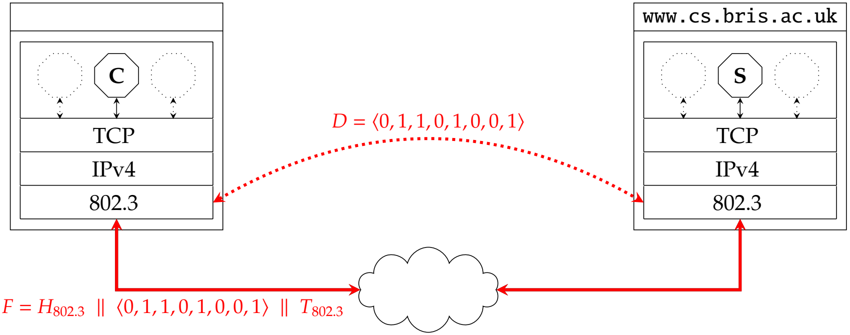
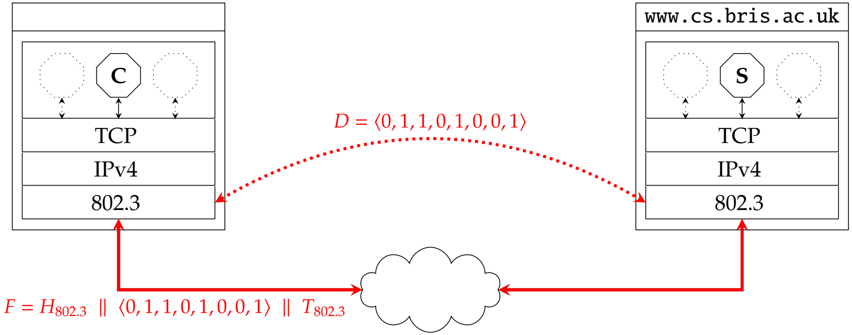
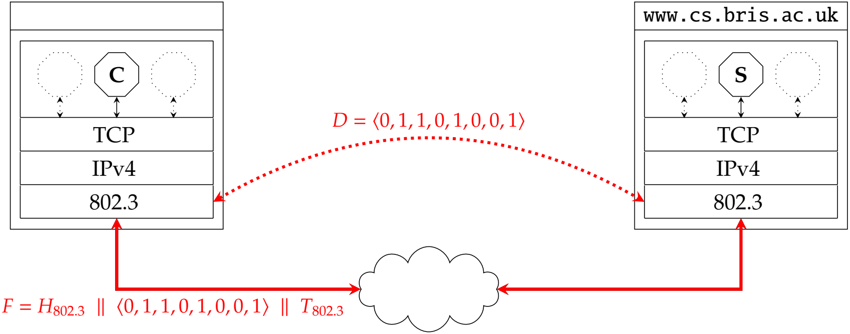


- In theory (per the OSI model): the link layer is composed of
  1. a higher-level **Logical Link Control (LLC)** sub-layer (e.g., 802.2) which interfaces with higher-level protocols, and
  2. a lower-level **Media Access Control (MAC)** sub-layer (e.g., 802.3) which manages the physical communication medium.

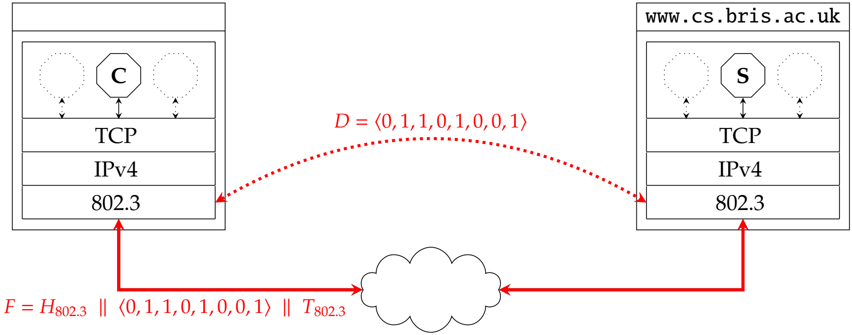


- In practice (per the Internet model [8, Section 2]):
  - separation of LLC and MAC sub-layers is less prescriptive, plus
  - if we only consider IPv4 and TCP above the link layer, the LLC sub-layer becomes very lightweight

  so we focus on the MAC sub-layer.



- In theory: the MAC sub-layer supports *either*
  1. point-to-point connections meaning dedicated access, *or*
  2. multi-point connections meaning shared access.

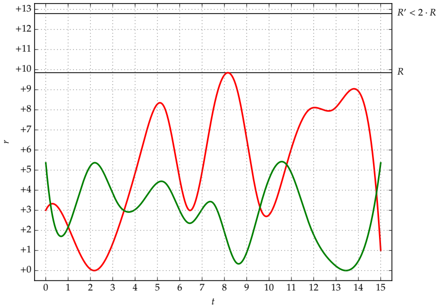


- In practice: point-to-point connections
  - prevents contention (i.e., require no management), *but*
  - imply a fixed topology which is hard to scale,
  - cannot support genuine broadcast transmission, plus
  - are likely to be under-utilised

so we focus on managing **multiple access** to a multi-point connection.

Concepts (1)

- Consider two hosts $\mathcal{H}_i$ and $\mathcal{H}_j$ communicating at some rate r:

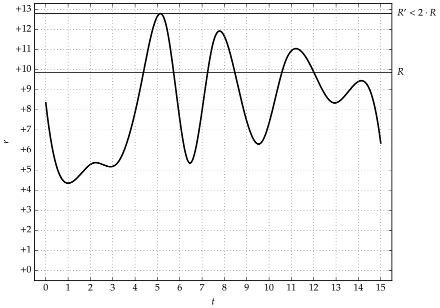


- Problem: how can we support shared access to a connection?
- Solution #1: use **static multiplexing**, i.e.,
  - assume a connection whose available bandwidth is $R > r$ for all t,
  - share that bandwidth, e.g., by using TDM or FDM

  noting this is ineffective if demand is "bursty".

