EL 536 Principles of Communication Networks

Data Link Layer

Data Link Control

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Flow Control

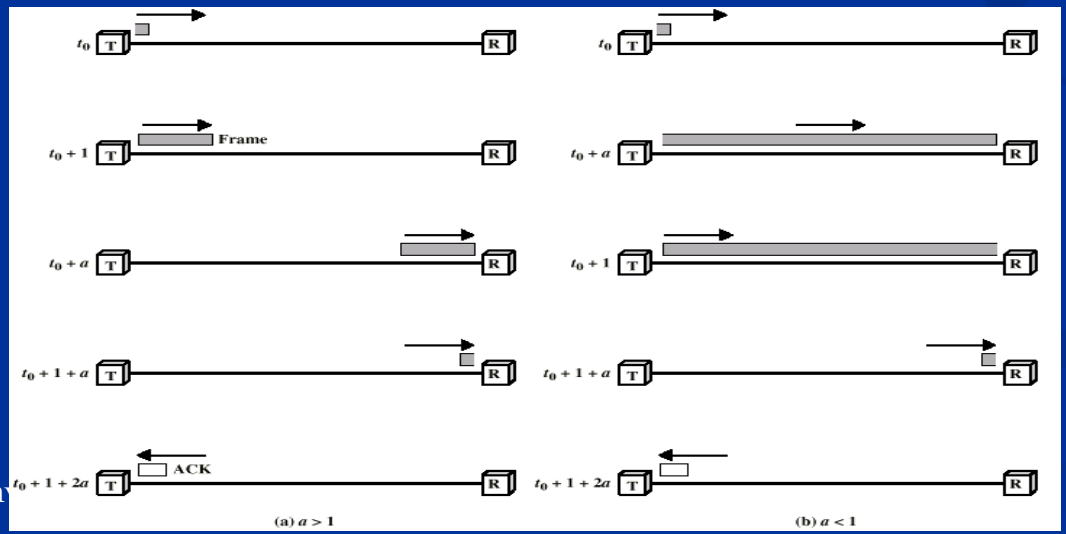
- Flow Control is a technique for speed-matching of transmitter and receiver. Flow control ensures that a transmitting station does not overflow a receiving station with data
- We will discuss two protocols for flow control:
  - **Stop-and-Wait Protocol**
  - **Sliding Window Protocol**
- For the time being, we assume that we have a perfect channel between sender and receiver (**no errors**)

Stop-and-Wait Flow Control

- Source transmits frame
- Destination receives frame and replies with acknowledgement
- Source waits for ACK before sending next frame
- Destination can stop flow by not send ACK
- Works well for a few large frames

Analysis of Stop-and-wait

- ***T:*** the total time to send a frame, $T = 2t_{prop} + t_{frame} + t_{proc} + t_{ack}$
- t_{prop}: propogation time
- t_{frame}: time to transmit a frame (time for the transmitter to send out all bits of a frame)
- t_{proc}: processing time at each station to react to an incoming event, relatively negligible
- t_{ack}: time to transmit an acknowledgement, very small compared to t_{frame}



$$T = 2t_{prop} + t_{frame}$$

Stop and Wait Link Utilization

- ***U***: the maximum utilization, or efficiency, of the link.

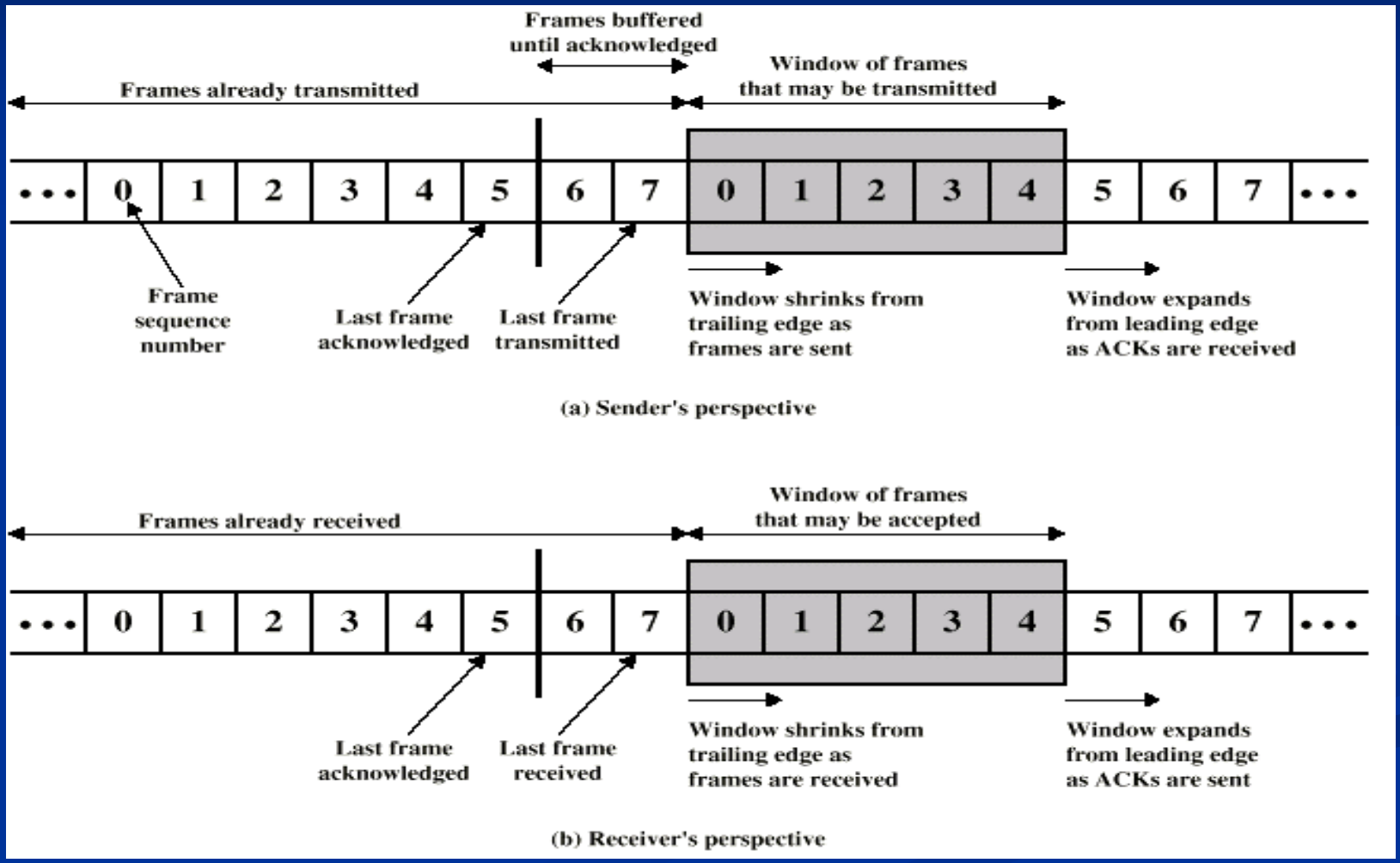
  $U = t_{frame} / (2t_{prop} + t_{frame}) = 1/(1+2a)$

