Networks & the IEEE Ethernet standard

An Introduction of the common IEEE 802.3 Ethernet Standard for local area networks (LAN's)

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The Ethernet Standard

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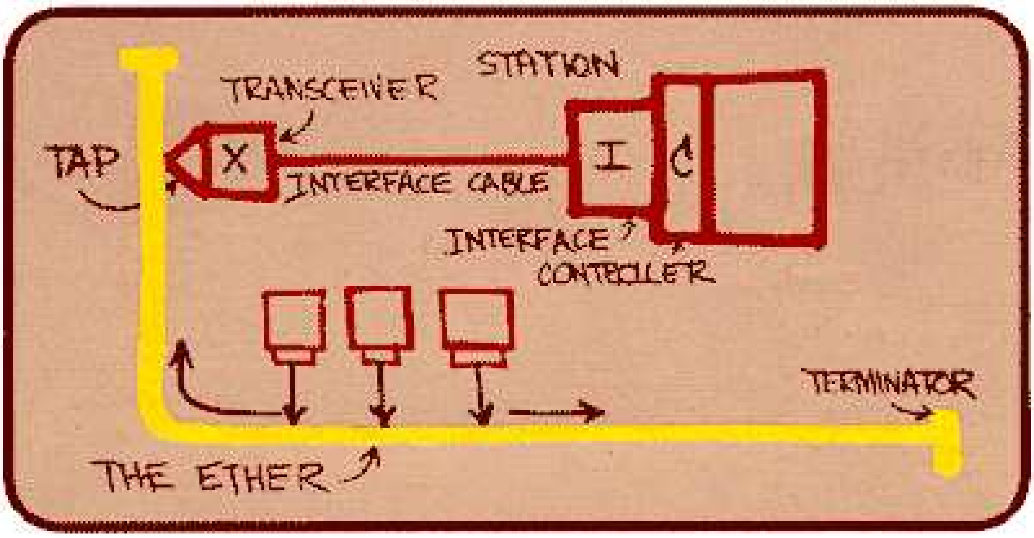


"The diagram ... was drawn by Dr. Robert M. Metcalfe in 1976 to present Ethernet ... to the National Computer Conference in June of that year. On the drawing are the original terms for describing Ethernet. Since then other terms have come into usage among Ethernet enthusiasts." **The Ethernet Sourcebook**, ed. Robyn E. Shotwell (New York: North-Holland, 1985), title page.

Introduction

- The Ethernet standard is a very popular and readily available LAN technologie, that transmits information between computers at a speed of 10 and 100 Mbps (megabits per second)
- The Ethernet belongs to the family of *best effort datagram service*
- The original Ethernet was invented by Dr. Robert M. Metcalfe at the Xerox Palo Alto Research Center in the 1970's.
- 1980 the experimental state of the Ethernet was changed to an open system standard by the multi-vendor consortium that created the DEC-Intel-Xerox (DIX) Standard
- 1985 the IEEE modificated the DIX Standard and incorporated it as IEEE 802.3 Ethernet into their LAN specification standard.
- Later in the 80's the ISO includes the IEEE LAN standard into their OSI-Model (ISO 8473)
- Recently: Ethernet included the new 100Mbps Fast Ethernet (e.g. 100BaseTx) standard.

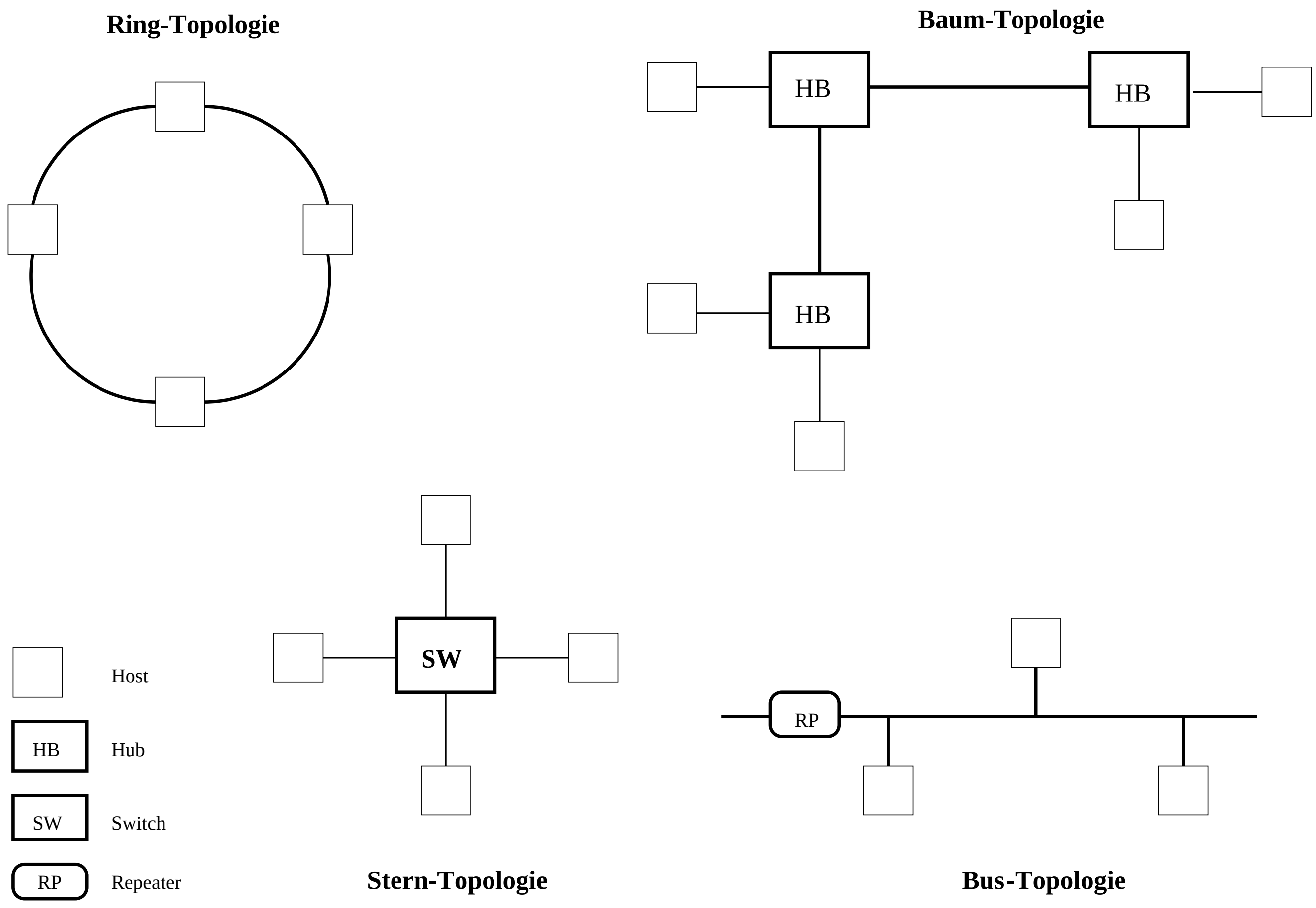
My little world- the LAN

A *local area network*, or LAN, is a privatly-owned network within a single building or campus of up to a few kilometers in size. LAN's are distinguished from other kinds of networks by three characteristics:

