Local Area Networks: Ethernet
Dots, Toomas Tommingas
Chair of Real-Time Systems (RAS)

PART A: The CSMA/CD Access Method

PART B: Network Aspects

Motivation for LANs
- goal: connect computers in same site (building, small campus)
- experience from host centric networks: bursty traffic
- basic idea: share a cable, no complex software in end system

Access Method
- multiaccess communication = share a communication medium
  - radio channel, cellular networks, satellite links
  - machine bus
  - local area cable
- shared medium requires an Access Method
  - deterministic:
    - Time Division Multiple Access (TDMA)
    - Token Passing (Token Ring, Token Bus, FDDI)
  - non-deterministic
    - Aloha
    - CSMA/CD

Access Method Topology
- Two topologies are used
  - bus:
    - all bits sent by one station are propagated to all stations
    - data die at end of bus
    - all stations see all frames
    - used by Ethernet, Token Bus
  - ring:
    - all bits are passed from one station to next station, then to next’s neighbour, etc
    - bits eventually return to originating station which has to remove them
    - all stations see all frames
    - used by Token Ring and FDDI
Access Method Topology (cont.)

- **Access Method topology** = physical topology = topology used by bits
- **Logical topology** = topology used by the token in case of Token Bus (logical ring over a physical bus)
- **Cabling topology** = layout of cables = star in most cases (see later)

**ALOHA**

```
while (i <= maxAttempts) do
  sent = false
  RTD = true
  if ack received then leave
  else:
    increment i
    and do
```

**CSMA**

- **Improvement 1**: Listen before you talk: “Carrier Sense Multiple Access”

- **Improvement 2**: Wait random time before retransmission

**CSMA/CD Time Diagram 1**

- A senses idle channel, starts transmitting
- Shortly before T, B senses idle channel, starts transmitting

**CSMA/CD Time Diagram 2**

- A senses collision, continues to transmit 32 bits (‘jam’)
- B senses collision, continues to transmit 32 bits (‘jam’)

**CSMA**

- **Improvement 3**: detect collisions as soon as they occur : “Carrier Sense Multiple Access / Collision Detection”

- **Improvement 4**: acknowledgments replaced by CD
- This is Ethernet (= 802.3, the standard conformant version of Ethernet)
Exponential Backoff

- Random time before re-transmission is given by:

\[ k = \min(10, \text{AttemptNb}) \]

\[ t = \text{random}(0, 2^k - 1) \times \text{slotTime} \]

- Examples:
  - First retransmission attempt:
    \( k = 1, t = 0 \) or \( t = \text{slotTime} \)
  - Second retransmission attempt (if preceding one failed):
    \( k = 2, t = 0, 1, 2 \) or \( 3 \times \text{slotTime} \)

SlotTime and Minimum Frame Size

- A minimum frame size equal to number of bits transmitted during one round trip is required to detect all collisions

- \( \text{slotTime} = \text{number of bits transmitted by a source during the maximum round trip time for any Ethernet network} \)
  - Includes propagation time in squares + margins
  - 4 terminals + 3 segments + 2 stations + 2.2/21.2 µs = 27 µs ≤ 48.4 µs

- A rule: In Ethernet, all frames must be as large as \( \text{slotTime} \)

- Properties:
  - P1: All collisions are detected by sources
  - P2: Collided frames are shorter than \( \text{slotTime} \)
  - P3: All previous idle
  - P4: Because collided frames are aborted by source at latest after \( \text{slotTime} \), including jam bits

Minimum Frame Size

- \( t = 0: \) A begins transmission

- \( t = 1: \) B begins transmission

- \( t = 1: \) B detects collision, stops transmitting

- \( t = 2: \) A detects collision

CSMA/CD Performance

- Bound on throughput:

\[ \theta \geq \frac{1}{(1 + 3.1 \alpha)} \]

where \( \alpha = \frac{\beta}{L} = 2.5 \times \text{propagation delay / transmission time} \) with \( L \) = frame size, \( \beta \) = bandwidth-delay product

