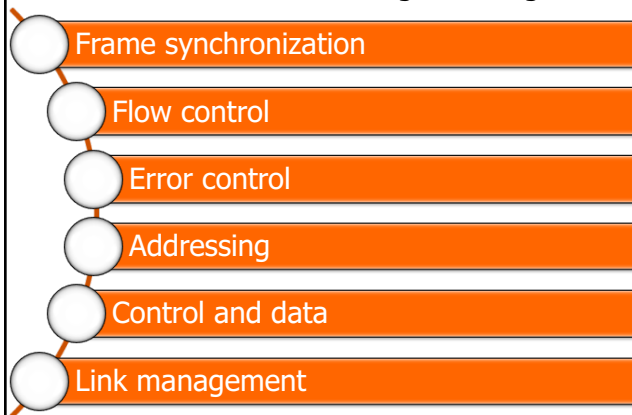# Chapter 7: Data Link Control

Data Link Control Protocols

- Need layer of logic above Physical to manage exchange of data over a link. Requirements and objectives for effective data communication between **two directly connected** transmitting-receiving stations:

Frame synchronization

Flow control

Error control

Addressing

Control and data

Link management

1

Background information

Just to get a feeling for the bigger picture, let's look at a historic example and start with the physical layer

Begin(...

—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)

Traditional Configurations

Host
(primary)

Terminals
(secondaries)
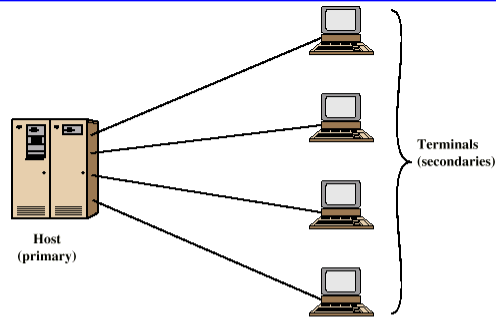
(a) Point-to-point
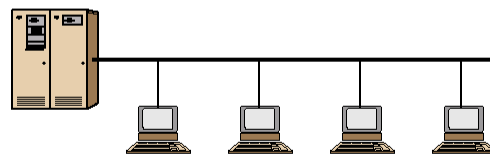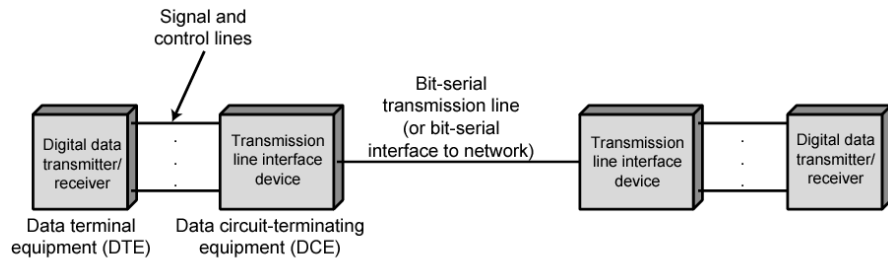
(b) Multipoint

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

3

Data Communications Interfacing

Signal and control lines

Bit-serial transmission line (or bit-serial interface to network)

Digital data transmitter/receiver

Transmission line interface device

Transmission line interface device

Digital data transmitter/receiver

Data terminal equipment (DTE)

Data circuit-terminating equipment (DCE)

(a) Generic interface to transmission medium

EIA-232/V.24 interface

Network

(b) Typical configuration

Characteristics of Interface

- Mechanical
  —Connection plugs
- Electrical
  —Voltage, timing, encoding
- Functional
  —Data, control, timing, grounding
- Procedural
  —Sequence of events

4

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

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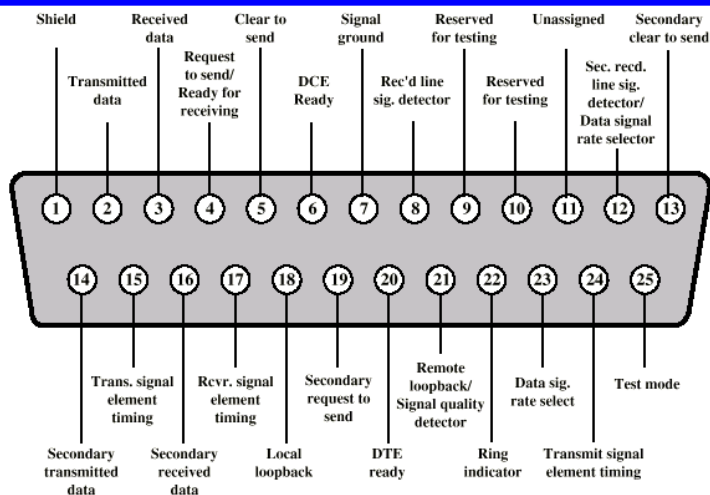V.28 issued in 1993

