Part I Syllabus

Date	Subject	File
Week 1: 9/Jan/2023 11/Jan/2023	Introduction: course logistics and Internet history	M1-L1-Introduction.pptx
	Layered Network Architecture	First part of M1-L2-Network Layer & Physical Resilience.pptx
Week 2: 16/Jan/2023 18/Jan/2023	Physical Layer: Network Resilience	Second part of M1-L2-Network Layer & Physical Resilience.pptx
	Data link layer – Flow control	M1-L3-DLL-Flow Control.pptx
Week 3: 25/Jan/2023	Data link layer – Error control	M1-L4-DLL-Error Control.pptx
Week 4: 30/Jan/2023 01/Feb/2023	Local area network – Introduction	M1-L5-LAN-Introduction.pptx
	Local area network – MAC	M1-L6-LAN-MAC.pptx
Week 5: 06/Feb/2023 08/Feb/2023	Local area network – Ethernet	First part of M1-L7-LAN-Ethernet.pptx
	Local area network – Ethernet Evolutions	Second part of M1-L7-LAN-Ethernet.pptx
Week 6: 13/Feb/2023 15/Feb/2023	Local area network – WLAN	M1-L8-LAN-WLAN.pptx
	Network paradigms	M1-L9-Paradigms.pptx

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Additional Materials

- **The related content talked today in https://eclass.teicrete.gr/modules/document/file.php/TP326/%CE%98%CE%B5%CF%89%CF%81%CE%AF%CE%B1%20(Lectures)/Computer_Networking_A_Top-Down_Approach.pdf is as follow:**
  - Error detection: P438 - P445
  - Automatic Repeat Request (ARQ): P207 – P230

- **You can also find other video materials about**
  - Error detection Error Detection - YouTube
  - Stop-and-Wait ARQ Stop-and-Wait ARQ Protocol - YouTube
  - Go-Back-N ARQ Go-Back-N ARQ - YouTube
  - Selective Reject ARQ Selective Repeat ARQ - YouTube

Chat over Unreliable Network

Lecture 4
Data Link Layer (DLL): Error Control

Contents

- **Error Detection**
  - Parity Check
  - CRC
- **Automatic Repeat ReQuest (ARQ)**
  - Stop-and-Wait ARQ
  - Go-Back-N ARQ
  - Selective Reject ARQ

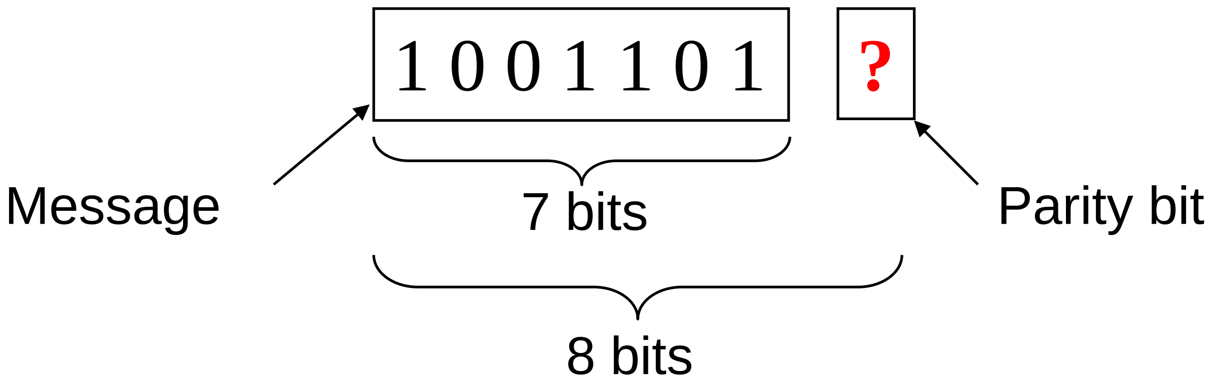
Error Control in Data Link Layer

- **Objective**
  - To detect and correct errors that occur in frame transmission
- **Frame Error in Data Link Layer (DLL)**
  - Lost Frame: the receiver does not receive a frame (or the header was corrupted such that the frame was not recognizable)
  - Damaged Frame: the receiver receives a frame, but some of its bits are in error

Error Detection Techniques

Error Detection: Parity Check

Parity Check (Odd/Even Parity): A single bit is appended to the original message (usually 7-bit) to describe the message characteristics.



