Introduction to Physical Layer
Physical Layer Outline

- Definitions
- Multiplexing
- Transmission Media
- End System Choices
- Residential Configurations
The time required to transmit a character depends on both the encoding method and the signaling speed (i.e., the modulation rate - the number of times/sec the signal changes its voltage).

- **baud** (D) - the number of changes per second.

- **bandwidth** (H) - the range of frequencies that is passed by a channel. The transmitted signal is constrained by the transmitter and the nature of the transmission medium in cycles/sec (hertz).

- **channel capacity** (C) - the rate at which data can be transmitted over a given channel under given conditions.  
  
  (This is also referred to as data rate (R).)
Modulation Rate

Figure 5.5 A Stream of Binary Ones at 1 Mbps

modulation rate is doubled
signals: electric or electromagnetic encoding of data.

signaling: is the act of propagating the signal along a suitable medium.

Analog signal - a continuously varying electromagnetic wave that may be propagated over a variety of medium depending on the spectrum (e.g., wire, twisted pair, coaxial cable, fiber optic cable and atmosphere or space propagation).
digital signal – a sequence of voltage pulses that may be transmitted over a wire medium.

Note – analog signals to represent analog data and digital signals to represent digital data are not the only possibilities.

There is where modems and codecs come into the picture.
# Analog vs Digital (three contexts)

## (a) Data and signals

<table>
<thead>
<tr>
<th>Analog data</th>
<th>Digital data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two alternatives: (1) signal occupies the same spectrum as the analog data; (2) analog data are encoded to occupy a different portion of spectrum.</td>
<td>Analog data are encoded using a codec to produce a digital bit stream.</td>
</tr>
<tr>
<td>Digital data are encoded using a modem to produce analog signal.</td>
<td>Two alternatives: (1) signal consists of two voltage levels to represent the two binary values; (2) digital data are encoded to produce a digital signal with desired properties.</td>
</tr>
</tbody>
</table>

## (b) Treatment of signals

<table>
<thead>
<tr>
<th>Analog signal</th>
<th>Digital signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is propagated through amplifiers; same treatment whether signal is used to represent analog data or digital data.</td>
<td>Assumes that the analog signal represents digital data. Signal is propagated through repeaters; at each repeater, digital data are recovered from inbound signal and used to generate a new analog outbound signal.</td>
</tr>
<tr>
<td>Not used</td>
<td>Digital signal represents a stream of 1s and 0s, which may represent digital data or may be an encoding of analog data. Signal is propagated through repeaters; at each repeater, stream of 1s and 0s is recovered from inbound signal and used to generate a new digital outbound signal.</td>
</tr>
</tbody>
</table>
Multiplexing {general definition} :: Sharing a resource over time.

(a) 

(b) 

MUX 

Trunk group 

Leon-Garcia & Widjaja: Communication Networks
Frequency Division Multiplexing (FDM) vs Time Division Multiplexing (TDM)

Example:
4 users

K & R
Figure 2-31. (a) The original bandwidths. (b) The bandwidths raised in frequency. (c) The multiplexed channel.

Tanenbaum
T1 - TDM Link

TDM: each host gets a **fixed** slot in revolving TDM frame

**Figure 2-33. T1 Carrier (1.544Mbps)**

Tanenbaum
Concentrator [Statistical Multiplexing]

In statistical multiplexing, the multiplexer visits the incoming channel buffers in some order. The multiplexer empties a buffer before moving to the next one. The buffer contents are tagged to indicate their incoming channel. An idle channel does not waste transmission time.
Packet Switching: Statistical Multiplexing

Sequence of A & B packets does **NOT** have fixed pattern, bandwidth shared on demand \( \Rightarrow \text{statistical multiplexing.} \)
Wavelength Division Multiplexing

Figure 2-32.
Physical Media: Twisted Pair

- **Bit**: propagates between transmitter/receiver pairs.
- **physical link**: what lies between transmitter & receiver.
- **guided media**:
  - signals propagate in solid media: copper, fiber, coax.
- **unguided media**:
  - signals propagate freely, e.g., radio.

Unshielded Twisted Pair (UTP)

- two insulated copper wires
  - Category 3: traditional phone wires, 10 Mbps Ethernet
  - Category 5:
    100Mbps Ethernet

Category 5e is now standard!!
Grade 1 - Unshielded Untwisted wiring.  
Commonly called inside wire by the Telco community.

Grade 2 - Unshielded twisted pair (UTP) derived from IBM Type 3 spec.

