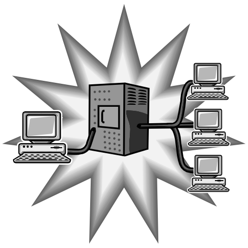
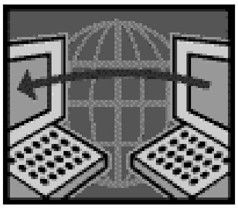
Data and Computer Comm.

Stallings – Chapter 7

Data Link Control Protocols



NOTE: Many figures and other materials in this presentation are borrowed from required and reference textbooks cited on the class web page.



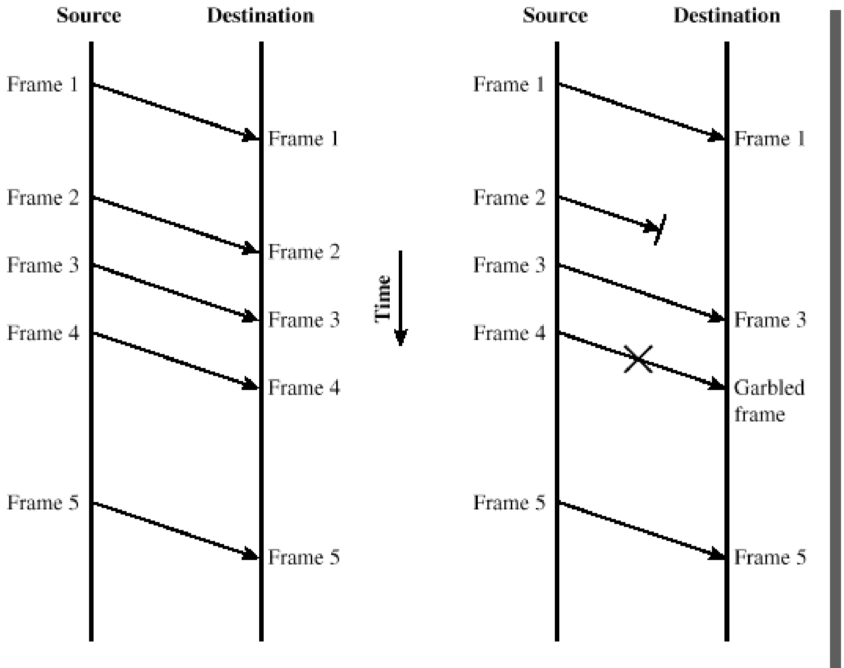
Data Link Control Protocols

Flow Control

Flow Control

- Ensuring the sending entity does not overwhelm the receiving entity
  - Preventing buffer overflow
- Transmission time
  - Time taken to emit all bits of frame onto medium
  - Proportional to length of frame (and data rate)
- Propagation time
  - Time for a bit to traverse link between source and destination (a function of velocity and distance)

Model of Frame Transmission



(a) Error-free transmission

(b) Transmission with losses and errors

Stop-and-Wait

- Simplest form of flow control
- Basic behavior
  - Source transmits frame
  - Destination receives frame and replies with acknowledgement (ACK)
  - Source waits for ACK before sending next frame
  - Destination can stop flow by not sending ACK
- Works well for a few large frames

Fragmentation

- Large block of data may be split into small frames
- Why?
  - Limited buffer size at receiver
  - Errors detected sooner (when flawed frame received)
  - On error, retransmission of smaller frames is needed
  - Prevents one station from occupying medium for long periods on shared medium
- S&W often becomes inadequate due to inherent inefficiency of link utilization
  - Particularly bad for high data rates and/or over long distances (i.e. where prop. time > trans. time)

