Course Outline

Introduction

Digital / Analog Signals

Data Transmission
- Simplex, Half Duplex, Full Duplex
- Synchronous Transmission
- Asynchronous Transmission
- Serial / Parallel

ISO Reference Model – Layer 1
- TWP (Twisted Wire Pair)
- CoAx
- Optical Fiber
- Unguided Media

Modulation
- Analog to Digital conversion
- Digital-to-Analog converters (DAC)

Telephonic Developments
- POTS
- Dial-Up Modems, DSL, Wireless, Cable Modem
- Mobile Phones

Internet

Pure Digital Data Transmission
International Standards Organisation (ISO)
Reference Model

1. Physical
2. Data link
3. Network
4. Transport
5. Session
6. Presentation
7. Application
Purpose of each of the layers:

Layer 1: Physical Layer
Transmit bits over channel
How many volts should a 1/0 be?
Is it analog / digital signal?

Layer 2: Datalink Layer
Turn channel into reliable medium, i.e. no undetected errors - Error detection / correction
Flow control

Layer 3: Network Layer
‘Packets’ of data routed from source to destination

Layer 4: Transport Layer
Accept data from session layer, split it up into smaller units, pass to network layer

Layer 5: Session Layer

Layer 6: Presentation Layer
Encoding data in a standard format( ASCII, UNICODE, EDCDIC)

Layer 7: Application Layer
E-MAIL, Word, Excel, etc
Digital and Analog Signals

- Digital Signals

Computers generate and utilise digital signals

Signal usually a voltage, but sometimes signal might be current, light beam – Fibre optics, Radio Wave, MicroWave, IR, etc

Signal corresponds to binary number 0 / 1, On / Off, Low / High, Open / closed, etc

- Voltage = 5 volts = Binary 1
- Voltage = 0 volts = Binary 0
- Light on = Binary 1
- Light off = Binary 0
- Frequency of Radio wave = 50 Hz = Binary 0
- Frequency of Radio wave = 100 Hz = Binary 1

Graphically DC voltage signal depicted as follows:

![Graphical representation of a digital voltage signal showing high and low levels with time on the x-axis.](image)

Computer generated data – digital - can be transmitted directly over digital communications media
• Analog Signals

Analog signal continuous cycle or wave

Has two main characteristics:

• Amplitude - Height of the wave, i.e. Voltage, current

• Frequency - Number of times wave repeats itself during specific time interval, Hertz, Hz

Possible to superimpose number of analog signals together
Data Transmission

• Simplex Transmission: Unidirectional, Sends data in one direction only

Numerous applications:
  • Keyboards
  • Monitors
  • Optical Scanners
  • Some printers

• Half Duplex Transmission: Bi-directional, allows transmission in either direction but only one way at a time

  E.g. CB radio

  ![Half Duplex Diagram]

• Full Duplex Transmission: Bi-directional, allows transmission in both directions at once

  E.g. Telephone conversation

  ![Full-Duplex Diagram]
Data Transmission

Sending data works correctly provided receiving device is *Ready* to accept data

*Ready* implies that receiving device is able to ‘keep in step’ with sending device

All data comms must have some mechanism of control over flow of data

Techniques used to keep sender / receiver in step:

- Asynchronous Transmission
- Synchronous Transmission
Asynchronous Transmission – Byte of data at a time

Data grouped together into a sequence of bits (5 - 8)

Then, prefix data with a start bit, and add a stop bit at end

Transmitter/receiver agree on transfer rate, i.e. speed

Most common protocol sends 11 bits: 8 bits of data, 1 parity bit, 1 start bit and 1 stop bit

When receiver gets start signal, it accept message bits

<table>
<thead>
<tr>
<th>Start</th>
<th>D0</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>D4</th>
<th>D5</th>
<th>D6</th>
<th>D7</th>
<th>Stop</th>
</tr>
</thead>
</table>

Line (Wire) idle state = 0v
- Synchronous Transmission – Packet at a time

Start / stop bits removed, data combined into data packet

Line idle state changed to a known sequence (7E), used to synchronise receiver / sender

Data packet prefixed with header information, suffixed with trailer information that includes checksum value (used by the receiver to check for errors in sending).

Header information used to convey address information (sender and receiver), packet type and control data.