- $a = t_{prop} / t_{frame} = (d/V)/(L/V) = (Rd)/(VL)$
  - *d*: distance
  - *V*: the velocity of propagation
  - *L*: the length of the frame in bits
  - *R*: the data rate

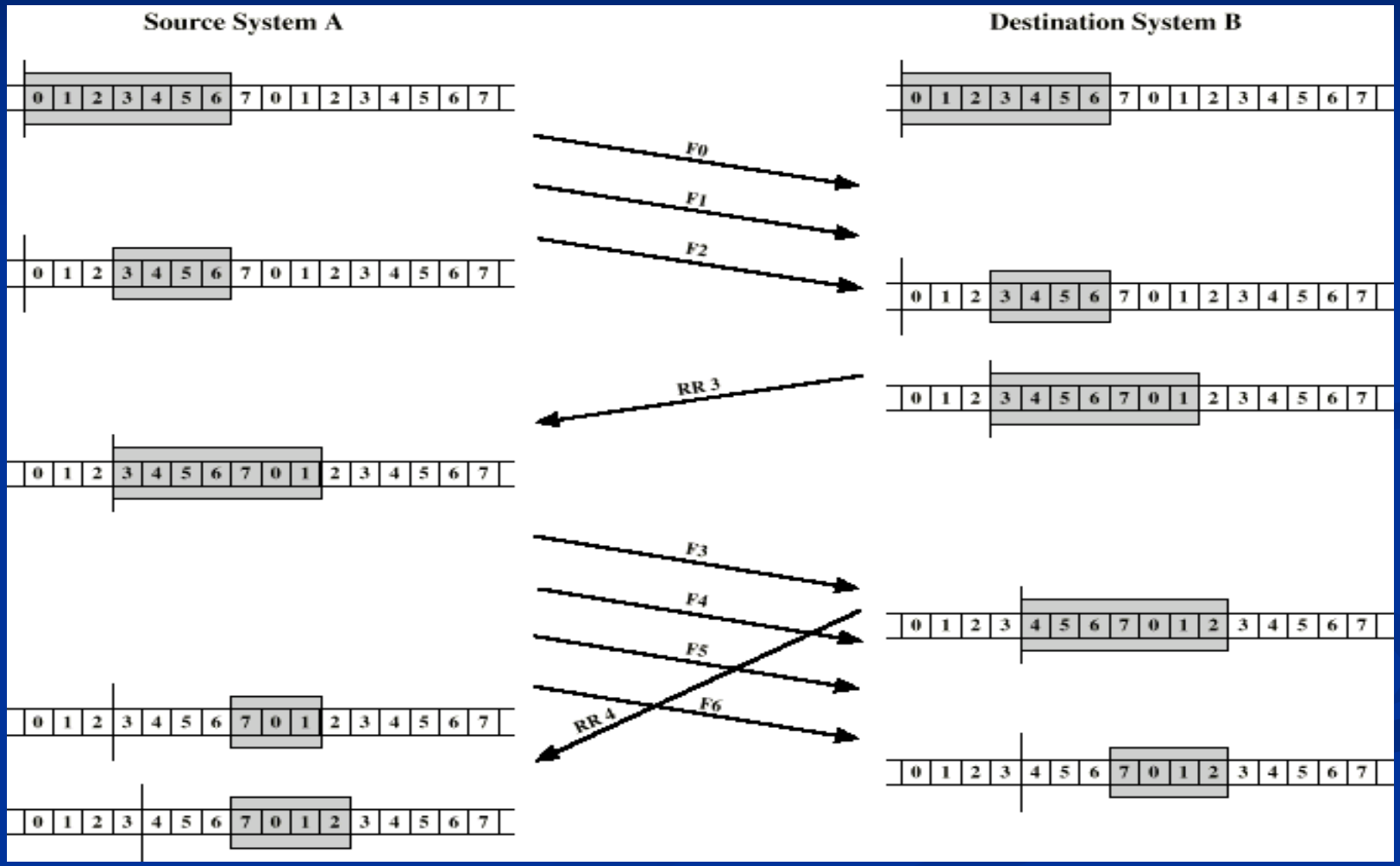
Sliding Window Flow Control

- Allow multiple frames to be in transit
- Receiver has buffer *W* long
- Transmitter can send up to *W* frames without ACK
- Each frame is numbered
- ACK includes number of next frame expected
- Sequence number bounded by size of field (k)
  - Frames are numbered modulo 2^k

