Computer Networks 1

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DATA LINK CONTROL PROTOCOLS

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OUTLINE

- Flow Control
- Error Control
- High-Level Data Link Control (HDLC)

OUTLINE

Flow Control

Error Control

High-Level Data Link Control (HDLC)

WHY FLOW CONTROL?

- Assuring that a transmitting entity does not overwhelm a receiving entity with data
- Finite data buffer at receiver
- Data processing before passing the data to the higher-level at receiver
- Avoiding the receiver's buffer to fill up and overflow

STOP-AND-WAIT FLOW CONTROL

- The simplest form of flow control
- A source entity transmits a frame
- After the destination entity receives the frame, it send back an acknowledgment to the frame just received.
- The source must wait until it receives the acknowledgment before sending the next frame.
- The destination can thus stop the flow of data simply by withholding acknowledgment

LINK ANALYSIS

- B: Length of the link (bits)
  - Number of bits present on the link at an instance in time when a stream of bits fully occupies the link
- R: Data rate of the link (bps)
- d: Length, or distance, of the link (meters)
- V: Velocity of propagation (m/s)

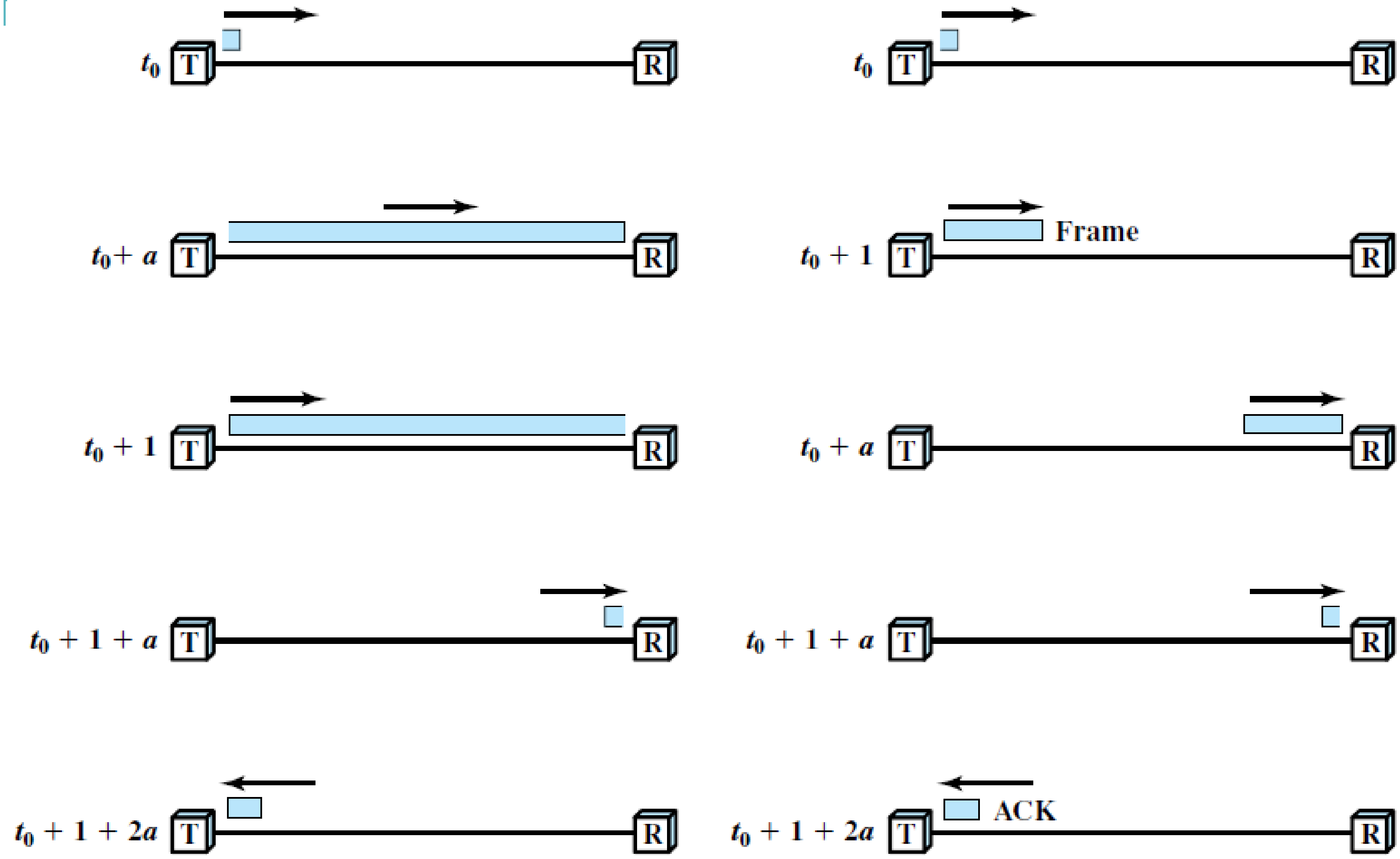
$$B = R\frac{d}{V}$$

PROPAGATION DELAY

- L: Frame length (bits)
  - Number of bits in the frame
- Normalized transmission time
  - The time it takes for a station to transmit a frame
- a: Propagation delay
  - The time it takes for a bit to travel from sender to receiver

$$a = \frac{B}{L}$$

STOP-AND-WAIT LINK UTILIZATION



(a) $a < 1$ (b) $a > 1$

STOP-AND-WAIT PROS. & CONS.

- Works fine when a message is sent in a few large frames
- With the use of multiple frames for a single message, the stop-and-wait procedure may be inadequate
- The essence of the problem is that only one frame at a time can be in transit
- In situations where the bit length of the link is greater than the frame length, serious inefficiencies result

PERFORMANCE ANALYSIS
STOP-AND-WAIT FLOW CONTROL

- Half-duplex point-to-point line between stations A and B
- Long message is to be sent as a sequence of frames $F_1, F_2, \dots, F_n$ from A to B:
  - Station A sends F_1
  - Station B sends an acknowledgment.
  - Station A sends F_2
  - Station B sends an acknowledgment

STOP-AND-WAIT PERFORMANCE ANALYSIS

- T_F: Time to send one frame and receive an acknowledgment
- t_{prop}: Propagation time from A to B
- t_{frame}: Time to transmit a frame
  - Time for the transmitter to send out all of the bits of the frame
- t_{proc}: Processing time at each station to react to an incoming event
- t_{ack}: Time to transmit an acknowledgment
- $T_F = t_{prop} + t_{frame} + t_{proc} + t_{prop} + t_{ack} + t_{proc}$
- Total time to send the data: $T = nT_F$

