Lecture 3
Transmission and Physical model

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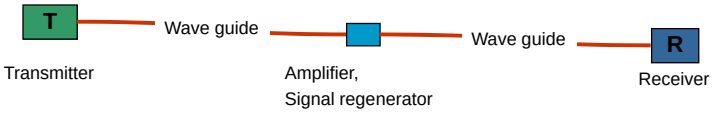
Topics

- Transmission Media
  - Attenuation and link budget
  - Signal distortion
  - Capacity limitations
- Modulation and line coding
- Synchronization and framing
- Multiplexing
- Capacity requirements
- Examples—TDM, ADSL, SDH

Transmission Media



- Guided media
  - Electrical
    - Twisted pair cable
    - Coaxial cable
  - Optical
    - Single-mode and multimode
- Unguided media
  - Electromagnetic waves in air
    - Radio
    - Microwaves (terrestrial and satellite)

Attenuation

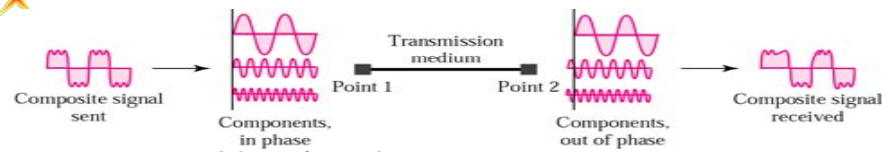
$10 \log_{10} P_{in}/P_{out}$

Power and Sensitivity

- No link is perfect
- Attenuation
  - Power loss between sender and receiver
  - *Relationship* between incoming and outgoing power
  - Measured in decibel [dB]
    - Example:
    - P_{in} = 120 mW
    - P_{out} = 30 mW
    - Attenuation = $10 \log_{10} 4$ » » » 6 dB

- **Measured in "decibel watt" dBW or "decibel milliwatt" dBm**
  - » **PdbW = 10 $\log_{10}$ P**
  - » **PdBm= 10 $\log_{10}$ P/(1×10^{-3})**
- **For example, transmitter output power and receiver input sensitivity**
- **Note: absolute power measures!**

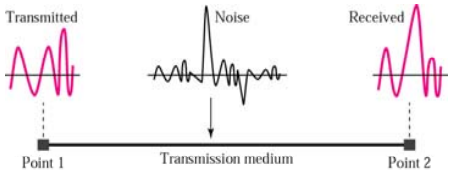
Transmission Quality—Distortion and Noise



- Signal changes form or shape
- Each frequency component has its own speed through the medium

Transmission Quality—Noise

- **Undesired signal added to the transmitted signal**
  - **Thermal noise**
    - **Random motion of electrons**
    - **Independent of frequency ("white noise") and amplitude**
    - **Added to the signal**
- **Signal-to-noise ratio, SNR**
  - **S/N, where S is signal power, N is noise power**



Transmission Quality—Counter Measures

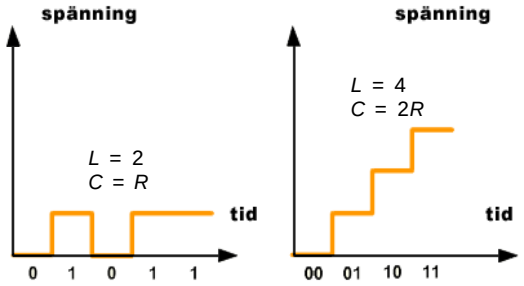
- Amplification
  - Compensates for attenuation and other losses
  - Adds noise
- Regeneration (for digital signals)
  - Recreates the shape of the signal
- Noise filters
  - Can attenuate the signal
- Protection against disturbances and crosstalk
  - For example shielding against electromagnetic fields
- Protection against distortion
  - Equalizers
  - Dispersion compensation

Bit Rate and Baud Rate

- Link capacity: number of bits per second (bit rate)
- Baud rate: number of signal elements per second