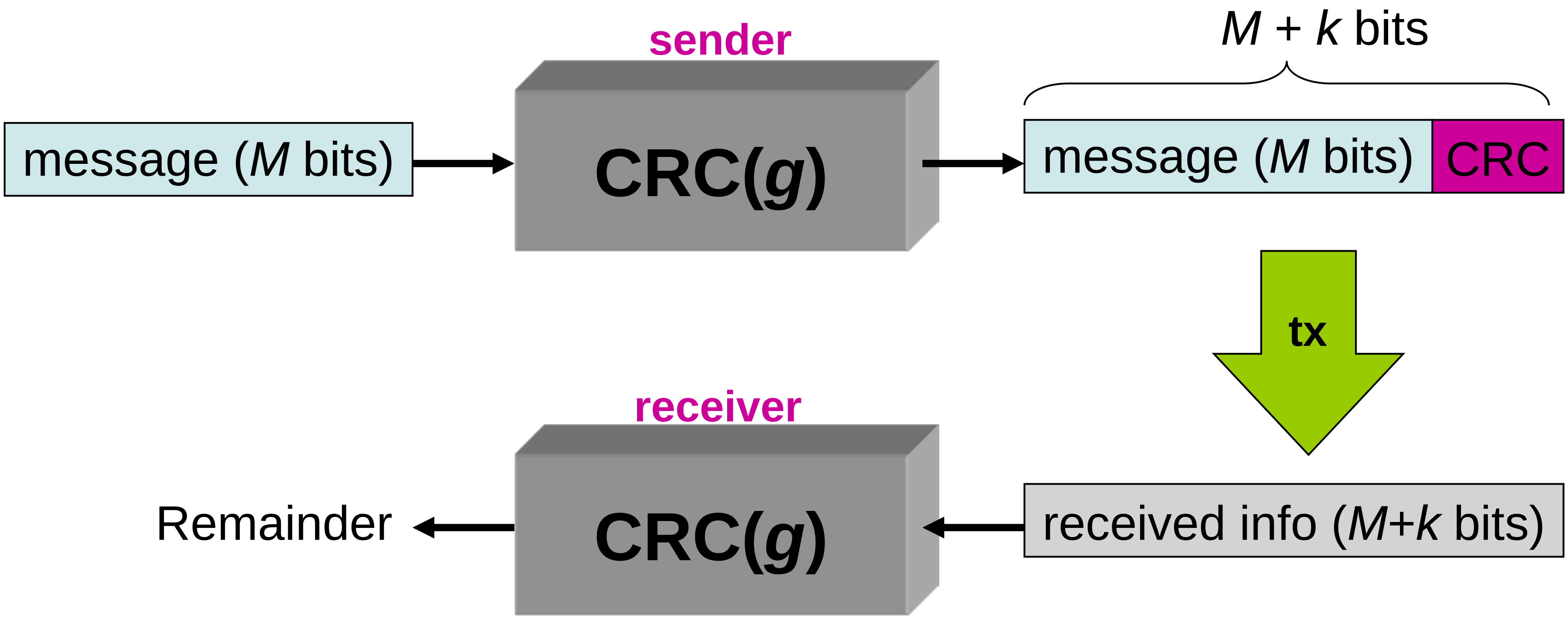
Even Parity: The total number of 1s is even, ie. 10011010

Odd Parity: The total number of 1s is odd, ie. 10011011

☹ However, Parity Check can only detect odd numbers of errors!

Error Detection: CRC

Cyclic Redundancy Check (CRC): multiple parity bits are appended to the original message.



(Remainder = 0 indicates no error)

Error Correction Technique: Automatic Repeat Request (ARQ)

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Error Correction Techniques

- **Forward Error Correction (FEC)**
  - Send more redundant bits in the message
  - Example: Hamming code, Reed-Solomon code
- **Automatic Repeat Request (ARQ)**
  - **<u>Retransmission after timeout</u>**: The source retransmits a frame when an expected ACK fails to return within a predetermined time duration
  - **<u>Retransmission when requested</u>**: The destination replies a negative ACK to inform the source about an error. The source then retransmits the corrupted frames accordingly.

ARQ Variants

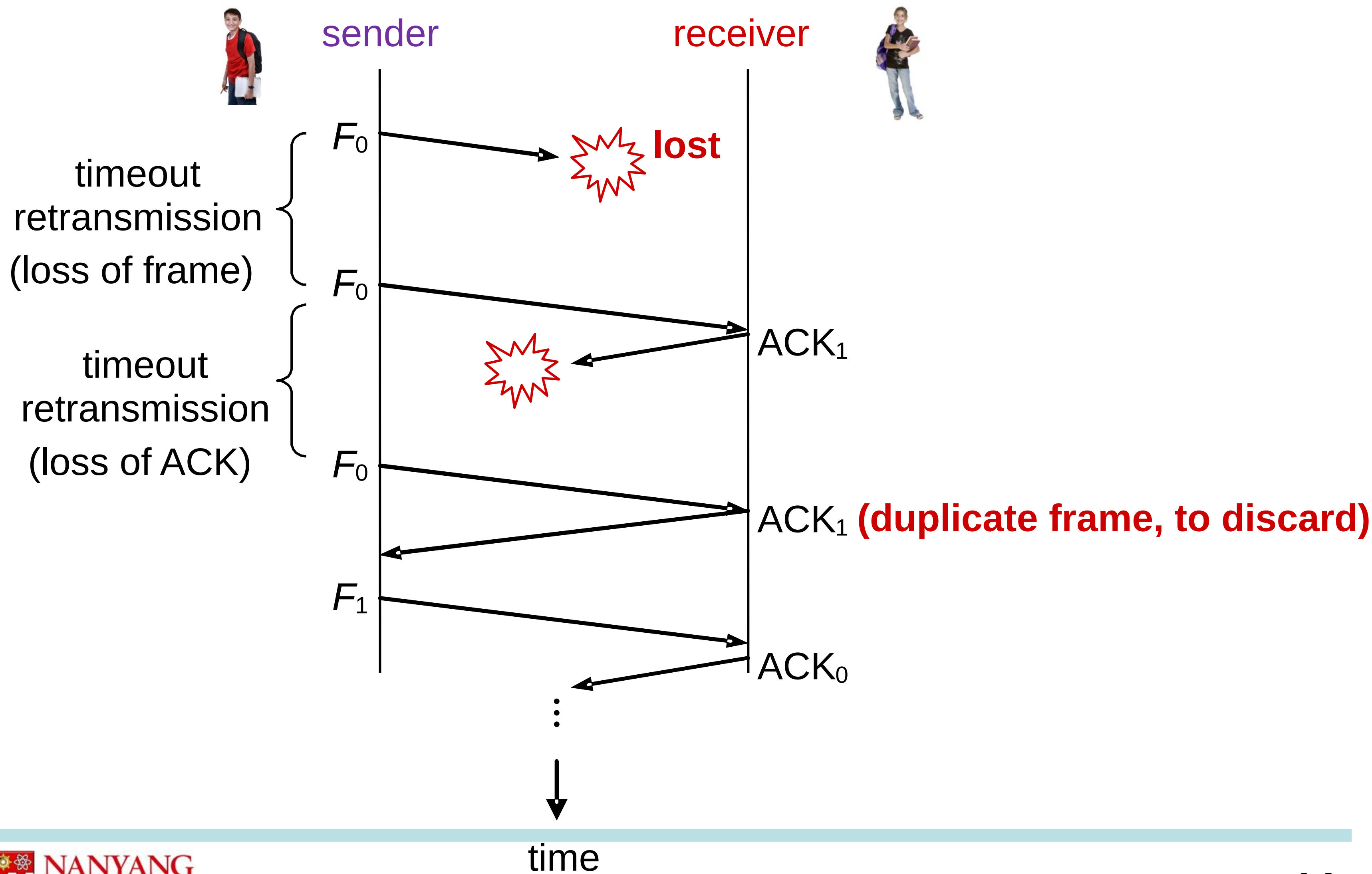
- **Commonly implemented ARQ mechanisms:**
  - **Stop-and-Wait ARQ**
  - **Sliding Window - Go-back-N ARQ:**

