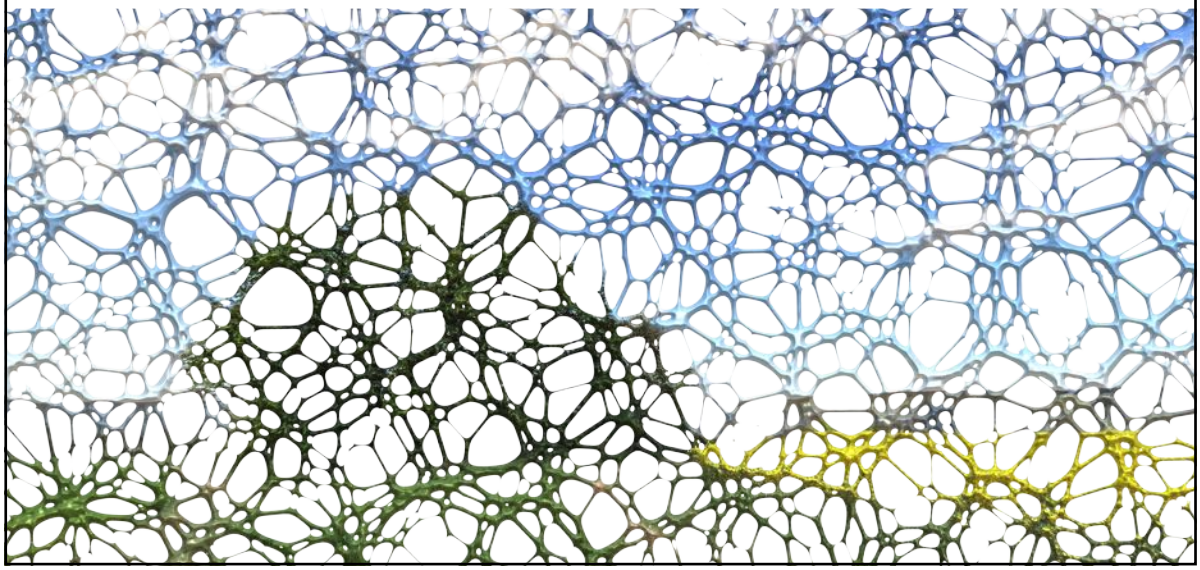
Rechnernetze

Peter Sturm, AG SysSoft, Universität Trier



Rechnernetze

4. Layer 1-3 am Beispiel Ethernet

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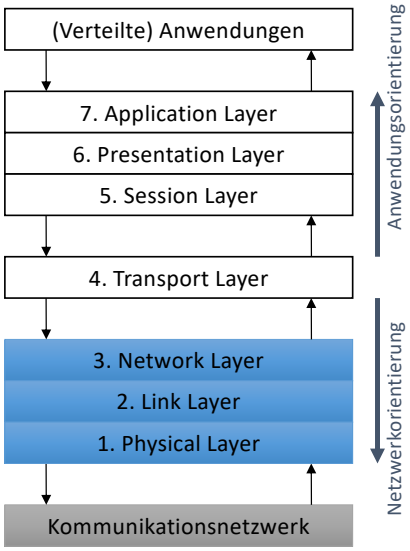
ISO-Referenzmodell

- OSI-Modell = Reference Model for Open Systems Interconnection
- Referenzmodell !
- Realisierung
  - Ebene 1-3: Hardware (Firmware)
    - Netzwerk-Controller
  - Ebene 4-7: Software



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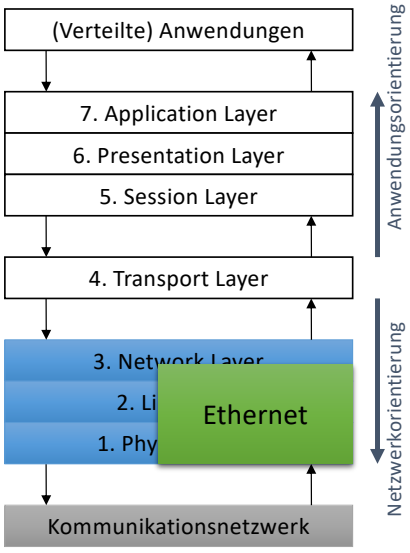

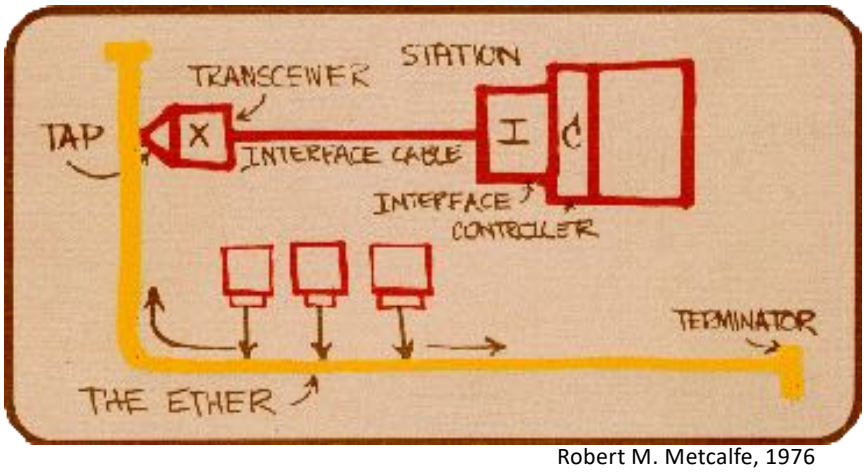

Robert M. Metcalfe, 1976

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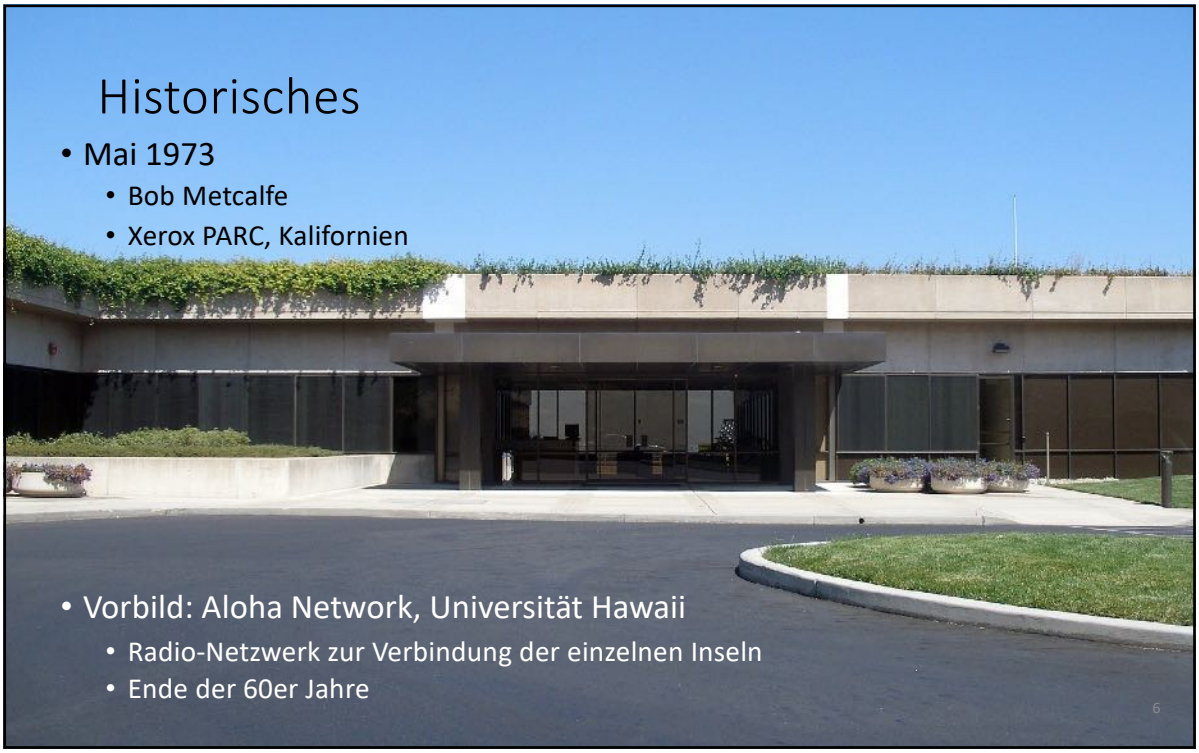
Historisches

- Mai 1973
  - Bob Metcalfe
  - Xerox PARC, Kalifornien



- Vorbild: Aloha Network, Universität Hawaii
  - Radio-Netzwerk zur Verbindung der einzelnen Inseln
  - Ende der 60er Jahre