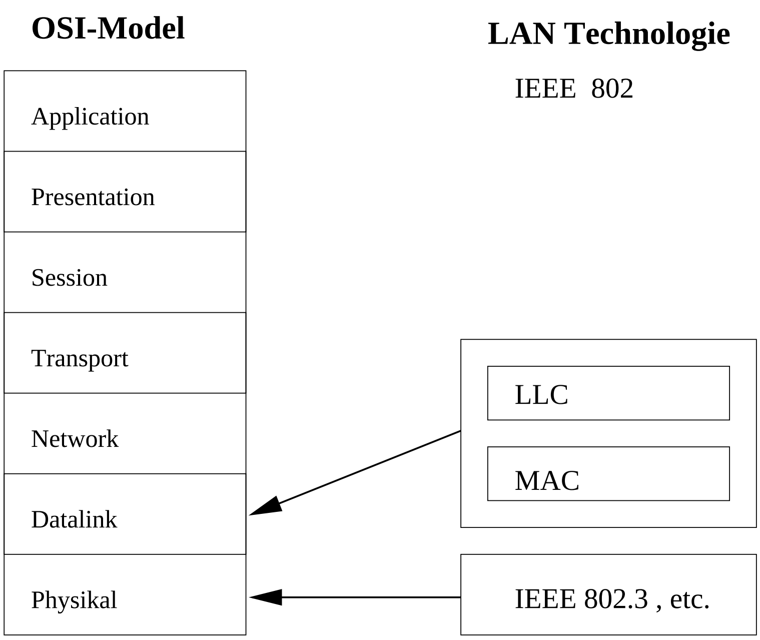
- Total length of cable/ the extension of the network
  (The 10Mbps Ethernet allows a maximum length of 2500 meters)
- Transmission Technology
- Network topology

Interprocessor distance	Processors located in same	Example
0.1 m	Circuit board	Data flow machine
1 m	System	Multicomputer
10 m	Room	
100 m	Building	Local area network
1 km	Campus	
10 km	City	Metropolitan area network
100 km	Country	Wide area network
1,000 km	Continent	
10,000 km	Planet	The internet

Some common LAN topologies



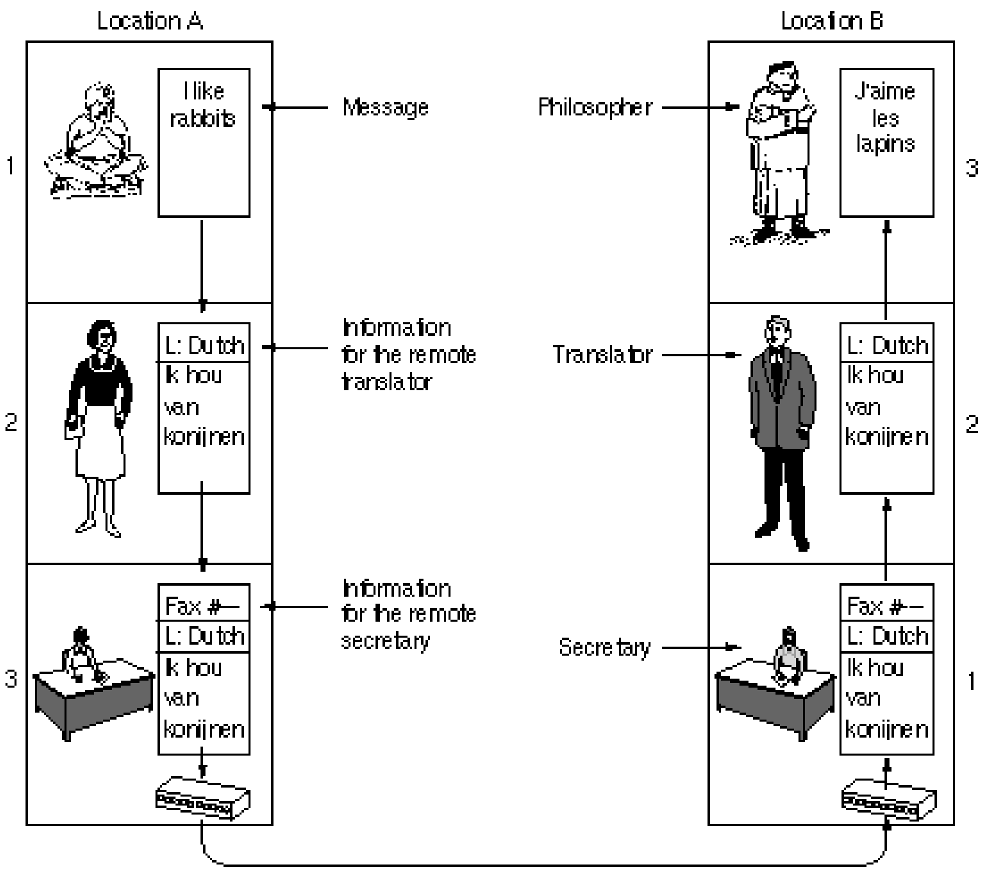
The OSI Reference Model



- The international standard organisation (ISO) has developed the "well-known" *Open System Interconnection* (OSI) Model to supply a common standard protocol stack for all networks.

- The basic characteristic of the OSI-Model is the layered structure where every protocol uses the services of the protocols of the layer beyond.

- The main use of the OSI-Model today is not the real application, but the provision of a general "logical" reference.



- In general, the data of the higher level protocols will be enclosed by their header of the lower protocols.

