Data Link Control

Used for transfer of data from point to point

node to node in a network

provides

- transparency
- flow control
- error detection and correction

Transparency

Header	Data	Checksum

- Datalink level must be able to transmit any bit patterns
- So: how do we know where the header ends and the data begins?

Character stuffing

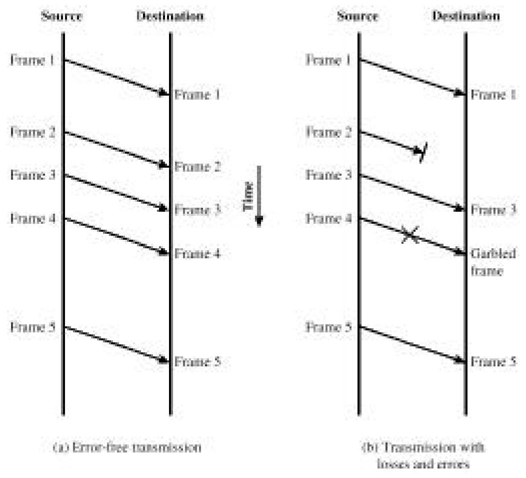
- Early protocols used particular ASCII codes for marking out the parts of the frame
  - SOH start of header
  - STX start of text
  - ETX end of text
- and used an escape character DLE whenever a control character has to be sent
  - STX DLE STX...

Bit-stuffing

- Modern protocols use fixed format headers
- but they still need to mark the start and end of a frame
- marked with bit pattern 01111110 **flag** byte
  - whenever 5 1's occur in a row in the data itself, a 0 bit is "stuffed" into the channel

Model of Frame Transmission

Murphy's law is valid here



Error Detection

- Additional bits are added by transmitter for error detection code
  - placed in trailer of frame
- Simple technique: 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
    - not good at detecting bursts of errors

Cyclic Redundancy Check

- For a block of k bits transmitter generates additional 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
  - easily implemented in hardware
    - very small delay overhead
  - For math see Tanenbaum pp 186-190,
  - For math and hardware implementation, see Stallings chapter 7 pp202-207

Error Control

- Means detection and correction of errors
- including
  - Lost frames
  - Damaged frames
- Automatic request for repeat
  - Error detection
  - Positive acknowledgment
  - Retransmission after timeout
  - Negative acknowledgement and retransmission

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

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 (ignoring errors)

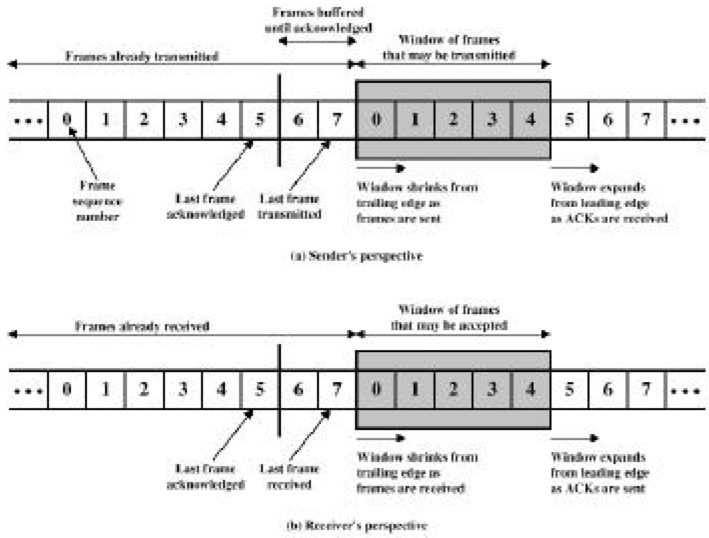
Fragmentation

- Large block of data is normally split into small frames
  - Limited buffer size
  - Errors detected sooner
  - On error, retransmission of smaller frames is needed
  - Prevents one station occupying medium for long periods
- Stop and wait becomes inadequate
  - propagation delay is also a possible problem

