Data Link Layer: Sliding Window Protocols

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Experience

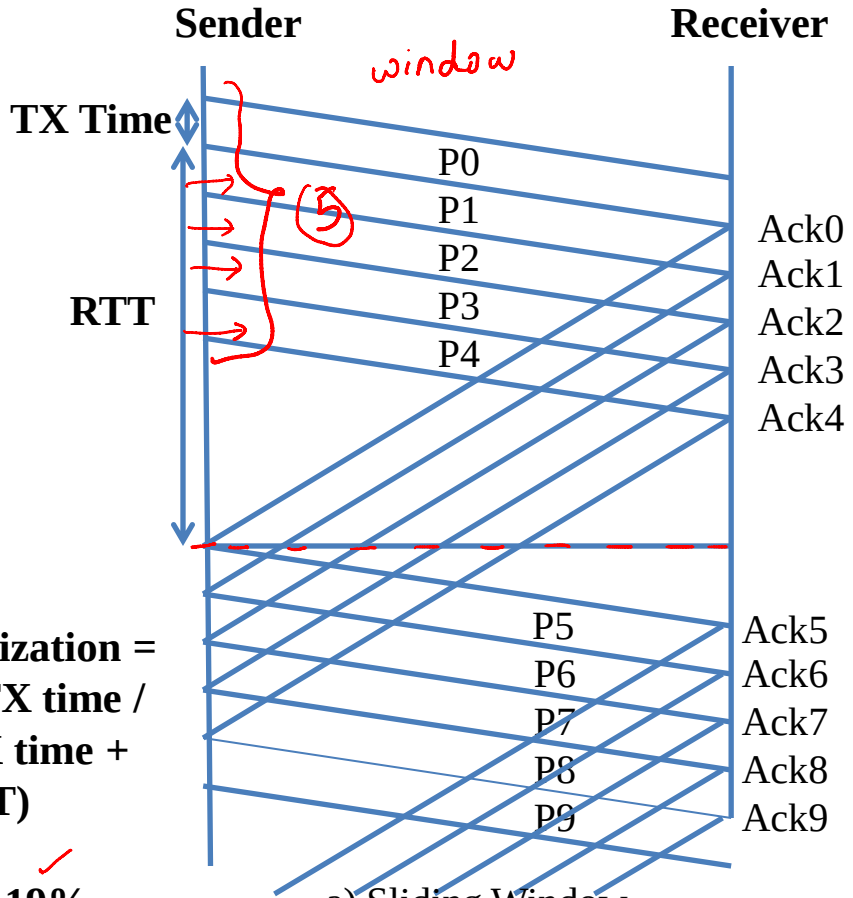
A man who carries a cat by the tail learns something he can learn in no other way.

-- Mark Twain

Recap

- Incrementally built the framework for a Reliable Data Transfer (RDT) protocol
  - Required Functionality
  - Stop and Wait Protocol: Works correctly but performance is poor
- Sliding Window Protocols: Can improve performance considerably

