The Physical Layer

Chapter 2

- Theoretical Basis for Data Communications
- Guided Transmission Media
- Wireless Transmission
- Communication Satellites
- Digital Modulation and Multiplexing
- Public Switched Telephone Network
- Mobile Telephone System
- Cable Television

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The Physical Layer

Foundation on which other layers build

- Properties of wires, fiber, wireless limit what the network can do

Key problem is to send (digital) bits using only (analog) signals

- This is called modulation
Theoretical Basis for Data Communication

- Fourier analysis »
- Bandwidth-limited signals »
- Maximum data rate of a channel »
Fourier Analysis

• We model the behavior of variation of voltage or current with mathematical functions

• Fourier series is used

\[ g(t) = \frac{1}{2} c + \sum_{n=1}^{\infty} a_n \sin(2\pi n ft) + \sum_{n=1}^{\infty} b_n \cos(2\pi n ft) \]

• Function reconstructed with

\[ a_n = \frac{2}{T} \int_{0}^{T} g(t) \sin(2\pi n ft) \, dt \quad b_n = \frac{2}{T} \int_{0}^{T} g(t) \cos(2\pi n ft) \, dt \quad c = \frac{2}{T} \int_{0}^{T} g(t) \, dt \]
Fourier Analysis

• A time-varying signal can be equivalently represented as a series of frequency components (harmonics):

\[ g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi n ft) + \sum_{n=1}^{\infty} b_n \cos(2\pi n ft) \]

Signal over time \( \rightarrow \)  

\( \text{a, b weights of harmonics} \)
Bandwidth-Limited Signals

A binary signal and its root-mean-square Fourier amplitudes. (b) – (c) Successive approximations to the original signal.
Bandwidth-Limited Signals

- Having less bandwidth (harmonics) degrades the signal.
### Bandwidth-Limited Signals (3)

<table>
<thead>
<tr>
<th>Bps</th>
<th>T (msec)</th>
<th>First harmonic (Hz)</th>
<th># Harmonics sent</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>26.67</td>
<td>37.5</td>
<td>80</td>
</tr>
<tr>
<td>600</td>
<td>13.33</td>
<td>75</td>
<td>40</td>
</tr>
<tr>
<td>1200</td>
<td>6.67</td>
<td>150</td>
<td>20</td>
</tr>
<tr>
<td>2400</td>
<td>3.33</td>
<td>300</td>
<td>10</td>
</tr>
<tr>
<td>4800</td>
<td>1.67</td>
<td>600</td>
<td>5</td>
</tr>
<tr>
<td>9600</td>
<td>0.83</td>
<td>1200</td>
<td>2</td>
</tr>
<tr>
<td>19200</td>
<td>0.42</td>
<td>2400</td>
<td>1</td>
</tr>
<tr>
<td>38400</td>
<td>0.21</td>
<td>4800</td>
<td>0</td>
</tr>
</tbody>
</table>
Maximum Data Rate of a Channel

- Nyquist’s theorem relates the data rate to the bandwidth (B) and number of signal levels (V):
  \[
  \text{Max. data rate} = 2B \log_2 V \text{ bits/sec}
  \]

- Shannon's theorem relates the data rate to the bandwidth (B) and signal strength (S) relative to the noise (N),
  \[
  \text{Max. data rate} = B \log_2 (1 + S/N) \text{ bits/sec}
  \]

How fast signal can change
How many levels can be seen
Guided Transmission (Wires & Fiber)

Media have different properties, hence performance

– Reality check
  • Storage media »

– Wires:
  • Twisted pairs »
  • Coaxial cable »
  • Power lines »

– Fiber cables »
Reality Check: Storage media

Send data on tape / disk / DVD for a high bandwidth link

- Mail one box with 1000 800GB tapes (6400 Tbit)
- Takes one day to send (86,400 secs)
- Data rate is 70 Gbps.

Data rate is faster than long-distance networks!