    Frames are accepted strictly in the sequence.
  - **Sliding Window - Selective-Reject ARQ:**

    Sometimes called "Selective Repeat ARQ". Frames which arrive out of sequence (but are within the open window at the receiver) are accepted.

Flow Control
- **Stop-and-Wait**
  - **Stop-and-Wait**
- **Sliding Window**
  - **Go-back-N**
  - **Selective Reject**

Stop-and-Wait ARQ: Illustration



Stop-and-Wait ARQ (Protocol)

- **Source: transmits a single frame and waits for ACK.**
- **Destination:**
  - ➢ **Frame received correctly - send an ACK.**
  - ➢ **Damaged frame received - There are two variations:**
    - – **Discard it, and do nothing else.**
    - – **Send a NAK (negative acknowledgement).**
- **Source:**
  - ➢ **If ACK is received properly, transmit next frame.**
  - ➢ **If NAK is received, retransmit the same frame.**
  - ➢ **If no ACK is received within timeout, transmitter timeouts, and retransmits the same frame.**
  - ➢ **If ACK is damaged, transmitter will not recognize it, transmitter will timeout and retransmit the same frame. Receiver gets two copies of the same frame, discard one.**

Stop-and-Wait ARQ: Performance

$$\text{Throughput (U) (Link Utilization)} = \frac{\text{The time that the link carries useful information}}{\text{The total time}} = \frac{T_{frame}}{T_{cycle}}$$

$$U_{SaW}^{ARQ} = \frac{1}{1+2a}\Pr\{\text{no error}\} + 0 \cdot \Pr\{\text{frame error}\}$$

$$= \frac{1}{1+2a}(1-P) + 0 \cdot P$$

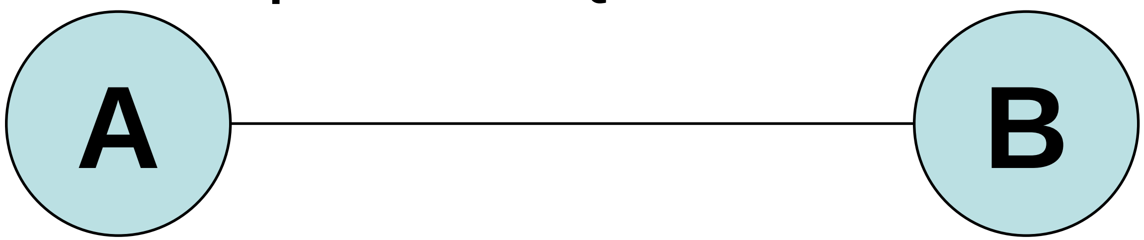
$$= \frac{1-P}{1+2a}$$

P: Frame loss probability

a: normalized prop. delay

Example

A communication link exists between two nodes A and B. The transmission rate on the link is 2.4 Mbps. The distance between A and B is 50 *km* and the signal velocity is $2\text{x}10^8$ *m/s*. The frame length is 300 bytes. Frame loss probability is 0.1. Calculate the link unitization for the stop-&-wait ARQ mechanism.



R= 2.4 Mbps, L=300 bytes =2400bits

H=50km, v = $2\text{x}10^8$ *m/s*

P=0.1

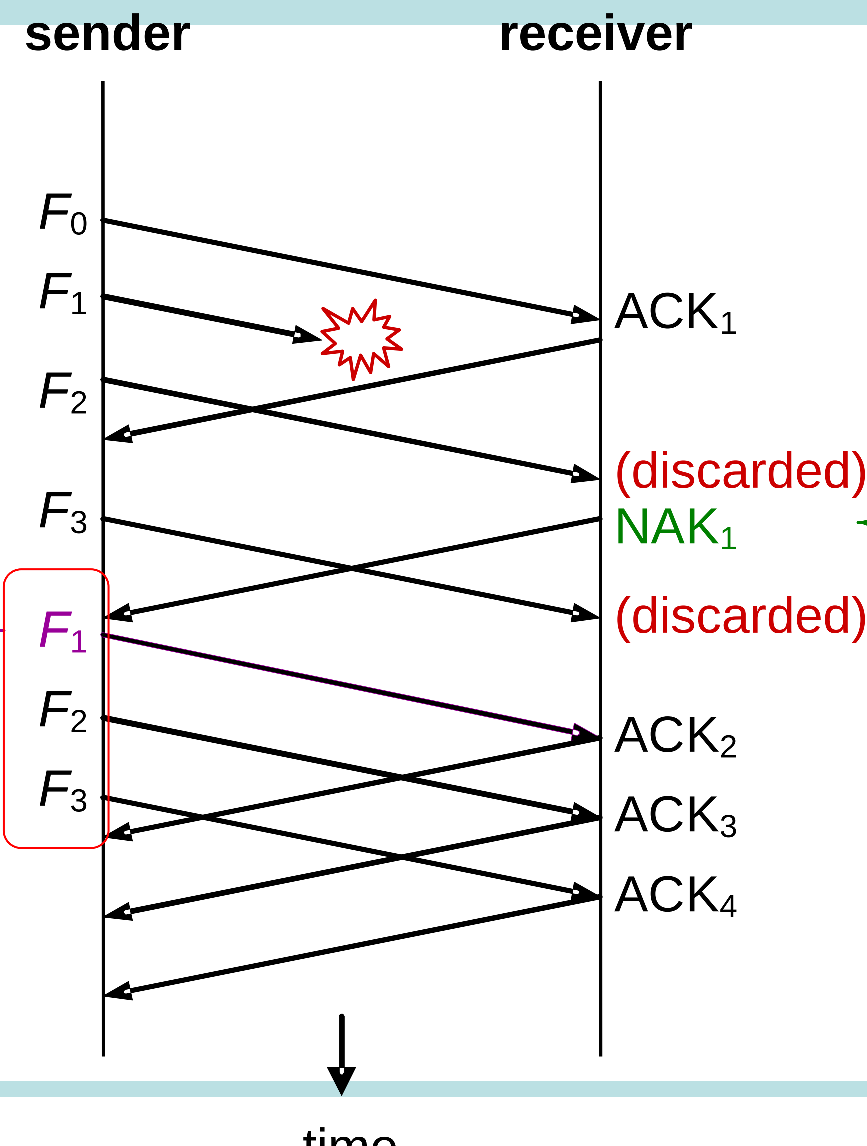
$U=(1-P)/(1+2\mathbf{a}) \longrightarrow a = \mathbf{T_p/T_f} \longrightarrow T_p=H/V=5\text{x}10^4/2\text{x}10^8 = 250\ \mu s$

