The Link Layer and LANs

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Audio/Video recordings of this lecture are available on-line at:
http://www.cse.wustl.edu/~jain/cse473-11/
1. Datalink Services
2. Error Detection
3. Multiple Access
4. Bridging
5. Point-to-Point Protocol and MPLS

Note: This class lecture is based on Chapter 5 of the textbook (Kurose and Ross) and the figures provided by the authors.
Link Layer Services

- Link = One hop
- Framing: Bit patterns at begin/end of a frame
- Multiple Access: Multiple users sharing a wire
- Flow Control
- Error Detection/Correction
- Reliable Delivery:
- Duplex Operation
Line Duplexity

- Simplex: Transmit or receive, e.g., Television

- Full Duplex: Transmit and receive simultaneously, e.g., Telephone

- Half-Duplex: Transmit and receive alternately, e.g., Police Radio
Overview

Error Detection

- Parity Checks
- Check Digit Method
- Modulo 2 Arithmetic
- Cyclic Redundancy Check (CRC)
- Popular CRC Polynomials
Parity Checks

Odd Parity

Even Parity

1-bit error

3-bit error

2-bit error
Two Dimensional Parity

- Detect and correct single bit errors

\[
\begin{array}{cccccc}
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
\downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \\
\text{column} & \text{parity} & & & & \\
\hline
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \\
\text{row} & \text{parity} & & & & \\
\hline
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \\
\text{diagram:} & & & & & \\
\begin{array}{cc}
101011 & 101011 \\
111100 & 101100 \\
011101 & 011011 \\
001010 & 001010 \\
\text{no errors} & \text{parity error} \\
\text{correctable single bit error}
\end{array}
\end{array}
\]
Check Digit Method

- Make number divisible by 9

**Example**: 823 is to be sent

1. Left-shift: 8230
2. Divide by 9, find remainder: 4
3. Subtract remainder from 9: 9-4=5
4. Add the result of step 3 to step 1: 8235
5. Check that the result is divisible by 9.

Detects all single-digit errors: **7235**, **8335**, **8255**, **8237**
Detects several multiple-digit errors: **8765**, **7346**
Does not detect some errors: **7335**, **8775**, ...
Modulo 2 Arithmetic

\[
\begin{array}{c c c}
1111 & 11001 & 110 \\
+1010 & \times 11 & 11 | 1010 \\
\hline \\
0101 & 11001 & 010 2 \\
11001 & x11 & 011 3 \\
\hline \\
101011 & 001 1 \text{ Mod 2} \\
x00 & 101 5 \text{ Binary} \\
\hline \\
x0 & \\
\end{array}
\]
Cyclic Redundancy Check (CRC)

- **Binary Check Digit Method**
- Make number divisible by $P=110101$ (n+1=6 bits)

**Example:** $M=1010001101$ is to be sent

1. Left-shift $M$ by $n$ bits $2^nM = 101000110100000$
2. Divide $2^nM$ by $P$, find remainder: $R=01110$
3. Subtract remainder from $P$ ← Not required in Mod 2
4. Add the result of step 2 to step 1: $T=101000110101110$
5. Check that the result $T$ is divisible by $P$. 
**Modulo 2 Division**

\[ Q = 1101010110 \]
\[ P = 110101 \times 1010001101000000 = 2^n M \]

\[
\begin{array}{c}
110101 \\
111011 \\
110101 \\
011101 \\
000000 \\
110100 \\
110101 \\
011111 \\
000000 \\
111110 \\
110101
\end{array}
\]

\[
\begin{array}{c}
010110 \\
000000 \\
101100 \\
110101 \\
110010 \\
110101 \\
001110 \\
000000 \\
01110 = R
\end{array}
\]
Checking At The Receiver

\[
\begin{array}{c}
1101010110 \\
110101)101000110101110110 \\
110101 \\
111011 \\
110101 \\
011101 \\
000000 \\
111010 \\
110101 \\
011111 \\
000000 \\
111110 \\
110101 \\
\end{array}
\]
1. Parity bits can help detect/correct errors
2. Remainder obtained by diving by a prime number provides good error detection
3. CRC uses mod 2 division
Homework 5A

- Find the CRC of 1001100 using a generator 1011. Use mod 2 division. Show all steps.
Review Exercises

- Do not submit
- R2
- P1, P2, P5, P6, P7
- Read Sections 5.1-5.2 (Pages 441-455)
Overview

Ethernet and ARP

1. Multiple Access
2. CSMA/CD
3. IEEE 802.3 CSMA/CD
4. Ethernet Standards
5. CSMA/CD Performance
6. Distance-B/W Principle
7. Ethernet vs. Fast Ethernet
8. IEEE 802 Address Format
9. Address Resolution Protocol
Multiple Access

- How multiple users can share a link?
- Time Division Multiplexing

```
<table>
<thead>
<tr>
<th>Frequency</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8</td>
<td>1 2 3 4 5 6 7 8</td>
</tr>
</tbody>
</table>
```

- Frequency Division Multiplexing

```
<table>
<thead>
<tr>
<th>Frequency</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8</td>
<td>1 2 3 4 5 6 7 8</td>
</tr>
</tbody>
</table>
```
CSMA/CD