But, the message delay is very poor.
Twisted Pair

(a) Category 3 UTP.
(b) Category 5 UTP.
Twisted Pairs

Twisted pair

Category 5 UTP cable with four twisted pairs
Link Terminology

Full-duplex link
- Used for transmission in both directions at once
- e.g., use different twisted pairs for each direction

Half-duplex link
- Both directions, but not at the same time
- e.g., senders take turns on a wireless channel

Simplex link
- Only one fixed direction at all times; not common
Coaxial Cable

A coaxial cable.

Copper core

Insulating material

Braided outer conductor

Protective plastic covering
Power Lines

A network that uses household electrical wiring.
Fiber Optics (1)

Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles.
Fiber Cables (1)

Common for high rates and long distances
- Long distance ISP links, Fiber-to-the-Home
- Light carried in very long, thin strand of glass

Light source (LED, laser)  \[\rightarrow\]  Light trapped by total internal reflection  \[\rightarrow\]  Photodetector
Fiber Cables (2)

Fiber has enormous bandwidth (THz) and tiny signal loss – hence high rates over long distances.
Fiber Cables (3)

**Single-mode**
- Core so narrow (10um) light can’t even bounce around
- Used with lasers for long distances, e.g., 100km

**Multi-mode**
- Other main type of fiber
- Light can bounce (50um core)
- Used with LEDs for cheaper, shorter distance links
Comparison of the properties of wires and fiber:

<table>
<thead>
<tr>
<th>Property</th>
<th>Wires</th>
<th>Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>Short (100s of m)</td>
<td>Long (tens of km)</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>Moderate</td>
<td>Very High</td>
</tr>
<tr>
<td>Cost</td>
<td>Inexpensive</td>
<td>Less cheap</td>
</tr>
<tr>
<td>Convenience</td>
<td>Easy to use</td>
<td>Less easy</td>
</tr>
<tr>
<td>Security</td>
<td>Easy to tap</td>
<td>Hard to tap</td>
</tr>
</tbody>
</table>
Fiber Optic Networks

A fiber optic ring with active repeaters.
Fiber Optic Networks (2)

A passive star connection in a fiber optics network.
Wireless Transmission

- Electromagnetic Spectrum »
- Radio Transmission »
- Microwave Transmission »
- Light Transmission »
- Wireless vs. Wires/Fiber »
Electromagnetic Spectrum (1)

Different bands have different uses:

- Radio: wide-area broadcast; Infrared/Light: line-of-sight
- Microwave: LANs and 3G/4G; Networking focus
Electromagnetic Spectrum (2)

To manage interference, spectrum is carefully divided, and its use regulated and licensed, e.g., sold at auction.

Part of the US frequency allocations


300 MHz ➔ 3 GHz ➔ 3 GHz ➔ 30 GHz ➔ 3 GHz ➔ 3 GHz ➔ 3 GHz ➔ 3 GHz

WiFi (ISM bands)
Fortunately, there are also unlicensed (“ISM”) bands:

- Free for use at low power; devices manage interference
- Widely used for networking; WiFi, Bluetooth, Zigbee, etc.
The Electromagnetic Spectrum (2)

Spread spectrum and ultra-wideband (UWB) communication
Radio Transmission

(a) In the VLF, LF, and MF bands, radio waves follow the curvature of the earth.

(b) In the HF band, they bounce off the ionosphere.
Microwave Transmission

- Microwaves have much bandwidth and are widely used indoors (WiFi) and outdoors (3G, satellites)
  - Signal is attenuated/reflected by everyday objects
  - Strength varies with mobility due to multipath fading, etc.
Light Transmission

Line-of-sight light (no fiber) can be used for links

- Light is highly directional, has much bandwidth
- Use of LEDs/cameras and lasers/photodetectors
Wireless vs. Wires/Fiber

Wireless:
+ Easy and inexpensive to deploy
+ Naturally supports mobility
+ Naturally supports broadcast
  • Transmissions interfere and must be managed
  • Signal strengths hence data rates vary greatly

