Local Area Networks (LANs) and Legacy Ethernet

Principles, Standards IEEE 802,
Logical Link Control (LLC), Ethernet Fundamentals

Agenda

- **Introduction**
- **IEEE 802**
- **Logical Link Control**
- **Ethernet**
  - Introduction
  - CSMA/CD
  - Elements and Basic Media-Types
  - Repeater, Link Segments
  - Framing

LAN History

- **Local Area Network (LAN), invented late 70`s**
  - initially designed for a common transmission medium
    - shared media
  - high speed
    - 4 Mbit/s, 10 Mbit/s, 16 Mbit/s, 100 Mbit/s
    - nowadays up to 10 Gbit/s
  - limited distance
    - up to some km
    - hence local
  - because of high speed
    - no network elements with store and forward and no routing
    - originally no packet switching on layer 2 !!!
    - note: Ethernet bridging / Ethernet switching invented as L2 packet switching technology in the late 80´s
  - therefore simple topologies
    - bus, ring, star

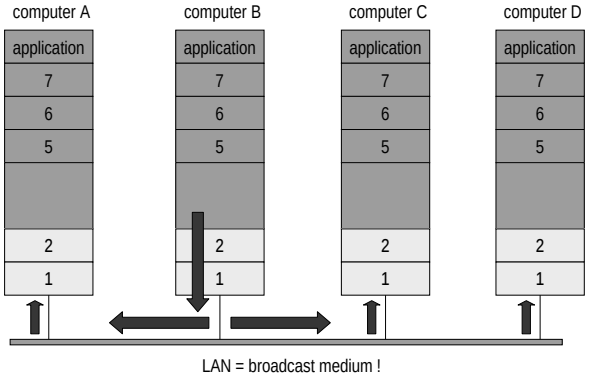
LAN History

- **Local Area Network (LAN)**
  - all network stations share the same media
  - all stations have equal rights
    - no Master - Slave
  - a station can directly communicate with all other stations of the same LAN
  - basis for client - server computing
  - basis for distributed computing
  - high speed extension of internal computer bus

LAN Characteristics

- **multipoint line**
  - access control necessary
    - Media Access Control (MAC)
  - addressing necessary
    - MAC-Address
    - unstructured addresses
    - note: initially no routing requirements !
- **broadcast behaviour**
  - message sent out by one station reaches all other stations on same LAN
- **layer 1 and layer 2 of the OSI model**
  - are sufficient to fulfil communication aspects on LAN

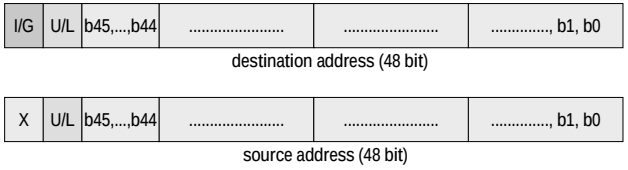
LAN Communication



MAC Addresses

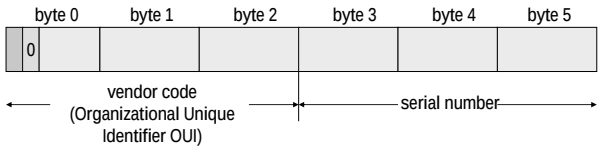
- **every station**
  - is identified by unique MAC-address used as source MAC-address in frames
    - so called “Burn-In” Address (BIA) in case address is administered universally by IEEE
- **MAC address**
  - 6 Byte (48 bit)
  - I/G (Individual/Group) bit
    - 0 ... individual address
    - 1 ... group address
  - U/L (Universal/Local) bit
    - 0 ... universal administered
    - 1 ... local administered

IEEE-MAC-Address Format



- I/G Individual / Group (only for DA):
  I/G = 0 individual address, I/G = 1 group broadcast
  (broadcast for a group is called multicast)
  address with all bits set to 1 .... broadcast-address
  hex FFFF FFFF FFFF (note: U/L is set to 1)
- U/L Universal / Local:
  U/L = 0 global address, administered by IEEE
  U/L = 1 local administered address
  bit 47 (x) not used for source address

IEEE Administered Addresses (U/L = 0)



IEEE assigns each vendor of network components an unique vendor code (OUI, byte 0, 1, 2)

vendors use byte 3, 4 and 5 for numbering their network components (serial number)

called “Burned In” Address (BIA)

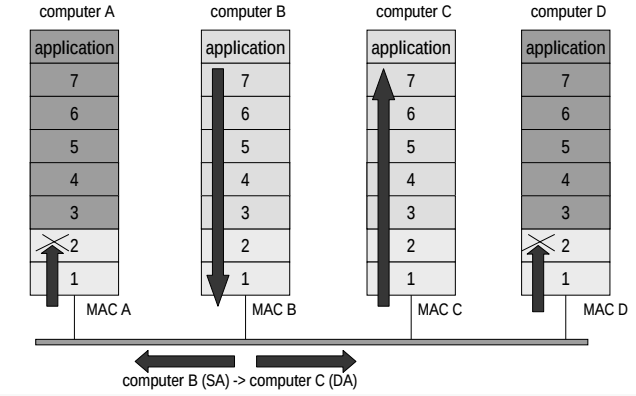
Receipt of frames (1)