- Aloha at Univ of Hawaii:
  Transmit whenever you like
  Worst case utilization = 1/(2e) = 18%
- Slotted Aloha: Fixed size transmission slots
  Worst case utilization = 1/e = 37%
- CSMA: Carrier Sense Multiple Access
  Listen before you transmit
- p-Persistent CSMA: If idle, transmit with probability p. Delay by one time unit with probability 1-p
- CSMA/CD: CSMA with Collision Detection
  Listen while transmitting. Stop if you hear someone else
IEEE 802.3 CSMA/CD

- If the medium is idle, transmit (1-persistent).
- If the medium is busy, wait until idle and then transmit immediately.
- If a collision is detected while transmitting,
  - Transmit a jam signal for one slot
    (= 51.2 µs = 64 byte times)
  - Wait for a random time and reattempt (up to 16 times)
  - Random time = Uniform[0,2^{\min(k,10)}-1] slots
- Collision detected by monitoring the voltage
  High voltage ⇒ two or more transmitters ⇒ Collision
  ⇒ Length of the cable is limited to 2 km
IEEE 802.3 CSMA/CD Flow Chart

Start

Counter ← 0

Wait Backoff

Counter > 16?

Yes → Abort

No → Counter++

Medium Idle?

Yes → Start Transmission

No → Wait 1 Slot

Jam

Yes → Collision During Transmission?

No → Done

No → Start Transmission
CSMA/CD Operation

- Collision window = 2 × One-way Propagation delay = 51.2 μs

One way delay = 25.6 μs
Max Distance < 2.5 km
IEEE 802 Address Format

- **Multicast** = “To all bridges on this LAN”
- **Broadcast** = “To all stations”

<table>
<thead>
<tr>
<th>Organizationally Unique Identifier (OUI)</th>
<th>24 bits assigned by OUI Owner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual/Group</td>
<td>Universal/Local</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

- Multicast = “To all bridges on this LAN”
- Broadcast = “To all stations”

= 11111111...111 = FF:FF:FF:FF:FF:FF:FF
Bridges

LAN A

Station 1
Station 2
Station 10
Bridge

F addresses 11 through 20 are accepted and repeated on LAN B

LAN B

Station 11
Station 12
Station 20

F addresses 1 through 10 are accepted and repeated on LAN A
Bridge: Functions

- Monitor all frames on LAN A
- Pickup frames that are for stations on the other side
- Retransmit the frames on the other side
- Knows or learns about stations are on various sides
  - Learns by looking at source addresses ⇒ Self-learning
- Makes no modification to content of the frames.
  - May change headers.
- Provides storage for frames to be forwarded
- Improves reliability (less nodes per LAN)
- Improves performance (more bandwidth per node)
- Security (Keeps different traffic from entering a LAN)
- May provide flow and congestion control
Interconnection Devices

- **Repeater**: PHY device that restores data and collision signals
- **Hub**: Multiport repeater + fault detection, notification and signal broadcast
- **Bridge**: Datalink layer device connecting two or more collision domains
- **Router**: Network layer device (does not propagate MAC multicasts)
Address Resolution Protocol

- Problem: Given an IP address find the MAC address
- Solution: Address resolution protocol
- The host broadcasts a request:
  “What is the MAC address of 127.123.115.08?”
- The host whose IP address is 127.123.115.08 replies back:
  “The MAC address for 127.123.115.08 is 8A-5F-3C-23-45-56_{16}”
- A router may act as a proxy for many IP addresses
Ethernet and ARP: Review

1. CSMA/CD = Listen while transmitting and stop on collision
2. IEEE 802.3 uses a *truncated binary exponential backoff*.
3. Ethernet uses 48-bit addresses of which the first bit is the unicast/multicast, 2nd bit is universal/local, 22-bits are OUI (Organizationally unique identifier).
4. Address Resolution Protocol (ARP) is used to find the MAC address for a given IP address and vice versa.
Review Exercises

- Do not submit
- Review questions R1-R4, R8-R12
- Problems: P14-P23, P25-P27, P28, P29-P32
  (Skip Problems P8-P13, P24)
- Read Sections 5.3-5-4 (Pages 469-486)
Submit answer to the Problem 18:

Suppose nodes A and B are on the same 10 Mbps Ethernet bus, and the propagation delay between the two nodes is 325 bit times. Suppose node A begins transmitting a frame and, before it finishes, node B begins transmitting a frame. Can A finish transmitting before it detects that B has transmitted? Why or why not? In the worst case when does B’s signal reach A? (Minimum frame size is 512+64 bits).
1. Virtual LAN
2. PPP
3. Multiprotocol Label Switching (MPLS)
What is a LAN?

- LAN = Single broadcast domain = Subnet
- No routing between members of a LAN
- Routing required between LANs
What is a Virtual LAN

- Physical View
  - Users
  - Switches
  - Servers
  - Switches

- Logical View
  - Marketing LAN
  - Engineering LAN
  - Manufacturing LAN
  - Router

Routers
Virtual LAN

- Virtual LAN = Broadcasts and multicast goes only to the nodes in the virtual LAN
- LAN membership defined by the network manager ⇒ Virtual
VLAN: Why?