S&W Link Utilization

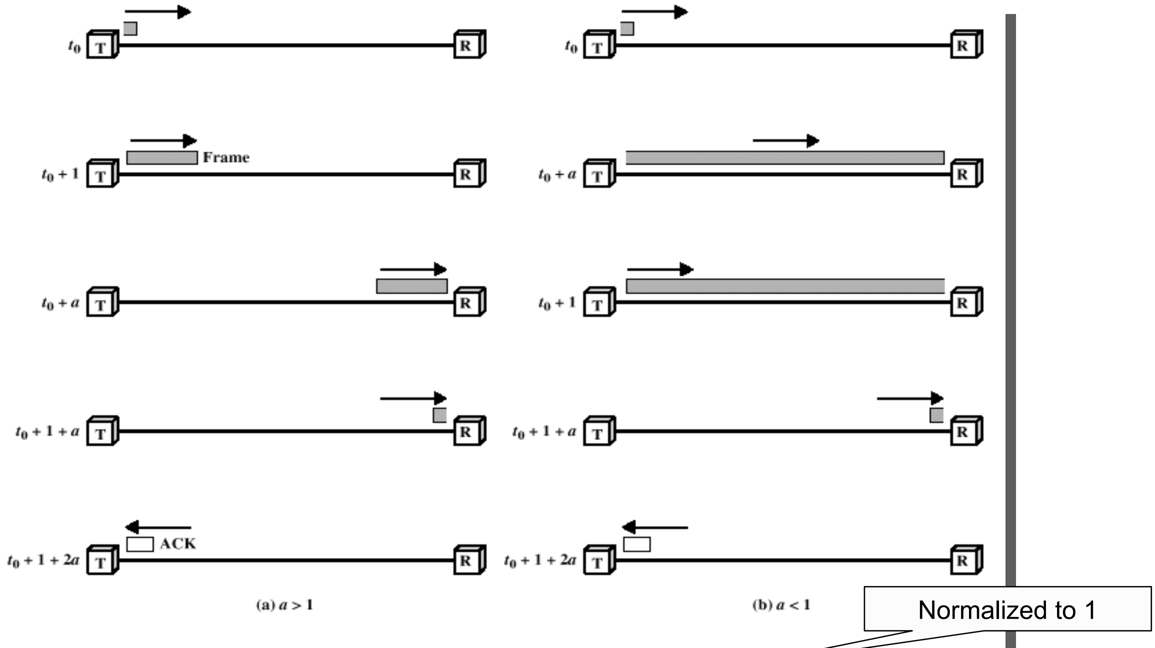


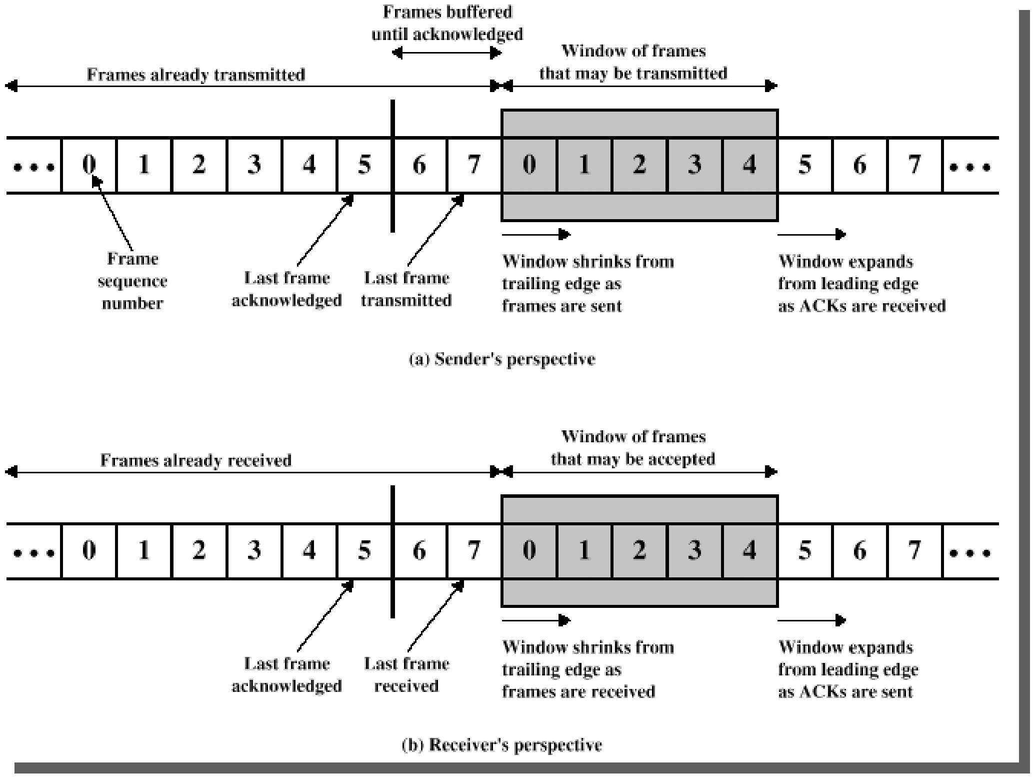
Figure 7.2 Stop-and-Wait Link Utilization (transmission time = 1; propagation time = a)

Note: Transmission time of ACK here is assumed negligible.

