Part I Syllabus

Lecture	Date	Subject
1	11/08/2020	Introduction
		Network layer & physical resilience
2	18/08/2020	Data link layer – Flow control
		Data link layer – Error control
3	25/08/2020	Local area network – Introduction
4	01/09/2020	Local area network – MAC
		Local area network – Ethernet
5	08/09/2020	Local area network – WLAN
		Mobile Access Networks: From 1G to 5G
6	22/09/2020	Packet switch network – Network paradigm

Chat over Unreliable Network

Call

Contact Info

2013-1-30 0:35

Do you want to go out for a movie tonight?

Sure

Sure

Sure

Shoot!

Wrong message!

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CE3005/CZ3006 Computer Networks

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

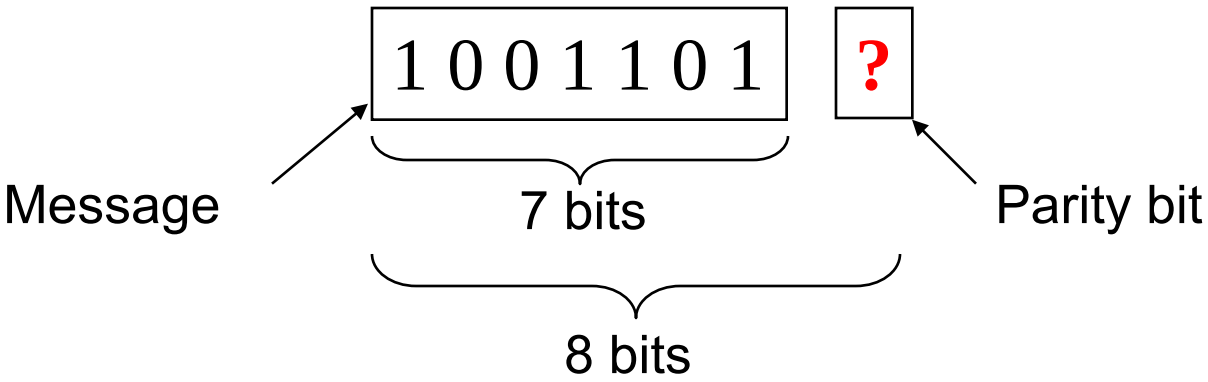
Error Control in Data Link Layer

- **Objective**
  - To detect and correct errors that occur in frame transmission
- **Frame Error in 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

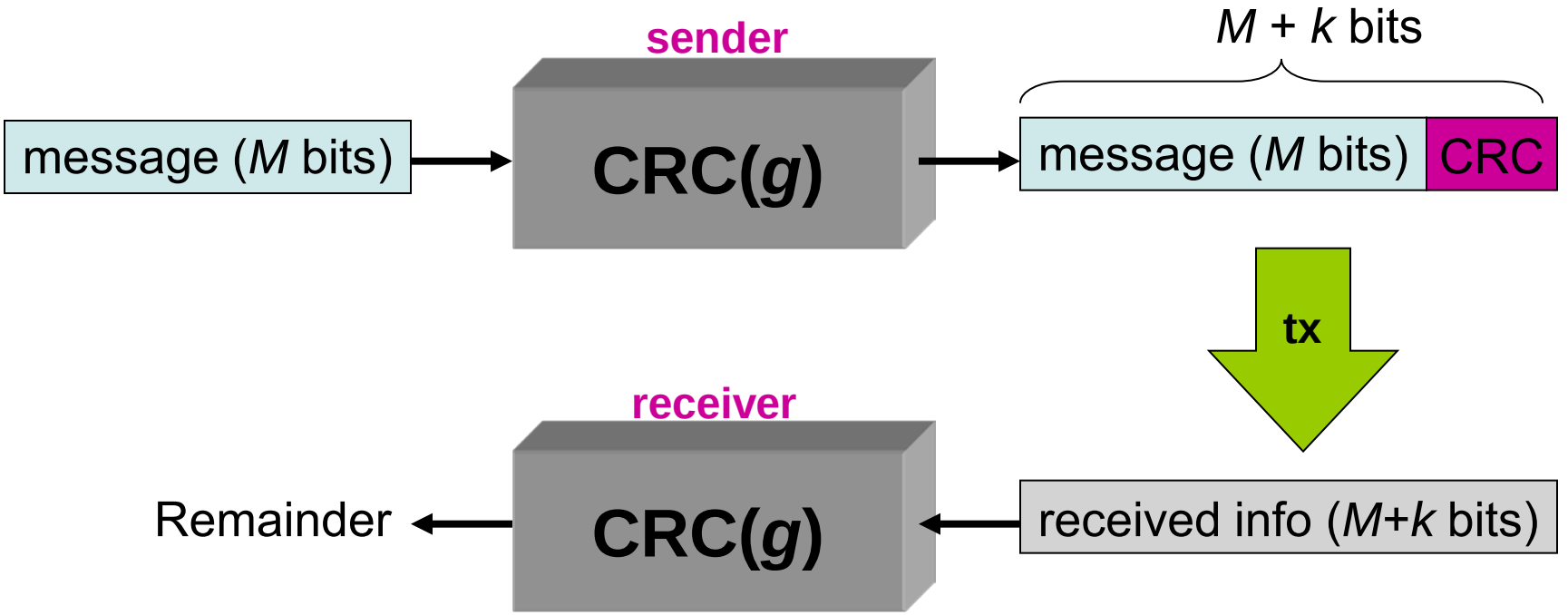
☹ However, Parity Check can only detect odd numbers of errors !

