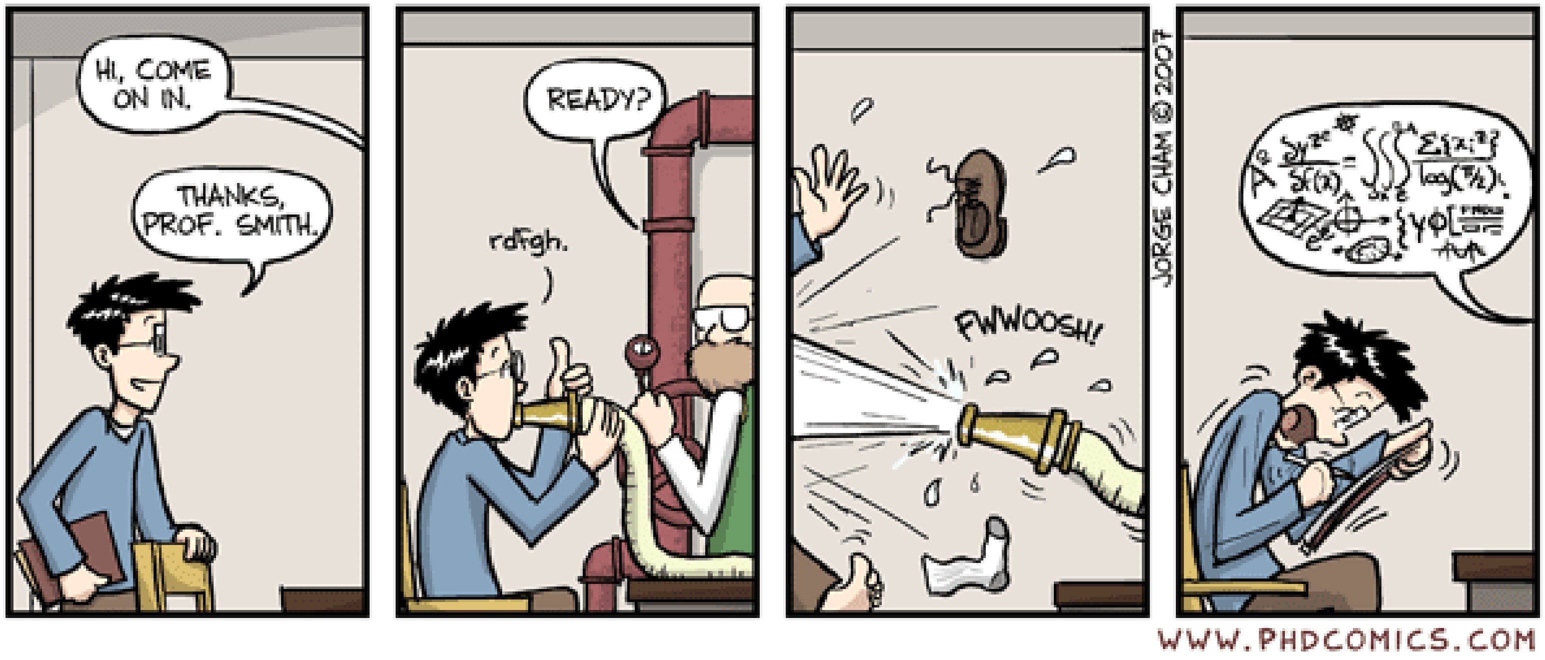
Part I Syllabus

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

Drinking from Fire Hose

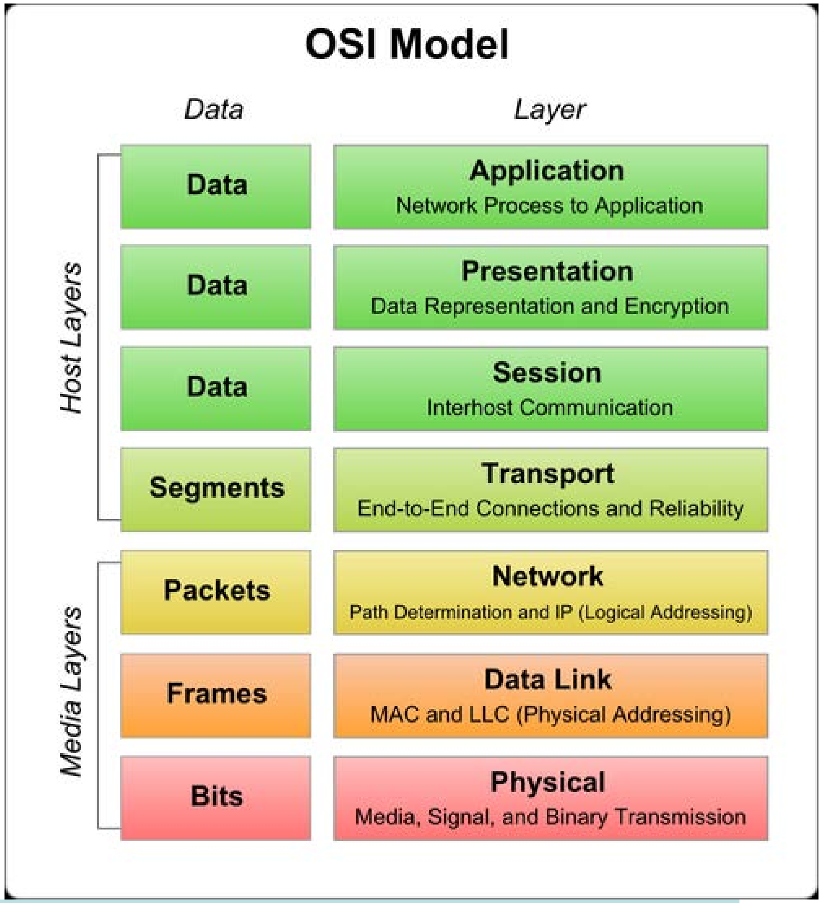


CE3005/CZ3006 Computer Networks

Lecture 3
Data Link Layer (DLL): Flow Control

Contents

- **Data Link Layer Fundamentals**
  - DLL Services
  - Framing mechanisms
  - Link configuration
- **Flow Control in DLL**
  - Main purpose of flow control
  - Stop-and-wait mechanism
  - Sliding window mechanism



OSI Model
Data
Layer
Host Layers
Media Layers
Data
Application
Network Process to Application
Data
Presentation
Data Representation and Encryption
Data
Session
Interhost Communication
Segments
Transport
End-to-End Connections and Reliability
Packets
Network
Path Determination and IP (Logical Addressing)
Frames
Data Link
MAC and LLC (Physical Addressing)
Bits
Physical
Media, Signal, and Binary Transmission

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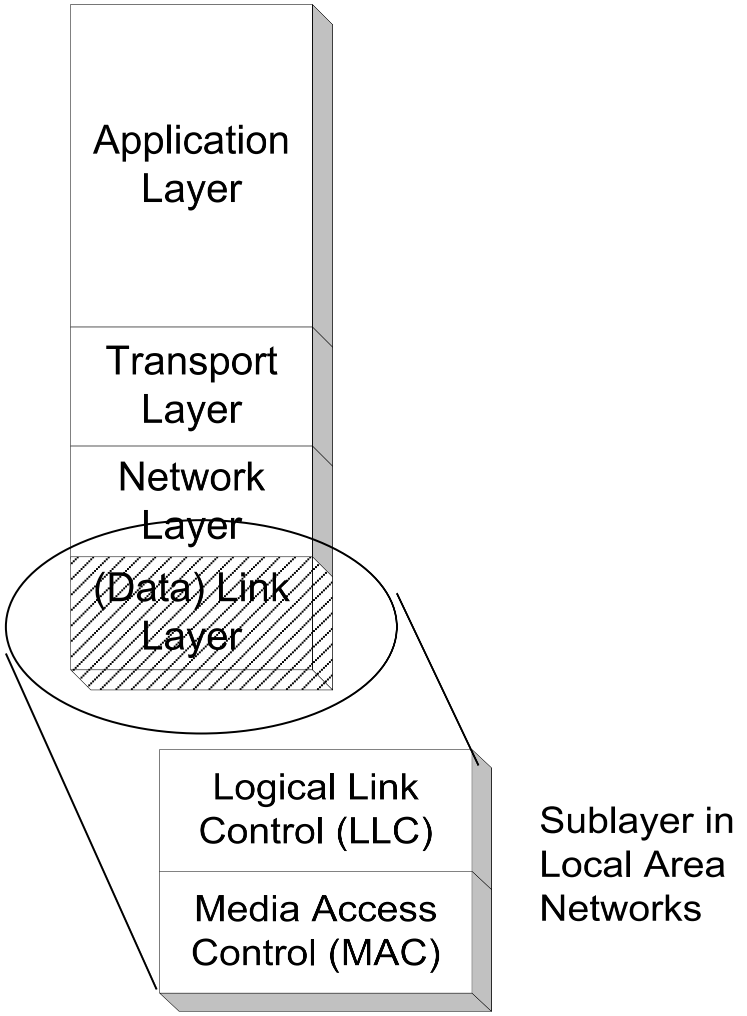
Data Link Layer Fundamentals

