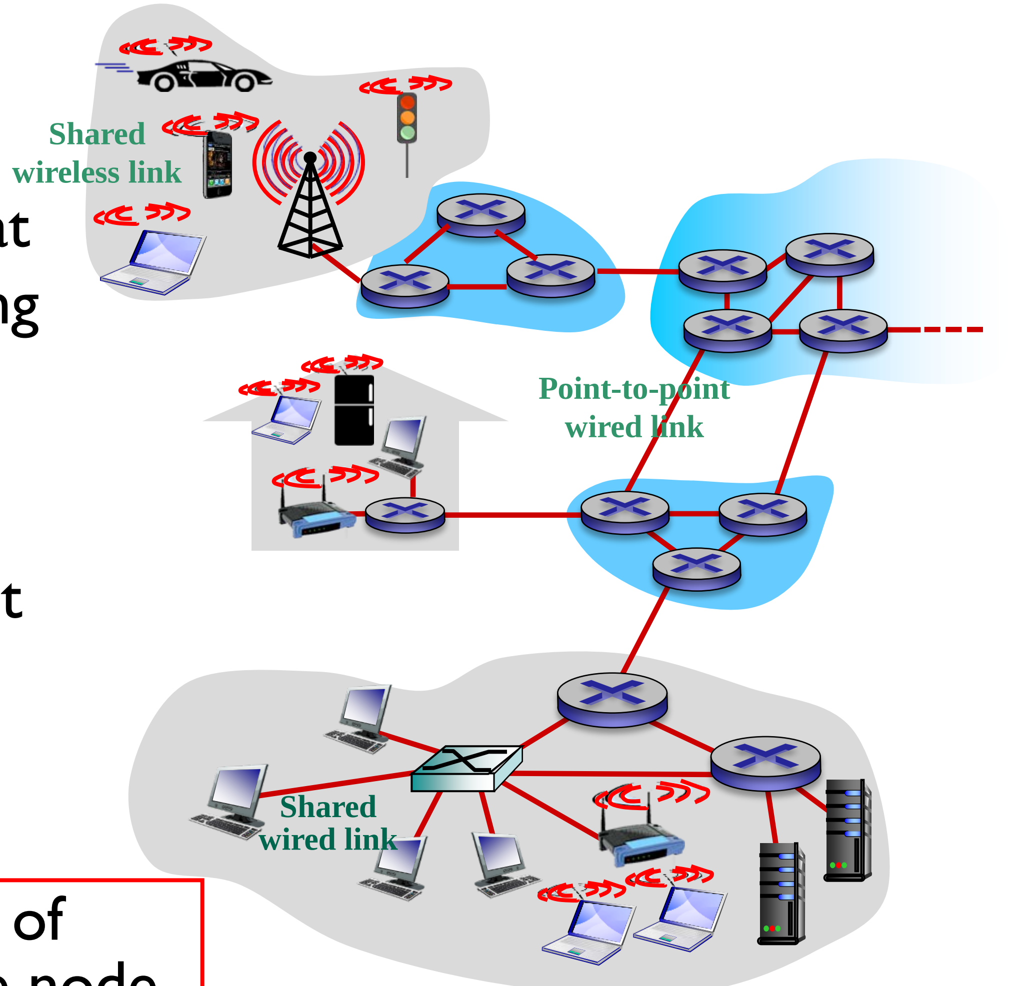
Chapter 7

Data Link Control Protocols

introduction

terminology:

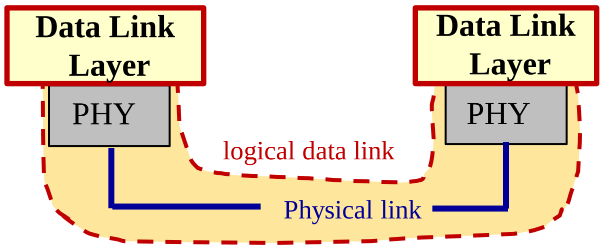
- hosts and routers: nodes
- communication channels that connect adjacent nodes along communication path: links
  - point-to-point
    - wireless, wired
  - shared $\xrightarrow{\text{MAC}}$ point-to-point
    - wireless, wired
- layer-2 packet: frame, encapsulates datagram



data-link layer has responsibility of transferring datagram from one node to *physically adjacent* node over a link

Data Link Layer Functions

- Framing
  - encapsulate datagram into frame, adding header and trailer
  - Frame sync



- Flow Control
  - Control a rate of transmission to prevent over-run
- Error Control
  - Correct transmission errors (by retransmission)
- Addressing
  - When many nodes share transmission link: Addresses used in frame headers to identify source and destination (different from IP address) within the access network
- Logical Link Management
  - Initiation, maintenance, & termination of a sustained data exchange

Frame Sync

- The receiver should be able to recognize the start and end of each frame
- Special preamble and postamble bit patterns: indicate the start/end of a frame (data block)

Synchronous frame format

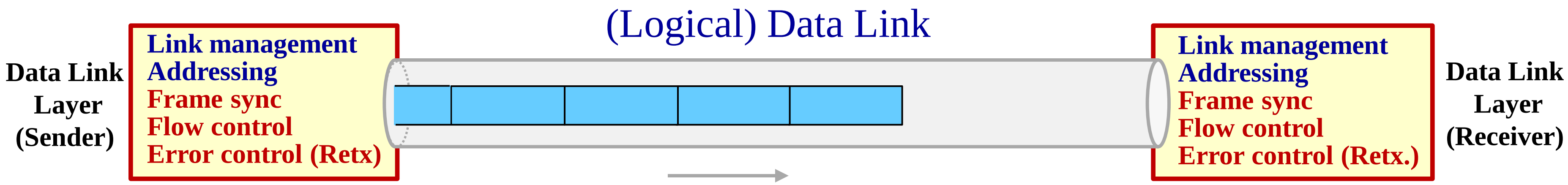
- For data transparency, bit stuffing is typically used.

··· 0001001101111110010101000011000000101···01000010000001010001111110101···

PHY

Flow Control

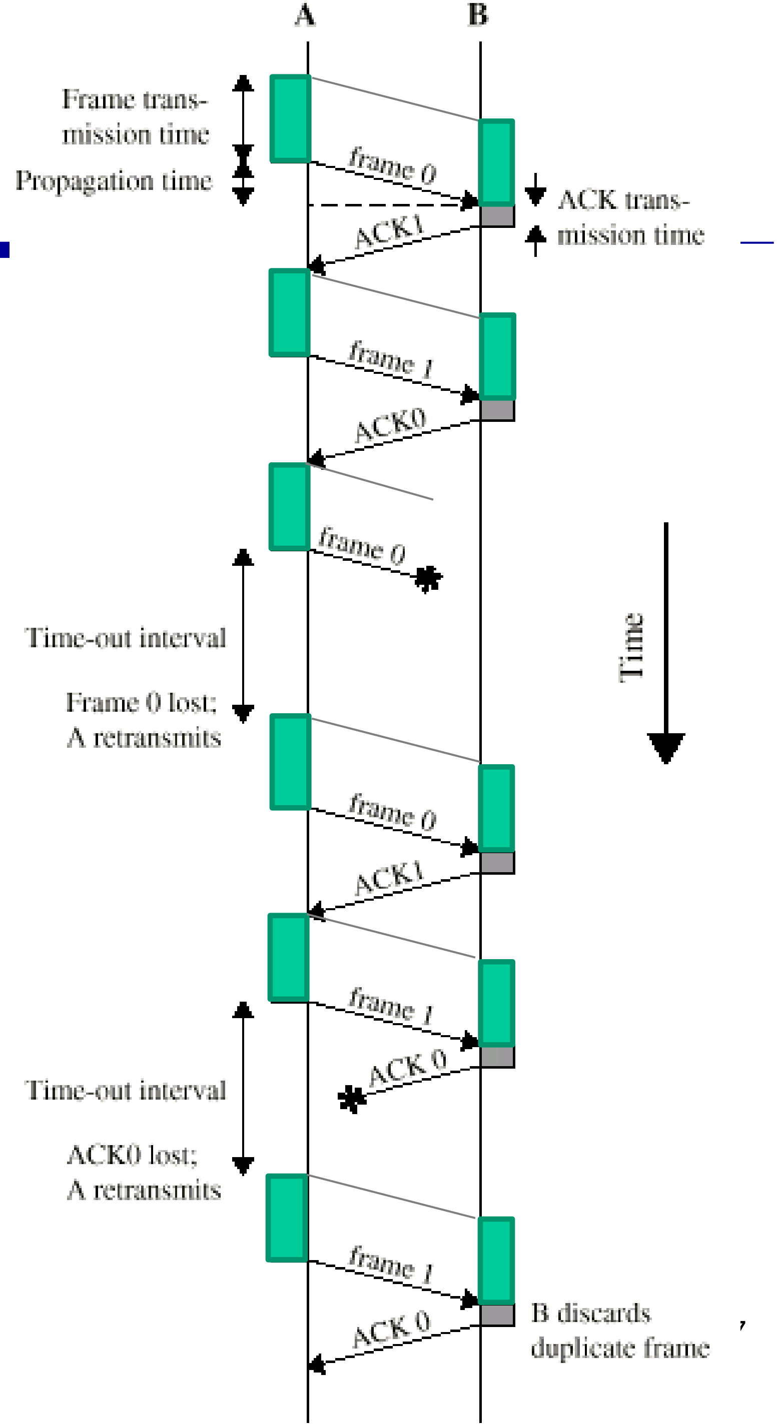
- Technique for controlling a data rate so that a sender does not over-run a receiver
  1. Stop-and-wait
  2. Sliding-window



