Data Link Control Protocols

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These slides are available on-line at:

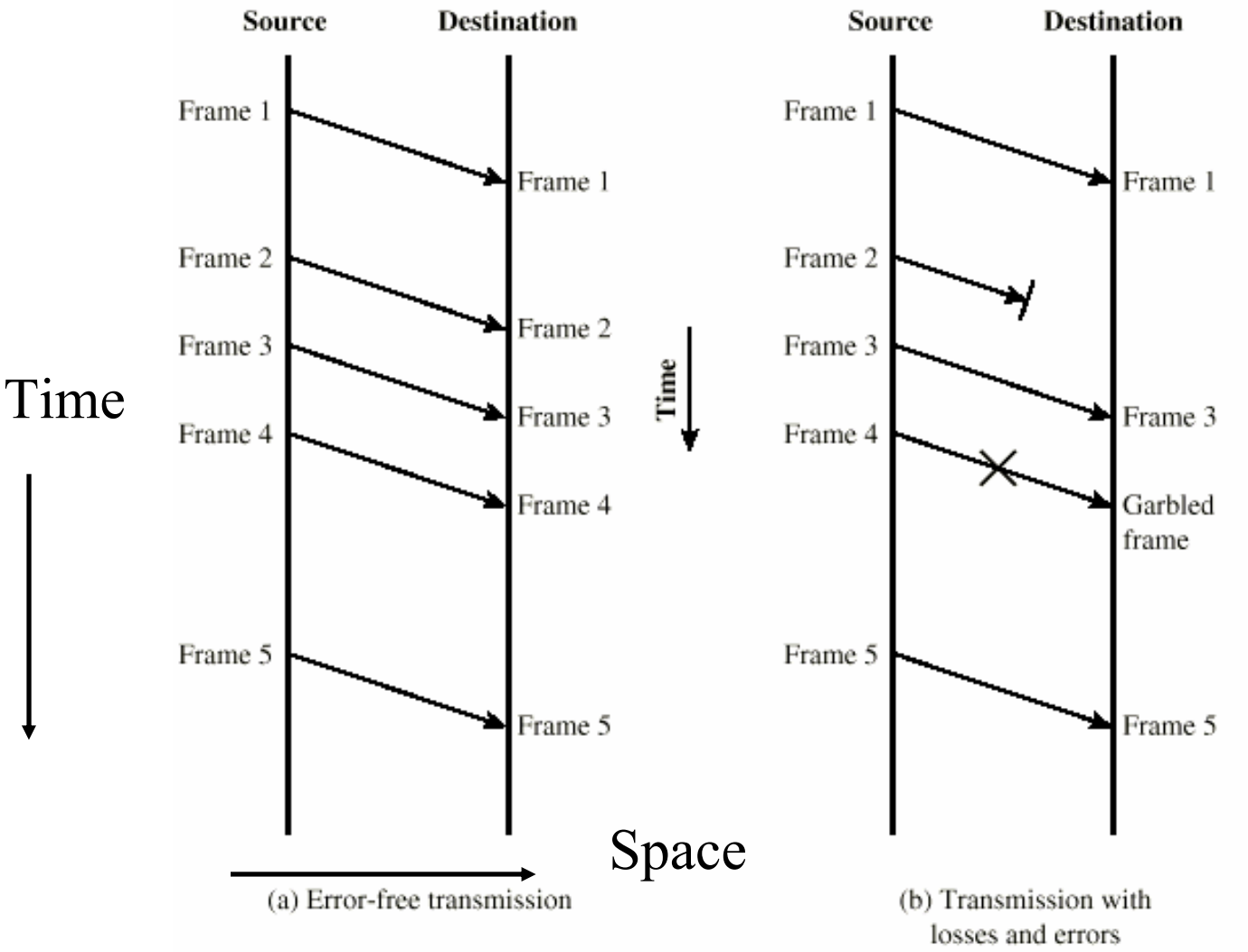
http://www.cse.wustl.edu/~jain/cse473-05/

- Flow Control
- Effect of propagation delay, speed, frame size
- Error Recovery
- HDLC

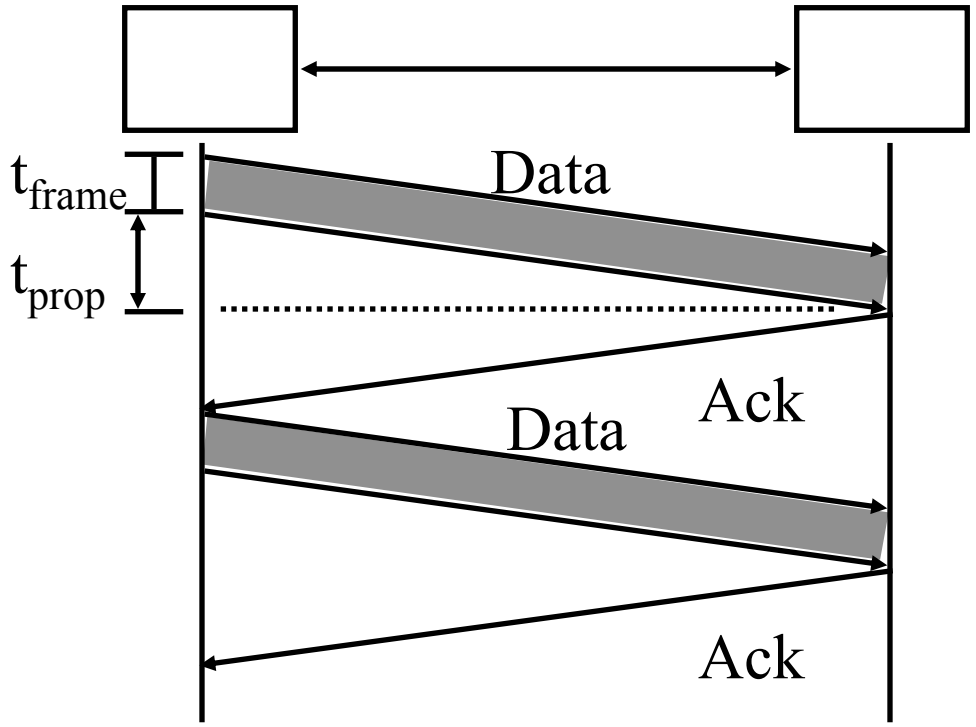
Flow Control

- Flow Control Goals:
  1. Sender does not flood the receiver,
  2. Maximize throughput
- Sender throttled until receiver grants permission

Space-Time Diagrams



Stop and Wait Flow Control



$$U = \frac{t_{frame}}{2t_{prop}+t_{frame}} = \frac{1}{2\alpha + 1}$$

$$\alpha = \frac{t_{prop}}{t_{frame}} = \frac{\text{Distance/Speed of Signal}}{\text{Bits Transmitted /Bit rate}} = \frac{\text{Distance} \times \text{Bit rate}}{\text{Bits Transmitted} \times \text{Speed of Signal}}$$

Light in vacuum = 300 m/μs
Light in fiber = 200 m/μs
Electricity = 250 m/μs

Utilization: Examples

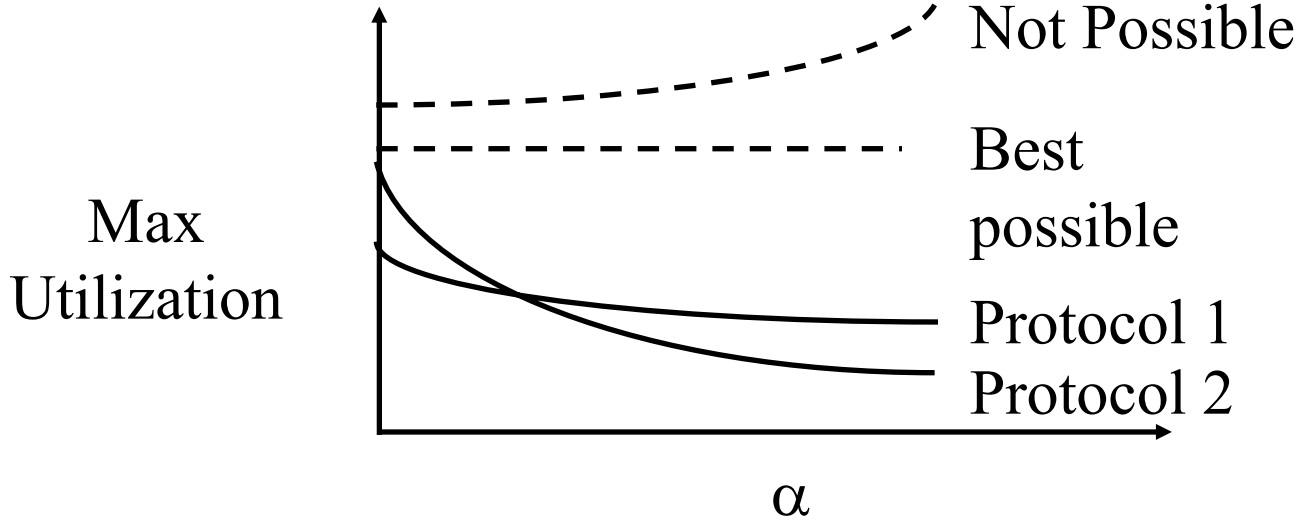
- Satellite Link: Propagation Delay t_{prop} = 270 ms
  Frame Size = 500 Bytes = 4 kb
  Data rate = 56 kbps $\Rightarrow$ t_{frame} = 4/56 = 71 ms
  $\alpha = t_{prop}/t_{frame} = 270/71 = 3.8$
  $U = 1/(2\alpha+1) = 0.12$