Sliding Window Operation



Example of Sliding Window



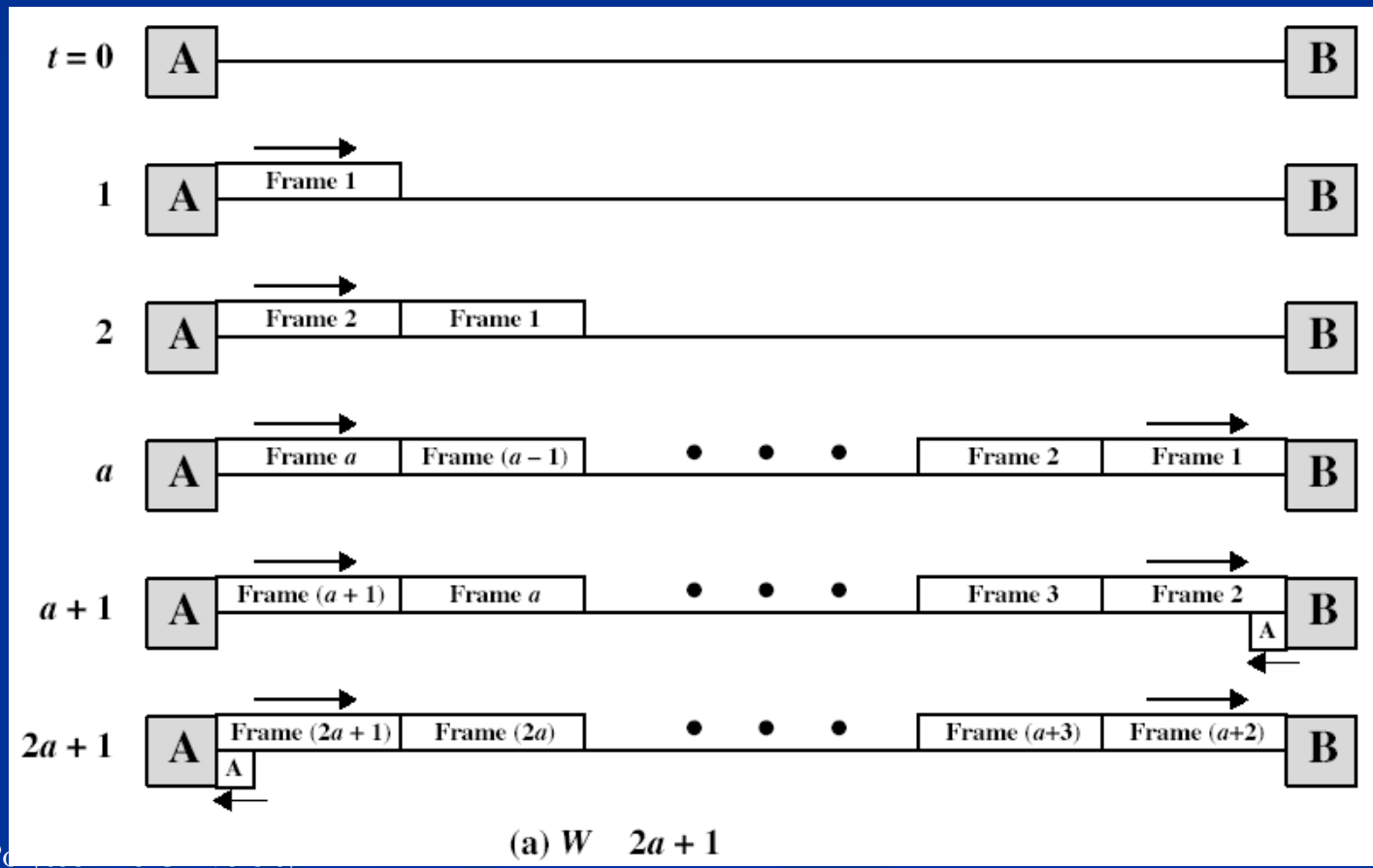
Error-Free Sliding-Window Analysis

- For convenience, normalize frame transmission time to a value of 1; thus the propagation time is *a*.
- Assume that the acknowledge frame is so small that transmission time is negligible.
- Utilization:

$$U = \begin{cases} 1 & W \geq 2a+1 \\ \dfrac{W}{2a+1} & W < 2a+1 \end{cases}$$

Error-Free Sliding-Window Analysis

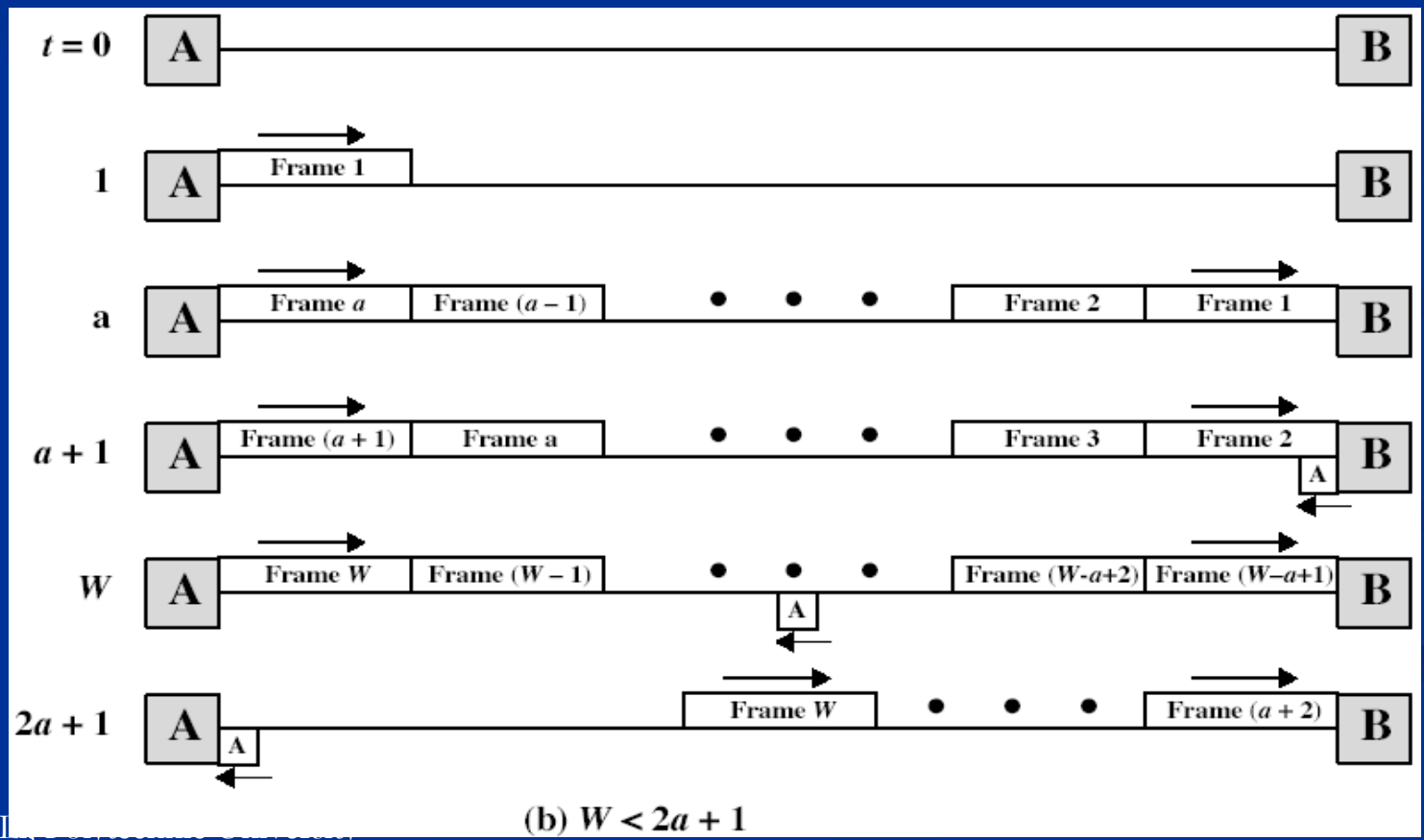
- Case 1: W ≥ 2a +1



(a) $W \quad 2a + 1$

Error-Free Sliding-Window Analysis

- Case 2: W < 2a +1



(b) $W < 2a + 1$

Sliding Window Enhancements

- Receiver can acknowledge frames without permitting further transmission (Receive Not Ready)
- Must send a normal acknowledge to resume
- If duplex, use piggybacking
  - If no data to send, use acknowledgement frame
  - If data but no acknowledgement to send, send last acknowledgement number again, or have ACK valid flag (TCP)

