Computer Networks

Data Link Control Protocols

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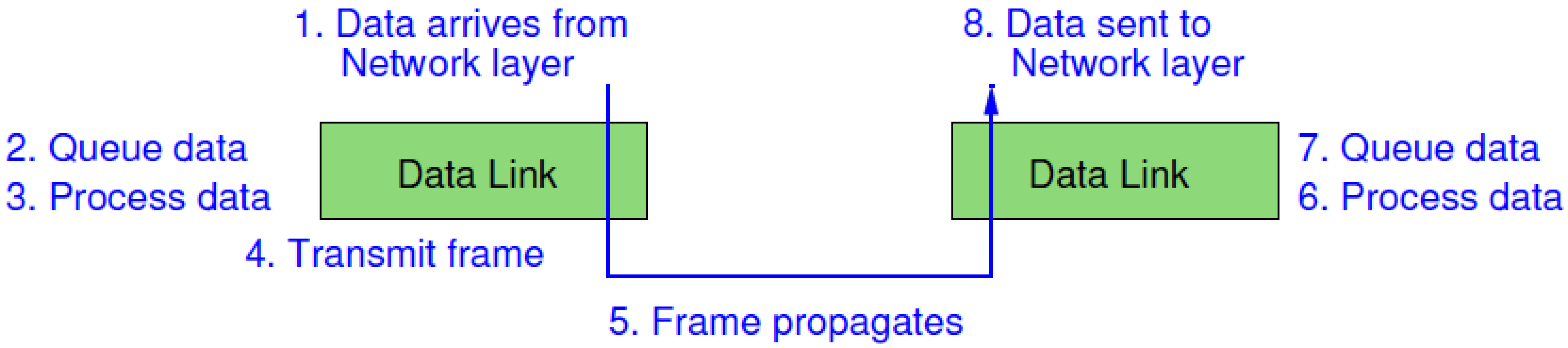
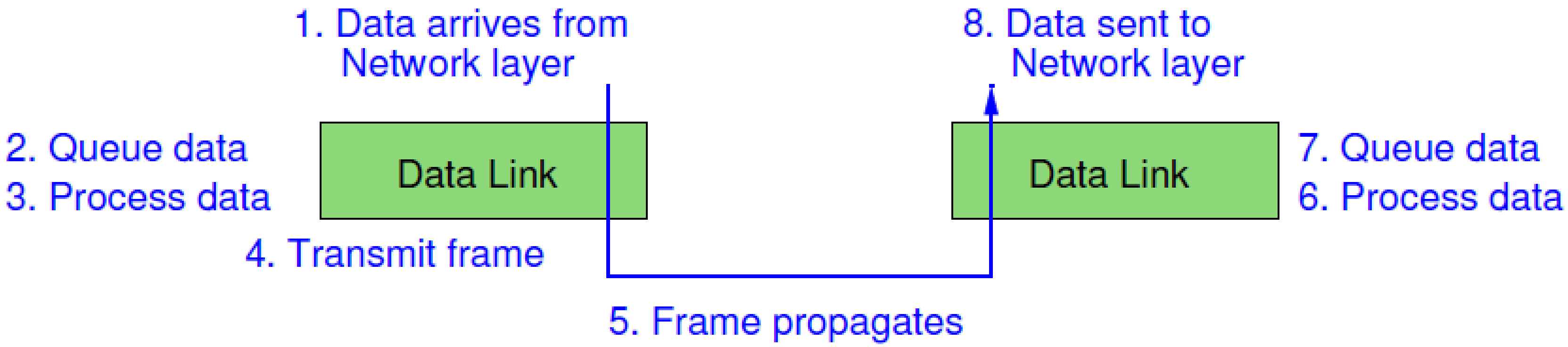
Flow Control

Flow Control



- Flow control assures that a transmitting entity does not overwhelm a receiving entity with data
  - If the transmitter transmits too fast, then the receiver buffer may overflow
    - This may lead to data loss, retransmission, and performance reduction
  - Assumptions:
    - All transmitted frames are successfully received
    - No frames are lost and none arrive with error
    - Transmitted frames suffers from an arbitrary and variable amount of delay

Flow Control

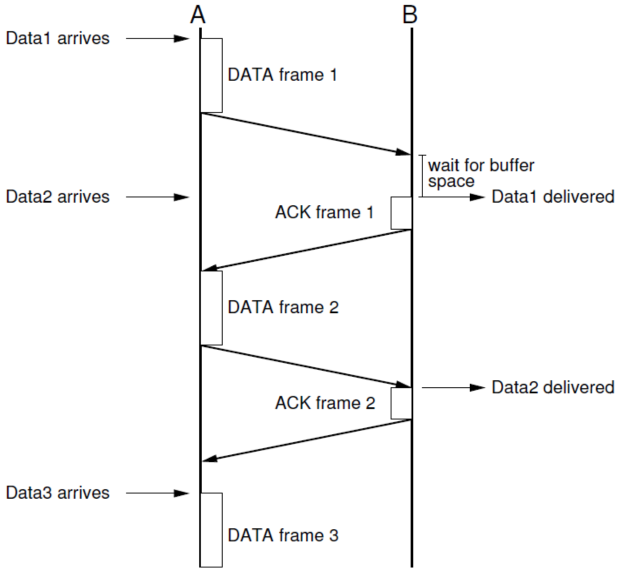


- Flow control:
    - Stop and Wait Flow Control
    - Sliding Window Flow Control

