Section outline

Signals
- Time and frequency domain
- Sampling & reconstruction of a signal
- Bandwidth and channel capacity

Media that carry content (emphasis on multimedia signals)
- Compression – audio, image, video
  - Lossless and lossy
  - Leads to burstiness
  - Layered coding → prioritisation
  - Adaptive applications
- Characteristics and requirements
  - Dealing with jitter
- Dealing with loss

Media used for transmission (Physical signals)
- Transmission impairments
- Transmission media
- Modulation
- Transmission coding
Outline

Transmission impairments
- Attenuation
- Delay distortion
- Noise
- Interference

Transmission media
- Evaluation criteria
- Guided media
  - Twisted pair
  - Coaxial cable
  - Optical fibre
- Unguided media
  - Wireless networks
  - Satellite communications
Transmission impairments

... cause the received signal to differ from the transmitted signal.

4 main types:
- Attenuation
- Distortion
  - predictable
- Noise
  - random
- Interference
Signal attenuation

Defined: Fall in signal strength as signal propagates further.

Causes:
- Absorption by medium.
  Often more severe for higher frequency components.
- Radio signal being spread over larger area (e.g. \( SA(\text{sphere}) \propto r^4 \))

Impact: Signal needs to be:
- Strong enough for detection by receiver circuitry.
- Distinguishable from noise

Solution: Amplify signal periodically.
Distortion

Different components of signal incur different transmission impairments

**Frequency distortion:** Higher frequencies may be attenuated more than lower frequencies. ⇒
- Equalisers: attenuate strong frequencies more
- Frequency-dependent dependent amplifiers

**Delay distortion:**
- **Cause:** Propagation speed depends on frequency.
- **Can cause digital signals to “spill over” into each other’s time slot**

Recall Fourier transform: square wave = superposition of cosine waves *with particular phase*
Attenuation + delay distortion

http://www.cse.ohio-state.edu/~jain/talks/ftp/netsema.pdf
Noise

Unwanted signals added to the transmitted signal as it propagates.

Thermal noise
- Temperature causes electrons to move in conductor.
- Uniformly distributed across the spectrum – “white noise”.
- Continuous / always present

Impulse noise
- Brief (e.g. ms) pulses/spikes of noise → bursty
- Caused by lightning, spark plugs, transient transmission faults, etc
Noise

Data transmitted: 0 1 0 1 1 0 0 1 1 0 0 1 0 1 0

Signal

Noise

Signal + Noise

Sampling times

Data received: 0 1 0 1 1 0 1 1 1 0 0 1 0 1 0

Original data: 0 1 0 1 1 1 0 1 1 0 0 1 0 1 0

bits in error
White noise

http://www.educatorscorner.com/index.cgi?CONTENT_ID=573
Interference

Other signals that share the communication channel may interfere with each other.

Intermodulation noise
- Signals at two frequencies may combine to produce additional signals at additional frequencies, which may interfere with existing signals at those frequencies.

Crosstalk
- Coupling between signals: Energy from one signal spreads to channel carrying another signal
- e.g. analog phone systems
Multipath interference

Multiple paths may be caused by reflection, diffraction, scattering.

The signal following the most direct path will:
- Arrive first – others may add delay distortion
- Often be the strongest, but may be obstructed ⇒ only reflected paths may reach receiver.

Whether reflected signals reinforce or annul each other depends on phasing → path length

e.g. detect FM radio deadspot when stopped @ traffic lights; roll car slightly to evade

at 2.4GHz, $\lambda = 12.5\text{cm}$
⇒ walking @ 1m/s covers $\lambda$ in 125ms
⇒ “fading” effect may last 10s of ms for mobile user.
Outline
Transmission systems

Received signal quality depends on:
- Transmission medium & associated impairments
- Transmitted signal (e.g. quality of radio signal influenced by type of antenna)

Guided media: Confine signals to a waveguide.
- Readily concentrate signal energy
- Guide signal around attenuating obstructions
- No need for spectrum licensing
- Predictable transmission path characteristics
- Need “rights of way” to deploy
Physical transmission media

Particle transfer
- Physical transport of storage systems
- Sonar
- Electronic media
  - Twisted pair
  - Coaxial cable

Wave transfer
- Guided:
  - Microwave waveguides
  - Optical fibre
- Unguided: Signals propagate in freespaces.
  - Directivity:
    - Omnidirectional/Directional
  - Wireless LANs, satellite

“Never underestimate the bandwidth of a station wagon full of tapes hurtling down the highway.” – Tanenbaum, p. 91

e.g. 112 x 4GB DVDs in car @ 50kph
= 1Gb/s over 50km in 1 hour.
Main problem here is the delay. OK for backup.
Evaluation criteria

Data rate
- Bandwidth
- Noise and interference levels (Shannon capacity)
- Span: Attenuation/km
- Spread: Number of receivers. e.g.:
  - with electrical conductors, each receiver adds capacitance, requiring more power to drive the line in the same time
  - optical signal split amongst more receivers gives less power to each.