Wires/Fiber:
+ Easy to engineer a fixed data rate over point-to-point links
  • Can be expensive to deploy, esp. over distances
  • Doesn’t readily support mobility or broadcast
Communication Satellites

Satellites are effective for broadcast distribution and anywhere/anytime communications

– Kinds of Satellites
– Geostationary (GEO) Satellites
– Low-Earth Orbit (LEO) Satellites
– Satellites vs. Fiber
Kinds of Satellites

Satellites and their properties vary by altitude:

- Geostationary (GEO). Medium-Earth Orbit

<table>
<thead>
<tr>
<th>Altitude (km)</th>
<th>Type</th>
<th>Latency (ms)</th>
<th>Sats needed for global coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>35,000</td>
<td>GEO</td>
<td>270</td>
<td>3</td>
</tr>
<tr>
<td>30,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20,000</td>
<td>Upper Van Allen belt</td>
<td>35–85</td>
<td>10</td>
</tr>
<tr>
<td>15,000</td>
<td>MEO</td>
<td>35–85</td>
<td>10</td>
</tr>
<tr>
<td>10,000</td>
<td></td>
<td>1–7</td>
<td>50</td>
</tr>
<tr>
<td>5,000</td>
<td>Lower Van Allen belt</td>
<td>1–7</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>LEO</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The principal satellite bands.

<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>
Geostationary Satellites

GEO satellites orbit 35,000 km above a fixed location

- VSAT (computers) can communicate with the help of a hub
- Different bands (L, S, C, Ku, Ka) in the GHz are in use but may be crowded or susceptible to rain.
(a) The Iridium satellites from six necklaces around the earth.

(b) 1628 moving cells cover the earth.
Globalstar

(a) Relaying in space.
(b) Relaying on the ground.
Satellite vs. Fiber

Satellite:

+ Can rapidly set up anywhere/anytime communications (after satellites have been launched)
+ Can broadcast to large regions
  • Limited bandwidth and interference to manage

Fiber:

+ Enormous bandwidth over long distances
  • Installation can be more expensive/difficult
Digital Modulation and Multiplexing

Modulation schemes send bits as signals; multiplexing schemes share a channel among users.

- Baseband Transmission »
- Passband Transmission »
- Frequency Division Multiplexing »
- Time Division Multiplexing »
- Code Division Multiple Access »
Baseband Transmission

Line codes: (a) Bits, (b) NRZ, (c) NRZI, (d) Manchester, (e) Bipolar or AMI.
Baseband Transmission

- Line codes send **symbols** that represent one or more bits
  - NRZ is the simplest, literal line code (+1V=“1”, -1V=“0”)
  - Other codes tradeoff bandwidth and signal transitions

Four different line codes

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Clock Recovery

• To decode the symbols, signals need sufficient transitions
  – Otherwise long runs of 0s (or 1s) are confusing, e.g.:
    
    1 0 0 0 0 0 0 0 0 0 0 0 0 um, 0? er, 0?

• Strategies:
  – Manchester coding, mixes clock signal in every symbol
  – 4B/5B maps 4 data bits to 5 coded bits with 1s and 0s:

<table>
<thead>
<tr>
<th>Data</th>
<th>Code</th>
<th>Data</th>
<th>Code</th>
<th>Data</th>
<th>Code</th>
<th>Data</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>11110</td>
<td>0100</td>
<td>01010</td>
<td>1000</td>
<td>10010</td>
<td>1100</td>
<td>11010</td>
</tr>
<tr>
<td>0001</td>
<td>01001</td>
<td>0101</td>
<td>01011</td>
<td>1001</td>
<td>10011</td>
<td>1101</td>
<td>11011</td>
</tr>
<tr>
<td>0010</td>
<td>10100</td>
<td>0110</td>
<td>01110</td>
<td>1010</td>
<td>10110</td>
<td>1110</td>
<td>11100</td>
</tr>
<tr>
<td>0011</td>
<td>10101</td>
<td>0111</td>
<td>01111</td>
<td>1011</td>
<td>10111</td>
<td>1111</td>
<td>11101</td>
</tr>
</tbody>
</table>