Stop and Wait Flow Control

- Source:
  - Source transmits a DATA frame
  - Source waits for ACK frame before sending next DATA frame

- Destination:
  - Destination receives DATA frame → replies back with an ACK if ready to accept more data
  - Destination can stop flow of data by withholding ACK

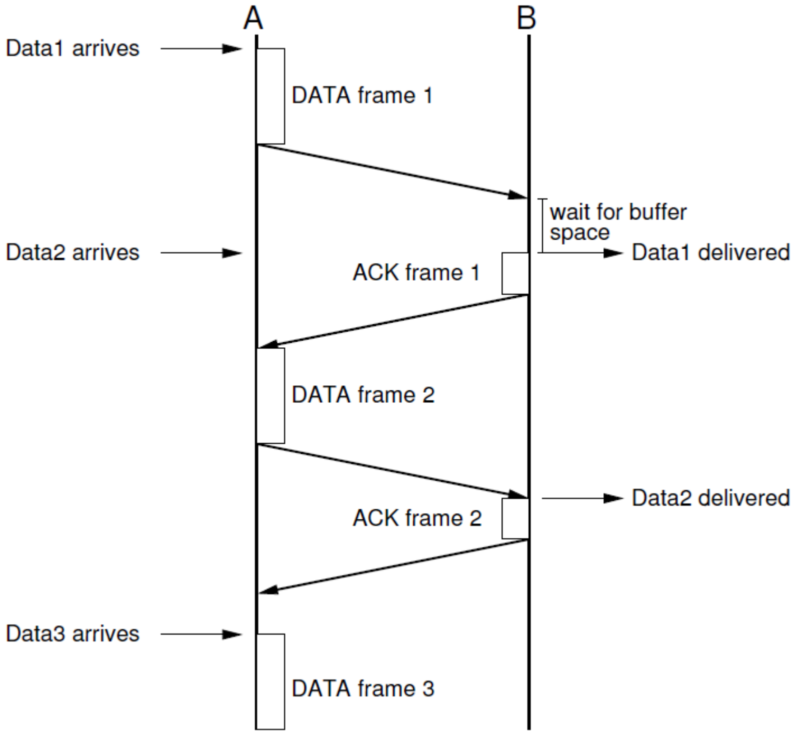


Efficiency Calculation

$$\eta = \frac{\text{Data}}{\text{Data} + \text{Hdr} + \text{Ack} + 2 \times \text{Prop}}$$

$$a = \frac{\text{Propagation Time}}{\text{Transmission Time}}$$

$$\boxed{U = \frac{1}{1 + 2a}}$$



Sliding Window Flow Control

- Stop-and-wait allows only 1 frame to be in transit at a time
  - Leads to serious inefficiencies especially when the frame size is small
  - Efficiency can be greatly improved by allowing multiple frames to be in transit at a time → which is the idea of Sliding-window flow control