Data Link Layer: Roles

- **DLL Services**
  - Framing: encapsulate each network-layer datagram within a link-layer frame before transmission over the link
  - Link Access: MAC protocol specifying the rules by which a frame is transmitted onto the link
  - Flow Control: control of data flow to ensure sender not overwhelm the receiver with data
  - Reliable Delivery: move each network-layer datagram across the link without error

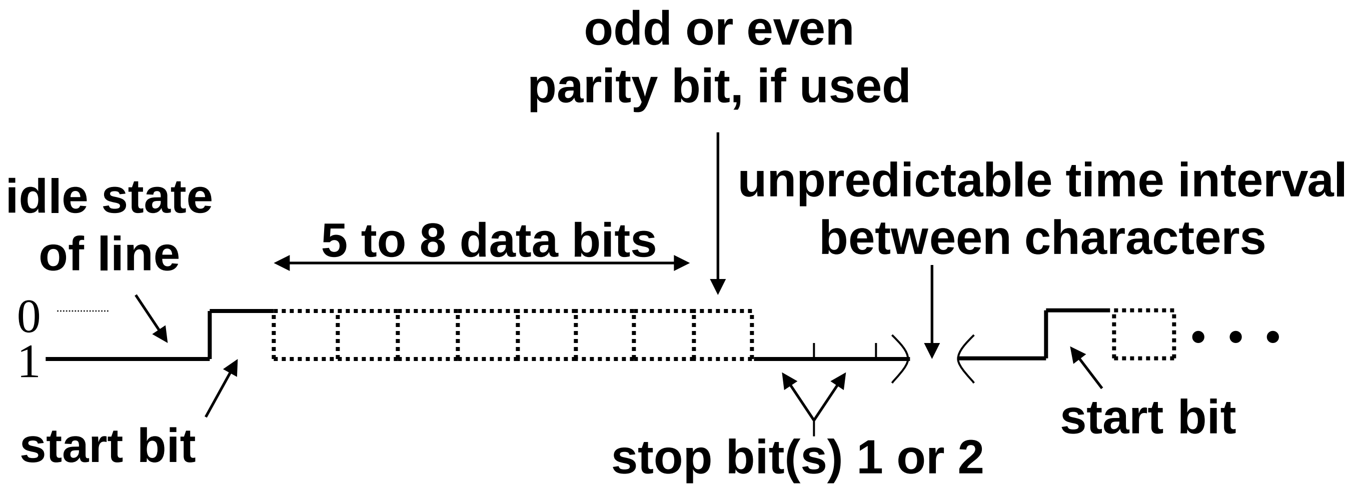

Application Layer
Transport Layer
Network Layer
(Data) Link Layer
Logical Link Control (LLC)
Media Access Control (MAC)
Sublayer in Local Area Networks

Framing

- **Byte Oriented (Character Oriented):**
  - Information is framed into a fixed 8-bit basic unit.
  - Some of these basic units are used for signaling (protocol control).
  - Good solution when digital technology was in its primitive age (late 60s).
- **Bit Oriented (HDLC)**
  - A flag is used to frame the bits sent.
  - Header/Trailer are used to describe the content of a frame. Frames may be used for control.
  - Used by all modern protocols (e.g., HDLC, PPP, Ethernet, etc).

Byte-Oriented Async. Transmission

- **Pre-determined frame format**
  - Start/stop bit
  - Parity check bit
  - Data bits

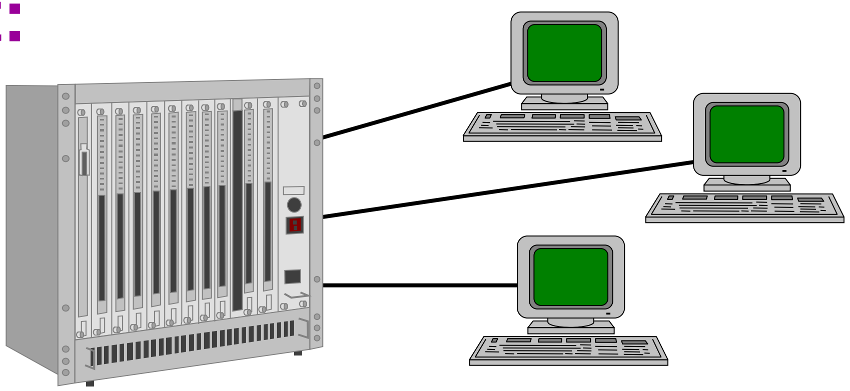


Link Configuration/Access

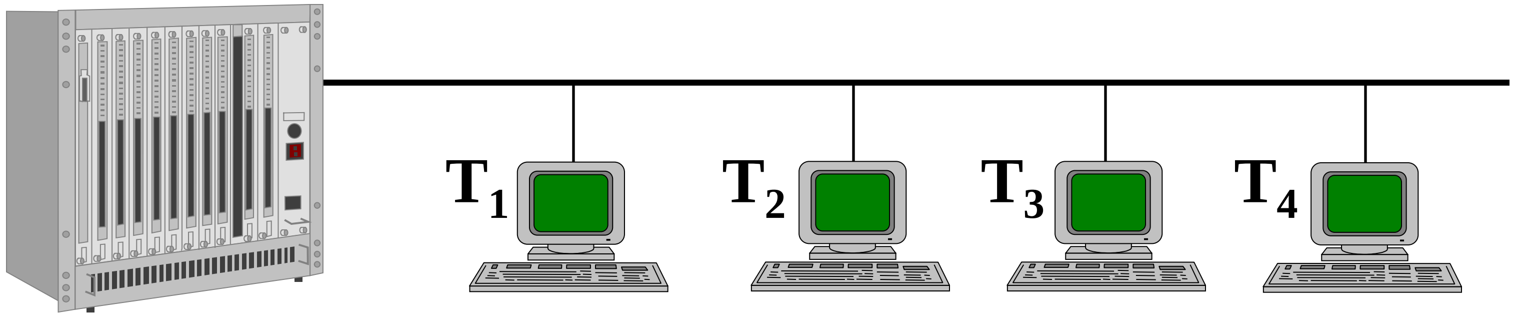
- **Objective: determine *who* gets to transmit at *when* on a link**
- **Topology: physical arrangement of stations**
  - Point-to-Point: pairs of hosts are directly connected
  - Broadcast: all stations share a single channel
- **Duplexity**
  - Half Duplex: Only one party may transmit at a time.
  - Full Duplex: Allows simultaneous transmission and reception between two parties (e.g., two logical half-duplex channels on a single physical channel).

