Part I Syllabus

Date	Subject	File
Week 1: 9/Jan/2023 11/Jan/2023	Introduction: course logistics and Internet history	M1-L1-Introduction.pptx
	Layered Network Architecture	First part of M1-L2-Network Layer & Physical Resilience.pptx
Week 2: 16/Jan/2023 18/Jan/2023	Physical Layer: Network Resilience	Second part of M1-L2-Network Layer & Physical Resilience.pptx
	Data link layer – Flow control	M1-L3-DLL-Flow Control.pptx
Week 3: 25/Jan/2023	Data link layer – Error control	M1-L4-DLL-Error Control.pptx
Week 4: 30/Jan/2023 01/Feb/2023	Local area network – Introduction	M1-L5-LAN-Introduction.pptx
	Local area network – MAC	M1-L6-LAN-MAC.pptx
Week 5: 06/Feb/2023 08/Feb/2023	Local area network – Ethernet	First part of M1-L7-LAN-Ethernet.pptx
	Local area network – Ethernet Evolutions	Second part of M1-L7-LAN-Ethernet.pptx
Week 6: 13/Feb/2023 15/Feb/2023	Local area network – WLAN	M1-L8-LAN-WLAN.pptx
	Network paradigms	M1-L9-Paradigms.pptx

Additional Materials

- **The related content about flow control talked today in https://eclass.teicrete.gr/modules/document/file.php/TP326/%CE%98%CE%B5%CF%89%CF%81%CE%AF%CE%B1%20(Lectures)/Computer_Networking_A_Top-Down_Approach.pdf is as follow:**
  - stop-and-wait: p207-p218
  - sliding window: p218-p229
- **And here is another resource for your reference https://www.geeksforgeeks.org/flow-control-in-data-link-layer/**
- **You can also find other video materials about**
  - stop-and-wait Stop-and-Wait Protocol - YouTube
  - sliding window Sliding Window Protocol - YouTube

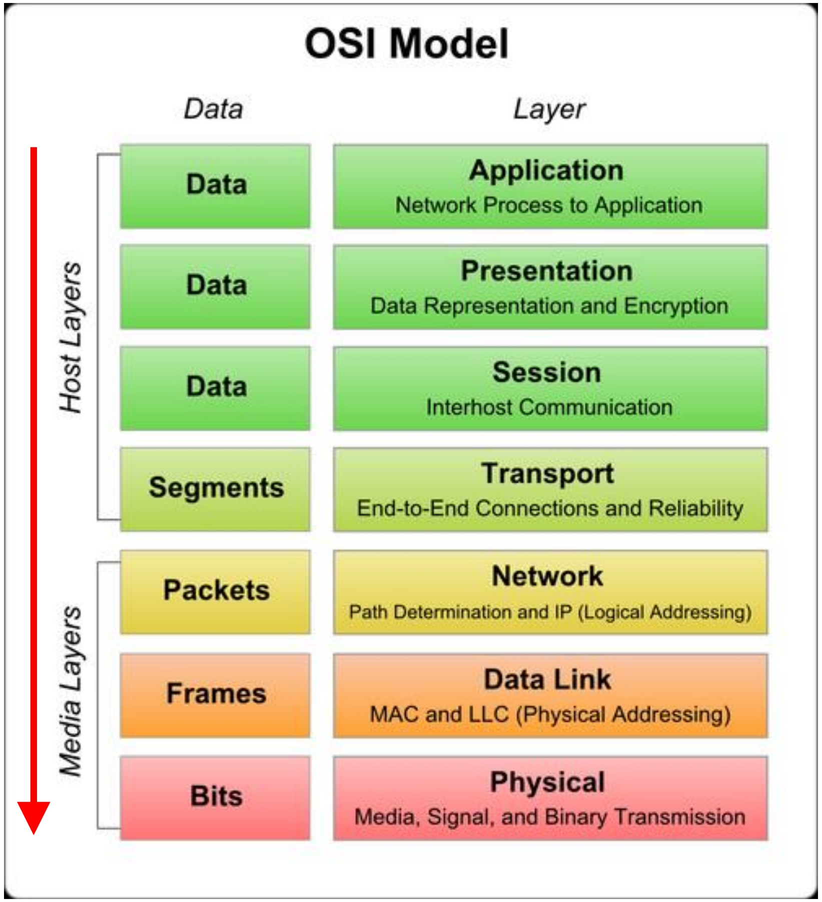
Drinking from Fire Hose

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

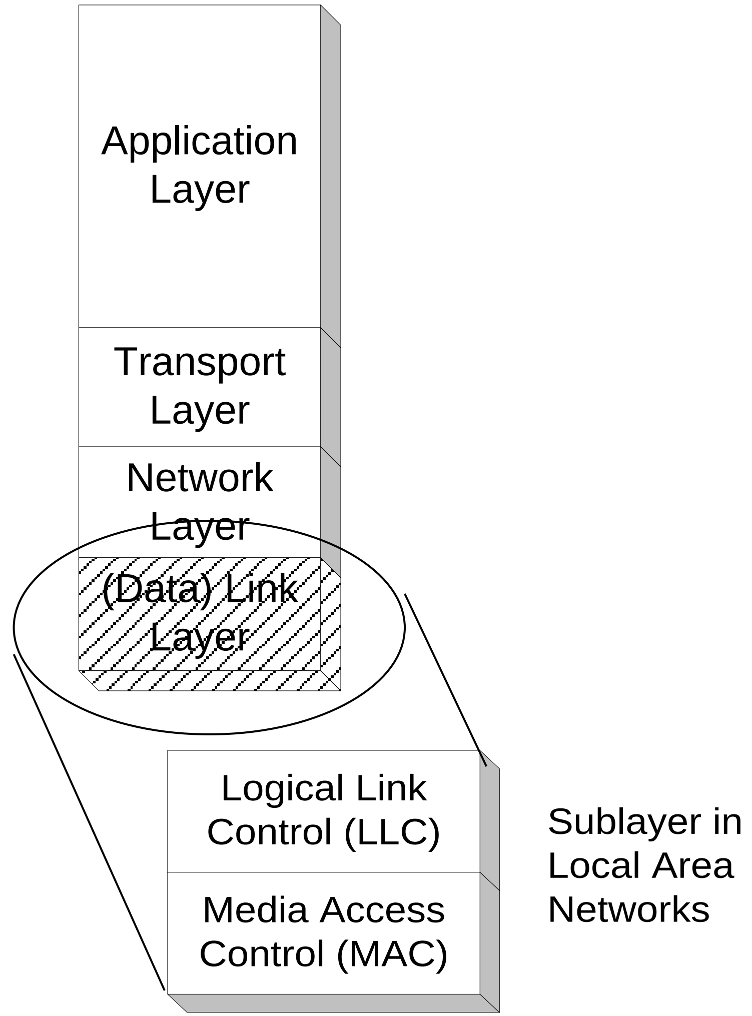
Encapsulation:
information gets bulkier and bulkier



