Introduction to Computer Networks

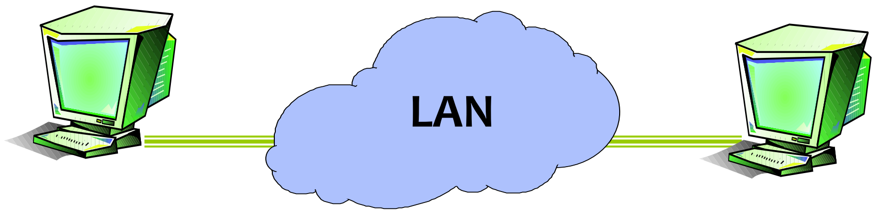
Reliable Transmission

Outline

- Introduction
- Stop-and-Wait protocol
- Sliding Window Protocol
- Issues with Sliding Window Protocol

Reliable Transmission

- Data transmissions over a communication link may have errors caused by signal interference.
- Usually, CRC is used to detect errors.
- Some error codes are strong enough to correct errors but the overhead is typically too high.
- Corrupt frames must be discarded.
- For reliable transmission, we must recover from these discarded frames.



Reliable Transmission

- We can do this by using a combination of two fundamental mechanisms
  - Acknowledgements
  - Timeouts
- An *acknowledgement* (ACK for short) is a small control frame that a protocol sends back to its peer saying that it has received the earlier frame.
  - A control frame is a frame with header only (no data).
- The receipt of an *acknowledgement* indicates to the sender that its frame was successfully delivered.

Reliable Transmission

- If the sender does not receive an *acknowledgment* after a reasonable amount of time, then it retransmits the original frame.
- The action of waiting a reasonable amount of time is called a *timeout*.
- The general strategy of using *acknowledgements* and *timeouts* to implement reliable delivery is sometimes called Automatic Repeat reQuest (ARQ).

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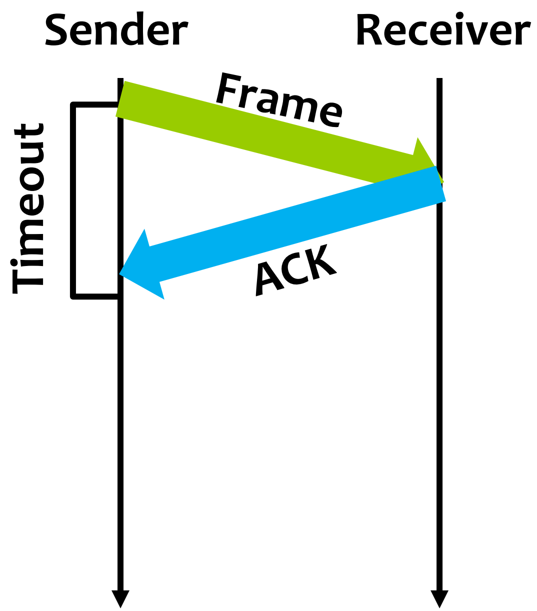
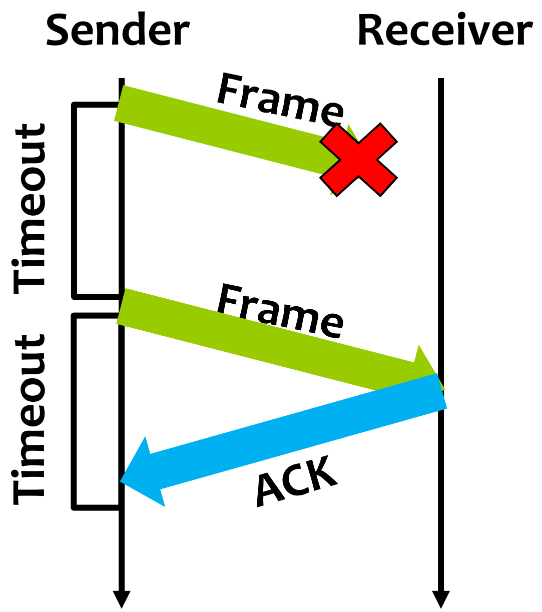
Stop and Wait Protocol

- Idea of stop-and-wait protocol is straightforward
  - After transmitting one frame, the sender waits for an acknowledgement before transmitting the next frame.
  - If the acknowledgement does not arrive after a certain period of time, the sender times out and retransmits the original frame