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name	description
IEEE 802.1	Bridging (networking) and Network Management
IEEE 802.2	Logical link control
IEEE 802.3	Ethernet
IEEE 802.4	Token bus
IEEE 802.5	Defines the MAC layer for a Token Ring
IEEE 802.6	Metropolitan Area Networks
IEEE 802.7	Broadband LAN using Coaxial Cable
IEEE 802.8	Fiber Optic TAG
IEEE 802.9	Integrated Services LAN
IEEE 802.10	Interoperable LAN Security
IEEE 802.11 a/b/g/n	Wireless LAN & Mesh (Wi-Fi certification)
IEEE 802.12	demand priority
IEEE 802.13	
IEEE 802.14	Cable modems
IEEE 802.15	Wireless PAN
IEEE 802.15.1	Bluetooth certification
IEEE 802.15.4	ZigBee certification
IEEE 802.16	Broadband Wireless Access (WiMAX certification)
IEEE 802.16e	(Mobile) Broadband Wireless Access
IEEE 802.16.1	Local Multipoint Distribution Service
IEEE 802.17	Resilient packet ring
IEEE 802.18	Radio Regulatory TAG
IEEE 802.19	Coexistence TAG
IEEE 802.20	Mobile Broadband Wireless Access
IEEE 802.21	Media Independent Handoff
IEEE 802.22	Wireless Regional Area Network
IEEE 802.23	Broadband ISDN system

wikipedia

IEEE 802

- LMSC = LAN/MAN Standards Committee (Project 802)
  - 802 zufällig nächste freie Zahl
  - oder erstes Treffen (Februar 1980)
- Link-Layer (LLC)
- Medium-Access (MAC)
  - Untere Network Layer

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Ziele

- Einfach zu erweiterndes Kommunikationssystem
  - Mehrere Gebäude
- Kostengünstige Lösung
  - Passives System
  - Alle Kontrolle in den kommunizierenden Endgeräten
  - Einfache Erweiterbarkeit der Topologie
- “Reliability through Simplicity”
  - Keine redundante Verbindungen
  - Kein Store-And-Forward Netz

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Varianten

Benennung	Übertragunsrate	Charakteristika
10BASE5	10 MBit/s	Original; Thick Ethernet
10BASE2	10 MBit/s	Thin Ethernet
10BASE-T	10 MBit/s	Twisted-Pair-Kabel (TP)
100BASE-TX	100 MBit/s	
100BASE-FX	100 MBit/s	Lichtwellenleiter
1000BASE-T	1 GBit/s	Häufigste Fassung (verwendet TP)
1000BASE-**	1 GBit/s	Diverse Lösungen mittels Glasfaser
10GBASE-**	10 GBit/s	Primär Lösungen auf Basis Glasfaser
10GBASE-T	10 GBit/s	Oder doch auch mit Kupferkabel?
…	…	…

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Rechnernetze

4.1 Thick Ethernet

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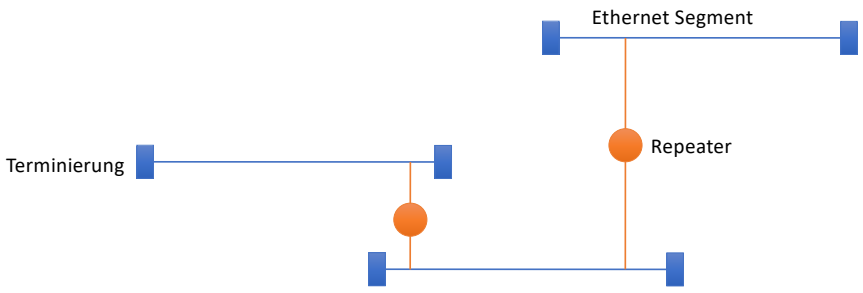
Topologie

- Wurzelloser Baum
  - Nur ein Weg zwischen jeweils zwei Rechnern
  - In jeder Richtung erweiterbar



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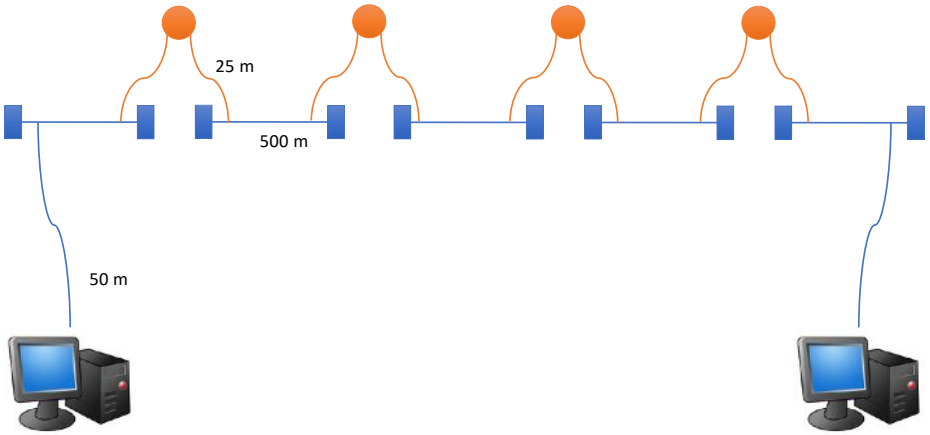
Maximale Ausdehnung

- 2800 Meter



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Transceiver – 10 MB Thick Ethernet

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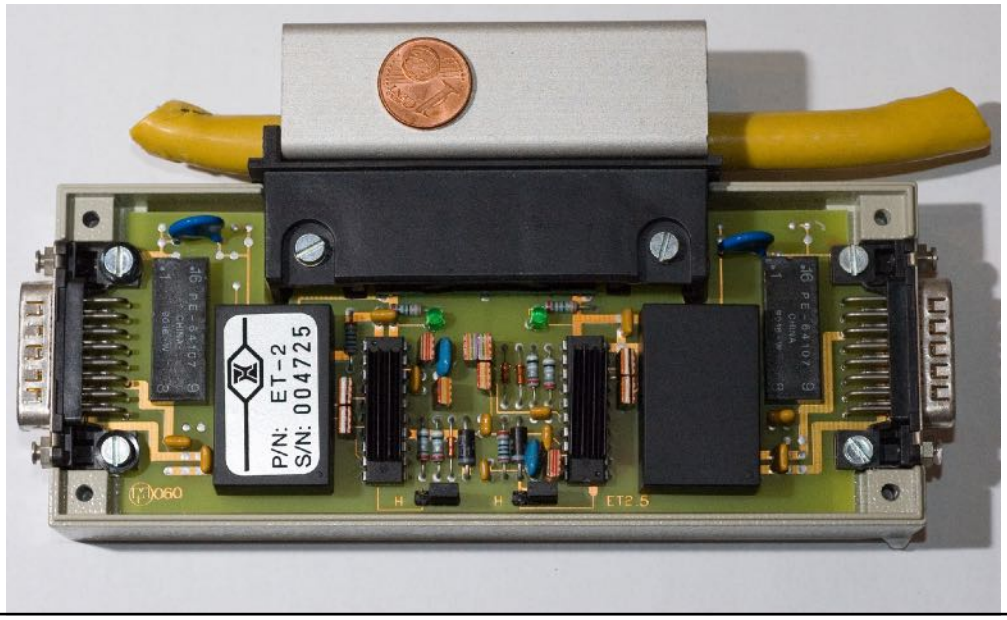
Transceiver – 10 MB Thick Ethernet (2)



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Transceiver – 10 MB Thick Ethernet (3)

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Transceiver – 10 MB Thick Ethernet (4)

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Aufbau Ethernet-Frame (10 MBit)

Preamble	56 Bit
SFD	8 Bit
Destination Address	48 Bit
Source Address	48 Bit
Length/Type Indicator	16 Bit
Data 46-1500 Byte	
Pad (optional)	
Frame Check Sequence	32 Bit

- Preamble
  - Uhrensynchronisation
- SFD = Start of Frame Delimiter
- 48 Bit Ethernet-Adressen
- Pad
  - Falls weniger als 512 Datenbits
  - Minimale Framegröße
- Frame Check Sequence
  - CRC-Summe zur Fehlererkennung

