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ECE 462 – Data and Computer Communications

Lecture 11/12: Data Link Control Protocols

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October 10/15, 2007

Outline

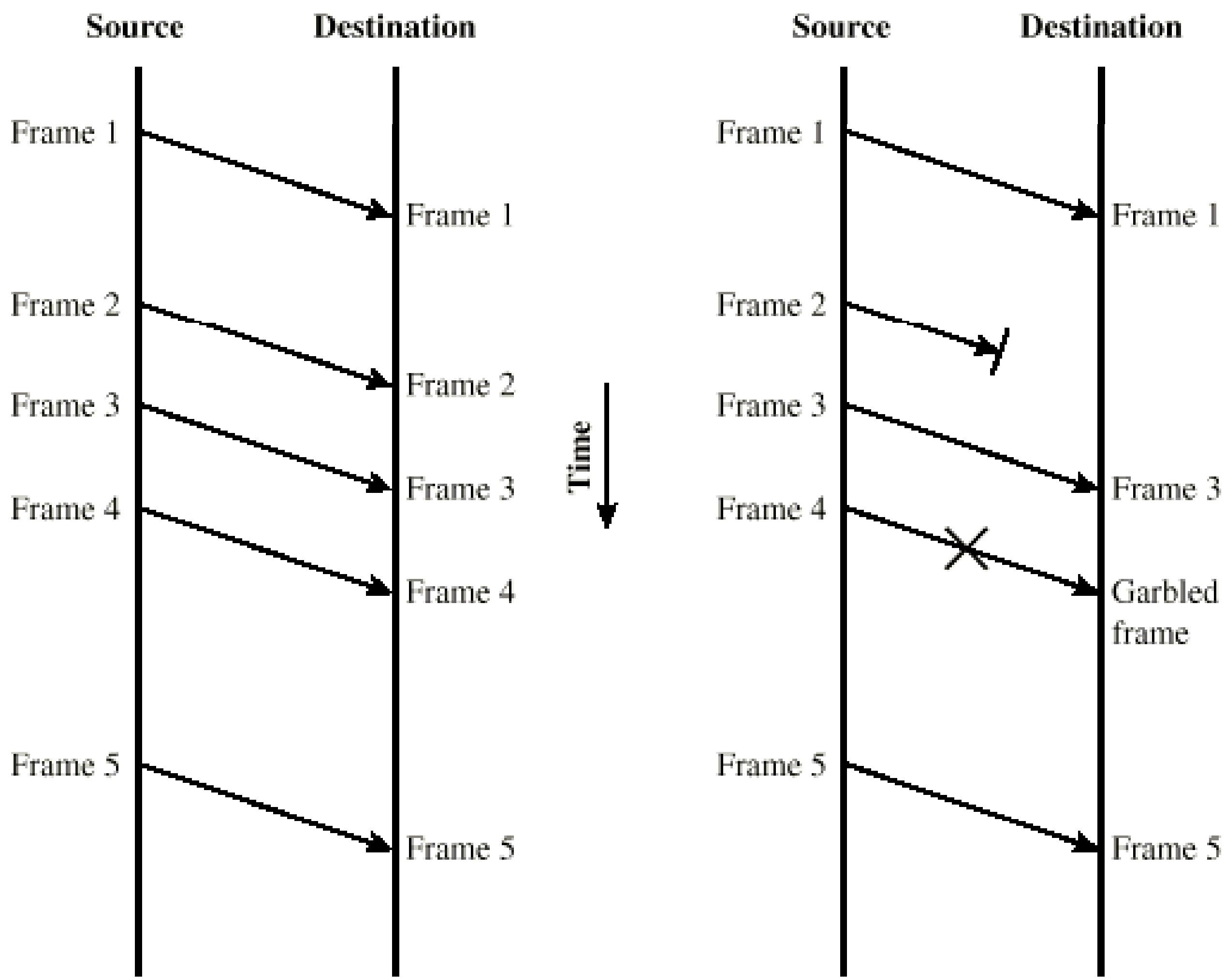
- Flow Control
- Stop and Wait
- Sliding Window Protocol
- Error Control
- Automatic Repeat Request (ARQ)
- High Level Data Link Control
- HDLC Frame Structure
- HDLC Operation

Note: Some material adapted from various textbook. In particular, the sequences of slides have been sorted to match closely that of the textbook Data and Computer Communications by W. Stallings, 8th Edition, Prentice Hall, 2007

