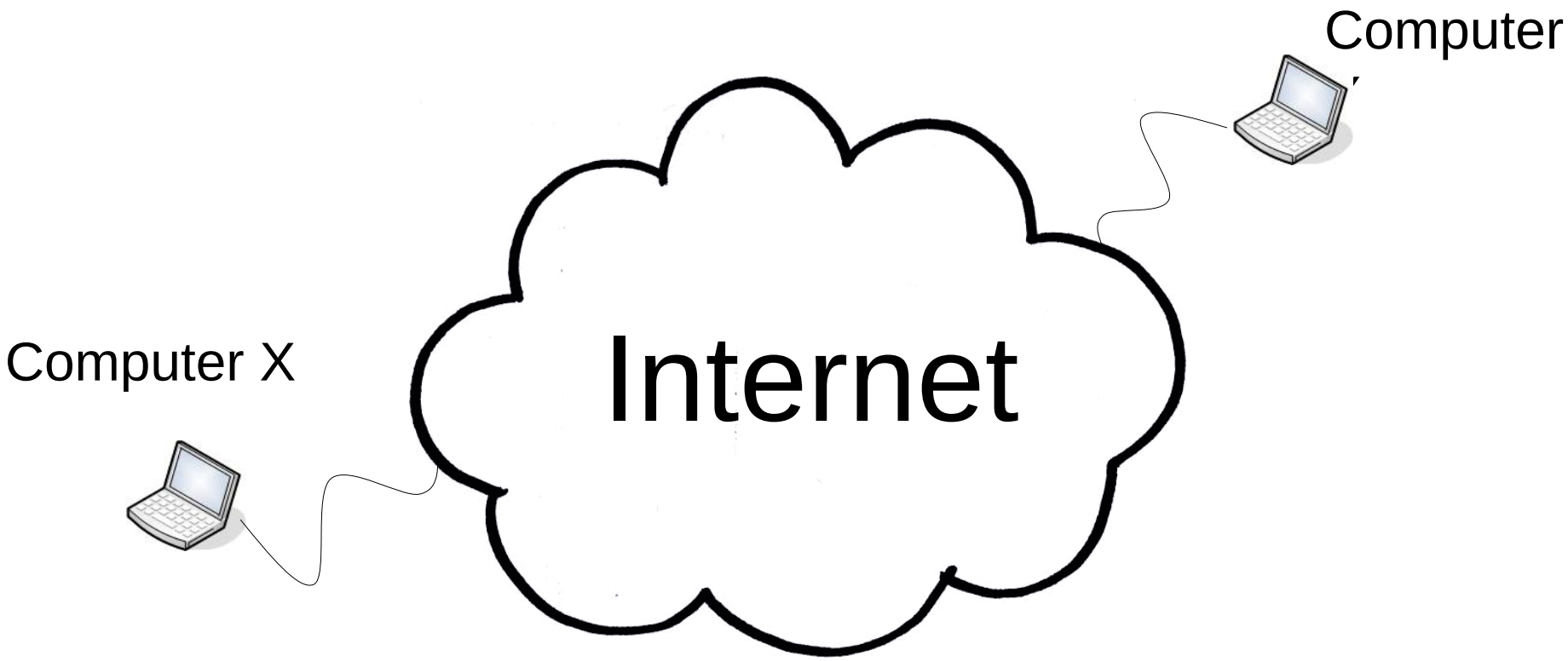
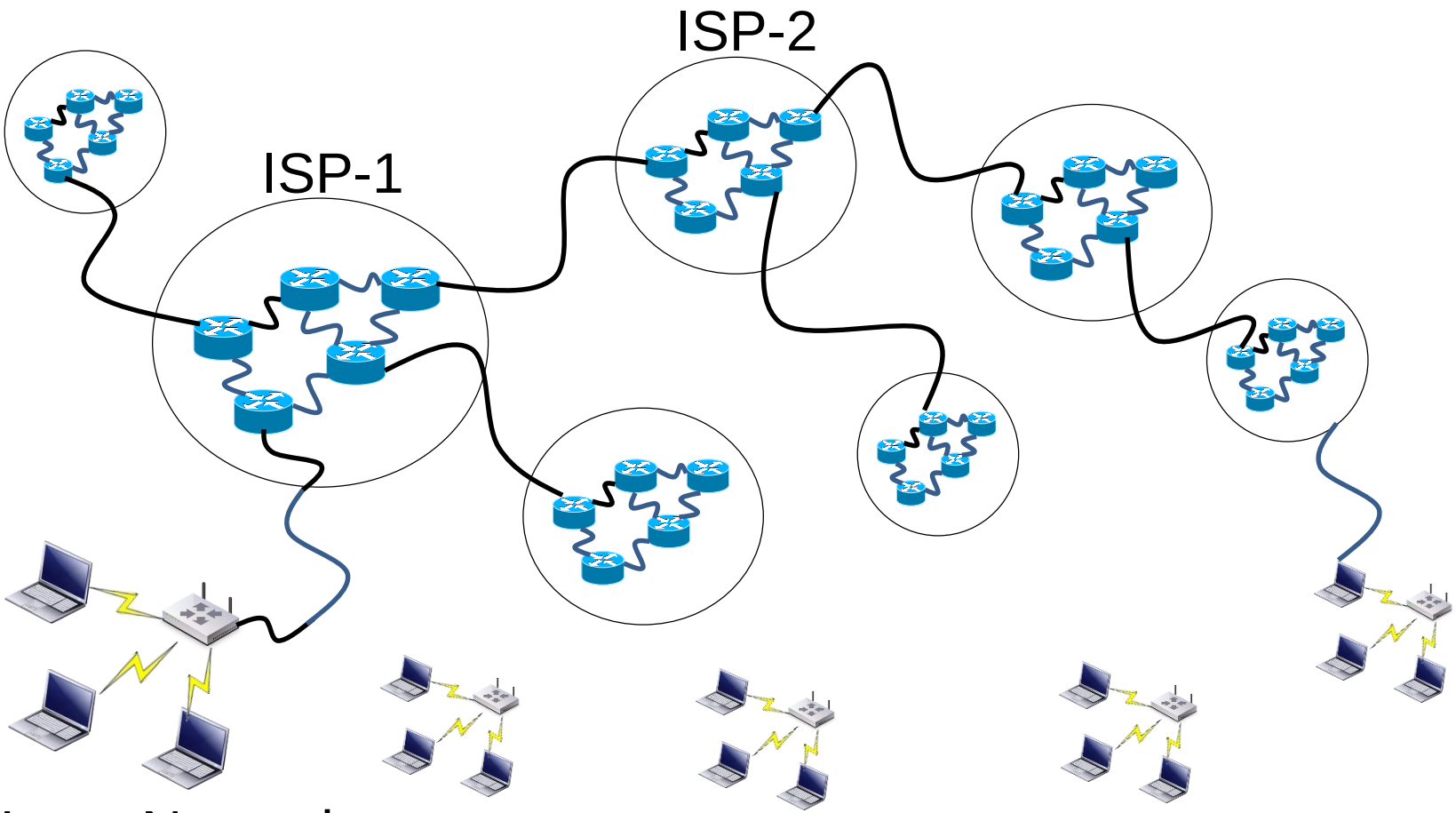
CS2031
Telecommunications II

Flow Control

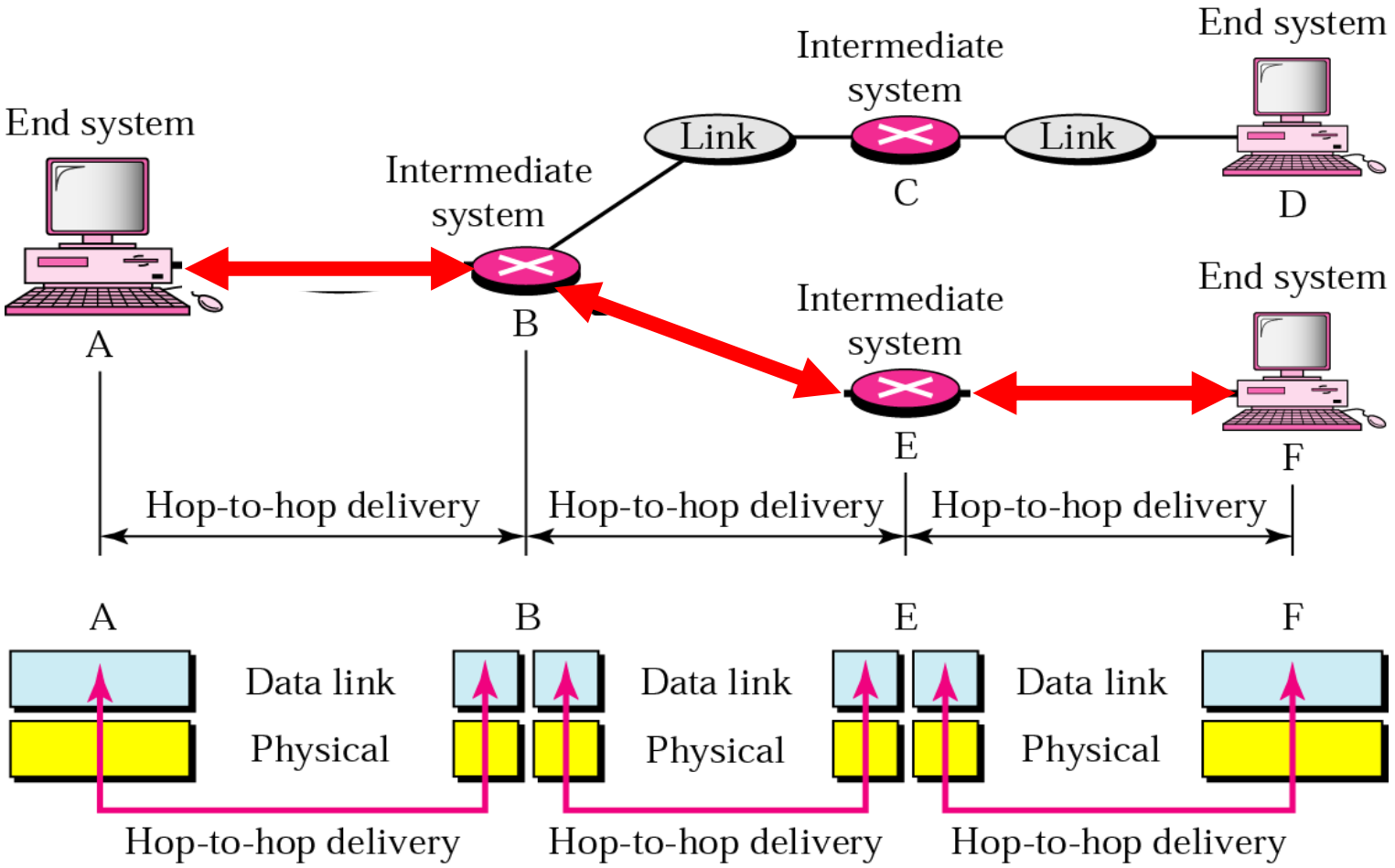
Aim of the Module



Internet = Network of Networks

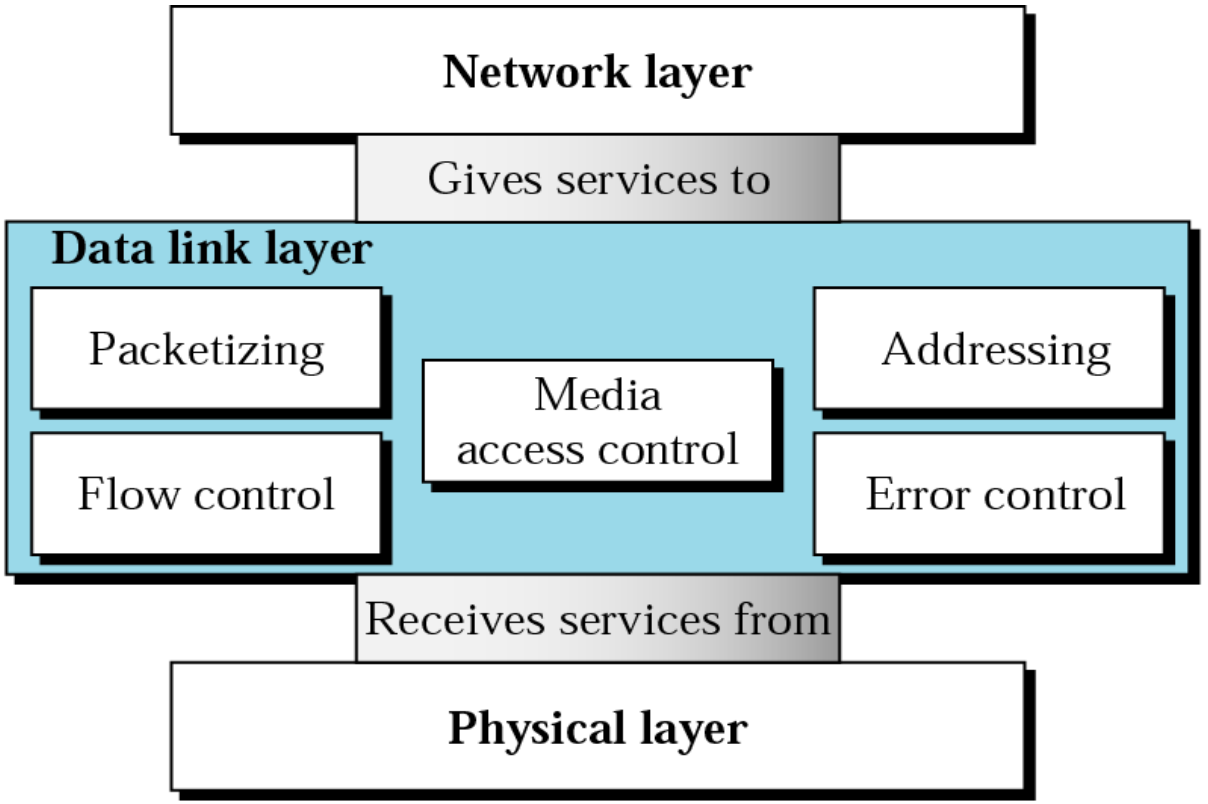


Link Layer



* Figure is courtesy of B. Forouzan

Duties of the Data Link Layer

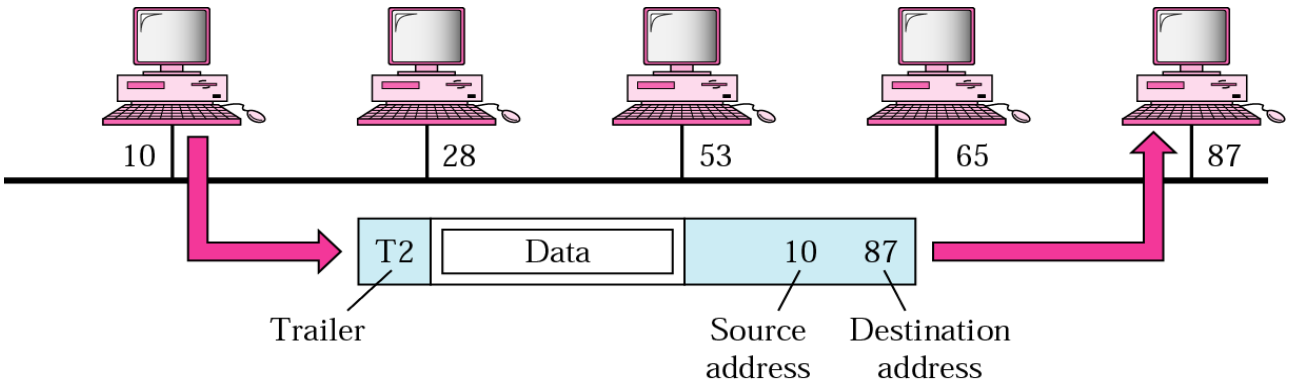


The data link layer is responsible for transmitting frames from one node to the next.

* Figure is courtesy of B. Forouzan

Packetizing & Addressing

- Packetizing: Encapsulating data in frame or cell i.e. adding header and trailer
- Addressing: Determining the address of the next hop (LANs) or the virtual circuit address (WANs)



* Figure is courtesy of B. Forouzan

Communication

- What is telecommunication really about?

