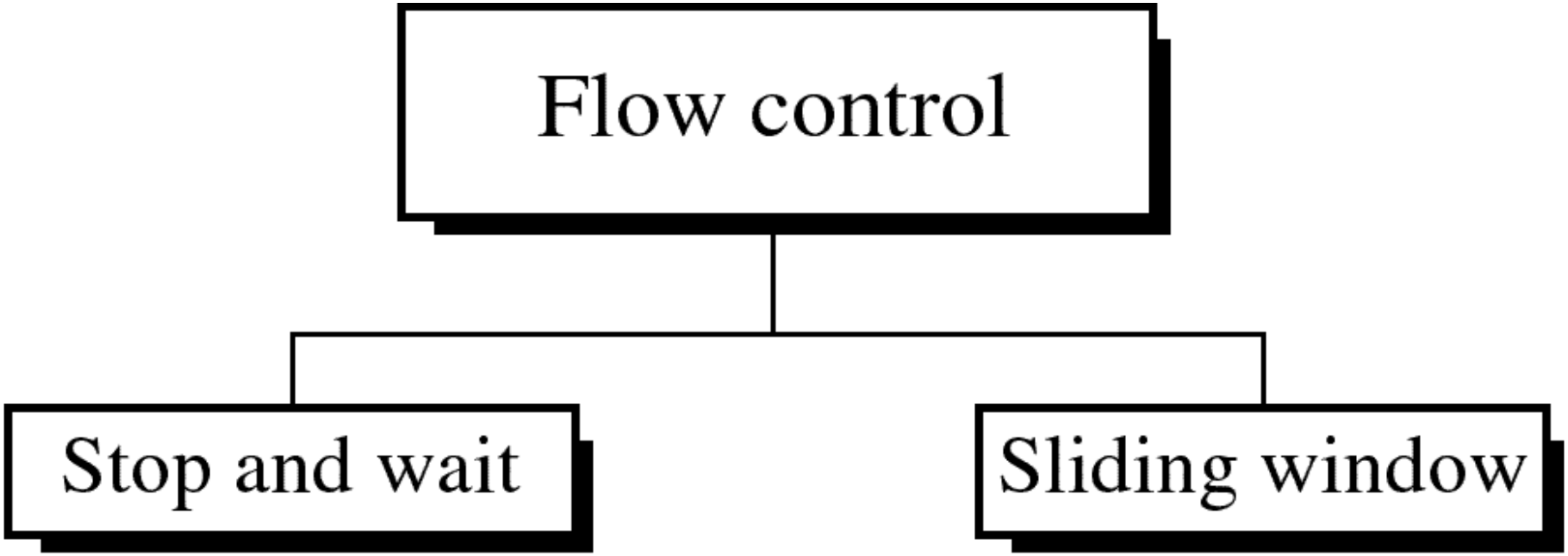
Flow & Error Control

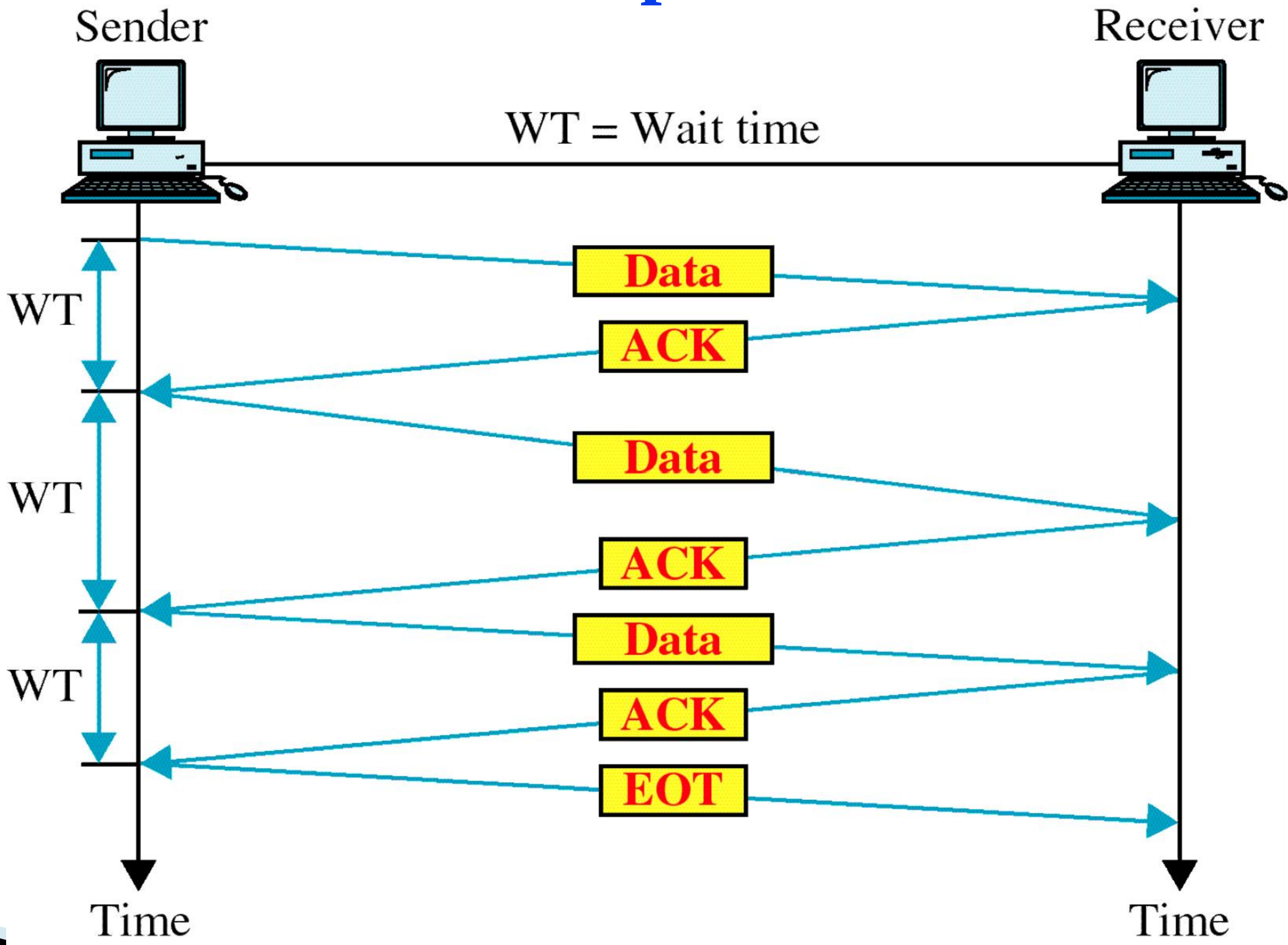
- The most important responsibilities of the data link layer are flow control and error control. Collectively, these functions are known as data link control.
  - Flow control refers to a set of procedures used to restrict the amount of data that the sender can send before waiting for acknowledgment.
  - Error control in the data link layer is based on automatic repeat request (ARQ) , which is the retransmission of data.