If data can't fit in a single packet, then use multiple packets and number them

Generally, fixed size

<table>
<thead>
<tr>
<th>7E 7E 7E</th>
<th>Tail</th>
<th>Data</th>
<th>Header</th>
<th>7E 7E 7E</th>
</tr>
</thead>
</table>

Data packet
Serial / Parallel

Two modes of data transfer:
  • Parallel Comm: Distances < 15 m
  • Serial Comm: Distances > 15 m

Parallel:

Number of bits of data moved simultaneously
Number of separate data lines

Many data lines

Additional wires used for control information, e.g. clock signal used to inform receiver when data is available

Additional wires may be used by receiver to inform sender that the data has been accepted, and its ready for more data – Flow Control
Serial:

One Data bit transferred at a time
Not as fast as parallel
Serial port referred to as COM1 through to COM4 on PC’s

Additional wires used for control information

Main difference between parallel and serial is speed and cost.
EBCDIC “A”
1 0 0 0 0 0 1 1

Serial Channel

Parallel Channel

1
0
0
0
0
0
1
1
Parallel Port

Often referred to as printer port

Can send number of bits of information simultaneously

Issue with parallel port is crosstalk, interference from voltage on one line with voltage on another line

Parallel connector generally has a large number of connections, e.g. 25, 36, 50

In addition to actual data lines (8 lines, 16 lines, 32 lines) some line are used to transmit information as to how data will be transmitted between two devices, i.e. control information

Parallel port referred to as LPT1 on PC’s
Transmission Speeds

- **Bandwidth**

Amount of data that can be transmitted per unit time

Related to difference between the minimum and maximum frequencies allowed

Voice channel that can transmit between 300 and 3400Hz has a bandwidth of 3100 Hz

Directly proportional to the maximum data transmission speed of the medium

Higher the bandwidth, higher the data-carrying capacity

- **Baud Rate**

Also a measure of the amount of data that can be transmitted per unit time

Can be expressed in Bits per Seconds (bps) or Bytes per second ( Bps )
ISO Reference Model – Layer 1

Data transmission using

- Guided Media
  - TWP (Twisted Wire Pair)
  - CoAx
  - Optical Fiber

- Unguided Media
  - Air
  - Vacuum
  - Sea Water

Key concerns are data rate and distance
Most common medium, very fast over short distances, < 10Mbps over 1Km

Telephone network
- Between house and local exchange (subscriber loop, local loop)

Within buildings
- To private branch exchange (PBX)

For local area networks (LAN)
- 10Mbps or 100Mbps

Advantages of TWP
- Cheap
- Easy to work with

Disadvantages of TWP
- Low data rate (10Mbps)
- Susceptible to interference and noise
- Short range:
  - Analog => Amplifiers every 5km to 6km
  - Digital => Repeater every 2Km or 3Km
Unshielded and Shielded TP

Unshielded Twisted Pair (UTP)
- Ordinary telephone wire – Cat 1
- Cheapest
- Easiest to install
- Suffers from external EM interference

Shielded Twisted Pair (STP)
- Metal braid or sheathing that reduces interference
- More expensive
- Harder to handle (thick, heavy)

Cat 3
- Up to 16MHz
- Voice grade found in most offices

Cat 4
- Up to 20 MHz

Cat 5 / Cat 5 E
- Frequencies Up to 100MHz / 1000MHz
- Speeds up to 1000 Mbps
- Commonly pre-installed in new office buildings
- More twists than Cat 3, more insulation
- 4 twisted pairs of copper wire terminated by RJ45 connectors

Cat 6, Cat 6E, Cat 7 – Full Motion Video, TeleRadiology
Co-Axial

Wire that consists of a center wire surrounded by insulation and then a grounded shield of braided wire

Primary type of cabling used by cable television industry

Widely used for computer networks

More expensive than twp, less susceptible to interference and can carry much more data

• Most versatile medium
• Television distribution
  • Ariel to TV
  • Cable TV
• Long distance telephone transmission
  • Can carry 10,000 voice calls simultaneously
  • Being replaced by fiber optic
• Short distance computer systems links
• Local area networks
• Data rates up to 500Mbps
• Analog
  
  • Amplifiers every few km
  • Closer if higher frequency
  • Up to 500MHz

• Digital
  
  • Repeater every 1km
  • Closer for higher data rates
Core diameter between 8-100µm

Core and cladding one of either glass or plastic

- Greater capacity
  - Data rates of up to 40 Gbps OC-768

- Smaller size & weight

- Lower attenuation (data loss)

- Electromagnetic isolation

- Greater repeater spacing (can carry signal further)
  - 40s of km at least

- Expensive, difficult to repair breaks
Transmission Characteristics

Semiconductor device that emits beam of light

- Light Emitting Diode (LED)
  - Cheaper
  - Wider operating temp range
  - Last longer

- Injection Laser Diode (ILD)
  - More efficient
  - Greater data rate

- Wavelength Division Multiplexing

  Many different colours (i.e. wavelengths) each carrying separate channel of data

  100 beams at 10 Gbps producing total of 1Tbps
  (1 Tera = $10^{12}$ bits / second)
Fibre Optics operate in one of three different modes:

- **Single Mode (MonoMode):** Diameter of opening very small, light travels in straight lines, no bouncing
  
  More expensive than other modes but can travel longer distances
  
  Offers the greatest information carrying capacity

- **Multimode**
   
  Wider Core
   
  a.) **Step Index:** Light reflected (bounced) along core
      
      Definite change between areas of low density and areas of high density
   
  b.) **Graded Index:** Light bent rather than bounced along core
      
      Gradual change between areas of low density and areas of high density
(a) Step-index multimode

(b) Graded-index multimode

(c) Single mode
OC-768 (Optical Carrier 768) currently fastest synchronous optical network rate of data transmission

Number is multiple of base rate bandwidth of 51.85 Mbps

OC-768 supports rates of 40 gigabits per second (Gbps) on a fiber optic carrier

Equivalent of seven CD-ROM's worth of data in one second

Uses dense wavelength division multiplexing (DWDM) to carry multiple channels of data on a single optic fiber

New DWDM systems are now in development to run at 10 trillion bits per second (10 Tbps) per fiber

Translates into theoretical capability of one fiber to support, simultaneously, active Internet connection to every household in U.S.
Wireless

- Unguided media

- Transmission and reception via antenna

- Directional
  - Focused beam
  - Careful alignment required

- Omnidirectional
  - Signal spreads in all directions
  - Can be received by many antennae
When electrons move, generate electromagnetic waves that can propagate through space

When antenna attached to electric circuit, EM waves broadcast

All EM waves travel at same speed, i.e. speed of light $3 \times 10^8$ m/sec – Ultimate speed limit, no signal can move faster than it

In Copper or fibre, speed slows to .66 of speed of light
Radio Waves - OmniDirectional

Easy to generate, can travel long distances, can penetrate buildings easily

But problem with interferences

Bluetooth
Microwave Transmission

Uses line-of-sight transmission of data signals through atmosphere

Signals cannot bend around earth, relay stations are positioned around 30 miles apart
Terrestrial Microwave

- Parabolic dish
- Focused beam
- Line of sight
- Long haul telecommunications
- Higher frequencies give higher data rates

Advantages

- Fast – 12Mbps -> 270Mbps
- Easy to implement
- Cost effective

Disadvantages

- Interference - Weather, Other signals
- Limited by line-of-sight
- Insecure
Satellites

Play key role in large number of areas:

- Global Positioning Systems (GPS)
- Emergency Radio Beacons
- Television
- Communications
- Weather prediction
- Military

Satellite basically an object that revolves around a planet.

Moon (240K miles above Earth) is Earth’s original satellite, but many many artificial satellites closer to Earth.

Satellite generally custom built, exceptions are GPS and Iridium satellites.

23,000 -> 26,000 items of space junk floating around Earth.

First satellite Sputnik launched October ‘57

- 23 inches and 184 pound metal ball
- Included radio transmitter, battery and thermometer
- Transmitted at frequency of 27MHz

After 92 days gravity took over and Sputnik burned in Earth’s atmosphere!!
Different satellites orbit at different altitudes

Orbital velocity of a satellite depends on the satellites altitude, the lower the altitude, the faster the satellite must travel, i.e. its orbital velocity

<table>
<thead>
<tr>
<th>Altitude (Miles)</th>
<th>Orbital Velocity (MPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>124</td>
<td>17K</td>
</tr>
<tr>
<td>23K (GEO)</td>
<td>7K</td>
</tr>
<tr>
<td>240K (Moon)</td>
<td>2.3K</td>
</tr>
</tbody>
</table>

Geostationary satellites orbit the earth at 23K miles, the altitude and orbital velocity permits the satellite to make one revolution in 24 hours

A satellite at 23K miles altitude stays right over the same spot all of the time – called Geostationary orbit

Earth’s circumference is 25,000 miles, each point on earth moves approx 1K mph
Inside a typical Satellite

Metal body that holds everything together - called Bus

Power source – Solar cells, batteries, fuel cells, nuclear power or some combination

On board computer

Radio system – Transmitter / receiver

Altitude control system

Satellite costs vary from $50M -> $ 500M
Satellite Microwave / Radio Waves

Satellites suspended about 22,300 miles above earth

Satellite is relay station, i.e. receives on one frequency, amplifies or repeats signal and transmits on another frequency

Requires geo-stationary orbit

Used for
- Television
- Long distance telephone
- Private business networks

Basic components of Satellite transmission are:

- Earth stations which send and receive signals
- Satellite component called a transponder

Transponder:

1. Receives transmission from earth station
   - Uplink
2. Amplifies the signal
3. Changes the frequency
4. Re-transmits the data to a receiving earth station
   - Downlink
Transmits data via very-high-frequencies (VHF) radio waves or Microwaves

<table>
<thead>
<tr>
<th>Band</th>
<th>Downlink</th>
<th>Uplink</th>
<th>Bandwidth</th>
<th>Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>1.5 GHz</td>
<td>1.6 GHz</td>
<td>15 MHz</td>
<td>Low bandwidth; crowded</td>
</tr>
<tr>
<td>S</td>
<td>1.9 GHz</td>
<td>2.2 GHz</td>
<td>70 MHz</td>
<td>Low bandwidth; crowded</td>
</tr>
<tr>
<td>C</td>
<td>4.0 GHz</td>
<td>6.0 GHz</td>
<td>500 MHz</td>
<td>Terrestrial interference</td>
</tr>
<tr>
<td>Ku</td>
<td>11 GHz</td>
<td>14 GHz</td>
<td>500 MHz</td>
<td>Rain</td>
</tr>
<tr>
<td>Ka</td>
<td>20 GHz</td>
<td>30 GHz</td>
<td>3500 MHz</td>
<td>Rain, equipment cost</td>
</tr>
</tbody>
</table>

Different altitudes, GEO, MEO, LEO
Comparing Fiber and Satellite

Single fibre more bandwidth than all satellites launched, but bandwidth not available to most users

Bandwidth possible with satellite dish

Mobile computing

Broadcasting
Hostile terrain

Laying fibre difficult and expensive

Rapid deployment
Infrared

- Modulate non-coherent infrared light
- Line of sight (or reflection)
- Blocked by walls e.g. TV remote control, IRD port
Media Selection Criteria

Factors influencing choice of a medium for data communications

<table>
<thead>
<tr>
<th>Cost</th>
<th>Security</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>Distance</td>
</tr>
<tr>
<td>Availability</td>
<td>Environment</td>
</tr>
<tr>
<td>Expandability</td>
<td>Application</td>
</tr>
<tr>
<td>Error Rates</td>
<td>Maintenance</td>
</tr>
</tbody>
</table>

- Cost

Cost of medium plus cost or additional hardware and software

Cost of future expansion
**Speed**

Tremendous range of transmission speeds available

<table>
<thead>
<tr>
<th><strong>Theoretical Throughput</strong></th>
<th><strong>Type of Service</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>28.8 kbps</td>
<td>Plain Old Telephone System (POTS)</td>
</tr>
<tr>
<td>56 kbps</td>
<td>Switched 56</td>
</tr>
<tr>
<td>640 kbps / 6 Mbps</td>
<td>Asymmetric Digital Subscriber Line (ADSL)</td>
</tr>
<tr>
<td>(upstream/downstream)</td>
<td></td>
</tr>
<tr>
<td>720 kbps</td>
<td>Bluetooth wireless PAN (2.4 GHz band)</td>
</tr>
<tr>
<td>1 and 2 Mbps</td>
<td>IEEE 802.11 wireless (2.4 GHz band)</td>
</tr>
<tr>
<td>1 Mbps</td>
<td>Cable Modem</td>
</tr>
<tr>
<td>10 Mbps</td>
<td>10Base-T Ethernet</td>
</tr>
<tr>
<td>11 Mbps</td>
<td>IEEE 802.11b wireless Wi-Fi (2.4 GHz band)</td>
</tr>
<tr>
<td>12 Mbps</td>
<td>Universal Serial Bus (USB)</td>
</tr>
<tr>
<td>20-24 Mbps</td>
<td>U-NII Wireless</td>
</tr>
<tr>
<td>25.6-155.52 Mbps</td>
<td>Asynchronous Transfer Mode (ATM)</td>
</tr>
<tr>
<td>54 Mbps</td>
<td>IEEE 802.11a wireless WLAN (5 GHz band)</td>
</tr>
<tr>
<td>54 Mbps / 11 Mbps</td>
<td>IEEE 802.11g wireless WLAN (2.4 GHz band)</td>
</tr>
<tr>
<td>80 Mbps (10 MBps)</td>
<td>Fast SCSI</td>
</tr>
<tr>
<td>100 Mbps</td>
<td>100Base-T Ethernet (Fast Ethernet)</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------</td>
<td>------------------------------</td>
</tr>
<tr>
<td>160 Mbps (20 MBps)</td>
<td>Fast Wide SCSI</td>
</tr>
<tr>
<td>160 Mbps (20 MBps)</td>
<td>Ultra SCSI</td>
</tr>
<tr>
<td>320 Mbps (40 MBps)</td>
<td>Wide Ultra SCSI</td>
</tr>
<tr>
<td>400 Mbps</td>
<td>FireWire (IEEE 1394A)</td>
</tr>
<tr>
<td>480 Mbps</td>
<td>USB 2.0</td>
</tr>
<tr>
<td>622.08 Mbps</td>
<td>OC-12/STM-4</td>
</tr>
<tr>
<td>640 Mbps (80 MBps)</td>
<td>Wide Ultra2 SCSI</td>
</tr>
<tr>
<td>800 Mbps</td>
<td>FireWire 800 (IEEE 1394B)</td>
</tr>
<tr>
<td>800 Mbps (100 MBps)</td>
<td>ATA/100 (parallel)</td>
</tr>
<tr>
<td>1 Gbps</td>
<td>Gigabit Ethernet</td>
</tr>
<tr>
<td>1.244 Gbps</td>
<td>OC-24/STM-8</td>
</tr>
<tr>
<td>1.280 Gbps (160 MBps)</td>
<td>Ultra160 SCSI</td>
</tr>
<tr>
<td>1.280 Gbps (160 MBps)</td>
<td>Ultra3 SCSI</td>
</tr>
<tr>
<td>1.5 Gbps</td>
<td>Ultra Serial ATA 1500</td>
</tr>
<tr>
<td>1.866 Gbps</td>
<td>OC-36/STM-12</td>
</tr>
<tr>
<td>2.488 Gbps</td>
<td>OC-48/STM-16</td>
</tr>
<tr>
<td>2.560 Gbps (320 MBps)</td>
<td>Ultra320 SCSI</td>
</tr>
<tr>
<td>4.976 Gbps</td>
<td>OC-96/STM-32</td>
</tr>
<tr>
<td>9.953 Gbps</td>
<td>OC-192/STM-64</td>
</tr>
<tr>
<td>10 Gbps</td>
<td>10G Ethernet (IEEE 802.3ae)</td>
</tr>
<tr>
<td>13.271 Gbps</td>
<td>OC-255</td>
</tr>
<tr>
<td>40 Gbps</td>
<td>OC-768</td>
</tr>
</tbody>
</table>
• Availability

