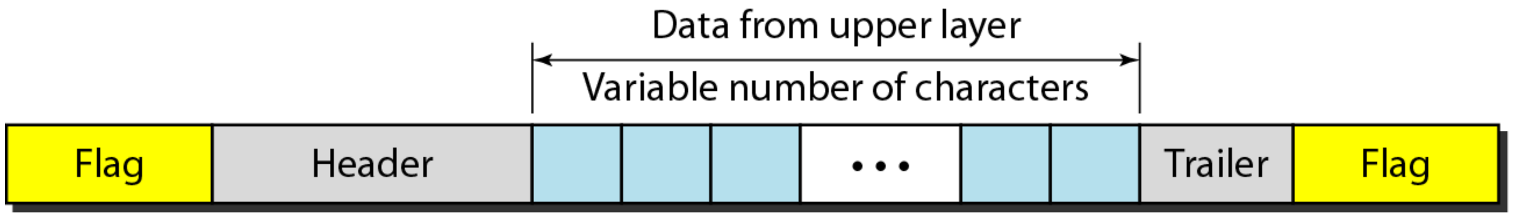
Data Link Control

Framing

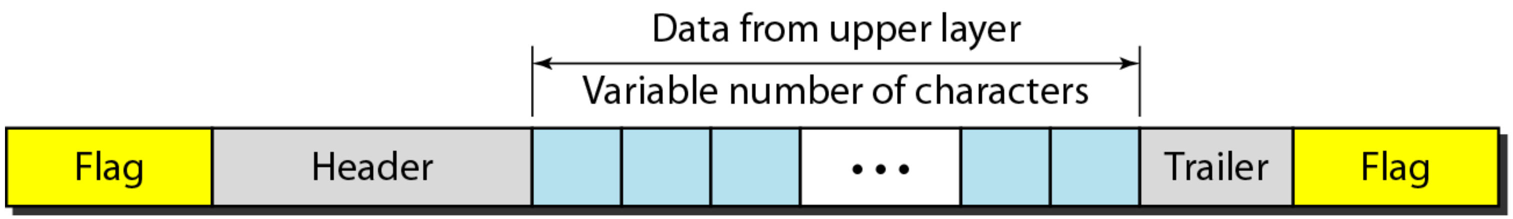
- Process of wrapping data with certain info before sending out



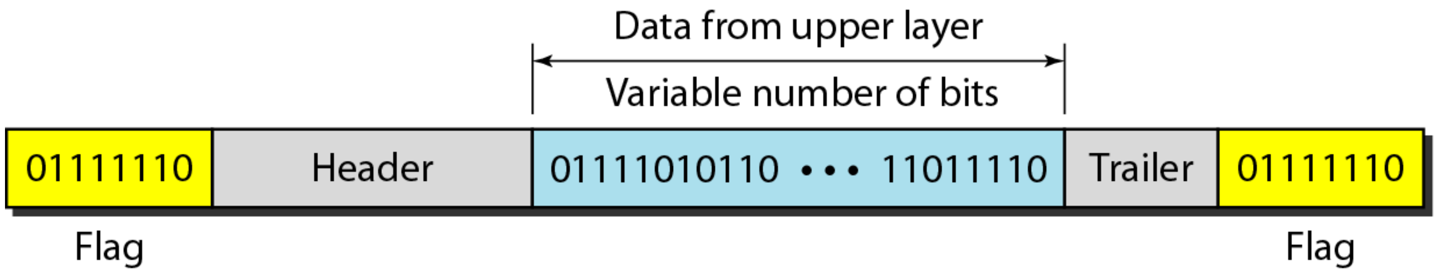
- A frame typically consists of
  - Flag: indication for start and end of a frame
  - Header: source/destination addresses, as well as other control information
  - Data from the upper layer
  - Trailer: error detection/correction code