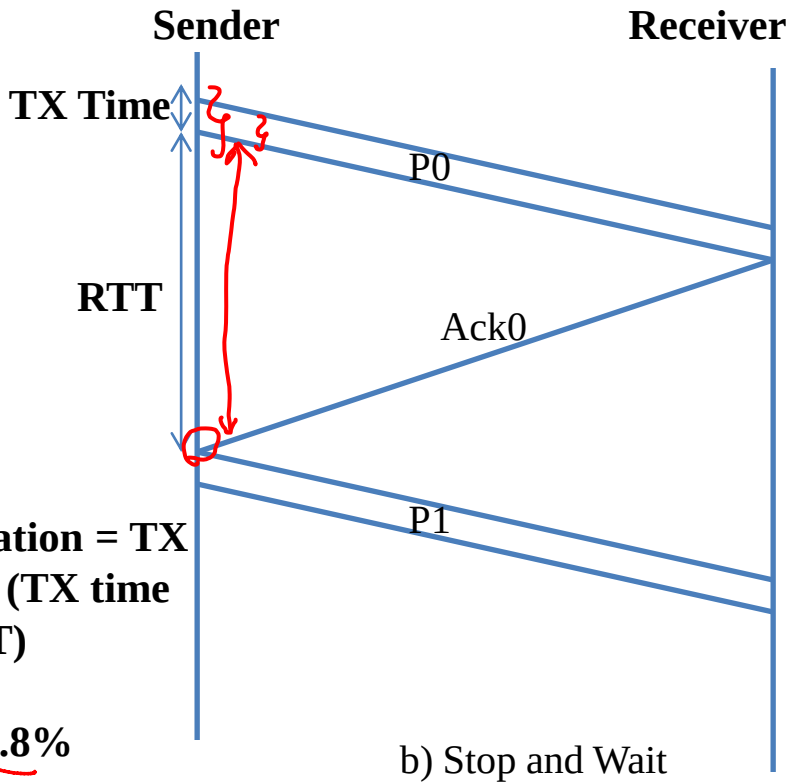
General Idea



Utilization = 5*TX time / (TX time + RTT)

Eg: 19%

a) Sliding Window



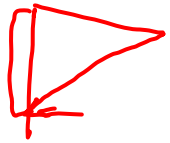
Utilization = TX time / (TX time + RTT)

Eg: 3.8%

b) Stop and Wait

Bandwidth-Delay Product

- Sender can send a maximum of W packets (window size) without waiting for an ACK
- What can the window size be?
  - To keep utilization maximum, sender can send ‘roughly’ upto Data-Rate*RTT before hearing an ack
  - Window size = Bandwidth * RTT bits
    - Divide by packet size to get the number of packets

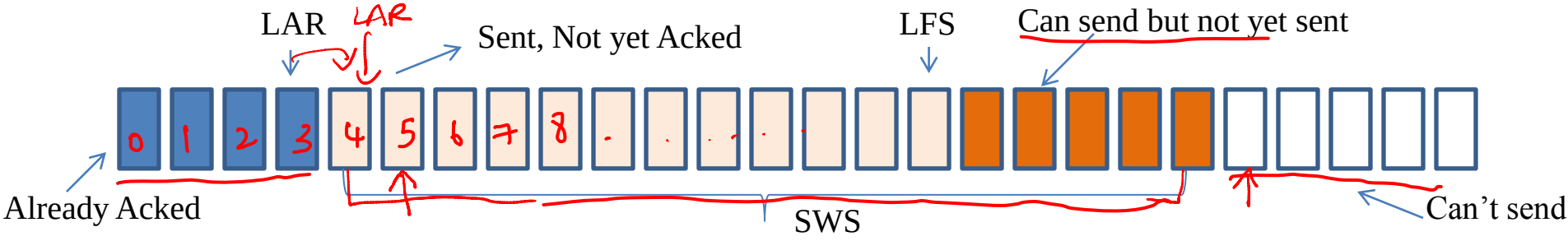


Sliding Window

- At any given time, no more than W packets can be outstanding (their status not known at sender)
- As status of packets gets known at sender, the window of sequence number slides to encompass newer sequence numbers
  - Permits sender to send subsequent packets