Concepts (1)

- Consider two hosts $\mathcal{H}_i$ and $\mathcal{H}_j$ communicating at some rate r:

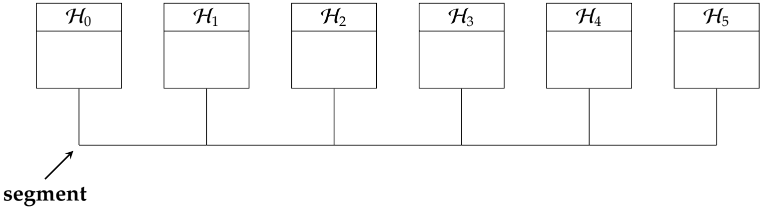


- Problem: how can we support shared access to a connection?
- Solution #2: use **statistical multiplexing**, i.e.,
  - assume a connection whose available bandwidth is $R' < 2 \cdot R$,
  - enforce a **multiple access protocol** that considers the *combined* rate at a given t, thus
  - *dynamically* sharing the bandwidth based on *demand*.

Concepts (3)

Definition (**segment**)

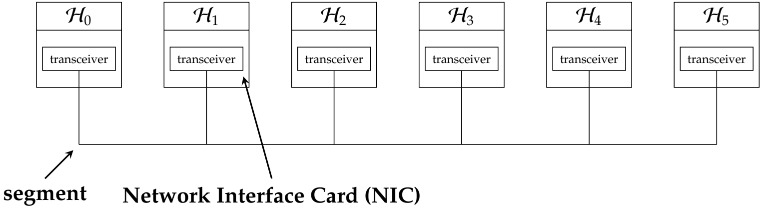
A network **segment** is a portion of said network, typically (but not necessarily, depending on the network type) understood as a portion on which attached hosts are physically connected.



Concepts (3)

Definition (Network Interface Card (NIC))

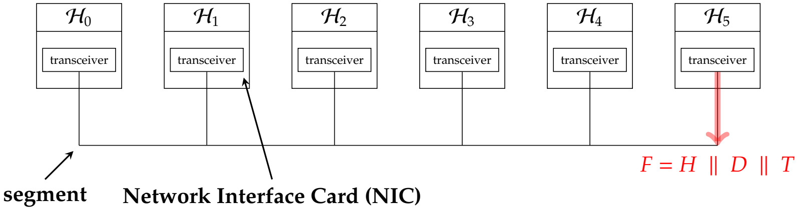
Each host is connected to a network segment via a transceiver, which we normally term a **Network Interface Card (NIC)**.



Definition (**frame** and **framing**)

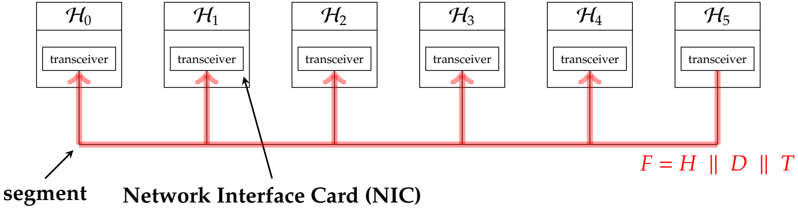
When a host wants to transmit some payload, it encapsulates it in a **frame** then presented to the physical layer: the act of **framing**

1. deliniate the start and end of the frame st. it can be parsed from an unstructured bit-sequence, and
2. adds relevant control information.



Definition (**broadcast domain**)

A **broadcast domain** is a logical (sub)division of a network st. all hosts within it can communicate with each other through use of broadcast transmission.

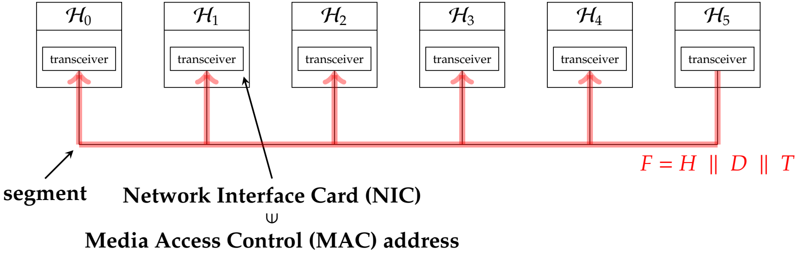


Definition (**Media Access Control (MAC) address**)

To disambiguate broadcast transmissions, each host is identified by a **Media Access Control (MAC) address**:

- typically hard-coded into NIC,
- needs to be unique wrt. broadcast domain,
- formed from an **Organisationally Unique Identifier (OUI)** and a NIC-specific identifier.

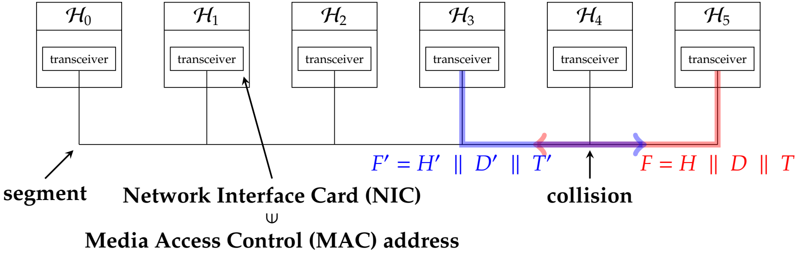
which form source/destination fields in the frame header. There is typically a reserved **broadcast address** allowing *all* hosts to receive a transmitted frame.



Concepts (3)

Definition (**collision** and **collision domain**)

A **collision domain** is a logical (sub)division of a multiple access network st. transmission by one host may **collide** (or interfere) with a (simultaneous) transmission by another. In general, collision domains are smaller than (i.e., contained within) an associated broadcast domain.

