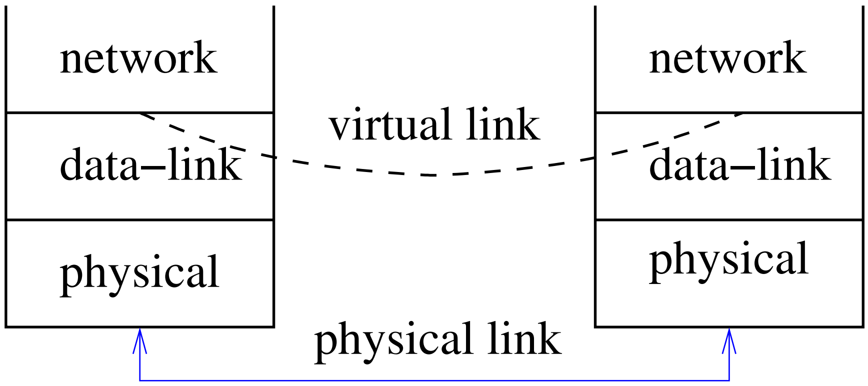
DATA-LINK LAYER

I) Data-Link Layer Functions

- Provides a virtual link between two peer network layer entities over a physical link.



- Framing.
- Error detection and retransmission.
- Flow control.
- Various data-link protocols: point-to-point, multipoint, LAN.

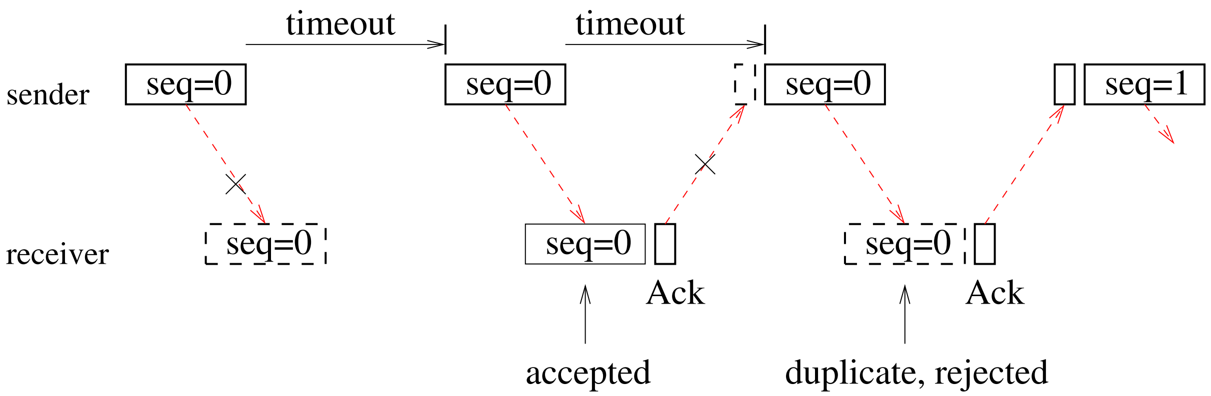
II) Data-Link Layer Services

1. Unacknowledged Connectionless Service
   - No connection is established.
   - No acknowledgement and no data loss recovery.
   - Suitable for the environment where the error rate is low or the traffic is real-time (such as voice).
2. Acknowledged Connectionless Service
   - No connection is established.
   - Each frame is individually acknowledged.
   - Used in industrial process control environment.
3. Connection-Oriented Service
   - Connection is established before data transfer.
   - The data link service guarantees that each frame sent will be received correctly and exactly once.
   - Provides an errorless virtual link to the upper layers.

III) Stop-and-Wait (Idle RQ) Protocols

1. Basic protocol

- Connection-oriented service.
- The transmitter must wait for the acknowledgement from the receiver after each frame transmission before it is allowed to transmit another frame.
- Half-duplex transmission.
- Each frame carries a sequence number to avoid the frame duplication.



