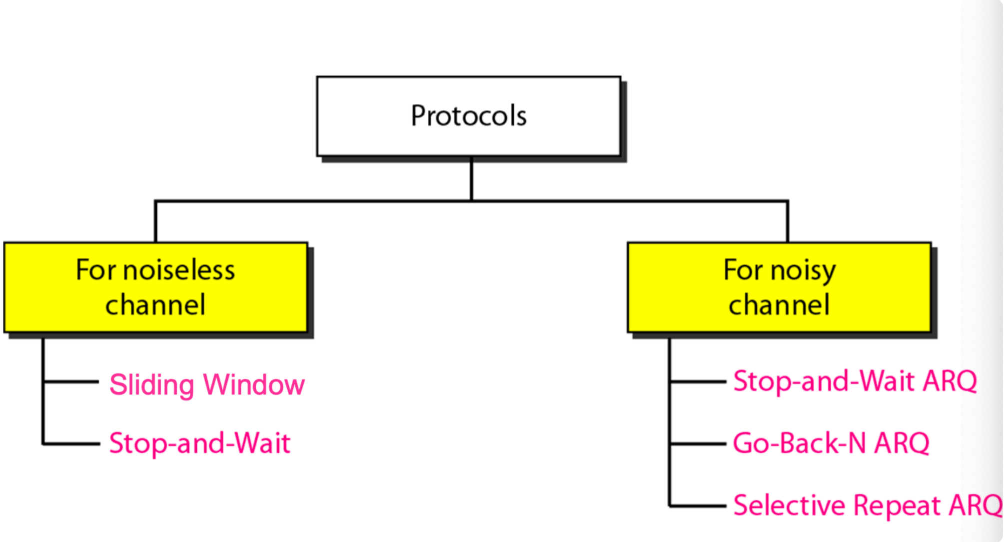
lecture 4 Data Link Layer - Flow Control and Error Control

Flow Control

Flow Control

- Flow control refers to a set of procedures used to restrict the amount of data that the sender can send before waiting for acknowledgment.
- Ensuring the sending entity does not overwhelm the receiving entity
- Influenced by
  - Transmission time
  - Propagation time



Stop and Wait Flow control

Link Utilization (Normalized Throughput)

- Definition: - the fraction of time the channel is used to transmit useful data bits
- Mathematically if T_D seconds is the amount of time the channel transmits useful data bits out of a total of T seconds examined

$$U = \frac{T_D}{T}$$

- For Stop and Wait flow control:
  - $T_D = t_{\text{frame}}$ (frame transmission time)
  - $T = 2\, t_{\text{prop}} + t_{\text{frame}}$

Assume ACK is short and hence the transmission time of ACK is neglected

- Link Utilization:

$$U = \frac{T_D}{T} = \frac{t_{frame}}{t_{frame} + 2t_{prop}}$$

$$= \frac{1}{1+2a}$$

where $$a = \frac{\text{Propagation Time}}{\text{Transmission Time}} = \frac{t_{prop}}{t_{frame}}$$

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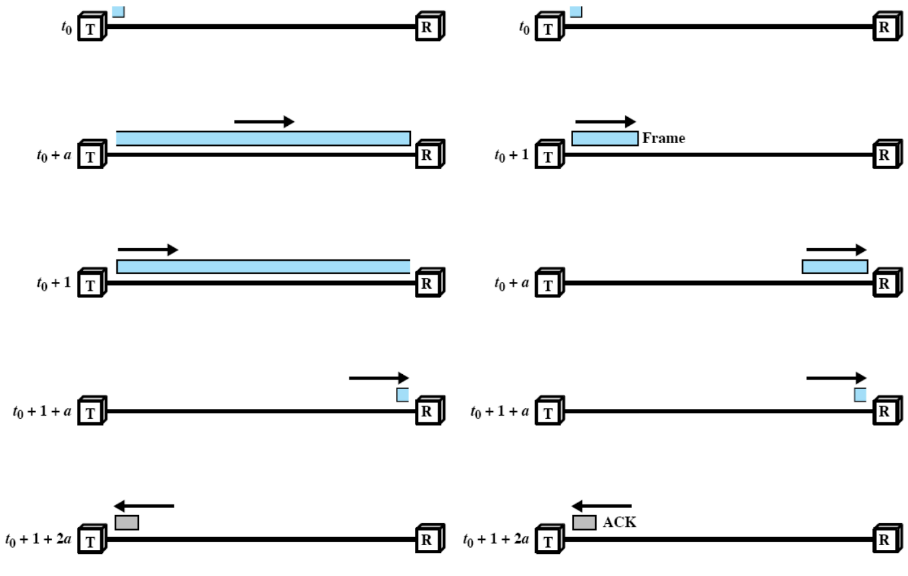
- Note that for a >1, the line is always underutilized and even for a <1, the line is inefficiently utilized.
- In essence, for very high data rates, for very long distances between sender and receiver, stop-and-wait flow control provides inefficient line utilization.