$C = R \log_2 L$

C: capacity
L: number of levels
R: baud rate



Nyquist Bit Rate
Channel Capacity—Shannon's Formula

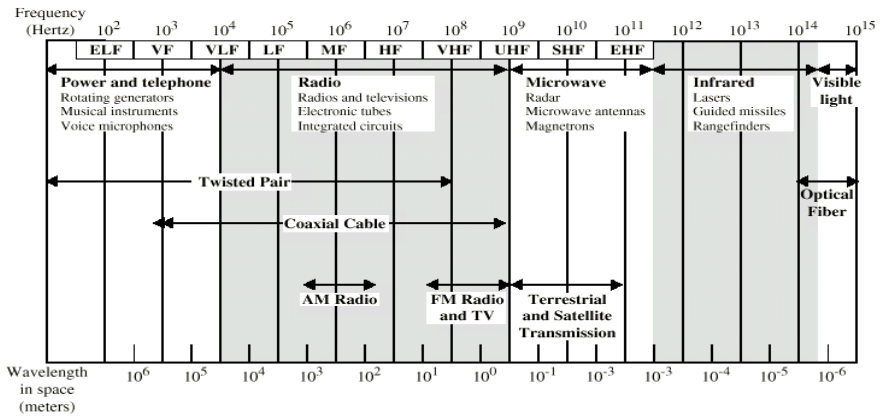
$C_{max} = 2B \log_2 L$

- Harry Nyquist (1889 – 1976)
- Also Nyquist's/Hartley's Law
- Nyquist bit rate C_{max} is the maxiumum bit rate on an ideal channel
  - So maximum baud rate is $2B$

$C = B \log_2 (1 + S/N)$

- **Claude Shannon (1916 – 2001)**
  - **"Father of information theory"**
- **Highest possible bit rate in a channel with white noise**
  - ***B* is channel bandwidth**
  - ***S/N* is signal to noise ratio**
- **Example**
  - ***B* = 3100 Hz**
  - ***S/N* = 20 dB = 100 times**
  - ***C* = 3100 $\log_2(1 + 100)$ = 20.6 kb/s**
- **Telephone line**
  - ***B*: 3100-3500 Hz**
  - ***S/N*: 33-39 dB**
  - ***C* » 33-45 kb/s**
  - **(What about ADSL and 56K modems?)**

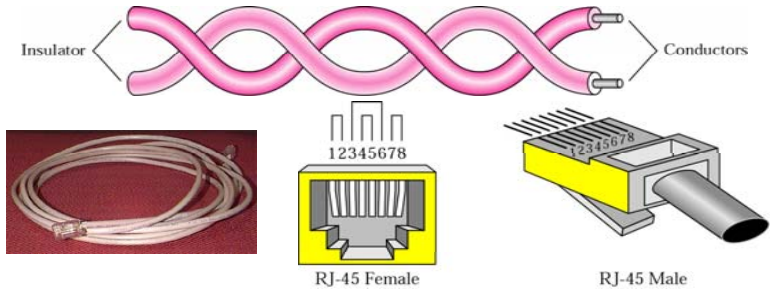
Bandwidth for Different Media



Guided Media

- Wires, cables
- Twisted pair cables
- Coaxial cables
- Optical fibers

Twisted Pair Cable



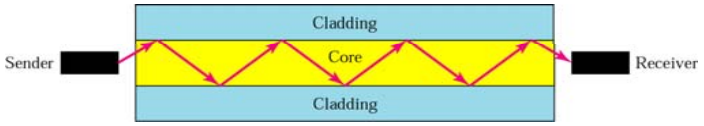
- Separately insulated
- Pair of cables twisted together
  - Even out external disturbances
  - Receiver operates on signal differences

- **Several pairs bundled together**
- **Often with RJ-45 connector**
- **Often installed in building when built**
- **Shielded (STP) and unshielded (UTP)**
  - **Shielding protects from noise and crosstalk**
  - **Bulkier and more expensive**

