Direct link multi-access networks
- Local Area Networks - Multi-access networks
from ALOHA to Ethernet

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- Adapted slides of Prof. B. Plattner (plattner@tik.ee.ethz.ch)
- Add-on material included of Peterson, Davie: ‘Computer Networks’
Multi-access communication

- Senders and receivers share one medium
- Examples:
  - Early Ethernet Local Area Network (1975-1995)
  - IBM Token Ring, Distributed Queue Dual Bus MAN
  - Access to satellite channel
  - Wireless multi-access communication (including Wireless LAN)
Problem statement

- How can we co-ordinate multiple independent senders and receivers that use a shared medium for data exchange?

Solution space

- Various multiplexing schemes: Frequency Division Multiplexing (FDM, or Multiple Access -> FDMA), Time Division MA (TDMA), Code Division Multiplexing (CDM, or MA -> CDMA)
- Distributed or centralized co-ordination
- Pre-allocate medium to each sender (synchronous TDMA, static FDM)
- Allocate medium on demand
  - Constant frame lengths (cell-based approaches, e.g., Asynchronous Transfer Mode - ATM)
  - Variable frame lengths (e.g., Local Area Network – LAN)
    - Random access, contention-based (e.g. Ethernet)
    - Reservation-based (e.g. Token Ring)

- LAN technology today: distributed, on-demand, variable frame length \(\rightarrow\) corresponding Medium Access Control (MAC)
Typical properties of LANs with shared links

- Span a room, building, or campus (10 m to 2.5 km)
- 10-50 computers connected to one LAN
- Raw transmission rate (channel encoding) 10 Mbit/s – 1 Gbit/s (up to 100 Gbit/s)
- Cheap adapters available (CHF 10 and up)
- Build and operate it yourself
- New computers may be connected easily
- Standardized equipment, products from different vendors are compatible (IEEE 802.x series of standards)

Cisco CRS-3 1-Port
100 Gigabit Ethernet interface module, product Website
University of Hawaii, in 1970: Birthplace of LANs

- Central computing facility on main Manoa campus, near famous Waikiki beach (Oahu)
- To connect remote parts of the campus to central computing infrastructure
AlohaNet

- Low cost, amateur radio components
- Packet based
- All station send packets on the same frequency, in the same channel to central hub
- Central hub returns the received packets on another frequency, i.e., dedicated channel
- AlohaNet became the ancestor of today‘s Ethernet Local Area Network (LAN) and Wireless LAN technology
Historical ancestor: Aloha (1970)

<table>
<thead>
<tr>
<th>Hosts</th>
<th>Channel</th>
<th>Collisions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Time $t$
Issues to be considered

- Collision resolution
- Performance: $f(\text{number of stations, traffic load, traffic characteristics, parameters of medium})$
  - Total throughput
  - Throughput of each station
  - Medium access delay
- Fairness: Does every station receive a similar service?

References

- Original work done 1970
Aloha medium access control algorithm

/* send one frame */
repeat
    send(data);
    r = receive();
    if r <> ack then
        wait_random_time();
    endif;
until r == ack;
A model for the Aloha medium access algorithm

$q_i \ldots$ probabilities

Idle

Send new frame with $q_a$

Success with $1-q_e$

Sending

Collission with $q_e$

Retry with $q_r$

Back-logged
Scenario for calculating the throughput

- # of stations
- Equal frame lengths
- Sending times statistically independent (Poisson distr.)
- Compute collision probability
- Throughput: Rate of frames without collision

Frames colliding with observed frame

Vulnerable during interval: $2m$
Extensions to pure ALOHA

- Pure ALOHA
- Slotted ALOHA
  - Time is slotted, packets must be transmitted within a slot – station waits for next slot → reduces the interval of vulnerability ($m$ instead of $2m$)

- Add sensing → CSMA (Carrier Sense Multiple Access)
  - “Listen before talk”

- Add Collision Detection → CSMA/CD
Throughput of Aloha

Graph source: Tanenbaum, Computer Networks

See reader „Performance Analysis of Aloha“ for the derivation of this result
Model for CSMA
Vulnerable interval with CSMA

\[ \tau = t_p + t_D \]

\( 2\tau \) Depending on length of medium!
Performance tuning of CSMA

Maximum throughput is roughly indirectly proportional to $\beta$:

$$\beta = \frac{\tau}{m} = \frac{\tau \cdot C}{L}$$

$\tau$: Propagation delay [s]
$m$: Frame length [s]
$L$: Frame length [bit]
$C$: Transmission rate [bit/s]

Rule of thumb: For good performance, $\beta$ should be $\leq 0.01$. 
Variants of CSMA