Stop & Wait ARQ (1)

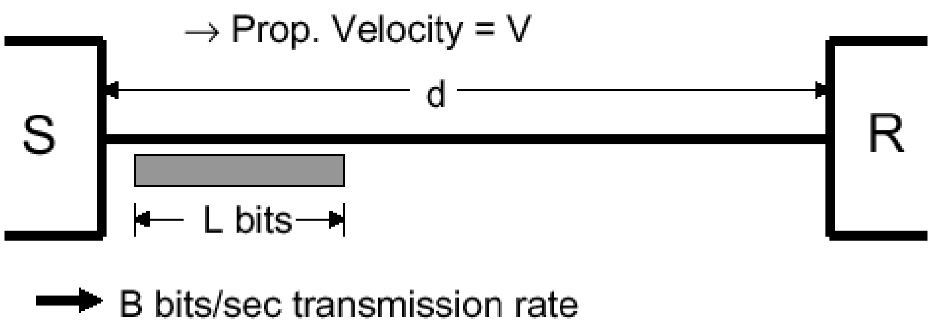
- Simplest flow control scheme
  - Sender transmits a message frame
  - Receiver checks the received frame for errors; sends ACK/NAK
  - Sender waits for ACK/NAK
    - NAK $\Rightarrow$ retrans
    - ACK $\Rightarrow$ next frame
  - Frame/ACK could be lost $\Rightarrow$ Uses a timeout mechanism
  - Possibility of duplication $\Rightarrow$ Number frames
  - Only need a 1-bit frame number alternating 1 and 0
- Minimum buffer requirement but ineffective

Stop-and-Wait ARQ (2)



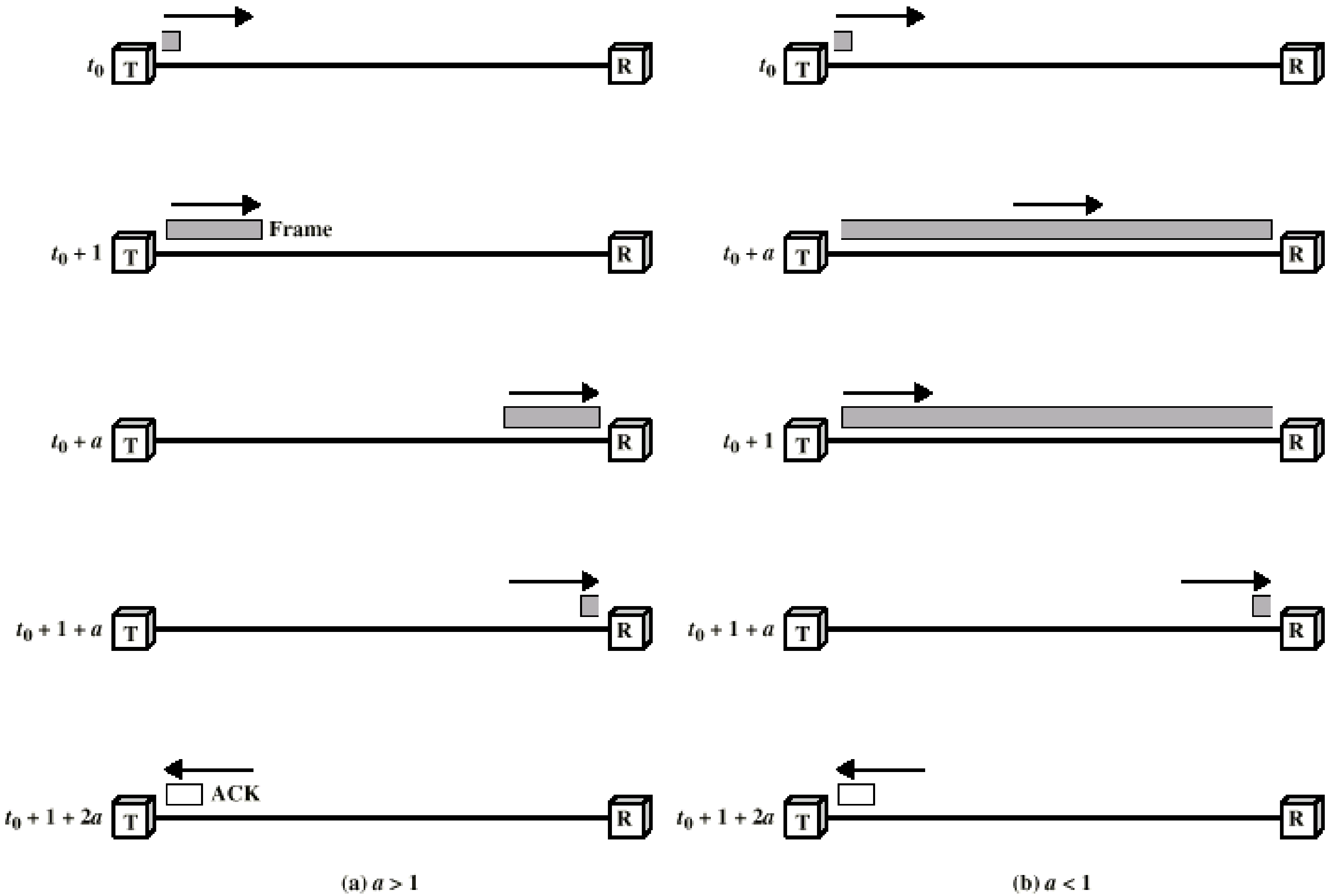
Link Utilization of Stop & Wait (1/4)

Refer to Chapter 16



- Propagation time (T_p)
  - time taken for signal to travel from S to R: T_p=d/V.
- Transmission time (T_t)
  - time taken to emit all bits of frame at sender: T_t=L/B
- $a = \frac{\text{Propagation time}}{\text{Transmission time}} = \frac{T_p}{T_t} = \frac{d}{V} \cdot \frac{B}{L}$

Utilization of Stop & Wait (2/4)



(Transmission time=1, propagation delay = a)

Utilization of Stop & Wait (3/4)

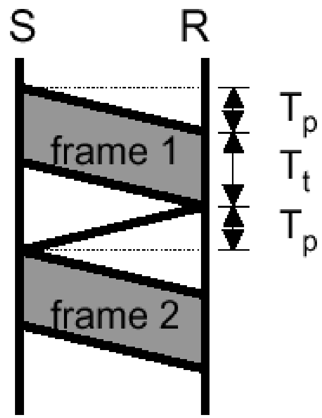
Error-Free

– Utilization (Efficiency) = U

= Tt / (Time bet. Succ. Trans.)

$$= \frac{T_t}{T_p + T_t + T_p}$$

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

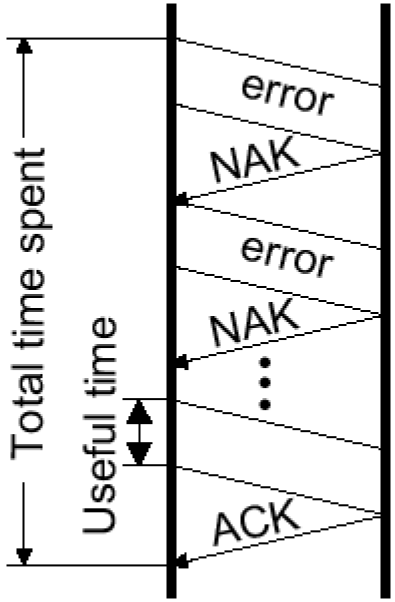


$$a = \frac{d}{V} \cdot \frac{B}{L}$$

– With stop & wait scheme, for high channel utilization, we need small a (since U=1/(1+2a))
– small $a \Rightarrow$ L as large as possible
– In practice, it is desirable to limit the frame length L
  - Frame error probability increases with L
– So a more efficient scheme is requested, especially for WAN/satellite communication and/or high rate communication

Utilization of Stop & Wait (4/4)

When Considering Frame Error



$$U = \frac{\text{Useful time}}{\text{Total time}} = \frac{T_t}{N_r(T_t + 2T_p)} = \frac{1}{N_r(1+2a)}$$

Where N_r = expected # of attempts needed for successful transmission
Let P = prob. of error in frame transmission.