Byte vs. Bit Oriented

- Framing in byte-oriented protocols

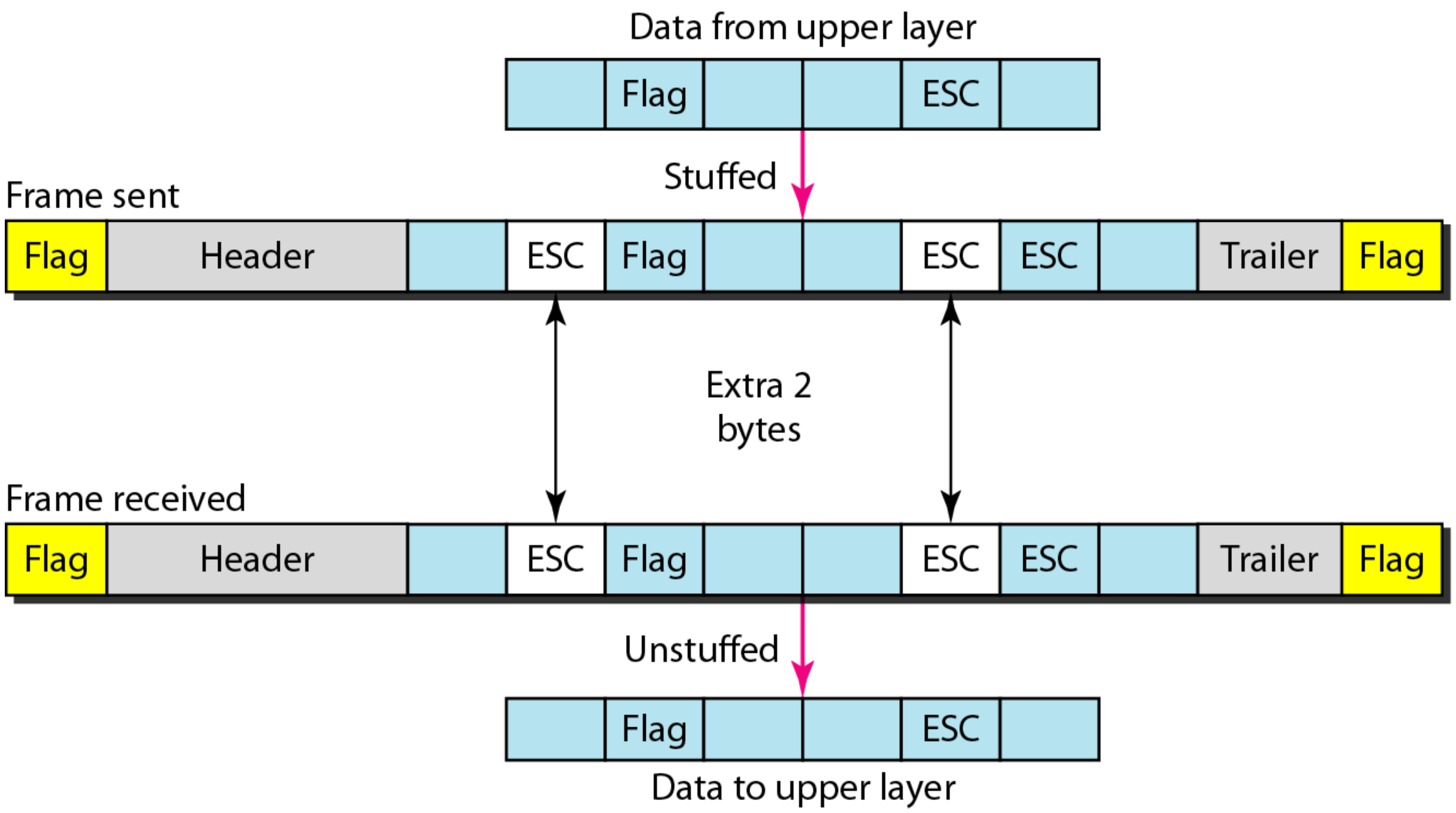


- Framing in bit-oriented protocols



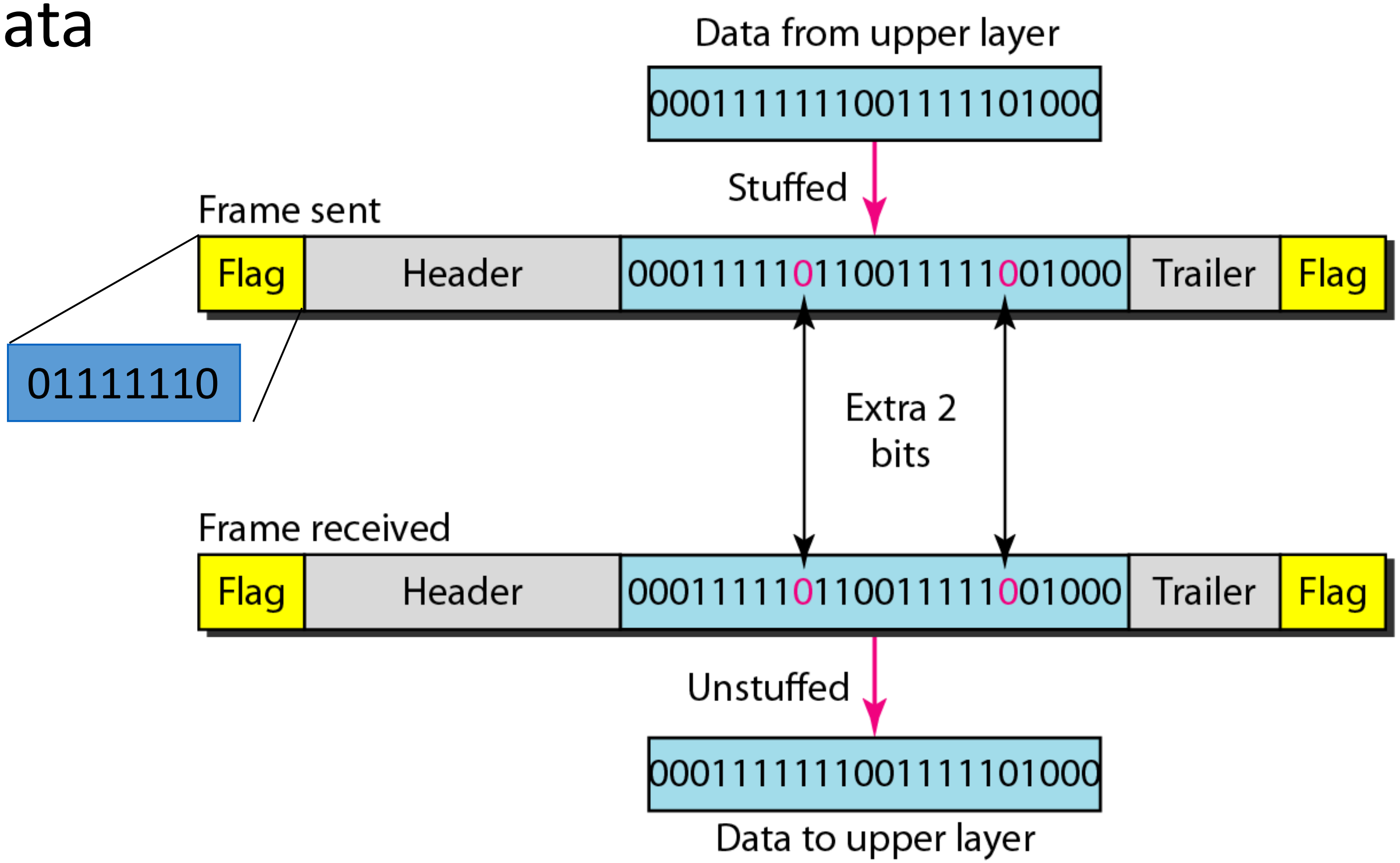
Byte Stuffing

- Process of adding extra byte whenever there is an escape or a flag character in the data



Bit Stuffing

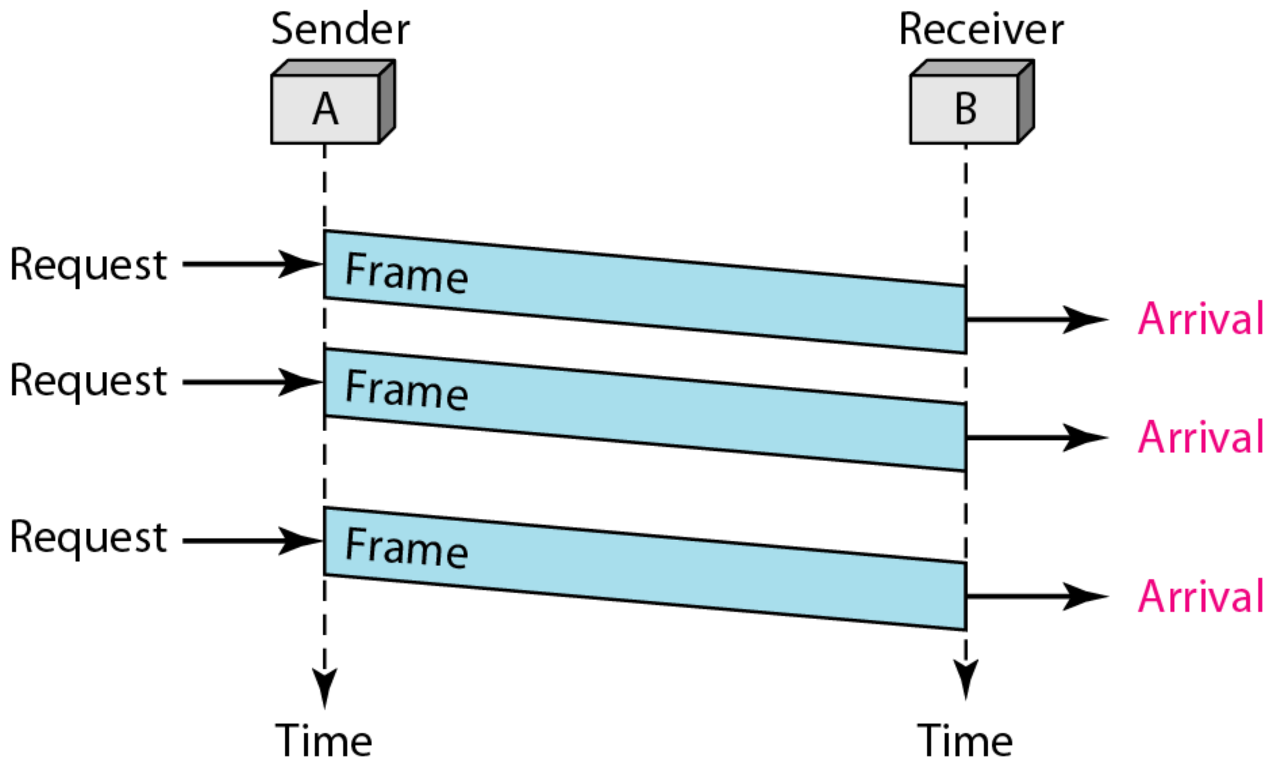
- Process of adding extra bit to ensure flag sequence does not appear in the data



Flow Control and Error Control

- Flow control
  - A set of procedures that tells the sender how much data can be sent before waiting for acknowledgment
- Error control
  - Includes both error detection and correction
  - Allows receiver to inform sender of lost or duplicate frames
  - Mostly based on Automatic Repeat Request (ARQ)

