# ETSF15: Lecture 3
# - L2 Error and Flow Control
## - Framing
- Performance

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# This is our quest!

Make an application communicate over a distance

Hi!

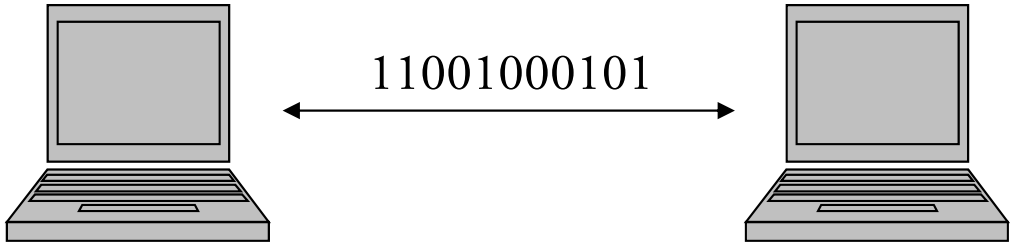
Hi!

Buy milk, please.

Will do!

Bye!

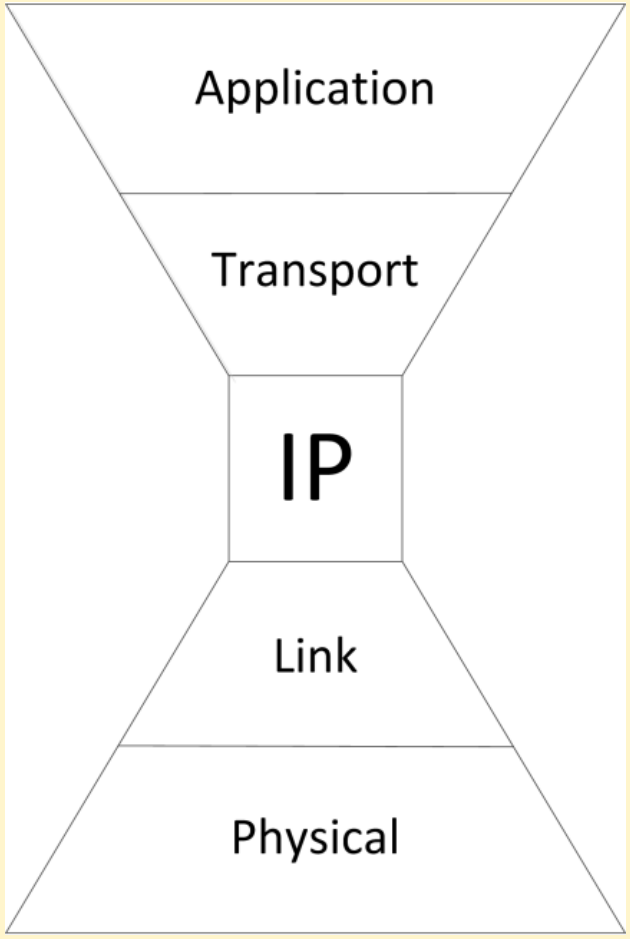
Bye!



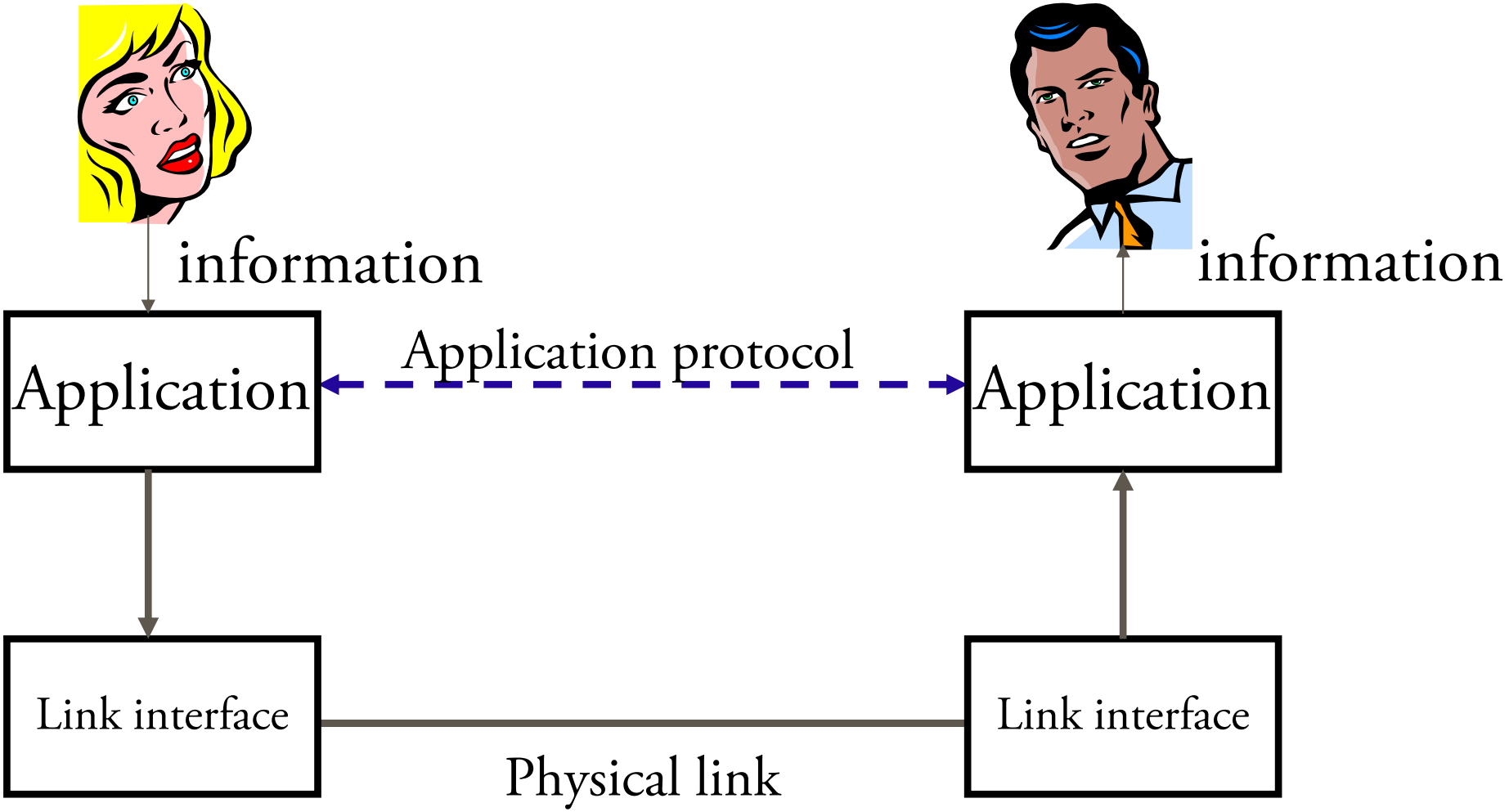
# Layered network models

- To complicated to solve everything in one application
  - ***Divide and conquer***
  - Hierarchical
  - Specialising
  - Simplifying

# Actual reference model: Hour glass model

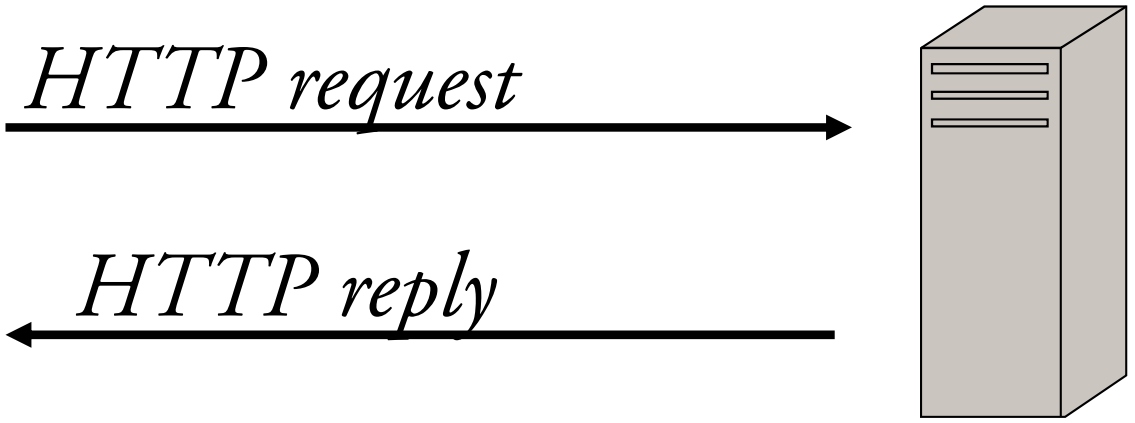


# Protocols

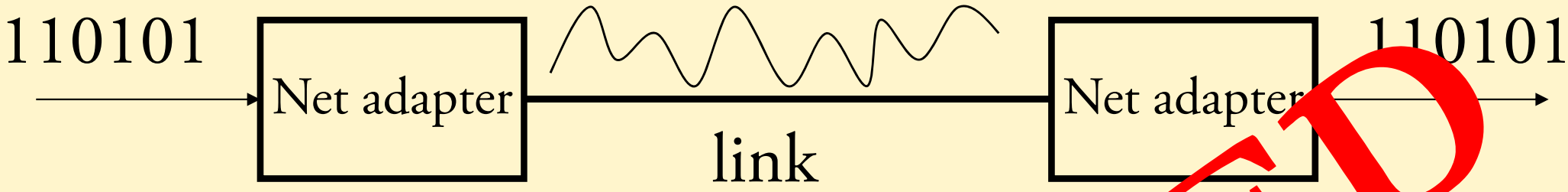

information
information
Application
Application protocol
Application
Link interface
Link interface
Physical link

# HTTP, an application protocol

- Hyper Text Transfer Protocol = HTTP



# Problem 1: Digital communication




- In the transmitter there is an adapter that converts bits into signals that are then sent on the link.
- An adapter in the receiver translates the signals into bits again.

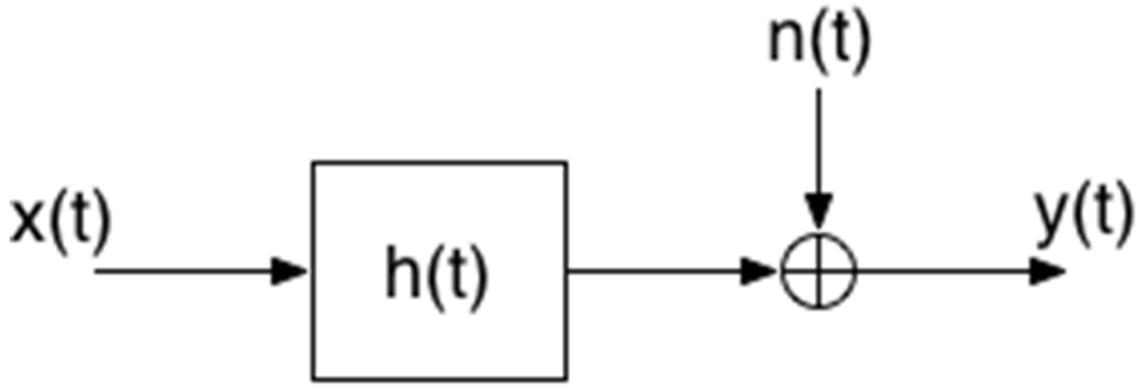
SOLVED

# Problem 4

- How to detect transmission errors (and correct)?
  - Stupid to transfer 1GB only to discover that a bit error occurred

# Error control

Find errors in transmitted data?




$y(t) = x(t)$ for all t?

$x(t)$ : ... 01100101001000011110 ...