Stop and Wait Protocol



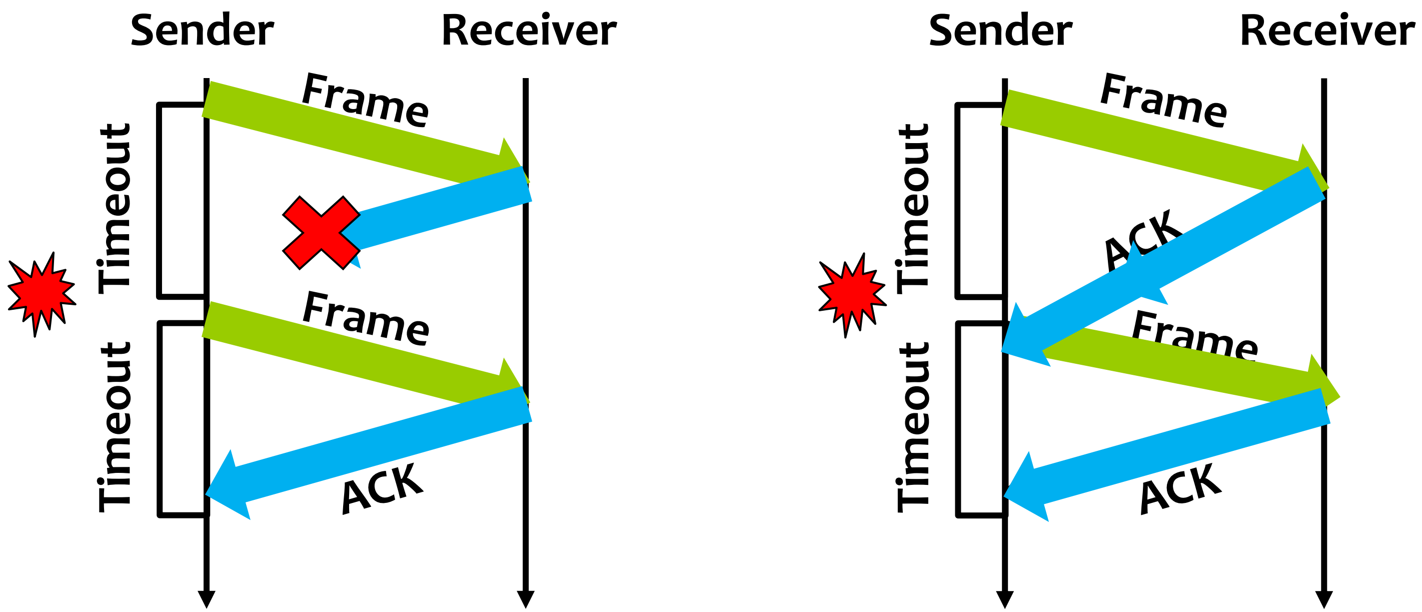


Four different scenarios for the stop-and-wait algorithm.

(a) The ACK is received before the timer expires;

(b) The original frame is lost;

Stop and Wait Protocol

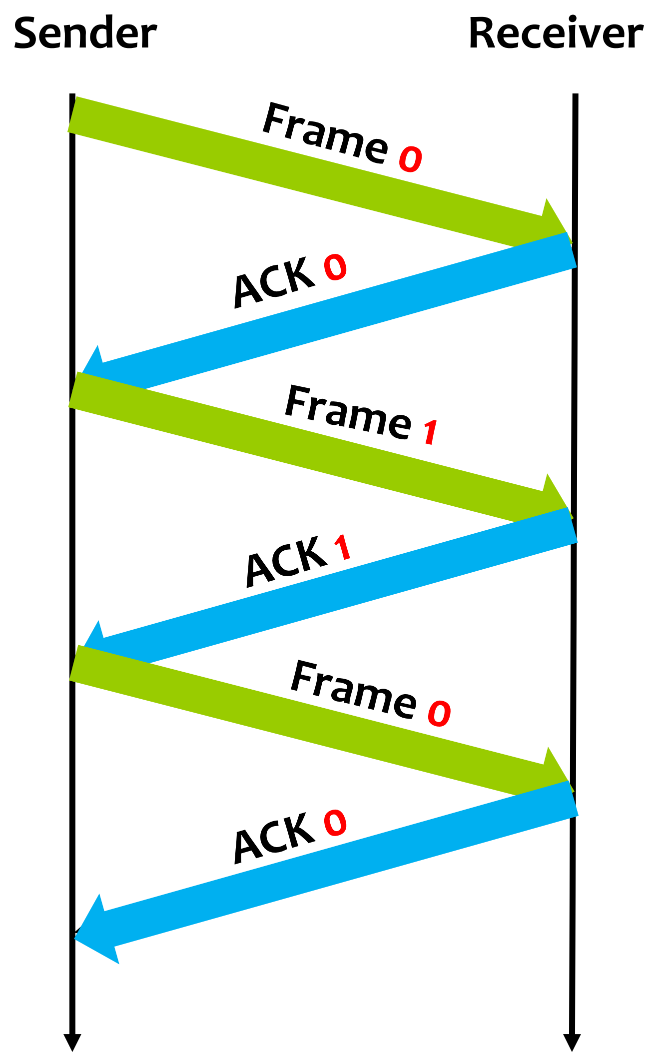


Four different scenarios for the stop-and-wait algorithm.
(c) The ACK is lost;
(d) The timeout fires too soon (or the ACK is delayed)

Stop and Wait Protocol

- If the acknowledgment is lost or delayed in arriving
  - The sender times out and retransmits the original frame.
  - As a result, duplicate copies of frames will be delivered
- How to solve this ?
  - Use 1 bit sequence number (0 or 1)
  - When the sender retransmits frame 0, the receiver can determine that this is a second copy of frame 0 rather than the first copy of frame 1 and therefore can ignore it (the receiver still acknowledges it, in case the first acknowledgement was lost)

Stop and Wait Protocol



Timeline for stop-and-wait with 1-bit sequence number

Stop and Wait Protocol

- The sender has only one outstanding frame on the link at a time -- Far below the link's capacity
- For example, consider a 2 Mbps link with a 40 ms RTT
  - The link has a delay × bandwidth product of 80 Kb or 8 KB
  - Since the sender can send only one frame per RTT and assuming a frame size of 1 KB
  - Maximum Sending rate
    - Bits per frame/Time per frame = 8kb ÷ 40ms = 200 Kbps

      Or about 1/10 of the link's capacity (2Mbps)
  - To fully use the link, the sender should transmit up to ten frames before having to wait for an ACK.