Mechanical Specification

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

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
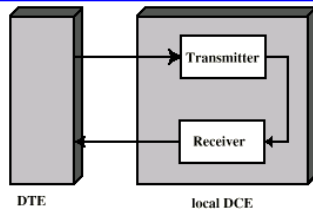
Functional Specification

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

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

Functional Specification

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

Local and Remote Loopback

Transmitter

Receiver

DTE   **local DCE**

(a) Local loopback Testing

Transmitter   Receiver

Receiver   Transmitter

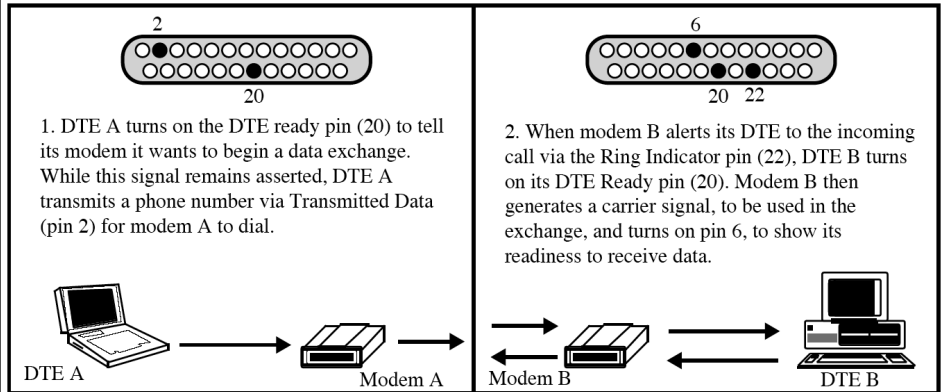**DTE**   **local DCE**   **remote DCE**
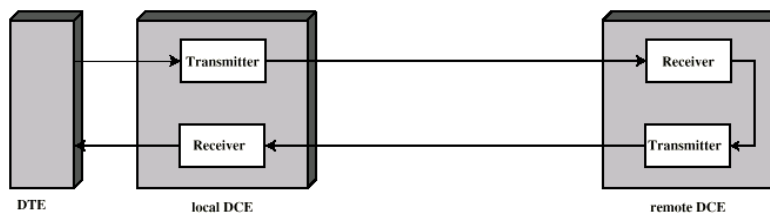
(b) Remote loopback Testing
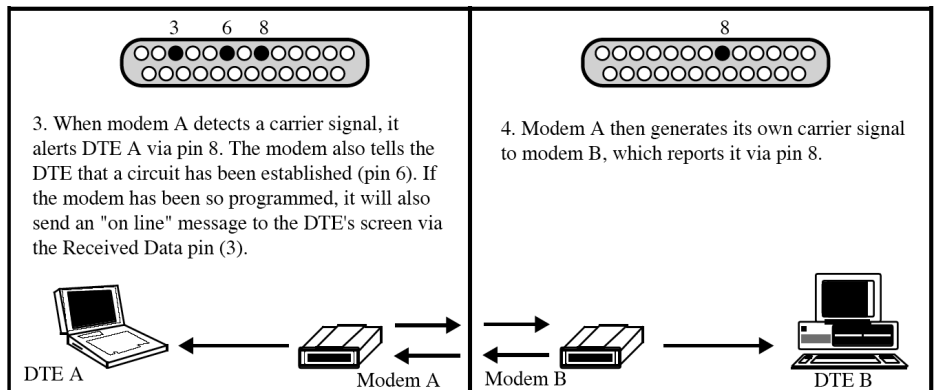
Procedural Specification