Use more than one channel,

compare received $y_1$, $y_2$, $y_3$ …

# L2: Error control

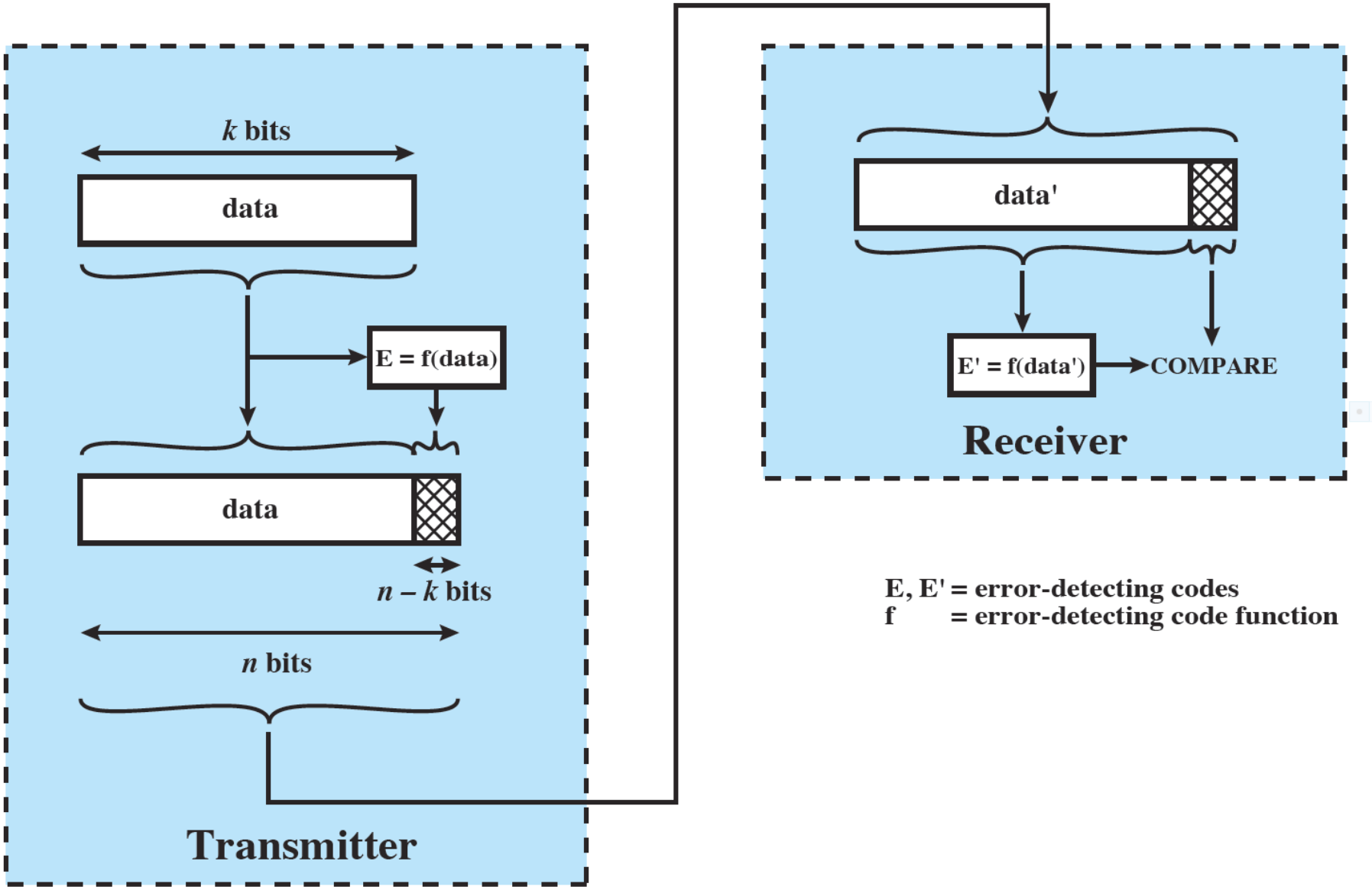
Solution: Frames/Packets!

$$x(t): \ 01100101001000011110$$

(t is a limited number)

- Finite number of bits per frame
- Add extra bits to each frame:
  - Parity bits
  - CRC: Cyclic Redundancy Check

# Error detection process



# Parity bit

- Sender adds one bit to vector
  - Even parity: even number of 1s in new vector
  - Odd parity: odd number of 1s in new vector

| 10011100 | + | 0 | = | 100111000 |
|---|---|---|---|---|

# Modula 2 Arithmetic

| $\oplus$ | 0 | 1 |
|---|---|---|
| 0 | 0 | 1 |
| 1 | 1 | 0 |

| $\otimes$ | 0 | 1 |
|---|---|---|
| 0 | 0 | 0 |
| 1 | 0 | 1 |

$$1 \oplus 1 = 0$$

$$1 - 1 = 0$$

# Polynom represents vector

$$\boldsymbol{a} = a_{L-1}a_{L-2} \ldots a_1 a_0$$

$$a(x) = \sum_{i}^{L-1} a_i x^i$$

$$= a_{L-1}x^{L-1} + a_{L-2}x^{L-2} + \cdots + a_0 x^0$$

$$Number\ of\ bits = deg(a) + 1$$

# Adding ‘parity’ bits

Data to be transmitted:

$$d(x) = d_{k-1}x^{k-1} + d_{k-2}x^{k-2} + \cdots + d_1x^1 + d_0$$

$$deg(d) = k - 1$$

Add $n - k$ bits giving a codeword of length $n$:

$$r(x) = r_{n-k-1}x^{n-k-1} + \cdots + r_1x^1 + r_0$$

$$deg(r) = n - k - 1$$

Codeword:

$$c(x) = d(x)x^{n-k} + r(x)$$

# Theorem

A polynomial $c(x)$ with $deg(c(x)) < n$ is a codeword if and only if $g(x)|c(x)$.

$g(x)|c(x)$ = c(x) is a multiple of g(x)

# Find r(x)

Use generator polynomial:

$$g(x) = x^{n-k} + g_{n-k-1}x^{n-k-1} + \cdots + g_1 x + 1$$

Note:

$$deg(g) = n - k = deg(r) + 1$$

$$g_{n-k} = 1$$

$$g_0 = 1$$

$$\boldsymbol{r(x) = R_{g(x)}\left(d(x)x^{n-k}\right)}$$

# At the receiver side

Received codeword:

$$y(x) = c(x) + e(x)$$

Calculate *syndrome* of received vector:

$$s(x) = R_{g(x)}(y(x)) = R_{g(x)}(c(x) + e(x))$$
$$= R_{g(x)}\left(R_{g(x)}(c(x)) + R_{g(x)}(e(x))\right)$$
$$= R_{g(x)}(e(x))$$

- $R_{g(x)}(c(x))=0$ (see Theorem)
- $s(x) = 0$ transmission OK!

# Find the parity bits (binary)

- All term constants are either 1 or 0
  - Represent g(x) binary
- All subtractions in the division process is actually bitwise XOR
- For g(x): The constant of term with highest exponent is always = 1
- This bit always lines up with a bit = 1 in the data vector

# Find parity bits (cont …)

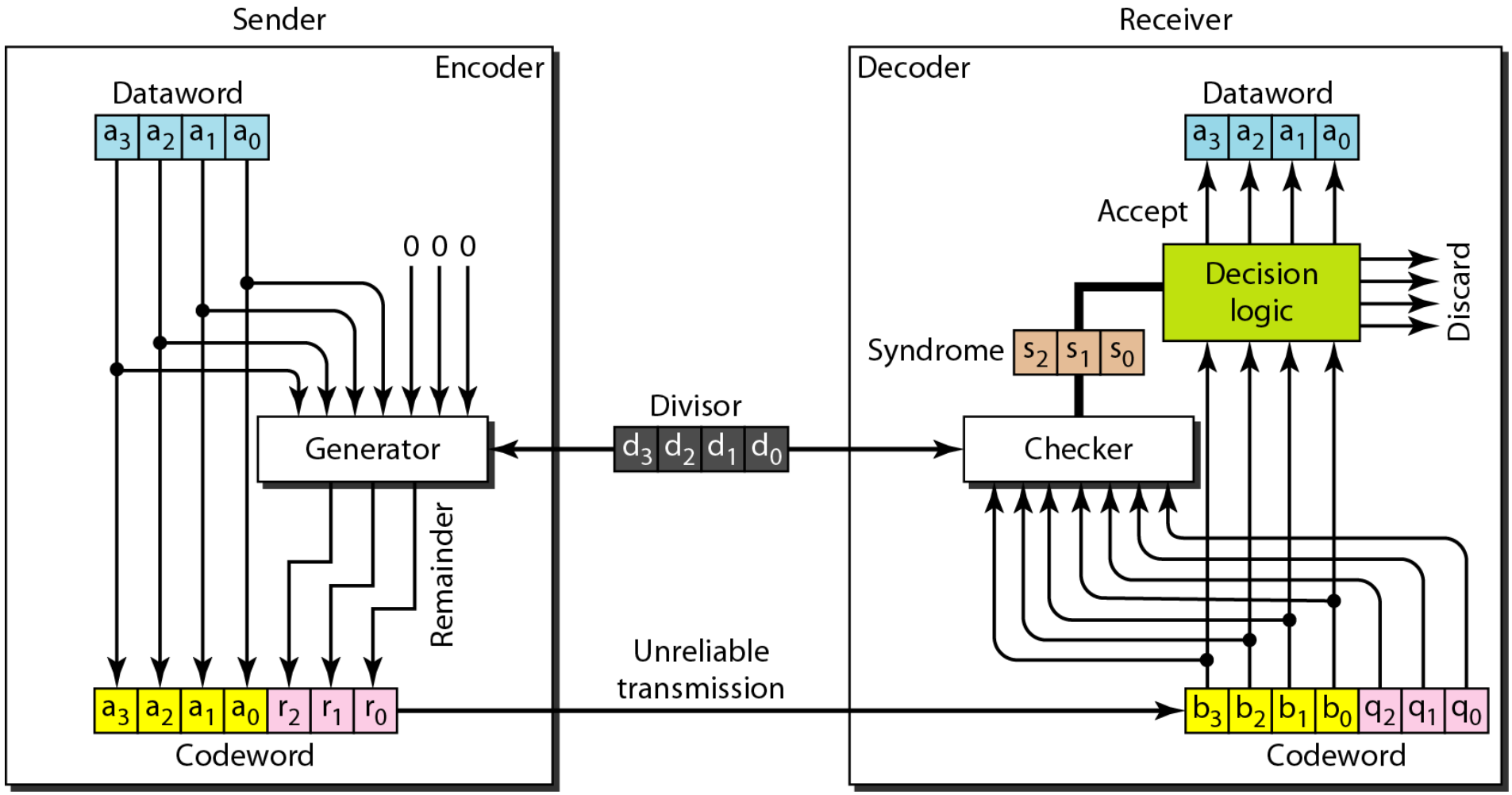
Example of generator: CRC8 Bluetooth

- $g(x) = x^8 + x^7 + x^5 + x^2 + x^1 + 1$
- $grad(g) = 8$
- Hex notation 0xA7
  - Note! Constant for $x^8$ omitted
  - The rest fits neatly into a byte!