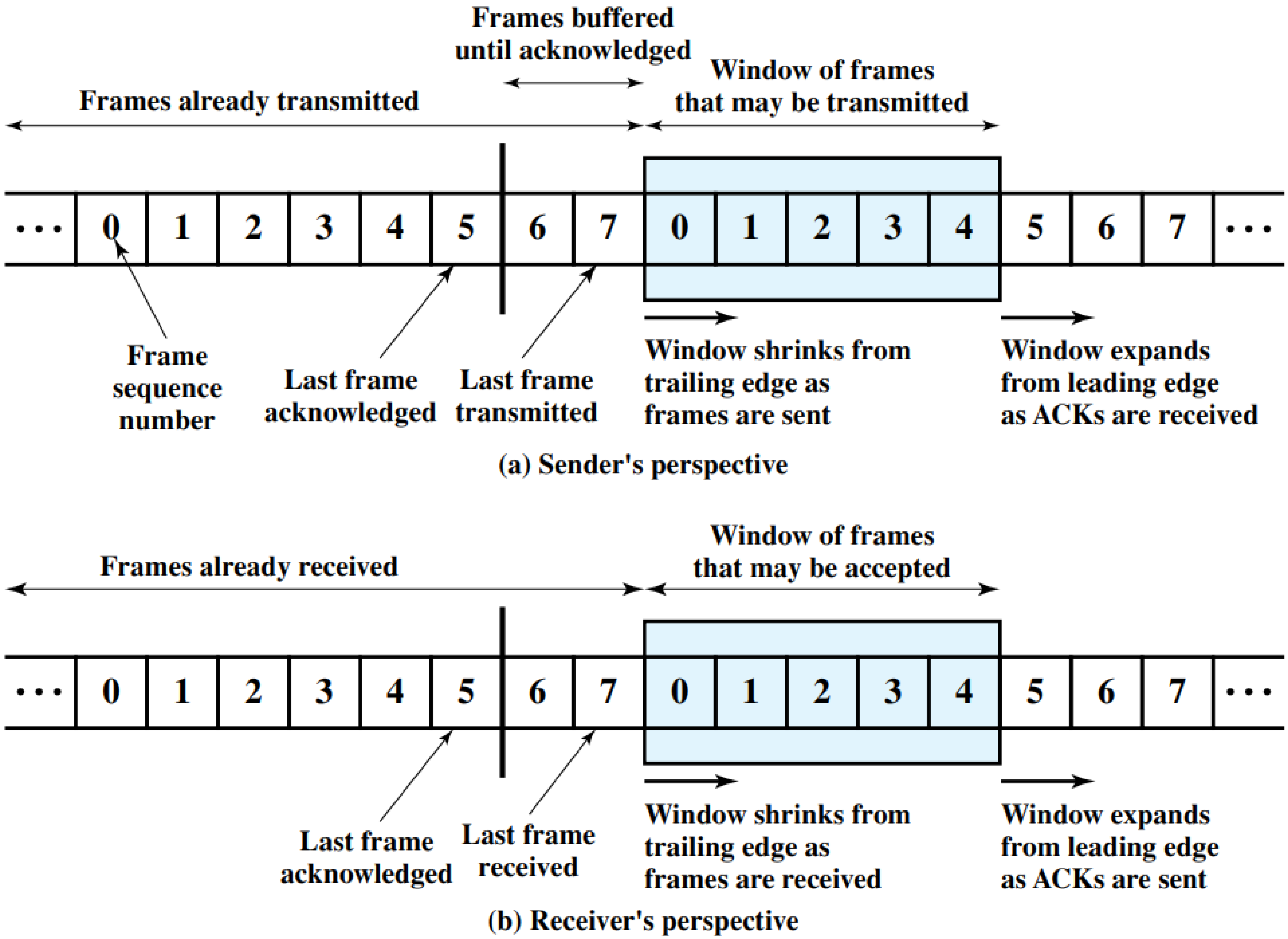
Sliding Window Flow Control

- Receiver allocates a buffer space of W frames
- Sender can send up to W frames without waiting for an ACK

- Each frame is labeled with a sequence number
  - Frames are numbered modulo 2^k
  - Giving max window size of up to $2^k – 1$ (will learn during error control)

- Receiver acknowledges a frame by sending an ACK (or Receiver Ready, RR)
- ACK includes the sequence number of the next frame expected
  - ACK also implicitly says that the receiver can receive the next W frames

Sliding Window Flow Control



Frames buffered until acknowledged
Frames already transmitted
Window of frames that may be transmitted
··· 0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7 ···
Frame sequence number
Last frame acknowledged
Last frame transmitted
Window shrinks from trailing edge as frames are sent
Window expands from leading edge as ACKs are received
Frames already received
Window of frames that may be accepted
··· 0 1 2 3 4 5 6 7 0 1 2 3 4 5 6 7 ···
Last frame acknowledged
Last frame received
Window shrinks from trailing edge as frames are received
Window expands from leading edge as ACKs are sent