Category 3 - Unshielded twisted pair with 100 ohm impedance and electrical characteristics supporting transmission at frequencies up to 16 MHz. May be used with 10Base-T, 100Base-T4, and 100Base-T2 Ethernet. (Obsolete)

Category 4 - Unshielded twisted pair with 100 ohm impedance and electrical characteristics supporting transmission at frequencies up to 20 MHz. May be used with 10Base-T, 100Base-T4, and 100Base-T2 Ethernet. (Obsolete)

Category 5 - Unshielded twisted pair with 100 ohm impedance and electrical characteristics supporting transmission at frequencies up to 100 MHz. May be used with 10Base-T, 100Base-T4, 100Base-T2, and 100Base-TX Ethernet. May support 1000Base-T, but cable should be tested. (Superceded by Cat5e)
# "Modern" Twisted Pair

## Table 4.2 Twisted Pair Categories and Classes

<table>
<thead>
<tr>
<th></th>
<th>Category 5e Class D</th>
<th>Category 6 Class E</th>
<th>Category 6A Class E&lt;sub&gt;A&lt;/sub&gt;</th>
<th>Category 7 Class F</th>
<th>Category 7&lt;sub&gt;A&lt;/sub&gt; Class F&lt;sub&gt;A&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bandwidth</strong></td>
<td>100 MHz</td>
<td>250 MHz</td>
<td>500 MHz</td>
<td>600 MHz</td>
<td>1,000 MHz</td>
</tr>
<tr>
<td><strong>Cable Type</strong></td>
<td>UTP</td>
<td>UTP/FTP</td>
<td>UTP/FTP</td>
<td>S/FTP</td>
<td>S/FTP</td>
</tr>
<tr>
<td><strong>Insertion loss (dB)</strong></td>
<td>24</td>
<td>21.3</td>
<td>20.9</td>
<td>20.8</td>
<td>20.3</td>
</tr>
<tr>
<td><strong>NEXT loss (dB)</strong></td>
<td>30.1</td>
<td>39.9</td>
<td>39.9</td>
<td>62.9</td>
<td>65</td>
</tr>
<tr>
<td><strong>ACR (dB)</strong></td>
<td>6.1</td>
<td>18.6</td>
<td>19</td>
<td>42.1</td>
<td>44.1</td>
</tr>
</tbody>
</table>

UTP = Unshielded twisted pair  
FTP = Foil twisted pair  
S/FTP = Shielded/foil twisted pair
Physical Media: Coaxial Cable and Optical Fiber

Coaxial cable:
- two concentric copper conductors
- bidirectional
- baseband:
  - single channel on cable
  - legacy Ethernet
- broadband:
  - multiple channels on cable
  - HFC

Fiber optic cable:
- glass fiber carrying light pulses, each pulse a bit
- high-speed operation:
  - point-to-point transmission (e.g., 10's-100's Gps)
- low error rate: repeaters spaced far apart; immune to electromagnetic noise.
Physical Media: Radio Signals

- signal carried in electromagnetic spectrum.
- no physical "wire"
- bidirectional

**propagation environment effects:**
  - reflection
  - obstruction by objects
  - interference

**Radio link types:**

- terrestrial microwave
  - e.g. up to 45 Mbps channels
- **LAN (e.g., Wifi)**
  - 11Mbps, 54 Mbps, 200Mbps
- **wide-area (e.g., cellular)**
  - 4G cellular: ~ 100 Mbps
- **satellite**
  - Kbps to 45Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus low altitude
Dial-up Modem

- Uses existing telephony infrastructure.
- Home is connected to central office (analog signals).
- up to 56Kbps direct access to router (often less)
- Can’t surf and phone at same time: not “always on”.

![Diagram of dial-up modem setup](image-url)
Digital Subscriber Line (ADSL)

- Uses existing telephone infrastructure.
- up to 1 Mbps upstream (today typically < 256 kbps)
- up to 8 Mbps downstream (today typically < 1 Mbps)
- dedicated physical line to telephone central office

Existing phone line:
- 0-4KHz phone; 4-50KHz upstream data; 50KHz-1MHz downstream data