Is the medium available when I want it??

Is there sufficient carrying capacity to handle the volume of data ??

Consider operation using switched telephone lines on a bank holiday, Mother’s Day !!!

• Expandability

Expand by adding more devices or locations

Expansion difficult and expensive with some media - leased telephone lines - but easy for other media - satellite and coaxial cables

Design networks for the future

• Error Rates

Very few errors when transmitting voice but error could be catastrophic in digital data transmission

• Security
Providing complete security is impossible

Some media are easier than others to tap into

Greater number of locations, greater the risk !!

- Environment

Local building but no wires allowed,  
Earth station not allowed,  
Humid weather

- Application

Some application very specific to speed and connection method

- Maintenance

All media subject to failure

Must consider severity of failures and probable duration

Need a contingency or backup plan
## Media Comparison Chart

<table>
<thead>
<tr>
<th></th>
<th>Wires</th>
<th>Coaxial</th>
<th>Fiber Optics</th>
<th>MicroWave</th>
<th>Satellite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good/Fair</td>
<td>Fair</td>
</tr>
<tr>
<td>Expandability</td>
<td>Fair</td>
<td>Fair</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Errors</td>
<td>Fair</td>
<td>Good</td>
<td>Good</td>
<td>Fair</td>
<td>Fair</td>
</tr>
<tr>
<td>Security</td>
<td>Fair</td>
<td>Fair</td>
<td>Good</td>
<td>Poor</td>
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<tr>
<td>Environment</td>
<td>Fair</td>
<td>Fair</td>
<td>Good</td>
<td>Fair</td>
<td>Fair</td>
</tr>
</tbody>
</table>
Modulation

Telephone lines traditionally analog media

Data communication means moving digital information from one place to another

If digital signals transmitted on analog media, square waves of digital signals distorted by analog media

Receiver unable to interpret accurately incoming signals

Solution is to **Convert Digital Signals Into Analog** using technique called Modulation

Modifying some basic analog signal in a known way in order to encode info in that basic signal

Device that changes signal at transmitter called Modulator

Device at receiver called Demodulator
Different forms of modulation:

- **Amplitude Modulation**
  
  Different wave amplitudes (i.e. wave heights) voltage levels used to represent digital data

- **Frequency Modulation**
  
  Different frequencies are used to represent digital data

- **Phase Modulation**
  
  Change the shape – phase – of waveform to represent digital data

  Phase shift can be $90^0$, $180^0$, $270^0$,

  Technique also called 'Phase Shift Keying' (PSK)