# Find parity bits in code

- Concatenate data vector with zero vector of length = grad(g)
- While length(data vector) > 0
  - Shift data vector into bit buffer of length = grad(x)
  - If bit shifted out of buffer = 1 perform bitwise XOR with generator
- Bitbuffer = parity bits
- Use the fact that MSB of generator XOR with shifted out bit always = 0

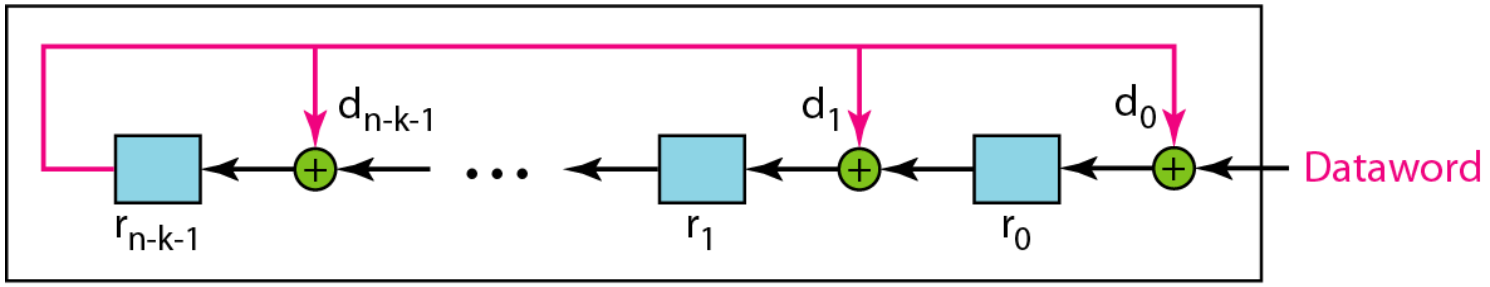
# CRC block diagram



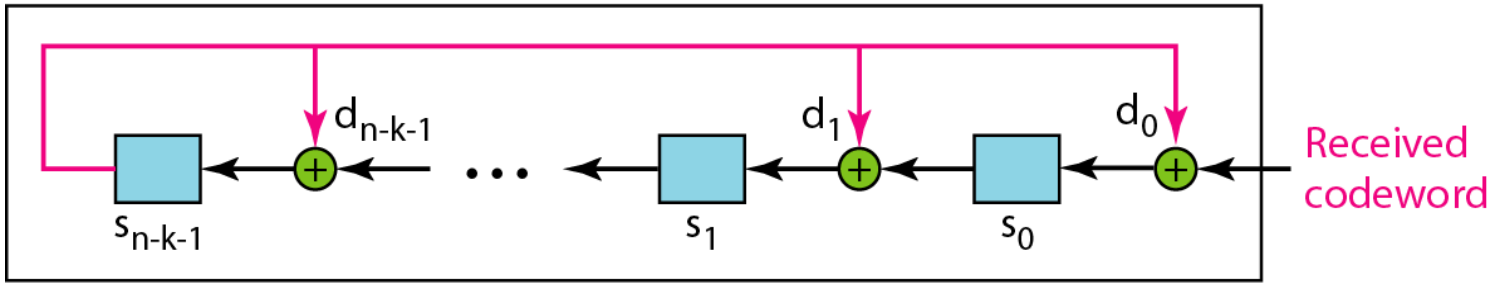
# CRC division in the digital domain

Note:

The divisor line and XOR are missing if the corresponding bit in the divisor is 0.




a. Encoder




b. Decoder

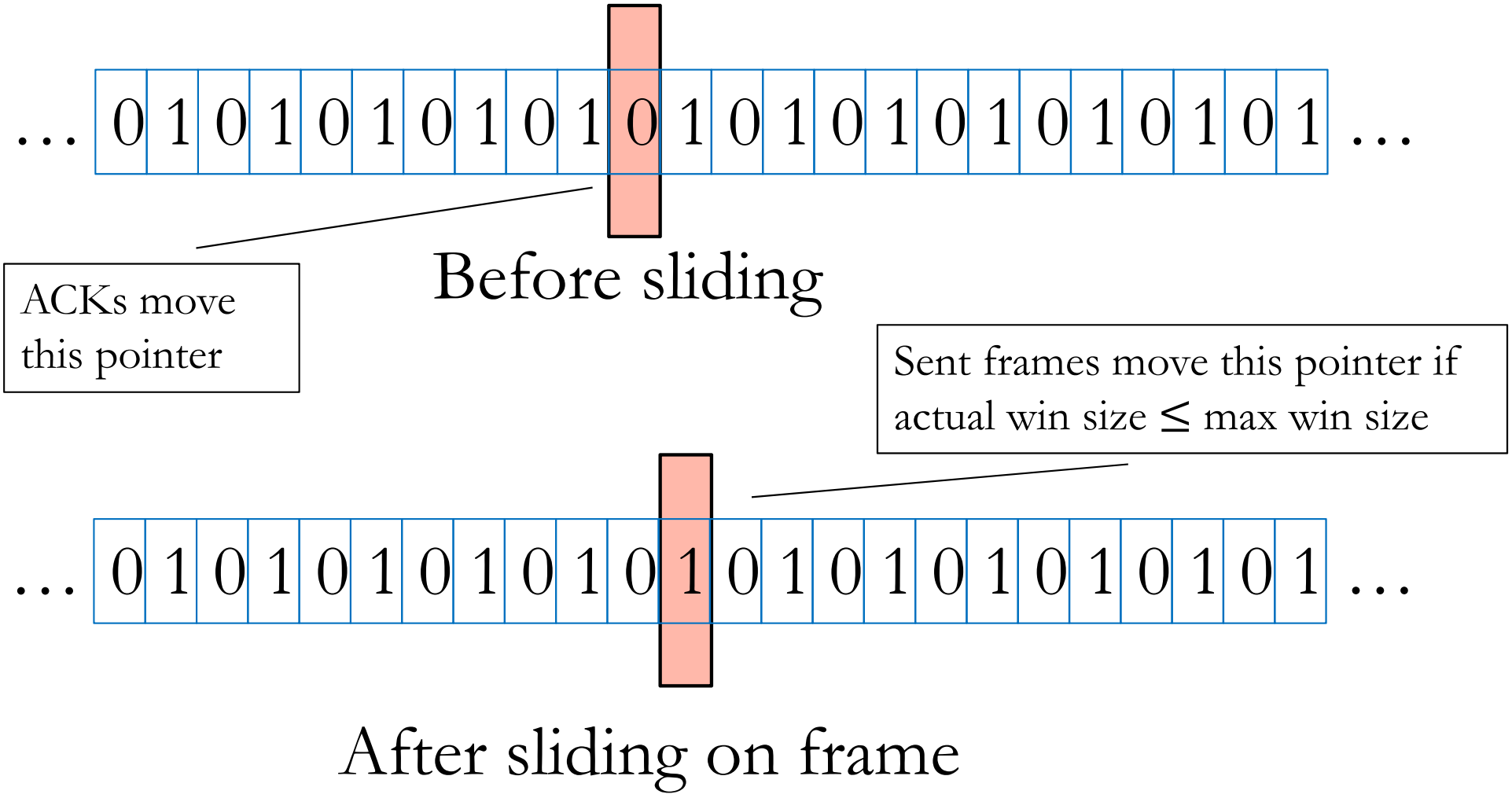
# L2: Error correction

- Forward Error Correction:
  - Add extra bits so a limited number of errors can be fixed
  - Costly
  - What to do with errors that can be detected but not fixed?
- Retransmit
  - Automatic Repeat reQuest ARQ

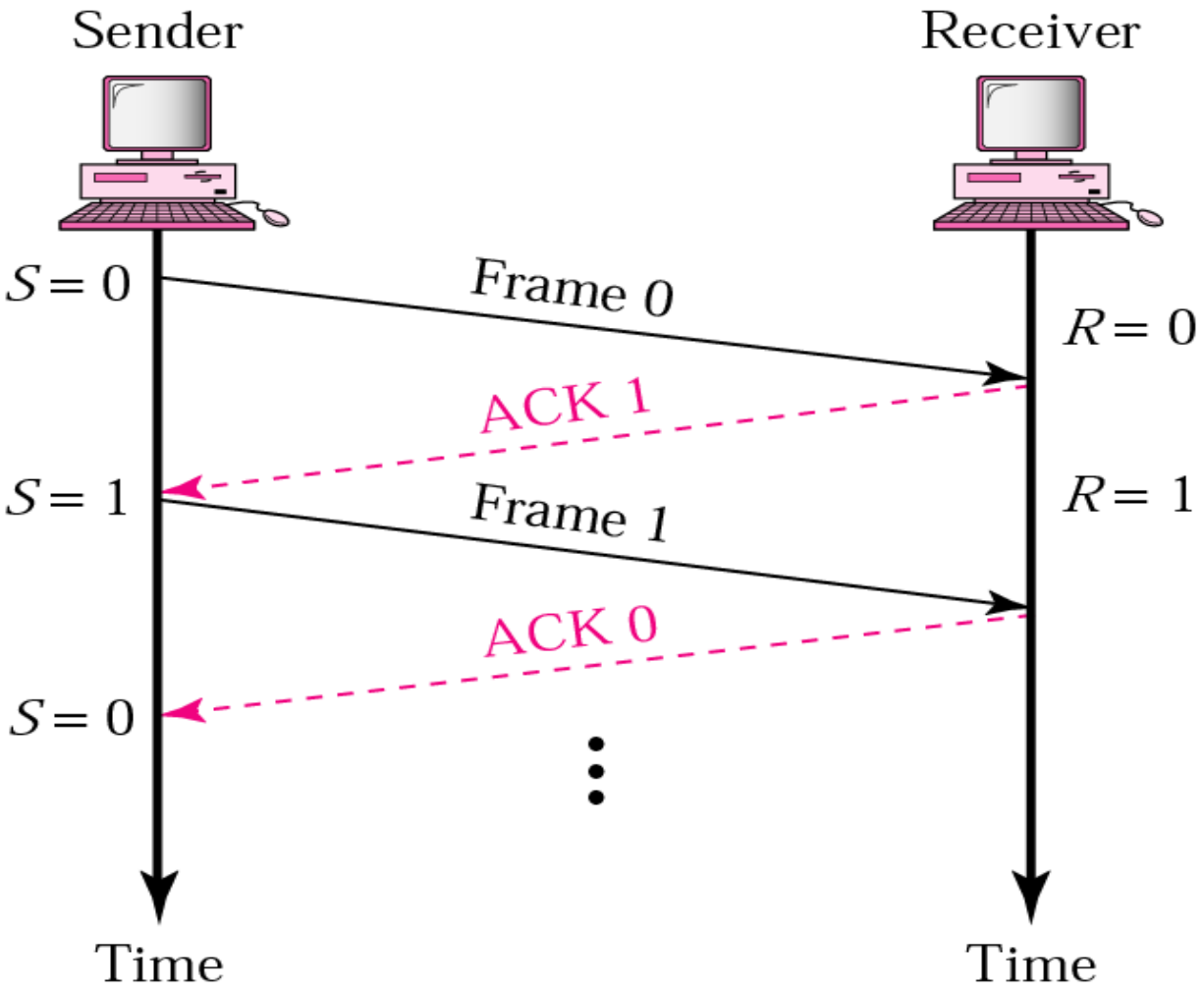
# Automatic Repeate reQuest (ARQ)

- All sent frame has to be acknowledged (ACK) before sending next frame(s)
- Three versions:
  - Stop-And-Wait
  - Go-Back-N
  - Selective-Repeate
- Use Sliding Window
  - Sender keeps track of sent and ACKed frames
  - Receiver keeps track of received frames

