2nd Slide Set
Computer Networks

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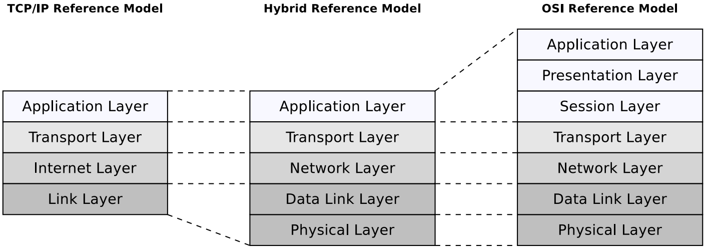
Physical Layer

- Functions of the Physical Layer
  - Bit transmission on wired or wireless transmission paths
  - Provides network technologies (e.g. Ethernet) and transmission media
  - Frames from the Data Link Layer are encoded with line codes into signals



Exercise sheet 2 repeats the contents of this slide set which are relevant for these learning objectives

- Devices: Repeater, Hub (Multiport Repeater)
- Protocols: Ethernet, Token Ring, WLAN, Bluetooth,. . .

Learning Objectives of this Slide Set

- Physical Layer (part 1)
  - Network technologies
    - Ethernet
    - Token Ring
    - Wireless LAN (WLAN)
    - Bluetooth
  - Transmission Media
    - Coaxial cables
    - Twisted pair cables
    - Fiber-optic cables

Ethernet (IEEE 802.3)

- Developed in the 1970s by Robert Metcalfe and others at the Xerox Palo Alto Research Center
  - Data rate of this first Ethernet version: 2,94 Mbps
- 1983: IEEE standard with 10 Mbps
- Most frequently used (cable-based) LAN technology since the 1990s
  - Ethernet displaced other standards (e.g. Token Ring) or made them niche products for special applications (e.g. FDDI)
- Several Ethernet standards exist
  - They differ among others in the **data rate** and the **transmission medium** used
    - Versions for coaxial cables, twisted pair cables and fiber-optic cables, with data rates up to 40 Gbit/s exist

Some Variants of Ethernet

- All these variants are extensions of Thick Ethernet (10BASE5)

Standard	Mbps	Transmission Medium
10BASE2/5	10	Coaxial cables (50 ohm impedance)
10BROAD36	10	Coaxial cables (75 ohm impedance)
10BASE-F	10	Fiber-optic cables
10BASE-T	10	Twisted pair cables
100BASE-FX	100	Fiber-optic cables
100BASE-T4	100	Twisted pair cables (Cat 3)
100BASE-TX	100	Twisted pair cables (Cat 5)
1000BASE-LX	1.000	Fiber-optic cables
1000BASE-SX	1.000	Fiber-optic cables (Multi-mode fiber)
1000BASE-ZX	1.000	Fiber-optic cables (Single-mode fiber)
1000BASE-T	1.000	Twisted pair cables (Cat 5)
1000BASE-TX	1.000	Twisted pair cables (Cat 6)
2.5GBASE-T	2.500	Twisted pair cables (Cat 5e)
5GBASE-T	5.000	Twisted pair cables (Cat 6)
10GBASE-SR	10.000	Fiber-optic cables (Multi-mode fiber)
10GBASE-LR	10.000	Fiber-optic cables (Single-mode fiber)
10GBASE-T	10.000	Twisted pair cables (Cat 6A)
40GBASE-T	40.000	Twisted pair cables (Cat 8.1)

- 2 different transmission modes exist:
  1. **Baseband** (BASE)
  2. **Broadband** (BROAD)

Naming convention

- Part 1: Data rate
- Part 2: Transmission method (baseband or broadband)
- Part 3: 100 times the maximum segment length or the transmission medium

10BASE5 for example means...

- Data rate: 10 Mbps
- Transmission method: Baseband
- Maximum segment length: $5 * 100\text{m} = 500\text{m}$

Variants of Ethernet – Baseband (BASE)

- Almost all Ethernet standards implement the baseband transmission method (BASE)
  - Single exception: 10BROAD36
- Baseband systems have **no carrier frequencies**
  - This means that **data is directly (at baseband) transmitted on the transmission medium**
- Digital signals are injected directly as impulses into the copper cable or fiber-optic and occupy the entire bandwidth of the cable or a part of it
  - Unused bandwidth can not be used for other services

In short. . .

Baseband systems provide just a **single channel**

Variants of Ethernet – Broadband (BROAD)

Image Source: AVM

- The data is **modulated to a carrier frequency**
  - This allows to transmit multiple signals at the same time in **different frequency ranges** ('bands')
- Only 10BROAD36 uses the broadband method
  - Because of high hardware costs for the modulation, the system was no economic success
- The broadband concept, used together with Ethernet, was no success, but the concept itself is used today in many areas of communication and telecommunication

Some fields of application of the broadband concept

- Via cable television, different TV channels, and with different carrier frequencies, also radio channels, telephone and internet is available
- The electrical power grid can be used to establish network connections ($\Longrightarrow$ Power line communication)

Token Ring (IEEE 802.5)

- LAN standard, in which the terminal devices are logically connected as a ring
- A **token** circles in the ring
  - It is passed from one node to the next one
- 1981: Developed by the English company Procom
  - 1985: 4 Mbps
  - 1989: 16 Mbps
  - 1998: 100 Mbps
- Until the mid-1990s: IBM's preferred networking technology
  - Obsolete, since IBM stopped the marketing and distribution in 2004

Token Ring is legacy technology since approx. 2 decades

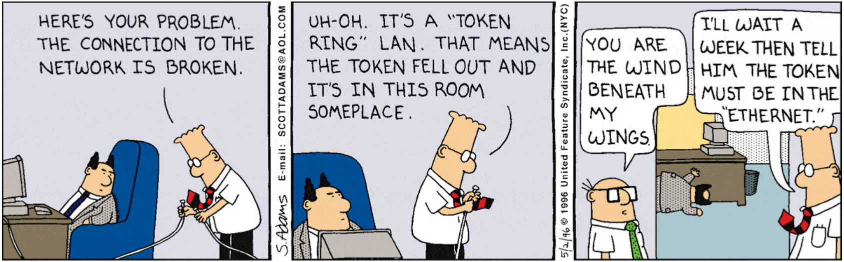
- But it is an interesting example that shows that alternatives to Ethernet existed and the design principles of Ethernet were not all the time without alternative
- Some installations might still be in use today...

https://www.reddit.com/r/networking/comments/4xr6jl/im_actually_curious_does_token_ring_still_exist/
https://www.reddit.com/r/sysadmin/comments/2014wf/just_curious_anyone_still_running_token_ring/
https://www.reddit.com/r/vintagecomputing/comments/k7xk6u/ibm_type_1_token_ring_network_cabling_still_in/

Functioning of Token Ring

Image Source: Scott Adams (http://dilbert.com)

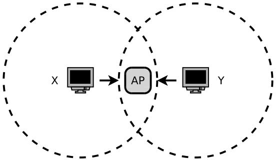
- The token frame is passed from one node to the next one
  - If a terminal device wants to send data, it waits for the token frame
    - Then, the terminal device appends its **payload** at the token
    - It adds the required **control signals** to the token
    - It sets the **token bit** from value 0 (*free token*) to 1 (*data frame*)
  - If a data frame token reaches its destination, the receiver copies the payload data and **acknowledges the receive**
    - The sender receives the acknowledgment and sends the token with the next payload data or it puts a free token on the ring



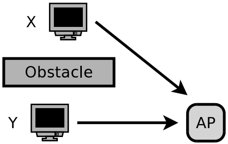
Challenges of Wireless Networks (1/2)