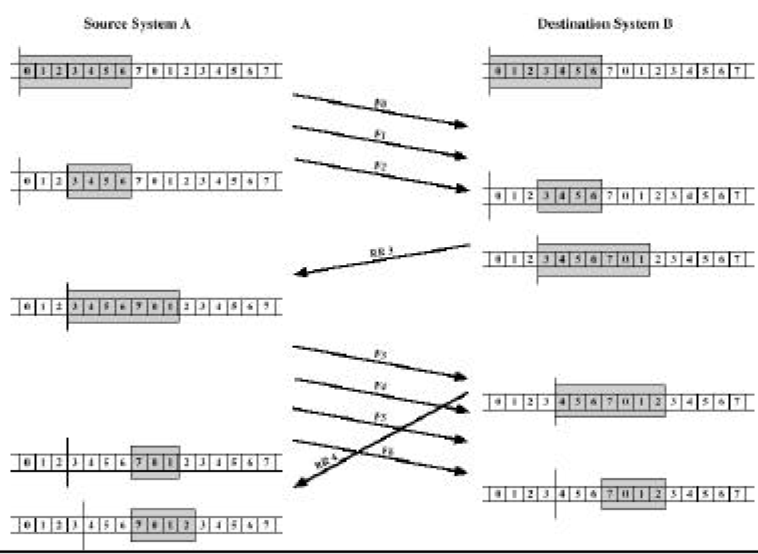
Sliding Windows Flow Control

- 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



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)

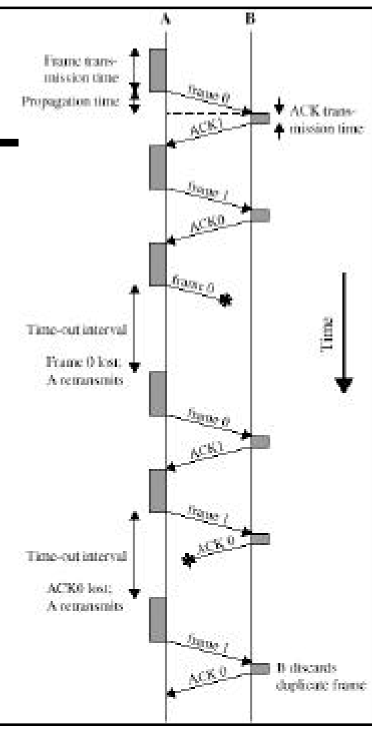
Automatic Request for Repeat (ARQ)

- 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
  - Receiver gets two copies of frame
  - Use ACK0 and ACK1

Stop and Wait - Diagram



Stop and Wait - Pros and Cons

- Simple
- Inefficient
  - round trip delay before next packet can be transmitted

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

Go Back N - Lost Frame (1)

- Frame *i* lost
- Transmitter sends *i+1*
- Receiver gets frame *i+1* out of sequence
- Receiver sends reject *i*
- Transmitter goes back to frame *i* and retransmits

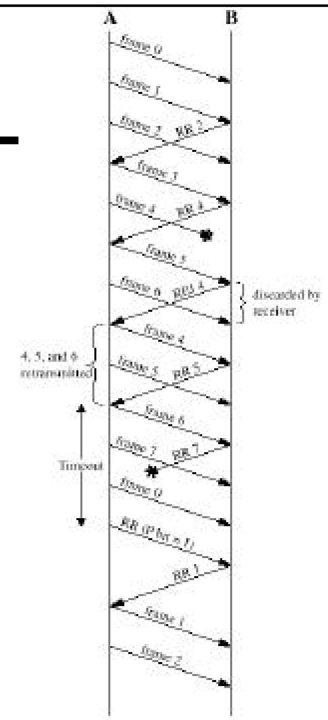
Go Back N - Lost Frame (2)

- 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

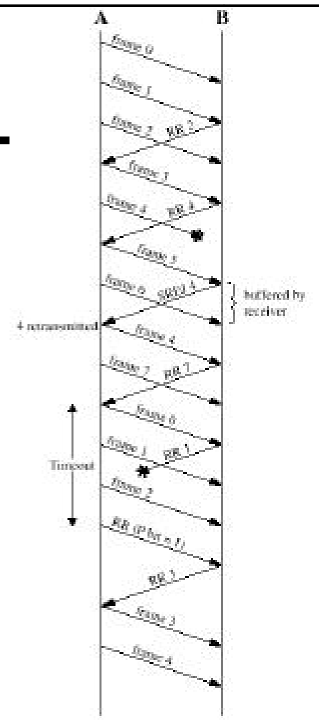
Go Back N - Diagram



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 log 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

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 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

