Data Link Protocols

- Directly connected, wire-like
- Losses & errors, but no out-of-sequence frames
- Applications: Direct Links; LANs; Connections across WANs

Data Links Services
- Framing
- Error control
- Flow control
- Multiplexing
- Link Maintenance
- Security: Authentication & Encryption

Examples
- PPP
- HDLC
- Ethernet LAN
- IEEE 802.11 (Wi-Fi) LAN

5.4 Framing

- Mapping stream of physical layer bits into frames
- Mapping frames into bit stream
- Frame boundaries can be determined using:
  - Character Counts
  - Control Characters
  - Flags
  - CRC Checks
Character-Oriented Framing

Data to be sent

A DLE B ETX DLE STX E

After stuffing and framing

DLE STX A DLE DLE B ETX DLE DLE STX E DLE E

- Frames consist of integer number of bytes
  - Using ASCII to transmit printable characters
  - Octets with HEX value <20 are nonprintable
- Special 8-bit patterns used as control characters
  - STX (start of text) = 0x02; ETX (end of text) = 0x03;
- Byte used to carry non-printable characters in frame
  - DLE (data link escape) = 0x10
  - DLE STX (DLE ETX) used to indicate beginning (end) of frame
  - Insert extra DLE in front of occurrence of DLE STX (DLE ETX) in frame
  - All DLEs occur in pairs except at frame boundaries

Framing & Bit Stuffing

HDLC frame

<table>
<thead>
<tr>
<th>Flag</th>
<th>Address</th>
<th>Control</th>
<th>Information</th>
<th>FCS</th>
<th>Flag</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>any number of bits</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Frame delineated by flag character
- HDLC uses bit stuffing to prevent occurrence of flag 01111110 inside the frame
- Transmitter inserts extra 0 after each consecutive five 1s inside the frame
- Receiver checks for five consecutive 1s
  - if next bit = 0, it is removed
  - if next two bits are 10, then flag is detected
  - If next two bits are 11, then frame has errors
Example: Bit stuffing & de-stuffing

(a) Data to be sent
011011111111100

After stuffing and framing
011111100110111110111100001111110

(b) Data received
011111110000111011111011111011001111110

After destuffing and deframing
*000111011111-11111-110*

Byte-Stuffing in PPP

- PPP is character-oriented version of HDLC
- Flag is 0x7E (01111110)
- Control escape 0x7D (01111101)
- Any occurrence of flag or control escape inside of frame is replaced with 0x7D followed by original octet XORed with 0x20 (00100000)

Data to be sent

<table>
<thead>
<tr>
<th>41</th>
<th>7D</th>
<th>42</th>
<th>7E</th>
<th>50</th>
<th>70</th>
<th>46</th>
</tr>
</thead>
</table>

After stuffing and framing

| 7E | 41 | 7D | 5D | 42 | 7D | 5E | 50 | 70 | 46 | 7E |
Byte-Stuffing in PPP

- 7D \rightarrow 7D 5D 7E \rightarrow 7D 5E
- Problems with PPP byte stuffing
  - Size of frame varies unpredictably due to byte insertion
  - Malicious users can inflate bandwidth by inserting 7D & 7E

<table>
<thead>
<tr>
<th>PLI</th>
<th>cHEC</th>
<th>Type</th>
<th>tHEC</th>
<th>GEH</th>
<th>GFP payload</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload length indicator</td>
<td>Core header error checking</td>
<td>Payload type</td>
<td>Type header error checking</td>
<td>GFP extension headers</td>
<td>GFP payload</td>
</tr>
</tbody>
</table>

- GFP combines frame length indication with CRC
  - PLI indicated length of frame, then simply count characters
  - cHEC (CRC-16) protects against errors in count field (single-bit error correction + error detection)
- GFP designed to operate over octet-synchronous physical layers (e.g. SONET)
5.5 PPP: Point-to-Point Protocol

- Data link protocol for point-to-point lines in Internet
  - Router-router; dial-up to router
1. Provides *Framing and Error Detection*
  - Character-oriented HDLC-like frame structure
2. *Link Control Protocol*
  - Bringing up, testing, bringing down lines; negotiating options
  - **Authentication**: key capability in ISP access
3. A family of *Network Control Protocols* specific to different network layer protocols
  - IP, OSI network layer, IPX (Novell), Appletalk

**PPP Applications**

PPP used in many point-to-point applications
- Telephone Modem Links 30 kbps
- Packet over SONET 600 Mbps to 10 Gbps
  - IP→PPP→SONET

- PPP is also used over shared links such as Ethernet to provide LCP, NCP, and authentication features
  - PPP over Ethernet (RFC 2516)
  - Used over DSL
PPP can support multiple network protocols simultaneously
• Specifies what kind of packet is contained in the payload
  • e.g. LCP, NCP, IP, OSI CLNP, IPX...

