Data Link Control
Protocols

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These slides are available on-line at:
http://www.cse.wustl.edu/~jain/cse473-05/
Overview

Flow Control
Effect of propagation delay, speed, frame size
Error Recovery
HDLC
Flow Control

Flow Control Goals:
1. Sender does not flood the receiver,
2. Maximize throughput
   Sender throttled until receiver grants permission
Space-Time Diagrams

(a) Error-free transmission

(b) Transmission with losses and errors
Stop and Wait Flow Control

\[ U = \frac{t_{\text{frame}}}{2t_{\text{prop}} + t_{\text{frame}}} = \frac{1}{2\alpha + 1} \]

\[ \alpha = \frac{t_{\text{prop}}}{t_{\text{frame}} \text{ Distance/Speed of Signal}} = \frac{\text{Bits Transmitted}}{\text{Bit rate}} = \frac{\text{Distance} \times \text{Bit rate}}{\text{Bits Transmitted} \times \text{Speed of Signal}} \]

Light in vacuum
= 300 m/μs
Light in fiber
= 200 m/μs
Electricity
= 250 m/μs
Utilization: Examples

Satellite Link: Propagation Delay $t_{\text{prop}} = 270$ ms
Frame Size = 500 Bytes = 4 kb
Data rate = 56 kbps $\Rightarrow$ $t_{\text{frame}} = 4/56 = 71$ ms
$\alpha = t_{\text{prop}}/t_{\text{frame}} = 270/71 = 3.8$
$U = 1/(2\alpha+1) = 0.12$

Short Link: 1 km = 5 μs,
Rate=10 Mbps,
Frame=500 bytes $\Rightarrow$ $t_{\text{frame}} = 4k/10M= 400$ μs
$\alpha=t_{\text{prop}}/t_{\text{frame}}=5/400=0.012$ $\Rightarrow$ $U=1/(2\alpha+1)=0.98$

**Note:** The textbook uses B for $t_{\text{prop}}$ and L for $t_{\text{frame}}
For all protocols, the maximum utilization (efficiency) is a *non-increasing* function of $\alpha$.

$$\alpha = \frac{t_{\text{prop}}}{t_{\text{frame}}} = \frac{\text{Distance} \times \text{Bit rate}}{\text{Bits Transmitted} \times \text{Speed of Signal}}$$
Sliding Window Protocols

Window = Set of sequence numbers to send/receive

Sender window

Sender window increases when ack received

Packets in sender window must be buffered at source
Sliding Window Diagram

(a) Sender's perspective

(b) Receiver's perspective
Sliding Window Example

Source System A

Destination System B

0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7

0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7

0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7

0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7

0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7

0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7

0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7

0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7
Sliding Window Protocol Efficiency

\[
U = \frac{W \cdot t_{\text{frame}}}{2t_{\text{prop}} + t_{\text{frame}}}
\]

\[
= \begin{cases} 
W & \text{if } W > 2\alpha + 1 \\
1 & \text{if } W \leq 2\alpha + 1 
\end{cases}
\]
Effect of Window Size

Larger window is better for larger $\alpha$
Piggybacking

Data

Header

Data

Ack

Data

Header

Data

$t_{frame}$

$t_{prop}$

Data+Ack
Error Control

Error Control = Deliver frames without error, in the proper order to network layer

Error control Mechanisms:

- Ack/Nack: Provide sender some feedback about other end
- Time-out: for the case when entire packet or ack is lost
- Sequence numbers: to distinguish retransmissions from originals
Stop-and-Wait ARQ

Automatic Repeat reQuest (ARQ)
Go-Back-N ARQ

Receiver does not cache out-of-order frames
Sender has to **go back** and retransmit all frames after the lost frame
Go-back-N (Cont)

All possible scenarios are handled:

1. Damaged Frame:
   - Frame received with error
   - Frame lost
   - Last frame lost

2. Damaged Ack:
   - One ack lost, next one makes it
   - All acks lost

3. Damaged Nack:
   - Maximum Window = $2^n - 1$
   - with $n$-bit sequence numbers
Selective Reject ARQ

Receiver caches out-of-order frames
Sender retransmits only the lost frame
Selective Reject: Window Size