- WLAN = most popular technology for wireless computer networks
  - The transmission medium has some special characteristics
    - These cause the following challenges

1. **Fading over distance** (decreasing signal strength)
   - Electromagnetic waves are gradually weakened by physical barriers (e.g. walls) and in free space



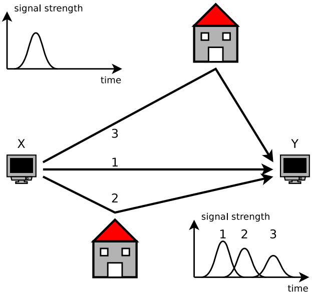
2. **Hidden terminal problem** (invisible or hidden terminal devices)
   - Terminal devices, communicating with the same device (e.g. an Access Point), do not recognize each other and therefore interfere with each other
     - Reason: Physical barriers



Source: Computernetzwerke, *James F. Kurose, Keith W. Ross*, Pearson (2008)

Challenges of Wireless Networks (2/2)

3. **Multipath propagation**
   - Electromagnetic waves are reflected and therefore go paths of different lengths from the sender to the destination
     - Result: A difficult to interpret signal arrives at the receiver because the reflections influence subsequent transmissions
   - Similar problem: If objects move between sender and receiver, the propagation paths may change

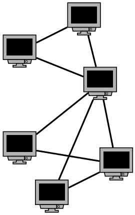


4. **Interferencing with other sources**
   - Examples: WLAN and Bluetooth
     - Both network technologies operate on the same frequency band and therefore can interfere
   - Also electromagnetic noise, caused by motors or microwave ovens can cause interferences

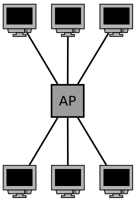
Source: Computernetzwerke, *James F. Kurose, Keith W. Ross*, Pearson (2008)

Ad-hoc Mode and Infrastructure Mode

- Communication between WLAN devices is possible in. . .
- **Ad-hoc mode**: Terminal devices create a **meshed network**
  - The terminal devices communicate directly with each other
    - Each terminal device can have multiple connections to other devices
  - To build up an ad-hoc network, the same network name – Service Set Identifier (SSID) and the same encryption parameters must be set on all terminal devices



- **Infrastructure mode**: Each terminal device registers with its MAC address at the Access Point
  - The Access Point sends at adjustable intervals (e.g. 10 times per second) small beacon frames to all terminal devices in range
    - The beacons contain among others the network name (SSID), the list of supported data rates and the encryption type



Data Rate of WLAN

- **All stations share the bandwidth for upload and download**
  - For this reason, the net transmission rate is under optimal conditions little more than the half gross rate

Wi-Fi	IEEE-Standard	Standard since	Frequencies 2.4 GHz	5 GHz	6 Ghz	Maximum (gross) Data Rate	Realistic (net) Data Rate
–	802.11	1997	X			2 Mbit/s	1 Mbit/s
–	802.11b	1999	X			11 Mbit/s[1]	5-6 Mbit/s
–	802.11a	1999		X		54 Mbit/s[2]	20-22 Mbit/s
–	802.11h	2003		X		54 Mbit/s[2]	20-22 Mbit/s
–	802.11g	2003	X			54 Mbit/s	20-22 Mbit/s
4	802.11n	2009	X	X		600 Mbit/s[3]	50-60 Mbit/s
5	802.11ac	2013		X		6930 Mbit/s[4]	400-500 Mbit/s
6	802.11ax	2021	X	X		9600 Mbit/s[4]	500-600 Mbit/s
6E	802.11ax	2021	X	X	X	9600 Mbit/s[5]	500-600 Mbit/s
7	802.11be	2024	X	X	X	40000 Mbit/s	still unknown

[1] Some manufacturers implement support for 22 Mbps at 40 MHz channel width
[2] Some manufacturers implement support for 108 Mbps at 40 MHz channel width
[3] When using 4x4 MIMO and 80 MHz channel width
[4] When using 8x8 MIMO and 160 MHz channel width. Values that are unusual in practice
[5] Per antenna in the station or terminal device

Transmission Power of WLAN

Image Source: Google Image Search

- WLAN is designed for use inside buildings
  - For this reason, it transmits with a relative low transmission power (up to 100 mW at 2.4 GHz, 1 W at 5 GHz and 200 mW at 6 GHz)
    - Such transmission power levels are considered safe for health
    - For comparison, the transmission power of GSM phones, that operate in the frequency range 880-960 MHz, is about 2 W
  - Some WLAN devices for 2.4 GHz provide a higher transmission power
    - Operating such devices is illegal in many countries $\Longrightarrow$ slide 15

Measuring Vehicle of the Federal Network Agency

Seen in Ludwigshafen-Oggersheim (November 26th, 2018)

WLAN Standards, Frequencies and Channels

- Most WLAN standards use the frequency blocks 2.4000-2.4835 GHz and 5.150-5.725 GHz in the microwave range
  - The standards differ among others in the frequency blocks used, data rates and modulation methods, as well as the resulting channel width

Wi-Fi	IEEE-Standard	Standard since	Frequencies 2.4 GHz	5 GHz	6 Ghz	Maximum (gross) Data Rate	Realistic (net) Data Rate
–	802.11	1997	X			2 Mbit/s	1 Mbit/s
–	802.11b	1999	X			11 Mbit/s[1]	5-6 Mbit/s
–	802.11a	1999		X		54 Mbit/s[2]	20-22 Mbit/s
–	802.11h	2003		X		54 Mbit/s[2]	20-22 Mbit/s
–	802.11g	2003	X			54 Mbit/s	20-22 Mbit/s
4	802.11n	2009	X	X		600 Mbit/s[3]	50-60 Mbit/s
5	802.11ac	2013		X		6930 Mbit/s[4]	400-500 Mbit/s
6	802.11ax	2021	X	X		9600 Mbit/s[4]	500-600 Mbit/s
6E	802.11ax	2021	X	X	X	9600 Mbit/s[5]	500-600 Mbit/s
7	802.11be	2024	X	X	X	40000 Mbit/s	still unknown

IEEE 802.11h is an adaptation of IEEE 802.11a to avoid disturbing military radar systems and satellite radio in Europe

Only differences to IEEE 802.11a: Additional skills dynamic frequency selection and transmission power control

Despite the fact that WLAN is used worldwide, legal differences exist

Example: In Germany, using 5.15-5.35 GHz is only allowed in enclosed rooms with 200 mW maximum transmission power

Permitted use of WLAN in the 2.4 GHz Frequency Block

- The frequency blocks are split into channels
  - Television and radio broadcasting follow the same principle
  - The frequency block 2.4 GHz is split into 13 channels
    - Bandwidth of each channel: 5 MHz
  - In Japan, an additional channel 14 can be used
    - Channel 14 is restricted for use only with the modulation method DSSS
    - Channel 14 is located 12 MHz above channel 13

Channel	Frequency [GHz]	EU	USA	Japan
1	2.412	X	X	X
2	2.417	X	X	X
3	2.422	X	X	X
4	2.427	X	X	X
5	2.432	X	X	X
6	2.437	X	X	X
7	2.442	X	X	X
8	2.447	X	X	X
9	2.452	X	X	X
10	2.457	X	X	X
11	2.462	X	X	X
12	2.467	X	X	X
13	2.472	X	X	X
14	2.484			X