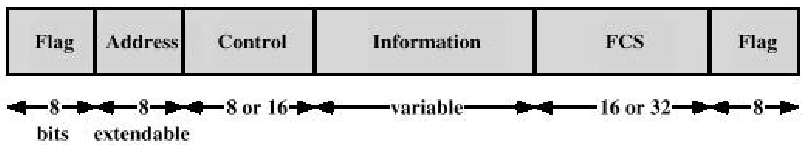
HDLC Transfer Modes (3)

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

Frame Structure

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

Frame Structure Diagram

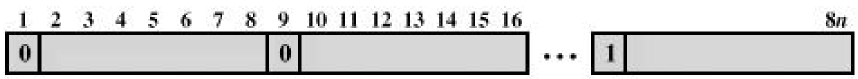


Flag Fields

- 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

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



(b) Extended Address Field

Control Field

- Different for different frame types
  - 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 field 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

Supervisory Frames

1	0	**Type**	**P/F**	Next

Next - 1st Frame in seq that has not been received correctly

Poll/Final Field - to probe terminal to send frames
Type: defines different supervisory frames

- Type 0 - acknowledgement frame used to indicate receiver is ready (Receiver Ready)
- Type 1 - negative acknowledgement to indicate transmission error
- Type 2 - Receiver Not Ready - it acknowledges all frames up to but not including next, it tells sender to stop SND
- Type 3 - Selective Repeat - it calls for retransmission of only the frame specified

Unnumbered Frames

1	1	**Type**	**P/F**	**Modifier**

used for control purposes
also used to carry data over unreliable connectionless channels
5 bits are used to define frame type - 32 possible combinations

- Disconnect Frame
- Announce a machine presence (set Normal Response Mode)
- FrameReject (FRMR) - a frame arrived with correct CRC, but impossible semantics
- other types of frames deal with
  - initialization
  - polling and status

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

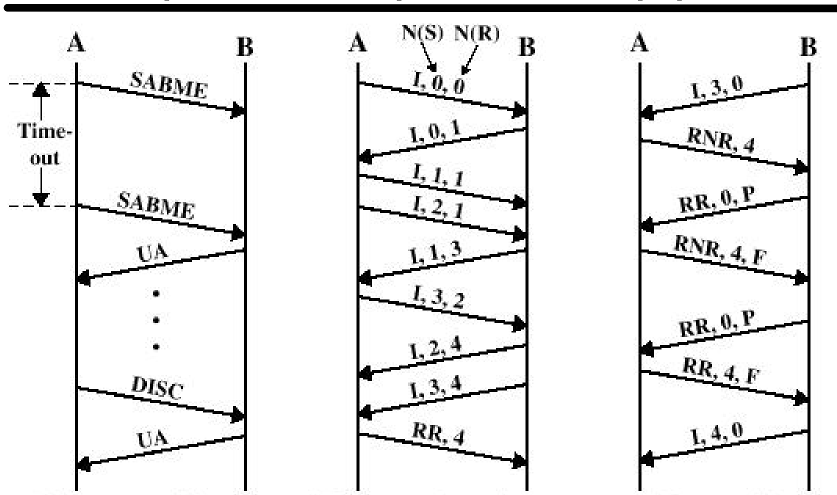
Frame Check Sequence Field

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

HDLC Operation

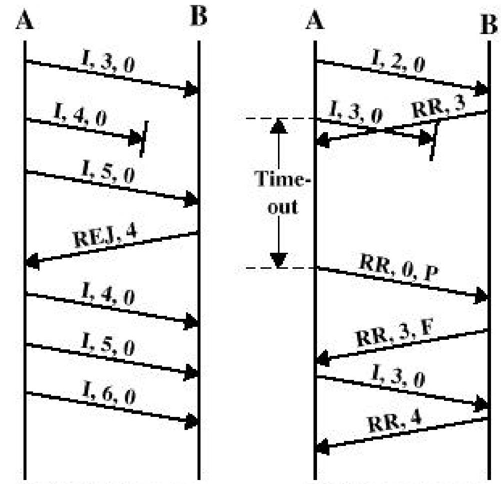
- Exchange of information, supervisory and unnumbered frames
- Three phases
  - Initialization
  - Data transfer
  - Disconnect

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
  - will discuss later

Other DLC Protocols (Frame Relay) (1)

- Streamlined capability over high speed packet switched networks
- Used in place of X.25
  - which was the original WAN network level protocol
- 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