Sender Side

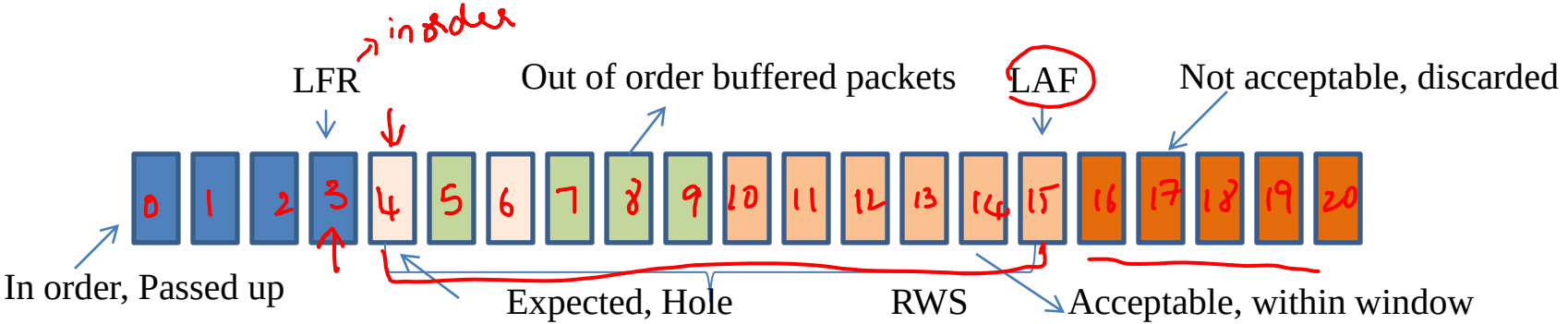
- Assign a sequence number to each frame
- Maintain 3 variables:
  - Send Window Size (SWS): upper bound on number of outstanding frames
  - LAR: Seq. No of Last Acknowledgment Received; Advance LAR when ACK arrives
  - LFS: Sequence number of Last Frame Sent
- Maintain Invariant: LFS-LAR <= SWS



Receiver Side

- Maintains the following three variables
  - Received Window Size (RWS): upper bound on the number of out of order frames
  - LAF denotes sequence number of last acceptable frame
  - LFR denotes sequence number of last frame received
- Set LAF = LFR + RWS

RWS > SWS ?
RWS ≤ SWS
RWS = 1 ?
Receiver accept only in order packets



Consequences

- Need a range of sequence numbers (two won't suffice)
- Sender has to buffer more than one frame (buffer all transmitted but not yet acked)
- Receiver may also have to buffer (out of order frames)
- Range of protocols based on sliding window
  - Go Back N, Selective Repeat, TCP
  - Actions taken on events (like frame/ack rcvd, duplicate ack, timeout etc) differ

Action at the sender

- On receiving a packet from higher layer:
  - Send the packet or buffer it or discard it?
- On receiving ACK:
  - Send packet?
  - If so, which one?
- Timeout: Retransmit packet, update timer

Action at Receiver

- On receiving a packet:
  - Should I accept it or discard?
  - Whether accepted or not, should I generate ACK?
  - If ACK generated, what should I acknowledge in it?

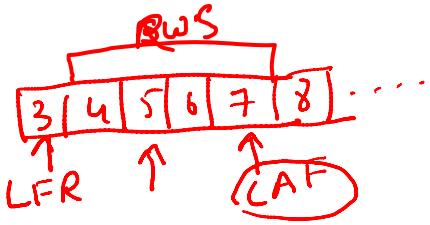
Receiver Side Details

- Frame "SeqNum" arrives
  - If SeqNum <= LFR or SeqNum > LAF, discard frame
  - If LFR< SeqNum <= LAF, accept
- Always good to send an ACK (improves performance by early detection of losses)
  - Exception: depends on protocol (e.g. Go-Back-N doesn't send Ack when frames are discarded)
- Types of ACK: Cumulative Ack; Selective ACK
  - Tradeoff: Simplicity vs Performance

Cumulative ACK

- SeqNumToAck
  - Largest sequence number received such that all frames with sequence number less than SeqNumToAck have also been received
  - LFR is set to this value

Example



- Frames 0,1,2,3,5,7 arrive in that order
- State: Receiver acked frame 3, assume RWS is 4
  - When 5 arrives: Buffer 5, ack 3, LFR=3, LAF=7
  - When 7 arrives, Buffer 7, ack 3, LFR=3, LAF=7
  - When 4 arrives (say due to sender retransmission), it fills the hole,
    - Accept 4 and pass up packets till 5, ack 5, LFR=5, LAF=9
  - When 6 arrives, accept/pass up, ack 7, LFR=7, LAF=11