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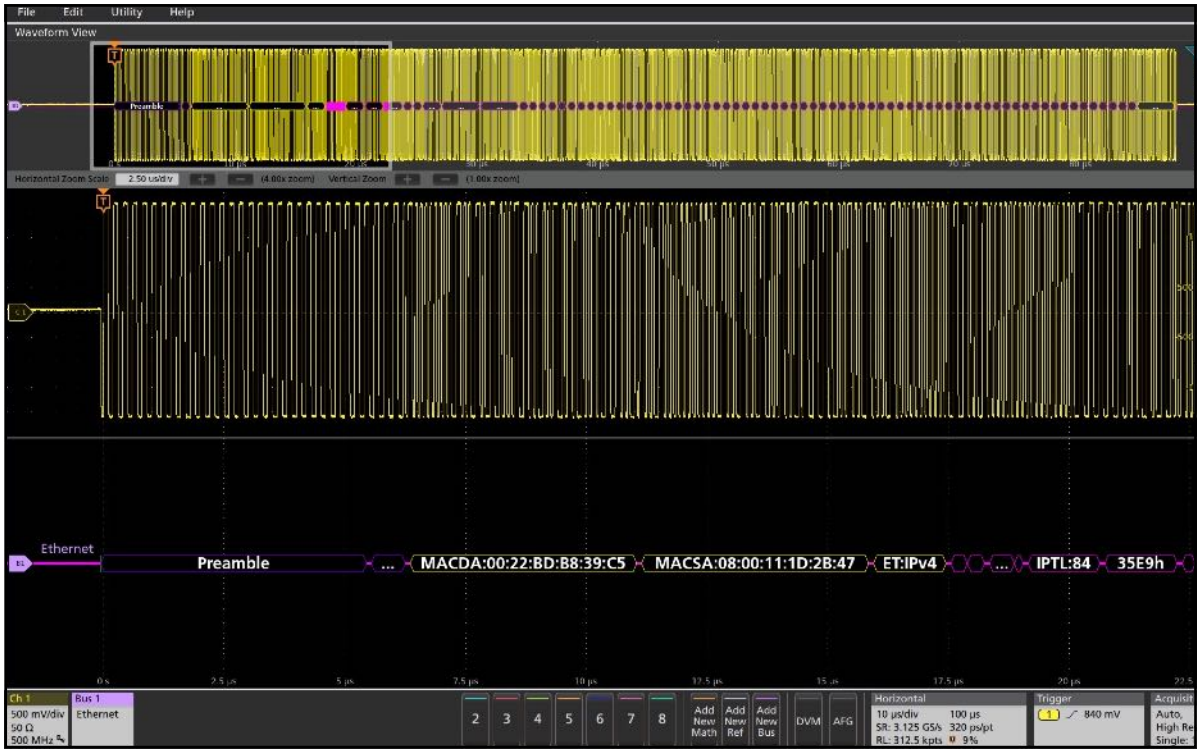
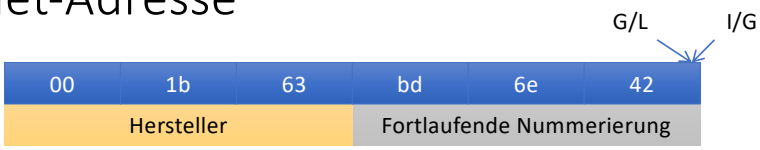


Ethernet-Adresse



- Hersteller = 24 Bit OUI (Organizationally Unique Identifier)
  - Wird von IEEE-SA (Standards Association) vergeben
- Aktuell über 12400 Kennungen vergeben (0.07%)
- I/G-Bit
  - Unicast (0), Multicast (1), Broadcast (alle Bits 1)
- G/L-Bit
  - GAA Globally administered Address (0, Normalfall)
  - LAA Locally Administered Address (1)

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OUI Beispiele

```
00-1B-60   (hex)            NAVIGON AG
001B60     (base 16)        NAVIGON AG
                            Berliner Platz 11
                            Wuerzburg Bavaria 97080
                            GERMANY

00-1B-61   (hex)            Digital Acoustics, LLC
001B61     (base 16)        Digital Acoustics, LLC
                            37 Sherwood Terrace
                            Lake Bluff IL 60044
                            UNITED STATES

00-1B-62   (hex)            JET Optoelectronics Co.,Ltd.
001B62     (base 16)        JET Optoelectronics Co.,Ltd.
                            Hetian Industrial Park 2rd,Houjie Town, Donguan,
                            Dongguan Guangdong 523945
                            CHINA

00-1B-63   (hex)            Apple Computer Inc.
001B63     (base 16)        Apple Computer Inc.
                            1 Infinite Loop
                            Cupertino California 95014
                            UNITED STATES

00-1B-64   (hex)            IsaacLandKorea Co., Ltd,
001B64     (base 16)        IsaacLandKorea Co., Ltd,
                            Rm 608, Hangang-Hyundai-Hyel Bldg. 2-36,
                            Hangangno 2-ga, Yongsan-gu,
                            Seoul  140-871
                            KOREA, REPUBLIC OF

00-1B-65   (hex)            China Gridcom Co., Ltd
001B65     (base 16)        China Gridcom Co., Ltd
                            21/F, Huaneng Building, No. 2068 Shennan Main Road
                            Shenzhen Guangdong 0086
                            CHINA

00-1B-66   (hex)            Sennheiser electronic GmbH & Co. KG
001B66     (base 16)        Sennheiser electronic GmbH & Co. KG
```

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Länge/Typ

- Unterschiedliche Bedeutung je nach Herkunft
  - Typ = ursprüngliches DIX-Format (Ethernet_II)

Typ	Dezimal	Protokoll
0-05dc	0-1500	Länge
0600	1536	XEROX IDP
0800	2048	IP
0805	2053	X.25
0806	2054	ARP
8035	32821	RARP
809b	32923	AppleTalk
8137	33079	Novell
…	…	…

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Weitere EtherTypes

EtherType	Protocol
0x0800	Internet Protocol, Version 4 (IPv4)
0x0806	Address Resolution Protocol (ARP)
0x0842	Wake-on-LAN
0x8035	Reverse Address Resolution Protocol (RARP)
0x809B	AppleTalk (Ethertalk)
0x80F3	AppleTalk Address Resolution Protocol (AARP)
0x8100	VLAN-tagged frame (IEEE 802.1Q)
0x8137	Novell IPX (alt)
0x8138	Novell
0x86DD	Internet Protocol, Version 6 (IPv6)
0x8808	MAC Control
0x8819	CobraNet
0x8847	MPLS unicast
0x8848	MPLS multicast
0x8863	PPPoE Discovery Stage
0x8864	PPPoE Session Stage
0x888E	EAP over LAN (IEEE 802.1X)
0x889A	HyperSCSI (SCSI over Ethernet)
0x88A2	ATA over Ethernet
0x88A4	EtherCAT Protocol
0x88A8	Provider Bridging (IEEE 802.1ad)
0x88B5	AVB Transport Protocol (AVBTP)
0x88CD	SERCOS-III
0x88D8	Circuit Emulation Services over Ethernet (MEF-8)
0x88E1	HomePlug
0x88E5	MAC security (IEEE 802.1AE)
0x88F7	Precision Time Protocol (IEEE 1588)
0x8906	Fibre Channel over Ethernet
0x8914	FCoE Initialization Protocol
0x9100	Q-in-Q
0xCAFE	Veritas Low Latency Transport (LLT)

wikipedia

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Rechnernetze

Ethernet Frames in Wireshark

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Modifiziertes netcat (UDP, Python)

```python
def sendPacket(sock,host,port,l):
    """Send a packet of given length l with content 01020304..ff0001.."""
    bs = bytearray(l)
    for i in range(l):
        bs[i] = i % 255
    sock.sendto(bs,(host,port))


def findMaximumPacketSize(sock,host,port):
    """Determine the maximum packet size to be send"""
    low = 1024
    high = maxBufferSize
    while high-low > 1:
        m = (low + high) // 2
        try:
            sendPacket(sock,host,port,m)
            low = m
        except OSError:
            high = m
    return low


def sendPackets(host,port):
    with socket.socket(socket.AF_INET, socket.SOCK_DGRAM) as c_sock:
        msize = findMaximumPacketSize(c_sock,host,port)
        print("maximum packet size is {0}".format(msize))
        me = math.floor(math.log2(msize))+1
        sizes = [2 ** i for i in range(me)]
        sizes.append(msize)
        for l in sizes:
            try:
                sendPacket(c_sock,host,port,l)
                sendPacket(c_sock,host,port,l+1)
            except OSError:
                continue
```