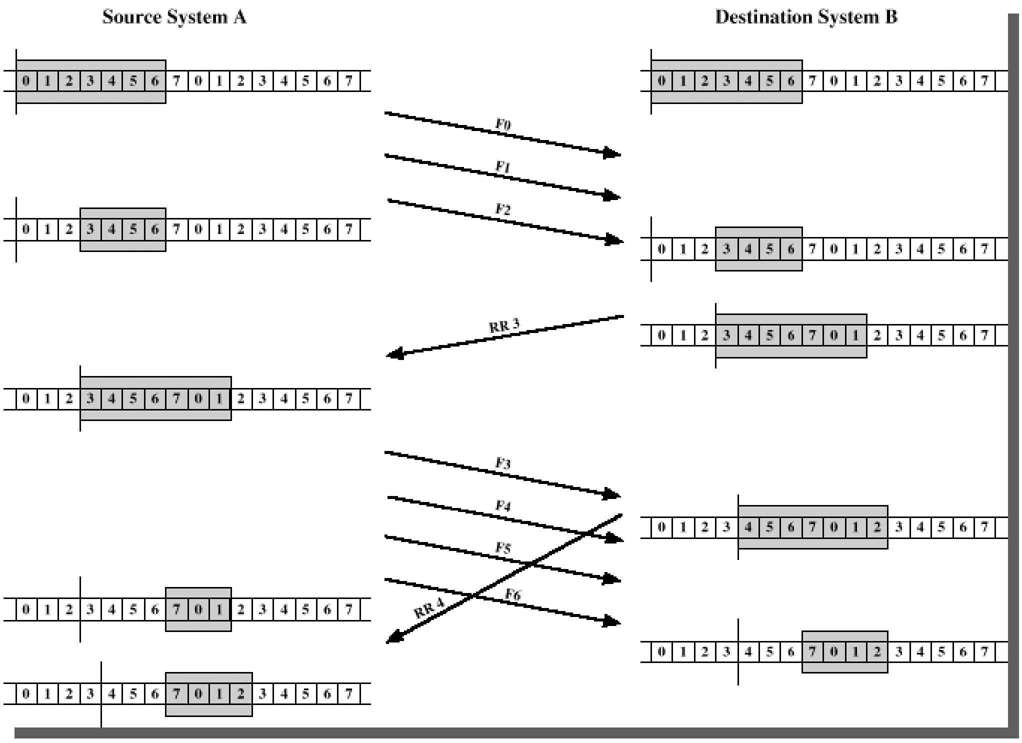
Sliding-Window Flow Control

- Allow multiple frames to be in transit
  - Transmission link is treated as a *pipeline*
- Receiver has buffer that is W frames long
- Transmitter can send up to W frames w/o ACK
- Each frame is numbered
- ACK includes number of next frame expected (RR = Receive Ready)
- Range of seq. numbers bounded by size of field
  - *k*-bit field => seq. #s 0 thru 2^k-1
  - Actual window size may be < max. possible size
  - Frames are numbered modulo 2^k

Sliding-Window Diagram



Sliding-Window Example



Here we have 3-bit seq. number, window size of 7 frames

Sliding-Window Enhancements

- Receiver can acknowledge frames without permitting further transmission (Receive Not Ready = RNR)
  - But, must later send a normal ACK to resume
- If duplex, can use piggybacking
  - Each data frame includes both seq. # of that frame plus seq. # used for ACK of reverse direction
  - If no data to send, use acknowledgement frame
  - If data but no acknowledgement to send, send last acknowledgement number again

Data Link Control Protocols

Error Control

Error Control

- Detection and correction of errors
- What do we worry about?
  - Lost frames (fail to arrive)
  - Damaged frames (some bits garbled)
- Automatic repeat request (ARQ)
  - Error detection (e.g. CRC)
  - Positive acknowledgment (from receiver on success)
  - Retransmission after timeout (when timer expires)
  - Negative acknowledgement and retransmission
    - Instead of making sender wait for timeout to retransmit, receiver returns NACK to frames where error detected

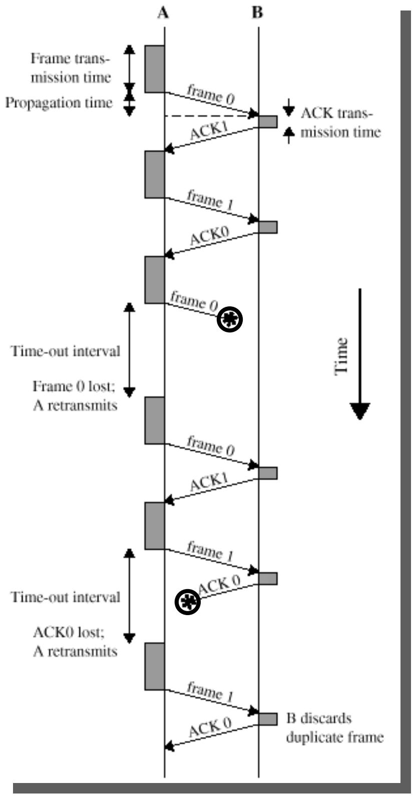
Automatic Repeat Request (ARQ)

- Three versions are standardized
  - Stop-and-Wait ARQ
  - Go-Back-N ARQ
  - Selective-Reject ARQ
- Each is an extension to S&W or sliding-window schemes for flow control that we previously studied
  - Extended for error control