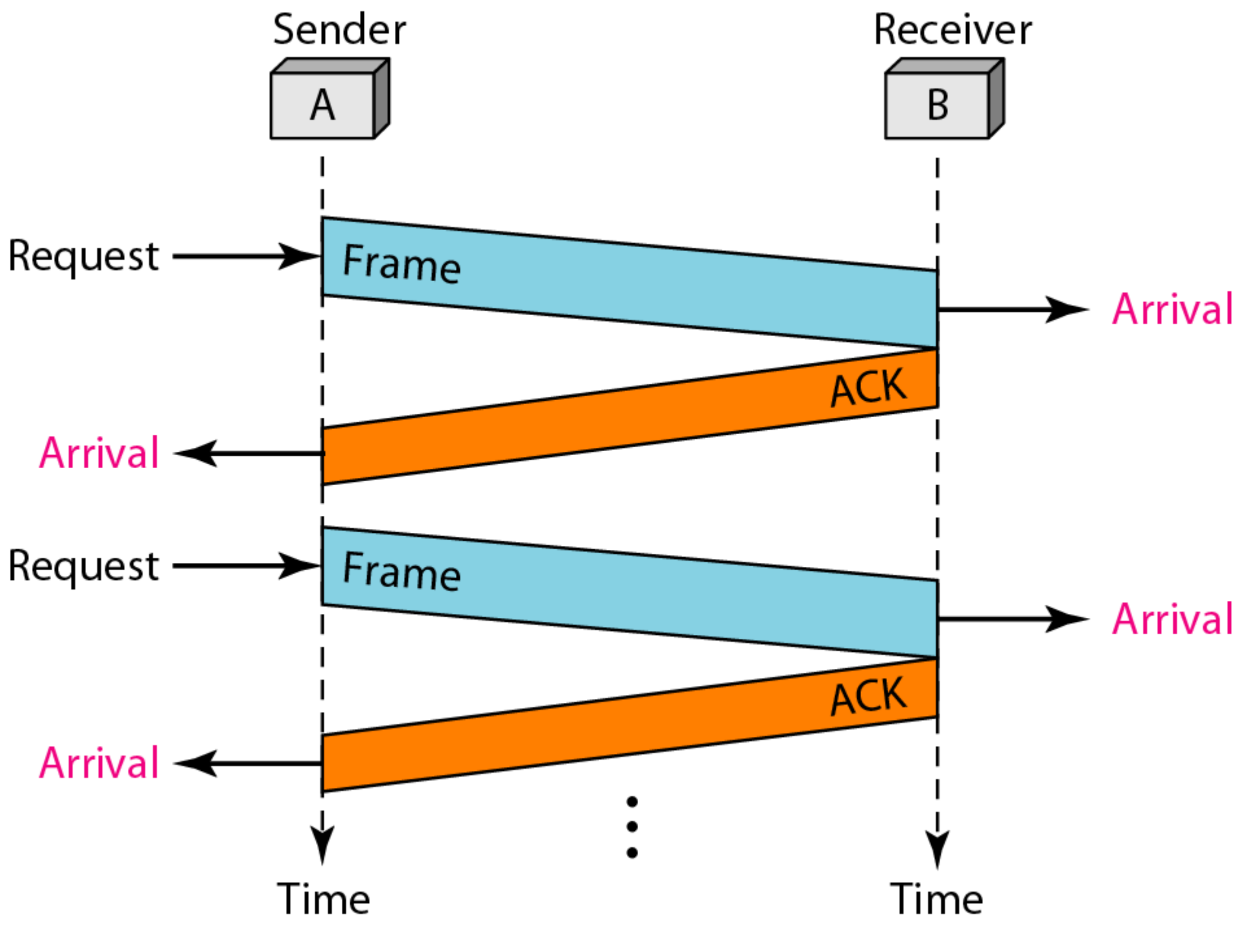
"Simplest": Flow Diagram



Stop-and-Wait Mechanism

- Still noiseless channel
- Receiver has limited buffer
  - Requires flow control
- Sender sends one frame at a time and wait for an acknowledgment

Stop-and-Wait: Flow Diagram



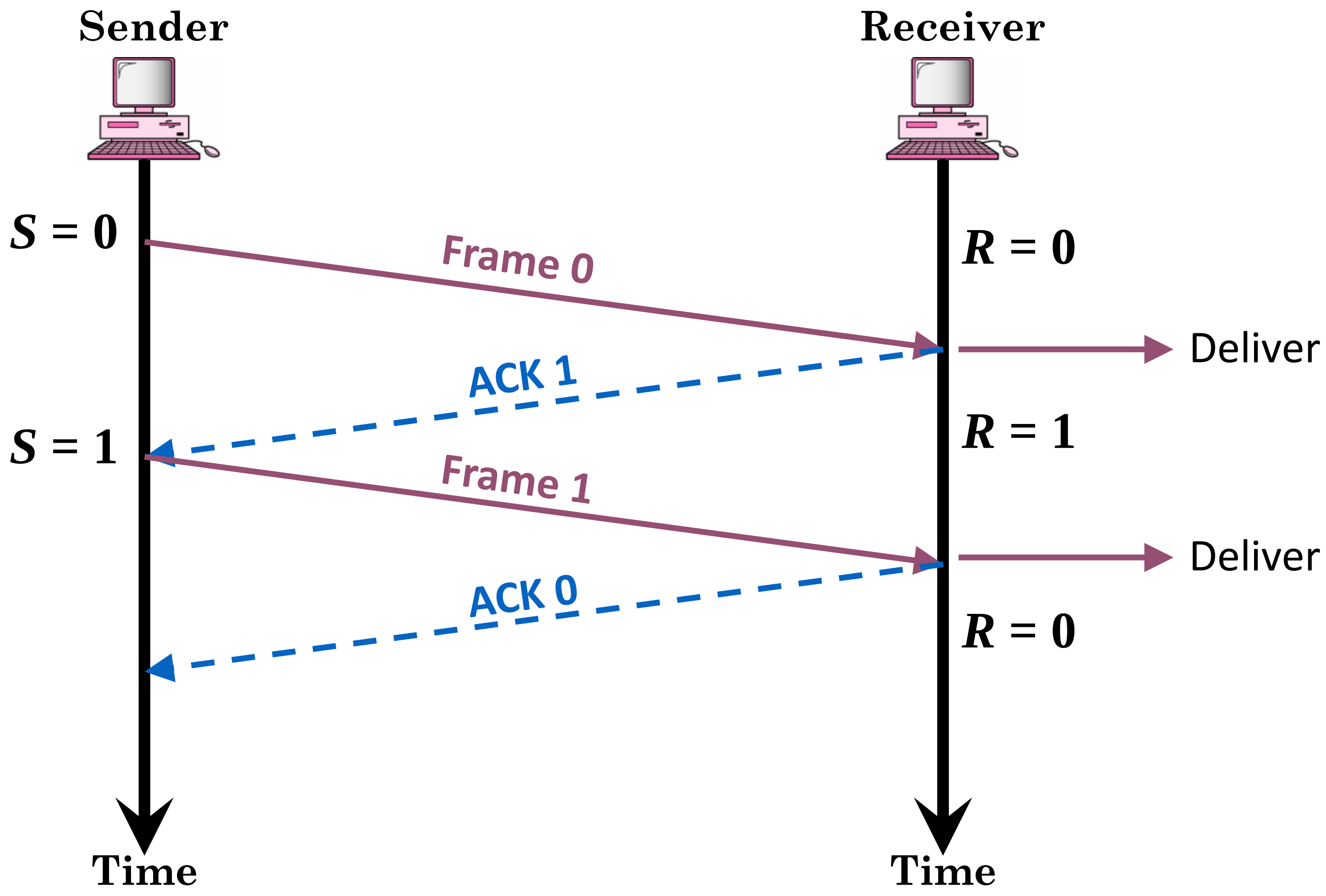
Noisy Channel

- Realistic
  - Error can and will happen
  - Require error control
- Mechanisms:
  - Stop-and-Wait ARQ
  - Go-Back-N ARQ
  - Selective Repeat ARQ

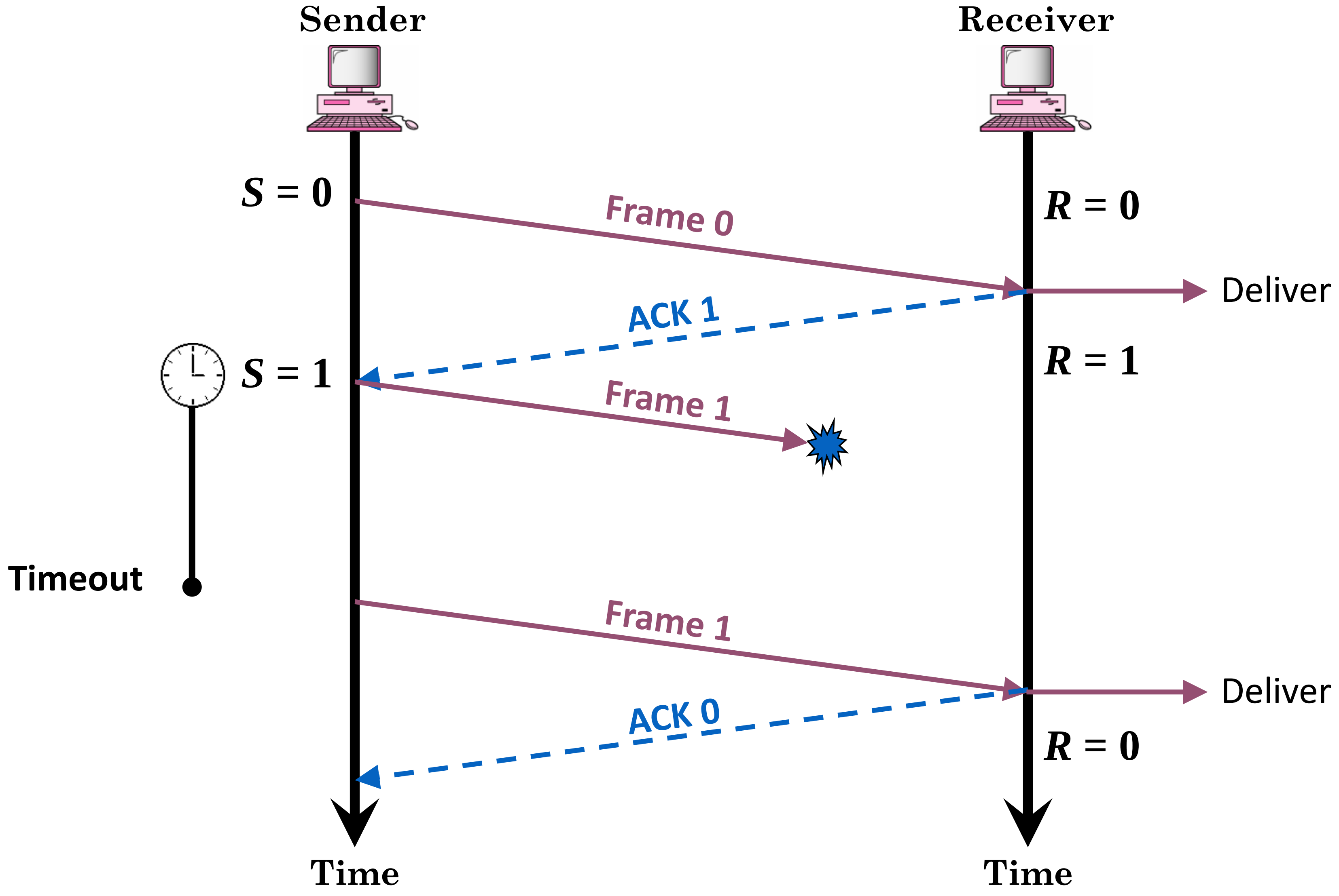
Stop-and-Wait ARQ

- Sender keeps a copy of sent frame until successful delivery is ensured
- Receiver responds with an ack when it successfully receives a frame
- Both data and ack frames must be numbered
- When sender does not receive an ack within certain time, it assumes frame is lost, then retransmits the same frame.