$U=(1-0.1)/(1+2*0.25) \longleftarrow a = \mathbf{0.25} \longleftarrow T_f=L/R=2400/2.4\text{x}10^6 = 1000\ \mu s$

$= \mathbf{0.6}$

Go-Back-N ARQ: Illustration

Cautious Scheme !



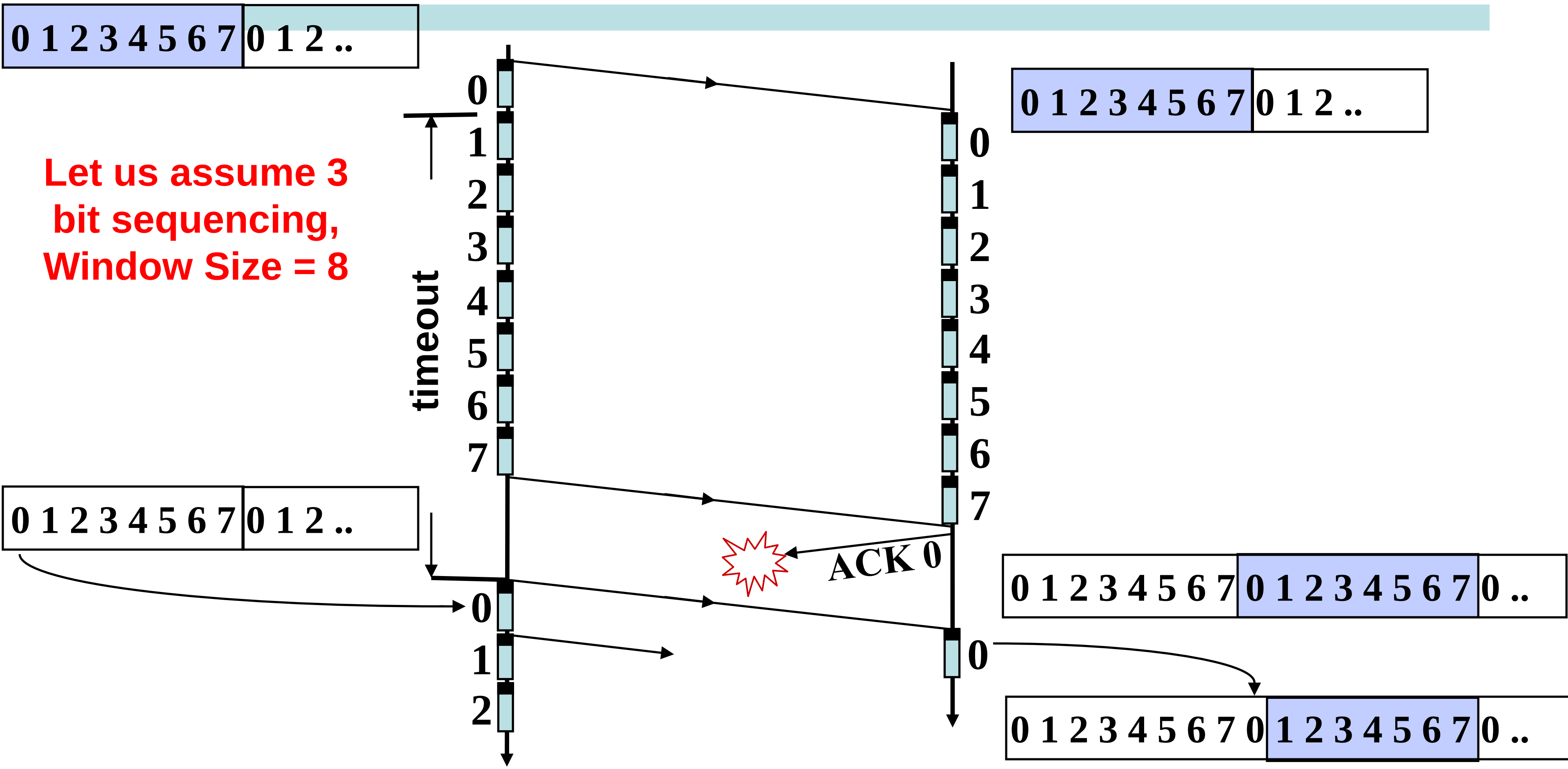
The sender must go back to transmission F_1 when NAK_1 is received

The receiver expects F_1, but F_2 arrives instead. Hence NAK1 is replied. All received frames will be discarded until F_1 arrives.