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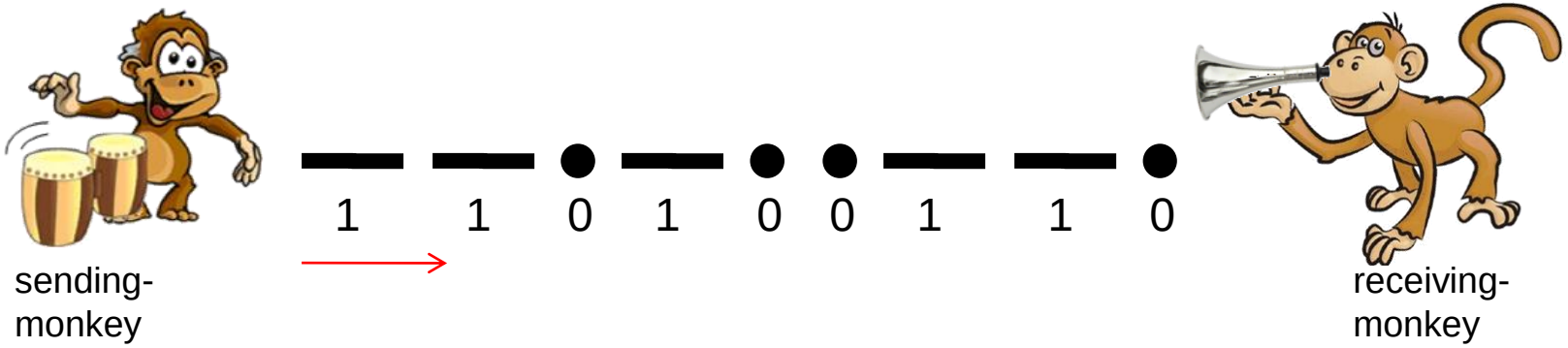
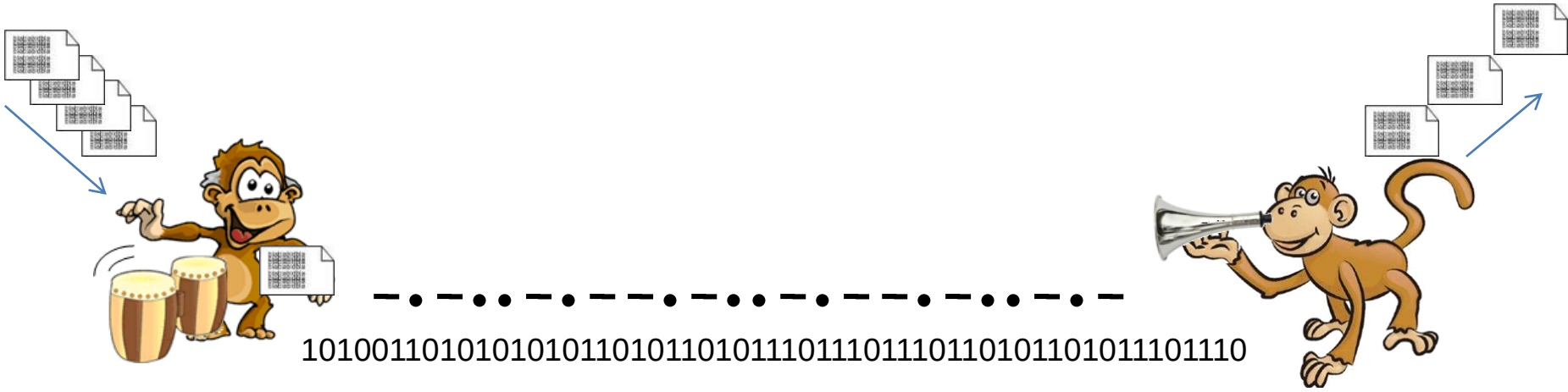


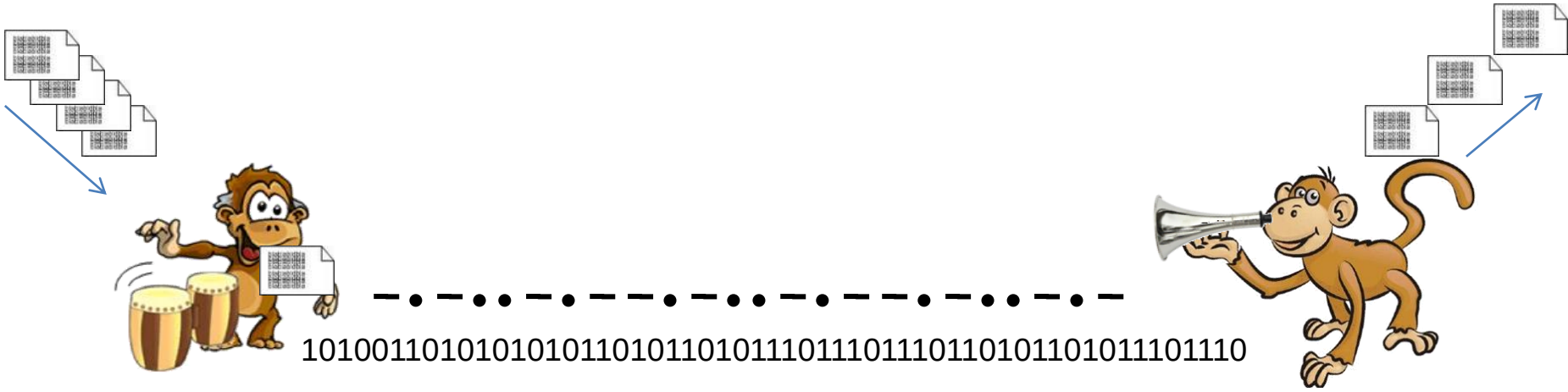
Bongo-Playing Monkeys Doing Morse-code!

Framing



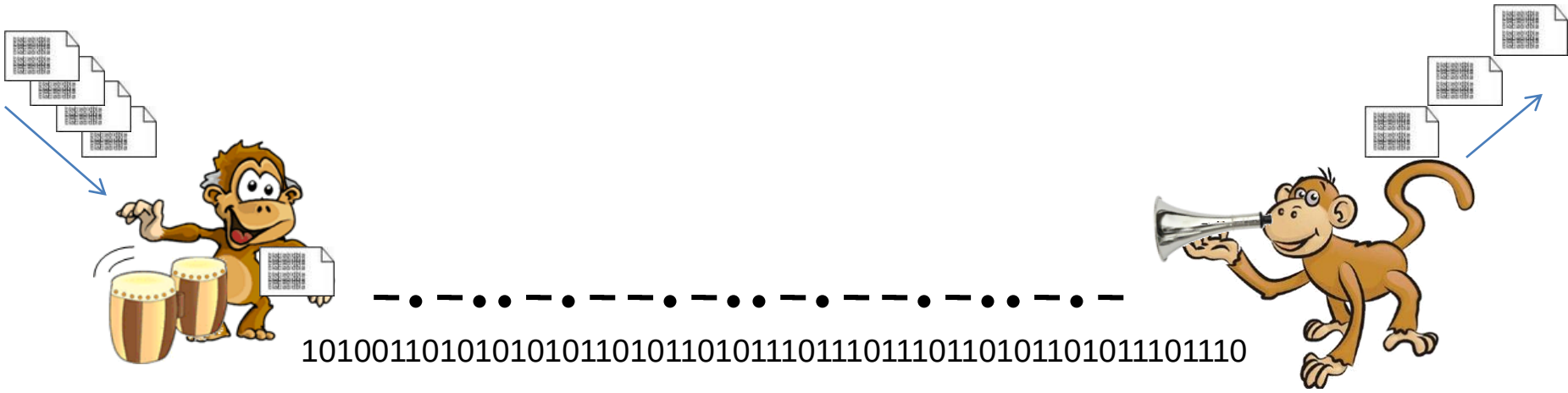
- Spews out signals at a furious rate

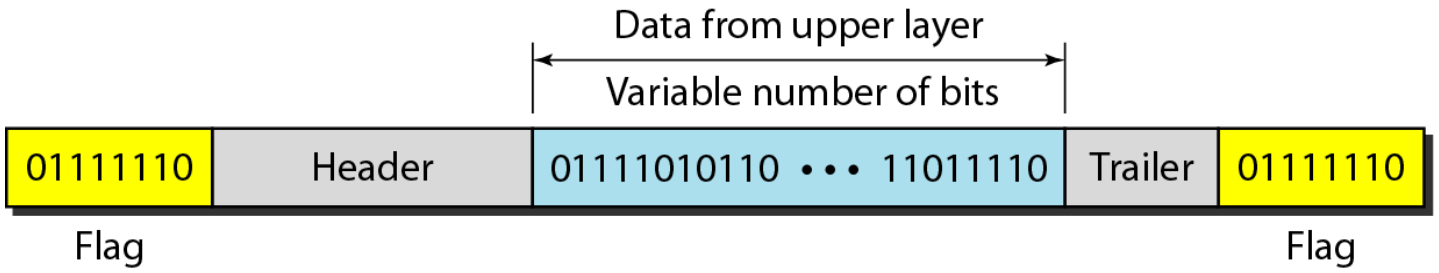
Framing



- Spews out signals at a furious rate
- How does receiving-monkey know when a unit of information begins?

Framing

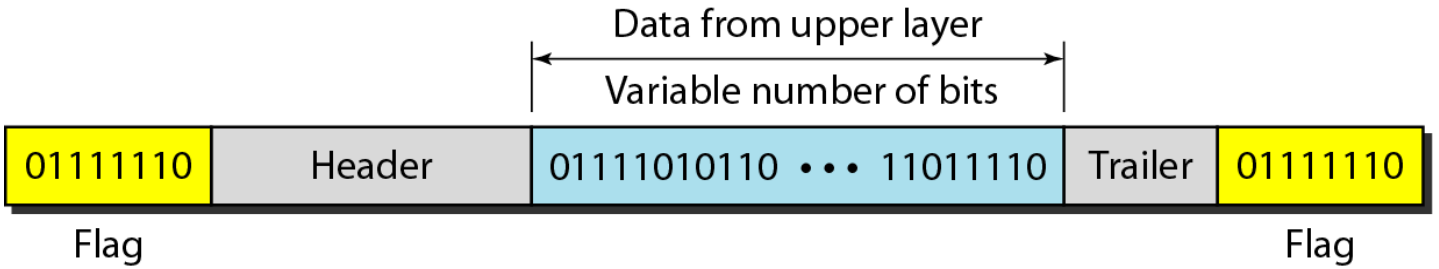


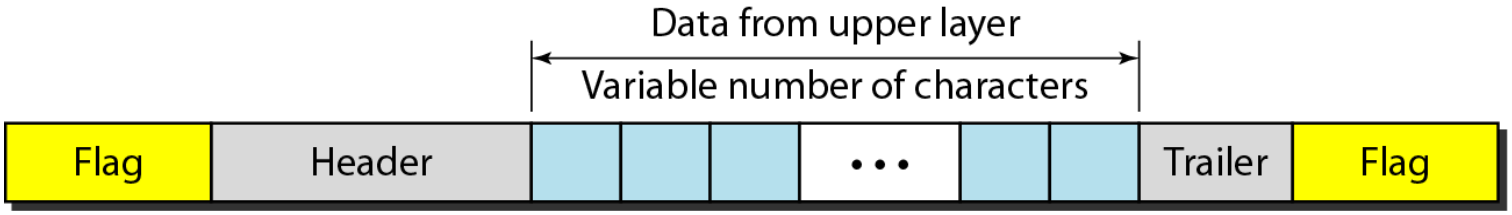


* Figure is courtesy of B. Forouzan

Bit- & Byte-Oriented Protocols

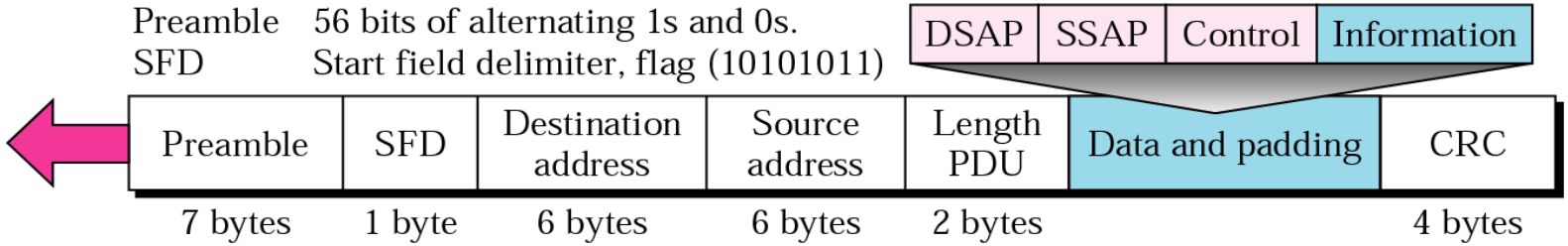
- Two Variations





* Figure is courtesy of B. Forouzan

Example: 802.3 MAC Format

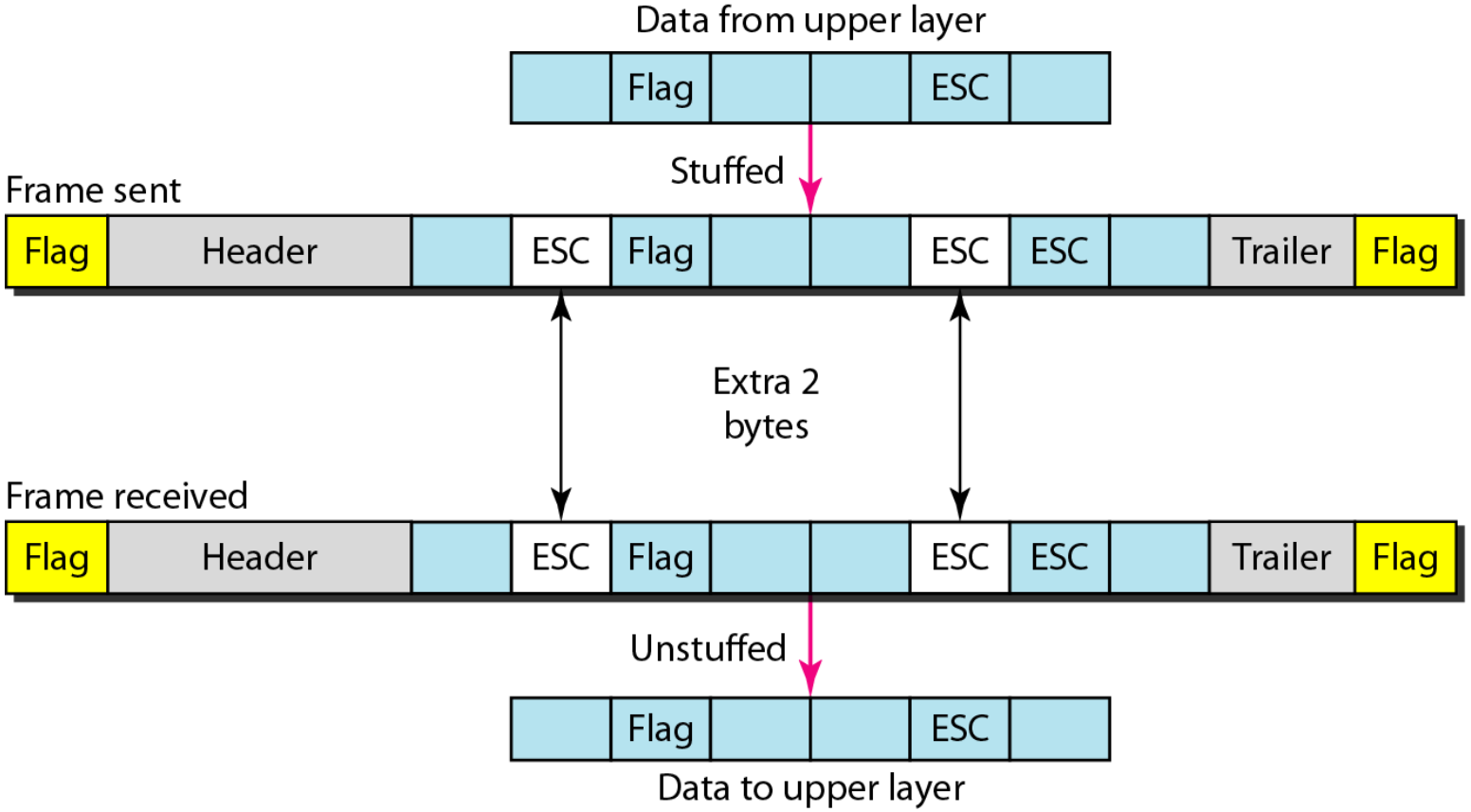


- 64-bit frame preamble (10101010) used to synchronize reception
  - 7 bit preamble (10101010) + 1 start flag (10101011)

- Maximum frame length: 1518 bytes
  - ⇨ max 1500 bytes payload
- Minimum frame length: 64 bytes
  - ⇨ min 46 bytes payload