- Short Link: 1 km = 5 μs,
  Rate=10 Mbps,
  Frame=500 bytes $\Rightarrow$ t_{frame}= 4k/10M= 400 μs
  $\alpha=t_{prop}/t_{frame}=5/400=0.012 \Rightarrow U=1/(2\alpha+1)=0.98$

Note: The textbook uses B for t_{prop} and L for t_{frame}

Efficiency Principle

- For **all** protocols, the maximum utilization (efficiency) is a *non-increasing* function of α.

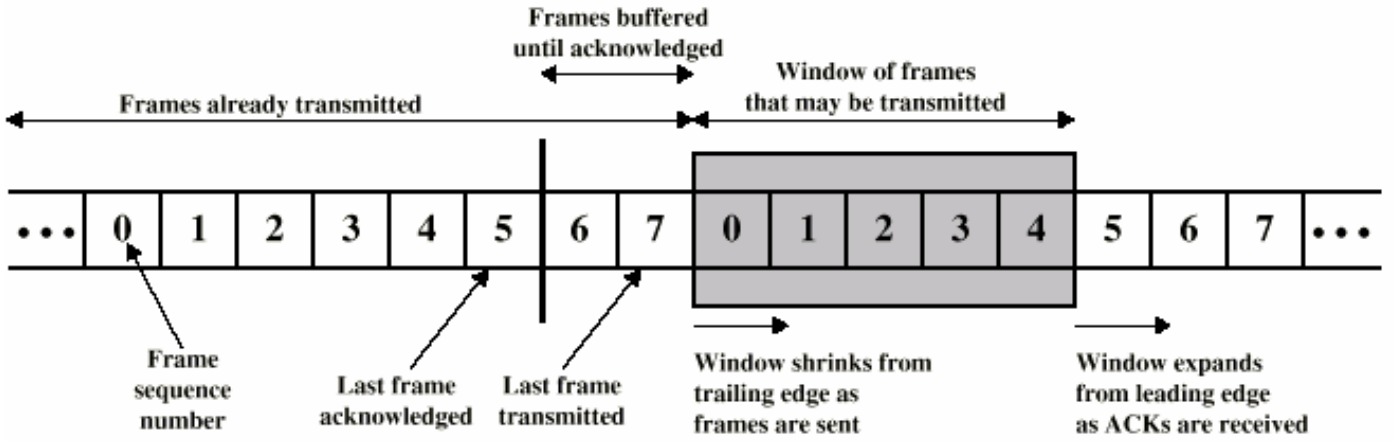


$$\alpha = \frac{t_{prop}}{t_{frame}} = \frac{\text{Distance} \times \text{Bit rate}}{\text{Bits Transmitted} \times \text{Speed of Signal}}$$

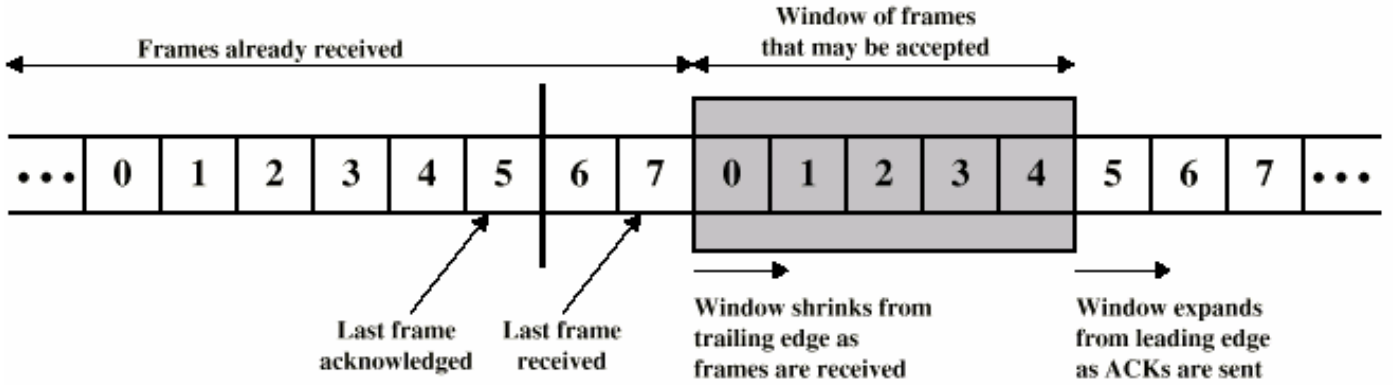
Sliding Window Protocols

- Window = Set of sequence numbers to send/receive
- Sender window
  - Sender window increases when ack received
  - Packets in sender window must be buffered at source