- **every frame is received by the Network Interface Card (NIC) of the station**
  - because of the inherent broadcast behaviour of a LAN
- **the NIC decides if a frame should be forwarded to the higher layers (3-7) of a station**
  - depending on its BIA and the destination address of the frame
  - usually NIC interrupts the CPU of the station if frame is to be forwarded
  - otherwise frame is silently discarded by the NIC

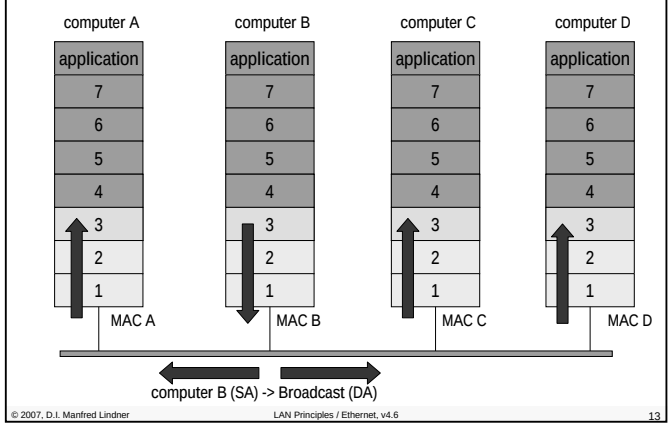
Receipt of frames (2)

- **higher layers (3-7) will see a received frame only**
  - if destination MAC-address is equal to the station MAC-address
  - if destination MAC-address of the frame is the “all broadcast” address
  - if a multicast address was configured in the station and the destination MAC-address is equal to the configured
- **to avoid interruption of all stations by broadcast frames**
  - frames are destined to station specific MAC-addresses during normal operation
  - broadcast should be used in initialization phases of a network only

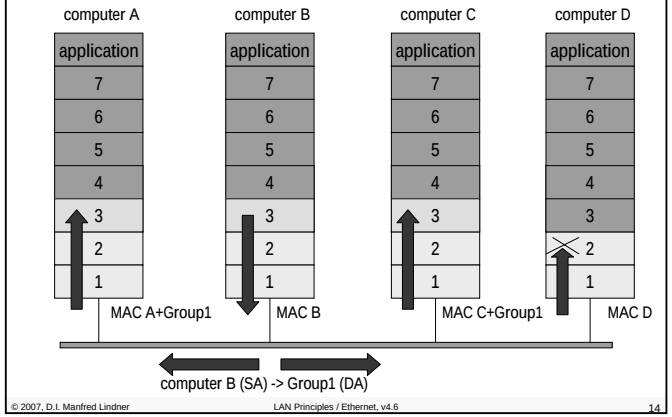
Direct Communication



Broadcast



Multicast



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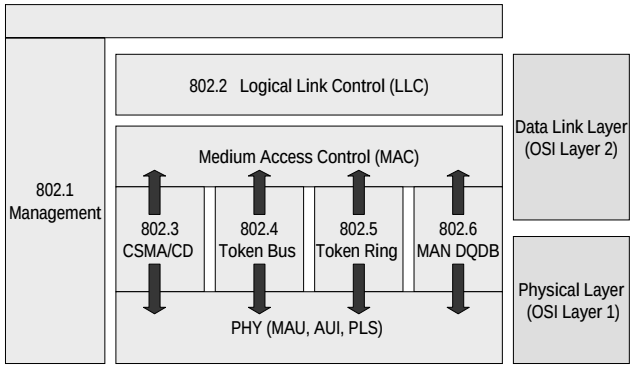
IEEE 802

- **LAN Standardization is done**
  - by IEEE (Institute of Electrical and Electronics Engineers)
  - workgroup 802 (February 1980)
- **OSI Data Link Layer (Layer 2)**
  - was originally designed for point-to-point line
  - but LAN = multipoint line, shared media
- **therefore OSI Layer 2 must be split into two sublayers**
  - Logical Link Control
  - Media Access Control

IEEE 802 versus OSI



Tasks of LAN Layers

- **layer 1**
  - physical layer (PHY) specifies actual transmission technique
  - provides
    - electrical/optical and mechanical interface
    - encoding
    - bit synchronisation
  - consists of
    - MAU (Medium Attachment Unit)
    - AUI (Attachment Unit Interface)
    - PLS (Physical Layer Signalling)

Tasks of LAN Layers

- **layer 2**
  - MAC (Media Access Control) takes care for medium access algorithms, framing, addressing and error detection
    - avoid collisions
    - grant fairness
    - handle priority frames
  - LLC (Logical Link Control) provides original services of data link layer
    - connection-oriented services
    - connection-less service
    - SAPs (Service Access Points) for the higher layers