* Figure is courtesy of B. Forouzan

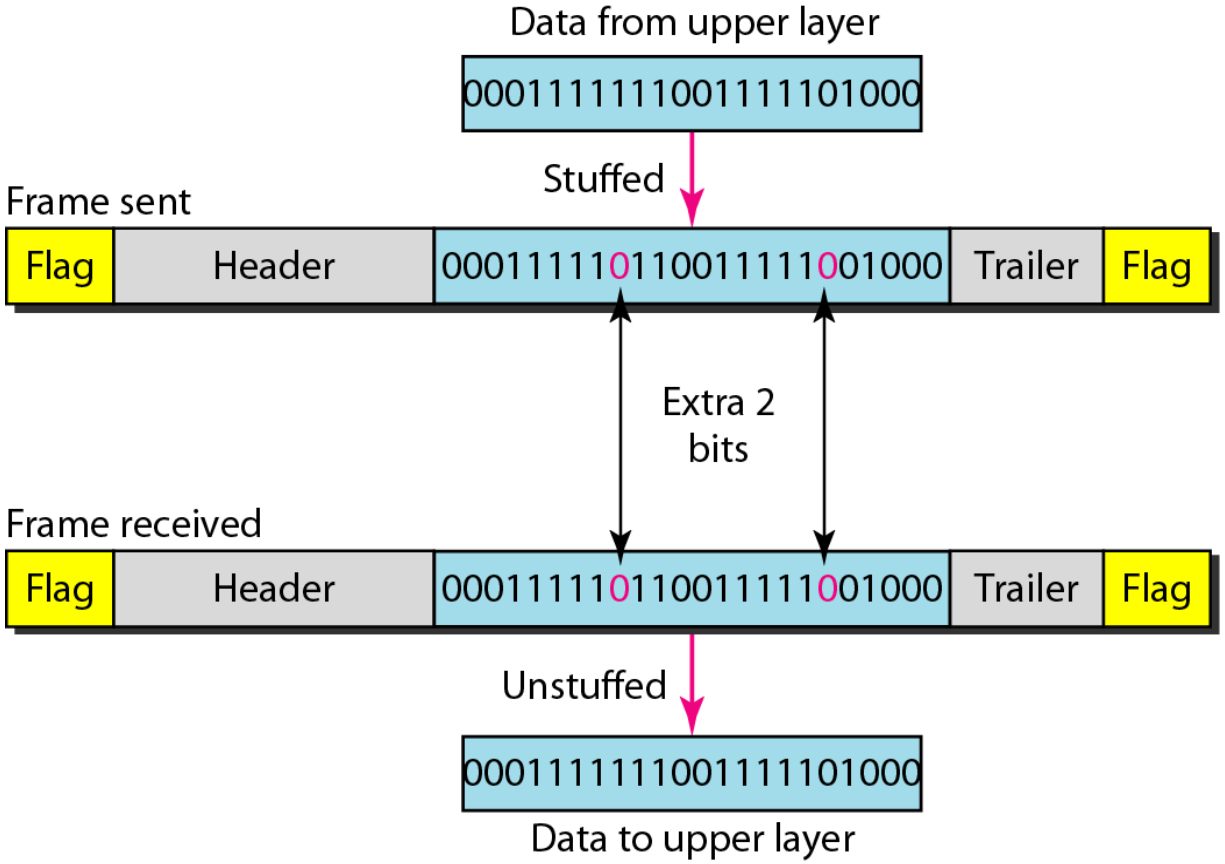
Byte Stuffing



Process of adding 1 extra byte whenever there is a flag or escape character in the text.

* Figure is courtesy of B. Forouzan

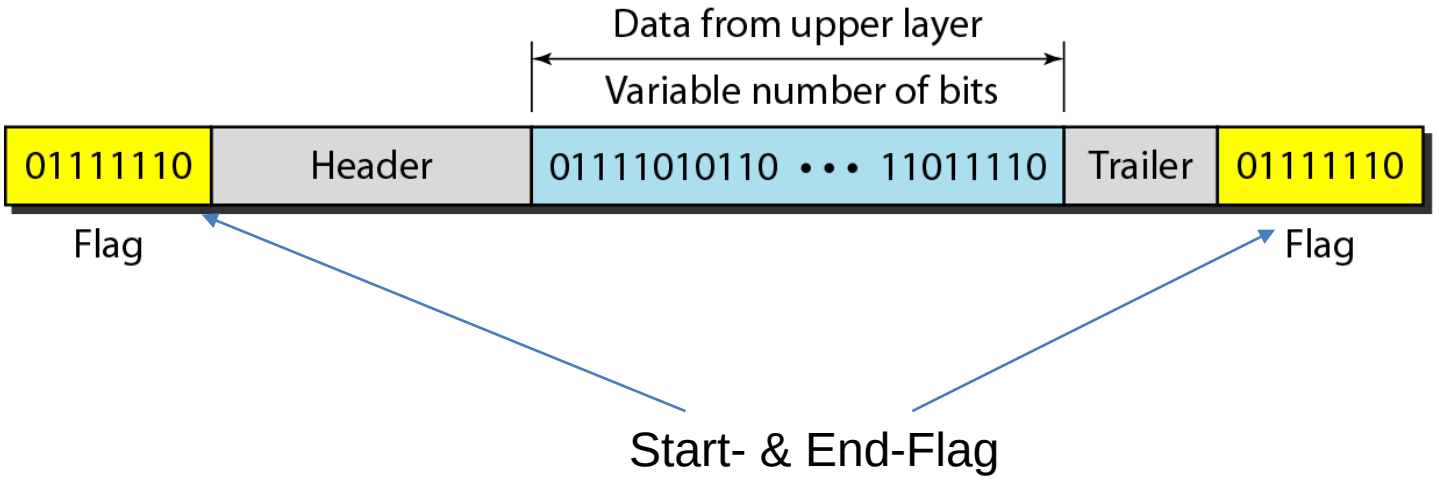
Bit Stuffing



Process of adding an extra 0 whenever five consecutive 1s follow a 0 in the data

* Figure is courtesy of B. Forouzan

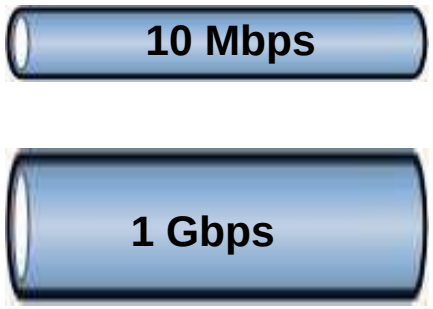
Framing



* Figure is courtesy of B. Forouzan

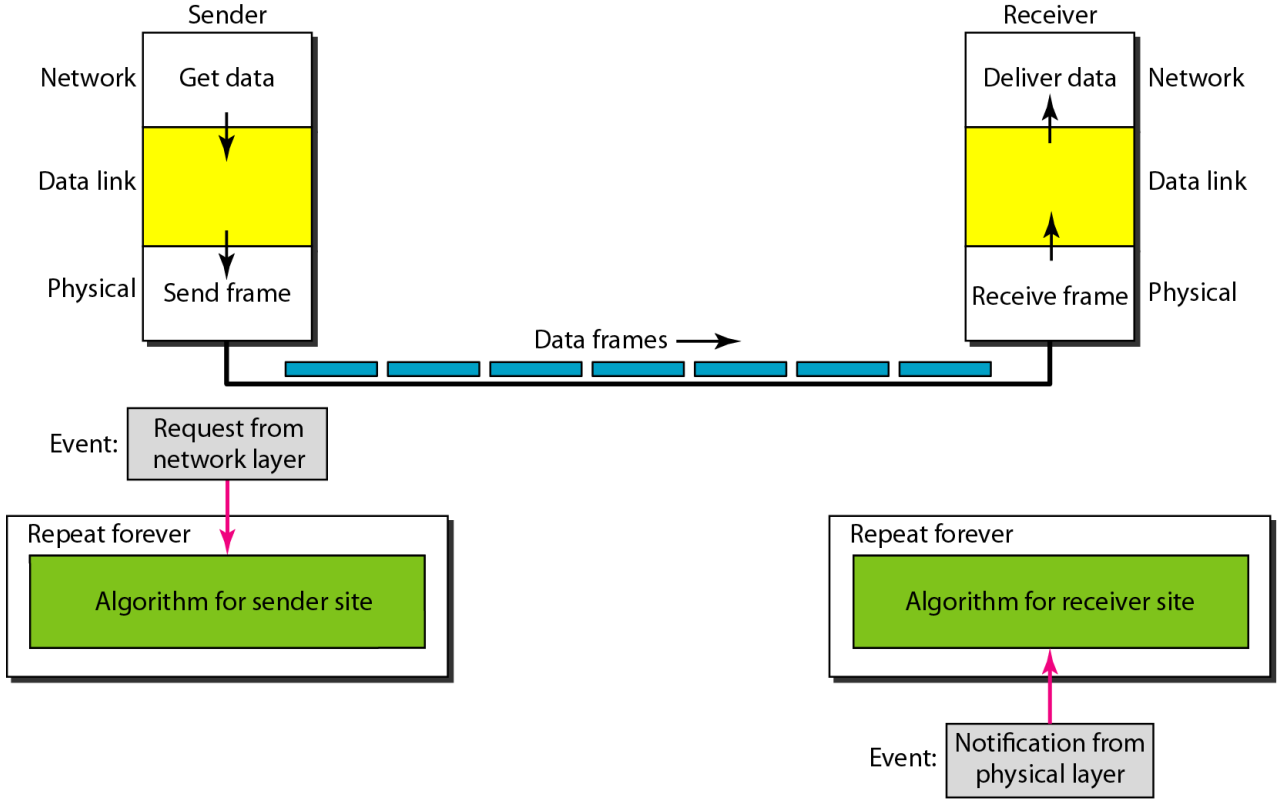
Networking Issues

- Time → Latency
- Amount → Throughput



- Management Information → Overhead
  - May lead to better efficiency
- Overhead vs Payload

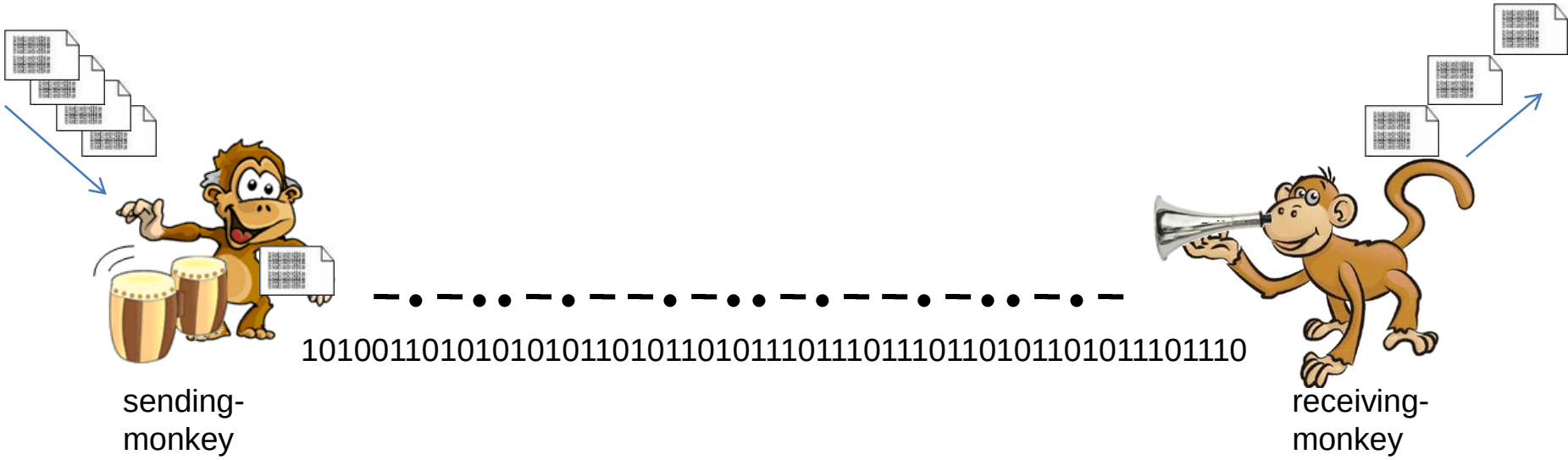
Simplest Protocol



- Hope that the receiver is fast enough!
- No overhead

* Figure is courtesy of B. Forouzan

Flow Control



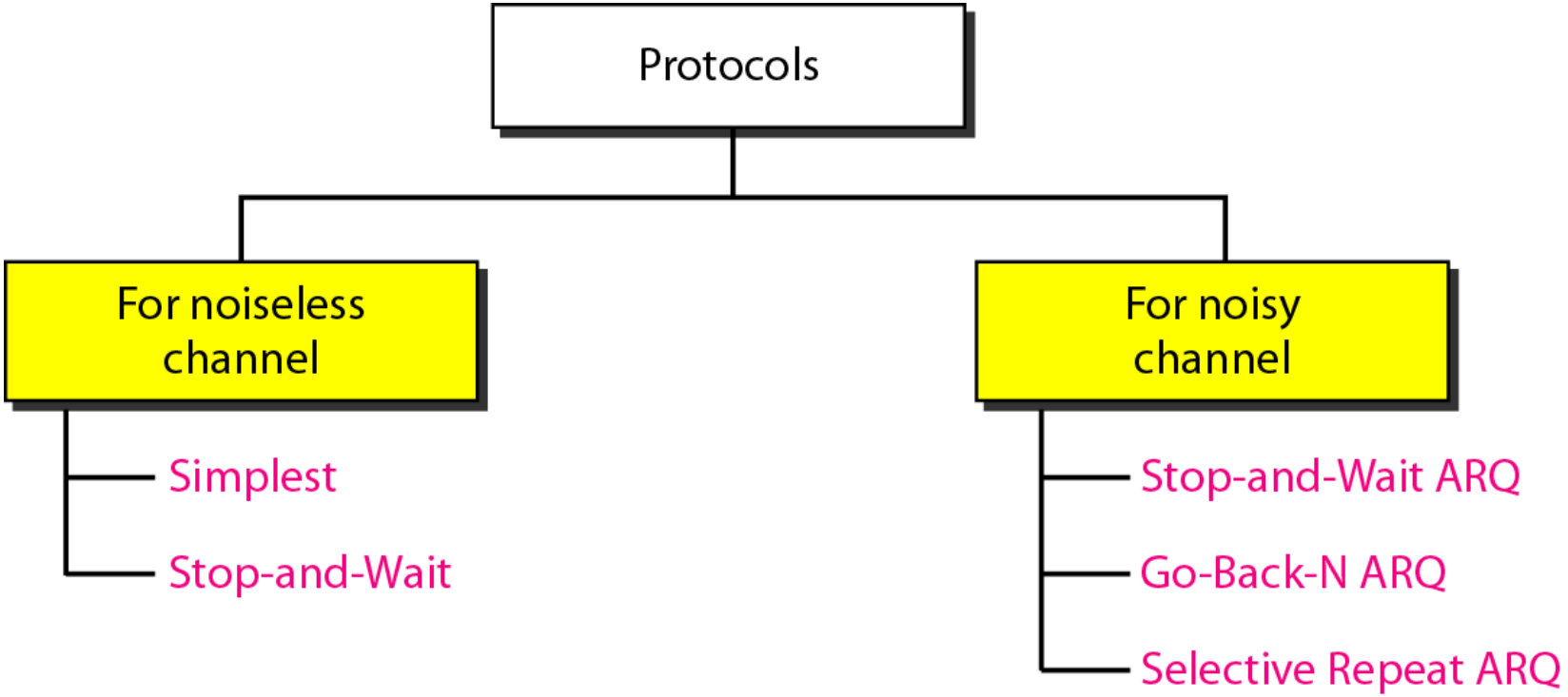
- What happens if sending-monkey can drum faster than receiving-monkey can write?

Flow Control

- Forouzan's Definition: Flow control refers to a set of procedures used to restrict the amount of data that the sender can send before waiting for acknowledgment.

- "My" Definition: Flow Control refers to the control of the amount of data that a sender can transmit without overflowing the receiver.