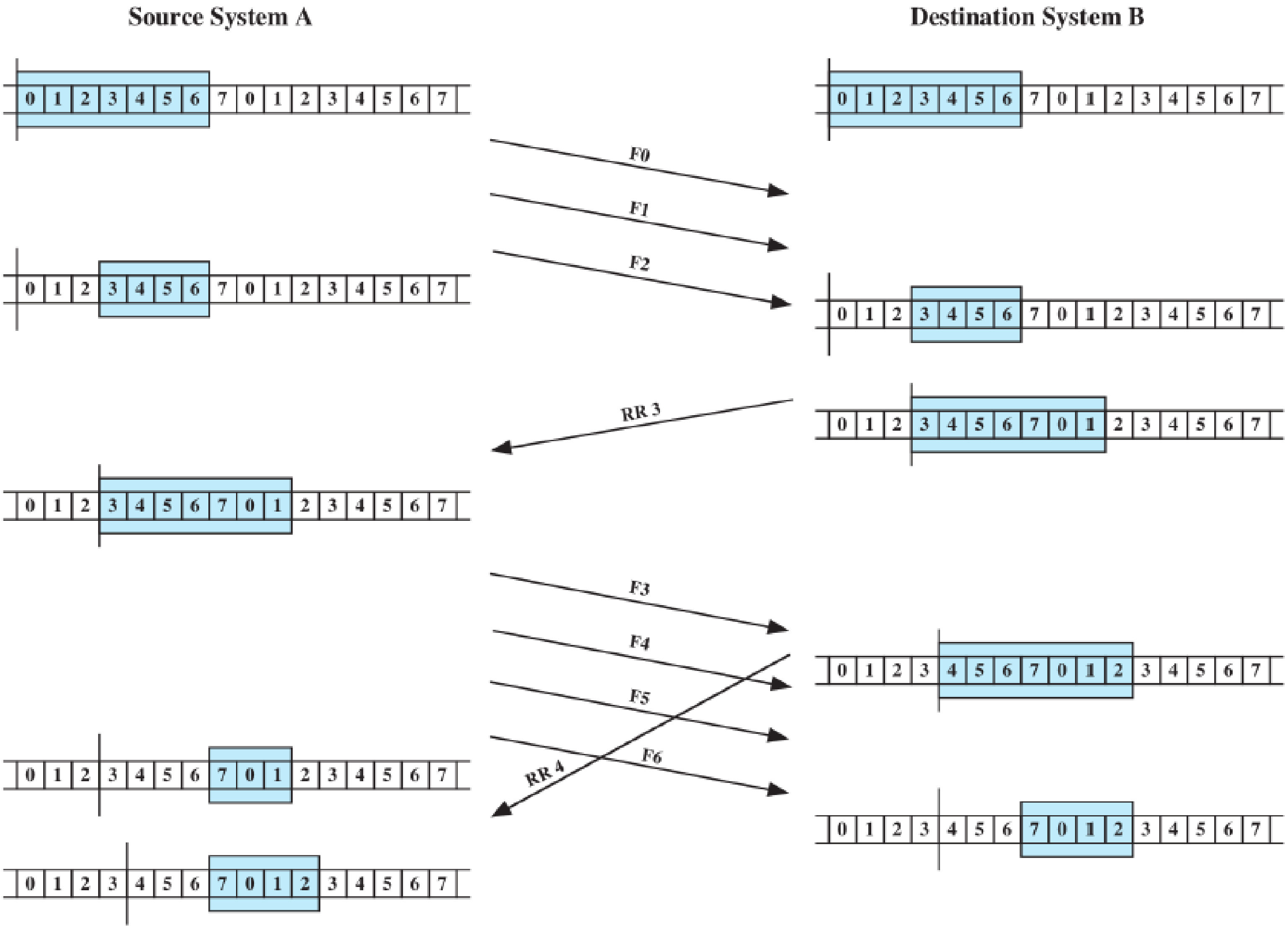
(a) Sender's perspective

(b) Receiver's perspective

Sliding Window Flow Control

- Sender and Receiver record:
  - Last frame acknowledged
  - Last frame transmitted (in case of sender) or received (in case of receiver)
  - Window of frames that may be transmitted (in case of sender) or received (in case of receiver)