The IEEE Working Groups

- 802.1 Higher Layer LAN Protocols
- 802.2 Logical Link Control
- 802.3 Ethernet
- 802.4 Token Bus
- 802.5 Token Ring
- 802.6 Metropolitan Area Network (DQDB, MAN)
- 802.7 Broadband TAG
- 802.8 Fiber Optic TAG
- 802.9 Isochronous LAN (VGAnyLAN)
- 802.10 Security
- 802.11 Wireless LAN (WLAN)
- 802.12 Demand Priority
- 802.13 Not Used
- 802.14 Cable Modem
- 802.15 Wireless Personal Area Network (Bluetooth)
- 802.16 Broadband Wireless Access
- 802.17 Resilient Packet Ring

IEEE 802.1 Standards

- **IEEE 802.1**
  - specifies a common framework for all 802.x LANs
    - addressing rules, relations to the OSI model
    - subnet addressing, Bridging Ethernetv2 to 802.2 LANs
    - Management (802.1B)
    - Bridging (802.1D) including STP (Spanning Tree Protocol)
      - Single STP in case of VLANs
    - System Load Protocol (802.1E)
    - Virtual (V) LANs (802.1Q)
      - Tagging
    - STP Rapid Configuration (802.1w)
    - Multiple STP (802.1w)
      - Multiple STP instances in case of VLANs
    - EAP Authentication (802.1x)
      - Extensible Authentication Protocol

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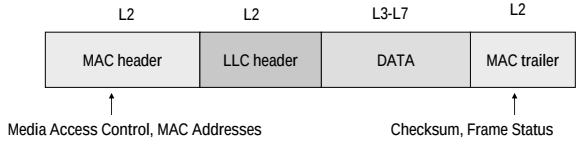
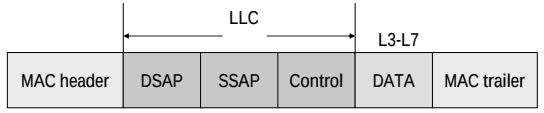
LAN Framing with LLC

- **every data block is encapsulated in a L2 LAN frame**
- **L2 LAN frame consists of**
  - MAC header
  - followed by LLC in case of IEEE 802 LAN
  - MAC trailer
- **MAC header and trailer are LAN type specific**



LLC Header

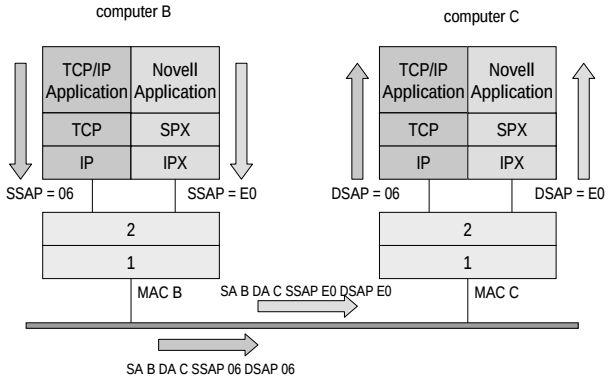
- **LLC header is appended to higher layer data**
  - DSAP (Destination Service Access Point), 8 bit
  - SSAP (Source Service Access Point), 8 bit
  - Control Field, 8 or 16 bit



DSAP and SSAP

- **a IEEE 802 LAN**
  - can be used by different protocol families sharing the same communication media
    - e.g. TCP/IP parallel to Novell IPX, IBM SNA, NetBeui, Appletalk
- **DSAP and SSAP**
  - identify the higher level protocol family, which is the destination and the source of the given frame
  - protocol type or protocol stack identifier

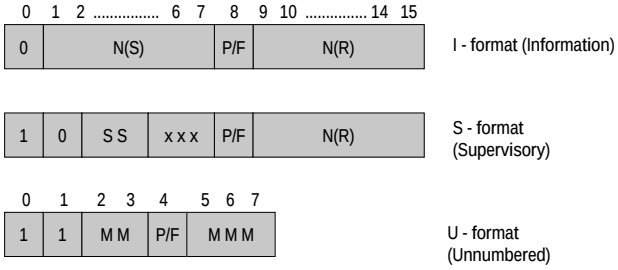
Protocol Stack Distinction



LLC Control Field

- **LLC Control field and protocol procedures are very similar to HDLC**
  - remember: HDLC procedures allow connection-less and connection-oriented services on a layer 2 link
- **connection-less mode is used by**
  - IP, IPX, AppleTalk, etc
- **connection-oriented mode is used by**
  - SNA over LLC Type 2
  - NetBIOS over LLC Type 2 (NetBeui)
    - e.g. Microsoft Network

LLC Control Field



N(S), N(R) ..... send- and receive - sequence numbers
S S, MMM ..... selection bits for several functions
P / F ..... poll / final bit (P in commands, F in responses; distinction of commands and responses through a dedicated SSAP bit -> C/R bit)

