ETSF15: Lecture 3
- Physical propagation media
- Network structures & Performance
- L2 Flow and Error Control
- Framing

Jens A Andersson

Example of propagation media

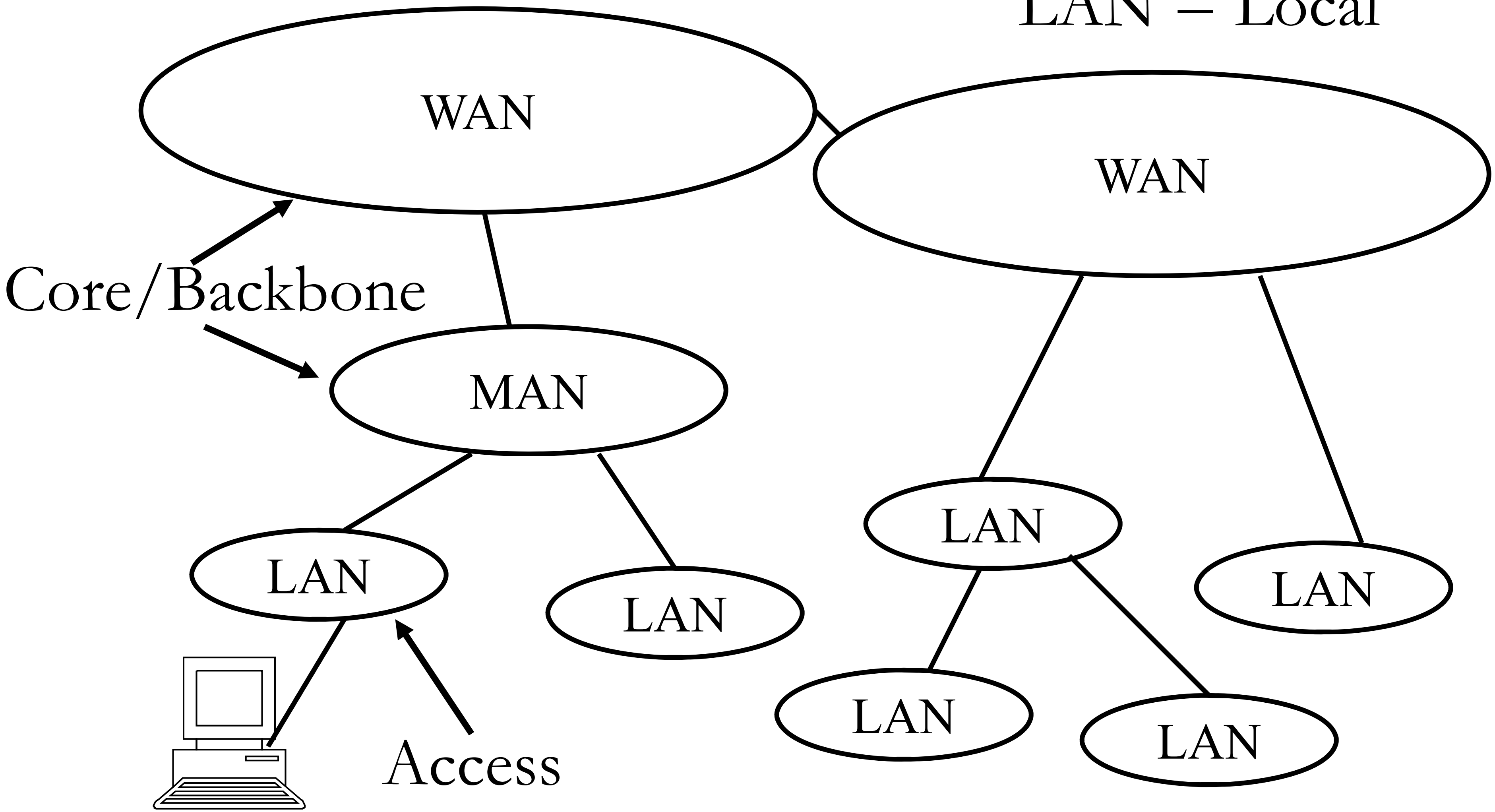
- Glass
  - optic fibre
  - FTTH, GPON
- Metal
  - coaxial, twisted pair
  - Ethernet, xDSL
- Electromagnetic fields
  - mobile/cellular, "ethernet over radio", light
  - WiFi, Bluetooth, IrDA, WiMAX Free Space Optical (FSO)

Network structures

WAN = Wide

MAN = Metropolitan

LAN = Local



Network structures (cont …)

- Not very well defined …
- A local backbone can be seen as core in another context
- The ISP's access network stops at the CPE. This is were your own access netwwork terminates. (CPE = Customer Premises Equipment)

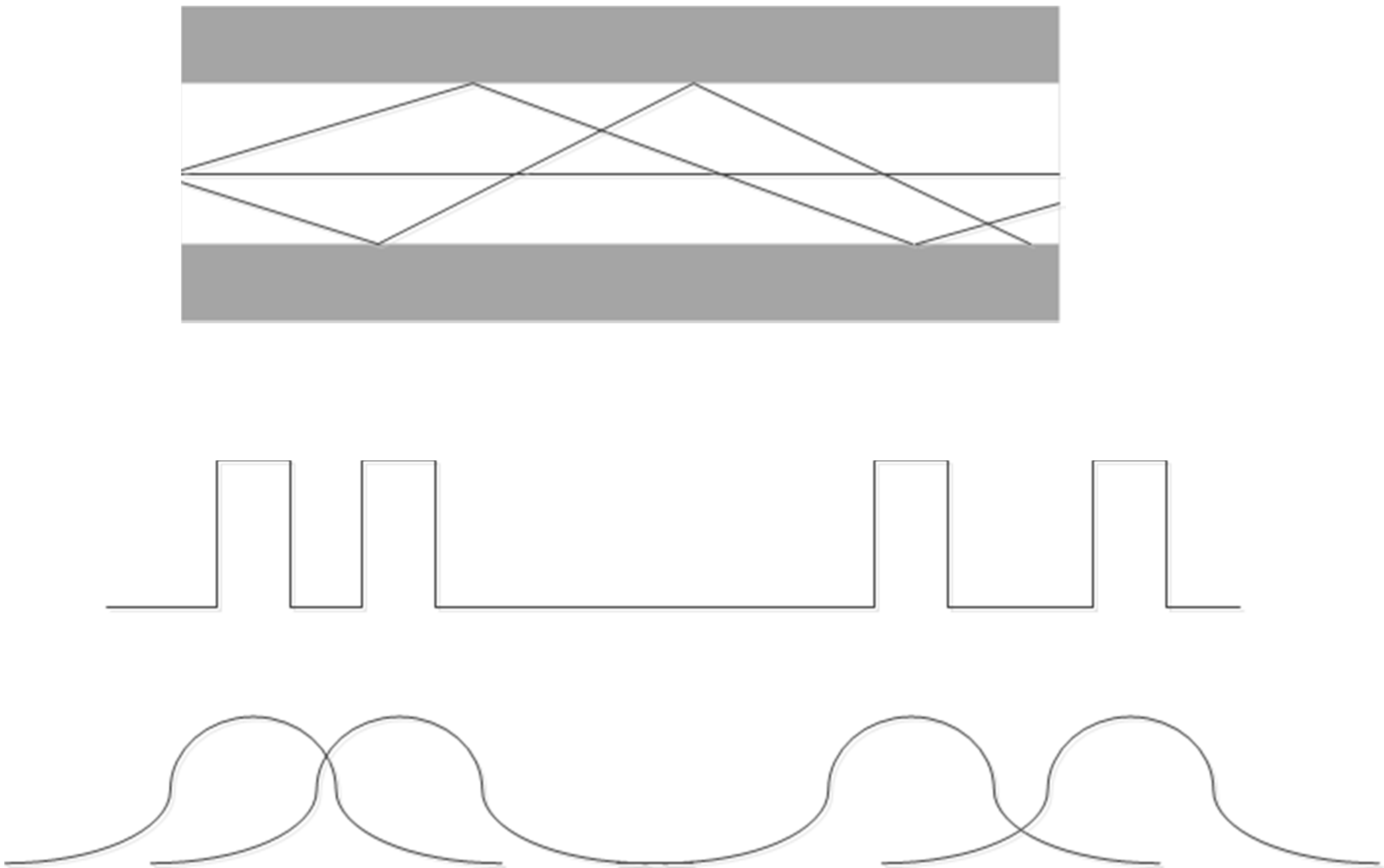
Link/Channel User Modes

- 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

Reach Limitations

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

Modal dispersion

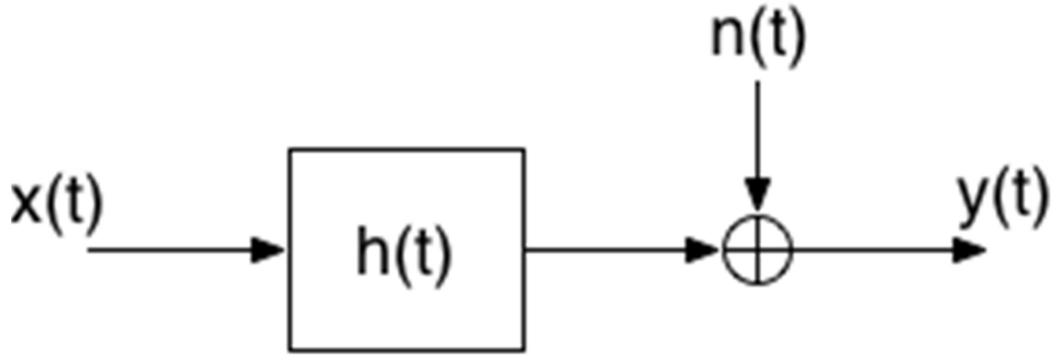


Performance: data rate and reach

- 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)