Monitor the medium before accessing it

If transmission unsuccessful: collision. Repeat after random wait

persistent CSMA

free: send
occ.: wait until free, then send

non-persistent

free: send
occ: wait random time, then re-test medium; send if free

p-persistent

free: send with probability $p$
occ: wait till free, then send with probability $p$
Ethernet: CSMA with Collision Detection (CSMA/CD)

- Stations can only detect collisions reliably if frame has minimum length.
- Jamming signal makes sure that every station knows that the channel is in a collision state:
  - 64-bit preamble + 32-bit jamming sequence.
- Random wait time increases exponentially with repeated collisions → *Binary Exponential Backoff* ($2^k$, with $k = 0, 1, 2, ..$).
CSMA/CD Algorithm

/* send one frame */
t = 0;
Repeat
    wait_channel_available();
    r = monitor_while_sending(data);
    if r == collision then
        send (jamming signal);
        t = t+1;
        wait(backoff(t));
    endif;
until r == success or t >= tmax

Binary Exponential Backoff

- Collisions indicate congestion
- Measure for overall load
- Backoff decreases load generated by backlogged stations
Collisions: Worst case scenario

(a) A sends a frame at time $t$
(b) A’s frame arrives at B at time $t + d$
(c) B begins transmitting at time $t + d$ and collides with A’s frame
(d) B’s runt (32-bit) frame arrives at A at time $t + 2d$

Figure source: Petersen, Davie: ‘Computer Networks’
Achievable throughput for various variants

Graph source: Tanenbaum, Computer Networks
Throughput with different $\beta$
Medium access delay increases with load
Ethernet history

- Developed at Xerox Palo Alto Research Center (PARC), ~1970-73
- CSMA/CD medium access control algorithm
- Industry standard set by DEC, Intel, Xerox (DIX), 1978
- Standardized by IEEE (802.3) and ISO (8802-3)
- Variants:
  - (3 Mbit/s) 10 Mbit/s, 100 Mbit/s, 1 Gbit/s, 10 Gbit/s, 100 Gbit/s
  - Thick coax, thin coax, shielded twisted pair (STP), unshielded twisted pair (UTP), fiber
  - Segment lengths: 500 m, 200 m, 100 m
  - Baseband and modulated carrier versions
- Ethernet is a true success story!

IEEE 802.x standard architecture

- network
  - logical link control (LLC)
    - medium access control (MAC)
      - physical
        - medium
        - medium
IEEE 802.3 service interfaces

- **MAC sub-layer**
  - Connectionless, unreliable
  - Unicast, multicast, and broadcast addressing
  - FCS checked (Frame Check Sequence)

- **LLC sub-layer**
  - Type 1: connection-less, unreliable, all addressing modes
  - Type 2: connection-oriented, reliable, flow control, …
  - Type 3: connection-less, request / response type of service
## CSMA/CD Frame Format

<table>
<thead>
<tr>
<th></th>
<th>preamble</th>
<th>SFD</th>
<th>DA</th>
<th>SA</th>
<th>length</th>
<th>payload</th>
<th>pad</th>
<th>fcs</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td></td>
<td>1</td>
<td>2/6</td>
<td>2/6</td>
<td>2</td>
<td>max. 1500</td>
<td>max. 46</td>
<td>4 (byte)</td>
</tr>
</tbody>
</table>

- **Preamble**: Bit synchronization
- **SFD**: Byte synchronization
- **DA**: Destination address
- **SA**: Source address
- **Length**: Length of payload
- **Payload**: Upper layer frame
- **Pad**: To fill up a short frame
- **FCS**: 32-Bit CRC for error detection
Addressing

- 48 bit MAC addresses, globally unique (universal)
- Vendors purchase OUI address spaces
- Assigned by IEEE

<table>
<thead>
<tr>
<th>Organizationally Unique Identifier (OUI)</th>
<th>Unique number assigned by vendor</th>
</tr>
</thead>
<tbody>
<tr>
<td>U / L / G</td>
<td>00-50-8b-xx-xx-xx, Compaq</td>
</tr>
<tr>
<td>I / G</td>
<td>00-07-E9-xx-xx-xx, Intel</td>
</tr>
<tr>
<td>Individual (0) / Group (1)</td>
<td>00-60-2F-xx-xx-xx, Cisco</td>
</tr>
<tr>
<td>Universal (0) / Local (1)</td>
<td>00-15-F2-xx-xx-xx, ASUS</td>
</tr>
</tbody>
</table>
Evolution of frame formats

Original DIX Ethernet frame format

<table>
<thead>
<tr>
<th>preamble</th>
<th>SFD</th>
<th>DA</th>
<th>SA</th>
<th>type</th>
<th>payload</th>
<th>fcs</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>1</td>
<td>2/6</td>
<td>2/6</td>
<td>2</td>
<td>max. 1500, min. 46</td>
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DIX … Dec, Intel, Xerox

CSMA/CD frame format

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</tr>
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</table>
Hardware components

- Ethernet segment is implemented on cable
- Hosts connect to an Ethernet segment by tapping into it.
- Transceiver
  - Detects if the line is idle
  - Applies signal when the host is transmitting
  - Receives incoming signal
- Adaptor: incorporates protocol

Figure source: Petersen, Davie: ‘Computer Networks’
Technical realizations

Fig. 4-18. Three kinds of 802.3 cabling. (a) 10Base5. (b) 10Base2. (c) 10Base-T.