“Duplexity”?:
- **Simplex** media allow transmission in one direction only.
- **Full duplex** media allow simultaneous bidirectional communication.
- **Half duplex** media: Bidirectional communication, but only one direction at a time.
Exponentially increasing transmission rates

Outline
Twisted pair

Pair of insulated copper wires, providing single communication line.
Individual wires act as antennas ⇒ twist pairs to reduce radiation.
Often bundle multiple pairs to form a cable.
2 varieties:
• **Unshielded Twisted Pair (UTP):** Cable wrapped in plastic sheath (as illustrated).
• **Shielded Twisted Pair (STP):** Cable wrapped in metal braid (which reduces interference) under plastic sheath. Metal braid ↑ cost and weight ⇒ rare.
UTP cables

- Usually contain 4 twisted pairs
- Popular within buildings & traditionally between telephone customer and local exchange.
- Standard connector is a RJ-45
- Wiring arrangement is standardised by EIA/TIA 568 (usually 568a; 568b sometimes used, e.g. for one end of a crossover cable, providing direct connection between 2 terminals)

RJ = Registered Jack (from when AT&T standardised these for use in the US)
Monochrome figure from Cisco. Source of colour figure unknown.
TP transmission characteristics

Twisting Frequency: $\uparrow \Rightarrow \downarrow$ crosstalk, $\uparrow$ wire needed = cost

**Category 3 UTP:** 16MHz bandwidth.
Widely deployed: Traditional phone wiring provides 4 pairs to each outlet.

**Category 5 UTP:** 100MHz bandwidth. More twists/cm.

Data rate vs distance for DSL over cat 3 UTP

![Graph](image-url)
Residential access over twisted pair

- **Dialup via modem**
  - up to 56Kbps direct access to router (often less)
  - Can’t surf and phone at same time: can’t be “always on”

- **ADSL: asymmetric digital subscriber line**
  - up to 1 Mb/s upstream (today typically < 256 kb/s)
  - up to 8 Mb/s downstream (today typically < 1 Mb/s)
  - **FDM:** 50 kHz - 1 MHz for downstream
    - 4 kHz - 50 kHz for upstream
  - 0 kHz - 4 kHz for ordinary telephone
Coaxial cable ("co-ax")

Two concentric copper conductors (coaxial), separated by insulating material.
May transmit different signals at different frequencies: Baseband + higher frequencies (broadband).

Types:
- **75Ω**: Used for television (easy to match to 300Ω antennas) ⇒ cable TV ⇒ cable modems.
- **50Ω**: Preferred for digital transmission.
"Attenuation versus frequency for coaxial cable [after Smith 1985].”
[Leon-Garcia and Widjaja, p. 153]
Outline
Electromagnetic spectrum

“Unlicensed” Industrial, Scientific and Medical (ISM) bands: 902-928MHz, 2.4-2.4835GHz, 5.735-5.86GHz
Hertz

http://www.educatorscorner.com/index.cgi?CONTENT_ID=547
Electromagnetic transmission

- Waveguides
  - Optical fibre
  - Microwave

- Freespace
  - Omnidirectional
  - Directional

Need careful alignment, but offer higher performance (focused signal concentrates energy). Adaptive beamforming antennas are complicated but automate the process.
Optical fibre

Fibre consists of:

- **Glass (silica) core**: 2 - 125µm in diameter.
- **Glass cladding**: Thicken fibre to make it less fragile. $n_{\text{cladd}} < n_{\text{core}} \Rightarrow \text{internal reflection}$
- **Plastic jacket**: Protection

Rays ("modes") of light are confined to fibre by total internal reflection

Using a thin core restricts propagation to one mode only. Such "single mode fibre" offers higher data rates/distance than multi-mode fibre (but is more expensive)

- **✗** Often need separate cable to provide power to devices.
- **✓** Immune to electromagnetic noise
- **✓** Low attenuation for wide bandwidth ...

Photo from Kurose & Ross. Fig. 2.5 and 2.7
Fibre – Attenuation in silica

approximate wavelengths of visible light

0.85µm band (cheap LEDs) 1.3µm and 1.5µm bands (lasers)

Bandwidth of tens of THz (tens of Tb/s with simple modulation)

Monochrome figure from Cisco http://www.cisco.com/univercd/illus/4/87/48087.gif
Signals on optical fibres

Form of signal: Usually just on-off modulation (c.f. frequency, phase, amplitude modulation for radio transmissions)

Generating the signal:
- Light Emitting Diode (LED)
  - Cheaper
  - Wider operating temp range
  - Last longer
- Injection Laser Diode (ILD)
  - More efficient
  - Greater data rate

Often can only modulate at up to 10Gb/s << THz fibre BW
⇒ Wavelength Division Multiplexing: Transmit independent signals at different wavelengths on one fibre.
Summary of guided media

<table>
<thead>
<tr>
<th>Transmission Medium</th>
<th>Total data rate</th>
<th>Bandwidth</th>
<th>Repeater Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twisted Pair</td>
<td>4 Mbps</td>
<td>3 MHz</td>
<td>2 – 10 km</td>
</tr>
<tr>
<td>Coaxial Cable</td>
<td>500 Mbps</td>
<td>350 MHz</td>
<td>1 – 10 km</td>
</tr>
<tr>
<td>Optical Fibre</td>
<td>2 Gbps</td>
<td>2 GHz</td>
<td>10 – 100 km</td>
</tr>
</tbody>
</table>

Note that data rate falls with distance, as signals:
- attenuate
- disperse due to frequency/delay distortion.
- accumulate more noise

Slide from Binh Thai’s TELE3018, 2002