  – Scrambler XORs tx/rx data with pseudorandom bits
Clock Recovery

<table>
<thead>
<tr>
<th>Data (4B)</th>
<th>Codeword (5B)</th>
<th>Data (4B)</th>
<th>Codeword (5B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>11110</td>
<td>1000</td>
<td>10010</td>
</tr>
<tr>
<td>0001</td>
<td>01001</td>
<td>1001</td>
<td>10011</td>
</tr>
<tr>
<td>0010</td>
<td>10100</td>
<td>1010</td>
<td>10110</td>
</tr>
<tr>
<td>0011</td>
<td>10101</td>
<td>1011</td>
<td>10111</td>
</tr>
<tr>
<td>0100</td>
<td>01010</td>
<td>1100</td>
<td>11010</td>
</tr>
<tr>
<td>0101</td>
<td>01011</td>
<td>1101</td>
<td>11011</td>
</tr>
<tr>
<td>0110</td>
<td>01110</td>
<td>1110</td>
<td>11100</td>
</tr>
<tr>
<td>0111</td>
<td>01111</td>
<td>1111</td>
<td>11101</td>
</tr>
</tbody>
</table>

4B/5B mapping.
Passband Transmission (1)

Modulating the amplitude, frequency/phase of a carrier signal sends bits in a (non-zero) frequency range.

- NRZ signal of bits
- Amplitude shift keying
- Frequency shift keying
- Phase shift keying
Passband Transmission (2)

(a) QPSK. (b) QAM-16. (c) QAM-64.
Gray-coding assigns bits to symbols so that small symbol errors cause few bit errors:

When 1101 is sent:

<table>
<thead>
<tr>
<th>Point</th>
<th>Decodes as</th>
<th>Bit errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1101</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>1100</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>1001</td>
<td>1</td>
</tr>
<tr>
<td>D</td>
<td>1111</td>
<td>1</td>
</tr>
<tr>
<td>E</td>
<td>0101</td>
<td>1</td>
</tr>
</tbody>
</table>
Modems (3)

(a) V.32 for 9600 bps.

(b) V32 bis for 14,400 bps.
Frequency Division Multiplexing (1)

Gray-coded QAM-16.
Frequency Division Multiplexing (2)

Frequency division multiplexing. (a) The original bandwidths. (b) The bandwidths raised in frequency. (c) The multiplexed channel.
Frequency Division Multiplexing (3)

Orthogonal frequency division multiplexing (OFDM).
Time Division Multiplexing (TDM)

Time division multiplexing shares a channel over time:

- Users take turns on a fixed schedule; this is not packet switching or STDM (Statistical TDM)
- Widely used in telephone / cellular systems
Code Division Multiple Access (CDMA)

CDMA shares the channel by giving users a code
- Codes are orthogonal; can be sent at the same time
- Widely used as part of 3G networks

\[
A = \begin{pmatrix} +1 \\ -1 \\ +1 \\ -1 \end{pmatrix}
\]

\[
B = \begin{pmatrix} +1 \\ +1 \\ -1 \\ -1 \end{pmatrix}
\]

\[
C = \begin{pmatrix} +1 \\ -1 \\ -1 \\ +1 \end{pmatrix}
\]

\[
S = A + B
\]

\[
S = A - B
\]

\[
S = +A - B
\]

\[
S \times A = +2 +2
\]

\[
S \times B = -2 -2
\]

\[
S \times C = +2
\]

**Sender Codes**

**Transmitted Signal**

**Receiver Decoding**

\[
S \times A = +2 +2
\]

Sum = 4
A sent “1”

\[
S \times B = -2 -2
\]

Sum = -4
B sent “0”

\[
S \times C = +2
\]

Sum = 0
C didn’t send
Code Division Multiplexing (1)