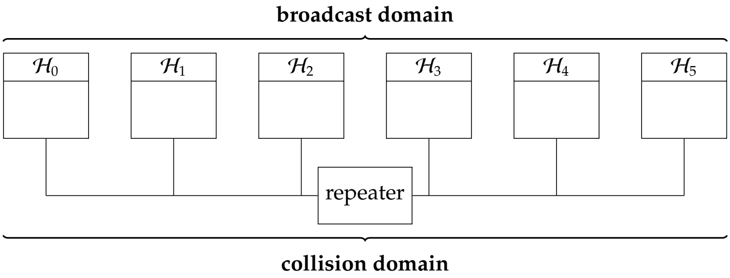


Definition (**repeater**, **bridge**, **hub** and **switch**)

Using a suitable component (or **network appliance**), e.g.,

1. a **repeater**,
2. a **bridge**,
3. a **hub**, or
4. a **switch**

one can connect multiple separate networks, or network segments, into a single aggregate network. These components a) operate in different layers, and so b) have somewhat differing capabilities and purposes.



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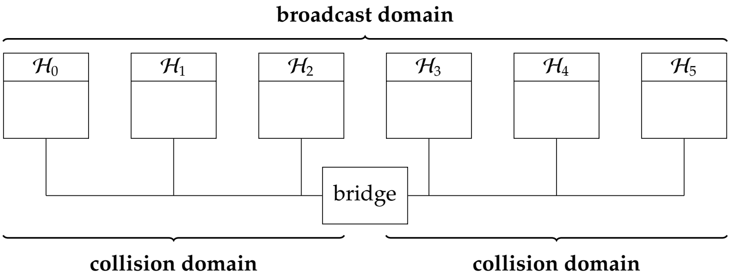

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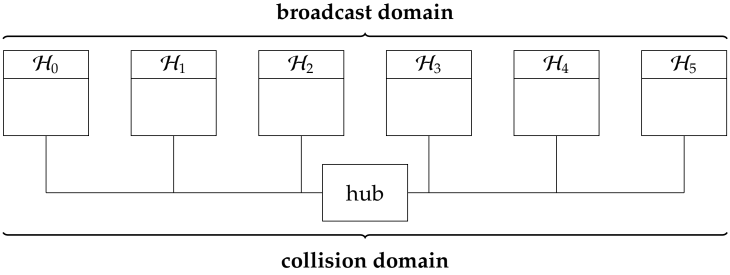

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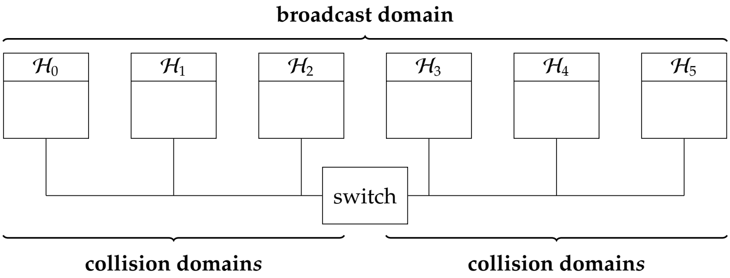


- 802.3 is based on a number of more general principles.
- In 802-like terminology:
  1. uses a p-persistent **Carrier Sense Multiple Access (CSMA)** protocol,
  2. reduces the cost of collisions via **Collision Detection (CD)**,
  3. reduces the probability of collision synchronisation via **Binary Exponential Back-off (BEB)**

  which is probably clear as mud!

802.3 (1)

- 802.3 is based on a number of more general principles.

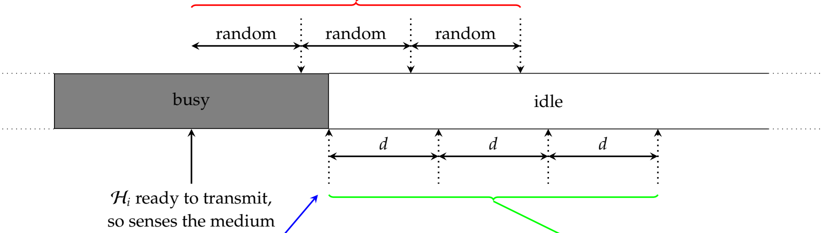
- In English:
  1. senses the medium, and transmits with probability p if idle,
  2. stops transmitting when a collision is detected,
  3. waits upto $2^m \cdot d$ time units when the m-th successive collision is detected

  which *hopefully* makes more sense.

802.3 (2) – CSMA/CD

0-persistent CSMA:

1. if idle, transmit immediately,
2. if busy, wait for random period then retry,
3. if collision, back-off then retry.



1-persistent CSMA:

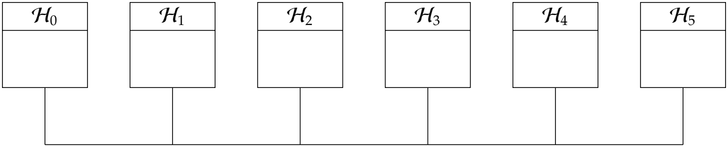
1. if idle, transmit immediately,
2. if busy, wait until idle.
3. if collision, back-off then retry.

p-persistent CSMA:

1. if idle,
   - with probability p transmit immediately, or
   - with probability $1 - p$ wait for d time units then retry
2. if busy, wait until idle.
3. if collision, back-off then retry.