- Virtual is Better than Real
  - Location-independent
    - Marketing LAN can be all over the building
  - Users can move but not change LAN
  - Traffic between LANs is routed
    - Better to keep all traffic on one LAN
  - Switch when you can, route when you must
    - Do not VLAN over expensive WAN links
  - Better security
Types of Virtual LANs

- Layer-1 VLAN = Group of Physical ports
- Layer-2 VLAN = Group of MAC addresses
- Layer-3 VLAN = IP subnet

<table>
<thead>
<tr>
<th>Switch Port</th>
<th>VLAN 1</th>
<th>VLAN 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>A2</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>A3</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>B2</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

VLAN1

- A1B234565600
- D34578923434
- 1345678903333
- 3438473450555
- 4387434304343
- 4780357056135
- 4153953470641
- 3473436374133
- 3403847333412
- 348343433143
- 4343134134234

VLAN2

- 21B234565600
- 634578923434
- 8345678903333
- 9438473450555
- 5387434304343
- 6780357056135
- 9153953470641
- 4073436374133
- 8403847333412
- 483434343143
- 0343134134234

VLAN1: 23.45.6
VLAN2: IPX
PPP: Introduction

- Point-to-point Protocol
- Originally for User-network connection
- Now being used for router-router connection
- Three Components: Data encapsulation, Link Control Protocol (LCP), Network Control Protocols (NCP)
PPP (Cont)

- Typical connection setup:
  - Home PC Modem calls Internet Provider's router: sets up physical link
  - PC sends Link Control Protocol (LCP) packets
    + Select PPP (data link) parameters. Authenticate.
  - PC sends Network Control Protocol (NCP) packets
    + Select network parameters, E.g., Get IP address
- Transfer IP packets
PPP Design Requirements [RFC 1557]

- **Packet Framing**: Bit stream to frames
- **Protocol Multiplexing**: carry any network layer protocol (not just IP) at same time
- **Bit Transparency**: must carry any bit pattern in data
- **Error Detection**: (no correction)
- **Connection Liveness**: Signal link failures
- **Network Layer Address Negotiation**: Endpoints can learn/configure each other’s network address

**Non-Goals**:
- No error correction/recovery
- No flow control
- Out of order delivery OK
- No need to support multipoint links (e.g., polling)
# PPP in HDLC-Like Framing

<table>
<thead>
<tr>
<th>Flag</th>
<th>Address</th>
<th>Control</th>
<th>Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>01111110</td>
<td>11111111</td>
<td>00000011</td>
<td></td>
</tr>
</tbody>
</table>

(Broadcast)

<table>
<thead>
<tr>
<th>Info</th>
<th>Padding</th>
<th>CRC</th>
<th>Flag</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>01111110</td>
</tr>
</tbody>
</table>

- Flag = 0111 1110 = 7E
- Byte Stuffing: 7E \(\Rightarrow\) 7D 5E
  
  7D \(\Rightarrow\) 7D 5D

- **Byte stuffing method indicated in the textbook is incorrect.**
- Address=FF \(\Rightarrow\) All stations. Control=03 \(\Rightarrow\) Unnumbered
- 16-bit CRC default. 32-bit CRC can be negotiated using LCP.
Multiprotocol Label Switching (MPLS)

- Allows virtual circuits in IP Networks (May 1996)
- Each packet has a virtual circuit number called ‘label’
- Label determines the packet’s queuing and forwarding
- Circuits are called Label Switched Paths (LSPs)
- LSP’s have to be set up before use
- Allows traffic engineering
Label Switching Example

Ethernet Header | IP Header | Payload

Ethernet Header | Label | IP Header | Payload

A

B

R1

R2

R3

C

Ethernet Header

IP Header

Payload

64

3

5

<64>

<3>

<5>

<5>

<2>

5

3

2

5-42
1. Virtual LANs allow hosts to be moved to different broadcast domains (subnets).
2. Point-to-Point protocol (PPP) is used for link and network layer configuration and framing.
3. Multiprotocol Label Switching (MPLS) allows label-switched paths (LSPs) in IP networks.
Summary

1. CRC uses mod-2 division using polynomial representation for binary numbers
2. IEEE 802.3 uses a *truncated binary exponential backoff*.
3. Address Resolution Protocol (ARP) is used to find the MAC address for a given IP address and vice versa.
4. PPP is used for configuration and framing on point-to-point links
5. MPLS allows virtual circuits (LSPs) on IP networks.
Review Exercises

- Do not submit.
- Try the following textbook problems: R15, R16, P35-P36
- Read Sections 5.6-5.8 (Pages 486-504)
Submit answer to Problem P35:

Consider the MPLS network shown in Figure 5.36 and the labels described on page 503. Suppose that routers R5 and R6 are now MPLS enabled. Suppose that we want to perform traffic engineering so that packets from R6 destined for A are switched to A via R6-R4-R3-R1 and packets from R5 destined for A are switched via R5-R4-R2-R1. Show the MPLS tables in R5 and R6 as well as the modified table in R4 that would make this possible.