Stop-and-Wait ARQ

- Source transmits single frame
- Waits for ACK
- If received frame damaged, receiver discards it
  - Sender has timeout (equipped with a timer)
  - If no ACK within timeout, sender retransmits
- If ACK is damaged, sender will not recognize it
  - Sender will retransmit
  - Receiver gets two copies of frame
  - How to solve duplication at receiver?
    - Frames alternately numbered with 0 or 1 by sender
    - Positive ACKs from receiver use ACK0 and ACK1 alternately
      - e.g. like sliding-window, ACK0 means "#1 good, send me #0" !
    - Receiver recognizes duplicate and discards one

Example: Stop-and-Wait ARQ



Stop-and-Wait ARQ Tradeoffs

- Pro
  - Simple
- Con
  - Inefficient

Go-Back-N ARQ

- Based on sliding-window flow control
- Use window to control # of outstanding frames
- If no error, ACK from receiver as usual with # of next frame expected (via RR or piggyback)
- If error detected, reply with rejection (REJ)
  - Destination *discards that frame and all future frames* until error frame received correctly
  - Source must go back and *retransmit that frame and all subsequent frames*

Several Contingencies

- Go-back-N ARQ accounts for several contingencies
  - Damaged/lost data frame
  - Damaged/lost RR
  - Damaged/lost REJ
- Note
  - Distinction between *damaged* and *lost* frame is minor here, since with only error detection all bits in frame are suspect
  - Thus, we cannot tell if damaged frame was a garbled data frame, RR, REJ, etc.

Damaged/lost Data Frame

- Case (a)
  - Sender transmits frame *i*
  - Frame *i* is lost or damaged in transit
    - If latter, detected and discarded by receiver
  - Sender soon after sends *i+1*
  - Receiver gets frame *i+1* out of sequence
  - Receiver sends REJ-*i*
  - Sender retransmits frame *i* and all subsequent frames
- Case (b)
  - Frame *i* lost or damaged/discarded and no additional frames are sent
  - Receiver gets nothing, returns neither ack. nor rejection
  - When sender's timer expires, it transmits RR including special P bit set
    - P=1 tells destination this is a command that must be acknowledged
  - Receiver responds with RR-*i* and sender then retransmits frame *i*
- Alternative
  - Receiver could send REJ-*x* (*x* the next frame expected) when it discards an error frame, but receiver does not know the purpose of damaged frame and thus might be rejecting a good frame currently in flight ☹

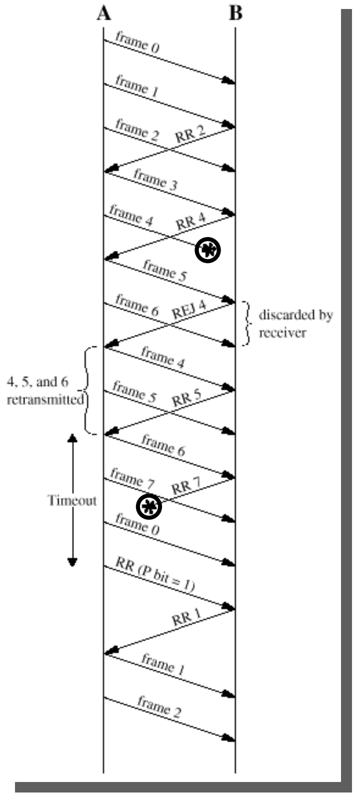
Damaged/lost RR

- Case (a)
  - Receiver gets frame *i* and sends RR (*i* + 1)
  - *RR* is lost in transit
  - Since acks. are cumulative, a subsequent RR for subsequent frame may arrive before sender's timer expires on frame *i*
  - Thus, problem worked itself out on its own ☺
- Case (b)
  - If sender times out, it sends RR to receiver with P=1 as before
  - Sender sets another timer (P-bit timer)
  - If receiver fails to respond or response is damaged, P-bit timer expires
  - If so, sender again sends RR with P=1 and resets P-bit timer
  - This procedure can be repeated # of times before some limit is reached and reset procedure is initiated

Damaged/lost REJ

- Same procedure as lost data frame
  - If sender sends more frames, REJ-*i* repeated
  - If sender does not, it times out
    - Sends RR with P=1 to receiver as before
    - Receiver responds with RR-*i*
    - Sender then retransmits frame *i*