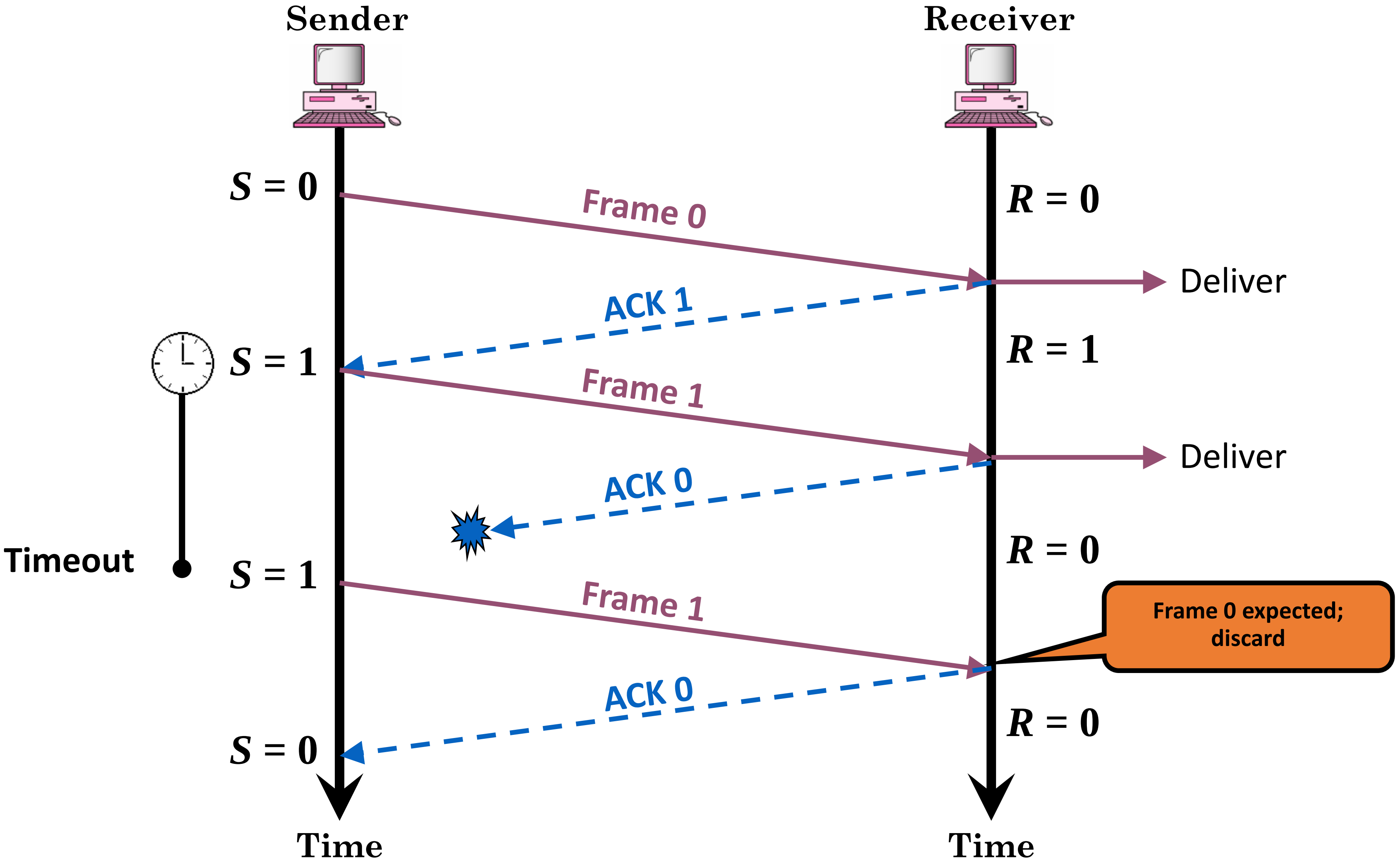
Flow Diagram: Normal Operation



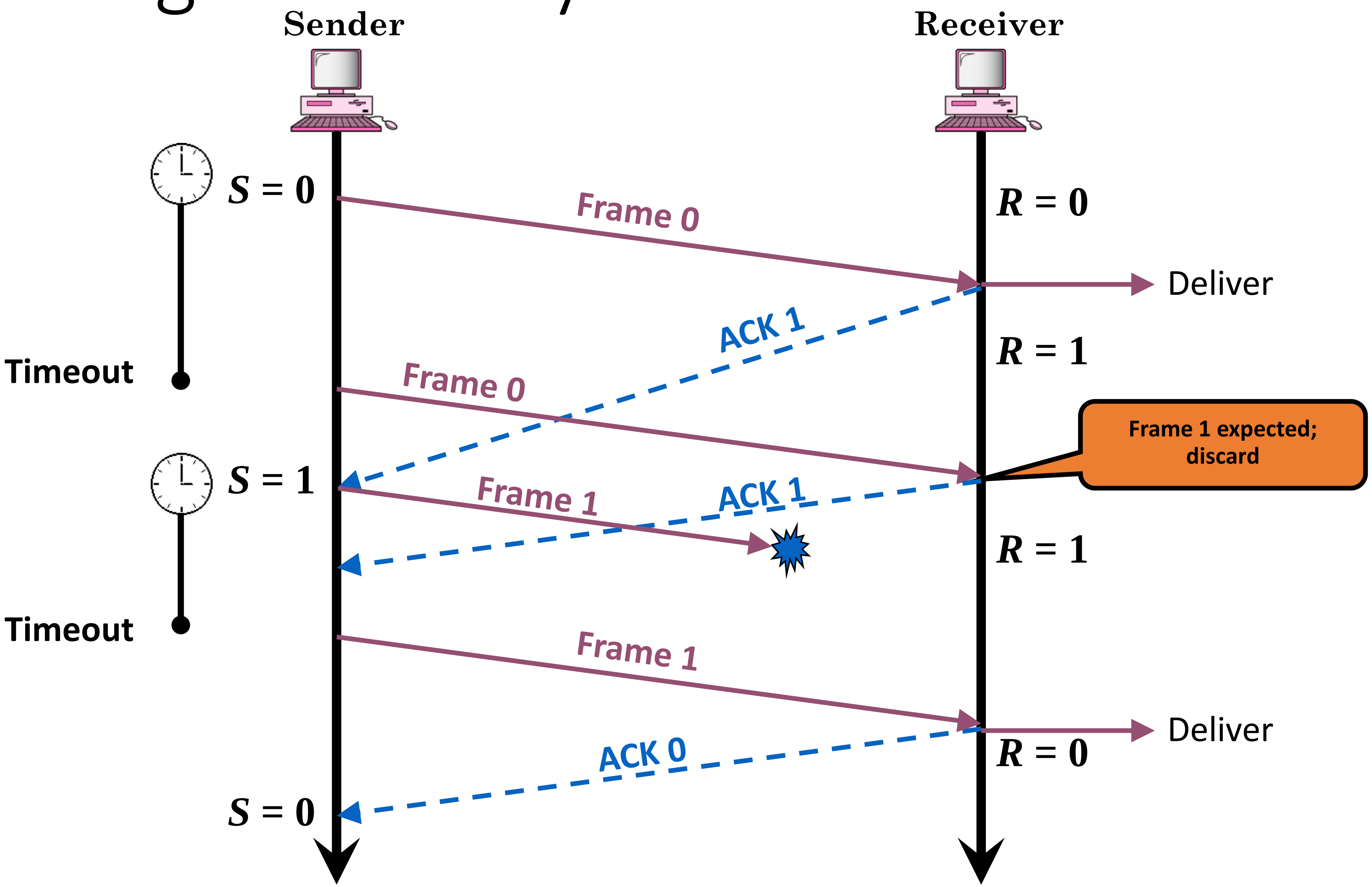
Flow Diagram: Lost Frame



Flow Diagram: Lost ACK

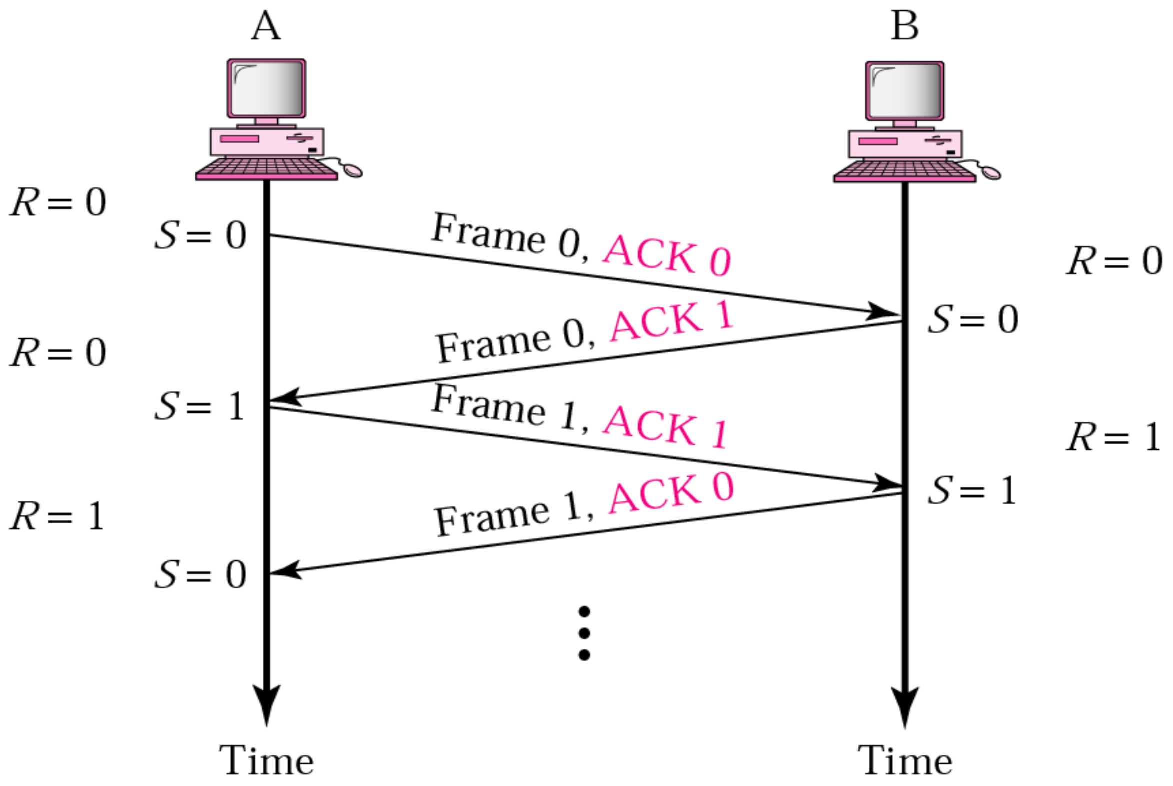


Flow Diagram: Delayed ACK



Bidirectional Transmission

- Data are transferred both ways
- ACK are "piggybacked" with data frames



Example

- Assuming a communication system where:
  - Stop-and-Wait ARQ is used
  - Bandwidth of the link is 1 Mbps
  - Propagation delay is 10 ms
  - One-way data flow
- Questions
  - What should be an appropriate time-out value?
  - What is the bandwidth-roundtrip-delay product?
  - If the system data frames are 1000 bits in length, what is the utilization of the link?

Performance Metrics

- Throughput
  - Effective rate at which data is transmitted – Bitrate acheived
  - Data transmitted per unit time
  - Protocol induced delay added to delay on transmission link
- Latency
  - Transmission Delay – Depends on data size and data rate of link
  - Propagation Delay – Depends on distance, speed of signal
  - Queueing Delay – Only if data is switched across multiple links
- Bandwidth-Delay Product
  - Measure of number of bits that can be held in transit on a link
  - Volume of link

Improving Link Utilization