Prob(k attempts are needed)
$= P^{k-1}(1-P)$

$$\text{Then, } N_r = \sum_{k=1}^{\infty} k \cdot \text{Prob(k attempts are needed)}$$

$$= \sum_{k=1}^{\infty} k \cdot P^{k-1}(1-P) = \frac{(1-P)}{P}\sum_{k=1}^{\infty} k \cdot P^{k} = \frac{1-P}{P} \cdot \frac{P}{(1-P)^2} = \frac{1}{1-P}$$

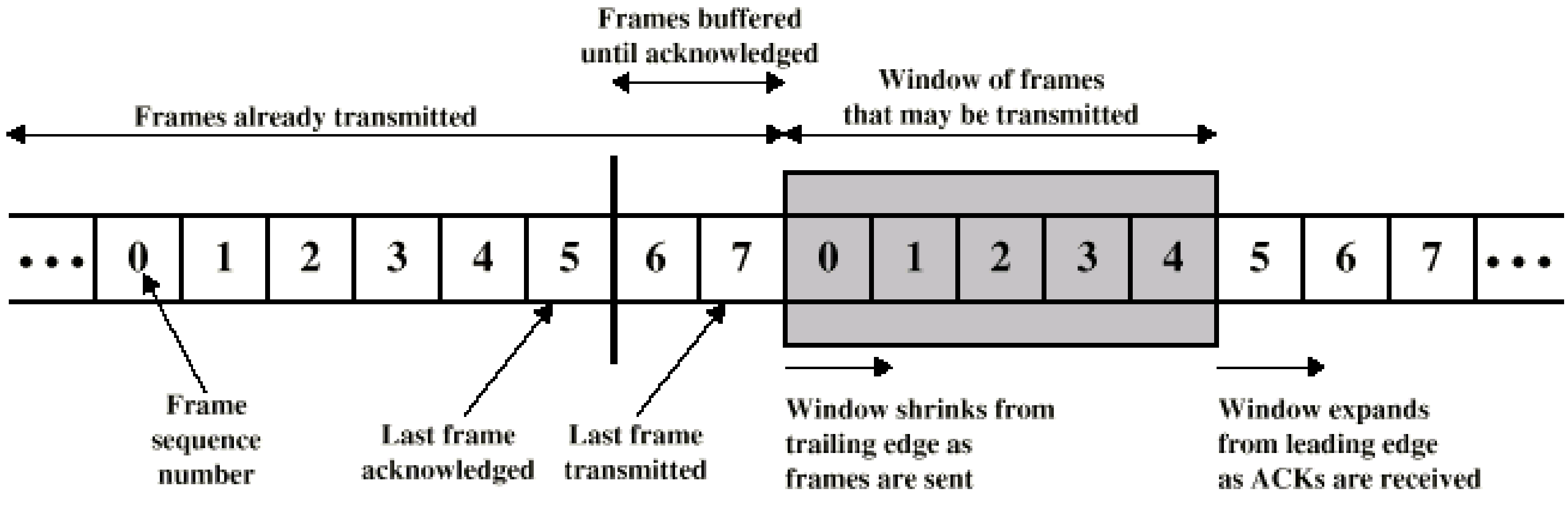
$$\therefore\ U = \frac{1}{N_r(1+2a)} = \frac{1-P}{1+2a}$$

Sliding-Window Flow Control (1)

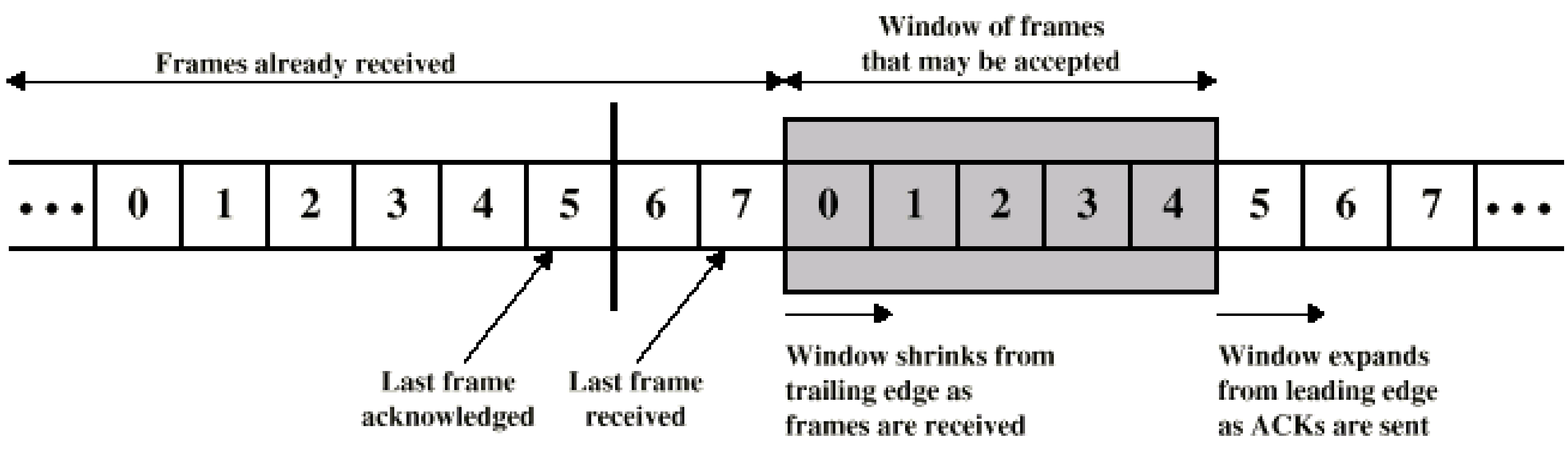
- Pipeline transmission of successive frames
- Transmit up to “W” frames if necessary without receiving ACKs
- Wait for ACKs when “W” unacked frames are in transmitting
- For duplex transmission, each station needs sending window & receiving window

Simplex: A ⟶ B (only one direction)
Duplex
- Half duplex: A⟶B, B⟶A (only one at a time)
- Full duplex: A⟷ B (simultaneously)

Sliding-Window Flow Control (2)