Categories of Unshielded Twisted Pair

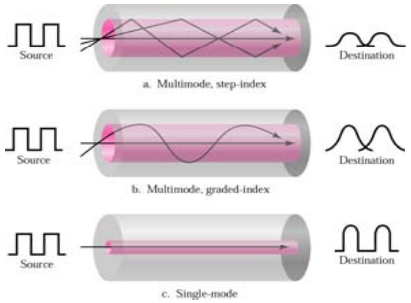
Category	Bandwidth	Data Rate	Digital/Analog	Use
1	very low	< 100 kbps	Analog	Telephone
2	< 2 MHz	2 Mbps	Analog/digital	T-1 lines
3	16 MHz	10 Mbps	Digital	LANs
4	20 MHz	20 Mbps	Digital	LANs
5	100 MHz	100 Mbps	Digital	LANs
6 (draft)	200 MHz	200 Mbps	Digital	LANs
7 (draft)	600 MHz	600 Mbps	Digital	LANs

Optical Fiber



- Core of glass or plastic
- Cladding with lower index of refraction
- Light Emitting Diode (LED) or laser

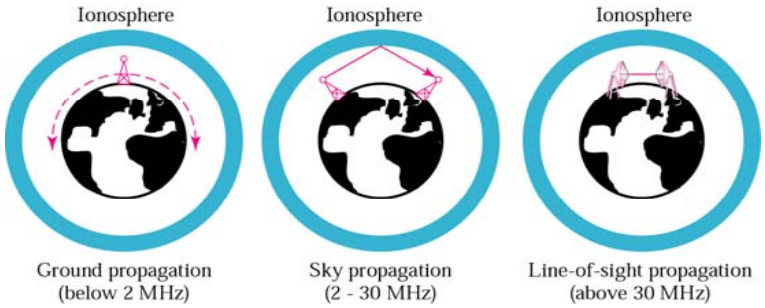
Fiber Transmission Modes



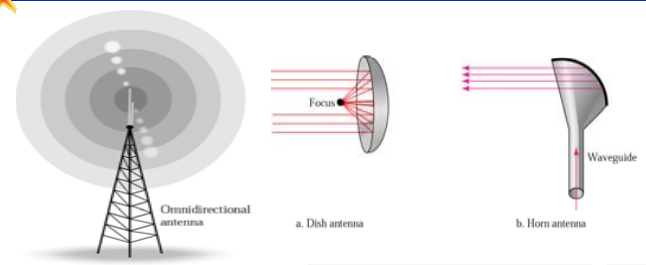
Fiber Advantages and Disadvantages

- Advantages
  - Very high capacity
  - Low attenuation
  - Low crosstalk: no interference between photons
  - Not sensitive to electromagnetic noise
  - Light weight
- Disadvantages
  - Installation/maintenance
  - Unidirectional

Propagation Methods for Unguided Signals



Radio Waves| Microwaves| Infrared

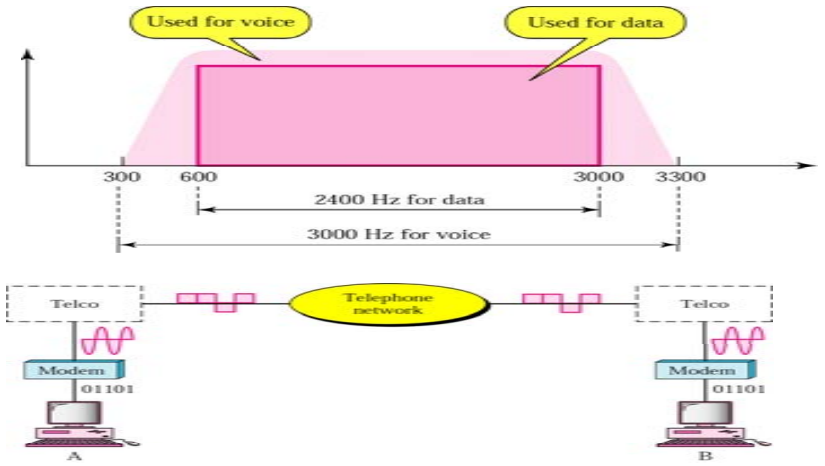


- Radio, television, etc
- Up to 1 GHz
- Ground and sky propagation
- Omnidirectional antennas