- Minimum sequence space is {0,1}.
- Advantage: simple.
- Disadvantage: not very efficient for link utilization.

2. <u>Link Utilization</u>

- Utilization:

$$\eta = \frac{t_f}{t_f + 2(t_{prop} + t_{proc}) + t_a}$$

where
t_f = Time of transmitting a data frame;
t_{prop} = Propagation delay;
t_{proc} = Processing delay;
t_a = Time of transmitting an ACK frame.

- Assumptions: $t_f >> t_a$ and $t_f >> t_{proc}$

$$\eta \approx \frac{1}{1+2a},$$

where $a = \frac{t_{prop}}{t_f}$.

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$$\text{Effective data rate} = \eta \times \frac{n_f - n_o}{n_f} \times R.$$

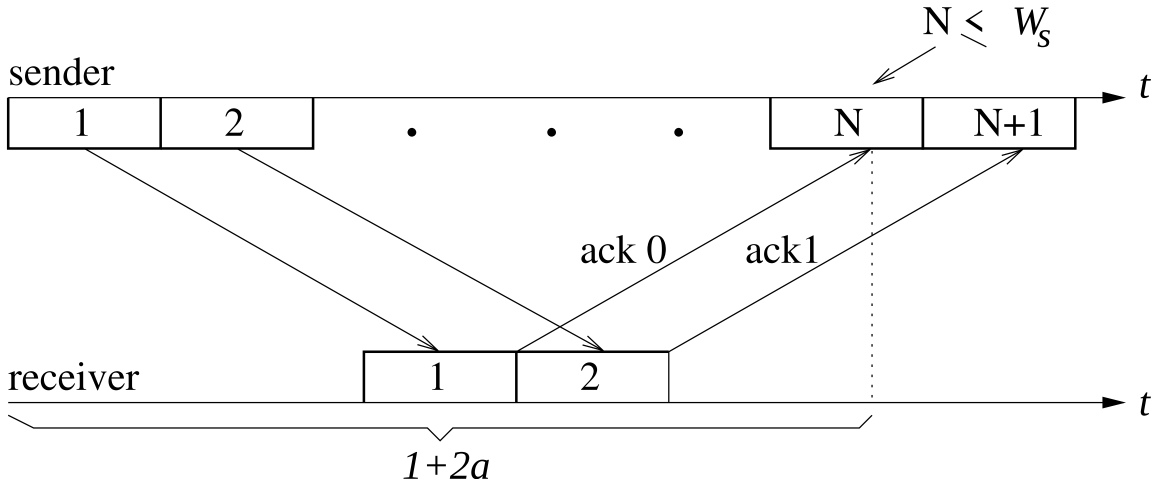
where
R = Channel data rate;
n_f = size of the data frame;
n_o = size of the frame overhead.

IV) Sliding-Window (Continuous RQ) Protocols

1. Basic Operations

- The sending station can transmit up to W_S outstanding frames.

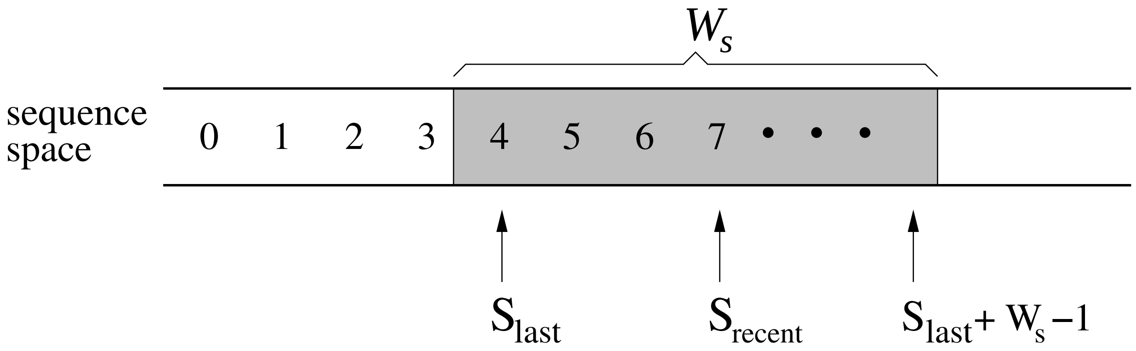
- Full-duplex transmission.
- With proper design, 100% link efficiency can be achieved.



