CMPE 150 – Winter 2009

Lecture 5

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CMPE 150 -- Introduction to Computer Networks

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  http://www.soe.ucsc.edu/classes/cmpe150/Winter09/
- Text: Tannenbaum: Computer Networks  
  (4th edition – available in bookstore, etc.)
# Syllabus

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Today’s Agenda

- Physical Layer
  - Finish tour of Data Communications

- Link Layer
  - Signaling / Timing
  - Encoding
  - Error detection
  - Error correction
Topics / terms

- Full duplex, half duplex, simplex
- Local (subscriber) loop vs. trunk (backbone)
  - Alternatives to local / subscriber loop
    (WiMax – 802.16)
- Multiplexing (TDM, FDM)
- FDM via modulation on a carrier
- Baseband (no modulation)
- Baud vs. bps
Frequency Division Multiplexing

- (a) The original bandwidths.
- (b) The bandwidths raised in frequency.
- (b) The multiplexed channel.
Fig 2-28  ADSL with multi-tone channels
Cable TV Spectrum Allocation
Wavelength Division Multiplexing

- division multiplexing.
Time Division Multiplexing

The T1 carrier (1.544 Mbps).
Time Division Multiplexing (2)

- Delta modulation.
Time Division Multiplexing (3)

- Multiplexing T1 streams into higher carriers.

Diagram showing the process of multiplexing T1 streams into higher carriers.
Time Division Multiplexing (4)

Two back-to-back SONET frames.
Time Division Multiplexing (4)

<table>
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<th>Optical</th>
<th>SDH</th>
<th>Data rate (Mbps)</th>
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<td>Gross</td>
<td>SPE</td>
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<td>50.112</td>
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<td>OC-192</td>
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- SONET and SDH multiplex rates.
Spread Spectrum

- Frequency Hopping
- Direct Sequence
(a) Transmitter
(b) Receiver
Circuit Switching

- (a) Circuit switching.
- (b) Packet switching.
Message Switching

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

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

- First-Generation Mobile Phones: Analog Voice
- Second-Generation Mobile Phones: Digital Voice
- Third-Generation Mobile Phones: Digital Voice and Data
(a) Frequencies are not reused in adjacent cells.
(b) To add more users, smaller cells can be used.
Channel Categories

The 832 channels are divided into four categories:

1. Control (base to mobile) to manage the system
2. Paging (base to mobile) to alert users to calls for them
3. Access (bidirectional) for call setup and channel assignment
4. 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

GSM uses 124 frequency channels, each of which uses an eight-slot TDM system.
• A portion of the GSM framing structure.

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

Bits  3  57  26  57  3
Voice/data bit
**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

|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|A:  | 0  | 0  | 0  | 1  | 1  | 0  | 1  | 1  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|B:  | 0  | 0  | 1  | 0  | 1  | 1  | 1  | 0  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|C:  | 0  | 1  | 0  | 1  | 1  | 1  | 0  | 0  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|D:  | 0  | 1  | 0  | 0  | 0  | 0  | 1  | 0  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

(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.)
Cable Television

- Community Antenna Television
- Internet over Cable
- Spectrum Allocation
- Cable Modems
- ADSL versus Cable
Community Antenna Television

- An early cable television system.
Internet over Cable

- Cable television
Internet over POTS

The fixed telephone system.
Spectrum Allocation

- Frequency allocation in a typical cable TV system used for Internet access.
Cable Modems

- Typical details of the upstream and downstream channels in North America.

![Diagram showing upstream and downstream channels with Coaxial cable, Fiber, Head-end, ISP, Modem, Downstream and Upstream channels with specifications for traffic.]
Link Layer

Chapter 3 of Tannenbaum Text
Terms / Definitions

- **Term**
- Data Element
  
  *(a single binary “1”, “0”)*
- Data Rate
  
  *(rate data elements get transmitted)*
- Signal Element
  
  *(part of signal that occupies shortest interval of signaling code)*
- Signaling or Modulation rate
  
  *(rate signal elements are transmitted)*

- **Units**
- Bit
  
  *Bits/second (bps)*
- Digital: a voltage pulse of constant amplitude
- Analog: a pulse of constant freq., amp. or phase
- Baud (signal elements / sec.)
Terms