Flow Control- Definitions

- Ensuring the sending entity does not overwhelm the receiving entity
  - Preventing buffer overflow
- Transmission time
  - Time taken to transmit all bits into medium
  - t_I=Number of bits/Bit rate
- Propagation time
  - Time for a bit to traverse the link
  - t_p=Number of bits/Bit rate

Model of Frame Transmission



(a) Error-free transmission

(b) Transmission with losses and errors

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 sending 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 & Wait Analysis

$$a = \frac{B}{L}$$

- ***L***: **number of bits in the frame**
- ***B***: **length of the link in bits**

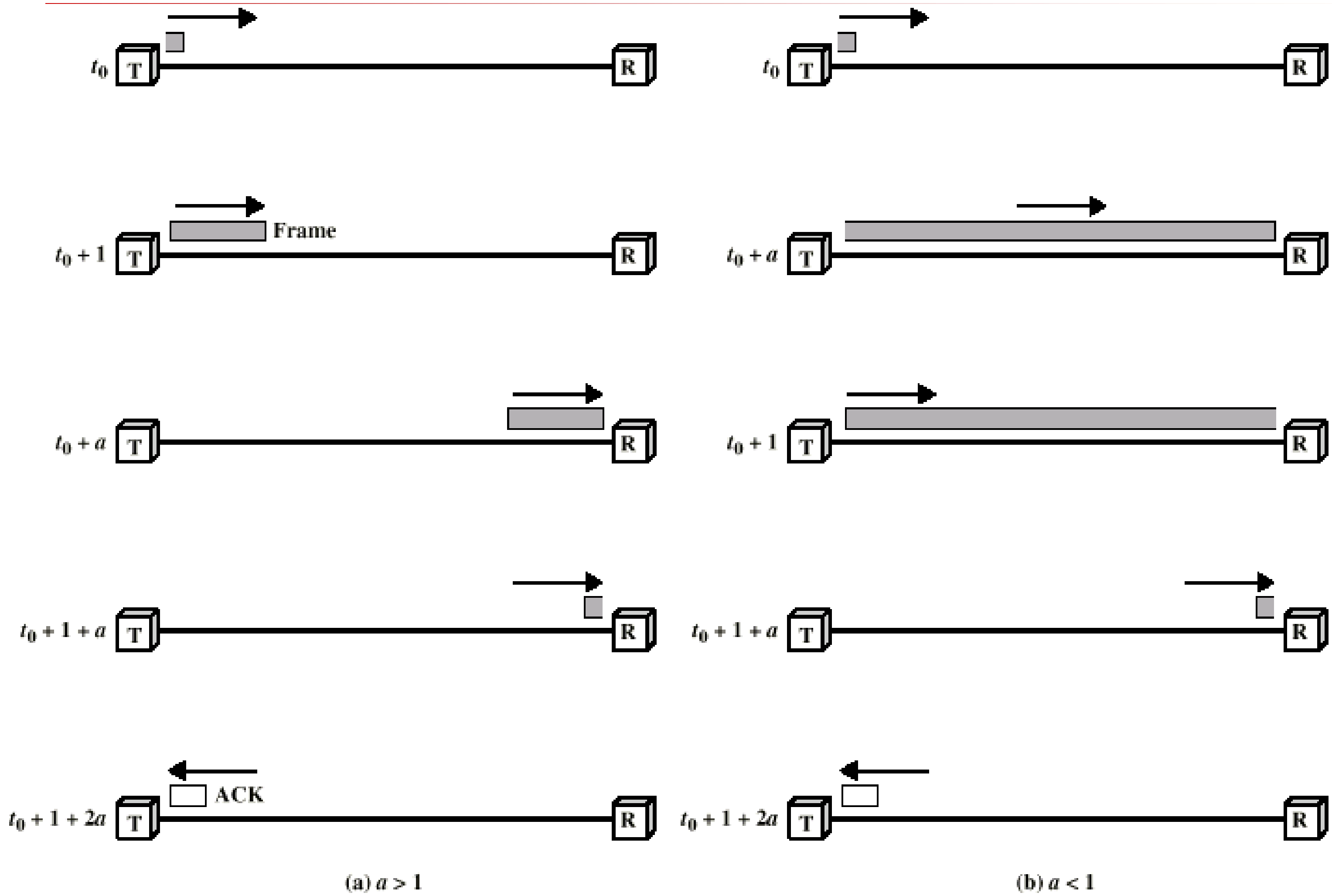
$$B = \frac{d}{v} \times R$$

- ***d: link length***
- ***v: speed of propagation (m/s)***
- ***R: data rate of the link (b/s)***
- ***if a<1, propagation time is less than transmission time***