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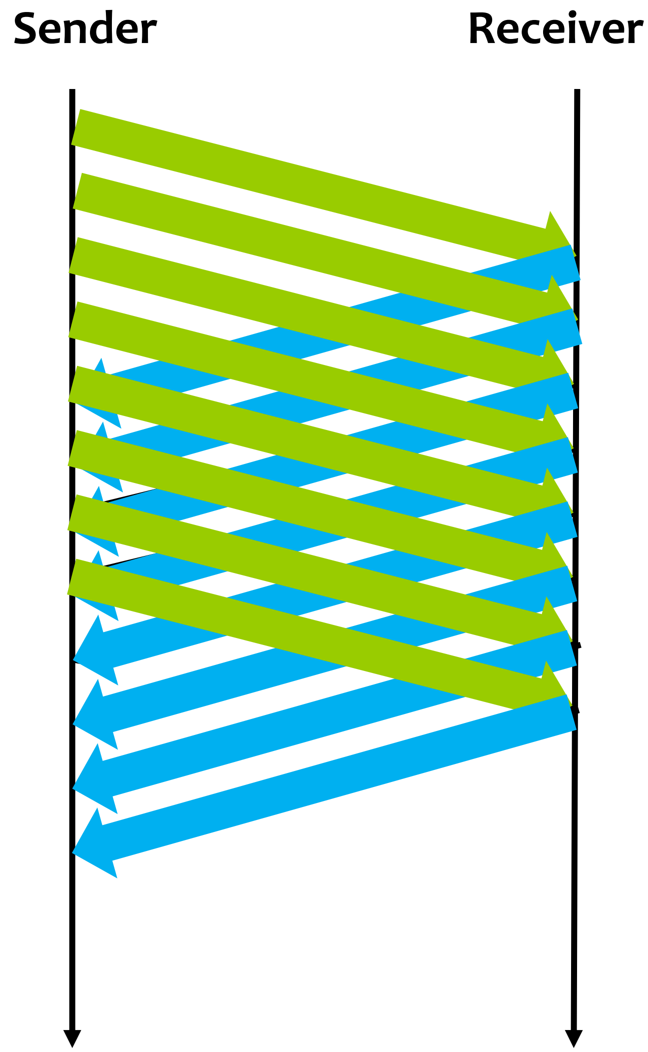
Sliding Window Protocol



Timeline for Sliding Window Protocol

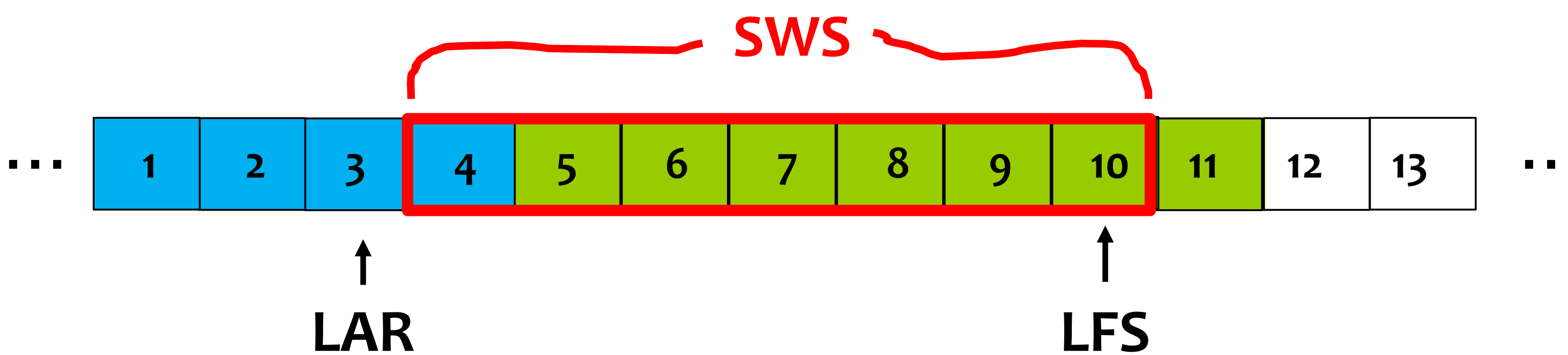
Sliding Window Protocol

- Sender assigns a sequence number denoted as SeqNum to each frame.
  - Assume it can grow infinitely large
- Sender maintains three variables
  - Sending Window Size (SWS)
    - Upper bound on the number of outstanding (unacknowledged) frames that the sender can transmit
  - Last Acknowledgement Received (LAR)
    - Sequence number of the last acknowledgement received
  - Last Frame Sent (LFS)
    - Sequence number of the last frame sent