- Approximation:

\[ \theta \approx \frac{1}{(1 + 2.5 \alpha)} \]

- Key for high utilization is: bandwidth delay product \( << \) frame size
Bandwidth Delay Product

- Interpretation of bandwidth-delay product

\[ \text{last bit sent by A arrives} \]

\[ \beta = 2 \text{DR} \]

- large \( \beta \) means: delayed feedback

CSMA/CD Performance

- We have:
  \[ \alpha = \frac{x}{R} \]
  \[ \beta = \frac{1}{x} \text{ in average} \]
  \[ E(x) = \text{collision occurred} = 1 - \text{exp}(-R/x) \]
  \[ P_{\text{success}} = \text{transmission} = 1 \]
  \[ P_{\text{collision}} = \text{transmission} = \text{exp}(-R/x) \]

The last formula is because collisions can occur only if an arrival occurs during the propagation time \( R \), because of collision avoidance. The average cycle time is thus, for this worst case scenario:

\[ \tau = \left( \frac{1}{x} + \left( 2R \cdot \text{exp}(-R/x) + T \text{exp}(-R/x) \right) \right) \]

computing the maximum of \( \tau \) with respect to \( x = R/\mu \) gives the formula (maximum obtained for \( x = 0.40 \)). Note that \( \mu = 2R/\tau \).

- the approximation shown is based on simulations
  - for a large network, \( \beta \) is close to 60 Bytes; for traffic with small frames \( \beta \approx 64 \) bytes, the utilization is less than 30%. For large frames (1500 Bytes), it is around 30%.

IEEE Architecture Model

MAC Service

- data packet = MAC service data unit (SDU)
- MAC frame = MAC protocol data unit (PDU)

Repeaters

- Extend network beyond cable length limit
- Function of a simple (2 port-) repeater:
  - repeat bits received on one port to other port
  - if collision sensed on one port, repeat random bits on other port
- One repeated network = one collision domain
- Even with repeaters, network is limited:
  - propagation time
  - IEEE 802 slotTime includes repeater
  - at most 4 repeaters in one path
  - Repeaters perform physical layer functions only (bit repeaters)
From Repeaters to Hubs

- **Multiport repeater:**
  - \((n\) ports) logically equivalent to \(n\) simple repeaters connected to one internal Ethernet segment
  - Multiport repeaters are possible to use point-to-point segments (Ethernet in the box)
  - Value of point to point cabling?
    - ease of management
    - fault isolation

- **Multiport Repeater** [Diagram]
- **Ethernet Hub**
- **S1**
- **S2**
- **S3**
- **UTP segment**

From Bus to Star and Tree

- Ethernet today = active concentrators allow star wiring
- UTP on point-to-point configurations only
- remote network management
- How many frames can be transmitted in parallel in this network?

Switched Ethernet

- Switched Ethernet = Bridge in the Box
- Total Bandwidth is not shared: parallel frame transmission
- An Ethernet Switch is a connectionless data switch
- Ethernet used as a point-to-point mechanism!

Repeater and Bridges in OSI

- 7 Application
- 6 Presentation
- 5 Session
- 4 Transport
- 3 Network
- 2 LLC
- 1 MAC
- 1 Physical
- Repeater
- Bridge
- End system

Today's Concentrators

- Concentrators (thehub) combine bridging (frame switching) and port switching (assign repeater ports to the same collision domain)
- NB! Broadcast!