Data Link Layer Fundamentals

Data Link Layer (DLL): 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

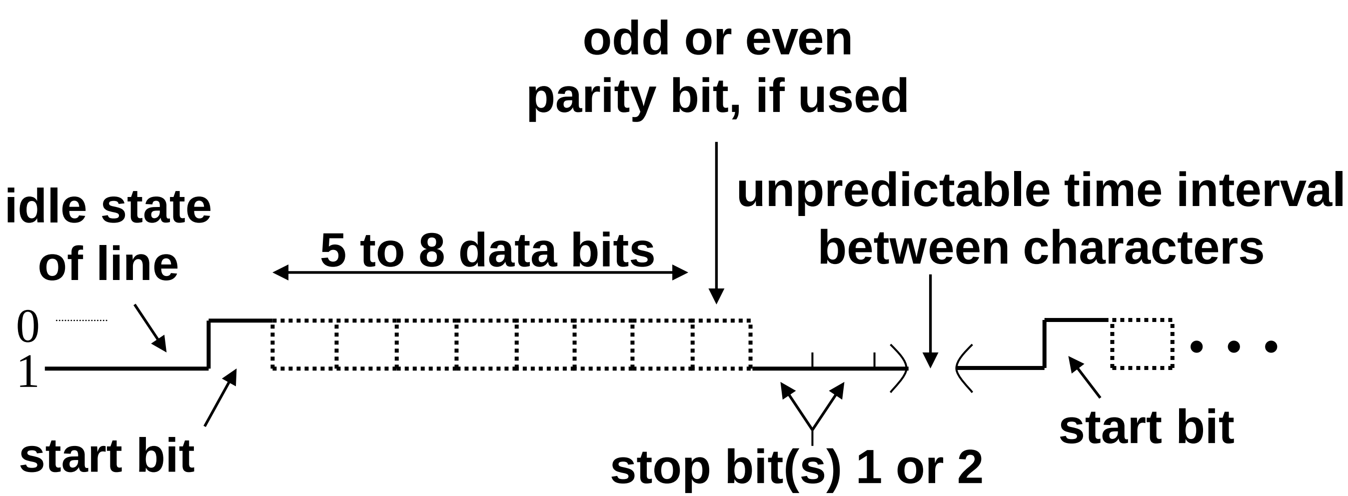


Framing

- **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

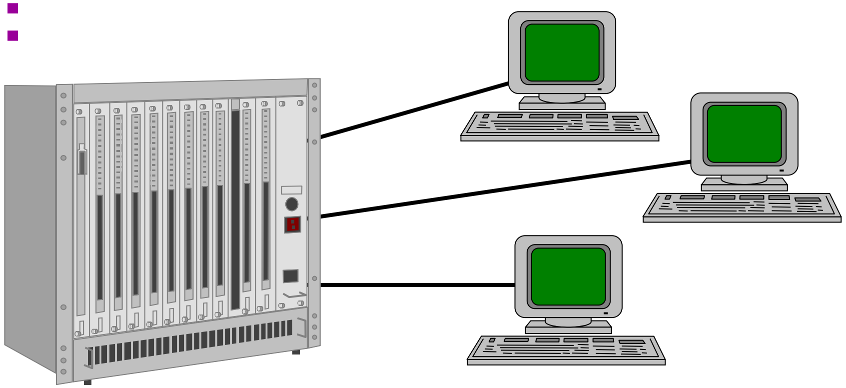


Link Configuration/Access

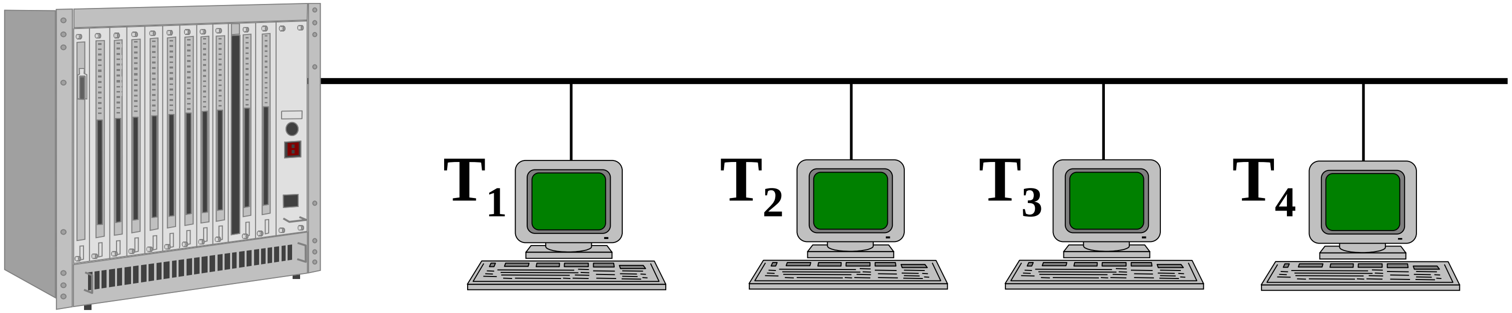
- **Objective: determine *who* gets to transmit at *when* on a link**
- **Topology: physical arrangement of stations**
  - Point-to-Point: pairs of hosts are directly connected
  - Broadcast: all stations share a single channel
- **Duplexity**
  - Half Duplex: Only one party may transmit at a time.
  - 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):

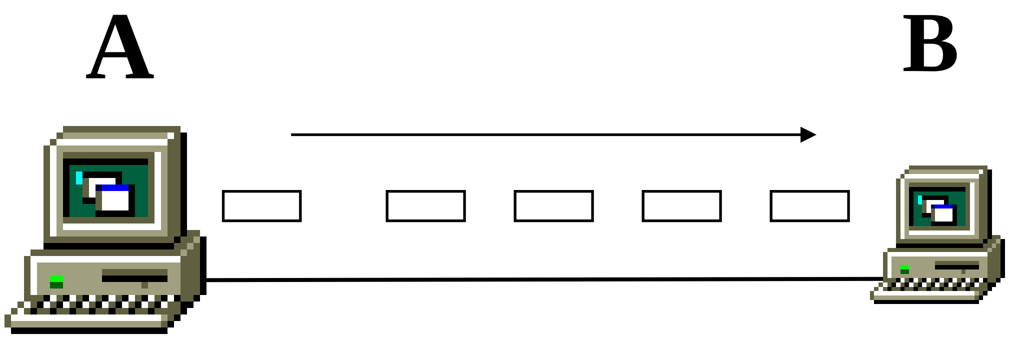


All terminals share the same medium controlled by the primary station (mainframe)