# Sender Sliding Window



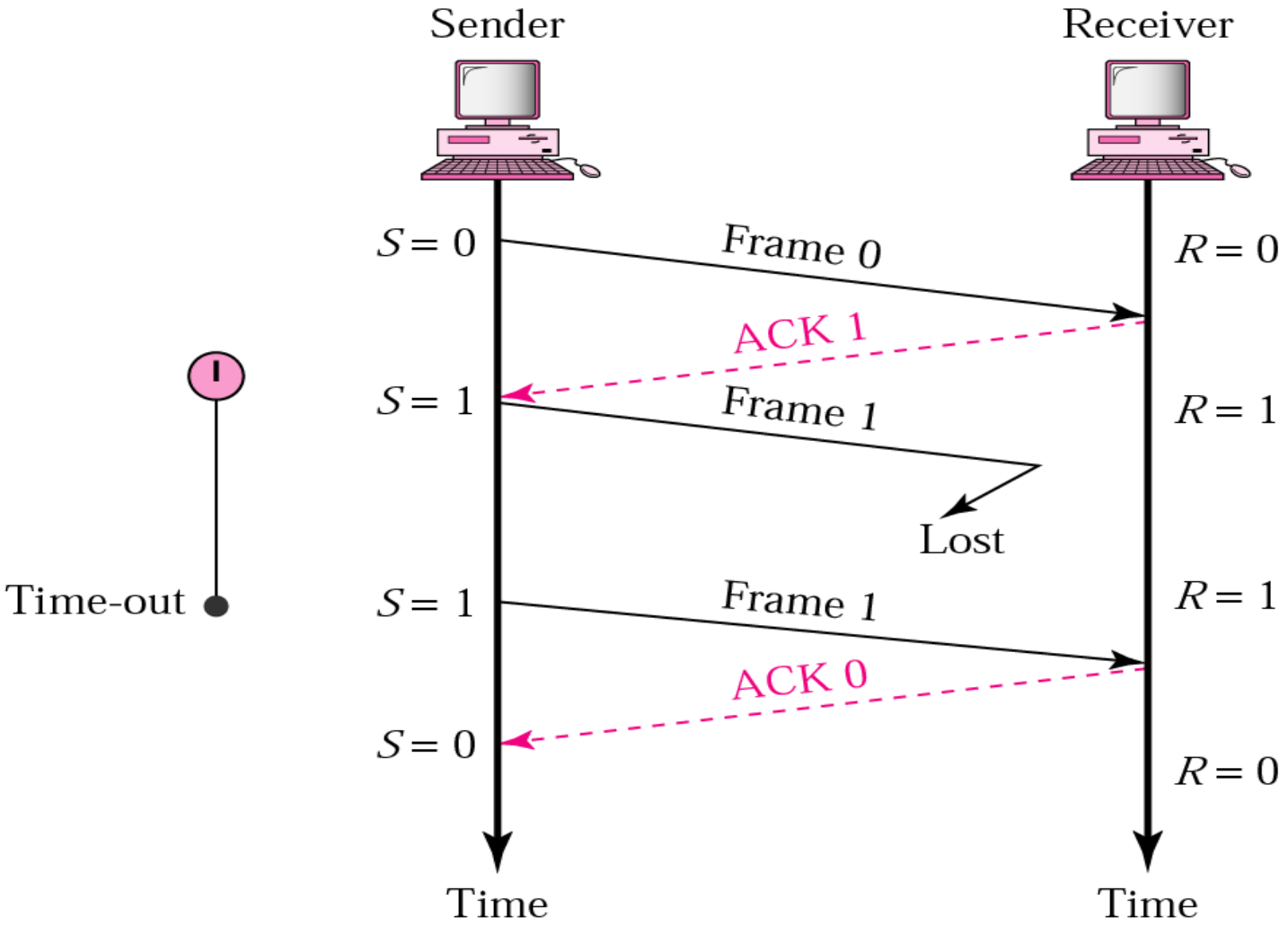
# Stop-and-Wait Normal operation



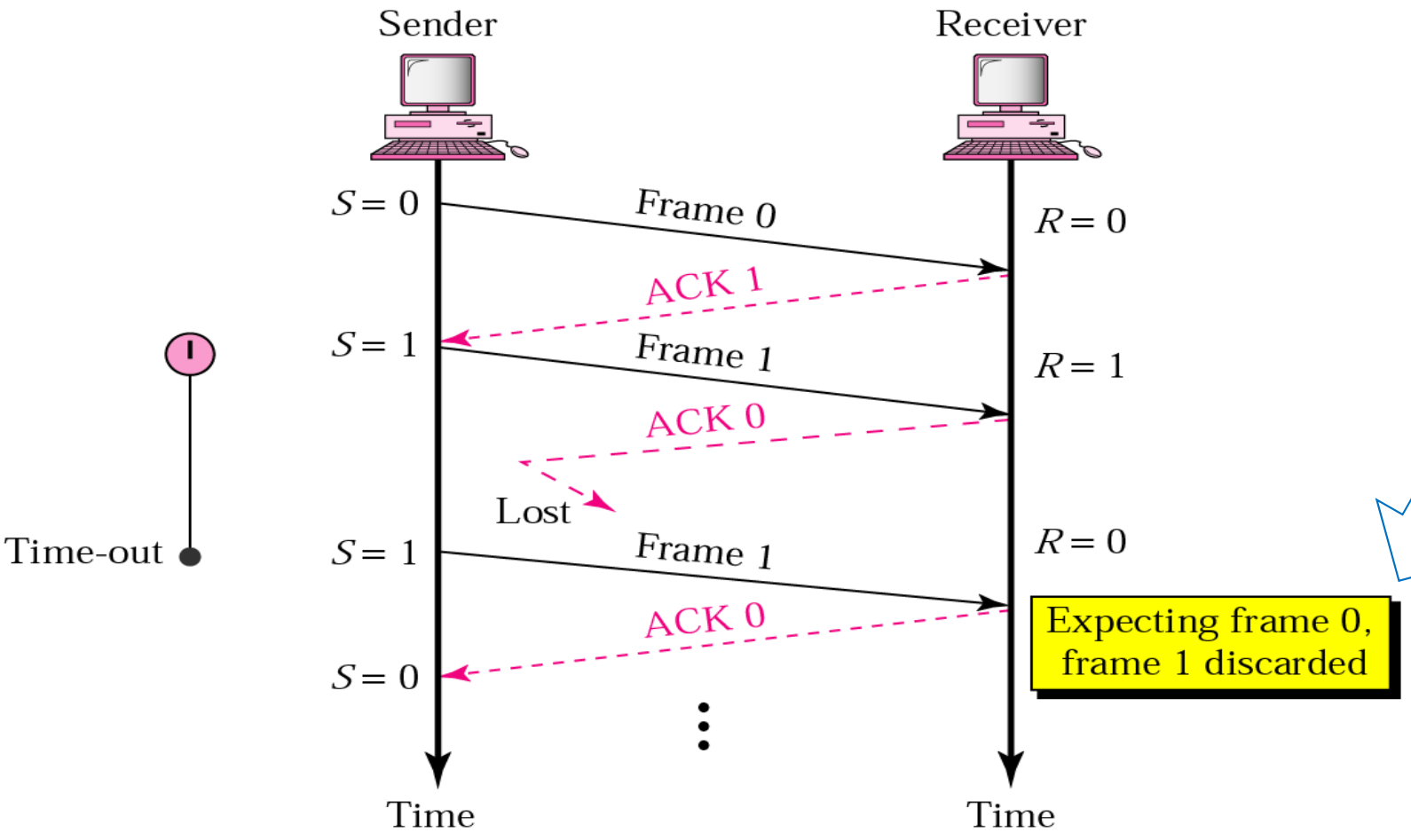

Note!