Go-Back-N ARQ: Protocol

- **Source:** **transmits frames sequentially based on sliding window.**
- **Destination:**
  - **For error-free frames, ACKs are sent as usual. ACK is usually called 'Receive Ready' (RR)**
  - **Can use 'Receiver Not Ready' (RNR) for controlling the flow.**
  - **If a damaged frame is received, NAK is sent. NAK is usually called 'Reject' (REJ). The destination discards that frame, and all subsequent frames until erroneous frame is received correctly.**
- **Source:**
  - **If NAK is received, retransmit that frame and all subsequent frames.**

Go-Back-N: Max Window Size



Frame 0 is inserted at a wrong place. For this reason, maximum window size allowed is one less than that permitted by the sequence number. With *k* bit sequencing, max. window size is 2^k-1.

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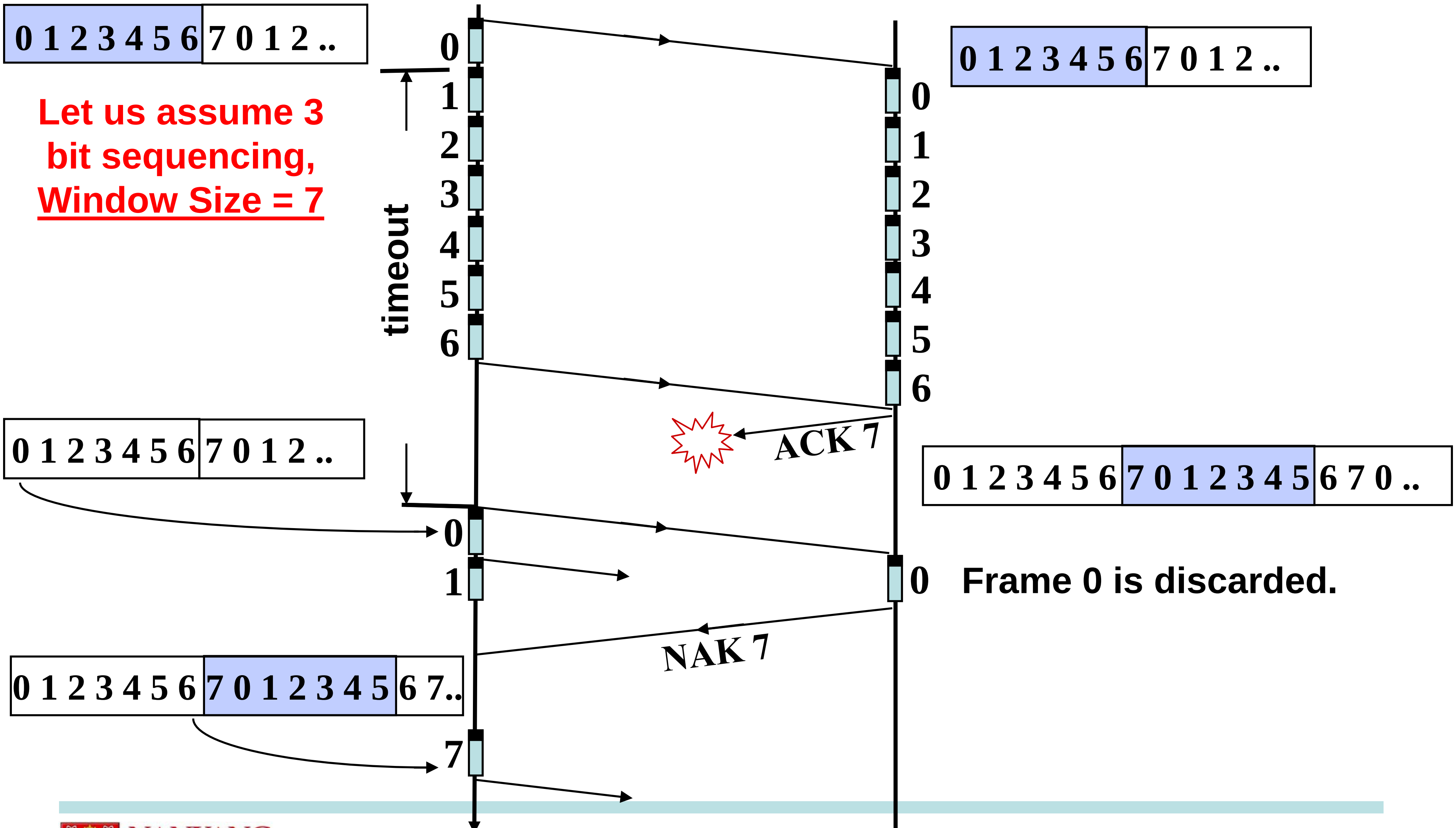
Go-Back-N: Max Window Size