(a) Chip sequences for four stations.
(b) Signals the sequences represent

\[ A = (-1 -1 -1 +1 +1 -1 +1 +1) \]
\[ B = (-1 -1 +1 -1 +1 +1 -1 +1) \]
\[ C = (-1 +1 -1 +1 +1 +1 -1 -1) \]
\[ D = (-1 +1 -1 -1 -1 +1 -1 -1) \]
Code Division Multiplexing (2)

(a) Six examples of transmissions.
(b) Recovery of station C’s

| $S_1$ = C $=$ | $(-1 +1 -1 +1 +1 +1 -1 -1)$ | $S_1 \cdot C = [1+1-1+1+1+1-1-1]/8 = 1$ |
| $S_2$ = B+C $=$ | $(-2 0 0 0 +2 +2 0 -2)$ | $S_2 \cdot C = [2+0+0+0+2+2+0+2]/8 = 1$ |
| $S_3$ = A+B $=$ | $(0 0 -2 +2 0 -2 0 +2)$ | $S_3 \cdot C = [0+0+2+2+0-2+0+2]/8 = 0$ |
| $S_4$ = A+B+C $=$ | $(-1 +1 -3 +3 +1 -1 -1 +1)$ | $S_4 \cdot C = [1+1+3+3+1-1-1-1]/8 = 1$ |
| $S_5$ = A+B+C+D $=$ | $(-4 0 -2 0 +2 0 +2 -2)$ | $S_5 \cdot C = [4+0+2+0+2+0-2+2]/8 = 1$ |
| $S_6$ = A+B+C+D $=$ | $(-2 -2 0 -2 0 -2 +4 0)$ | $S_6 \cdot C = [2-2+0-2+0-2-4+0]/8 = -1$ |
Public Switched Telephone System

- Structure of the Telephone System
- The Politics of Telephones
- The Local Loop: Modems, ADSL and Wireless
- Trunks and Multiplexing
- Switching
Structure of the Telephone System

(a) Fully-interconnected network.
(b) Centralized switch.
(c) Two-level hierarchy.
A hierarchical system for carrying voice calls made of:

- Local loops, mostly analog twisted pairs to houses
- Trunks, digital fiber optic links that carry calls
- Switching offices, that move calls among trunks
The Politics of Telephones

• In the U.S., there is a distinction for competition between serving a local area (LECs) and connecting to a local area (at a POP) to switch calls across areas (IXCs)
  – Customers of a LEC can dial via any IXC they choose
The relationship of LATAs, LECs, and IXCs. All the circles are LEC switching offices. Each hexagon belongs to the IXC whose number is on it.
Major Components of the Telephone System

• Local loops
  ▪ Analog twisted pairs going to houses and businesses

• Trunks
  ▪ Digital fiber optics connecting the switching offices

• Switching offices
  ▪ Where calls are moved from one trunk to another
Local loop (2): Digital Subscriber Lines

DSL broadband sends data over the local loop to the local office using frequencies that are not used for POTS

- Telephone/computers attach to the same old phone line
- Rates vary with line
  - ADSL2 up to 12 Mbps
- OFDM is used up to 1.1 MHz for ADSL2
  - Most bandwidth down
Local loop (3): Fiber To The Home

FTTH broadband relies on deployment of fiber optic cables to provide high data rates for customers.

- One wavelength can be shared among many houses.
- Fiber is passive (no amplifiers, etc.)
The Local Loop: Modems, ADSL, and Wireless

The use of both analog and digital transmissions for a computer to computer call. Conversion is done by the modems and codecs.
Digital Subscriber Lines

![Graph showing bandwidth versus distance for DSL over category 3 UTP.](CN5E by Tanenbaum & Wetherall, © Pearson Education-Prentice Hall and D. Wetherall, 2011)
Digital Subscriber Lines (2)

Operation of ADSL using discrete multitone

256 4-kHz Channels

Voice 25 Upstream 1100 kHz Downstream

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Digital Subscriber Lines (3)