Sliding Window Protocol

- Sender also maintains the following invariant

LFS – LAR ≤ SWS



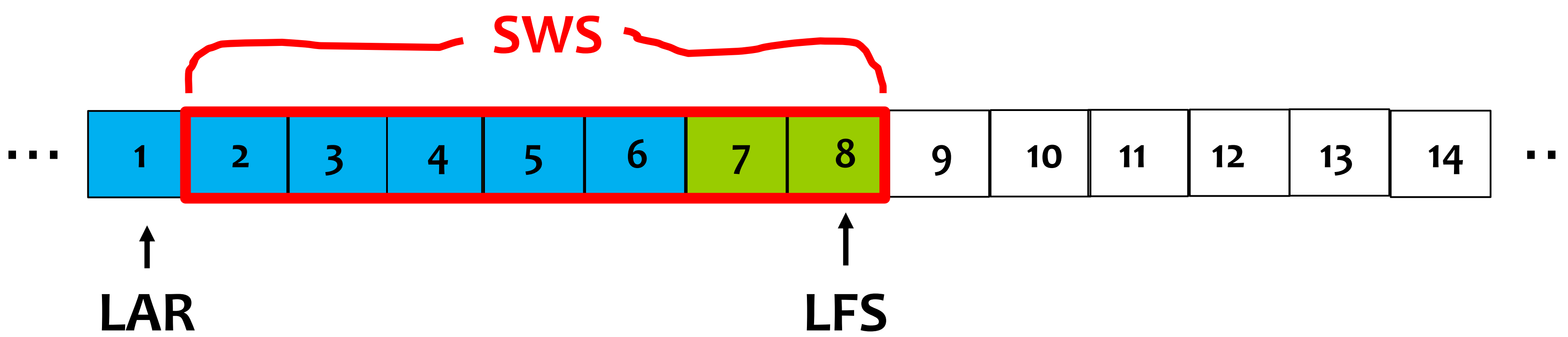
Sliding Window on Sender

Sliding Window Protocol

- When an acknowledgement arrives
  - the sender moves LAR to right, thereby allowing the sender to transmit another frame
- Also the sender associates a timer with each frame it transmits
  - It retransmits the frame if the timer expires before the ACK is received
- Note that the sender needs to buffer up to SWS frames for retransmissions, if necessary

Sliding Window Protocol

- When the sender is allowed to slide its Window ?
  - When the acknowledgement of LAR+1 is received



Sliding Window on Sender

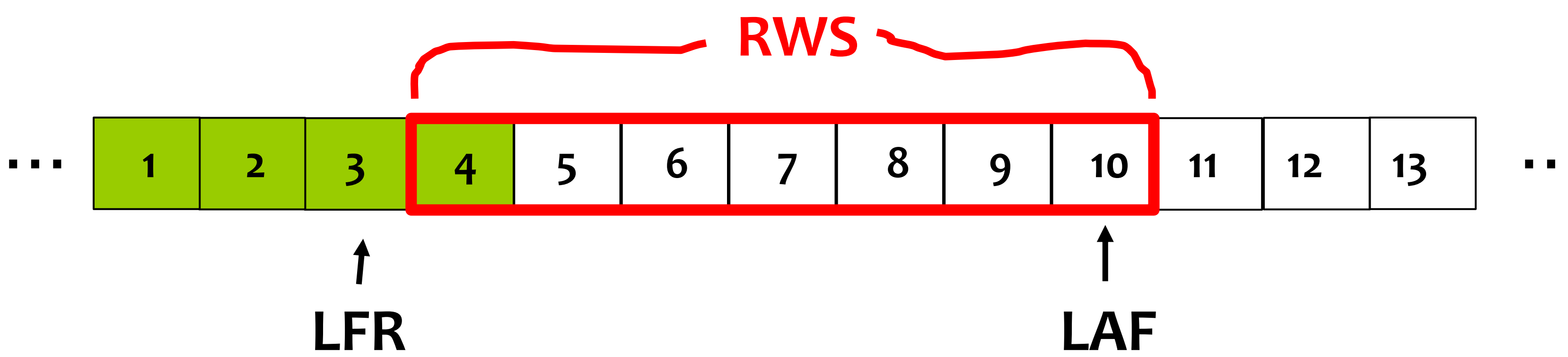
Sliding Window Protocol

- Receiver maintains three variables
  - Receiving Window Size (RWS)
    - Upper bound on the number of out-of-order frames that the receiver is willing to accept
  - Largest Acceptable Frame (LAF)
    - Sequence number of the largest acceptable frame
  - Last Frame Received (LFR)
    - Sequence number of the last frame received

Sliding Window Protocol

- Receiver also maintains the following invariant

LAF – LFR ≤ RWS



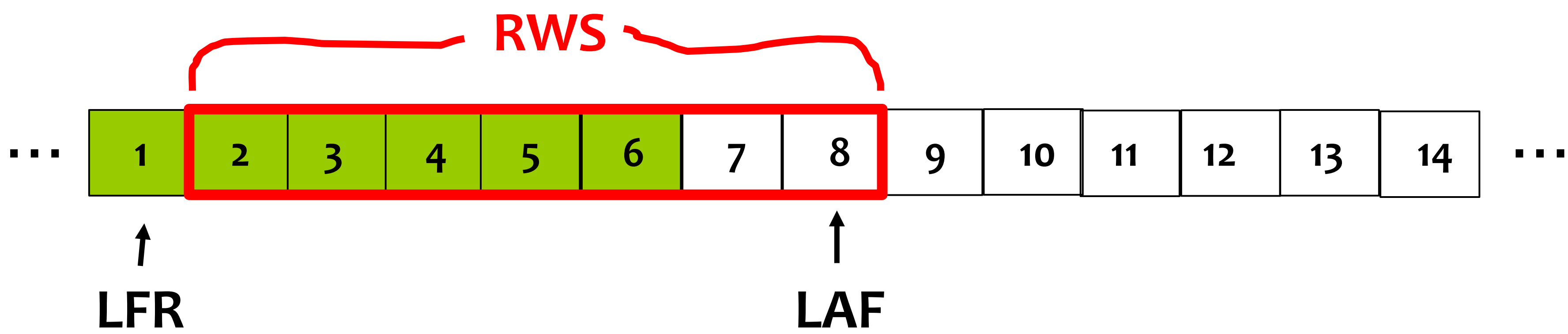
Sliding Window on Receiver

Sliding Window Protocol

- When a frame with sequence number SeqNum arrives, what does the receiver do?
  - If SeqNum ≤ LFR or SeqNum > LAF
    - Discard it (the frame is outside the receiver window)
  - If LFR < SeqNum ≤ LAF
    - Accept it