Flow Control

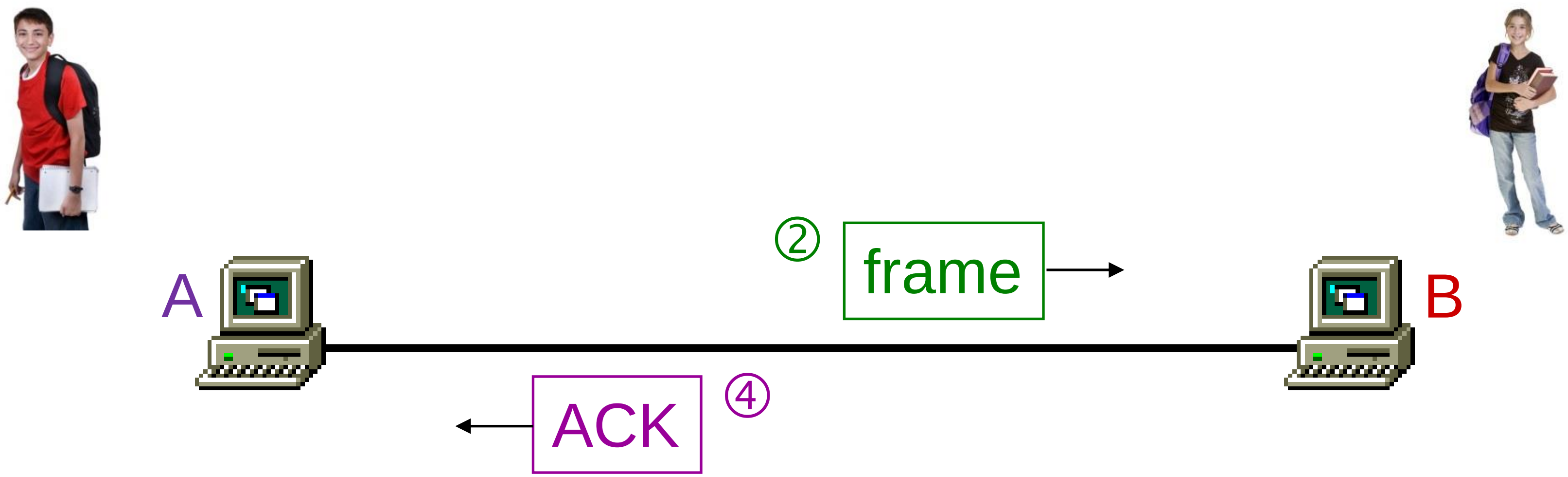
Functions and Mechanisms

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



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

Stop-and-Wait Flow Control



<u>Operations:</u>

① *A* packs binary information into a frame

② *A* sends the frame to *B*

③ *A* waits for an ACK

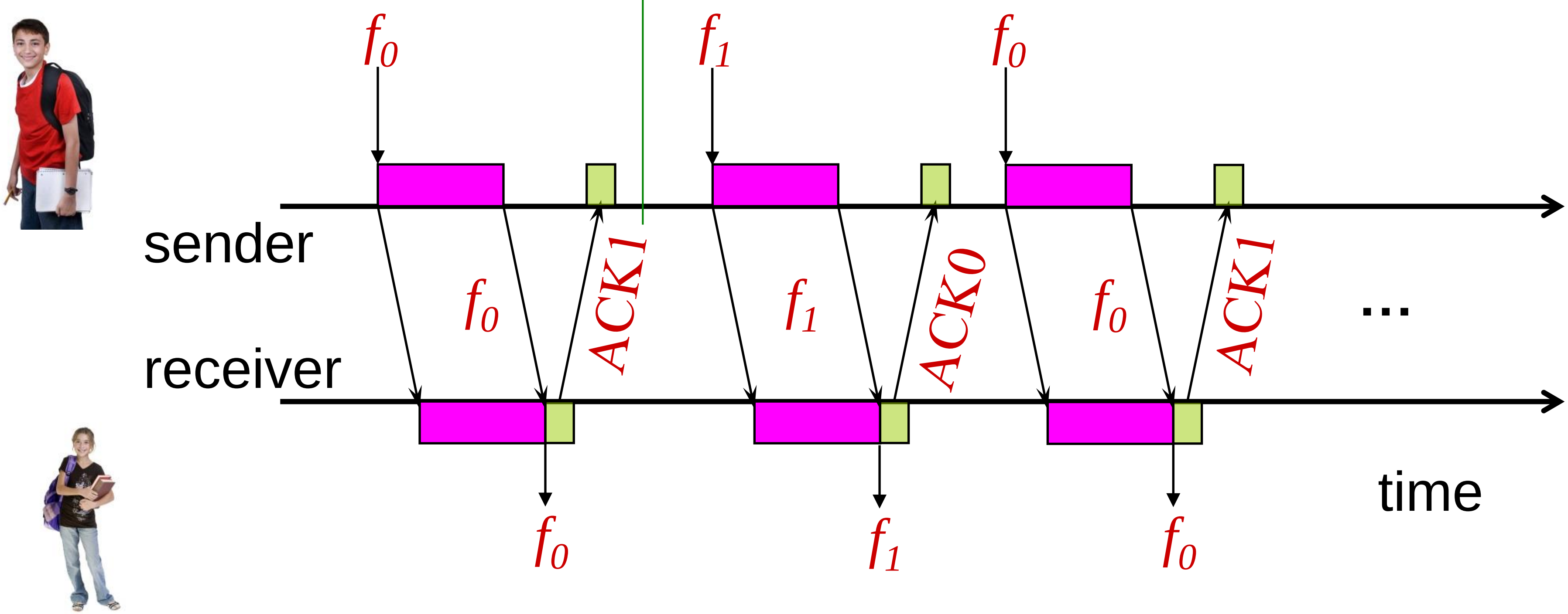
④ When *B* has received the frame, *B* sends an ACK