STOP-AND-WAIT LINE UTILIZATION

- Reasonable assumptions:
  - Processing time is relatively negligible
  - Acknowledgment frame is very small compared to a data frame
- $T = n(2t_{prop} + t_{frame})$
- $n \times t_{frame}$: Actually spent transmitting data
- The line utilization(efficiency): U
- $U = \frac{n \times t_{frame}}{n(2t_{prop}+t_{frame})} = \frac{t_{frame}}{2t_{prop}+t_{frame}}$
- $a = \frac{t_{prop}}{t_{frame}}$ $\quad (a = \frac{d/V}{L/R} = \frac{Rd}{VL}, \quad a = \frac{B}{L})$
- $U = \frac{1}{2a+1}$
- The maximum possible utilization of the link
  - Actual utilization is lower
  - The frame contains overhead bits

SLIDING-WINDOW FLOW CONTROL

- Allowing multiple frames to be in transit at the same time
- Improving efficiency
- Two stations, A and B, connected via a full-duplex link
- Station B allocates buffer space for W frames
  - B can accept W frames
  - A is allowed to send W frames without waiting for any acknowledgments

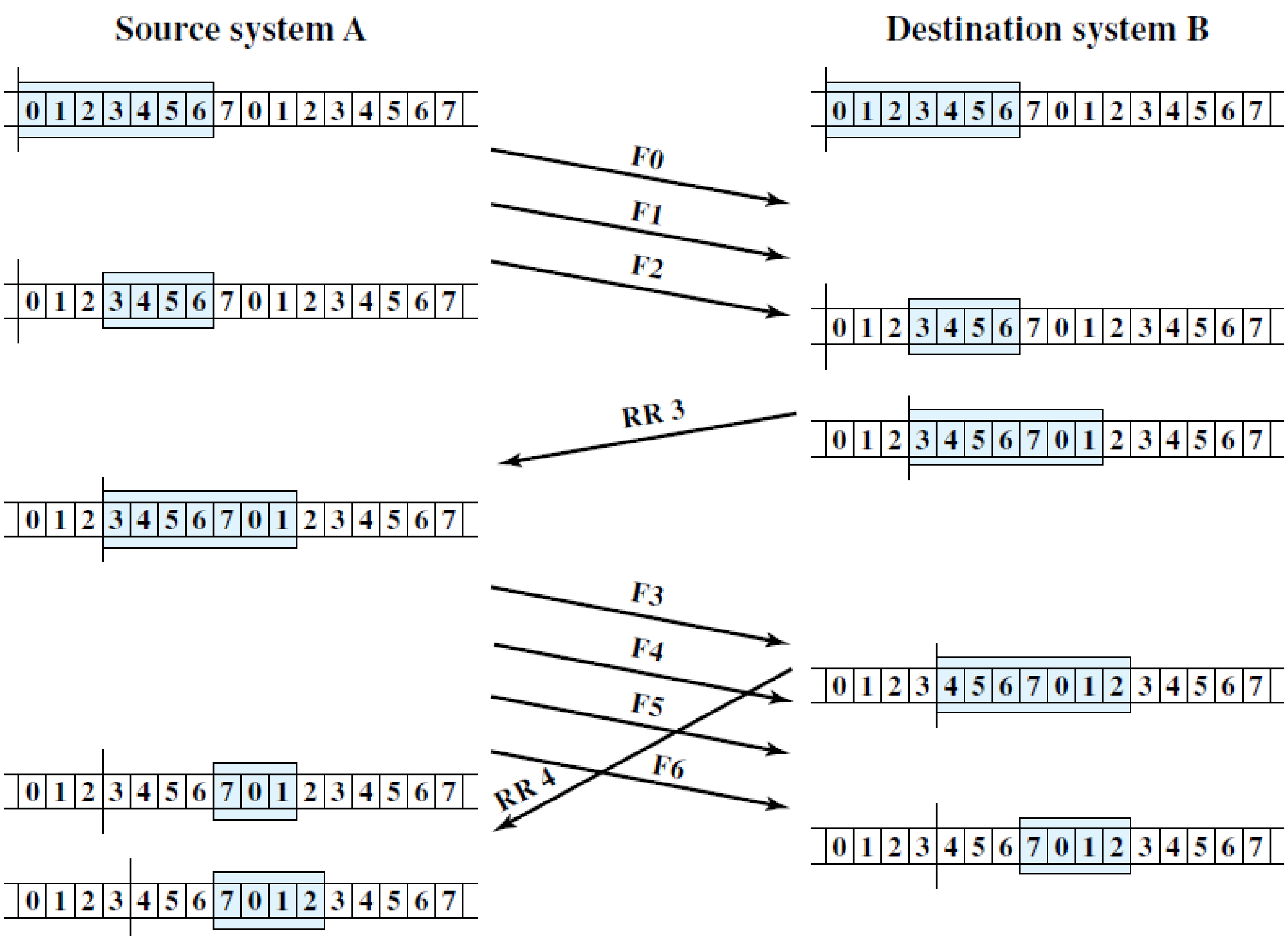
SLIDING-WINDOW FLOW CONTROL

- B acknowledges a frame by sending an ack
  - Includes the sequence number of the next frame expected
  - B is prepared to receive the next W frames, beginning with the number specified
  - Acknowledge multiple frames
- *window* of frames at A, B
  - A maintains a list of sequence numbers allowed to send
  - B maintains a list of sequence numbers prepared to receive