Error control

Find errors in transmitted data?



$$y(t) = x(t) \text{ for all t?}$$

$$x(t) : \ldots 0110010100100011110 \ldots$$

Use more than one channel,

compare received y_1, y_2, y_3 …

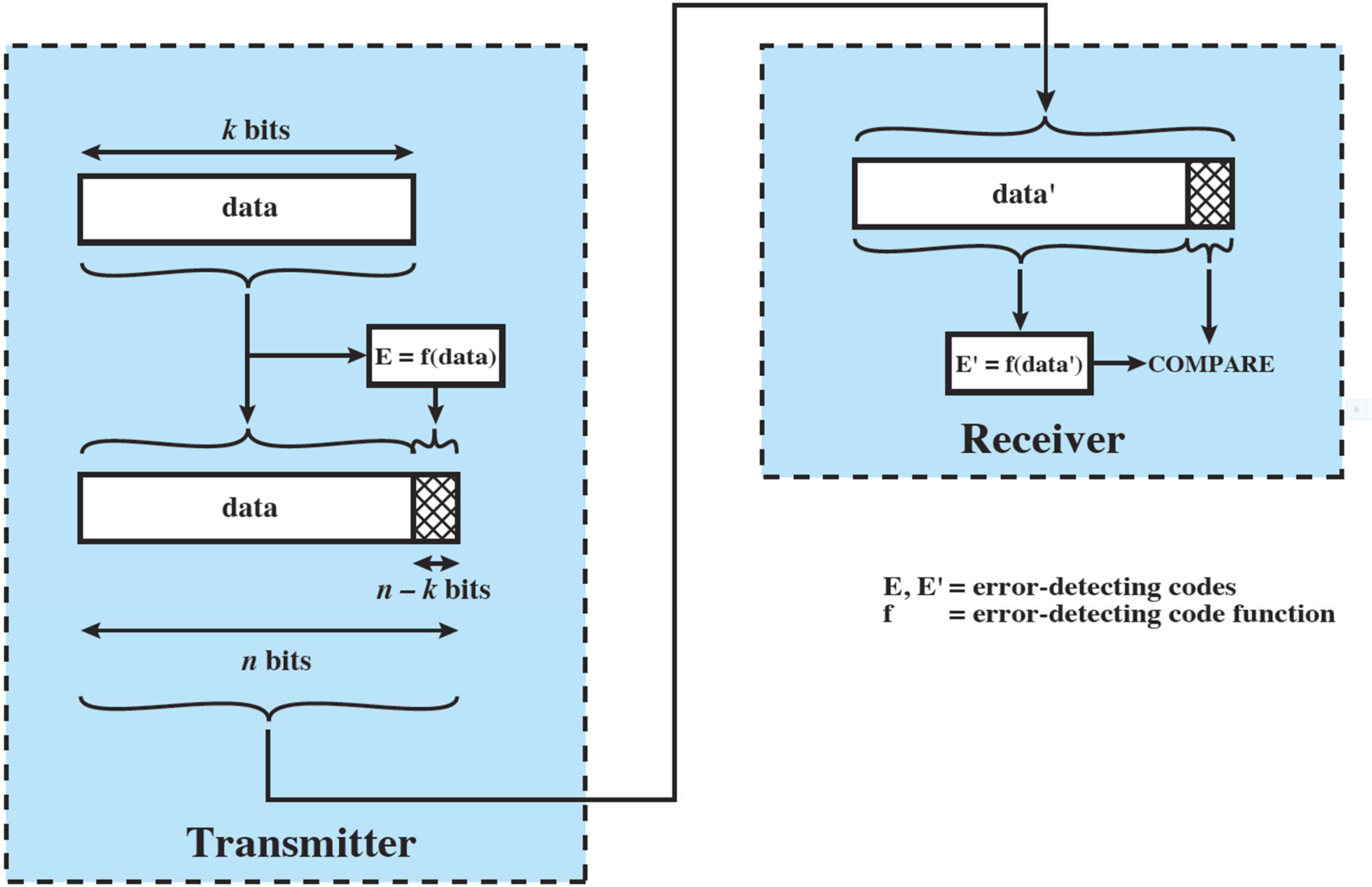
L2: Error control

Solution: Frames/Packets!

$$x(t): \ 0110010100100011110$$

- Finite number of bits per frame
- Add extra bits to each frame:
  - Parity bit
  - 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

$$\boldsymbol{a} = a_{L-1}a_{L-2}\ldots a_1a_0$$

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

$$= a_{L-1}x^{L-1} + a_{L-2}x^{L-2} + \cdots + a_0x^0$$

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

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:

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

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:

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

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

$$g_0 = 1$$

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

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)

At the receiver side

Received codeword:

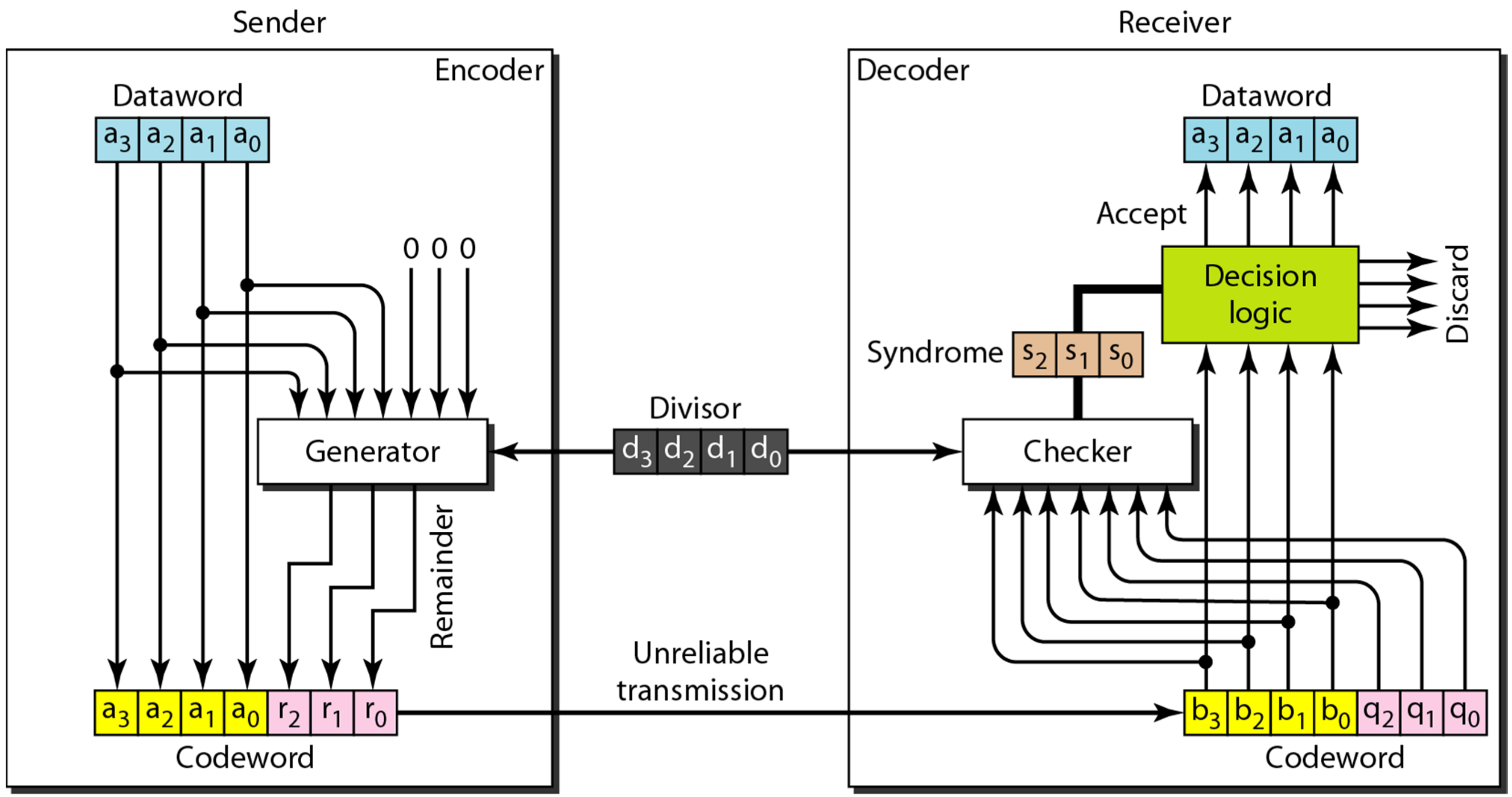
$$y(x) = c(x) + e(x)$$

Calculate *syndrome* of received vector:

$$\begin{aligned} s(x) = R_{g(x)}(y(x)) &= R_{g(x)}(c(x) + e(x)) \\ &= R_{g(x)}\big(R_{g(x)}(c(x)) + R_{g(x)}(e(x))\big) \\ &= R_{g(x)}(e(x)) \end{aligned}$$