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

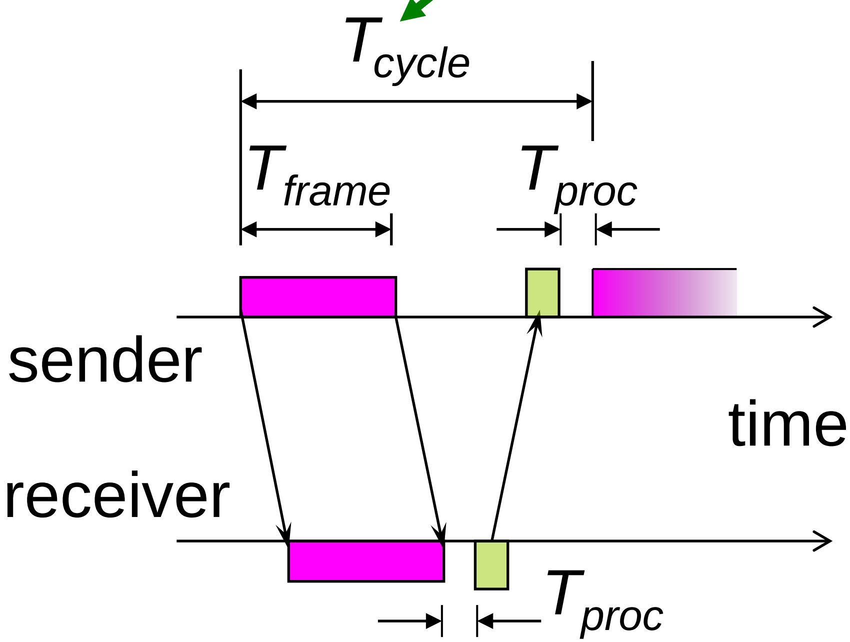
Binary sequence number is sufficient



Flow-Control Link Utilization

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

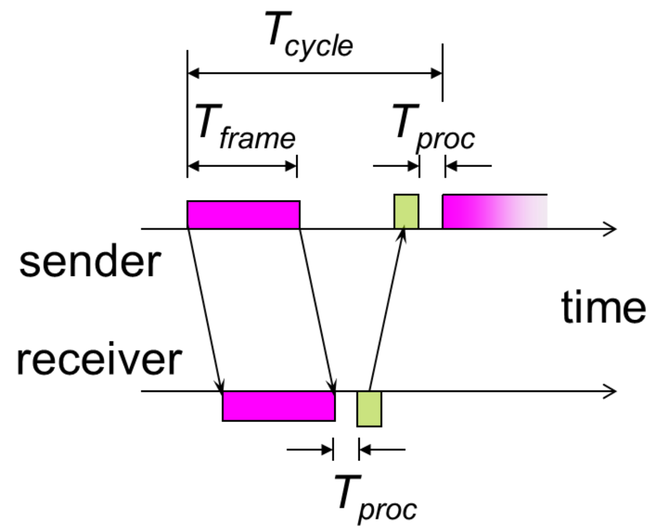
$$T_{cycle} = T_{frame} + T_{prop} + T_{proc} + T_{ack} + T_{prop} + T_{proc}$$



- T_{cycle}: Total time needed to send a frame
- T_{proc}: Processing time
- T_{frame}: Frame transmission time (i.e., to pump out a frame's bits from your computer)
- T_{ack}: ACK transmission time
- T_{prop}: Signal Propagation delay

Link Utilization 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:

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

where:

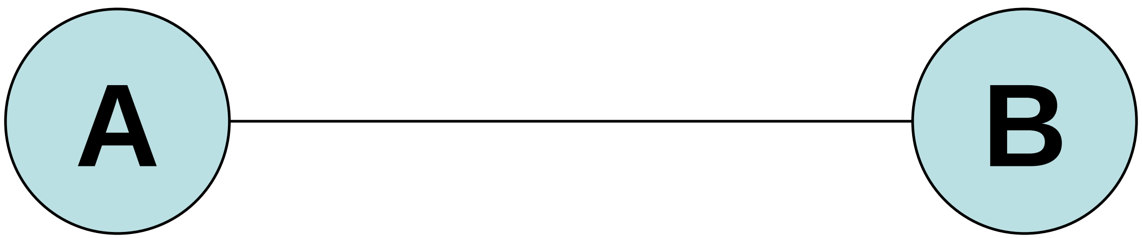
we define $a = T_{prop} / T_{frame}$

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

Parameter '*a*' is called 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.



Here T_p and T_f are short for T_{prop} and T_{frame}, respectively.

R= 2.4 Mbps, L=300 bytes =2400bits

D=50km, v = $2\text{x}10^8$ *m/s*

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

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

= **2/3**

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μs means microsecond; i.e., 10^{-6} seconds.

Stop-and-Wait: Disadvantages

- **If frame or ACK is lost, long waiting time is expected**
  - To fix this, use a TIMEOUT control in the sender
- **If the normalized propagation delay is long, the sender must wait a long time before it can perform the next transmission.**
  - The link utilization $U = \frac{1}{1+2a}$ is low.
  - To fix this, use **Buffers** at the sender/receiver (sliding window operation). This will improve the numerator. Note that the denominator 1+2a cannot be improved.

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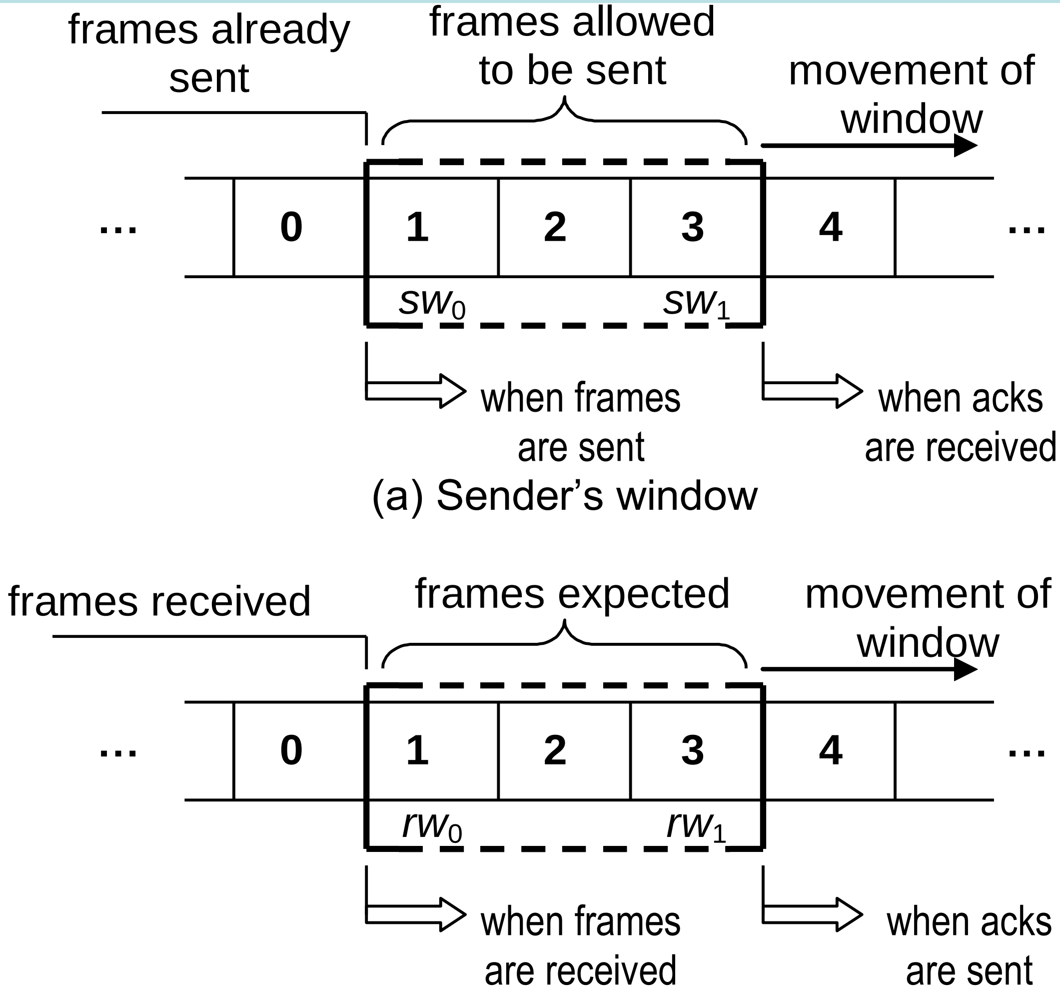
Sliding Window Flow Control