7 Prisoners with 1 Psycho Cop

- You are in a group of 7 prisoners who are captured by a crooked, psycho cop. He decides to execute the lot of you, but to play a game to give some of you a chance to live. His plan is to put either a **blue** or **red** hat on each of your heads, and then he will ask each person what color his hat is. If they guess correctly, they may leave freely. Otherwise, **BANG!** he shoots them dead.
- The cop will first line all of you up in a single line, all facing in one direction, such that each person is facing the next prisoner's back. Every criminal can see the hats of every one in front of them, but not their own hat or anyone behind them. The Cop will ask each of you in order, starting from the back of the line and moving forward.

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)

Error Correction Techniques

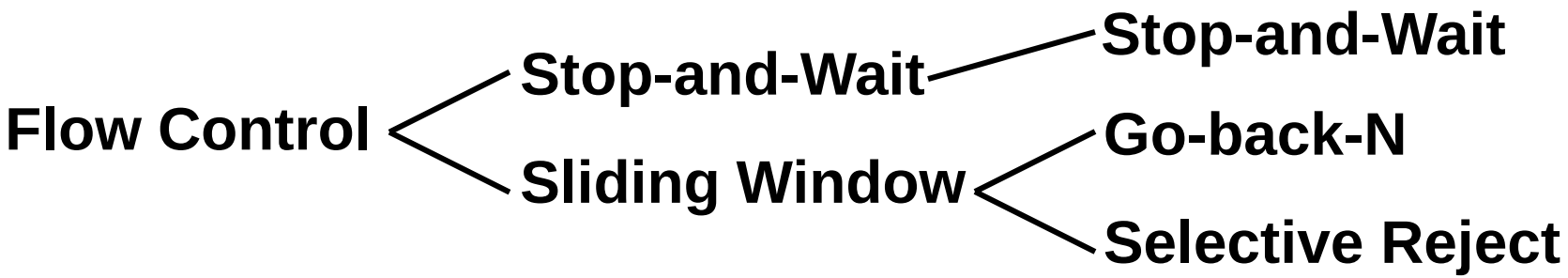
- **Forward Error Correction (FEC)**
  - Send more redundant bits in the message
  - Example: Hamming code, Reed-Solomon code
- **Automatic Repeat Request (ARQ)**
  - **Retransmission after timeout**: The source retransmits a frame when an expected ACK fails to return within a predetermined time duration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

ARQ Variants

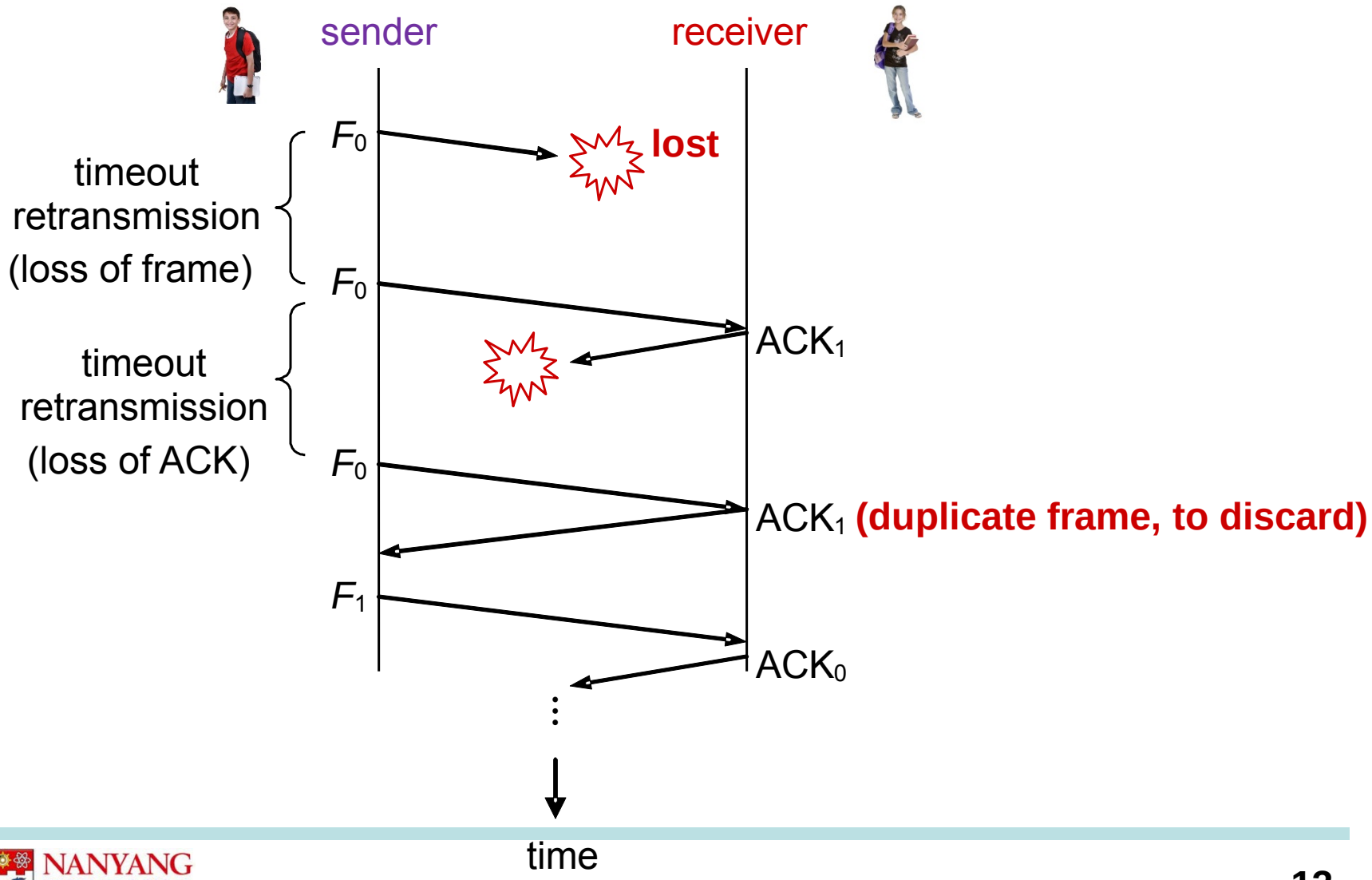
- **Commonly implemented ARQ mechanisms:**
  - **Stop-and-Wait ARQ**
  - **Sliding Window - Go-back-N ARQ:**