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

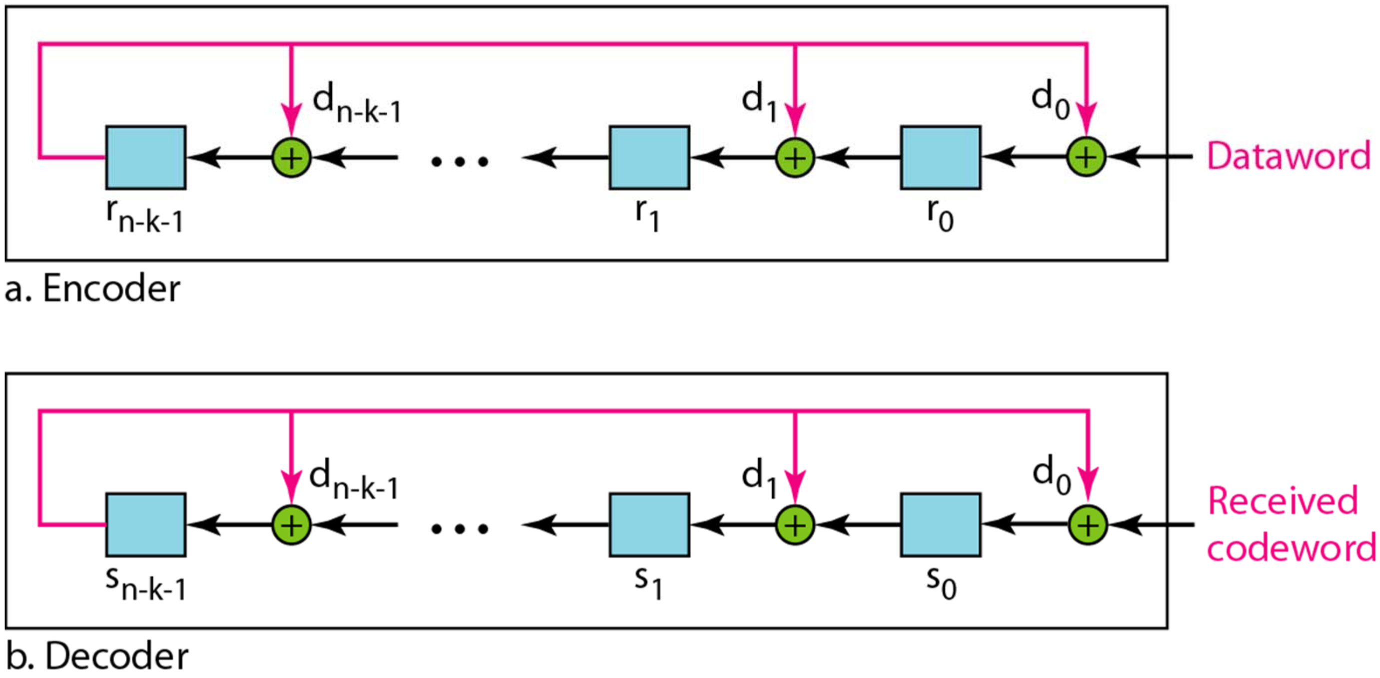
CRC block diagram



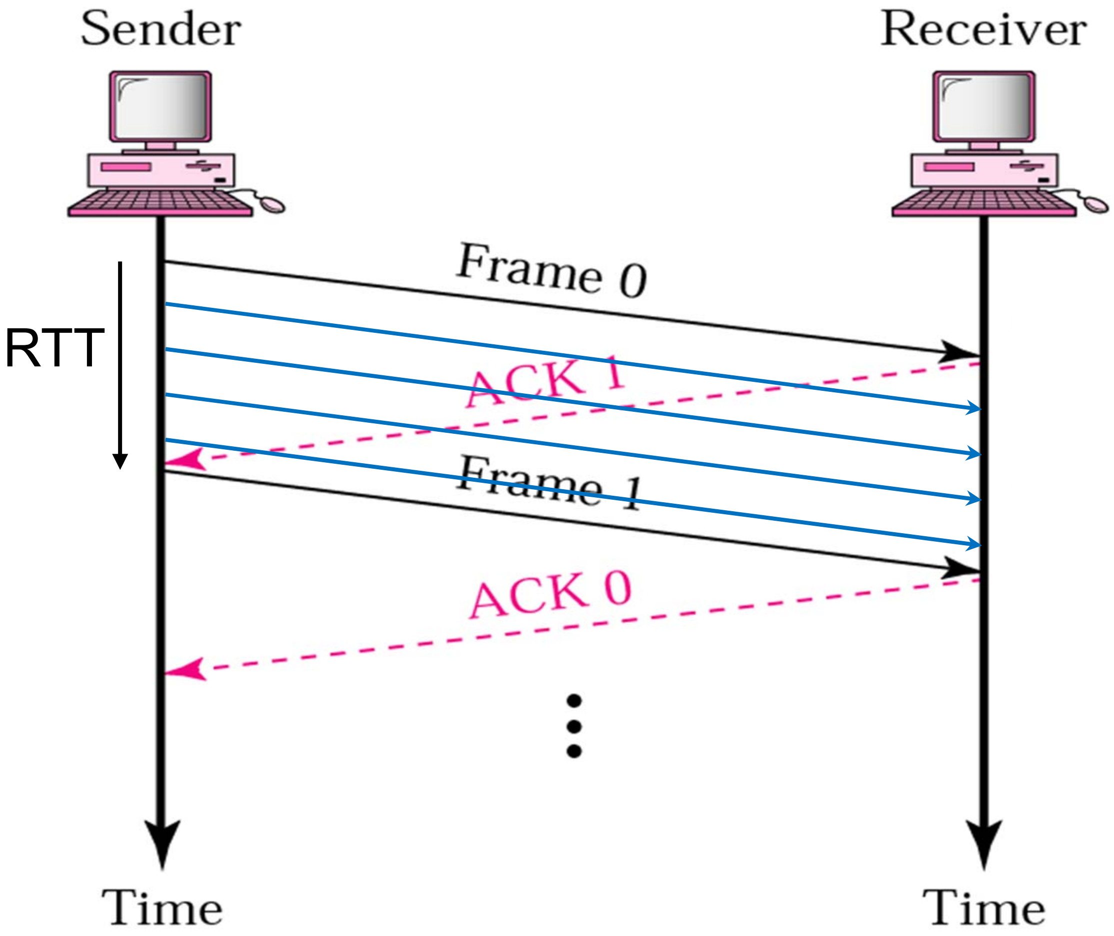
CRC division in the digital domain

Note:

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



L2: Flow control

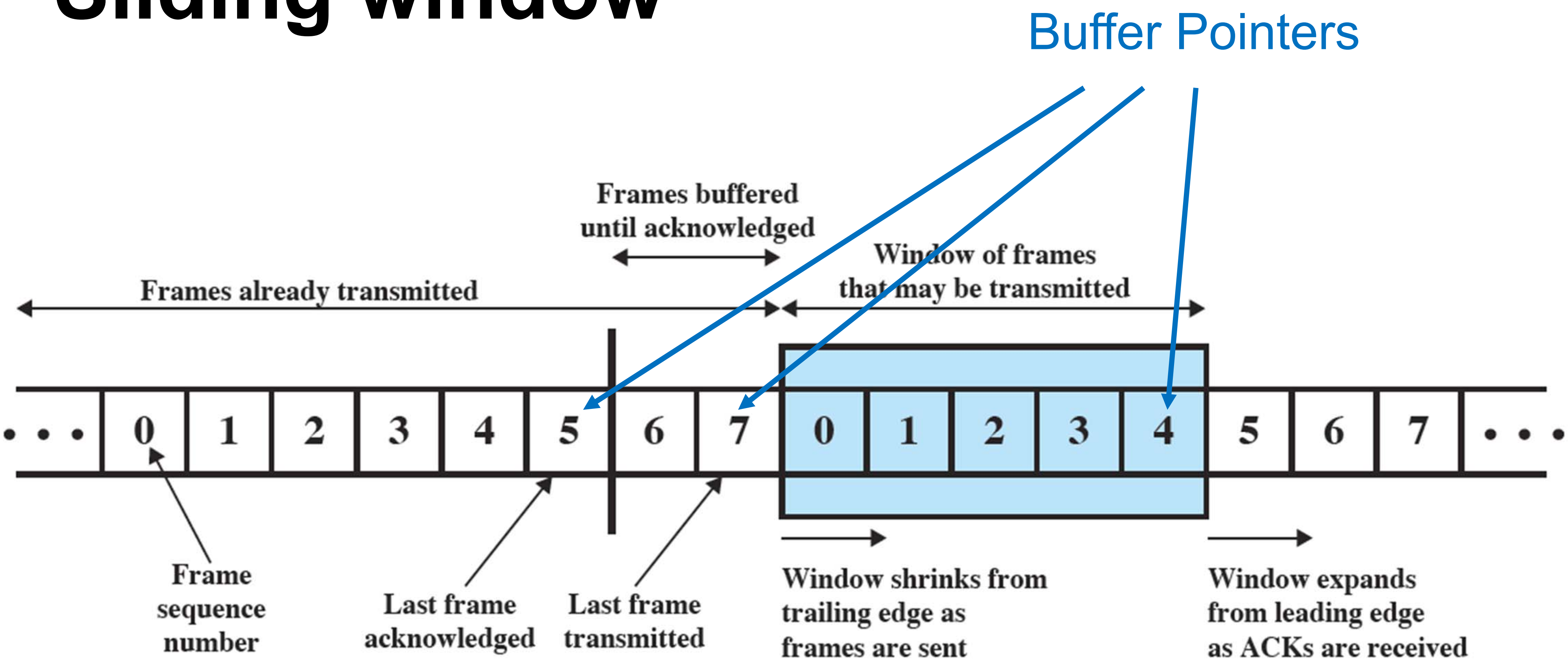


RTT = Round Trip Time

Idea:

- Assume error free transmission
- Allow frames to be sent until ACK for first frame is expected = RTT
- Check RTT during transmission
- Intro:
  Sliding window

Sliding window



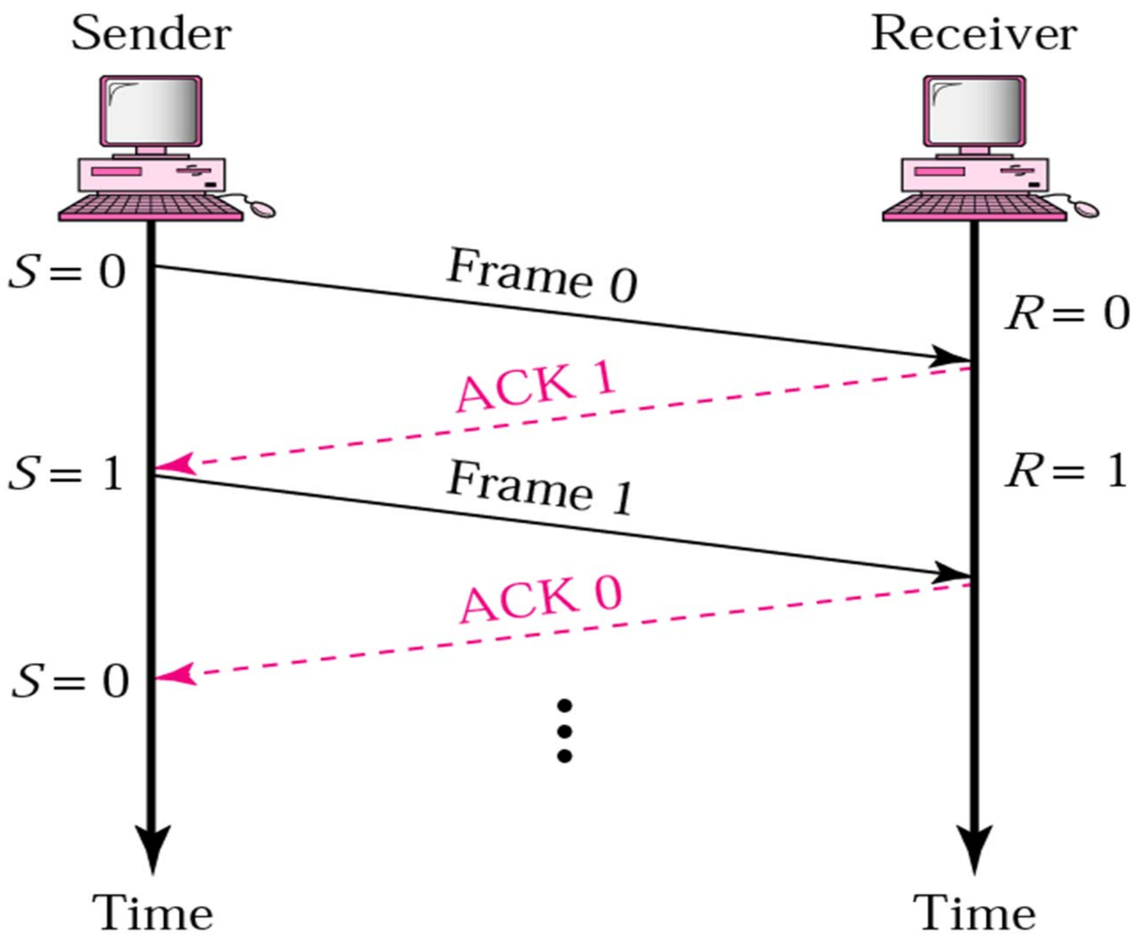
L2: Error correction

- 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

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 the Sliding Window
  - Sender keeps track of sent and ACKed frames
  - Receiver keeps track of received frames