Sliding Window Protocol

- When the receiver is allowed to slide its Window ?
  - When the frame of LFR+1 is received



Sliding Window on Receiver

Sliding Window Protocol

- For example, suppose LFR = 1 and RWS = 7

  → LAF = 8

- If frames 4,6,3 and 5 arrive sequentially, they are out of order, but will still be buffered because they are within the receiver window
- But no ACK will be sent since frame 2 is yet to arrive
- Finally, frame 2 arrives (retransmitted or delayed)
- Now Receiver Acknowledges Frame 6

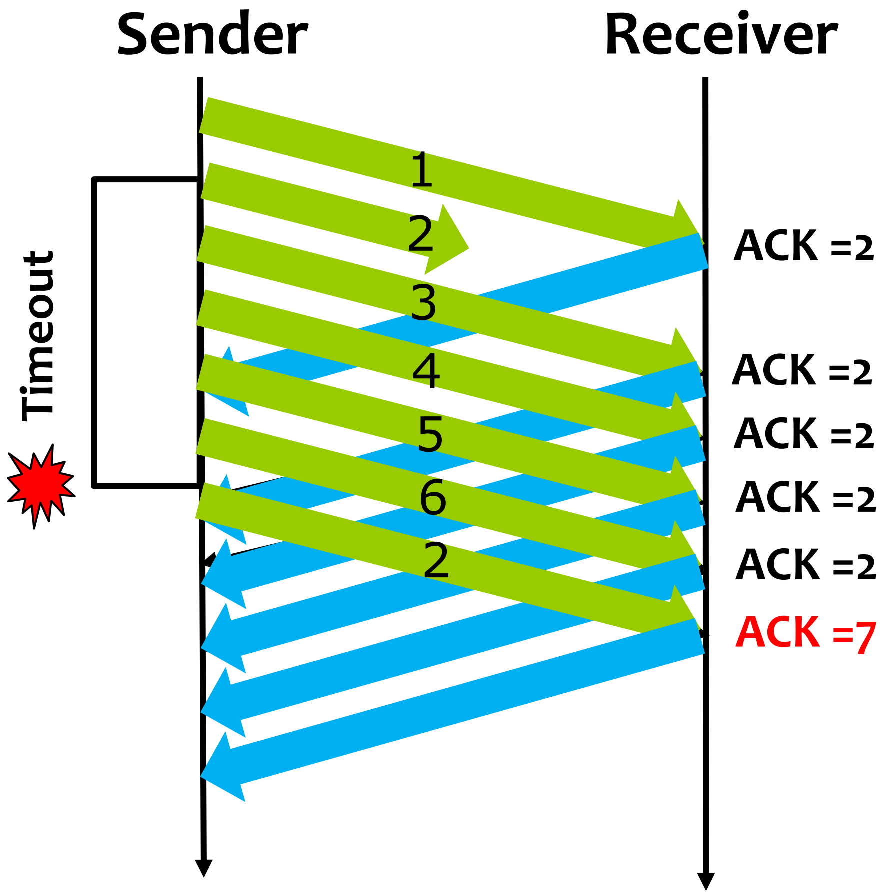
  and bumps LFR to 6

  and LAF to 13 (Window sliding)

Sliding Window Protocol

- **Cumulative Acknowledgement**
  - Let **SeqNumToAck** denote the largest sequence number not yet acknowledged, such that all frames with sequence number **less than SeqNumToAck have been received**
  - The receiver acknowledges the receipt of **SeqNumToAck** even if high-numbered packets have been received
    - This acknowledgement is said to be **cumulative.**
  - The receiver then sets
    - LFR = SeqNumToAck -1 and
    - LAF = LFR + RWS (Window sliding)

Sliding Window Protocol



Cumulative Acknowledgement example (SeqNumToAck = 2)

Outline

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Issues with Sliding Window Protocol

- When timeout occurs, the amount of data in transit decreases
  - Since the sender is unable to advance its window
- When the packet loss occurs, this scheme is no longer keeping the pipe full
  - The longer it takes to notice that a packet loss has occurred, the more severe the problem becomes
- How to improve this
  - Negative Acknowledgement (NAK)
  - Additional Acknowledgement
  - Selective Acknowledgement

Issues with Sliding Window Protocol

- **Negative Acknowledgement (NAK)**
  - Receiver sends NAK for frame 2 when frame 3 arrive (in the cumulative acknowledgement example)
    - However this is unnecessary since sender's timeout mechanism will be sufficient to catch the situation
- **Additional Acknowledgement**
  - Receiver sends additional ACK for frame 2 when frame 3 arrives
    - Sender uses duplicate ACK as a clue for frame loss
- **Selective Acknowledgement**
  - Receiver will acknowledge exactly those frames it has received, rather than the highest number frames
    - Receiver will acknowledge frames 3,4,5, and 6
    - Sender knows frame 2 is lost
    - Sender can keep the pipe full (additional complexity)

Issues with Sliding Window Protocol

How to select the window size ?