- Sequence numbers
- Sliding Window size = 1 frame

# Stop-and-Wait ARQ, frame lost



# Stop-and-Wait ARQ, lost ACK frame

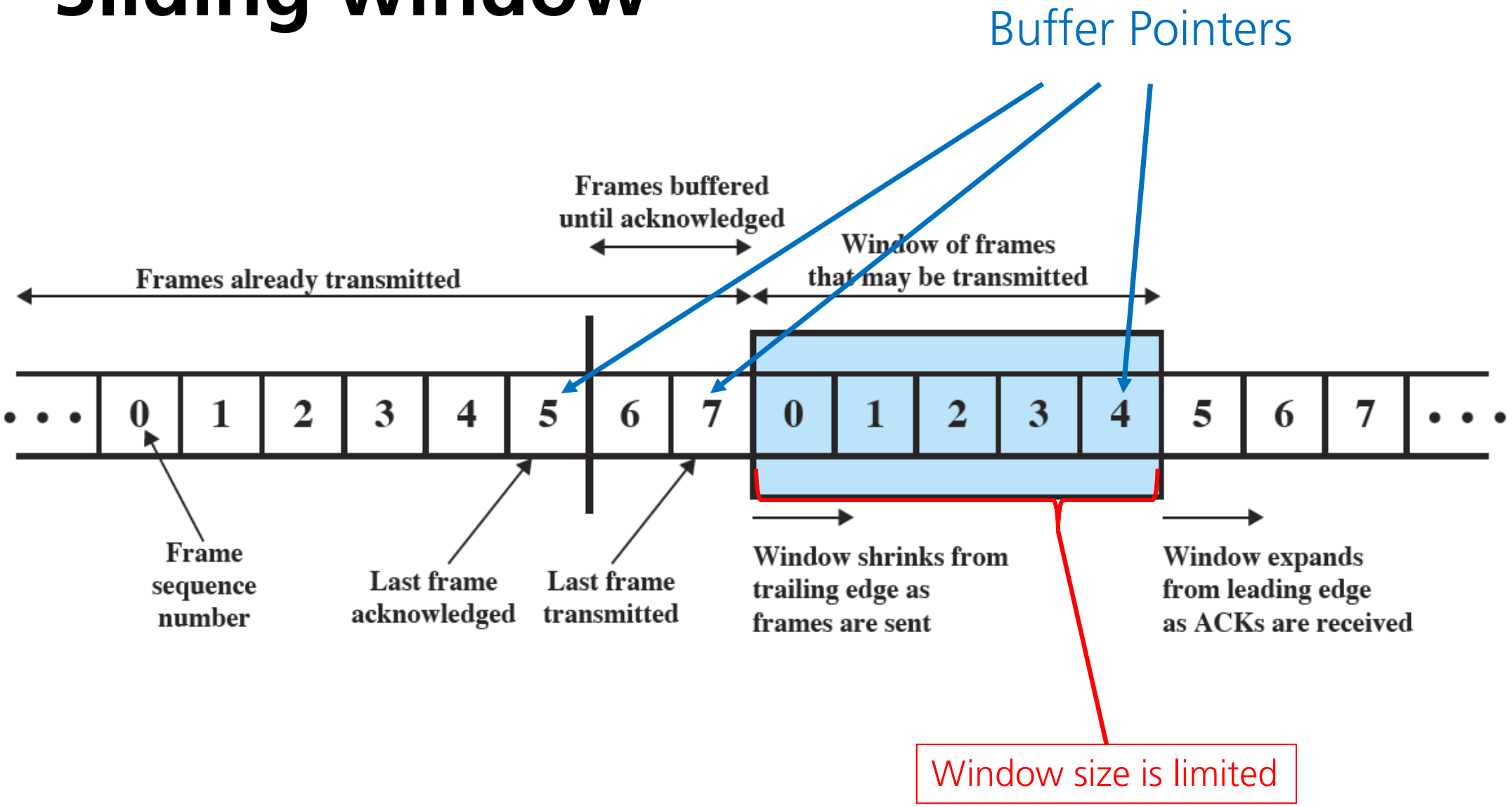



Explaining the need for SEQ num

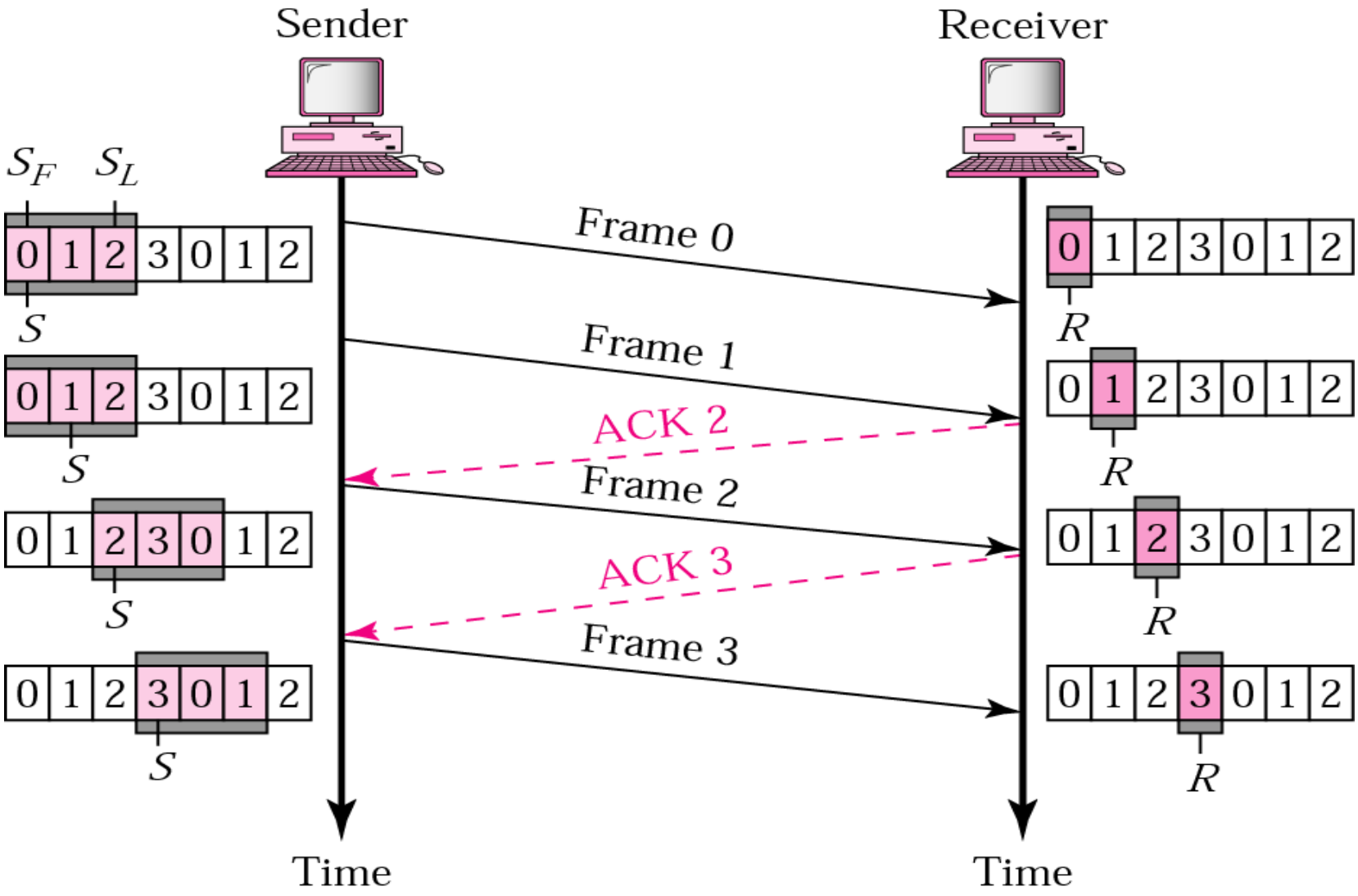
# Go-Back-N

- Increase sliding window size
  - Sender can send as long as the sliding window includes frames not sent
  - Retransmitt requested frames and all following frames

