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
  - Adaptive applications
- Characteristics and requirements
- 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 predictable
- Distortion random
- Noise
- Interference

Signal attenuation

Defined: Fall in signal strength as signal propagates further.

Causes:
- Absorption by medium
- Radio signal being spread over larger area (e.g. \(SA(\text{sphere}) = r^2\))

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

Solution: Amplify signal periodically

Amplifier
**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 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

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**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

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**Attenuation + delay distortion**

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

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**Noise**

State from Binh Thai, TE3018, 2007
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 free space.
  - 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. 112x 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)

TP transmission characteristics
Twisting Frequency: ↑⇒ ↓crosstalk,
↑ 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
Attenuation for twisted pair

\[
\text{Attenuation (dB/mi)} \times f (kHz) \\
\begin{array}{|c|c|c|c|}
\hline
\text{Gauge} & 19 & 22 & 24 & 26 \\
\hline
6 & 12 & 15 & 18 & 21 \\
\hline
12 & 24 & 27 & 30 & \\
\hline
\end{array}
\]

- Reference sample: 10dB/mi@0.1MHz (for comparison with coaxial cable)

"Attenuation versus frequency for twisted pair [after Smith 1985]." [Leon-Garcia and Widjaja, p. 149]

Residential access over twisted pair

- Dialup via modem
  - up to 56Kbps direct access to router (often less)
  - Can't surf and phone at the 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

Attenuation for coaxial cable

- 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) \(\Rightarrow\) cable TV \(\Rightarrow\) cable modems.
    - 50Ω: Preferred for digital transmission.

Outline

Electromagnetic spectrum

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.
  - \( n_{\text{cladding}} < n_{\text{core}} \) ⇒ 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...

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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.

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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 Gertz</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