

## Data Link Layer, Part 5

### Sliding Window Protocols

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## Preface

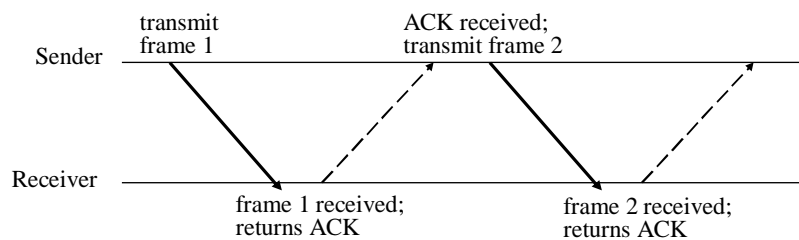
- ❑ We are about to discuss a series of protocols used between a pair of directly-connected sender and receiver.
- ❑ These protocols serve three purposes
  1. to guarantee delivery **reliability**,
  2. to enforce correct **ordering** of frames delivered to the network layer at the receiving end, and
  3. to provide **flow control**.

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## Stop And Wait

- ❑ The sender transmits a frame.
- ❑ If the receiver successfully receives the frame, it delivers the frame to its network layer and returns an **acknowledgement (ACK)** to the sender.
- ❑ Only after receiving the ACK will the sender be allowed to transmit the next frame.

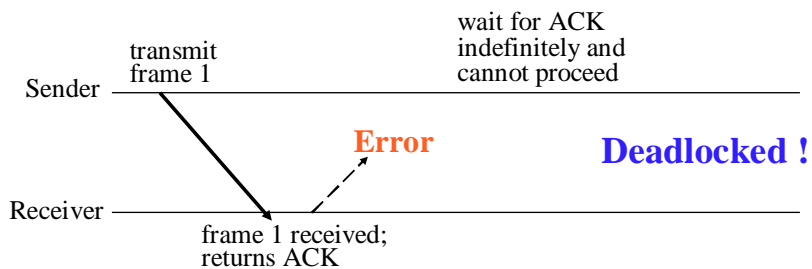


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## Problem

- ❑ This simple protocol provides flow control but does not enforce reliability
  - Actually, it fails in noisy links.
  - What would happen when a transmission (the frame or the ACK) is corrupted?



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## Discussion

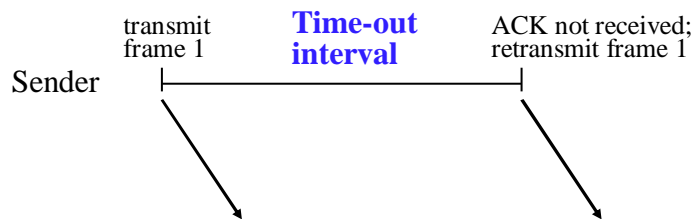
- ❑ What could cause the receiver not to receive the frame successfully ?
  - transmission errors reported by the error detection mechanism
  - the frame is so corrupted by noises that the receiver dose not even recognize its arrival
  - when the frame arrives at the receiver, there is not enough memory to accommodate it

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## The Time-out Mechanism

- ❑ The sender re-transmits a frame if the ACK does not arrive within some predetermined length of time.



- ❑ This implies that the sender DLL must keep the frame until it receives the ACK.