- On a link of 1Mbps, transmitting 1000 bits takes 11ms (including prop. delay of 10ms)
- Stop-and-wait can send only 1000 bits in 21ms leading to bitrate of 47.6kbps (only about 5% utilization)
- Prefer to send more frames before waiting for ACK
- Example:
  - Recalculate the link utilization if we allow up to 15 frames to be sent before waiting for an ACK

Go-Back-N ARQ

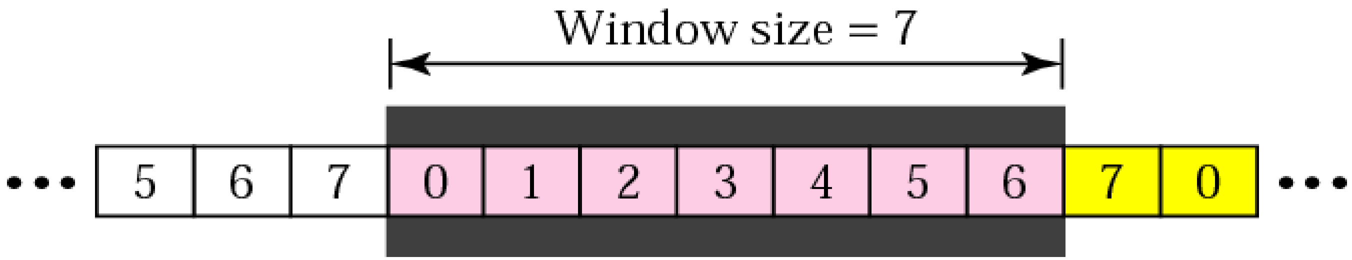
- Allows multiple frames to be sent before waiting for ACK
  - These frames must be numbered differently
  - Frame numbers are called Sequence numbers
- Frames must be received in the correct order
- If a frame is lost, the lost frame and all of the following frames must be retransmitted

Sequence Numbers

- Frame header contains *m* bits for sequence number
- That allows up to 2^m different frame numbers
- How big should *m* be?

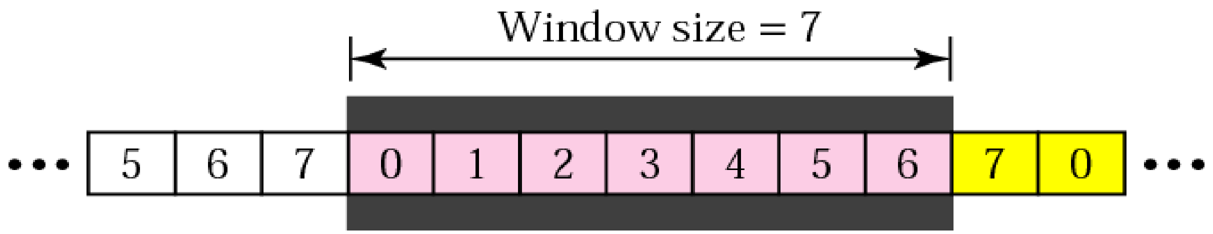
Sending Window

- Sending more than one frame at once requires sender to buffer multiple frames
  - Known as "sending window"
  - Any of these frames in the window can be lost

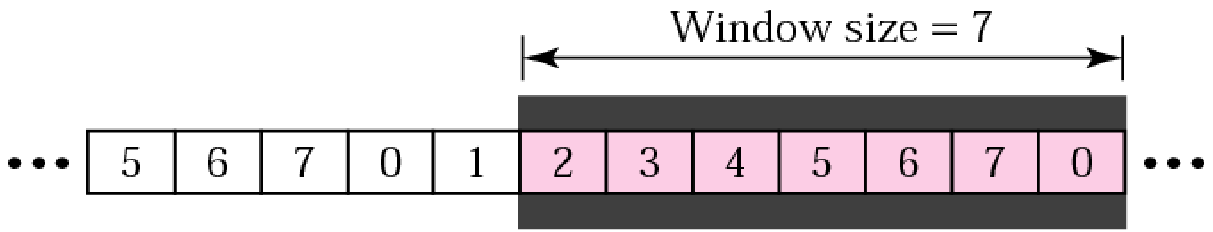


"Sliding" Window

- Once the first frames in the window is ACKed
  - ACKed frames are removed from the buffer
  - More frames are transmitted
  - Result: The window slides to the right