    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.



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

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

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

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

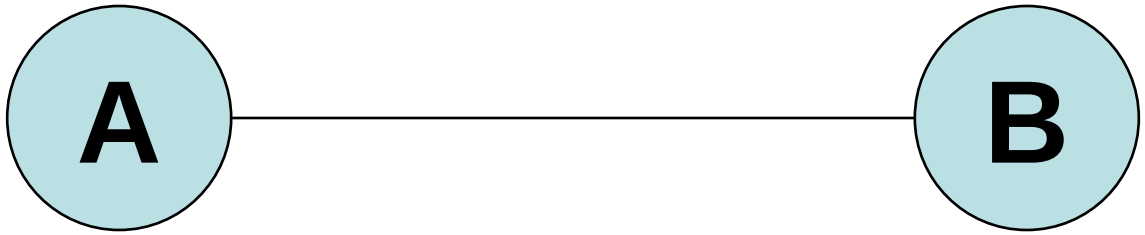
$$= \frac{1-P}{1+2a}$$

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 $2x10^8$ *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 = $2x10^8$ *m/s*

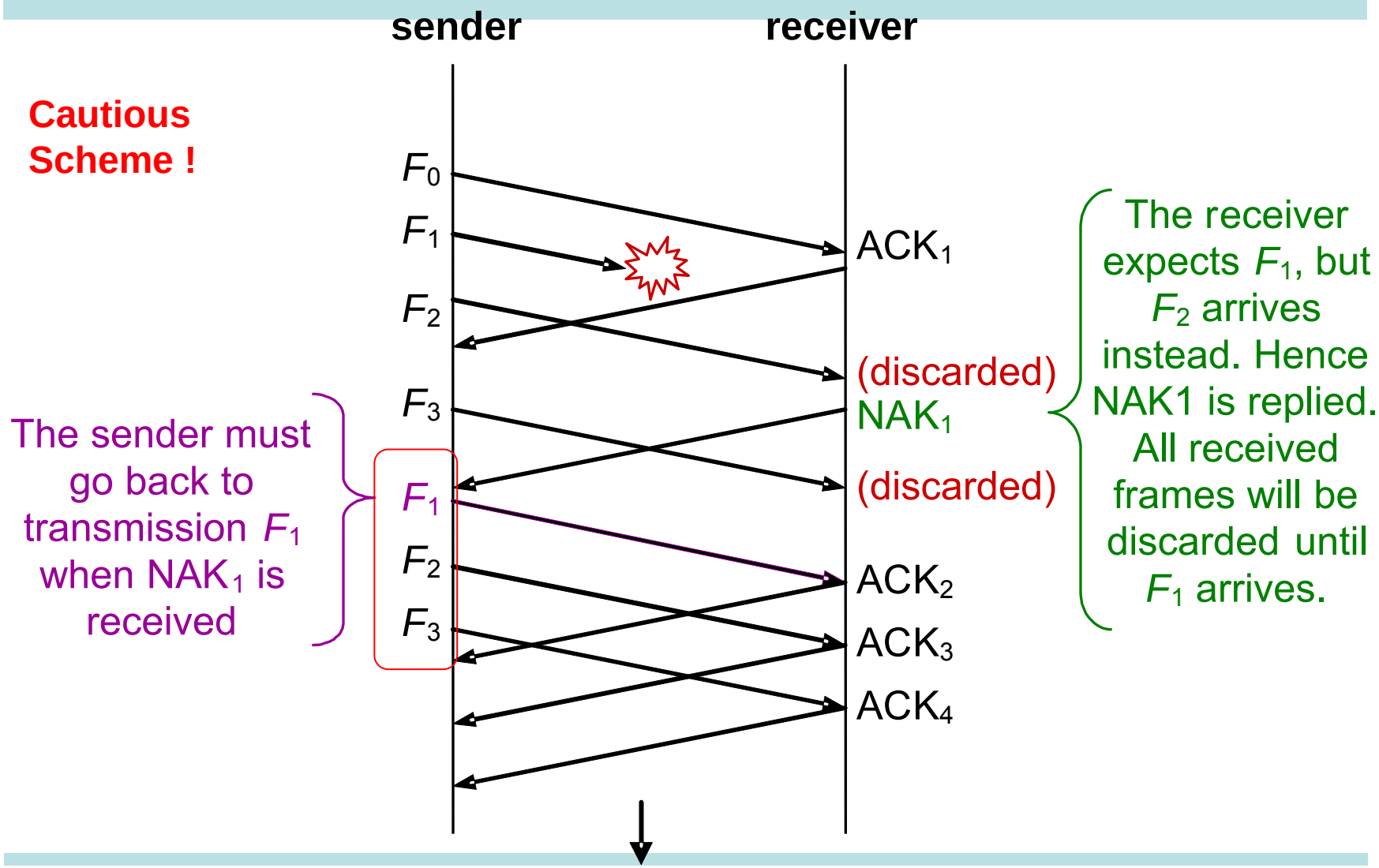
P=0.1

$U=(1-P)/(1+2\mathbf{a}) \longrightarrow a = \mathbf{T_p/T_f} \longrightarrow T_p=H/V=5x10^4/2x10^8 = 250\ \mu s$

$U=(1-0.1)/(1+2*0.25) \longleftarrow a = \mathbf{0.25} \longleftarrow T_f=L/R=2400/2.4x10^6 = 1000\ \mu s$