Sliding Window Flow Control: Example

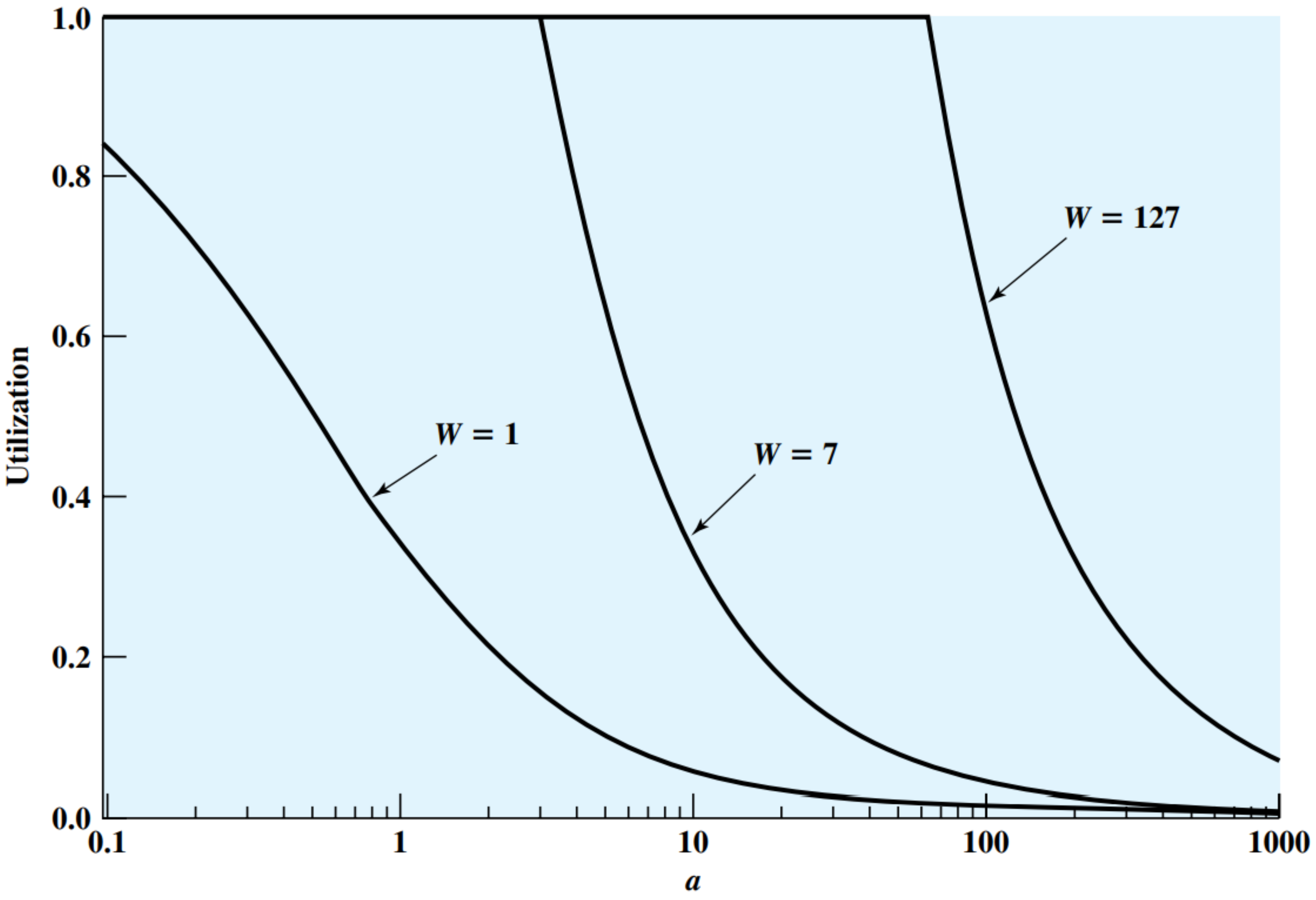


Sliding Window Flow Control

- Additional features:
  - Receive Not Ready (RNR): Receiver can ACK frames without permitting further transmission
  - RNR 5: received frames up to 4, but unable to accept any more
  - Must send a normal acknowledge to resume
  - Piggybacking: DATA frame includes sequence number of the frame and sequence number used for ACK (i.e. next expected frame number)
  - If a station has a DATA and ACK to send, it sends bot together → saves communication capacity
  - If the station has an ACK but no DATA to send, it sends normal ACK (RR or RNR)
  - If the station has DATA to send but no new ACK → repeats the last ACK seq. no.

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

Sliding Window Flow Control



Error Control

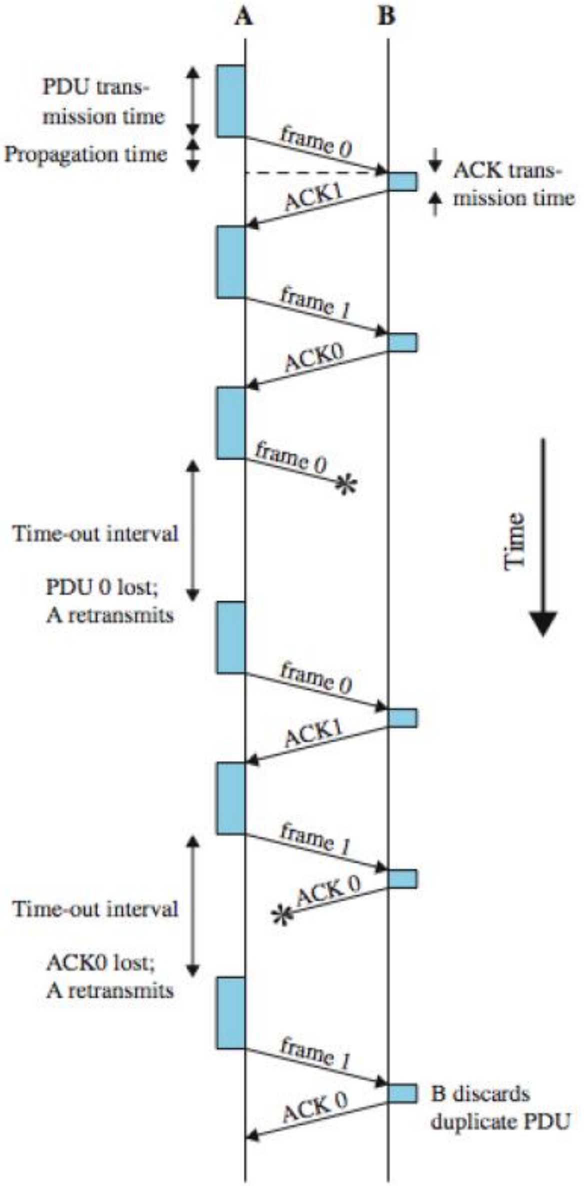
Error Control

- Two types of error
  - Lost frame: A frame fails to arrive at the other end
  - Damaged frame: A frame arrives at the destination, but few bits are damaged