- 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
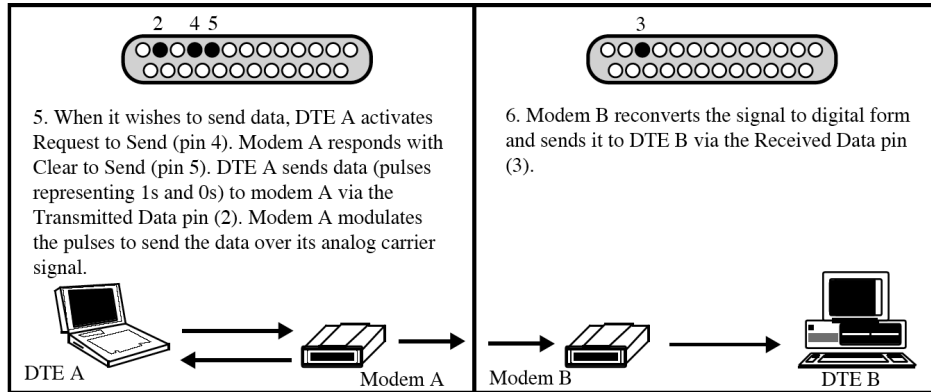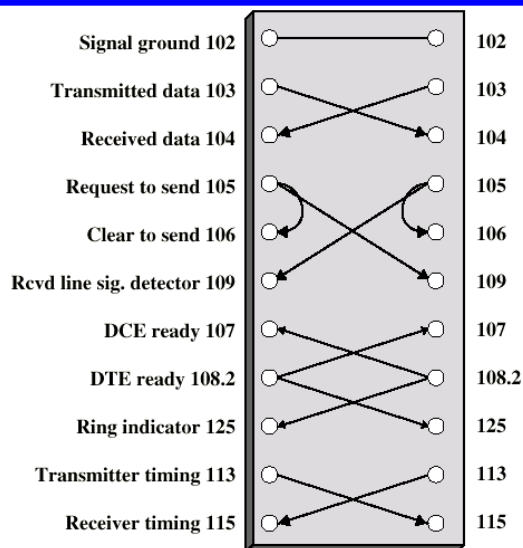
8

Dial Up Operation (1)

2

20

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.

DTE A

Modem A

6

20 22

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.

Modem B

DTE B

Dial Up Operation (2)

3   6   8

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).

DTE A

Modem A

8

4. Modem A then generates its own carrier signal to modem B, which reports it via pin 8.

Modem B

DTE B

9

Dial Up Operation (3)

2 4 5

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).

DTE A

Modem A

Modem B

DTE B

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

10

…and then there was ISDN. Physical Interface Diagram

Terminal Equipment (TE)

Network Equipment (NE)

Power source 3

Integrated
Service
Digital
Network

a · a
b · b
c · c
d · d

Transmit

Receive

Receive

Transmit

e · e
f · f

Power sink 2

g · g
h · h

Power source 2
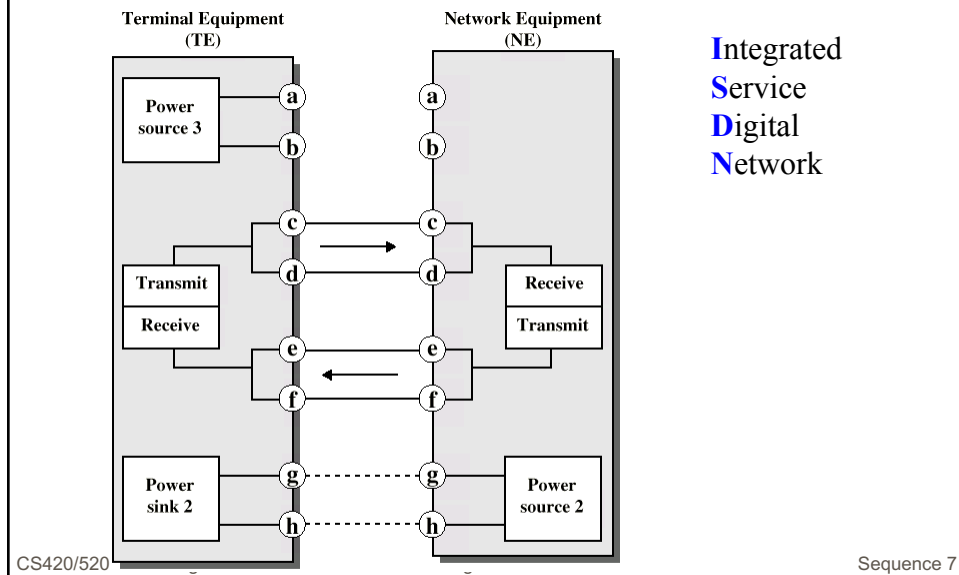
ISDN Physical Interface

- 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

11

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	Destination	Source	Destination