Frame Types and Classes

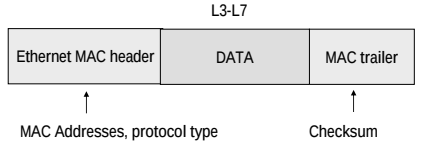
	Cmd	Control	Resp	Control	Class 1	2	3	4
Type 1	UI	1100p000			x	x	x	x
	XID	1111p111	XID	1111f111	x	x	x	x
	TEST	1100p111	TEST	1100f111	x	x	x	x
Type 2	I	0 n(s) p n(r)	I	0 n(s) f n(r)		x		x
	RR	10000000 p n(r)	RR	10000000 f n(r)		x		x
	RNR	10100000 p n(r)	RNR	10100000 f n(r)		x		x
	REJ	10010000 p n(r)	REJ	10010000 f n(r)		x		x
	SABME	1111p110	UA	1100f110		x		x
	DISC	1100p010	DM	1111f001		x		x
			FRMR	1110f001		x		x
Type 3	AC0	1110p110	AC0	1110f110			x	x
	AC1	1110p111	AC1	1110f111			x	x

LLC Control Field

- **four service methods defined for LANs**
  - Class 1:
    - connectionless unacknowledged service (datagram)
    - type 1 - frames: UI,XID,TEST
  - Class 2:
    - connection oriented service plus Class 1
    - type 2 - frames: I,RR,RNR,REJ, SABME,UA,DM
  - Class 3:
    - Class 1 plus connectionless acknowledged service
    - type 1 -frames plus additional type 3 - frames: AC0, AC1
  - Class 4:
    - Class 2 plus connectionless acknowledged service
    - type 2 - frames plus additional type 3 - frames: AC0, AC1

LAN Framing with Ethernetv2

- **every data block is encapsulated in an Ethernetv2 LAN frame**
- **most common framing used today**
- **only connectionless service possible on layer 2**
- **LAN frame consists of**
  - Ethernet MAC header
  - Protocol stack identified by protocol type field in MAC header
  - Ethernet MAC trailer



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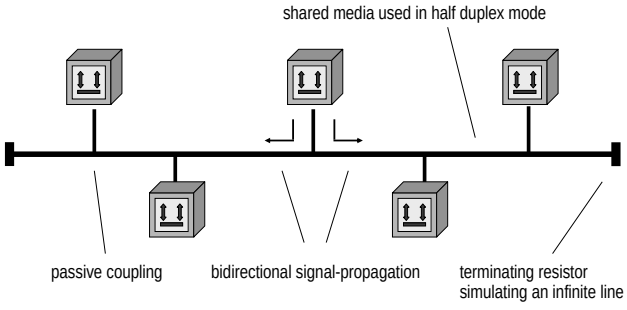
Origin of IEEE 802.3 (Ethernet)

- bus topology based on coax-cables
  - passive, uninterrupted coupling
  - shared media like the „Ether“ of air
- bidirectional signal-propagation
  - termination resistors avoid signal reflections
- definite transmitting power of network stations
  - limits cable length and number of (receiver-) stations
- two types with baseband transmission with Manchester encoding, 10 Mbit/s
  - 10Base5 "Yellow Cable“
  - 10Base2 "Cheapernet"
- one type with modulation (broadband)
  - 10Broad36 (broadband)

Basic Idea of Ethernet Bus System



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Media Access Control of Ethernet 1

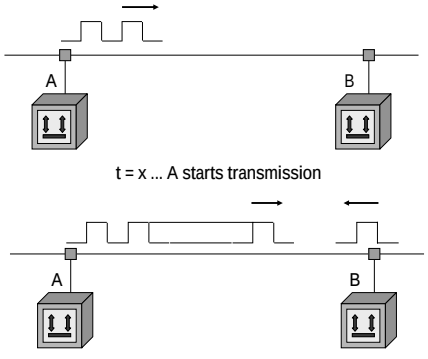
- **CSMA/CD**
  - Carrier Sense Multiple Access / Collision Detection
  - access control based on contention
  - network stations listen to the bus before they start a transmission
  - network stations can detect ongoing transmission (CS) and will not start own transmission before ongoing transmission is over
  - but still simultaneous transmissions (MA) cause collisions (bus conflict)
  - collisions are detected (CD) by observing the DC-level on the medium

Media Access Control of Ethernet 2

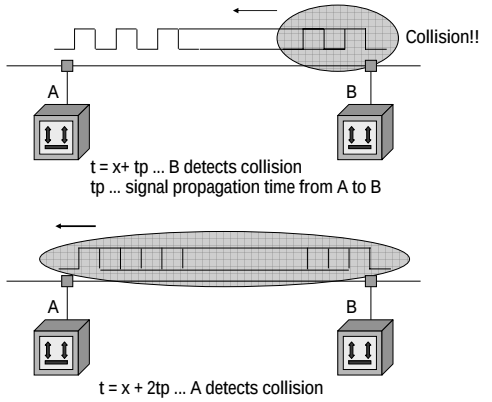
- **conflict resolution**
  - aborting of transmission by all involved stations
  - sending of a JAM-signal (32 bit)
    - to make sure that every station can recognize the collision
    - collision is spread to a minimum length
  - starting a random number generator to create a timeout value

    truncated binary exponential backoff algorithm (the more often a collision occurs the larger is the range for the random number)
  - after timeout expired, station attempts a retransmission
  - number of retransmission-trials is limited to 16
    - after 16 collisions in a sequence a error is signalled to the higher layer