Illustration source: Tanenbaum, Computer Networks
Pictures: wikipedia.org, netgear.com
Cables

- 10Base5 (10 Mbit/s, baseband, 500m), 10Base2 (200m): thinner
  - Repeaters and terminations
- 10BaseT (twisted pair, 100m)
  - Hubs

Figure source: Petersen, Davie: ‘Computer Networks’
Limits of shared medium Ethernet technology

- Shared medium: Realized as a hub with UTP - Unshielded Twisted Pair - cabling
- Not more than 4 hubs in between any station in the network
- Network diameter max. 500 m for 10 Mbit/s, smaller for higher speed variants
- 10 Mbit/s, 100 Mbit/s, 1000 Mbit/s

- Hubs were replaced by switches
Hubs vs. LAN Switches

- At similar locations in networks.
- Hubs **repeat signals** while switches **forward frames**.
- Switches require address examination and forwarding.
  - Store-and-forward: Store the entire packet before forwarding
  - Cut-through: Examines destination and starts forwarding (without storing full packet)
  - Blocking vs. non-blocking (highly parallel) architectures.
  - Congestion: buffering, backpressure via CSMA/CD mechanism
  - Half-duplex and full-duplex modes (full-duplex requires 2 twisted pairs per link)
  - CSMA/CD collision domain is greatly reduced or even eliminated
Topologies (1)

- Shared backbone and shared workgroup LANs
- Switched backbone (collapsed backbone)
- Multi-switch backbone
Topologies (2)

- Workgroup Segmentation (decentralized)

- Workgroup Segmentation (centralized)

- Micro Segmentation (today’s approach) → Universal Cabling System
Fast Ethernet

- 100 Mbit/s version of Ethernet, using CSMA/CD algorithm (later addition to IEEE 802.3).
- 10 times faster than “original” Ethernet (10baseX), and 10 times smaller (max. app. 200 m between stations).
- Easy upgrade path from Ethernet, simply replace Ethernet hubs, adapters, and driver software!
- Autosensing of physical media (10/100 Mbit/s)
- Current technology for home networks; being gradually replaced by Gbit Ethernet
Gigabit Ethernet

- Marketing aspect
  - Term Ethernet used to hint at easy and cheap upgrade, reliability.

- Theory is different
  - Ethernet = CSMA/CD (historically)
  - If CSMA/CD is used on a shared medium, the allowable size of a Gigabit Ethernet segment will be rather small (roughly 20 m). Shared Gbit-Ethernet is not very useful.
  - If CSMA/CD is not used, is it still an Ethernet?

- Realistically, a Gigabit/s LAN need not be a CSMA/CD-based LAN to grant compatibility.
  - Important are cost, compatibility with existing cabling, and availability of good drivers for popular operating systems.
Gigabit Ethernet – IEEE 802.3z and 802.3ab

- Half- and full-duplex operation at 1000 Mbit/s
- Complies with IEEE 802.3 Ethernet frame format
- CSMA/CD access method (!)
- Allows one repeater per physical collision domain.
- Address compatibility with Ethernet and Fast Ethernet technologies
- Media: Fiberoptics, STP, UTP (Shielded/Unshielded Twisted Pair)
Frame format

- Frames compatible with classic Ethernet
- Preamble: 101010 ... 10.
- Start Delimiter: 10101011
- Padding: Even # of Bytes
- Extension used to safely detect collisions
- Bursts: Concatenation of max. 65536 Byte
Gigabit Ethernet – Physical Media

- **Standard for UTP cabling** accepted in June 1999 (802.3ab, 1000BASE-T)
- Smaller distances for fiber cabling compared to Fast Ethernet due to dispersion.