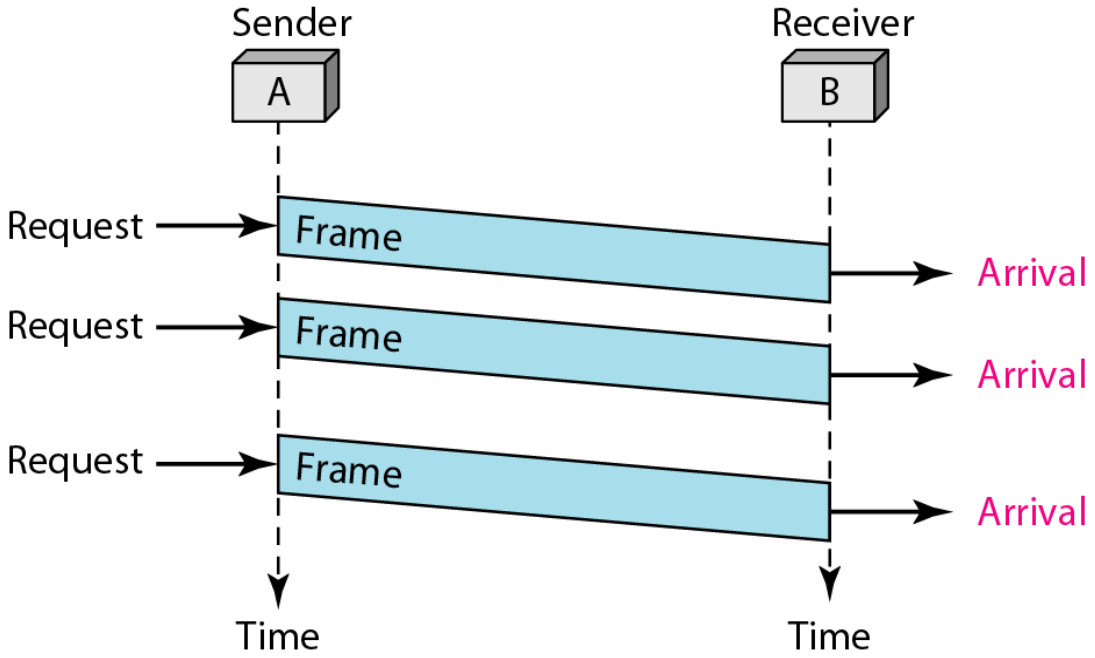
Flow Control Protocols



* Figure is courtesy of B. Forouzan

Simplest Protocol: Flow Diagram

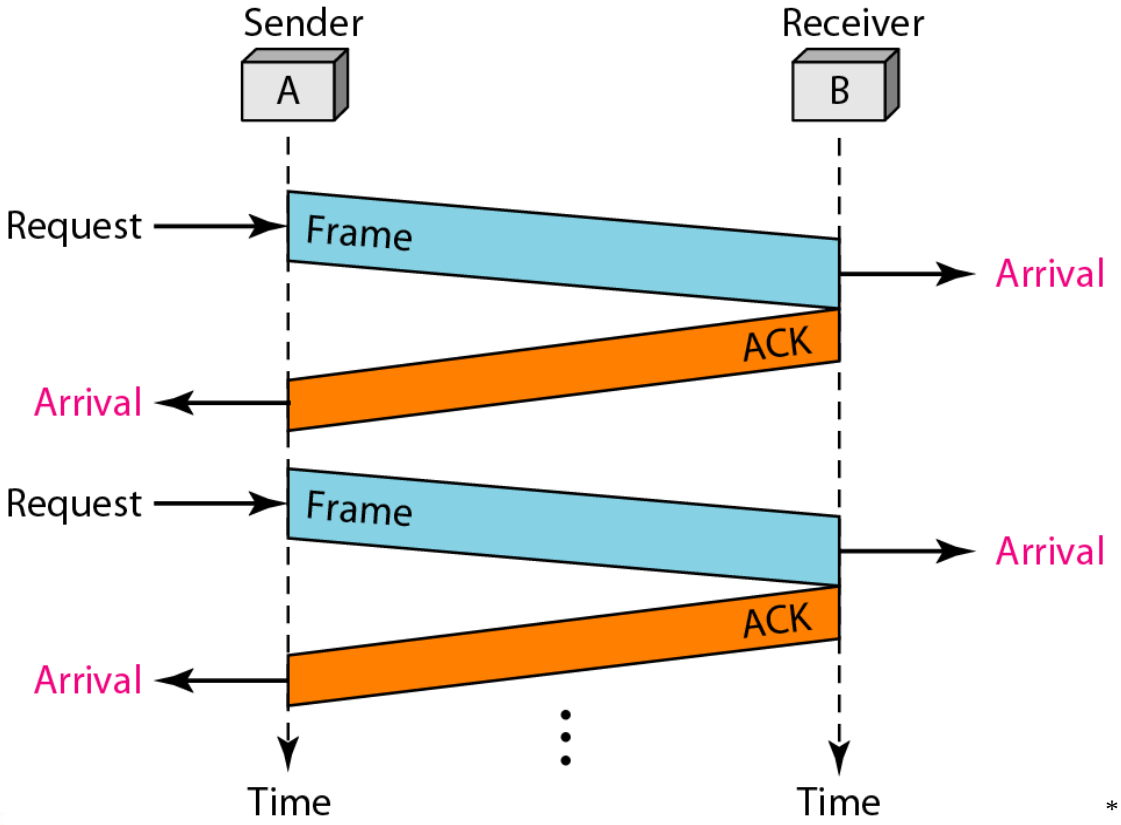
- Sender sends frames as fast as data arrives
- Receiver receives all data sent



* Figure is courtesy of B. Forouzan

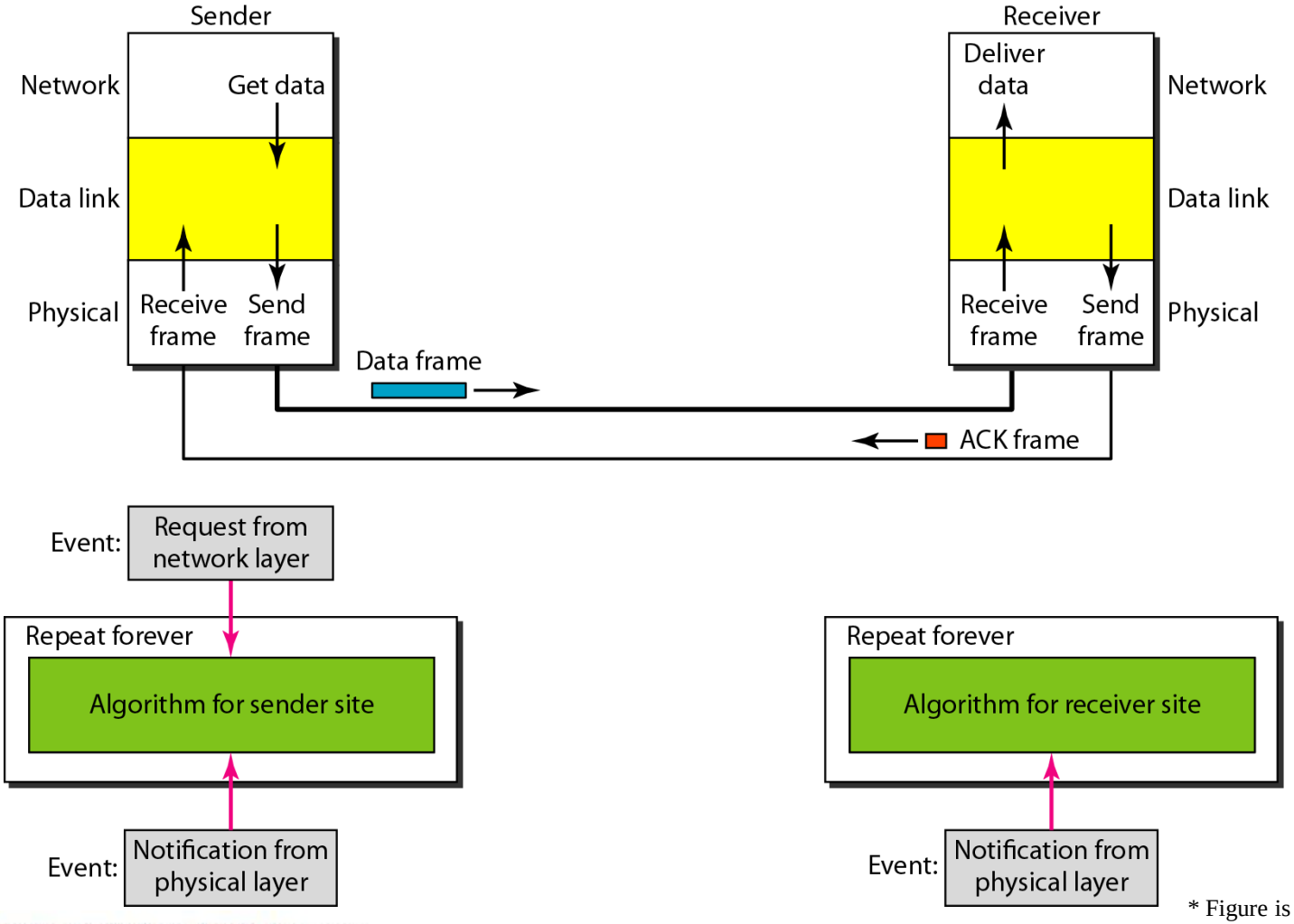
Stop-and-Wait: Flow Diagram

- Sender sends frame and waits for ACK
- Receiver replies to received frame with ACK



* Figure is courtesy of B. Forouzan

Stop-and-Wait Protocol



* Figure is courtesy of B. Forouzan

Error Control

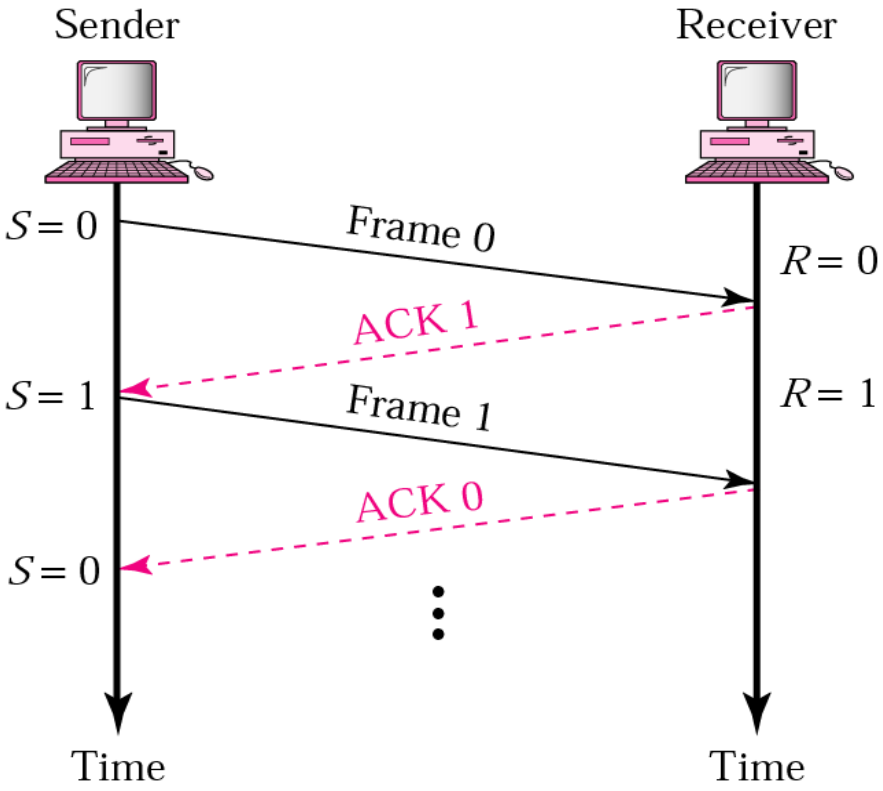
- Frames may get lost or corrupted
  - Incorrect checksum, CRCs, etc
- Error control need to ensure retransmission
- Error Control Protocols:
  - Stop-and-Wait ARQ*
  - Go-back-N ARQ
  - Selective Repeat ARQ

*ARQ = Automatic Repeat Request

Ingredients for Error Control

- Error detection
- Positive acknowledgement
  - Receiver returns positive ACK for received, error-free frames
- Retransmission after timeout
  - Sender retransmit packet after given time
- Negative acknowledgement and retransmission
  - Receiver returns negative ACK - or NACK - for packets with errors

Stop-and-Wait ARQ

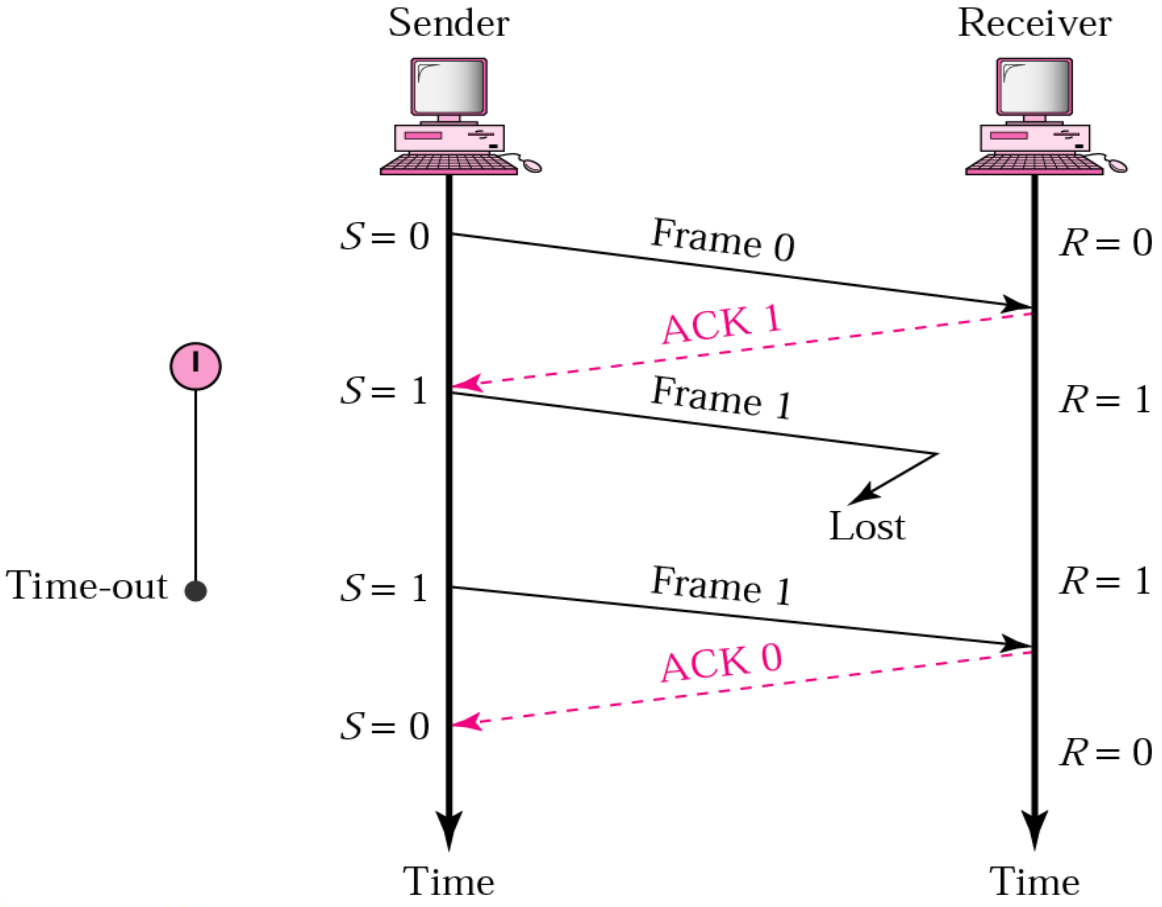


- ACK = received packet, ready to receive packet #
- ARQ = Automatic Repeat Request