Sliding Window Diagram

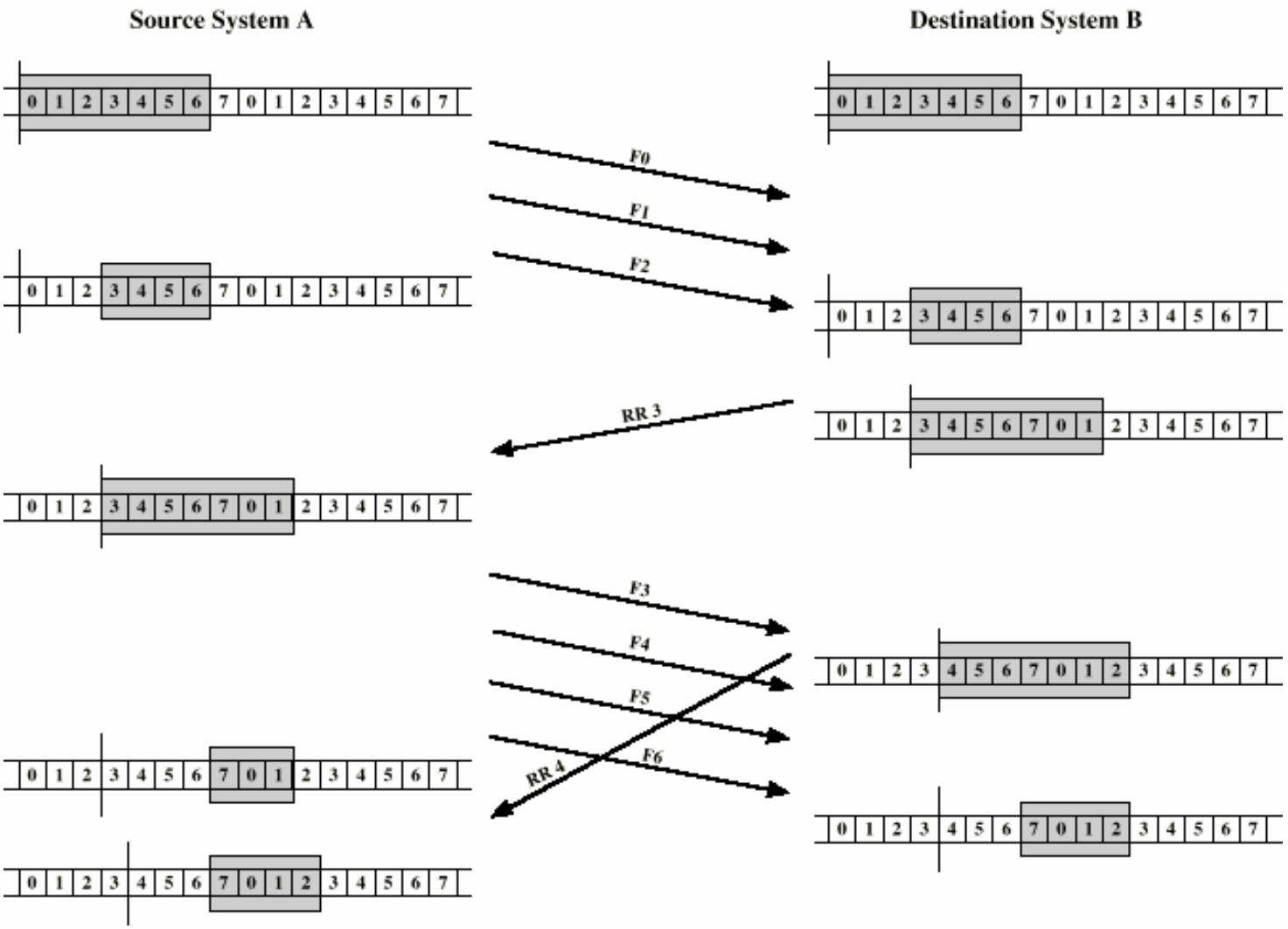


(a) Sender's perspective

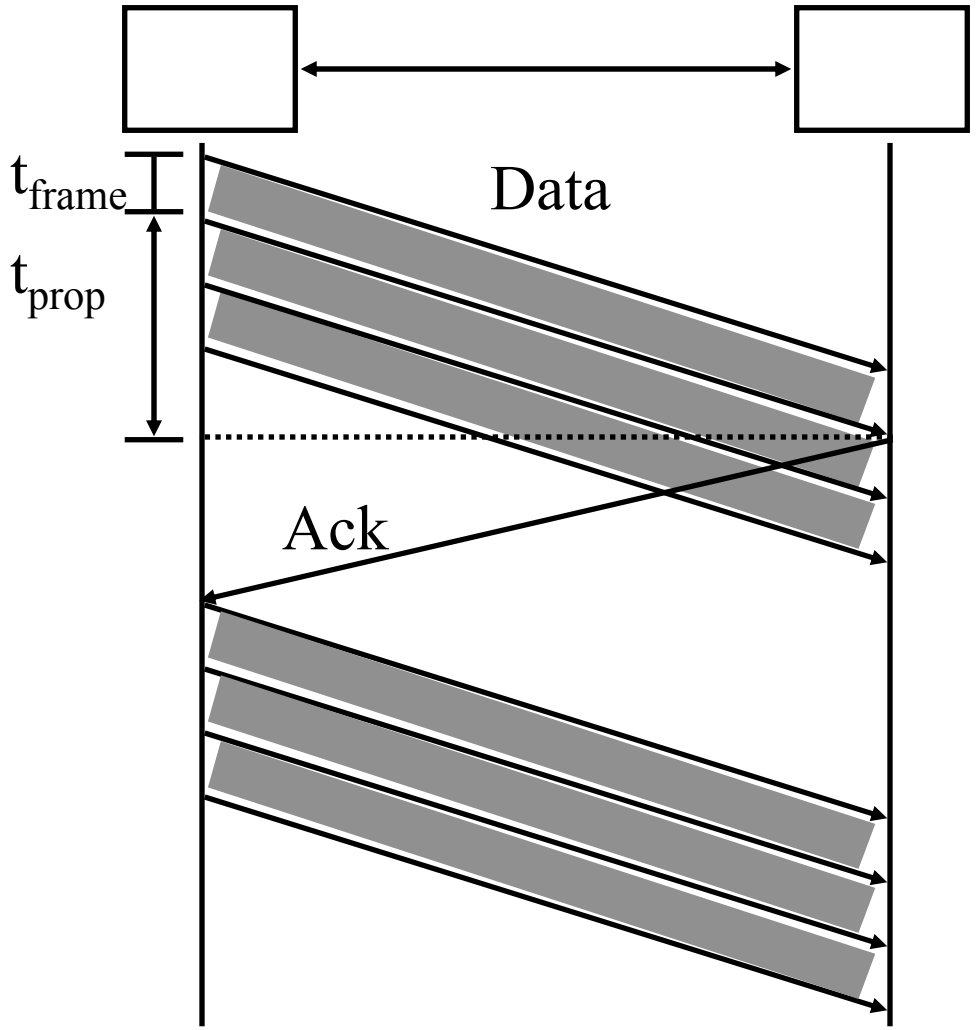


(b) Receiver's perspective

Sliding Window Example



Sliding Window Protocol Efficiency

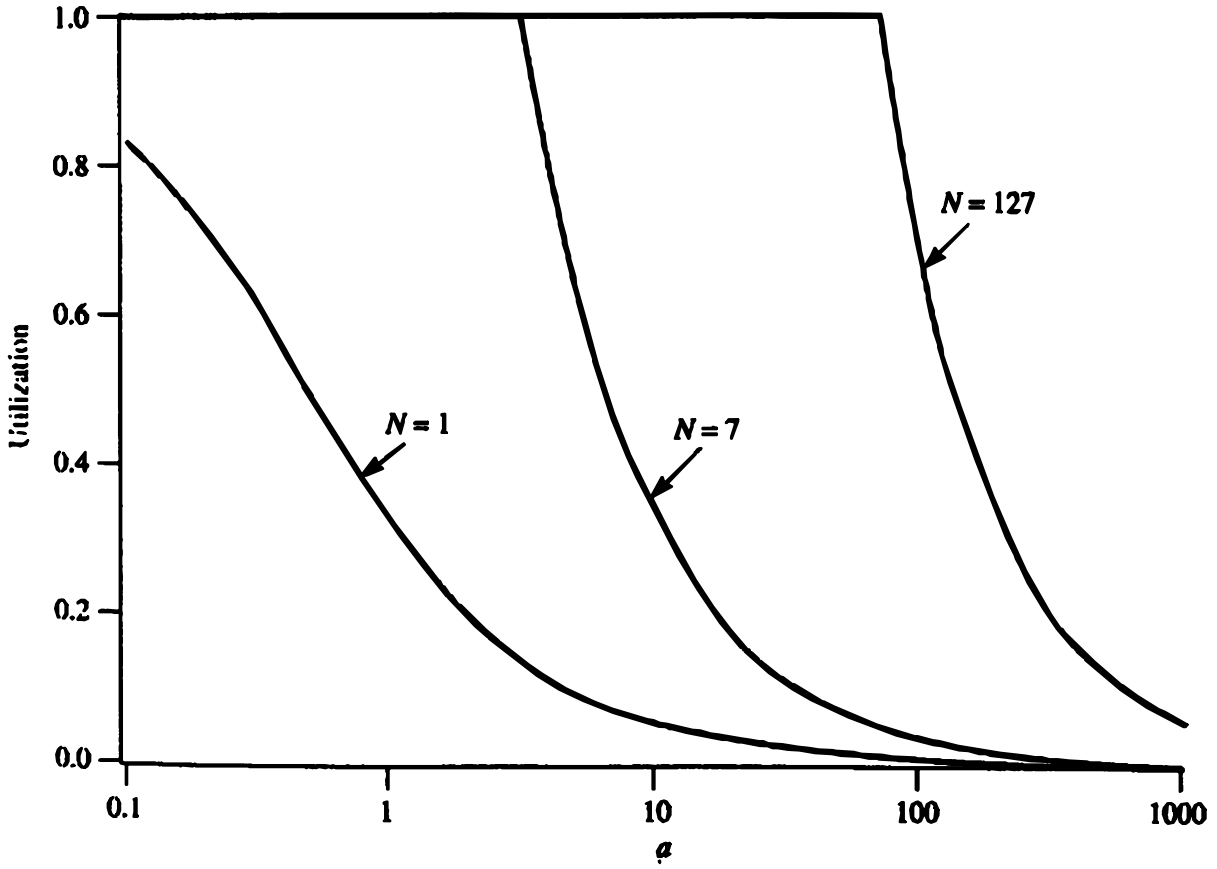


$$U = \frac{W\, t_{frame}}{2t_{prop}+t_{frame}}$$

$$= \begin{cases} \dfrac{W}{2\alpha+1} \\ 1 \text{ if } W>2\alpha+1 \end{cases}$$