Finding $a = t_p / t_I$

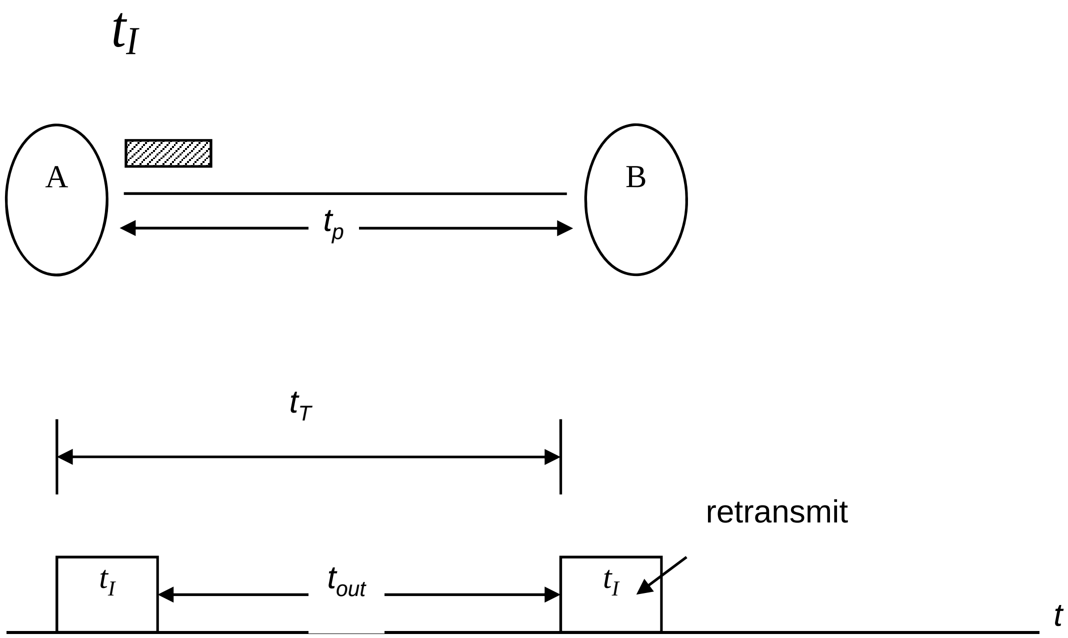
- In Local Area Networks
  - 200 Meter Fiber Optic link operating at R=1 Gbps and Fame length of 1000 Octets
  - t_I=8*1000/1*10^9=8 microsec
  - t_p=200*5*10-9=1 microsec
  - *a*= t_p/t_I = 1 microsec/8 microsec =0.125
- Satellite Channel
  - Distance of 36000 Km operating at R=1 Mbps and Fame length of 1000 Octets
  - t_I=8*1000/1*10^6=8 msec
  - t_p=2*36000000*5*10-9=~240 msec
  - *a*= t_p/t_I = 240 msec/8 msec =30

Stop and Wait Link Utilization



Effect of $a = t_p / t_l$ Frame Tx time (t_l)=1, Prop Time (t_p)

Stop & Wait analysis



Stop & Wait analysis

- *tv*: average time to get a frame thru correctly
- *p*: prob. of a frame in error

$$t_v = t_T \cdot (1-p) + 2t_T \cdot p(1-p) + 3t_T \cdot p^2(1-p) + 4t_T \cdot p^3(1-p) + \cdots$$

$$= t_T \cdot (1-p)\{1 + 2p + 3p^2 + 4p^3 + \cdots + np^{n-1}\}, n \to \infty$$

$$= t_T(1-p)\frac{1}{(1-p)^2}$$

$$t_v = \frac{t_T}{1-p} \qquad \alpha = \frac{t_T}{t_I}$$

- *throughput (λ):*
- *utilization (ρ):*

$$\lambda = \frac{1}{t_v} = \frac{1-p}{t_T} = \frac{1-p}{\alpha \cdot t_I} \qquad \rho = \lambda \cdot t_I = \frac{1-p}{\alpha}$$

