Chapter 7
Data Link Control
Flow Control

- Ensuring the sending entity does not overwhelm the receiving entity
  - Preventing buffer overflow
- Transmission time
  - Time taken to emit all bits into medium
- Propagation time
  - Time for a bit to traverse the link
Model of Frame Transmission

(a) Error-free transmission

(b) Transmission with losses and errors
Stop and Wait

- Source transmits frame
- Destination receives frame and replies with acknowledgement
- Source waits for ACK before sending next frame
- Destination can stop flow by not send ACK
- Works well for a few large frames
**Fragmentation**

- Large block of data may be split into small frames
  - Limited buffer size
  - Errors detected sooner (when whole frame received)
  - On error, retransmission of smaller frames is needed
  - Prevents one station occupying medium for long periods
- Stop and wait becomes inadequate
Stop and Wait Link Utilization

Figure 7.2  Stop-and-Wait Link Utilization (transmission time = 1; propagation time = a)
Sliding Windows Flow Control

- Allow multiple frames to be in transit
- Receiver has buffer $W$ long
- Transmitter can send up to $W$ frames without ACK
- Each frame is numbered
- ACK includes number of next frame expected
- Sequence number bounded by size of field ($k$)
  - Frames are numbered modulo $2^k$
Sliding Window Diagram

(a) Sender's perspective

(b) Receiver's perspective
Example Sliding Window
Sliding Window Enhancements

- Receiver can acknowledge frames without permitting further transmission (Receive Not Ready)
- Must send a normal acknowledge to resume
- If duplex, use piggybacking
  - If no data to send, use acknowledgement frame
  - If data but no acknowledgement to send, send last acknowledgement number again, or have ACK valid flag (TCP)
Error Detection

- Additional bits added by transmitter for error detection code
- Parity
  - Value of parity bit is such that character has even (even parity) or odd (odd parity) number of ones
  - Even number of bit errors goes undetected
Cyclic Redundancy Check

- For a block of $k$ bits transmitter generates $n$ bit sequence
- Transmit $k+n$ bits which is exactly divisible by some number
- Receive divides frame by that number
  - If no remainder, assume no error
  - For math, see Stallings chapter 7
Error Control

- Detection and correction of errors
- Lost frames
- Damaged frames
- Automatic repeat request
  - Error detection
  - Positive acknowledgment
  - Retransmission after timeout
  - Negative acknowledgement and retransmission
Automatic Repeat Request (ARQ)

- Stop and wait
- Go back N
- Selective reject (selective retransmission)
Stop and Wait

* Source transmits single frame
* Wait for ACK
* If received frame damaged, discard it
  - Transmitter has timeout
  - If no ACK within timeout, retransmit
* If ACK damaged, transmitter will not recognize it
  - Transmitter will retransmit
  - Receive gets two copies of frame
  - Use ACK0 and ACK1
Stop and Wait - Diagram
Stop and Wait - Pros and Cons

- Simple
- Inefficient
Go Back N (1)

- Based on sliding window
- If no error, ACK as usual with next frame expected
- Use window to control number of outstanding frames
- If error, reply with rejection
  - Discard that frame and all future frames until error frame received correctly
  - Transmitter must go back and retransmit that frame and all subsequent frames
Go Back N - Damaged Frame

- Receiver detects error in frame $i$
- Receiver sends rejection-$i$
- Transmitter gets rejection-$i$
- Transmitter retransmits frame $i$ and all subsequent
Frame \( i \) lost

Transmitter sends \( i+1 \)

Receiver gets frame \( i+1 \) out of sequence

Receiver send reject \( i \)

Transmitter goes back to frame \( i \) and retransmits
Go Back N - Lost Frame (2)

- Frame \( i \) lost and no additional frame sent
- Receiver gets nothing and returns neither acknowledgement nor rejection
- Transmitter times out and sends acknowledgement frame with P bit set to 1
- Receiver interprets this as command which it acknowledges with the number of the next frame it expects (frame \( i \))
- Transmitter then retransmits frame \( i \)
Go Back N - Damaged Acknowledgement

- Receiver gets frame \( i \) and send acknowledgement \((i+1)\) which is lost
- Acknowledgements are cumulative, so next acknowledgement \((i+n)\) may arrive before transmitter times out on frame \( i \)
- If transmitter times out, it sends acknowledgement with P bit set as before
- This can be repeated a number of times before a reset procedure is initiated
As for lost frame (2)
Go Back N - Diagram
Selective Reject

- Also called selective retransmission
- Only rejected frames are retransmitted
- Subsequent frames are accepted by the receiver and buffered
- Minimizes retransmission
- Receiver must maintain large enough buffer
- More complex login in transmitter
Selective Reject - Diagram
High Level Data Link Control

- HDLC
- ISO 33009, ISO 4335
HDLC Station Types

- **Primary station**
  - Controls operation of link
  - Frames issued are called commands
  - Maintains separate logical link to each secondary station

- **Secondary station**
  - Under control of primary station
  - Frames issued called responses

- **Combined station**
  - May issue commands and responses
HDLC Link Configurations

- **Unbalanced**
  - One primary and one or more secondary stations
  - Supports full duplex and half duplex

- **Balanced**
  - Two combined stations
  - Supports full duplex and half duplex
Normal Response Mode (NRM)
- Unbalanced configuration
- Primary initiates transfer to secondary
- Secondary may only transmit data in response to command from primary
- Used on multi-drop lines
- Host computer as primary
- Terminals as secondary
HDLC Transfer Modes (2)

Asynchronous Balanced Mode (ABM)

- Balanced configuration
- Either station may initiate transmission without receiving permission
- Most widely used
- No polling overhead
Asynchronous Response Mode (ARM)
- Unbalanced configuration
- Secondary may initiate transmission without permission from primary
- Primary responsible for line
- Rarely used
Frame Structure