* Figure is courtesy of B. Forouzan

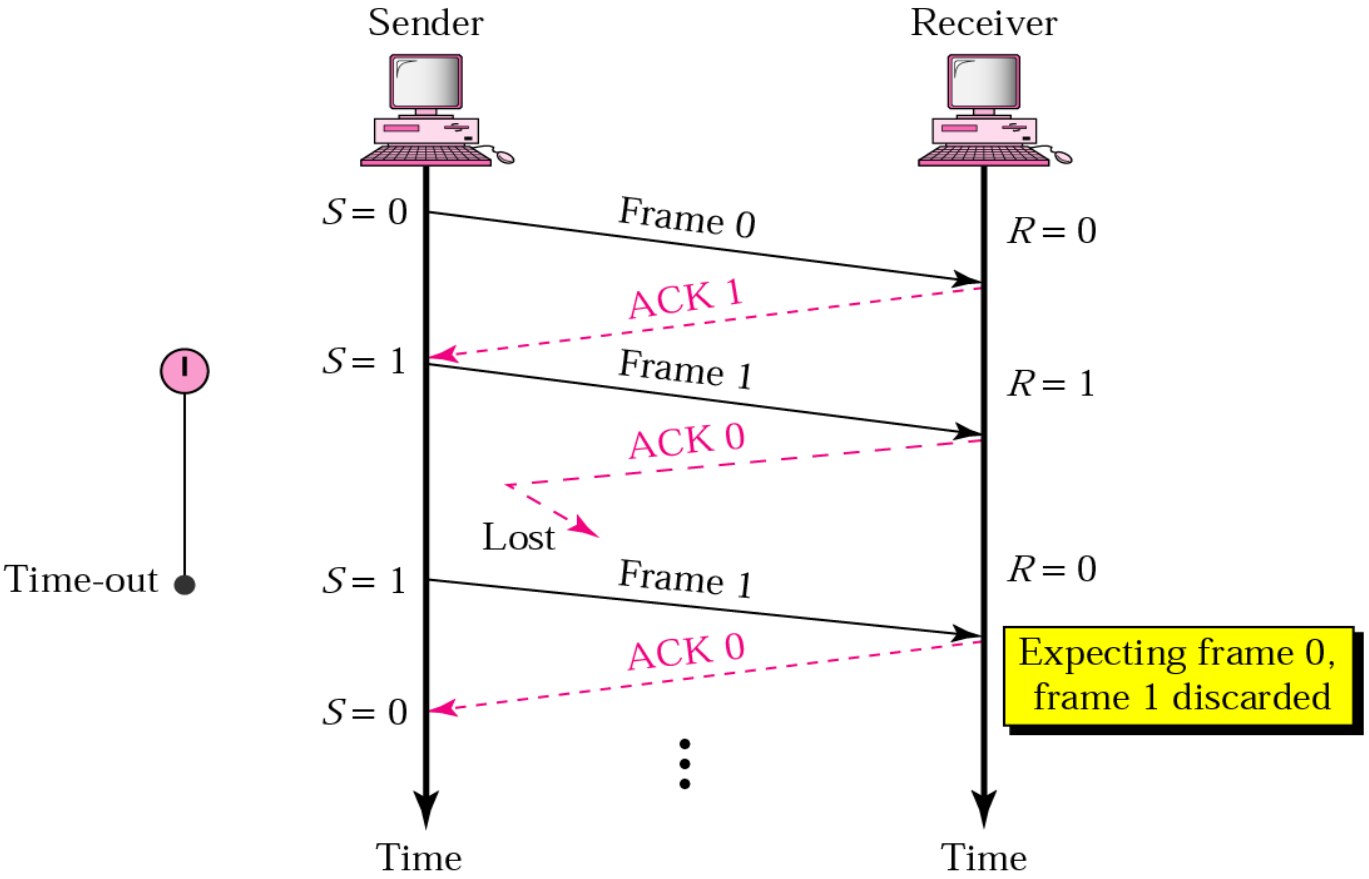
Stop-and-Wait ARQ: Time-Out

- Frame is lost during transmission



* Figure is courtesy of B. Forouzan

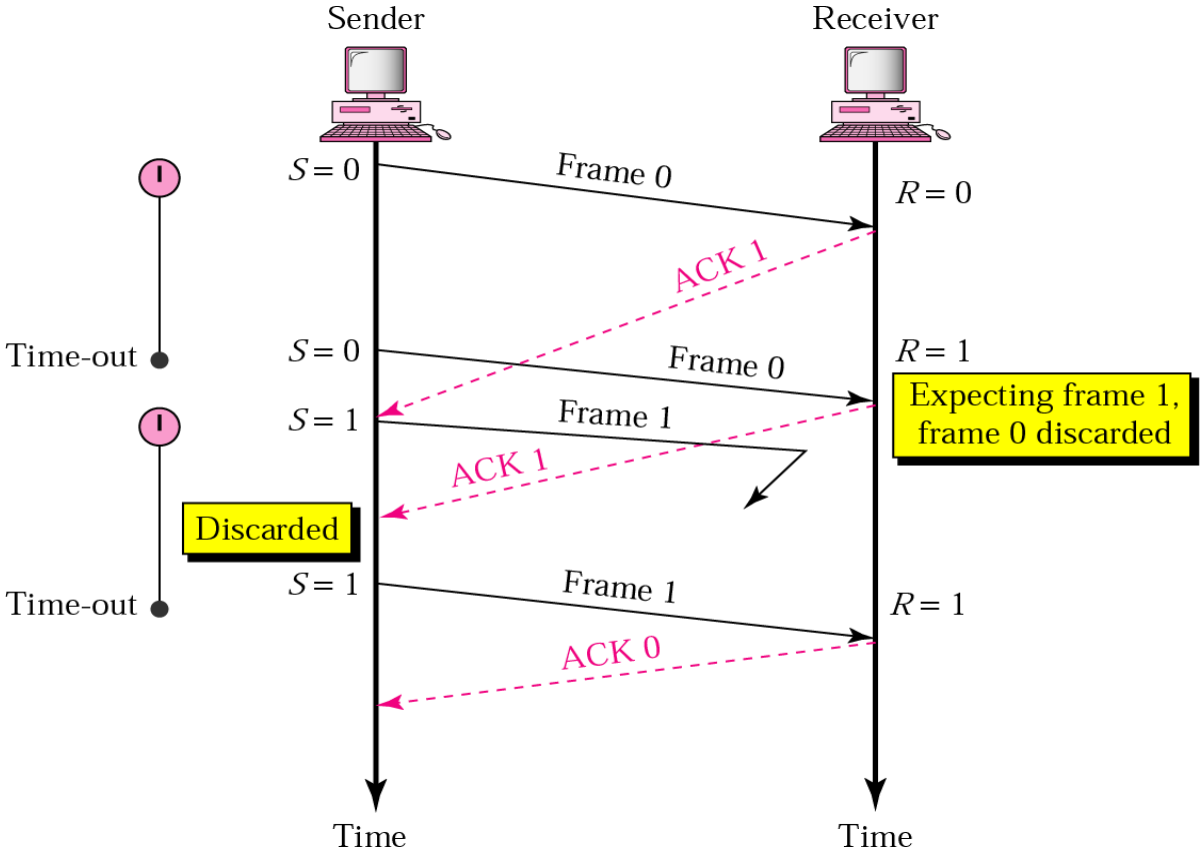
Stop-and-Wait ARQ: Lost-ACKs



- Numbering frames prevents retaining duplicate frames
- Every received frame is acknowledged

* Figure is courtesy of B. Forouzan

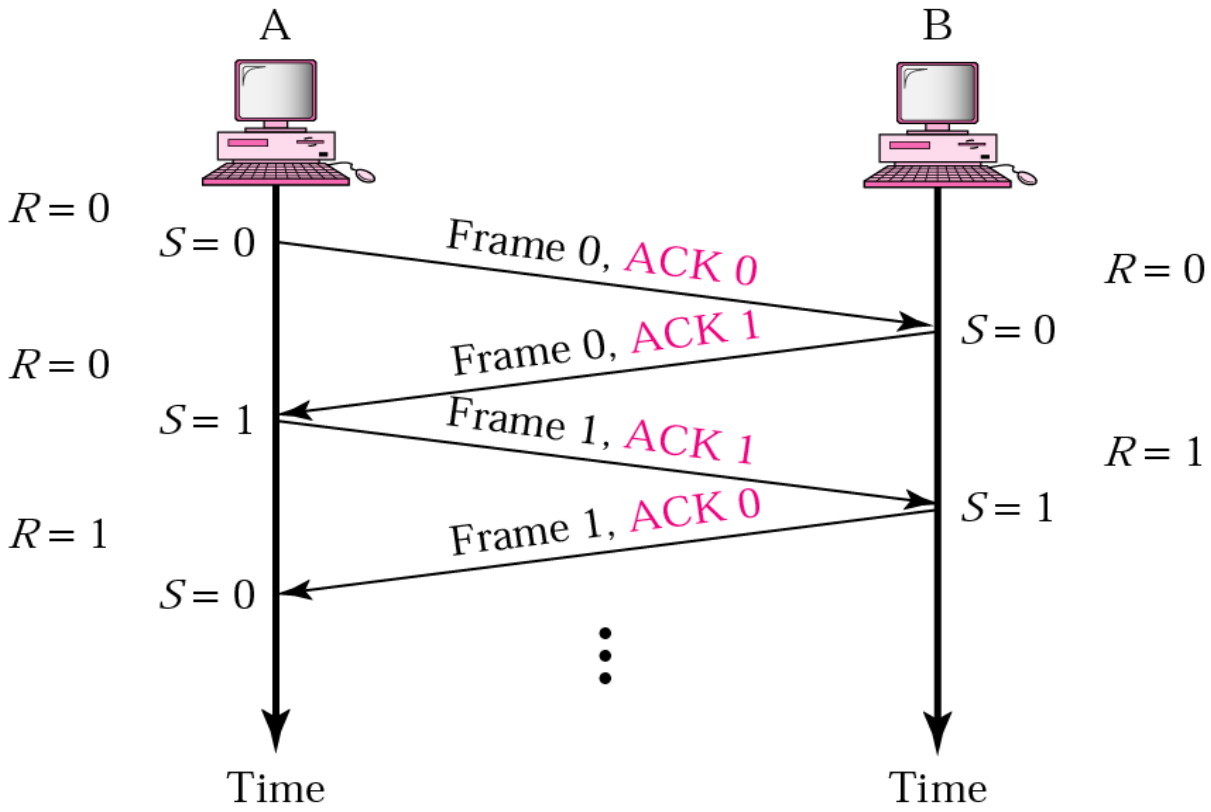
Stop-and-Wait ARQ: Delayed ACK



Numbered acknowledgments are needed if an acknowledgment is delayed and the next frame is lost.