- Automatic Repeat Request (ARQ):
  - Stop-and-wait ARQ
  - Go-back-N ARQ
  - Selective-reject ARQ

Stop-and-Wait ARQ

- Based on Stop-and-Wait flow control
- Source:
  - Source transmits single frame, waits for an ACK
  - It also starts a timer and maintains the copy
  - If ACK received, stop timer and transmit next frame
  - Sender has timeout → if no ACK within timeout, retransmit
- Destination:
  - Destination sends ACK if frame received correctly (with no errors)
  - If frame received is damaged, discard it

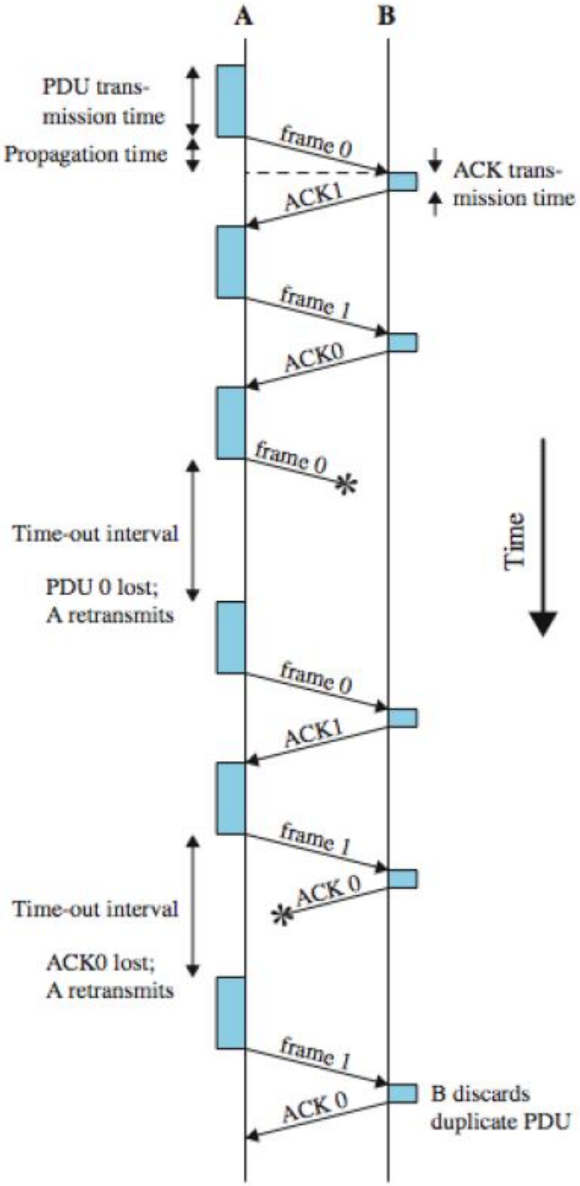


Stop-and-Wait ARQ

- Based on Stop-and-Wait flow control

- If ACK is damaged, transmitter will not recognize
  - Transmitter will retransmit after the timeout
  - Receiver gets two copies of frame
  - Solution: use 1-bit frame SEQ number and ACK0 / ACK1

- Stop-and-Wait ARQ is simple, but inefficient



Go-Back-N ARQ

- Based on Sliding Window flow control → Most commonly used error control

- Source:
  - Sender must go back and retransmit that frame and all subsequent frames
  - If no ACK received from Destination after timeout, the Source may send an ACKRequest or RR (with P bit = 1)
    - Alternately the sender can retransmit the previous frame asked by the receiver

- Destination:
  - If no error, the destination will ACK incoming frames as in sliding window
    - RR=receive ready, or piggybacked acknowledgment with sequence number of next expected frame
  - If the destination station detects an error in a frame, it may send a negative acknowledgment
    - REJ=reject with sequence number of next expected frame
  - Destination will discard that frame and all future frames until the frame in error is received correctly
  - Upon receipt of ACKRequest, the Destination sends a normal ACK

- Max window size = $2^k – 1$ (for a k-bit sequence number)

Selective Reject ARQ

- Also called selective retransmission
- Only rejected or timeout frames are retransmitted
- Subsequent frames are accepted by the receiver and buffered

- Pros:
  - Minimizes retransmission

- Cons:
  - Receiver must maintain large enough buffer to store out-of-order frames
  - More complex logic in transmitter