Let us assume 3 bit sequencing, <u>Window Size = 7</u>



Go-Back-N: Performance

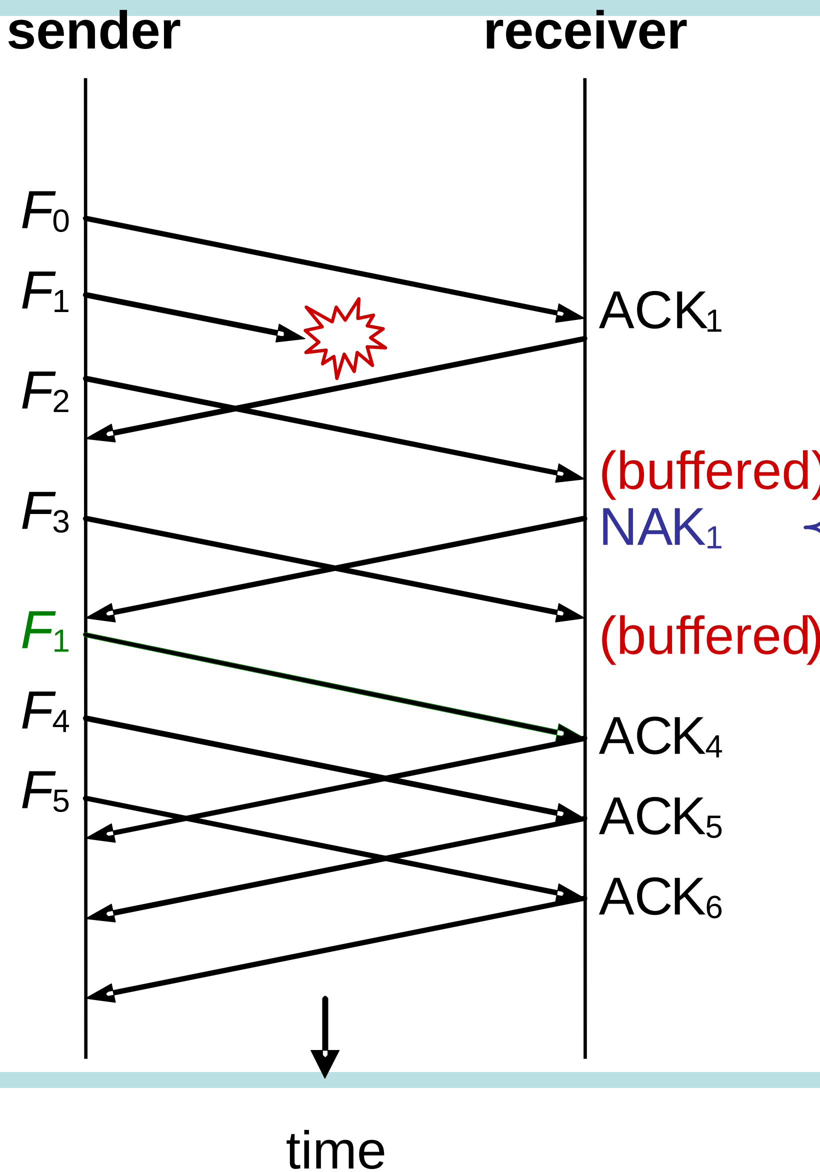
Assumptions:

1. T_{ack} and T_{proc} are negligible.
2. Frames are never completely lost on the medium.
3. ACKs and NAKs are never in error.
4. Each frame is (individually) acknowledged immediately.
5. Sender always has frames to send.

$$U_{GBN}^{ARQ} = \begin{cases} \dfrac{1-P}{1+2aP} & N \geq 2a+1 \\[2ex] \dfrac{N(1-P)}{(1-P+NP)(1+2a)} & N < 2a+1 \end{cases}$$

Selective Reject ARQ: Illustration

Efficient Scheme !



The sender will only repeat transmission F_1 when NAK_1 is received

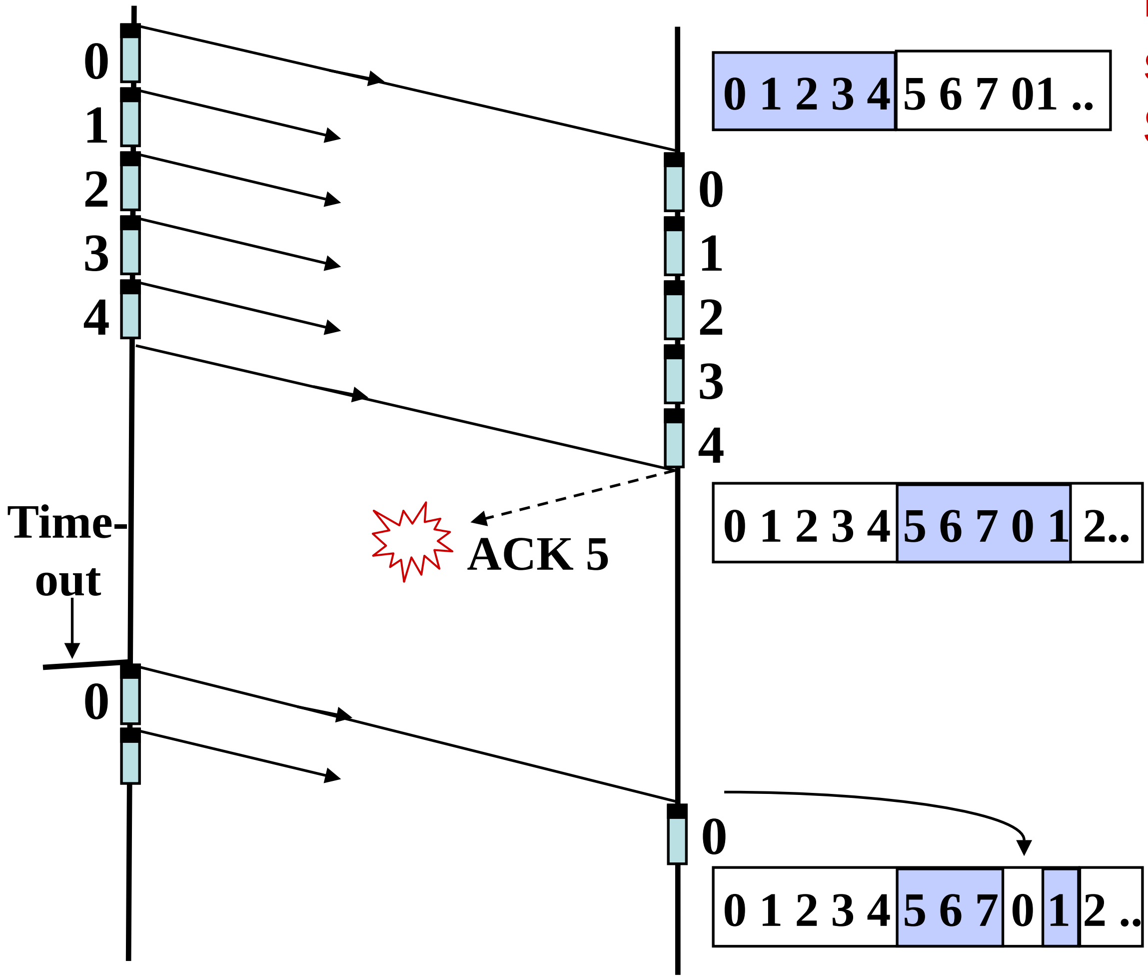
The receiver expects F_1, but F_2 arrives instead. Hence NAK1 is replied. All received frames will be buffered before F_1 arrives.