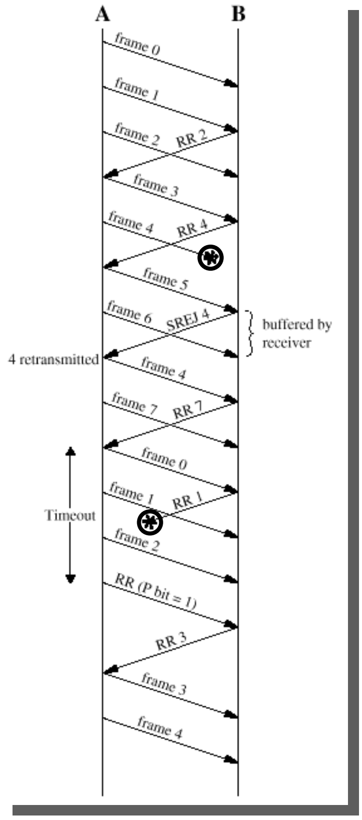
Example: Go-Back-N ARQ



Selective-Reject ARQ

- Also called *selective retransmission*
- Key features
  - Only selectively rejected frames (via SREJ) are retransmitted
  - Subsequent frames are accepted by the receiver and buffered
  - Receiver orders frames before presenting to higher layer
- Pros and cons
  - Minimizes retransmission
  - Receiver more complex
    - Must maintain buffer big enough to save post-SREJ frames until frame in error is retransmitted
    - Extra logic for reinserting retransmitted frame in proper sequence
  - Sender more complex
    - Extra logic for sending a frame out of sequence

Example: Selective-Reject ARQ



Maximum window size? (1)

- Assume a k-bit sequence field
- W limited by interaction b/w error control and ack.
- Go-Back-N ARQ
  - $W \leq 2^k - 1$
    - e.g. $k = 3 \Rightarrow W \leq 7$
  - Why can't we let $W = 2^k$?
    - Example ($k = 3$, $W = 2^3$) involving hosts A and B
      - A sends frame 0 then gets back an RR1 from B
      - A sends frames 1, 2, 3, 4, 5, 6, 7, 0
      - A gets back an RR1 from B
      - But what does RR1 mean? Could be cumulative ack. or could be repeat of previous RR1 with all 8 frames lost in transit?
    - Problem solved by limiting $W \leq 2^k - 1$

Maximum window size? (2)

- Selective-Reject ARQ
  - $W \leq 2^{k-1}$
    - e.g. $k = 3 \Rightarrow W \leq 4$
  - Why more restricted than with GBN?
    - Example (k = 3, $W = 2^k - 1$) involving hosts A and B
      - A sends frames 0, 1, 2, 3, 4, 5, 6 to B
      - B receives all frames then cumulatively acks. with RR7
      - RR7 is lost in transit
      - A times out and retransmits frame 0
      - However, B has already advanced its window to accept next frames (7, 0, 1, 2, 3, 4, 5)
      - Thus, upon receiving retransmitted frame 0, B assumes it is a new frame 0 and accepts it as such assuming that frame 7 must have been lost
    - Problem caused by overlap b/w sending and receiving windows
      - Solved by limiting $W \leq 2^{k-1}$

Data Link Control Protocols

High-Level Data Link Control (HDLC)

High-Level Data Link Control

- HDLC
- Important data-link control protocol
  - Widely used
  - Also, many others based on HDLC with various alterations
- 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)

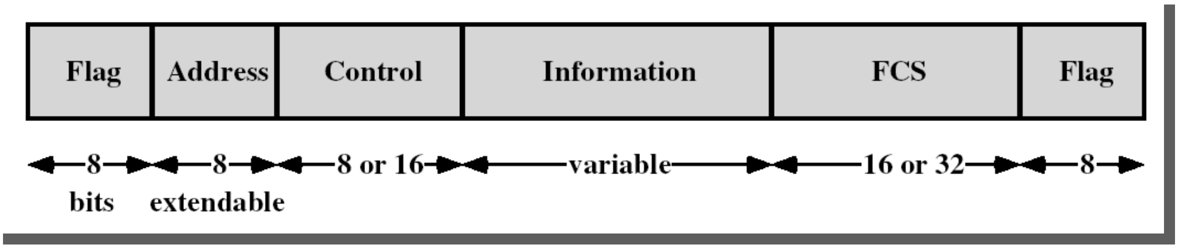
- Asynchronous Response Mode (ARM)
  - *Unbalanced* configuration
  - Secondary may initiate transmission without permission from primary
  - Like NRM, primary responsible for line
    - Initialization, error recovery, logical disconnection
  - Rarely used

HDLC Transfer Modes (3)

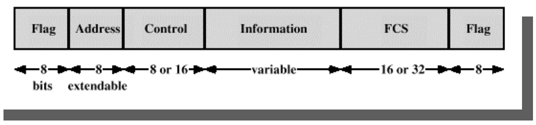
- Asynchronous Balanced Mode (ABM)
  - *Balanced* configuration
  - Either station may initiate transmission without receiving permission
  - No polling overhead
  - *Most widely used*