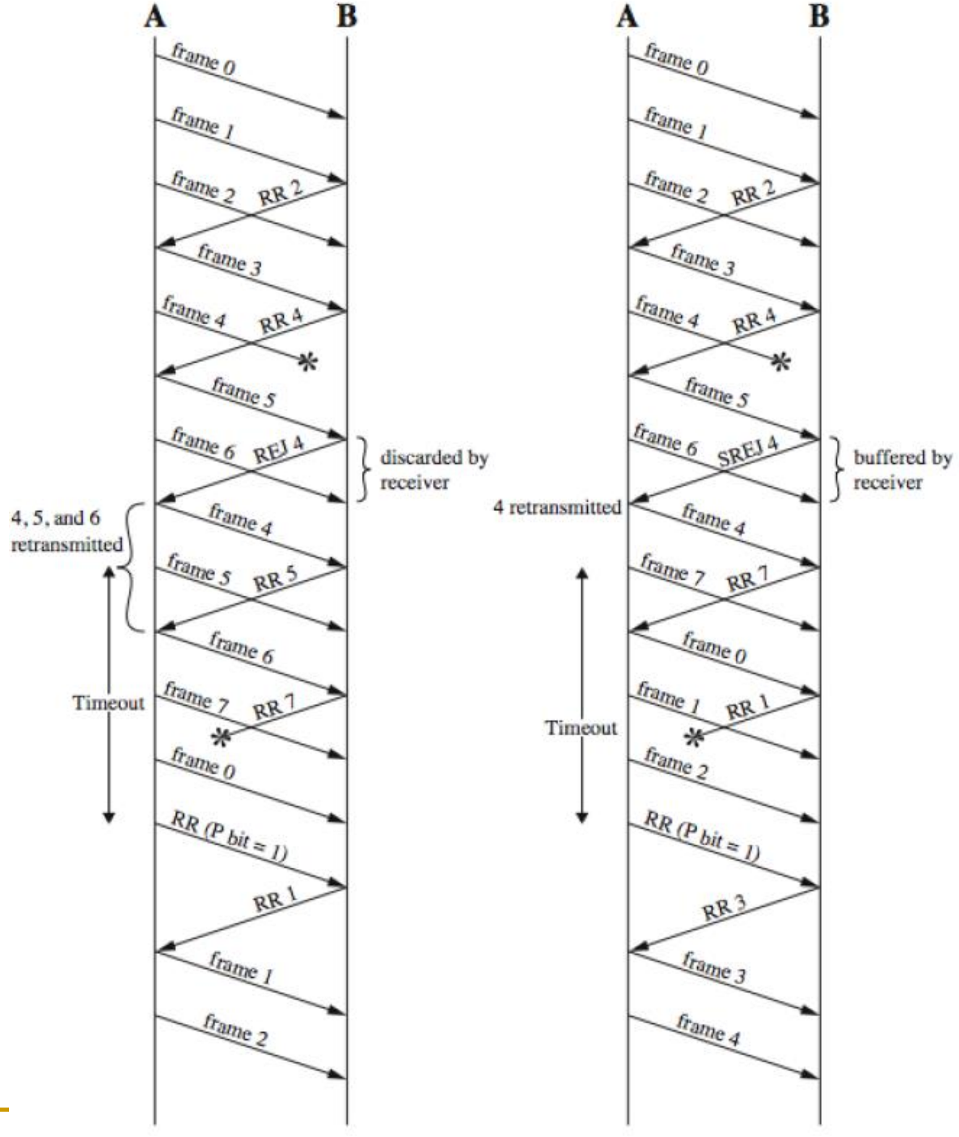
- Less widely used
- Useful for satellite links with long propagation delays

- Max window size = 2^{k-1}

Comparison

- Go-back-N ARQ:
  - Max window size = $2^k - 1$

- Selective-reject ARQ:
  - Max window size = 2^{k-1}



(a) Go-back-N ARQ

(b) Selective-reject ARQ

Go-Back-N ARQ

- A k-bit sequence number provides a sequence number range of 2^k
  - However the maximum window size is limited to $2^k - 1$

- Let’s assume that the data are being exchanged in both directions

- As a case of 3-bit sequence number (i.e. sequence number space is 8)

- Suppose sender sends frame 0 and gets back an RR 1
- Then sends frames 1, 2, 3, 4, 5, 6, 7, 0 and gets another RR 1

- This could mean that all eight frames were received correctly and the RR 1 is a cumulative acknowledgment
- It could also mean that all eight frames were damaged or lost in transit, and the receiving station is repeating its previous RR 1
- The problem is avoided if the maximum window size is limited to 7, i.e. $2^3 - 1$

- Max window size = $2^k – 1$ (for a k-bit sequence number)

Selective Reject ARQ

- Window size limitation is more restrictive for selective-reject than for go-back-N
- Consider the case of a 3-bit sequence number size for selective-reject
  - Sender sends frames 0 through 6
  - Receiver receives all seven frames and cumulatively acknowledges with RR 7
  - Because of a noise burst, the RR 7 is lost
  - Sender times out and retransmits frame 0
  - Receiver has already advanced its receive window to accept frames 7, 0, 1, 2, 3, 4, and 5
  - It assumes that frame 7 has been lost and that this is a new frame 0, which it accepts
- The problem is that there is an overlap in between the sending and receiving window
  - To overcome the problem, the maximum window size should be no more than half the range of sequence numbers
- Max window size = 2^{k-1} (for a k-bit sequence number)