Quadrature Amplitude Modulation (QAM) allows transmission of data using both phase shift of PM and signal magnitude of AM at same time
AM and FM are terms that are used throughout telephone and radio transmission.
Analog to Digital Conversion

Pulse Code Modulation (PCM):

Idea behind PCM is divide analog signal into a number of equal sized time slots

Measure amplitude of analog signal at each instant in time, amplitude represents a value

Convert this value to a digital format - Hexadecimal

Transmit the digital value along communications channel

At the receiver, the receiver converts the digital values into corresponding heights

All heights together constitute the reconstructed analog signal
The diagram illustrates a communication channel with digital values transmitted from a sender to a receiver over time. The digital values are displayed on a timeline, indicating the sender's signal. The receiver interprets these signals, showing a graph of the received data. The digital values transmitted are 8 9 10 11 11 11 12 11...
As conversion from analog to digital and visa versa is so critical to computer operation special devices are manufactured to perform this conversion automatically

- Analog-to-Digital converters (ADC)
- Digital-to-Analog converters (DAC)

Actual conversion is performed within hardware
POTS system
Local Loop, Last Mile, analog technology

Human voice in range of 300Hz to 3.3KHz

Very costly to convert to digital technology

Modem used to convert digital data to analog data

Internet Service Provider has number of modems each connected to different local loop

Analog signals suffer from attenuation, distortion, noise and crosstalk

Discuss number of different technologies
- Dial-Up Modems
- DSL
- WireLess Local Loop
- Cable Modem
• Dial-Up Modems

Data transmission between distant computers via existing phone network

Most phone lines designed to transmit analog information - voices, while computers work in digital form – pulses

Converter between two systems needed – Modem (MOdulation / DEModulation)

Accepts serial binary pulses, modulates some property (amplitude, frequency, or phase) of analog signal in order to send signal in analog medium

Performs opposite on other side of connection

Modems come in two types:

• Internal: Fitting into slot inside PC

• External: Connected to PC via serial ports (COM1 or COM2) using RS232 standard
Various protocols used to format data to be transmitted over telephone lines

Modem standards tended to develop in haphazard way

Standards define
- Speed
- Compression
- Error control

CCITT (Comite Consultatif International Telegraphique et Telephonique) and ITU (International Telecommunications Union) ratify ‘V dot’ standards

V.22bis, V.32 and V.32bis early standards specifying speeds of 2.4Kbit/s, 9.6Kbit/s and 14.4Kbit/s respectively.

V.34 standard introduced ‘94, supporting 28.8Kbit/s, and now considered minimum acceptable standard

V.34 modems able to drop speed to communicate with slower modems

1996 standard upgraded to V.34bis, allows speeds of up to 33.6Kbit/s

To increase data rate, modems compress data and test line before transmission
Effective modem speed can be lower, equal to or higher than official rating

‘97 arrival of 56Kbit/s modem, utilising V.90 standard

Upstream channel (i.e. user to ISP) of 33.6 kbps but a downstream channel (ISP to user) of 56 kbps

More data from ISP to user than visa versa

V.92 standard

Upstream channel of 48 kbps but a downstream channel of 56 kbps
Modem Features

- **Auto-Answer**: Modem answers all incoming calls
- **Auto-Disconnect**: Modem automatically disconnects a call whenever the other parts hangs up
- **Auto-Dial**: Allows user to call another computer with a minimum of action
- **Automatic Redial**: Redial a call that resulted in a busy signal
- **Data Compression**: Send data faster
- **Time delay**: Call a computer at a future time, e.g. night time for lower telephone costs
- **Self-Testing**: Test modem for failure
- **Voice-Over**: Both data and voice can be transmitted over same communication link, not at same time
- **Compatibility**: Variety of modems exist, adherence to widely accepted standards help establish connections
• Digital Subscriber Lines (DSL)

Technology developed by telephone companies in effort to increase data throughput

Collectively called Broadband technology

Very high-speed connection that uses same wires ad regular telephone line

Advantages of DSL
  - Faster than modem (1.5Mb vs 56kbps)
  - No new wiring required
  - Use Internet and voice simultaneously

Disadvantages
  - Service not available everywhere
  - Connection works better if you are closer to central office- Distance sensitive technology
  - Connection faster for receiving data rather than sending data

Telephone systems designed for human voice, 300 Hz -> 3.3KHz

Filters in telephone systems used to cut-off all frequencies outside this range

Trick that makes DSL work is to use a different switch, one
that doesn't have these filters, thus making the full range of frequencies available to the user

Asymmetric Digital Subscriber Lines has different data rates for upstream and downstream