Frame 1 → Frame 1

Frame 2 → Frame 2

Frame 3 → Frame 3

Frame 4 → Frame 4

Time ↓

Frame 5 → Frame 5

Frame 1 → Frame 1

Frame 2 →

Frame 3 → Frame 3

Frame 4 → Garbled frame

Frame 5 → Frame 5
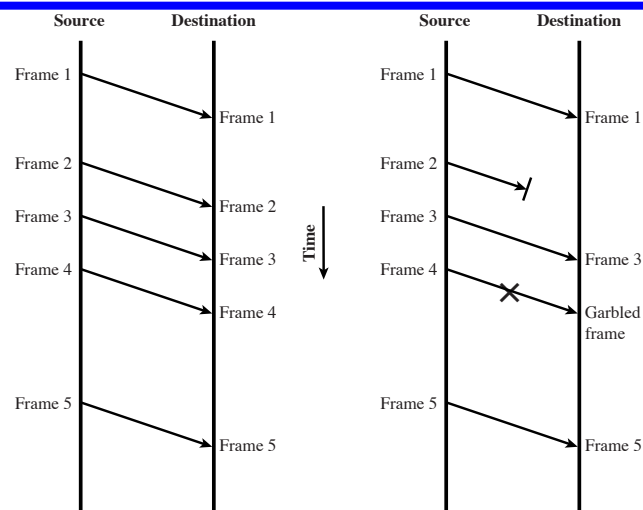
(a) Error-free transmission

(b) Transmission with losses and errors

13

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:
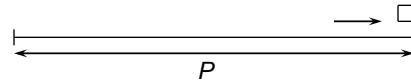   1. At time (t_0), A starts transmission of first bit in packet:

       P
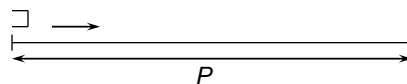
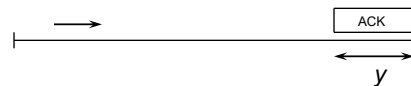   2. At time ($t_0 + x$), A finished packet transmission
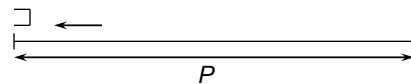
       x
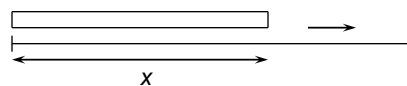
Data Link Basics

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

$$P$$

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

ACK

$$y$$

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

$$P$$

Data Link Basics

• Link Utilization:

— Maximum Utilization of A - B link

$$U = \frac{x}{x + y + 2P}$$

$= $ data transmission time/overhead time

$= \dfrac{x}{x + 2P}$, neglecting y

$= \dfrac{1}{1 + 2\left(\frac{P}{x}\right)}$

$= \dfrac{1}{1 + 2a}$, $a = \left(\frac{P}{x}\right)$ 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
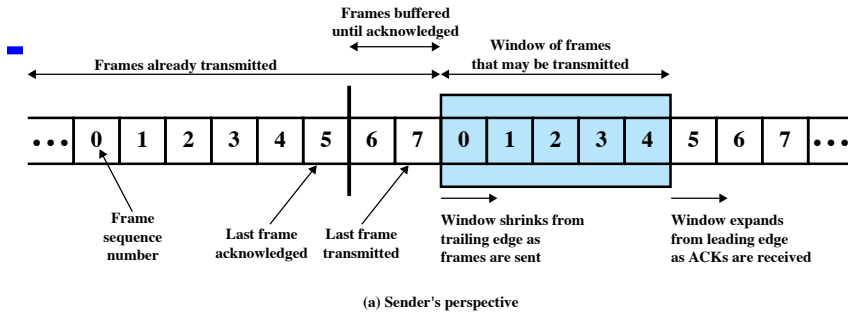R = rate of the link, in bps
d = length in m
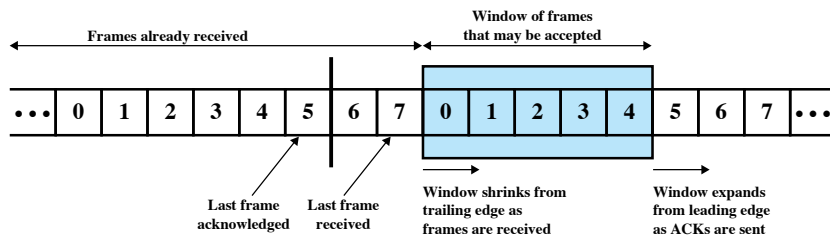v = velocity of propagation, in m/s