Modulation Methods of the WLAN Standards

- The different WLAN standards use different modulation methods

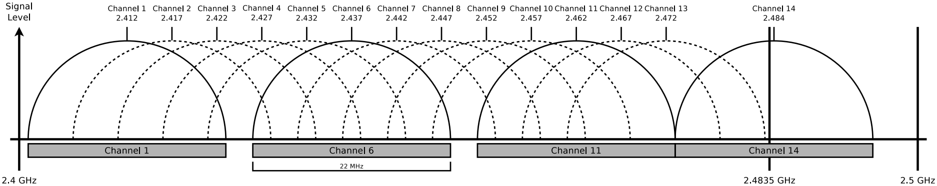
IEEE Standard	Modulation Method	Channel Width
802.11	FHSS[1] or DSSS[2]	22 MHz
802.11a	OFDM[3]	20 MHz
802.11b	DSSS[2]	22 MHz
802.11g	OFDM[3]	20 MHz
802.11h	OFDM[3]	20 MHz
802.11n	OFDM[3]	20 or 40 MHz
802.11ac	OFDM[3]	20, 40, 80 or 160 MHz
802.11ax	OFDMA[4]	20, 40, 80 or 160 MHz
802.11be	Enhanced OFDMA	20, 40, 80, 160 or 320 MHz

[1] Frequency Hopping Spread Spectrum
[2] Direct Sequence Spread Spectrum
[3] Orthogonal Frequency-Division Multiplexing
[4] Orthogonal Frequency Division Multiple Access

Why is the modulation method relevant?

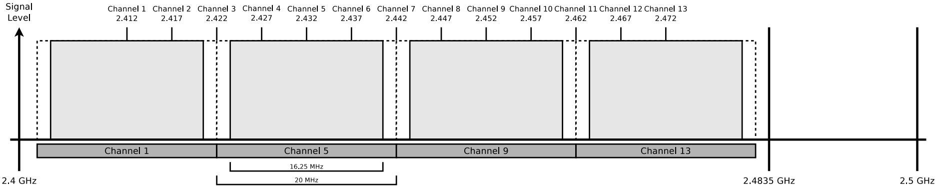
- It specifies the channel width
- The width of the single channels specifies how many channels can be used in the permitted frequency ranges

Non-overlapping Channels of IEEE 802.11b



- IEEE 802.11b uses the Direct Sequence Spread Spectrum (**DSSS**) modulation scheme with **22 MHz wide channels** and **5 MHz channel spacing**
  - Thus, only 3 (EU and U.S.) or 4 (Japan) channels exist, whose signals do not overlap
    - Channel 1, 6, 11 and 14 (only in Japan)
- **DSSS distributes the payload over a wide frequency range**
  - Therefore, it is almost insensitive to narrow-band interferences (e.g. Bluetooth)

Non-overlapping Channels of 802.11g and 802.11n

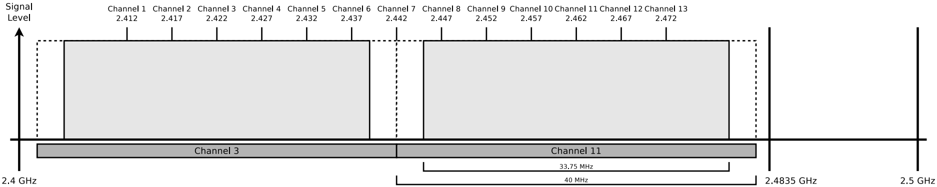


- IEEE 802.11g and 802.11n both use the Orthogonal Frequency-Division Multiplexing (**OFDM**) modulation method
  - OFDM is a **multi-carrier method**
    - Each channel is 20 MHz wide and consists of 64 sub-carriers, which are each 0.3125 MHz wide
    - Only 52 of the 64 sub-carriers are used
    - Thus, the **effective bandwidth per channel** is only **16.25 MHz**
    - Therefore, only 4 non-overlapping channels exist: 1, 5, 9 and 13

802.11a devices also use the OFDM modulation method with 20 MHz wide channels. . .

but they operate exclusively in the frequency block 5.150-5.725 GHz

Non-overlapping Channels of IEEE 802.11n



- 802.11n also supports 40 MHz wide channels
- If 40 MHz wide channels are used in the frequency block 2.4000-2.4835 GHz, only 2 channels exist (channels 3 and 11) whose signals do not overlap
  - Each channel consists of 128 sub-carriers, which are each 0.3125 MHz wide
    - Only 108 of the 128 sub-carriers are used
  - Thus, the effective bandwidth per channel is only 33.75 MHz

High quality terminal devices, which support 802.11n, can also use the frequency block 5.150-5.725 GHz

Non-overlapping Channels in the City Center. . .

```
Datei  Bearbeiten  Ansicht  Suchen  Terminal  Hilfe

CH 11 ][ Elapsed: 1 hour 10 mins ][ 2011-09-08 19:25 ][ WPA handshake: C0:C1:C0:36:74:10

BSSID              PWR  Beacons    #Data, #/s  CH  MB   ENC  CIPHER AUTH ESSID

00:C0:A8:CD:CA:DC   -1        0        0    0 133  -1                    <length:  0>
02:18:8B:B6:0E:E9   -1    36691        0    0  11  11   OPN              print server 2F53F0
C0:C1:C0:36:74:10  -65    39725     4724    0  11  54   WPA2 CCMP   PSK  Neverland
1C:AF:F7:82:FC:54  -70       36        0    0   6  54e. WPA  TKIP   PSK  PRIVAT-PC_Netzwerk
00:04:0E:D3:C5:69  -77    31403        0    0  11  54e  WPA  TKIP   PSK  WLAN-00040ED3C569
00:19:CB:9F:41:BC  -77        6        0    0   1  54 . WEP  WEP         o2DSL
BC:05:43:A8:B0:D1  -79    38409     1444    0  11  54e. WPA2 CCMP   PSK  FRITZ!Box 6360 Cable
00:26:4D:05:35:19  -79       18        1    0   1  54e. WPA2 CCMP   PSK  WLAN-053553
00:04:0E:64:4D:77  -81        2        0    0   7  54   WPA  TKIP   PSK  MUECKES FUNK
00:23:08:2F:70:BC  -82       16        0    0  13  54e  WPA2 CCMP   PSK  WLAN-2F7071
F0:7D:68:80:58:CC  -83        4        0    0   5  54e. WPA2 TKIP   PSK  Lasse
00:1A:2B:26:1C:4D  -84       20       15    0   3  54e  WPA2 CCMP   PSK  WLAN-261C24
00:23:08:AD:F0:84  -85       13        4    0  13  54e  WPA2 CCMP   PSK  ete
00:1C:28:50:93:C5  -85        0        0    0   9  54e. WPA2 CCMP   PSK  BUDIMIR
00:26:4D:E9:FA:20  -85        5        0    0   1  54e  WPA2 CCMP   PSK  EasyBox-E9FA62
00:1B:11:FA:43:8C  -86        2        0    0   6  54 . WPA  TKIP   PSK  W-LAN PWW
00:1F:3F:75:F8:B1  -86     2733        2    0  10  54e. WPA2 CCMP   PSK  Atlanta
00:1A:4F:97:D5:0F  -89     2929        0    0  11  54e  WPA  TKIP   PSK  BF610
00:1A:4F:44:97:AF  -90      222        4    0  11  54e  WPA2 CCMP   PSK  WLAN-001A4F4497AF
00:1F:3F:62:50:67  -90        2        0    0   1  54e. WPA2 CCMP   PSK  troester
00:1A:4F:19:06:ED  -90      765        0    0  11  54e  WPA2 CCMP   PSK  WLAN-001A4F1906ED
00:1A:70:5D:A1:D6  -91       69        2    0  11  54 . WPA  TKIP   PSK  Funk
00:12:BF:4F:0C:B8  -93     2742        6    0  11  54 . WEP  WEP         Heidelore
00:22:6B:8E:01:82  -89     1206       24    0  11  54   WPA2 CCMP   PSK  linksys
00:1D:19:D9:F0:94  -90       31        3    0  11  54e  WPA2 CCMP   PSK  Speedport303V

BSSID              STATION            PWR   Rate    Lost  Packets  Probes

00:C0:A8:CD:CA:DC  00:26:C7:7E:08:40  -89    0 - 1     13        2
(not associated)   00:C0:A8:AF:64:11  -83    0 - 1     97     4280  Yosi_1,EW_WAN
(not associated)   00:22:58:10:90:9D  -82    0 - 1      0      171  WLAN-CE8034
(not associated)   00:1F:CF:52:82:FF  -87    0 - 1      0      103  Lasse
(not associated)   00:24:9F:53:02:21  -88    0 - 2      0        2  EasyBox C33E15
(not associated)   00:18:DE:86:E1:DF  -90    0 - 1      0       19  Intel 802.11 Default SSID,FRITZ!Box WLAN 3050
(not associated)   40:A6:D9:A6:02:44  -90    0 - 1      0       10  Fneu
(not associated)   00:15:AF:D9:AF:7D  -92    0 - 1      0      132  audi,De Dijk 49,ALICE-WLAN36,FRITZ!Box Fon WLAN
02:18:8B:B6:0E:E9  00:20:00:2F:53:F0  -77    0 - 1      0    37341
C0:C1:C0:36:74:10  00:05:4E:49:75:56    0   36 - 1      0     4623  Neverland
C0:C1:C0:36:74:10  38:E7:D8:15:E2:BC  -63   48 -54      0      275  Neverland,linksys
BC:05:43:A8:B0:D1  7C:6D:62:52:33:7E   -1   36e- 0      0      707
00:26:4D:05:35:19  00:0E:35:81:A7:CB  -60    0 - 1e     0      192  WLAN-053553
```