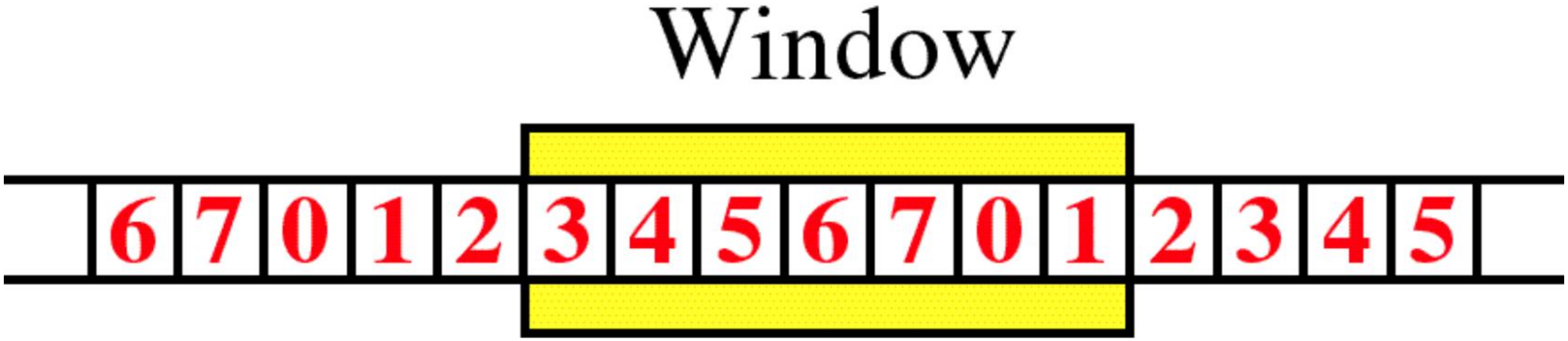
Send one frame at a time

Send several frames at a time

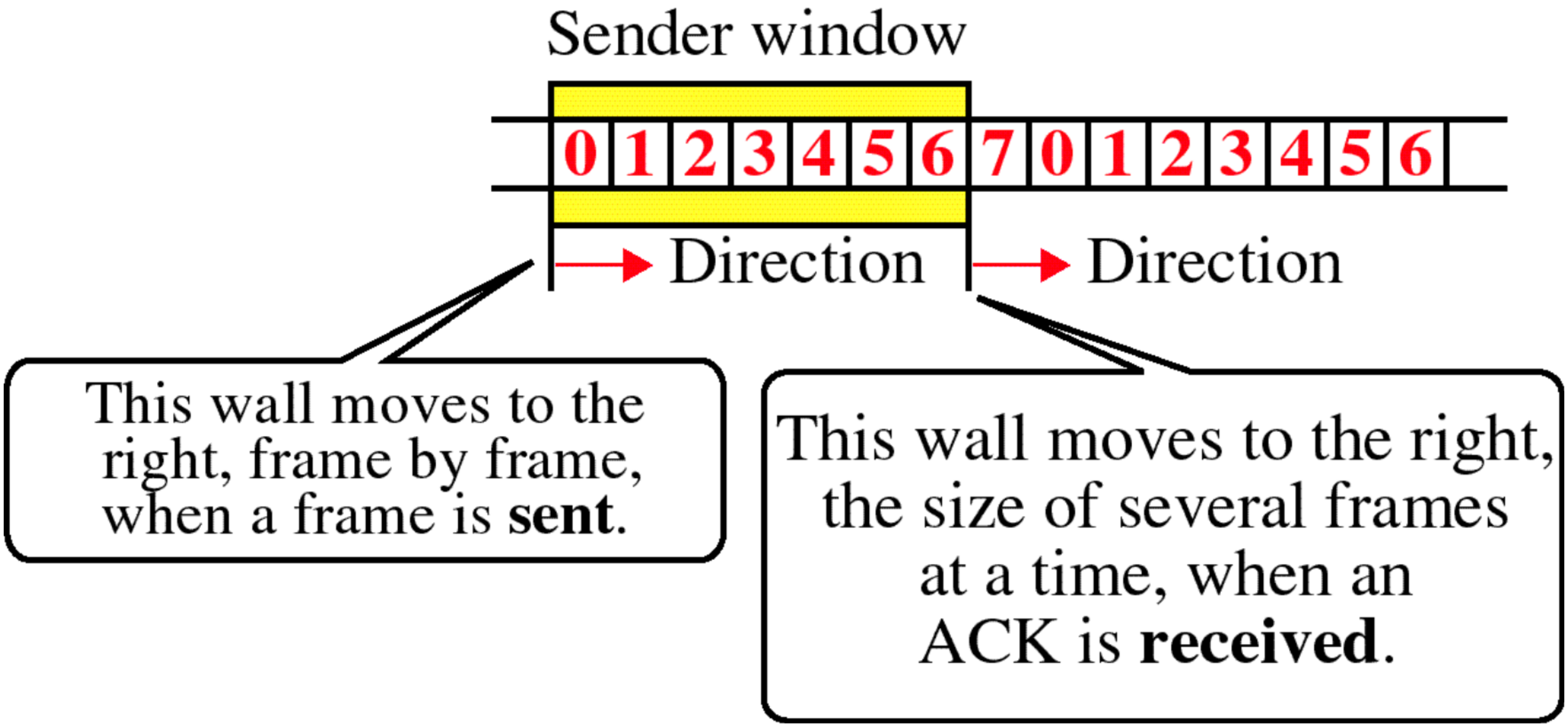
Flow Control : Stop and Wait



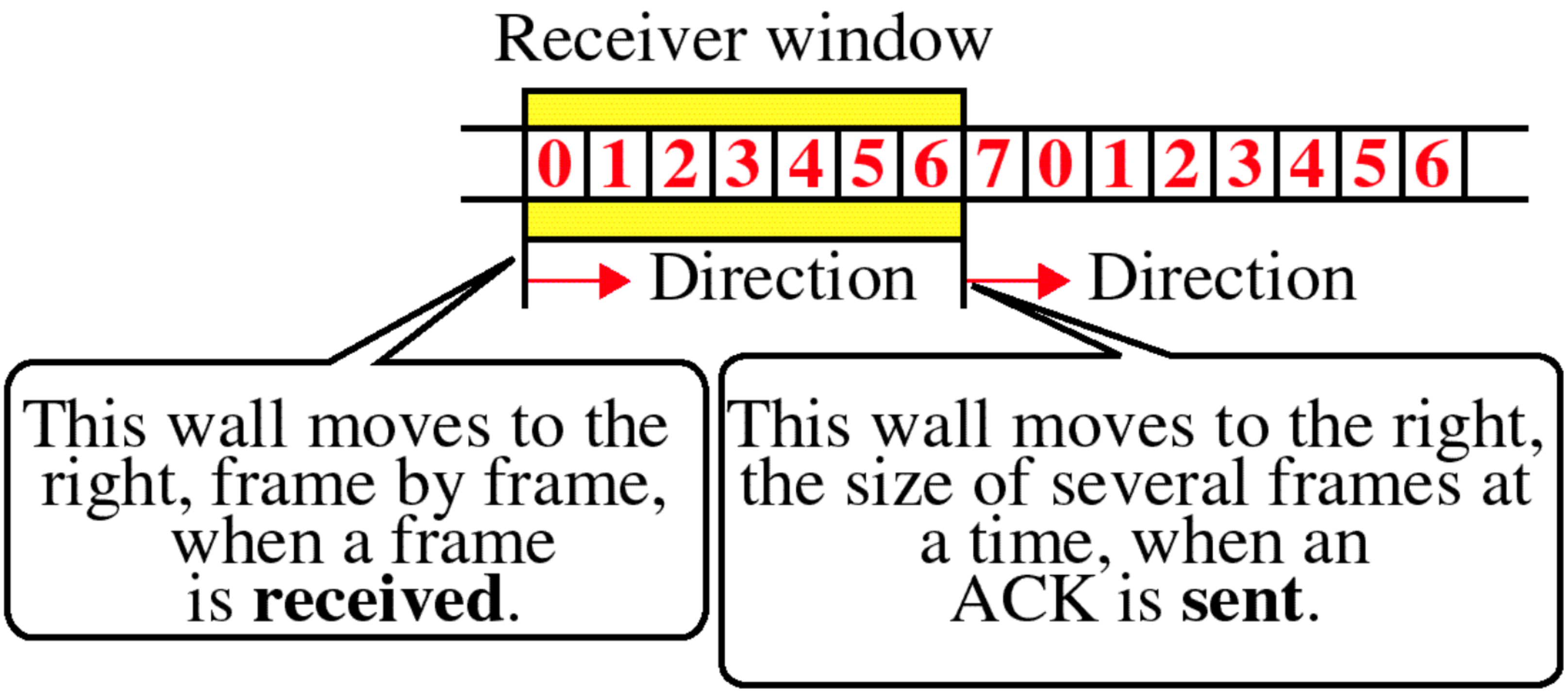
Sliding Window



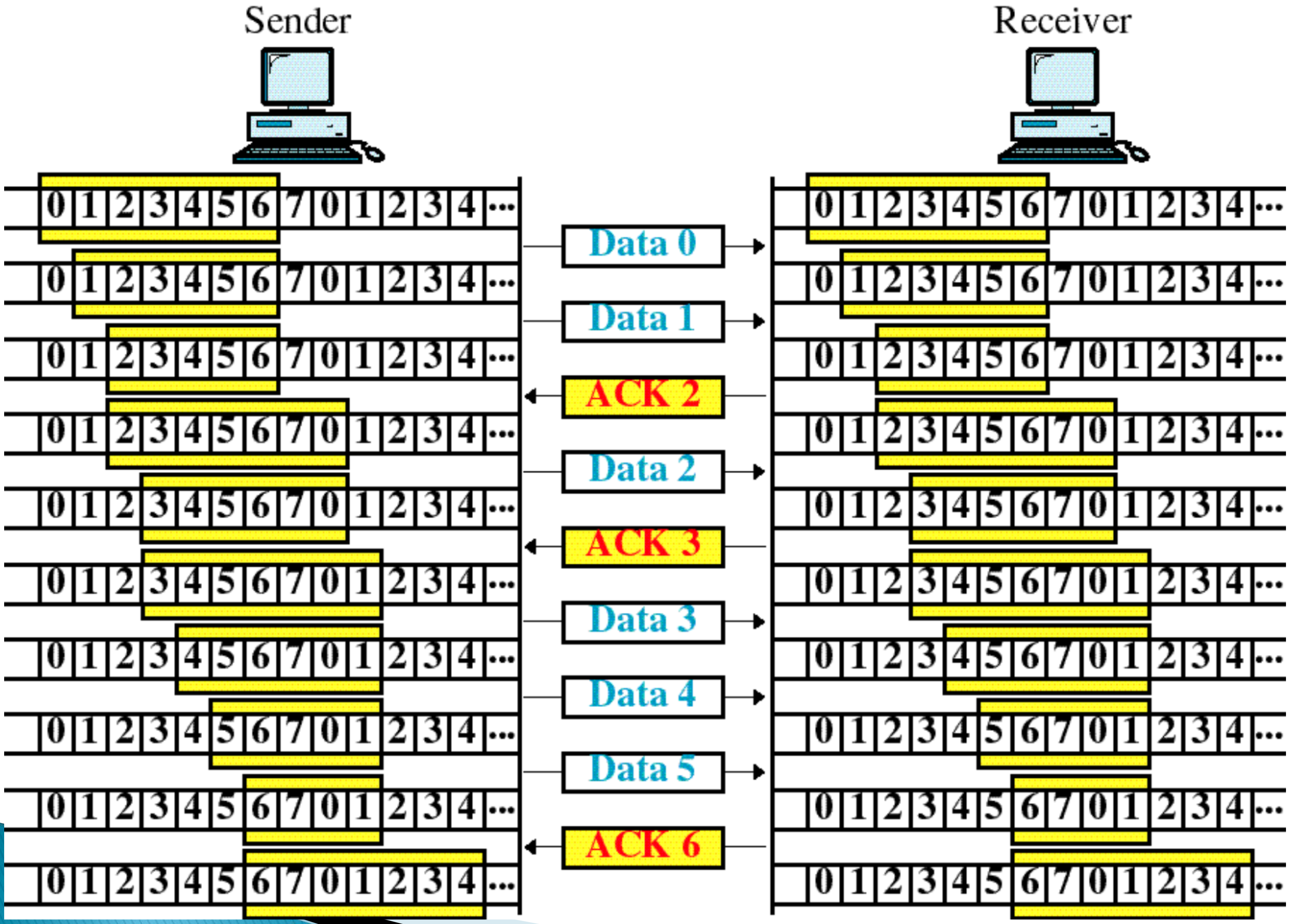
Sender Sliding Window

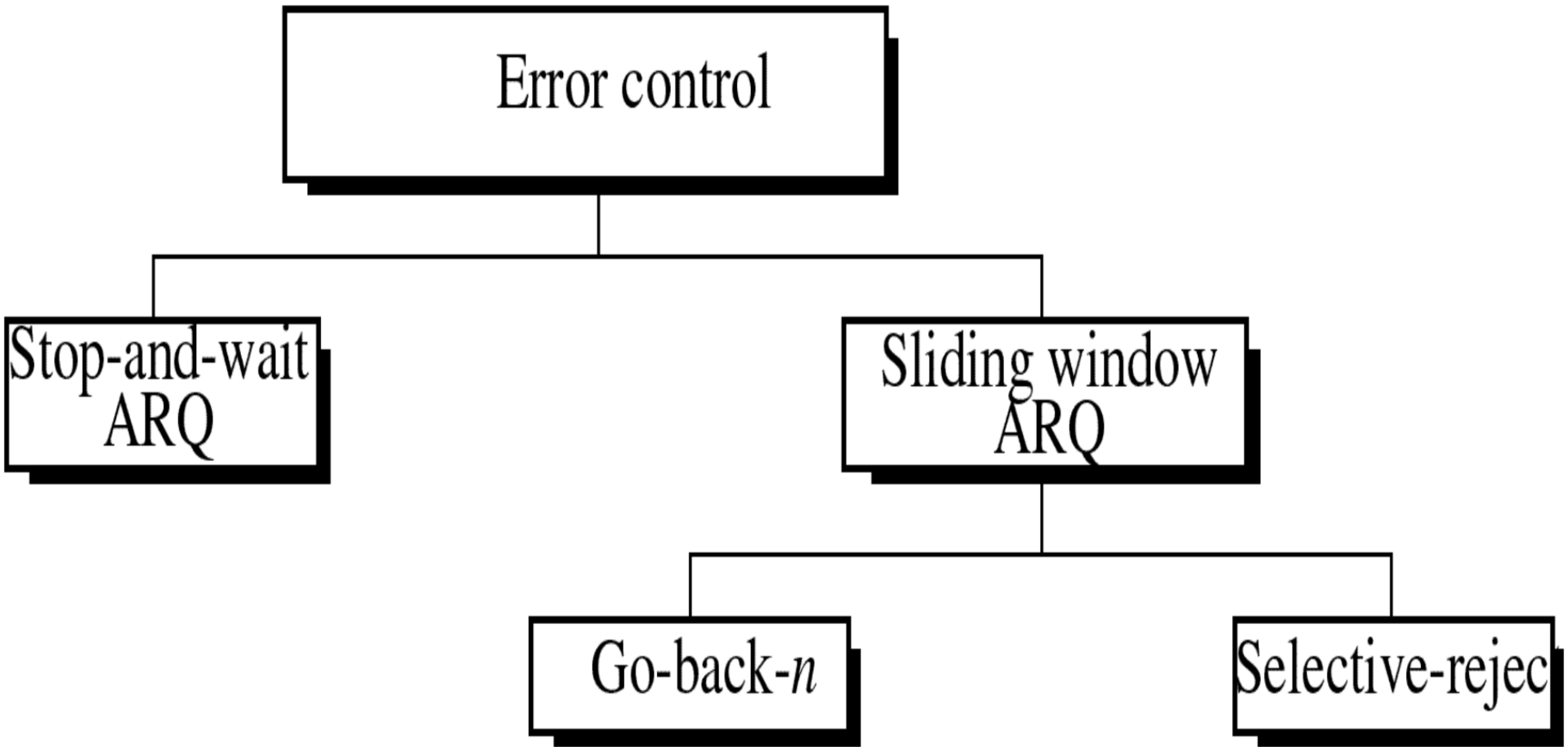