- Utilization for the case without transmission error:
  - $W_S \geq 1 + 2a : \ U = 100\%$.
  - $W_S \leq 1 + 2a : \ U = \frac{W_S}{1+2a}$.
- Sliding window mechanism is used to keep track of the sequence number.

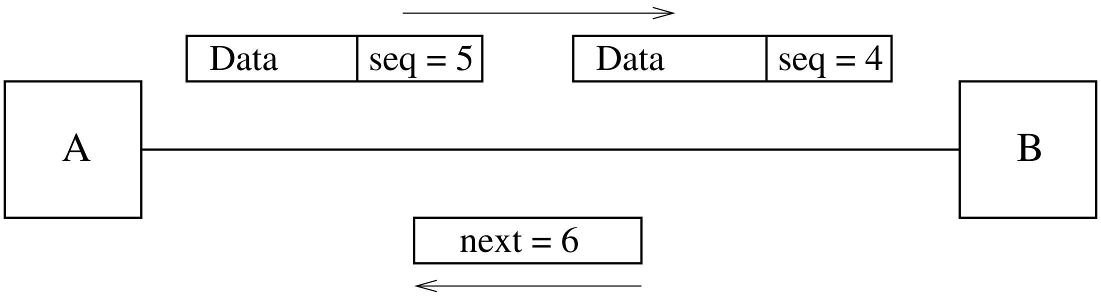
2. Sending Window Mechanism

- A sending window contains the sequence numbers of the outstanding frames and the sequence numbers that can be used to send new frames.



- When an acknowledgement(ACK) frame arrives,
  $S_{last} \leftarrow S_{last} + K$.
  - K is the number of frames acknowledged by the ACK frame.

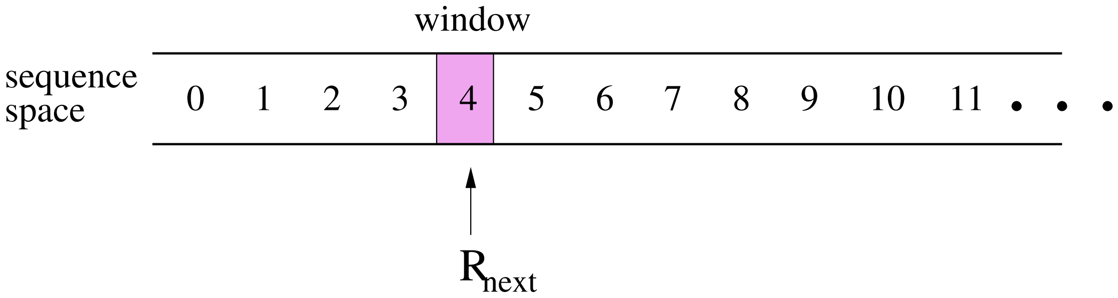
- Inclusive acknowledgement



- When a new frame is sent,
  $S_{recent} \leftarrow S_{recent} + 1$.