are hard to find

Just have a look what is going on in the neighborhood. . .

Request WLAN interface status:

`# airmon-ng`

Activate monitor mode of the interface:

`# airmon-ng start <device>`

Check WLAN interface status again:

`# airmon-ng`

Collect WLAN frames:

`# airodump-ng <device>`

Only for 2.4 GHz frequency block:

`# airodump-ng -band bg <device>`

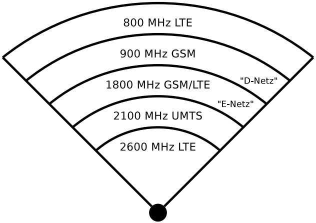
Only for 5 GHz frequency block:

`# airodump-ng -band a <device>`

Channel	Frequency	EU	USA	Japan
36	5.180 GHz	X[1]	X	X[1]
40	5.200 GHz	X[1]	X	X[1]
44	5.220 GHz	X[1]	X	X[1]
48	5.240 GHz	X[1]	X	X[1]
52	5.260 GHz	X[1,2,3]	X[2]	X[1,2,3]
56	5.280 GHz	X[1,2,3]	X[2]	X[1,2,3]
60	5.300 GHz	X[1,2,3]	X[2]	X[1,2,3]
64	5.320 GHz	X[1,2,3]	X[2]	X[1,2,3]
100	5.500 GHz	X[2,3]	X[2]	X[2,3]
104	5.520 GHz	X[2,3]	X[2]	X[2,3]
108	5.540 GHz	X[2,3]	X[2]	X[2,3]
112	5.560 GHz	X[2,3]	X[2]	X[2,3]
116	5.580 GHz	X[2,3]	X[2]	X[2,3]
120	5.600 GHz	X[2,3]	X[2]	X[2,3]
124	5.620 GHz	X[2,3]	X[2]	X[2,3]
128	5.640 GHz	X[2,3]	X[2]	X[2,3]
132	5.660 GHz	X[2,3]	X[2]	X[2,3]
136	5.680 GHz	X[2,3]	X[2]	X[2,3]
140	5.700 GHz	X[2,3]	X[2]	X[2,3]
144	5.720 GHz	X[2,4]	X[2]	—
149	5.745 GHz	X[2,4]	X	—
153	5.765 GHz	X[2,4]	X	—
157	5.785 GHz	X[2,4]	X	—
161	5.805 GHz	X[2,4]	X	—
165	5.825 GHz	X[2,4]	X	—

[1] Indoor only
[2] Dynamic Frequency Selection (DFS)
[3] Transmit Power Control (TPC)
[4] Short Range Devices (SRD) = 25 mW max.

- **Permitted use of WLAN in the 5 GHz Frequency Block**
- The higher the frequency, the stronger is the attenuation caused by the transmission medium
    - For this reason, WLAN at 2.4 GHz reaches with the same transmission power greater ranges than at 5 GHz



- Physical barriers cause with 5 GHz more problems than with 2.4 GHz

IEEE 802.11n – Multiple Input Multiple Output (MIMO)

- The maximum gross data rate, when using IEEE 802.11n, depends on the number of antennas in the stations and is 150, 300, 450 or 600 Mbps
  - The reason for this performance increase in contrast to IEEE 802.11a/b/g/h, is because 802.11n implements **MIMO**
- In addition to the extended channel width (40 MHz), up to 4 antennas are used in MIMO mode
  - They allow simultaneous working in the frequency blocks 2.4 GHz and 5 GHz
- With each parallel data stream (antenna), a maximum data rate (gross) of 150 Mbps can be achieved and up to 4 data streams can be bundled
  - The corresponding number of antennas (up to 4) need to be equal on both sides

Img. source: pixabay.com (CC0)

Image source: pxhere.com (CC0)

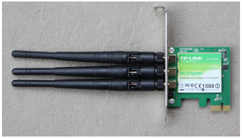


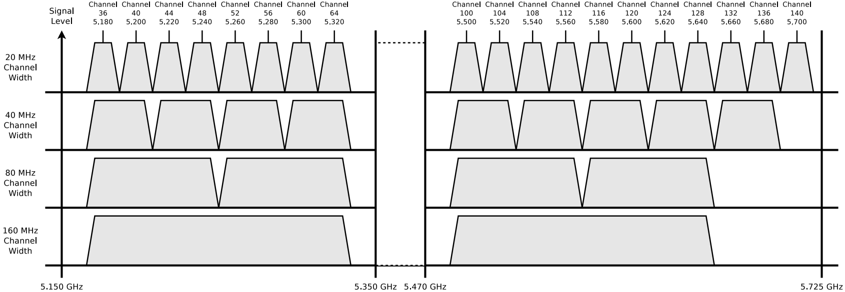
Image source: Christian Baun

IEEE 802.11ac

- Also IEEE 802.11ac implements **MIMO**
  - 8 parallel streams (antennas) are possible
  - Extended channel width possible: 40/80/160 MHz
  - Operates only in the 5 GHz frequency block
  - Maximum (gross) data rate: 6.936 GBit/s
    - With 8×MIMO and 160 MHz channel width

Img. source: Cookiemonster1979. `Wikimedia` (CC-BY-SA-4.0)

Such numbers are not common in practice. A realistic scenario is e.g. MIMO with 4 antennas in the access point and 80 MHz channel width. In this case, the maximum (gross) transmission rate with 802.11ac would be 1733 Mbit/s



WLAN Security – WEP

- WLAN 802.11 implements the security standard **Wired Equivalent Privacy (WEP)**, which is based on the RC4 algorithm
  - Calculation of a XOR of the payload bit stream and the pseudo random bit stream generated from the RC4 algorithm
  - Works with **static keys** that have a length of 40-bit or 104-bit
  - Can be cracked by known-plaintext attacks because the headers of the 802.11 protocol are predictable
    - The calculation of the WEP key with the help of a few minutes of recorded data only takes a few seconds with tools such as Aircrack

WEP encryption of WLAN cracked in less than a minute

The Technical University of Darmstadt has managed another breakthrough in cracking WEP encrypted wireless networks. As Erik Tews, Andrei Pychkine and Ralf-Philipp Weinmann described in a paper, they were able to reduce the amount of captured packets which are required for a successful attack to less than a tenth. According to the researchers, a wireless network, secured with a 128-bit WEP key can be cracked with their attack in less than a minute...