HDLC Frame Structure

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



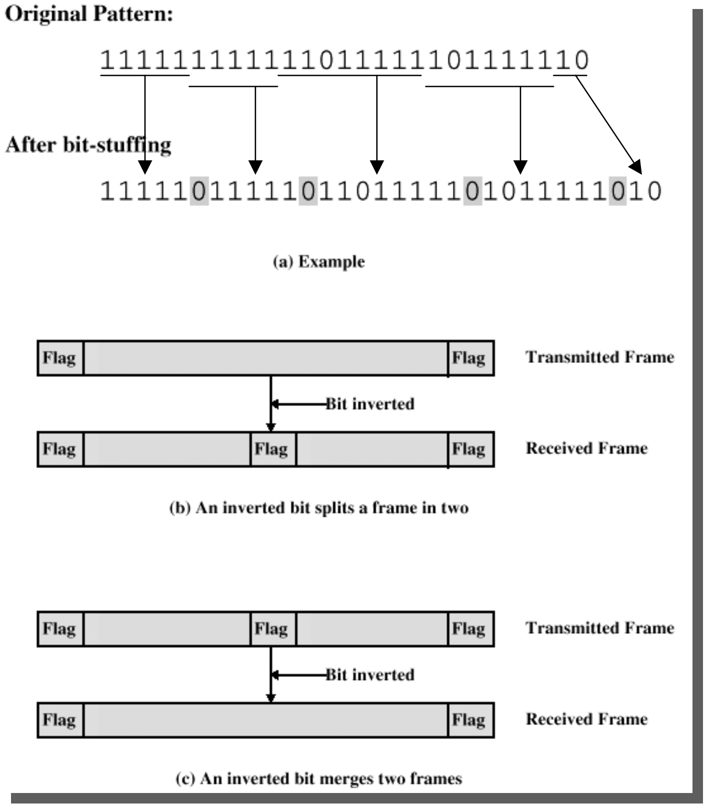
Flag Fields



- Delimit frame at both ends
- Flag = 01111110
- May use to close one frame and open another
- Receiver hunts for flag sequence to synchronize
- Bit stuffing used to avoid confusion with data containing same pattern 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

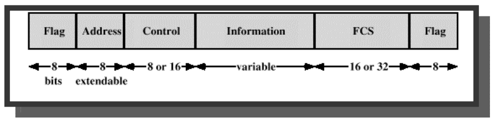
Bit Stuffing

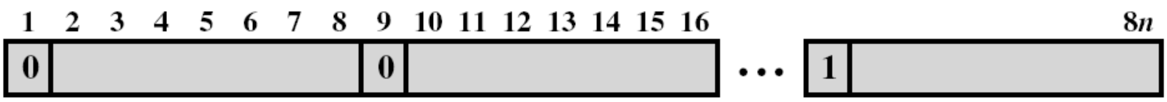
- Example with possible errors



Address Field

- Identifies secondary station that sent or will receive frame
  - Not needed for pt-to-pt links but included for uniformity
  - Field is usually 8 bits long
- Extensible by prior agreement, multiples of 7 bits
  - Leftmost bit of each octet indicates whether it is last octet (1) or not (0)
- All ones (11111111) is broadcast

