Chapter 7: Data Link Control

Data Link Control Protocols

- Need layer of logic above Physical to manage exchange of data over a link
  - frame synchronization
  - flow control
  - error control
  - addressing
  - control and data
  - link management
Background information

Begin(...)

— Speaking of Physical Layer:
— let’s consider the physical layer and the characteristics of interfaces

— Let’s just quickly go though this to the ... END slide

Line Configuration

• Topology
  — Physical arrangement of stations on medium
  — Point to point
  — Multi point
    • Computer and terminals, local area network
• Half duplex
  — Only one station may transmit at a time
  — Requires one data path
• Full duplex
  — Simultaneous transmission and reception between two stations
  — Requires two data paths (or echo canceling)
**Interfacing**

- Data processing devices (or data terminal equipment, DTE) do not (usually) include data transmission facilities.
- Need an interface called data circuit terminating equipment (DCE) — e.g. modem, NIC.
- DCE transmits bits on medium.
- DCE communicates data and control info with DTE — Done over interchange circuits — Clear interface standards required.
Data Communications Interfacing

Characteristics of Interface

- Mechanical
  - Connection plugs
- Electrical
  - Voltage, timing, encoding
- Functional
  - Data, control, timing, grounding
- Procedural
  - Sequence of events
**V.24/EIA-232-F**

- **ITU-T v.24**
  
  - ITU = Intl. Telecom. Union
  
  - ITU-T = ITU Telecom. Standardization Sector

- Only specifies functional and procedural
  
  - References other standards for electrical and mechanical

- **EIA-232-F (USA) (first issued in 1962)**
  
  - RS-232
  
  - Mechanical ISO 2110
  
  - Electrical v.28
  
  - Functional v.24
  
  - Procedural v.24

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**Mechanical Specification**

![Mechanical Specification Diagram](image)

*Figure 6.5 Pin Assignments for V.24/EIA-232 (DTE Connector Face)*

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**Notes:**

- EIA = Electronic Industry Alliance
- RS-232 first issued in 1962
- V.24 issued in 1996
- V.28 issued in 1993

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**References:**

- EIA = Electronic Industry Alliance
- RS-232 first issued in 1962
- V.24 issued in 1996
- V.28 issued in 1993
**Electrical Specification**

- Digital signals
- Values interpreted as data or control, depending on circuit
- Less than -3V is binary 1, more than +3V is binary 0 (NRZ-L)
- For control,
  - less than -3V is off,
  - more than +3V is on
- Signal rate < 20kbps
- Distance <15m

**Functional Specification**

- Circuits grouped in categories
  - Data
  - Control
  - Timing
  - Ground
- One circuit in each direction
  - Full duplex
- Two secondary data circuits
  - Allow halt or flow control in half duplex operation
- DTE = data terminal equipment
- DCE = data circuit-terminal equipment
### Functional Specification

#### Table 6.1 V.24/EIA-232-F Interchange Circuits

<table>
<thead>
<tr>
<th>V.24</th>
<th>EIA-232</th>
<th>Name</th>
<th>Direction to:</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DATA SIGNALS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>103</td>
<td>BA</td>
<td>Transmitted Data</td>
<td>DCE</td>
<td>Transmitted by DTE</td>
</tr>
<tr>
<td>104</td>
<td>BB</td>
<td>Received Data</td>
<td>DTE</td>
<td>Received by DTE</td>
</tr>
<tr>
<td>118</td>
<td>SBA</td>
<td>Secondary Transmitted Data</td>
<td>DCE</td>
<td>Transmitted by DTE</td>
</tr>
<tr>
<td>119</td>
<td>SBB</td>
<td>Secondary Received Data</td>
<td>DTE</td>
<td>Received by DTE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TIMING SIGNALS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>113</td>
<td>DA</td>
<td>Transmitter signal element timing</td>
<td>DCE</td>
<td>Clocking signal; transitions to ON and OFF occur at center of each signal element</td>
</tr>
<tr>
<td>114</td>
<td>DB</td>
<td>Transmitter signal element timing</td>
<td>DTE</td>
<td>Clocking signal; both 113 and 114 relate to signals on circuit 103</td>
</tr>
<tr>
<td>115</td>
<td>DD</td>
<td>Receiver signal element timing</td>
<td>DTE</td>
<td>Clocking signal for circuit 104</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GROUND</td>
<td></td>
<td></td>
</tr>
<tr>
<td>102</td>
<td>AB</td>
<td>Signal ground/common return</td>
<td></td>
<td>Common ground reference for all circuits</td>
</tr>
</tbody>
</table>