ARQ Error Control

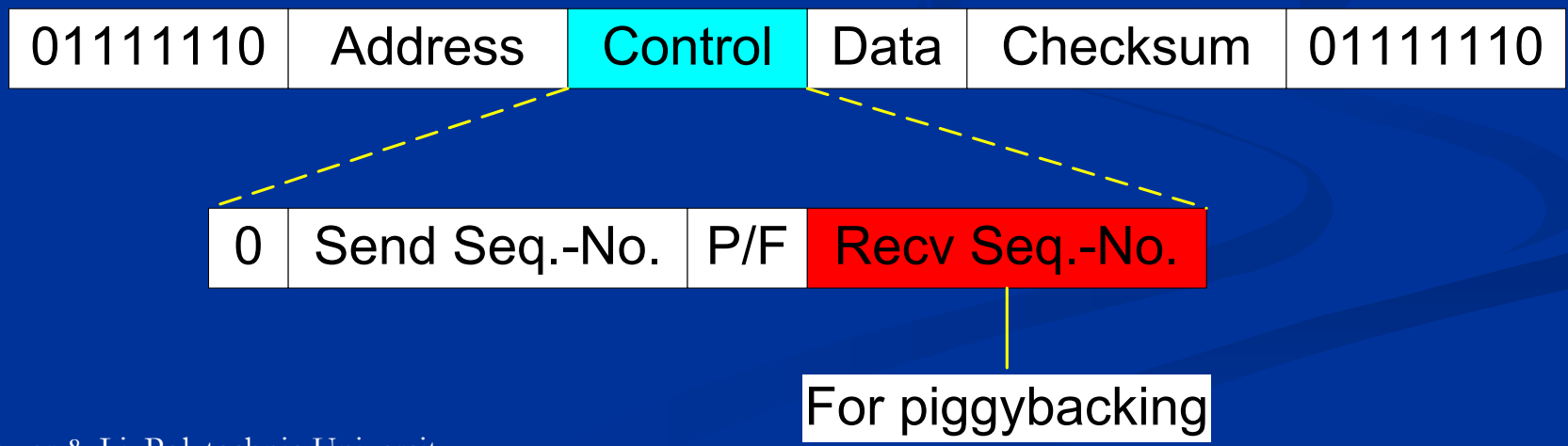
- **Two types of errors:**
  - Lost frames
  - Damaged Frames
- Most Error Control techniques are based on (1) Error Detection Scheme (e.g., Parity checks, CRC), and (2) Retransmission Scheme
- Error control schemes that involve error detection and retransmission of lost or corrupted frames are referred to as ***Automatic Repeat Request (ARQ)*** error control

ARQ Error Control

- All retransmission schemes use all or a subset of the following procedures:
  - Receiver sends an **acknowledgment (ACK)** if a frame is correctly received
  - Receiver sends a **negative acknowledgment (NAK)** if a frame is not correctly received
  - The sender retransmits a packet if an ACK is not received within a **timeout** interval
  - All retransmission schemes (using ACK, NAK or both) rely on the use of timers

ARQ Error Control

- **Note:** Once retransmission is used, a sequence number is required for every data packet to prevent duplication of packets
- Both **ACK**s and **NAK**s can be sent as special frames, or be attached to data frames going in the opposite direction (**Piggybacking**)



ARQ Schemes

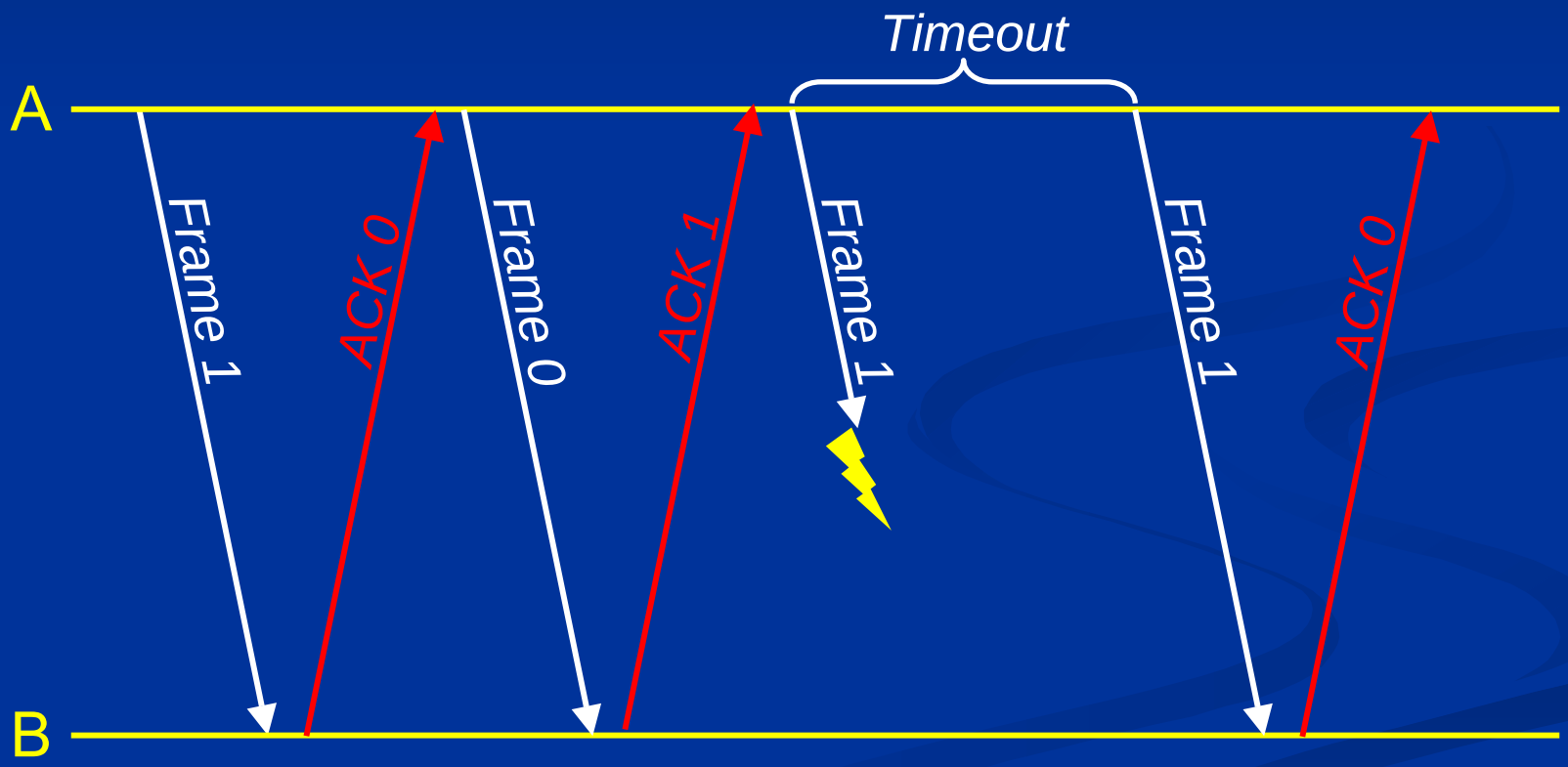
- The most common ARQ retransmission schemes:
  - Stop-and-Wait ARQ
  - Go-Back-N ARQ
  - Selective Repeat ARQ
- The protocol for sending ACKs in all ARQ protocols are based on the sliding window flow control scheme