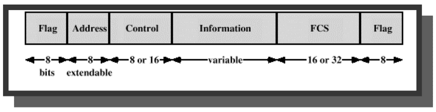




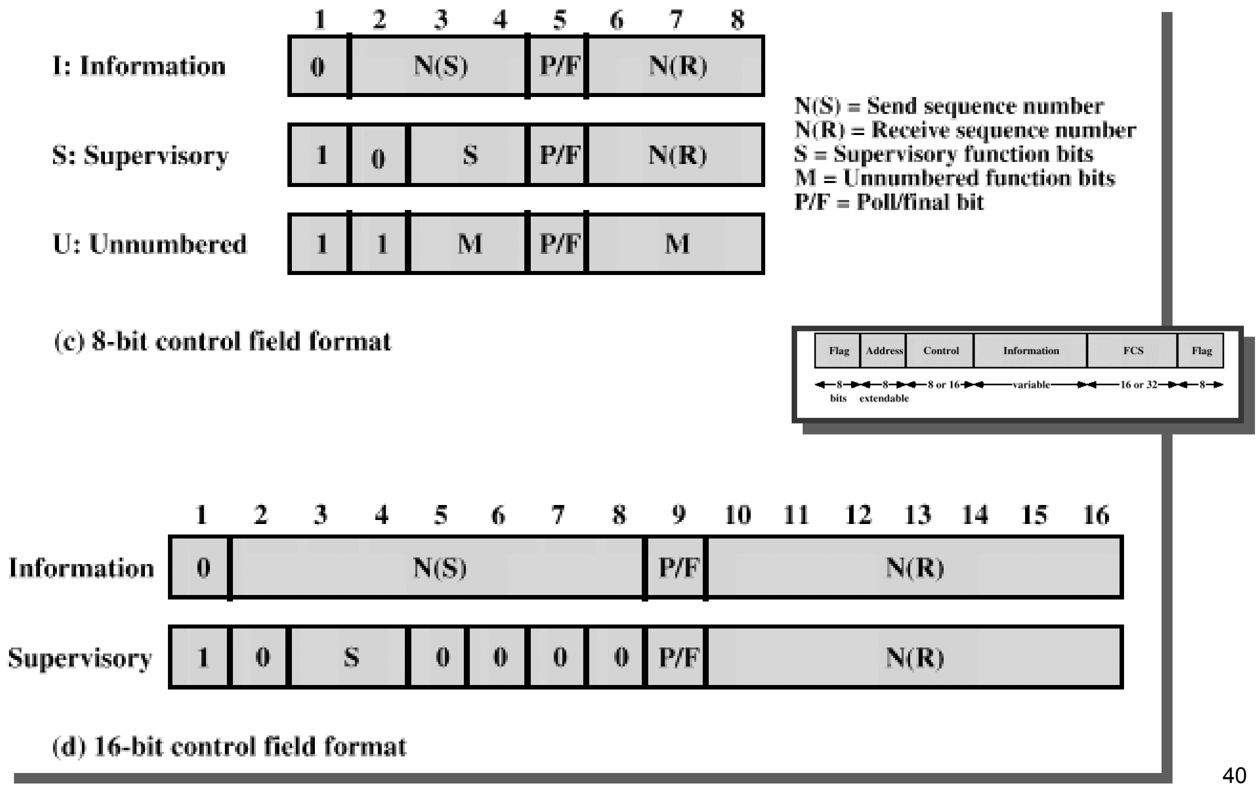
(b) Extended Address Field

Control Field

- Different for each frame type
  - Information frame (I-frame)
    - Data to be transmitted to user (next layer up)
    - Flow and error control piggybacked on information frames
  - Supervisory frame (S-frame)
    - Provides ARQ when piggyback not used
  - Unnumbered frame (U-frame)
    - Supplementary link control
- First 1-2 bits of control field identify frame type
- Remaining bits specify the control characteristics

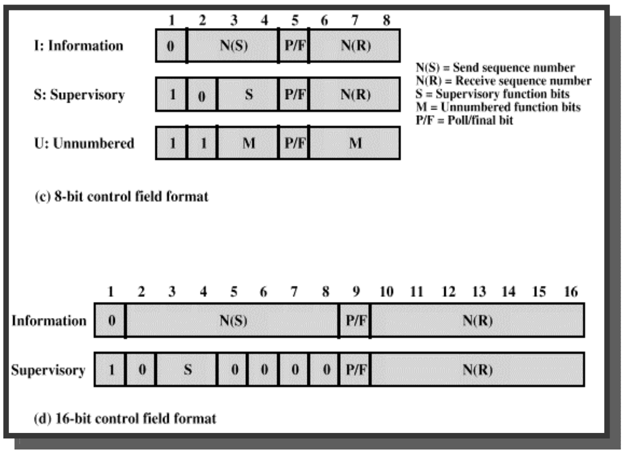


Control Field Diagram



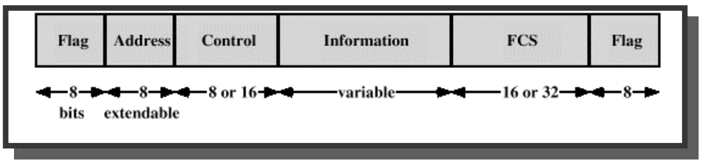
Poll/Final (P/F) Bit

- 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



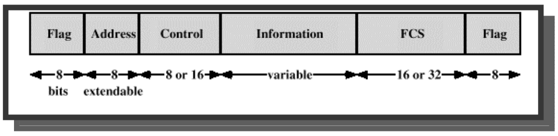
Information Field

- Only in I-frames and some U-frames
- Must contain integral number of octets
- Variable length up to some system-defined maximum



FCS Field

- Frame Check Sequence
- Error detection
- 16-bit CRC
  - CRC-CCITT: $P(X) = X^{16} + X^{12} + X^{5} + 1$
- Optional 32-bit CRC (CRC-32)