Sequence number space ≥ 2 window size
Window size ≤ 2^{n-1}
Performance: Maximum Utilization

Stop and Wait Flow Control: \( U = \frac{1}{1+2\alpha} \)

Window Flow Control:

\[
U = \begin{cases} 
1 & W \geq 2\alpha + 1 \\
\frac{W}{2\alpha+1} & W < 2\alpha + 1
\end{cases}
\]

Stop and Wait ARQ: \( U = \frac{1-P}{1+2\alpha} \)

Go-back-N ARQ:

\[
U = \begin{cases} 
\frac{1-P}{1+2\alpha P} & W \geq 2\alpha + 1 \\
\frac{W(1-P)}{[(2\alpha+1)(1-P+wP)]} & W < 2\alpha + 1
\end{cases}
\]

Selective Reject ARQ:

\[
U = \begin{cases} 
(1-P) & W \geq 2\alpha + 1 \\
\frac{W(1-P)}{2\alpha+1} & W < 2\alpha + 1
\end{cases}
\]
Performance Comparison

Utilization

\( \alpha \)

More bps or longer distance

\( W = 127 \) Go-back-N

\( W = 7 \) Go-back-N &

\( W = 7 \) Selective-reject

\( W = 127 \) Selective-reject

Stop-and-wait
**HDLC Family**

- Synchronous Data Link Control (SDLC): IBM
- High-Level Data Link Control (HDLC): ISO
- Link Access Procedure-Balanced (LAPB): X.25
- Link Access Procedure for the D channel (LAPD): ISDN
- Link Access Procedure for modems (LAPM): V.42
- Link Access Procedure for half-duplex links (LAPX): Teletex
- Point-to-Point Protocol (PPP): Internet
- Logical Link Control (LLC): IEEE
- Advanced Data Communications Control Procedures (ADCCP): ANSI
- V.120 and Frame relay also use HDLC
Primary station: Issue commands
Secondary Station: Issue responses
Combined Station: Both primary and secondary
Unbalanced Configuration: One or more secondary
Balanced Configuration: Two combined station
Normal Response Mode (NRM): Response from secondary
Asynchronous Balanced Mode (ABM): Combined Station
Asynchronous Response Mode (ARM): Secondary may respond before command
### HDLC Frame Structure

**Frame Format**

<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>8</td>
<td>8</td>
<td>8</td>
<td>8n</td>
<td>16</td>
<td>8</td>
</tr>
</tbody>
</table>

- **Control Field Format**
  - **I**: Information
  - **S**: Supervisory
  - **U**: Unnumbered

<table>
<thead>
<tr>
<th>Control Field Format</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>I: Information</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S: Supervisory</td>
<td></td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U: Unnumbered</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Extended Address Field**

<table>
<thead>
<tr>
<th>Extended Address Field</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>8n</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

- **Extended Control Field**

<table>
<thead>
<tr>
<th>Extended Control Field</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N(S)</td>
<td>P/F</td>
<td>N(R)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supervisory</td>
<td>1</td>
<td>0</td>
<td>S</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>P/F</td>
<td>N(R)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Field Definitions**
  - **N(S)**: Send sequence number
  - **N(R)**: Receive sequence number
  - **S**: Supervisory function bits
  - **M**: Unnumbered bits
  - **P/F**: Poll/final bit
Bit Stuffing

HDLC Flag = 01111110
Every where else in the frame:
Replace 11111 with 111110

Original Pattern

1111111111110111111101111110

After bit-stuffing

111110111111011011111101011111010

↑   ↑   ↑   ↑
(b) An inverted bit splits a frame in two

(c) An inverted bit merges two frames
HDLC Frames

Information Frames: User data
  Piggybacked Acks: Next frame expected
  Poll/Final = Command/Response
Supervisory Frames: Flow and error control
  Go back N and Selective Reject
  Final \(\Rightarrow\) No more data to send
Unnumbered Frames: Control
  Mode setting commands and responses
  Information transfer commands and responses
  Recovery commands and responses
  Miscellaneous commands and responses
# HDLC Commands and Responses