Effect of Window Size

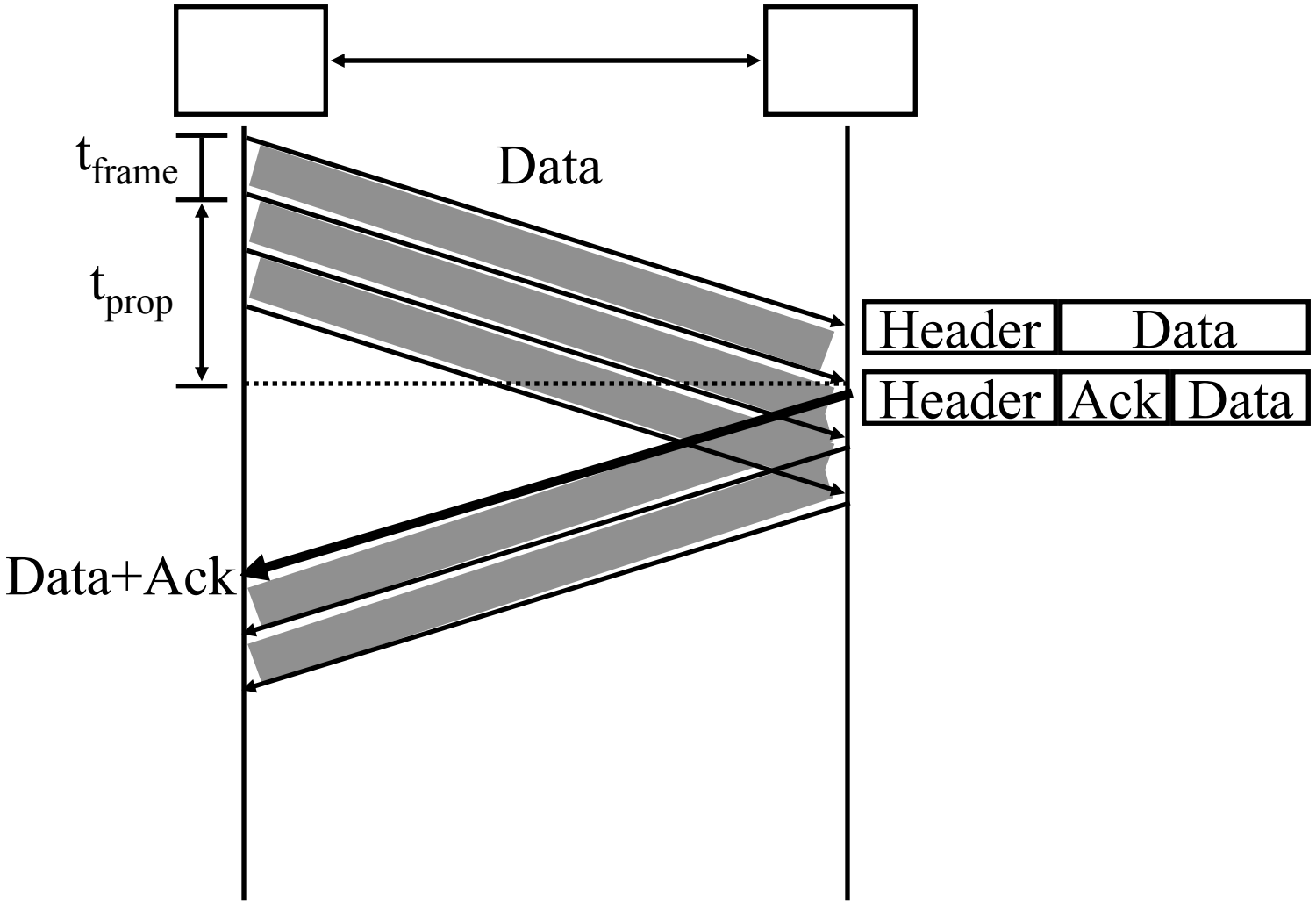
U



α

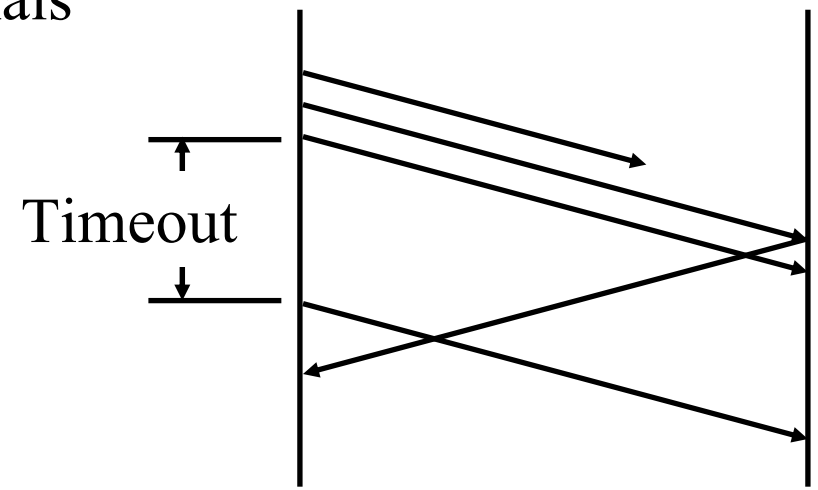
- Larger window is better for larger α

Piggybacking



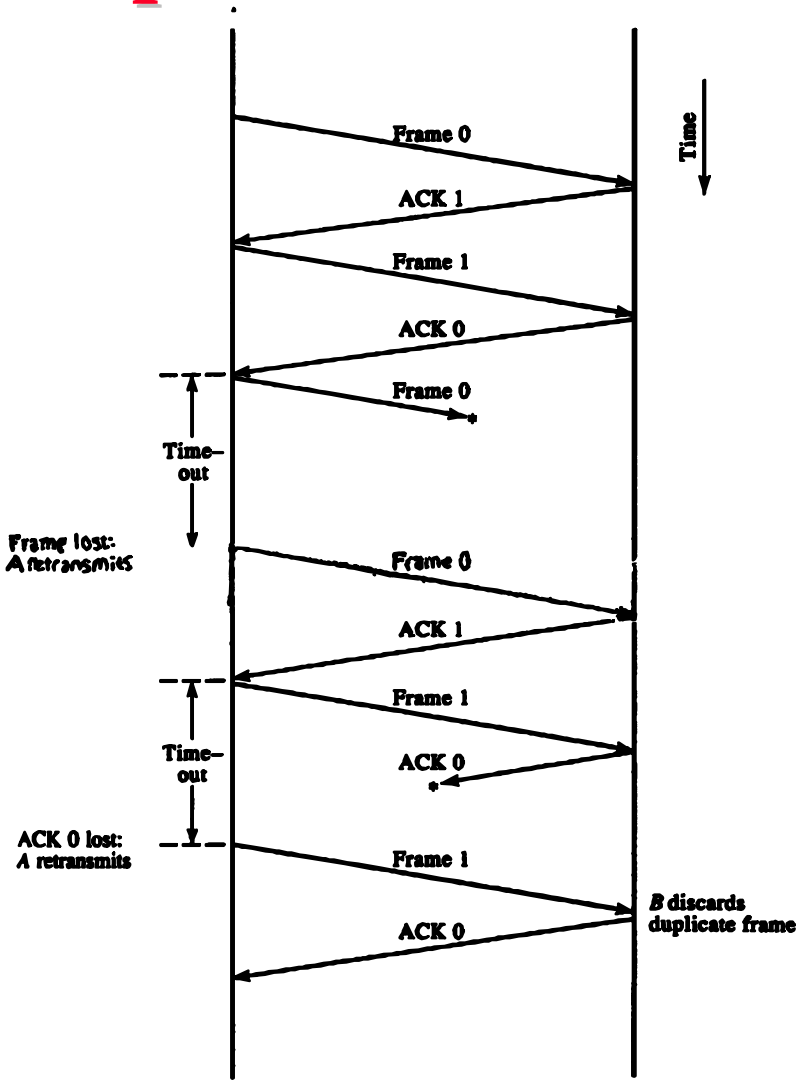
Error Control

- Error Control = Deliver frames without error, in the proper order to network layer
- Error control Mechanisms:
  - Ack/Nack: Provide sender some feedback about other end
  - Time-out: for the case when entire packet or ack is lost
  - Sequence numbers: to distinguish retransmissions from originals