$= \mathbf{0.6}$

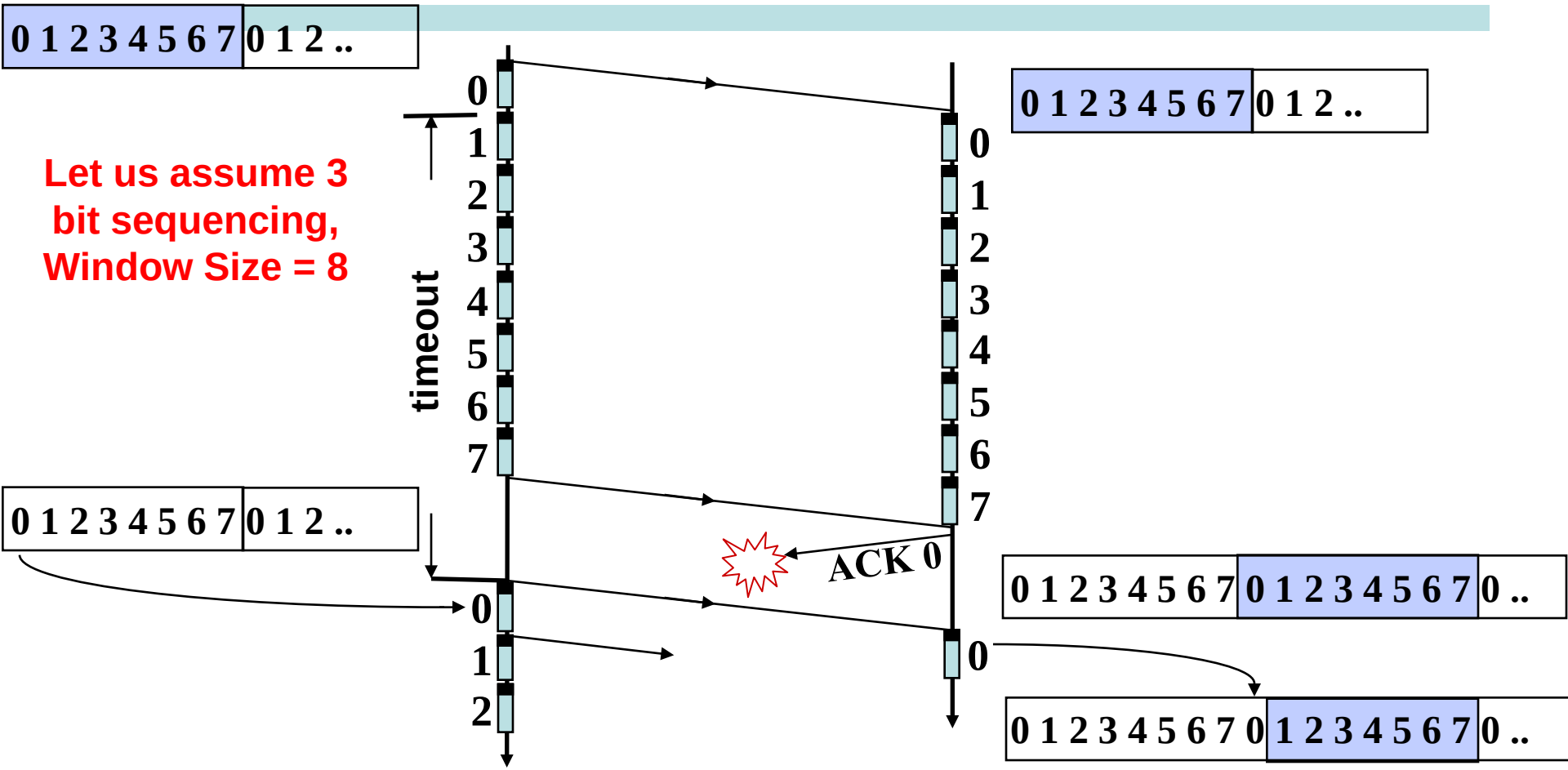
Go-Back-N ARQ: Illustration



Go-Back-N ARQ: Protocol

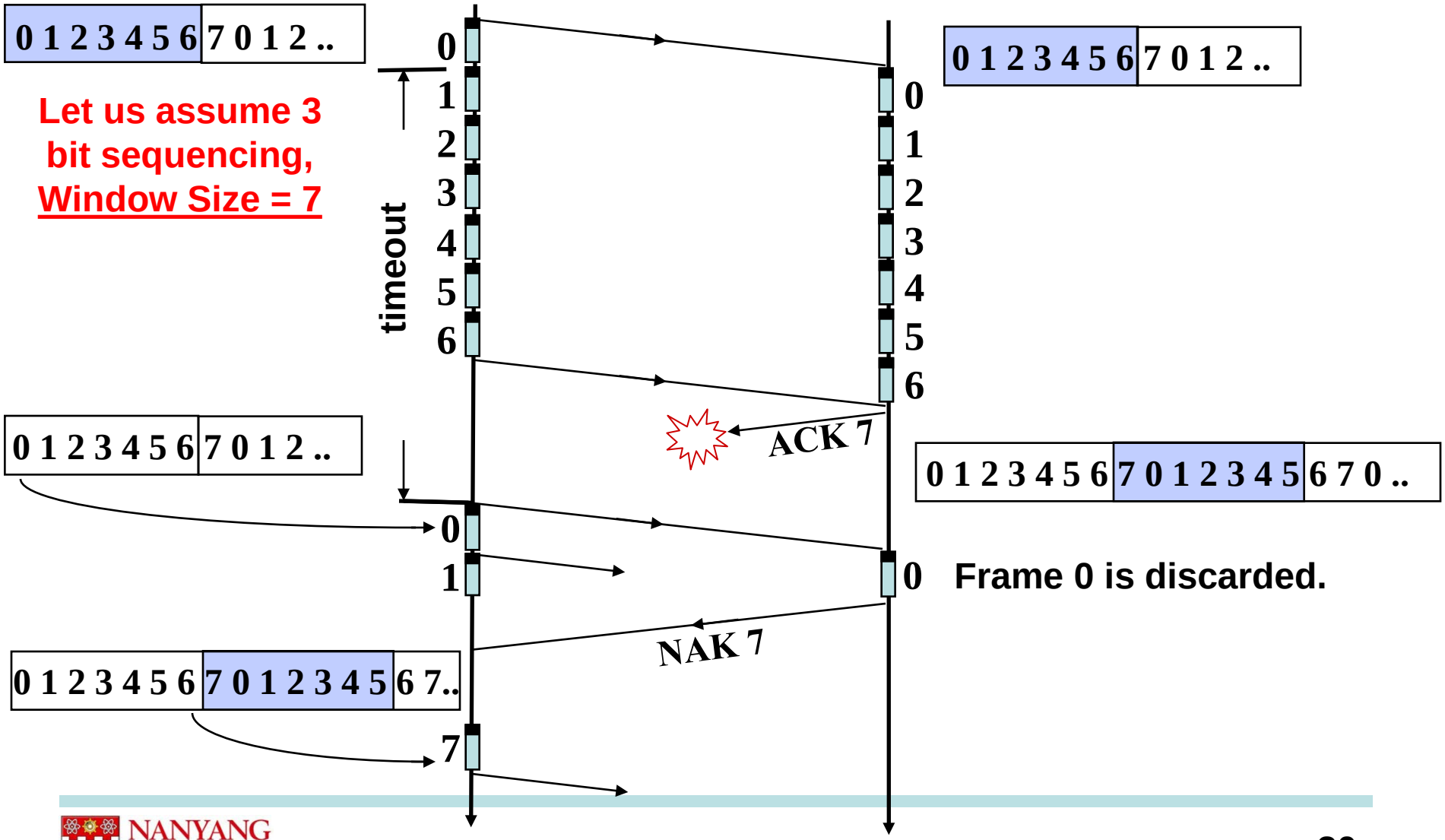
- **Source: transmits frames sequentially based on sliding window.**
- **Destination:**
  - **For error-free frames, ACKs are sent as usual. ACK is usually called 'Receive Ready' (RR)**
  - **Can use 'Receiver Not Ready' (RNR) for controlling the flow.**
  - **If a damaged frame is received, NAK is sent. NAK is called 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 $2^k - 1$.