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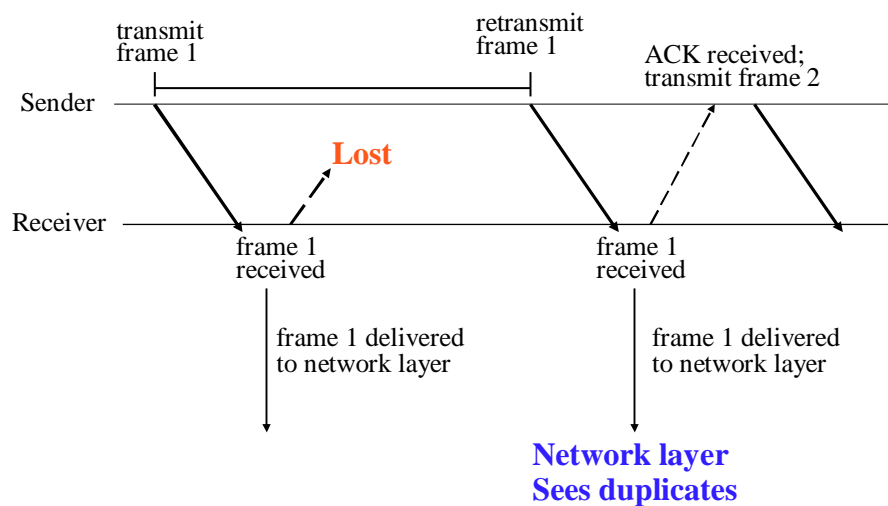
## Discussion

- ❑ Causes for not receiving the ACK:
  - the frame is not received due to previously discussed causes
  - the frame is successfully delivered but the ACK is not received by the sender
- ❑ This protocol is still flawed: although the delivery of the frame is guaranteed, the receiver's network layer may see multiple copies of a frame.

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## The Problem of Duplicates



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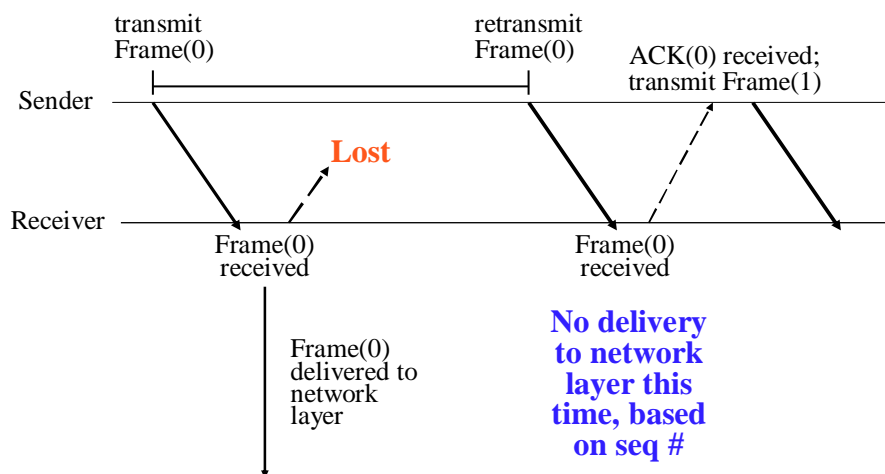
## Sequence Numbers

- ❑ Frames are numbered alternately:  
0, 1, 0, 1, ...
  - These are 1-bit sequence numbers.
- ❑ Receiver acknowledges the correct frames with an ACK of the same sequence number as the frame.
- ❑ If not receiving the corresponding ACK after a time-out period, the sender retransmits the frame.