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in Wireshark

```
29 0.008498 10.42.2.2 10.42.1.103   UDP          43 52855 → 4242 Len=1
30 0.008498 10.42.2.2 10.42.1.103   UDP          44 52855 → 4242 Len=2
31 0.008504 10.42.2.2 10.42.1.103   UDP          44 52855 → 4242 Len=2
32 0.008528 10.42.2.2 10.42.1.103   UDP          45 52855 → 4242 Len=3
33 0.008544 10.42.2.2 10.42.1.103   UDP          46 52855 → 4242 Len=4
34 0.008655 10.42.2.2 10.42.1.103   UDP          47 52855 → 4242 Len=5
35 0.008656 10.42.2.2 10.42.1.103   UDP          50 52855 → 4242 Len=8
36 0.008656 10.42.2.2 10.42.1.103   UDP          51 52855 → 4242 Len=9
37 0.008656 10.42.2.2 10.42.1.103   UDP          58 52855 → 4242 Len=16
38 0.008656 10.42.2.2 10.42.1.103   UDP          59 52855 → 4242 Len=17
39 0.008656 10.42.2.2 10.42.1.103   UDP          74 52855 → 4242 Len=32
40 0.008656 10.42.2.2 10.42.1.103   UDP          75 52855 → 4242 Len=33
41 0.008656 10.42.2.2 10.42.1.103   UDP         106 52855 → 4242 Len=64
42 0.008669 10.42.2.2 10.42.1.103   UDP         107 52855 → 4242 Len=65
43 0.008673 10.42.2.2 10.42.1.103   UDP         170 52855 → 4242 Len=128
44 0.008731 10.42.2.2 10.42.1.103   UDP         171 52855 → 4242 Len=129
45 0.008731 10.42.2.2 10.42.1.103   UDP         298 52855 → 4242 Len=256
46 0.008731 10.42.2.2 10.42.1.103   UDP         299 52855 → 4242 Len=257
47 0.008812 10.42.2.2 10.42.1.103   UDP         554 52855 → 4242 Len=512
48 0.008813 10.42.2.2 10.42.1.103   UDP         555 52855 → 4242 Len=513
49 0.008913 10.42.2.2 10.42.1.103   UDP        1066 52855 → 4242 Len=1024
50 0.008983 10.42.2.2 10.42.1.103   UDP        1067 52855 → 4242 Len=1025
51 0.009202 10.42.2.2 10.42.1.103   IPv4       1514 Fragmented IP protocol (proto=UDP 17, off=0, ID=a103) [Reassembled in #52]
52 0.009203 10.42.2.2 10.42.1.103   UDP         610 52855 → 4242 Len=2048
53 0.009309 10.42.2.2 10.42.1.103   IPv4       1514 Fragmented IP protocol (proto=UDP 17, off=0, ID=a91b) [Reassembled in #54]
54 0.009309 10.42.2.2 10.42.1.103   UDP         611 52855 → 4242 Len=2049
55 0.009746 10.42.2.2 10.42.1.103   IPv4       1514 Fragmented IP protocol (proto=UDP 17, off=0, ID=4aff) [Reassembled in #57]
56 0.009747 10.42.2.2 10.42.1.103   IPv4       1514 Fragmented IP protocol (proto=UDP 17, off=1480, ID=4aff) [Reassembled in #57]
57 0.009747 10.42.2.2 10.42.1.103   UDP        1178 52855 → 4242 Len=4096
58 0.009951 10.42.2.2 10.42.1.103   IPv4       1514 Fragmented IP protocol (proto=UDP 17, off=0, ID=62f4) [Reassembled in #60]
59 0.009952 10.42.2.2 10.42.1.103   IPv4       1514 Fragmented IP protocol (proto=UDP 17, off=1480, ID=62f4) [Reassembled in #60]
60 0.009953 10.42.2.2 10.42.1.103   UDP        1179 52855 → 4242 Len=4097
61 0.010475 10.42.2.2 10.42.1.103   IPv4       1514 Fragmented IP protocol (proto=UDP 17, off=0, ID=27e1) [Reassembled in #66]
62 0.010476 10.42.2.2 10.42.1.103   IPv4       1514 Fragmented IP protocol (proto=UDP 17, off=1480, ID=27e1) [Reassembled in #66]
```

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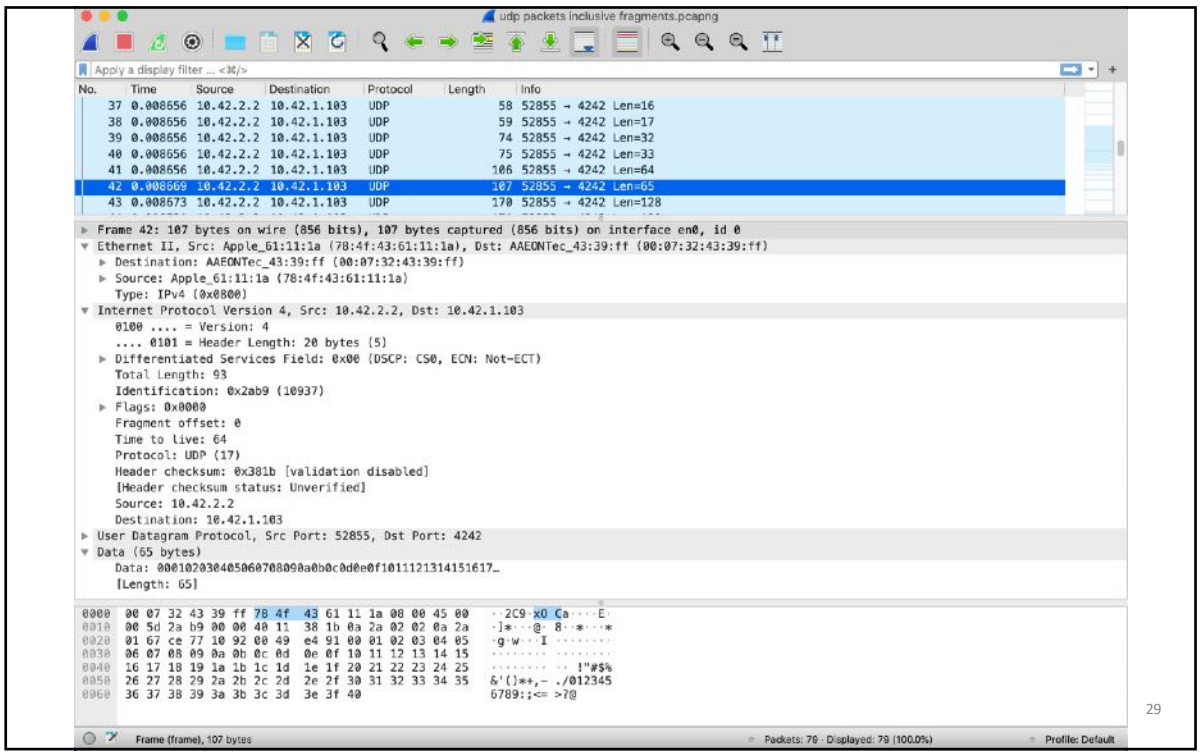
udp packets inclusive fragments.pcapng
Apply a display filter ... <⌘/>
No. Time Source Destination Protocol Length Info
37 0.008656 10.42.2.2 10.42.1.103 UDP 58 52855 → 4242 Len=16
38 0.008656 10.42.2.2 10.42.1.103 UDP 59 52855 → 4242 Len=17
39 0.008656 10.42.2.2 10.42.1.103 UDP 74 52855 → 4242 Len=32
40 0.008656 10.42.2.2 10.42.1.103 UDP 75 52855 → 4242 Len=33
41 0.008656 10.42.2.2 10.42.1.103 UDP 106 52855 → 4242 Len=64
42 0.008669 10.42.2.2 10.42.1.103 UDP 107 52855 → 4242 Len=65
43 0.008673 10.42.2.2 10.42.1.103 UDP 170 52855 → 4242 Len=128
Frame 42: 107 bytes on wire (856 bits), 107 bytes captured (856 bits) on interface en0, id 0
Ethernet II, Src: Apple_61:11:1a (78:4f:43:61:11:1a), Dst: AAEONTec_43:39:ff (00:07:32:43:39:ff)
Destination: AAEONTec_43:39:ff (00:07:32:43:39:ff)
Source: Apple_61:11:1a (78:4f:43:61:11:1a)
Type: IPv4 (0x0800)
Internet Protocol Version 4, Src: 10.42.2.2, Dst: 10.42.1.103
0100 .... = Version: 4
.... 0101 = Header Length: 20 bytes (5)
Differentiated Services Field: 0x00 (DSCP: CS0, ECN: Not-ECT)
Total Length: 93
Identification: 0x2ab9 (10937)
Flags: 0x0000
Fragment offset: 0
Time to live: 64
Protocol: UDP (17)
Header checksum: 0x381b [validation disabled]
[Header checksum status: Unverified]
Source: 10.42.2.2
Destination: 10.42.1.103
User Datagram Protocol, Src Port: 52855, Dst Port: 4242
Data (65 bytes)
Data: 000102030405060708090a0b0c0d0e0f101112131415161 7…
[Length: 65]
0000 00 07 32 43 39 ff 78 4f 43 61 11 1a 08 00 45 00
0010 00 5d 2a b9 00 00 40 11 38 1b 0a 2a 02 02 0a 2a
0020 01 67 ce 77 10 92 00 49 e4 91 00 01 02 03 04 05
0030 06 07 08 09 0a 0b 0c 0d 0e 0f 10 11 12 13 14 15
0040 16 17 18 19 1a 1b 1c 1d 1e 1f 20 21 22 23 24 25
0050 26 27 28 29 2a 2b 2c 2d 2e 2f 30 31 32 33 34 35
0060 36 37 38 39 3a 3b 3c 3d 3e 3f 40
Frame (frame), 107 bytes
Packets: 79 · Displayed: 79 (100.0%)
Profile: Default