<table>
<thead>
<tr>
<th>Name</th>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information (I)</td>
<td>C/R</td>
<td>Exchange user data</td>
</tr>
<tr>
<td>Supervisory (S)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Receive Ready (RR)</td>
<td>C/R</td>
<td>Positive Acknowledgement; ready to receive I-frame</td>
</tr>
<tr>
<td>Receive Not Ready (RNR)</td>
<td>C/R</td>
<td>Positive acknowledgement; not ready to receive</td>
</tr>
<tr>
<td>Reject (REJ)</td>
<td>C/R</td>
<td>Negative acknowledgement; go back N</td>
</tr>
<tr>
<td>Selective Reject (SREJ)</td>
<td>C/R</td>
<td>Negative acknowledgement; selective reject</td>
</tr>
<tr>
<td>Unnumbered (U)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set Normal Response /</td>
<td>C</td>
<td>Set mode;extended=two-octet control field</td>
</tr>
<tr>
<td>Extended Mode (SNRM / SNRME)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set Asynchronous Response /</td>
<td>C</td>
<td>Set mode;extended=two-octet control field</td>
</tr>
<tr>
<td>Extended Mode (SARM / SARME)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set Asynchronous Balanced /</td>
<td>C</td>
<td>Set mode;extended=two-octet control field</td>
</tr>
<tr>
<td>Extended Mode (SABM / SABME)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Set Initialization Mode (SIM)</td>
<td>C</td>
<td>Initialize link control functions in addressed station</td>
</tr>
<tr>
<td>Name</td>
<td>Function</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>----------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Disconnect (DISC)</td>
<td>C</td>
<td>Terminate logical link connection</td>
</tr>
<tr>
<td>Unnumbered Acknowledgement (UA)</td>
<td>R</td>
<td>Acknowledges acceptance of one of the above set-mode commands</td>
</tr>
<tr>
<td>Disconnect Mode (DM)</td>
<td>R</td>
<td>Secondary is logically disconnected</td>
</tr>
<tr>
<td>Request Disconnect (RD)</td>
<td>R</td>
<td>Request for DISC command</td>
</tr>
<tr>
<td>Request Initialization Mode (RIM)</td>
<td>R</td>
<td>Initialization needed; request for SIM command</td>
</tr>
<tr>
<td>Unnumbered Information (UI)</td>
<td>C/R</td>
<td>Used to exchange control information</td>
</tr>
<tr>
<td>Unnumbered Poll (UP)</td>
<td>C</td>
<td>Used to solicit control information</td>
</tr>
<tr>
<td>Reset (RSET)</td>
<td>C</td>
<td>Used for recovery; resets N(R), N(S)</td>
</tr>
<tr>
<td>Exchange Identification (XID)</td>
<td>C/R</td>
<td>Used to request/report identity and status</td>
</tr>
<tr>
<td>Test (TEST)</td>
<td>C/R</td>
<td>Exchange identical information fields for testing</td>
</tr>
<tr>
<td>Frame Reject (FRMR)</td>
<td>R</td>
<td>Reports receipt of unacceptable frame</td>
</tr>
</tbody>
</table>
Examples of HDLC Operation

(a) Link setup and disconnect

(b) Two-way data exchange

(c) Busy condition
Examples of Operation (Cont)

(d) Reject Recovery

(e) Timeout Recovery
Flow Control: Stop and Wait, Sliding window
Effect of propagation delay, speed, frame size
Piggybacking
Error Control: Stop and wait ARQ, Go-back-N, Selective Reject
HDLC: Primary and secondary stations, NRM, ABM, ARM
HDLC Frames: Flag, Bit stuffing, I-Frame, RR, RNR
Reading Assignment

Read Chapter 7 and Appendix 7A of 7th edition of Stallings.

Do the following Exercise from the textbook:
7.8 (maximum link utilizations)

There is no need to submit the answers.
Next Monday is the first mid-term.