(a) $a < 1$ (b) $a > 1$

(Transmission time for ACK is neglected)

(transmission time $= 1$; propagation time $= a$)

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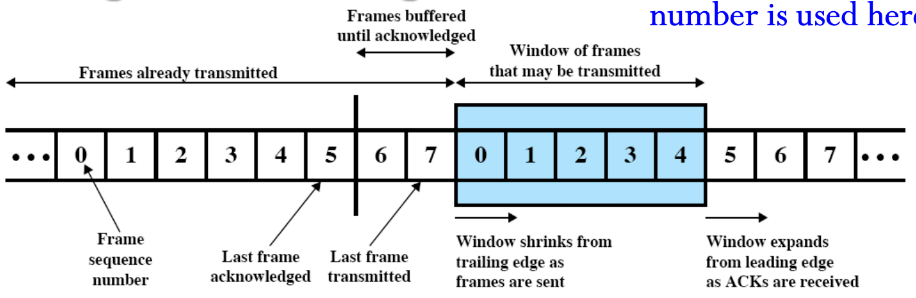
Sliding Window Flow Control

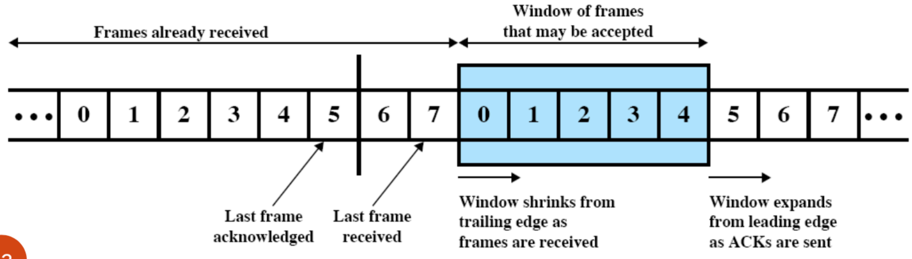
- Allow multiple frames to be in transit
- Receiver has a buffer of storing W frames
- Transmitter can send up to W frames without ACK
- Each frame is numbered
- ACK includes the sequence number of the next frame expected
- Sequence number bounded by size of field (k)
    - Frames are numbered modulo 2^k
- sender maintains a list of consecutive Sequence Numbers (SNs) corresponding to frames that are allowed to send.
- The window size need not be the maximum possible size for a given sequence number length