3. Go-Back-n

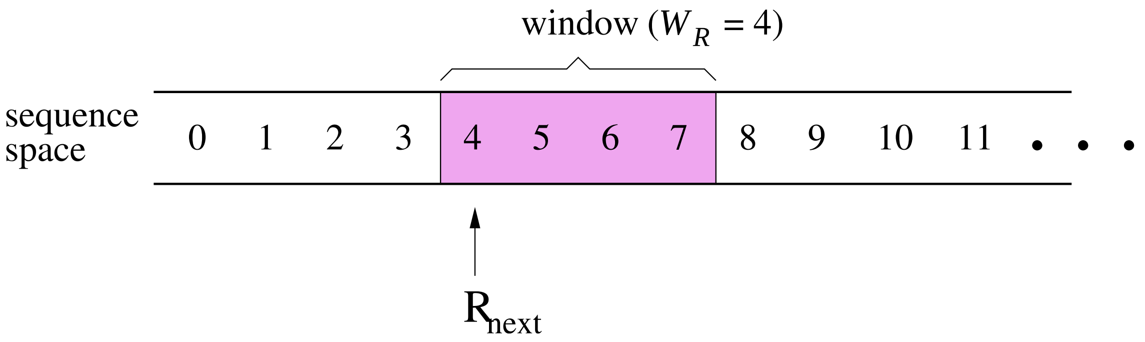
- Receiving window size (W_R) is 1.



- The receiver does not accept out-of-sequence frames.
- Retransmit the corrupted frame and all other frames that were transmitted after the corrupted frame.
- Does not need buffer space to store out-of-sequence frames.
- For a maximum sending window size of W_S, the minimum sequence space is $\{0,1,2,\ldots,W_S\}$.

4. Selective Repeat

- $W_R = W_S$.
- Accept out-of-sequence frames. Sender only need to retransmit the corrupted frame.



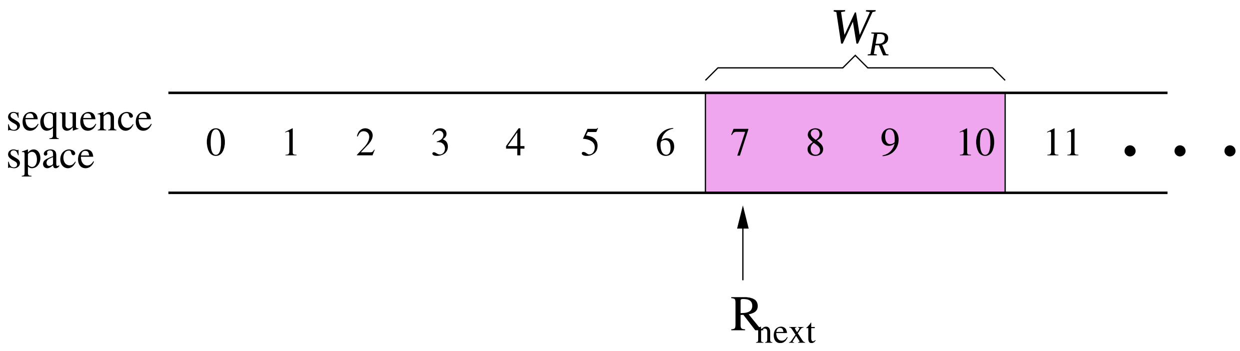
  - If SeqNum outside the window, frame discarded.
  - If SeqNum inside the window, frame accepted. Acknowledgement is sent if the frame is in sequence.
  - The receiver accepts out-of-sequence frames.

- The receiver need buffer to store the out-of-sequence frames.

- Example:

  (a) Frames 5 and 6 arrive.
  window remains at the same position.
  No Ack is sent.