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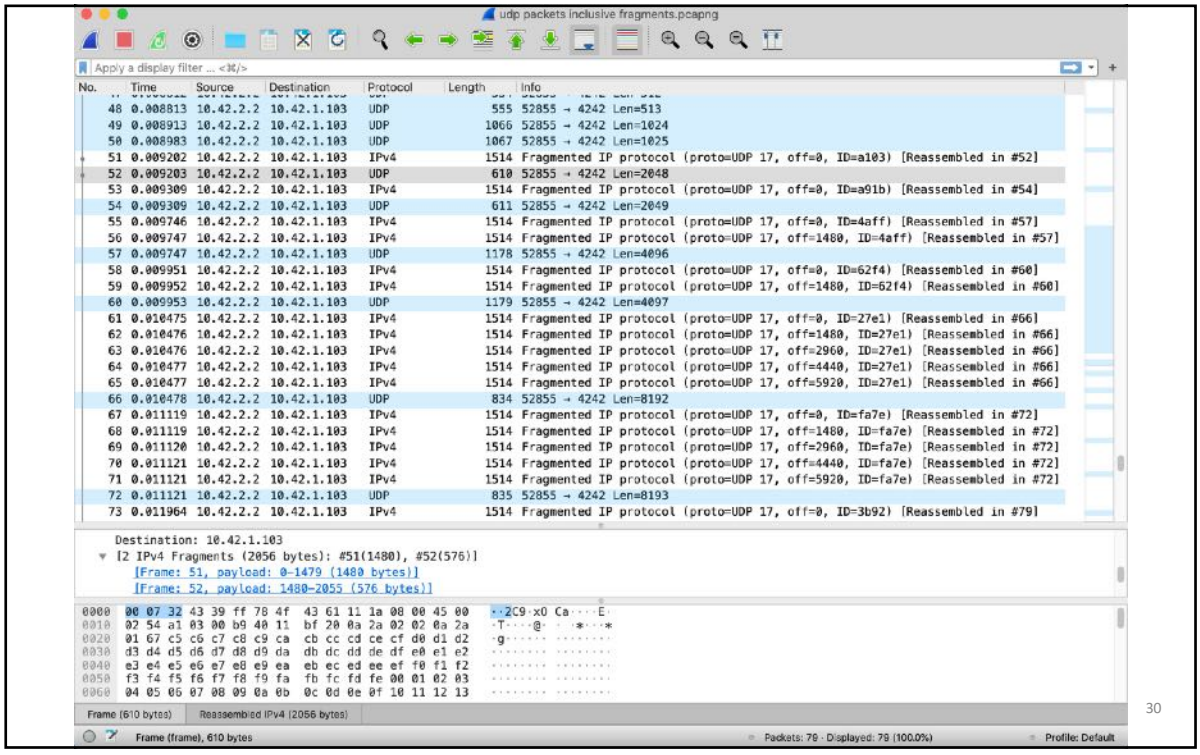

udp packets inclusive fragments.pcapng
Apply a display filter ... <⌘/>
No. Time Source Destination Protocol Length Info
48 0.008813 10.42.2.2 10.42.1.103 UDP 555 52855 → 4242 Len=513
49 0.008913 10.42.2.2 10.42.1.103 UDP 1066 52855 → 4242 Len=1024
50 0.008983 10.42.2.2 10.42.1.103 UDP 1067 52855 → 4242 Len=1025
51 0.009202 10.42.2.2 10.42.1.103 IPv4 1514 Fragmented IP protocol (proto=UDP 17, off=0, ID=a103) [Reassembled in #52]
52 0.009203 10.42.2.2 10.42.1.103 UDP 610 52855 → 4242 Len=2048
53 0.009309 10.42.2.2 10.42.1.103 IPv4 1514 Fragmented IP protocol (proto=UDP 17, off=0, ID=a91b) [Reassembled in #54]
54 0.009309 10.42.2.2 10.42.1.103 UDP 611 52855 → 4242 Len=2049
55 0.009746 10.42.2.2 10.42.1.103 IPv4 1514 Fragmented IP protocol (proto=UDP 17, off=0, ID=4aff) [Reassembled in #57]
56 0.009747 10.42.2.2 10.42.1.103 IPv4 1514 Fragmented IP protocol (proto=UDP 17, off=1480, ID=4aff) [Reassembled in #57]
57 0.009747 10.42.2.2 10.42.1.103 UDP 1178 52855 → 4242 Len=4096
58 0.009951 10.42.2.2 10.42.1.103 IPv4 1514 Fragmented IP protocol (proto=UDP 17, off=0, ID=62f4) [Reassembled in #60]
59 0.009952 10.42.2.2 10.42.1.103 IPv4 1514 Fragmented IP protocol (proto=UDP 17, off=1480, ID=62f4) [Reassembled in #60]
60 0.009953 10.42.2.2 10.42.1.103 UDP 1179 52855 → 4242 Len=4097
61 0.010475 10.42.2.2 10.42.1.103 IPv4 1514 Fragmented IP protocol (proto=UDP 17, off=0, ID=27e1) [Reassembled in #66]
62 0.010476 10.42.2.2 10.42.1.103 IPv4 1514 Fragmented IP protocol (proto=UDP 17, off=1480, ID=27e1) [Reassembled in #66]
63 0.010476 10.42.2.2 10.42.1.103 IPv4 1514 Fragmented IP protocol (proto=UDP 17, off=2960, ID=27e1) [Reassembled in #66]
64 0.010477 10.42.2.2 10.42.1.103 IPv4 1514 Fragmented IP protocol (proto=UDP 17, off=4440, ID=27e1) [Reassembled in #66]
65 0.010477 10.42.2.2 10.42.1.103 IPv4 1514 Fragmented IP protocol (proto=UDP 17, off=5920, ID=27e1) [Reassembled in #66]
66 0.010478 10.42.2.2 10.42.1.103 UDP 834 52855 → 4242 Len=8192
67 0.011119 10.42.2.2 10.42.1.103 IPv4 1514 Fragmented IP protocol (proto=UDP 17, off=0, ID=fa7e) [Reassembled in #72]
68 0.011119 10.42.2.2 10.42.1.103 IPv4 1514 Fragmented IP protocol (proto=UDP 17, off=1480, ID=fa7e) [Reassembled in #72]
69 0.011120 10.42.2.2 10.42.1.103 IPv4 1514 Fragmented IP protocol (proto=UDP 17, off=2960, ID=fa7e) [Reassembled in #72]
70 0.011121 10.42.2.2 10.42.1.103 IPv4 1514 Fragmented IP protocol (proto=UDP 17, off=4440, ID=fa7e) [Reassembled in #72]
71 0.011121 10.42.2.2 10.42.1.103 IPv4 1514 Fragmented IP protocol (proto=UDP 17, off=5920, ID=fa7e) [Reassembled in #72]
72 0.011121 10.42.2.2 10.42.1.103 UDP 835 52855 → 4242 Len=8193
73 0.011964 10.42.2.2 10.42.1.103 IPv4 1514 Fragmented IP protocol (proto=UDP 17, off=0, ID=3b92) [Reassembled in #79]
Destination: 10.42.1.103
[2 IPv4 Fragments (2056 bytes): #51(1480), #52(576)]
[Frame: 51, payload: 0-1479 (1480 bytes)]
[Frame: 52, payload: 1480-2055 (576 bytes)]
0000 00 07 32 43 39 ff 78 4f 43 61 11 1a 08 00 45 00
0010 02 54 a1 03 00 b9 40 11 bf 20 0a 2a 02 02 0a 2a
0020 01 67 c5 c6 c7 c8 c9 ca cb cc cd ce cf d0 d1 d2
0030 d3 d4 d5 d6 d7 d8 d9 da db dc dd de df e0 e1 e2
0040 e3 e4 e5 e6 e7 e8 e9 ea eb ec ed ee ef f0 f1 f2
0050 f3 f4 f5 f6 f7 f8 f9 fa fb fc fd fe 00 01 02 03
0060 04 05 06 07 08 09 0a 0b 0c 0d 0e 0f 10 11 12 13
Frame (610 bytes)
Reassembled IPv4 (2056 bytes)
Frame (frame), 610 bytes
Packets: 79 · Displayed: 79 (100.0%)
Profile: Default