Sliding Window Diagram

A 3-bit sequence number is used here



(a) Sender's perspective

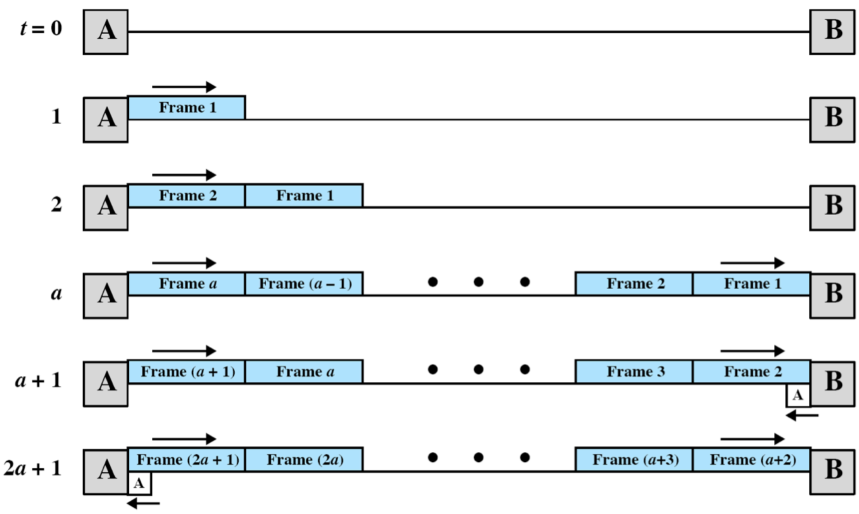


(b) Receiver's perspective

Link Utilization for Sliding Window Flow Control

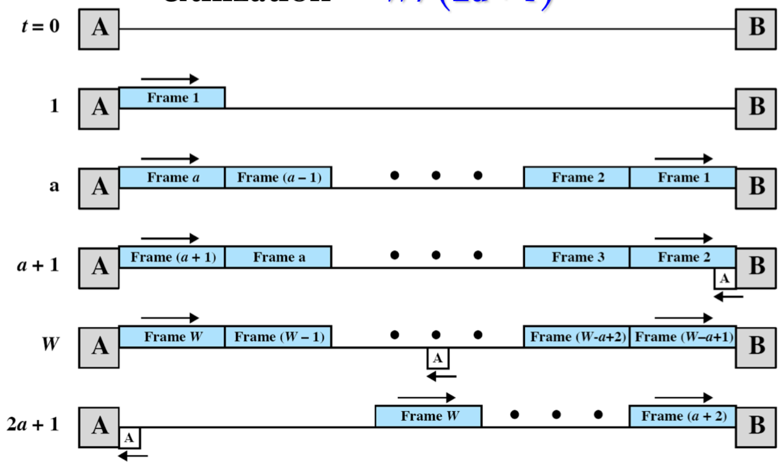
- For convenience, transmission time = 1, propagation time = a
- Consider a full duplex point-to-point line:
  - The sender begins to transmit at time t = 0, then the ACK for the first frame reaches it at t = 2a+1. (Ignore the transmission time of the ACK frame)

Case 1: $W \geq 2a + 1$ The acknowledgement for frame 1 reaches A before A has exhausted its window. Thus A can transmit continuousl with no pause and utilization is 1.



Case 2: $W < 2a + 1$ A exhausts its window at $t = W$ and cannot send additional frames until $t = 2a+1$. Hence

Utilization = $W/(2a+1)$



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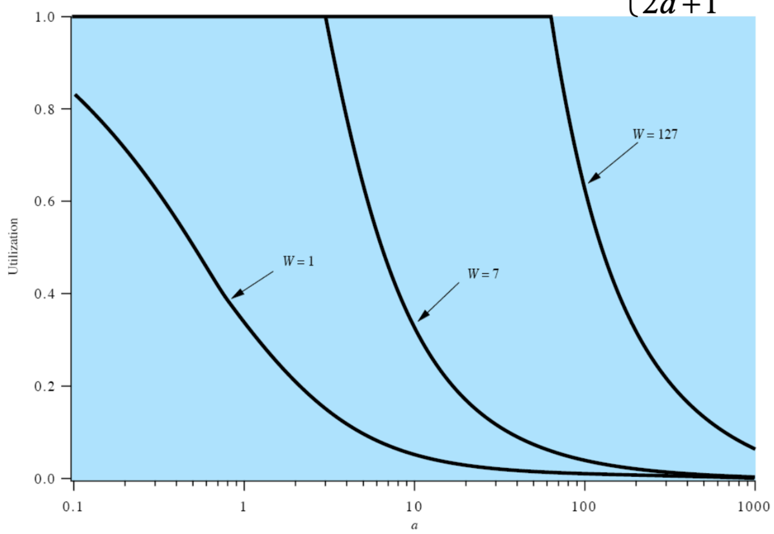
- Link utilization as a function of a:

$$a = \frac{\text{Propagation Time}}{\text{Transmission Time}} = \frac{t_{prop}}{t_{frame}}$$

$$U = \begin{cases} 1 & W \geq 2a+1 \\ \dfrac{W}{2a+1} & W < 2a+1 \end{cases}$$



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Error Control - Stop and Wait ARQ

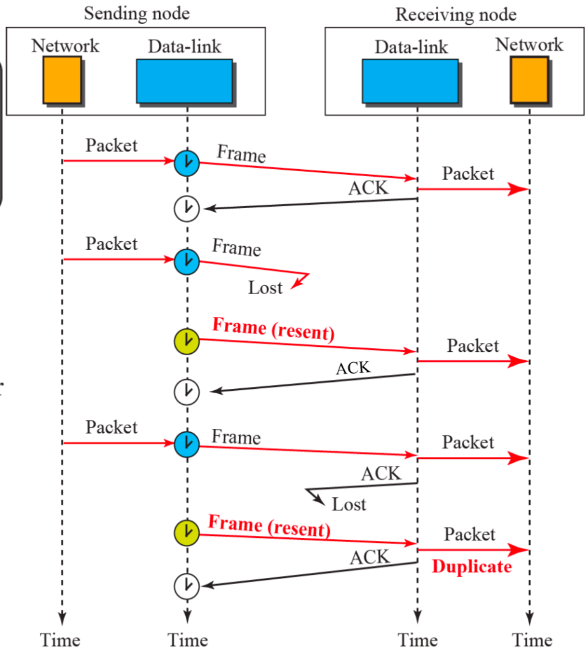
Automatic Repeat Request (ARQ)