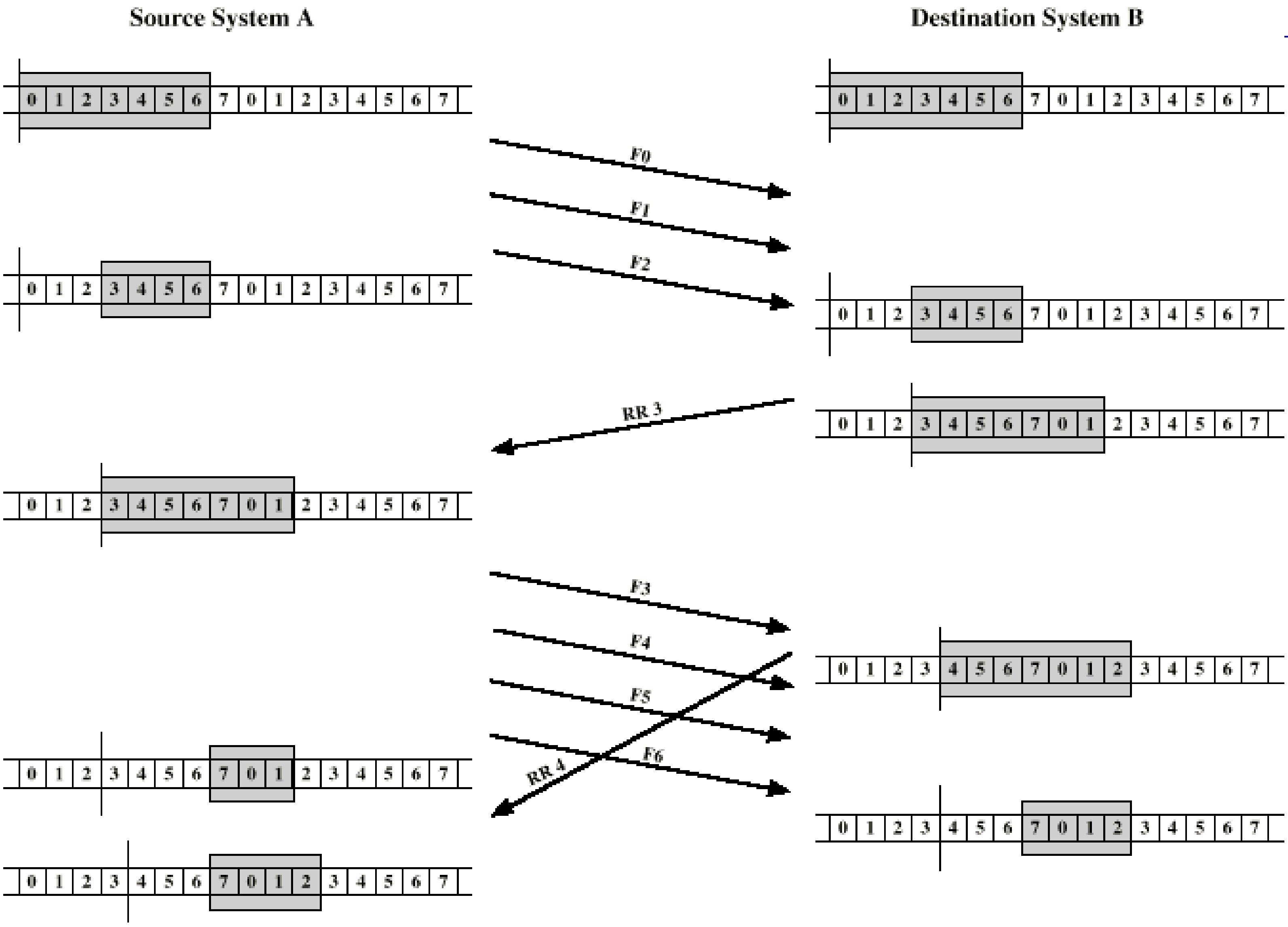


(a) Sender's perspective



(b) Receiver's perspective

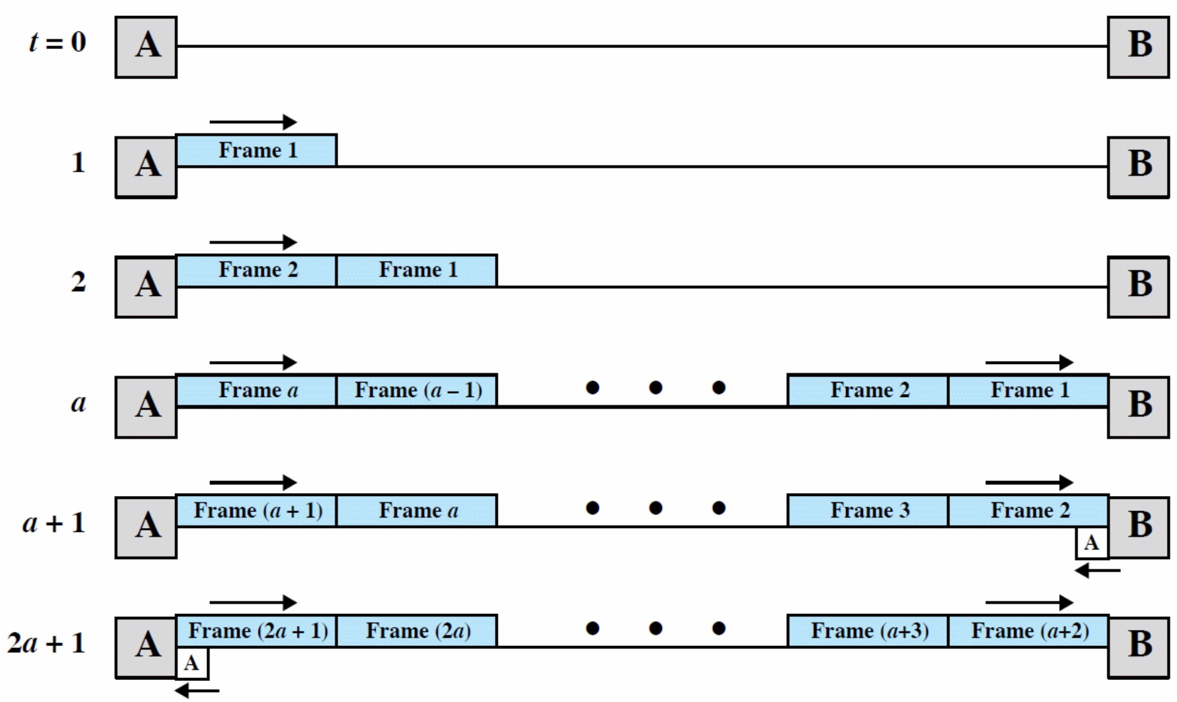
Sliding-Window Flow Control (3)



Link Utilization of Sliding Window (1/3)

Refer to Chapter 16

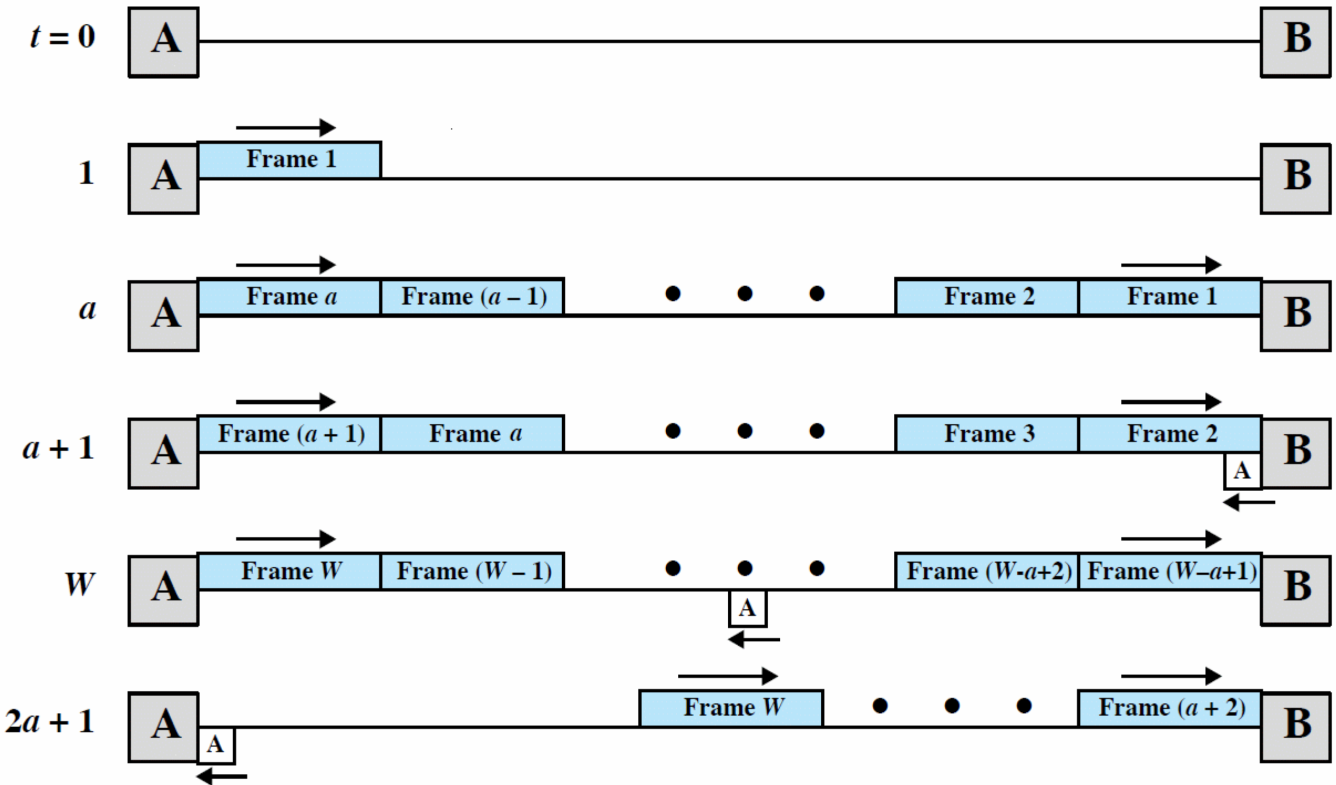
- Assume error-free
- Utilization : U is a function of *a* and *W*
  - Case 1 : W > 2*a*+1 : U = 1
    - Ack for frame 1 reaches sender before transmission of W[th] frame ⇒ continuous transmission possible



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

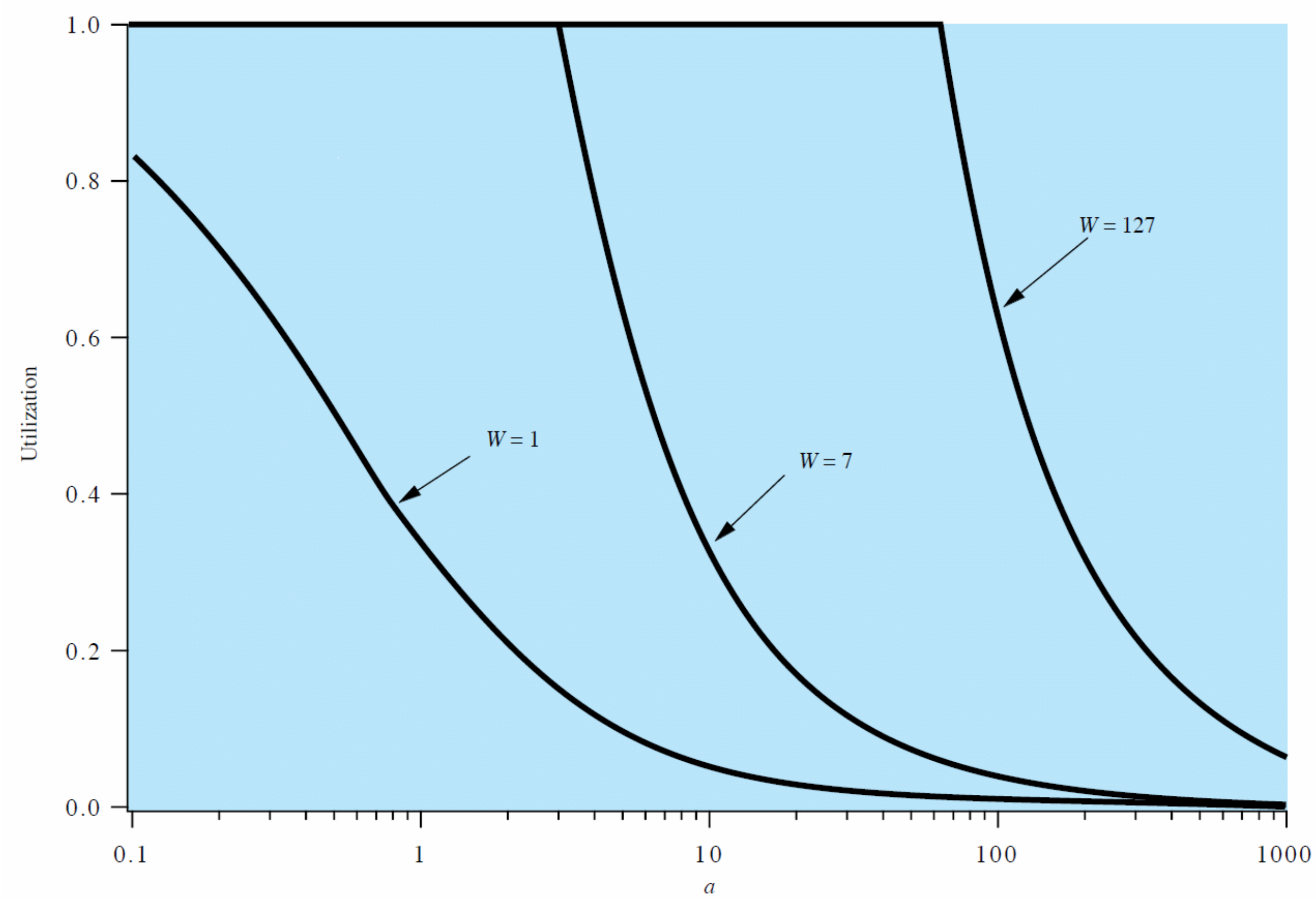
Link Utilization of Sliding Window (2/3)

- Case 2 : W < 1 + 2*a*   : U = W / (1+2*a*)
  - Wasted time between W and 1 + 2*a*