Collision Window / Slot Time 1



Collision Window / Slot Time 2



Collision Window / Slot Time 3

- **worst case**
  - stations have to wait (have to send bits) twice the maximum signal propagation time for reliable collision detection
    - otherwise a collision may not be seen by the transmitting station
  - the maximum allowed time for that in Ethernet transmission system
    - is called collision window or slot time
  - 10 Mbit/s Ethernet defines 51,2 microsecond for the collision window / slot time
    - 10 Mbit/s means 1 bit every 100ns
    - therefore 51,2 microsecond is equal to 512 bits
    - hence the minimal frame length is 64 byte

Collision Window / Slot Time 4

- **there is an interdependence**
  - maximum propagation time (cable and electronic components) or slot time, data rate, cable length and minimum frame size
  - if you choose one parameter, the others will follow
- **the request for reliable collision detection during sending of a frame and the definition of a given Ethernet slot-time**
  - limits the physical distance (network diameter) of Ethernet LANs for 10 Mbit/s
    - around 2500 - 3000 meters
- **the request for fairness**
  - limits the maximum frame size, too
  - 1518 byte is the maximum allowed frame size

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Collision Window / Slot Time 5

Technology	Bit-Time (sec)	Collision Window (sec)	Slot Time (bit-times)		Minimum Frame (bit-times / byte)	Distance (m)
10Mbit/s	100ns	51,2µs	512	=	512 / 64	2000-3000
100Mbit/s	10ns	5,12µs	512	=	512 / 64	~200
1000Mbit/s	1ns	0,512µs	512		512 / 64	~10-20
1000Mbit/s	1ns	4,096µs	4096*	≠	512 / 64	200

*** by the usage of carrier extension and frame bursting**

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Exponential Backoff Details

- **Provides maximal utilization of bandwidth**
  - After collision, set basic delay = slot time
  - Total delay = basic delay * random
  - 0 <= random < 2^k
    - k = min (number of transmission attempts, 10)
- **After 16 successive collisions**
  - Frame is discarded, error message to higher layer and next frame is processed, if any
- **Truncated Backoff (k<=10)**
  - 1024 potential "slots" for a station
  - Thus maximum 1024 stations allowed on half-duplex Ethernet

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Collision Detection Details

- **10Base2, 10Base5**
  - Manchester with –40 mA DC level
  - "high" = 0 mA, "low" = –80 mA
  - Two signals at same time: DC Level < -40 mA
- **10BaseT**
  - Manchester with no DC offset
  - Collisions are detected by “Hub” component which sends a "Jam" signal back in case two or more stations start at the same time
  - Similar at 100BaseT and 1000BaseT

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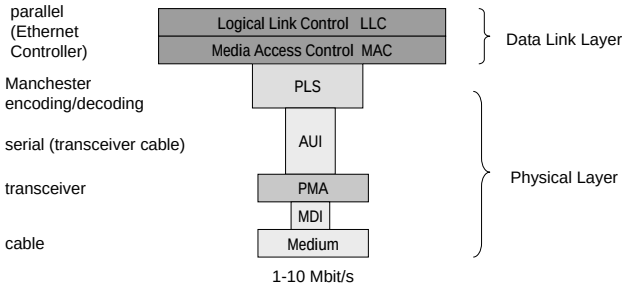
Physical Layer Functions



AUI...Attachment Unit Interface, PLS...Physical Layer Signalling, MDI...Medium Dependent Interface, Interface, PMA...Physical Medium Attachment, MAU...Medium Attachment Unit

PHY Sublayers

- **Physical Layer Signaling (PLS) serves as abstraction layer between MAC and PHY**
- **PLS provides**
  - data encoding/decoding (Manchester)
  - translation between MAC and PHY
  - Attachment Unit Interface (AUI) to connect with PMA
- **Physical Medium Attachment (PMA)**
  - interface between PLS and MDI
- **Medium Attachment Unit (MDI)**
  - specification of the various connectors