The IEEE 802.3 Ethernet Standard

The Ethernet ist part of the IEEE 802 LAN specifications. Other norms which are coverrd by IEEE 802 are the Token Ring (IEEE 802.5) and Token Bus (IEEE 802.4) network technologies.
The Ethernet's main characteristics are:

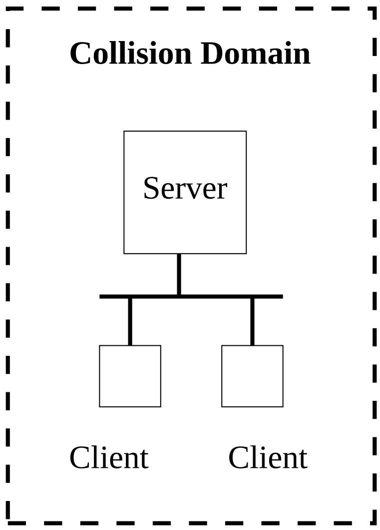
- "Unreliable data transfer".
  To ensure a reliable transfer, one must use higher protocols such as TCP.
- Asynchronous transfer.
- The use of a non-exclusive multi access channel.
- Global Ethernet addresses
- A transmission rate of 10Mbps (or 100Mbps with 100BaseTx)
- Relatively cheap hardware

On abstract level the Ethernet consists of three elements:

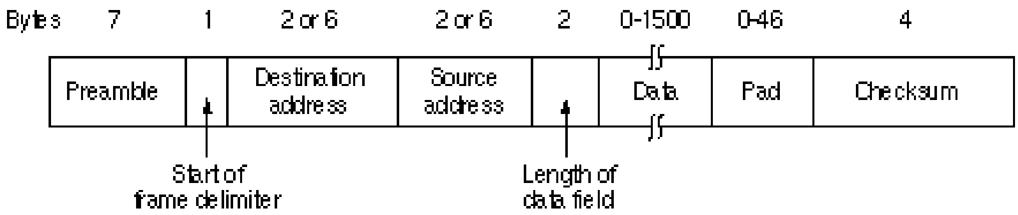
- A suit of protocols which controls the access to the multi-access channel
- A standard format for the transmission of data
- The hardware for the access on the channel and the transmission of data

CSMA/CD

- "1-persistent" - *Carrier Sense Multi-Access with Collision Detection CSMA/CD-Protocol* is one of the main features of the Ethernet.
- It is part of the "Medium Access" MAC-Sublayer (cf. OSI-Model) and controls when data can be put on the channel (e.g. the channel is sensed) and how to deal with collisions. A *collision* appears, if two or more hosts put their data on a *Collision Domain* (Collision Domain describes a topology within which only one Interface can send without a collision occurring).
- Collision detection is primarily a hardware feature.
- CSMA/CD gives no guarantee of realiable data transmission.
- The behaviour of this protocol will be further discussed in the section: "Collision detection and dealing with collisions".

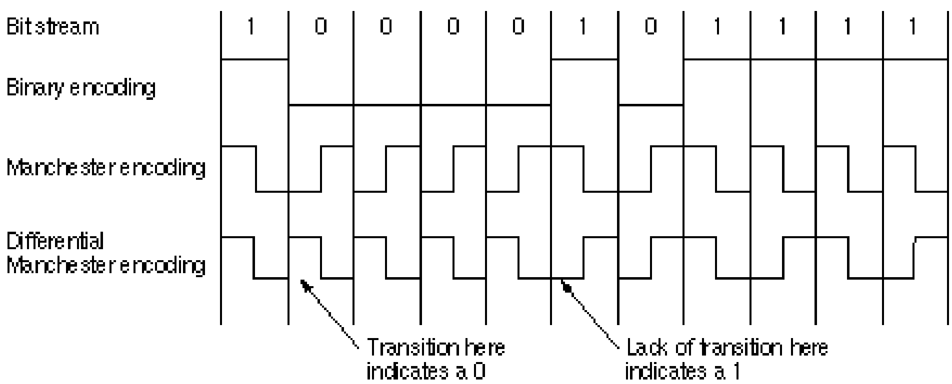


IEEE 802.3 Ethernet frame

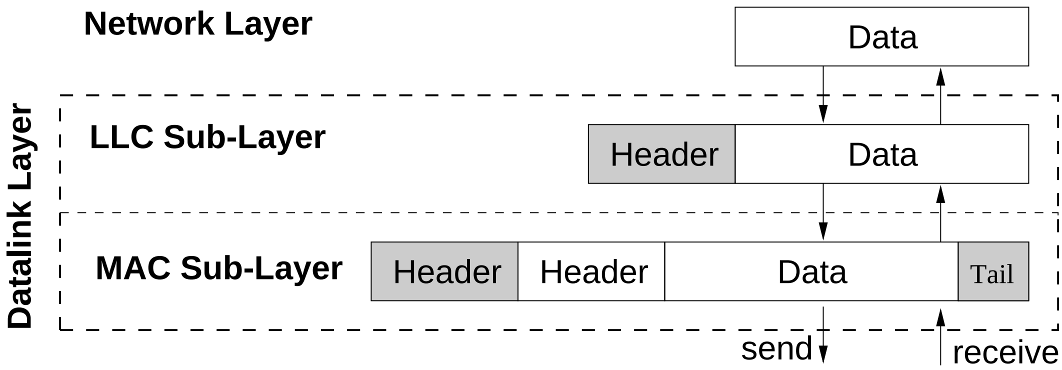


The Ethernet frame consists of six logical regions and has a minimum size of 68 bytes, and a maximum length of 1526 bytes. It encapsulates the packets of any protocol above the MAC-sublayer (s. figure next page).

- Preamble
  Is a standard sequence of bits (10101010). The *Manchester encoding* of this pattern allows the reciever to synchronize his clock with the senders'.



IEEE 802.3 Ethernet frame



- Destination Address
  10Mbps Ethernet uses a 6 byte destination address. The features of the address are:
  - Global addressing
  - Local addressing. (distinguished from global by bit no. 46)
  - Group addressing.
    (Multicast address: bit 47 is set to 1)
  - Broadcast addressing.
    (sequence of 1's)

- Source Address
  This field consists of the 6-byte Ethernet address of the sender's networkinterface.

IEEE 802.3 Ethernet frame

- "Length of data field"
  This field determines how many bytes are present in the data field. The possible length is 0 to 1500 bytes.

- Data field/Pad
  - This section contains usually the data of any higher protocols (above the MAC layer).
  - The Pad provides that the data field always has at least the minimal length of 46 bytes.