News story from April 4th 2007. Source: `http://heise.de/-164971`

WLAN Security – WPA und WPA2

- A better security standard is **Wi-Fi Protected Access** (WPA)
  - Bases on the RC4 algorithm too, but it offers increased security by using **dynamic keys**
    - The algorithm encrypts each data packet with a different key
  - Can be cracked by brute-force or via dictionary attacks on the password
- Much better standard: **Wi-Fi Protected Access 2 (WPA2)**
  - Bases on the Advanced Encryption Standard (AES)
  - A WLAN with WPA2 encryption, that is protected with a sufficiently long password is currently considered secure
- Best security standard today: **Wi-Fi Protected Access 3 (WPA3)**
  - Implements an improved key negotiation and exchange method (cryptographic handshake) based on the Diffie-Hellman algorithm for key exchange

More information about RC4, AES, Diffie-Hellman algorithm... $\Longrightarrow$ slide sets 11 + 12

Bluetooth

- Wireless network system for short distance data transmission
  - It is designed to replace short cable connections between different devices
- Development was initiated by the Swedish company Ericsson in 1994
  - Further development is done by the Bluetooth Special Interest Group (BSIG)

Bluetooth is named after the Danish Viking King Harald Bluetooth

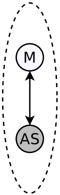
He was famous among other things for his communication skills

- Bluetooth devices use the frequency block 2.402-2.480 GHz
  - WLANs, cordless phones and microwave ovens can cause interferences if they operate in the same frequency band
  - To avoid interferences, Bluetooth uses a frequency hopping method, in which the frequency band is divided into into 79 frequency stages at intervals of 1 MHz
    - The frequency stages change up to 1600 times per second

Network Topologies of Bluetooth (1/2)

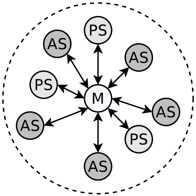
- Bluetooth devices organize themselves in so-called **piconets**
  - A piconet consists of $\leq$ 255 nodes ($\leq$ 8 are in active state)
    - The master can change the status of the other nodes (activate/deactivate)
  - 1 active node is the **master**
    - The remaining 7 active nodes are **slaves**

Piconet



1 Master
1 Slave

Piconet

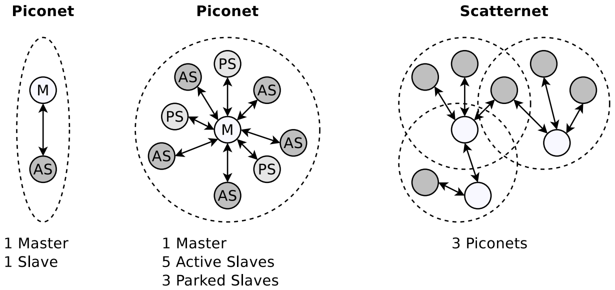


1 Master
5 Active Slaves
3 Parked Slaves

- The master coordinates the media access
  - It assigns the transmission medium (the air) to the nodes by providing transmission slots to the slaves
    - This procedure is called: Time Division Multiplexing
- All nodes must share the bandwidth of the network

Network Topologies of Bluetooth (2/2)

- Each Bluetooth device can be registered in multiple Piconets
  - But it can only be the master of a single network
- If a node is in range of 2 Piconets, it can combine them to a **Scatternet**
  - Up to 10 Piconets form a Scatternet
  - Each Piconet is identified by the different alternations in the frequency hopping method
  - The data rates of Scatternets are usually low



Versions of the Bluetooth Standards

- Different versions of the Bluetooth standard exist
- Maximum data rate:
  - Bluetooth up to version 1.2: 1 Mbps (721 kbit is payload)
  - Bluetooth 2.0: 3 Mbps (2.1 Mbps is payload)
- Bluetooth 3.0 + HS (High Speed) uses WLAN to increase the data rate
  - A 3 Mbps Bluetooth connection is used for the transmission of the control data and the session key
  - If 2 devices want to exchange large amounts of data, they switch into high-speed mode and establish an **ad-hoc connection via WLAN 802.11g** with a data rate of 54 Mbps
    $\Longrightarrow$ Bluetooth 3.0 + HS **combines Bluetooth with WLAN**
  - The possible (net) data rate is about 24 Mbps
- Bluetooth 4 offers e.g. reduced power consumption
- Bluetooth 5 improves e.g. the range (max. 200 m)

Pairing of Bluetooth Devices

- Before 2 Bluetooth devices can communicate with each other, they need to know each other
  - **Pairing** = the process of *getting to know each other*
- Before Bluetooth 2.1, pairing is complex
  - Both users need to enter an identical PIN
  - The PIN is the shared key for encryption and authentication
    - It ensures that no third device can listen to the connection or do a **man-in-the-middle attack**
- Bluetooth 2.1 introduced **Secure Simple Pairing**
  - This method uses the Diffie-Hellman algorithm ($\Longrightarrow$ slide set 12) for key distribution instead of a PIN
  - The security of this pairing method depends on whether the terminal devices are equipped with displays
    - If both devices have a display, each user needs to confirm a common code by pressing a key

If a device lacks a display to show the code, the confirmation is impossible

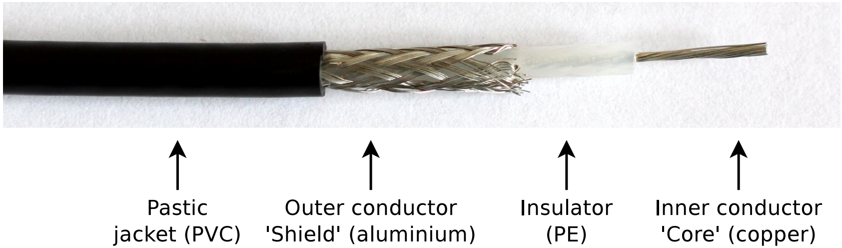
Then a man-in-the-middle attack is still possible

Transmission Media

- Different transmission media for computer networks exist

1. **Cable-based transmission media**
   - **Copper cable**: Data is transferred as electrical impulses via twisted pair cables or coaxial cables
   - **Fiber-optic cable**: Data is transferred as light-impulses
2. **Wireless transmission**
   - **Directed**:
     - **Radio technology**: Data is transferred as electromagnetic waves (radio waves) in the radio spectrum (e.g. WLAN and satellite internet access)
     - **Infrared**: Data is transferred as electromagnetic waves in the for the human eye invisible infrared spectrum range (e.g. IrDA)
     - **Laser**: Data is transferred as light-impulses via Laser Bridge
   - **Undirected**:
     - Undirected wireless transmission is always based of radio technology (e.g. mobile telephony, LTE, radio broadcasting and broadcasting via satellites)