Selective ACK

- For out of order packets: ACK sequence number of whatever packet accepted
- In previous example: 0, 1, 2, 3, 5, 7
  - When 5 arrives, ack 3, sack 5
  - When 7 arrives, ack 3, sack 7 5
  - When 4 arrives, ack 5, sack 7
  - When 6 arrives, ack 7

Sender Side Details

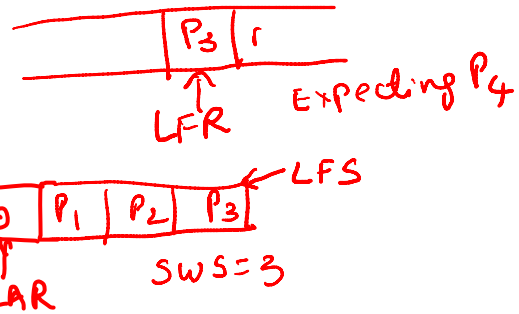
- On receiving packet from higher layers:
  - Determine next sequence number to use (SeqNum)
  - If SeqNum – LAR <= SWS, send the packet, else buffer or inform application

Sender Side Details

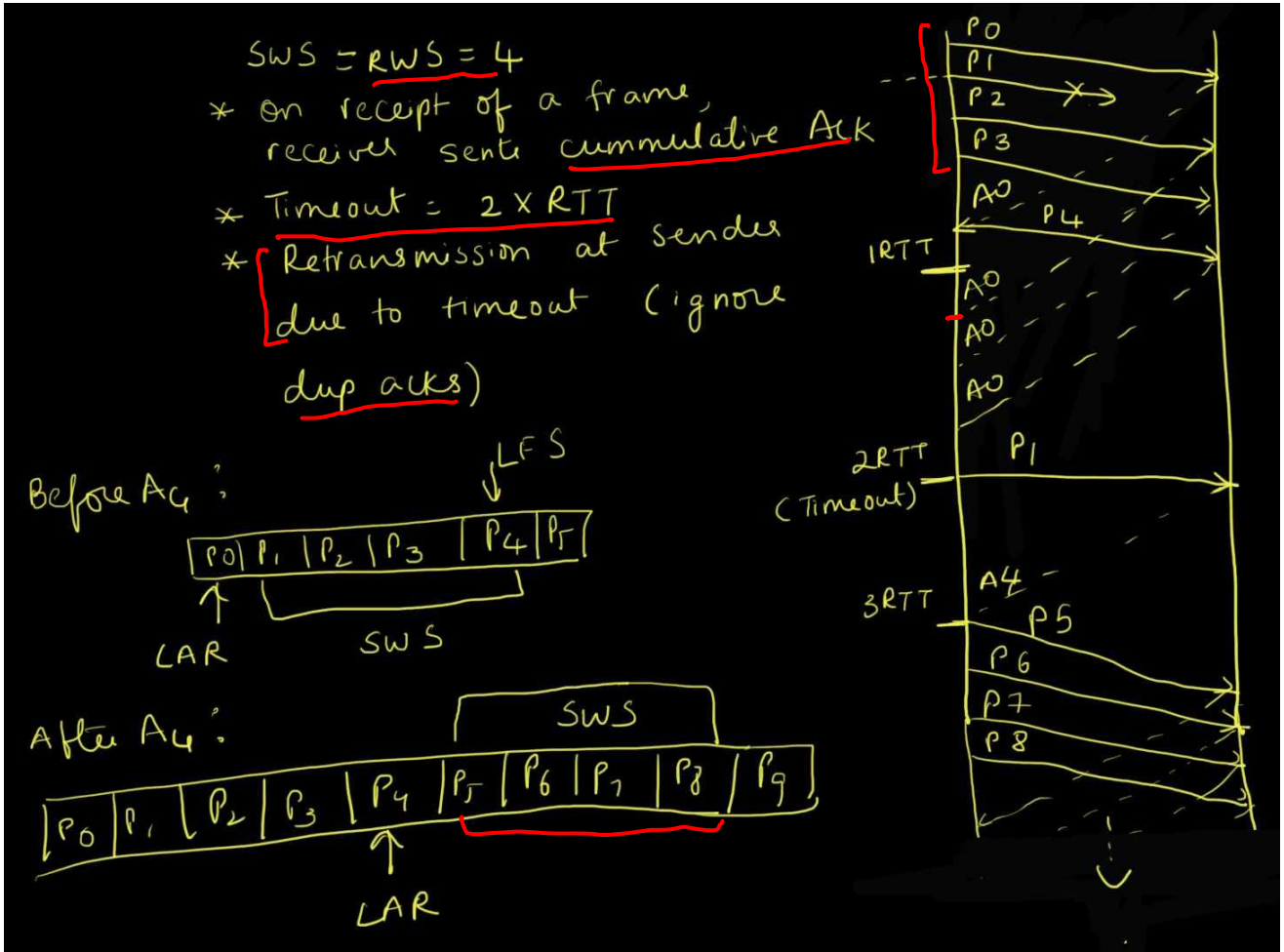
- On receiving ACK: action function of ACK type
  - Can get very complex (e.g. TCP variants)
  - Duplicate Acks and selective acks can be used to determine packet loss, which in turn trigger retransmission
    - Timeout is a backup mechanism → empty the pipe
  - Simple Version: Use cumulative ack to advance window
    - If SeqNum in ACK > LAR, LAR = SeqNum in ACK
    - If SeqNum of Buffered packets <= LAR+SWS, send them