- **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 number bounded by field size (*k* bits)**
  - **Frames are numbered modulo 2^k**
  - ***Sequence number $[0, 2^k-1]$***

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

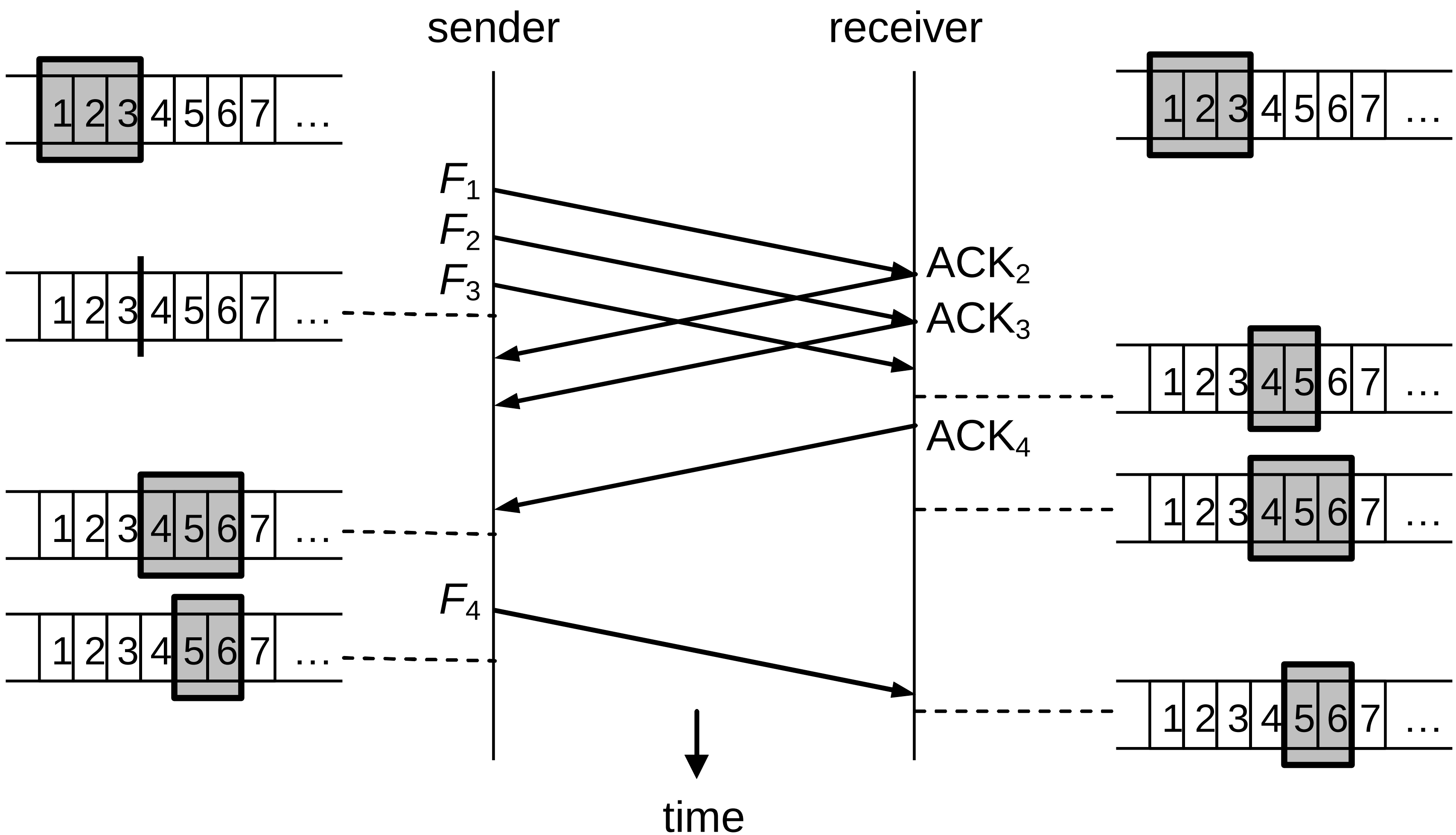
(b) Receiver's window

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.**

- **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 */
  }
}
```