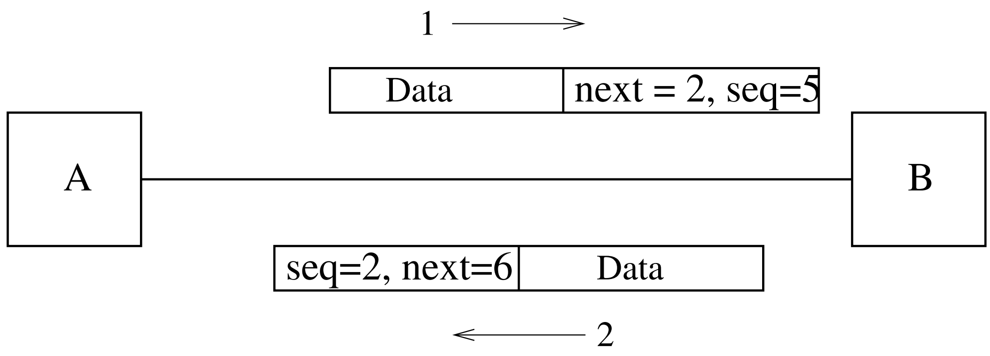
  (b) Frame 4 arrives.
  Frames 4, 5, and 6 are passed to the upper layer.
  Ack of 6 is sent (inclusive acknowledgement)
  window moves up by 3.



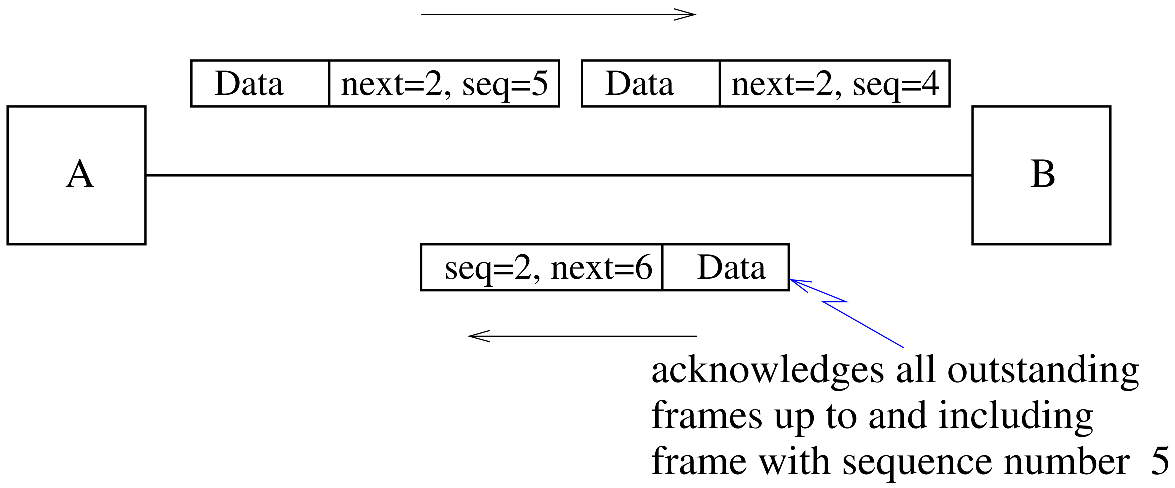
- For a maximum sending window size of W_S, the minimum sequence space is $\{0,1,2,...,2W_S - 1\}$.

5. Piggybacking

- Station can receive and send at the send time.
- acknowledgement information is piggybacked onto data frames.

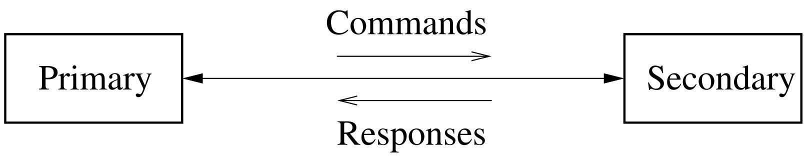


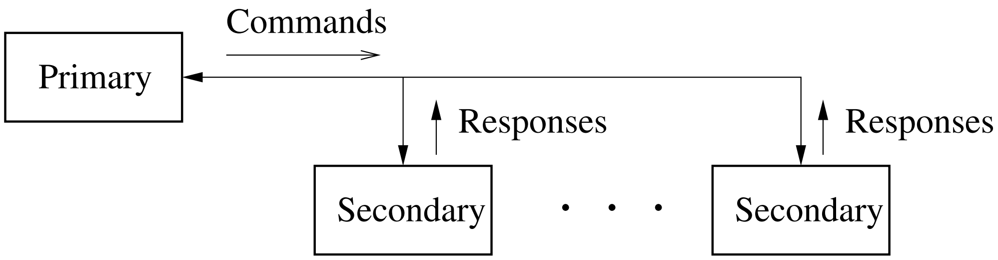
- Piggybacking with inclusive acknowledgement