Selective Reject ARQ

- **Only rejected frames are retransmitted, (and of course those that time out).**
- **Receiver informs transmitter of rejected frame *n* by sending 'NAK *n*' ('Selective Reject *n*' or simply 'SREJ *n*' in HDLC implementation)**
- **After receiving an erroneous frame, subsequent frames are accepted by the receiver and buffered.**
- **After receiving the valid copy of the error frame, frames are put in proper order and passed to the higher layer.**
- **Minimizes retransmission, and thus more efficient than Go-back-N.**
- **Receiver requires more complex buffer management.**

Selective Reject ARQ: Max Window Size

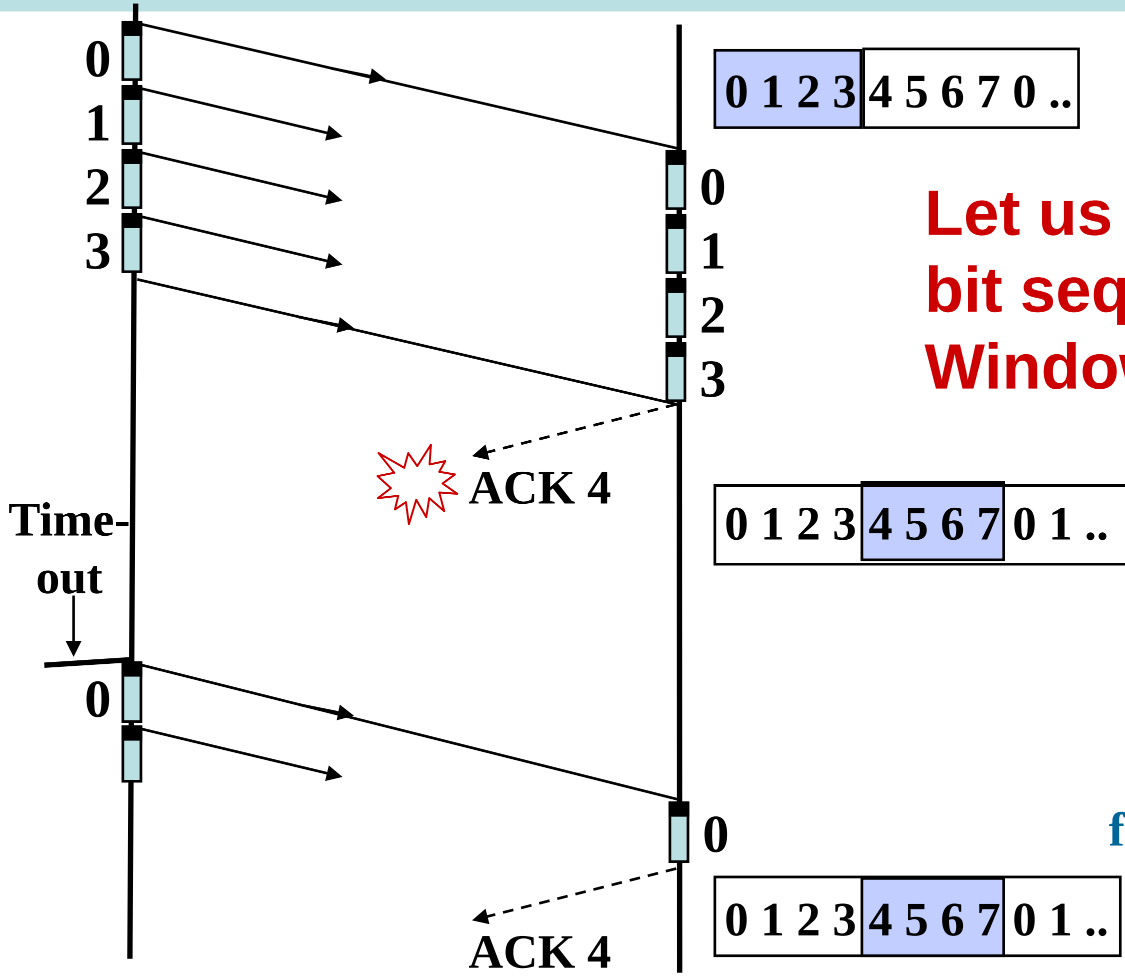
Let us assume 3 bit sequencing. Window Size = 5



The station assumes that frames 5, 6, & 7 have been lost, and it will accept frame 0, (and 1).

Conclusion: Window size of 5 cannot be permitted with 3 bit sequencing

Selective Reject ARQ: Max Window Size



Let us assume 3 bit sequencing, Window Size = 4.

Discard the frame, and send ACK again.