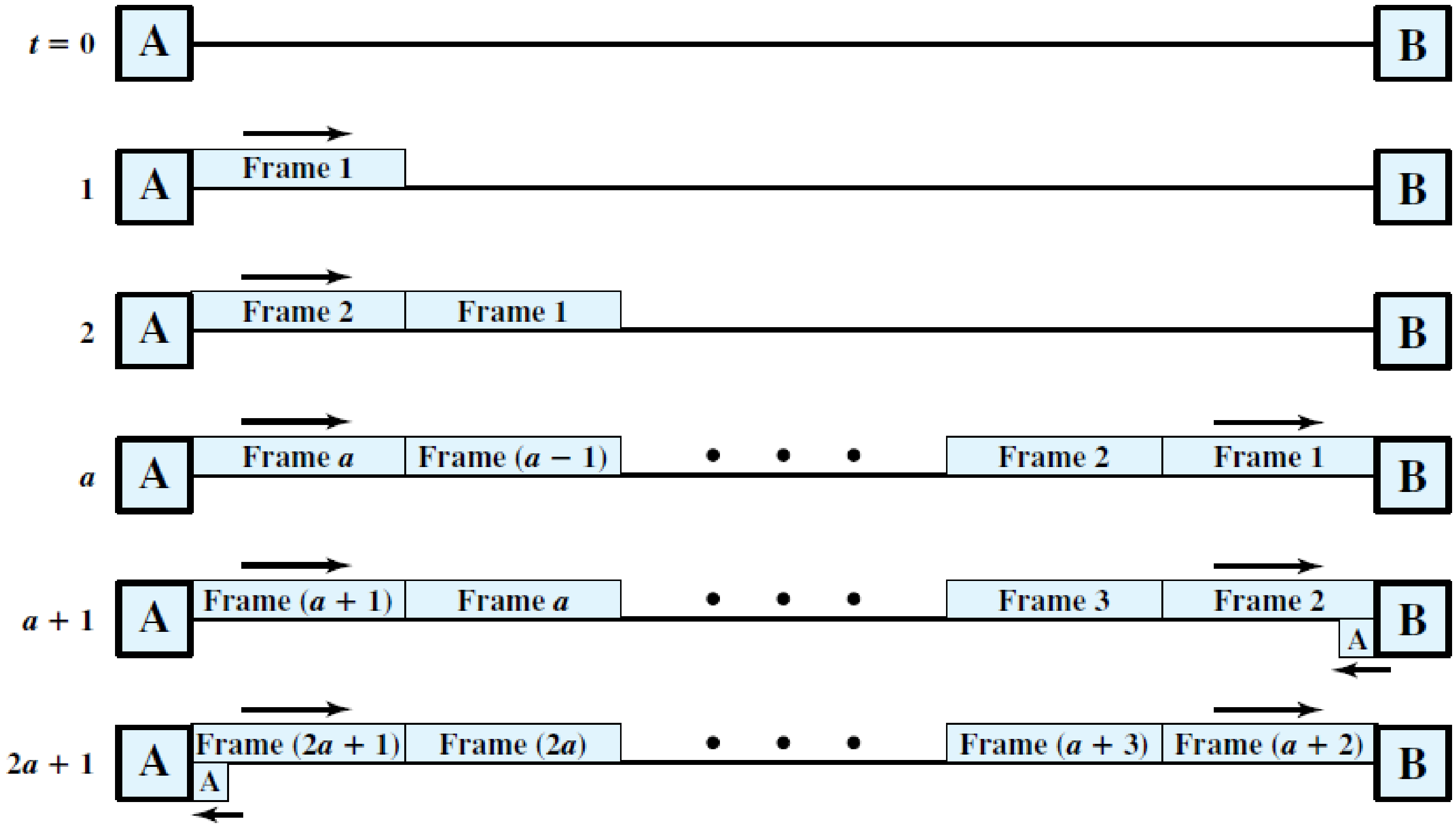
SLIDING-WINDOW SEQUENCE NUMBER

- Each frame is labeled with a sequence number
  - To keep track of which frames have been acknowledged
- The sequence number occupies a field in the frame
  - Limited to a range of values
- *k*-bit field
  - Range of sequence numbers: *0* through $2^k - 1$
  - Frames are numbered modulo 2^k
  - Maximum window size: $2^k - 1$
- Ex:3-bit field
  - The sequence number can range from 0 to *7*
  - Frames are numbered modulo 8
  - After sequence number *7*, the next number is 0

EXAMPLE OF A SLIDING-WINDOW PROTOCOL



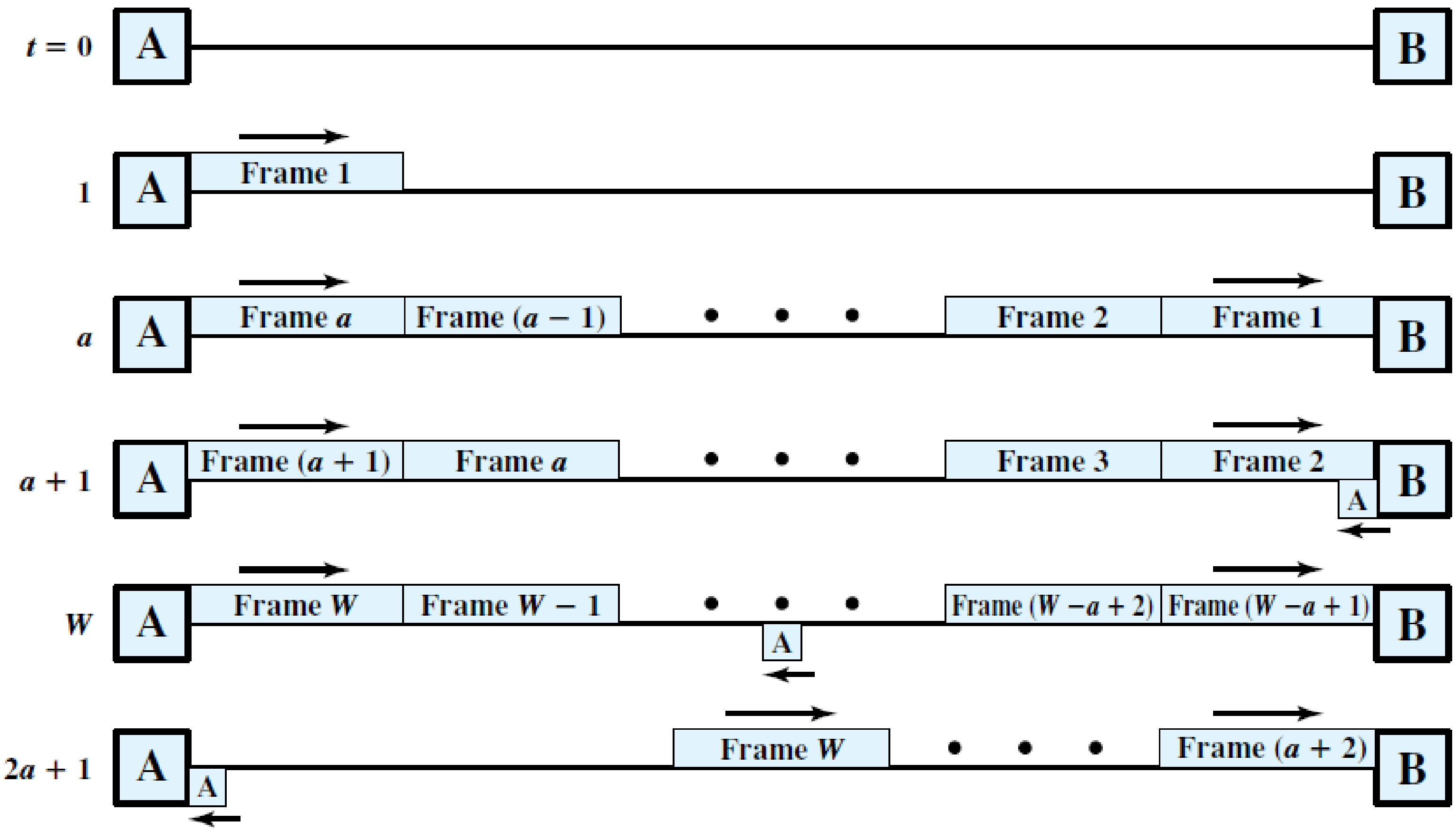
ERROR-FREE SLIDING-WINDOW FLOW CONTROL PERFORMANCE ANALYSIS



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

- The acknowledgment for frame 1 reaches A before A has exhausted its window
- A can transmit continuously with no pause
- Normalized throughput : $U = 1$