Go-Back-N: Max Window Size

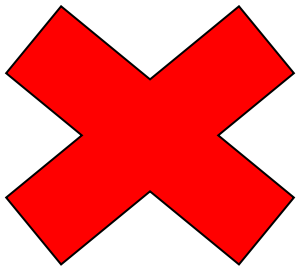


Go-Back-N: Performance

Assumptions:

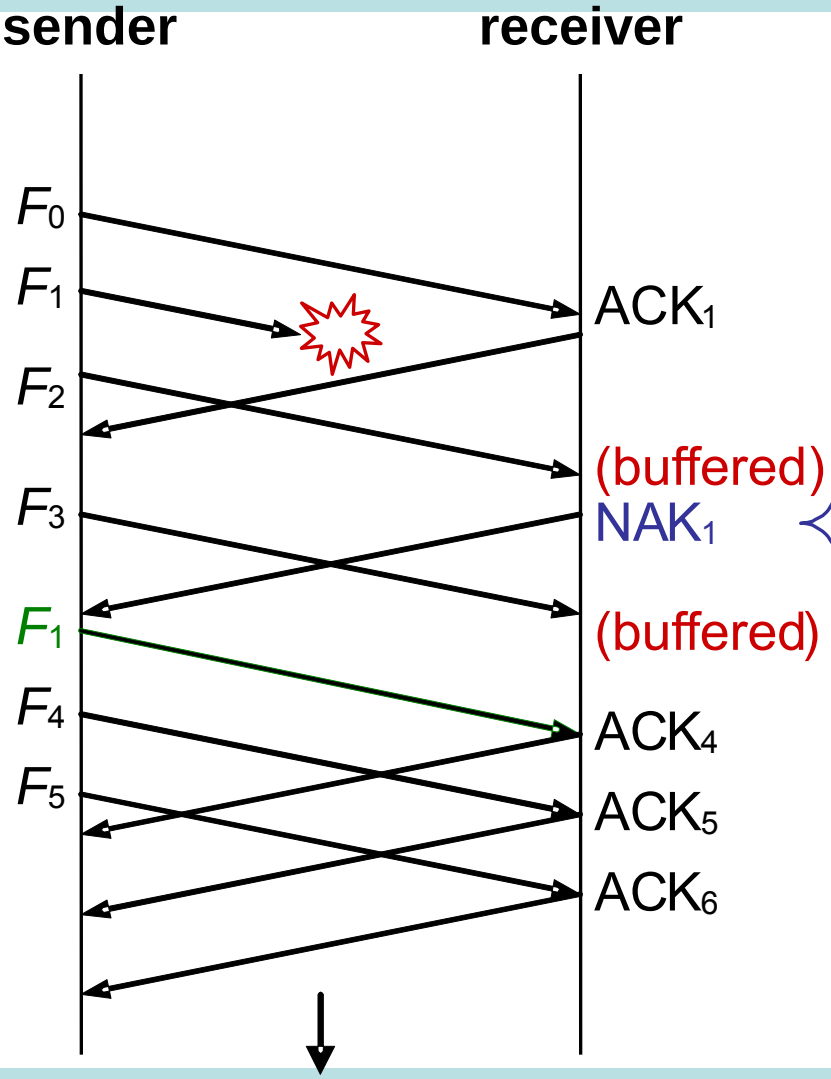
1. T_{ack} and T_{proc} are negligible.
2. Frames are never completely lost on the medium.
3. ACKs and NAKs are never in error.
4. Each frame is (individually) acknowledged immediately.
5. Sender always has frames to send.

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



Selective Reject ARQ: Illustration

Efficient Scheme !