Receiver Sliding Window



Sliding Window Example

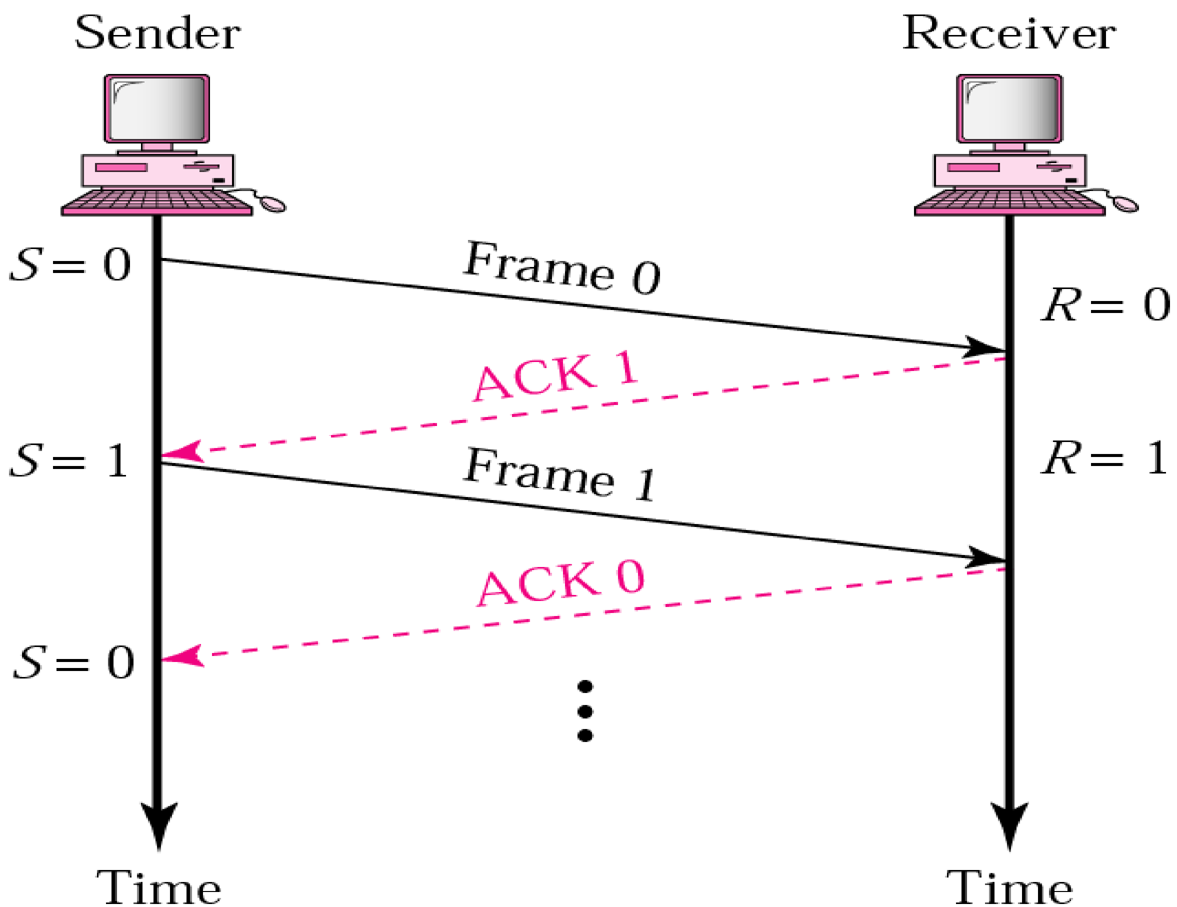



Error control
Stop-and-wait ARQ
Sliding window ARQ
Go-back-n
Selective-rejec

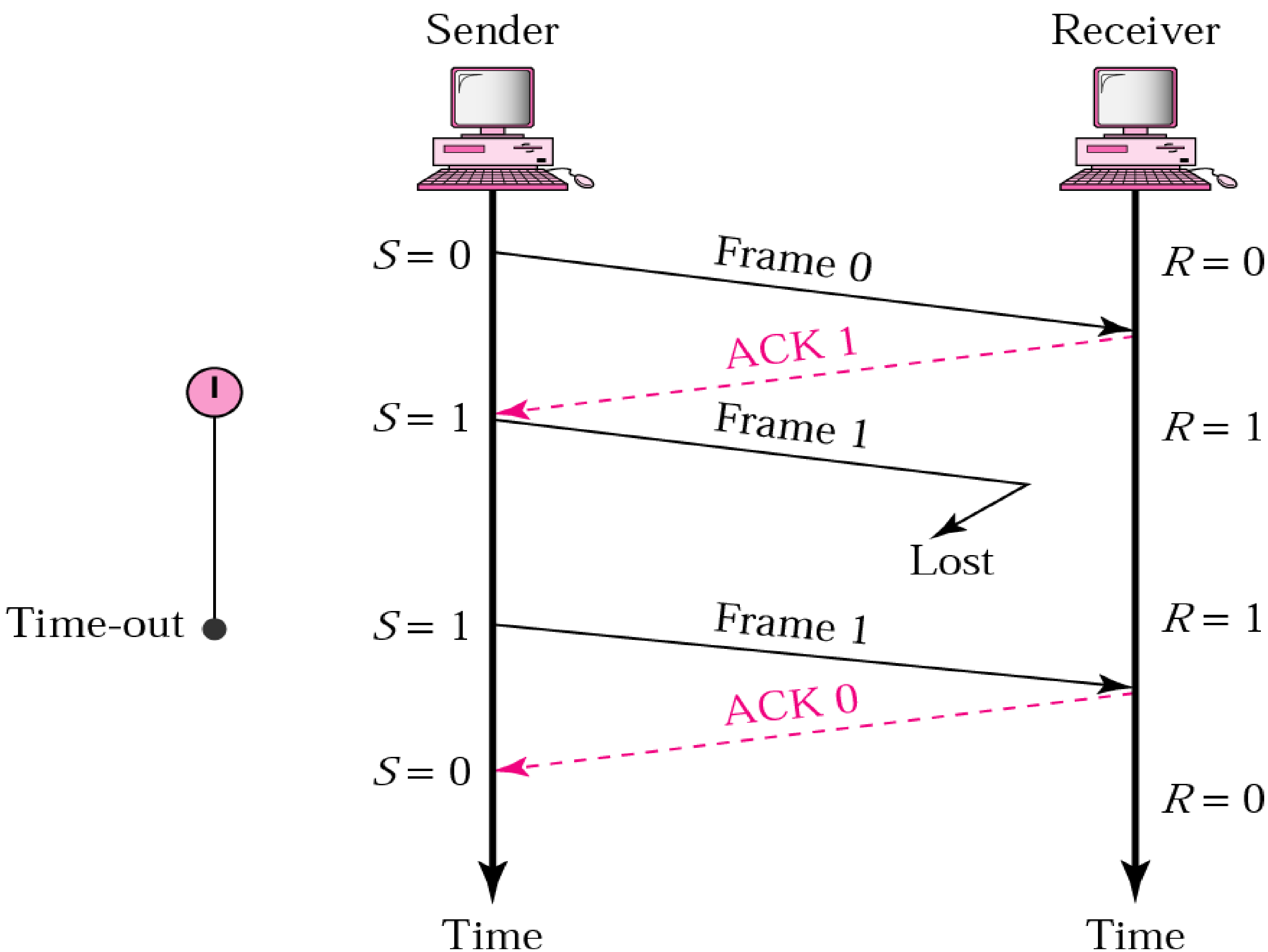
Stop & Wait ARQ

- Normal operation
- The Frame is lost/ damaged
- The ACK is lost.
- The ACK is delayed.