30

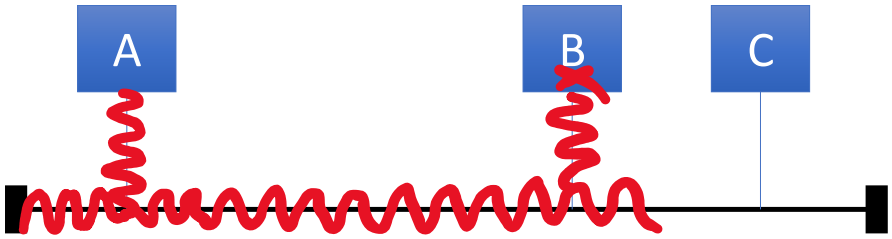
Keine Kollision

32

Keine Kollision

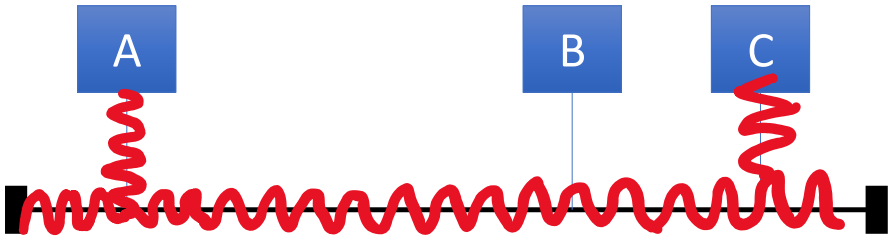
33

Keine Kollision



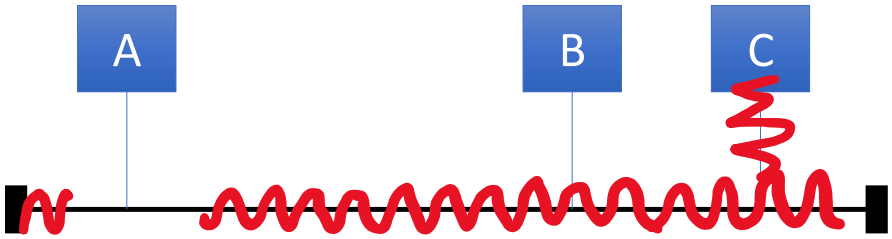
34

Keine Kollision



35

Keine Kollision



36

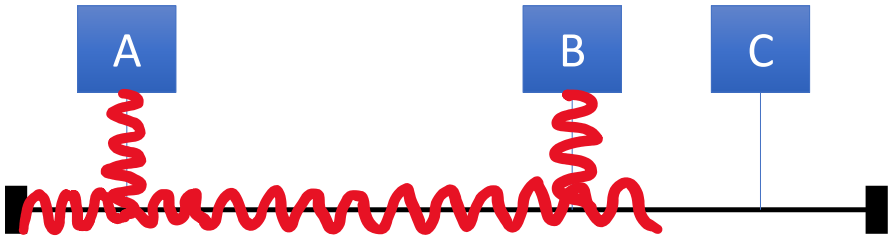
Keine Kollision

37

Keine Kollision

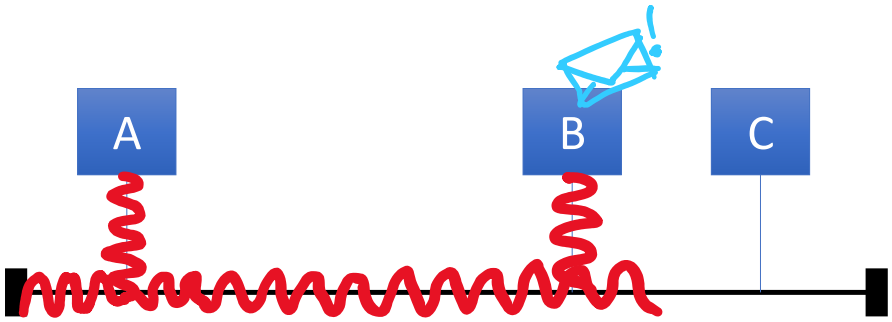
38

Keine Kollision aber belegt



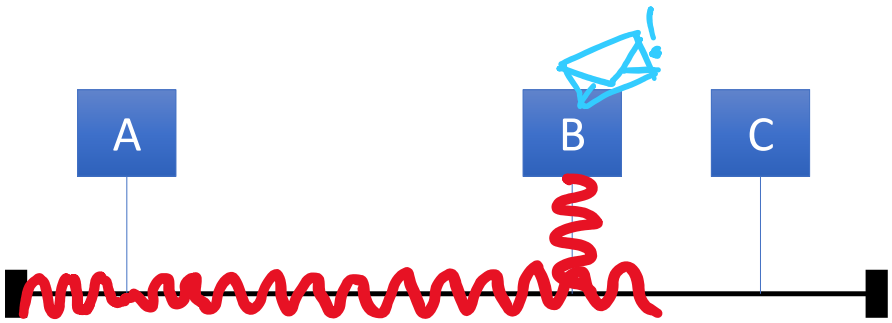
39

Keine Kollision aber belegt



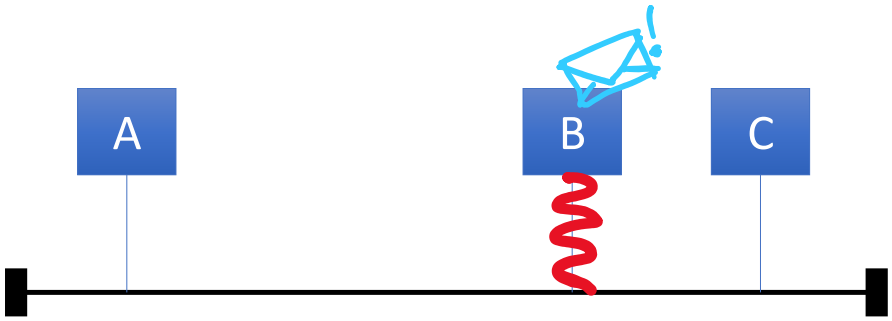
40

Keine Kollision aber belegt



41

Keine Kollision aber belegt



42

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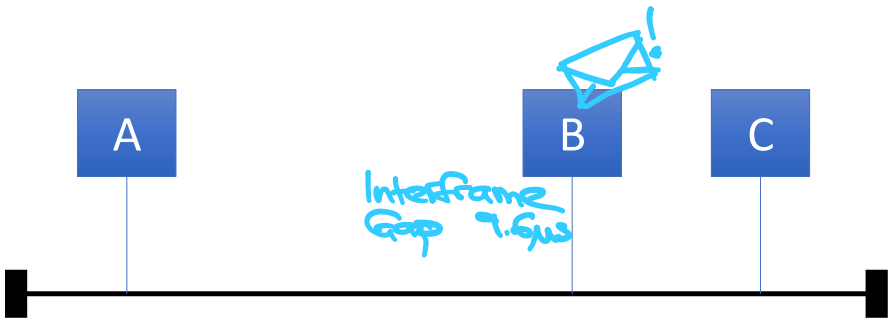

43

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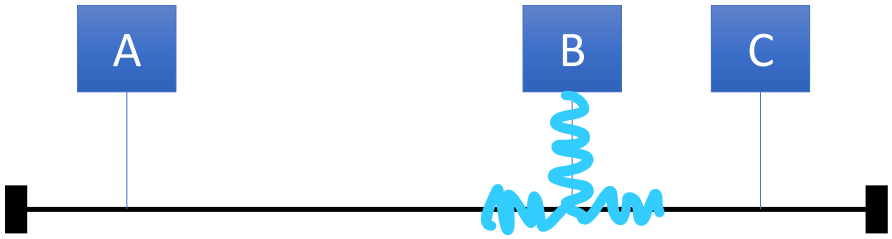


