2 Computer Networks Data Communications

Part 6
Data Link Control

Data link layer functions

- Framing
  - Needed to synchronise TX and RX
  - Account for all bits sent
- Error control
  - Detect and correct errors
- Flow control
  - TX must not overwhelm RX, so
  - Have well-defined rules for TX and RX
- *Efficient transfer*

Framing (1)

- Start and ending characters with character stuffing
  - IF DLE is part of the data, add a DLE before it

A	DLE	B						Data send by the network layer
STX	DLE	A	DLE	DLE	B	DLE	ETX	after character stuffed by the data link layer
A	DLE	B						Data passed the network layer on the receiving side

Framing (2)

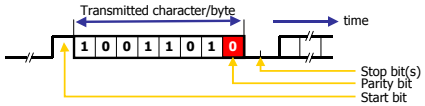
- Starting and ending flags with bit stuffing
  - Each frame starts and ends with the special bit pattern 01111110
  - to avoid the special bit pattern in the data stream, the sender inserts a 0 after every five 1's in data stream
  - Receiver removes the 0.
  - This works for arbitrary sized characters
- Physical layer coding violations
  - E.g: Manchester encoding 0=10, 1=01

Error Detection

- Additional bits added by transmitter for error detection
- Hamming distance – number of bit positions two codewords differ
- To detect d errors need a distance of d+1
- 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

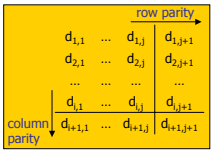
Parity Checking (1)

Single Bit Parity: Detect single bit errors



Parity Checking (2)

Two Dimensional Bit Parity:
Detect and *correct* single bit errors



1	0	1	0	1
1	1	1	1	0
0	1	1	1	0
0	0	1	0	1

no error

1	0	1	0	1
1	0	1	1	0
0	1	1	1	0
0	0	1	0	1

parity error

parity error

correctable single bit error

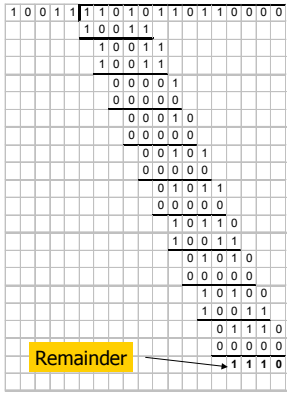
Cyclic Redundancy Check (1)

- For a block of *k* bits transmitter generates *r* bit sequence ➔ frame check sequence
- Transmit *k+r* bits which is exactly divisible by some number – the generator polynomial
- Receiver divides frame by that number
  - If no remainder, assume no error
  - If remainder, error has occurred

Cyclic Redundancy Check (2)

- Checksum computation done in hardware using simple circuits
  - Example: Frame: 1101011011, Gen: 10011
  - CRC-16, generates 16-bit checksum
  - $X^{16} + x^{15} + x^2 + 1$ is commonly used for 8-bit chars

(3)



Frame: 1101011011
Generator: 10011 ➔ x^4+x+1
Message after appending 4 zero bits: 11010110110000

Step1: Check degree of polynomial ➔ if fourth degree polynomial add four 0's
Step2: Divide the modified bit string from step1 by the generator
Step3: Append the remainder to the initial bit string

Transmitted frame: 11010110111110

Step4: The destination node receives the transmitted frame from step3 and performs same division
No remainder ➔ no error
remainder ➔ error has occurred

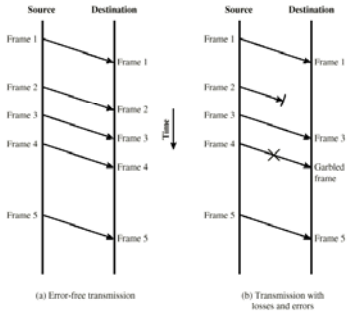
Error Control

- Must deal with:
  - Lost frames
  - Damaged frames
- Automatic repeat request (ARQ)
  - 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

Model of Frame Transmission



Stop and Wait Flow Control

- 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

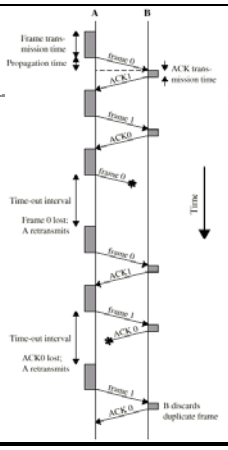
Fragmentation

- 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 ARQ

- 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
- The sender must wait a total time Tt of:
  - Tt= Tix+ Tip + Tp + Tax + Tap + Tp
  - Tt ≈ Tix +2Tp
  - Efficiency, U = Tix/ (Tix + 2Tp) = 1 /(1+2a)
  - a = Propagation time/transmission time ➔ (d/c)/(L/R)=Rd/cL
- Inefficient