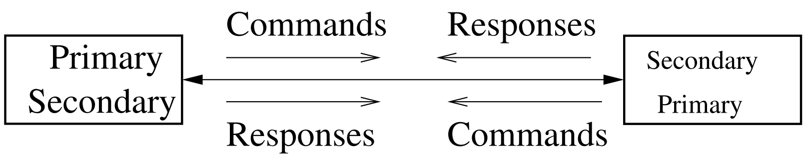


V High-Level Data Link Control (HDLC)

- Configurations:





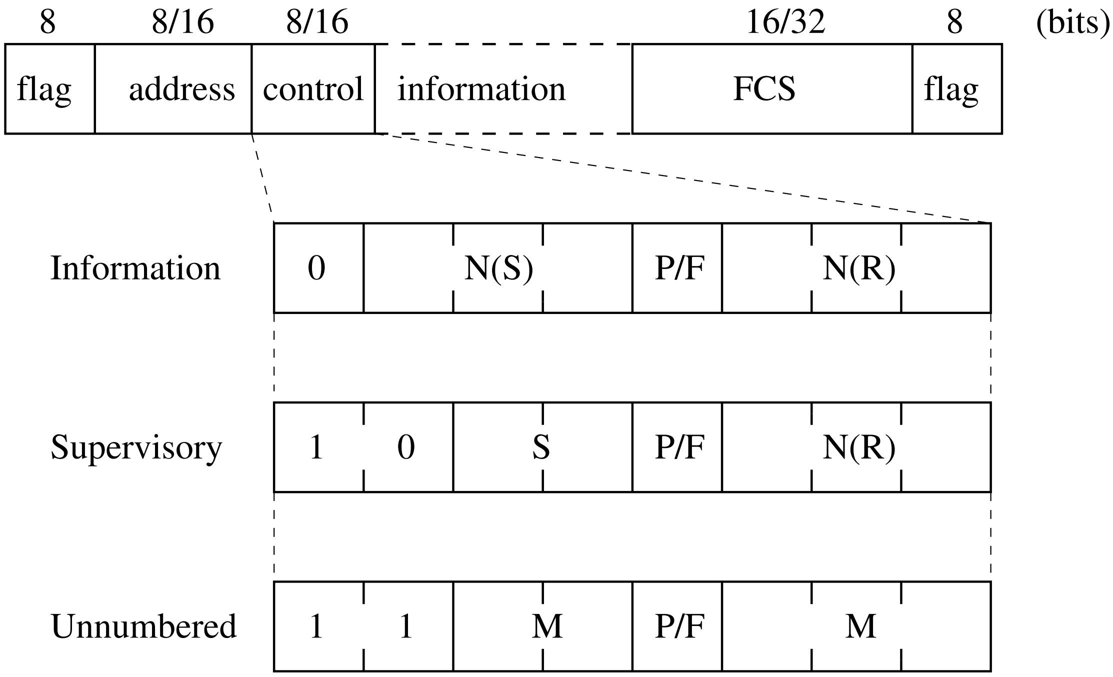


- Normal Response Mode (NRM): The secondary may only transmit data in response to a poll from the primary.

- Asynchronous Response Mode (ARM): The secondary may initiate transmission without explicit permission of the primary. The primary is in charge of the link management.

- Asynchronous Balanced Mode (ABM): Either station may initiate transmission without receiving permission from the other station. The link is managed by both stations.