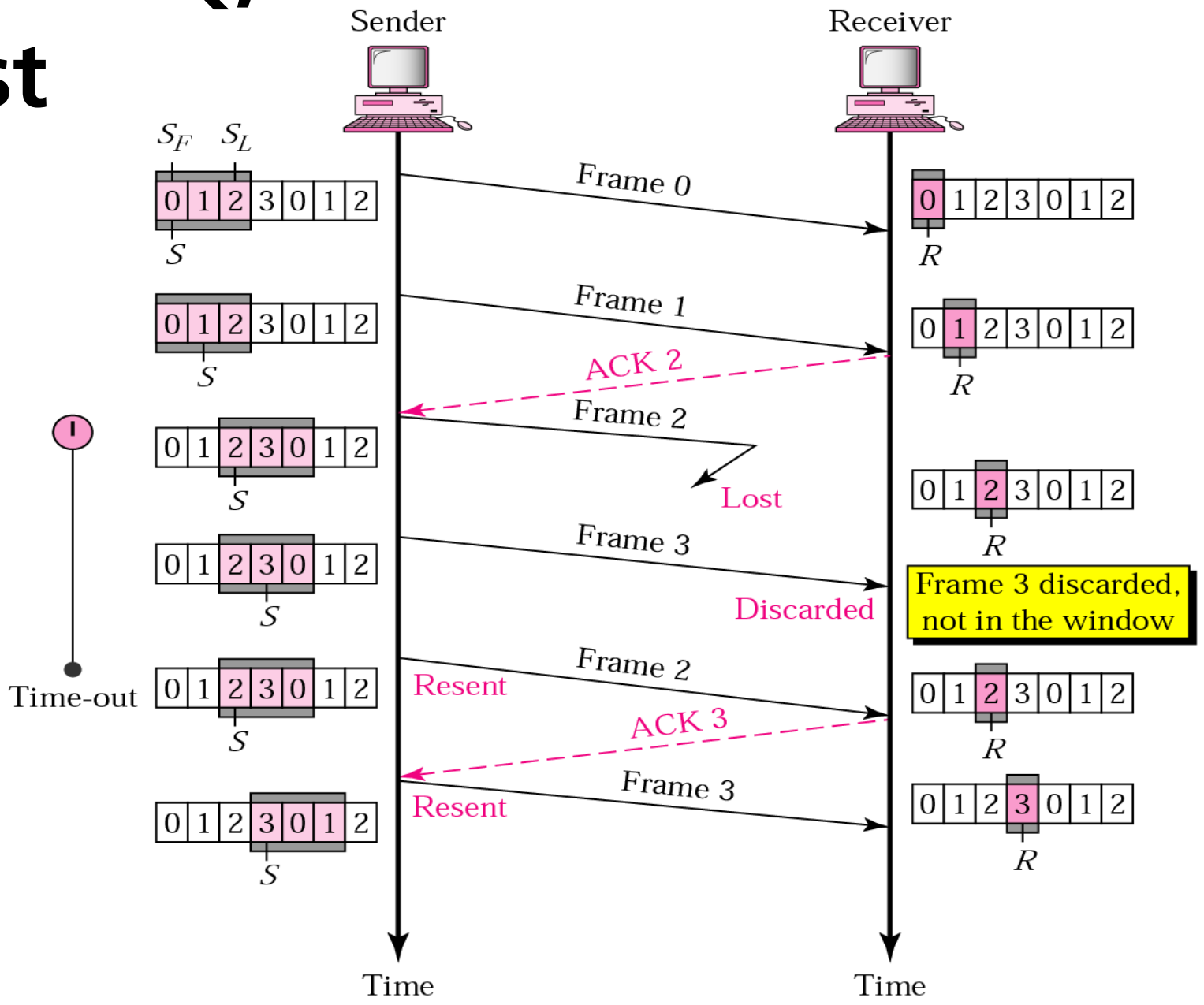
# Sliding window



# Go-Back-N ARQ, normal operation



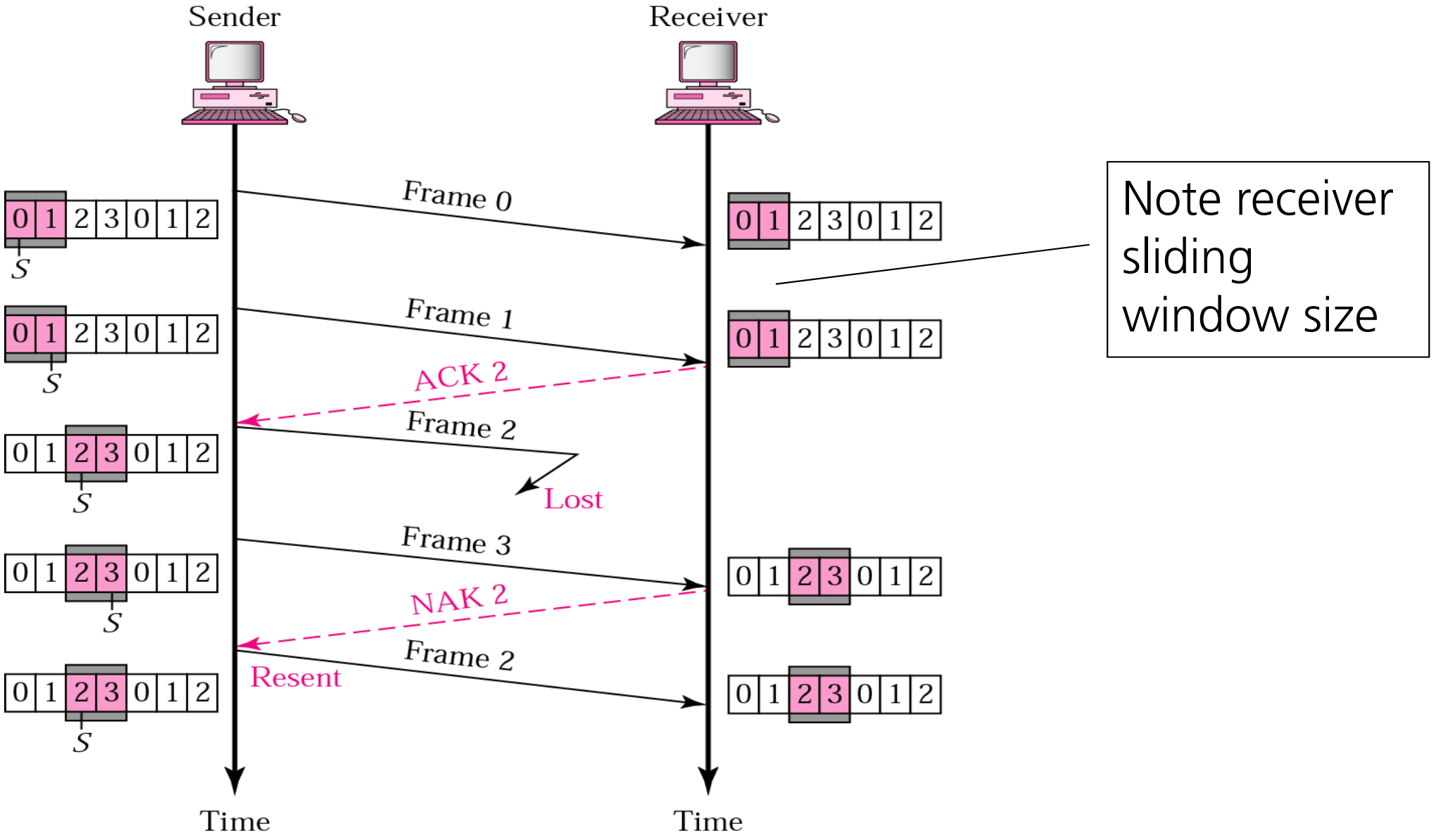
# Go-Back-N ARQ, frames lost



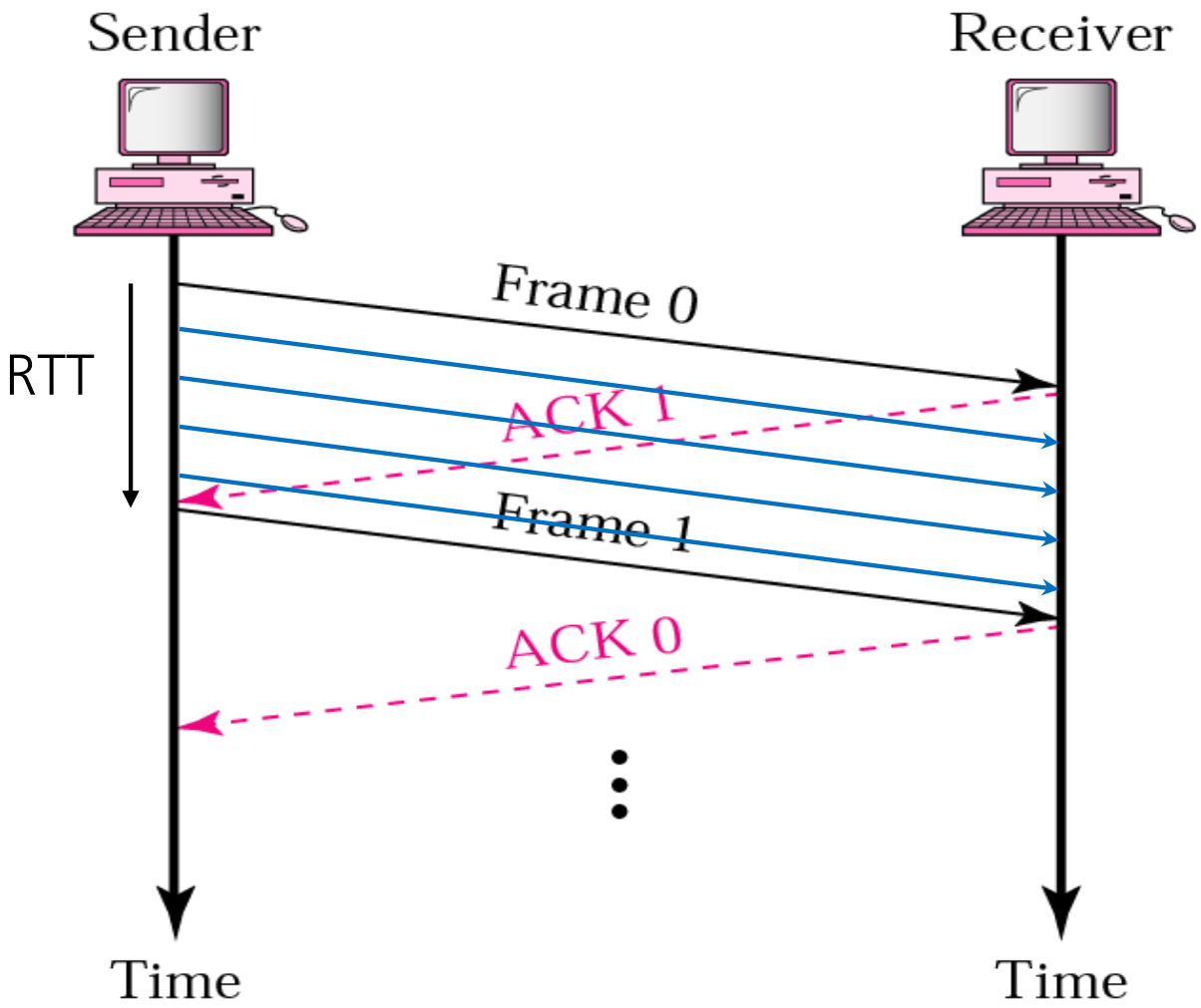
# Selective-Repeate

- Same as Go-Back-N but
- Retransmitt only requested frames
- More efficienent regarding network utilisation
- Higher demands on receiver and sender
  - Receiver must have bigger buffer

# Selective Repeat ARQ, lost frame



# L2: Flow control




RTT = Round Trip Time

Idea:

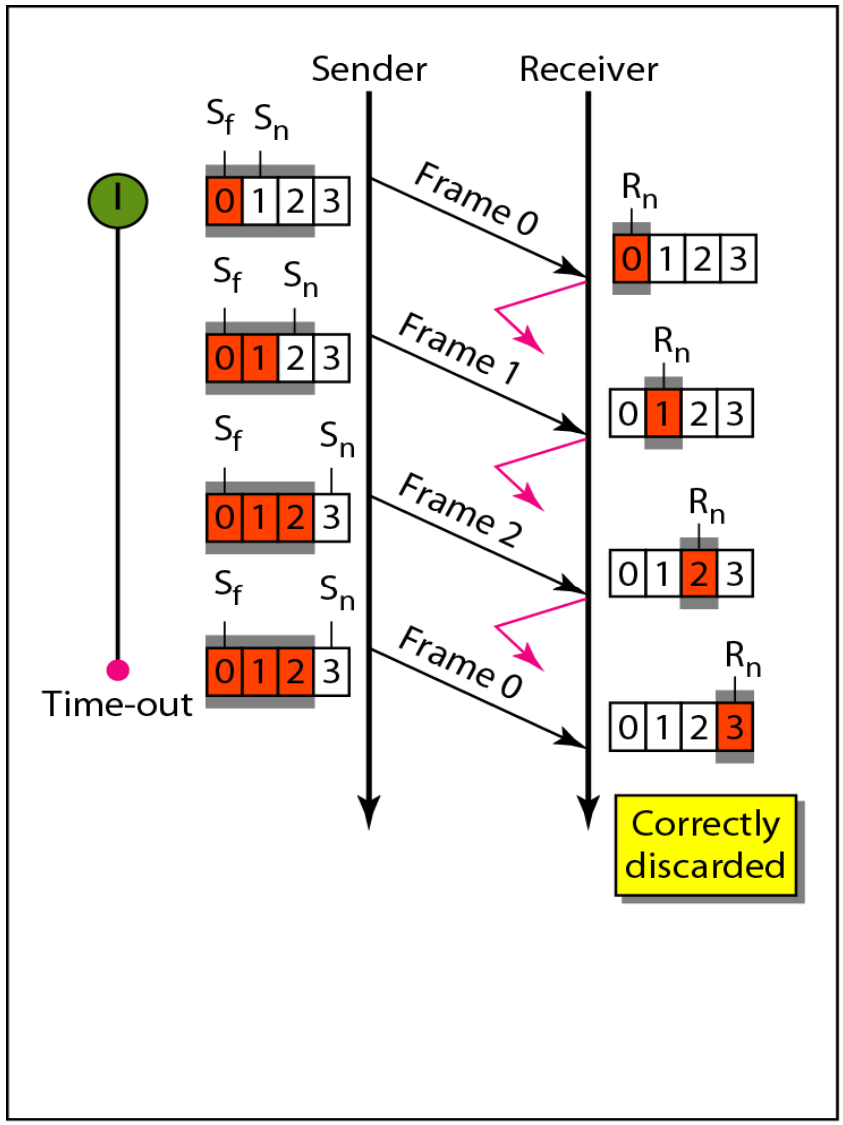
- Assume error free transmission
- Allow frames to be sent until ACK for first frame is expected = RTT
  - Check RTT during transmission
- Thus, sliding window size = f(RTT)

# Some notes

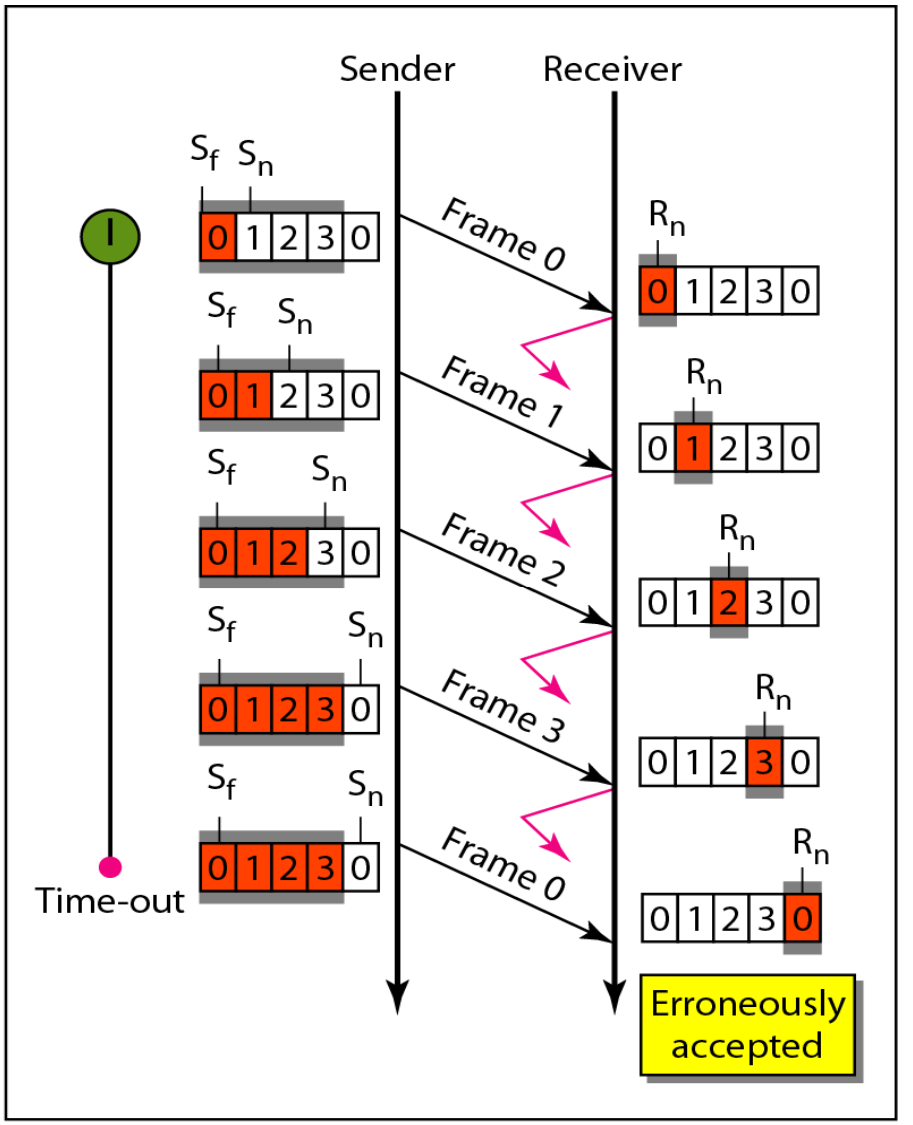
- Piggy backing
  - Data and ACKs can share frame

- The number of bits for the sequenze number is a function of the max window size
  - Seq numbers wrap!