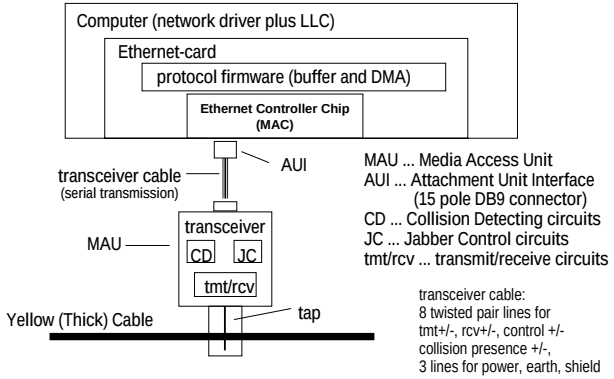
Media-Connection by Transceiver

- **transmitter / receiver**
- **transceiver provides electronic circuits for:**
  - inserting and receiving signal currents
  - collision detection
    - measurement of DC level
    - 10Base5: Level High (1) = 0 mA, Level Low (0) = -80 mA
    - DC of Manchester-encoded signal = -40 mA
    - two signals at same time: DC Level < -40 mA
  - heartbeat function
    - SQE Signal Quality Error
  - jabber control
    - jabber: continuously emitting of frames beyond the maximal frame size

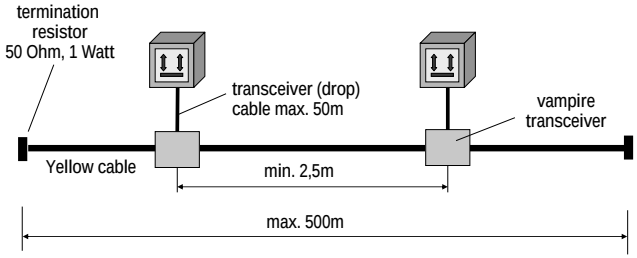
External / Internal Transceiver

- **transceiver types:**
  - 10Base5, 10Base2,
  - FOIRL (Fiber Optic Inter Repeater Link) and 10BaseT, 10BaseF (these types will be handled later in this presentation)
- **external transceiver:**
  - AUI interface (with or without transceiver cable) connects end system and transceiver
  - transceiver powered by end system
- **integrated transceiver:**
  - transceiver is integrated on network card of end system
  - network card provides necessary physical connector
    - BNC (10Base2)
    - RJ45 (10BaseT)
    - ST (10BaseF)

AUI-Connection with 10Base5 Transceiver

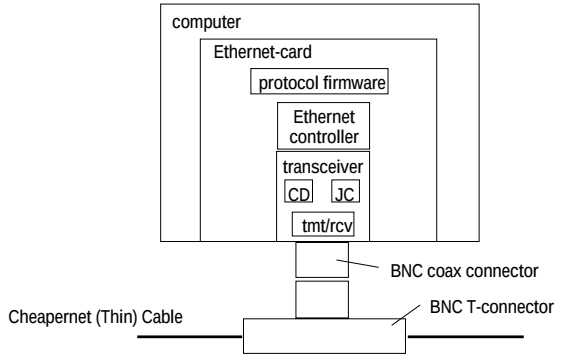


10Base5 Parameter

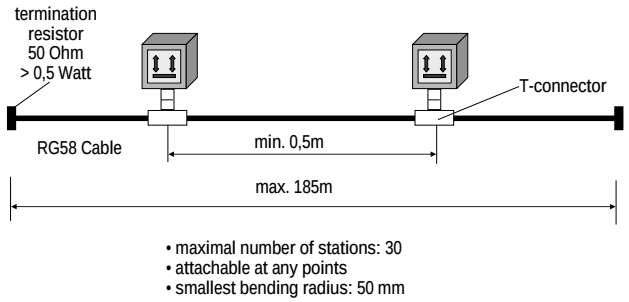


- maximal number of stations: 100
- attachable only at marked points
- cable splitting via coax couplers
- individual cable parts have a length of 23,4m or 70,2m or 117,5m (wave minimum on standing waves due to inhomogeneous media)
- smallest bending radius: 254mm

Integrated Transceiver for 10Base2



10Base2 Parameter



- maximal number of stations: 30
- attachable at any points
- smallest bending radius: 50 mm

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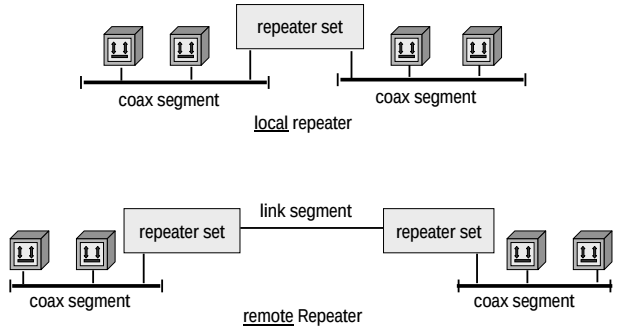
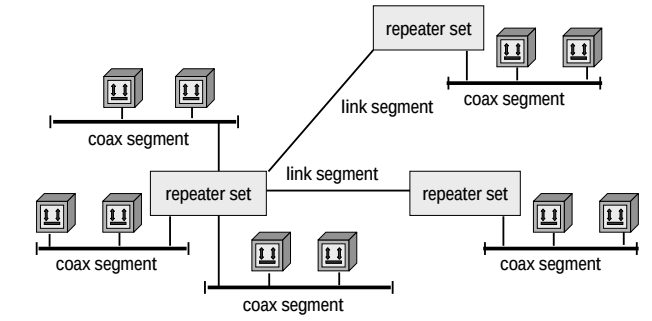
Repeater