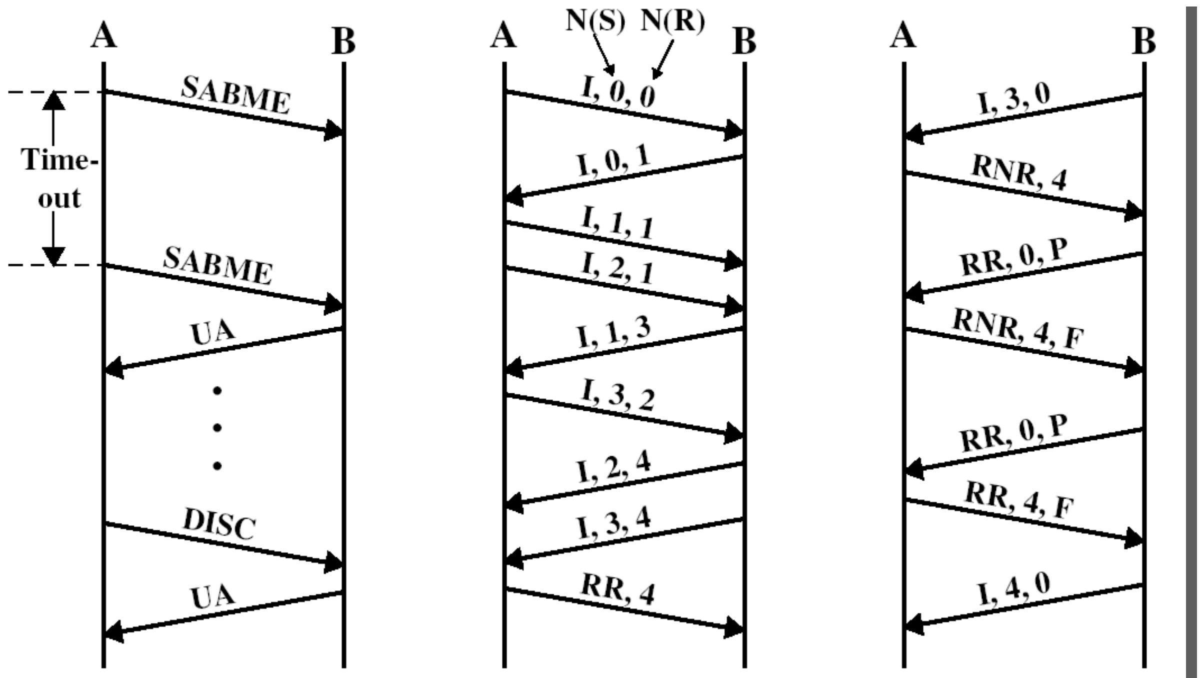
HDLC Operation

- Exchange of information, supervisory, and unnumbered frames
- Three phases
  - Initialization
  - Data transfer
  - Disconnect
- See Table 7.1 for HDLC Commands and Responses
  - Many types of U-frames including 6 set-mode commands
  - 4 types of S-frames

Table 7.1 HDLC Commands and Responses

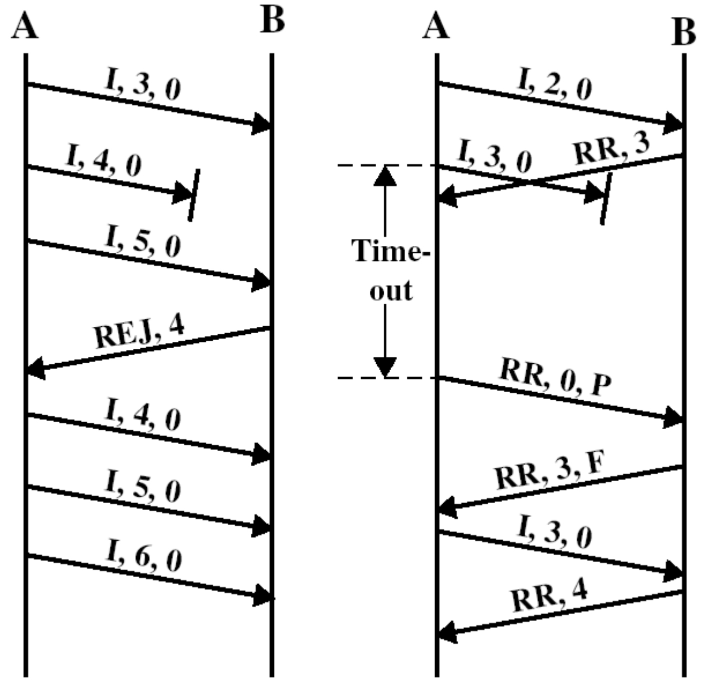
Name	Command/ Response	Description
Information (I)	C/R	Exchange user data
Supervisory (S)		
Receive ready (RR)	C/R	Positive acknowledgment; ready to receive I-frame
Receive not ready (RNR)	C/R	Positive acknowledgment; not ready to receive
Reject (REJ)	C/R	Negative acknowledgment; go back N
Selective 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

Examples of Operation (1)



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

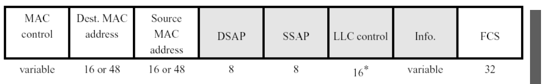
Examples of Operation (2)



(d) Reject recovery (e) Timeout recovery

Other DLC Protocols (e.g. LLC)

- Logical Link Control (LLC)
  - **IEEE 802.2**
  - Different frame format
  - Link control split between two sublayers, medium access layer (MAC) and LLC (on top of MAC)
  - No primary and secondary - all stations are peers
  - Two MAC addresses needed
    - Sender and receiver
  - Error detection at MAC sub-layer
    - 32-bit CRC
  - Destination and source access points (DSAP, SSAP) at LLC sub-layer
  - LLC control field same as HDLC but only 7-bit seq. #s



(c) LLC/MAC