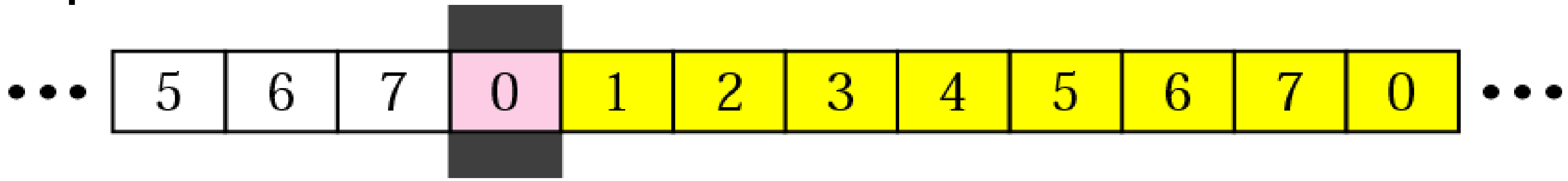
a. Before sliding



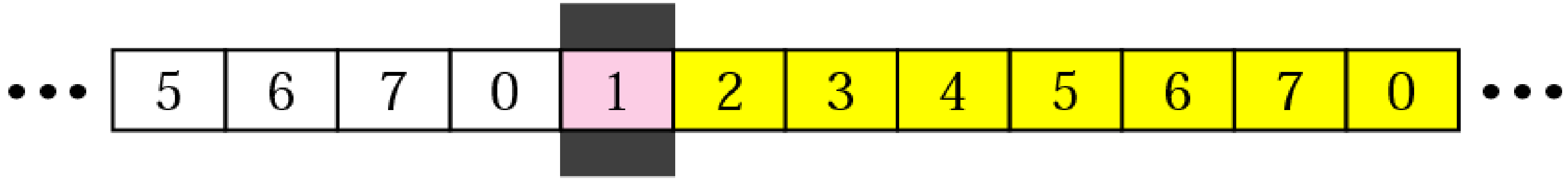
b. After sliding two frames

Receiving Window

- Receiver expects one frame at a time

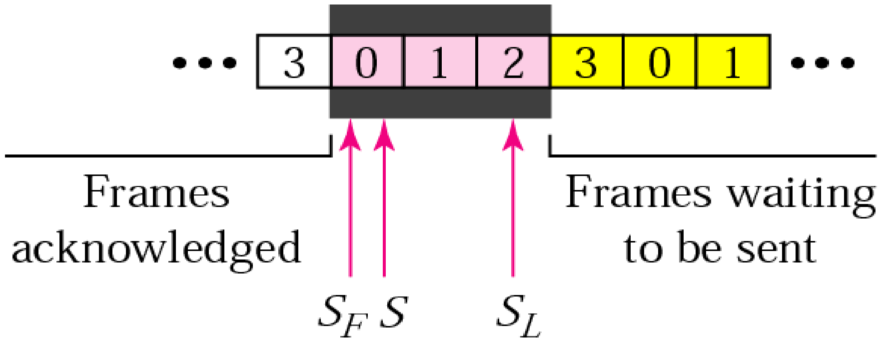


a. Before sliding

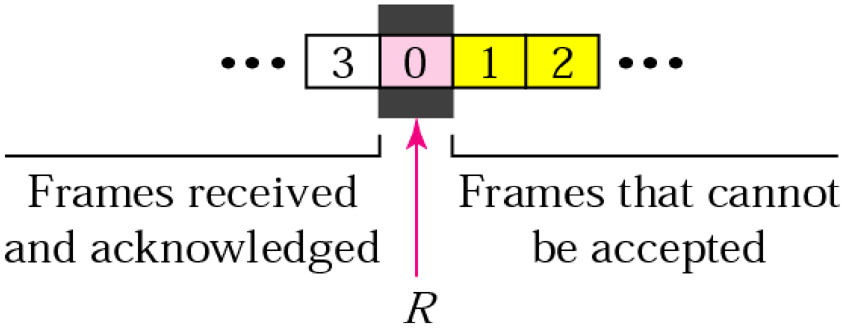


b. After sliding

Send vs. Receive Windows



a. Sender window

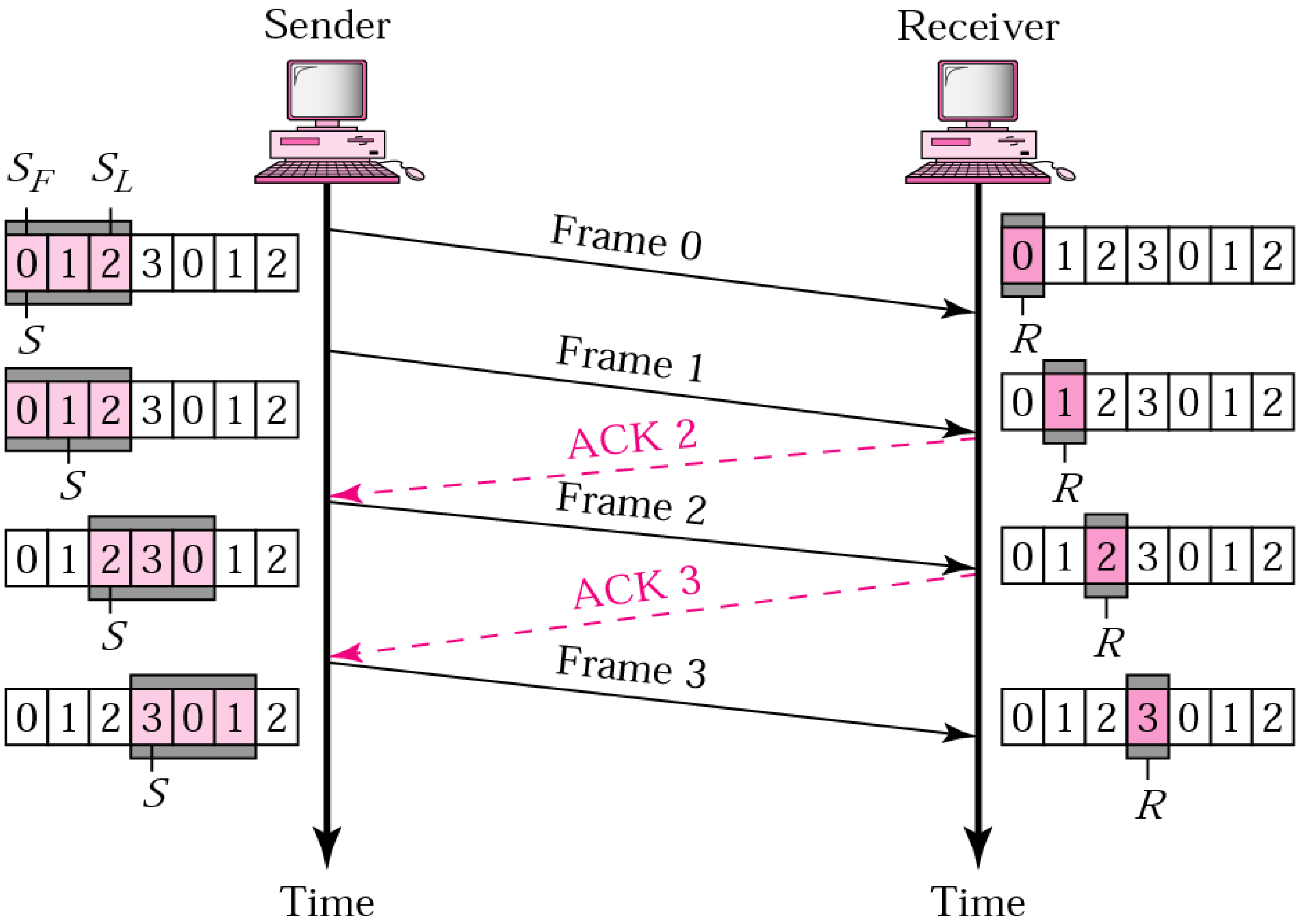


b. Receiver window

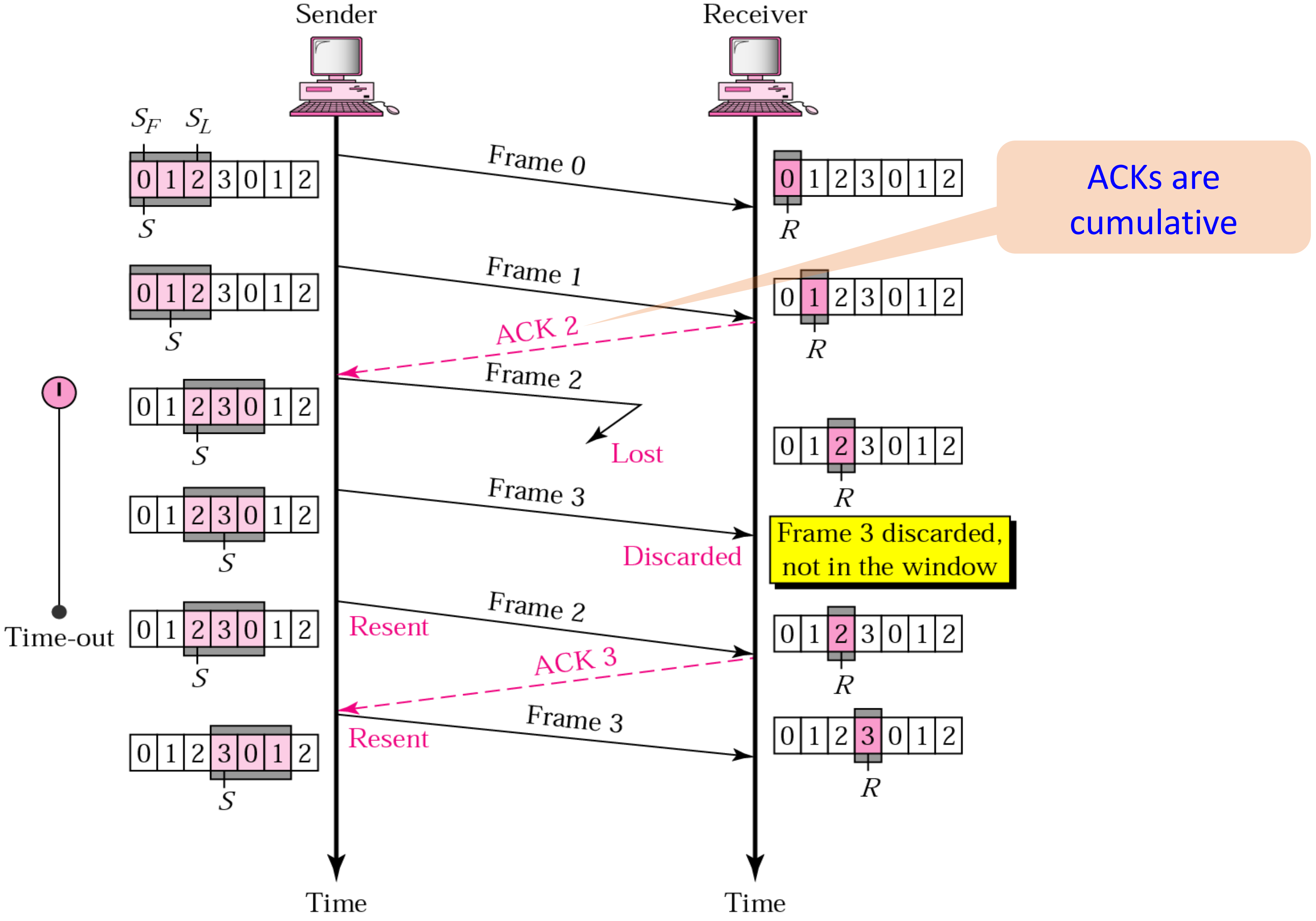
Go-Back-N: Window Sizes

- For *m*-bit sequence numbers
- Send window size: at most 2^m-1
  - $\rightarrow$ Up to 2^m-1 frames can be sent without ACK