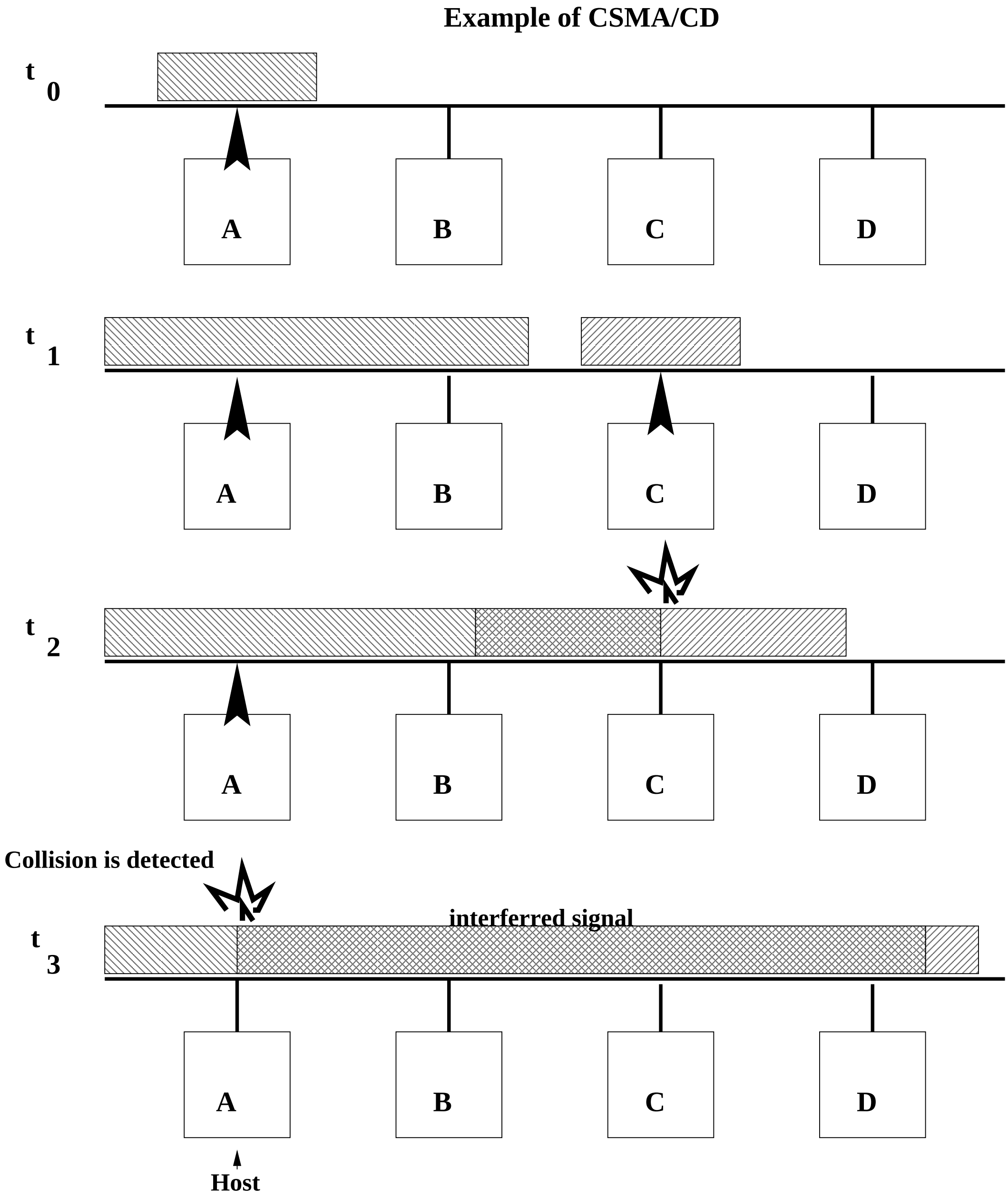
- Checksum
  - The checksum consists of a 32 bit hash coding of the data.
  - It provides information for the CSMA/CD protocol to detect errorneously changed databits.

Collision detection and dealing with collisions

The "Carrier-Sense Multi-Access with Collision-Detection (CSMA/CD-Protocol)" controls the transmission of Ethernet packet over an multi-accessed channel.
Because the Ethernet is an asynchronous data transfer service over a multi accesssed channel, sometimes collisions occurs.
The rules of CSMA/CD are:

1. If the medium is idle, transmit; otherwise, go to step 2.
2. If the medium is busy, continue to listen until the channel is idle, then transmit immediately
3. If a collision is detected **during** transmission, transmit a brief jamming signal to assure that all stations know that there has been a collision and then cease transmission.
4. After transmitting the jamming signal, wait a random amount of time, then attempt to transmit again. (repeat from step 1.)

Example

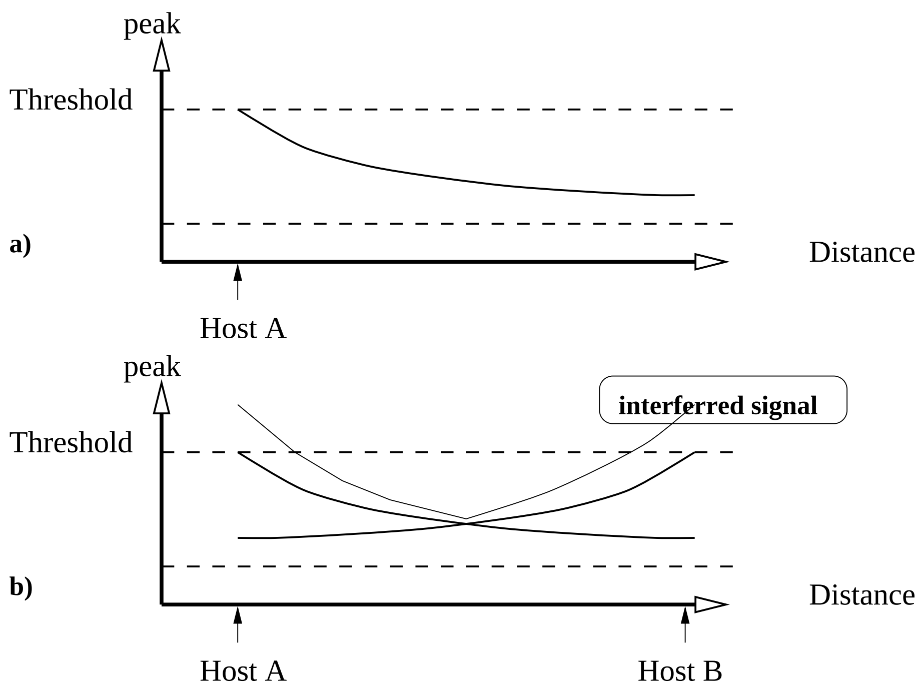

Example of CSMA/CD
t 0
A
B
C
D
t 1
A
B
C
D
t 2
A
B
C
D
Collision is detected
interferred signal
t 3
A
B
C
D
Host

Example

1. Host A perceived, that the channel is "quite" and puts his datagram on it.
2. Because of the unlasting propagation speed, Host C put his data on a "sense" channel.
3. Two datagram collide and the noise of the event reaches Host C, during his own transmission! Host C performs the following steps:
   (a) Stop the normal transmission
   (b) Send a 48-bit noise burst to warn all other stations
   (c) Wait a random amount of time, before starting re-transmission.
4. Host A gets the noisy transmission of host B and stops his transmission too.

Conclusions

- A host can detect a collision **during** a transmission only! Because the signals interfere, the maximum peak of the signal on the channel will be higher than the transmitter-specific threshhold. So the transmitter knows that there is a collision.
- The collision detection needs a concrete amount of time which depends on the distance between the hosts involved, and the transmission speed of the channel.
- The propagation time of a datagram should be longer than the minimal amount of time which is needed for the collision detection.