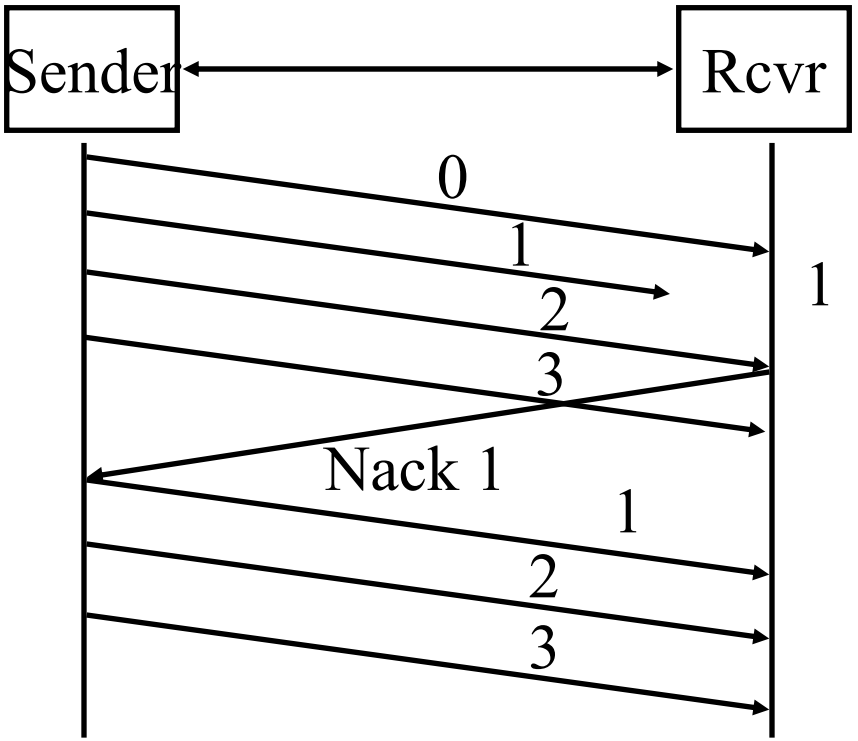


Stop-and-Wait ARQ

Automatic
Repeat
re**Q**uest
(ARQ)



Go-Back-N ARQ



- Receiver does not cache out-of-order frames
- Sender has to ***go back*** and retransmit all frames after the lost frame

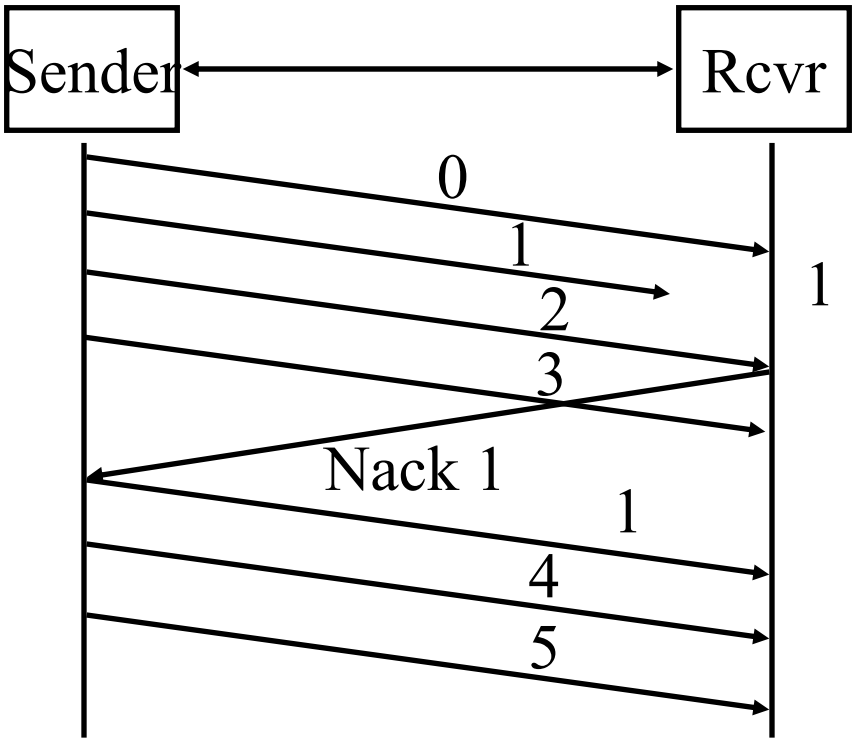
Go-back-N (Cont)

All possible scenarios are handled:

1. Damaged Frame:
   - Frame received with error
   - Frame lost
   - Last frame lost
2. Damaged Ack:
   - One ack lost, next one makes it
   - All acks lost
3. Damaged Nack:

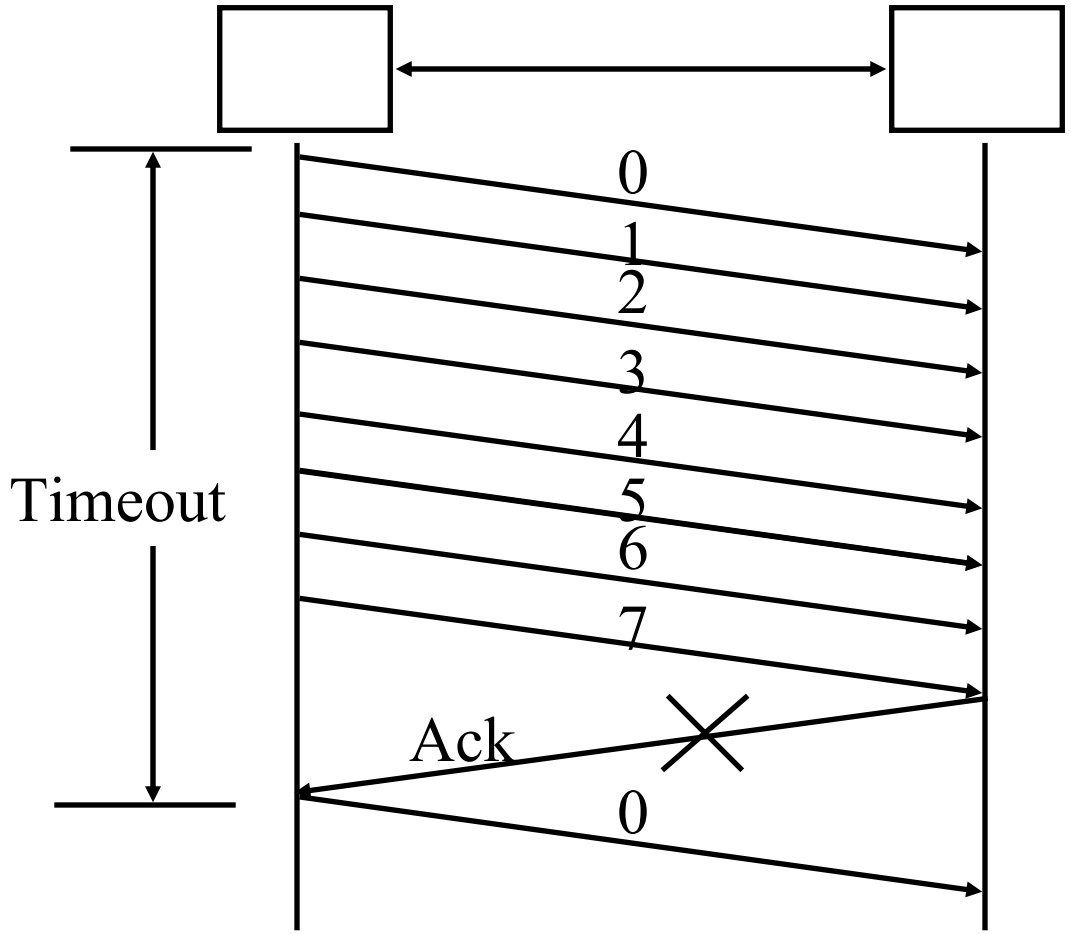
- Maximum Window = 2^n -1
  with *n*-bit sequence numbers

Selective Reject ARQ



- Receiver caches out-of-order frames
- Sender retransmits only the lost frame

Selective Reject: Window Size



Sequence number space $\geq$ 2 window size

Window size $\leq 2^{n-1}$

Performance: Maximum Utilization

- **Stop and Wait Flow Control**: $U = 1/(1+2\alpha)$
- **Window Flow Control**:

$$U = \begin{cases} 1 & W \geq 2\alpha+1 \\ W/(2\alpha+1) & W < 2\alpha+1 \end{cases}$$