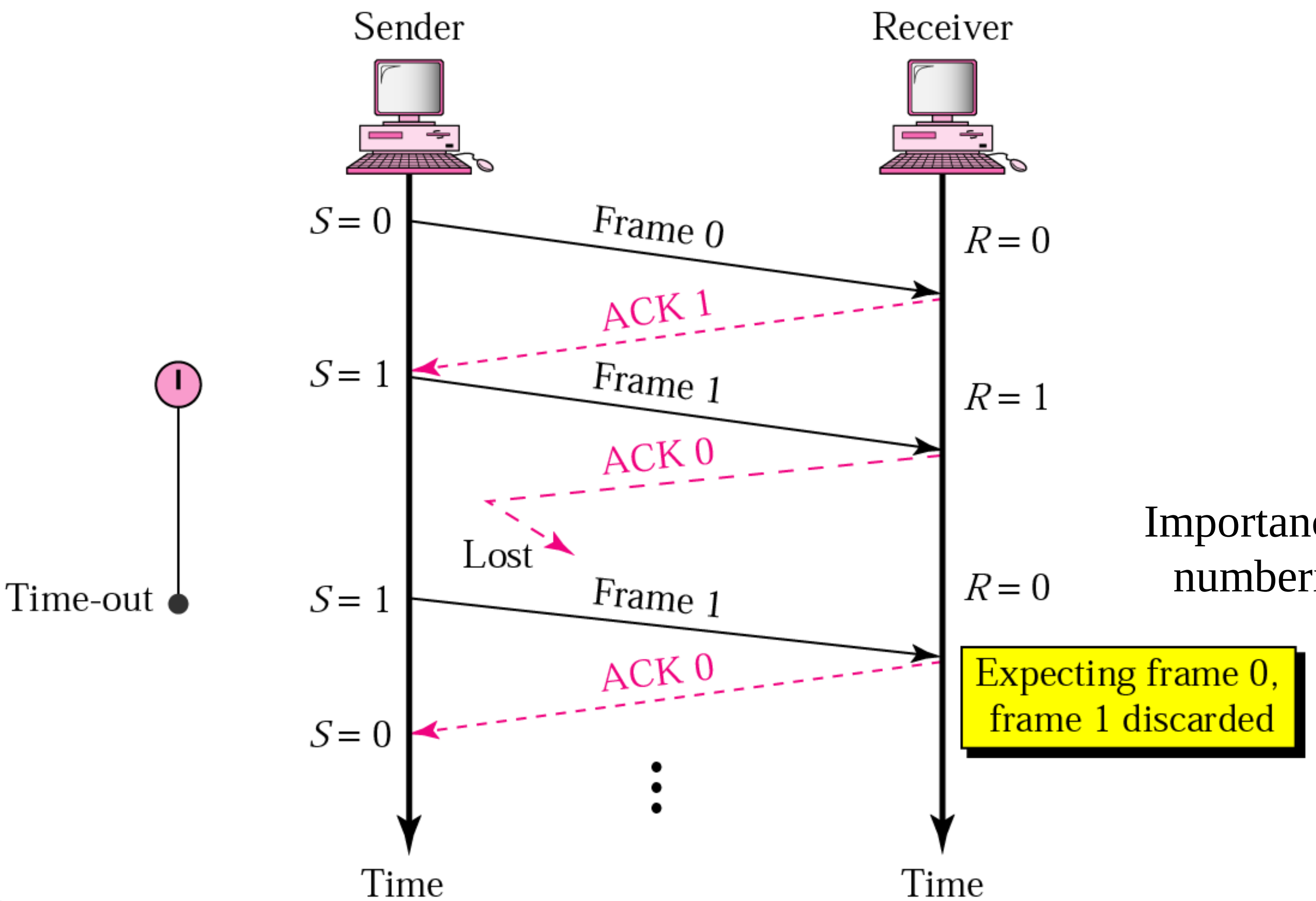
Stop & Wait ARQ : Normal Operation



Stop & Wait ARQ: Damaged Frame/ lost Frame

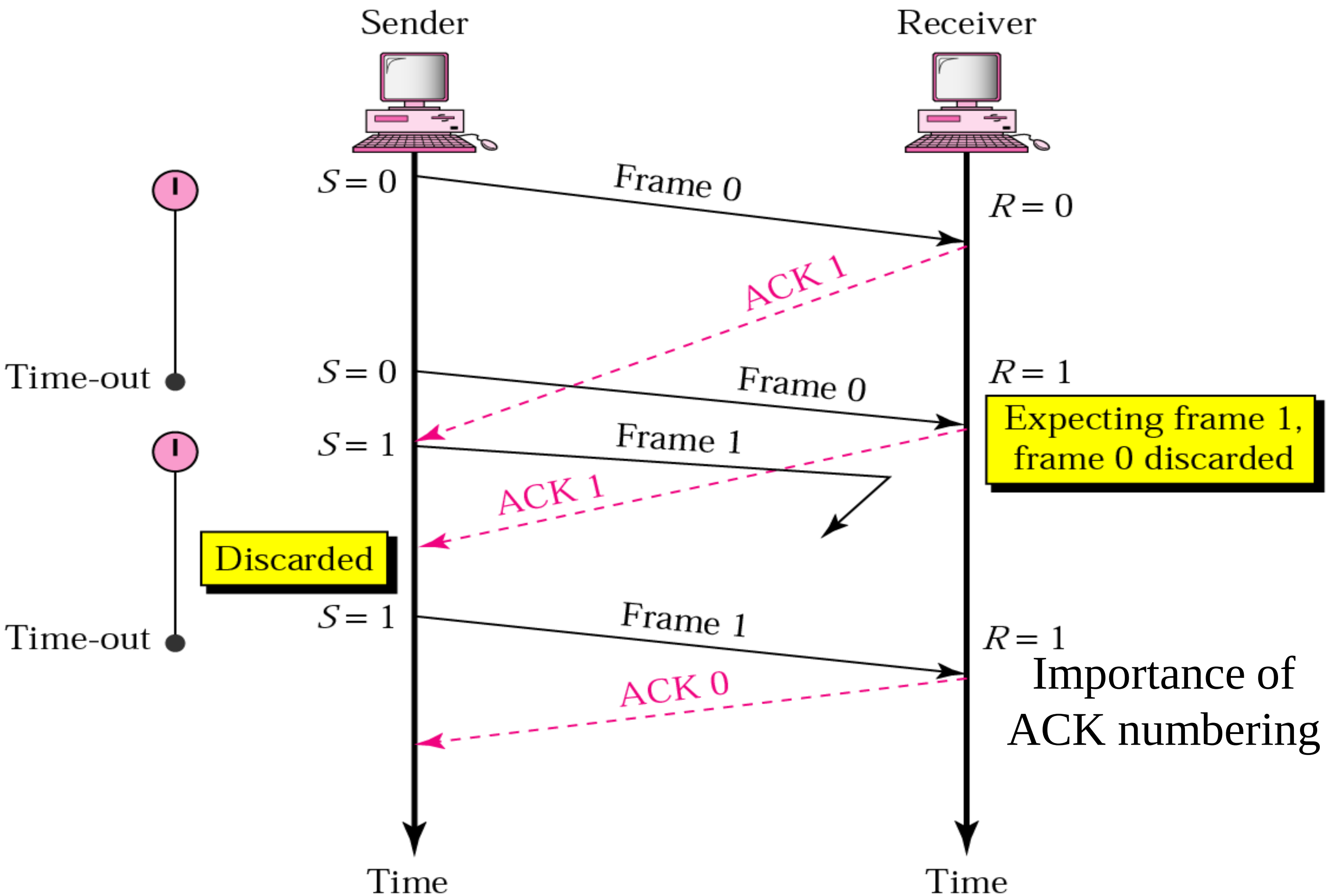


Stop & Wait ARQ : Lost ACK



Importance of numbering

Stop & Wait ARQ : Delayed ACK



Importance of ACK numbering

Summary : Stop-and-Wait ARQ

- Error correction in Stop and Wait ARQ is done by keeping a **copy of the sent frame** and retransmitting of the frame when the timer expires.
- In Stop-and-Wait ARQ, we use sequence numbers to number the frames. The sequence numbers are based on **modulo-2** arithmetic.
- In Stop-and-Wait ARQ, the acknowledgment number always announces in **modulo-2** arithmetic the sequence number of the next frame expected.

Drawbacks of Stop-and-Wait ARQ

- After each frame sent the host must wait for an ACK
  - **inefficient use of bandwidth**
- To improve efficiency ACK should be sent after multiple frames
- Alternatives: **Sliding Window protocols**

Sliding Window Protocols

Pipelining :

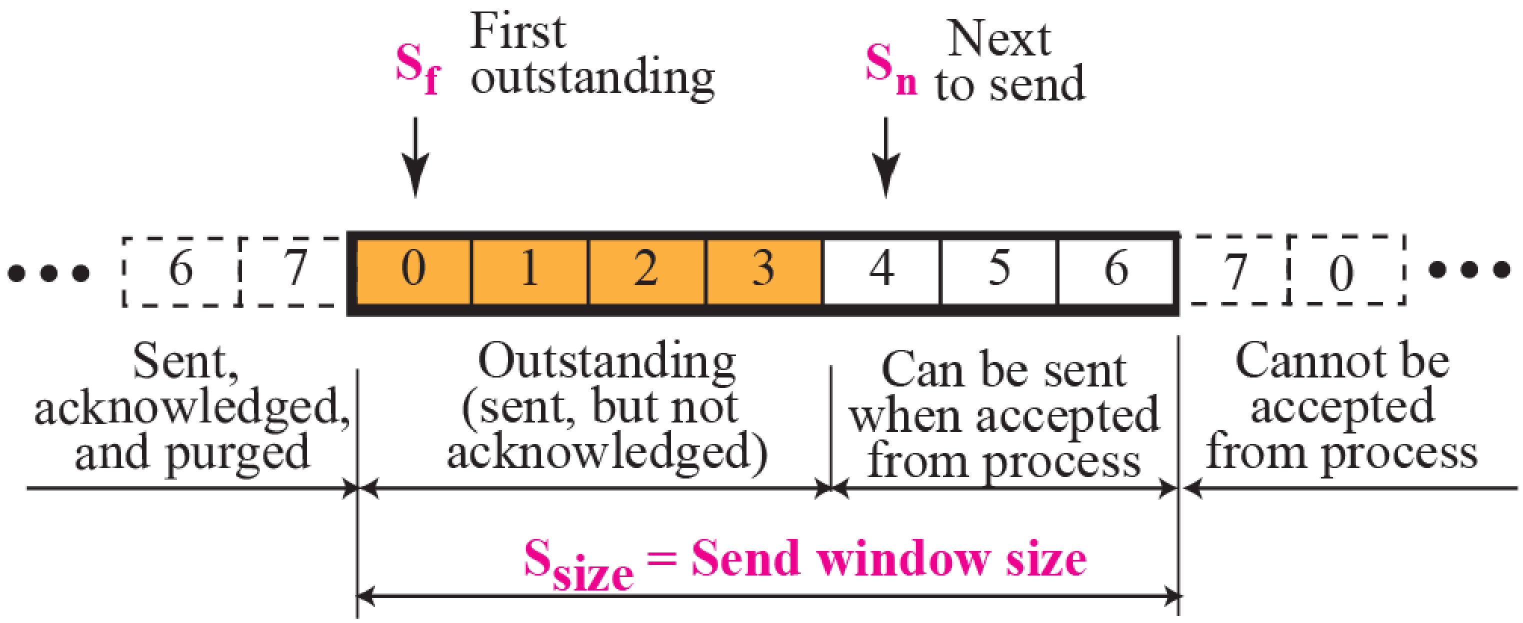
One task begins before the previous task ends.