44

Eine Kollision

45

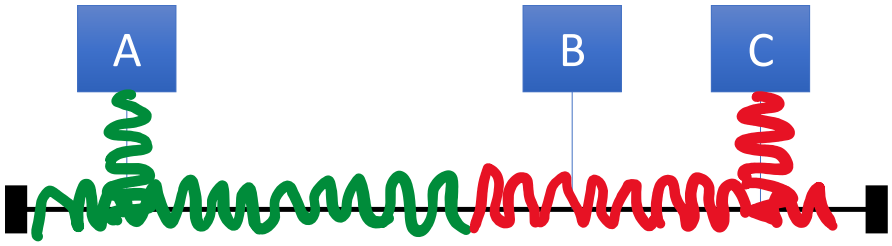
Eine Kollision

46

Eine Kollision

47

Eine Kollision

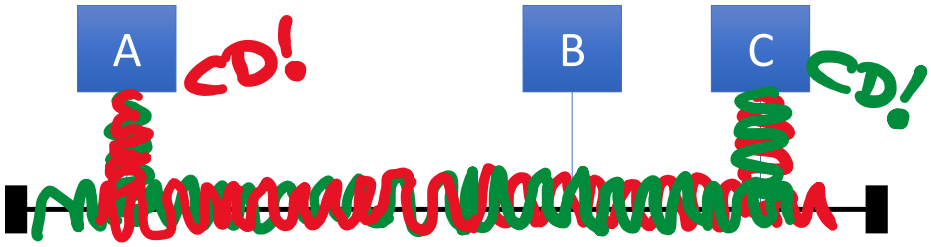


48

Eine Kollision

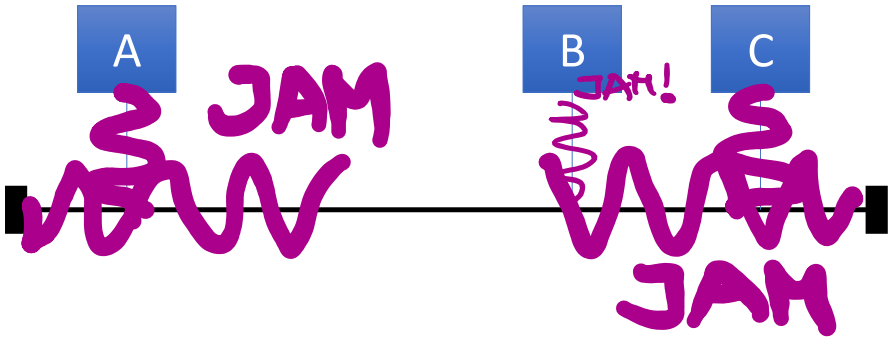
49

Eine Kollision



50

Eine Kollision



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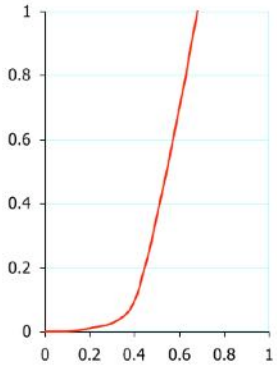
Reaktion auf Kollisionen

- Kritisches Kollisionsfenster
- Zeitpunkt der Wiederholung?
  - Warum nicht konstante Zeit warten?
- „Truncated Binary Exponential Backoff“
  - Zufallszeit in Intervall I warten
  - Intervall I wächst exponentiell mit jeder Wiederholung
  - Obere Schranke bei Wiederholungen



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Repeater und Hubs

- Repeater
  - OSI-Layer 1
  - Bereit Signal lediglich auf
- Hub
  - Ein Segment versteckt sich in einem Gehäuse
  - Mehrere Anschlüsse
- Keine Trennung von Kollisionsdomainen

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Thin Ethernet

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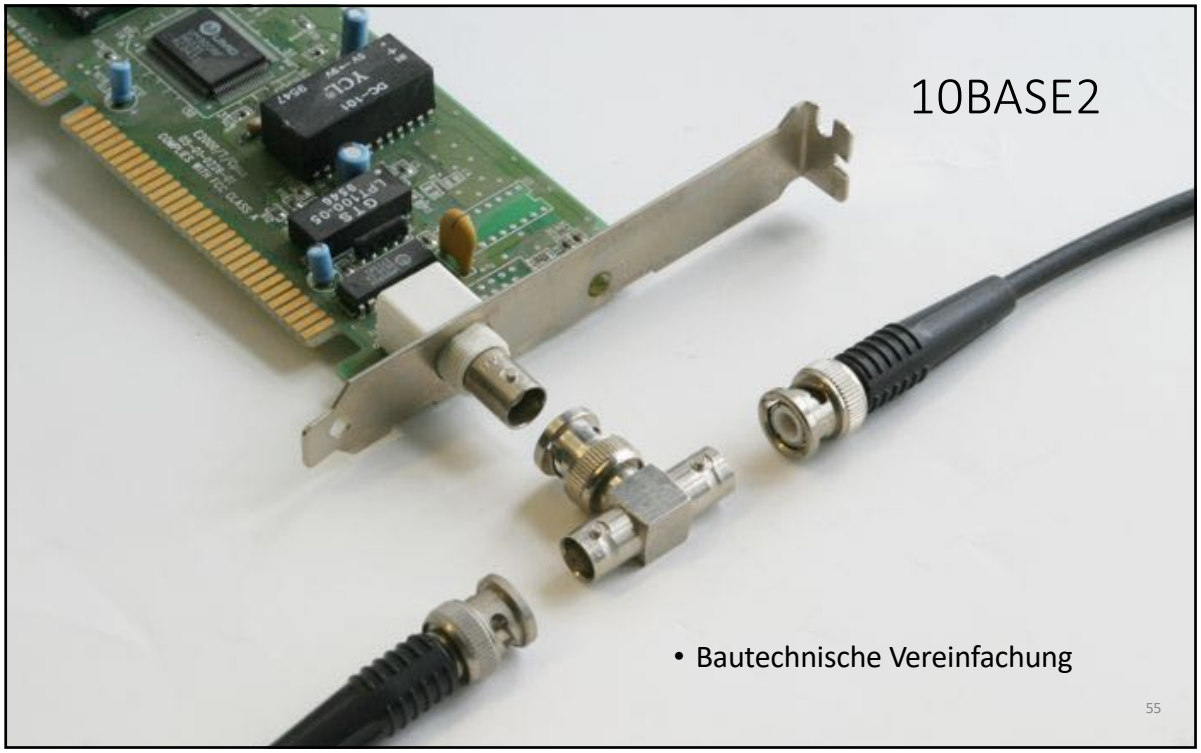

10BASE2

- Bautechnische Vereinfachung

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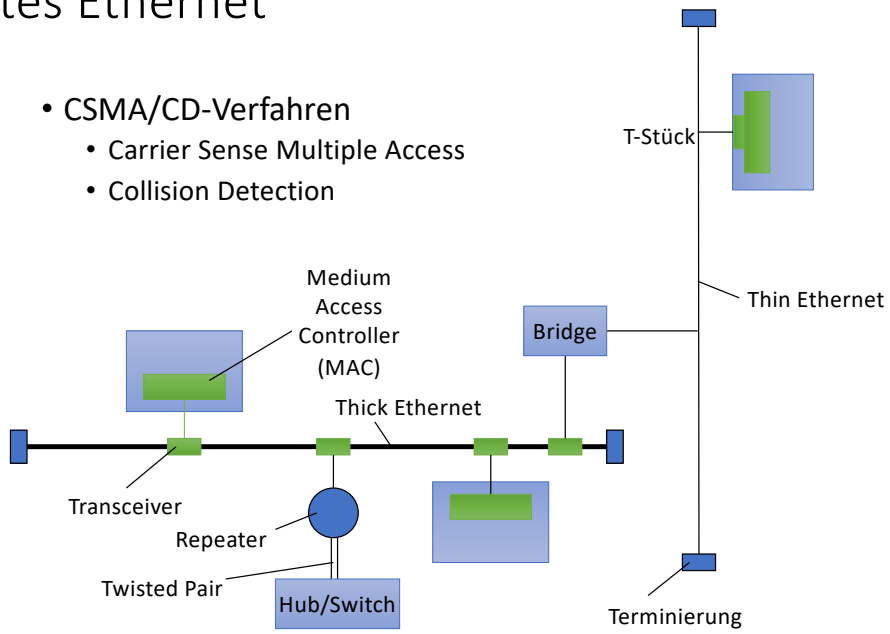
Altes Ethernet

- CSMA/CD-Verfahren
  - Carrier Sense Multiple Access
  - Collision Detection



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Modern Ethernet (Switched)