- SWS is easy to calculate
  - Delay × Bandwidth
- RWS is more flexible
  - Two common settings
    - RWS = 1

      No buffer at the receiver for frames that arrive out of order
    - RWS = SWS

      The receiver can buffer frames that the sender transmits
- Does it make any sense to keep RWS > SWS ?

Issues with Sliding Window Protocol

- Finite Sequence Number
  - Frame sequence number is specified in the header field
    - Finite size
      - 3 bits: eight possible sequence number: 0, 1, 2, 3, 4, 5, 6, 7
    - It is necessary to wrap around

Issues with Sliding Window Protocol

- **How to distinguish between different frames of the same sequence number?**
  - **Number of possible sequence number must be larger than the number of outstanding frames allowed**
    - **Stop and Wait: One outstanding frame**
      - **2 distinct sequence number (0 and 1)**
    - **Let MaxSeqNum be the number of available sequence numbers**
    - **SWS + 1 ≤ MaxSeqNum**
      - **Is this sufficient?**
      - **Depends on RWS**
      - **If RWS = 1, then sufficient**
      - **If RWS = SWS, then not good enough**

Issues with Sliding Window Protocol

For example, we have eight sequence numbers

0, 1, 2, 3, 4, 5, 6, 7

RWS = SWS = 7 = 8-1

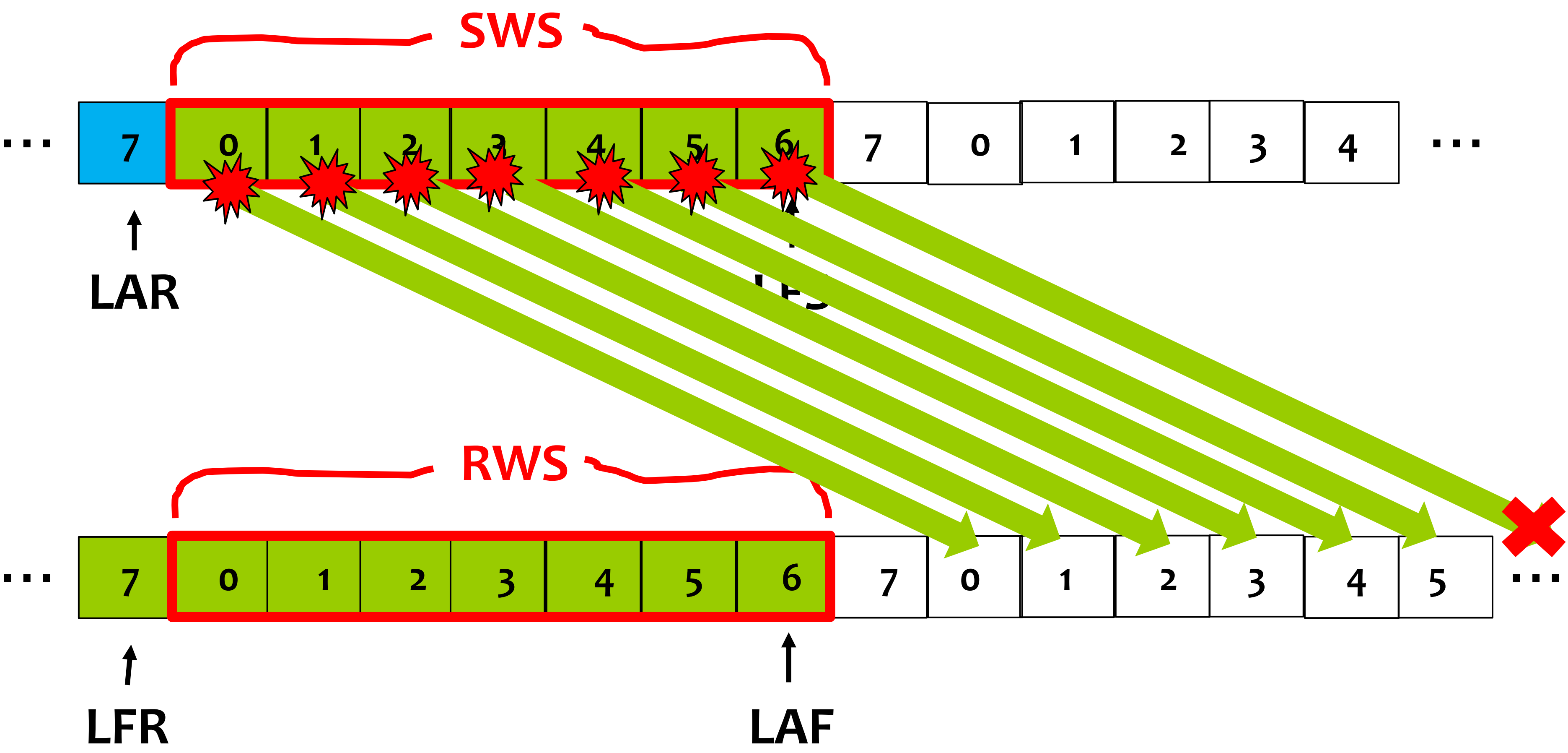
1. Sender sends 0, 1, …, 6
2. Receiver receives 0, 1, … ,6
3. Receiver acknowledges 0, 1, …, 6

   but ACK (0, 1, …, 6) are lost
4. Sender timeouts and retransmits 0, 1, …,5, 6
5. Receiver is expecting 7, 0, …., 5