- There is no pipelining in Stop-and-Wait ARQ because we need to wait for a frame to reach the destination and be acknowledged before the next frame can be sent.
- Pipelining **improves the efficiency** of the transmission.
- **Sliding Window protocols apply Pipelining :**
  1. Go-back-*N* ARQ
  2. Selective Repeat ARQ

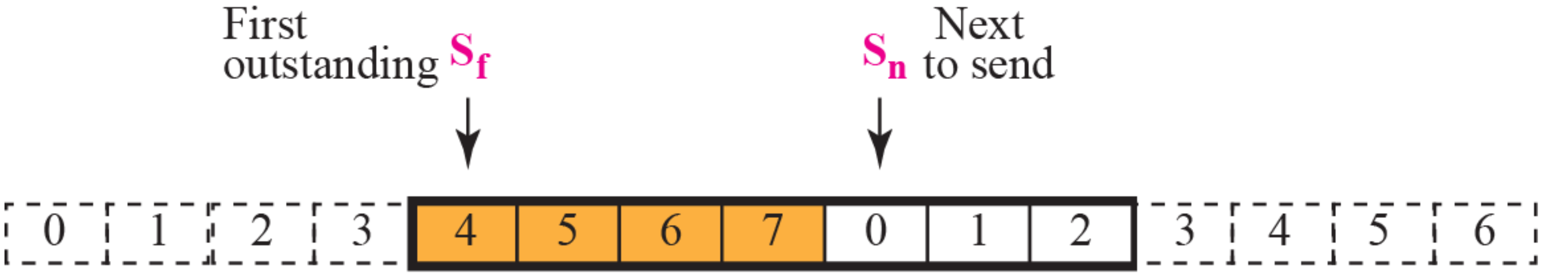
Go-back-N ARQ

- In this protocol we can send several frames before receiving acknowledgements; we keep a copy of these frames until the acknowledgements arrive.
- **Sequence number filed :**
- In Go-Back-N protocol, the sequence numbers are **modulo 2^m** , where m is the size of the sequence number field in bits. (header of the frame).

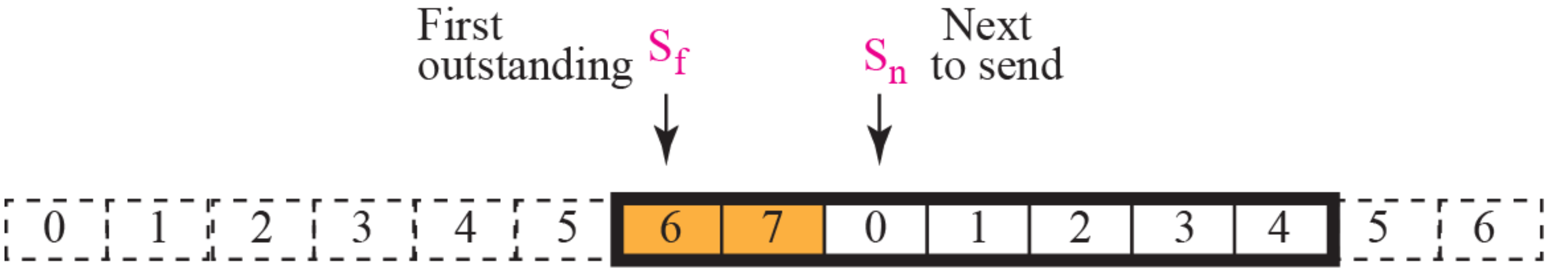
Send window for Go-back-N ARQ



Sliding the send window

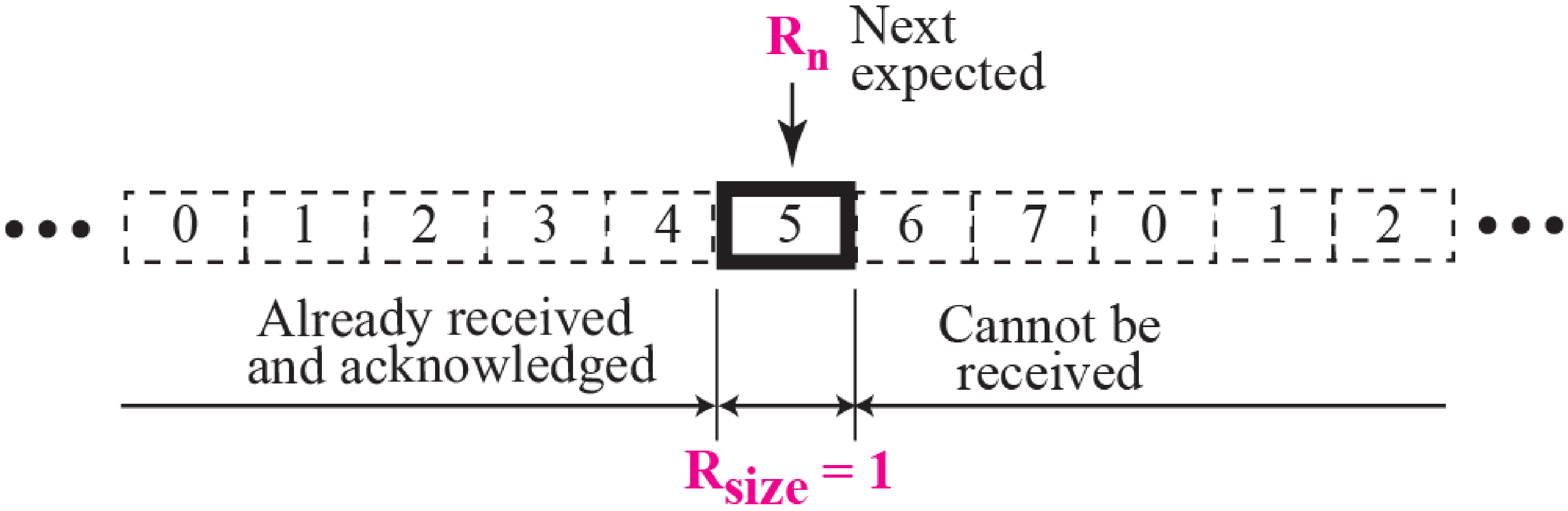


a. Window before sliding

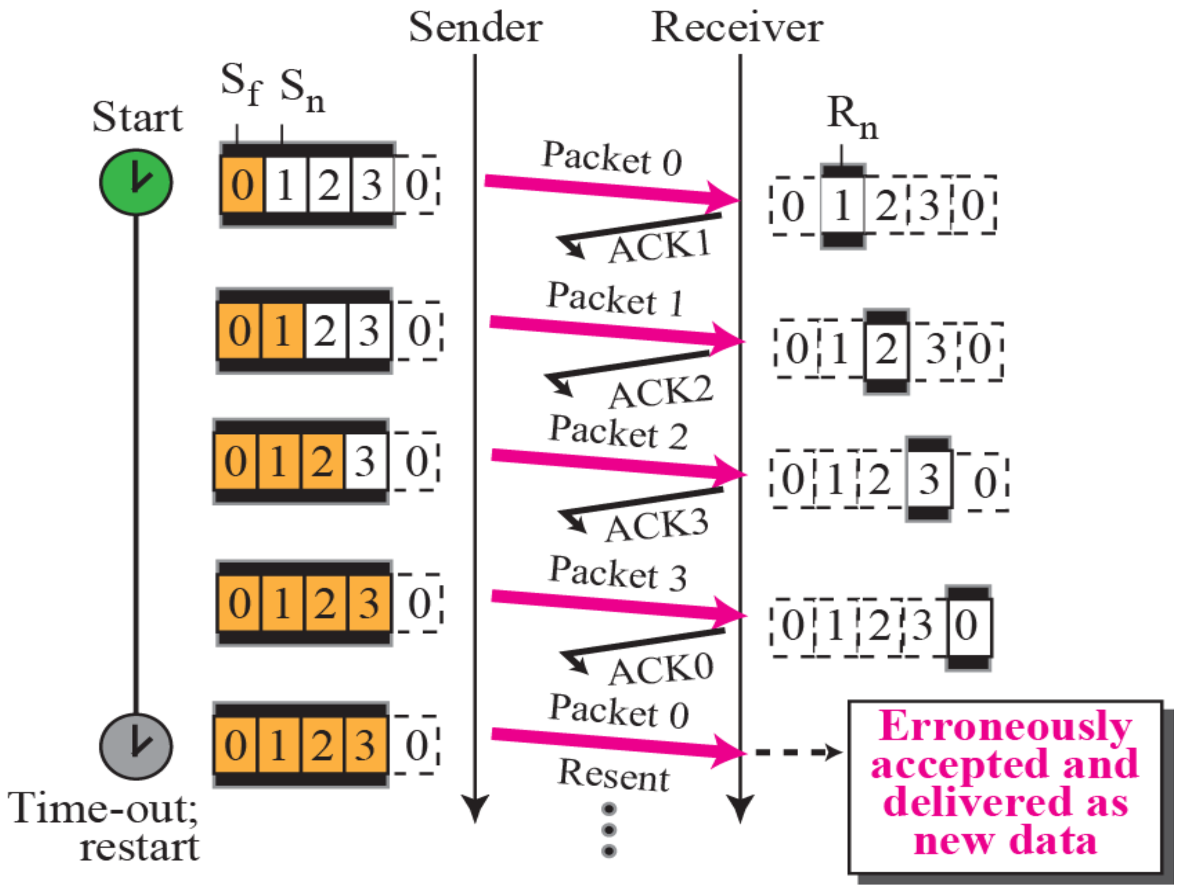


b. Window after sliding (an ACK with ackNo = 6 has arrived)