---

### Functional Specification

#### CONTROL SIGNALS

<table>
<thead>
<tr>
<th>V</th>
<th>EIA-232</th>
<th>Name</th>
<th>Direction to:</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>105</td>
<td>CA</td>
<td>Request to send</td>
<td>DCE</td>
<td>DTE wishes to transmit</td>
</tr>
<tr>
<td>106</td>
<td>CB</td>
<td>Clear to send</td>
<td>DTE</td>
<td>DTE is ready to receive; response to Request to send</td>
</tr>
<tr>
<td>107</td>
<td>CC</td>
<td>DCE ready</td>
<td>DTE</td>
<td>DCE is ready to operate</td>
</tr>
<tr>
<td>108</td>
<td>CD</td>
<td>DTE ready</td>
<td>DCE</td>
<td>DTE is ready to operate</td>
</tr>
<tr>
<td>125</td>
<td>CE</td>
<td>Ring indicator</td>
<td>DTE</td>
<td>DCE is receiving a ringing signal on the channel line</td>
</tr>
<tr>
<td>109</td>
<td>CF</td>
<td>Received line signal detector</td>
<td>DTE</td>
<td>DCE is receiving a signal within appropriate limits on the channel line</td>
</tr>
<tr>
<td>110</td>
<td>CG</td>
<td>Signal quality detector</td>
<td>DTE</td>
<td>Indicates whether there is a high probability of error in the data received</td>
</tr>
<tr>
<td>111</td>
<td>CH</td>
<td>Data signal rate selector</td>
<td>DCE</td>
<td>Selects one of two data rates</td>
</tr>
<tr>
<td>112</td>
<td>CI</td>
<td>Data signal rate selector</td>
<td>DTE</td>
<td>Selects one of two data rates</td>
</tr>
<tr>
<td>133</td>
<td>CJ</td>
<td>Ready for receiving</td>
<td>DCE</td>
<td>On/off flow control</td>
</tr>
<tr>
<td>120</td>
<td>SCA</td>
<td>Secondary request to send</td>
<td>DCE</td>
<td>DTE wishes to transmit on reverse channel</td>
</tr>
<tr>
<td>121</td>
<td>SCB</td>
<td>Secondary clear to send</td>
<td>DTE</td>
<td>DCE is ready to receive on reverse channel</td>
</tr>
<tr>
<td>122</td>
<td>SCF</td>
<td>Secondary received line signal detector</td>
<td>DTE</td>
<td>Same as 109, for reverse channel</td>
</tr>
<tr>
<td>140</td>
<td>RL</td>
<td>Remote loopback</td>
<td>DCE</td>
<td>Instructs remote DCE to loop back signals</td>
</tr>
<tr>
<td>141</td>
<td>LL</td>
<td>Local loopback</td>
<td>DCE</td>
<td>Instructs DCE to loop back signals</td>
</tr>
<tr>
<td>142</td>
<td>TM</td>
<td>Test mode</td>
<td>DTE</td>
<td>Local DCE is in a test condition</td>
</tr>
</tbody>
</table>
**Local and Remote Loopback**

![Diagram of Local and Remote Loopback](image)

**Procedural Specification**

- Example: Asynchronous private line modem
- When turned on and ready, modem (DCE) asserts DCE ready
- When DTE ready to send data, it asserts Request to Send
  - Also inhibits receive mode in half duplex
- Modem responds when ready by asserting Clear to Send
- DTE sends data
- When data arrives, local modem asserts Receive Line Signal Detector and delivers data
**Dial Up Operation (1)**

1. DTE A turns on the DTE ready pin (20) to tell its modem it wants to begin a data exchange. While this signal remains asserted, DTE A transmits a phone number via Transmitted Data (pin 2) for modem A to dial.

2. When modem B alerts its DTE to the incoming call via the Ring Indicator pin (22), DTE B turns on its DTE Ready pin (20). Modem B then generates a carrier signal, to be used in the exchange, and turns on pin 6, to show its readiness to receive data.

**Dial Up Operation (2)**

3. When modem A detects a carrier signal, it alerts DTE A via pin 8. The modem also tells the DTE that a circuit has been established (pin 6). If the modem has been so programmed, it will also send an "on line" message to the DTE's screen via the Received Data pin (3).