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

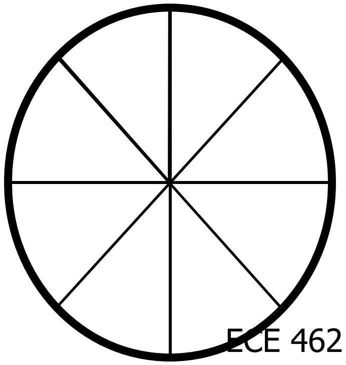
Sequence Numbering Operation Mod 128 (and Mod 8)

- Each frame is sequentially numbered (0 to 127). After reaching 127, it cycles through the range 0 to 127. That is modulo 128
- The maximum number of unacknowledged frames at any given time never exceeds 127, (i.e. modulus minus one)
- Sequence numbering is used both at the transmit and receive points
- Can be represented by window concept
- Used for lost, errored and mis-sequenced frame

Window Concept

- Illustration of the window concept using mod 8
- Suppose Node-A transmits I0, I1, I2
- Node-A shrinks its window with transmission of each frame
- Node A can transmit a total of 7 frames
- Therefore, Node A is represented by a window that is open to transmit 4 additional frames

- Node A can transmit 4 frames



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

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
- Cyclic Redundancy Check

Automatic Repeat Request (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
  - Receive gets two copies of frame
  - Use ACK0 and ACK1
- Simple but 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

Go Back N - Lost Frame (1)

- Frame *i* 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

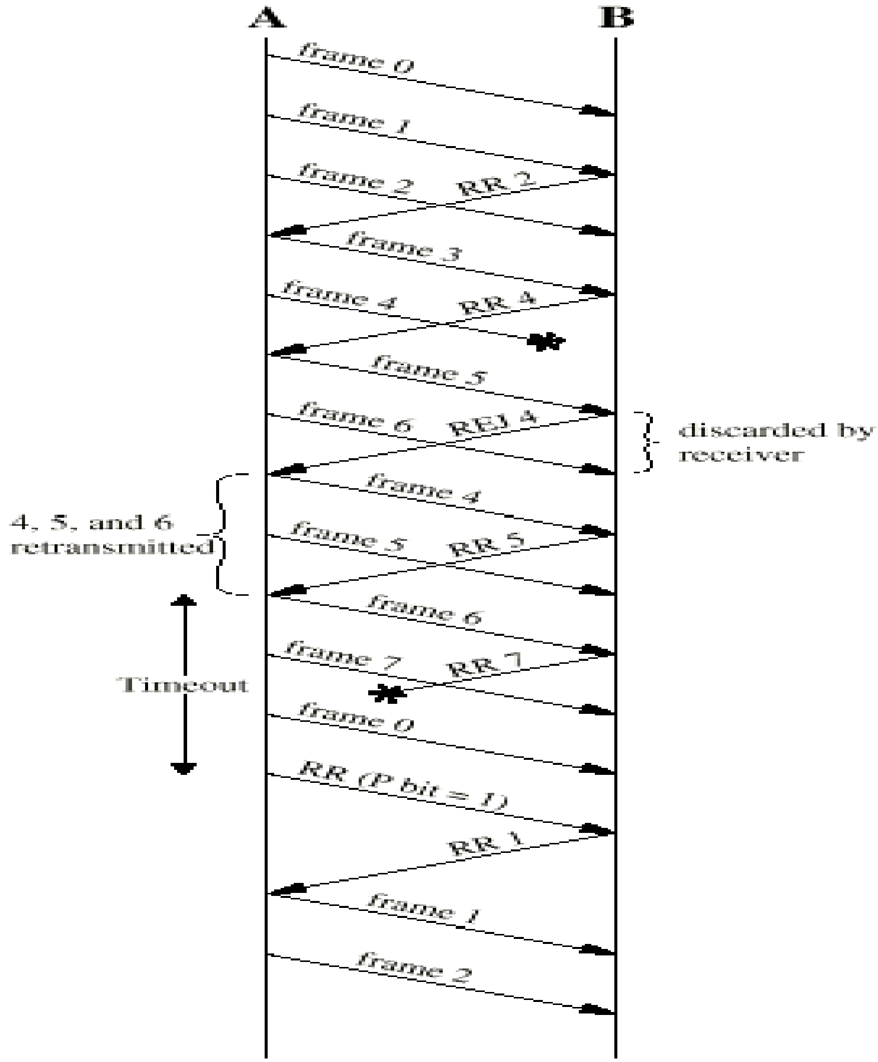
Go Back N - Lost Frame (2)