Conclusions

The rules mentioned above lead to these concrete specifications in the IEEE 802.3 Ethernet:

- For any allowed cable type in 10Mbps Ethernet, a maximum cable length is defined. It is necessary to limit the cable length on the strength of decay in the cable.
- The absolute distance between two hosts on the 10Mbps Ethernet should be at most 2500 meters. (This refers to the rule that no more as four repeaters should be used, and the minimal length of the Ethernet packet)
- A Ethernet packet has a minimal size of 64 bytes for a 10Mbps network. So any collision will occur during a transmission.
- The "famous" 5-4-3 Repeater rule.
  The network can only have **5** segments connected; it can only use **4** repeaters; and of the five segments, only **3** can have users attached to them. The other two must be inter-repeater links (IRL). (see picture in the appendix)

A question of time

- The 10Mbps Ethernet means that $10 * 10^6$ bits will be transmitted in one second!
- Because, the *M*anchester Encoding uses one oscillation to represent one bit, the 10Mbps Ethernet interface generates a $10 * 10^6$ (10-MHz) square wave .
- From this it follows that one bit refers to $\frac{1}{1*10^7} = 0,1 * 10^{-6} sec = 0.1 \mu sec$
- The minimum 64 bytes Ethernet frame must be transmitted by producing a 10-MHz square wave for $51.2\mu sec$.
- The propagation time for electro magnetic waves depends on the medium (see medium specific propagation factor):

  1 :Vacuum
  0.77 :Coax
  0.6 :Twisted pair
  0.67 :Fibre optic

- A signal with the length of $51.2\mu sec$ will cover a distance of :

$$0.77 * 3 * 10^8 = 231 * 10^6 \quad \frac{meter}{sec} (coax)$$

$$231 * 10^6 \quad * 51.2 * 10^{-6} = 11827.20m = 11.82km$$

The 100Mbps Ethernet

What happens if we use a faster medium for example, 100Mbps Ethernet ?.

- If we still keep the standard CSMA/CD protocol and the packet format of the 10Mbps Ethernet. The maximal distance between hosts must be decreased. (eg. 200m in 100Base-TX and 100Base-FX). So any collision still occur during a transmission.

The Binary Exponential Backoff Algorithm

After a collision occurs, the sender waits a random amount of time before it starts re-transmission. If both hosts (remember the last example), take the same time before start to transmit again, another collision will occur. Task of the “Binary Exponential Backoff Algorithm” is to decrease the probability that the hosts wait the same time, depending on the channel load. The algorithm performs the following steps:

- A *Slot* (S) is assigned with $51.2\mu sec$. The time corresponds to the maximal allowed distance between hosts (2500m).
- Let I be the amount of collisions that occured.
- *M* is the *multitude* defined as:

$$M = \{m_i = (2^i - 1) * S| \quad 0 \leq i \leq I\}$$

- Every host takes its arbitrary transmission delay m_i as element of M. (The max. allowed delay is 1023*S)
- If more than 16 collisions occured on the channel, than the retransmission of the actual datagramm will be aborted and the device reports failure back to the computer .

Because of this algorithm, the probability that two hosts wait the same time will decrease rapidly (eg. after 1 collision the probability is 0.5, after 2 it is 0.25, after 3 it is 0.125 ...)

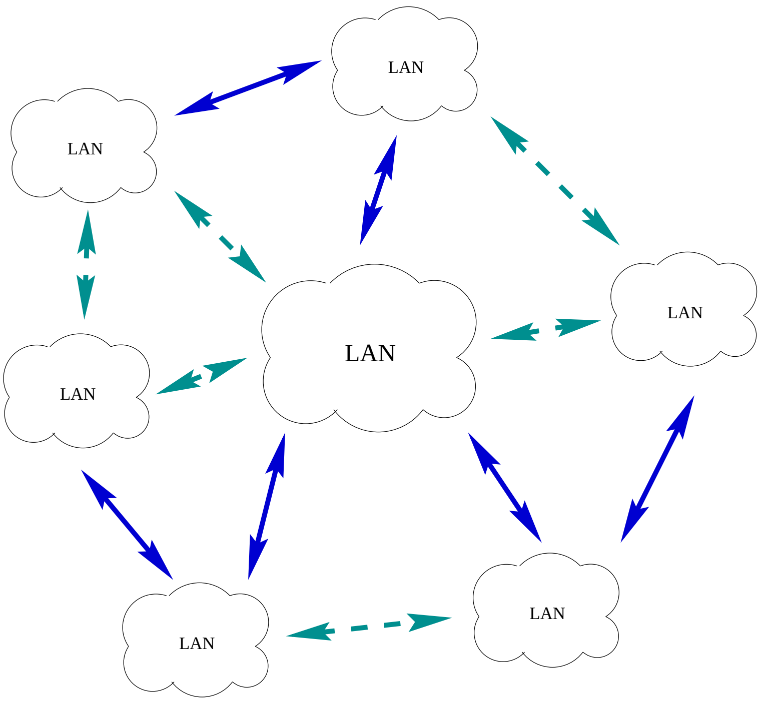
High-level protocols and the Ethernet: ARP

If host A wants to send an IP-datagram to another host B on the Ethernet network, he must discover the logical IP and the real hardware address of the destination host. If the destination IP address is known by the sender, only the Ethernet address has to be recovered. This could be done by the *Address Resolution Protocol* ARP. ARP performs the following steps:

- Host A puts a broadcast Ethernet frame on the channel. The Frame includes the ARP request:
  "Will the station on this Ethernet channel that has the IP address of 129.70.123.133 please tell me what the address of its Ethernet interface is ?"
- Since the ARP request is send in a broadcast frame, every interface reads it and hands the ARP request to the networking software.
- "Only" host B with the right IP address will respond, by sending a packet containing the Ethernet address of its own interface to host A.

Keywords of the LAN

- **Segment**
  A (network) segment could be simply a cable or a more complex structure. For example every port of a Hub belongs to the same network segment.
- **Collision Domain**
  A Collision Domain describes a part of the network where only one node can put its data on the channel without causing a collision. This property defines a network segment.
- **Physical Topology**
  This describes the topology of a network from the physical point of view. It is only a graphical conststruct conveying the shape and structure of the LAN. If we talk about nework topologies, we normally mean the physical one.
- **Logical Topology**
  This describes the toplogy of a network from the viewpoint of the MAC-Sublayer. In this case, every port of a Hub counts towards the same network segment (logical Bus topology).
- **Network Performance**
  The network performance is based on the network capacity and describes the availability of the network (e.g. the number of collisions decreases the network performance).



Example for the Spanning Tree Algorithm

- **Spanning Tree Algorithm**
  The algorithm is specified in the IEEE 802.1d Standard. It is used for avoiding loops in a network in which multiple paths exist. For example, the Bridges could be linked together as in the picture above (all arrows). The blue (non-broken) arrows show the tree which has been selected by the Bridge's "Spanning Tree Algorithm". After such a tree has been determined, every Ethernet packet will be routed along this logical path. Normally it is possible to draw different logical trees.
- **Network Capacity**
  Average data transmission rate with respect to the number of nodes per segment.