Sequence Number Space

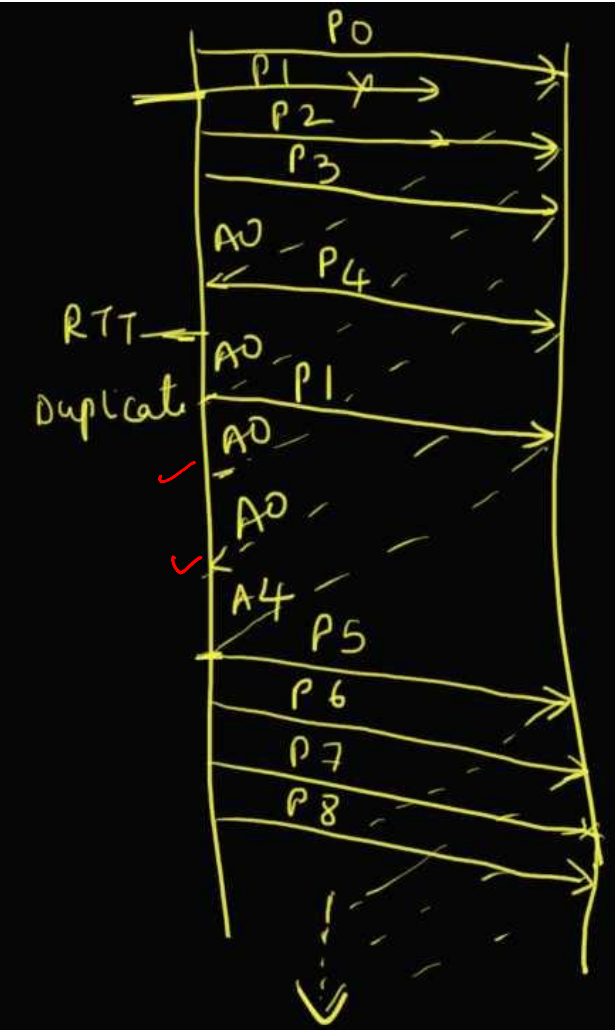
- How many sequence numbers do you need?
- Suppose RWS = 1, SWS = 3
  - Maxseqno = 4 i.e. 0,1,2, 3?
- Suppose RWS=SWS=3
  - Maxseqno=4 sufficient?
- What is the general rule?