- 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

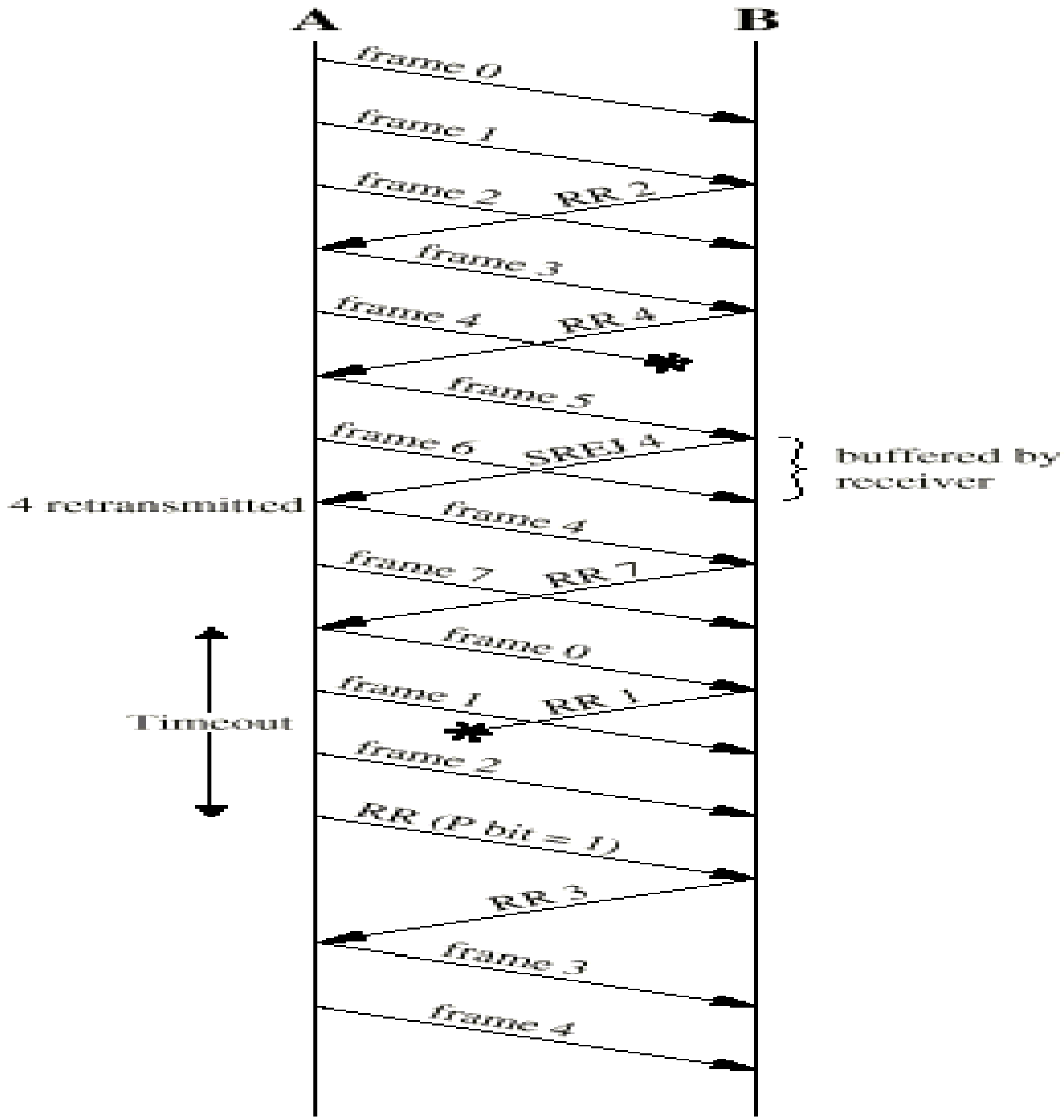
Go Back N Diagram



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 login in transmitter

Selective Reject Diagram



Data Link Functions

- Frame delimitation
- alignment
- Error detection
- Error correction
- Link error monitoring
- Flow/Congestion control
- Initial alignment

Other Protocols

- Other L2 protocols may have Length Indicator (LI) as part of the field to indicate the number of octets following the LI octet and preceding the check bit