Receive window for Go-back-N ARQ

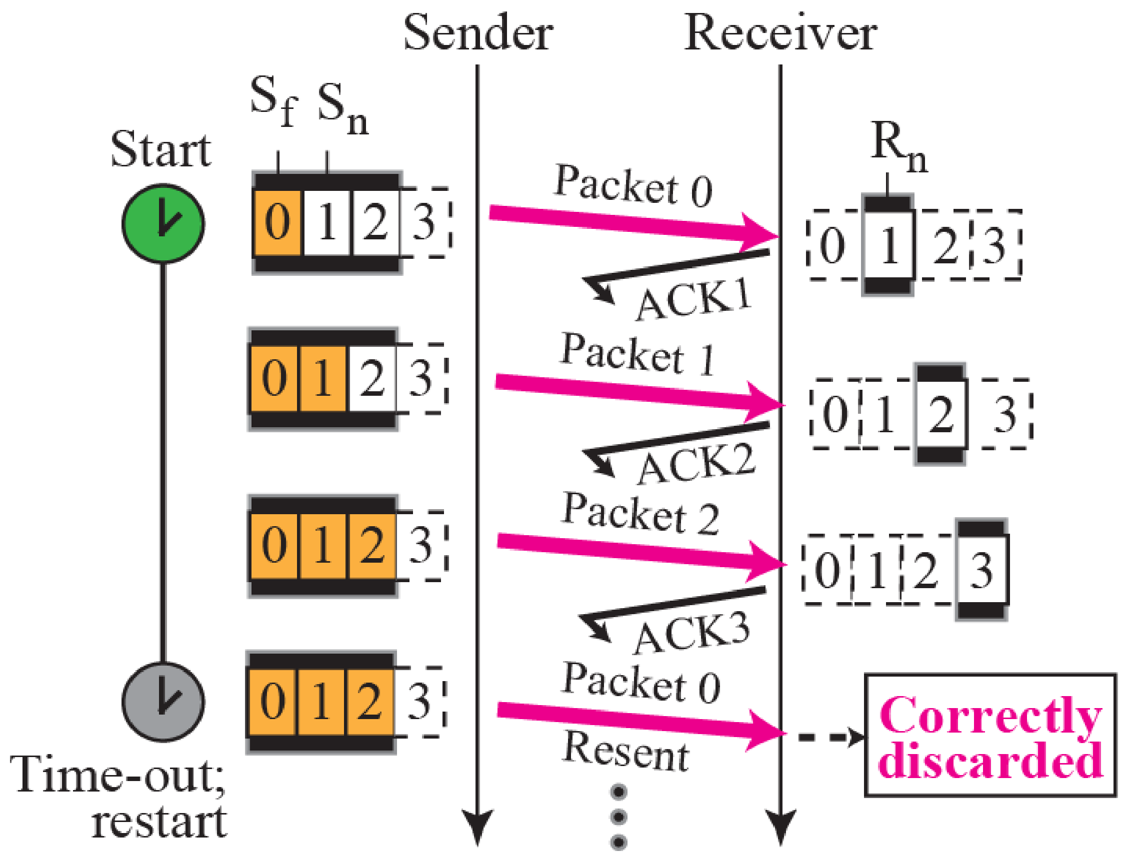


Send window size for Go-Back-N



b. Send window of size = 2^m

Send window size for Go-Back-N

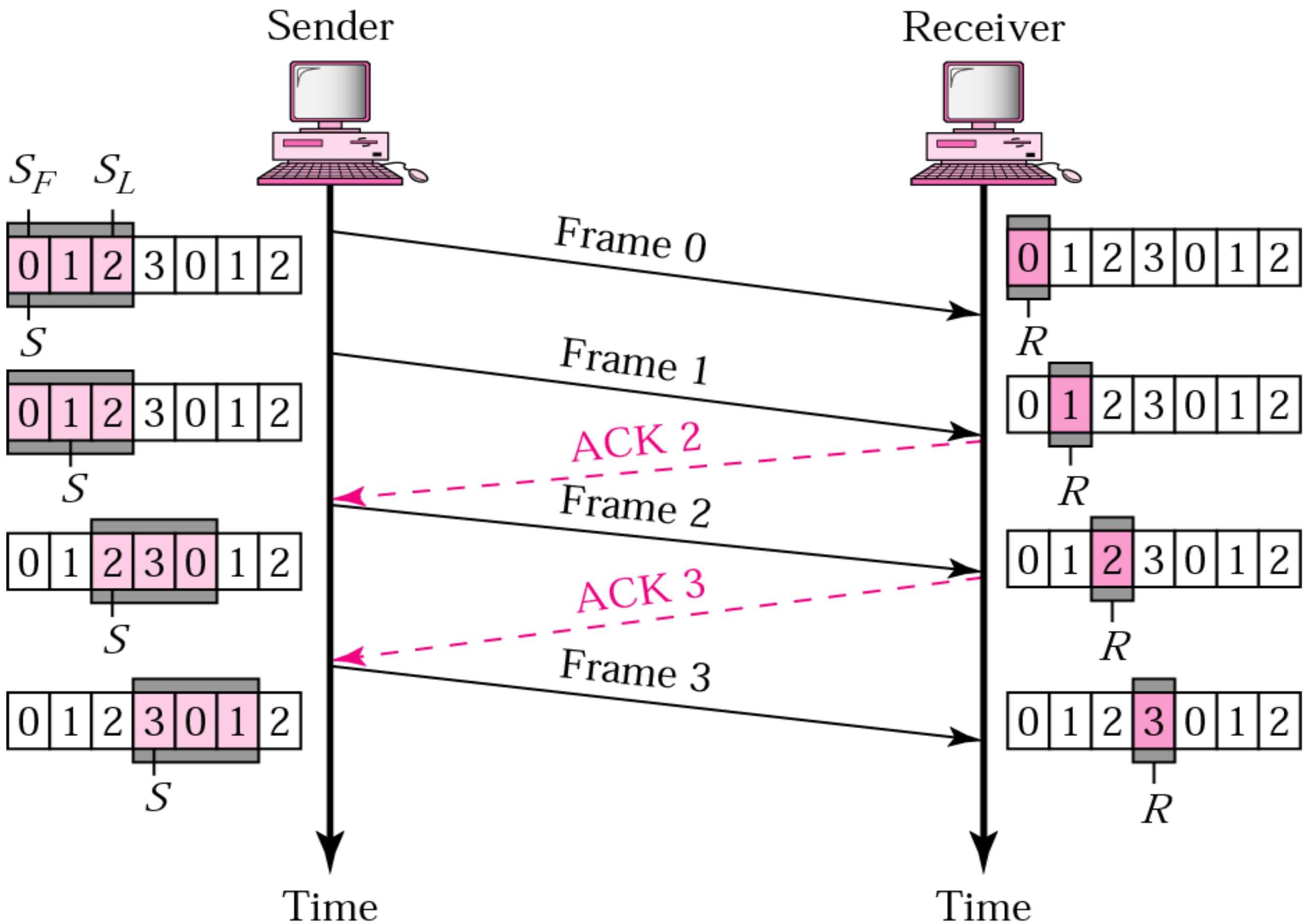


a. Send window of size $< 2^m$

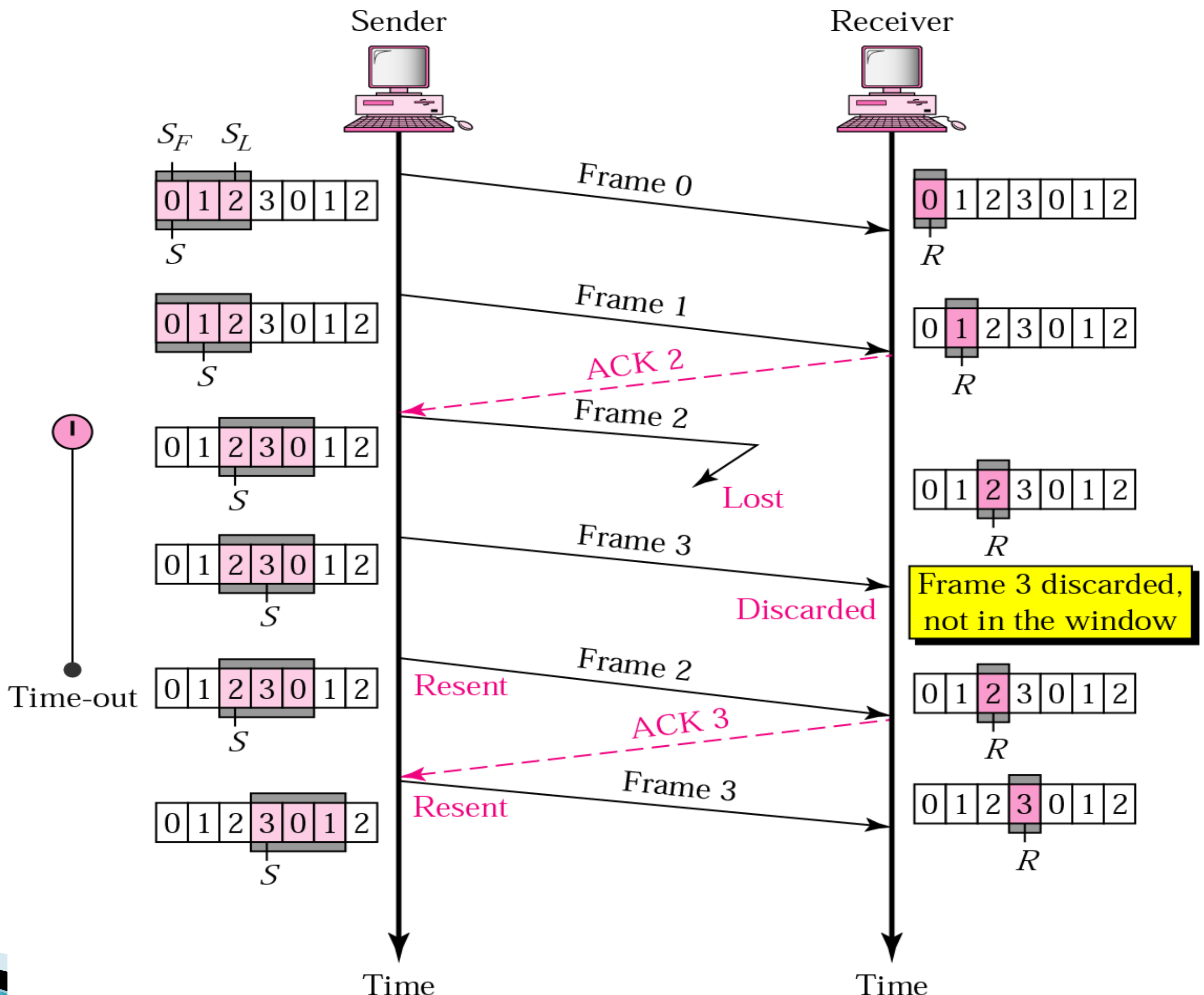
Go-back-N ARQ

- In the Go-Back-N protocol, the size of the **send window must be less than 2^m .**
- The size of the **receive window is always 1**.