➔ frames 0-5 will be accepted (duplicated !!)

frame 6 will be discarded (correct)

Issues with Sliding Window Protocol



Problem when SWS + 1 ≤ MaxSeqNum and SWS = RWS

MaxSeqNum = 8, SWS = RWS = 7

Issues with Sliding Window Protocol

To avoid this,

If RWS = SWS

SWS < (MaxSeqNum + 1)/2

Issues with Sliding Window Protocol

For example, we have eight sequence numbers

0, 1, 2, 3, 4, 5, 6, 7

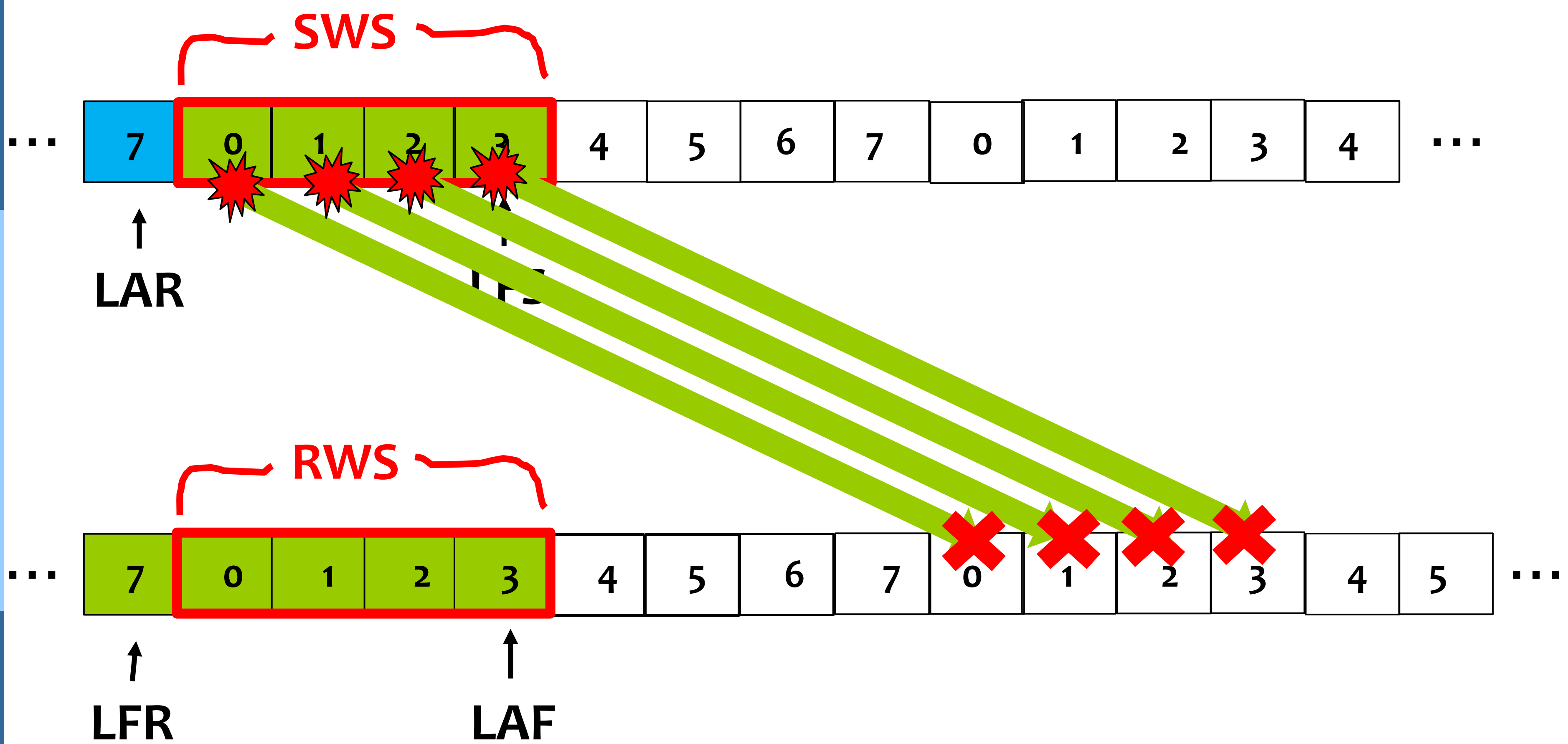
RWS = SWS = 4 < (8+1)/2 = 4.5

1. Sender sends 0, 1, 2, 3
2. Receiver receives 0, 1, 2, 3
3. Receiver acknowledges 0, 1, 2, 3

   but ACK (0, 1, 2, 3) are lost
4. Sender timeouts and retransmits 0, 1, 2, 3
5. Receiver is expecting 4,5,6,7

➔ all frames 0-3 will be discarded (correct now !!)