Simple Sliding Window Example



* SWS = RWS = 4
* on receipt of a frame, receiver sends Cumm. Ack
* Timeout = 2 RTT
* Retransmission @ sender due to duplicate ACK



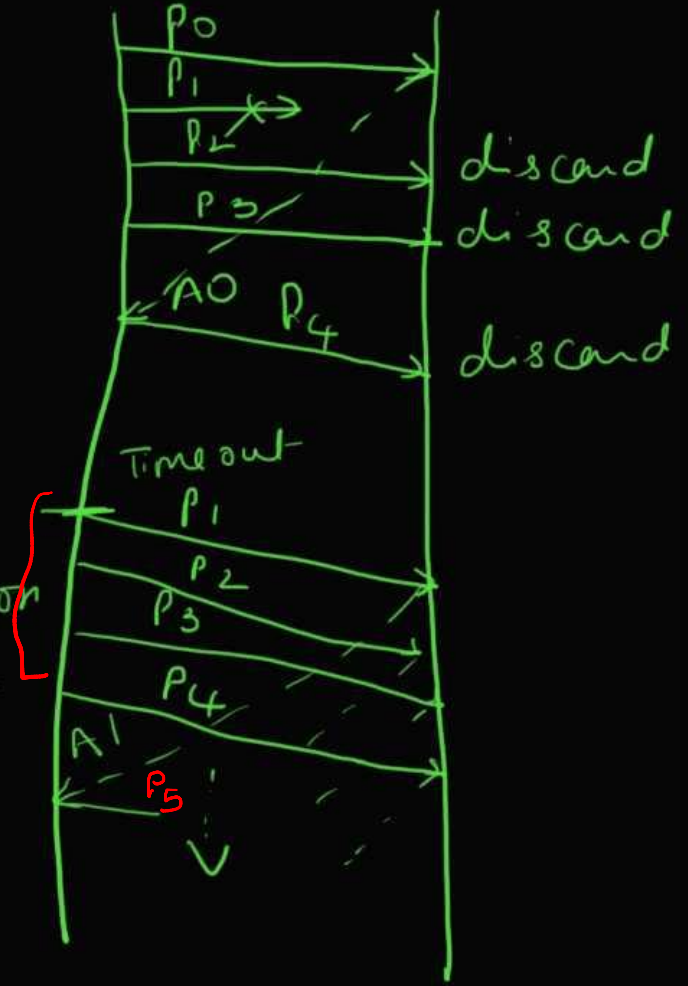
Go Back N

state maintence easy

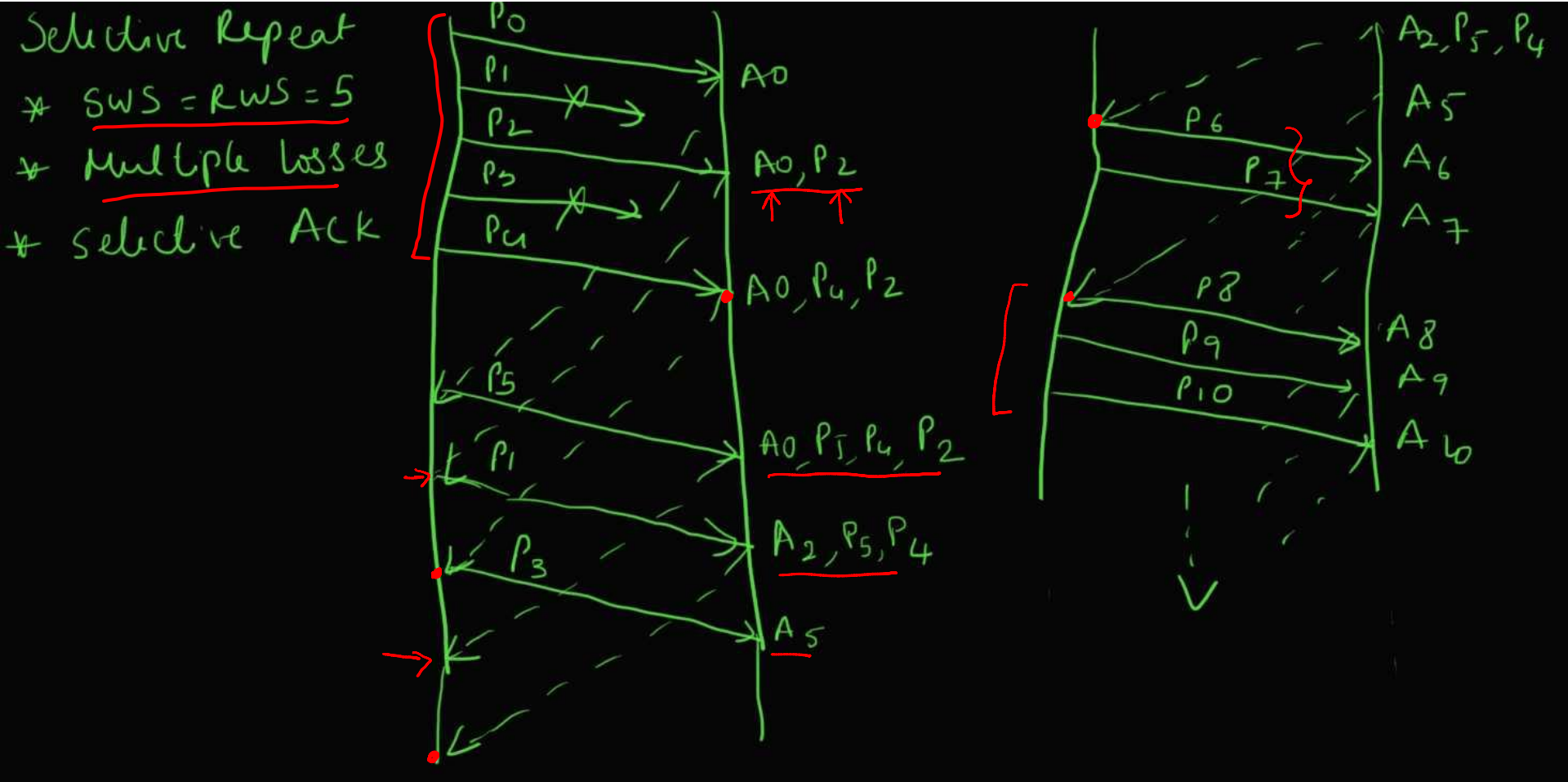
- On TimeOut, sender resends all packets that have been previously sent but unack'ed
- RWS = 1
  - Receiver accepts only in order packet and generates cumulative ack
  - Discards out of order packets, no ack generated
- Inefficient but receiver design is very simple

Go Back N

* Receiver discards out of order Packets; NO ACK generated
* Generates cumm. ACK for in order Packets
* Sender relies on Timeout for Retransmission
* On timeout, all sent but unacked packets are sent



Selective Repeat



TCP

Flow Control

- Prevents the sender from overflowing the receiver buffer

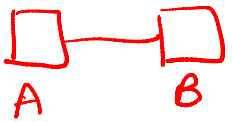
small

- Receiver informs sender how many frames it has room to receive.
  - Sender will always respect this when sending frames

SWS

Summary

- Sliding Window protocols rely on 'window of packets' to improve performance
  - More complex (range of sequence numbers, types of acks, action at sender/receiver)
- In addition to reliability, they provide
  - In-order delivery ✓
  - Flow control ✓



- Milestone: Achieved point-to-point reliable and efficient data transfer (Building block)