Topology

Point-to-point:



Point-to-Multipoint (Broadcast):



All terminals share the same medium controlled by the primary station (mainframe)

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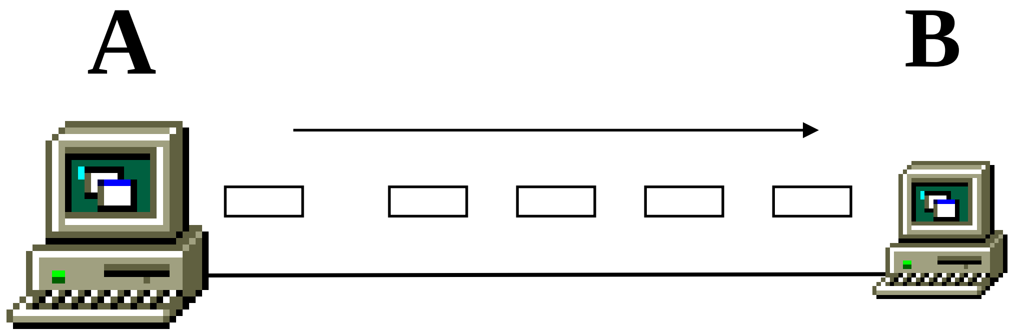
Flow Control

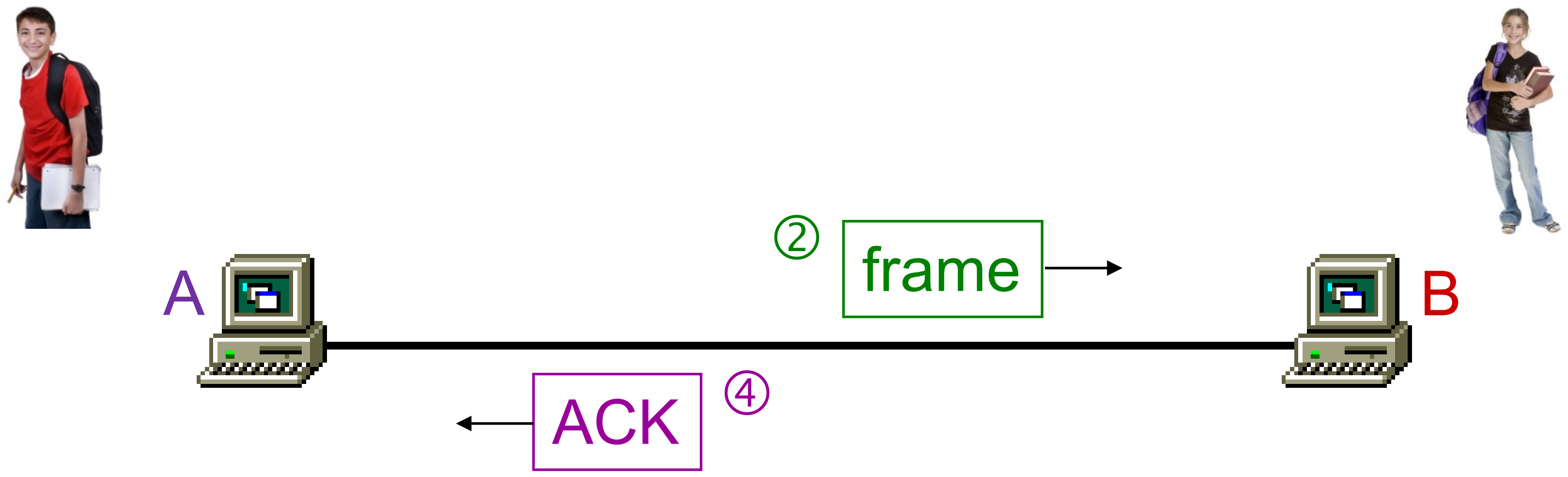
Functions and Mechanisms

- **Flow control**
  - Ensuring that a transmitting station does not overwhelm a receiving station with data, i.e., buffers at the receiver do not get overflow.
  - No frame error



- **Two Flow-Control Mechanisms**
  - Stop-and-Wait
  - Sliding Window

Stop-and-Wait Flow Control



Operations:

① *A* packs binary information into a frame

② *A* sends the frame to *B*

③ *A* waits for an ACK

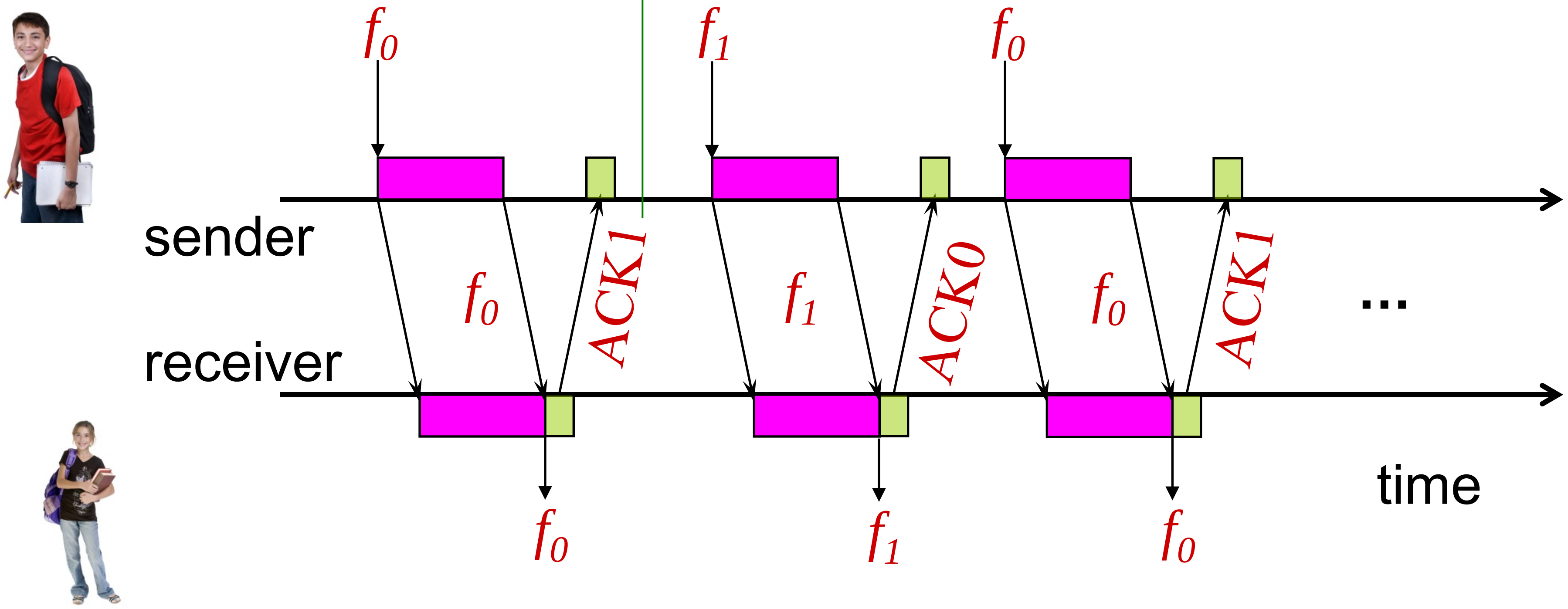
④ When *B* has received the frame, *B* sends an ACK