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)
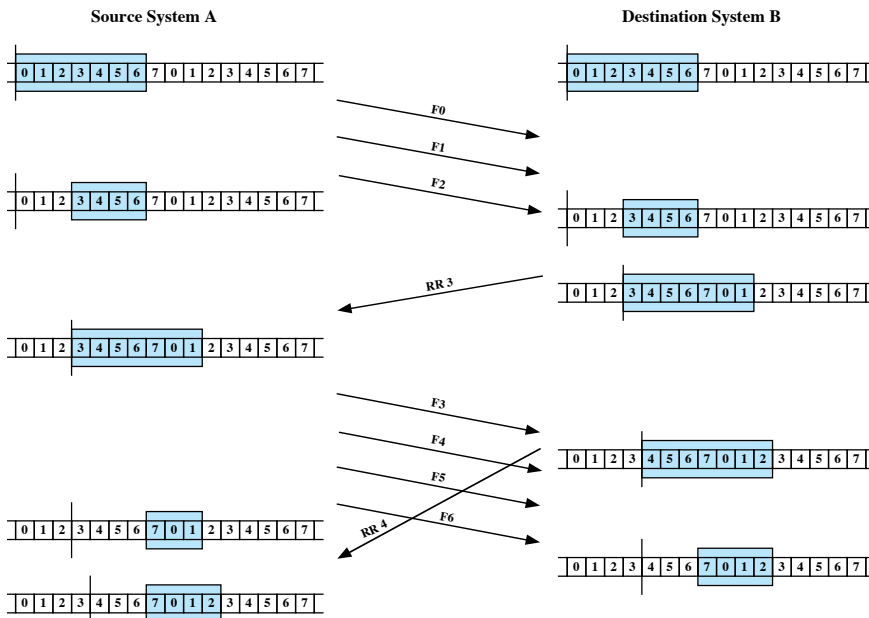 - Frames are numbered modulo 2^k

Sliding Window Diagram

Frames buffered until acknowledged

Window of frames that may be transmitted

Frames already transmitted

... | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | **0** | **1** | **2** | **3** | **4** | 5 | 6 | 7 | ...

Frame sequence number

Last frame acknowledged

Last frame transmitted

Window shrinks from trailing edge as frames are sent

Window expands from leading edge as ACKs are received

(a) Sender's perspective

Window of frames that may be accepted

Frames already received

... | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | **0** | **1** | **2** | **3** | **4** | 5 | 6 | 7 | ...

Last frame acknowledged

Last frame received

Window shrinks from trailing edge as frames are received

Window expands from leading edge as ACKs are sent

(b) Receiver's perspective

Example Sliding Window

Source System A

Destination System B

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

F0

F1

F2

| 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 |

RR 3

| 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 |

F3

F4

F5

F6

RR 4

| 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 |

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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
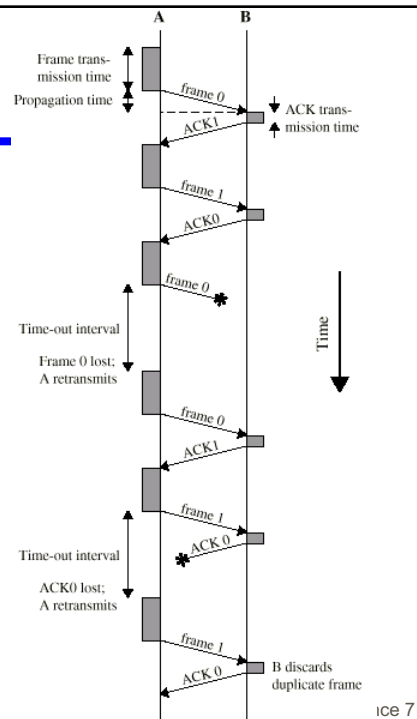
Frame trans-mission time
Propagation time
ACK trans-mission time

frame 0
ACK1
frame 1
ACK0
frame 0

Time

Time-out interval
Frame 0 lost; A retransmits

frame 0
ACK1
frame 1
ACK 0

Time-out interval
ACK0 lost; A retransmits

frame 1
ACK 0
B discards duplicate frame

A   B

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 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