802.3 (3) – CSMA/CD

- CSMA reduces but does not *eliminate* collisions:



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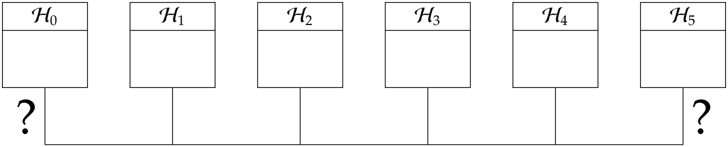

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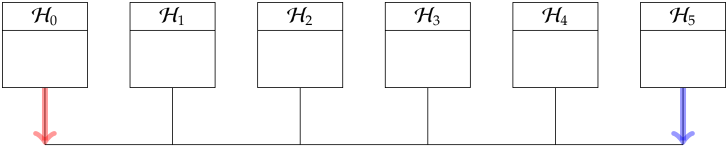

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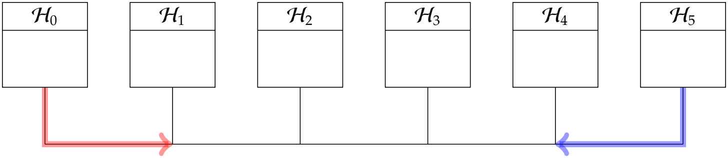

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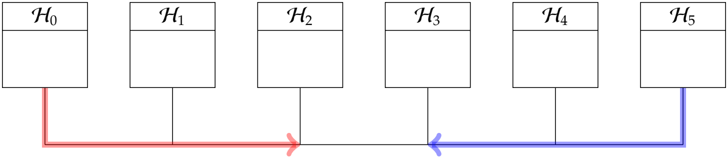

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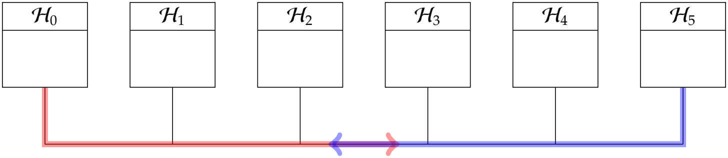

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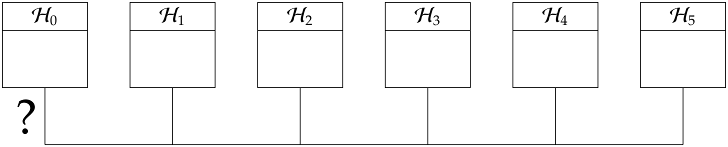

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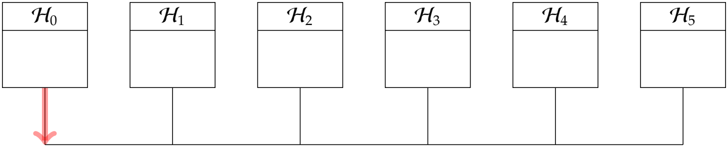

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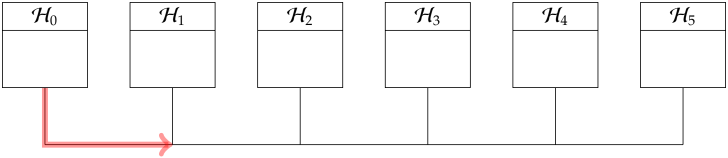

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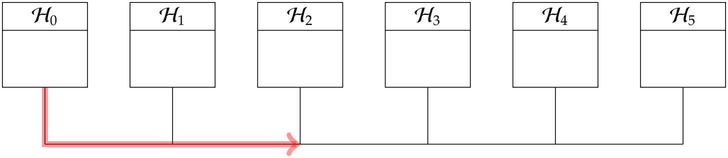

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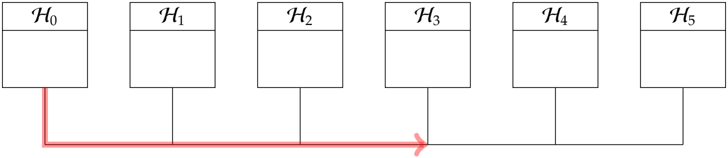

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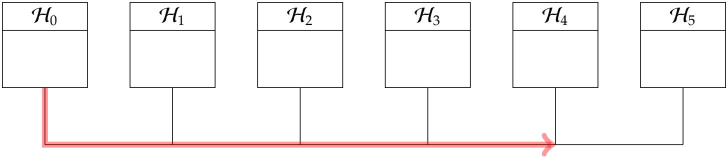

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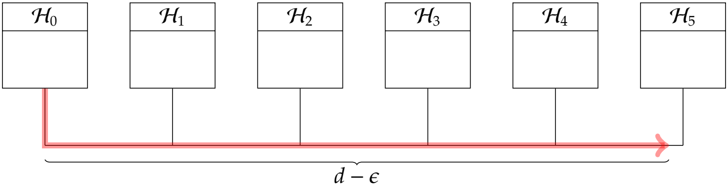

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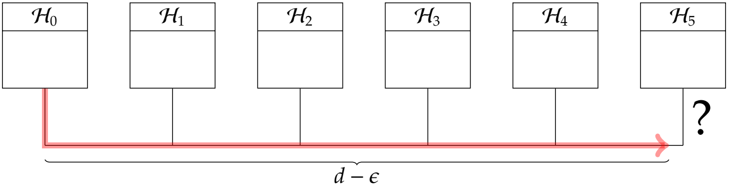

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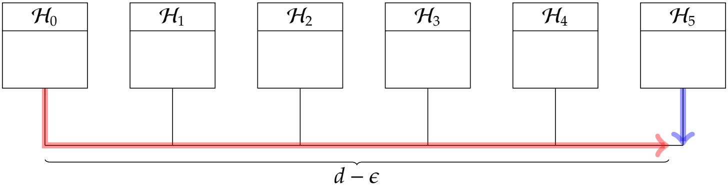

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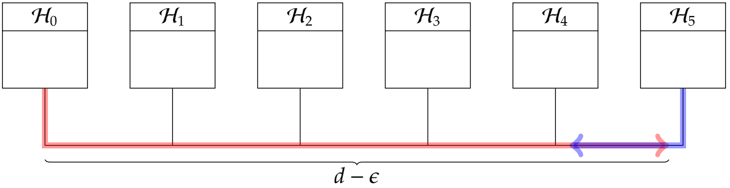

802.3 (3) – CSMA/CD

- CSMA reduces but does not *eliminate* collisions ...
- ... and, even then, the addition of collision detection via CSMA/CD

CSMA/CD:

1. if idle, follow appropriate CSMA persistence strategy,
2. if busy, follow appropriate CSMA persistence strategy,
3. if collision,
   - abort transmission,
   - transmit **jam signal**,
   - back-off then retry.

focuses on optimisation rather than elimination:

1. all hosts are guaranteed to detect each collision, so there is no need for acknowledgements, and
2. hosts can stop transmitting as soon as a collision is detected, so the medium is idle again sooner.