- Frame structure:



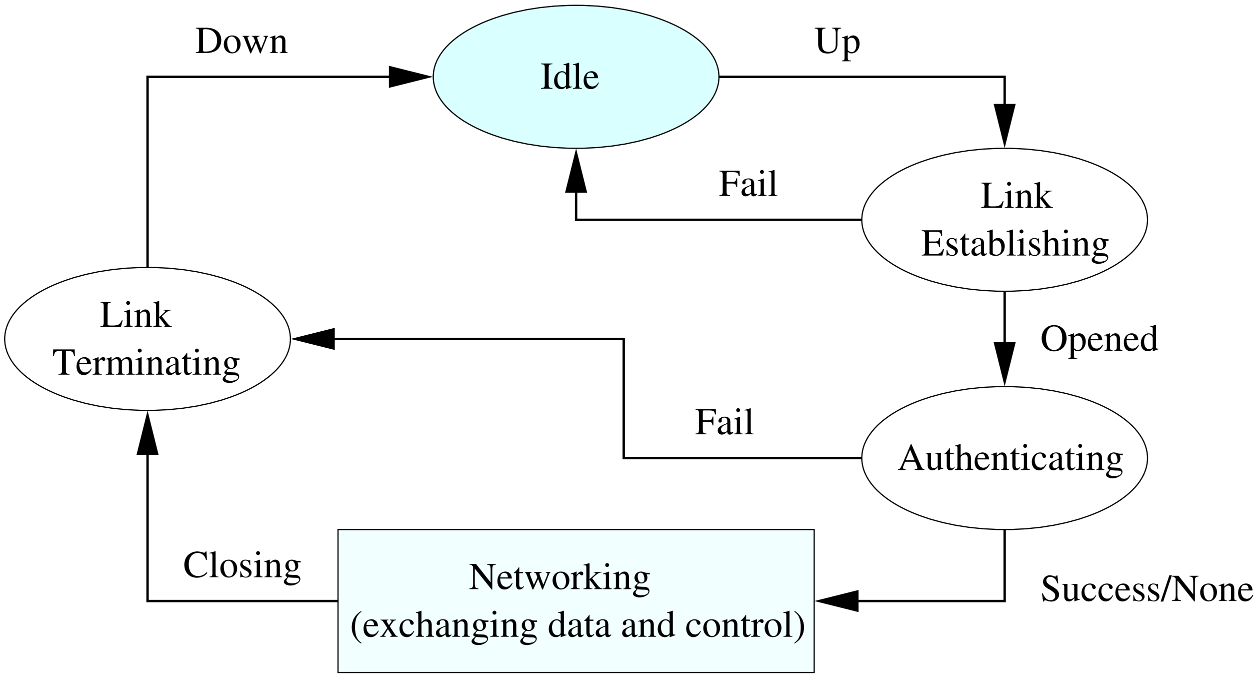
N(S) = sequence number; N(R) = acknowledgement number;

S = supervisory frame types; M = unnumbered commands.

- Information frames: contains data, sequence number, and acknowledgement number.
- Supervisory frames.
  - Receiver Ready (RR): acknowledges all information frames up to but not including N(R).
  - Receiver Not Ready (RNR): same as RR execpt that it also informs the sender to stop sending.
  - Reject (REJ): it requests retransmissions of all outstanding frames starting from N(R).
  - Selective Reject (SREJ): it requests a retransmission of frame N(R).

VI Point-to-Point Protocol (PPP)

- PPP transition diagram (finite-state machine):



- Frame format: based on HDLC.