Go Back N - Damaged Rejection

- As for lost frame (2)

Go Back N - Diagram

24
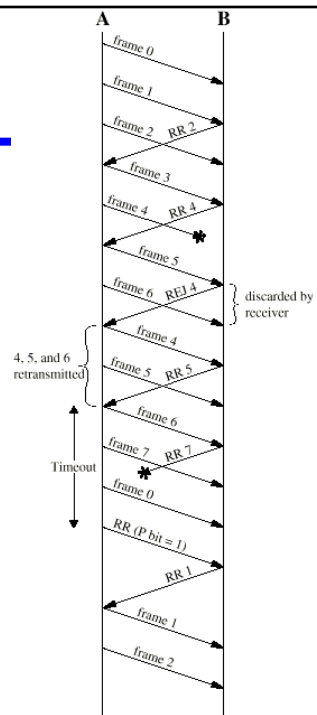
Selective Reject

- 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 log mechanism in transmitter

Selective Reject - Diagram

25
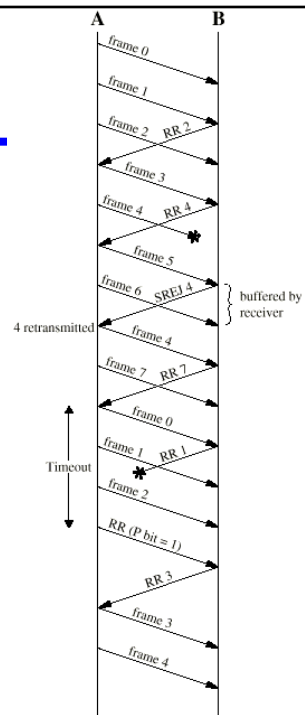
Data Link Basics

Performance: Stop & Wait ARQ

— note that utilization $U = T_f/T_t$ 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:

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

— for errors, $U = T_f/(N_r T_t)$, 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 <u>single frame is in error</u>.
- Further assume ACKs and NAKs are never in error.
- The probability that we have i transmissions of a frame is:

    $P^{i-1}(1-P)$

- 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:

$$U = \begin{cases} 1 & N \ge 2a+1 \\ \dfrac{N}{2a+1} & N < 2a+1 \end{cases}$$

— For Selective Repeat we have:

$$U = \begin{cases} 1-P & N \ge 2a+1 \\ \dfrac{N(1-P)}{2a+1} & N < 2a+1 \end{cases}$$

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

$$U = \begin{cases} \dfrac{1-P}{1+2aP} & N \ge 2a+1 \\[4mm] \dfrac{N(1-P)}{(1+2a)(1-P+NP)} & N < 2a+1 \end{cases}$$

Data Link Basics

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

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

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

then

Total # frames transmitted if original frame must be transmitted i times

$$N_r = (1-K)\sum_{i=1}^{\infty} P^{i-1}(1-P) + K\sum_{i=1}^{\infty} i P^{i-1}(1-P)$$

with $\displaystyle\sum_{i=0}^{\infty} r^i = \sum_{i=1}^{\infty} r^{i-1} = \frac{1}{1-r}$ and $\displaystyle\sum_{i=1}^{\infty} i r^{i-1} = \frac{1}{(1-r)^2}$

we get

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

High Level Data Link Control

Most important data link control protocol:
- HDLC specified as ISO 33009, ISO 4335
- Basis for other data link control protocols

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)
    - Most widely used
    - Balanced configuration
    - Either station may initiate transmission without receiving permission
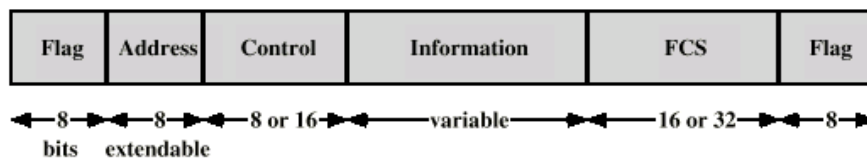   - No polling overhead

HDLC Transfer Modes (3)