Expanding the Ethernet network

We discuss the possibilities of expanding an existing Ethernet network with different kinds of hardware (still concerning the 10Mbps standard).

- **Simple**
  Expanding the total length of the cable by using Hubs and Repeaters.
- **Increase network performance**
  Breaking down big segments into smaller ones using Bridges and Switches.
- **Connecting different LANs**
  Using Routers and Gateways to connect different types of network.

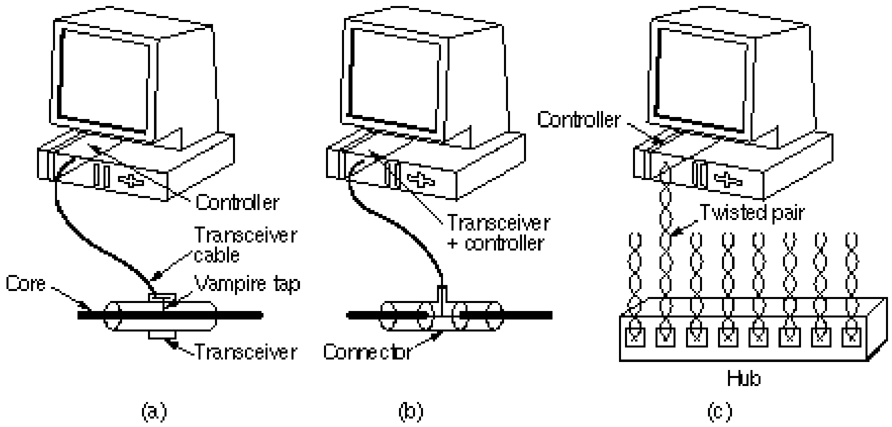
Ethernet hardware

Common Ethernet hardware can be divided into two levels. The low level consists of the Ethernet cable. The high level is based on the "more expensive" hardware, such as *Repeater, Hub, Bridge, Switch, Router, Gateway*.

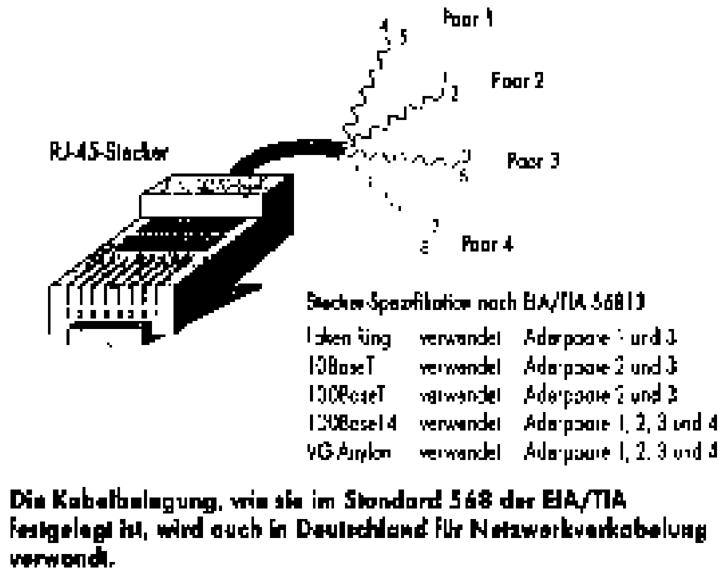
Name	Kabeltype	Specification	Max. Segment length	Advantages
10Base2	Thin Coax	RG-85C/U	185m	cheap
10BaseT	Twisted Pair	EIA / TIA 568 Cat-3 = UTP-3	100m	easy maintenace
10Base5	Thick coax		500m	good for backbones
10BaseF	Fiber optics		2000m	good for backbones

The cable is specified from the U.S. *Electronic Industry Association and Telecommunication Industry Association* (EIA/TIA).
The number in the IEEE Cable Specification shows the data transfer rate (eg. **10**BaseT used in 10Mbps Ethernet). The word *Base* represents the **Baseband-Type**. In contrast to the Broadband-Type the cable carries only one kind of signals - the Ethernet data.