- **1-300 GHz**
- **Cellular phones, satellite networks, wireless LANs**
- **Line of sight propagation**
- **Unidirectional antennas**

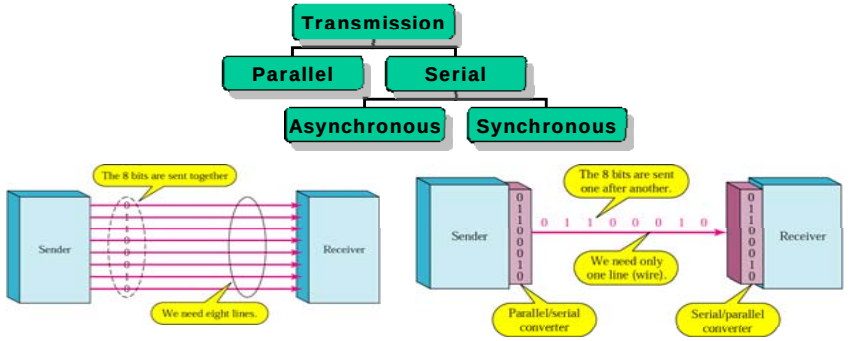
- **300 GHz – 400 THz**
- **Line-of-sight propagation**
- **Closed areas**
  - **Interference from sun rays**
- **Short distances**

Data Transmission Over Telephone Lines



- **Modulator/demodulator**

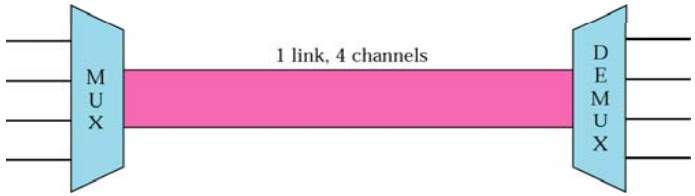
Data Transmission Modes



- **High capacity**
- **But costly, if it requires multiple cables**

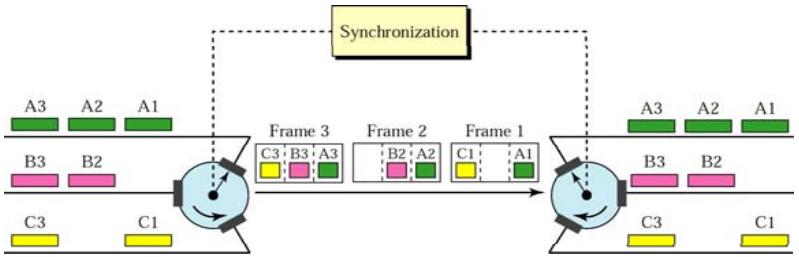
- **Need for synchronization at bit level**
  - **External clock, such as GPS**
  - **Separate link for clock signal**
  - **Line coding with embedded clock**
    - **Manchester coding, for example**
  - **Receiver resynchronization**

Multiplexing



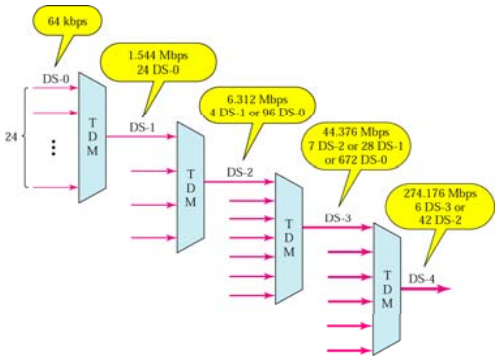
- Subdivision of a link into multiple channels
  - Multiple sender/receiver pairs can share the link
- Resource sharing
  - Bandwidth divided into frequency channels
  - Transmission time divided into time slots

Synchronous Time Division Multiplexing



- Access according to time slots
- Time slots grouped into frames
- If *n* is the number of inputs, the output link needs to be *n* times faster than each input link
- Frame duration is the same as the duration of a data unit on the input