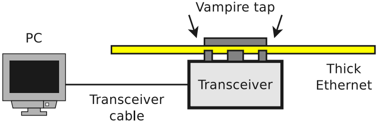
Coaxial Cables (*Coax Cables*)



- Bipolar cable with concentric (coaxial) structure
- The inner conductor (**core**) carries the electrical signals
- The outer conductor (**shield**) is kept at ground potential and completely surrounds the inner conductor
  - The shielding of the signal-carrying conductor by the outer conductor that is kept at ground potential, reduces electromagnetic interferences

Coaxial Cable for 10BASE5 – Thick Ethernet

- 10BASE5 (*Yellow Cable* or *Thick Ethernet*)
- 10 mm thick coaxial cable (RG-8) with 50 ohm impedance
- For connecting terminal devices, a hole must be drilled (!) into the cable through the outer shielding to contact the inner conductor
- Through the hole, the *transceiver* is connected via a *vampire tap* with the inner conductor
- The terminal device is connected via a transceiver cable (DB15), called AUI (Attachment Unit Interface) with the transceiver



Working Principle of Ethernet by Robert Metcalfe (1976)

- With this drawing Robert Metcalfe demonstrated in June 1976 the working principle of Ethernet on the National Computer Conference

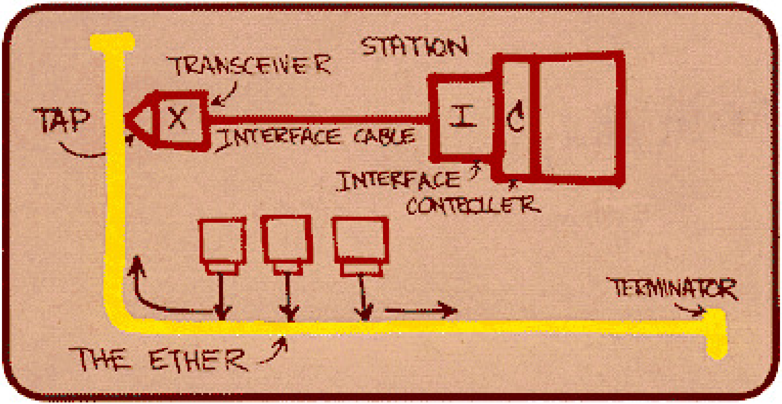
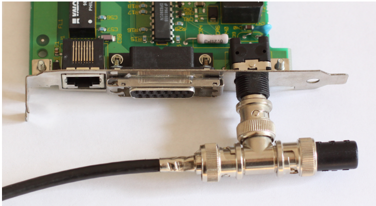


Image source: Robert M. Metcalfe (1976)

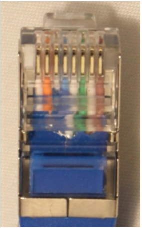
Coaxial Cable for 10BASE2 – Thin Ethernet

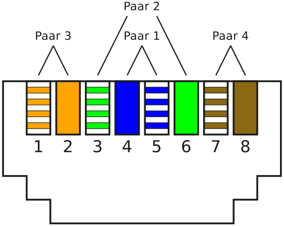
- The hardware required for Thick Ethernet is cost intensive
- A less expensive solution is 10BASE2
    - It is called *Thin Ethernet*, *ThinWire* and sometimes *Cheapernet*
- 6 mm thick coaxial cable (RG-58) with 50 ohm impedance
    - The cables are thinner and more flexible, and therefore more simple to install
- Cables and devices have BNC connectors (Bayonet Neill Concelman)
- T-Connectors are used to connect devices with the transmission medium
- Terminators (50 ohm) are used to prevent reflections

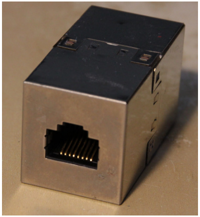


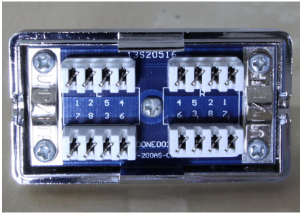
Twisted Pair Cables (1/2)

- The wires of twisted-pair cables are pairwise twisted with each other.
- Twisted pairs are better protected against alternating magnetic fields and electrostatic interferences from the outside than parallel signal wires
- All variants of the Ethernet standard, that use twisted pair cables as transmission medium, use plugs and jacks according to the standard 8P8C, which are usually called RJ45









Twisted Pair Cables (2/2)

- Since the 1990s, twisted-pair cables and RJ45 plugs and jacks are **standard for copper-based IT networking**

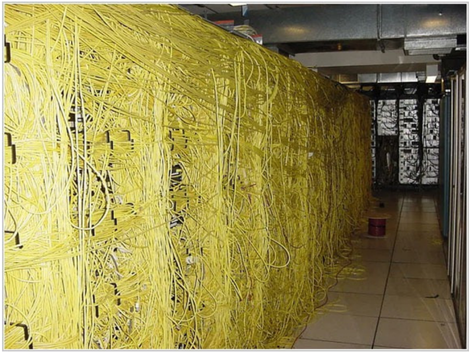
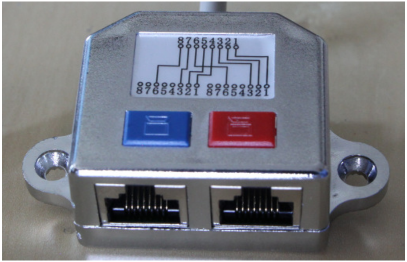


Image source: `memegenerator.net`

> **Why are 2 pairs of wires used for sending and receiving?**
>
> See ‘Complementary Signal’ on slide 42

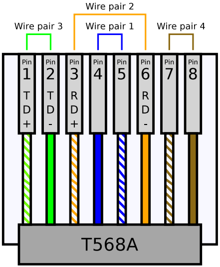
- Ethernet 10BASE-T and Fast Ethernet 100BASE-TX both only use 2 pairs of wires for sending and receiving
- This allows using **Ethernet Splitters**

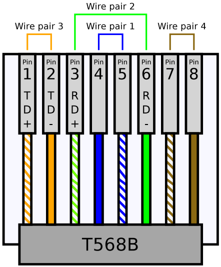


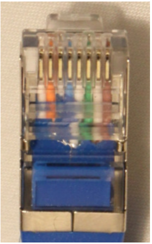
- Fast Ethernet 100BASE-T4 and Gigabit Ethernet 1000BASE-T both use all 4 pairs of wires for sending and receiving

Wiring

- T568A and T568B are standards for the pin assignment of the RJ45 plugs and jacks and are used for Fast Ethernet 100BASE-TX and Gigabit Ethernet 1000BASE-T
  - Difference: The wire pairs 2 and 3 (green and orange) are interchanged
  - Mixing T568A and T568B in a computer network is a bad idea







This is T568B

When using 10BASE-T, 4 PINs are used – The remaining wire pairs are not used

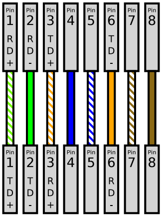
- TD+ and TD- (Trancieve Data) is the wire pair for data output signal
- RD+ and RD- (Recieve data) is the wire pair for data input

Crossover Cables and Patch Cables

- A **Crossover cable** can connect 2 terminal devices directly
  - It connects the send and receive lines of both devices
- To connect more than just 2 network devices, **patch cables** are used
  - In this case, a Hub or a Switch is required