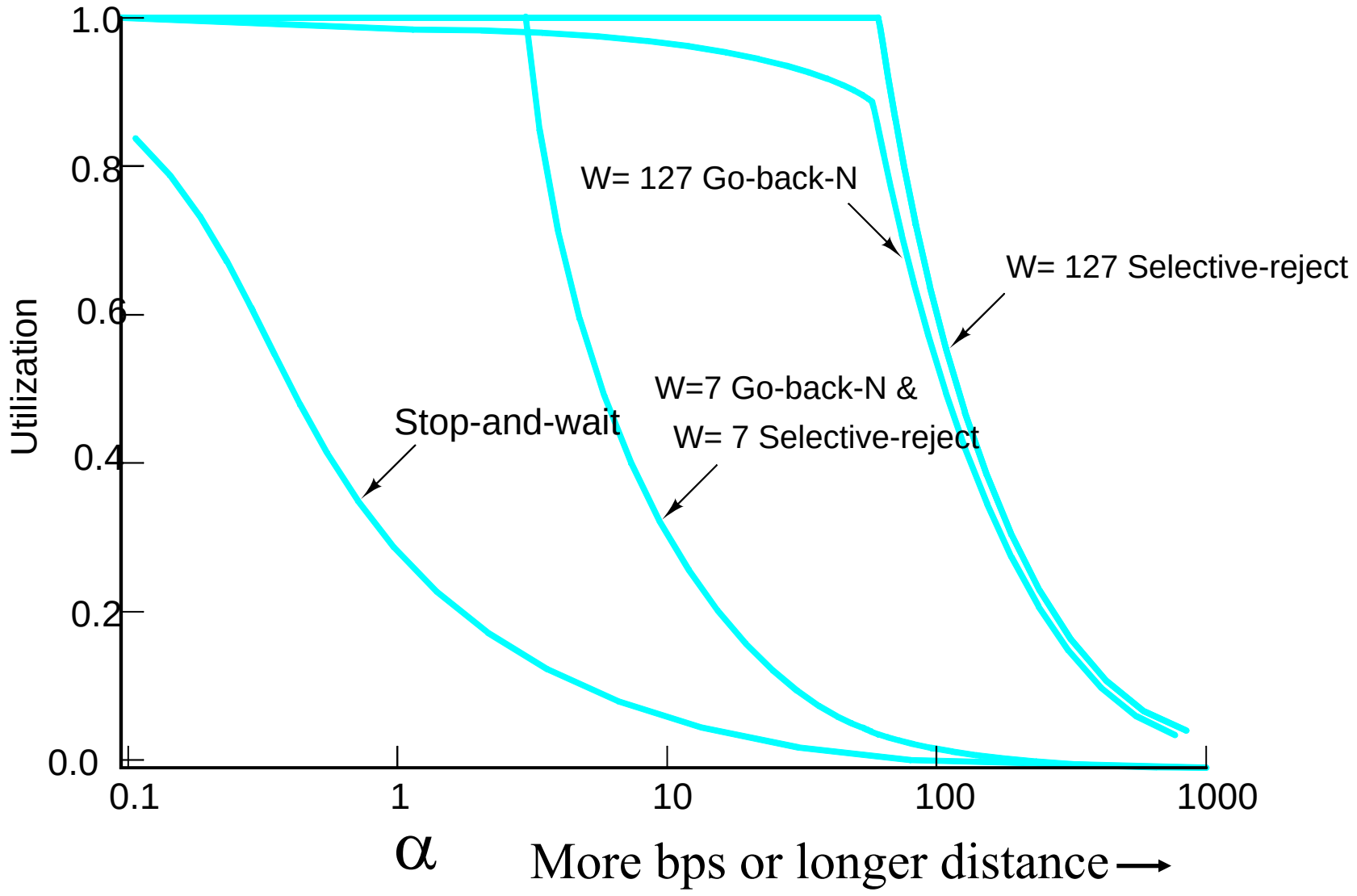
- **Stop and Wait ARQ**: $U = (1-P)/(1+2\alpha)$
- **Go-back-N ARQ**:

$$U = \begin{cases} (1-P)/(1+2\alpha P) & W \geq 2\alpha+1 \\ W(1-P)/[(2\alpha+1)(1-P+wP)] & W < 2\alpha+1 \end{cases}$$

- **Selective Reject ARQ**:

$$U = \begin{cases} (1-P) & W \geq 2\alpha+1 \\ W(1-P)/(2\alpha+1) & W < 2\alpha+1 \end{cases}$$

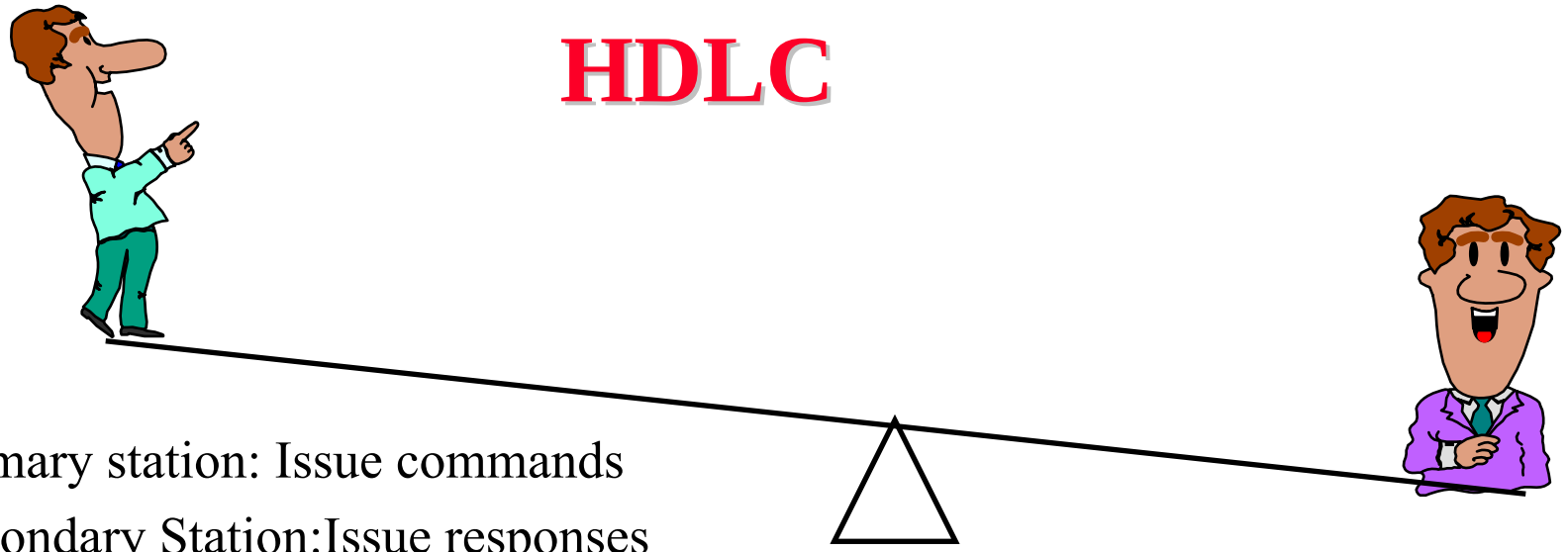
Performance Comparison



HDLC Family

- Synchronous Data Link Control (SDLC): IBM
- High-Level Data Link Control (HDLC): ISO
- Link Access Procedure-Balanced (LAPB): X.25
- Link Access Procedure for the D channel (LAPD): ISDN
- Link Access Procedure for modems (LAPM): V.42
- Link Access Procedure for half-duplex links (LAPX): Teletex
- Point-to-Point Protocol (PPP): Internet
- Logical Link Control (LLC): IEEE
- Advanced Data Communications Control Procedures (ADCCP): ANSI
- V.120 and Frame relay also use HDLC