Go-Back- N ARQ : Normal Operation



Go-Back- N ARQ : damaged or lost frame



The name of Go-back-N: why?

- Re-sending frame
  - when the frame is damaged the sender <u>**goes back**</u> and sends a set of frames starting from the last one ACKn'd
  - the number of retransmitted frames is <u>***N***</u>

<u>**Example:**</u>

- The window size is 4.
- A sender has sent frame 6 and the timer expires for frame 3 (frame 3 not ACKn'd). The sender <u>goes back</u> and re-sends the frames 3, 4, 5 and 6.

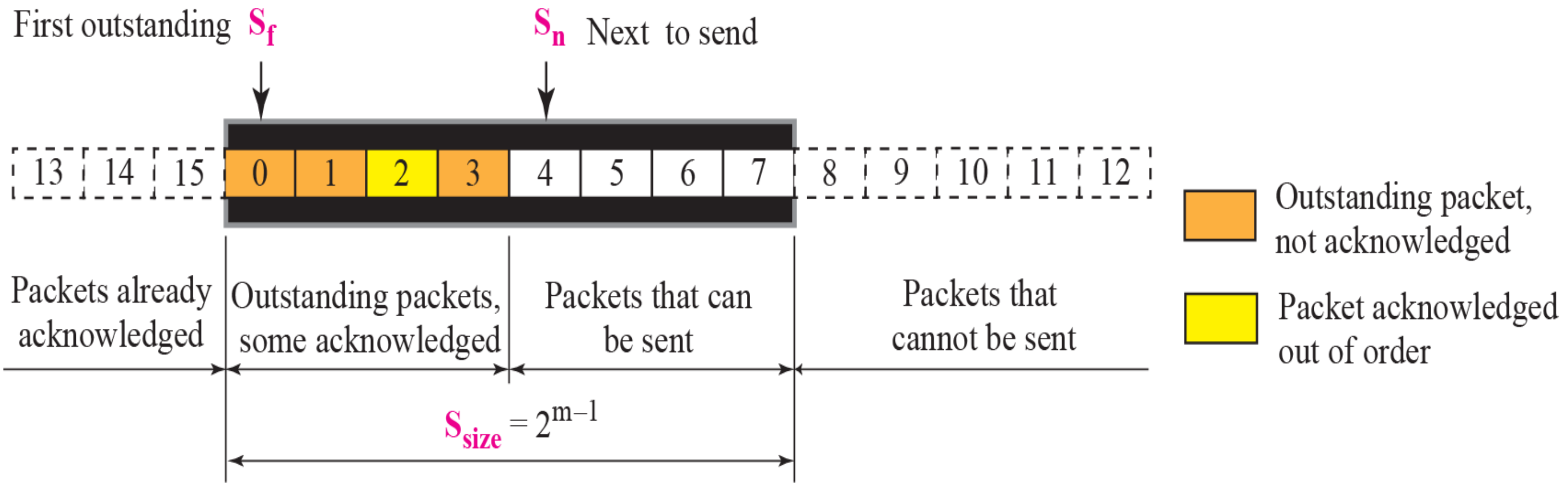
Summary : Go-Back- N ARQ

- **Inefficient**
  - all out of order received packets are discarded
- This is a problem in a noisy link
  - many frames must be retransmitted
  - This resending consumes the bandwidth and slow down the transmission.
- Solution
  - re-send only the damaged frames
- Alternative: **Selective Repeat ARQ**
  - avoid unnecessary retransmissions

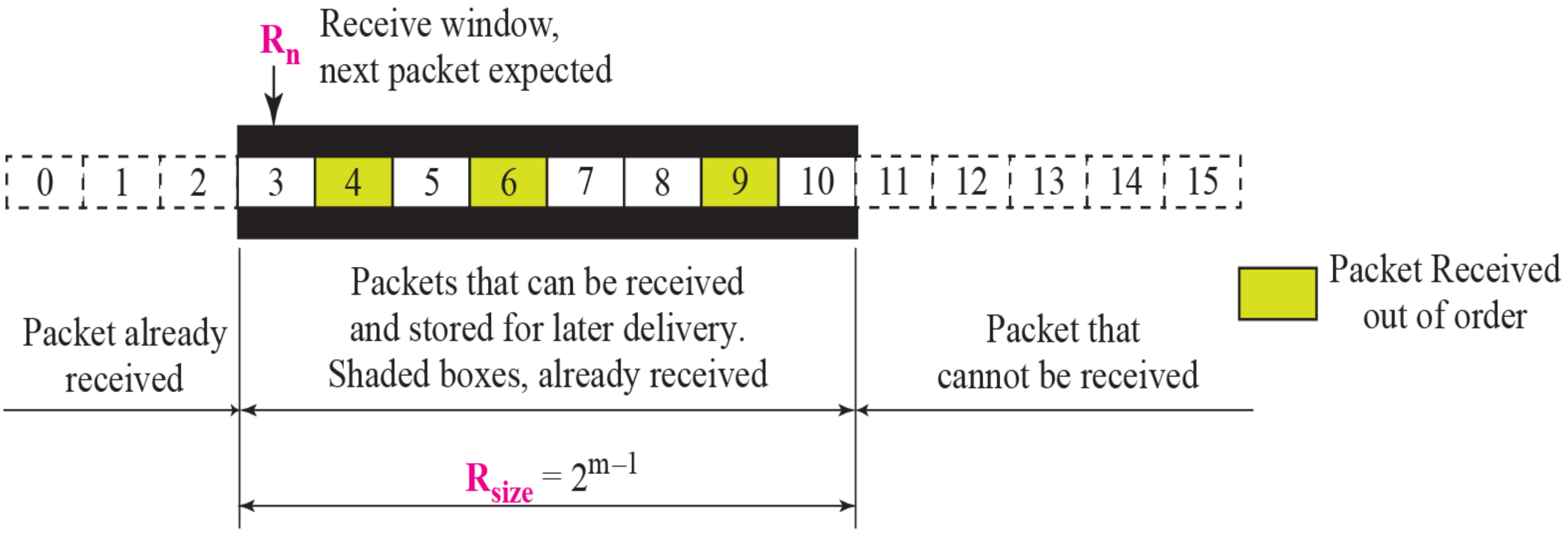
Selective Repeat ARQ

- Resent only Damaged Frame
- It defines a negative acknowledgment (**NAK**) that report the sequence number of a damaged frame before the timer expires.
- It is more efficient for noisy link, but the processing at the receiver is more complex.