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

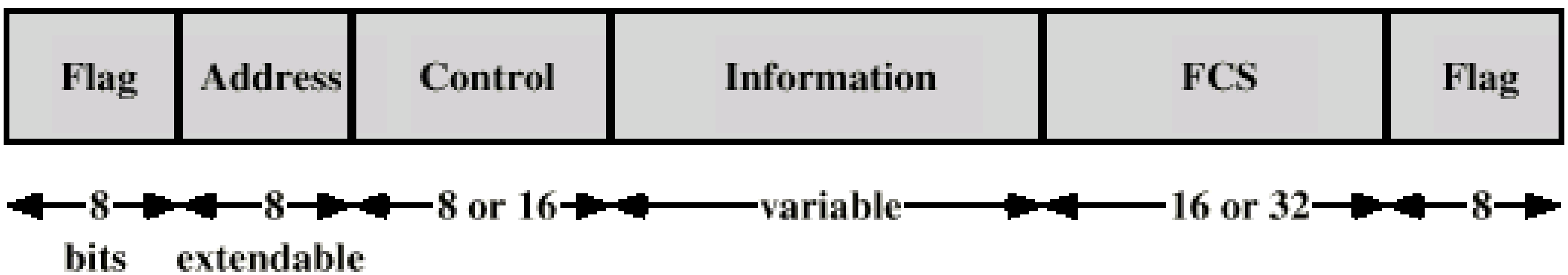
HDLC Transfer Modes (3)

- 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



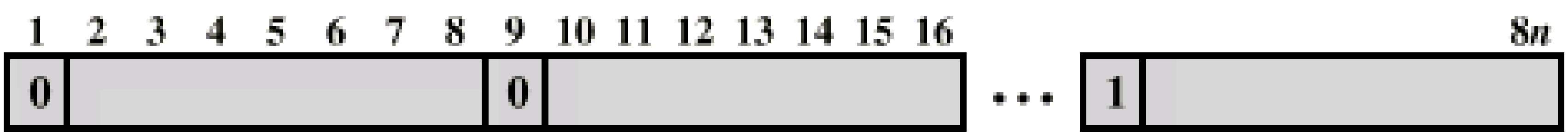
(a) Frame format

Flag Fields

- As covered previously
- 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

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

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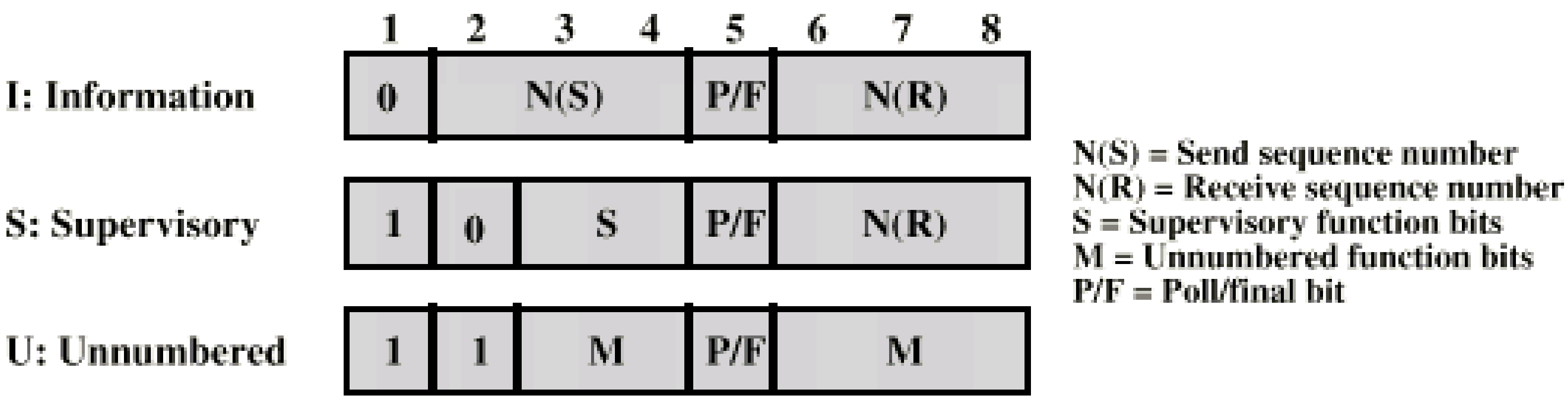
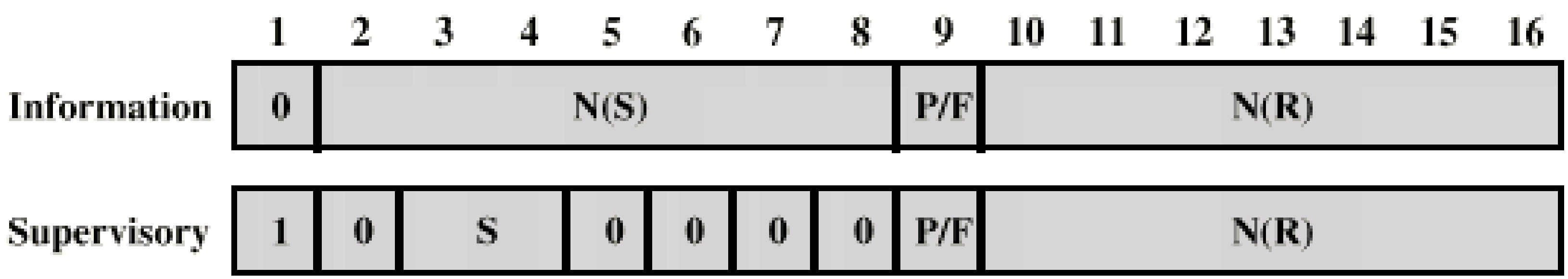
Control Field