- **a Repeater is an amplifier expanding the maximal distance of an Ethernet-LAN segment**
  - regenerate signals on the receiving port, amplify them, and send these signals to all connected net segments
  - no buffering, just a short delay, which must be taken into account for the collision window
  - collisions are detected and all other ports are notified by jam-signal
  - optionally auto partition on erroneous ports
- **collision domain**
  - is preserved by repeaters
- **local repeaters directly connect two (coax) segments**
- **remote repeaters are connected by so called link segments**

Local / Remote Repeater



Multiport Repeater - One Collision Domain



Link Segments for Repeater Interconnection

- **link segment**
  - first implementation for repeater interconnection only
  - point-to point connection
    - only two devices are connected by a physical cable
  - several types were defined
    - fibre based
    - copper based
  - FOIRL (Fibre Optic Inter Repeater Link)
    - maximal length 1000m
    - first FO specification
    - repeater - repeater

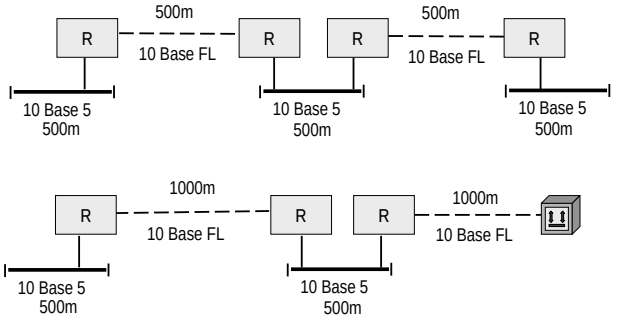
Link Segments for Repeater Interconnection

- **types cont.**
  - 10BaseFL (Fibre)
    - asynchronous
    - maximal length 2000m
    - repeater - repeater, end system - multiport repeater
  - 10BaseFB (Fibre)
    - synchronous (idle signals during communication pauses)
    - maximal length 2000m
    - for repeater - repeater links only
    - developed to overcome limitation based on repeater rules by defining a repeater less backbone infrastructure
  - 10BaseFP (Fibre)
    - passive hub, no active repeater function (remark: active means electrically powered)

Repeater-Rules 1

- **collision domain of an Ethernet LAN is limited**
  - collision window of 51,2 microsecond
- **topology of repeaters must obey**
  - maximal 5 segments over 4 repeater-sets are allowed, in this case 2 segments have to be link-segments (rest arbitrary), length of fibre optic link segments must not exceed 500m each
    - **-> results in a maximum diameter of 2500m**
  - on 4 segments with 3 repeater-sets, the length of a fibre optic link segment must not exceed 1000m, the segments may be mixed in any desired way
    - **-> results in a maximum diameter of 3000m**

Repeater-Rules 2



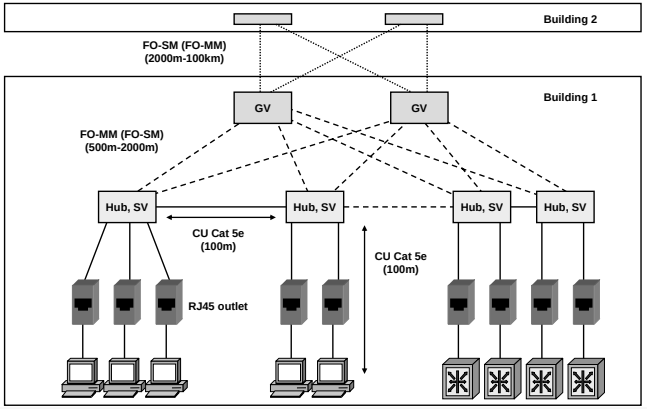
Link Segments for End Systems 1

- **link segment**
  - was later also defined for connection of a network station (end system) to a multiport repeater
    - using a dedicated point-to-point line
  - reason for that:
    - Ethernet was originally based on coax cabling and bus topology
    - later an international standard for structured cabling of buildings was defined
      - star wired to a central point(s)
      - based on twisted pair cabling
    - that excellently fits to Token ring cabling
    - Ethernet had been adapted to that in order to survive

Structured Cabling (LAN)

- **Physical Wiring**
  - Should follow the principle of structured cabling
  - Primary
    - End system to first “Hub” (Repeater or nowadays a L2 Switch)
      - “Stockwerkverteiler”
    - CU-UTP, Category 5e or better
    - FO for extreme conditions only
  - Secondary
    - Hubs to central functions
      - “Gebäudeverteiler”
    - FO-MM (FO-SM)
  - Tertiary
    - Interconnections of buildings
    - FO-MM (FO-SM)

Structured Cabling (LAN)