- Two sorts of errors could occur

Legend

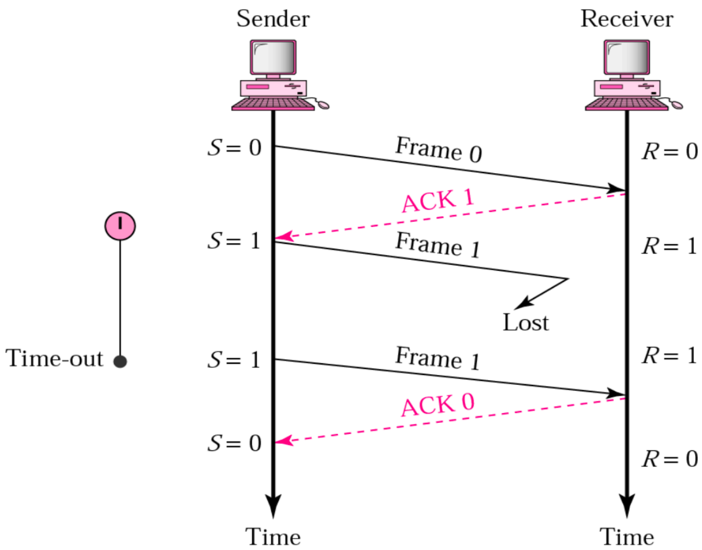
- Start the timer.
- Stop the timer.
- Restart a time-out timer.

Notes:
A lost frame means either lost or corrupted.
A lost ACK means either lost or corrupted.



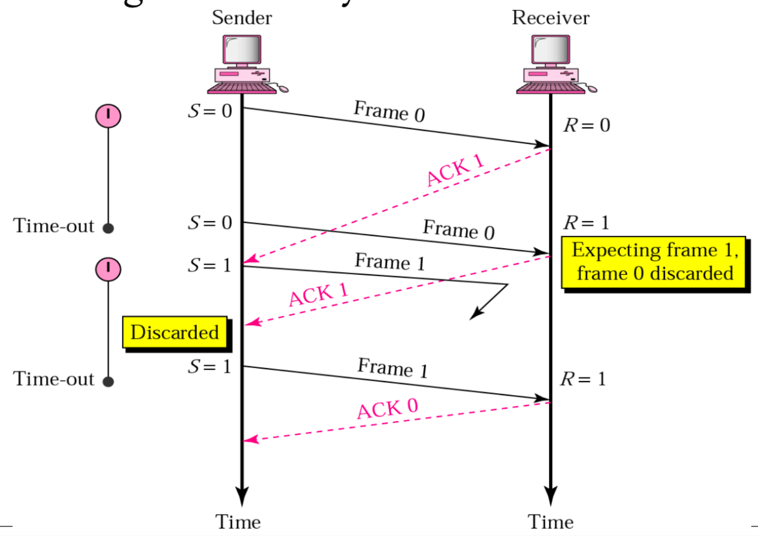
Needs to identify the duplicated frame

- **Lost frame:**

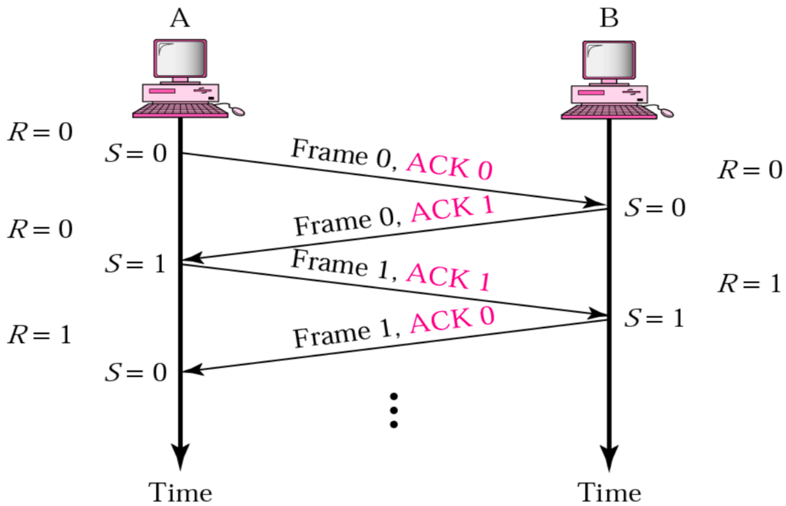


Note: The sender needs to maintain a copy of a transmitted frame until ACK is received.