⑤ When *A* has received the ACK, *A* repeats ①

Frame Flow in Stop-and-Wait

ACK1 means the receiver expects f_1, implying f_0 is received successfully

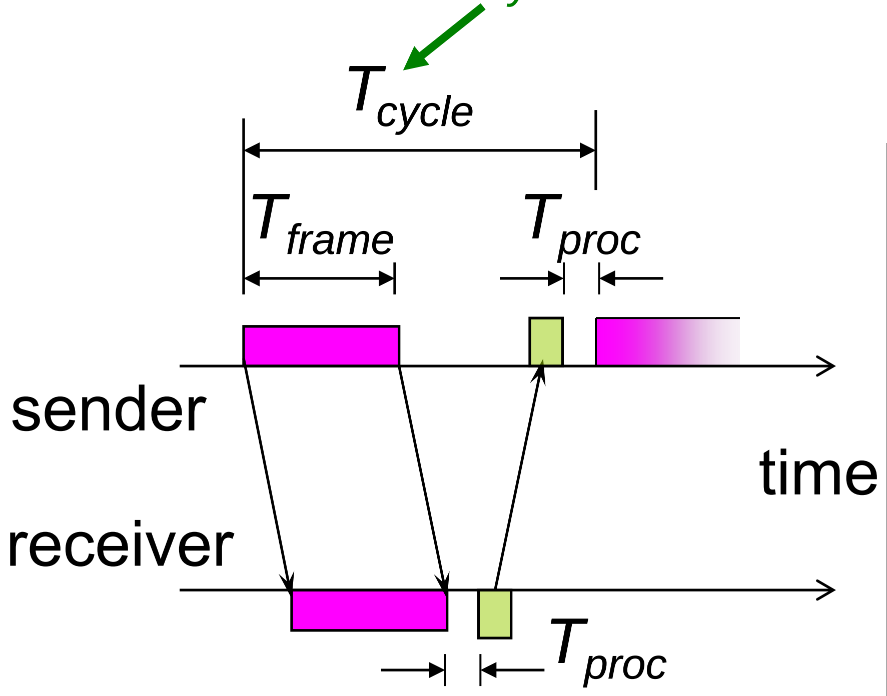
Binary sequence number is sufficient



Flow-Control Performance: Throughput

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

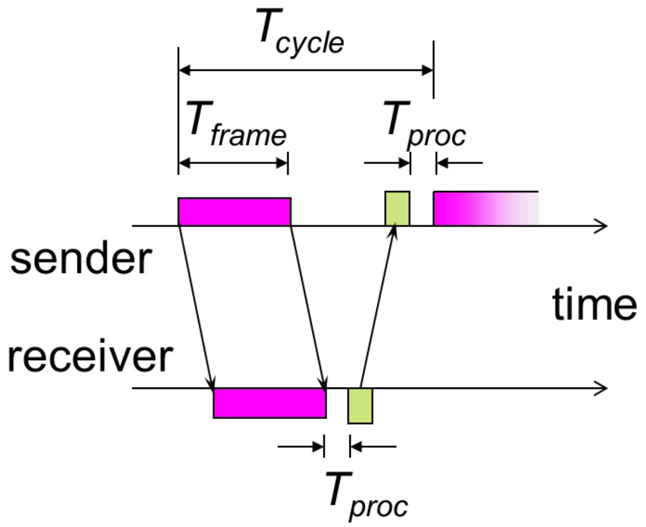
$$T_{cycle} = T_{frame} + T_{prop} + T_{proc} + T_{ack} + T_{prop} + T_{proc}$$



T_{cycle}:	Time needed to send a frame
T_{proc}:	Processing time
T_{ack}:	ACK Tx time
T_{frame}:	Frame Tx time
T_{prop}:	Signal Propagation delay

Throughput for Stop-and-Wait

- **Assumptions**
  - Input is saturated
  - No error
  - Ignoring T_{ack} & T_{proc}



We get:

$$T_{cycle} = T_{frame} + 2\,T_{prop}$$

Then:

$$U = T_{frame} / (T_{frame} + 2\,T_{prop})$$
$$= 1 / (1+2a)$$

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

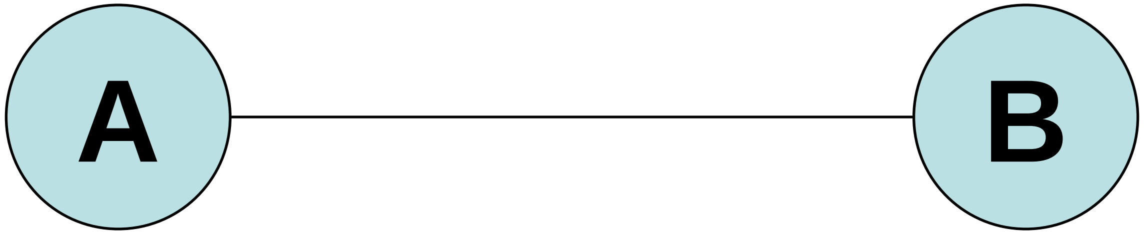
Where:

$$a = T_{prop} / T_{frame}$$

Parameter '*a*' is known as Normalized Propagation 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. No frame error. Calculate the link unitization for the stop-&-wait flow control mechanism.



R= 2.4 Mbps, L=300 bytes =2400bits
H=50km, v = $2\text{x}10^8$ *m/s*

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

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

$= \mathbf{2/3}$

Stop-and-Wait: Disadvantages

- **If frame or ACK is lost, long waiting time is expected**
  - Using a TIMEOUT control in the sender
- **If the propagation time is long, the sender must wait a long time before it can perform the next transmission**
  - Use **Buffers** at the sender/receiver (sliding window operation)

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

Sliding Window Flow Control

- **Allows multiple frames to be in transit.**
- **Sender and Receiver have buffer *N* long.**
- **Sender can send up to *N* frames without receiving ACKs.**
- **Each frame is numbered.**
- **ACK includes number of next expected frame.**
- **Sequence No. bounded by field size (*k* bits)**
  - **Frames are numbered modulo 2^k**
  - ***Sequence number $[0, 2^k-1]$***

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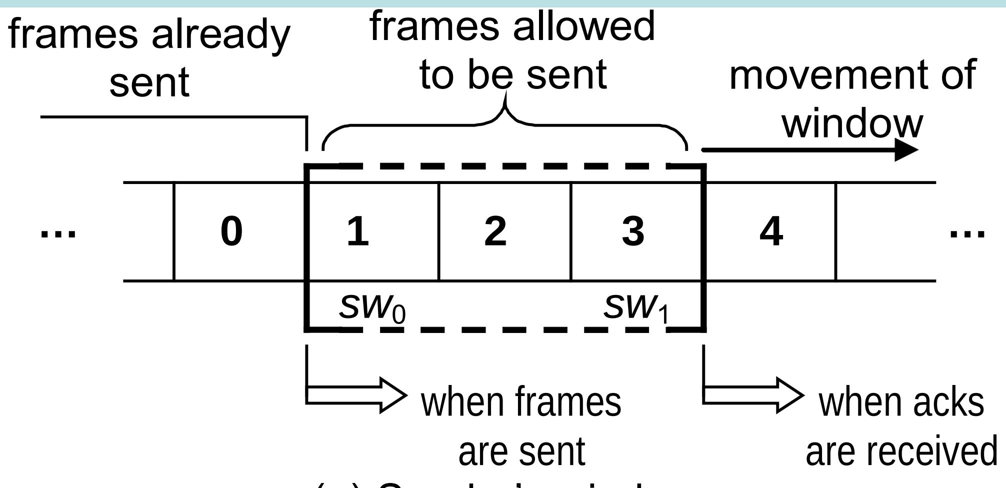
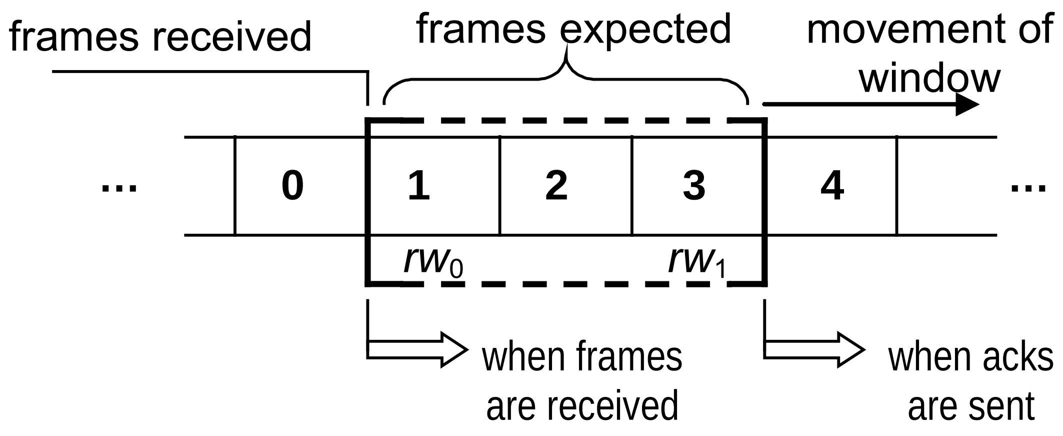
Sliding Window Operations

- **Sender**
  - Move lower bound when frames sent
  - Move upper bound when acks received
- **Receiver**
  - Move lower bound when frames received
  - Move upper bound when acks sent