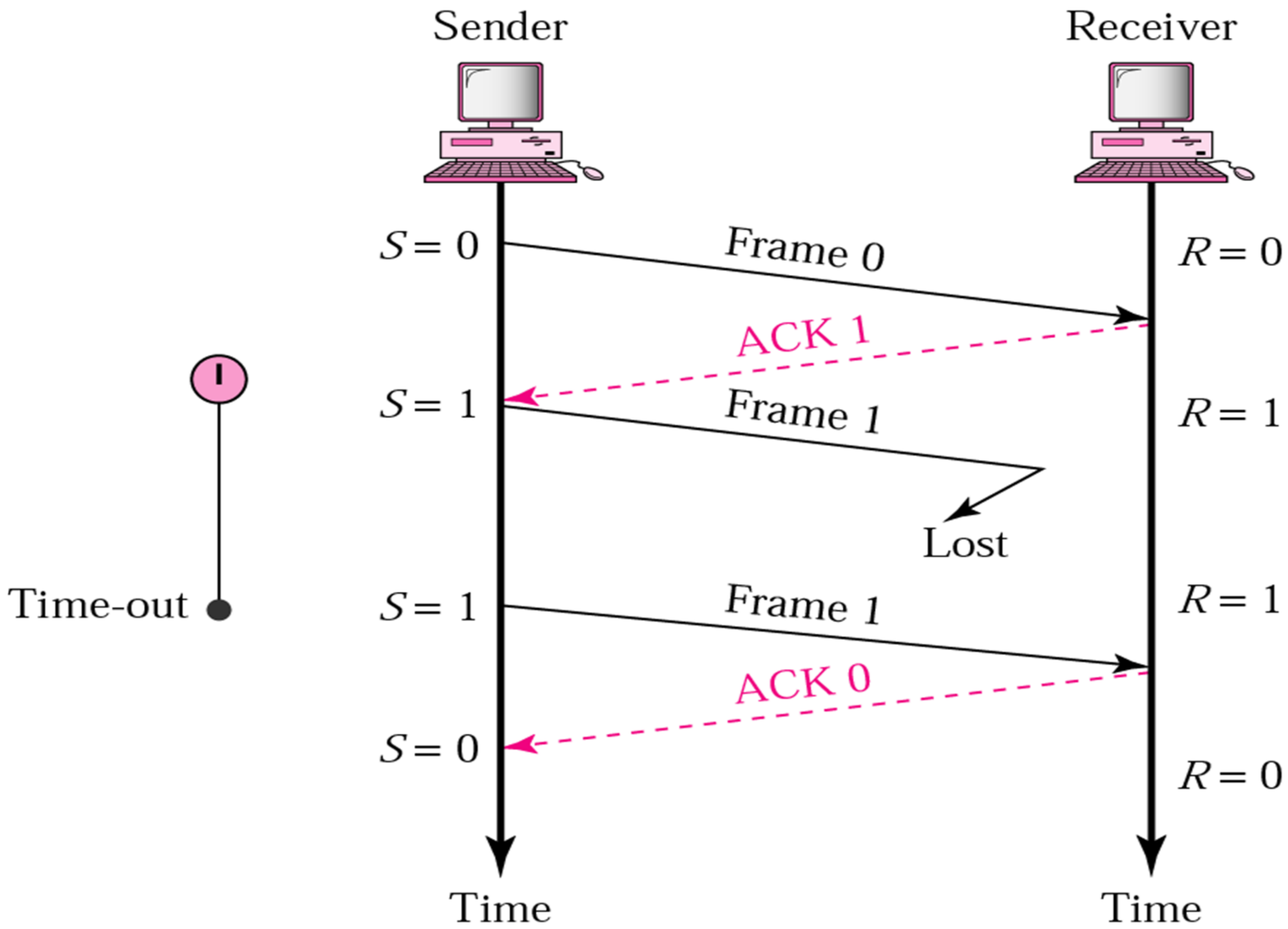
Stop-and-Wait Normal operation



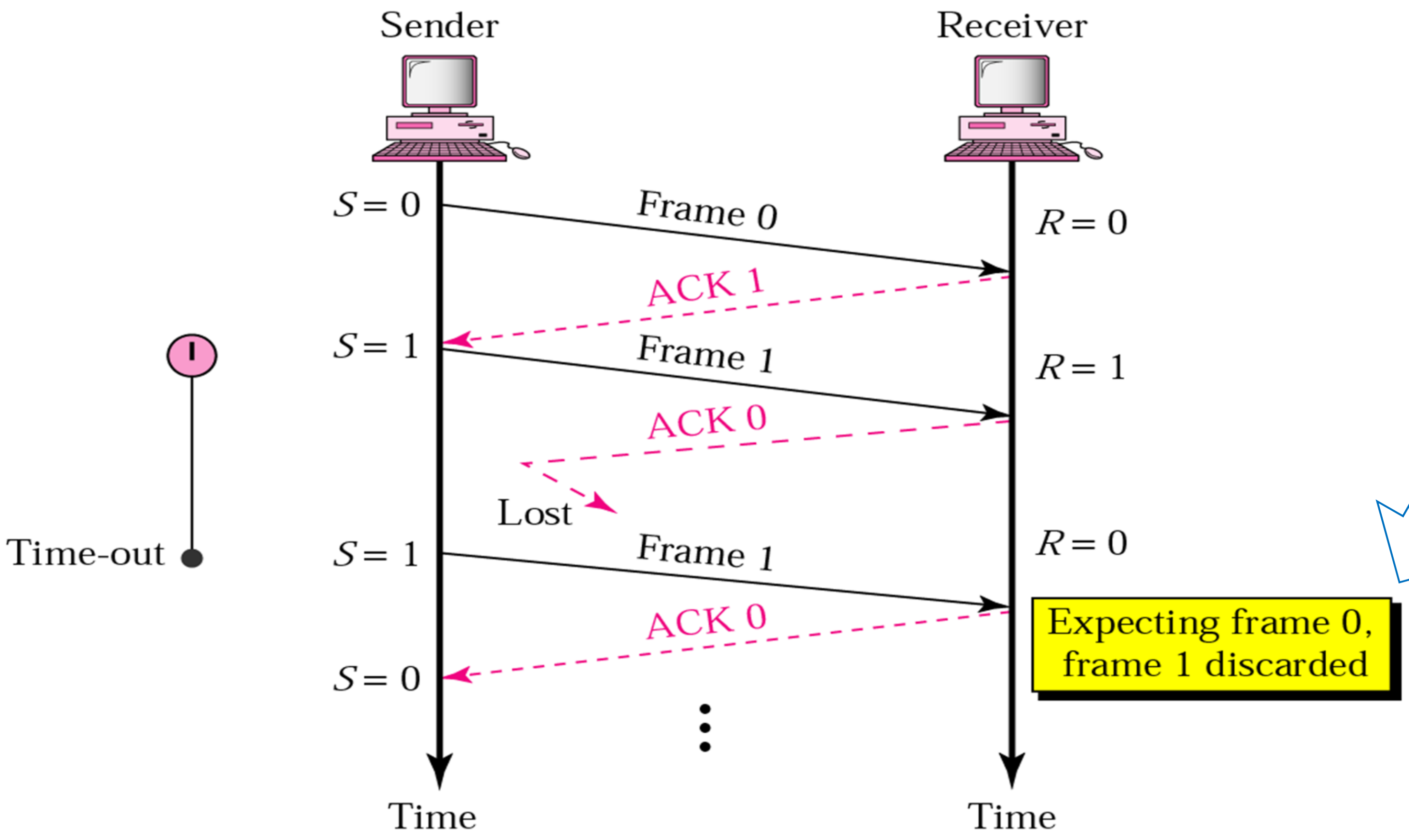
Note!