ADSL supports data rates from 1.5 to 9 Mbps for downstream data and from 16 to 640 Kbps for upstream data

PSTN

Network Interface device in customers house, also called
ADSL modem

Network card or USB port on customer PC required

Use sophisticated modulation schemes to pack data onto copper wires - DMT Discrete MultiTone

DMT divides up available frequencies into 256 channels, each channel having a capacity of 4kHz

System has total capacity of $256 \times 4kHz = 1.1MHz$

![Diagram of voice, upstream data, downstream data]

DSLAM = Digital Subscriber Line Access Multiplexer
rakes signals from many customers and aggregates them all onto a single line
Sometimes referred to as last-mile technologies as used only for connections from a telephone switching station to a home or office, not between switching stations.

DSL systems must:

- Work with existing cat 3 TWP
- Not affect customers existing tel / fax set-up
- Be faster than 56kbps
- Always be on - monthly charge

Allows data transmission over copper wires at far greater speed than standard POTS
• SDSL (Symmetric Digital Subscriber Line)

Supports data rates up to 3 Mbps

Works by sending digital pulses in high-frequency area of telephone wires and can not operate simultaneously with voice connections over the same wires

Requires special SDSL modem

Supports same data rates for upstream and downstream traffic
• WireLess Local Loop (Fixed Wireless)

Possible alternative to TWP local loop

Very low frequency radio waves, waves generated by system very small, very susceptible to distortion from rain, humidity, etc

Wave highly directional, clear line of sight
• Cable Modem

Modem designed to operate over cable TV lines using standard co-axial cable

As coaxial cable used by cable TV provides much greater bandwidth than telephone lines

Millions of homes already wired for cable TV

But:

Cable TV infrastructure designed to broadcast TV signals in one direction

Cable modems offer speeds up to 2 Mbps
Baseband and Broadband

* Broadband

Communication technique for transmitting voice and data over long distances at the same time

Uses high frequencies

Several pieces of data can be transmitted at the same time

* Baseband

Communication technique where digital signals are placed onto transmission line without modulation.

Cheaper than broadband, simpler cable connector

Coaxial Cable
Advantages

• High transmission rates

• Capability to add computers without interrupting existing services - Taps

• High immunity to signal distortion

• Reasonable cost over short distance

Disadvantage

• Cost
Telephonic Developments

Analog transmission dominated all communications

Historically, telephone system is based on Analog signals.

Two computers close together need to talk

Simplest thing to do is to connect a cable between two computers

Not possible when computers are a large distance apart

Overcome by using the public switched telephone network

Telephone system designed decades ago for purpose of transmitting human voice

Billions telephones in world

Possible to connect any two points via billions of possible combinations.

Reality, telephone system is organised as a Multilevel Hierarchy
Each telephone is connected to an end office (local central office, e.g. Mervue)

Area code and first three digits of a telephone number specify the End Office

Connection between the end office and the subscribers is called a Local Loop

If calling within local loop, all switching is via a direct electrical connection between the two subscribers.

If calling another End Office, each End Office has a number of lines connected to one or more Toll Offices.

If both callers on the same Toll Office, connection established within Toll Office
If callers not on same toll office, path must be established

Intermediate switching offices consist of sectional, regional and international offices

Communication lines between the switching offices is very high speed switching
Circuit Switching

Switching equipment within the telephone system seeks out the **physical** path all the way from the subscriber to the receivers.
Each box represents a carrier switching office
  • Three input calls
  • Three output calls

At switching office, physical connection established between input and output lines

Basic idea, once a call has been set-up, dedicated path exists between both ends and will continue until the call is finished
Delay in setting up the path if distance is large, i.e. time from once the number is dialed until the ringing tone is heard

Once call has been set-up, the only delay is the propagation delay of the physical medium.
Packet Switching

Original message is decomposed or broken up into a number of smaller messages or packets

No physical path is established between sender and receiver

Packets get forwarded one hop (station) at a time

Packets must be re-assembled again at the receiver station

Packet Switching networks ensure that no user can monopolise transmission line

To-day, packet switching used only for data transmission, but numerous companies try to send voice using packet switching - VOIP
Circuit Switching

- Reserves required transmission line in advance
- Any unused link is wasted
- No re-ordering is required
- Price based on distance and time only

Packet switching

- Acquires and releases transmission line as needed
- Link may be used by other packets from various sources going to various destinations
- Packets may arrive at destination out of order, original message must be ‘re-assembled ‘ at destination
- Price based on data transferred and connection fee, distance not usually matter
Mobile Phones

Three distinct generations:

1. Analog voice
2. Digital voice
3. Digital voice and data (Internet, e-mail, etc)

1. Analog voice

Improved Mobile Telephone System (IMTS) installed in ‘60’s

High power transmitter (200w) on top of hill utilising 2 frequencies, one for transmitting and one for receiving

Users could not hear one another – Half duplex - 23 channels

Adjacent systems several hundred Km apart to avoid interference

1982 Advanced Mobile Phone System (AMPS) developed by Bell Labs

Geographic region divided up into cells, 10-20km

Each cell uses some set of frequencies not used by neighbour, i.e. small cells and reuse of transmission frequencies
Smaller cell required less power (0.6w)

If congested, created smaller cells within one cell

Centre of each cell consist of base station to which all telephones in cell transmit

Base stations connected to Mobile Switching Office (MBO)

When phone physically leaves cell, base station notices the signal fading and asks all surrounding cells to notice if the telephone is in their cell

Base station then transfers ownership to cell with strongest signal

Telephone informed of new base station, switches to new frequency – Handoff 300msec channel
Handoff:
- **Soft Handoff**: No loss of continuity as new channel acquired prior to loss of old channel

  But telephone must be able to handle two frequency channels at same time

- **Hard Handoff**: Loss of continuity as new channel acquired after old channel lost

Amps uses 832 full-duplex radio wave channels

Divided into 4 groups:
1. Control (base to mobile) – manage system
2. Paging (base to mobile) – alert users to calls
3. Access (bi-directional) – call setup
4. Data (bi-directional) – voice, data fax, etc

Each telephone has 32-bit serial number and 10 digit (34 bit) telephone number

When phone turned-on, it scans control channels for most powerful signal, Phone then broadcasts serial number and telephone number

Base station hears announcement, tells MSC who records existence of new customer, informs home MSC of current location
Registers once every 15 minutes
Making call

User switches on phone, dials number and hits send

Phone transmits number and own identity on access channel

If collision occurs, retry

When base station gets request, informs MSC, who looks for idle frequency channel, idle channel number sent back to mobile phone via control channel

Mobile phone then automatically switches to selected voice channel and waits for call pickup

Getting call

Idle phone continuously listen for paging channel

When call made to mobile, packet sent to home MSC to find out where phone is physically located

Packet then sent to base station in current cell via paging channels

If phone alive and well, phone switches to indicted channel, and receives call
2. Digital Voice

D-AMPS fully digital

Works with analog MPS

Different frequency from AMPS, smaller antenna, smaller phones

Voice signal digitized and compressed by telephone

Can result in 3-6 users sharing single frequency using TDM

3. Digital Voice and data (Internet, e-mail, etc)

Uses for

- High quality voice
- Messaging
- Multimedia
- Internet access
Internet

Vast collection of different networks using common protocol and common services

Not planned by anyone and not controlled by anyone

Began in 1950, DoD wanted communication mechanism in event of attack on public telephone network
1957 Russia launched Sputnik, US furious and

US Amalgamated all defense research into Advanced Research Projects Agency (ARPA)

Connected all machines together to form ARPANET

Used 56 kbps leased telephone lines but software to run on network problem

Meeting convened and software design and implementation assigned out to graduate students

New protocol called TCP/IP designed and developed to handle communication over internetworks

System physically grew and grew, Formed backbone
POP => Point of Presence, Where ISP signals are removed from telephone system and injected into ISP own network

NAP => Network Access Point

Connection between backbones via high-bandwidth fiber optic link
Shaded area is a collection of routers, routes packets from one router to another.

Large corporations and hosting services run server farms (i.e. machines that can serve thousands of web pages per second). Often connected directly to routers on backbone for efficiency.

WWW / Web is an application that utilizes the Internet.

Application that uses HTML documents and enables the user to connect disparate parts together via hyperlink.

Developed in CERN, Switzerland by Tim Berners-Lee, who was compiling lots of documents and data.

Marc Andreessen developed a browser to view HTML documents.
Pure Digital Data Transmission

Telephone system currently analog but lower prices for digital transmission changing this situation

Advantages of digital transmission:

- Lower Error Rates

All signals loose strength the further it travels

Original Signal

Signal after loosing strength

But because digital signals are only two values it is possible to regenerate the original signal

Once restored, the signal can be forwarded to the next regeneration point or the final destination
Much harder to regenerate an analog signal

- Higher Transmission Rates

Increased transmission speed with speeds

- No Digital-Analog Conversion

Theoretically, digital transmission avoids the need for conversion between formats, reality, not yet the case

Integrated Services Digital Network (ISDN)
• Security

Possible to use a technique called Encryption to protect your digital data

Scramblers used on telephone lines

Principle similar to scramblers used in Cable TV

Possible to encrypt analog signals but digital signals have the potential for greater security