Asymmetric DSL
## Comparison of xDSL Alternatives

<table>
<thead>
<tr>
<th></th>
<th>ADSL</th>
<th>HDSL</th>
<th>SDSL</th>
<th>VDSL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data rate</strong></td>
<td>1.5 to 9 Mbps downstream</td>
<td>1.544 or 2.048 Mbps</td>
<td>1.544 or 2.048 Mbps</td>
<td>13 to 52 Mbps downstream</td>
</tr>
<tr>
<td></td>
<td>16 to 640 kbps upstream</td>
<td></td>
<td></td>
<td>1.5 to 2.3 Mbps upstream</td>
</tr>
<tr>
<td><strong>Mode</strong></td>
<td>Asymmetric</td>
<td>Symmetric</td>
<td>Symmetric</td>
<td>Asymmetric</td>
</tr>
<tr>
<td><strong>Copper pairs</strong></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Range (24-gauge UTP)</strong></td>
<td>3.7 to 5.5 km</td>
<td>3.7 km</td>
<td>3.0 km</td>
<td>1.4 km</td>
</tr>
<tr>
<td><strong>Signaling</strong></td>
<td>Analog</td>
<td>Digital</td>
<td>Digital</td>
<td>Analog</td>
</tr>
<tr>
<td><strong>Line code</strong></td>
<td>CAP/DMT</td>
<td>2B1Q</td>
<td>2B1Q</td>
<td>DMT</td>
</tr>
<tr>
<td><strong>Frequency</strong></td>
<td>1 to 5 MHz</td>
<td>196 kHz</td>
<td>196 kHz</td>
<td>≥ 10 MHz</td>
</tr>
<tr>
<td><strong>Bits/cycle</strong></td>
<td>Varies</td>
<td>4</td>
<td>4</td>
<td>Varies</td>
</tr>
</tbody>
</table>
VDSL

1.4 Km twisted pair limit
Residential Access: Cable Modems

- Does not use telephone infrastructure
  - Instead uses cable TV infrastructure.
- **HFC: hybrid fiber coax**
  - asymmetric: up to 40Mbps downstream, 6 Mbps upstream
- **network** of cable and fiber attaches homes to ISP router:
  - homes *share access* to router
  - unlike DSL, which has *dedicated access.*
Residential Access: Cable Modems

Diagram: http://www.cabledat.comnews.com/cmic/diagram.html
Cable Network Architecture: Overview

Typically 500 to 5,000 homes
Cable Network Architecture: Overview

- Cable Headend
- Cable Distribution Network
- Server(s)
- Home
Cable Network Architecture: Overview

Cable headend

Cable distribution network (simplified)

Home Environment

Set-Top Box

Coax

Splitter

Coax

10 Mbps Ethernet

PC

Cable Modem

TV
Cable Network Architecture: Overview

FDM

channels

V V V V
I I I I
D D D D
E E E E
O O O O
A A A A
C C C C

1 2 3 4 5 6 7 8 9

Cable headend

Cable distribution network

Home
DOCSIS (Data-Over-Cable Service Interface Specification)

Cisco DOCSIS 3.0 Solution

- uBR100012 CMTS
- <15K Subs/Hub
  - RFGW 1 EQAM
  - Up to 48 QAM Channels
- >15K Subs/Hub
  - RFGW 10 EQAM
  - > 480 QAM Channels

DPC3000 DOCSIS 3.0 Cable Modem
(4 channels)

DPC3202 eMTA
(4 channels)

Figure 4. M-CMTS and DOCSIS 3.0 Downstream Channel Bonding
FDM over upstream, downstream frequency channels

- multiple 40Mbps downstream (broadcast) channels (6MHz)
  - single CMTS transmits into channels and received by all modem receivers.
- Multiple 30 Mbps upstream channels (6.4MHz)
- TDM-like upstream mini-slots
Fiber to the Home

- Optical links from central office to the home
- Two competing optical technologies:
  - Passive Optical network (PON)
  - Active Optical Network (AON)
- Higher Internet rates. Fiber also carries television and phone services.
AON  Active Optical Network
- Uses electrical powered switches
- More range
- Less reliable

PON  Passive Optical Network
- Optical splitters do not need electrical power.
- Hard to isolate failure
- Transmission speed may be slower during peak hours.
Typically used in companies, universities, etc
- 10 Mbs, 100Mbps, 1Gbps, 10Gbps Ethernet
- Today, end systems typically connect into Ethernet switch.
Wireless Access Networks

- Shared **wireless** access network connects end system to router
  - via base station aka “access point”.
- **Wireless LANs:**
  - 802.11b/g/n (WiFi): 11, 54, 200 Mbps
- **Wider-area Wireless Access**
  - provided by telco operator
  - ~1Mbps over cellular system (EVDO, HSDPA) 3G and 4G LTE
  - next up (?): WiMAX (10’s Mbps) over wide area
Residential Networks

Typical Residential Network Components:
- DSL or cable modem
- router/firewall/NAT
- Ethernet
- wireless access point (AP)
Physical Layer Summary

- Definitions (analog versus digital)
- Multiplexing (FDM, TDM, statistical)
- Transmission Media (UTP, Coax, Fiber, Radio, Satellite)
- End System Choices (Dial-Up, ADSL, Cable, Ethernet, Wireless AP, Fiber-to-the Home)
- Residential Configurations