- Sequence numbers
- Sliding Window size = 1 frame

Stop-and-Wait ARQ, frame lost

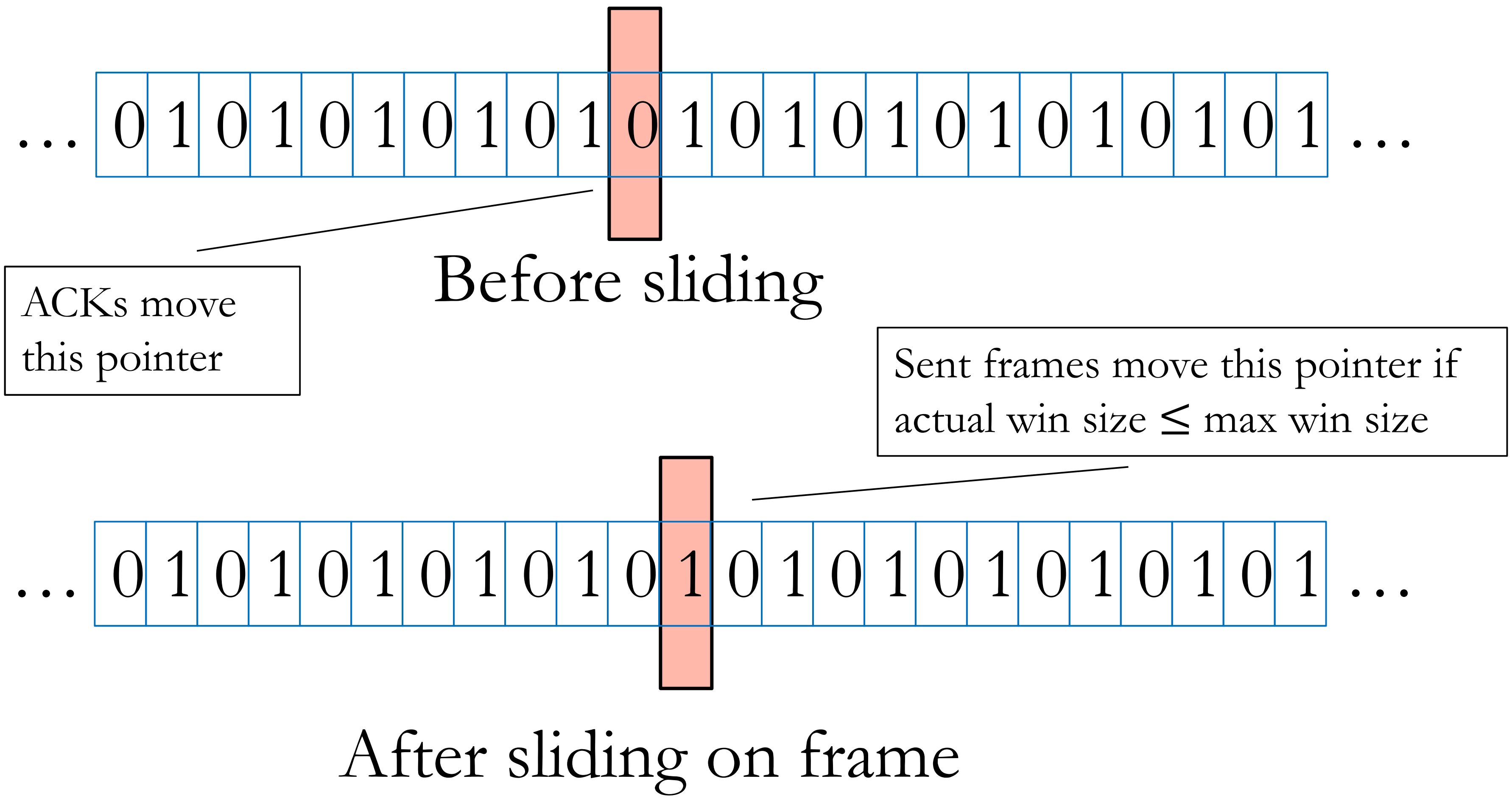


Stop-and-Wait ARQ, lost ACK frame



Explaining the need for SEQ num

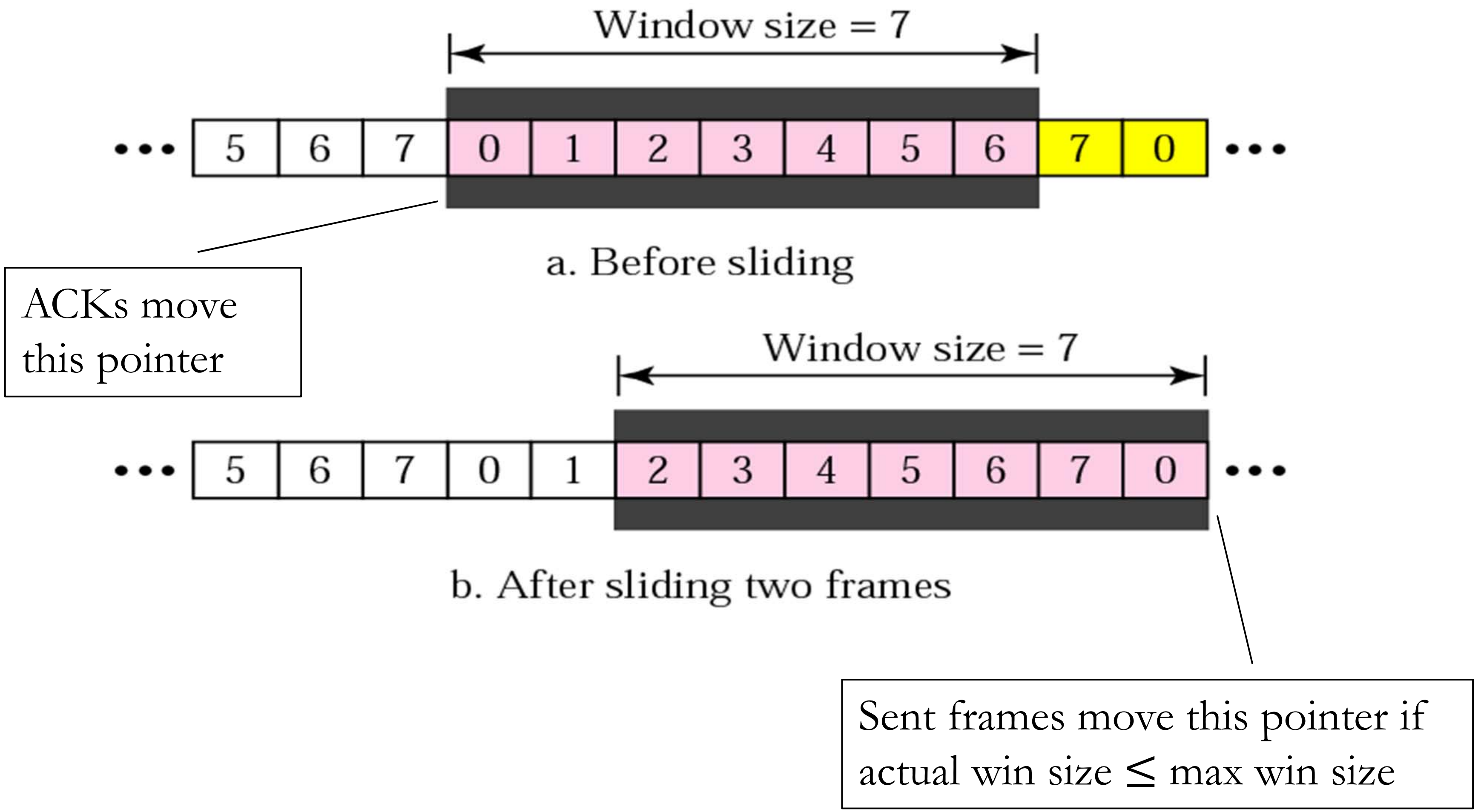
Sender Sliding Window



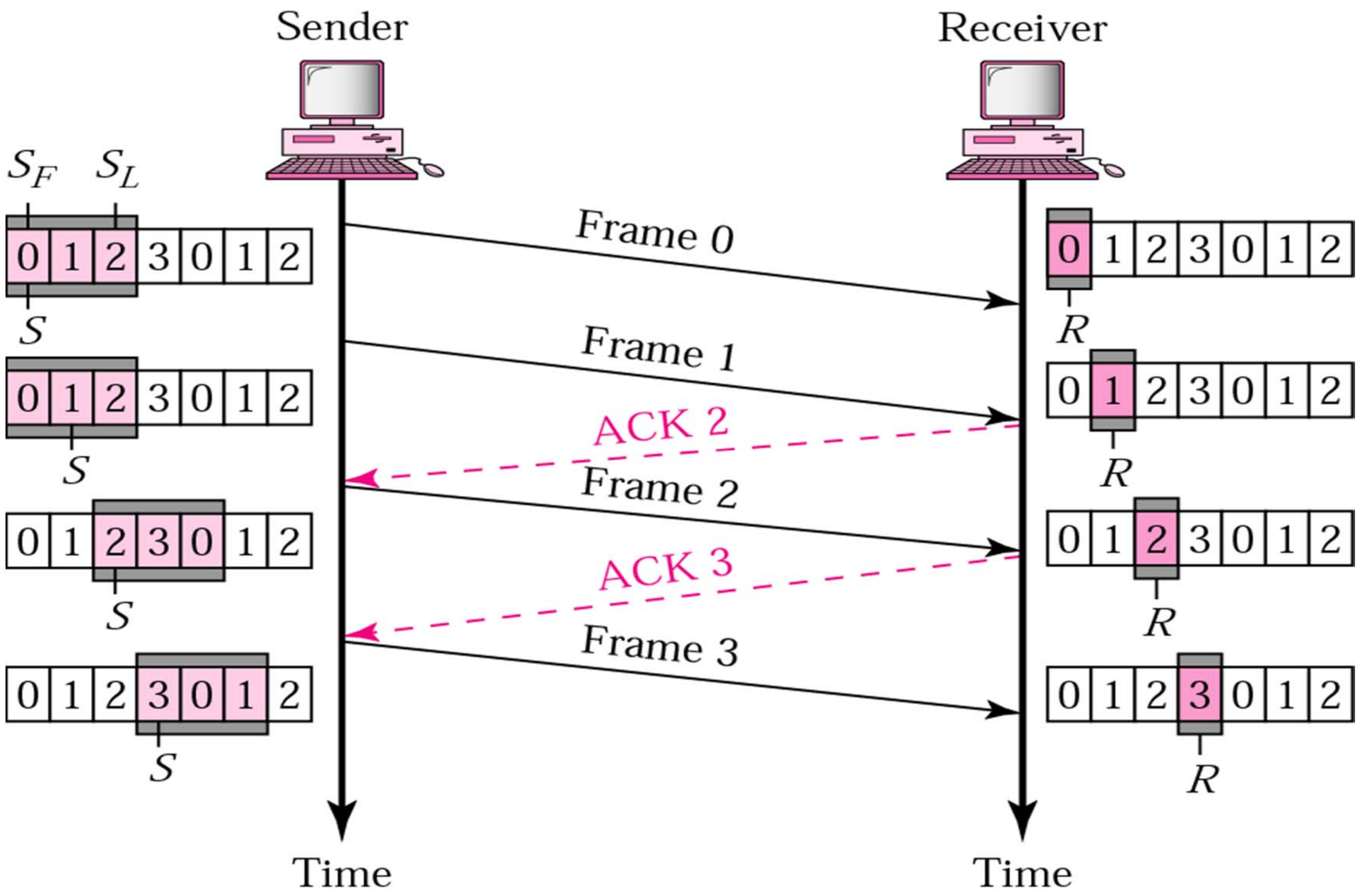
Go-Back-N

- Increase sliding window size
  - Sender can send as long as the sliding window includes frames not sent
  - Retransmitt requested frames and all following frames
  - Make use of the Round Trip Time (RTT)
    - Time it takes for one frame to reach receiver and for ACK to reache sender