(b) $W < 2a + 1$

Link Utilization of Sliding Window (3/3)



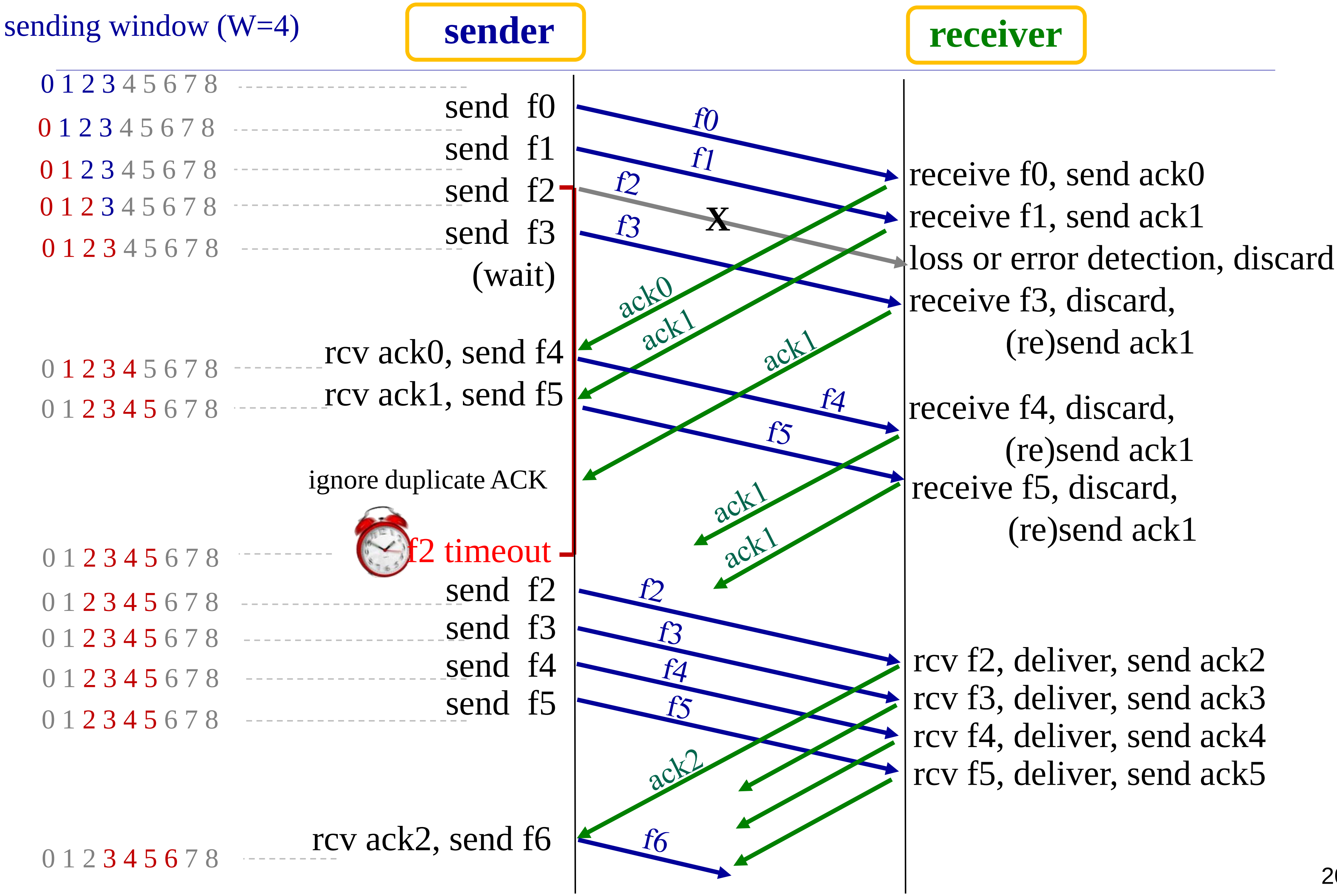
Error Control

- Error control techniques
  - Forward error control (forward error correction: FEC)
    - Error recovery by correction at the receiver
  - Backward error control
    - Error recovery by retransmissions (Automatic Repeat ReQuest)
    - Stop-and-wait ARQ
    - Go-back-N ARQ
    - Selective-repeat ARQ

Go-back-N ARQ

- If the receiver detects an error on a frame, it sends a NAK for that frame.
- The receiver will discard all future frames until the frame in error is correctly received.
- Thus the sender, when it receives a NAK or timeout, must retransmit the frame in error plus all succeeding frames.
- The sender must maintain a copy of each unacknowledged frame

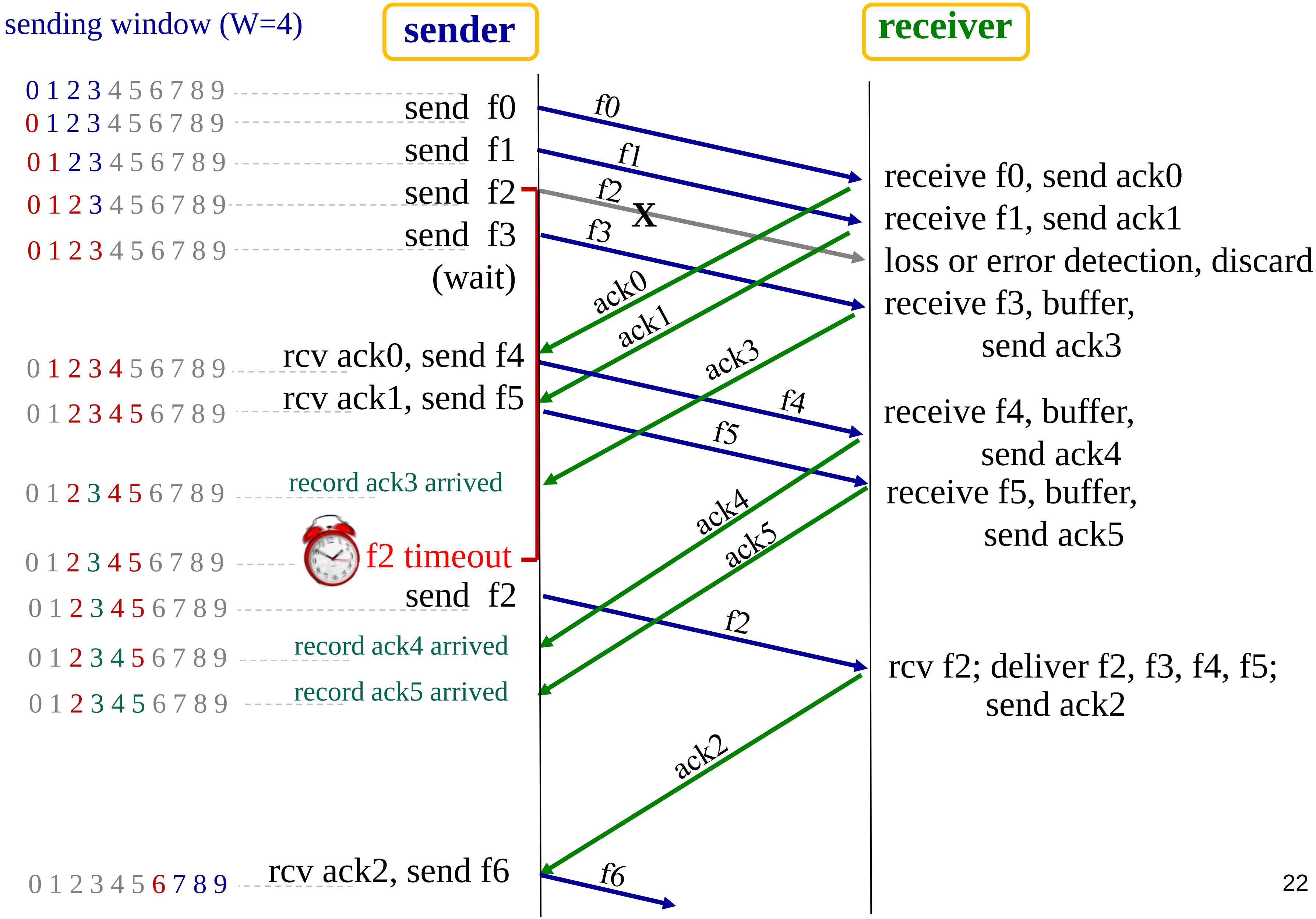
Go-back-N Example



Selective-repeat ARQ

- Only the frame that receives a NAK or timeout is retransmitted
- Can save retransmissions, but requires more buffer space and complicated logic