ERROR-FREE SLIDING-WINDOW FLOW CONTROL PERFORMANCE ANALYSIS



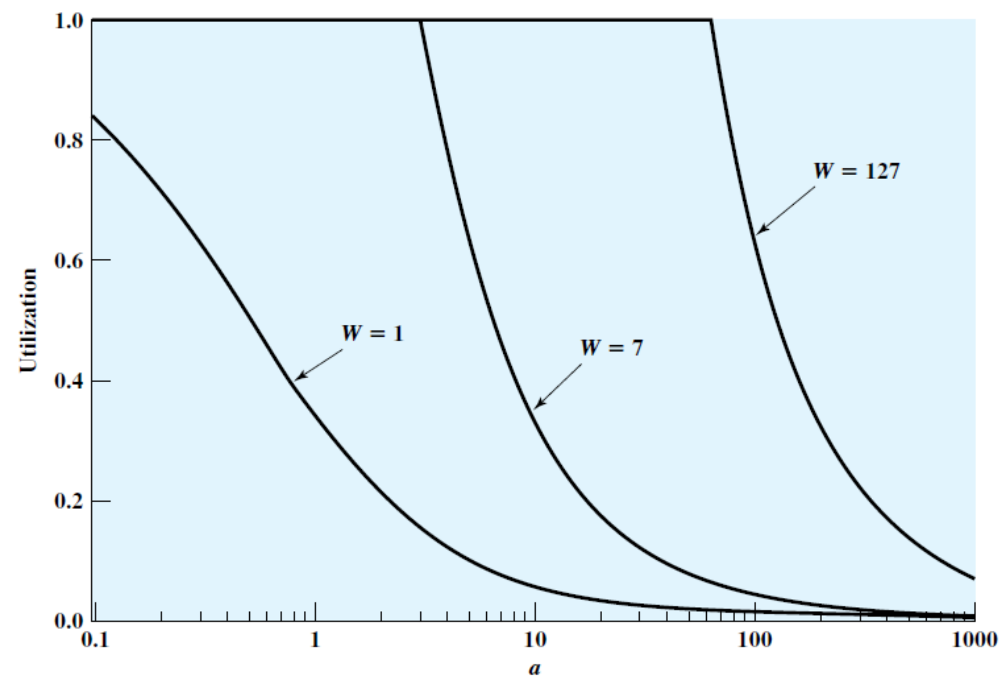
(b) $W < 2a + 1$

A exhausts its window at t =W and cannot send additional frames until $t = 2a + 1$

Normalized throughput is $U = \frac{W}{2a+1}$

SLIDING-WINDOW UTILIZATION

- *n*-bit field sequence number
- Maximum window size: $W = 2^n - 1$
- A window size of 1
  - stop and wait
- A window size of 7 (3 bits)
  - Adequate for many applications
- A window size of 127 (7 bits)
  - Adequate for larger values of *a*
  - high-speed WANs
- Sliding-window flow control is more efficient than stop-and-wait flow control



OUTLINE

- Flow Control
- **Error Control**
- High-Level Data Link Control (HDLC)

TYPES OF ERRORS

- Lost frame:
  - A frame fails to arrive at the other side
  - Ex:
    - A noise burst may damage a frame
    - Receiver is not aware a frame has been transmitted
- Damaged frame:
  - A recognizable frame does arrive
  - Some of the bits are in error

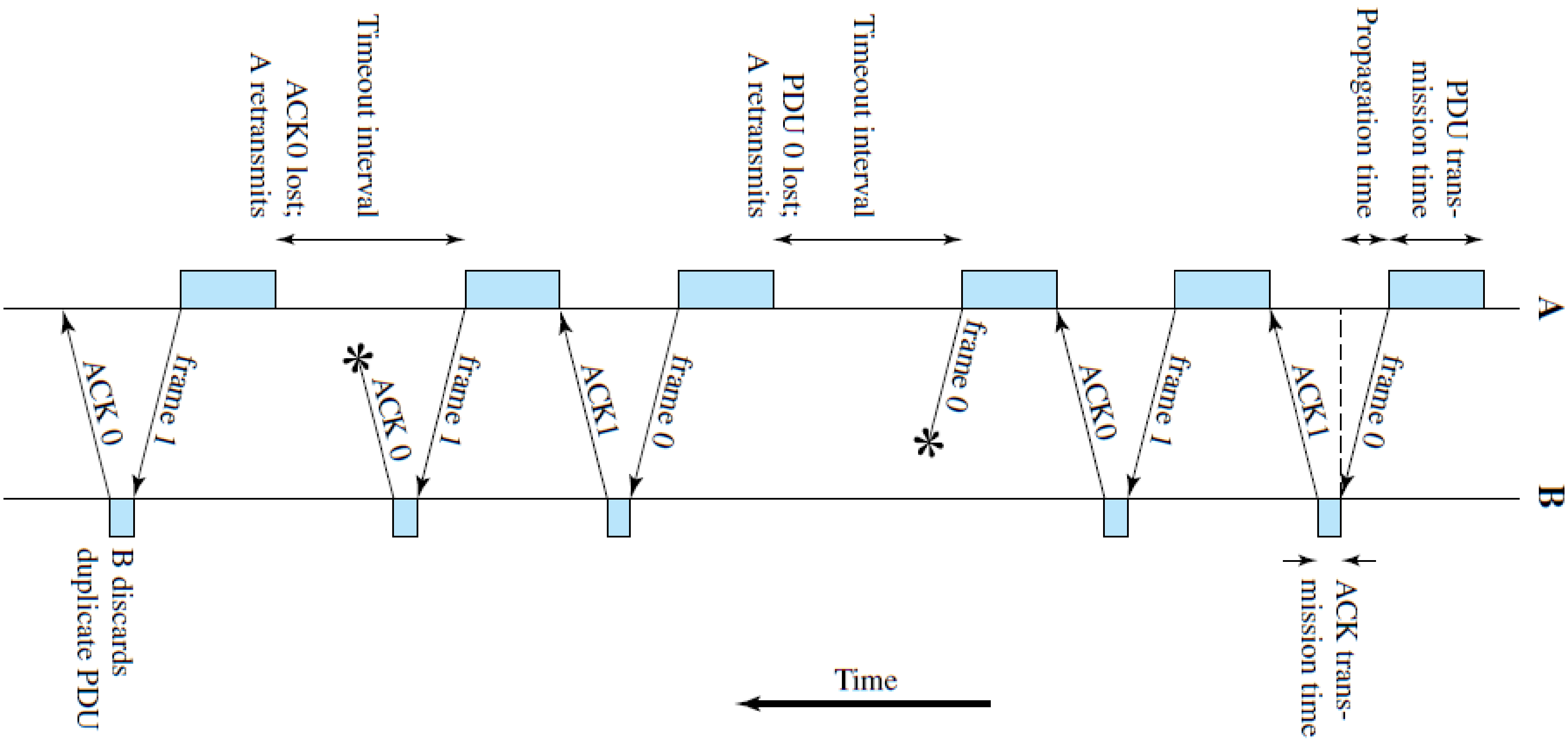
ERROR CONTROL MECHANISM

- Error detection
- Positive acknowledgment
  - Destination returns a positive acknowledgment to successfully received error-free frames
- Retransmission after timeout
  - Source retransmits a frame not been acknowledged after a predetermined amount of time
- Negative acknowledgment and retransmission
  - Destination returns a negative acknowledgment to frames in which an error is detected
  - The source retransmits such frames

