Physical layer

Ing. Yelena Trofimova

Department of Computer Systems
Faculty of Information Technology
Czech Technical University in Prague

Computer networks, BIE-PSI
SS 2020/21, Lecture 10

https://courses.fit.cvut.cz/BIE-PSI/

Content

- data channel and its properties
- encoding
- modulation
- multiplexing
- metallic media
- optical media

Data channel

- attributes
  - unidirectional x bidirectional (full-duplex, half-duplex)
  - point-to-point x multi-point (shared medium)
    - medium access control
  - medium capacity (bitrate, data rate, bandwidth, throughput)
  - transmission delay (latency)
  - error rate

Data channel - parameters I

- channel capacity (bitrate, data rate, bandwidth, throughput)
  - units: bits per second = bps, bit/s, b/s
    - sometimes: bytes per second = B/s
    - kilobit (kb) = 1000 bits
  - total number of transmitted bits per second including overhead
  - radio signal: speed of light
  - electrical or optical signal (cable, fiber) – by media type, about 2/3 of the speed of light

Data channel - parameters II

Bit rate (bps) & baud (Bd)

- baud – unit of modulation rate (baud rate)
- indicating the number of state changes of the transmission medium for one second
- relationship Bd and bps depends on the encoding
  - 1 Bd can correspond to 1 bps
  - example: 4 voltage level modulation: 1 Bd equals to 2 bps: "00" $\sim$ -10 V, "01" $\sim$ -2 V, "10" $\sim$ +2 V, "11" $\sim$ +10 V

Nyquist Formula

- Nyquist gives the upper bound for the bit rate of a transmission system by calculating the bit rate directly from the number of bits in a symbol (or signal levels) and the bandwidth of the system:

$$C = 2 \cdot B \cdot log_2 V$$

where:

- C = maximum capacity in bps (only for noiseless channel)
- B = bandwidth in Hz
- V = number of discrete values

Nyquist Formula – example 1

- Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The maximum bit rate can be calculated as

$$C = 2 \cdot B \cdot log_2 V = 2 \cdot 3000 \cdot log_2 2 = 6000 bps$$

Nyquist Formula – example 2

- Consider the same noiseless channel transmitting a signal with four signal levels (for each level, we send 2 bits). The maximum bit rate can be calculated as

$$C = 2 \cdot B \cdot log_2 V = 2 \cdot 3000 \cdot log_2 4 = 12000 bps$$

Nyquist Formula – example 3

We need to send 265 kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?

$$C = 2 \cdot B \cdot log_2 V$$

$$265000 = 2 \cdot 20000 \cdot log_2 L$$

$$log_2 L = 6.625$$

$$L = 98.7$$

Since this result is not a power of 2, we need to either increase the number of levels or reduce the bit rate. If we have 128 levels, the bit rate is 280 kbps. If we have 64 levels, the bit rate is 240 kbps.

Shannon Theorem

- Shannon's theorem gives the capacity of a system in the presence of noise:

  $$C = B \cdot log_2(1 + SNR)$$

  where:

- C = capacity in bps
- B = bandwidth in Hz
- SNR = signal to noise ratio

Consider an extremely noisy channel with $SNR = 0$. Than $C = B \cdot log_2(1 + 0) = 0bps$ (we cannot receive any data through this channel).

Shannon Theorem – example 1

- We can calculate the theoretical highest bit rate of a regular telephone line. A telephone line normally has a bandwidth of 3000. The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as

$$C = B \cdot log_2(1 + SNR) = 3000 \cdot log_2(1 + 3162) = 34860bps$$

- This means that the highest bit rate for a telephone line is 34.860 kbps. If we want to send data faster than this, we can either increase the bandwidth of the line or improve the signal-to-noise ratio.

Shannon Theorem – example 2

- We have a channel with a 1 MHz bandwidth. The SNR for this channel is 63. What are the appropriate bit rate and signal level?
- First, we use the Shannon formula to find the upper limit:

$$C = B \cdot log_2(1 + SNR) = 10^6 \cdot log_2(1 + 63) = 6Mbps$$

- The Shannon formula gives us 6 Mbps, the upper limit. For better performance we choose something lower, 4 Mbps, for example. Then we use the Nyquist formula to find the number of signal levels.

$$4Mbps = 2 \cdot 10^6 \cdot log_2 L \Rightarrow L = 4$$

Encoding

- purpose of encoding
  - Adaptation of the physical properties of the medium
  - Automatic detection/correction of errors
- NOT to make data unreadable for other (do not confuse with encryption!)

Encoding (line codes)

- NRZ (Non-return to zero) – without autosynchronization
- NRZI (Non-return to zero inverted) - USB
- Bipolar - no DC component
- MLT3 – Ethernet 100BASE-TX
- Manchester – IEEE 802.3
- Differential Manchester – Token Ring
- 4B5B – Ethernet 100BASE-TX

Encoding 4B5B

- 4 bits are coded as 5 bits
- "0" is not more than 3 times in a row

0	(0000)	11110	8	(1000)	10010
1	(0001)	01001	9	(1001)	10011
2	(0010)	10100	A	(1010)	10110
3	(0011)	10101	B	(1011)	10111
4	(0100)	01010	C	(1100)	11010
5	(0101)	01011	D	(1101)	11011
6	(0110)	01110	E	(1110)	11100
7	(0111)	01111	F	(1111)	11101