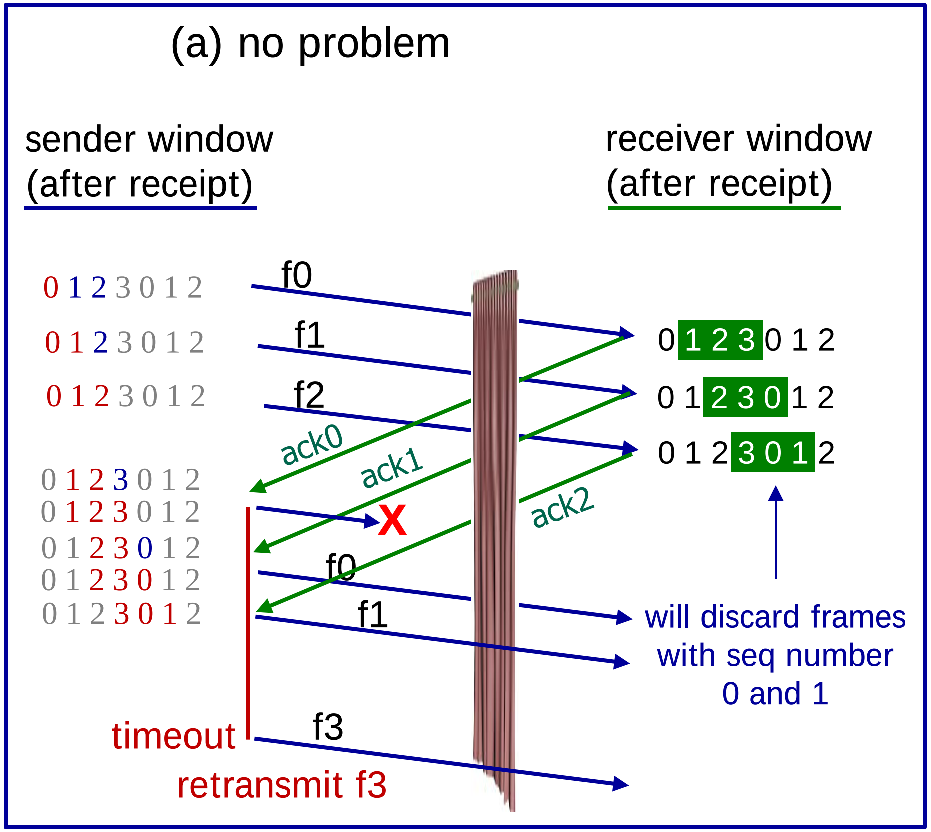
Selective-repeat Example

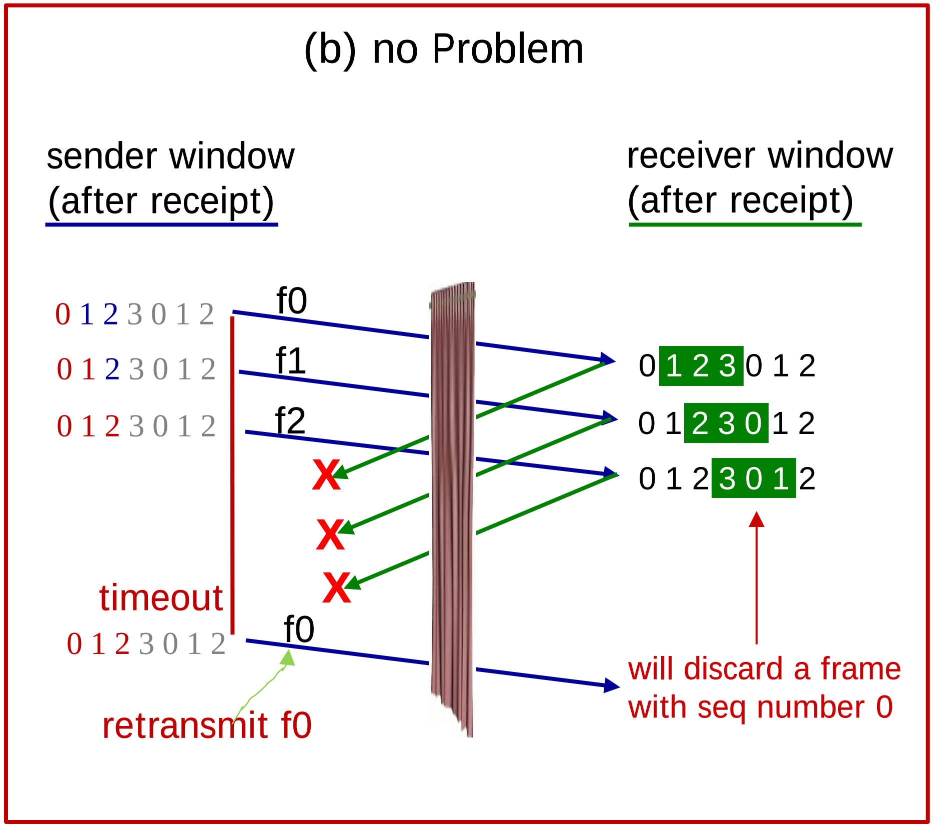


Selective Repeat Dilemma (1)

When the number of SN is W+1

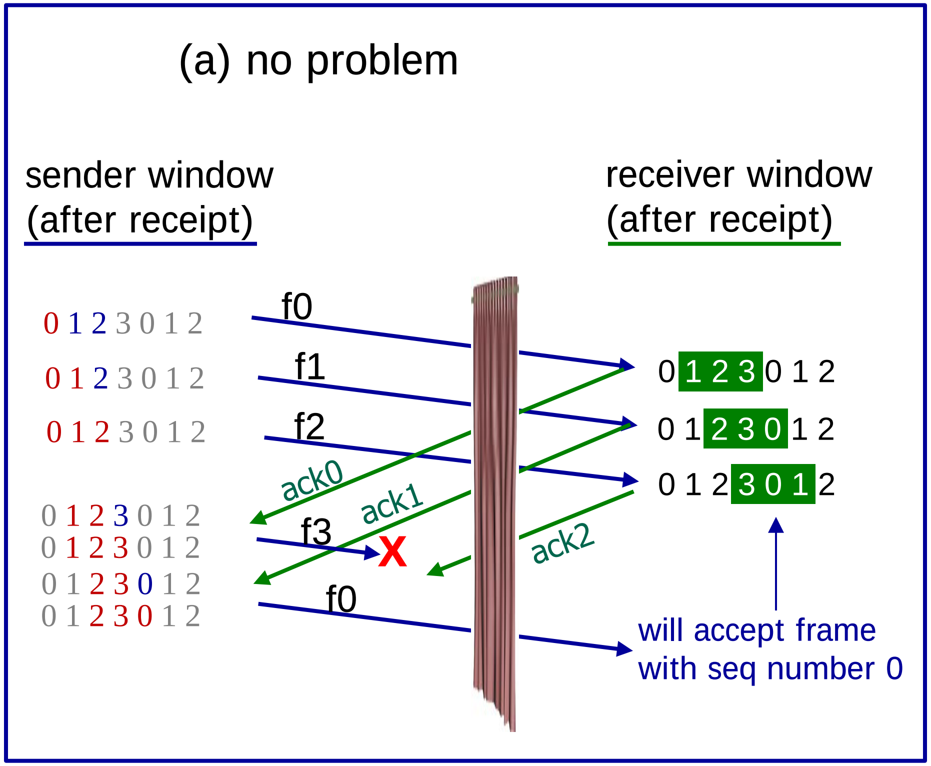
- In case of Go-back-N : W=3, 4 SNs (0, 1, 2, 3)

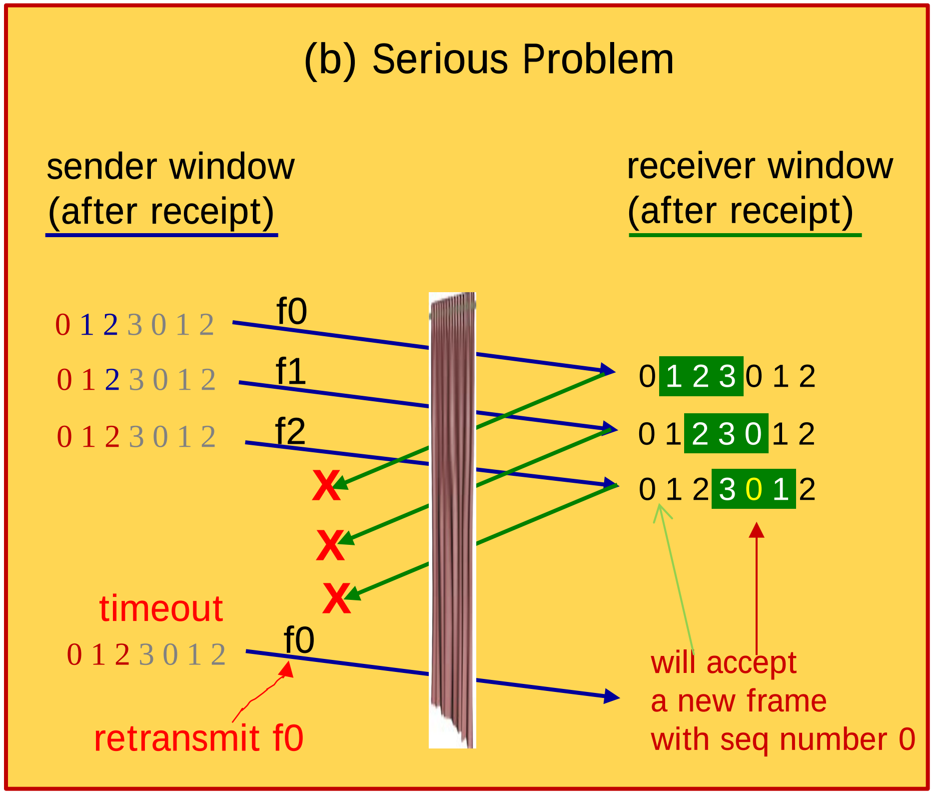




Selective Repeat Dilemma (2)