ARQ (AUTOMATIC REPEAT REQUEST)

- Previous mechanisms are all referred to as automatic repeat request
- To turn an unreliable data link into a reliable one
- Standard versions of ARQ
  - Stop-and-wait ARQ
  - Go-back-N ARQ
  - Selective-reject ARQ

STOP-AND-WAIT ARQ



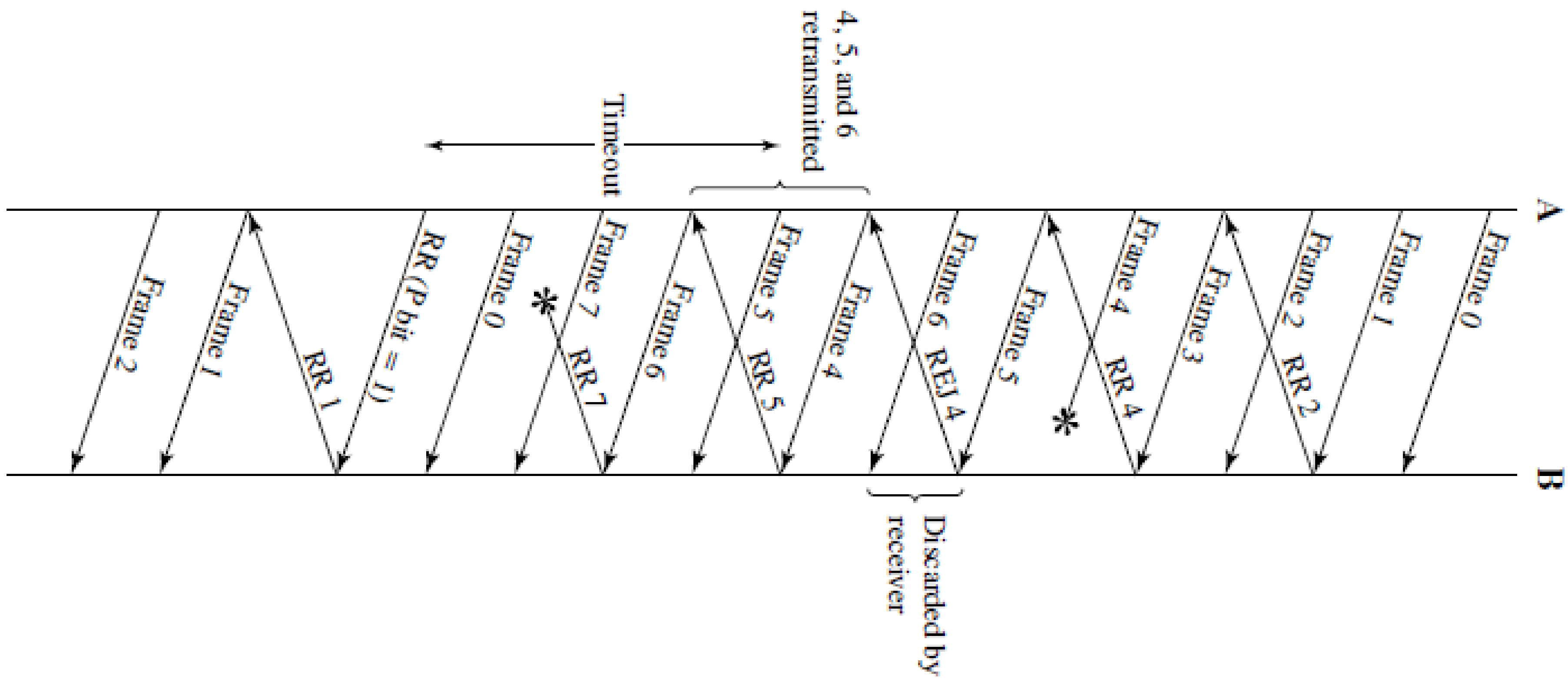
STOP & WAIT ARQ PERFORMANCE ANALYSIS

- N_r:Expected number of transmissions of a frame
- $U = \frac{t_{frame}}{N_r(2t_{prop}+t_{frame})}$
- $a = \frac{t_{prop}}{t_{frame}}$
- $U = \frac{1}{N_r(2a+1)}$
- Probability P: A single frame is in error
- $N_r = \frac{1}{1-p}$
- $U = \frac{1-p}{(2a+1)}$

GO-BACK-N ARQ

- While no errors occur
  - RR or piggybacked acknowledgment from destination
- If the destination station detects an error in a frame
  - Send REJ for that frame
  - Discard that frame and all future incoming frames until the frame in error is correctly received
  - Source station, when it receives a REJ, must retransmit the frame in error plus all succeeding frames transmitted