PPP Frame Format

<table>
<thead>
<tr>
<th>Flag</th>
<th>Address</th>
<th>Control</th>
<th>Protocol</th>
<th>Information</th>
<th>FCS</th>
<th>Flag</th>
</tr>
</thead>
<tbody>
<tr>
<td>01111110</td>
<td>1111111</td>
<td>00000011</td>
<td>01111110 01111110 1111111 00000011</td>
<td>variable</td>
<td>2 or 4</td>
<td>01111110</td>
</tr>
</tbody>
</table>

All stations are to accept the frame
HDLC Unnumbered frame
CRC 16 or CRC 32

PPP Authentication

• Password Authentication Protocol
  – Initiator must send ID & password
  – Authenticator replies with authentication success/fail
  – After several attempts, LCP closes link
  – Transmitted unencrypted, susceptible to eavesdropping

• Challenge-Handshake Authentication Protocol (CHAP)
  – Initiator & authenticator share a secret key
  – Authenticator sends a challenge (random # & ID)
  – Initiator computes cryptographic checksum of random # & ID using the shared secret key
  – Authenticator also calculates cryptographic checksum & compares to response
  – Authenticator can reissue challenge during session
5.6 High-Level Data Link Control (HDLC)

- Bit-oriented data link control
- Derived from IBM Synchronous Data Link Control (SDLC)
- Related to Link Access Procedure Balanced (LAPB)
  - LAPD in ISDN
  - LAPM in cellular telephone signaling

HDLC Data Transfer Modes

- Normal Response Mode
  - Used in polling multidrop lines

- Asynchronous Balanced Mode
  - Used in full-duplex point-to-point links
HDLC Frame Format

- Control field gives HDLC its functionality
- Codes in fields have specific meanings and uses
  - Flag: delineate frame boundaries
  - Address: identify secondary station (1 or more octets)
  - Control: purpose & functions of frame (1 or 2 octets)
  - Information: contains user data; length not standardized, but implementations impose maximum
  - Frame Check Sequence: 16- or 32-bit CRC

Control Field Format

<table>
<thead>
<tr>
<th>Information Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>N(S)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Supervisory Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unnumbered Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
</tbody>
</table>

- S: Supervisory Function Bits
- N(R): Receive Sequence Number
- N(S): Send Sequence Number
- M: Unnumbered Function Bits
- P/F: Poll/final bit used in interaction between primary and secondary
Information frames

• Each I-frame contains sequence number N(S)
• Positive ACK piggybacked
  – N(R)=Sequence number of next frame expected
    acknowledges all frames up to and including N(R)-1
• 3 or 7 bit sequence numbering
  – Maximum window sizes 7 or 127
• Poll/Final Bit
  – NRM: Primary polls station by setting P=1;
    Secondary sets F=1 in last I-frame in response
  – Primaries and secondaries always interact via paired
    P/F bits

Supervisory frames

Used for error (ACK, NAK) and flow control (Don’t Send):

• Receive Ready (RR), SS=00
  – ACKs frames up to N(R)-1 when piggyback not available
• REJECT (REJ), SS=01
  – Negative ACK indicating N(R) is first frame not received
    correctly. Transmitter must resend N(R) and later frames
• Receive Not Ready (RNR), SS=10
  – ACKs frame N(R)-1 & requests that no more I-frames be
    sent
• Selective REJECT (SREJ), SS=11
  – Negative ACK for N(R) requesting that N(R) be selectively
    retransmitted
Unnumbered Frames

- Setting of Modes:
  - SABM: Set Asynchronous Balanced Mode
  - UA: acknowledges acceptance of mode setting commands
  - DISC: terminates logical link connection
- Information Transfer between stations
  - UI: Unnumbered information
- Recovery used when normal error/flow control fails
  - FRMR: frame with correct FCS but impossible semantics
  - RSET: indicates sending station is resetting sequence numbers
- XID: exchange station id and characteristics