- Selective repeat, when the number of SN is W+1



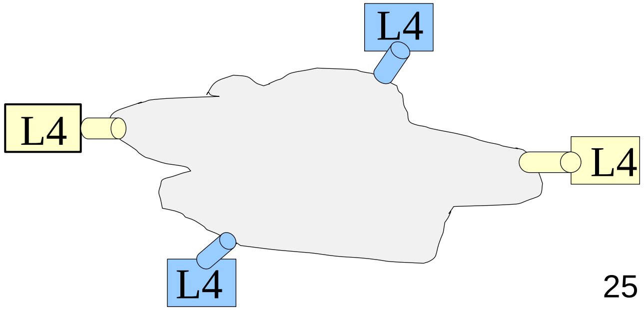


Minimum number of SN
- Go-back-N: W+1
- Selective-repeat: 2W

Much bigger SN space is required

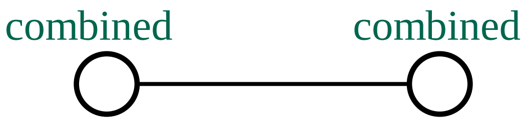
Reliable Transmission

- Efficient and Reliable Transmission
  - Flow Control & Error Control
- Point-to-Point (between two adjacent nodes) Transmission Control: Layer 2
- End-to-End (between source host and destination host) Transmission Control: Layer 4
  - Reliable Transmission : TCP
- TCP
  - Flow Control : a variant of sliding window (explicit amount of traffic)
    + Congestion control (flow control in viewpoint of network)
  - Error Control : Selective Repeat (default)

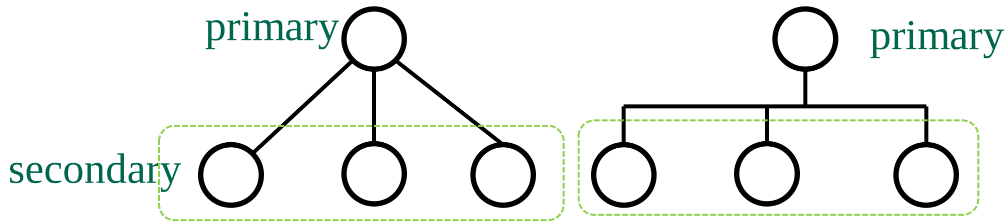


High-Level Data Link Control (HDLC)

- Basis for many other data link control protocols
- Connections can be point-to-point or multipoint (multidrop)



point-to-point link
(balanced link conf.)



multipoint link (unbalanced link conf.)

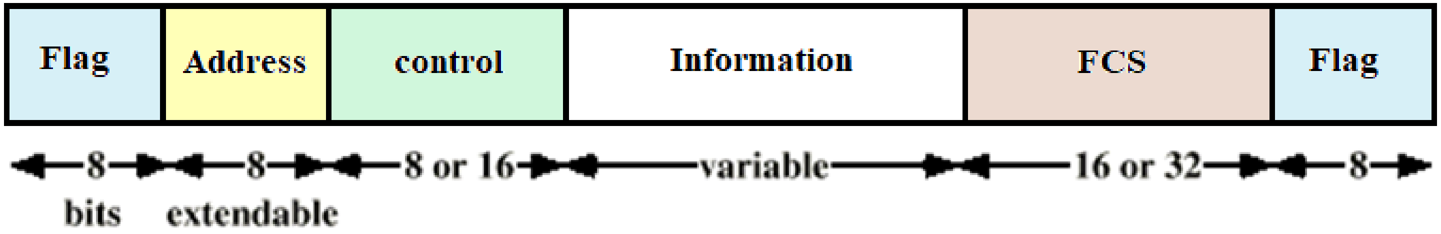
- Three types of stations
  - Primary station
    - Controls the operation of the link, issues commands, and receives response
  - Secondary station
    - Usually only communicates (response) to a primary station
  - Combined station
    - Can be both primary and secondary

HDLC (2)

- Two link configurations
  - Unbalanced configuration
    - One primary and muitiple secondary stations
  - Balanced configuration
    - Two combined stations
- Three data transfer modes
  - Normal response mode (NRM)
    - Unbalanced config.
    - Primary station always dictates who sends and receives.
    - Used on multipoint-line (Primary: Main computer, Secondary: terminal)
  - Asynchronous balanced mode (ABM)
    - Balanced config.
    - Either station initiates transmission
  - Asynchronous response mode (ARM)

HDLC (3)

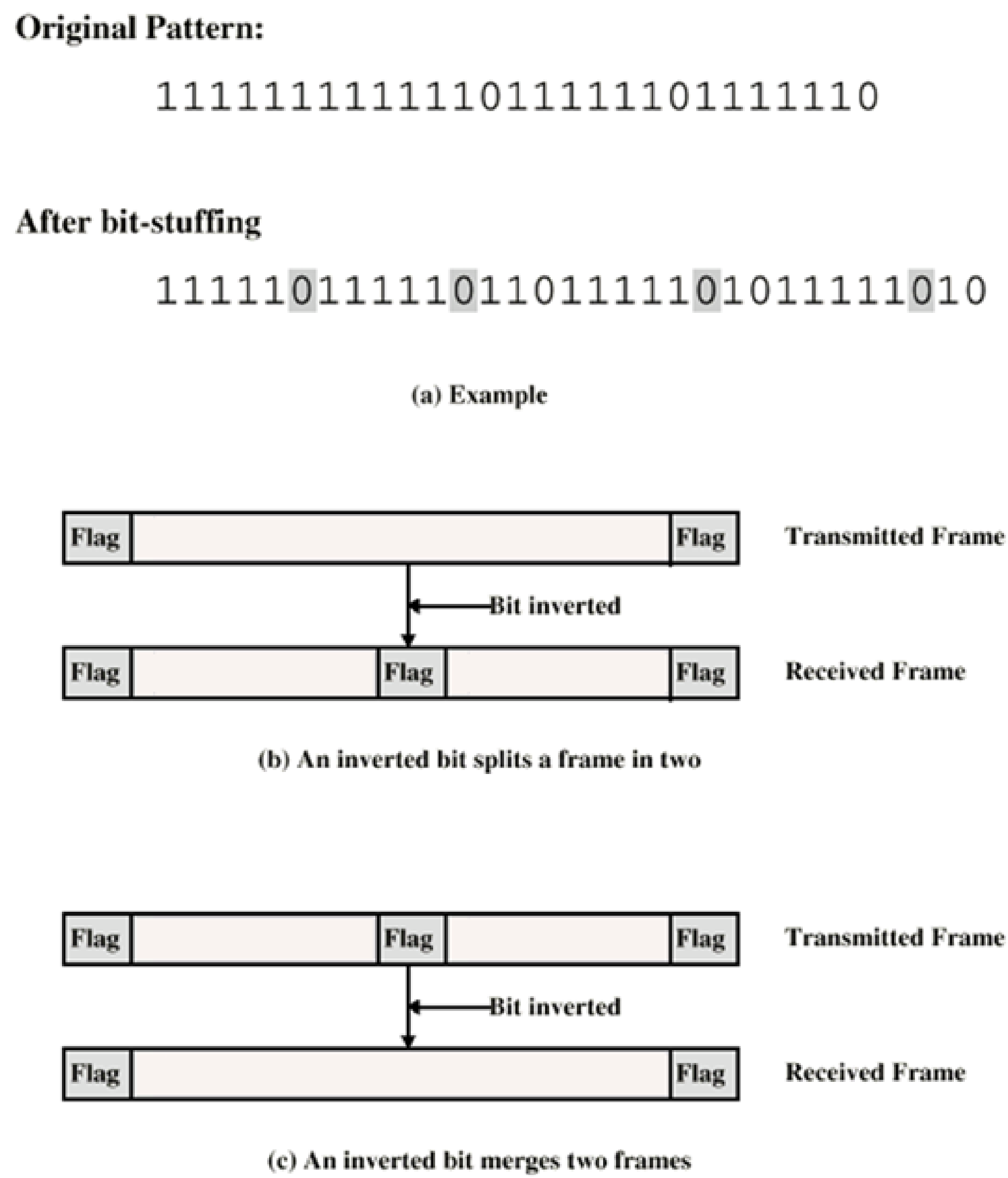
Frame Structure



HDLC (4)

Flag

- 8 bits (01111110)
- May close one frame and open another
- Frame sync
- Bit stuffing is used for data transparency
- Bit stuffing: whenever five 1’s are transmitted, extra zero is inserted



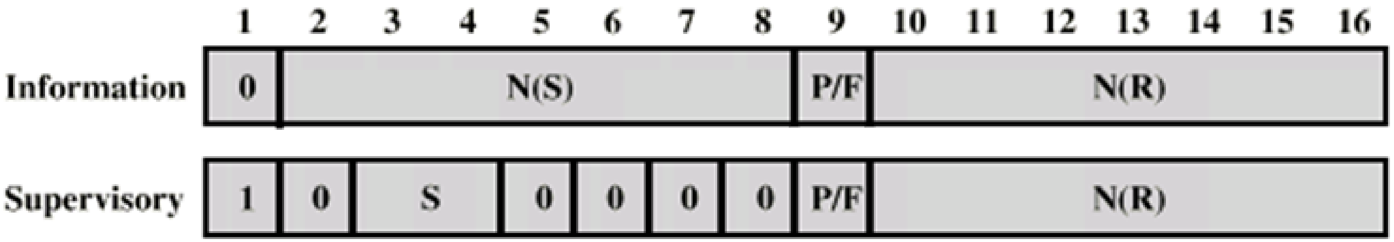
HDLC (5)

Control Field

- Different for different frame type
  - Information
    - Data to be transmitted to user
    - Flow control and error control piggybacked on information frames
  - Supervisory
    - ARQ when piggyback is not used
  - Unnumbered
    - supplementary link control
- First one or two bits of control field identify the frame type

HDLC – Control Field (1)

(c) 8-bit control field format



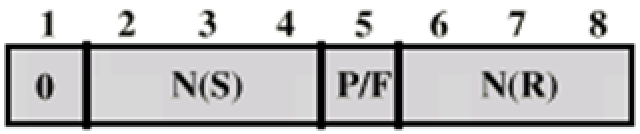
(d) 16-bit control field format

HDLC – Control Field (2)