GO-BACK-N ARQ

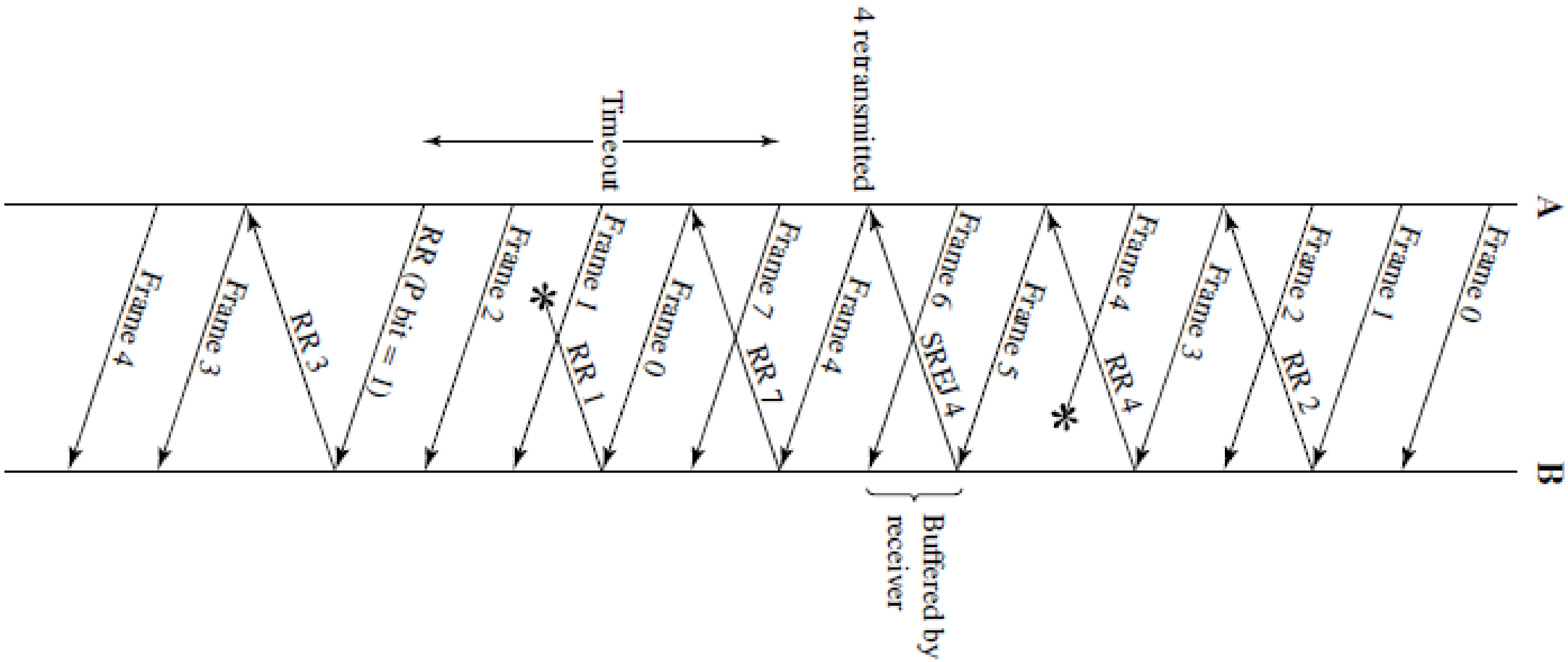


(a) Go-back-N ARQ

SELECTIVE-REJECT ARQ

- Only retransmitted frames
  - Those that receive a negative acknowledgment SREJ
  - Those that time out
- Minimizing the amount of retransmission
- More efficient than go-back-N
- Receiver must maintain a buffer large enough to save post-SREJ frames until the frame in error is retransmitted
- Receiver must contain logic for reinserting that frame in the proper sequence
- Transmitter requires more complex logic to send a frame out of sequence

SELECTIVE REJECT ARQ

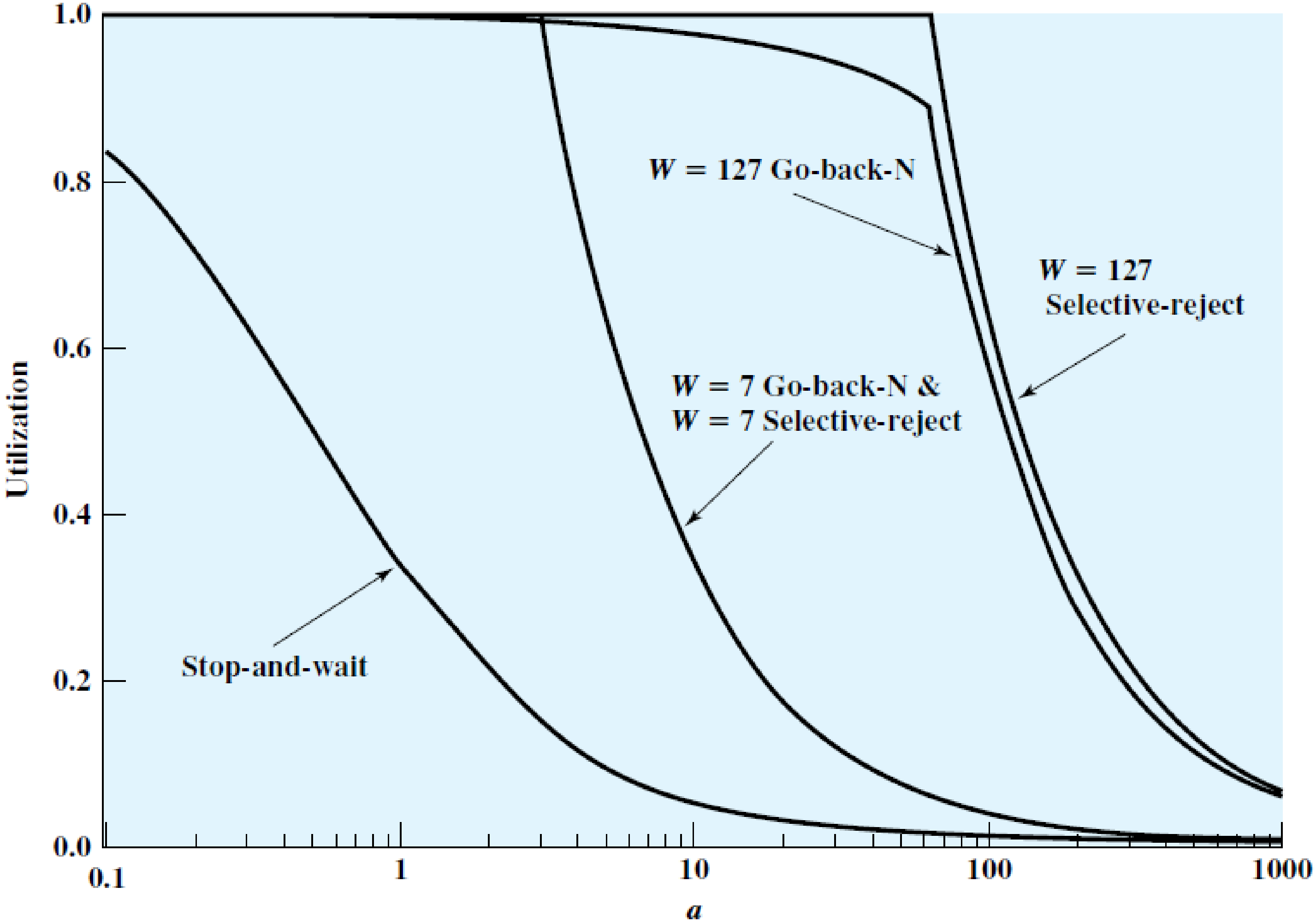


(b) Selective-reject ARQ

SELECTIVE-REJECT ARQ WINDOW SIZE

- More restrictive window size limitation
- *k*-bit field
  - Range of sequence numbers: *0* through $2^k - 1$
  - Maximum window size: 2^{k-1}
- Less widely used than go-back-N ARQ
- Useful choice for a satellite link
  - because of the long propagation delay

ARQ UTILIZATION



OUTLINE

- Flow Control
- Error Control
- **High-Level Data Link Control (HDLC)**

HDLC

- The most important data link control protocol
- Basis for many other important data link control protocols
- Three station types:
  - **Primary station**
    - Responsible for controlling the operation of the link
    - Frames issued by the primary : commands
  - **Secondary station**
    - Operates under the control of the primary station
    - Frames issued by a secondary: responses
    - The primary maintains a separate logical link with each secondary station on the line
  - **Combined station**
    - Combines the features of primary and secondary
    - May issue both commands and responses