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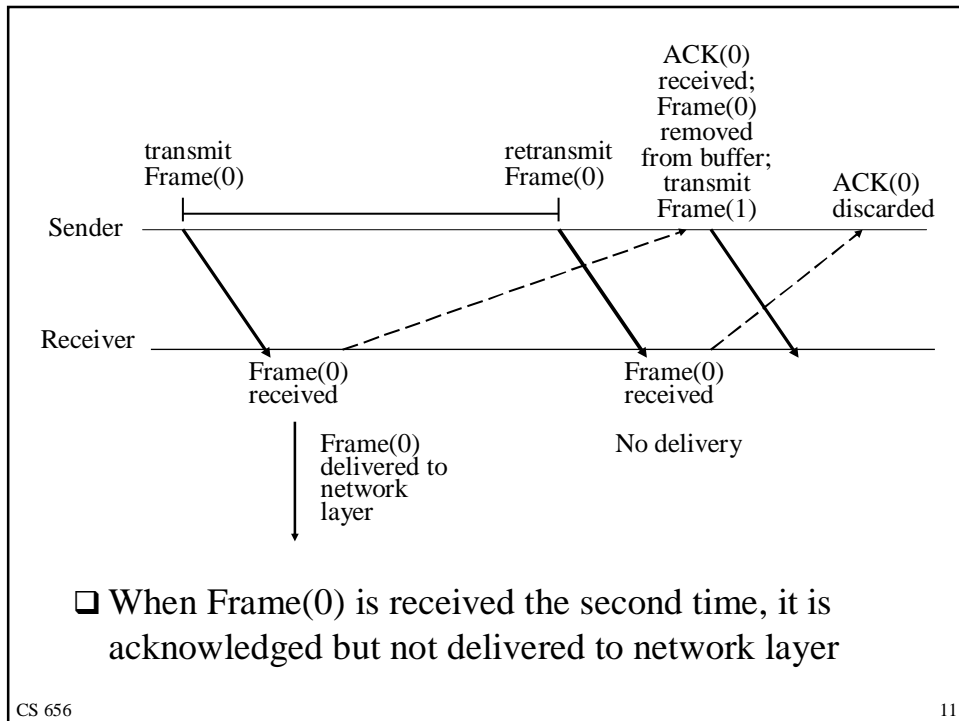
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## Example



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## Improving Performance

- ❑ “Stop-and-wait” wastes bandwidth.
- ❑ Solution is to allow multiple outstanding frames.
  - that is, to send the next frame before the current one is acknowledged.
- ❑ Two approaches:
  1. **go-back-n**: receiver discards all frames following an error, forcing the sender to “go back” to the lost frame, and retransmit all frames from that point
  2. **selective repeat**: receiver stores correct frames following the lost one(s); sender retransmits only lost frames

## Go-Back-N

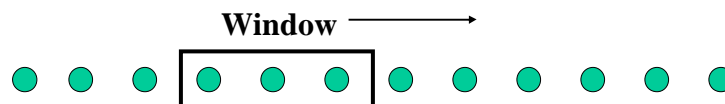
- ❑ Each frame is tagged with an  $n$ -bit sequence number.
- ❑ Only  $2^n - 1$  frames may be outstanding.
- ❑ The sender maintains a set of  $2^n - 1$  buffers, called a (sliding) **window**, to keep unacknowledged frames.
- ❑ When transmitting a frame, the frame is also copied to a slot of the window.
  - the copy is for retransmissions
  - the slot is freed when the frame's ACK arrives

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## Sliding Windows

- ❑ Imagine a sequence of frames waiting for transmission.
- ❑ Both Go-back-N and Selective-repeat define a window that slides from left to right over time.



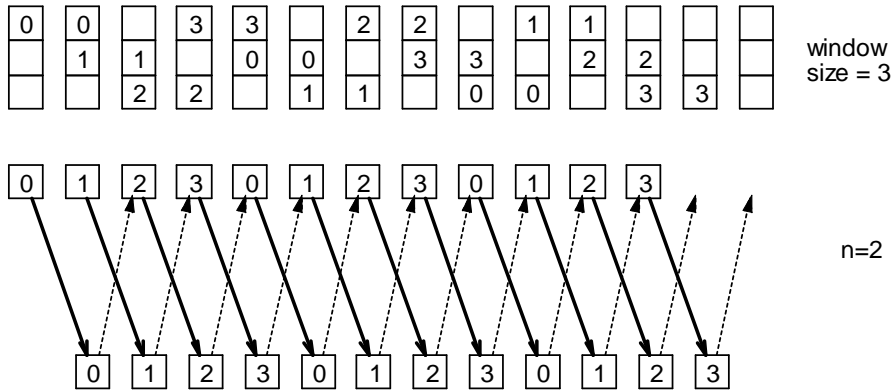
- ❑ At a given moment, only those frames in the window can be transmitted.
- ❑ They are thus called **Sliding Window Protocols**.