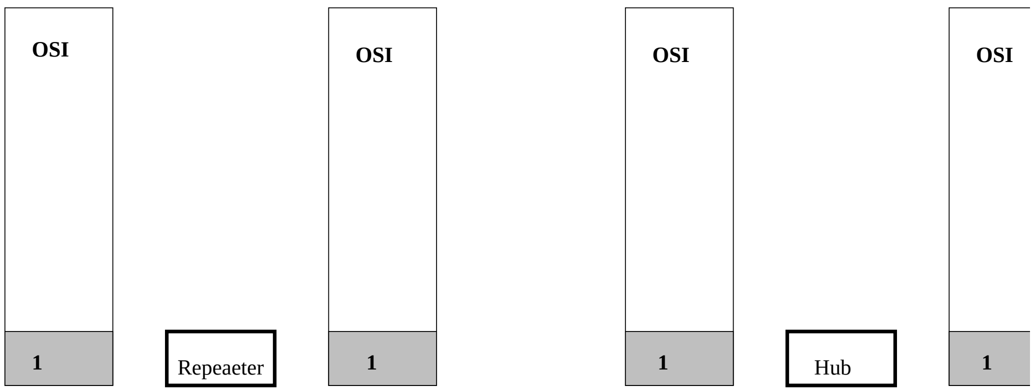
Ethernet hardware



Some 802.3 cabling standards are a) 10Base5, b) 10Base2, c) 10BaseT

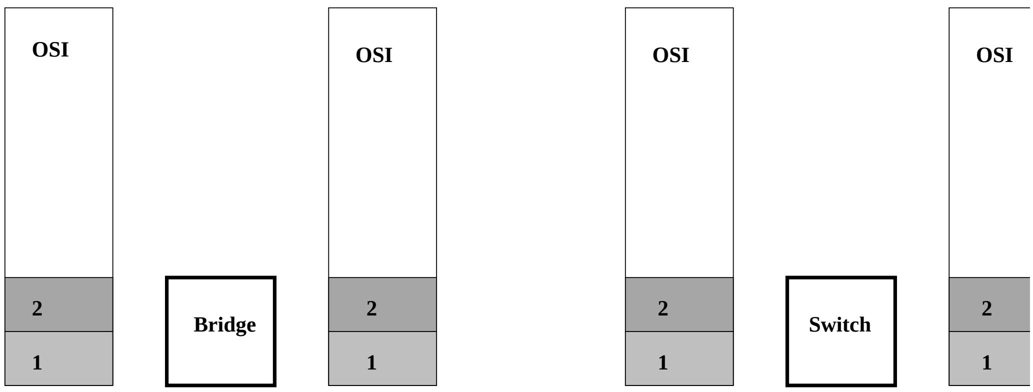


Network Ethernet hardware



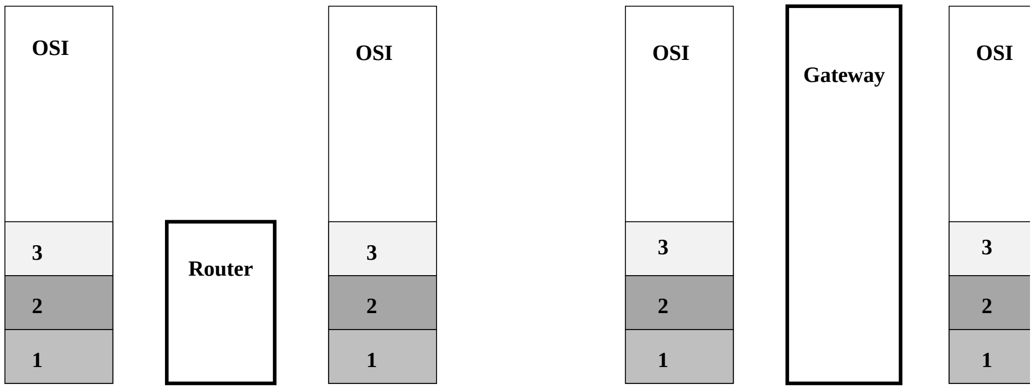
- Repeater
  1. Forwards bits from one network cable to another.
  2. Transparent to other network devices.
  3. Is used to expand the total length of cable.
  4. Doesn't enhance the network performance.
  5. Commonly used in bus topologies
- Hub
  1. Can be called as "multi-port repeater".
  2. Used in the tree topologies.
  3. Every port belongs to the same network segment.
  4. Same features like Repeater (1 - 4).

Network Ethernet hardware



- Bridge
  1. Can be used to connect LAN networks with a different physical and datalink layers (e.g.802.3 with 802.5).
  2. Can enhance the network performance, by splitting the LAN into sub-segments with the same collision domain (every port is assigned to a network segment).
  3. Transparent to other network devices.
  4. Allows redundant paths in the network design. Supports the "Spanning Tree Algorithm" to avoid loops.
- Switch
  1. Can be called as "multi-port bridge".
  2. Has the same features as a bridge (1 - 3).

Network Ethernet hardware



- Router
  1. Used to connect networks with different physical and datalink layers, but the same network protocol (eg. IP-Protocol).
  2. Supplies better isolation (= security) of the LAN, because certain designated frames (eg. Broadcast packets) can be constrained within the local network.
  3. Discriminates whether a datagram can be delivered in the local network, or should be routed to the outside.
  4. Normally used for avoiding network bottleneck by "dynamic routing".
- Gateway
  1. Can connect networks which are different in any layer from physical up to the application layer.
  2. "Behaves like" a router.

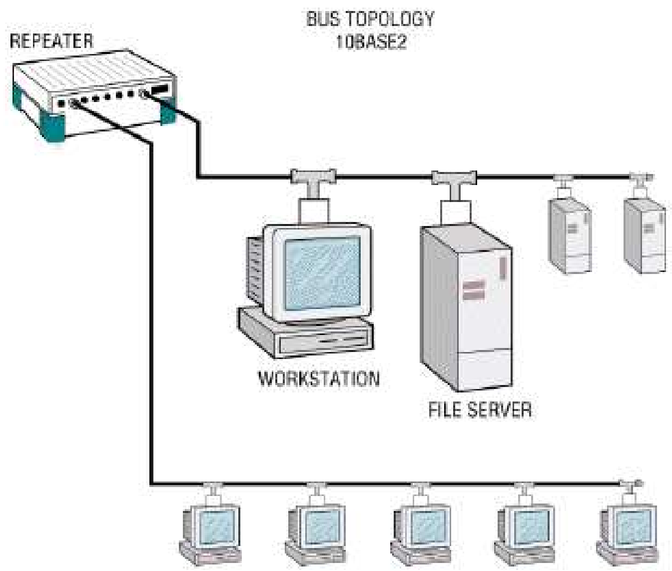
summary

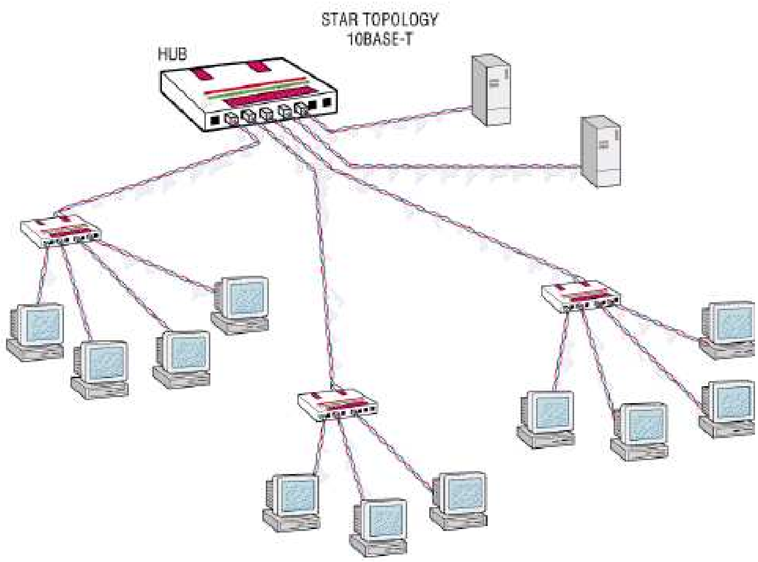
- The Ethernet belongs to the family of best-effort datagram services.
- The 10Mbps Ethernet allows a maximum distance between hosts of 2500 meters
- Ethernet is an asynchronous data-transfer service over a multi-accesssed channel
- The Ethernet frame consists of six logical regions and has a minimum size of 68 bytes, and a maximum length of 1526 bytes. It encapsulates the packets of any protocol above the MAC-sublayer.
- Carrier-Sense Multi-Access with Collision Detection CSMA/CD-Protocol is a main feature of the Ethernet
- The Ethernet is part of the IEEE 802 LAN specification. Other norms which are covered by IEEE 802 are the Token Ring (IEEE 802.5) and Token Bus (IEEE 802.4) network technologies.