HDLC LINK CONFIGURATIONS

Unbalanced configuration

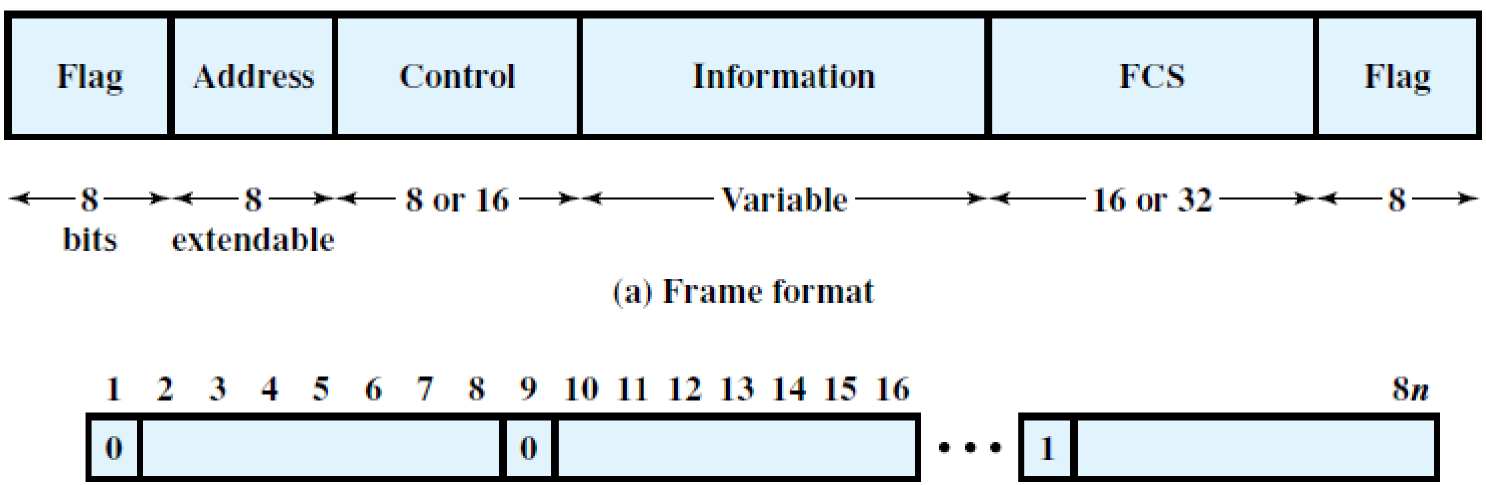
- One primary and one or more secondary stations
- Supports both full-duplex and half-duplex transmission

Balanced configuration

- Two combined stations and
- Supports both full-duplex and half-duplex transmission

HDLC FRAMING

- Synchronous transmission
- **Header :** flag, address, and control fields preceding the data field
- **Trailer:** FCS and flag fields following the data field



(a) Frame format

(b) Extended address field

FLAG FIELDS AND BIT STUFFING

Original pattern:

111111111111011111101111110

After bit-stuffing:

1111101111101101111101011111010

- Flag fields: unique pattern 01111110
- To avoid appearing the pattern 01111110 inside the frame
- For all bits between the starting and ending flags, the transmitter inserts an extra 0 bit after each occurrence of five 1s in the frame
- Using bit stuffing, arbitrary bit patterns can be inserted into the data field of the frame
- Known as data transparency

ADDRESS FIELD

- Identifying the secondary station
- Not needed for point-to-point links but included for uniformity
- Usually 8 bits long
- By prior agreement, an extended format can be used
  - Actual address length: multiple of 7 bits
  - Leftmost bit of each octet is 1 or 0
    - it is or is not the last octet of the address field
- All-stations address: single-octet address of 11111111
  - Allowing the primary to broadcast a frame for all secondaries

TYPES OF FRAMES

- 3 types of frames, with a different control field format
  - Information frames (I-frames)
    - Carrying the data to be transmitted for the user
    - Piggybacking flow and error control data
  - Supervisory frames (S-frames)
    - Providing ARQ mechanism when piggybacking is not used
  - Unnumbered frames (U-frames)
    - provide supplemental link control functions
- The first one or two bits of the control field serves to identify the frame type

HDLC CONTROL FIELD

	1	2	3	4	5	6	7	8
I: Information	0	N(S)			P/F	N(R)		
S: Supervisory	1	0	S		P/F	N(R)		
U: Unnumbered	1	1	M		P/F	M		

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

(c) 8-bit control field format

	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)						

(d) 16-bit control field format

CONTROL FIELD

- Poll/final (P/F) bit
  - In command frames:
    - Referred to as the P bit
    - Set to 1 to poll a response frame
  - In response frames:
    - Referred to as the F bit
    - Set to 1 to indicate the response frame transmitted as a result of a soliciting command
- Sequence number
  - 3-bit for basic control field of S- and I-frames
    - Extended control field: 7-bit sequence numbers
- U-frames always contain an 8-bit control field

INFORMATION FIELD

- Information Field
  - Present only in I-frames and some U-frames
  - Variable Length up to some system defined maximum
- Frame Check Sequence Field
- Error detecting code calculated from the remaining bits of the frame, exclusive of flags
- Normal code:16-bit CRC-CCITT: $X^{16} + X^{12} + X^5 + 1$
- Optional: 32-bit FCS, using CRC-32:

$$X^{32} + X^{26} + X^{23} + X^{22} + X^{16} + X^{12} + X^{11} + X^{10} + X^8 + X^7 + X^5 + X^4 + X^2 + X + 1$$

HDLC OPERATION

- Exchanging frames between stations
- Operation phases:
  - Initialization
  - Data Transfer
  - Disconnect

INITIALIZATION

- Either side may request initialization
- By issuing one of the six setmode commands for
  1. Signaling the other side that initialization is requested
  2. Specifying (NRM,ABM,ARM) is requested
  3. Specifying 3- or 7-bit sequence numbers
- If the other side accepts this request
  - Transmits an unnumbered acknowledged (UA)
- If the request is rejected
  - Disconnected mode (DM) frame is sent

DATA TRANSFER

- Exchanging user data and control information for flow and error control
- After initialization, A logical connection is established
- Both sides can send user data in Iframes, starting with sequence number 0
- I-frames sequence number: N(S)
- Acknowledgment for I-frames received: N(R)