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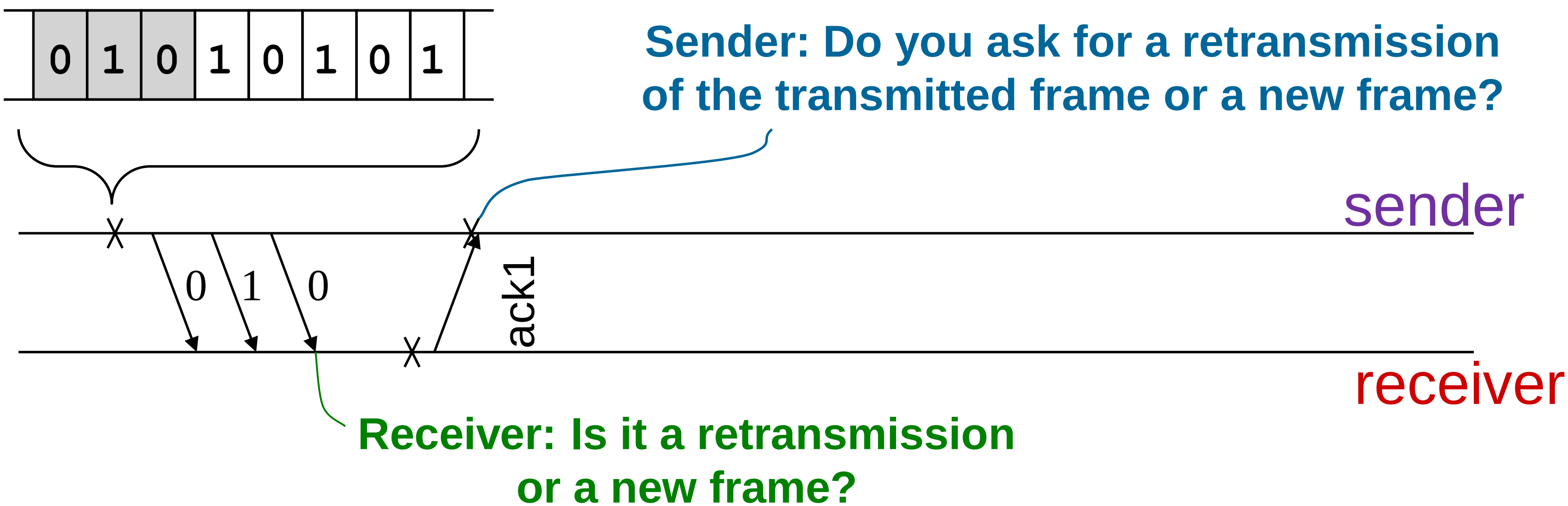
Window Size Consideration

Say, window size, *N* = 3
with *k*=1 bit sequence number



ⓘ Is the second $\boxed{0}$ a new frame or the retransmitted frame?

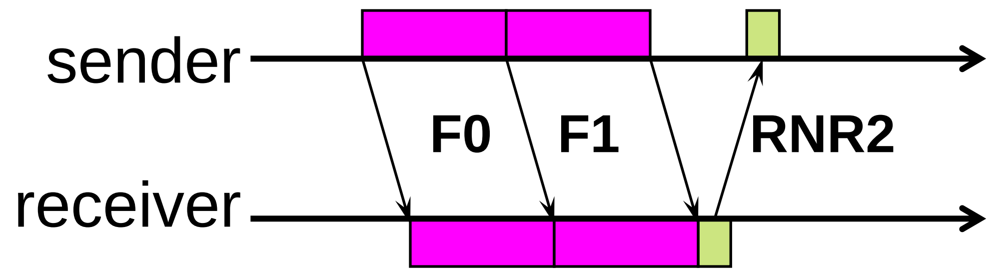
ⓘ Which frame is to be transmitted next after receiving ack1?

- **Based on the previous slide,**
  for window size *N* and *k* bits sequence number,
  we need

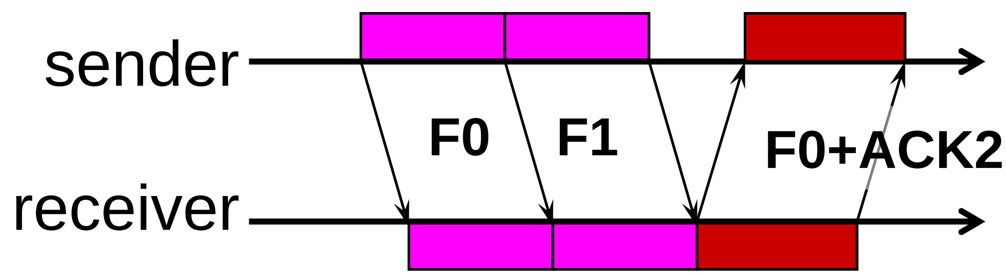
$$\boxed{N \leq 2^k}$$