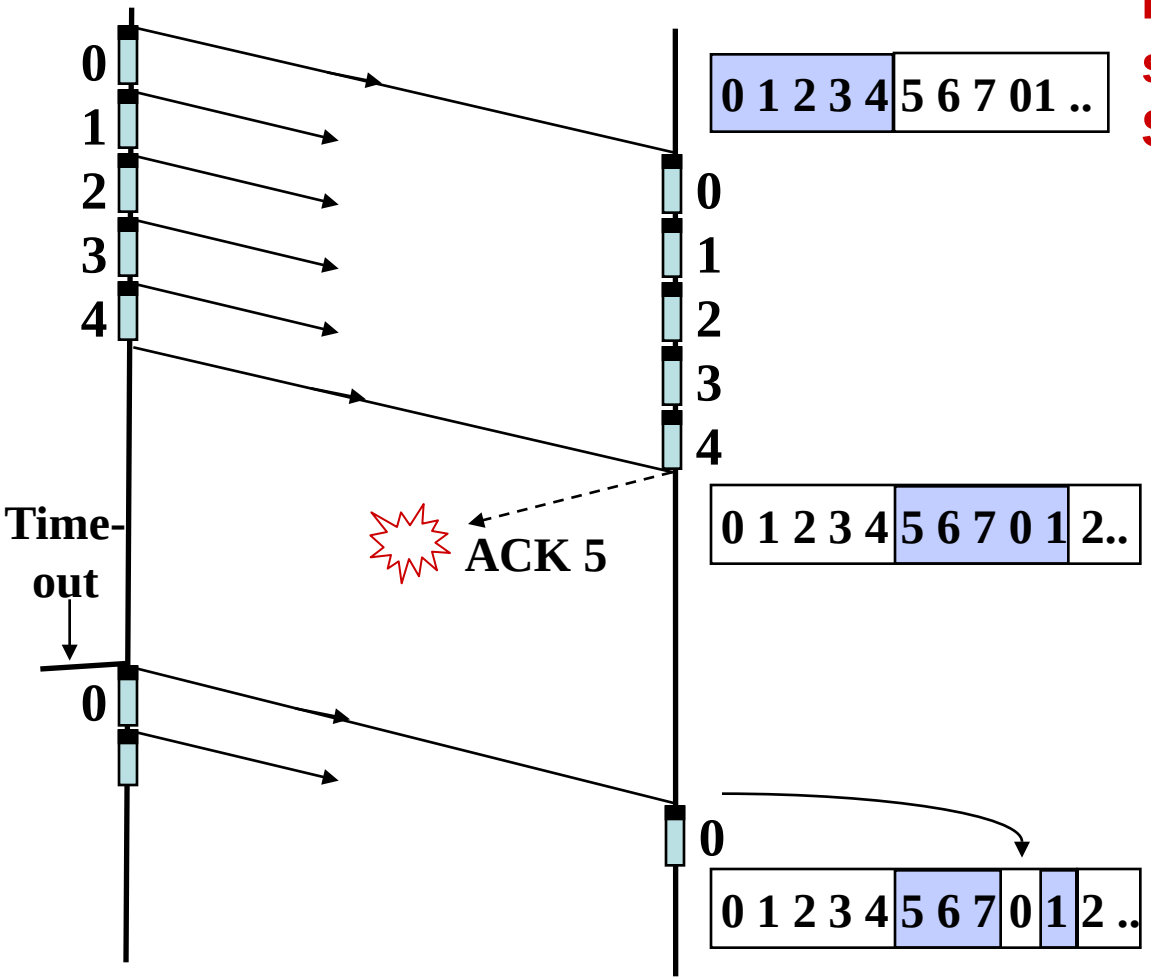
The sender will only repeat transmission F_1 when NAK_1 is received