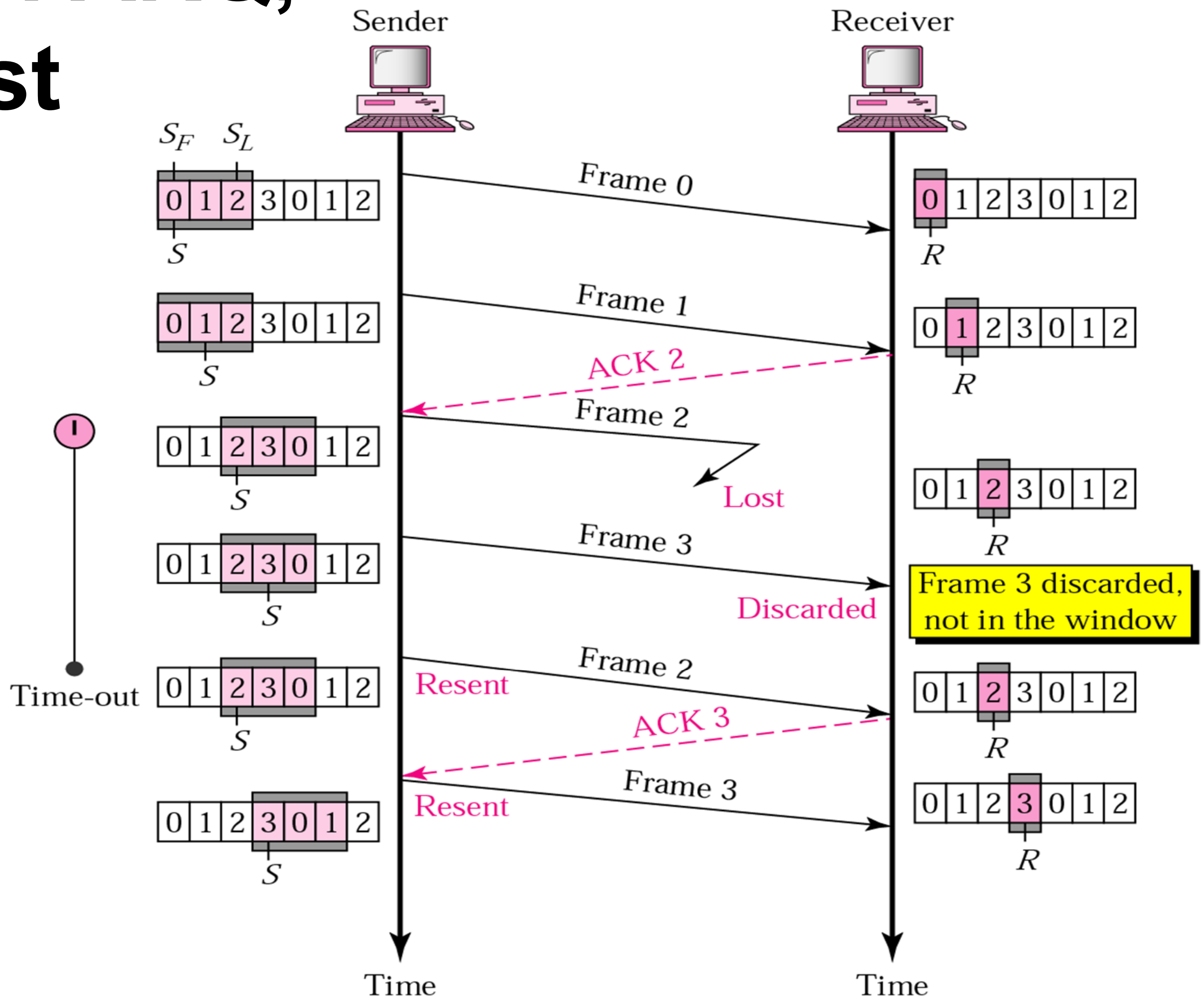
Go-Back-N: Sender sliding window



Go-Back-N ARQ, normal operation



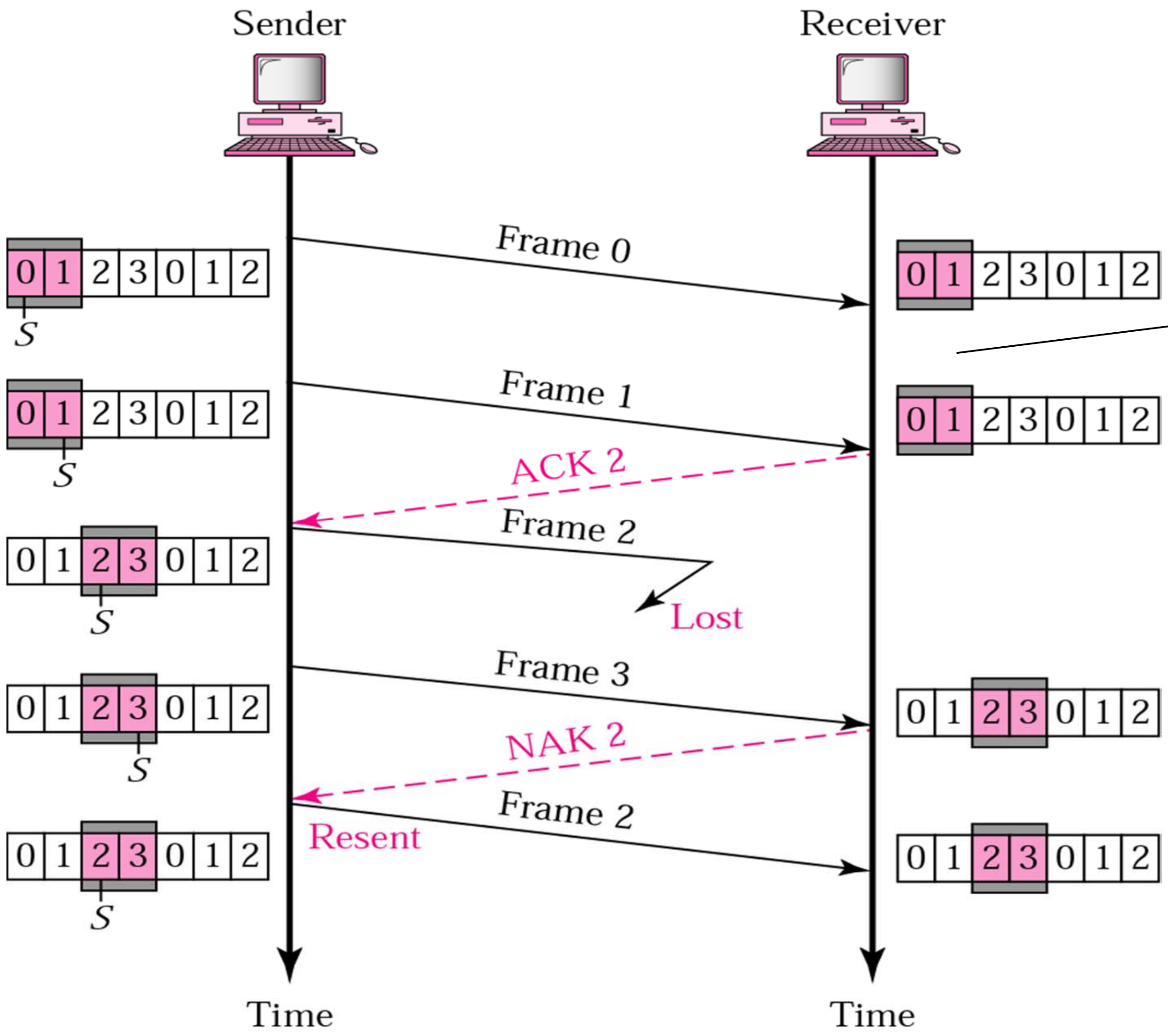
Go-Back-N ARQ, frames lost



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

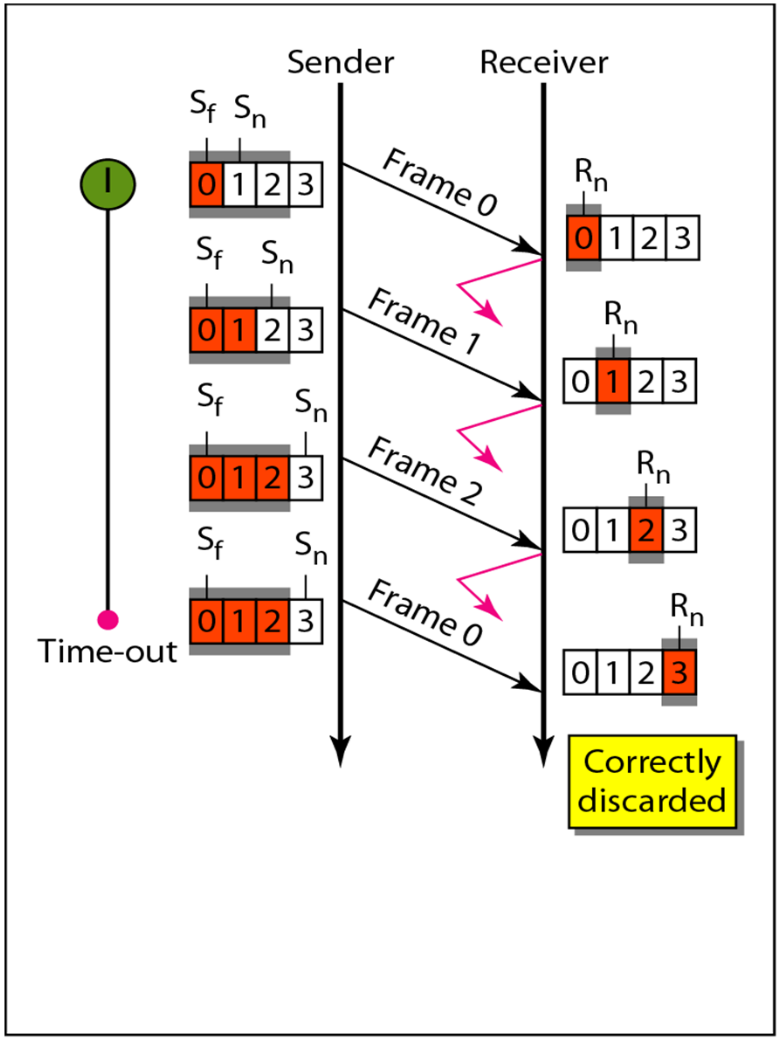


Note receiver sliding window size

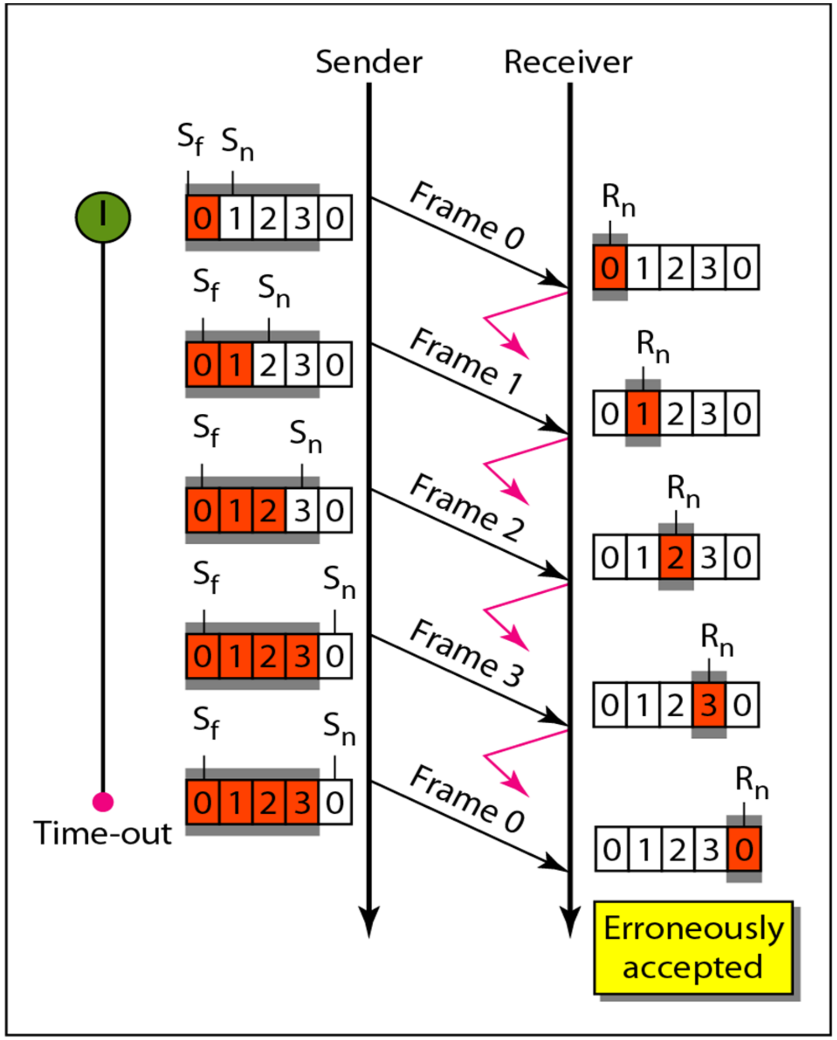
Some notes

- 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

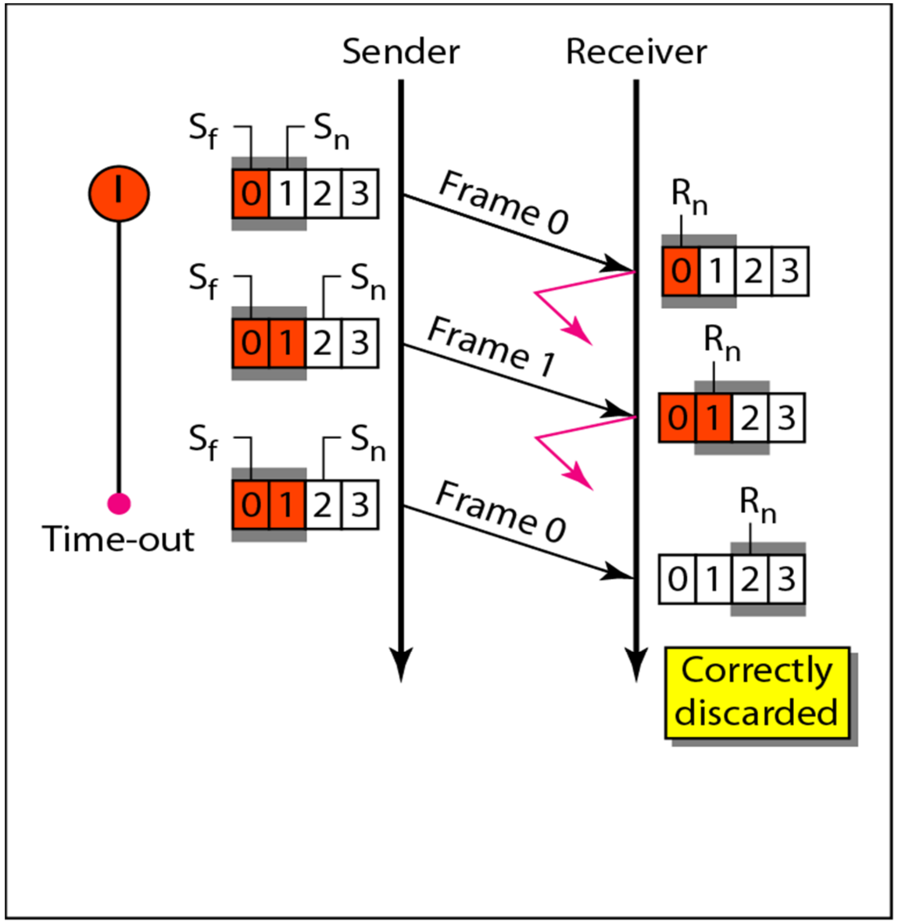


a. Window size $< 2^m$

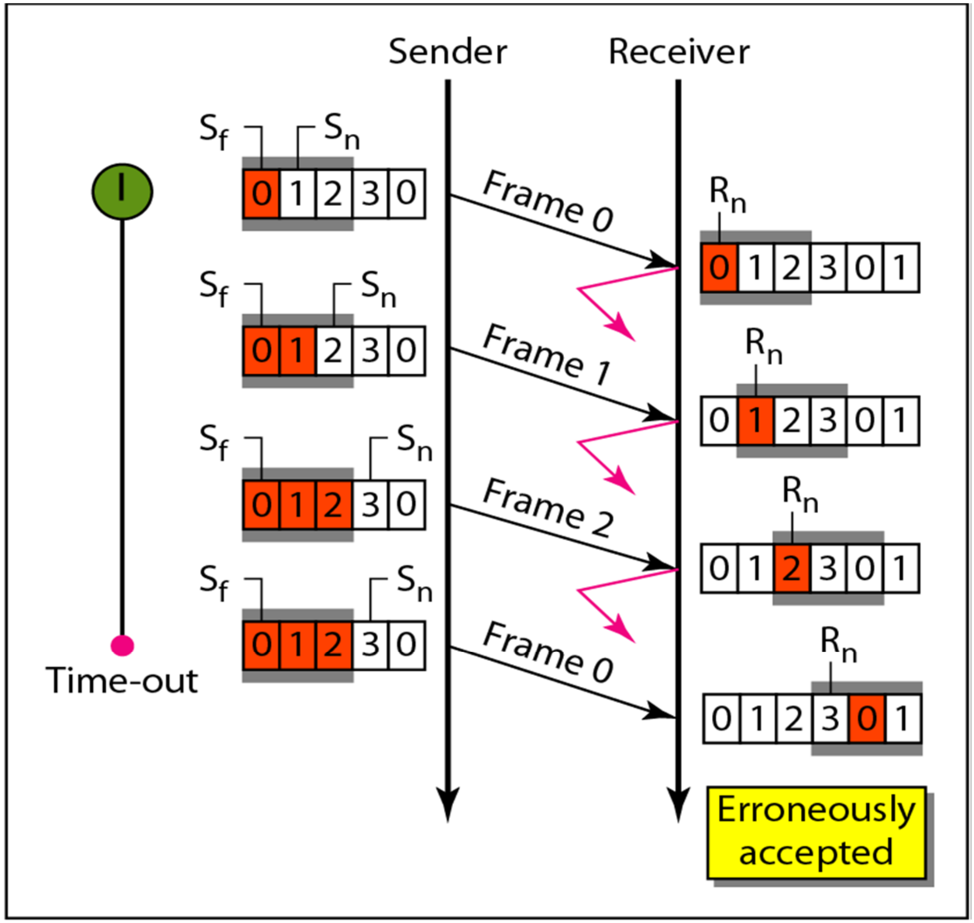


b. Window size $= 2^m$

Selective Repeat ARQ, window size



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



