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_END: 335₈ (octal) = 221₁₀ (decimal)
Data Link Control Framing (3/4)

- SLIP control characters
  - END: $300_8 = (11 000 000)_2 = 192_{10}$
  - ESC: $333_8 = (11 011 011)_2 = 219_{10}$
  - ESC_END: $334_8 = (11 011 100)_2 = 220_{10}$
  - ESC_ESC: $335_8 = (11 011 101)_2 = 221_{10}$
- END ($300_8$) character to identify end of frame
  - If $300_8$ appears in the payload (i.e., as a message byte) then escape sequence ESC-ESC_END ($300_8$ $334_8$) is inserted instead
  - If $333_8$ appears in the payload (i.e., as a message byte) then escape sequence ESC-ESC_ESC ($333_8$ $335_8$) is inserted instead

Data Link Control Framing (4/4)

- What if END-ESC_END ($300_8$ $334_8$) sequence appears in the message?
  $300_8$ $334_8$ $\rightarrow$ ($333_8$ $334_8$) $334_8$
- Also known as “byte stuffing”
- What is worst possible overhead due to the SLIP byte stuffing procedure?
  If message sequence consists entirely of END ($300_8$) and ESC ($333_8$) 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 $\rightarrow$ 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 $x^{16}+x^{12}+x^5+1$)

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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>Flag</th>
<th>A</th>
<th>Control</th>
<th>Information</th>
<th>FCS</th>
<th>Flag</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>
```

- Information (I) frame
- Supervisory (S) frame
- 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

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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 \((c_3, c_6, c_7, c_8)\) denote up to 32 additional command and response control functions
High-Level Data Link Control (15/15)

- Some unnumbered commands
  - Un-extended numbering set mode commands:
    - Set the particular Modulo 8 SN mode to be used
    - SNRM, SARM and SABM
  - Extended numbering set mode commands
    - Set the particular Modulo 128 SN to be used
    - Control field is extended to 2 bytes to accommodate the 7-bit SN
    - SNRME, SARME and SABME
  - Unnumbered ACK (UA): ACK receipt and execution of a mode setting, initialization, etc.
  - Unnumbered Information (UI)

HDLC Examples (1/5)

- “A, Y\(N(S)\)\(N(R)\), 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)

Primary Station (A)  Secondary Stations (B,C)

Primary Station (A)
- B, SNRM, P
- C, SNRM, P
- B, RR0, P
- B, RR4
- C, I00, P

Secondary Stations (B,C)
- B, UA, F
- C, UA, F
- B, I00
- B, I10
- B, I20
- B, I30, F
- C, RR1, F

Primary Station (A)  Secondary Stations (B,C)

Primary Station (A)
- B, I00
- B, I10
- B, I20, P
- B, I13
- B, I23, F
- (All), UI
- (All), UI
- C, I00, P

Secondary Stations (B,C)
- B, I03
- B, I13
- B, I23, F
- C, RR1, F

Fig. 4.18a

HDLC Examples (3/5)

Primary Station (A)  Secondary Stations (B,C)

Primary Station (A)
- B, RNR3
- (All), UI
- (All), UI
- C, I00, P

Secondary Stations (B,C)
- B, I03
- B, I13
- B, I23, F
- C, RR1, F

Fig. 4.18b
HDLC Examples (4/5)

Primary Station (A) Secondary Stations (B,C)

B, RR0, P → B, I00
B, SREJ0, P → B, I00
B, IO3, P → B, I00
C, IO0, P → C, I00
C, IO0, P → C, RR1

Errors

B, I03, P → B, I00
B, I00 → B, I00
B, I30, P → B, I00
B, I00 → B, I00
B, I40, P → B, I00
B, I00 → B, I00
B, I50, F → B, I00
B, I00 → B, I00
B, I31, P → B, I00
B, I00 → B, I00
B, I41, F → B, I00
B, I00 → B, I00
B, I51, F → B, I00
B, I00 → B, I00

Fig. 4.18c

HDLC Examples (5/5)

Primary Station (A) Secondary Stations (B,C)

B, RR0, P → B, I00
B, SREJ0, P → B, I00
B, IO3, P → B, I00
C, IO0, P → C, I00
C, IO0, P → C, RR1

Errors

B, I03, P → B, I00
B, IO0, P → B, I00
B, I30, P → B, I00
B, I00 → B, I00
B, I40, P → B, I00
B, I00 → B, I00
B, I50, F → B, I00
B, I00 → B, I00
B, I31, P → B, I00
B, I00 → B, I00
B, I41, F → B, I00
B, I00 → B, I00
B, I51, F → B, I00
B, I00 → B, I00

Fig. 4.18c
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