- Receive window size: 1
  - $\rightarrow$ Frames must be received in order

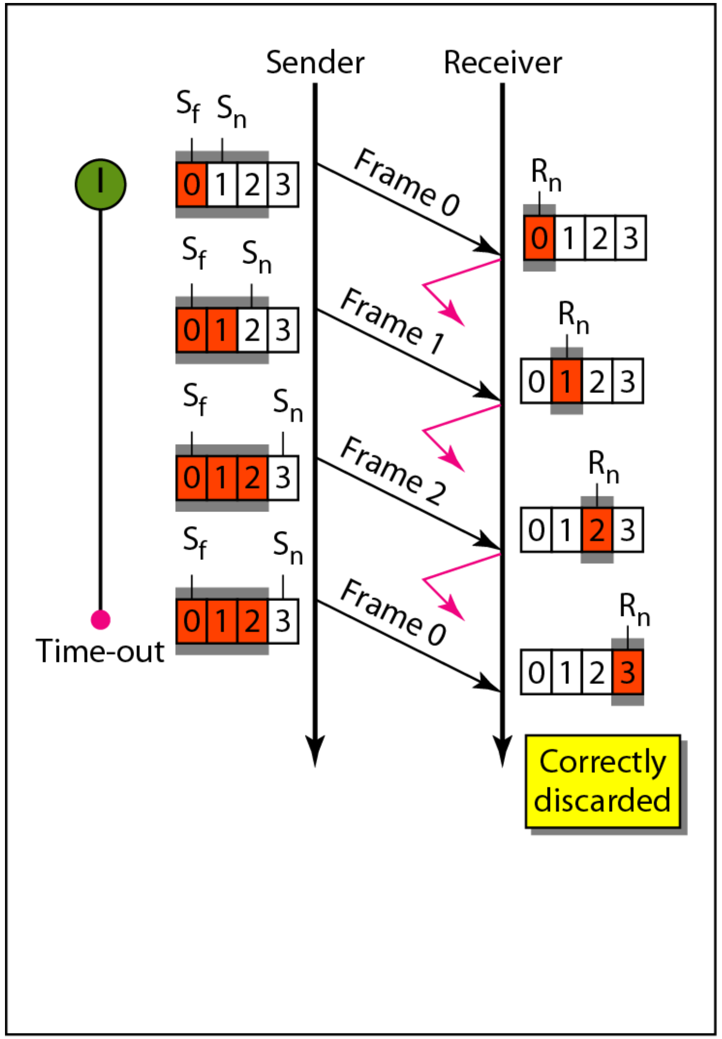
Go-Back-N: Normal Operation



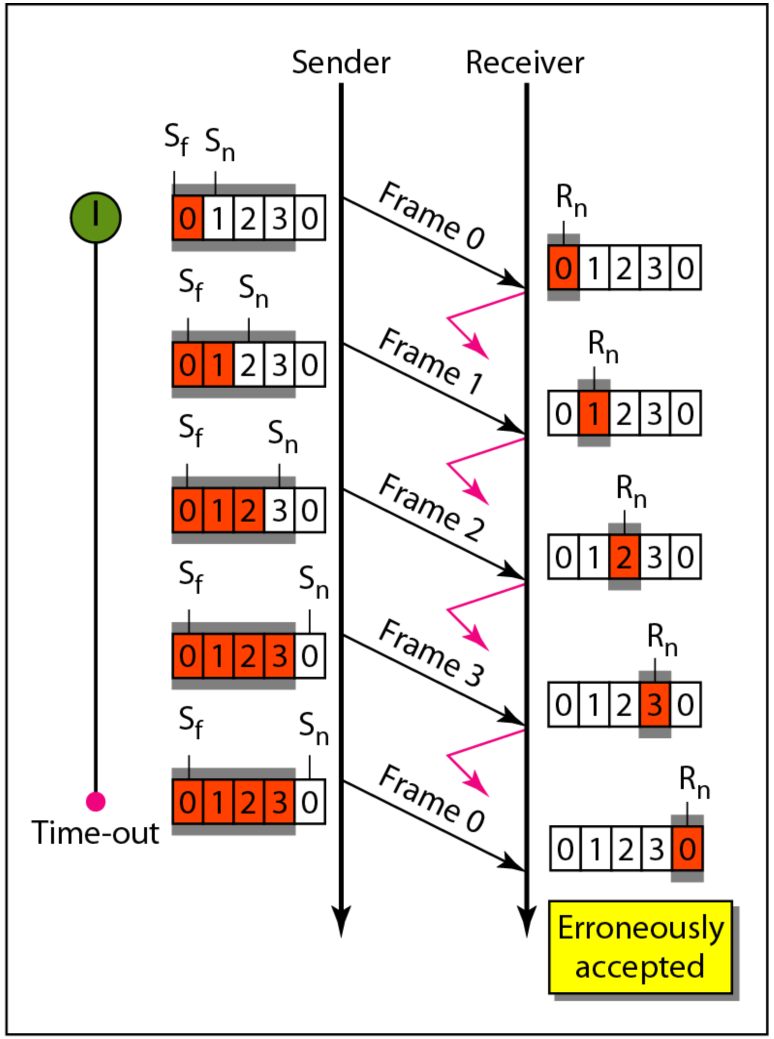
Go-Back-N: Lost Frame



Lost ACK: Window Size < 2^m



Lost ACK: Window Size = 2^m



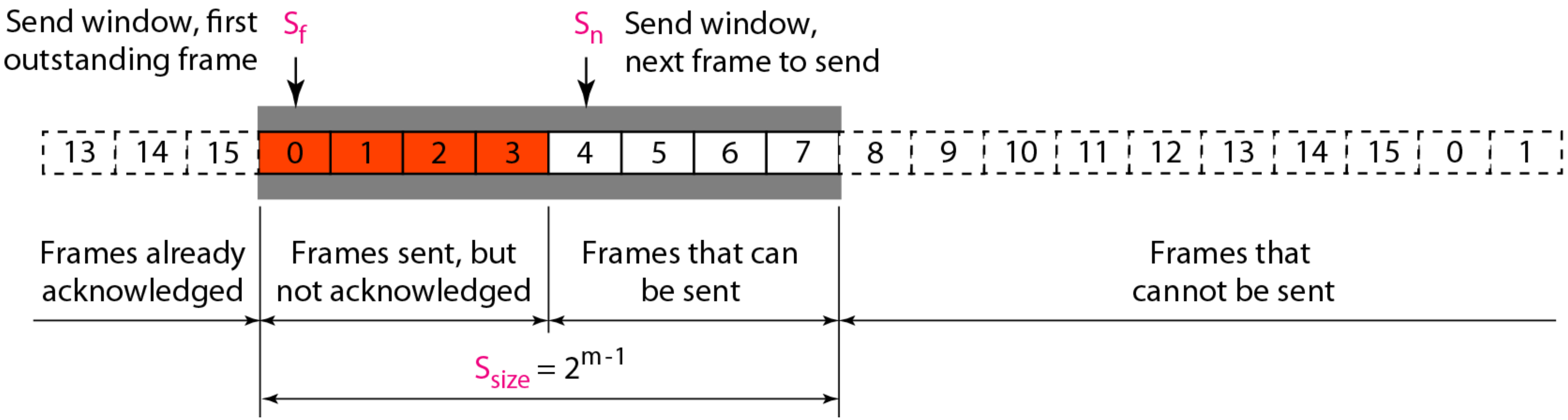
Selective Repeat ARQ

- Go-Back-N always discards out-of-order frames
  - Losing one frame may result in retransmission of multiple frames
  - Very inefficient in noisy link
- Selective Repeat ARQ allows frames to be received out of order
  - Therefore, receive window > 1