Patch Cable

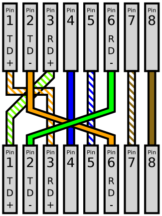
Hub / Switch



Terminal Device

Crossover Cable

Terminal Device



Terminal Device

- Some Hubs and Switches provide an **uplink port** for connecting another Hub or Switch
  - The uplink port is internally crossed

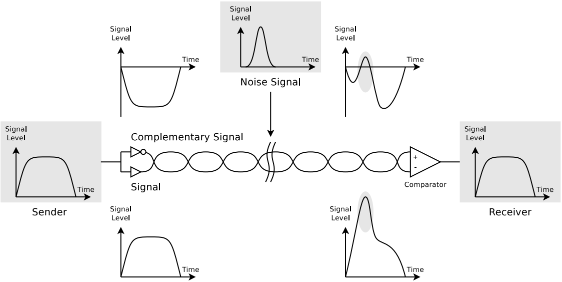
Auto-MDIX allows using crossover lines and patch cables any time

- Modern network devices automatically detect the send and receive lines of connected network devices
- All network devices, which support Gigabit Ethernet 1000BASE-T or faster, implement Auto-MDIX

Complementary Signal

Source: Jörg Rech. Ethernet. Heise. 2008 and Wikipedia

- Via the wire pair a complementary signal is sent (on one wire 0 V to +2.8 V and on the other wire 0 V to -2.8 V)
  - This allows the receiver to **filter out interfering signals**
  - Furthermore, it **reduces electromagnetic emission**



- The signal level of line A=Payload Signal+Noise
- The signal level of line B= −Payload Signal+Noise

- The difference of the signal levels of line A and line B at receiver side is: [+Payload Signal+Noise] − [−Payload Signal+Noise] = 2∗Payload Signal
- Result: Regardless of the level of the noise signal, the difference between the payload signal and the complementary signal remains the same

Shielding of different Twisted Pair Cables

- Twisted pair cables are often equipped with a metal shield to prevent electromagnetic interferences

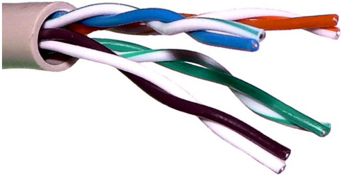
Label	Meaning	Cable shielding	Pair shielding
UUTP	*Unshielded Twisted Pair*	none	none
UFTP	*Foiled Twisted Pair*	none	foil
USTP	*Shielded Twisted Pair*	none	braiding
SUTP	*Screened Unshielded Twisted Pair*	braiding	none
SFTP	*Screened Foiled Twisted Pair*	braiding	foil
SSTP	*Screened Shielded Twisted Pair*	braiding	braiding
FUTP	*Foiled Unshielded Twisted Pair*	foil	none
FFTP	*Foiled Foiled Twisted Pair*	foil	foil
FSTP	*Foiled Shielded Twisted Pair*	foil	braiding
SFUTP	*Screened Foiled Unshielded Twisted Pair*	braiding and foil	none
SFFTP	*Screened Foiled Foiled Twisted Pair*	braiding and foil	foil

- The label scheme follows the schema `XXYZZ`
  - `XX` is the cable shield
    - `U` = unshielded, `F` = foil shielding , `S` = braided shielding, `SF` = braided shielding and foil
  - `Y` is the pair shielding
    - `U` = unshielded, `F` = foil shielding , `S` = braided shielding
  - `ZZ` stands for twisted pair (TP)

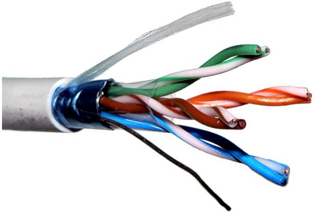
Twisted Pair Cables – Examples

Image Source: (Kabel): Wikipedia (CC0)

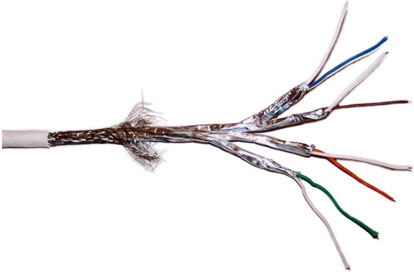
Example 1: UTP



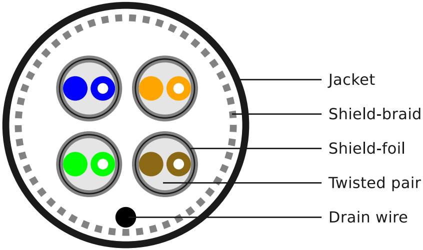
Example 2: FUTP = FTP



Example 3: SFTP

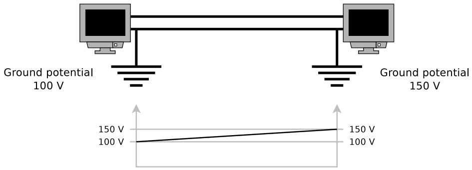


Structure (SFTP)



Shielded or Unshielded Cables?

- Shields must be electrically grounded on both sides of the cable
  - If only one end of a shielded cable is grounded, an antenna effect occurs



- This results in a compensation current ($I = \frac{V}{R}$)
  - Compensating currents cause problems during operation or even the destruction of network devices
- For this reason, shielding can only be used if both sides of the cable have the same ground potential and therefore **shielded cables cannot be used to connect different buildings**
  - Possible solutions are the installation of fiber-optic cables between buildings, laser bridges or wireless networks

Categories of Twisted Pair Cables (1/3)

- Different categories of twisted pair cables exist
- The performance of a network connection is determined by the component of the lowest category
  - Example: Devices, which support Cat6, are connected via a Cat5 cable
    - This reduces the performance of the connection to the values of Cat5
- **Category 1/2/3/4**
  - Not common today (except for telephone cables)
- **Category 5/5e**
  - Cat5e is guaranteed Gigabit Ethernet-compatible
    - It meets stricter test standards than Cat5 cables
  - Common in most current LANs

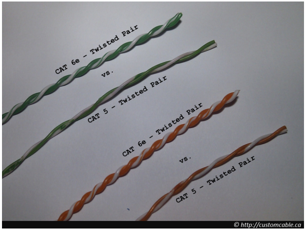
Category	Max. frequency	Compatible with...
Cat-5	100 MHz	100BASE-TX (100 Mbps, 2 wire pairs, 100 m)
		1000BASE-T (1 Gbps, 4 wire pairs, 100 m)
Cat-5e	100 MHz	2.5GBASE-T (2.5 Gbps, 4 wire pairs, 100 m)

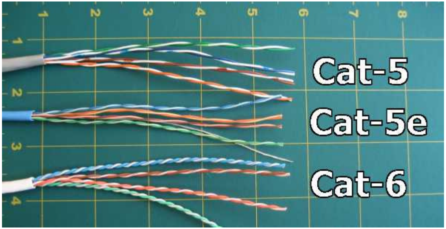
Categories of Twisted Pair Cables (2/3)

Image Source: Reddit

- **Category 6/6A**

Category	Max. frequency	Compatible with...
Cat-6	250 MHz	5GBASE-T (5 Gbps, 4 wire pairs, 100 m)
		10GBASE-T (10 Gbps, 4 wire pairs, 55 m)
Cat-6A	500 MHz	10GBASE-T (10 Gbps, 4 wire pairs, 100 m)





Main differences (of the structure) between the categories: number of twists per wire length (cm) and thickness of the jacket

- More twists per cm $\Longrightarrow$ less interference (noise)
- Cat 5/5e has 1-2 twists per cm. Cat 6 has 2 or more twists per cm
- Thickness of the cladding $\Longrightarrow$ less crosstalk
- Crosstalk is the mutual interference of parallel lines

Categories of Twisted Pair Cables (3/3)

- **Category 7/7A**
  - For Cat 7 and Cat 7A cables, other connectors (e.g., TERA or GG45) and sockets than RJ45 were initially intended
    - However, these connectors were not successful in the market
    - **Cat 7 and 7A cabling with RJ45 connectors offers no benefits over category 6A cables**

Category	Max. frequency	Compatible with...
Cat-7	600 MHz	10GBASE-T (10 Gbps, 4 wire pairs, 100 m)
Cat-7A	1000 MHz	10GBASE-T (10 Gbps, 4 wire pairs, 100 m)

- **Category 8.1**
  - This standard supports cables of up to 30 m in length
  - Cables of this length are mostly sufficient for data centers

Category	Max. frequency	Compatible with...
Cat-8.1	2000 MHz	40GBASE-T (40 Gbps, 4 wire pairs, 30 m)

Information printed on Twisted Pair Cables (1/2)

Do you understand the most important cable characteristics that are printed on twisted pair cables?