802.3 (4) – BEB

- Problem:
  - n hosts share access to the medium, and we ideally want 1 to transmit,
  - if each host transmits with probability $\frac{1}{n}$, then on average this satisfies the requirement ...
  - ... but we don't necessarily know what n is!
- Solution: BEB
  - estimate n, assuming more collisions implies larger n,
  - cater for low- and high-loads by starting optimistically, but allowing transmission probability to shrink quickly

  by (randomly) waiting upto $2^m \cdot d$ time units after m collisions.

802.3 (4) – BEB

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- Eh?! Basically,

$$\begin{array}{lclcl} 0 \text{ collisions} & \rightsquigarrow & \text{guess } n = 1 & \Rightarrow & \text{transmit immediately} \\ & & & \Rightarrow & \text{transmission probability is } \frac{1}{1} \end{array}$$

  then give up after ~ 16 attempts.

802.3 (4) – BEB

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- Eh?! Basically,

$$
\begin{array}{lclcl}
1 \text{ collisions} & \leadsto & \text{guess } n = 2 & \Rightarrow & \text{select } r \xleftarrow{\$} \{0, \ldots, 2^1 - 1\}\text{, wait for } r \cdot d \text{ time units} \\
 & & & \Rightarrow & \text{transmission probability is } \frac{1}{2}
\end{array}
$$

  then give up after ~ 16 attempts.

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  by (randomly) waiting upto $2^m \cdot d$ time units after m collisions.
- Eh?! Basically,

$$\begin{array}{lcl} 2 \text{ collisions} \rightsquigarrow \text{guess } n = 4 & \Rightarrow & \text{select } r \xleftarrow{\$} \{0, \ldots, 2^2 - 1\}, \text{ wait for } r \cdot d \text{ time units} \\ & \Rightarrow & \text{transmission probability is } \frac{1}{4} \end{array}$$

  then give up after ~ 16 attempts.

802.3 (4) – BEB

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  - n hosts share access to the medium, and we ideally want 1 to transmit,
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$$\begin{array}{lll} \text{3 collisions} \;\rightsquigarrow\; \text{guess } n = 8 & \Rightarrow & \text{select } r \xleftarrow{\$} \{0, \ldots, 2^3 - 1\}, \text{ wait for } r \cdot d \text{ time units} \\ & \Rightarrow & \text{transmission probability is } \frac{1}{8} \end{array}$$

  then give up after ~ 16 attempts.

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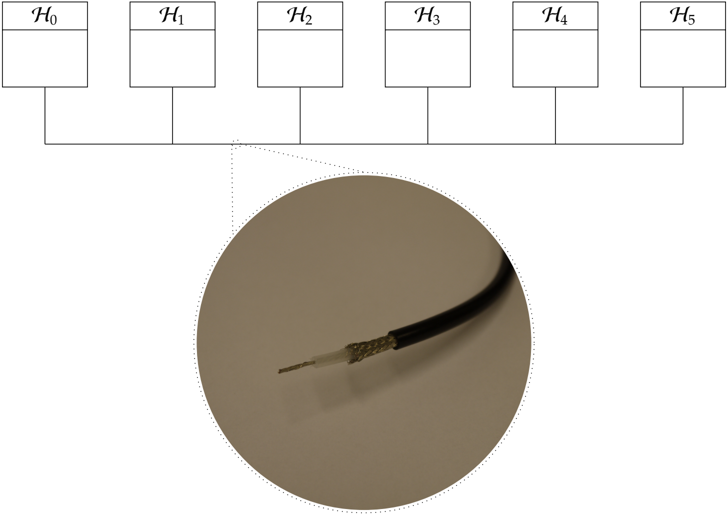
  by (randomly) waiting upto $2^m \cdot d$ time units after m collisions.
- Eh?! Basically,

$$
\begin{array}{lll}
m \text{ collisions} \rightsquigarrow \text{guess } n = 2^m & \Rightarrow & \text{select } r \xleftarrow{\$} \{0, \ldots, 2^m - 1\}, \text{ wait for } r \cdot d \text{ time units} \\
 & \Rightarrow & \text{transmission probability is } \frac{1}{m} \simeq \frac{1}{n}
\end{array}
$$

  then give up after ~ 16 attempts.