Sliding Window Flow Control (1)

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

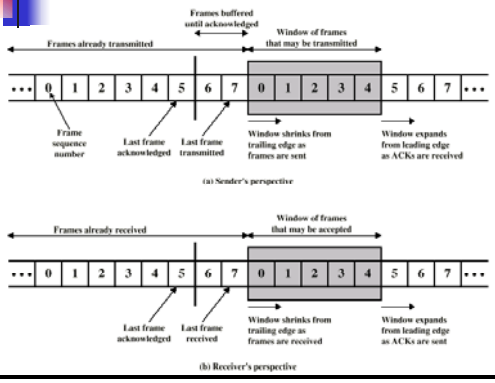
Sliding Window Flow Control (2)

- Send Window – sequence number of frames transmitter is allowed to send without acknowledgement
  - Retransmission list size is the max of this window
  - Window size varies as acks arrive and frames are sent
- Receive Window – sequence numbers of frames receiver is prepared to accept
  - Size varies as ACK's are sent, but has max size
  - Sequence numbers of frames received & not yet acknowledged kept

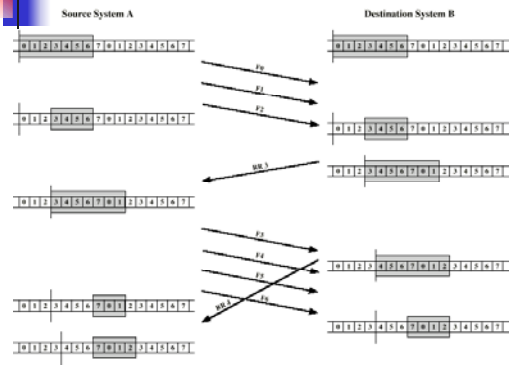
Sliding Window Flow Control (3)

- Send and receive windows sizes depends on
  - Max frame size, buffer storage size, tp, and R
  - Receive window also depends on Rx processing rate

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 Repeat Request (ARQ)

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

Continuous ARQ

- Sliding-window flow control technique sometimes referred to as continuous ARQ.
- Link utilization improved
- 100% link utilization if no errors and frame unrestricted
- Error occur
  - Go-Back N
  - Selective Reject (selective retransmission)

Go Back N

- 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(RR) 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*

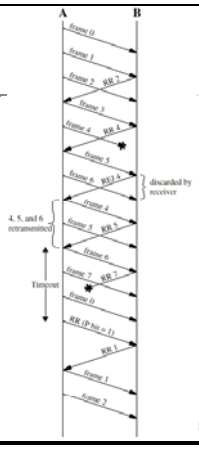
Go Back N – Damaged Acknowledgement

- 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 (RR) 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)

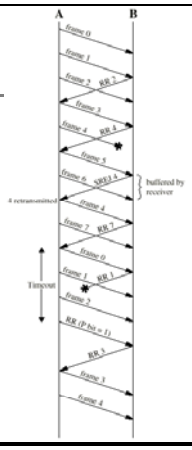
Go Back N - Diagram



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 logic in transmitter

Selective Reject - Diagram



High Level Data Link Control

- HDLC
- ISO 3309, 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

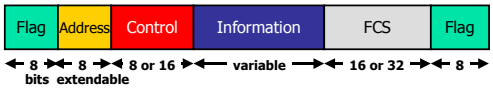
HDLC Transfer Modes (3)

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

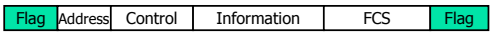
HDLC Frame Structure

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

HDLC - Frame Structure Diagram

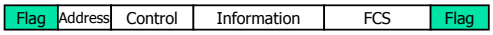


HDLC Frame: Flag Fields (1)



- Delimit frame at both ends
- 01111110
- Single flag may close one frame and open another
- Receiver hunts for flag sequence to synchronize