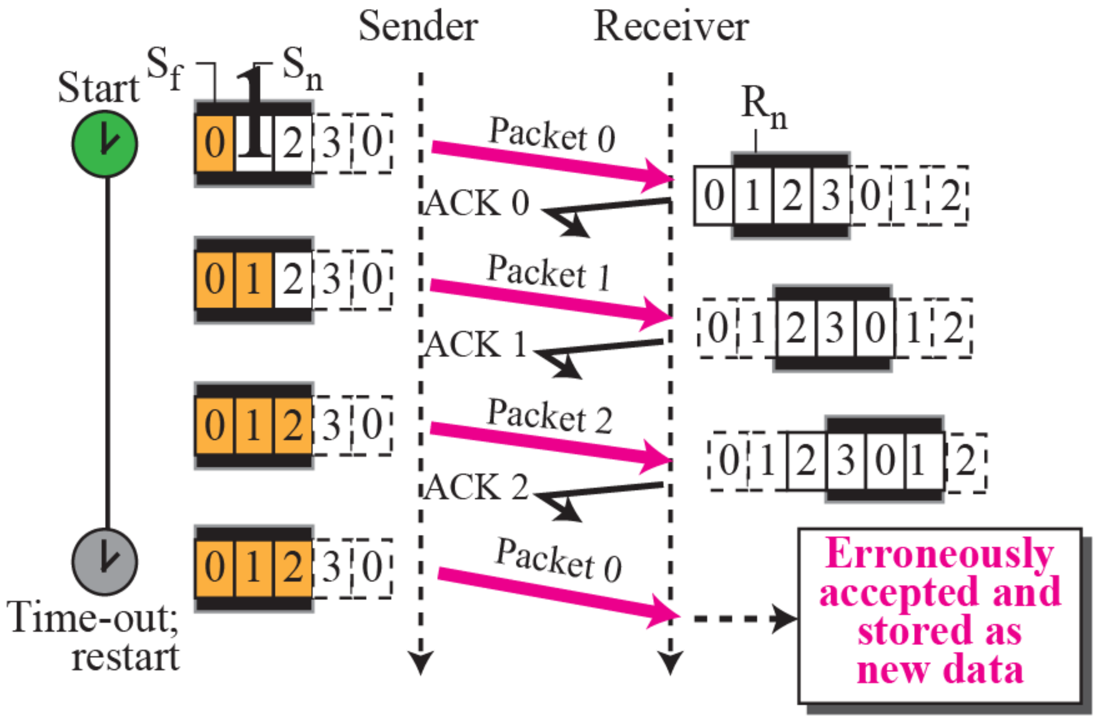
Send window for Selective-Repeat ARQ



Receive window for Selective-Repeat ARQ

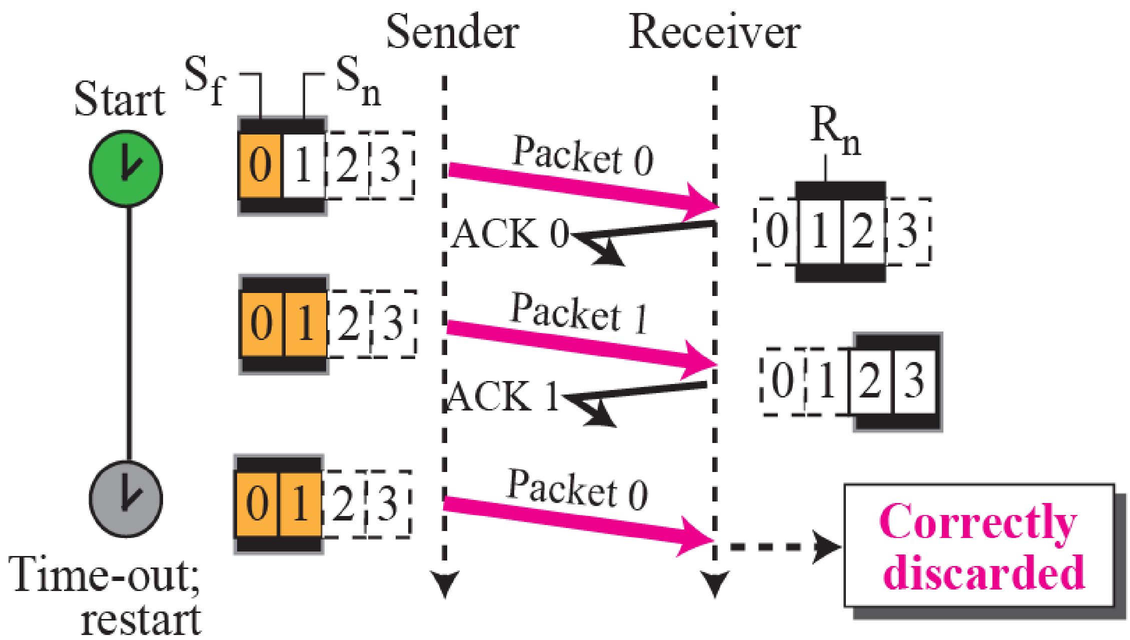


Selective-Repeat protocol : window size



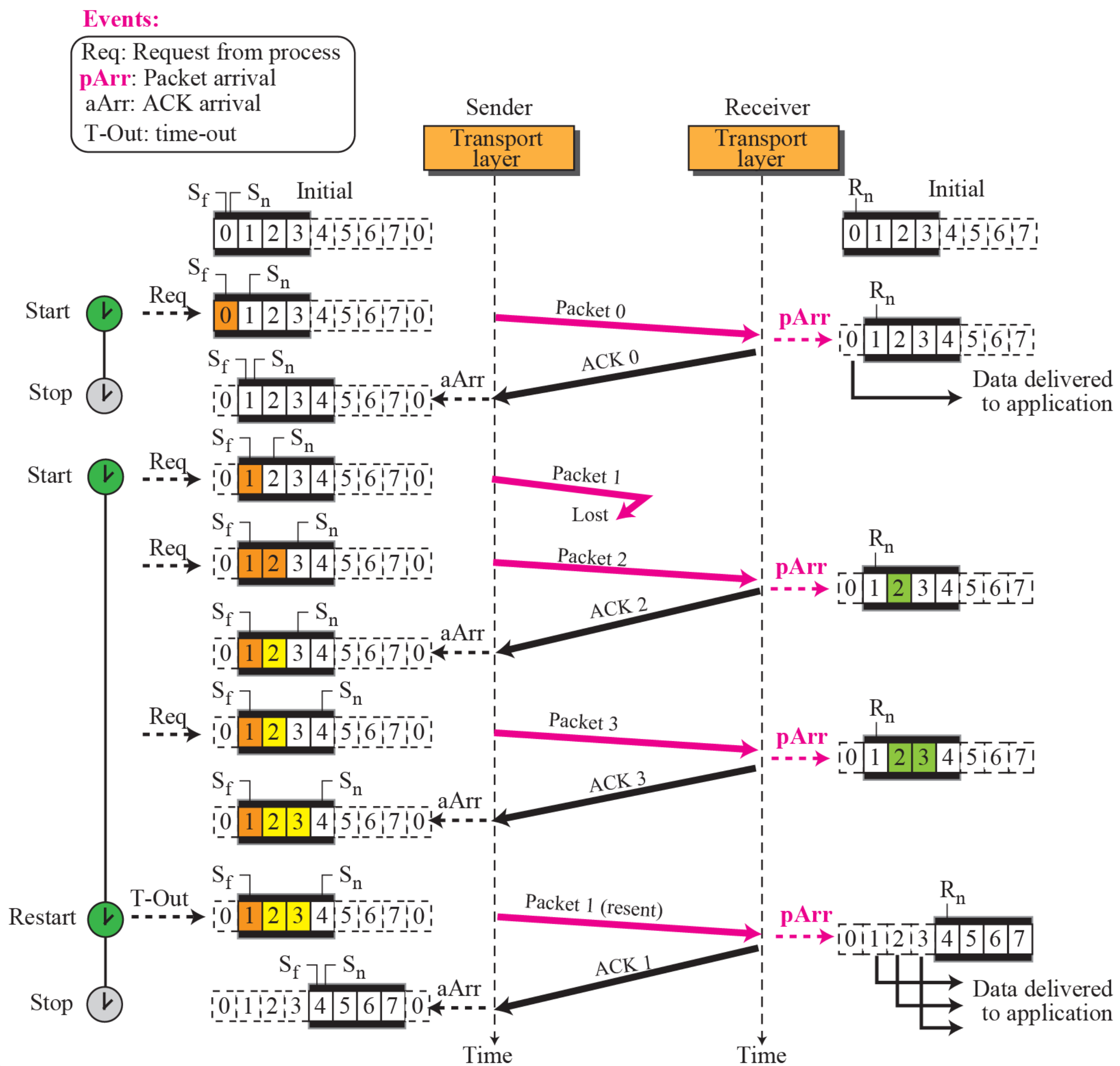
b. Send and receive windows of size $> 2^{m-1}$

Selective-Repeat protocol : window size



a. Send and receive windows of size = 2^{m-1}

Selective-Repeat ARQ : lost frame



Selective-Repeat protocol

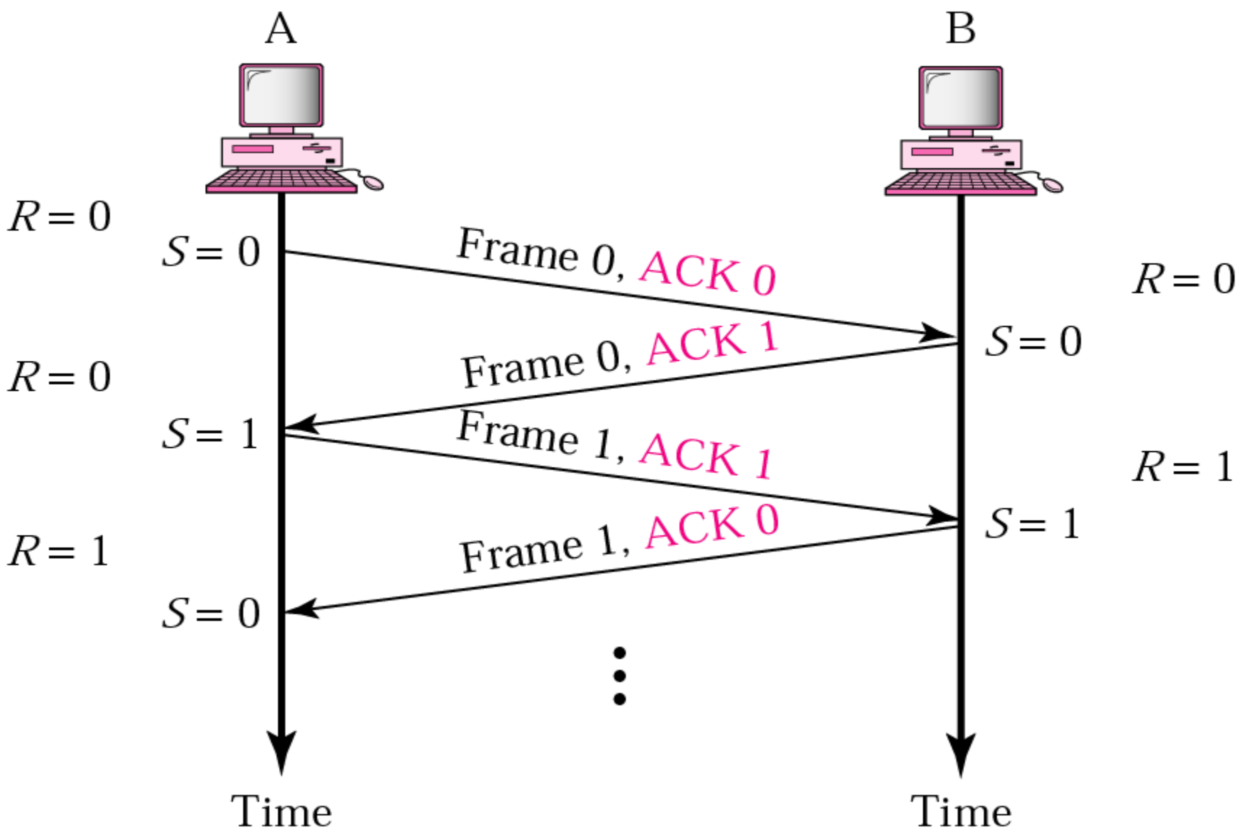
- In the Selective-Repeat protocol, an **acknowledgment number** defines the sequence number of the error free packet received.
- In Selective-Repeat, the size of the sender and receiver window can be **at most one-half of 2^m**.

	Max. Sender Window size	Max. Receiver Window size	Equation for sequence number	Sequence number
Stop & Wait	1	1	Modulo 2	0,1,0,1,0, 1
GBN	2^m-1	1	Modulo 2^m	0 to $2^m -1$
SR	2^{m-1}	2^{m-1}	Modulo 2^m	0 to $2^m -1$

Piggybacking

- Bidirectional Transmission.
- Combine data frame with acknowledgment. (less overhead saves bandwidth)

Piggybacking in Stop and Wait ARQ



Example: 1

Using 5-bit sequence numbers, what is the maximum size of the send and receive windows for each of the following protocols?

1) Stop and wait ARQ
2) Go back N ARQ
3) Selective Repeat ARQ

Solution :

1) Stop and wait ARQ : S.W. = 1 , R.W. = 1
2) Go back N ARQ : S.W. = 31 , R.W. = 1
3) Selective Repeat ARQ : S.W. = 16 , R.W. = 16

Example: 2

Assume a sender sends 6 packets: packets 0, 1, 2, 3, 4, and 5. The sender receives an ACK with ackNo = 3. What is the interpretation if the system is using GBN or SR?

Solution :

If the system is using GBN, it means that packets 0, 1, and 2 have been received uncorrupted and the receiver is expecting packet 3. If the system is using SR, it means that packet 3 has been received uncorrupted; the ACK does not say anything about other packets.

Example: 3

The maximum window size for data transmission using the selective reject protocol with n-bit frame sequence numbers is **(GATE 2005)**

a) 2^n

b) 2^{n-1}

c) 2^n-1

d) 2^{n-2}

Example: 4

Station A needs to send a message consisting of 9 packets to Station B using a sliding window (window size 3) and go-back-n error control strategy. All packets are ready and immediately available for transmission. If every 5th packet that A transmits gets lost (but no acks from B ever get lost), then what is the number of packets that A will transmit for sending the message to B? **(GATE 2006)**

(A) 12 (B) 14

(C) 16 (D) 18

Solution : (C) 16