Modulation

- carrier signal is analog, modulation is conversion to analog signal
- analog modulation
  - amplitude
  - frequency
  - phase
- digital modulation
  - PSK – phase-shift keying
  - FSK – frequency-shift keying
  - ASK – amplitude-shift keying
  - QAM, quadrature amplitude modulation

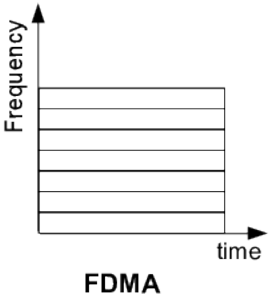
Multiplexing

multiple signals are combined over a shared medium

- FDMA – Frequency Division Multiple Access
- TDMA – Time Division Multiple Access
- CDMA – Code Division Multiple Access

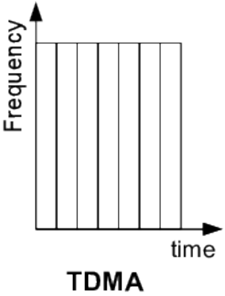
Frequency Division Multiple Access

- each channel has its own dedicated frequency band
- examples: Radio/TV broadcasting, ADSL and voice on the telephone line



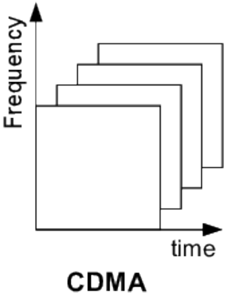
Time Division Multiple Access

- allows many different users to share the same frequency channel by dividing the signal into different time slots
- frame – transfer unit, which contains all channels
- examples: GSM



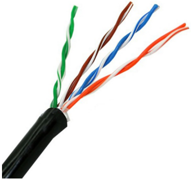
Code Division Multiple Access

- spread spectrum technology
  - modulated signal has a wider bandwidth than before modulation
- special coding scheme



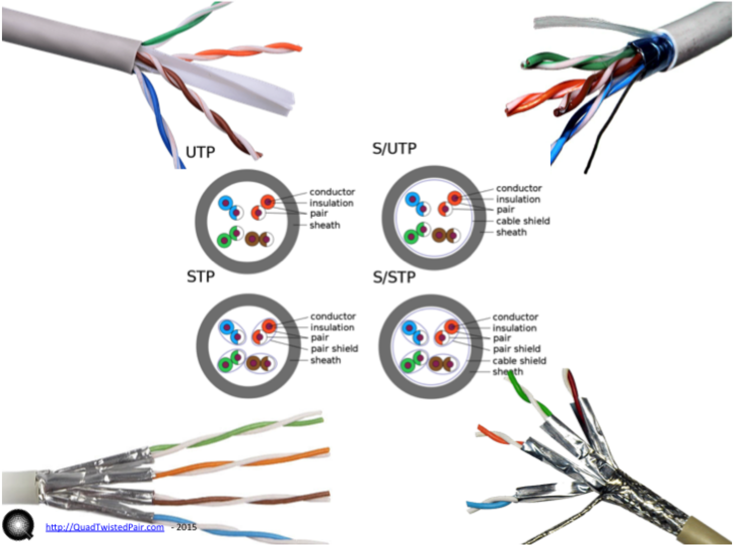
Metal cabling

- symmetric – twisted pair



- asymmetric – coaxial cable

UTP/STP

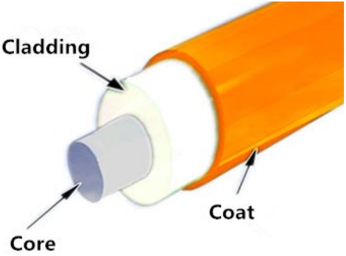

UTP
conductor
insulation
pair
sheath
S/UTP
conductor
insulation
pair
cable shield
sheath
STP
conductor
insulation
pair
pair shield
sheath
S/STP
conductor
insulation
pair
pair shield
cable shield
sheath
http://QuadTwistedPair.com - 2015

UTP categories

UTP Categories - Copper Cable				
UTP Category	**Data Rate**	**Max. Length**	**Cable Type**	**Application**
CAT1	Up to 1Mbps	-	Twisted Pair	Old Telephone Cable
CAT2	Up to 4Mbps	-	Twisted Pair	Token Ring Networks
CAT3	Up to 10Mbps	100m	Twisted Pair	Token Rink & 10BASE-T Ethernet
CAT4	Up to 16Mbps	100m	Twisted Pair	Token Ring Networks
CAT5	Up to 100Mbps	100m	Twisted Pair	Ethernet, FastEthernet, Token Ring
CAT5e	Up to 1 Gbps	100m	Twisted Pair	Ethernet, FastEthernet, Gigabit Ethernet
CAT6	Up to 10Gbps	100m	Twisted Pair	GigabitEthernet, 10G Ethernet (55 meters)
CAT6a	Up to 10Gbps	100m	Twisted Pair	GigabitEthernet, 10G Ethernet (55 meters)
CAT7	Up to 10Gbps	100m	Twisted Pair	GigabitEthernet, 10G Ethernet (100 meters)

Firewall.cx
Routing Information & Expertise To Network Professionals

Optical cable



Decibel

- dB
- logarithmic unit used to express the ratio between two values of a physical quantity, often power or intensity
- power or intensity: $L_{dB} = 10 \cdot log_{10}(P_1/P_0)$
- electrical circuits: $L_{dB} = 20 \cdot log_{10}(V_1/V_0)$
- $P = U^2/Z$ (power is proportional to the square of amplitude)