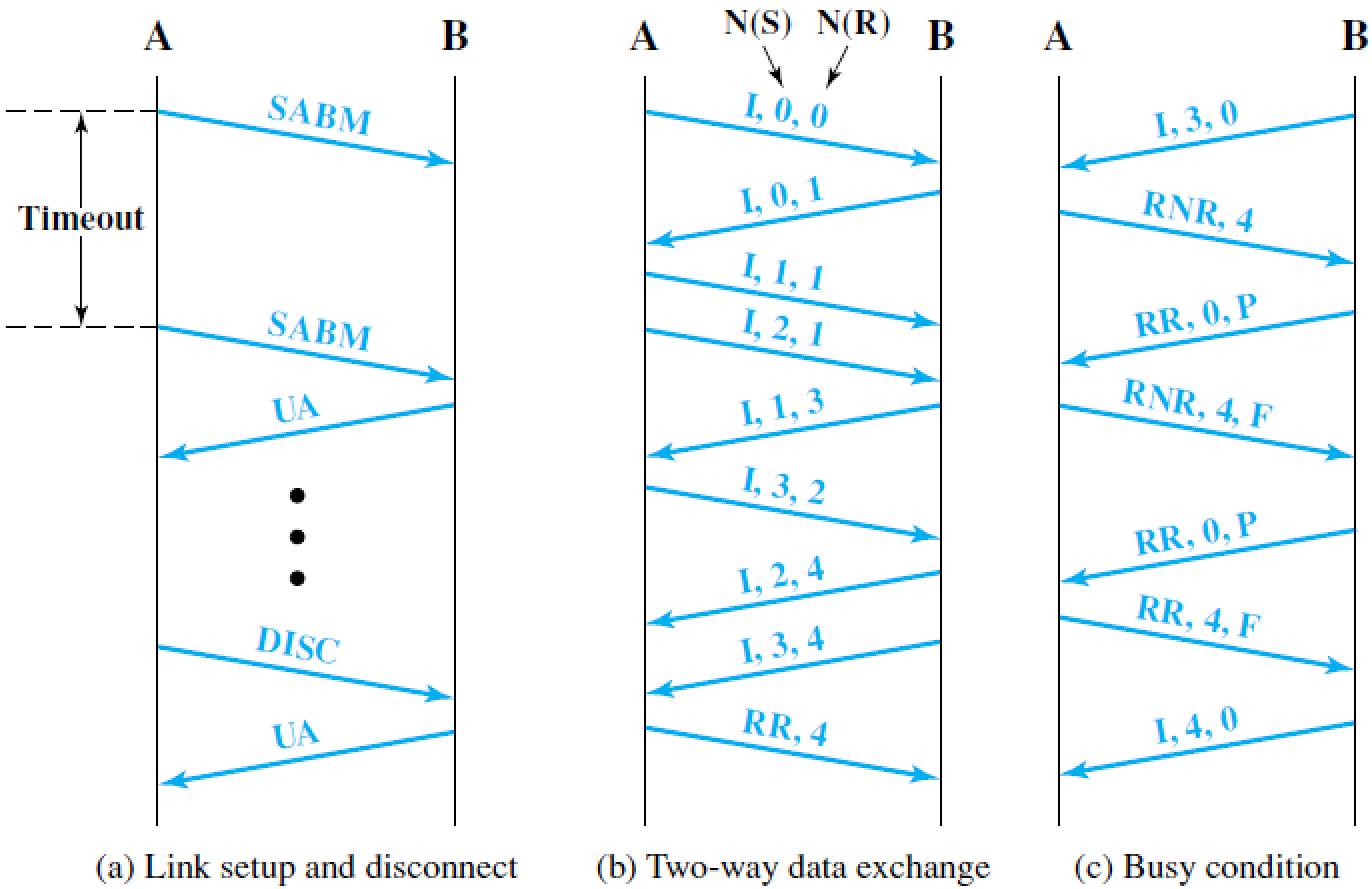
DATA TRANSFER
S-FRAMES FOR FLOW CONTROL AND ERROR CONTROL

- Receive ready (RR) frame
  - Acknowledging the last I-frame received
  - By indicating the next I-frame expected
  - Used when there is no reverse I-frames to carry an acknowledgment
- Receive not ready (RNR)
  - Acknowledging an I-frame
  - Also asking to suspend transmission of I-frames
  - When the entity is again ready, it sends an RR
- Reject (REJ)
  - Indicating the last I-frame received has been rejected
  - Initiating the go-back-N ARQ
  - Retransmission of all I-frames beginning with number N(R) is required
- Selective reject (SREJ)
  - Request retransmission of just a single frame

DISCONNECT

- Disconnecting
  - In case of fault
  - Or at the request of its higher-layer user
  - Issuing a disconnect by sending a disconnect (DISC) frame
- Accepting the disconnect
  - By replying with a UA
  - Informing its layer 3 that the connection has been terminated
- Unacknowledged I-frames may be lost
- Their recovery is the responsibility of higher layers

EXAMPLES OF HDLC OPERATION



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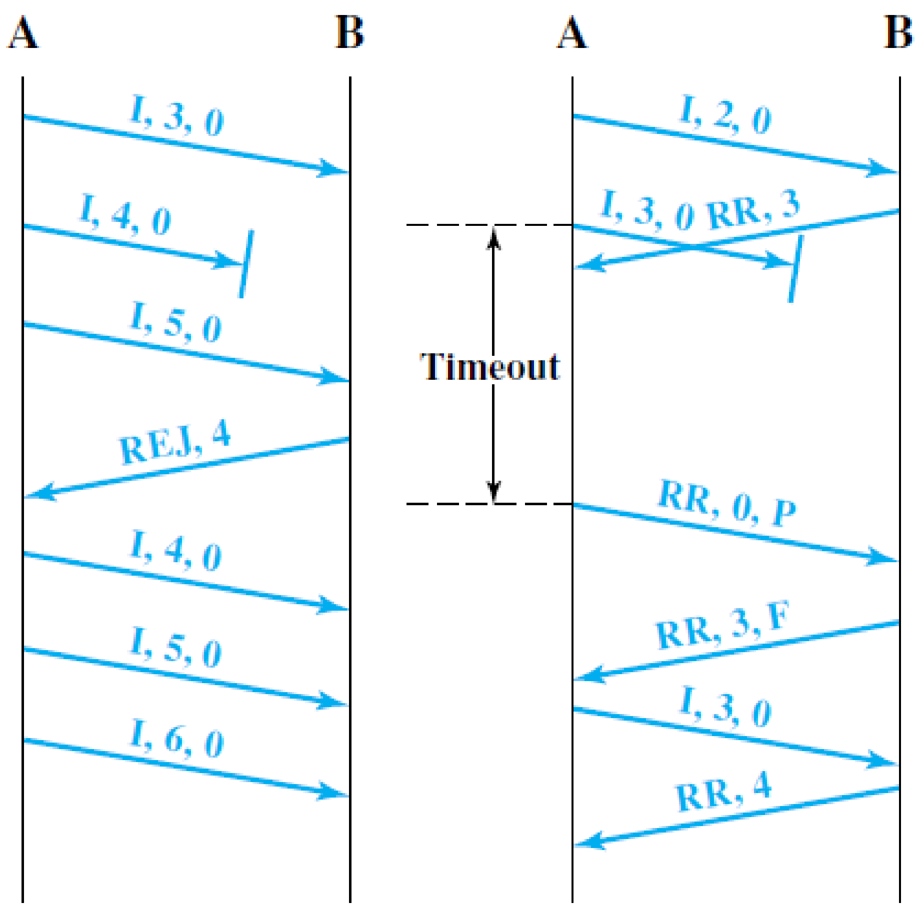

(d) Reject recovery (e) Timeout recovery