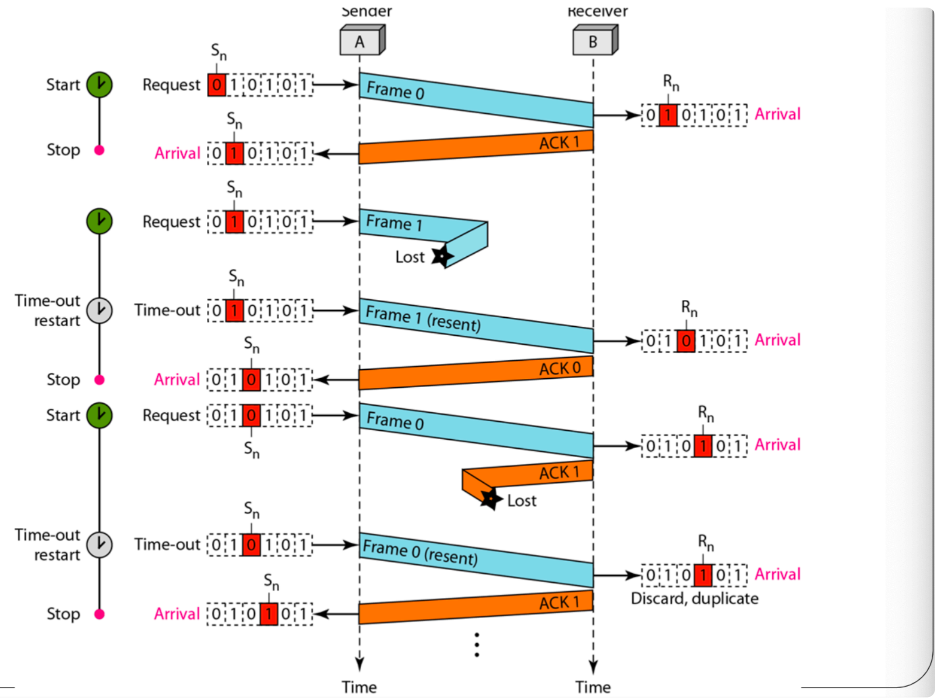
- **Delayed ACK:**
  - Numbered acknowledgments are needed if an acknowledgment is delayed and the next frame is lost.



- **Piggybacking**
  - The data in one direction is piggybacked with the acknowledgment in the other direction.



Example



Performance of Stop-and-Wait ARQ

$$\text{Utilization} = \frac{\text{Time for transmitter to emit a single frame}}{\text{Total time that line is engaged in the transmission of a single frame}}$$

- For Error Free $$U = \frac{1}{1+2a}$$
- With Error $$U = \frac{1}{N_r(1+2a)}$$

  where N_r is the expected number of transmissions of a frame
- The principal advantage of stop-and-wait ARQ is its simplicity. Its principal disadvantage is that stop-and-wait is an inefficient mechanism.

- Let P be the probability that a single frame is in error.
- Assume that ACKs and NAKs are never in error, the probability that it will take exactly i attempts to transmit a frame successfully is $P^{i-1}(1-P)$

$$N_r = \mathrm{E}(\text{transmissions}) = \sum_{i=1}^{\infty} (i \times P_r[i \text{ transmissions}])$$

$$= \sum_{i=1}^{\infty} (iP^{i-1}(1-P)) = \frac{1}{1-P}$$

- The Utilization for Stop and Wait ARQ is

$$U = \frac{1-P}{1+2a}$$

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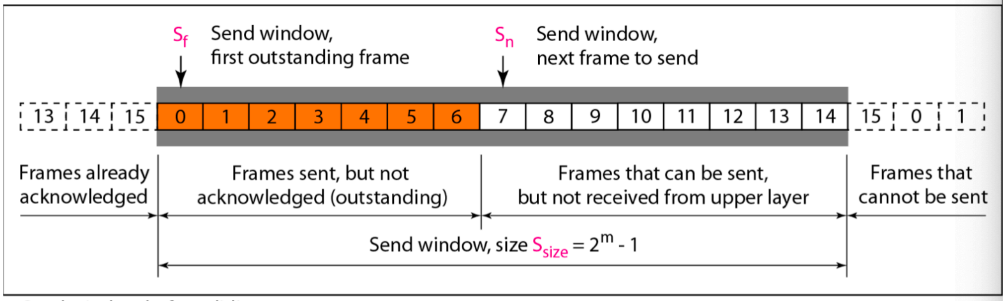
Go-Back-N ARQ