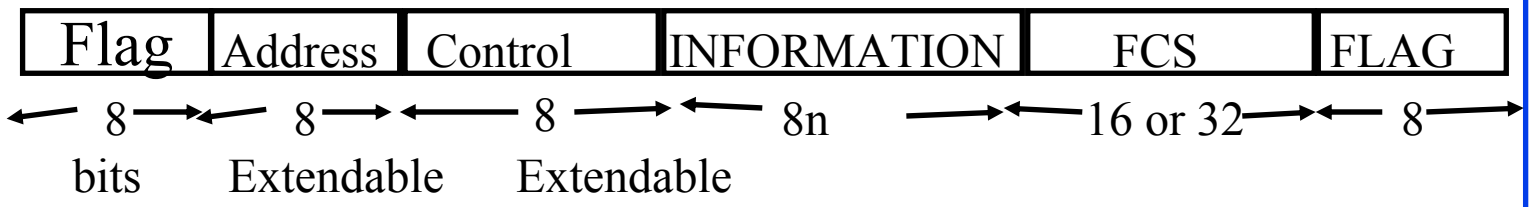
HDLC



- Primary station: Issue commands
- Secondary Station:Issue responses
- Combined Station: Both primary and secondary
- Unbalanced Configuration: One or more secondary
- Balanced Configuration: Two combined station
- Normal Response Mode (NRM): Response from secondary
- Asynchronous Balanced Mode (ABM): Combined Station
- Asynchronous Response Mode (ARM): Secondary may respond before command

HDLC Frame Structure

Frame Format



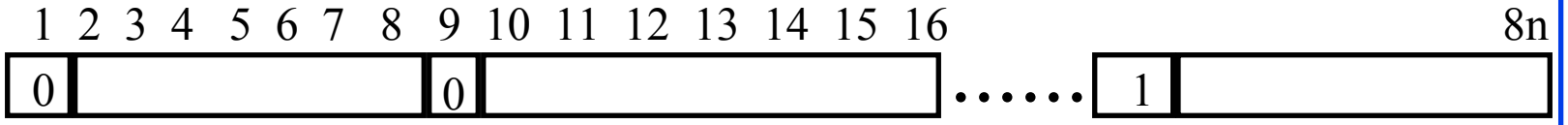
Control Field Format

I: Information
S: Supervisory
U: Unnumbered

1	2	3	4	5	6	7	8
0	N(S)			P/F	N(R)		
1	0	S		P/F	N(R)		
1	1	M		P/F	M		

N(S)= Send sequence number N(R)= Receive sequence number
S= Supervisory function bits M= Unnumbered bits P/F= Poll/final bit

Extended Address Field



Extended Control Field

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Information	0	N(S)							P/F	N(R)						
Supervisory	1	0	S		0	0	0	0	P/F	N(R)						

Bit Stuffing

- HDLC Flag = 01111110
- Every where else in the frame:
  Replace 11111 with 111110

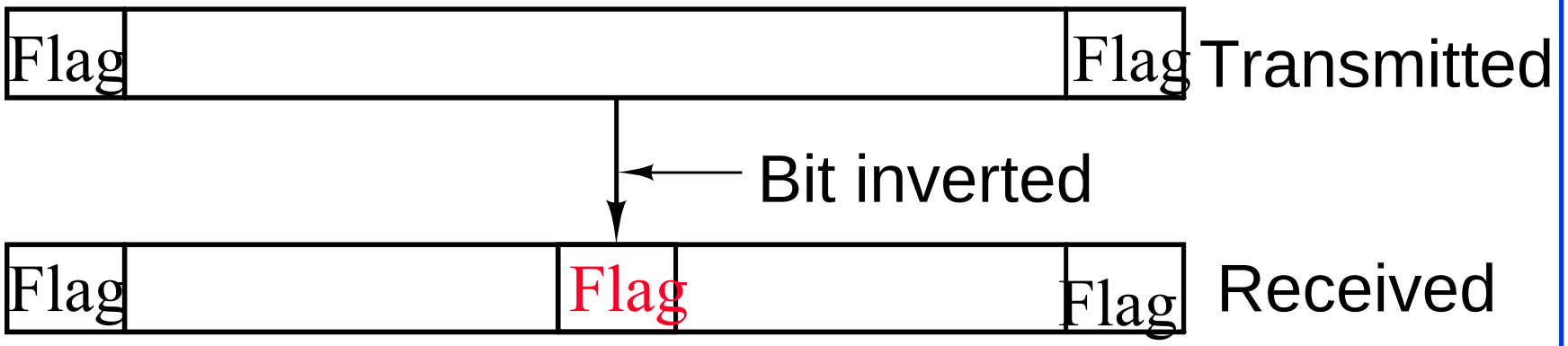
Original Pattern

11111111111101111101111110

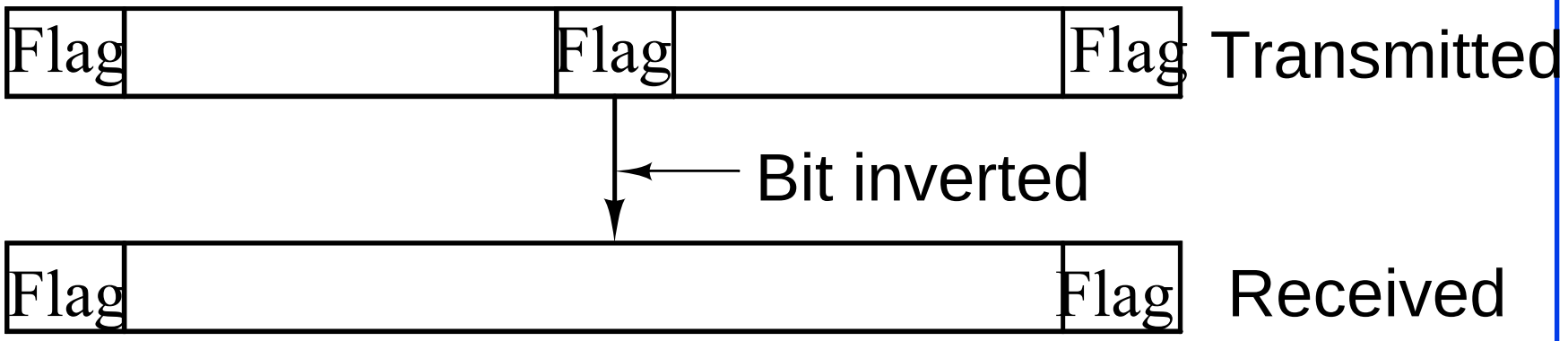
After bit-stuffing

11111011111011011111010111110 

Bit Stuffing (Cont)



(b) An inverted bit splits a frame in two



(c) An inverted bit merges two frames

HDLC Frames

- Information Frames: User data
  - Piggybacked Acks: Next frame expected
  - Poll/Final = Command/Response
- Supervisory Frames: Flow and error control
  - Go back N and Selective Reject
  - Final ⇒ No more data to send
- Unnumbered Frames: Control
  - Mode setting commands and responses
  - Information transfer commands and responses
  - Recovery commands and responses
  - Miscellaneous commands and responses

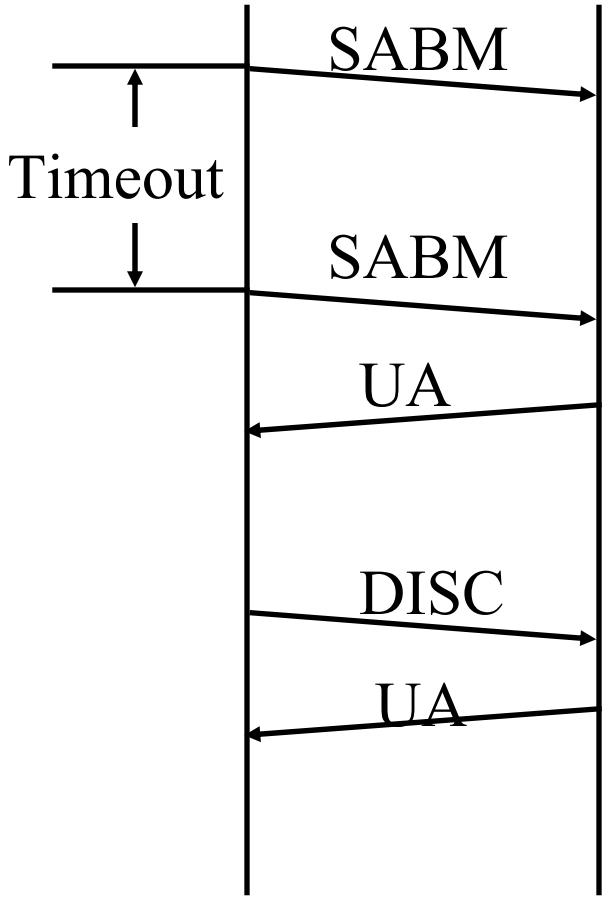
HDLC Commands and Responses

Name	Function	Description
Information (I)	C/R	Exchange user data
Supervisory (S)		
Receive Ready (RR)	C/R	Positive Acknowledgement; ready to receive I-frame
Receive Not Ready (RNR)	C/R	Positive acknowledgement; not ready to receive
Reject (REJ)	C/R	Negative acknowledgement; go back N
Selective Reject (SREJ)	C/R	Negative acknowledgement; selective reject
Unnumbered (U)		
Set Normal Response / Extended Mode (SNRM / SNRME)	C	Set mode;extended=two-octet control field
Set Asynchronous Response / Extended Mode (SARM / SARME)	C	Set mode;extended=two-octet control field
Set Asynchronous Balanced / Extended Mode (SABM / SABME)	C	Set mode;extended=two-octet control field
Set Initialization Mode (SIM)	C	Initialize link control functions in addressed station