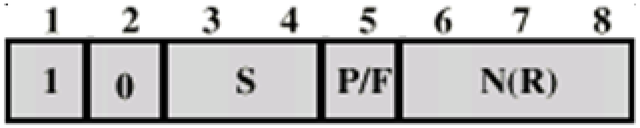
- Sequence Number
  - N(s) : the sequence number of Information frame
  - N(r) : acknowledgement number for piggyback ACK
- Poll/Final bit
  - Usage depends on context
  - Command frame
    - P bit
    - 1 to solicit (poll) response from peer
  - Response frame
    - F bit
    - 1 indicates response to soliciting command

HDLC – Control Field (3)

- Frame type
  - Information frame : data transmission



    - two 3-bits (or 7-bits) sequence numbers
    - Exchange of user data
  - Supervisory frame : flow and error control
    - 00 (Receive Ready: RR)
      - Positive ACK & Ready to receive I-frame
    - 01 (Reject: REJ)
      - a NACK in Go-back-N



    - 10 (Receive Not Ready: RNR)
      - Positive ACK & Not ready to receive I-frame
    - 11 (Selective Reject: SREJ)
      - a NACK in Selective Reject
    - a sequence number for acknowledgement

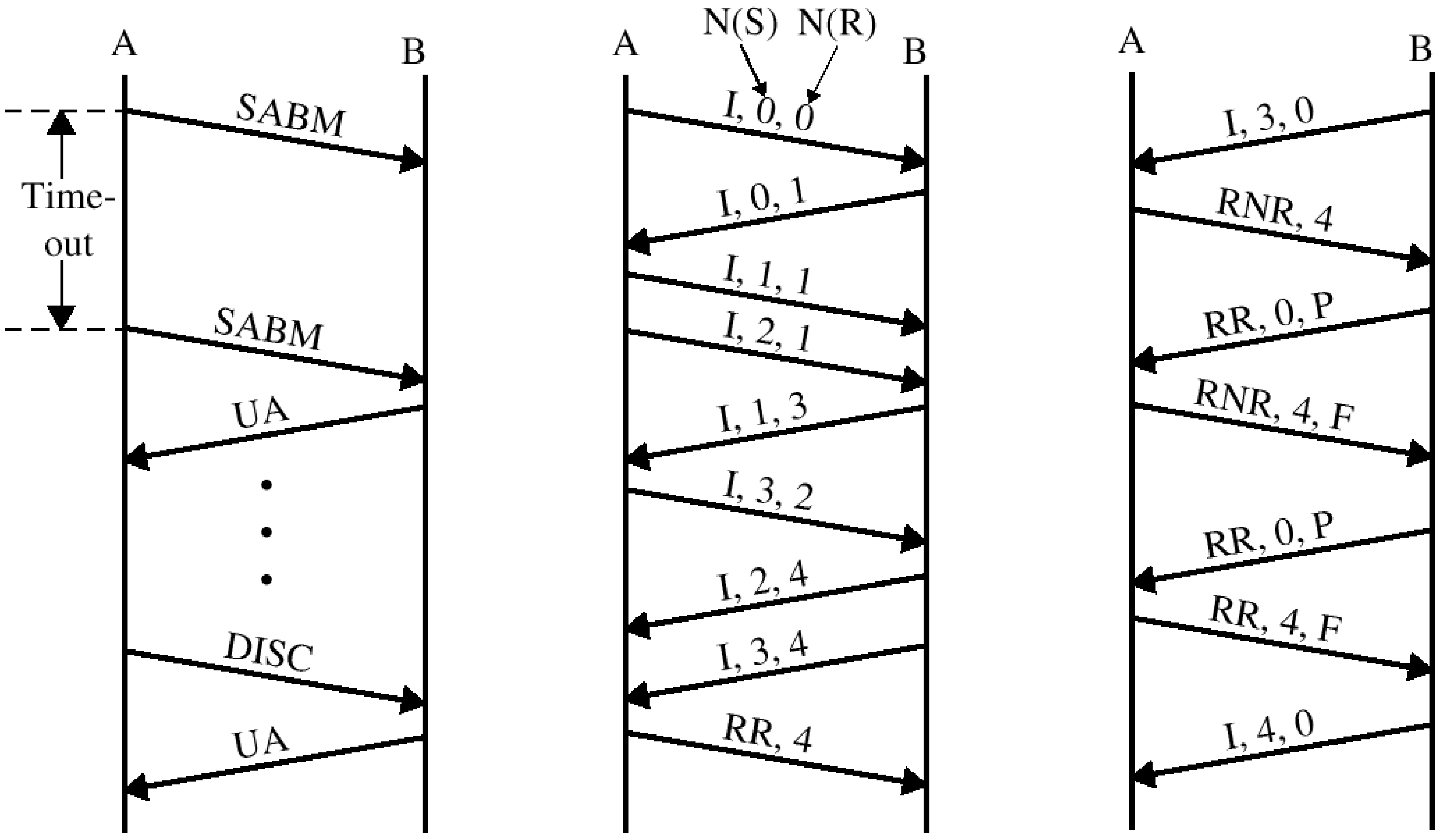
HDLC – Control Field (4)

- Unnumbered frame: Link setup & Disconnect
  - Sets up the data transfer mode and sequence number size
  - Reset the link
  - Has a variety of purposes

1	2	3	4	5	6	7	8
1	1	M		P/F	M		

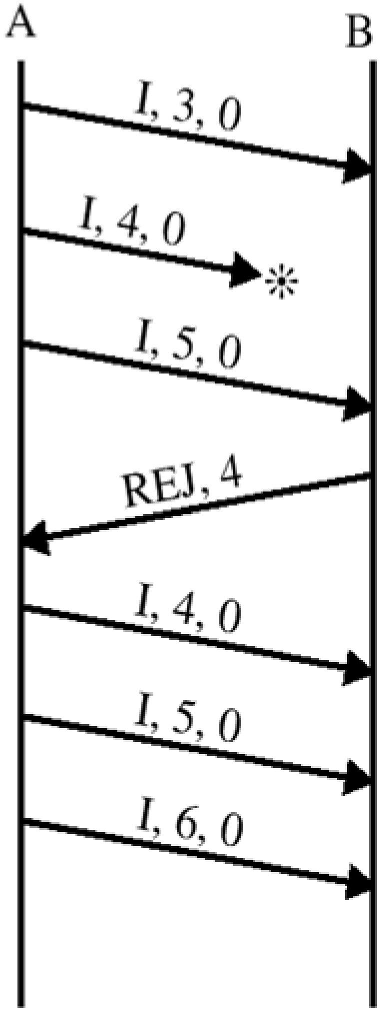
Unnumbered (U)		
Set normal response/extended mode (SNRM/SNRME)	C	Set mode; extended = 7-bit sequence numbers
Set asynchronous response/extended mode (SARM/SARME)	C	Set mode; extended = 7-bit sequence numbers
Set asynchronous balanced/extended mode (SABM, SABME)	C	Set mode; extended = 7-bit sequence numbers
Set initialization mode (SIM)	C	Initialize link control functions in addressed station
Disconnect (DISC)	C	Terminate logical link connection
Unnumbered Acknowledgment (UA)	R	Acknowledge acceptance of one of the set-mode commands

Examples of Operation under HDLC (1)

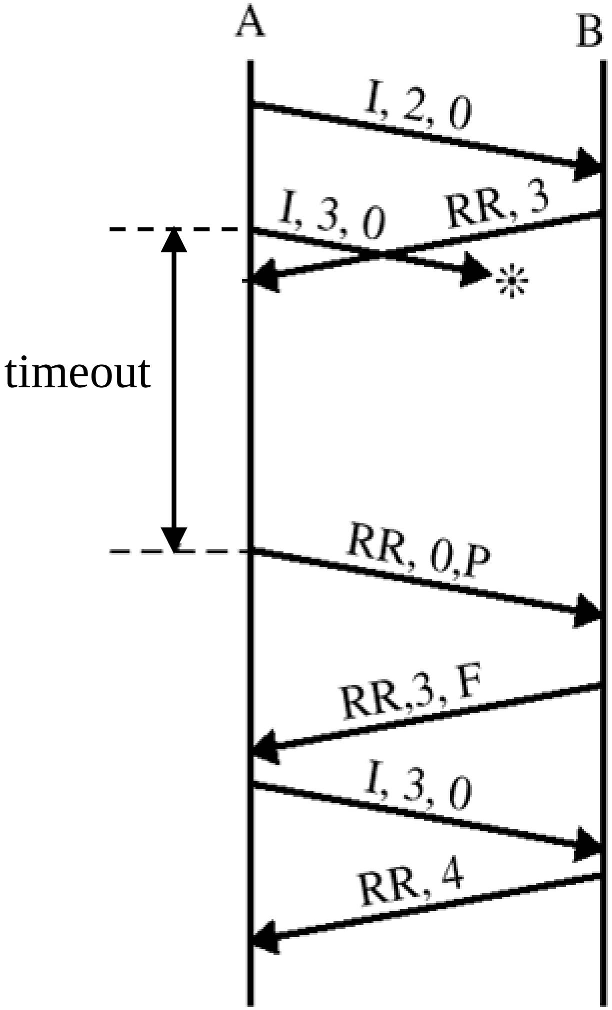


(a) Link setup and disconnect (b) Two-way data exchange (c) Busy condition

Examples of Operation under HDLC (2)



(d) Reject recovery



(e) Timeout recovery