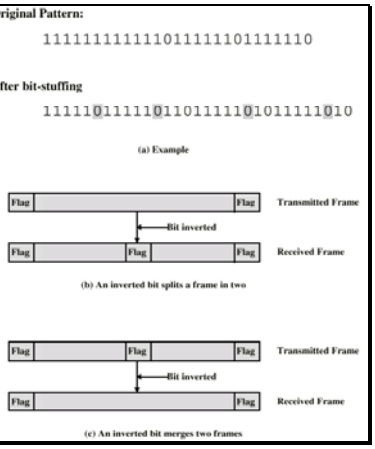
HDLC Frame: Flag Fields (2)



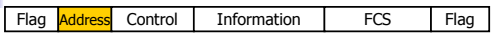
- Bit stuffing used to avoid confusion with data containing 01111110
  - 0 inserted after every sequence of five 1s
  - If receiver detects five 1s it checks next bit
  - If 0, it is deleted
  - If 1 and seventh bit is 0, accept as flag
  - If sixth and seventh bits 1, sender is indicating abort

Bit Stuffing

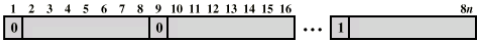
Example with possible errors



HDLC Frame: Address Field

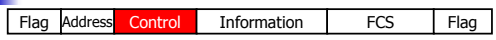


- Identifies secondary station that sent or will receive frame
- Usually 8 bits long
- May be extended to multiples of 7 bits
  - Leftmost bit of each octet indicates that it is the last octet (1) or not (0)
- All ones (11111111) is broadcast



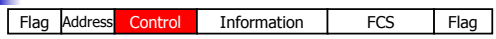
(b) Extended Address Field

HDLC Frame: Control Field

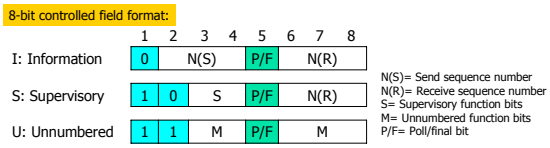


- Different for different frame type
  - *Information* frames- data to be transmitted to user (next layer up)
    - Flow and error control piggybacked on information frames
  - *Supervisory* frames- ARQ when piggyback not used
  - *Unnumbered* frames- supplementary link control
- First one or two bits of control filed identify frame type

HDLC Frame: Control Field Diagram

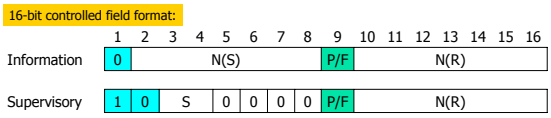


8-bit controlled field format:

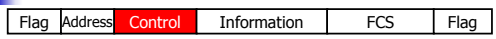


N(S)= Send sequence number
N(R)= Receive sequence number
S= Supervisory function bits
M= Unnumbered function bits
P/F= Poll/final bit

16-bit controlled field format:



HDLC Frame: Poll/Final Bit

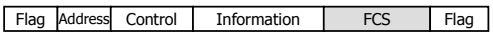


- Use depends on context
- Command frame
  - P bit
  - 1 to solicit (poll) response from peer
- Response frame
  - F bit
  - 1 indicates response to soliciting command

HDLC Frame: Information Field

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

HDLC Frame: Frame Check Sequence Field

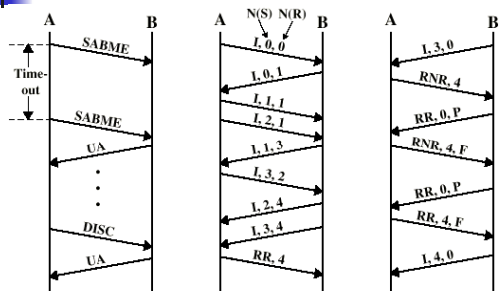


- FCS
- Error detection
- 16 bit CRC
- Optional 32 bit CRC

HDLC Operation

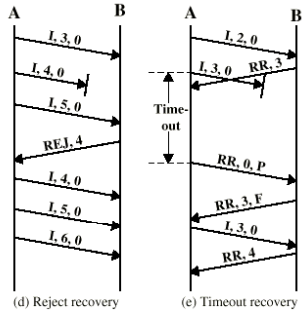
- Exchange of information, supervisory and unnumbered frames
- Three phases
  - Initialization of data link so that frames can be exchanged in order
  - Data transfer after initialization
  - Disconnect

Examples of HDLC Operation (1)



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

Examples of HDLC 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