- Voice switch
- Codec
- Splitter
- Telephone line
- To ISP
- DSLAM
- Customer premises
- NID
- ADSL modem
- Ethernet
- Computer
- Telephone
- Splitter
Wireless Local Loops

Architecture of an LMDS system.
Fiber To The Home

Passive optical network for Fiber To The Home.
Calls are carried digitally on PSTN trunks using TDM

- A call is an 8-bit PCM sample each 125 μs (64 kbps)
- Traditional T1 carrier has 24 call channels each 125 μs (1.544 Mbps) with symbols based on AMI
Time Division Multiplexing (2)

Consecutive samples always differ by ±1

Signal changed too rapidly for encoding to keep up

Digitization levels

Sampling interval

Time

Bit stream sent
Time Division Multiplexing (3)

Multiplexing T1 streams into higher carriers.

4 T1 streams in

1 T2 stream out

7 T2 streams in

6 T3 streams in

1.544 Mbps

6.312 Mbps

44.736 Mbps

274.176 Mbps

T1

T2

T3

T4
Time Division Multiplexing (4)

3 Columns for overhead

87 Columns

9 Rows

Sonet frame (125 μsec)

Sonet frame (125 μsec)

Section overhead  Line overhead  Path overhead  SPE
## Time Division Multiplexing (5)

<table>
<thead>
<tr>
<th>SONET</th>
<th>SDH</th>
<th>Data rate (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical</td>
<td>Optical</td>
<td>Gross</td>
</tr>
<tr>
<td>STS-1</td>
<td>OC-1</td>
<td>51.84</td>
</tr>
<tr>
<td>STS-3</td>
<td>OC-3</td>
<td>155.52</td>
</tr>
<tr>
<td>STS-9</td>
<td>OC-9</td>
<td>466.56</td>
</tr>
<tr>
<td>STS-12</td>
<td>OC-12</td>
<td>622.08</td>
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<td>STS-18</td>
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<td>STS-24</td>
<td>OC-24</td>
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<td>STS-48</td>
<td>OC-48</td>
<td>2488.32</td>
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<tr>
<td>STS-192</td>
<td>OC-192</td>
<td>9953.28</td>
</tr>
</tbody>
</table>
Wavelength Division Multiplexing

Fiber 1 spectrum

Fiber 2 spectrum

Fiber 3 spectrum

Fiber 4 spectrum

Spectrum on the shared fiber

Fiber 1 $\lambda_1$

Fiber 2 $\lambda_2$

Fiber 3 $\lambda_3$

Fiber 4 $\lambda_4$

Combiner

$\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4$

Splitter

Long-haul shared fiber

Filter

$\lambda_1$

$\lambda_2$

$\lambda_3$

$\lambda_4$
Switching (1)

- PSTN uses circuit switching: Internet uses packet switching
Switching (2)

Circuit switching requires call setup (connection) before data flows smoothly
- Also teardown at end (not shown)

Packet switching treats messages independently
- No setup, but variable queuing delay at routers
Message Switching

(a) Circuit switching  (b) Message switching  (c) Packet switching
# Packet Switching

## Comparison of Circuit-switched and Packet-switched Networks

<table>
<thead>
<tr>
<th>Item</th>
<th>Circuit-switched</th>
<th>Packet-switched</th>
</tr>
</thead>
<tbody>
<tr>
<td>Call setup</td>
<td>Required</td>
<td>Not needed</td>
</tr>
<tr>
<td>Dedicated physical path</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Each packet follows the same route</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Packets arrive in order</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Is a switch crash fatal</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Bandwidth available</td>
<td>Fixed</td>
<td>Dynamic</td>
</tr>
<tr>
<td>When can congestion occur</td>
<td>At setup time</td>
<td>On every packet</td>
</tr>
<tr>
<td>Potentially wasted bandwidth</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Store-and-forward transmission</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Transparency</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Charging</td>
<td>Per minute</td>
<td>Per packet</td>
</tr>
</tbody>
</table>

A comparison of circuit switched and packet-switched networks.
Mobile Telephone System

- Generations of mobile telephone systems
- Cellular mobile telephone systems
- GSM, a 2G system
- UMTS, a 3G system
Generations of mobile telephone systems

1G, analog voice
  • AMPS (Advanced Mobile Phone System) is example, deployed from 1980s. Modulation based on FM (as in radio).

