Data Link Layer Requirements (Revisited)

- Identify and synchronize frame/block transmissions
- Provide addressing of sender/receiver pairs (especially for multiple access links)
- Detect and recover from errors
- Manage buffers for flow control

Data Link Control Framing (1/4)

- ARQ protocols consider the following the data link control requirements:
  - Detect and recover from errors
  - Manage buffers for flow control
- Framing (i.e., identification and synchronization)
  - In packet-oriented networks, the RX end of a link needs to decide where successive frames start and stop
  - Types of framing
    - Character-based framing: Special control characters indicate beginning and ending of frames
    - Bit-oriented framing: Special strings of bits (flag sequence) delimit the frames

Data Link Control Framing (2/4)

- SLIP (Serial Line IP): A byte-oriented data link control protocol
  - IETF RFC 1055 [http://www.ietf.org/]
  - “SLIP defines a sequence of characters that frame IP packets on a serial line, and nothing more.”
  - Employed over point-to-point serial links connecting computers (1980s)
  - Special characters:
    - END: 3008 (octal) = 19210 (decimal)
    - ESC: 3338 (octal) = 21910 (decimal)
    - ESC_END: 3348 (octal) = 22010 (decimal)
    - ESC_ESC: 3358 (octal) = 22110 (decimal)

Data Link Control Framing (3/4)

- SLIP control characters
  - END: 3008 = (11 000 000)2 = 19210
  - ESC: 3338 = (11 011 011)2 = 21910
  - ESC_END: 3348 = (11 011 100)2 = 22010
  - ESC_ESC: 3358 = (11 011 101)2 = 22110
- END (3008) character to identify end of frame
  - If 3008 appears in the payload (i.e., as a message byte) then escape sequence ESC-ESC_END (3008 3348) is inserted instead
  - If 3338 appears in the payload (i.e., as a message byte) then escape sequence ESC-ESC_ESC (3338 3358) is inserted instead

Data Link Control Framing (4/4)

- What if END-ESC_END (3008 3348) sequence appears in the message?
  - 3008 3348 → (3338 3348) 3348
- Also known as "byte stuffing"
- What is worst possible overhead due to the SLIP byte stuffing procedure?
  - If message sequence consists entirely of END (3008) and ESC (3338) bytes then SLIP payload is twice the size of the message block (100% overhead)
High-Level Data Link Control (1/15)
- High-level data link control (HDLC)
- Example of a bit oriented framing protocol
- Features:
  - Delimits start and end of frames
  - Provides addressing (default 1-byte address and multi-byte extended address option)
  - Frame check sequence for error detection
  - Incorporates go-back-N, selective-reject and timeout mechanism for transmission errors
  - Default 3-bit sequence number (SN) with 7-bit extended SN option

High-Level Data Link Control (2/15)
- Frame format:
  - Flag: 8-bit flag sequence (01111110) to delimit start and end of frame
  - A: 8-bit (default) address field, extendable for multi-byte addresses
    - LSB of an address field block (i.e., byte) is set to 1 to indicate end of address field
    - LSB of an address field block is 0 if there are one or more additional bytes in the address
    - All 1s → broadcast address

High-Level Data Link Control (3/15)
- Frame format (continued):
  - Control: Control field to specify frame type, frame number, ACK number and a bit to indicate polling or final frame status
  - Information: Frame payload, i.e., data or message content
  - FCS: 16-bit frame check sequence (CRC calculated using polynomial \( x^{16}+x^{12}+x^5+1 \))

High-Level Data Link Control (4/15)
- Bit stuffing: What if flag sequence (01111110) is part of message data?
  - After a sequence of 5 consecutive 1s in data, TX inserts a 0
  - At RX and 5 consecutive 1s arrive:
    - If next bit is 0, then RX knows it was inserted at TX, removes it and continues processing bit stream as usual
    - If next bit is a 1 (i.e., 6 consecutive 1s), the RX looks at the following bit:
      - If 0 then 01111110 is received and RX assumes a flag sequence was received
      - If 1 then 01111111 is received and RX assumes a frame error occurred and frame is discarded

High-Level Data Link Control (5/15)
- Types of HDLC stations
  - Primary station:
    - Controls operation of the link (issues commands and receives expected responses)
    - E.g., mainframe computer
  - Secondary station:
    - Receive commands from primary station and issue responses in accordance with commands received
    - E.g., terminals or data display devices
  - Combined station:
    - Initialize and disconnect the link
    - Activate other combined stations
    - Can issue both commands and responses and receive both commands and responses
    - E.g., host computer or packet switching node (router)

High-Level Data Link Control (6/15)
- Link configurations
  - Unbalanced: one primary station connected to one or more secondary stations in point-to-point or multipoint mode
  - Balanced: one combined station is connected to another combined station in point-to-point mode
High-Level Data Link Control (7/15)

- Data transfer modes
  - Normal response mode (NRM):
    - Unbalanced configuration, single primary station with one or more secondary stations
    - Secondary stations transmit only after receiving permission (via polling messages) from primary station
  - Asynchronous response mode (ARM):
    - Like NRM, unbalanced configuration
    - Unlike NRM, however, secondary stations do not need explicit permission from primary station to initiate transmissions (responses)