- Asynchronous Response Mode (ARM)
    - Rarely used
    - Unbalanced configuration
    - Secondary may initiate transmission without permission form primary
    - Primary responsible for line

Frame Structure

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

Frame Structure

Flag	Address	Control	Information	FCS	Flag

◄—8—►◄—8—►◄—8 or 16—►◄——variable——►◄——16 or 32—►◄—8—►
bits   extendable

(a) Frame format

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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
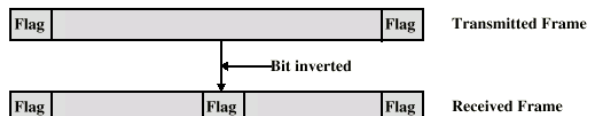
Bit Stuffing

Original Pattern:
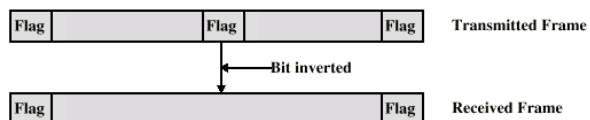
111111111111011111101111110

After bit-stuffing

- Example with possible errors

11111011111011011111101011111010

(a) Example

| Flag | | Flag | Transmitted Frame |

Bit inverted

| Flag | | Flag | | Flag | Received Frame |

(b) An inverted bit splits a frame in two

| Flag | | Flag | | Flag | Transmitted Frame |

Bit inverted

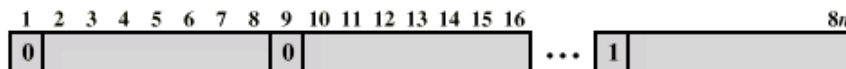| Flag | | Flag | Received Frame |

(c) An inverted bit merges two frames

Address Field

- Identifies secondary station that transmitted or will receive frame
- Usually 8 bits long
- May be extended to multiples of 7 bits
  - Leftmost bit indicates if it is is the last octet (1) or not (0)
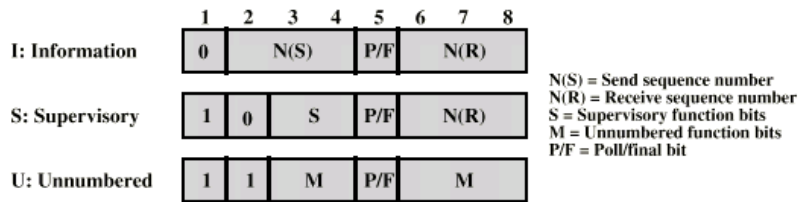- Address 11111111 allows a primary to broadcast a frame for reception by all secondaries

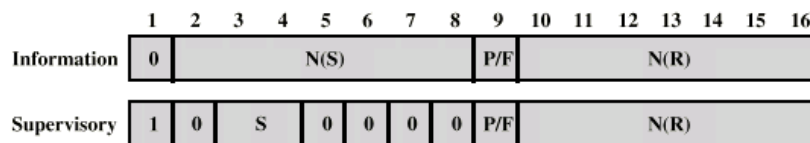**(b) Extended Address Field**

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

	1	2	3	4	5	6	7	8
I: Information	0		N(S)		P/F		N(R)	
S: Supervisory	1	0	S		P/F		N(R)	
U: Unnumbered	1	1	M		P/F		M	

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

(c) 8-bit control field format

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Information	0			N(S)					P/F			N(R)				
Supervisory	1	0	S		0	0	0	0	P/F			N(R)				

(d) 16-bit control field format

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

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Information Field

- Only in information and some unnumbered frames
- Must contain integral number of octets
- Variable length

Frame Check Sequence Fields

- FCS
- Error detection code calculated from the remaining bits of the frame, exclusive of flags
- Normal code is 16 bit CRC-CCITT
- Optional 32 bit CRC

HDLC Operation

➤ Consists of the exchange of I-frames, S-frames and U-frames and involves three phases:

Initialization
- Signals the other side that initialization is requested
- Specifies which of the three modes (NRM, ABM, ARM) is requested
- Specifies whether 3- or 7-bit sequence numbers are to be used

Data Transfer
- The N(S) and N(R) fields of the I-frame are sequence numbers that support flow control and error control
- An HDLC module will number them sequentially
- Receive Ready (RR) is used when there is no reverse user data traffic