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## Example 1: Large Window

When window size is large *relative* to the round-trip time, we can take full advantages of the bandwidth.

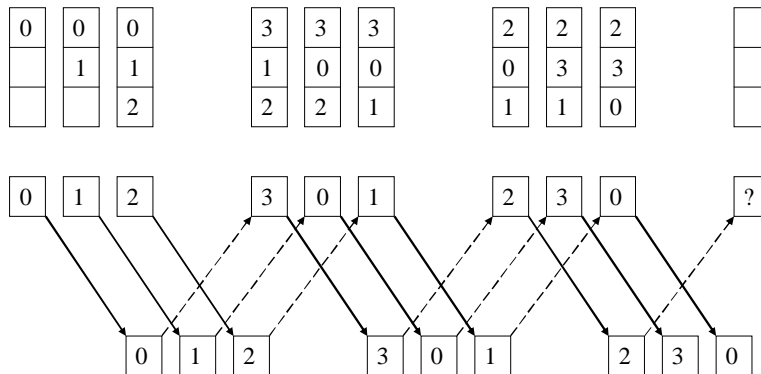


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## Example 2: Small Window

If window size is small *relative* to the round-trip time, then the “stop-and-wait” phenomenon still occurs.



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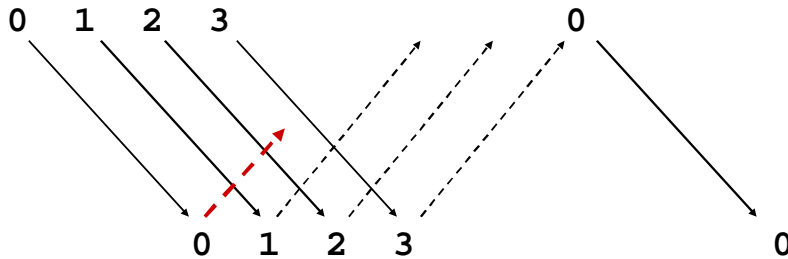
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## Scenario 2

- ❑ Timeout and retransmit 1st frame



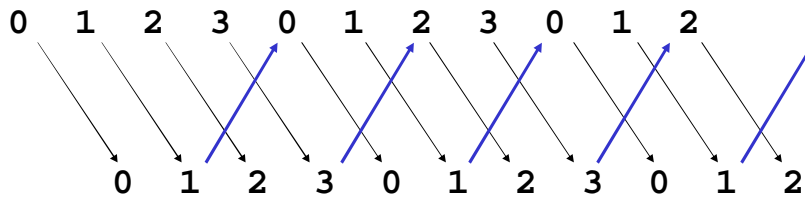
- ❑ The second frame 0 is a duplicate.
  - It must *not* be delivered to the network layer.
  - However, it *is* acknowledged to prevent the sender from time-out again.

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## Optimizations

- ❑ The receiver attaches ACKs to outgoing frames destined to the sender; this technique is called **piggybacking**.
- ❑ Further, we can “aggregate ACKs” that is, the ACK of the  $i$ -th frame also acknowledges the receipt of all the frames up to  $i$ .



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## Discussions

- ❑ One issue of piggybacking is how long the receiver should wait for an outgoing data frame
  - waiting too long may cause the sender to time out and retransmit unnecessarily
  - Impatient receivers, on the other hand, lose the opportunities of piggybacking
- ❑ Another optimization is to have the receiver, upon a corrupted frame, immediately replies a **negative acknowledgement (NACK)**, forcing the sender to retransmit before time-out.