Stop-and-Wait ARQ

- **Stop-and-Wait ARQ** is an addition to the Stop-and-Wait flow control protocol:
  - Frames have 1-bit sequence numbers (*SN* = 0 or 1)
  - Receiver sends an *ACK (1-SN)* if frame *SN* is correctly received
  - Sender waits for an *ACK (1-SN)* before transmitting the next frame with sequence number *1-SN*
  - If sender does not receive anything before a timeout value expires, it retransmits frame SN

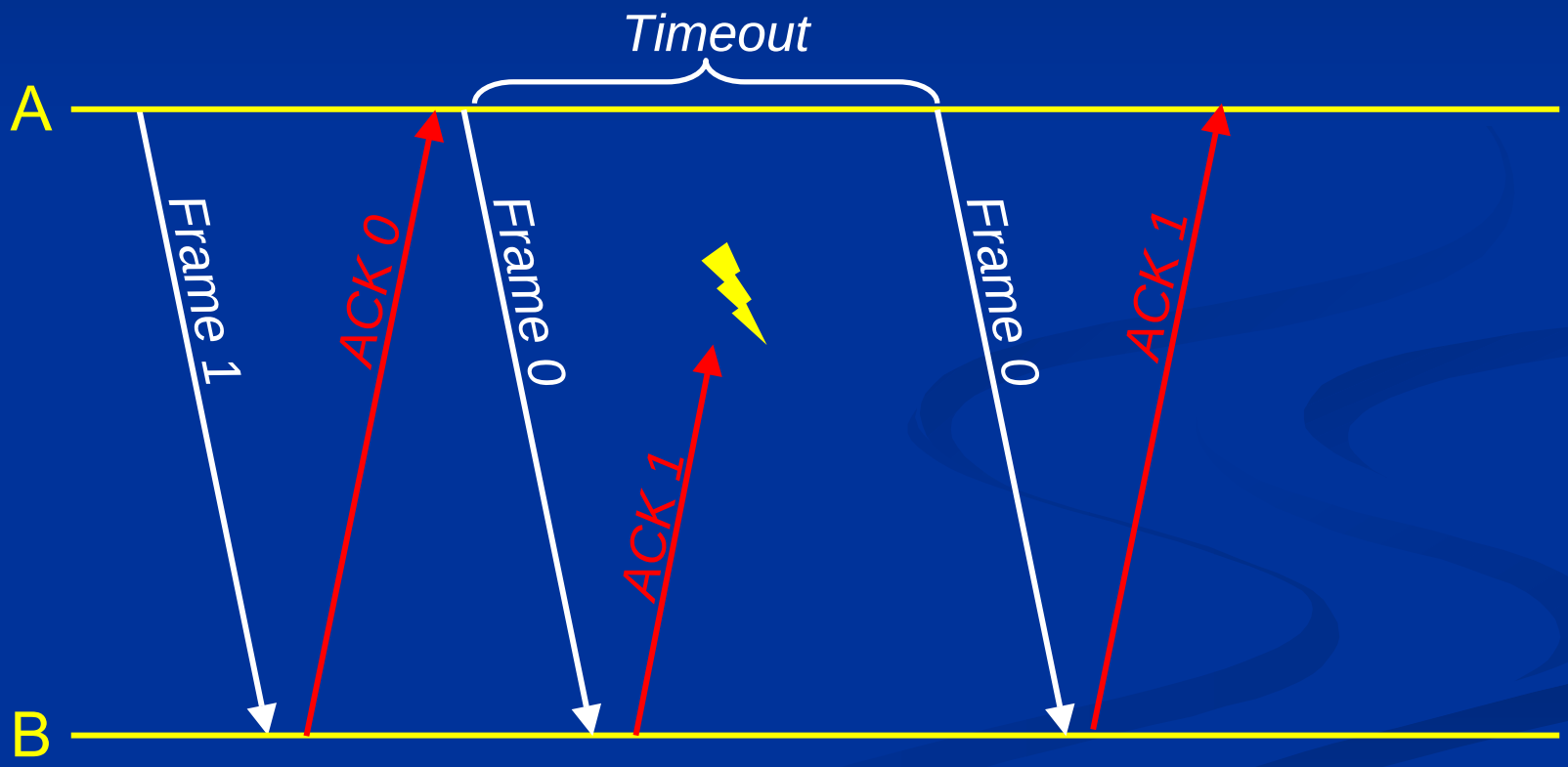
Stop-and-Wait ARQ

- Lost Frame



Stop-and-Wait ARQ

- Lost ACK

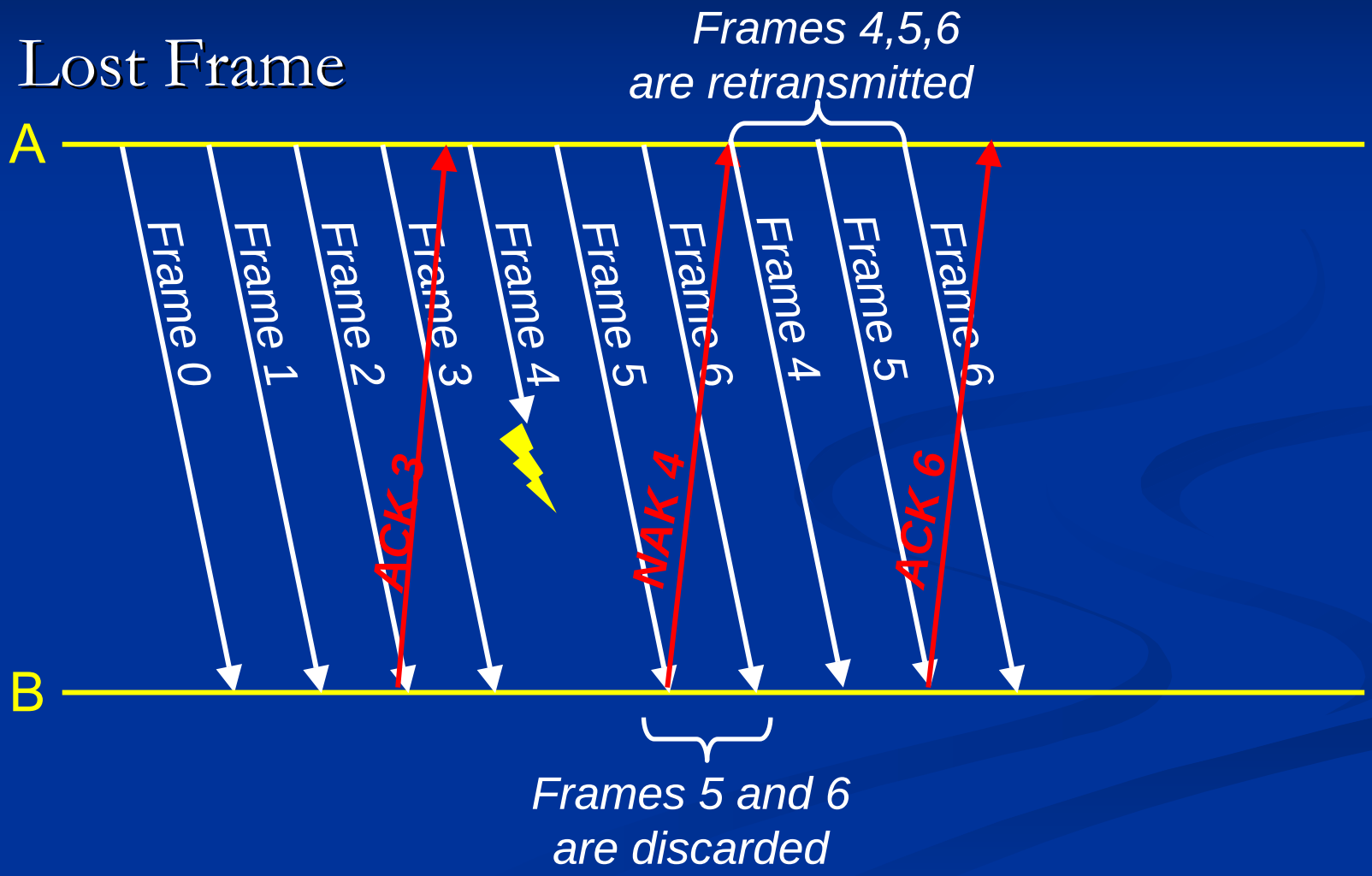


Go-Back-N ARQ

- Go-Back-N uses the sliding window flow control protocol. If no errors occur the operations are identical to Sliding Window
- Operations:
  - A station may send multiple frames as allowed by the window size
  - Receiver sends a ***NAK i*** if frame ***i*** is in error. After that, the receiver discards all incoming frames until the frame in error was correctly retransmitted
  - If sender receives a ***NAK i*** it will retransmit frame ***i*** and all packets ***i+1, i+2,...*** which have been sent, but not been acknowledged.