4. Modem A then generates its own carrier signal to modem B, which reports it via pin 8.
Dial Up Operation (3)

5. When it wishes to send data, DTE A activates Request to Send (pin 4). Modem A responds with Clear to Send (pin 5). DTE A sends data (pulses representing 1s and 0s) to modem A via the Transmitted Data pin (2). Modem A modulates the pulses to send the data over its analog carrier signal.

6. Modem B reconverts the signal to digital form and sends it to DTE B via the Received Data pin (3).

Null Modem

| Signal ground 102 | 102 |
| Transmitted data 103 | 103 |
| Received data 104 | 104 |
| Request to send 105 | 105 |
| Clear to send 106 | 106 |
| Rcvd line sig. detector 109 | 109 |
| DCE ready 107 | 107 |
| DTE ready 108.2 | 108.2 |
| Ring indicator 125 | 125 |
| Transmitter timing 113 | 113 |
| Receiver timing 115 | 115 |
ISDN Physical Interface

- Connection between
  - terminal equipment (c.f. DTE) and
  - network terminating equipment (c.f. DCE)
- ISO 8877
- Cables terminate in matching connectors with 8 contacts
- Transmit/receive carry both data and control
**ISDN Electrical Specification**

- Balanced transmission
  - Carried on two lines, e.g. twisted pair
  - Signals as currents down one conductor and up the other
  - Differential signaling
  - Value depends on direction of voltage
  - Tolerates more noise and generates less
  - (Unbalanced, e.g. RS-232 uses single signal line and ground)
  - Data encoding depends on data rate
  - Basic rate 192kbps
    - uses pseudoternary
  - Primary rate: two options
    - 1.544 Mbps uses AMI and B8ZS
    - 2.048 Mbps uses AMI and HDB3
  - reason for different schemes is historical, no advantage of disadvantage

---

**End of Background Information**

...END
**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**

- **Source** to **Destination**
  - Frame 1
  - Frame 2
  - Frame 3
  - Frame 4
  - Frame 5

- **Time**
  - Frame 1
  - Frame 2
  - Frame 3
  - Frame 4
  - Frame 5

- **Transmission**
  - (a) Error-free transmission
  - (b) Transmission with losses and errors

---

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

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Model of Frame Transmission

- Source to Destination
  - Frame 1 to Frame 1
  - Frame 2 to Frame 2
  - Frame 3 to Frame 3
  - Frame 4 to Frame 4
  - Frame 5 to Frame 5

- Time
  - Frame 1
  - Frame 2
  - Frame 3
  - Frame 4
  - Frame 5

- Transmission
  - (a) Error-free transmission
  - (b) Transmission with losses and errors
Data Link Basics

- Flow Control
  - Define:
    - \( L \) = length of a message (frame, packets, etc.) in bits
    - \( R \) = bit rate of the A to B link in bps
    - \( x = \) time to transmit a packet = \( L/R \) seconds
    - \( P \) = propagation delay from A to B in seconds
  - Two basic protocols
    - Stop and wait
    - Sliding window

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

**Data Link Basics**

- Stop and Wait Flow Control
  - also called Idle RQ (Repeat Request)
  - after A sends a message (packet), it waits for an ACK from B before sending the next packet.
  - analysis:
    1. At time \((t_0)\), A starts transmission of first bit in packet:

   ![Diagram of packet transmission](image)

   2. At time \((t_0 + x)\), A finished packet transmission

   ![Diagram of packet transmission](image)
Data Link Basics

3. At time \((t_0 + x + P)\), last bit of packet reaches B, true for both \(P > x\) and \(P < x\)

4. At time \((t_0 + x + P + y)\), last bit of ACK leaves B, given \(m\) bits in ACK packet and \(y = \frac{m}{R}\) seconds

5. At time \((t_0 + x + P + y + P)\), last bit of ACK reaches A and A can start next packet transmission

Data Link Basics

- Link Utilization:
  - Maximum Utilization of A - B link

\[
U = \frac{x}{x + y + 2P} = \frac{x}{x + \frac{1}{2}a} = \frac{1}{1 + 2\left(\frac{1}{x}\right)}
\]

\(a = \left(\frac{P}{x}\right)\) is normalized propagation delay
Data Link Basics

- How many bits are “stuck” in the media?

\[ B = R \frac{d}{v} \]

where:
- \( B \) = length of the link in bits
- \( R \) = rate of the link, in bps
- \( d \) = length in m
- \( v \) = velocity of propagation, in m/s

Sliding Windows Flow Control

- Allow multiple frames to be in transit
- Receiver has buffer of size \( W \)
- 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

Frames already transmitted and frames buffered until acknowledged form a window of frames that may be transmitted.