* Figure is courtesy of B. Forouzan

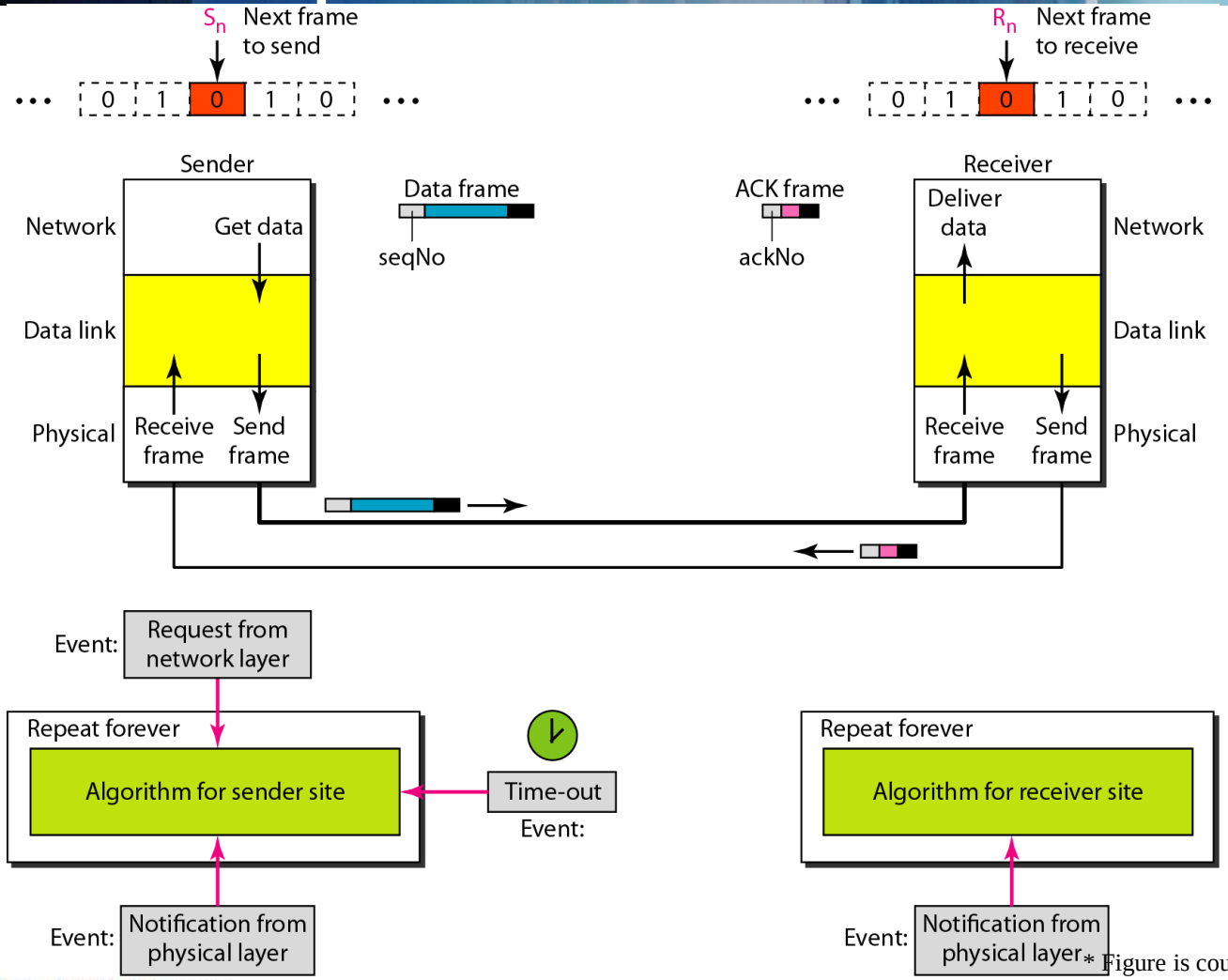
Piggybacking ACKs



Next data frame send carries
the acknowledgement for the last frame received

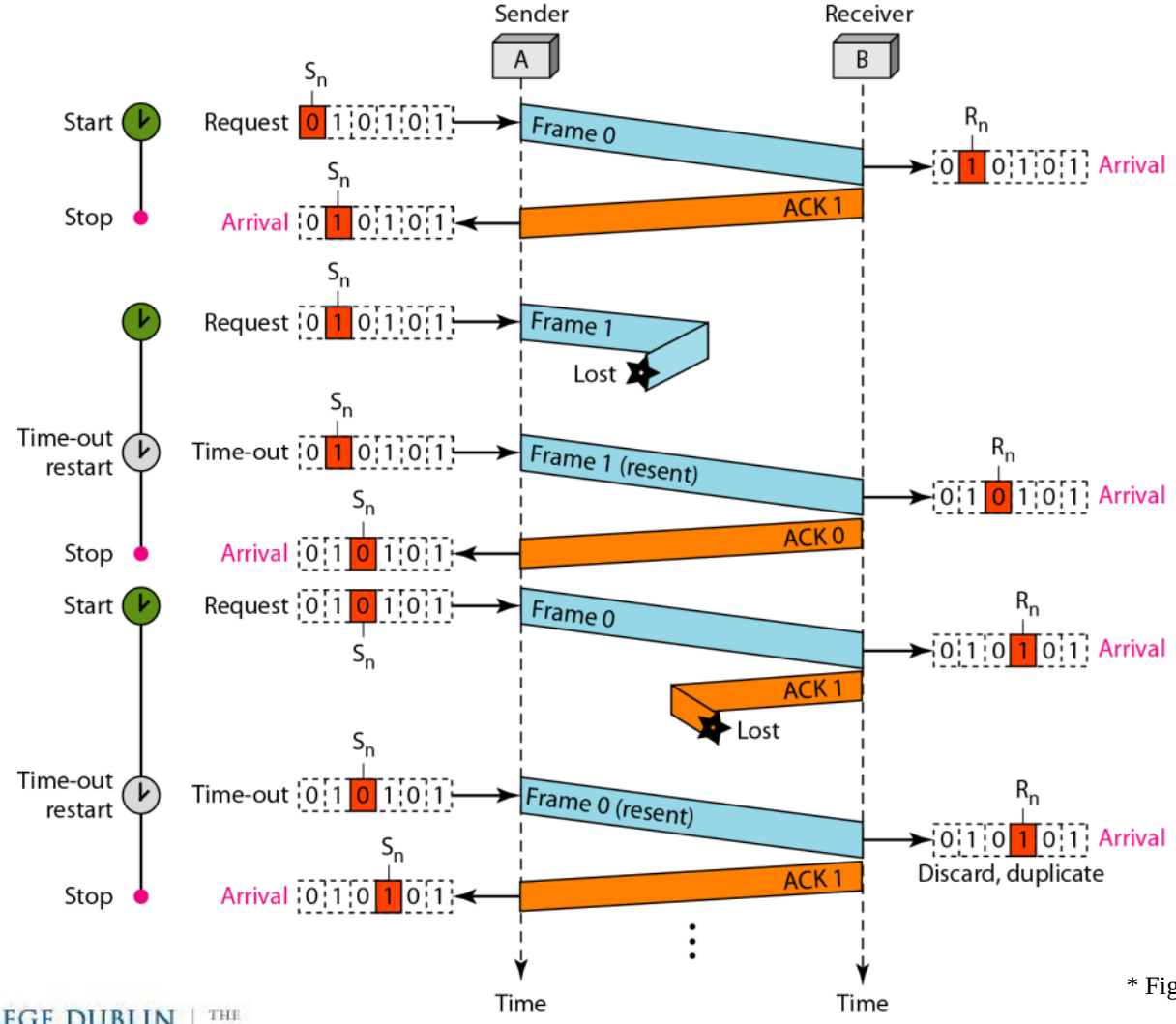
* Figure is courtesy of B. Forouzan

Stop-and-Wait ARQ



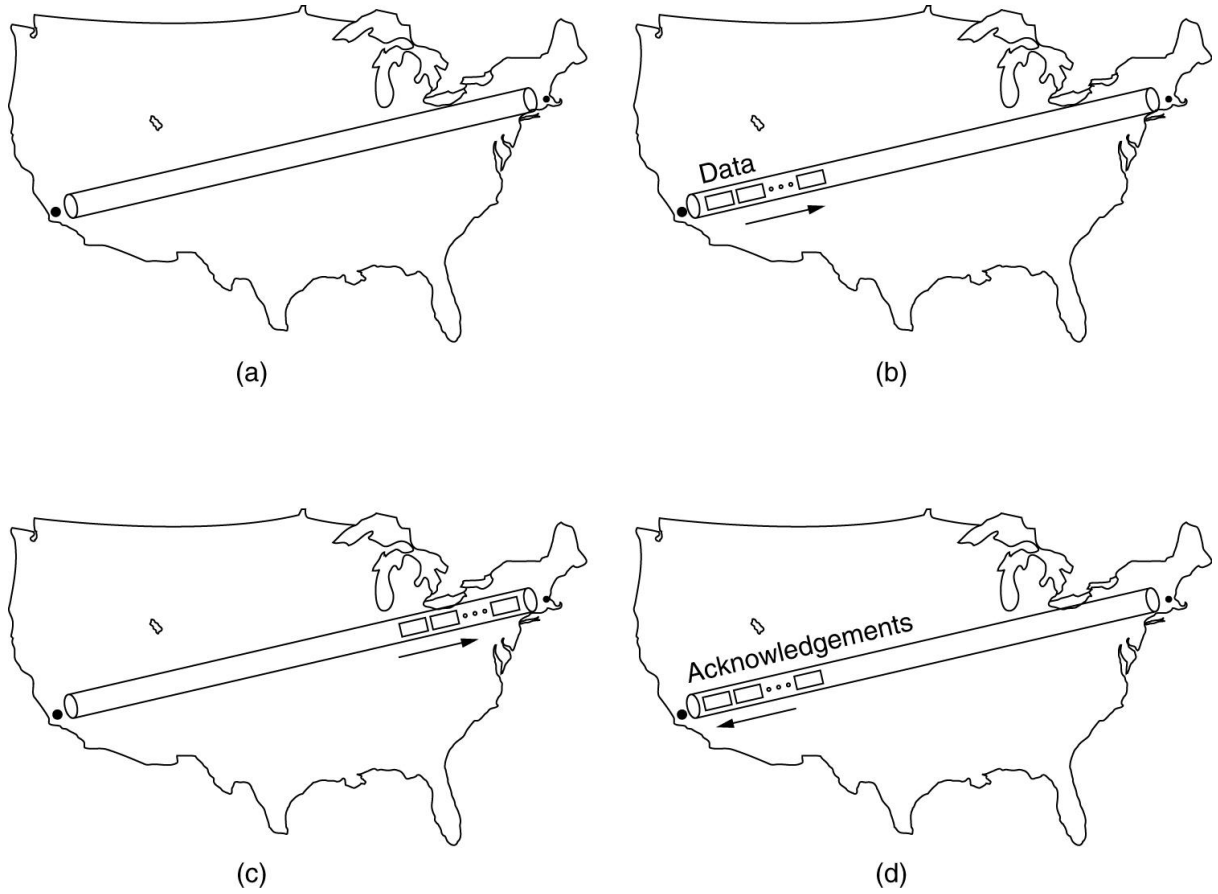
* Figure is courtesy of B. Forouzan

Stop-and-Wait ARQ: Flow Diagram



* Figure is courtesy of B. Forouzan

Round Trip Time



(a) At t = 0 (b) After 500 µsec (c) After 20 msec (d) after 40 msec

Flow Control

- Definitions
  - Transmission time
    - Time taken to emit all bits onto the medium
    - Proportional to length of frame
  - Propagation time
    - Time for a bit to traverse the link

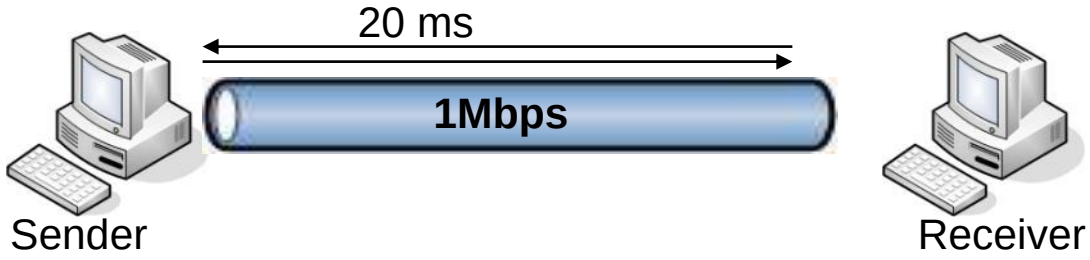
Bandwidth-Delay Product

- Bandwidth:
  - Size of the pipe
  - Determines how much data can be send
- Round-Trip Time (RTT)
  - Determines how long an ACK takes

- High Bandwidth (big pipe)
  - Lots of data can be send
- Depending on RTT
  - Sender may exhaust window quickly

- Bandwidth × RTT
  - Gives indication of amount of data that can be send while waiting for ACK

Delay Before Receiving ACK

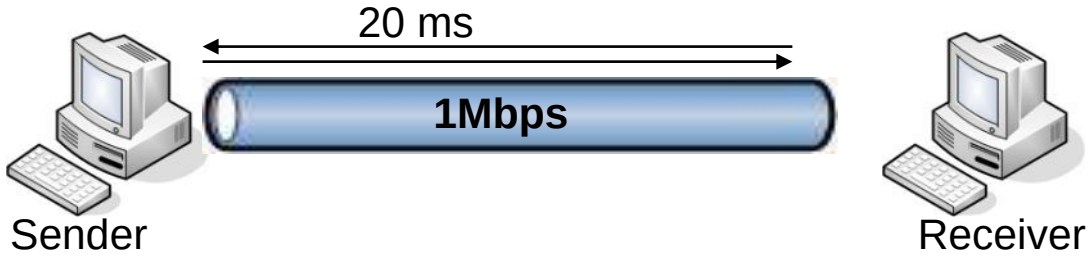


- Communication link with 1Mb/s
- Round-Trip time: 20 ms = 20 * 10^{-3} s

- How much data can you send during the time it takes for 1 bit e.g. an ACK to arrive at the sender:

$$20 * 10^{-3}\,s * \quad 1 * 10^{6}\,b/s \;=\; 20.000\ bits$$

Delay Before Receiving ACK



- Communication link with 1Mb/s
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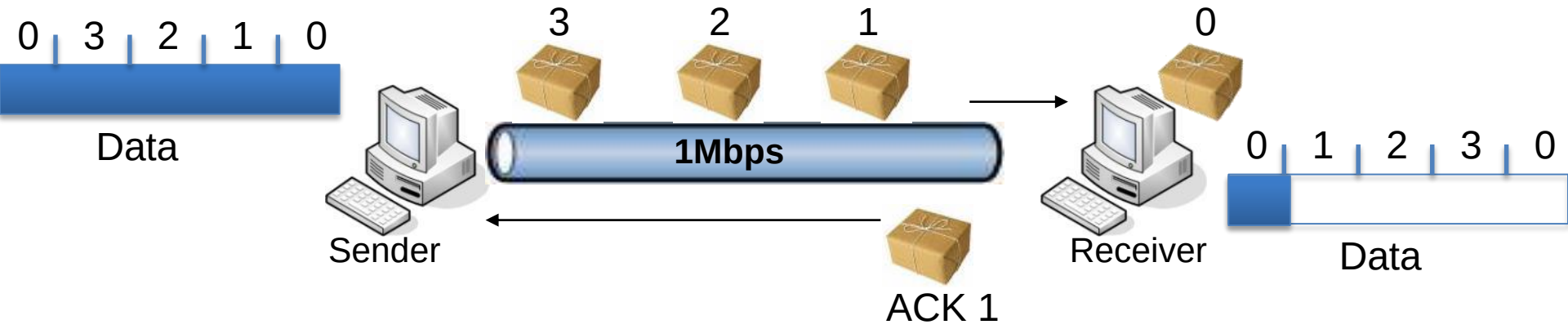
$$20 * 10^{-3}\,s * \quad 1 * 10^{6}\,b/s \;=\; 20.000 \text{ bits}$$

- Frame of 2000 bit $\Rightarrow$ 10% of bandwidth used

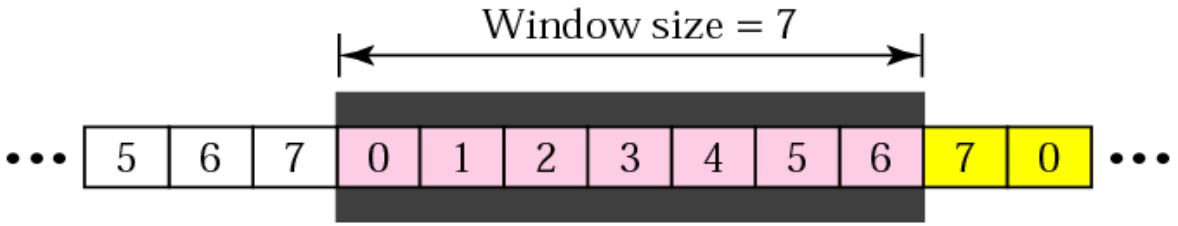
Ideal Solution to Filling the Pipe



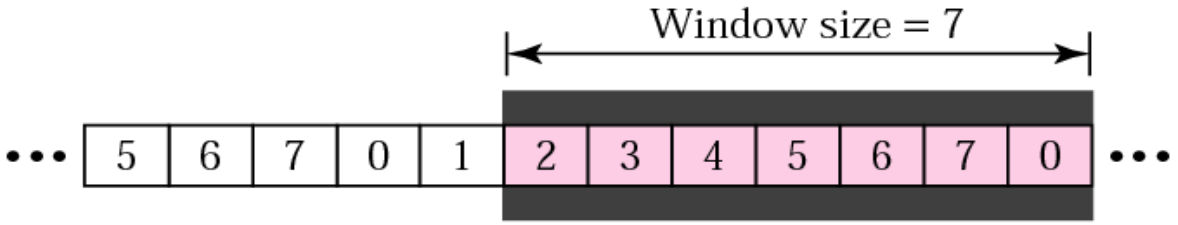
- Allow multiple frames to be in transit
- Receiver has a buffer
- Transmitter can send a number of frames
  - without receiving an ACK
- Each frame is numbered
- ACK includes number of next frame expected

Sliding Window

- m: Size of the sequence number field in bits
- 1...2^m: Sequence numbers
- Send window: Box of size $2^m - 1$



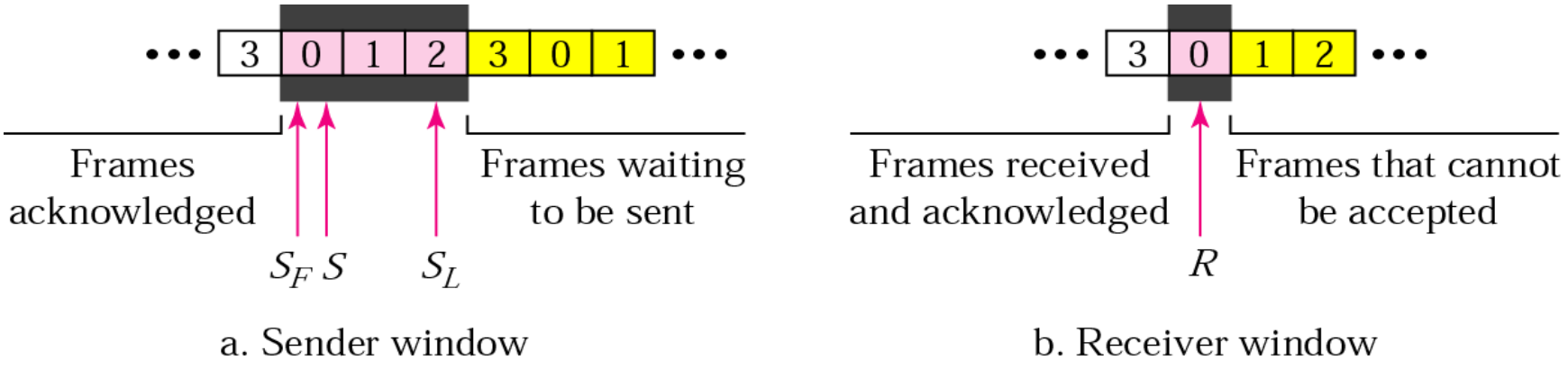
a. Before sliding



b. After sliding two frames

* Figure is courtesy of B. Forouzan

Go-Back-N ARQ: Control variables

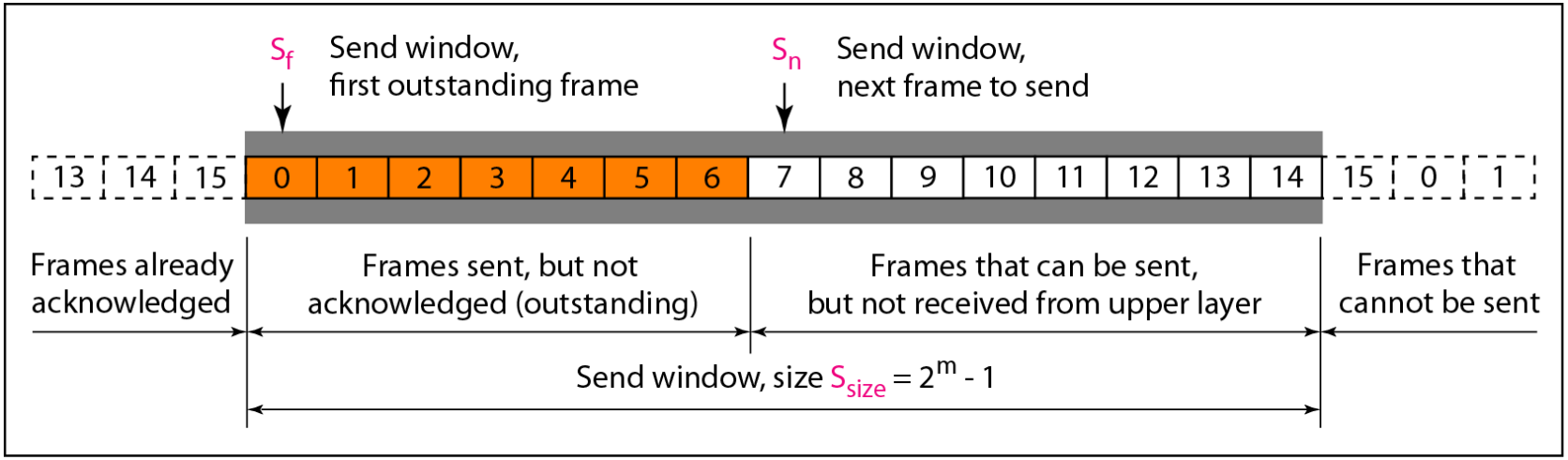


- S = # of recently send frame
- S_F= # of first send frame of window
- S_L= # of last send frame of window