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 (assume 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 $t = 2a + 1$, → $U = N/(1 + 2a)$

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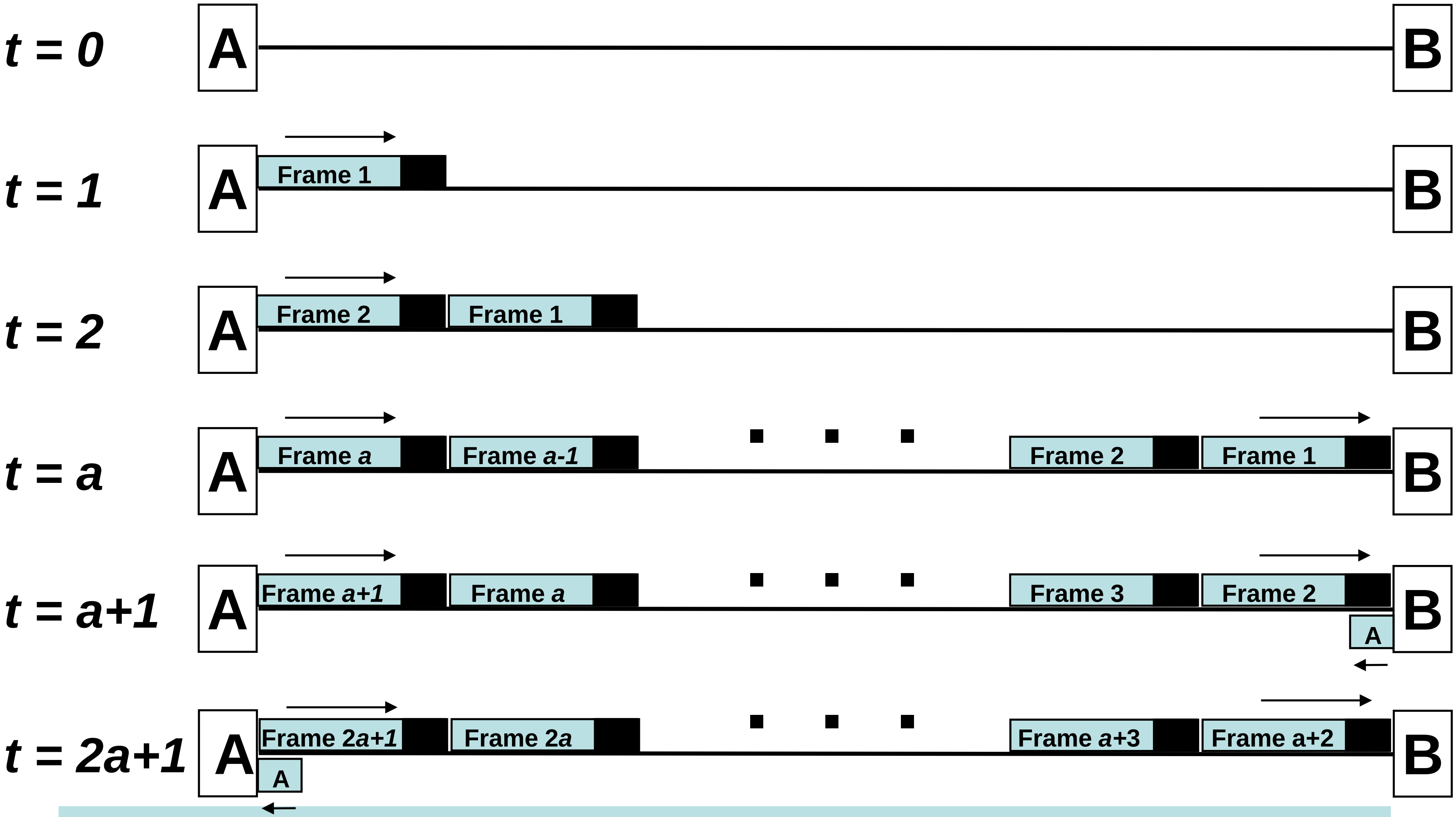
Case I: $N \geq 2a+1$ [U=1]



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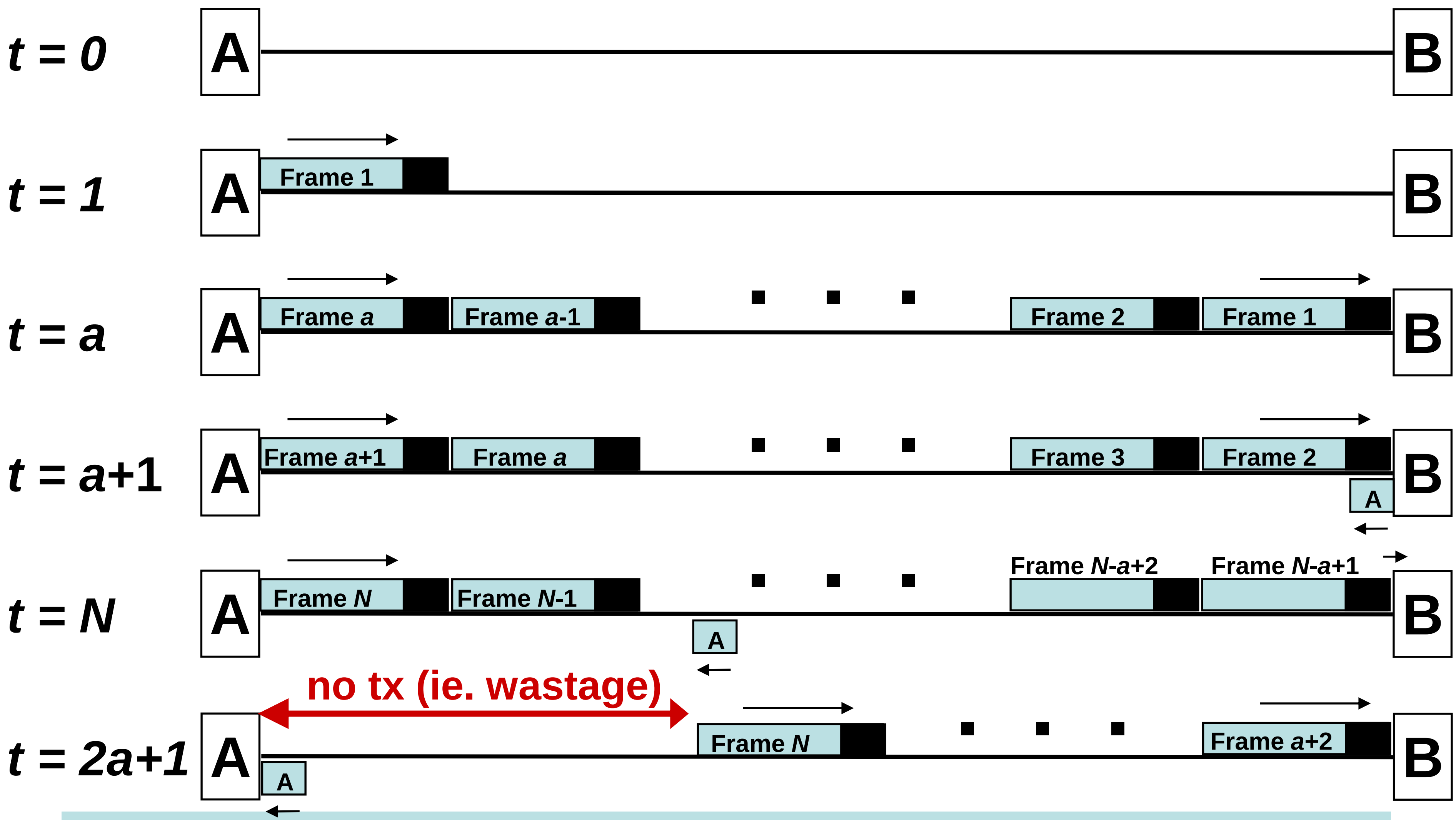
Case II: $N < 2a + 1$ [$U=N/(1+2a)$]



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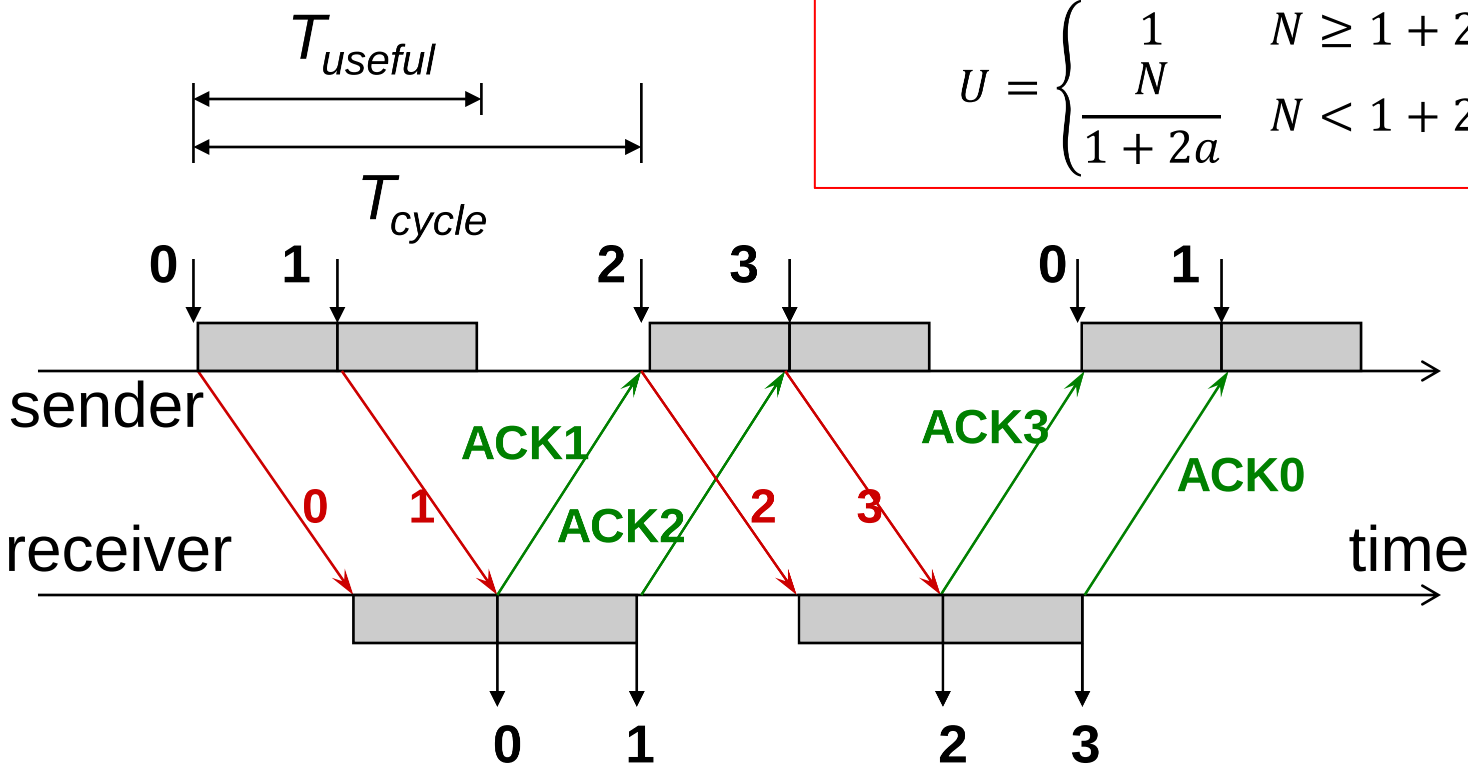