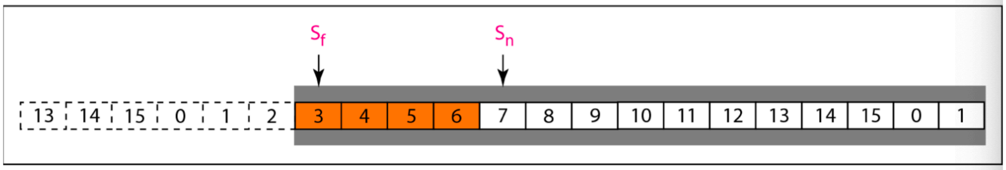
- Based on sliding window flow control
  - Sender sends up to W frames before worrying about acknowledgements
  - It keeps a copy of these frames
- Error: reply with rejection
  - destination will discard that frame and all future frames until frame in error is received correctly
  - transmitter must go back and retransmit that frame and all subsequent frames
- Damaged frame
  - error in frame i so receiver discards frame i
  - Receiver will either
    - do nothing and wait until the transmitter times out
    - send a Reject(i) signal to the transmitter
- Transmitter retransmits frames from i

Sender Sliding Window

- Hold the outstanding frames until they are acknowledged

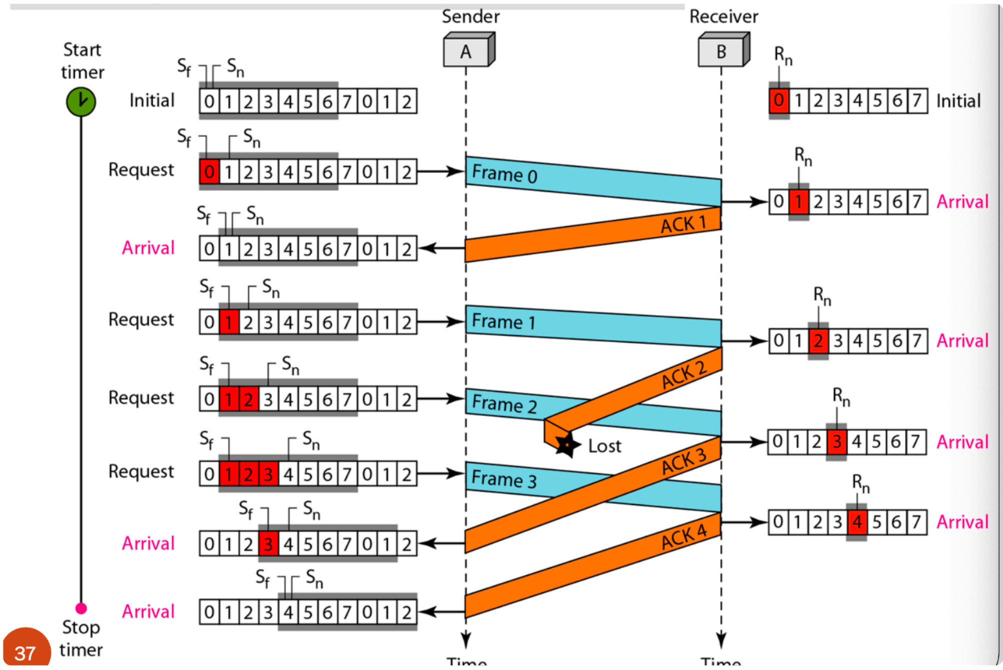


a. Send window before sliding

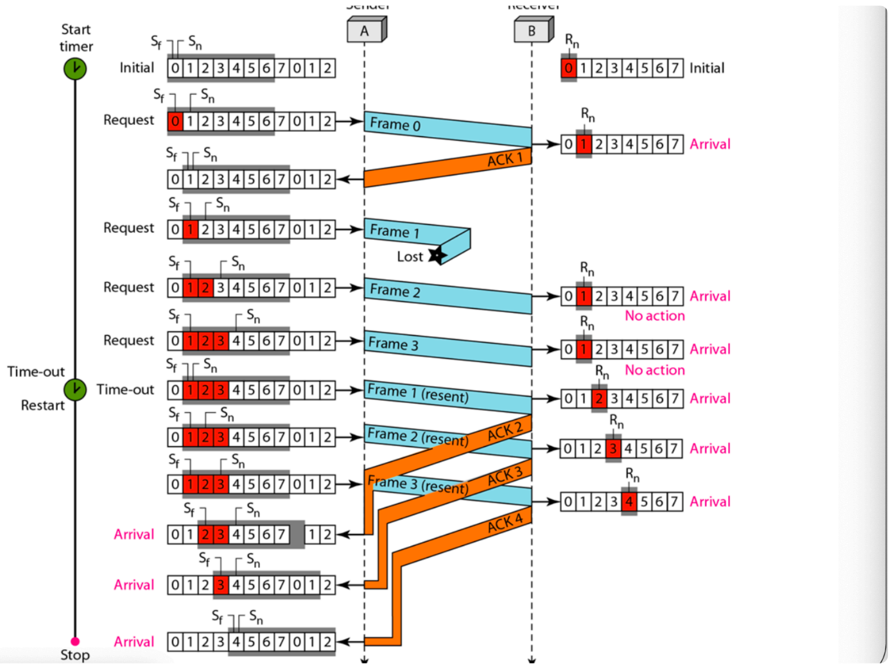


b. Send window after sliding

Example 1: Go-Back-N ARQ

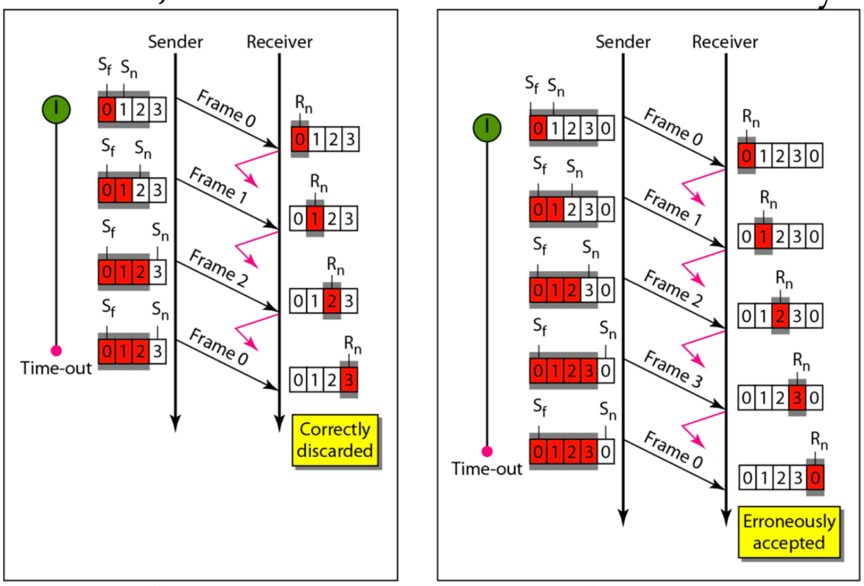


Example 2: Go-Back-N ARQ



Window Size of Go-Back-N ARQ

- In Go-Back-N ARQ, the size of the send window must be less than 2^m; the size of the receiver window is always 1.



a. Window size < 2^m

b. Window size = 2^m

Performance of Go-Back-N ARQ

- The utilization for Go-Back-N ARQ is

$$U = \begin{cases} \dfrac{1}{N_r} & W \geq 2a+1 \\ \dfrac{W}{N_r(2a+1)} & W < 2a+1 \end{cases}$$