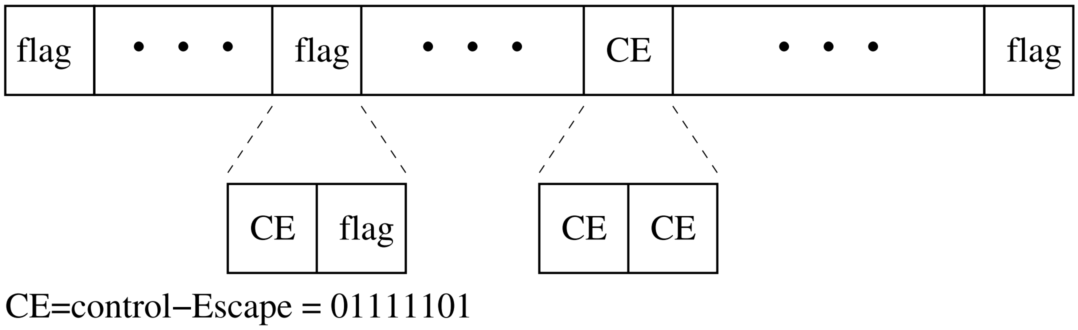
flag	add	ctld	protocol	Data (default max=1500 bytes)	CRC	flag

flag = 01111110
ctld = 00000011

LCP
IPCP
IPv4, IPv6
IPX
⋮

- Support various network protocols.

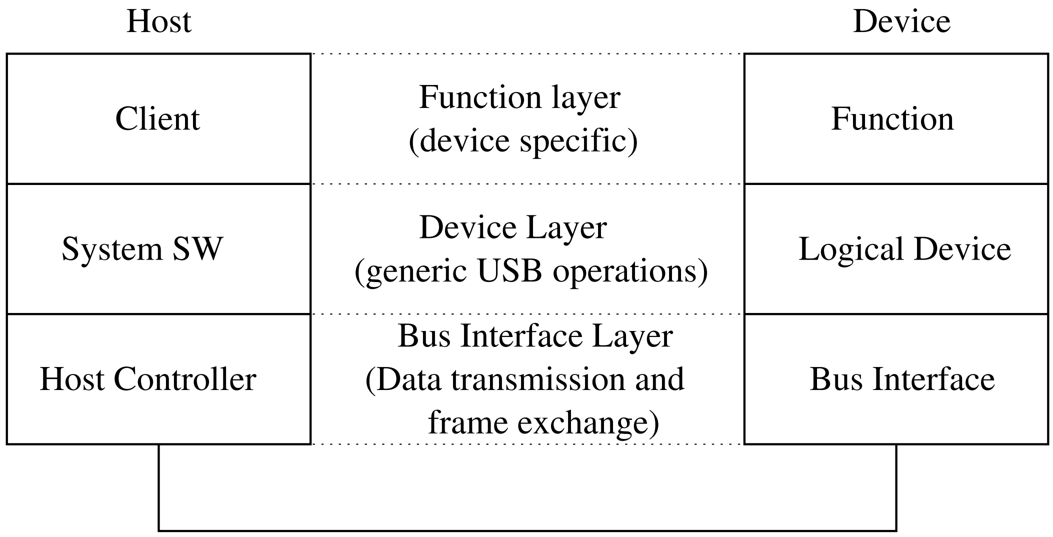
- Data transparency: octet stuffing.



- Link establish phase - negotiate link connection parameters:
  - Frame size, header compression, Authentication options, etc.
- Authentication phase (optional)
  - No authentication;
  - Password Authentication Protocol (PAP);
  - Challenge Handshake Authentication Protocol (CHAP).
- Network layer phase
  - Assign host IP address.
  - IP addresses of default gateway and Domain-Name server.
  - Data exchange.

VII Universal Serial Bus (USB)

- Industrial standard to support common connectivity between PC and its peripherals.
- Protocol stack



- Data transmission:
  - Data rates: 1.5 Mbps, 12 Mbps, and 480Mbps.
  - NRZI coding - signal level changes for the transmission of binary zero.
  - Bit stuffing in every 6 consecutive ones.
- Protocol layer:
  - Point-to-multipoint connection. The host uses polling to control the data transfer.
  - Bulk transfer: Stop-and-wait protocol.
  - Isochronous transfer: no error recovery.