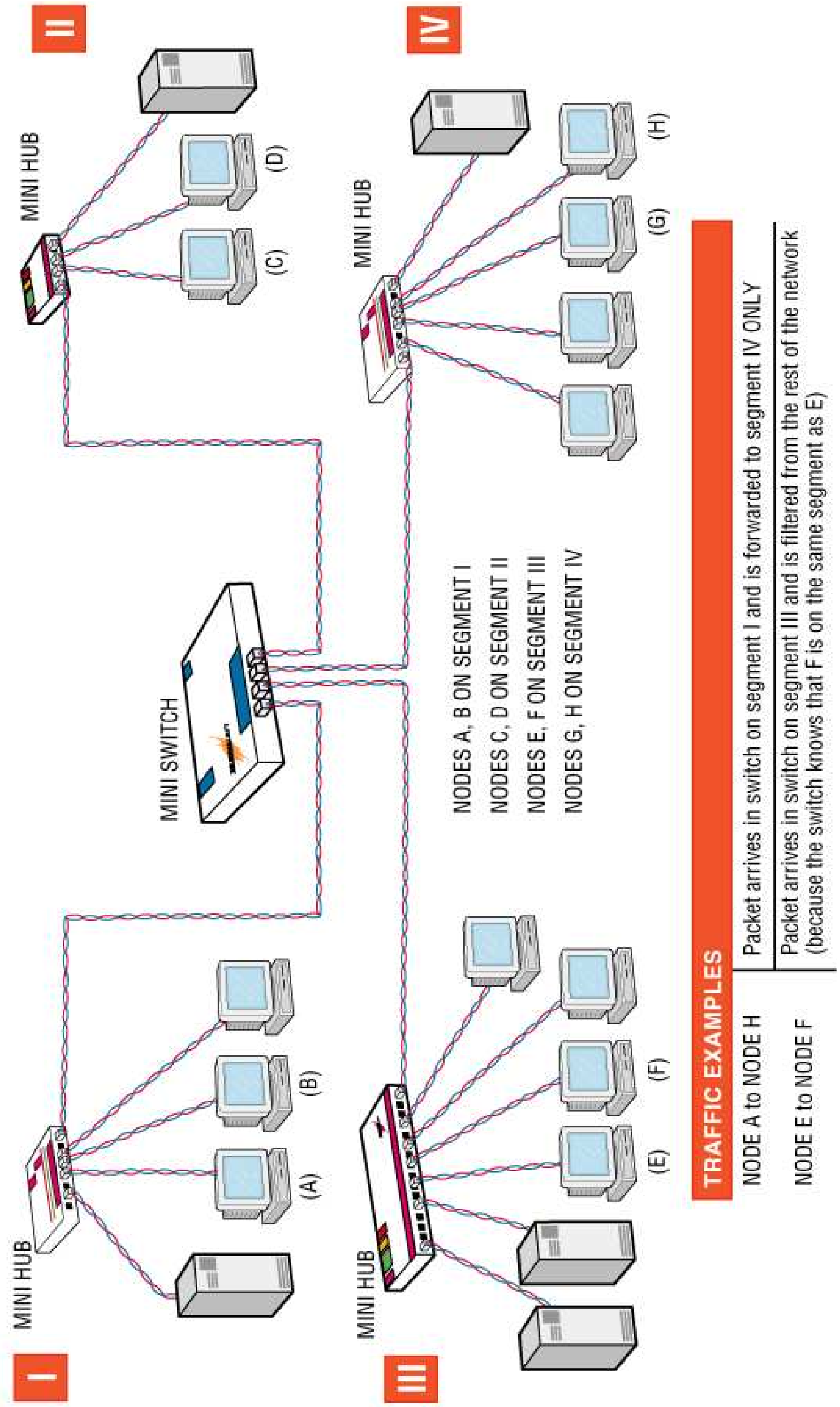
Where to get more information

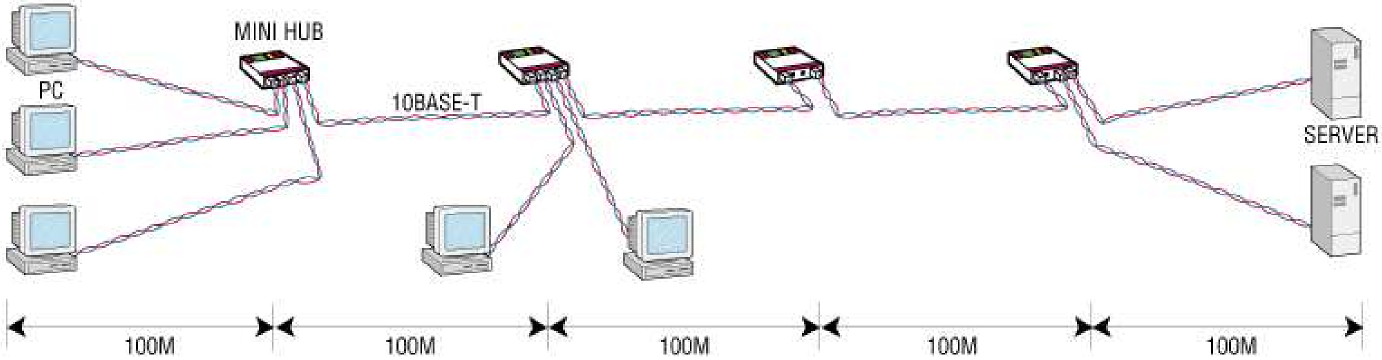
- take a look at my homepage
  (http://www.rvs.uni-bielefeld.de/∼mblume)
- Andrew S. Tanenbaum: Computer Networks, 3rd edition
  (http://www.prenhall.com/divisions/ptr/tanenbaum/)
- Charles Spurgeon's Ethernet Page
  (http://wwwhost.ots.utexas.edu/ethernet/ethernet-home.html)
- Optimized Engineering Technical Compendium
  (http://www.optimized.com/tech_cmp/index.html)
- William Stallings: Data and Computer Communications
  5th Edition, Prentice-Hall International Editions
- "Requests for Comments – RFCs"
  (ftp://src.doc.ic.ac.uk/rfc/rfc-index.txt)
- Michael Fromme: Breitbandkommunikation im LAN .
  (http://www.rvs.uni-hannover.de/arbeiten/studien/mfromme/)
- Hunt C.: TCP/IP Network Administration.
  O'Reilly & Assoc., 1995
- Industry Association and Telecommunication Industry Association (EIA/TIA)
  (http://www.eia.org/)
- Abstract of the original Ethernet Patent no. 4063220: "Multipoint data communication system with collision detection" (http://patent.womplex.ibm.com/) The IBM Patent Server.

Appendix


BUS TOPOLOGY
10BASE2
REPEATER
WORKSTATION
FILE SERVER


STAR TOPOLOGY
10BASE-T
HUB


I
II
III
IV
MINI HUB
MINI HUB
MINI HUB
MINI HUB
MINI SWITCH
(A)
(B)
(C)
(D)
(E)
(F)
(G)
(H)
NODES A, B ON SEGMENT I
NODES C, D ON SEGMENT II
NODES E, F ON SEGMENT III
NODES G, H ON SEGMENT IV
TRAFFIC EXAMPLES
NODE A to NODE H
Packet arrives in switch on segment I and is forwarded to segment IV ONLY
NODE E to NODE F
Packet arrives in switch on segment III and is filtered from the rest of the network (because the switch knows that F is on the same segment as E)



Network expansion with respect to the 5-4-3 Repeater rule