Example: `E188601 (UL) TYPE CM 75°C LL84201 CSA TYPE CMG FT4 CAT.5E PATCH CABLE TO TIA/EIA 568A STP 26AWG STRANDED`

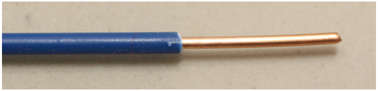
- **PATCH/CROSS/CROSSOVER**: see slide 41
- **UTP/STP/FTP/SFTP**: see slides 43-44
- **CAT5/5E/6/7/8**: see slides 46-48
- **24AWG/26AWG/28AWG**: American wire gauge (AWG) informs about the diameters of the wires
  - 24AWG = 0.51054 mm, 26AWG = 0.405 mm, 28AWG = 0.321 mm
  - Larger wire diameter $\Longrightarrow$ less electrical resistance for the electronic signals $\Longrightarrow$ lower attenuation
    - 24AWG cables have lower attenuation than 26AWG or 28AWG cables
  - 28AWG cables are thinner than 24AWG or 26AWG
    - Thinner cables block airflow in server racks less and simplify the installation

Information printed on Twisted Pair Cables (2/2)

Do you understand the most important cable characteristics that are printed on twisted pair cables?

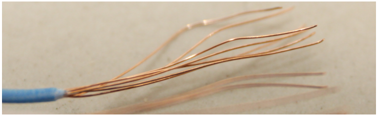
Example: `E188601 (UL) TYPE CM 75°C LL84201 CSA TYPE CMG FT4 CAT.5E PATCH CABLE TO TIA/EIA 568A STP 26AWG STRANDED`

- **60°C/75°C**: Temperature information stands for flame tests
- **SOLID/STRANDED**
  - **Solid** cables use solid copper wires. Such cables are well suited for permanent infrastructure installation. They have a lower attenuation and cost less compared to stranded cables
  - **Stranded** cables consist of multiple strands of wires wrapped around each other. They are typically used to create patch cables because they are very flexible. Attenuation of stranded cables is higher compared to solid cables. Thus, they are used for shorter distances



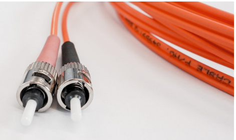
Left image: Solid cable

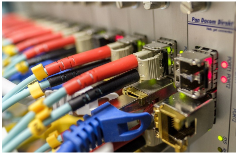
Right image: Stranded cable

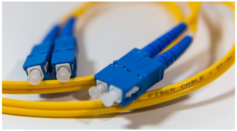


Fiber-optic Cables

Image Source: pixabay.com (CC0)





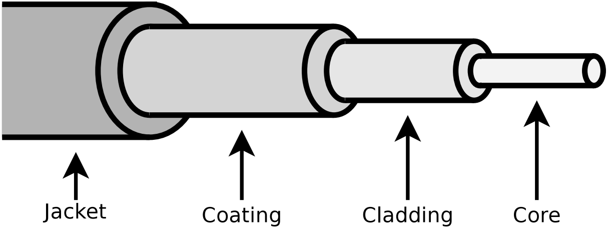


- Often called optical fiber
- Transfer data by using light
  - Light source: Normal LED or laser LED
  - Use wavelengths of 850, 1300 or 1550 nm
  - Propagation speed of the light in the glass: about 200,000 km/s
- Advantages over coaxial and twisted pair cables
  - Provide high data rates over large distances
  - Create no electromagnetic emission
  - Insensitive against electromagnetic influences
- Drawbacks:
  - Higher cost for cabling and active components (LEDs)
  - Existing twisted pair cable infrastructures can not be used
- Used only when copper cables cannot provide enough bandwidth

Structure of Fiber-optic Cables

Image Source (cable): pxhere.com (CC0)

- Components of an optical fiber (from inside to outside):
  1. Light-transmitting (*core*) made of quartz glass
  2. The core is surrounded by a *cladding* layer
     - The refractive index of the core must be greater than that of the cladding to enclose the optical signal
  3. The core is surrounded by a *coating* layer that protects it from moisture and physical damage
  4. The final layer is the outer *jacket* to protect the inner layers



Multi-mode Fibers and Mono-mode (Single-mode) Fibers

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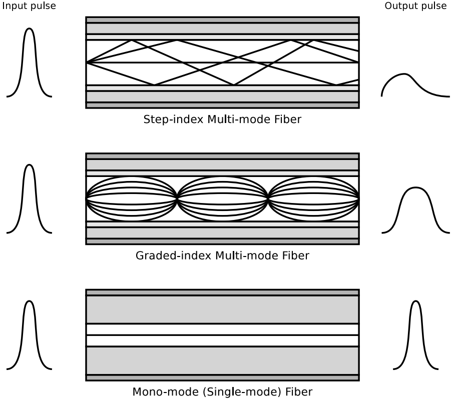
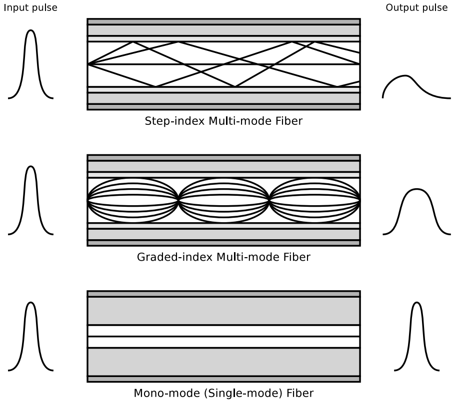
- Structure, dimensions and refractive index of core and cladding specify the number of **propagation modes**, by which light can propagate along the fiber
  - Each mode corresponds to one path in the optical fiber



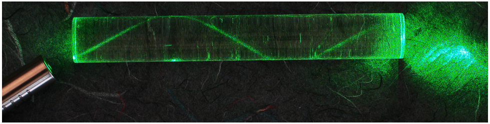
- **Multi-mode Fibers** provide up to several thousand propagation modes and **mono-mode (single-mode) fibers** only a single one
  - Short distance ($\approx<$ 500 m) $\Longrightarrow$ multi-mode fibers
  - Long distance ($\approx<$ 70 km) $\Longrightarrow$ mono-mode fibers

Types of Optical Fibers

- Multi-mode fibers are classified into **step-index** and **graded-index**



- On **step-index** fibers, there is an abrupt refraction index change between core and cladding
  - This reduces the output pulse
- On **graded-index** fibers there is a gradual change of the refraction index between core and cladding
  - The output pulse is well recognizable



The image demonstrates the reflection of light in a multi-mode graded-index fiber