Disconnect
- Either module can initiate
- Either on its own initiative if there is some sort of fault, or at the request of its higher-layer user
- Sends disconnect (DISC) frame
- Remote entity replies with a UA
- Any outstanding unacknowledged I-frames may be lost
- Recovery is the responsibility of higher layers

Name	Command/Response	Description
Information (I)	C/R	Exchange user data
Supervisory (S)		
Receive ready (RR)	C/R	Positive acknowledgment; ready to receive I-frame
Receive not ready (RNR)	C/R	Positive acknowledgment; not ready to receive
Reject (REJ)	C/R	Negative acknowledgment; go back N
Selective reject (SREJ)	C/R	Negative acknowledgment; selective reject
Unnumbered (U)		
Set normal response/extended mode (SNRM/SNRME)	C	Set mode; extended = 7-bit sequence numbers
Set asynchronous response/extended mode (SARM/SARME)	C	Set mode; extended = 7-bit sequence numbers
Set asynchronous balanced/extended mode (SABM, SABME)	C	Set mode; extended = 7-bit sequence numbers
Set initialization mode (SIM)	C	Initialize link control functions in addressed station
Disconnect (DISC)	C	Terminate logical link connection
Unnumbered Acknowledgment (UA)	R	Acknowledge acceptance of one of the set-mode commands
Disconnected mode (DM)	R	Responder is in disconnected mode
Request disconnect (RD)	R	Request for DISC command
Request initialization mode (RIM)	R	Initialization needed; request for SIM command
Unnumbered information (UI)	C/R	Used to exchange control information
Unnumbered poll (UP)	C	Used to solicit control information
Reset (RSET)	C	Used for recovery; resets N(R), N(S)
Exchange identification (XID)	C/R	Used to request/report status
Test (TEST)	C/R	Exchange identical information fields for testing
Frame reject (FRMR)	R	Report receipt of unacceptable frame

Table 7.1

HDLC Commands and Responses

(Table can be found on page 230 in the textbook)
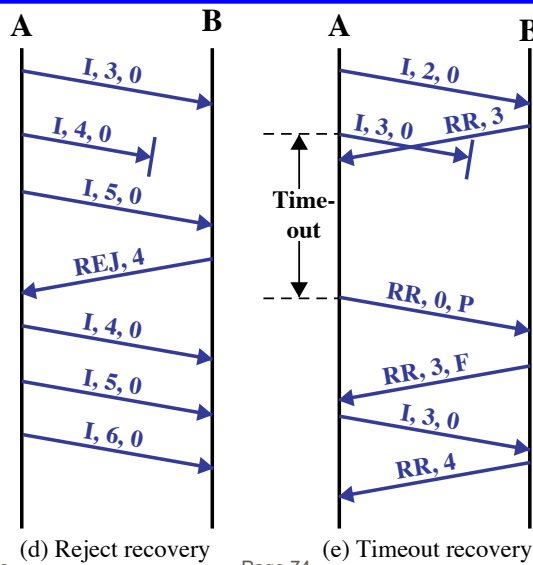
Examples of Operation (1)

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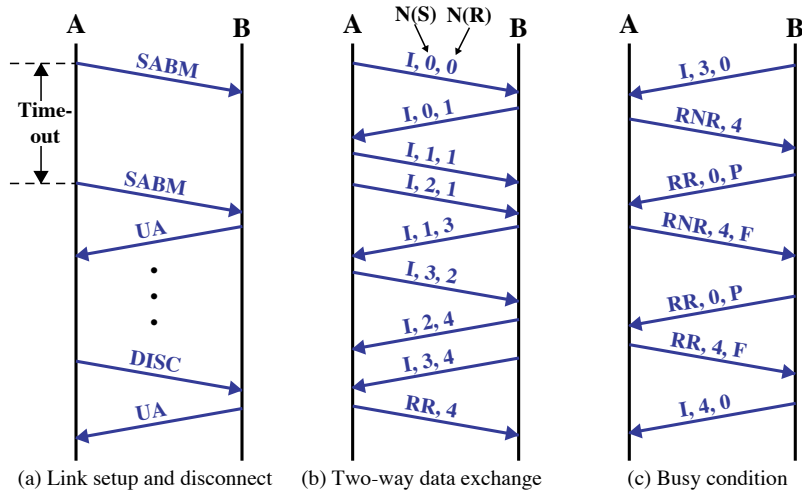
Examples of Operation (2)

(d) Reject recovery (e) Timeout recovery

Summary

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