(a) Sender's window



(b) Receiver's window

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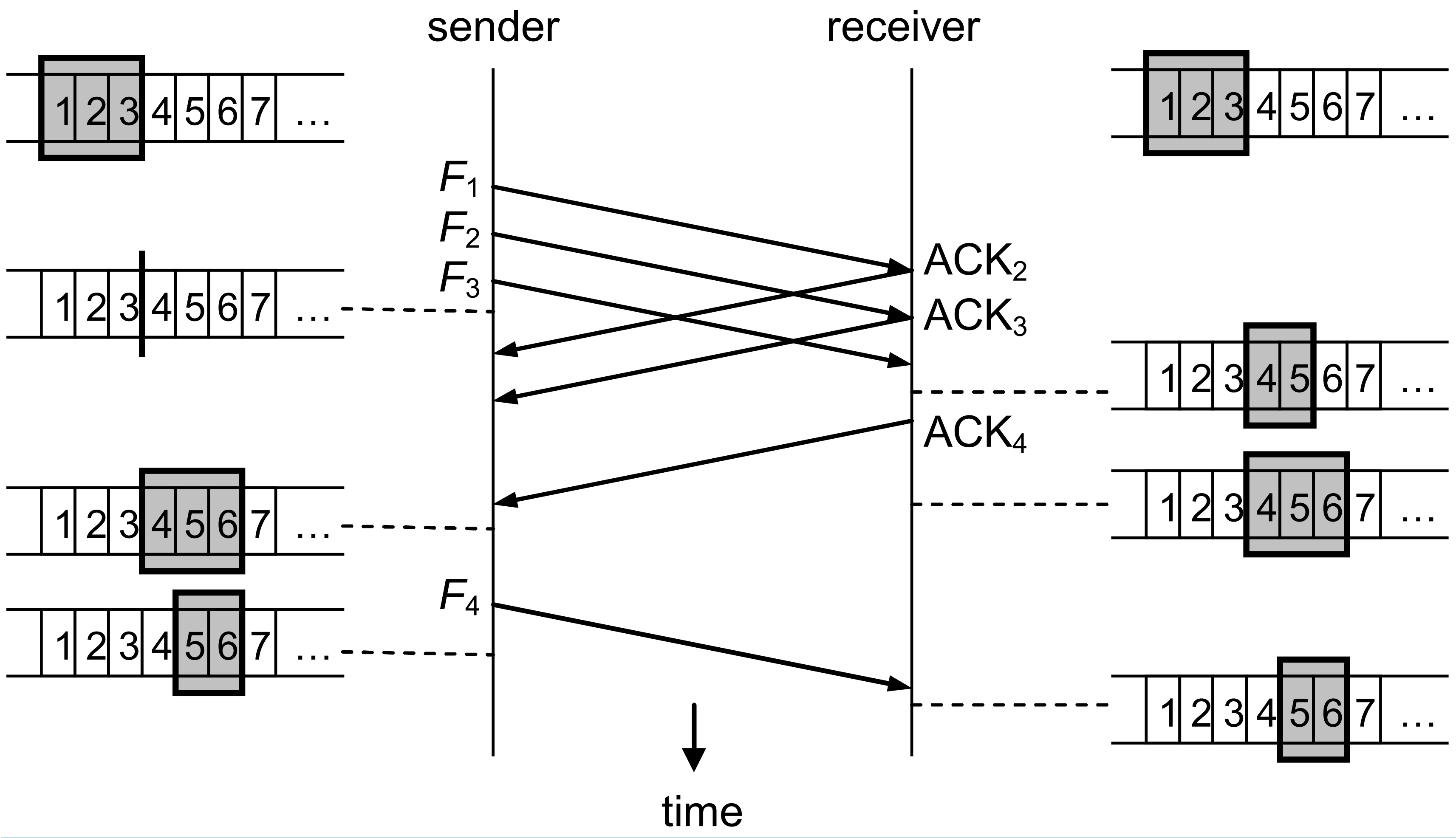
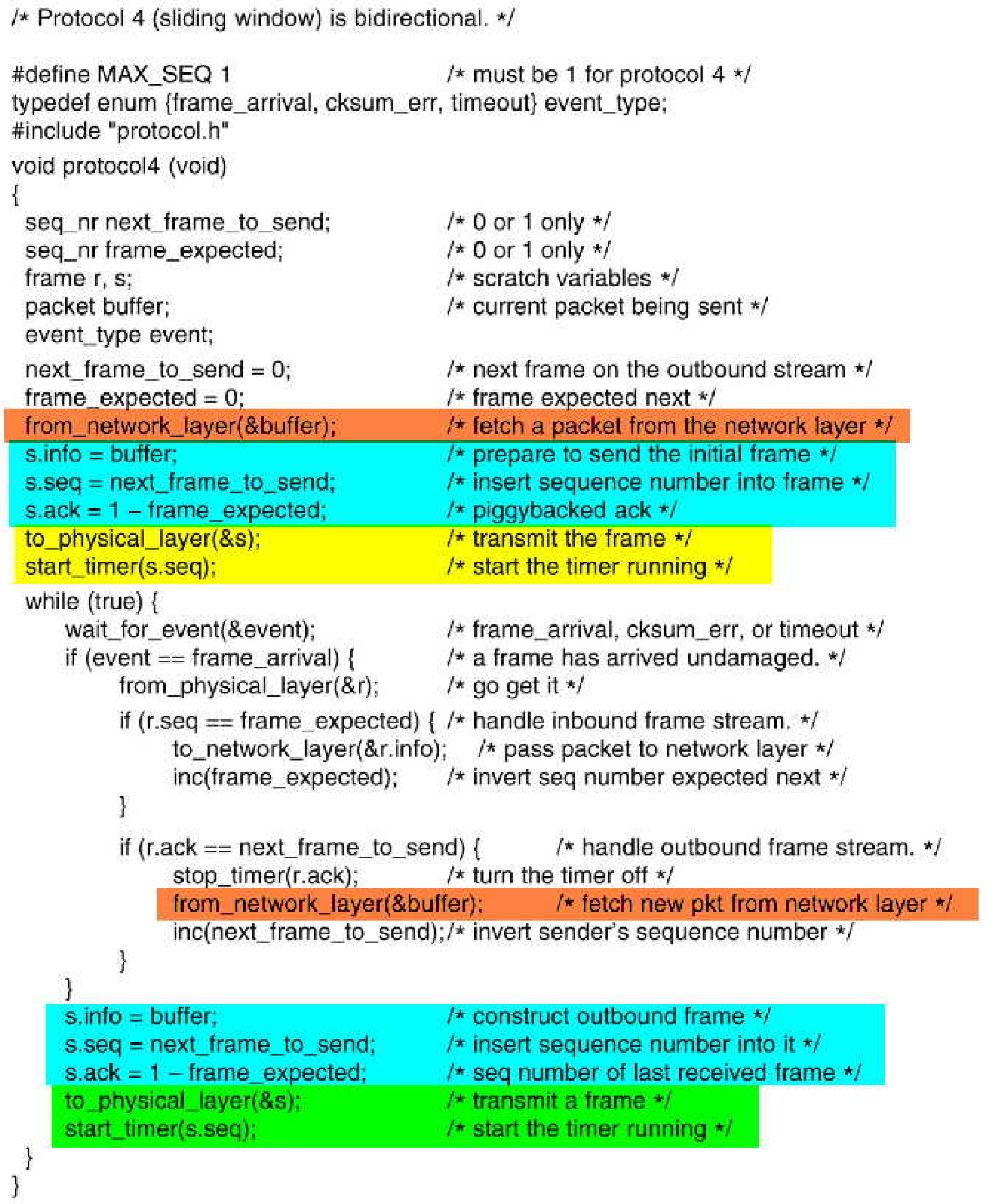
Sliding Window Operations

- Sender maintains a window, containing frame numbers that can be transmitted.
- Sender window shrinks from trailing edge (left side) as frames are sent.
- Frames are buffered at the sender until acknowledged.
- Receiver maintains a window as well, its window shrinks from trailing edge as frames are received.
- Receiver's window expands from the leading edge (right side) as ACKs are sent.
- Sender's window expands from the leading edge as ACKs are received.