- 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



(c) 8-bit control field format



(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

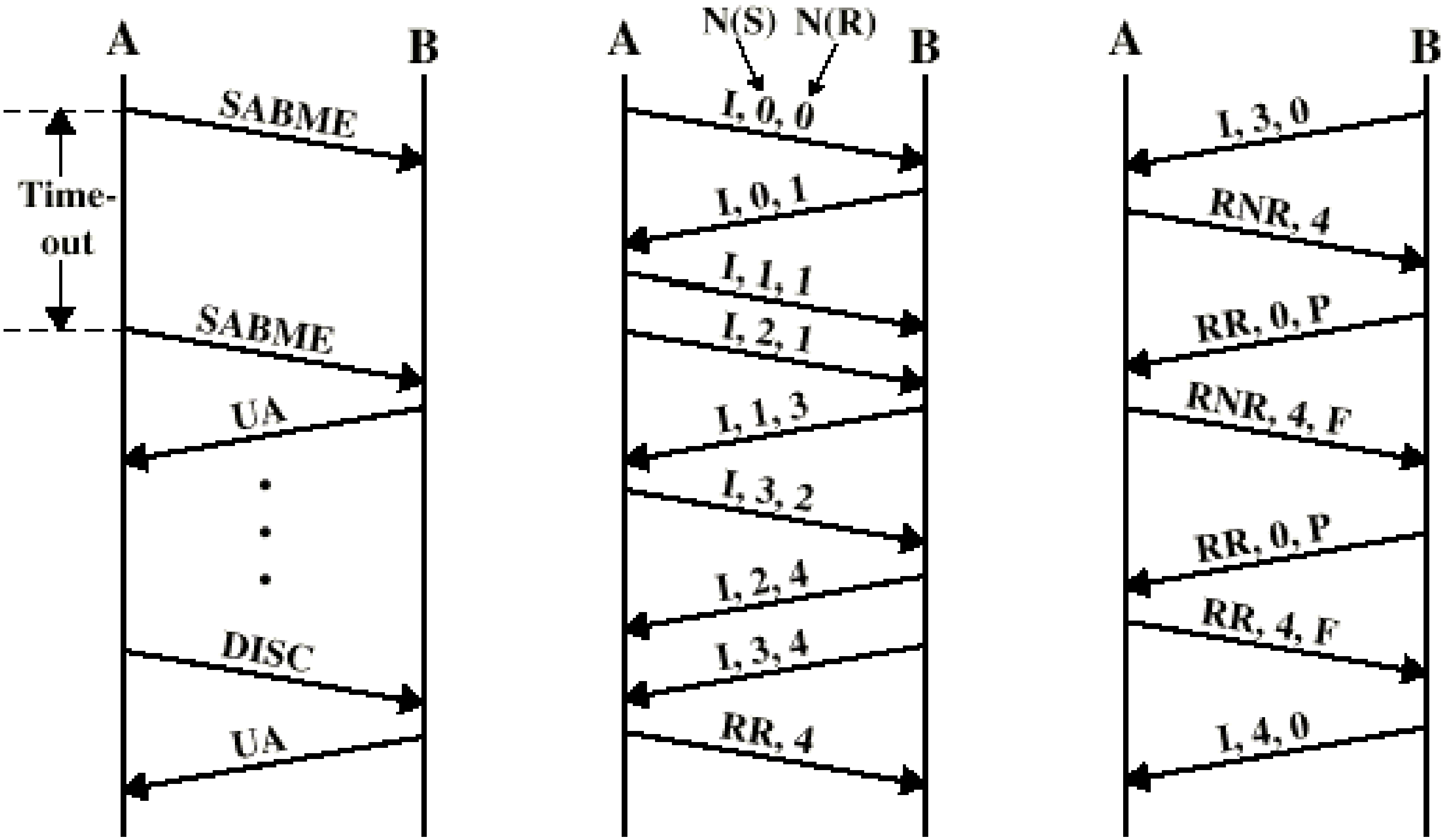
Frame Check Sequence Field

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