Send and Receive Windows

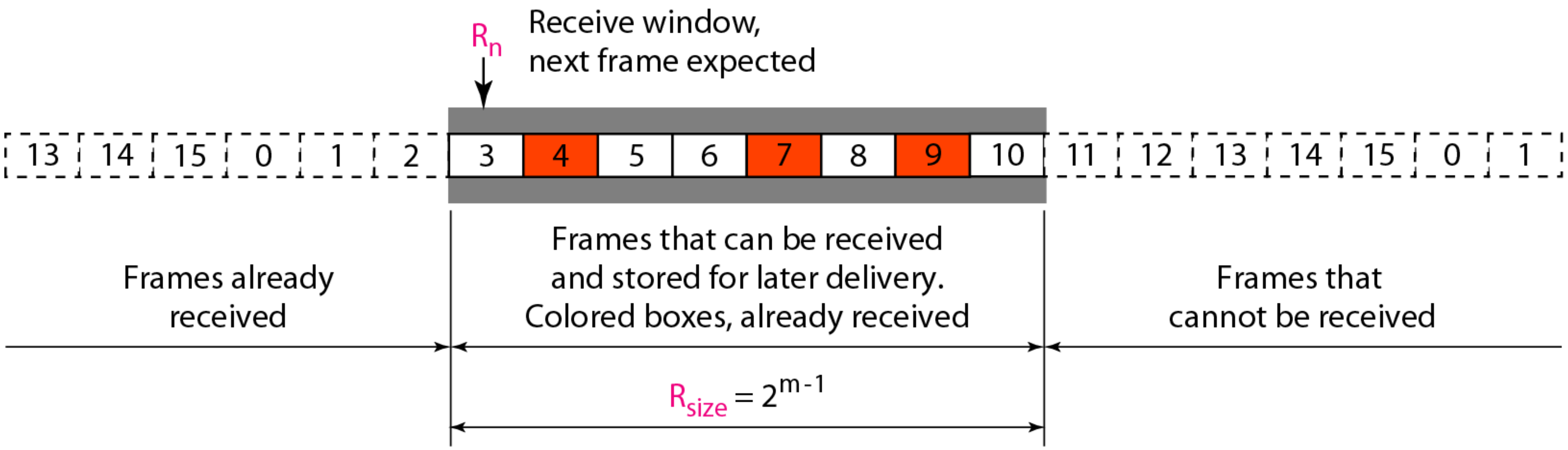
- Sender and receiver share window space equally
- For *m*-bit sequence numbers
  - Send window: up to 2^{m-1}
  - Receive window: up to 2^{m-1}

Send Window

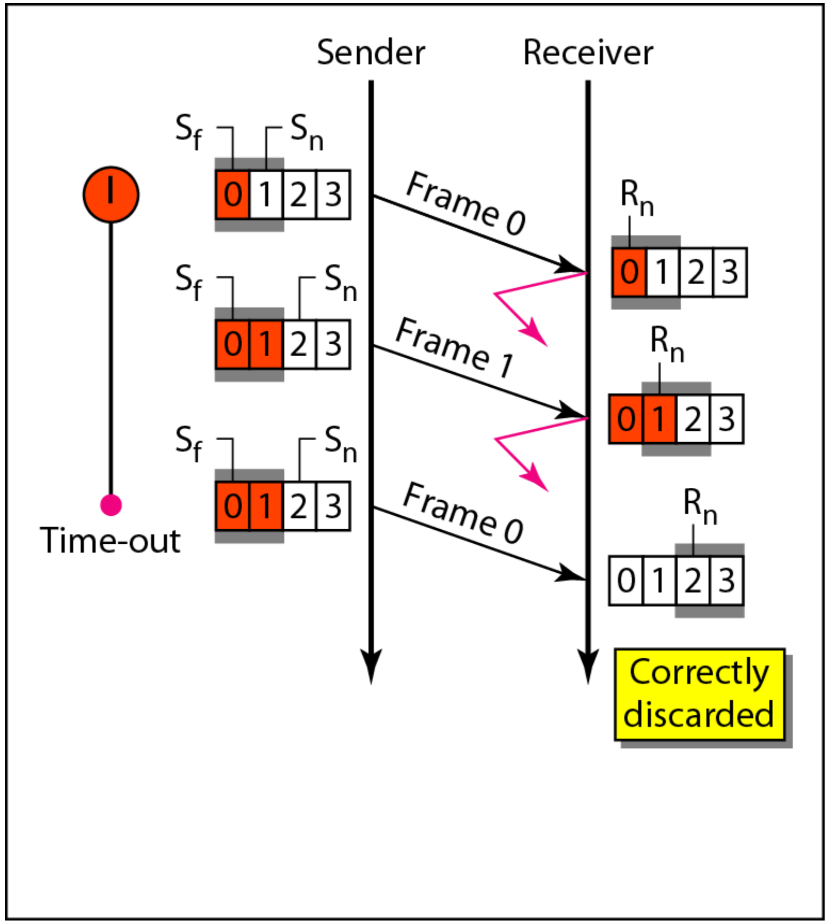


Send window, first outstanding frame
S_f
S_n
Send window, next frame to send
13
14
15
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0
1
Frames already acknowledged
Frames sent, but not acknowledged
Frames that can be sent
Frames that cannot be sent
$S_{size} = 2^{m-1}$

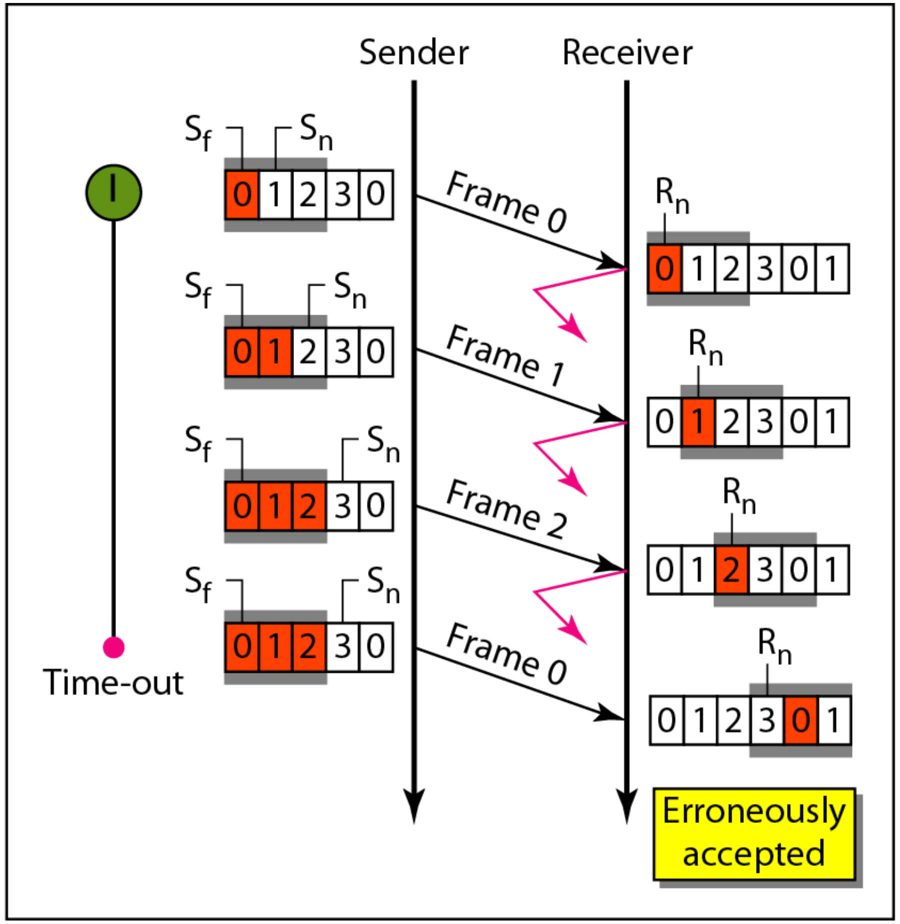
Receive Window



Selective Repeat: Window Size



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



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