High-Level Data Link Control (8/15)

- Data transfer modes (continued)
  - Asynchronous balanced mode (ABM):
    - Balanced configuration
    - Data transfer between two combined stations
  - For point-to-point operation, ARM or ABM is usually more efficient than NRM because they do not incur polling overhead

High-Level Data Link Control (9/15)

- Types of frames
  - Information frames:
    - Used for transfer of data consisting of any code or grouping of bits
    - Data may be variable length
  - Supervisory frames: Control flow of data
  - Unnumbered frames:
    - Provide additional control information
    - Not included in send/received sequence number

High-Level Data Link Control (10/15)

<table>
<thead>
<tr>
<th>Flags</th>
<th>A</th>
<th>Control</th>
<th>Information</th>
<th>FCS</th>
<th>Flags</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>≥ 0</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

0: Information (I) frame
1: Supervisory (S) frame
2: Unnumbered (U) frame

High-Level Data Link Control (11/15)

- Information (I) frames
  - Bit $c_1 = 0$ to distinguish I frames from S and U frames
  - Bits $(c_2, c_3, c_4)$ are the send SN to uniquely identify the frame
  - Bits $(c_6, c_7, c_8)$ are ACK notification and indicate the next frame expected
  - Bit $c_5$ (P/F):
    - For a command this is the P-bit and F-bit for a response
    - For NRM, primary station sets $P = 1$ to poll addressed secondary station while secondary station sets $F = 1$ to identify final frame sent frame

High-Level Data Link Control (12/15)

- Supervisory (S) frames
  - Bits $(c_1, c_2) = 10$ to identify as an S frame
  - Bits $(c_6, c_7, c_8)$ are as for I frame
  - Bit $c_5$ (P/F) is as for I frame
High-Level Data Link Control (13/15)

• Supervisory (S) frames (continued)
  – Bits \((c_3, c_4)\) denote supervisory functions
    • \((c_3, c_4) = 00\), Receive Ready (RR): ACK I frames received from other station and indicate readiness to receive
    • \((c_3, c_4) = 01\), Reject (REJ): Request transmission of all I frames from a given SN and ACK I frames already received from the other station
    • \((c_3, c_4) = 10\), Receive not ready (RNR): Indicates temporary busy condition and ACK I frames
    • \((c_3, c_4) = 11\), Selective reject (SREJ): Request retransmission of a single designate I frame previously transmitted

High-Level Data Link Control (14/15)

• Unnumbered (U) frames:
  – Bits \((c_1, c_2) = 11\) to identify as an U frame
  – Bit \(c_5 (P/F)\) is as for I frame
  – Bits \((c_3, c_4, c_5, c_6, c_7, c_8)\) denote up to 32 additional command and response control functions

HDLC Examples (1/5)

• “A, YN(S)N(R), P/F” notation
  – A: Address associated with a frame
  – Y: Abbreviation for the command or response, e.g.,
    • I34 indicates information frame with \(N(S) = 3\) an \(N(R) = 4\)
    • RR6 indicates a S frame (receive ready) with \(N(R) = 6\)
  – P/F: When present indicates that the P- or F-bit has been set to 1 and 0 when not present

HDLC Examples (2/5)

<table>
<thead>
<tr>
<th>Primary Station (A)</th>
<th>Secondary Station (B)</th>
<th>Secondary Station (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B, SNRM, P</td>
<td>B, UA, F</td>
<td>B, UA, F</td>
</tr>
<tr>
<td>C, SNRM, P</td>
<td>C, UA, F</td>
<td>C, UA, F</td>
</tr>
<tr>
<td>B, RR0, P</td>
<td>B, I00, F</td>
<td>B, I00, F</td>
</tr>
<tr>
<td>B, RR4</td>
<td>B, I10, P</td>
<td>B, I10, P</td>
</tr>
<tr>
<td>C, I00, P</td>
<td>B, I13, P</td>
<td>B, I13, P</td>
</tr>
<tr>
<td></td>
<td>B, I13, F</td>
<td>B, I13, F</td>
</tr>
<tr>
<td></td>
<td>C, RR1, F</td>
<td>C, RR1, F</td>
</tr>
</tbody>
</table>

Fig. 4.18a

HDLC Examples (3/5)

<table>
<thead>
<tr>
<th>Primary Station (A)</th>
<th>Secondary Station (B)</th>
<th>Secondary Station (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B, RR0</td>
<td>B, I00, P</td>
<td>B, I00, P</td>
</tr>
<tr>
<td>(All), UI</td>
<td>(All), UI</td>
<td>(All), UI</td>
</tr>
<tr>
<td>C, I00, P</td>
<td>(All), UI</td>
<td>(All), UI</td>
</tr>
</tbody>
</table>

Fig. 4.18b
Exam Info

- Friday, October 17, 5th period (2:50PM-4:10PM)
- Location:
  - Last names beginning A-J: Hill Center, Room 116
  - Last names beginning K-Z: SEC, Room 117
- Closed book, closed notes, no cheat sheet
- Please use a pen
- Exam coverage available on class web page
- Additional office hours:
  - Tuesday, October 14, 12 noon – 1:00PM, CoRE
  - Thursday, October 16, 3:00PM-4:00PM, ECE 232