Sliding Window: Example



Sliding Window Algorithm

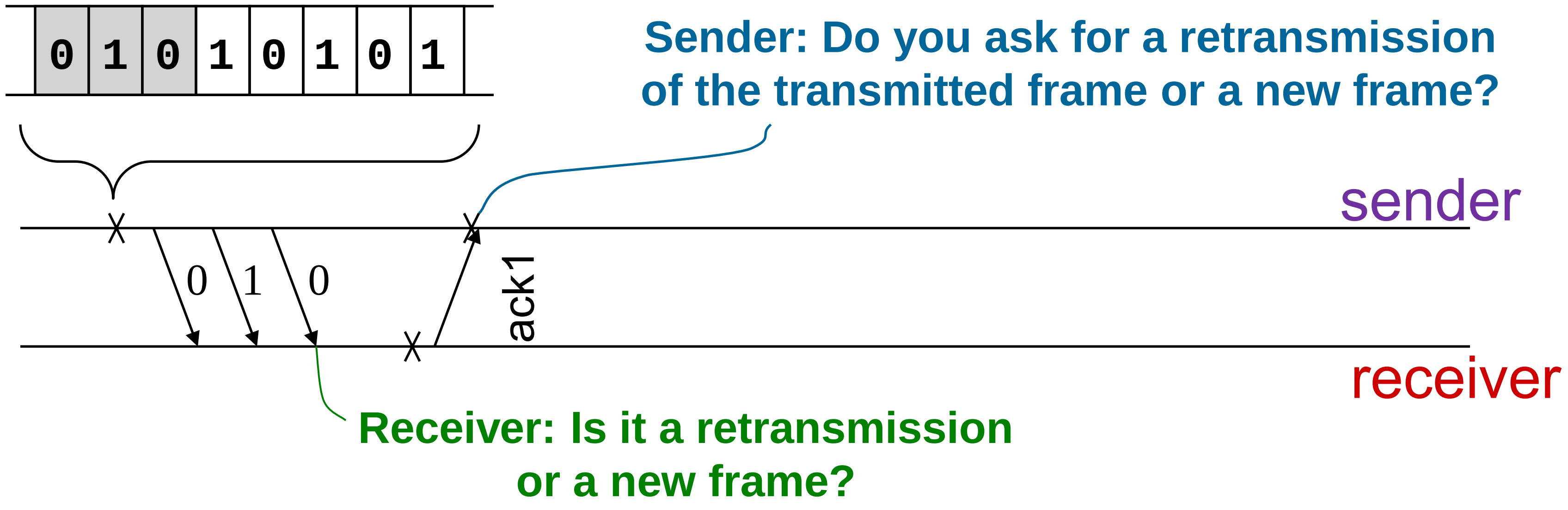


```
/* Protocol 4 (sliding window) is bidirectional. */

#define MAX_SEQ 1                          /* must be 1 for protocol 4 */
typedef enum {frame_arrival, cksum_err, timeout} event_type;
#include "protocol.h"

void protocol4 (void)
{
 seq_nr next_frame_to_send;                /* 0 or 1 only */
 seq_nr frame_expected;                    /* 0 or 1 only */
 frame r, s;                               /* scratch variables */
 packet buffer;                            /* current packet being sent */
 event_type event;

 next_frame_to_send = 0;                   /* next frame on the outbound stream */
 frame_expected = 0;                       /* frame expected next */
 from_network_layer(&buffer);              /* fetch a packet from the network layer */
 s.info = buffer;                          /* prepare to send the initial frame */
 s.seq = next_frame_to_send;               /* insert sequence number into frame */
 s.ack = 1 – frame_expected;               /* piggybacked ack */
 to_physical_layer(&s);                    /* transmit the frame */
 start_timer(s.seq);                       /* start the timer running */

 while (true) {
     wait_for_event(&event);               /* frame_arrival, cksum_err, or timeout */
     if (event == frame_arrival) {         /* a frame has arrived undamaged. */
          from_physical_layer(&r);         /* go get it */

          if (r.seq == frame_expected) {   /* handle inbound frame stream. */
               to_network_layer(&r.info);     /* pass packet to network layer */
               inc(frame_expected);        /* invert seq number expected next */
          }

          if (r.ack == next_frame_to_send) {        /* handle outbound frame stream. */
               stop_timer(r.ack);          /* turn the timer off */
               from_network_layer(&buffer);         /* fetch new pkt from network layer */
               inc(next_frame_to_send);/* invert sender's sequence number */
          }
     }
     s.info = buffer;                      /* construct outbound frame */
     s.seq = next_frame_to_send;           /* insert sequence number into it */
     s.ack = 1 – frame_expected;           /* seq number of last received frame */
     to_physical_layer(&s);                /* transmit a frame */
     start_timer(s.seq);                   /* start the timer running */
 }
}
```

Window Size Consideration

Say, Window Size, *N* = 3
with *k*=1 bit Sequence number

$\boxed{N<=2^k}$


0 1 0 1 0 1 0 1
Sender: Do you ask for a retransmission of the transmitted frame or a new frame?
sender
0
1
0
ack1
receiver
Receiver: Is it a retransmission or a new frame?

- Is the second $\boxed{0}$ a new frame or the retransmitted frame?
- Which frame is to be transmitted next after receiving ack1?

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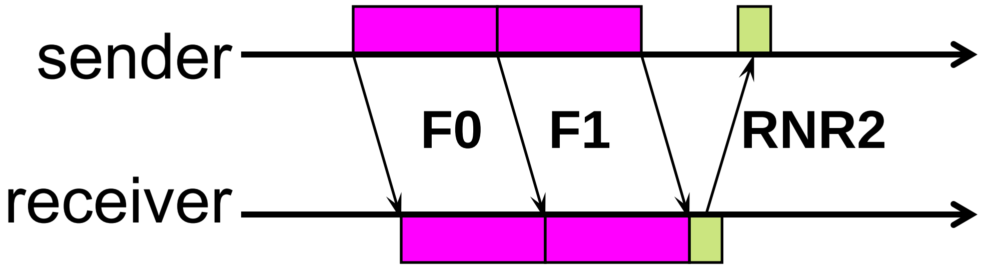
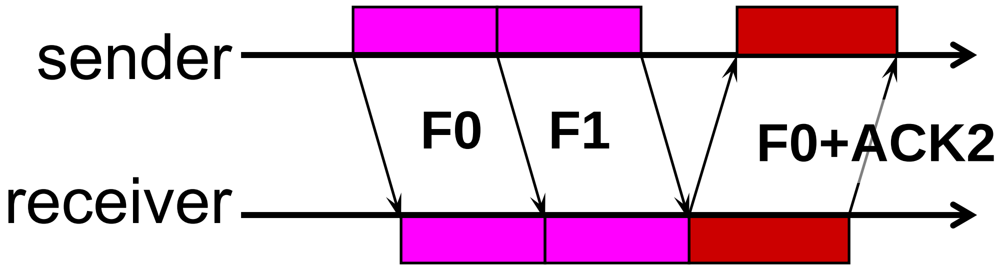
Sliding Window: Other Features

- **Receiver can acknowledge frames without permitting further transmission (by sending '*Receive Not Ready*', RNR frame). Receiver must send a normal acknowledgement to resume.**