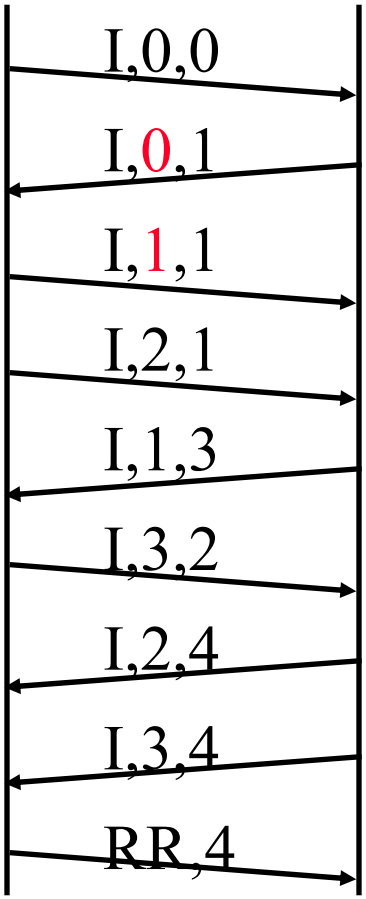
HDLC Commands and Responses (cont)

Name	Function	Description
Disconnect (DISC)	C	Terminate logical link connection
Unnumbered Acknowledgement (UA)	R	Acknowledges acceptance of one of the above set-mode commands
Disconnect Mode (DM)	R	Secondary is logically disconnected
Request Disconnect (RD)	R	Request for DISC command
Request Initialization Mode (RIM)	R	Initialization needed; request for SIM command
Unnumbered Information (UI)	C/R	Used to exchange control information
Unnumbered Poll (UP)	C	Used to solicit control information
Reset (RSET)	C	Used for recovery; resets N(R), N(S)
Exchange Identification (XID)	C/R	Used to request/report identity and status
Test (TEST)	C/R	Exchange identical information fields for testing
Frame Reject (FRMR)	R	Reports receipt of unacceptable frame

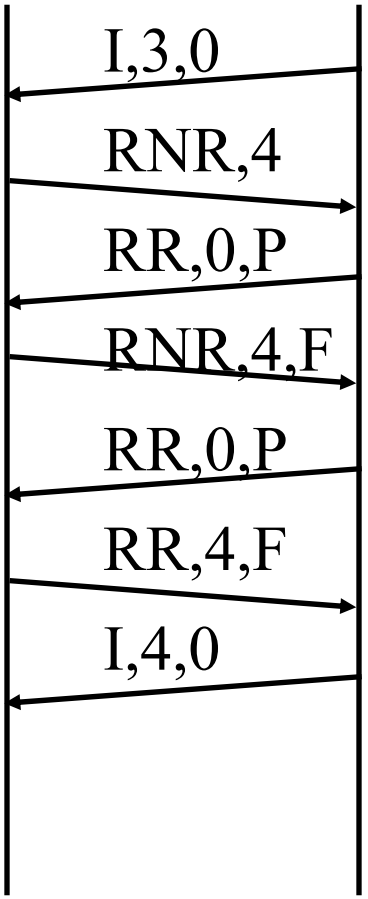
Examples of HDLC Operation



(a) Link setup and disconnect

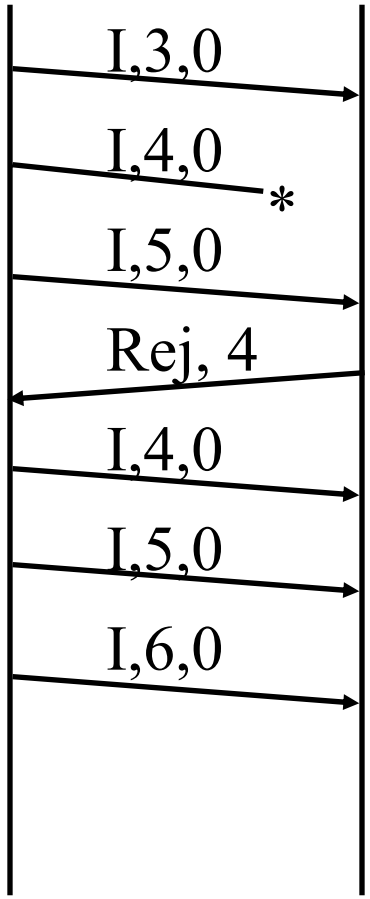


(b) Two-way data exchange

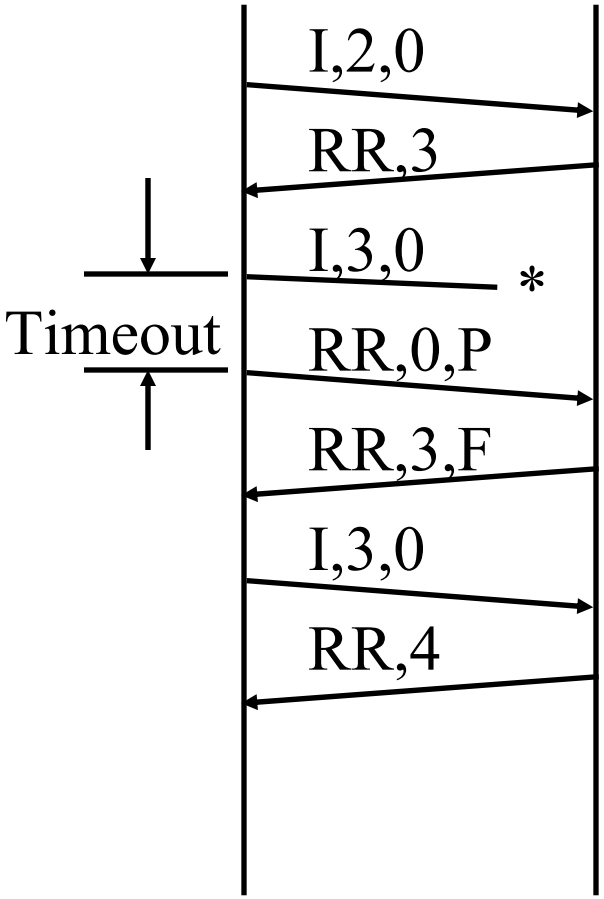


(c) Busy condition

Examples of Operation (Cont)

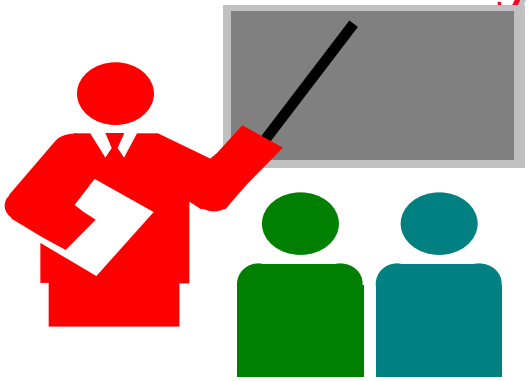


(d) Reject Recovery



(e) Timeout Recovery

Summary



- Flow Control: Stop and Wait, Sliding window
- Effect of propagation delay, speed, frame size
- Piggybacking
- Error Control: Stop and wait ARQ, Go-back-N, Selective Reject
- HDLC: Primary and secondary stations, NRM, ABM, ARM
- HDLC Frames: Flag, Bit stuffing, I-Frame, RR, RNR

Reading Assignment

- Read Chapter 7 and Appendix 7A of 7th edition of Stallings.
- Do the following Exercise from the textbook: 7.8 (maximum link utilizations)
- **There is no need to submit the answers. Next Monday is the first mid-term.**