(a) Receiver's perspective

Frames already received and window of frames that may be accepted to form the sliding window.

**Example Sliding Window**

Source System A

Destination System B

Sequence 7
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 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)**

Three common approaches:

1. Stop and wait
2. Go back N
3. 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

Frame numbers alternate between 0 and 1

Stop and Wait is:
+ 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 frames

Go Back N - Lost Frame (1)

- Frame $i$ is 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 sends 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
Go Back N - Damaged Rejection

- As for lost frame (2)
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
### Data Link Basics

#### Performance: Stop & Wait ARQ

—note that utilization $U = \frac{T_f}{T_t}$ where:

- $T_f =$ time for transmitter to emit a single frame
- $T_t =$ total time line is engaged in transmission of 1 frame

—for error free Stop & Wait:

$$U = \frac{T_f}{T_f + 2T_p}, \quad \text{if } a = \frac{T_f}{T_p} \text{ then } U = \frac{1}{1+2a}$$

—for errors, $U = \frac{T_f}{(N_rT_t)}$, where $N_r$ is the expected number of transmissions of a particular frame

$$U = \frac{1}{N_r(1 + 2a)}$$

---

#### Data Link Basics

- Assume $P =$ probability a single frame is in error.
- Further assume ACKs and NAKs are never in error.
- The probability that we have $i$ transmissions of a frame is: $P^i(1-P)$
- Therefore:

$$N_r = \sum_{i=1}^{\infty} iP^{i-1}(1-P) = \frac{1}{1-P}$$

- For Stop & Wait then:

$$U = \frac{1-P}{1+2a}$$
Data Link Basics

— For Sliding Window:

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

— For Selective Repeat we have:

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

— For Go-Back-N we have to consider all retransmitted:

\[ U = \begin{cases} \frac{1 - P}{1 + 2aP} & N \geq 2a + 1 \\ \frac{N(1-P)}{(1+2a)(1-P+NP)} & N < 2a + 1 \end{cases} \]

Data Link Basics

— For Go-Back-N we have to consider all retransmissions. Then \( N_r \) is the expected number of transmitted frames to successfully transmit one frame. Each error generates requirement to retransmit \( K \) frames.

\[ N_r = \sum_{i=0}^{\infty} f(i)P^{i-1}(1-P) \]

with \( f(i) = 1 + (i-1)K = (1-K) + Ki \)

then

\[ N_r = (1-K) \sum_{i=0}^{\infty} P^{i-1}(1-P) + K \sum_{i=0}^{\infty} iP^{i-1}(1-P) \]

with \( \sum_{i=0}^{\infty} r^i = \frac{1}{1-r} \quad \text{and} \quad \sum_{i=0}^{\infty} ir^{i-1} = \frac{1}{(1-r)^2} \)

we get

\[ N_r = 1 - K + \frac{K}{1-P} = \frac{1 - P + KP}{1-P} \]
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

**HDLC Transfer Modes (1)**

- **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 is primary
  - Terminals is 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

HDLC Transfer Modes (3)

- 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

<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-bit</td>
<td>8 bits</td>
<td>8 or 16</td>
<td>variable</td>
<td>16 or 32</td>
<td>8-bit</td>
</tr>
</tbody>
</table>

(a) Frame format
**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:**

```
111111111110111110111110
```

**After bit-stuffing**

```
1111101111101101111101011111010
```

(a) Example

![Diagram](transmitted_frame.png)

(b) An inverted bit splits a frame in two

![Diagram](received_frame_split.png)

(c) An inverted bit merges two frames

![Diagram](received_frame_merge.png)
**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**

<table>
<thead>
<tr>
<th>Field</th>
<th>Bits</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information</td>
<td>0</td>
<td>N(S) = Send sequence number</td>
</tr>
<tr>
<td>S: Supervisory</td>
<td>1</td>
<td>P bit</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>1 to solicit (poll) response from peer</td>
</tr>
<tr>
<td>U: Unnumbered</td>
<td>1</td>
<td>F bit</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1 indicates response to soliciting command</td>
</tr>
</tbody>
</table>

N(S) = Send sequence number
R(R) = Receive sequence number
S = Supervisory function bits
M = Unnumbered function bits
P/F = Poll/Final bit

**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

**Summary**

- introduced need for data link protocols
  - which included background on *interfacing*
- flow control
- error control
- HDLC