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

Framing

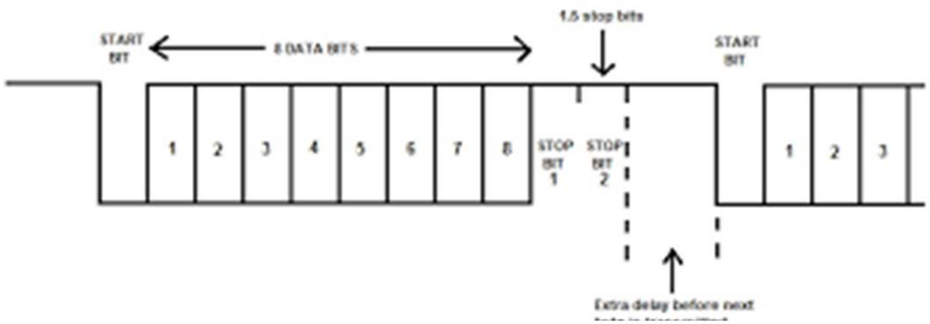
- Header:
  - Sequence and ACK numbers
  - More to come …
- Tail
  - CRC

Synchronisation

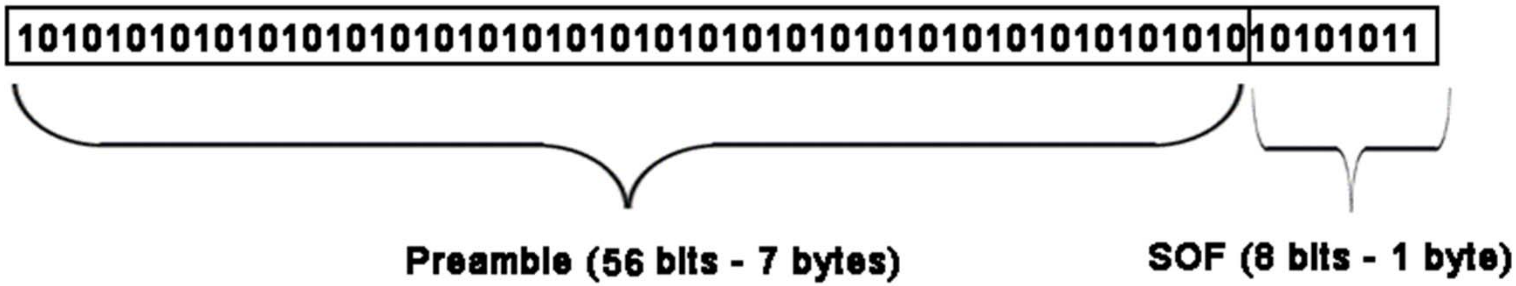
Preamble and start flag	Frame	End flag

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 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

011111101111100111000111111

→

01111101011111000111000111110**1**

One link layer protocol: HDLC

- HDLC = High-level Data Link Control

flag	address	controll	payload	CRC	flag

Flag = 01111110

16 or 32 bits CRC

Go-back-N or Selective-repeat ARQ