Conclusion: **With *k* bit sequencing, max window size is 2^{k-1}.**

Selective Reject ARQ: Performance

P: Frame loss probability
a: normalized prop. Delay

Since frame loss prob for each tx is independent, in 1+2a cycle, we expect N transmissions, each with prob P of failure due to errors.

$$U = \frac{N\overline{F}}{1+2a},\ N < 2a+1$$

where $\Pr\{F = n\} = \begin{cases} P, n = 0 \\ 1-P, n = 1 \end{cases}$

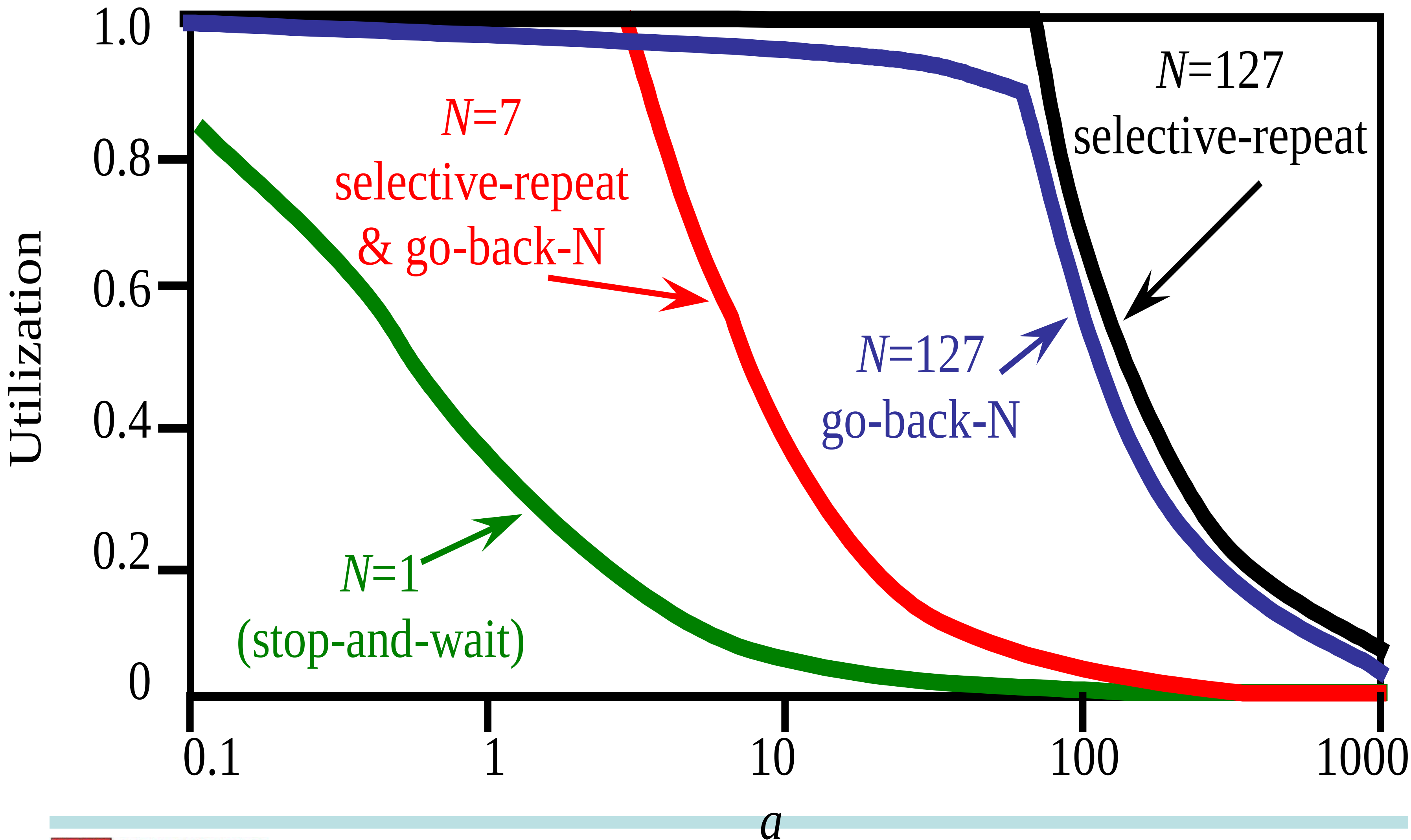
and $\overline{F} = 1-P$.

Hence $U_{Selective\ reject} = \dfrac{N(1-P)}{1+2a}$

$$\boxed{U_{SR}^{ARQ} = \begin{cases} 1-P & N \geq 2a+1 \\ \dfrac{N(1-P)}{1+2a} & N < 2a+1 \end{cases}}$$

Setting P=0 reduces the above to that of Sliding Window.

ARQ Performance



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Channel Utilization: Formulas

Stop-and-Wait ARQ

$$U_{Stop-and-Wait} = \frac{1-P}{1+2a}$$

Go-back-N ARQ

$$U_{Go-back-N} = \begin{cases} & N \ge 2a+1 \\ \frac{}{(1-P+NP)(1+2a)} & N < 2a+1 \end{cases}$$

Sliding Window (no errors)

$$U_{Sliding\ Window} = \begin{cases} 1 & N \ge 2a+1 \\ \frac{N}{1+2a} & N < 2a+1 \end{cases}$$

Selective Reject ARQ

$$U_{Selective\ reject} = \begin{cases} 1-P & N \ge 2a+1 \\ \frac{N(1-P)}{1+2a} & N < 2a+1 \end{cases}$$

P: frame error probability
a: normalized propagation delay
N: window size
U: Channel Utilization (between 0 and 1)

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Learning Objectives

- **Stop-and-Wait ARQ**
  - To label frame flow
  - Channel Utilization Calculation
- **Go-Back-N ARQ (GBN)**
  - To label frame flow
  - To determine Max Window Size
- **Selective Reject ARQ (SR)**
  - To label frame flow
  - To determine Max Window Size
  - Link utilization calculation
  - Comparison between GBN and SR