Issues with Sliding Window Protocol



Example when SWS < (MaxSeqNum+1)/2

MaxSeqNum = 8, SWS = RWS = 4 < (8+1)/2

Issues with Sliding Window Protocol

- Sliding Window Protocol provides three features
  - Reliable Transmission
  - Preserve the order
    - Each frame has a sequence number
    - Out of order frames will be buffered
  - Flow control
    - Receiver is able to throttle the sender by setting the value of RWS
    - Keeps the sender from overrunning the receiver

Summary

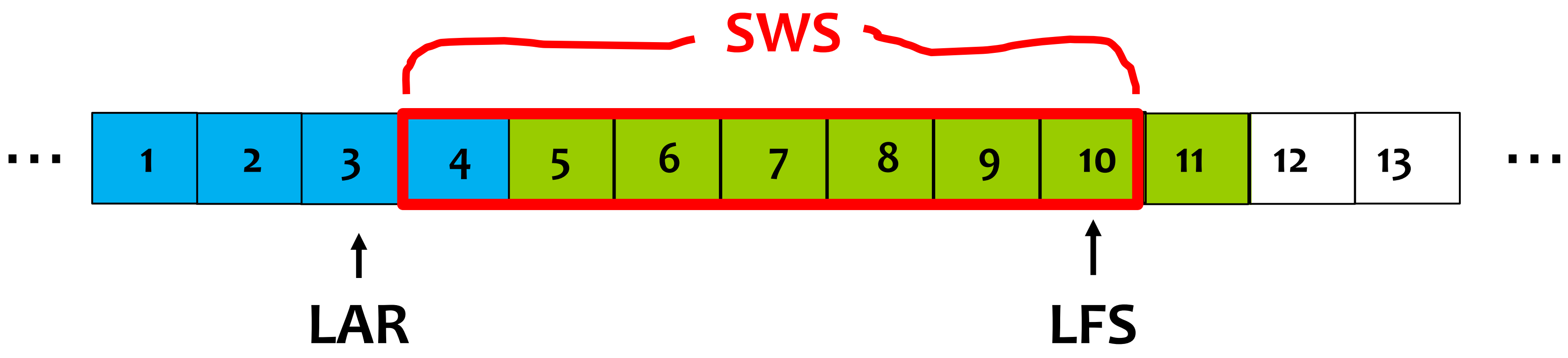
- Two fundamental mechanisms are used to provide reliable transmission over a communication link
  - Acknowledgements
  - Timeouts
- Stop-and-Wait Protocol is a reliable protocol, but the performance is not good enough
  - Only one outstanding frame
  - Receiver may receive duplicated frames

Summary

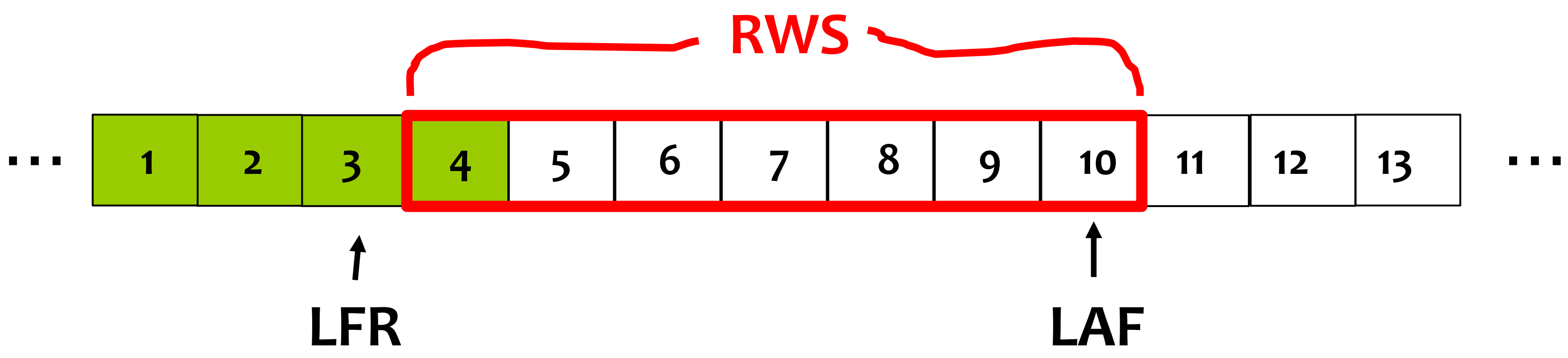
- Sliding Window Protocol is a reliable and good performance protocol
  - Sequence number is added for each frame
  - Multiple outstanding frames (keeping pipe full)
  - Sender
    - Sending Window Size (SWS) = delay x bandwidth
    - Last Acknowledgement Received (LAR)
    - Last Frame Sent (LFS)
  - Receiver
    - Receiving Window Size (RWS) = 1 or SWS
    - Largest Acceptable Frame (LAF)
    - Last Frame Received (LFR)

Summary

- Sender maintains the invariant: **LFS – LAR ≤ SWS**



- Receiver maintains the invariant: **LAF – LFR ≤ RWS**



Summary

- The values of SWS and RWS may be different.
- If RWS = SWS, it is better **SWS < (MaxSeqNum + 1)/2** otherwise, the receiver may still receive duplicated frames.
- The Acknowledgement mechanism is an option
  - **NAK**
  - **Cumulative acknowledgement**
- Sliding Window Protocol provides three features
  - **Reliable Transmission**
  - **Preserve the order**
  - **Flow control (receiver determines the RWS)**