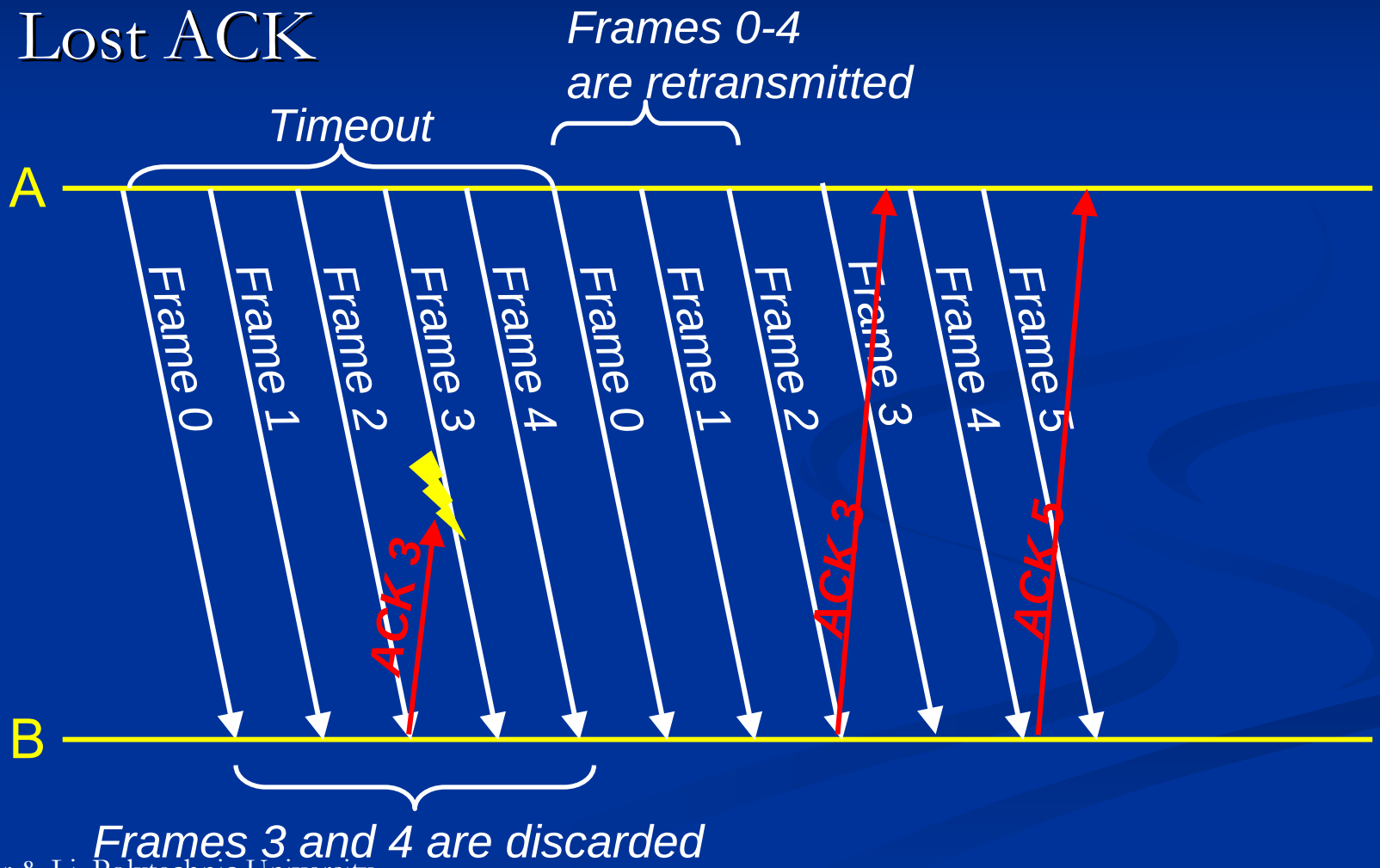
Go-Back-N ARQ

- Lost Frame

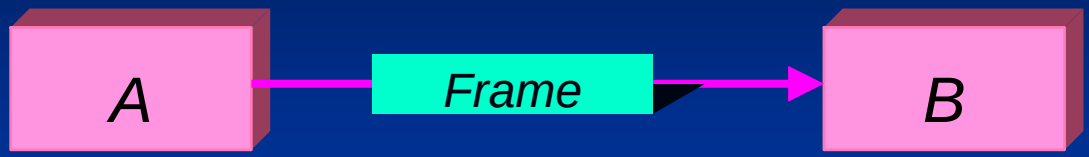


Go-Back-N ARQ

- Lost ACK



Details Go-Back-N ARQ



- Scenario 1:
  A transmits *frame i*, and B detects error in *frame i*, but has received *frames i-1, i-2,...* correctly

  ➔ B sends **NAK***i*

- Scenario 2:
  Frame i is lost or B does not recognize *frame i*
  Assume that A sends *frame i+1* and B receives it

  ➔ B sends **NAK***i*, or A will timeout and retransmit *frame i* and all subsequent frames

Details Go-Back-N ARQ

Scenario 3: B receives *frame i* and sends **ACK***(i+1)* which is lost

➔ B may send an **ACK(***i+k)* later which also acknowledges all frames $<i+k$ (**ACK**s are "cumulative")