MAC Frame Format

- MAC Frame
- PDU
- LLC Address Fields
- 1 LSA
- 2 SNAP value
- Information
LLC - LSAP

LSAP - LLC Access point, SAP Source and Destination

<table>
<thead>
<tr>
<th>VALUE</th>
<th>Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>TCP/IP (DoD)</td>
</tr>
<tr>
<td>10</td>
<td>NetWare</td>
</tr>
<tr>
<td>AA</td>
<td>SNAP (Subnetwork Access Protocol)</td>
</tr>
<tr>
<td>F0</td>
<td>NetBIOS</td>
</tr>
<tr>
<td>F5</td>
<td>LAN Network Manager Group</td>
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MAC Addresses

<table>
<thead>
<tr>
<th>MAC Frame</th>
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<tbody>
<tr>
<td>Address</td>
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<tr>
<td>Field</td>
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<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T + 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IG = 0</td>
<td>Individual address</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IG = 1</td>
<td>Group address</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U/L = 0</td>
<td>Globally administered</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U/L = 1</td>
<td>Locally administered</td>
<td></td>
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<tr>
<td>Field</td>
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</tr>
<tr>
<td>IG = 1</td>
<td>Address in 15 bits</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IG = 0</td>
<td>Address in 5 bits</td>
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</table>

Token Ring (IEEE 802.5)

<table>
<thead>
<tr>
<th>Frame</th>
<th>PS</th>
<th>SD</th>
<th>AC</th>
<th>VC</th>
<th>DA</th>
<th>SA</th>
<th>Data</th>
<th>FCS</th>
<th>ED</th>
<th>FS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Token</td>
<td>PS</td>
<td>SD</td>
<td>AC</td>
<td>ED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AC</td>
<td>PPP Priority bits, T-Token bit, M-monitor bit, RRR Reservation bits</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ED</td>
<td>J.K non-data (CPF/SK), I-intermediate frame, E-error bit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FS</td>
<td>A address recognition bit, C-Copy bit, r-reversed</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>

FDDI MAC protocol

- Key differences compared to 802.5:
  - seize token by aborting the token transmission instead of flipping the T-bit;
  - early token release (already in 16 Mbps version)
- Frame Status (FS) field
  - each station checks any passing frames and sets E-bit accordingly
  - MAC protocol does not attempt to retransmit the frame with E-bit set. It is the responsibility of LLC or some higher-layer protocol.

FDDI Capacity Allocation

- The priority scheme of 802.5 not applicable due to “early token release”
- FDDI capacity-allocation scheme seeks to accommodate a mixture of stream and bursty traffic
- use of synchronous and asynchronous frames
FDDI Capacity Allocation

\[ \text{TTRT} - \text{Target Token Rotation Time:} \]

\[ D_{\text{Max}} + F_{\text{Max}} + \text{TokenTime} + \sum S_a \leq \text{TTRT} \]

\( S_a \) = synchronous allocation for station

\( D_{\text{Max}} \) = propagation delay for one complete circuit of the ring

\( F_{\text{Max}} \) = time required to transmit a max length frame (4500 b)

\( \text{TokenTime} \) = time required to transmit a token

IEEE 802.3 Physical Layer

<table>
<thead>
<tr>
<th>100 BASE-TX</th>
<th>100 BASE-FX</th>
<th>100 BASE-T4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission medium</td>
<td>2 pair, STP</td>
<td>2 pair, Cat 5 UTP</td>
</tr>
<tr>
<td>Signalling technique</td>
<td>4B5B, MLT-3</td>
<td>4B5B, MLT-3</td>
</tr>
<tr>
<td>Data rate</td>
<td>100 Mbps</td>
<td>100 Mbps</td>
</tr>
<tr>
<td>Maximum segment length</td>
<td>100 m</td>
<td>100 m</td>
</tr>
<tr>
<td>Network span</td>
<td>200 m</td>
<td>200 m</td>
</tr>
</tbody>
</table>

DQDB - Distributed Queue Dual Bus

<table>
<thead>
<tr>
<th>Node 0 (Head (A))</th>
<th>Node 1</th>
<th>Node 2</th>
<th>Node (N-1) (Head (B))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus A</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DQDB (IEEE 802.6)

<table>
<thead>
<tr>
<th>Frame, 125μs</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Slot, 53 Byte</th>
</tr>
</thead>
</table>