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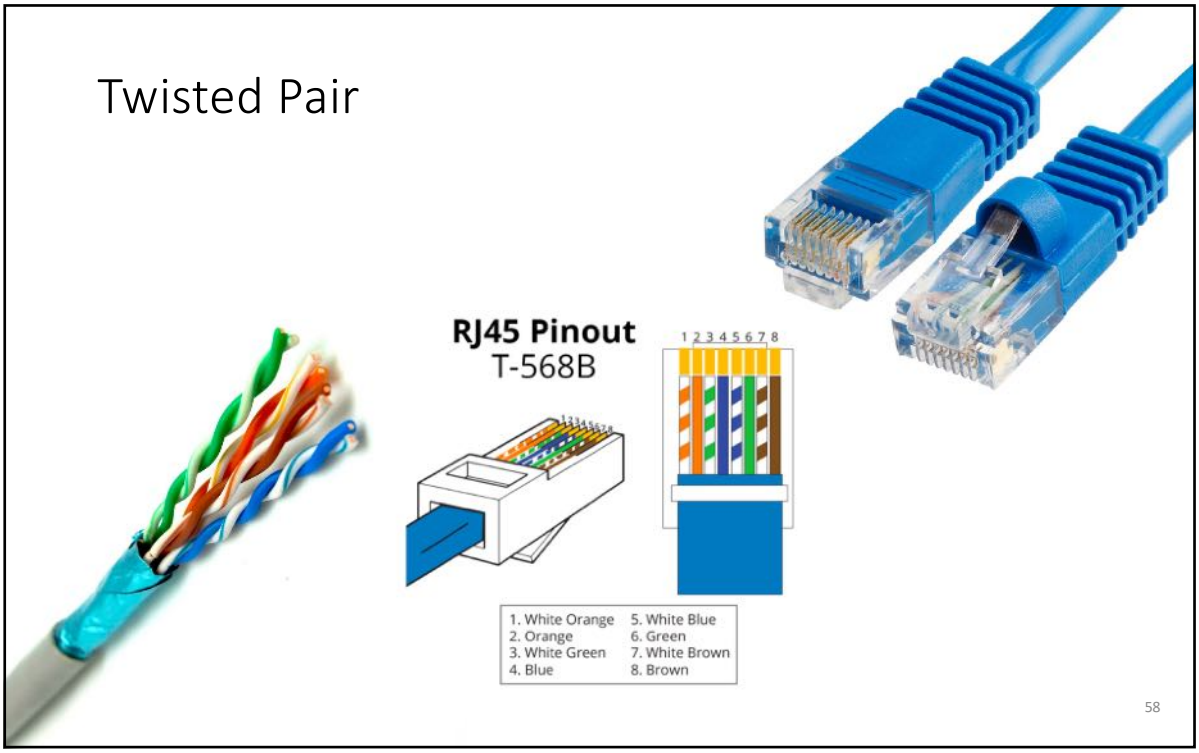
Twisted Pair



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Fast Ethernet

- 100 MBit/s
- 1 GBit/s und mehr
  - Halbduplex : CSMA/CD
  - Vollduplex : Sterntopologie, keine Kollisionen mehr
- Hauptproblem
  - Hohe Datenrate bei möglichst geringer Frequenzerhöhung
  - 1 GBit/s über Twisted Pair braucht “nur” 250 MHz

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Name	4b	5b	Description
0	0000	11110	hex data 0
1	0001	01001	hex data 1
2	0010	10100	hex data 2
3	0011	10101	hex data 3
4	0100	01010	hex data 4
5	0101	01011	hex data 5
6	0110	01110	hex data 6
7	0111	01111	hex data 7
8	1000	10010	hex data 8
9	1001	10011	hex data 9
A	1010	10110	hex data A
B	1011	10111	hex data B
C	1100	11010	hex data C
D	1101	11011	hex data D
E	1110	11100	hex data E
F	1111	11101	hex data F
Q	-NONE-	00000	Quiet (signal lost)
I	-NONE-	11111	Idle
J	-NONE-	11000	Start #1
K	-NONE-	10001	Start #2
T	-NONE-	01101	End
R	-NONE-	00111	Reset
S	-NONE-	11001	Set
H	-NONE-	00100	Halt

Kodierung 100 MBit/s

- 4B/5B Kodierung
  - Aus 4 Datenbits werden 5 übertragene Bits
  - Implizite Taktung
- NRZI-Kodierung
  - 1 : Pegelwechsel innerhalb der Bitperiode
  - 0 : Kein Pegelwechsel
  - Geringere Frequenz als bei Manchester notwendig

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1 GBit/s

- CSMA/CD nicht mehr umsetzbar
  - Kollisionsdomäne bestimmt Segmentlänge
  - Unverändert ergeben sich maximal 20 Meter
- Minimale Paketlänge erhöhen
  - Von 64 Byte auf 512 Byte

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Kodierung

- Ziel: Frequenz so wenig wie möglich erhöhen
- 8B/10B Kodierung (Glasfaser)
  - Codegruppe hat mindestens 4 und nicht mehr als 7 Pegelwechsel
  - Gleichspannungsfreiheit über 2 Codegruppen
- Kodierung (Twisted Pair)
  - Nutzung von 4 seriellen Aderpaaren
    - Vollduplex durch Echo-Cancellation
  - 4D-PAM5 / 8B1Q4 Kodierung
    - Aus 8 Bits werden 4 fünfwertige Symbole
    - 5 Spannungswerte -1 V, -0.5 V, 0 V, +0.5 V, 1 V
  - Trellis-Kodierung
  - Scrambling ~ Spread Spectrum

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Switches

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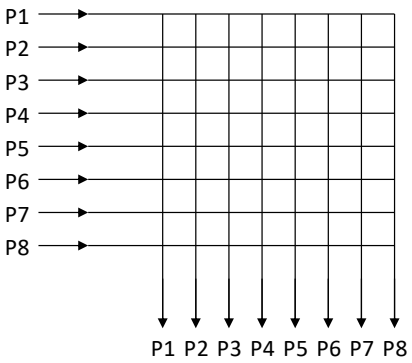
Ethernet-Switching

- Kreuzverschaltung von n Ports
  - Crossbar-Switch
- Port =
  - Einzelne Station (1 Adresse)
  - Segment
- Nominalleistung zwischen jeweils 2 Ports Pi und Pj
- Weitergabe von Frames
  - Store-and-Foreward
  - Cut-Through



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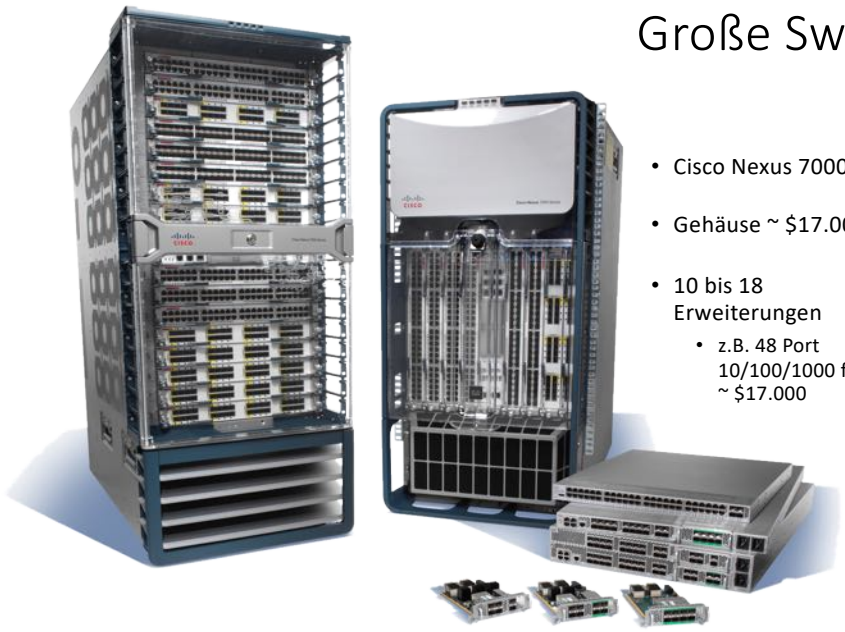
Große Switches



- Cisco Nexus 7000
- Gehäuse ~ $17.000
- 10 bis 18 Erweiterungen
  - z.B. 48 Port 10/100/1000 für ~ $17.000

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Literatur

- R.M. Metcalfe, D.R. Boggs, Ethernet: Distributed Packet Switching for Local Computer Networks, CACM, Vol. 19, No. 7, pp. 395-403, Juli 1976
- J. Rech, Ethernet, 2. Auflage, Heise Verlag, 2008
- C.E. Spurgeon, Ethernet – The Definitive Guide, O'Reilly, 2000

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