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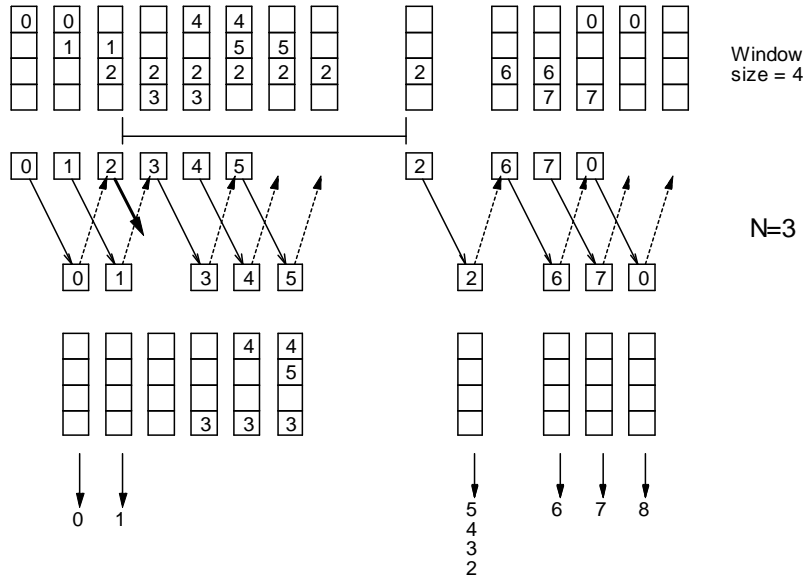
## Selective Repeat

- ❑ Sender maintains a window of size  $2^{n-1}$  to keep outstanding, unacknowledged frames.
- ❑ Sender retransmits a frame that is not acknowledged after time-out.
- ❑ Receiver acknowledges the receipt of a frame with an ACK containing the sequence no. of the frame.
- ❑ Receiver also maintains a window of size  $2^{n-1}$ , used to store frames following a damaged one.
- ❑ Frames delivered to the network layer in order.

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## Selective Repeat in Action



## Why the Restriction of $2^{n-1}$

□ Consider  $n=3$ . Let us allow 5 outstanding frames and see what happens.

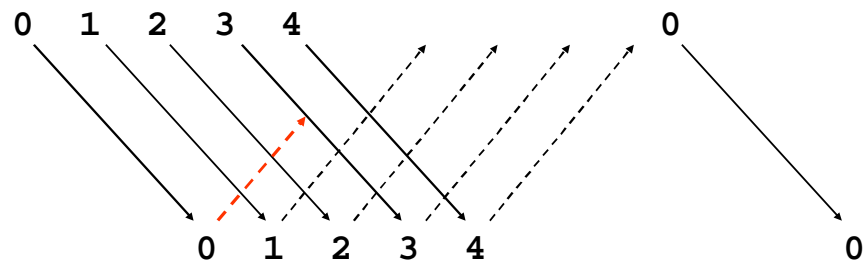
□ The receiver sees the following frames:

**0 1 2 3 4                      0**

□ Again there are two readings for the second frame 0 and the receiver has no way to tell.

## Scenario 1

- ❑ Timeout and retransmit the 1st frame

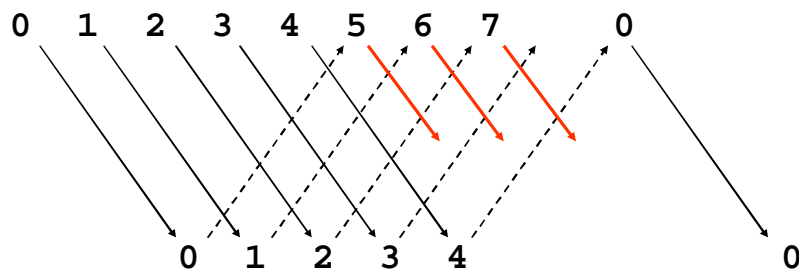


- ❑ The second frame 0 is a duplicate.

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## Scenario 2



- ❑ The second frame 0 is a new frame.
  - It shall be buffered in the receiver window to wait for the arrivals of 5 to 8.

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## Discussion

- ❑ Stop-and-wait, go-back-n, and selective repeat achieve the same functions; differences are in performance.
- ❑ How does a slow receiver curb the sender ?
- ❑ How is reliability enforced ?
- ❑ How is correct ordering enforced ?