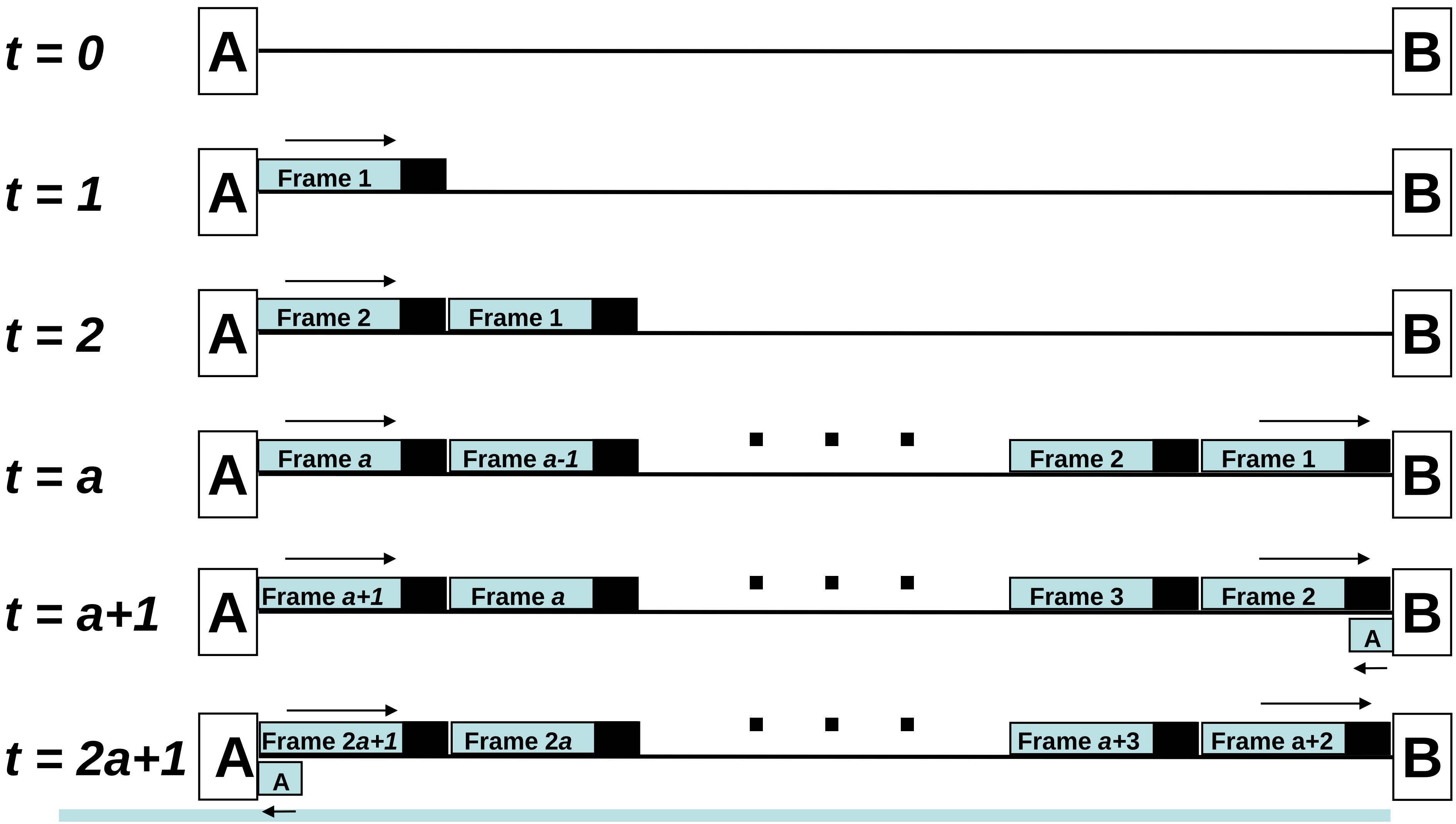
- **ACK can be *piggybacked* on the data frames in the reverse direction.**



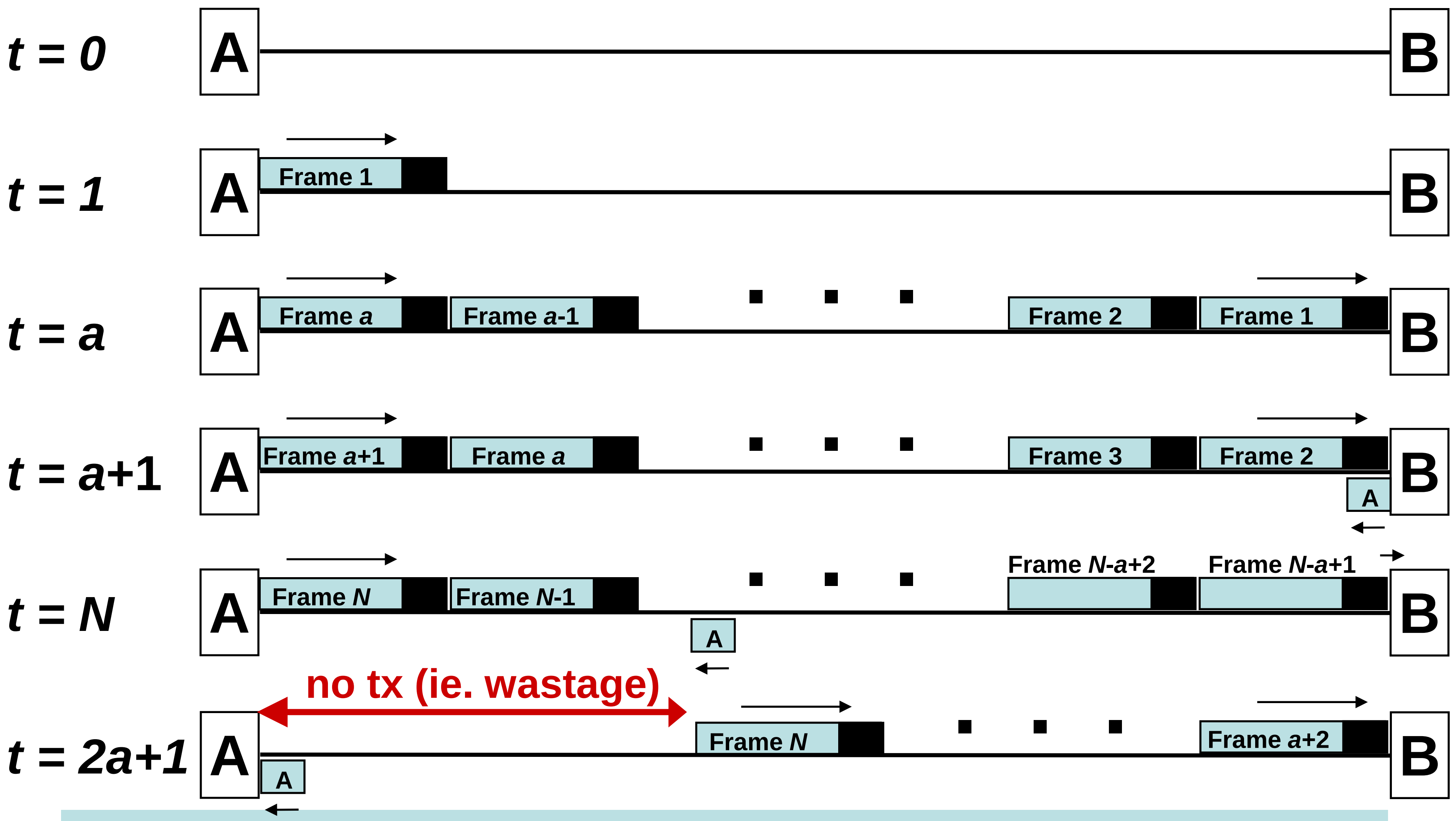
Sliding Window: Performance

- Performance depends upon (error-free operation):
  - Parameter *a*, and
  - Window size, *N*.
- Assumption: T_{ack} and T_{proc} are negligible.
- Frame transmission time = 1 (normalized to itself)
- Normalized propagation delay (one-way) = *a*
- We need to consider two cases:
  - $N \geq 2a + 1$: Station can transmit continuously without exhausting its window → $U = 1.0$
  - $N < 2a + 1$: Station's window is exhausted at $t = N$, and the station cannot send additional frames until $t = 2a + 1$, → $U = N/(1 + 2a)$

Case I: $N \geq 2a + 1$ [U=1]



Case II: $N < 2a + 1$ [U=N/(1+2a)]