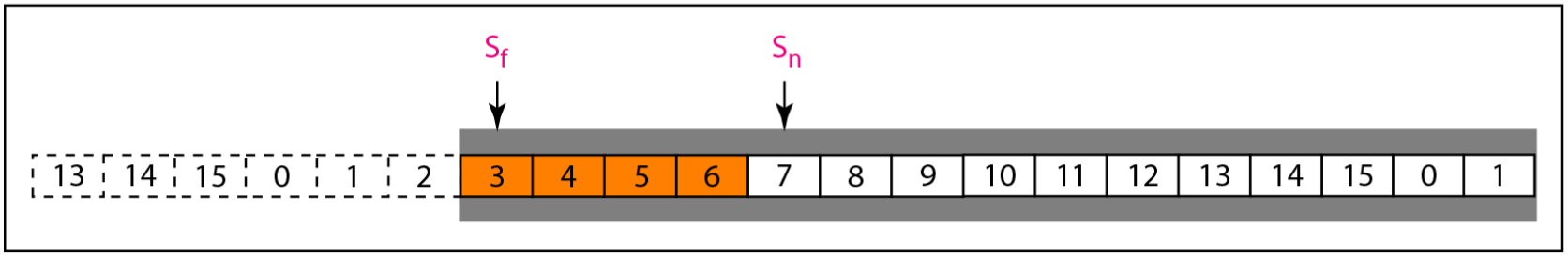
- R = # of recently received frame

* Figure is courtesy of B. Forouzan

Sliding Window



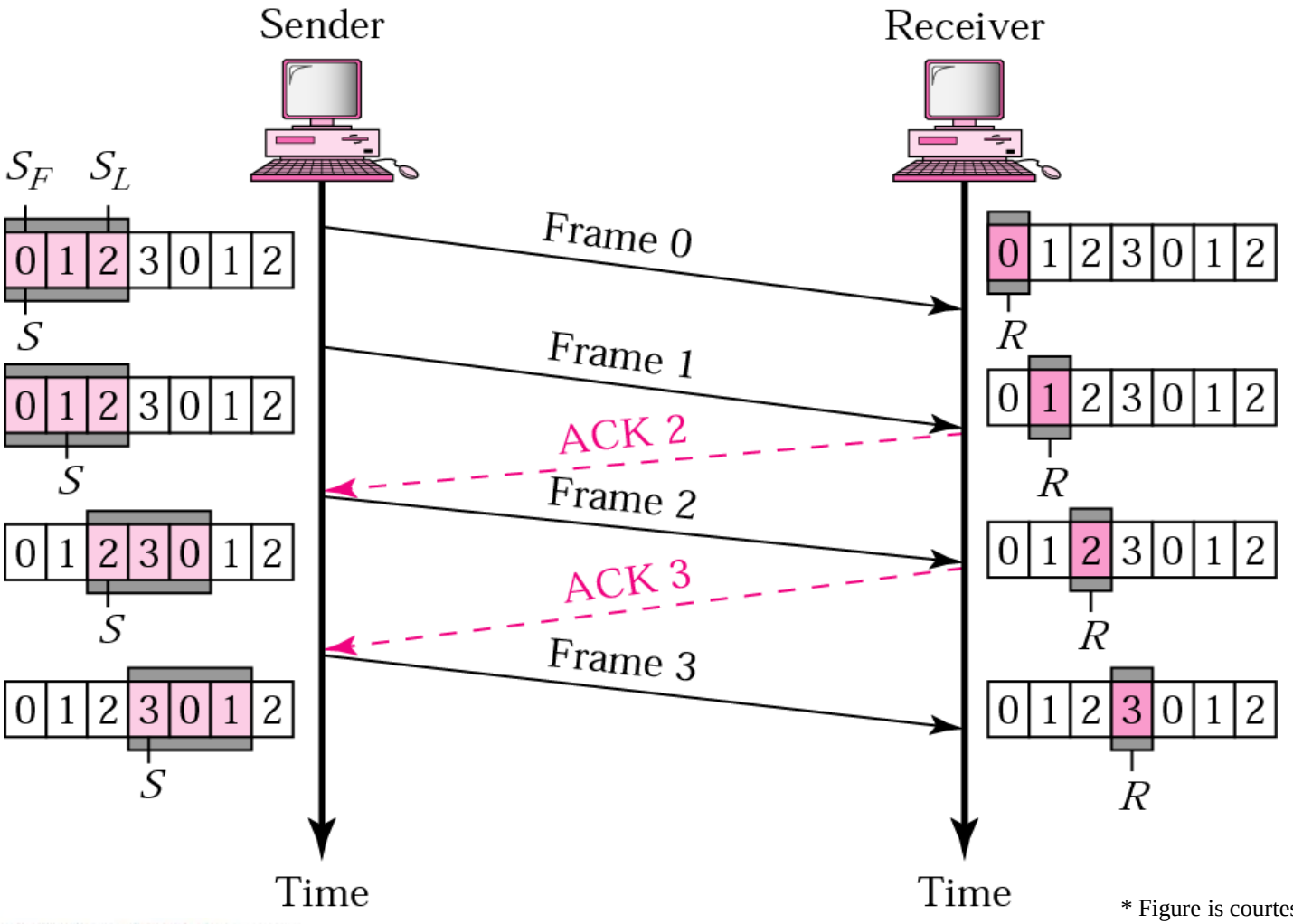
a. Send window before sliding



b. Send window after sliding

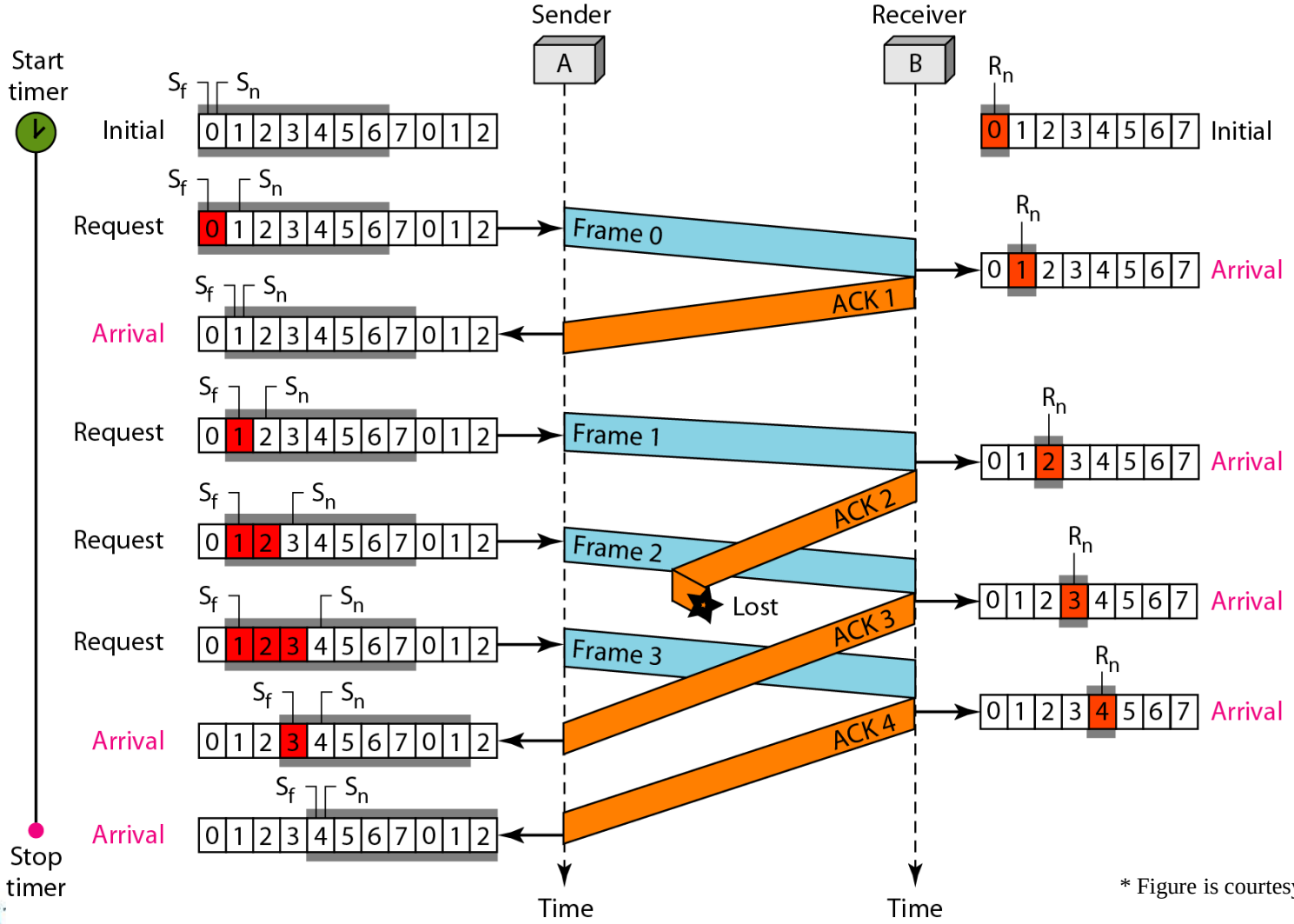
* Figure is courtesy of B. Forouzan

Go-Back-N ARQ



* Figure is courtesy of B. Forouzan

Go-Back-N: Lost ACK



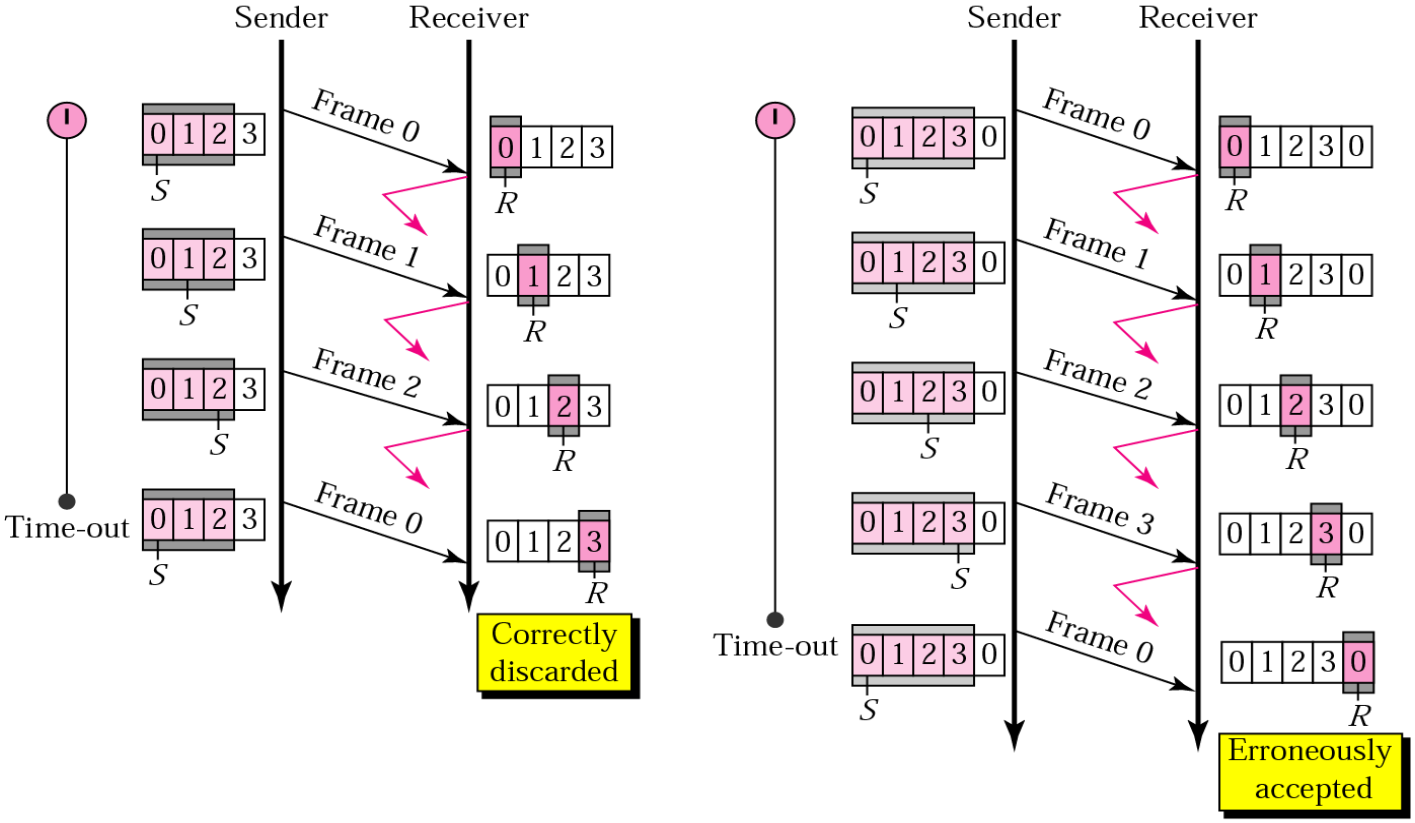
* Figure is courtesy of B. Forouzan

Window Size for Go-Back-N

- Depends on size of max. frame number
  - Frame # needs to be included in every frame
  - e.g. 4 bits – 2^4 = 16 frame numbers

- Trade-off between window size and frame size

Go-Back-N: Limitation of window size



a. Window size < 2^m

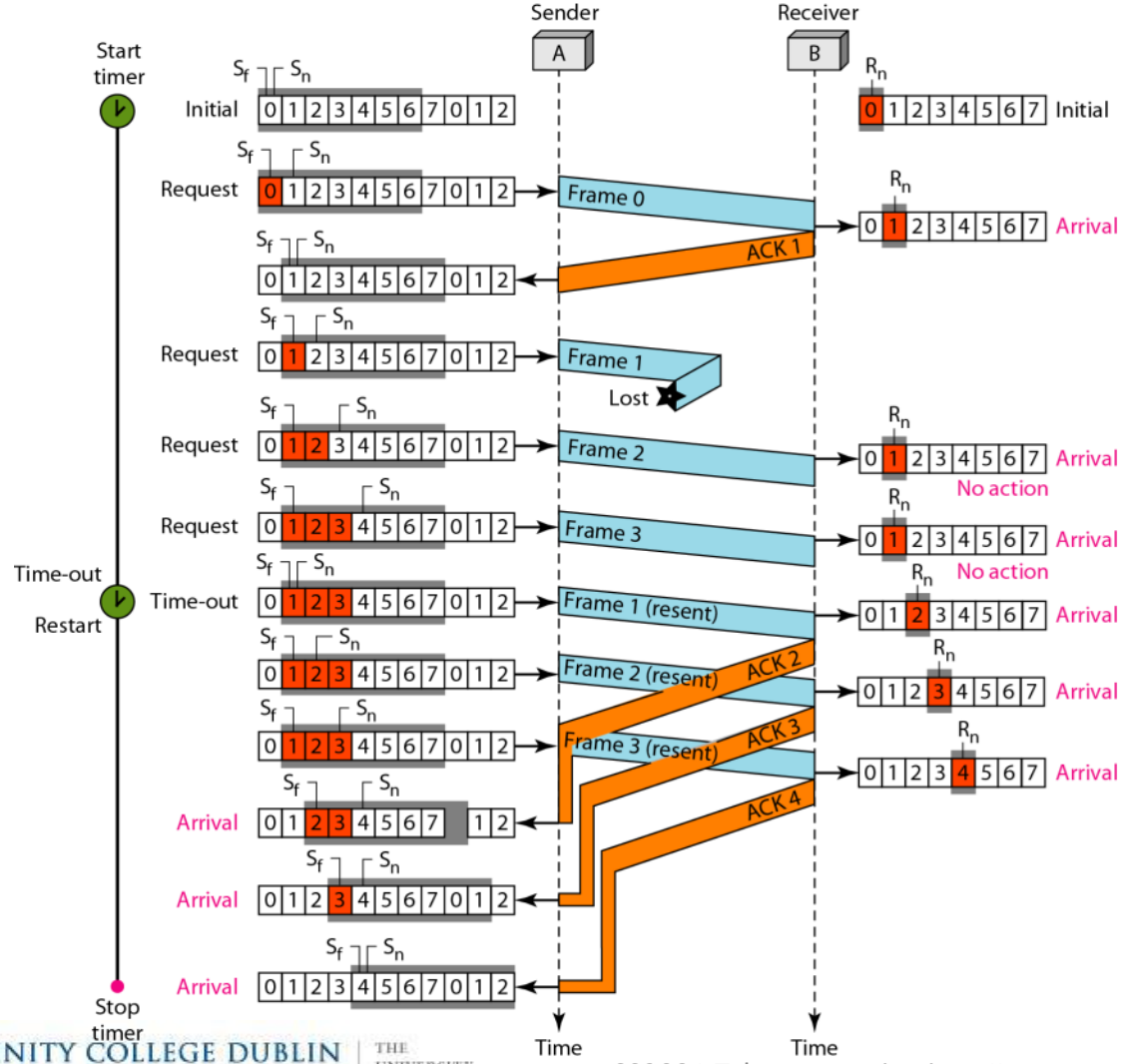
b. Window size = 2^m

m= # of bits for index

Size of the sender window must be less than 2^m

* Figure is courtesy of B. Forouzan

Go-Back-N ARQ: Bad Behaviour

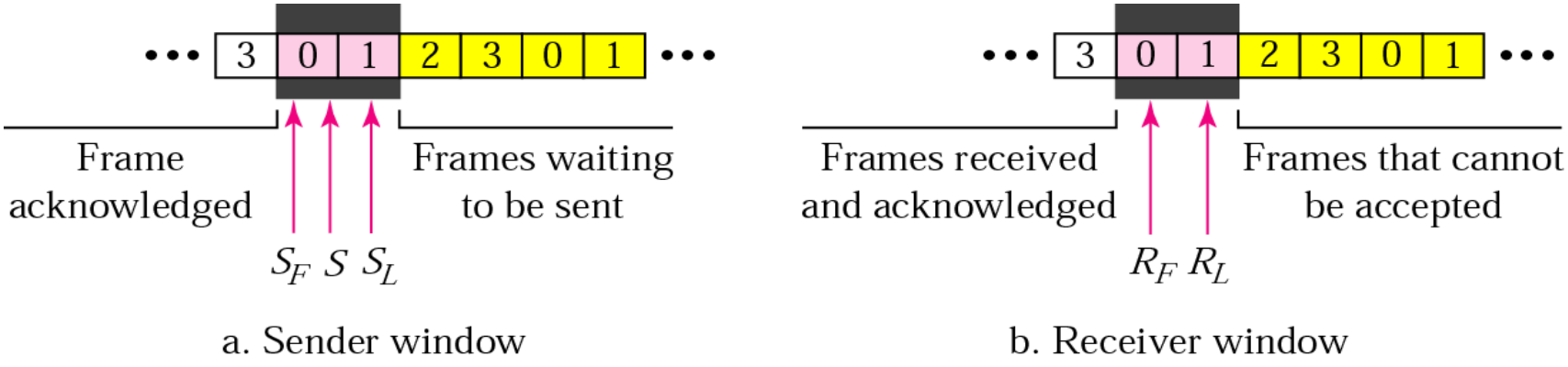


- Frame 1 lost
- Subsequent frames send
- All frames need to be resend

* Figure is courtesy of B. Forouzan

Selective Repeat

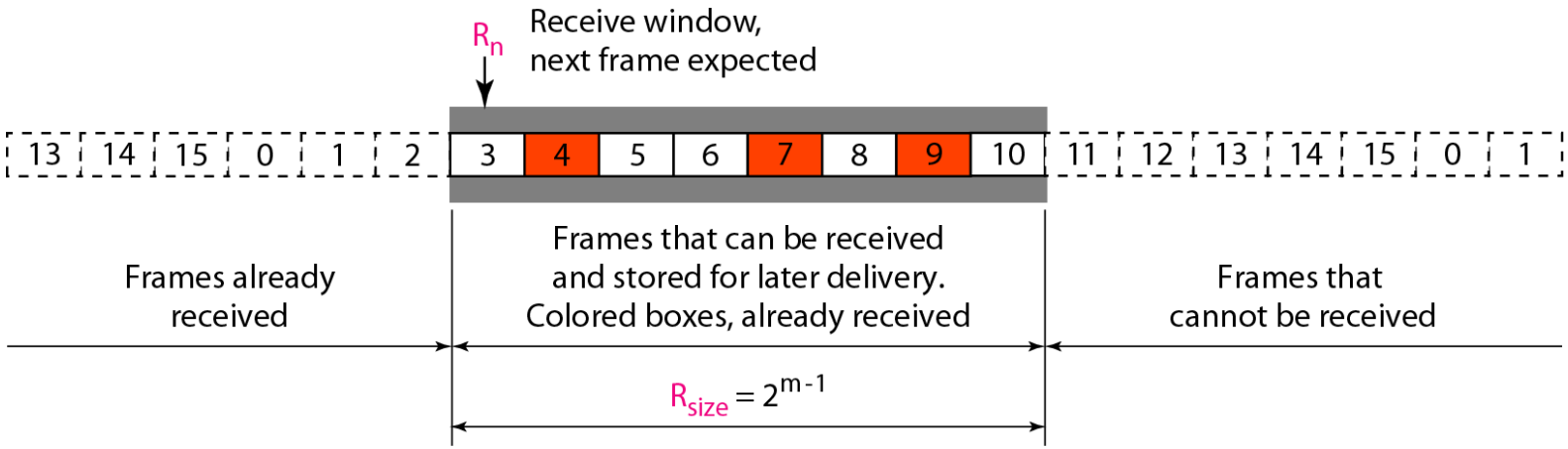
- Two Windows:
  - 1 Sender Window – 1 Receiver Window