- **Unipolar**
  - All signal elements have same sign

- **Polar**
  - One logic state represented by positive voltage
    - the other by negative voltage

- **Data rate**
  - Rate of data transmission in bits per second

- **Duration or length of a bit**
  - Time taken for transmitter to emit the bit
Terms

- **Modulation rate**
  - Rate at which the signal level changes
  - Measured in baud = signal elements per second

- **Mark and Space**
  - Binary 1 and Binary 0 respectively
Interpreting Signals

- Need to know
  - Timing of bits - when they start and end
  - Signal levels

- Factors affecting successful interpreting of signals
  - Signal to noise ratio (S/N or SNR)
  - Data rate
  - Bandwidth
Comparison of Encoding Schemes

• **Signal Spectrum**
  – Lack of high frequencies reduces required bandwidth
  – Lack of dc component allows ac coupling via transformer, providing isolation
  – Concentrate power in the middle of the bandwidth

• **Clocking**
  – Synchronizing transmitter and receiver
  – External clock vs.
  – Sync mechanism based on signal
Comparison of Encoding Schemes

- Error detection
  - Can be built in to signal encoding

- Signal interference and noise immunity
  - Some codes are better than others

- Cost and complexity
  - Higher signal rate (& thus data rate) lead to higher costs
  - Some codes require signal rate greater than data rate
Encoding Schemes

- Nonreturn to Zero-Level (NRZ-L)
- Nonreturn to Zero Inverted (NRZI)
- Bipolar -AMI
- Pseudoternary
- Manchester
- Differential Manchester
- B8ZS
- HDB3
Spectrum

Mean square voltage per unit bandwidth

Normalized Frequency

LEGEND
AMI = Alternate mark inversion
B8ZS = Bipolar with 8 zeros substitution
f = Frequency
HDB3 = High-density bipolar—3 zeros
NRZL-L = Nonreturn to zero level
NRZI = Nonreturn to zero inverted
R = Data rate

Stallings Fig. 5.3
Nonreturn to Zero-Level (NRZ-L)

- Two different voltages for 0 and 1 bits
- Voltage constant during bit interval
  - no transition i.e. no return to zero voltage
- e.g. Absence of voltage for zero, constant positive voltage for one
- More often, negative voltage for one value and positive for the other
- This is NRZ-L
Nonreturn to Zero Inverted

• Nonreturn to zero inverted on ones
• Constant voltage pulse for duration of bit
• Data encoded as presence or absence of signal transition at beginning of bit time
• Transition (low to high or high to low) denotes a binary 1
• No transition denotes binary 0
• An example of differential encoding
NRZ

NRZ-L

NRZI

Ref: Stallings, Fig. 5.2

NRZI used by USB
Differential Encoding

• Data represented by changes rather than levels
• More reliable detection of transition rather than level
• In complex transmission layouts it is easy to lose sense of polarity
NRZ pros and cons

• Pros
  – Easy to engineer
  – Make good use of bandwidth

• Cons
  – dc component
  – Lack of synchronization capability

• Used for magnetic recording
• Not often used for signal transmission
Multilevel Binary

• Use more than two levels

• Bipolar-AMI
  – zero represented by no line signal
  – one represented by positive or negative pulse
  – one pulses alternate in polarity
  – No loss of sync if a long string of ones (zeros still a problem)
  – No net dc component
  – Lower bandwidth
  – Easy error detection
Pseudoternary

- One represented by absence of line signal
- Zero represented by alternating positive and negative
- No advantage or disadvantage over bipolar-AMI
Bipolar-AMI and Pseudoternary

Bipolar-AMI
(most recent preceding 1 bit has negative voltage)

Pseudoternary
(most recent preceding 0 bit has negative voltage)

Ref: Stallings, Fig. 5.2
Trade Off for Multilevel Binary

• Not as efficient as NRZ
  – Each signal element only represents one bit
  – In a 3 level system could represent \( \log_2 3 = 1.58 \) bits
  – Receiver must distinguish between three levels (+A, -A, 0)
  – Requires approx. 3dB more signal power for same probability of bit error
Biphase