# Window size for Go-Back-N ARQ

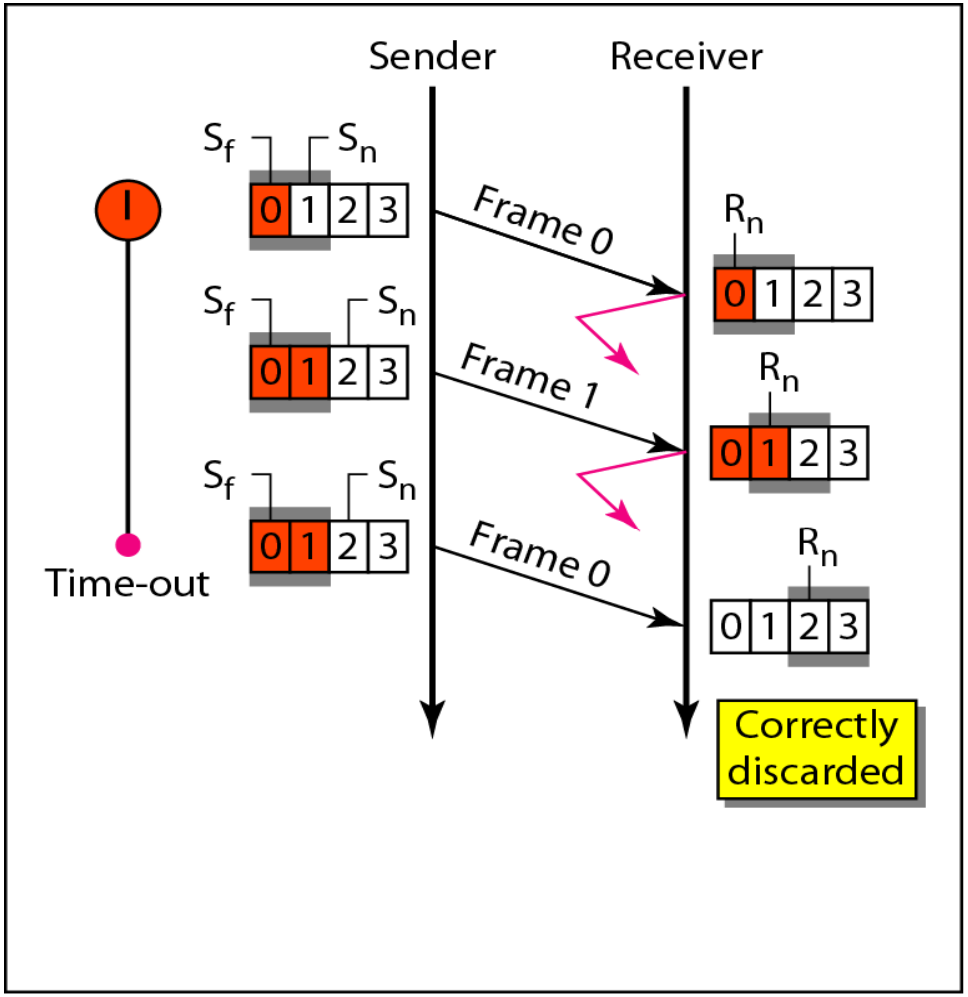



a. Window size $< 2^m$

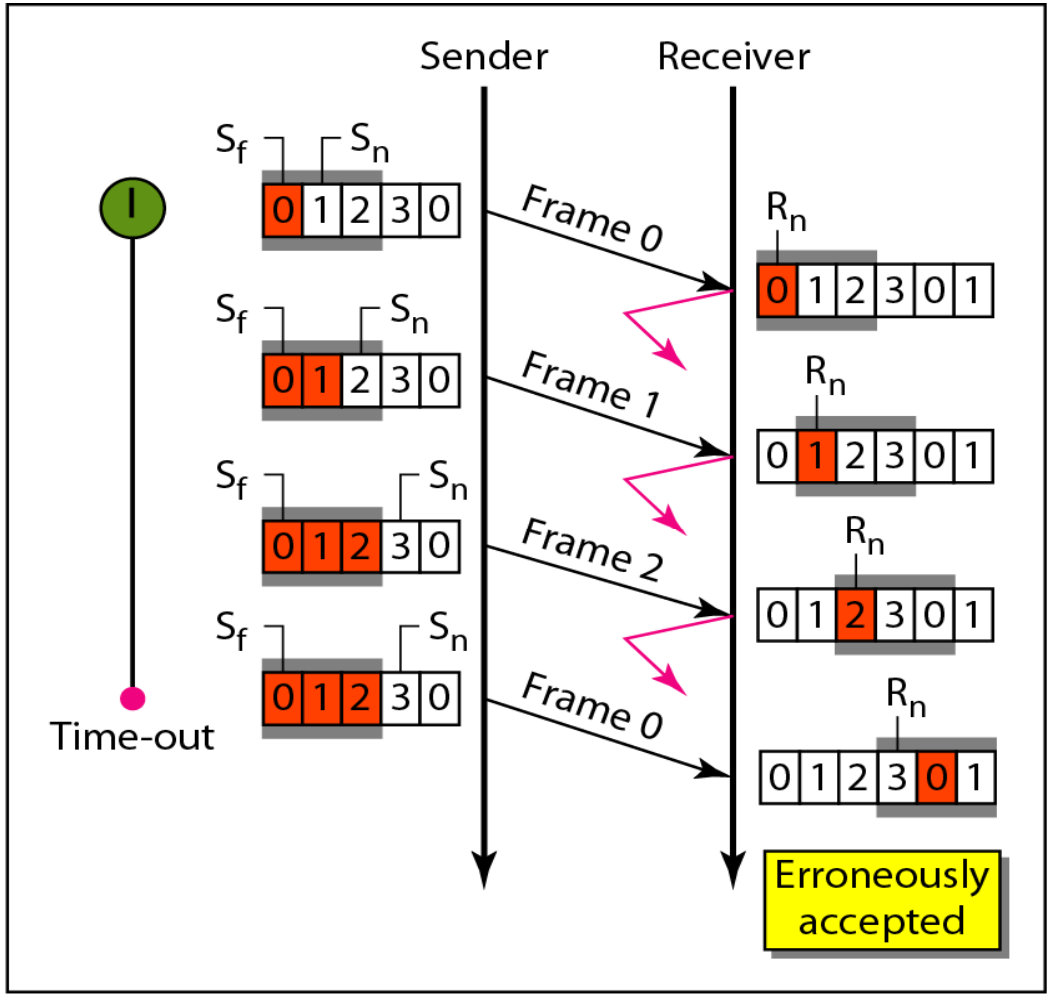



b. Window size $= 2^m$

# Selective Repeat ARQ, window size




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




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

# Framing

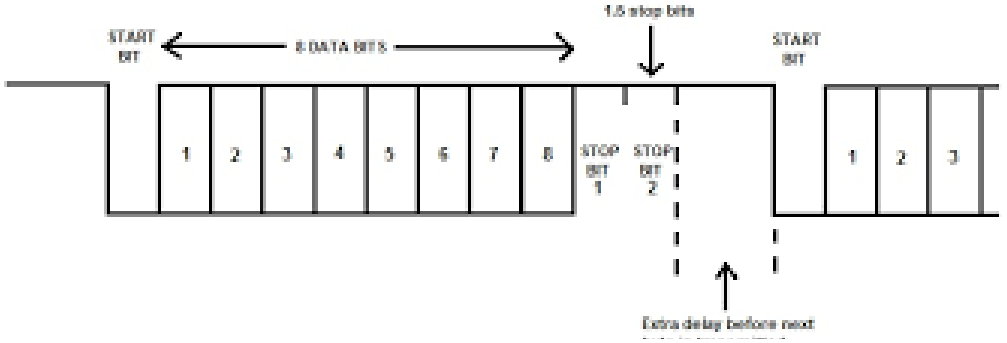

- Header:
  - Sequence and ACK numbers
  - More to come …
- Tail
  - CRC

# Synchronisation

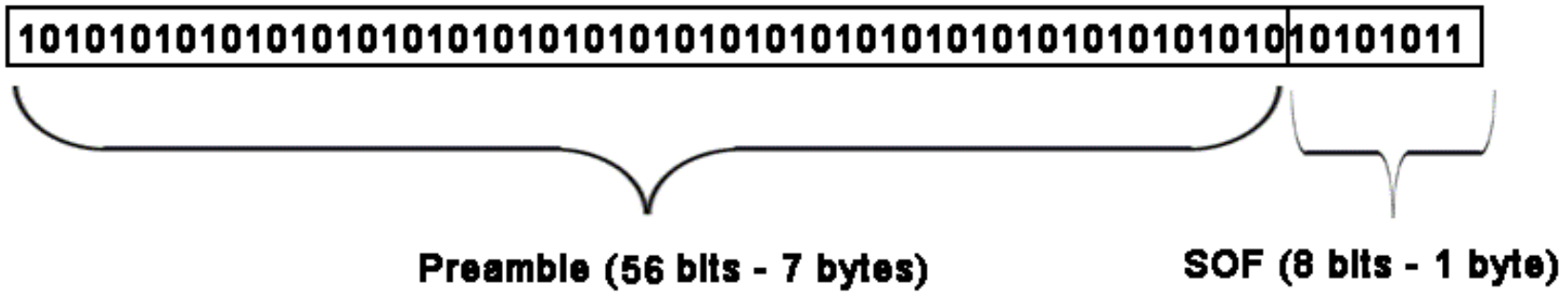
| Preamble and start flag | Frame | End flag |
|---|---|---|

Receiver has to synch to signal of a frame

RS.232/V.24




Ethernet



# Finding the start flag

- Corrolate incoming bit pattern with know flag
- If deploying end flag we have a problem
  - What if the end flag bit patterns = data bit pattern?

# Bit stuffing

- Given: Flag = 01111110
- Task: Avoid 6 consecutive bits = 1 in payload
- Solution:
  - Sender: In payload add a 0 after 5 consecutive bits = 1
  - Receiver: Remove bit following 5 consecutive bits = 1

01111110111111001110001111111

01111101011111**0**0011100011111**0**1

# One link layer protocol: HDLC

- HDLC = High-level Data Link Control

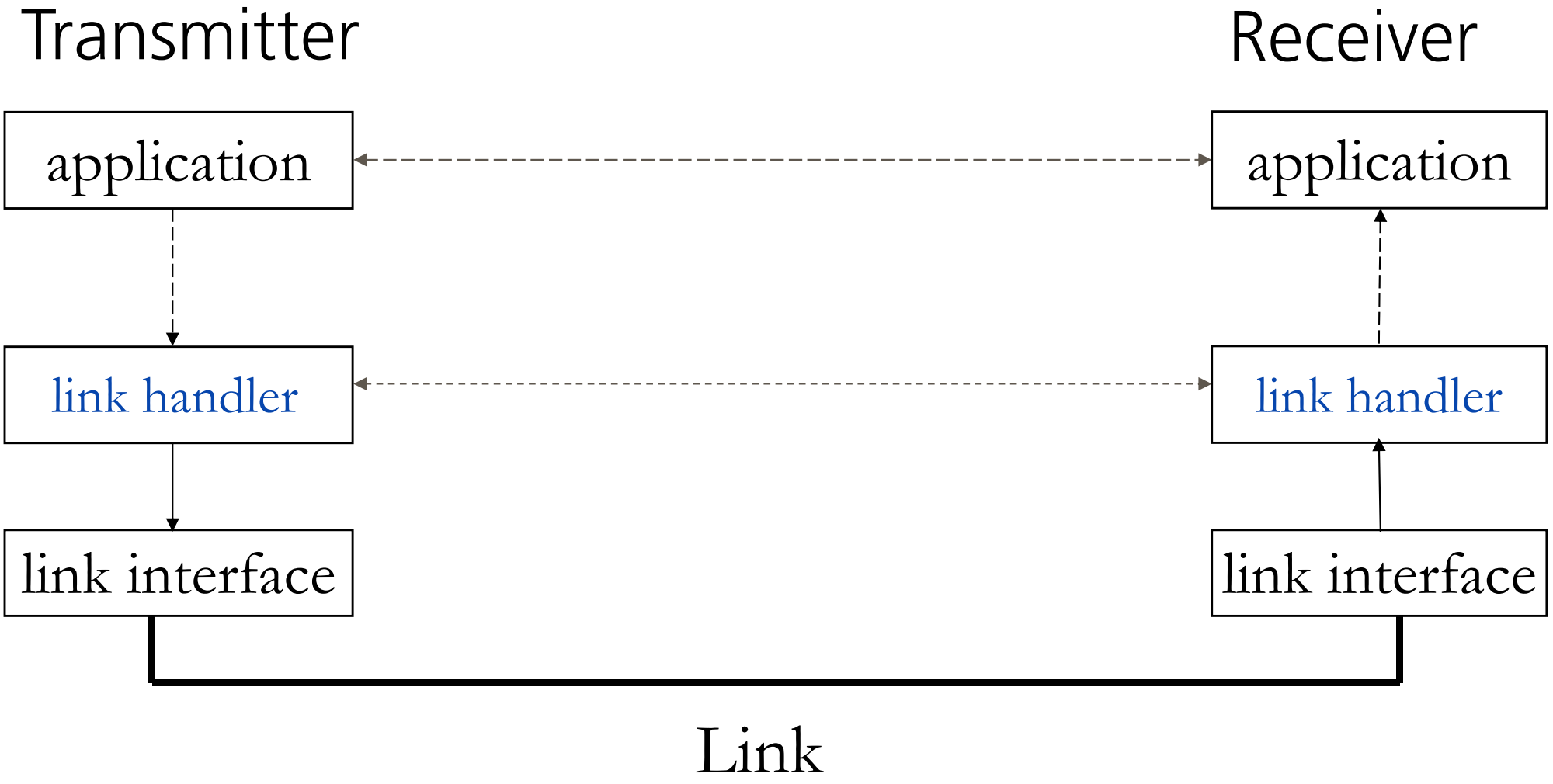

Flag = 01111110

16 or 32 bits CRC

Go-back-N or Selective-repeat ARQ

# Protocol structure so far (1)

Link handler: Framing, error detection(?), error control(?)