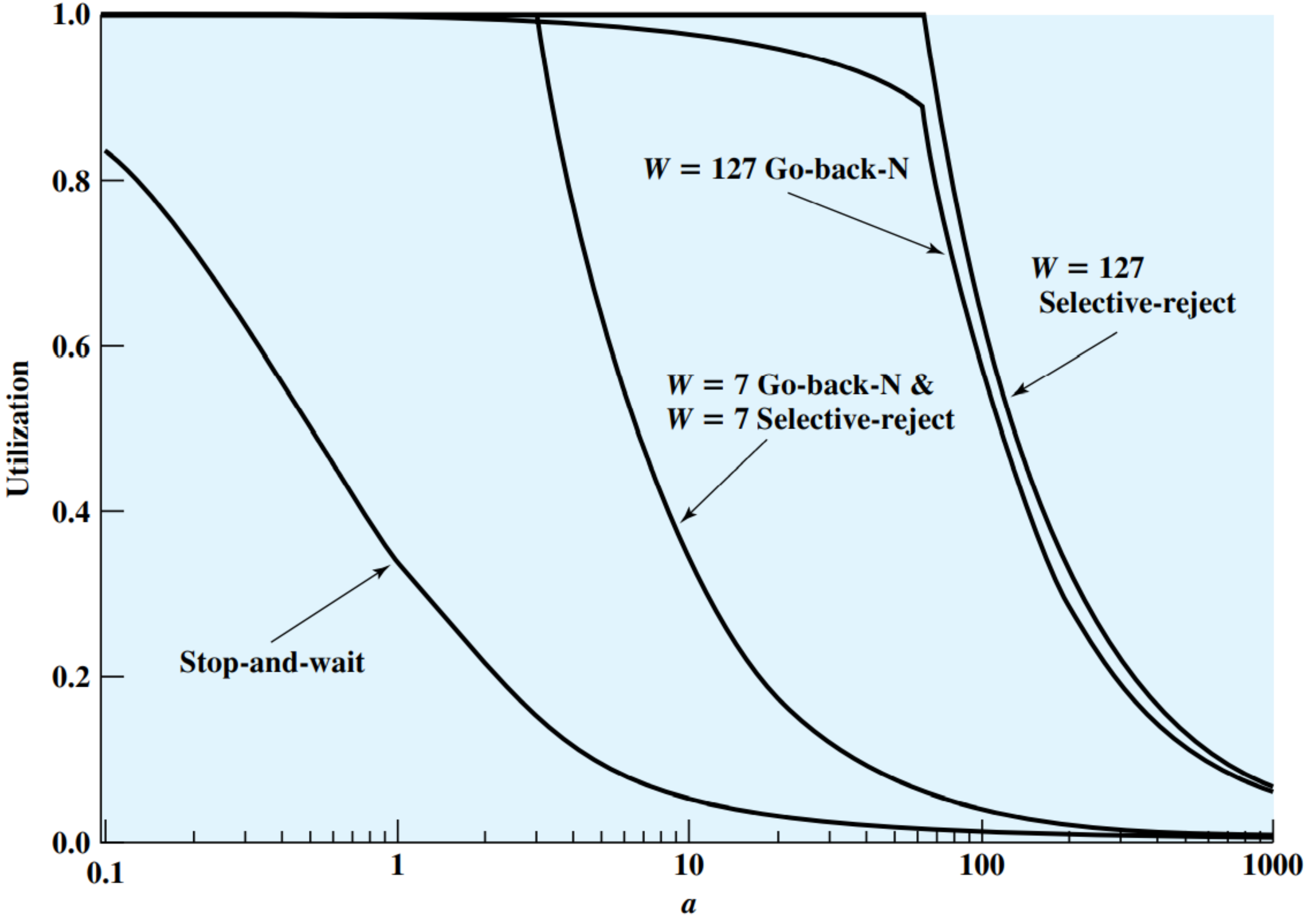
Comparison

Stop-and Wait: $U = \dfrac{1 - P}{1 + 2a}$

Selective Reject: $U = \begin{cases} 1 - P & W \geq 2a + 1 \\ \dfrac{W(1 - P)}{2a + 1} & W < 2a + 1 \end{cases}$

Go-back-N: $U = \begin{cases} \dfrac{1 - P}{1 + 2aP} & W \geq 2a + 1 \\ \dfrac{W(1 - P)}{(2a + 1)(1 - P + WP)} & W < 2a + 1 \end{cases}$

Comparison


1.0
0.8
0.6
0.4
0.2
0.0
Utilization
0.1
1
10
100
1000
a
W = 127 Go-back-N
W = 127
Selective-reject
W = 7 Go-back-N &
W = 7 Selective-reject
Stop-and-wait

THANK YOU

QUESTIONS???