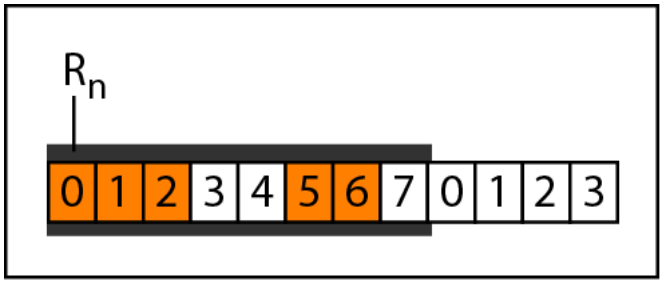


* Figure is courtesy of B. Forouzan

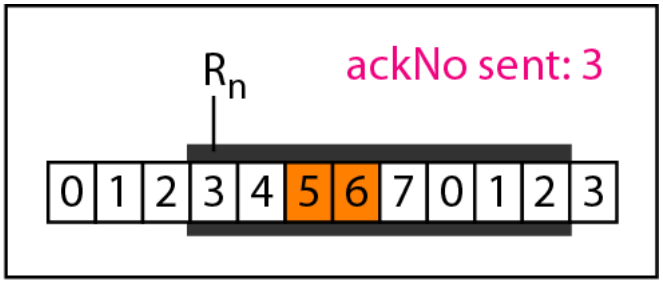
Selective Repeat ARQ

- Window records received frames:





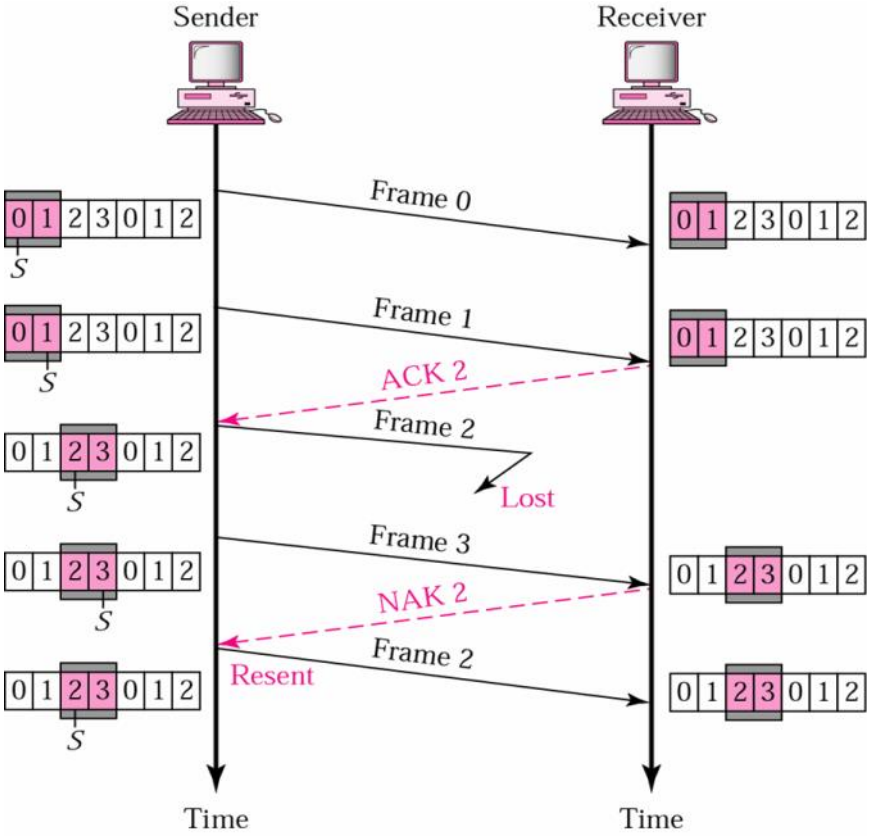
a. Before delivery



b. After delivery

* Figure is courtesy of B. Forouzan

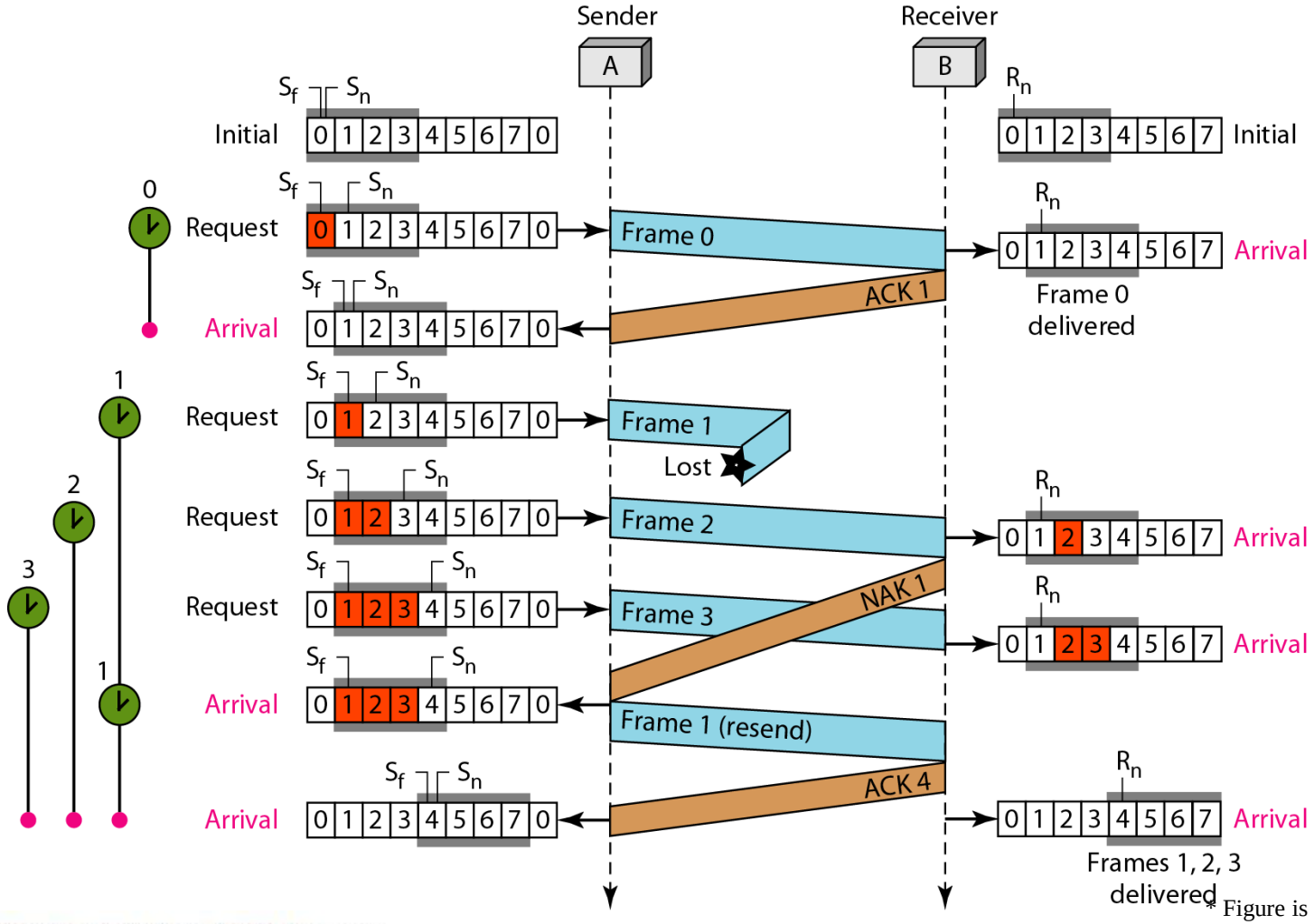
Selective Repeat ARQ: Lost Frame



- NAK = Negative Acknowledgement
- Sender still maintains timers for packets in case NAK gets lost

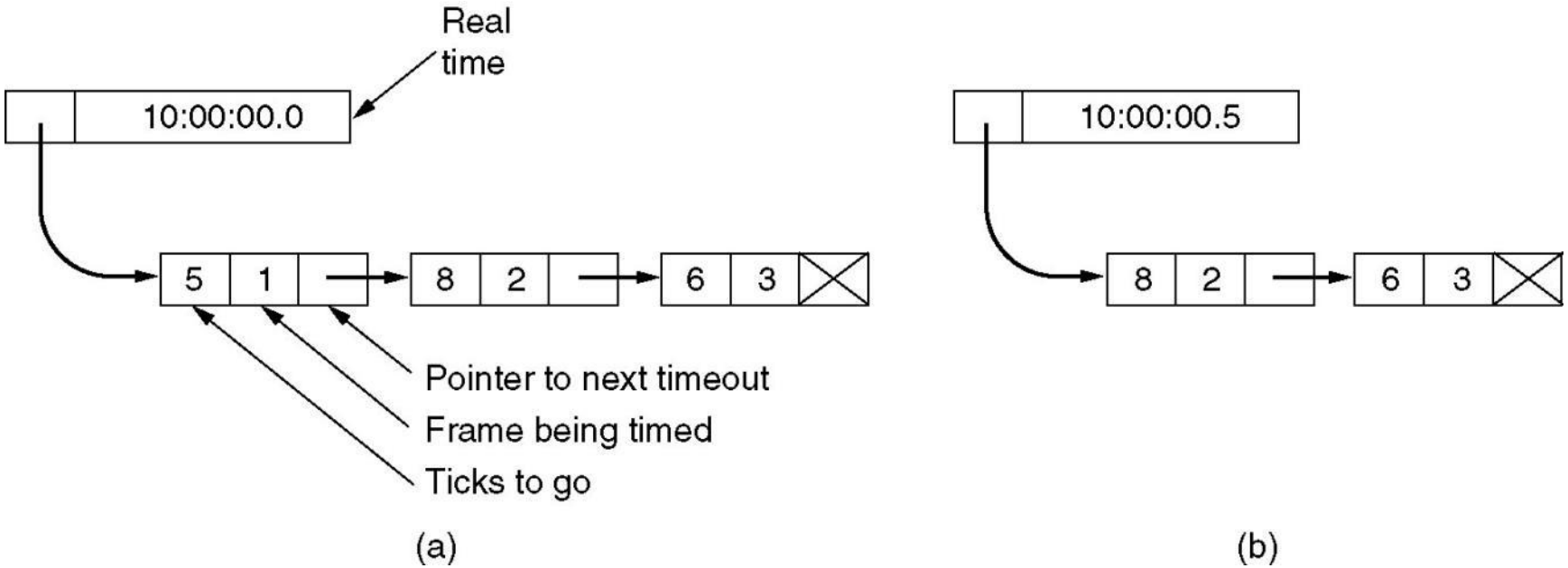
* Figure is courtesy of B. Forouzan

Selective Repeat ARQ



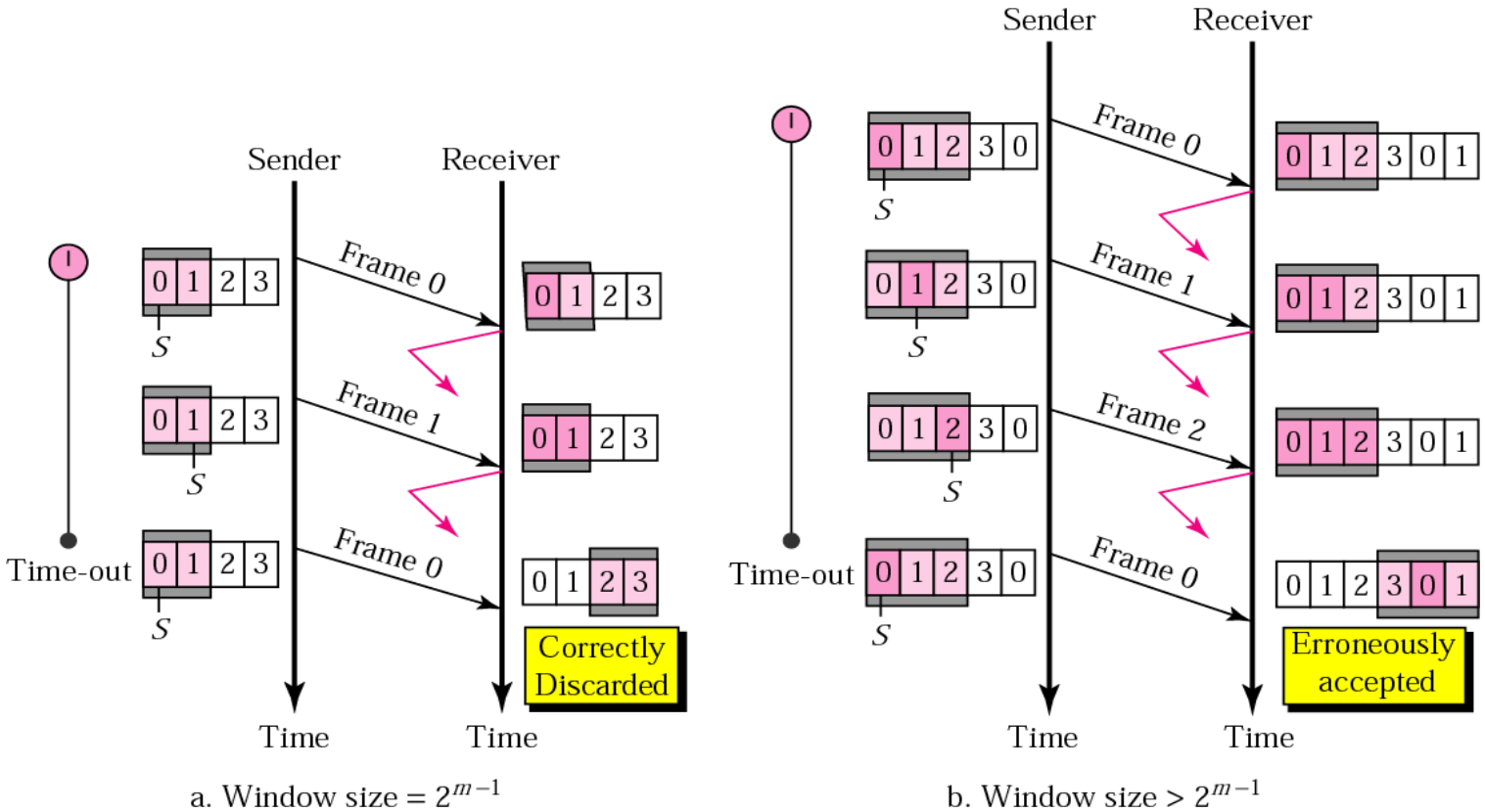
* Figure is courtesy of B. Forouzan

Simulation of Multiple Timers in Software



- Maintain linked list of timers
  - Number of frame
  - Offset from current time

Selective Repeat ARQ: Sender Window



Size of the sender and receiver window must be at most one-half of 2^m

* Figure is courtesy of B. Forouzan

Summary: Flow Control

- Flow Control:
  - Stop-and-Wait
  - Sliding Window
- Error Control
  - Stop-and-Wait ARQ
  - Go-back-N ARQ
  - Selective Repeat ARQ

Items from Today

- Bit-Stuffing/Byte-Stuffing
- Flow Control
- Stop-and-Wait
- Sliding Window


That's all folks
Telecomms II