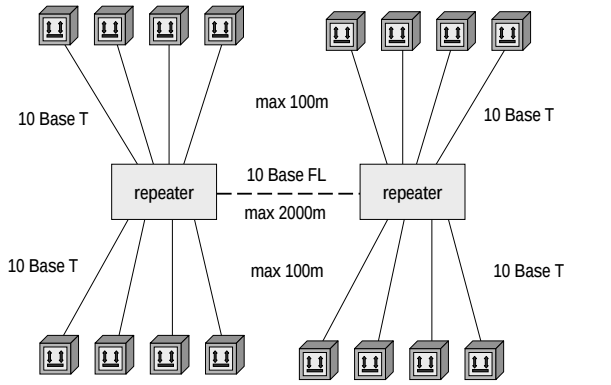
Link Segments for End Systems 2

- **link segment (cont.)**
  - 10BaseT (unshielded twisted pair)
    - maximal length 100m
    - 2 lines Tmt+-, 2 lines Rcv+-, RJ45 connector
    - Manchester-Code with no DC offset
      - collisions are detected by hub, if two or more signals are received at the same time, hub produce Jam signal on all ports, hence collision is recognized if signals are on the tmt and rcv line at the same time
    - during transmission pause
      - "Start of Idle" signal followed by periodic link test pulses (LTP) to check the link state
      - every 16ms a 100ns lasting LTP is sent by LAN devices, no signal on the wire means disconnected
    - repeater - repeater, end system - multiport repeater,
    - end system - end system via cross-over cable

Link Segments for End Systems 3

- **repeater with more than two segments and different physics**
  - multiport repeater repeater
- **end-systems and multiport repeater in a star like topology**
  - repeater is called a "Hub"
    - be careful using this expression because also used for L2 Ethernet-Switch
  - main usage for 10BaseT in today's Ethernet networks

Multiport Repeater as „Hub"



Agenda

- **Introduction**
- **IEEE 802**
- **Logical Link Control**
- **Ethernet**
  - Introduction
  - CSMA/CD
  - Elements and Basic Media-Types
  - Repeater, Link Segments
  - Framing

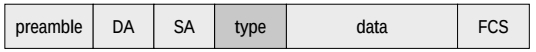
IEEE 802.3 Frame Format

preamble ..... for clock synchronization (64 bit)
(62 bits 10101.....01010 + 2bits 11 as SD,
bit synchronization within 18 bit times)
DA ..... Destination MAC-address (48 bit)
SA ..... Source MAC-address (48 bit)
length ..... of IEEE 802.3 frame (16 bit)
= octets following without CRC (46-1500)
data ..... payload
FCS ..... Frame Check Sequence (32 Bit)
parameters: interframe gap 9.6 microsecond
jam size 32 bit
slot time 512 bits, minimal frame length 64 Byte
(6+6+2+46+4, FCS counted, preamble not counted)
-> at maximum 14880 frames per second
maximal frame length 1518 byte (6+6+2+1500+4)

IEEE 802.3 <-> Ethernet Version 2

- **IEEE 802.3 relies on LLC (802.2) and SAPs**
  - the protocol-type is indicated by SSAP and DSAP (LLC)
- **Ethernet Version 2 uses a protocol-type-field instead of the length field**
  - there is no need for an additional sub layer (like LLC) in order to implement connectionless services only
  - layer 3 is directly attached on Ethernet V2
- **some values for the protocol-type-field (Ethertype):**
  - 0x0800 IP, 0x806 ARP, 0x8035 RARP, 0x814C SNMP
  - 0x6001/2 DEC MOP, 0x6004 DEC LAT, 0x6007 DEC LAVC, 0x8038 DEC Spanning Tree
  - 0x8138 Novell

Ethernet Version 2 (DEC, Intel, Xerox -> DIX)

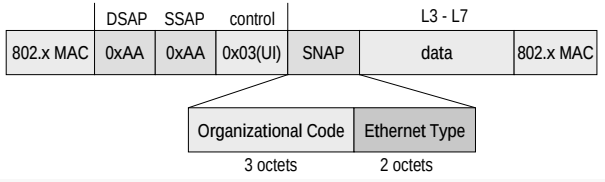


preamble ..... for clock synchronization
DA ..... Destination Address (48 Bit)
SA ..... Source Address (48 Bit)
type ..... protocol-type field (16 Bit)
(Ethernet Version II frame)
Data ..... payload
FCS ..... Frame Check Sequence (32 Bit)

- Ethernet V2 and 802.3 can coexist on the same cable, but each associated sending and receiving station must use the same format.
- Fortunately all type-field values are larger than 1518 (max frame length), so any incoming frame can be recognized and handled properly.

Ethernet Type over LLC with SNAP

- **SNAP (Subnetwork Access Protocol)**
  - convergence protocol to transport Ethernet V2 type information over IEEE LANs
  - reason: LLC SAP-fields (length 8 bit) can not carry some already defined Ethernet V2 protocol types (length 16 bit)
  - note: some IEEE LANs require the usage of LLC
    - e.g. Token Ring, FDDI



SAP, SNAP, Ethernet V2 - SUMMARY