Hierarchical Multiplexing

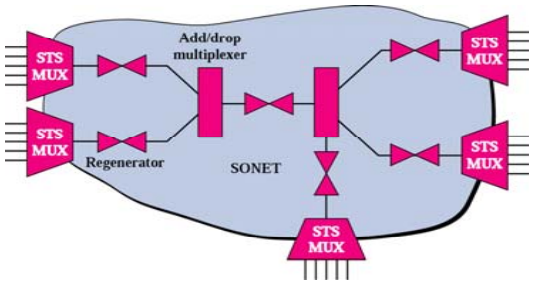


E Line	Rate (Mbps)	Voice Channels
E-1	2.048	30
E-2	8.448	120
E-3	34.368	480
E-4	139.264	1920

E Line Rates

Example: SDH/SONET

- ANSI: Synchronous Optical NETwork (SONET)
- ITU-T: Synchronous Digital Hierarchy (SDH)
- TDM system
  - Synchronous network
    - A single, common clock allows channel multiplexing
- Fiber-optic transmission system
- Can carry ”tributaries”
  - DS-0, DS-1, E1



STS: Synchronous Transport Signal

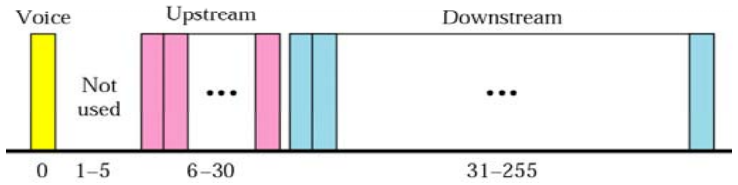
SONET/SDH Rates

Optical level	Electrical level	SDH equivalent	Line rate (Mb/s)	Payload rate (Mb/s)
OC-1	STS-1	-	51.84	50.112
OC-3	STS-3	STM-1	155.52	150.336
OC-12	STS-12	STM-4	622.08	601.344
OC-48	STS-48	STM-16	2488.32	2405.376
OC-192	STS-192	STM-64	9953.28	9621.604
OC-768	STS-768	STM-256	39813.120	38486.016

Example: Digital Subscriber Link (DSL)

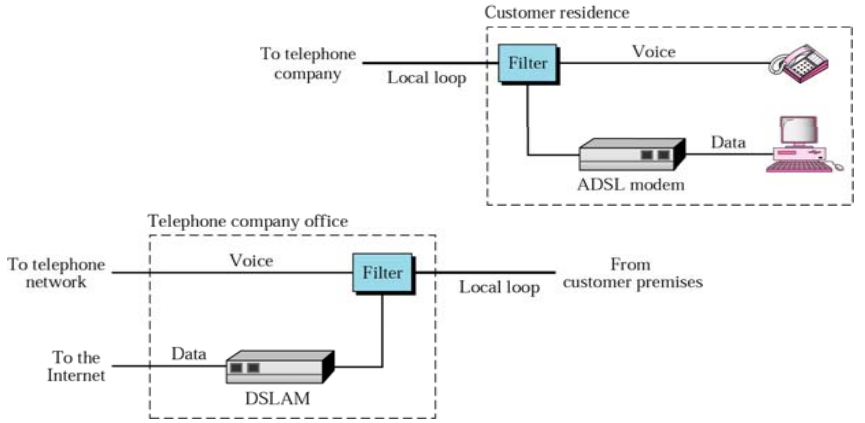
- High-speed Digital Access to Internet
- Exploit the actual bandwidth available in twisted pair cables in local loop (subscriber access lines)
  - Up to 1.1 MHz
  - Subject to strict physical limitations
    - Cable distance
    - Size of cable
    - Signaling

Asymmetrical DSL (ADSL)



- Adaptive
  - Bandwidth and data rate depends on conditions
- Lower rate in upstream direction (from subscriber)
  - For residential access
  - Upstream 64 kb/s to 1 Mb/s, Downstream 500 kb/s to 8 Mb/s
- Bandwidth (typically) divided into 4 kHz channels

ADSL Modems and DSLAMs



Digital Subscriber Line Access Multiplexer