HDLC Operation

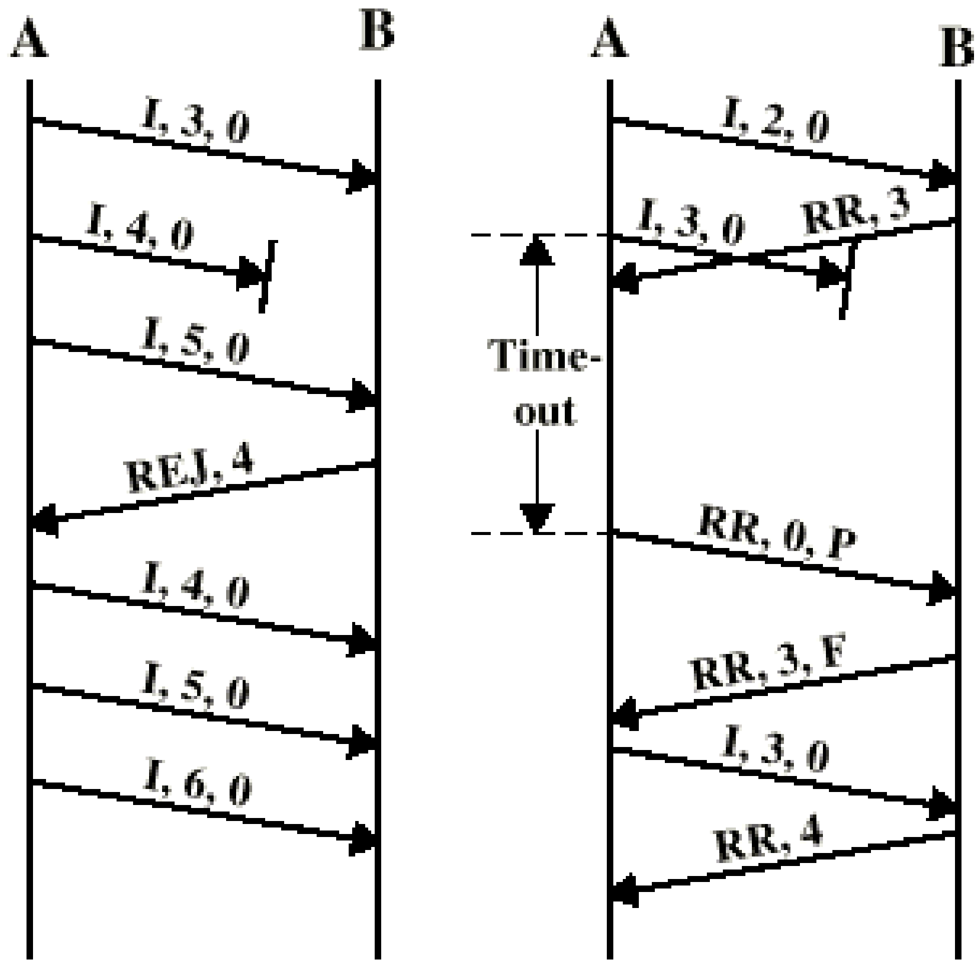
- Exchange of information, supervisory and unnumbered frames
- Three phases
  - Initialization
  - Data transfer
  - Disconnect

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