- Synchronous transmission
- All transmissions in frames
- Single frame format for all data and control exchanges
Flag Fields

- Delimit frame at both ends
- 01111110
- May close one frame and open another
- Receiver hunts for flag sequence to synchronize
- Bit stuffing used to avoid confusion with data containing 01111110
  - 0 inserted after every sequence of five 1s
  - If receiver detects five 1s it checks next bit
  - If 0, it is deleted
  - If 1 and seventh bit is 0, accept as flag
  - If sixth and seventh bits 1, sender is indicating abort
Bit Stuffing

Example with possible errors

Original Pattern:
11111111111011111101111110

After bit-stuffing
111110111110110111110101011111010

(a) Example

(b) An inverted bit splits a frame in two

(c) An inverted bit merges two frames
Address Field

❖ Identifies secondary station that sent or will receive frame
❖ Usually 8 bits long
❖ May be extended to multiples of 7 bits
   ▲ LSB of each octet indicates that it is the last octet (1) or not (0)
❖ All ones (11111111) is broadcast
Control Field

- Different for different frame type
  - Information - data to be transmitted to user (next layer up)
    - Flow and error control piggybacked on information frames
  - Supervisory - ARQ when piggyback not used
  - Unnumbered - supplementary link control

- First one or two bits of control filed identify frame type

- Remaining bits explained later
## Control Field Diagram

### (c) 8-bit control field format

**I: Information**

<table>
<thead>
<tr>
<th>Bit 1</th>
<th>Bit 2</th>
<th>Bit 3</th>
<th>Bit 4</th>
<th>Bit 5</th>
<th>Bit 6</th>
<th>Bit 7</th>
<th>Bit 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>N(S)</td>
<td>P/F</td>
<td>N(R)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **N(S)** = Send sequence number
- **N(R)** = Receive sequence number

**S: Supervisory**

<table>
<thead>
<tr>
<th>Bit 1</th>
<th>Bit 2</th>
<th>Bit 3</th>
<th>Bit 4</th>
<th>Bit 5</th>
<th>Bit 6</th>
<th>Bit 7</th>
<th>Bit 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>S</td>
<td>P/F</td>
<td>N(R)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **S** = Supervisory function bits

**U: Unnumbered**

<table>
<thead>
<tr>
<th>Bit 1</th>
<th>Bit 2</th>
<th>Bit 3</th>
<th>Bit 4</th>
<th>Bit 5</th>
<th>Bit 6</th>
<th>Bit 7</th>
<th>Bit 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>M</td>
<td>P/F</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **M** = Unnumbered function bits
- **P/F** = Poll/final bit

### (d) 16-bit control field format

**Information**

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

**Supervisory**

<table>
<thead>
<tr>
<th>Bit 1</th>
<th>Bit 2</th>
<th>Bit 3</th>
<th>Bit 4</th>
<th>Bit 5</th>
<th>Bit 6</th>
<th>Bit 7</th>
<th>Bit 8</th>
<th>Bit 9</th>
<th>Bit 10</th>
<th>Bit 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>S</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>P/F</td>
<td>N(R)</td>
<td></td>
</tr>
</tbody>
</table>
Poll/Final Bit

- Use depends on context

Command frame
- P bit
- 1 to solicit (poll) response from peer

Response frame
- F bit
- 1 indicates response to soliciting command
Information Field

❖ Only in information and some unnumbered frames
❖ Must contain integral number of octets
❖ Variable length
Frame Check Sequence Field

- FCS
- Error detection
- 16 bit CRC
- Optional 32 bit CRC
HDLC Operation

- Exchange of information, supervisory and unnumbered frames
- Three phases
  - Initialization
  - Data transfer
  - Disconnect
Examples of Operation (1)

(a) Link setup and disconnect
(b) Two-way data exchange
(c) Busy condition
Examples of Operation (2)

(d) Reject recovery

(e) Timeout recovery
Other DLC Protocols
(LAPB,LAPD)

❖ Link Access Procedure, Balanced (LAPB)
  ▶ Part of X.25 (ITU-T)
  ▶ Subset of HDLC - ABM
  ▶ Point to point link between system and packet switching network node

❖ Link Access Procedure, D-Channel
  ▶ ISDN (ITU-D)
  ▶ ABM
  ▶ Always 7-bit sequence numbers (no 3-bit)
  ▶ 16 bit address field contains two sub-addresses
    ▶ One for device and one for user (next layer up)
Other DLC Protocols (LLC)

- Logical Link Control (LLC)
  - IEEE 802
  - Different frame format
  - Link control split between medium access layer (MAC) and LLC (on top of MAC)
  - No primary and secondary - all stations are peers
  - Two addresses needed
    - Sender and receiver
  - Error detection at MAC layer
    - 32 bit CRC
  - Destination and source access points (DSAP, SSAP)
Other DLC Protocols
(Frame Relay) (1)

- Streamlined capability over high speed packet witched networks
- Used in place of X.25
- Uses Link Access Procedure for Frame-Mode Bearer Services (LAPF)
- Two protocols
  - Control - similar to HDLC
  - Core - subset of control
Other DLC Protocols
(Frame Relay) (2)

- ABM
- 7-bit sequence numbers
- 16 bit CRC
- 2, 3 or 4 octet address field
  - Data link connection identifier (DLCI)
  - Identifies logical connection
- More on frame relay later
Other DLC Protocols (ATM)

- Asynchronous Transfer Mode
- Streamlined capability across high speed networks
- Not HDLC based
- Frame format called “cell”
- Fixed 53 octet (424 bit)
- Details later
Required Reading

- Stallings chapter 7
- Web sites on HDLC, frame relay, Ethernet and ATM