802.3 (6) – “classic” Ethernet

- Basically, “classic” Ethernet = 1-persistent CSMA/CD with BEB:



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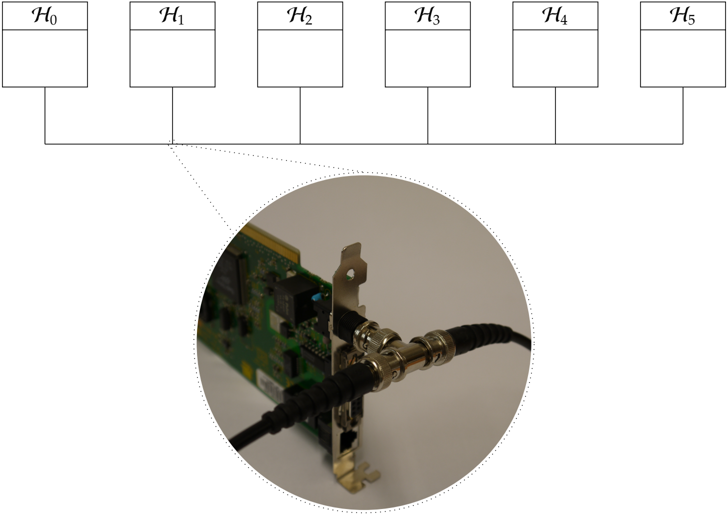
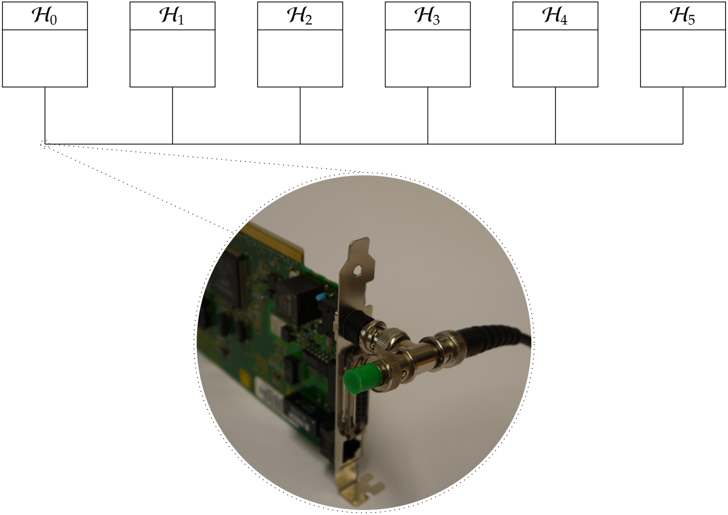


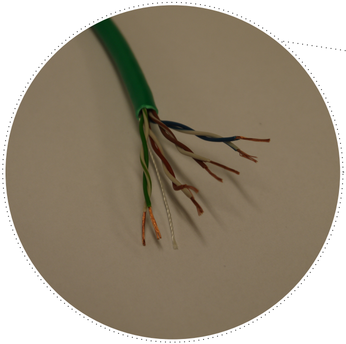
802.3 (6) – “classic” Ethernet

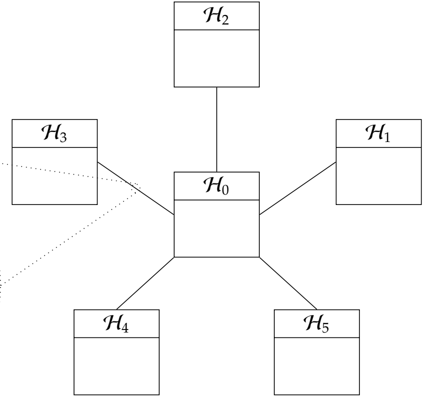
- Basically, “classic” Ethernet = 1-persistent CSMA/CD with BEB:



802.3 (7) – “modern” Ethernet

- Use of “modern” Ethernet differs significantly:





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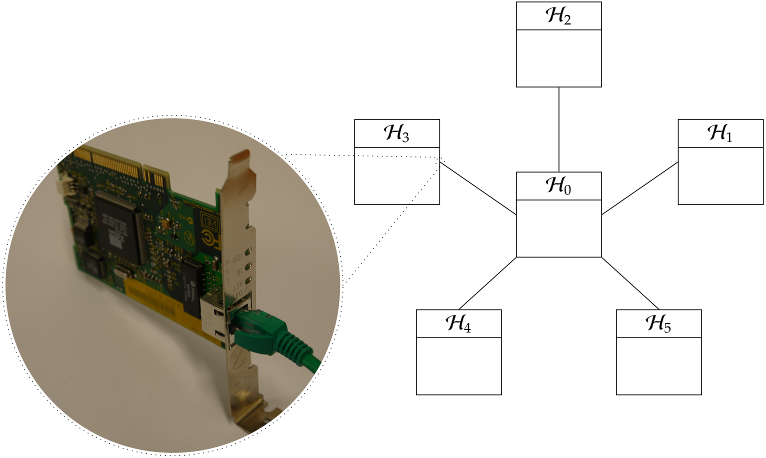
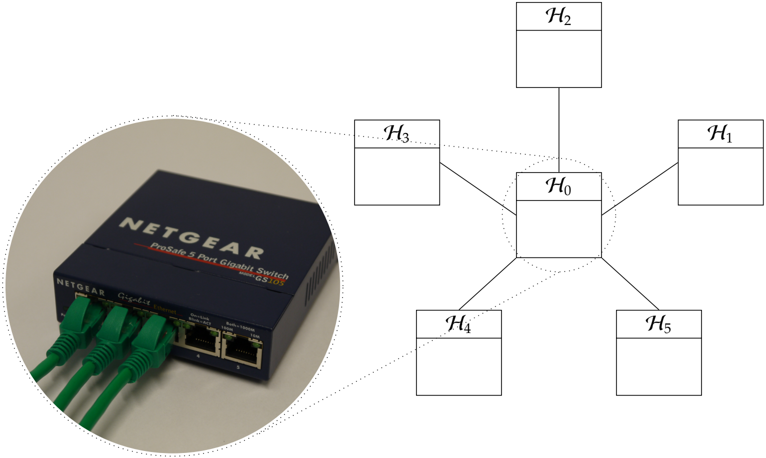


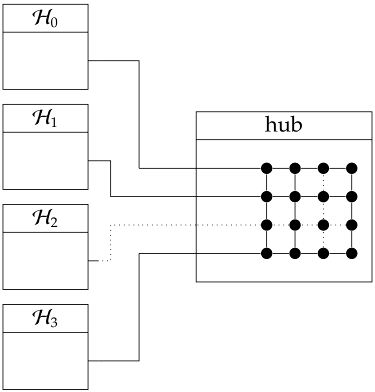
802.3 (7) – “modern” Ethernet

- Use of “modern” Ethernet differs significantly:

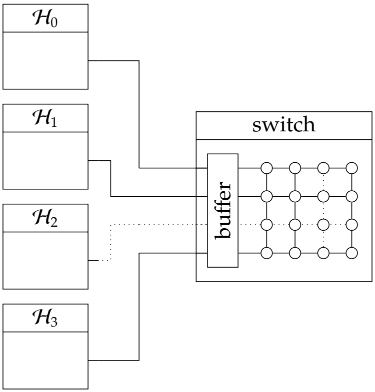


Daniel Page ⟨Daniel.Page@bristol.ac.uk⟩

802.3 (8) – “modern” Ethernet



- Note that:
  - operation of the switch is totally automatic, thus permitting flexible topology,
  - per port, i.e., per segment, everything uses CSMA/CD as normal,
  - get xMbit s^{-1} per *port* not shared across one segment, but
  - fails where topology includes cyclic connectivity!



Algorithm (backward learning)

1. Initialise
$$T[i] \leftarrow (\perp, \perp)$$
for each i-th entry.
2. Each time the switch receives a frame
$$F = H_{802.3}[\mathrm{src} = x, \mathrm{dst} = y] \parallel D \parallel T_{802.3}$$
on port p:
   - if $\exists i$ st. $T[i] = (y, p')$ then transmit F via port p' only,
   - otherwise broadcast F via *all* ports

   then

   - if $\exists j$ st. $T[j] = (x, p')$ then select that j-th entry
   - otherwise pick some unused j-th entry

   and update $T[j] \leftarrow (x, p)$.

- Note that:
  - operation of the switch is totally automatic, thus permitting flexible topology,
  - per port, i.e., per segment, everything uses CSMA/CD as normal,
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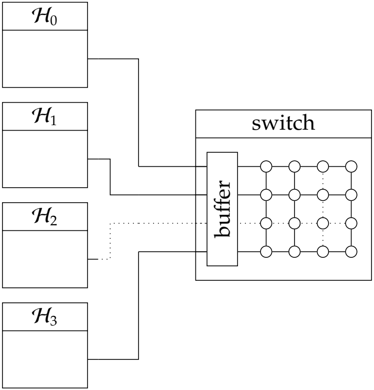
802.3 (8) – “modern” Ethernet



MAC address	port number
$\perp$	$\perp$
$\perp$	$\perp$
$\perp$	$\perp$
$\perp$	$\perp$
$\perp$	$\perp$
$\vdots$	$\vdots$

- Note that:
  - operation of the switch is totally automatic, thus permitting flexible topology,
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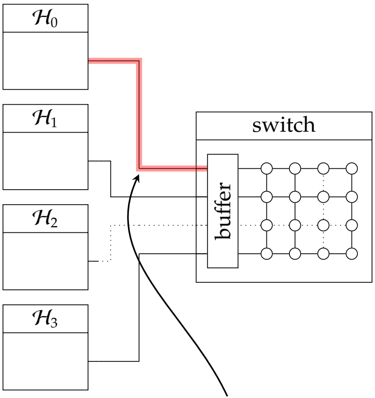

MAC address	port number
$\perp$	$\perp$
$\perp$	$\perp$
$\perp$	$\perp$
$\perp$	$\perp$
$\perp$	$\perp$
$\vdots$	$\vdots$

$$F = H_{802.3}[\text{src} = \mathcal{H}_0, \text{dst} = \mathcal{H}_1] \parallel D \parallel T_{802.3}$$

- Note that:
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  - per port, i.e., per segment, everything uses CSMA/CD as normal,
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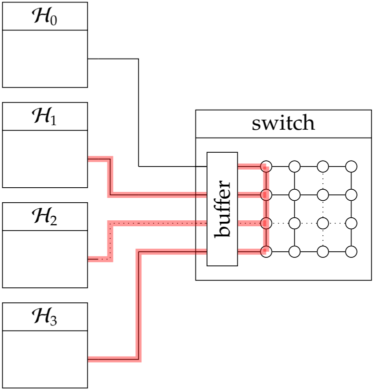

MAC address	port number
$\mathcal{H}_0$	0
$\perp$	$\perp$
$\perp$	$\perp$
$\perp$	$\perp$
$\perp$	$\perp$
$\vdots$	$\vdots$

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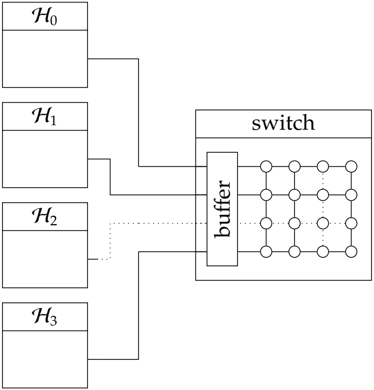

MAC address	port number
$\mathcal{H}_0$	0
$\perp$	$\perp$
$\perp$	$\perp$
$\perp$	$\perp$
$\perp$	$\perp$
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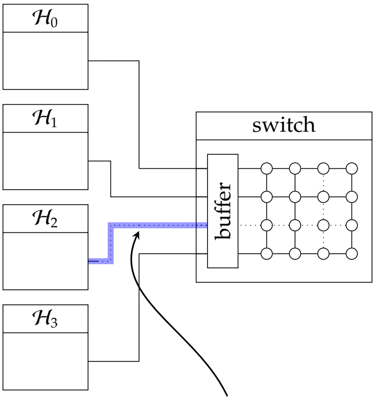

MAC address	port number
$\mathcal{H}_0$	0
$\perp$	$\perp$
$\perp$	$\perp$
$\perp$	$\perp$
$\perp$	$\perp$
$\vdots$	$\vdots$

$$F = H_{802.3}[\mathrm{src} = \mathcal{H}_2, \mathrm{dst} = \mathcal{H}_0] \parallel D \parallel T_{802.3}$$