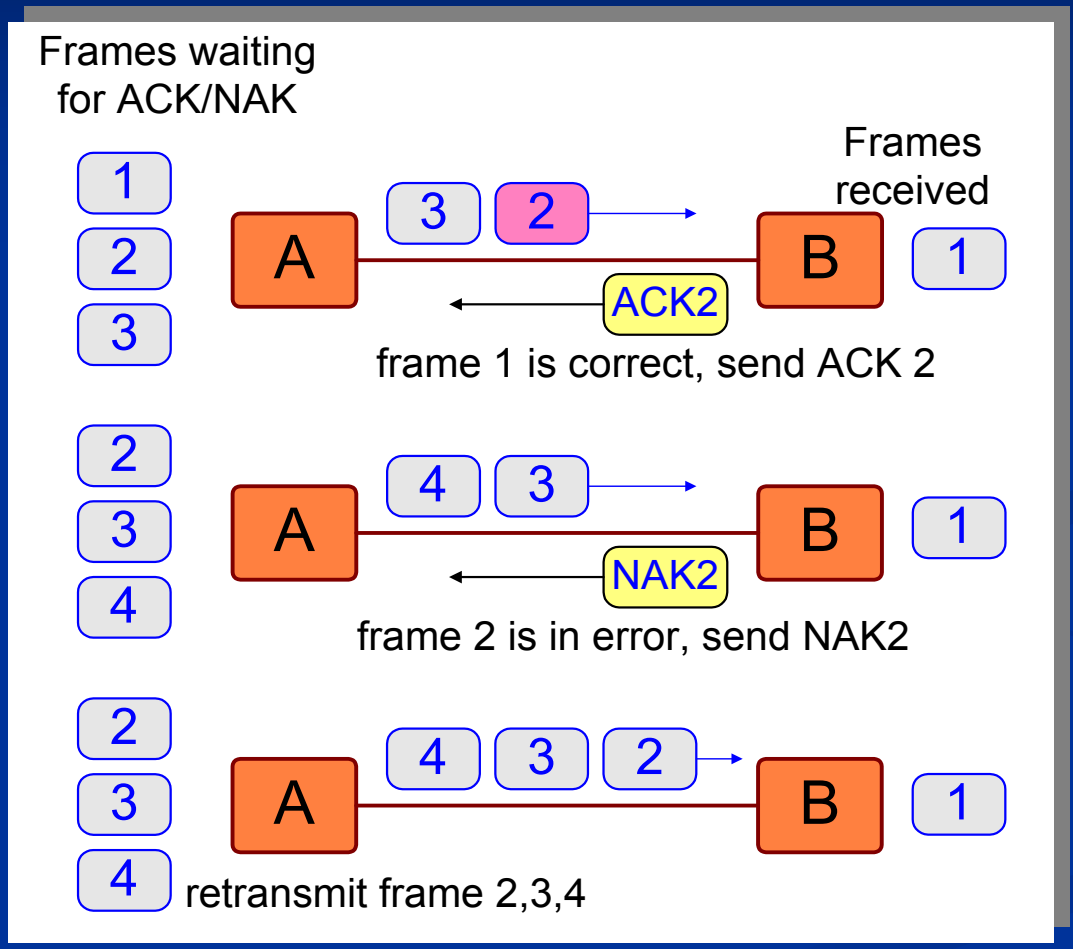
or

A retransmits *frame i* and all subsequent frames

Scenario 4: NAK*i* is lost

➔ A will eventually time out

Example of Go-Back-N ARQ



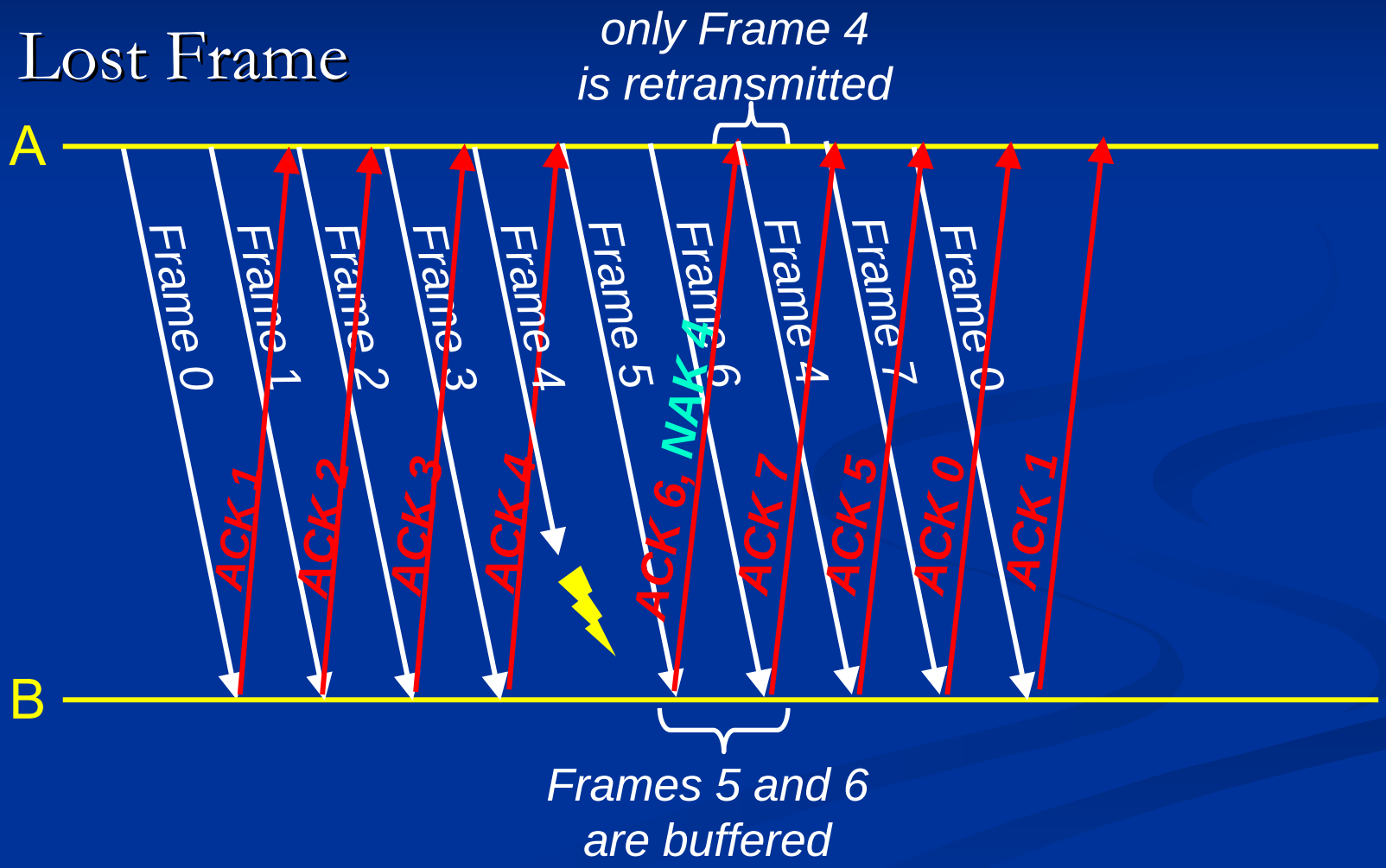
- In Go-back-N, if frames are correctly delivered, they are delivered in the correct sequence.
- Therefore, the receiver does not need to keep track of `holes' in the sequence of delivered frames.

Selective-Repeat ARQ

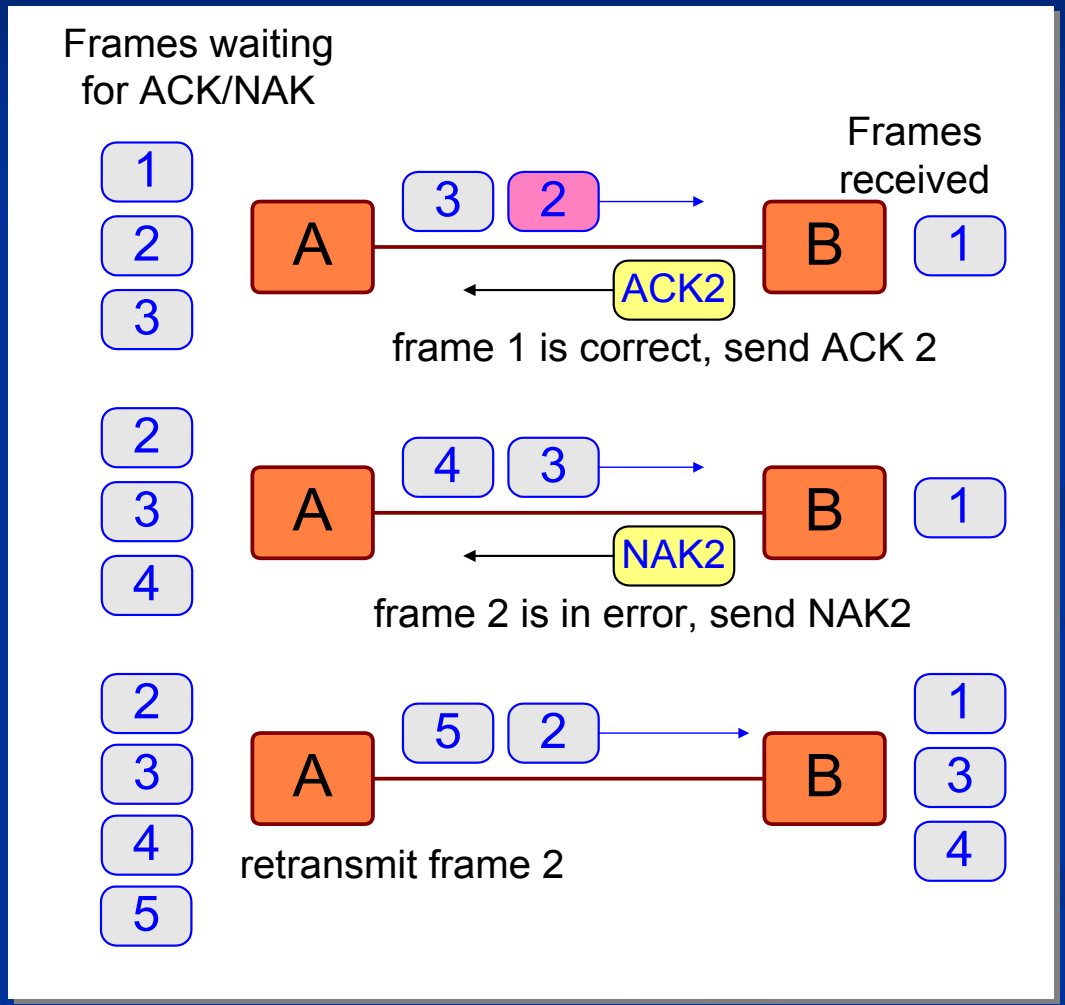
- Similar to Go-Back-N ARQ. However, the sender only retransmits frames for which a **NAK** is received
- **Advantage over Go-Back-N:**
  - Fewer Retransmissions.
- **Disadvantages:**
  - More complexity at sender and receiver
  - Each frame must be acknowledged individually (no cumulative acknowledgements)
  - Receiver may receive frames out of sequence

Selective-Repeat ARQ

- Lost Frame



Example of Selective-Repeat ARQ



- Receiver must keep track of `holes' in the sequence of delivered frames
- Sender must maintain one timer per outstanding packet