# Link/Channel User Modes

- Simplex
  - Signals possible only in one direction
    - Broadcast Radio/TV
- Half Duplex
  - Signals possible in both directions but only one at a time
    - Ch 16 VHF, Comm radio
- Full Duplex
  - Signals possible in both directions simultaniously
    - VHF traffic channels, Full duplex Ethernet
      - Two half duplex channels
    - POTS analog links

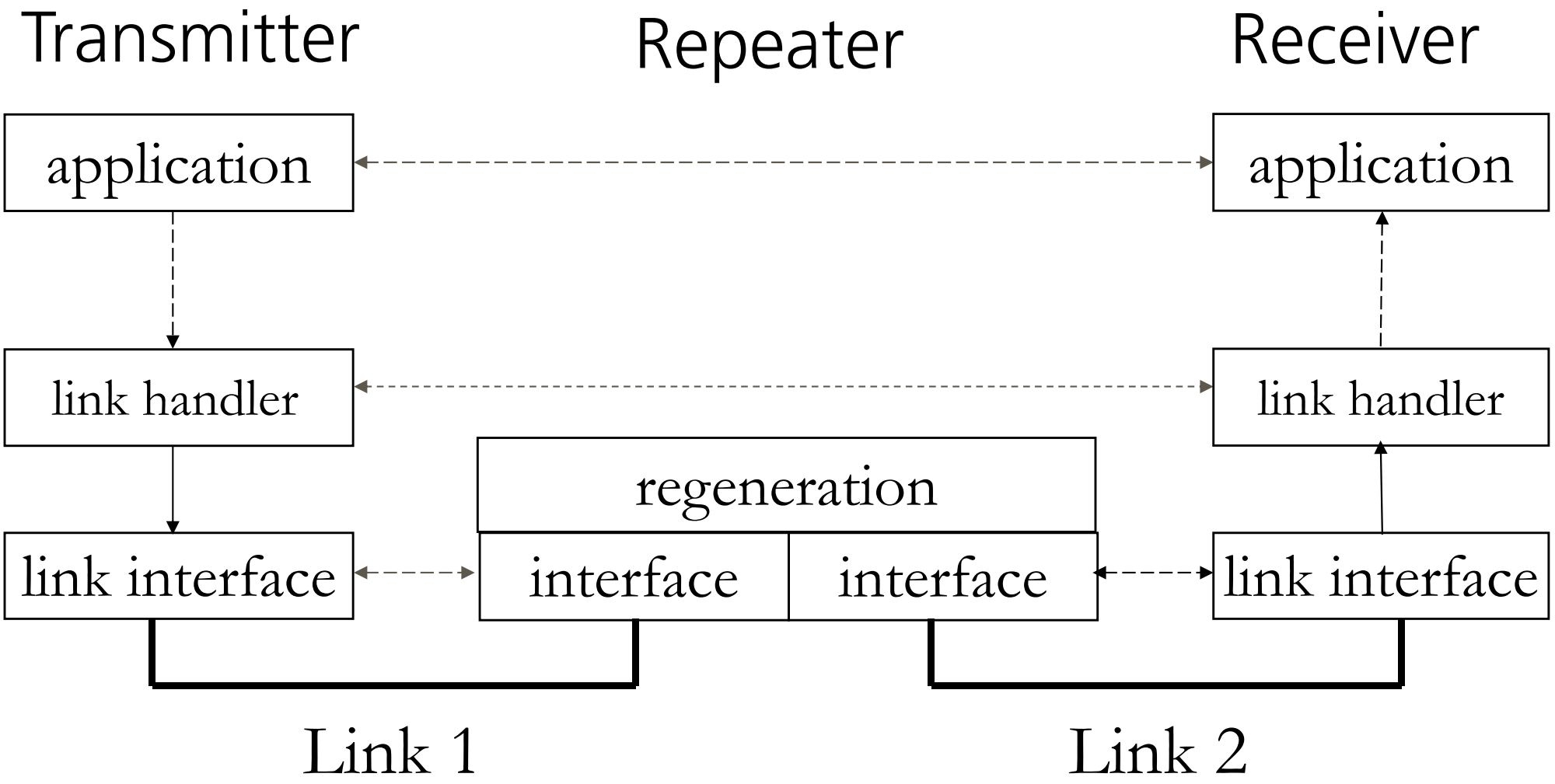
# Performance: data rate and reach

- 10BASE5: 10 Mb/s, max 500 m
- 1000BASE-T: 1000 Mb/s, max 100 m
- 1000BASE-LX10: 1000Mb/s, max 10 km (SM)
- ADSL2+: 24 Mb/s downstream, reach <5km
- VDSL2: 50 Mb/s downstream, reach <500m
- WiFi 802.11n: >72 Mb/s (MIMO), reach indoor ~70m, outdoor ~250m
- 4G: 100Mb/s (mobile) 1Gb/s (stationary)

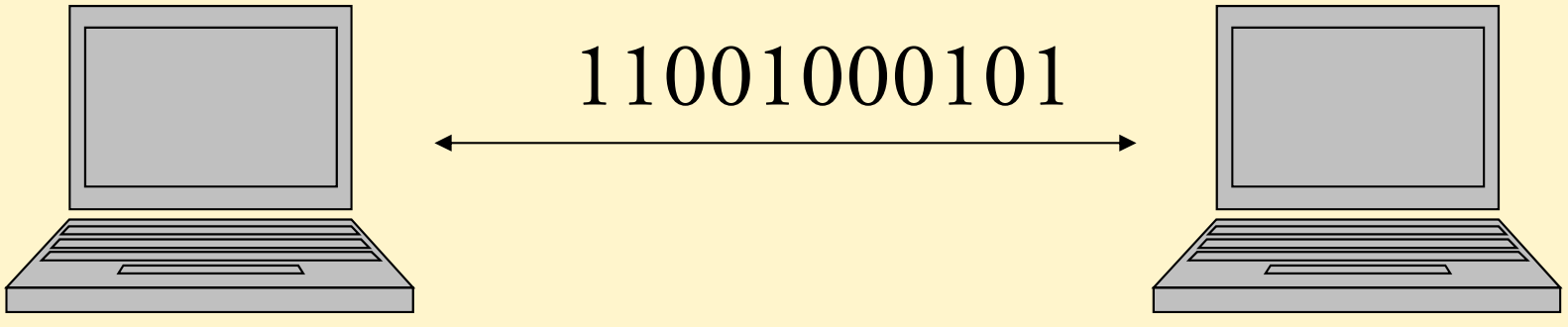
# Reach Limitations

- Dampening
- Noise
- Cross talk/Interferance
- Dispersion
  - Intermodal: Modes take different path
  - Wavelength: Wavelengths have different propagation speed
- Enter: Repeater!
  - Regenerates signal

# Protocol structure so far (2)



# This is our main problem!




- Two computers to communicate.
- Computers can understand only information in digital form, that is combinations of 1 and 0

# Dialog independent of communication media

Hi!

Hi!

*Dialog start*

Buy milk, please.

Will do!

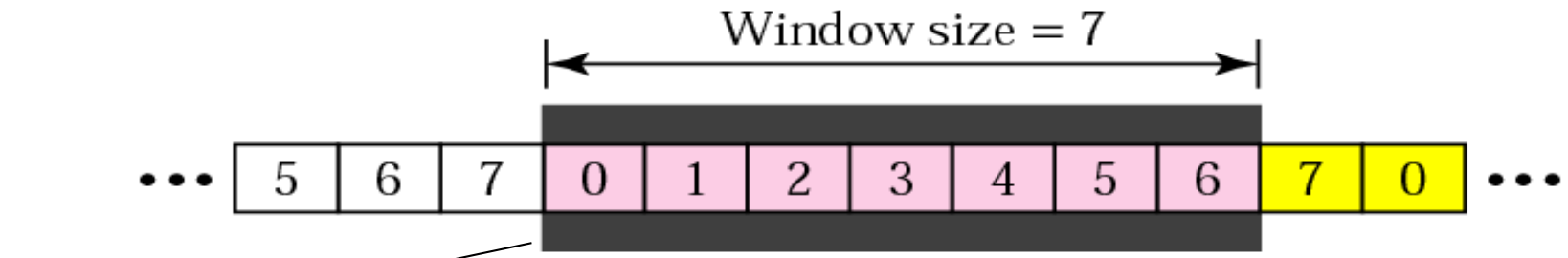
*Information exchange*

Bye!

Bye!

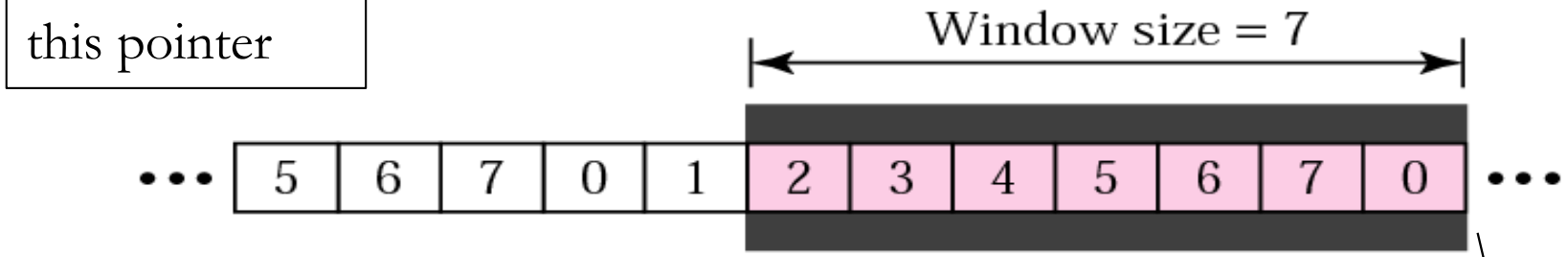
*Dialog finish*

# Go-Back-N: Sender sliding window




a. Before sliding

ACKs move this pointer




b. After sliding two frames

Sent frames move this pointer if actual win size ≤ max win size