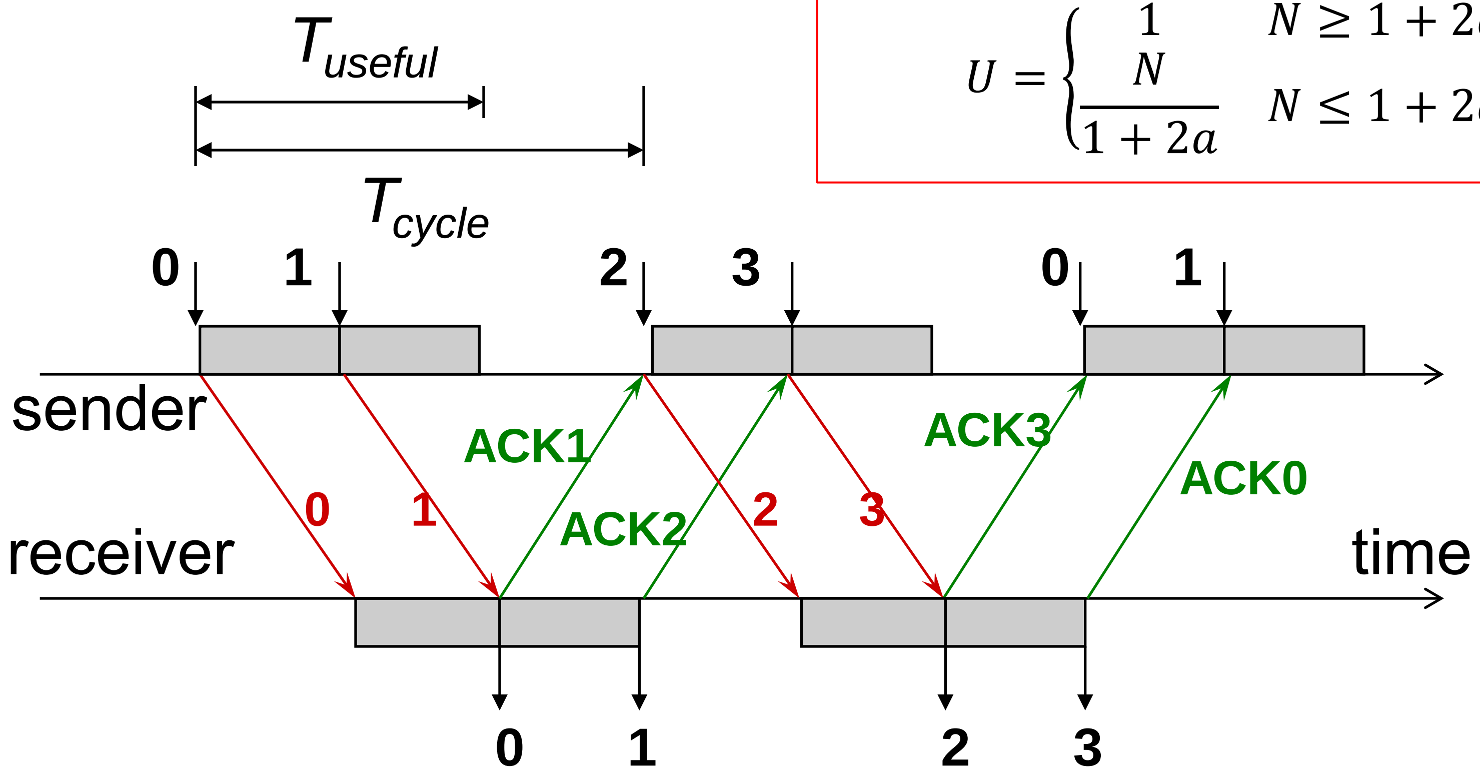
Sliding Window: Performance

Window Size = N

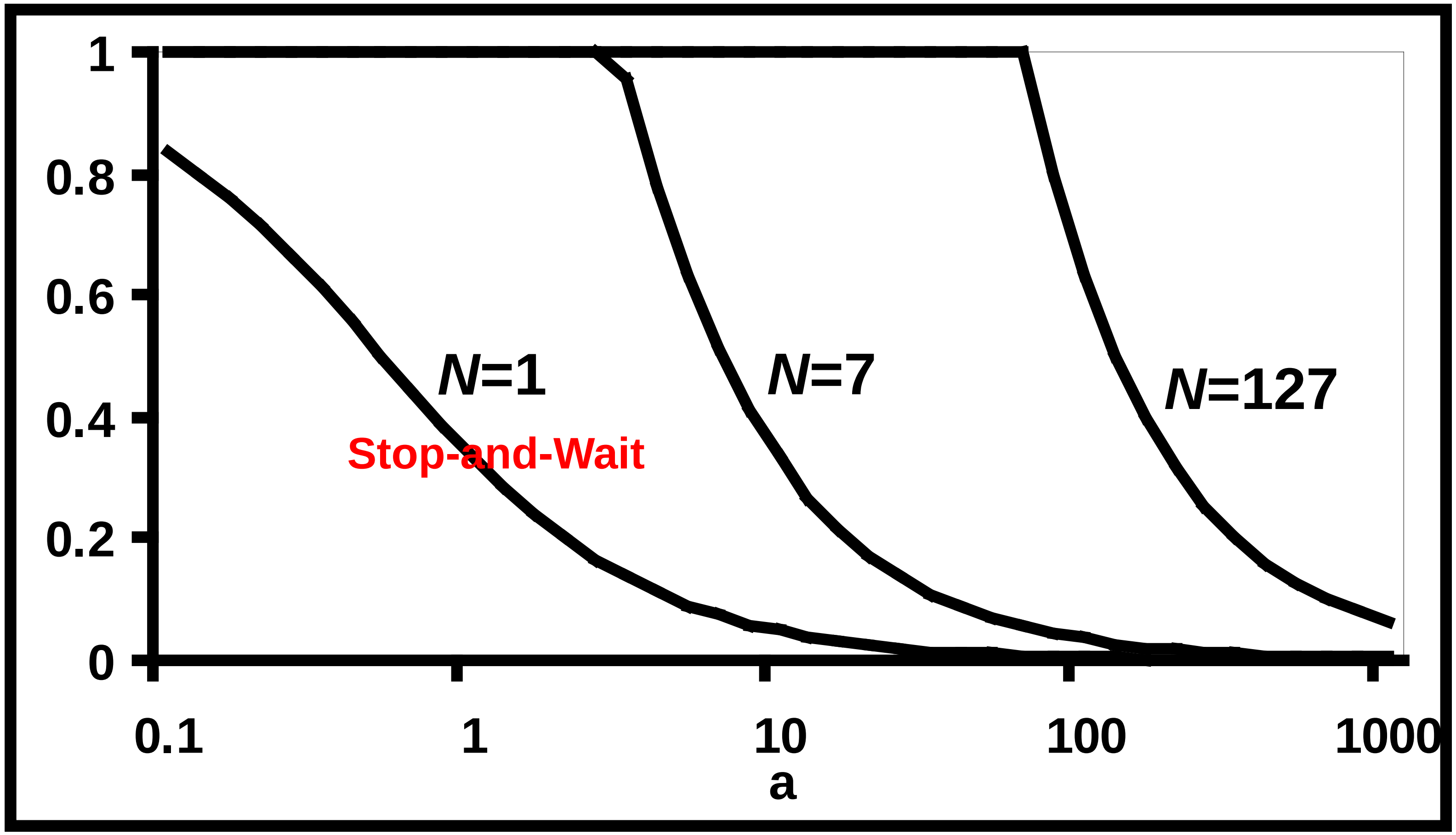
$T_{useful} = N^{*}T_{frame}$

$T_{cycle} = T_{frame}+2^{*}T_{prop}$

$$U = \begin{cases} 1 & N \geq 1+2a \\ \dfrac{N}{1+2a} & N \leq 1+2a \end{cases}$$



Flow Control: Link Utilization



Link Utilization versus *a*

Learning Objectives

- **Data Link Layer Fundamentals**
  - To understand its (four) main functions
- **Flow Control**
  - To understand its main purpose
  - Stop-and-Wait Flow-Control Mechanism
    - Operational protocol
    - Link utilization calculation
  - Sliding Window Flow-Control Mechanism
    - Operational protocol
    - Window size determination
    - Link utilization calculation (two cases)

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