- Note that:
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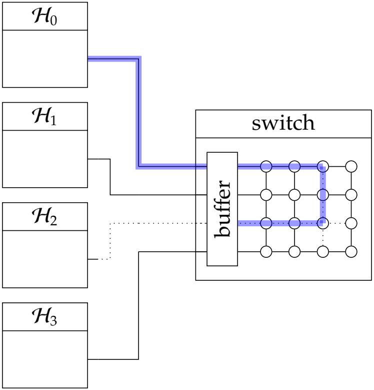

MAC address	port number
$\mathcal{H}_0$	0
$\mathcal{H}_2$	2
$\perp$	$\perp$
$\perp$	$\perp$
$\perp$	$\perp$
$\vdots$	$\vdots$

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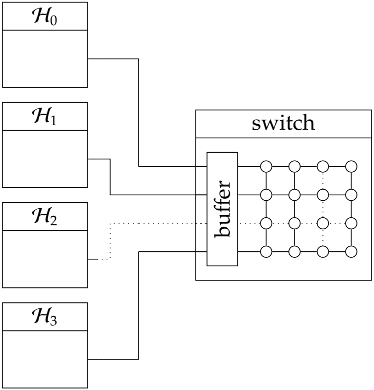

MAC address	port number
$\mathcal{H}_0$	0
$\mathcal{H}_2$	2
$\perp$	$\perp$
$\perp$	$\perp$
$\perp$	$\perp$
$\vdots$	$\vdots$

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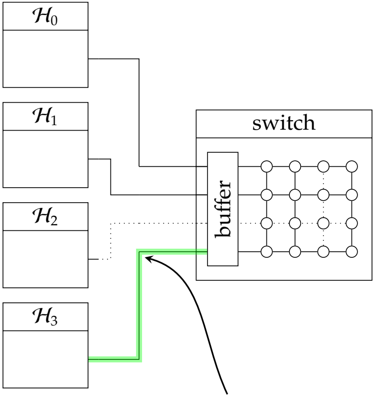

$$F = H_{802.3}[\text{src} = \mathcal{H}_3, \text{dst} = \star] \parallel D \parallel T_{802.3}$$

MAC address	port number
$\mathcal{H}_0$	0
$\mathcal{H}_2$	2
$\perp$	$\perp$
$\perp$	$\perp$
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$\vdots$	$\vdots$

- Note that:
  - operation of the switch is totally automatic, thus permitting flexible topology,
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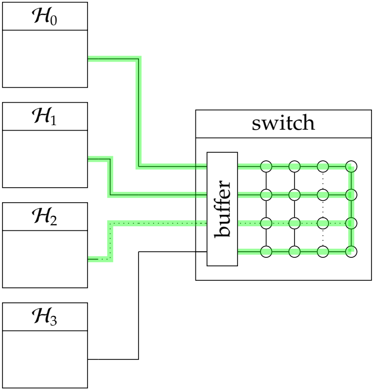

MAC address	port number
$\mathcal{H}_0$	0
$\mathcal{H}_2$	2
$\mathcal{H}_3$	3
$\perp$	$\perp$
$\perp$	$\perp$
$\vdots$	$\vdots$

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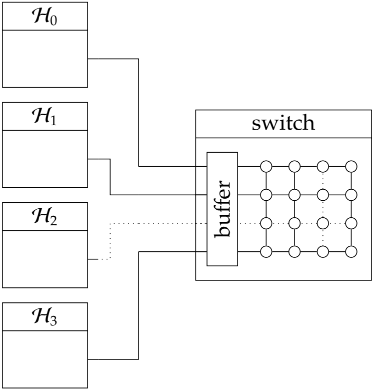

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Conclusions

- Take away point: we now have a **Local Area Network (LAN)**.
  - topological complexity is reduced using a shared medium,
  - this limits locality of connections (i.e., *local* area), and
  - we need a protocol to control access to the (shared) medium, but
  - once a host has access, the medium looks like a point-to-point connection.

References

[1] Wikipedia: ALOHAnet.
http://en.wikipedia.org/wiki/ALOHAnet.

[2] Wikipedia: Ethernet.
http://en.wikipedia.org/wiki/Ethernet.

[3] Wikipedia: IEEE 802.
http://en.wikipedia.org/wiki/IEEE_802.

[4] Wikipedia: Link layer.
http://en.wikipedia.org/wiki/Link_layer.

[5] Wikipedia: Logical link control.
http://en.wikipedia.org/wiki/Logical_link_control.

[6] Wikipedia: Media access control.
http://en.wikipedia.org/wiki/Media_access_control.

[7] N. Abramson.
The ALOHA system: Another alternative for computer communications.
In *Fall Joint Computer Conference (AFIPS)*, pages 281–285, 1970.

[8] R. Braden.
Requirements for Internet hosts – communication layers.
Internet Engineering Task Force (IETF) Request for Comments (RFC) 1122, 1989.
http://tools.ietf.org/html/rfc1122.

References

[9] R.M. Metcalfe and D.R. Boggs.
Ethernet: distributed packet switching for local computer networks.
Communications of the ACM (CACM), 19:395–404, 1976.

[10] R. Rom and M. Sidi.
Multiple Access Protocols: Performance and Analysis.
Springer, 2011.

[11] W. Stallings.
Chapter 16: Local area network overview.
In *Data and Computer Communications* [14].

[12] W. Stallings.
Chapter 17: Ethernet.
In *Data and Computer Communications* [14].

[13] W. Stallings.
Chapter 18: Wireless LANs.
In *Data and Computer Communications* [14].

[14] W. Stallings.
Data and Computer Communications.
Pearson, 9th edition, 2010.