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

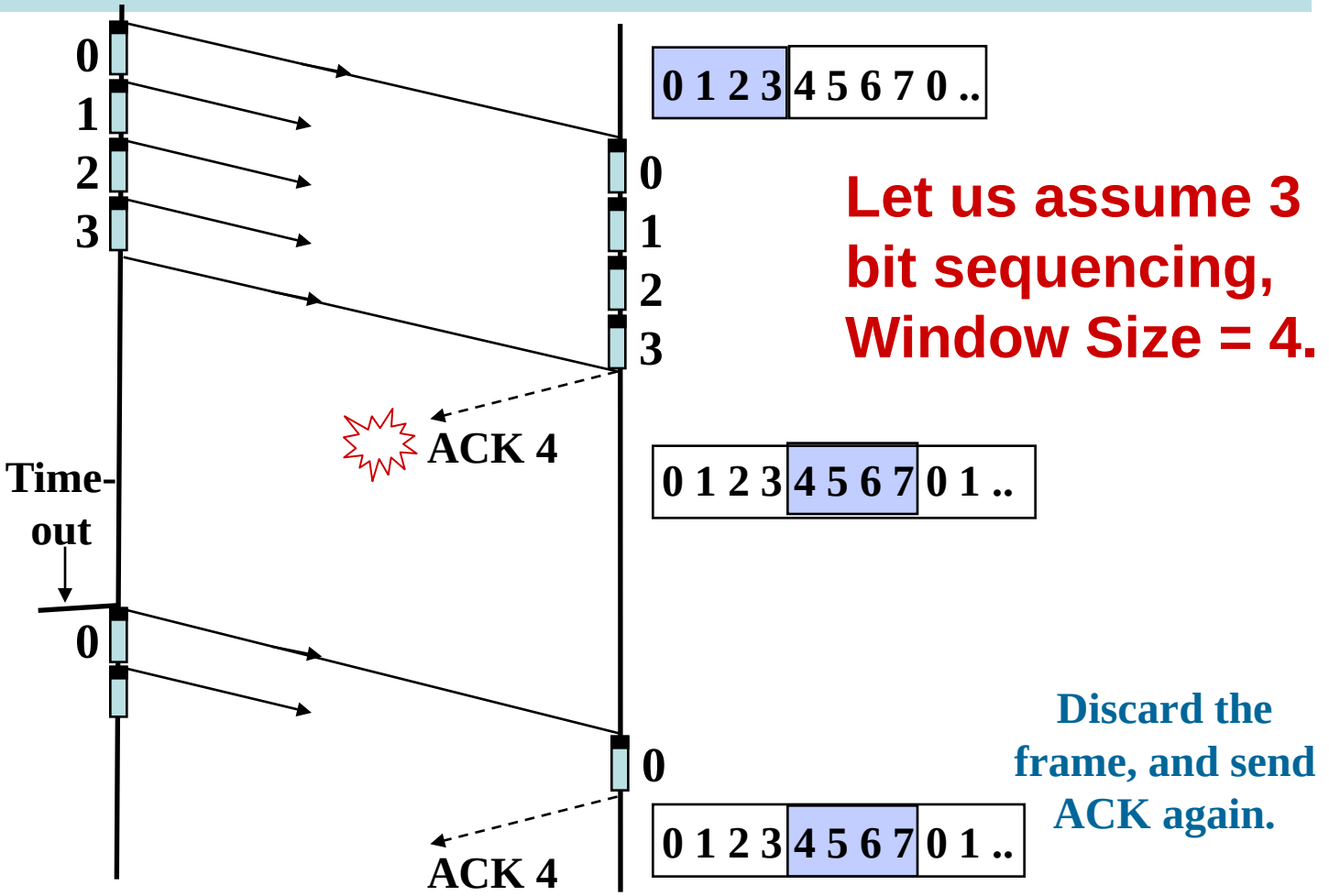


Let us assume 3 bit sequencing. Window Size = 5

The station assumes that frame 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



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

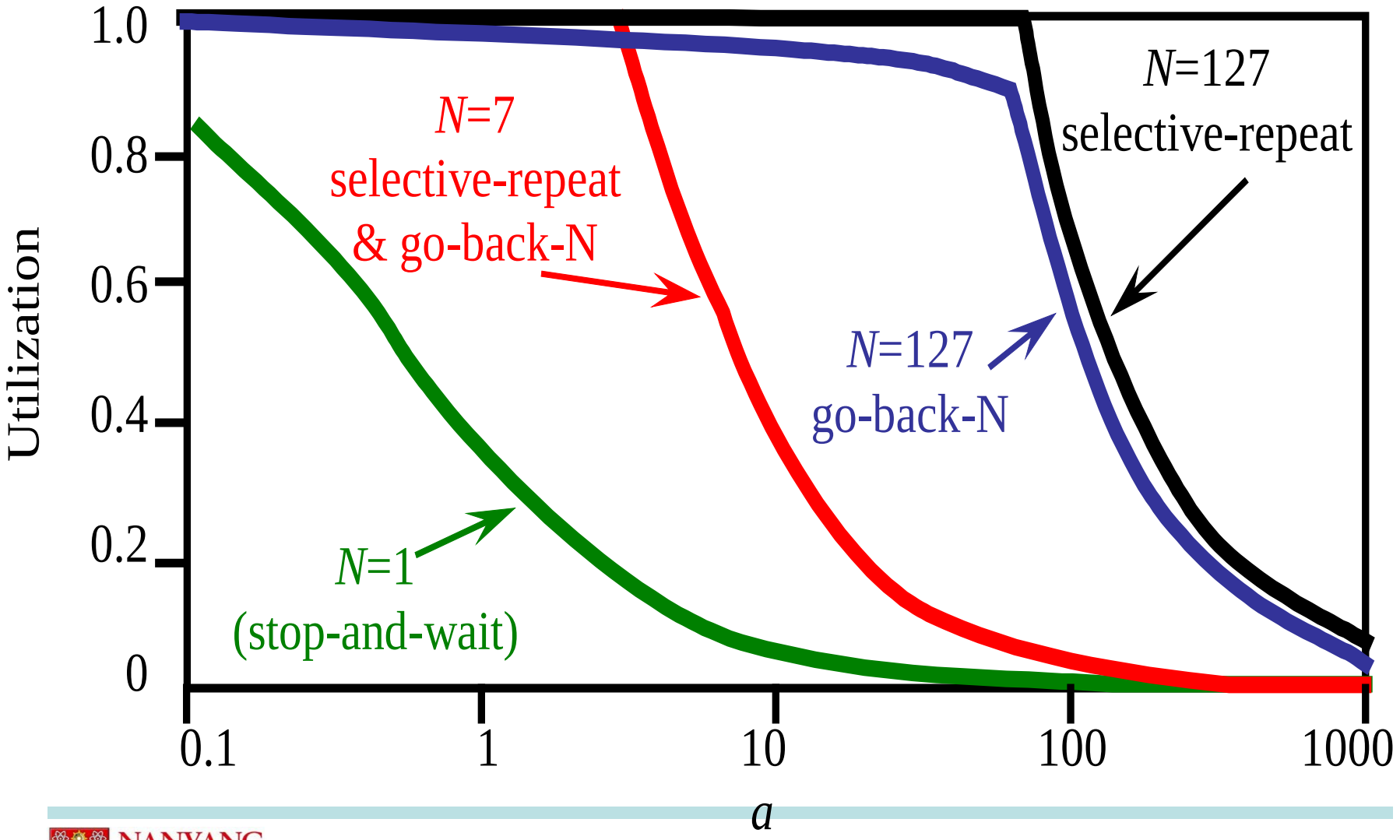
and $\overline{F} = 1 - P.$

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

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

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

ARQ Performance



Channel Utilization: Formulas

Stop-and-Wait ARQ

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

Go-back-N ARQ

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

Sliding Window (no errors)

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

Selective Reject ARQ

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

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

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
  - ~~Link utilization calculation~~
- **Selective Reject ARQ (SR)**
  - To label frame flow
  - To determine Max Window Size
  - Link utilization calculation
  - Comparison between GBN and SR