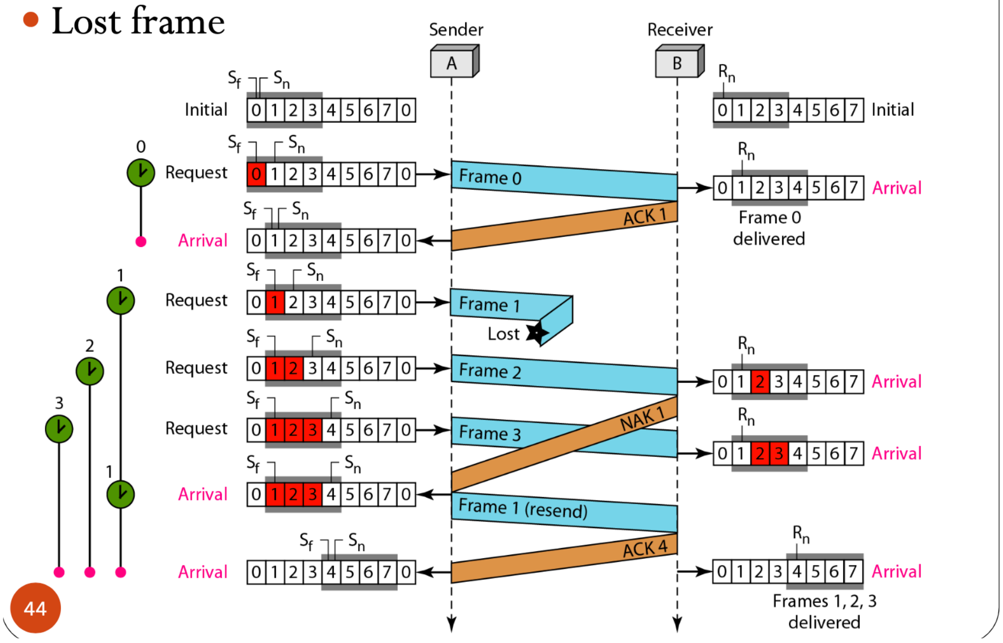
$$= \begin{cases} \dfrac{1-P}{1+2aP} & W \geq 2a+1 \\ \dfrac{W(1-P)}{(2a+1)(1-P+WP)} & W < 2a+1 \end{cases}$$

Selective-Repeat ARQ

- Also called selective retransmission or selective reject ARQ
- Main ideas:
  - Only resend the corrupted data
  - Allow the receiver to keep track of the received frame
  - Introduce a negative acknowledgment (NAK) that reports the sequence number of a damaged frame
- More efficient: minimizes the amount of retransmission
- Receiver must maintain a large enough buffer
- More complex logic in transmitter to send a frame out of sequence

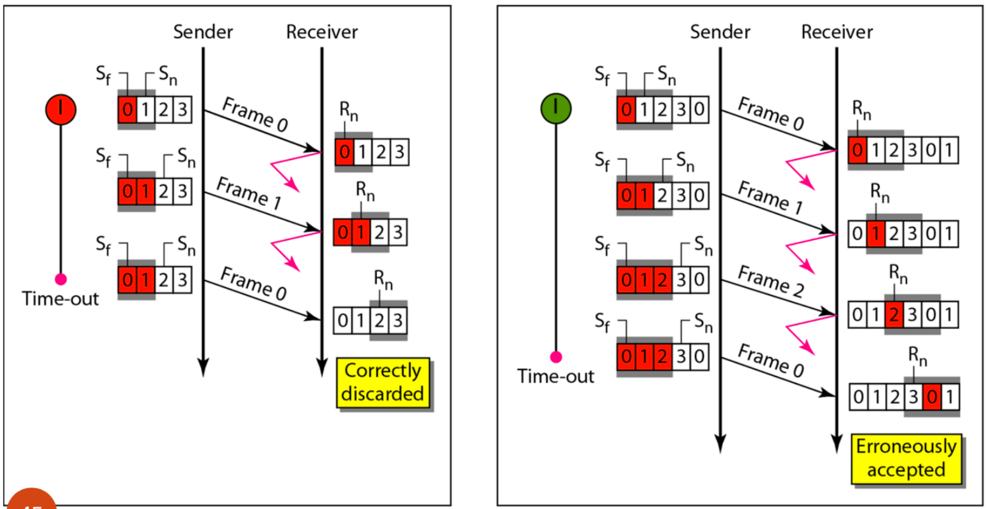
Example 1: Selective-Repeat ARQ

- Lost frame



Window Size of Selective Repeat ARQ

- In Selective Repeat ARQ, the size of the sender and receiver window must be at most one-half of 2^m.



a. Window size = 2^{m-1} b. Window size > 2^{m-1}

Performance of Selective-Repeat ARQ

- The utilization for Selective-Repeat ARQ is

$$U = \begin{cases} \dfrac{1}{N_r} & W \geq 2a+1 \\ \dfrac{W}{N_r(2a+1)} & W < 2a+1 \end{cases}$$

$$= \begin{cases} 1-P & W \geq 2a+1 \\ \dfrac{W(1-P)}{(2a+1)} & W < 2a+1 \end{cases}$$

Performance of ARQ

Performance of ARQ