Sliding Window: Performance

Window Size = N

$T_{useful} = N * T_{frame}$
$T_{cycle} = T_{frame} + 2 * T_{prop}$

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



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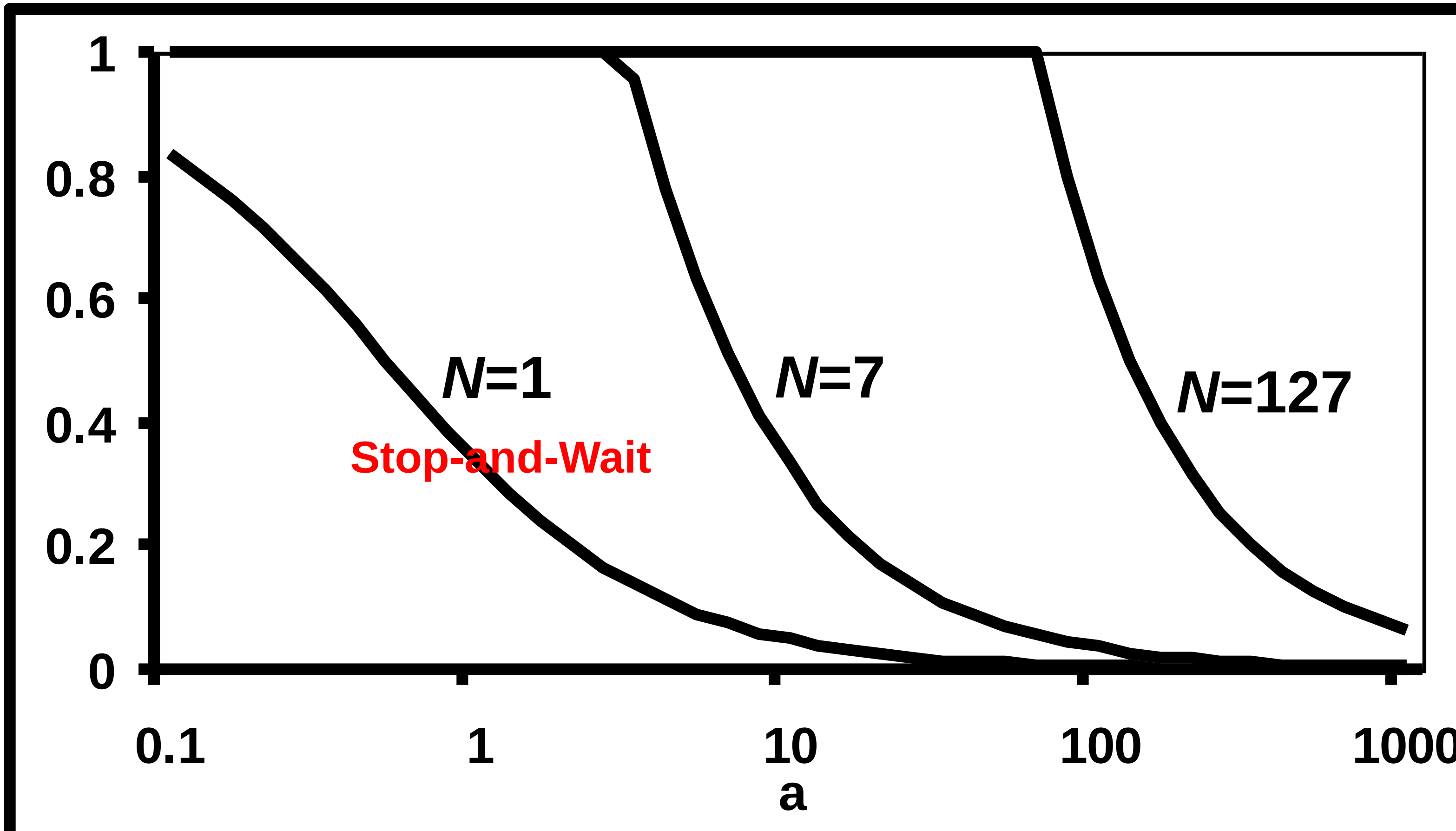
Flow Control: Link Utilization



Link Utilization versus *a*

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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)