• Manchester
  – Transition in middle of each bit period
  – Transition serves as clock and data
  – Low to high represents one
  – High to low represents zero
  – Used by IEEE 802.3

• Differential Manchester
  – Midbit transition is clocking only
  – Transition at start of a bit period represents zero
  – No transition at start of a bit period represents one
  – Note: this is a differential encoding scheme
  – Used by IEEE 802.5
Manchester Encoding

Manchester Encoding

bit sent

signal

baseline

time interval(s)
Differential Manchester Encoding

Differential Manchester Encoding

- bit sent
- signal
- baseline
- time interval(s)
Biphase Pros and Cons

• Con
  – At least one transition per bit time and possibly two
  – Maximum modulation rate is twice NRZ
  – Requires more bandwidth

• Pros
  – Synchronization on mid bit transition (self clocking)
  – No dc component
  – Error detection
    • Absence of expected transition
Modulation Rate

NRZI

1 bit = 1 μsec
1 signal element = 1 μsec

Manchester

1 bit = 1 μsec
1 signal element = 0.5 μsec

5 bits = 5 μsec

Ref: Stallings, Fig. 5.5
Scrambling

• Use scrambling to replace sequences that would produce constant voltage

• Filling sequence
  – Must produce enough transitions to sync
  – Must be recognized by receiver and replace with original
  – Same length as original

• No dc component

• No long sequences of zero level line signal

• No reduction in data rate

• Error detection capability
B8ZS

• Bipolar With 8 Zeros Substitution
• Based on bipolar-AMI
• If octet of all zeros and last voltage pulse preceding was positive encode as 000+-0+-
• If octet of all zeros and last voltage pulse preceding was negative encode as 000+-0+-
• Causes two violations of AMI code
• Unlikely to occur as a result of noise
• Receiver detects and interprets as octet of all zeros
HDB3

- High Density Bipolar 3 Zeros
- Based on bipolar-AMI
- String of four zeros replaced with one or two pulses
Internet Layering

Level 5 -- Application Layer
   (rlogin, ftp, SMTP, POP3, IMAP, HTTP..)

Level 4 -- Transport Layer (a.k.a. Host-to-Host)
   (TCP, UDP, ARP, ICMP, etc.)

Level 3 -- Network Layer (a.k.a. Internet) (IP)

Level 2 -- (Data) Link Layer / MAC sub-layer
   (a.k.a. Network Interface or Network Access Layer)

Level 1 -- Physical Layer
Data Link Layer Design Issues

- Services Provided to the Network Layer
- Framing
- Error Control
- Flow Control
Functions of the Data Link Layer

- Provide service interface to the network layer
- Dealing with transmission errors
- Regulating data flow
  - Slow receivers not swamped by fast senders
Functions of the Data Link Layer (2)

• Relationship between packets and frames.

Ref: Tannenbaum, Fig. 3-1
Services Provided to Network Layer

- (a) Virtual communication.
- (b) Actual communication.

Ref: Tannenbaum, Fig. 3-2
Services Provided to Network Layer (2)

Placement of the data link protocol.

Ref: Tannenbaum, Fig. 3-3
Framing

- A character stream.  (a) Without errors.  
(b) With one error.

Ref: Tannenbaum, Fig. 3-4
Framing (2)

(a) A frame delimited by flag bytes.

(b) Four examples of byte sequences before and after stuffing.

Ref: Tannenbaum, Fig. 3-5
Framing (3)

(a) 011011111111111111110010

(b) 0110111110111111011111010010

(c) 011011111111111111110010

Bit stuffing

- (a) The original data.
- (b) The data as they appear on the line.
- (c) The data as they are stored in receiver’s memory after destuffing.

Ref: Tannenbaum, Fig. 3-6
Error Detection and Correction

- Error-Correcting Codes
- Error-Detecting Codes
Hamming Distance

Hamming distance one
def

four
Hamming Distance
(2-D for error correction)

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E
Error-Correcting Codes

Use of a Hamming code to correct burst errors.

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<td>11111001100</td>
</tr>
<tr>
<td>e</td>
<td>1100101</td>
<td>00111000101</td>
</tr>
</tbody>
</table>

Ref: Tannenbaum, Fig. 3-7

Order of bit transmission