<table>
<thead>
<tr>
<th>Type</th>
<th>Cabling</th>
<th>Waves</th>
<th>Distance</th>
<th>Plugs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000BASE-SX</td>
<td>62,5 µm Fiber Multimode</td>
<td>830 nm</td>
<td>2 – 260 m</td>
<td>Duplex SC</td>
</tr>
<tr>
<td>1000BASE-SX</td>
<td>50,0 µm Fiber Multimode</td>
<td>830 nm</td>
<td>2 – 550 m</td>
<td>Duplex SC</td>
</tr>
<tr>
<td>1000BASE-LX</td>
<td>62,5 µm Fiber Multimode</td>
<td>1270 nm</td>
<td>2 – 550 m</td>
<td>Duplex SC</td>
</tr>
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<td>Duplex SC</td>
</tr>
<tr>
<td>1000BASE-LX</td>
<td>10,0 µm Fiber Monomode</td>
<td>1270 nm</td>
<td>2 – 3000 m</td>
<td>Duplex SC</td>
</tr>
<tr>
<td>1000BASE-CX</td>
<td>STP Twinax</td>
<td>25 m</td>
<td>DB9 (Style 1)</td>
<td></td>
</tr>
<tr>
<td>1000BASE-CX</td>
<td>IEC 61076 Twinax</td>
<td>25 m</td>
<td>IEC (Style 2)</td>
<td></td>
</tr>
<tr>
<td>1000BASE-T</td>
<td>UTP, Cat 5</td>
<td>100m</td>
<td>RJ-45</td>
<td></td>
</tr>
</tbody>
</table>
Another step: 10 Gigabit Ethernet (IEEE 802.3ae)

- Local and wide area interconnections
- No CSMA/CD! (only p-p, switched)
- Media
  - Single and multimode dark fiber (LAN PHY), up to 40 km
  - OC-192 SONET (WAN PHY)
- Applications
  - High-speed Internet access
  - Enterprise LAN interconnections
  - Connections to/between/within server farms / data centers
  - High-speed data transport and real-time streaming
Latest (last?) step: 100 Gbit/s Ethernet

- Support full-duplex operation only
- Preserve the 802.3 / Ethernet frame format utilizing the 802.3 MAC
- Preserve minimum and maximum frame size of current 802.3 standard
- Physical layer supporting 40 Gbit/s
  - 10 km on single mode fiber
  - 100m on multi-mode fiber
  - 10 m over copper cable
  - 1 m over a backplane
- Physical layer spec supporting 100 Gbit/s operation over:
  - at least 40 km on single-mode fiber
  - at least 100 m on multi-mode fiber
  - at least 10 m over a copper cable
- Applications: Data centers, Internet backbone
- Standardization task force established by the IEEE in 2007
- 2009: Juniper announces first 100G interface (pre-standard)
- IEEE 802.3ba standard approved on 17 June 2010

Other wire-based LAN standards ...

... are only of historical interest

- IEEE 802.5 Token Ring
- IEEE 802.4 Token Passing Bus
- IEEE 802.6 Distributed Queue Dual Bus MAN
- IEEE 802.12 Demand Priority Access (voice-grade anylan)
Complete list of IEEE 802 LAN standardization activities

<table>
<thead>
<tr>
<th>Active Working Groups</th>
<th>Disbanded Working Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.1 Higher Layer LAN Protocols Working Group</td>
<td>802.2 Logical Link Control Working Group</td>
</tr>
<tr>
<td>802.3 Ethernet Working Group</td>
<td>802.4 Token Bus Working Group</td>
</tr>
<tr>
<td>802.11 Wireless LAN Working Group</td>
<td>802.5 Token Ring Working Group</td>
</tr>
<tr>
<td>802.15 Wireless Personal Area Network (WPAN) Working Group</td>
<td>802.6 Metropolitan Area Network Working Group</td>
</tr>
<tr>
<td>802.16 Broadband Wireless Access Working Group</td>
<td>802.7 Broadband TAG</td>
</tr>
<tr>
<td>802.17 Resilient Packet Ring Working Group</td>
<td>802.8 Fiber Optic TAG</td>
</tr>
<tr>
<td>802.18 Radio Regulatory TAG</td>
<td>802.9 Integrated Services LAN Working Group</td>
</tr>
<tr>
<td>802.19 Wireless Coexistence Working Group</td>
<td>802.10 Security Working Group</td>
</tr>
<tr>
<td>802.20 Mobile Broadband Wireless Access (MBWA) Working Group</td>
<td>802.12 Demand Priority Working Group</td>
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<tr>
<td>802.21 Media Independent Handover Services Working Group</td>
<td>802.14 Cable Modem Working Group</td>
</tr>
<tr>
<td>802.22 Wireless Regional Area Networks</td>
<td></td>
</tr>
<tr>
<td>802.23 Emergency Services Working Group</td>
<td></td>
</tr>
</tbody>
</table>
Questions?
Thick coax transceiver („vampire tap“)
Thin coax barrel T-connector, extender, terminator
RJ 45 8-pin connector (UTP)
Simple 4-port hub and 24-port switch

http://www.tycoelectronics.com