2G, analog voice and digital data
  • GSM (Global System for Mobile communications) is example, deployed from 1990s. Modulation based on QPSK.

3G, digital voice and data
  • UMTS (Universal Mobile Telecommunications System) is example, deployed from 2000s. Modulation based on CDMA

4G, digital data including voice
  • LTE (Long Term Evolution) is example, deployed from 2010s. Modulation based on OFDM
Cellular mobile phone systems

All based on notion of spatial regions called cells

- Each mobile uses a frequency in a cell; moves cause handoff
- Frequencies are reused across non-adjacent cells
- To support more mobiles, smaller cells can be used
Channel Categories

The 832 channels are divided into four categories:

- **Control (base to mobile)** to manage the system
- **Paging (base to mobile)** to alert users to calls for them
- **Access (bidirectional)** for call setup and channel assignment
- **Data (bidirectional)** for voice, fax, or data
D-AMPS
Digital Advanced Mobile Phone System

(a) A D-AMPS channel with three users.
(b) A D-AMPS channel with six users.
GSM – Global System for Mobile Communications (1)

- Mobile is divided into handset and SIM card (Subscriber Identity Module) with credentials
- Mobiles tell their HLR (Home Location Register) their current whereabouts for incoming calls
- Cells keep track of visiting mobiles (in the Visitor LR)
GSM – Global System for Mobile Communications (2)

Air interface is based on FDM channels of 200 KHz divided in an eight-slot TDM frame every 4.615 ms

- Mobile is assigned up- and down-stream slots to use
- Each slot is 148 bits long, gives rate of 27.4 kbps
GSM (2)

32,500-Bit multiframe sent in 120 msec

1250-Bit TDM frame sent in 4.615 msec

148-Bit data frame sent in 547 μsec

Reserved for future use

8.25-bit (30 μsec) guard time

Voice/data bit
UMTS – Universal Mobile Telecommunications System (1)

Architecture is an evolution of GSM; terminology differs
Packets goes to/from the Internet via SGSN/GGSN
CDMA – Code Division Multiple Access

(a) Binary chip sequences for four stations

(b) Bipolar chip sequences

(c) Six examples of transmissions

(d) Recovery of station C’s signal
Third-Generation Mobile Phones: Digital Voice and Data

Basic services an IMT-2000 network should provide

• High-quality voice transmission
• Messaging (replace e-mail, fax, SMS, chat, etc.)
• Multimedia (music, videos, films, TV, etc.)
• Internet access (web surfing, w/multimedia.)
Digital Voice and Data (2)

Soft handoff (a) before, (b) during, and (c) after.
Cable Television

- Internet over cable »
- Spectrum allocation »
- Cable modems »
- ADSL vs. cable »
Community Antenna Television

An early cable television system.

- **Antenna** for picking up distant signals
- **Headend**
- **Drop cable**
- **Tap**
- **Coaxial cable**
Internet over Cable

Internet over cable reuses the cable television plant

- Data is sent on the shared cable tree from the head-end, not on a dedicated line per subscriber (DSL)
Spectrum Allocation

Upstream and downstream data are allocated to frequency channels not used for TV.
Cable Modems

Cable modems at customer premises implement the physical layer of the DOCSIS standard

- QPSK/QAM is used in timeslots on frequencies that are assigned for upstream/downstream data
Cable vs. ADSL

Cable:

+ Uses coaxial cable to customers (good bandwidth)
  • Data is broadcast to all customers (less secure)
  • Bandwidth is shared over customers so may vary

ADSL:

+ Bandwidth is dedicated for each customer
+ Point-to-point link does not broadcast data
• Uses twisted pair to customers (lower bandwidth)
End

Chapter 2