EE 122: Error detection and reliable transmission

Ion Stoica

September 16, 2002

High Level View

- Goal: transmit correct information
- Problem: bits can get corrupted
  - Electrical interference, thermal noise
- Solution
  - Detect errors
  - Recover from errors
    - Correct errors
    - Retransmission

Overview

- Error detection
- Reliable transmission

Error Detection

- Problem: detect bit errors in packets (frames)
- Solution: add redundancy bits to each packet
- Goals:
  - Reduce overhead, i.e., reduce the number of redundancy bits
  - Increase the number and the type of bit error patterns that can be detected
- Examples:
  - Two-dimensional parity
  - Checksum
  - Cyclic Redundancy Check (CRC)

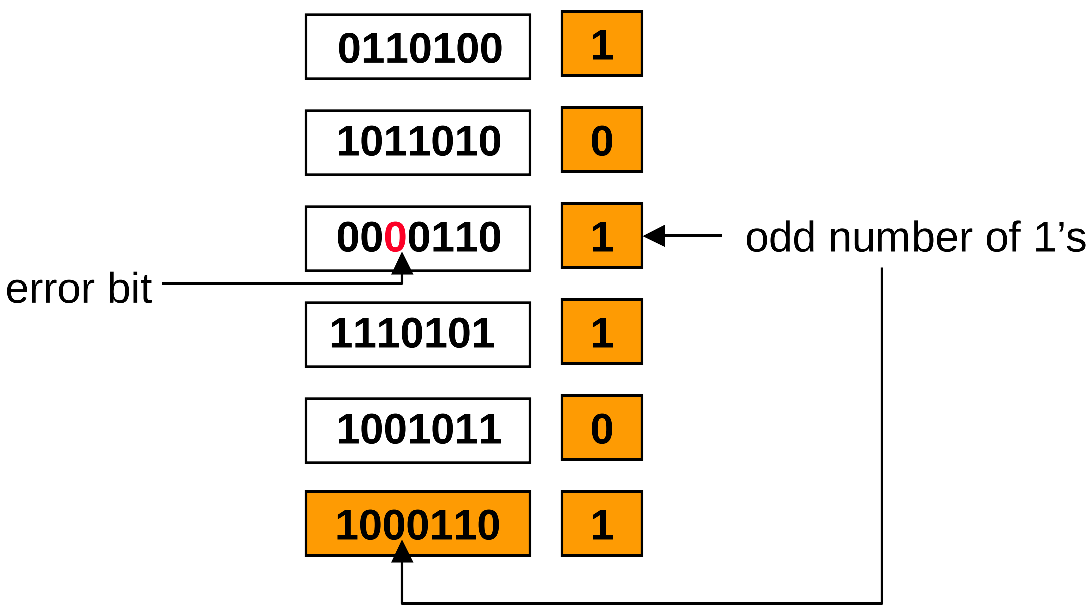
Two-dimensional Parity

- Add one extra bit to a 7-bit code such that the number of 1's in the resulting 8 bits is even (for even parity, and odd for odd parity)
- Add a parity byte for the packet
- Example: five 7-bit character packet, even parity

0110100	1
1011010	0
0010110	1
1110101	1
1001011	0
1000110	1

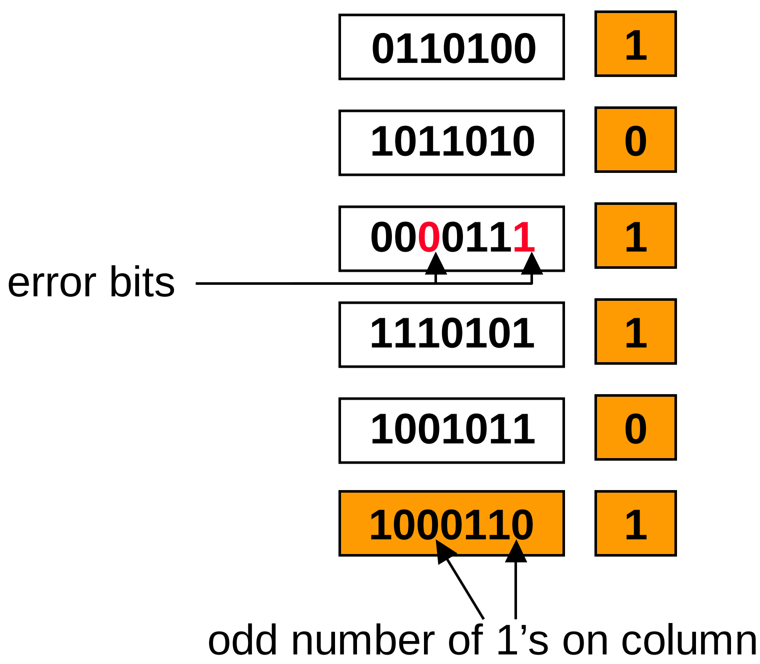
How Many Errors Can you Detect?

- All 1-bit errors
- Example:



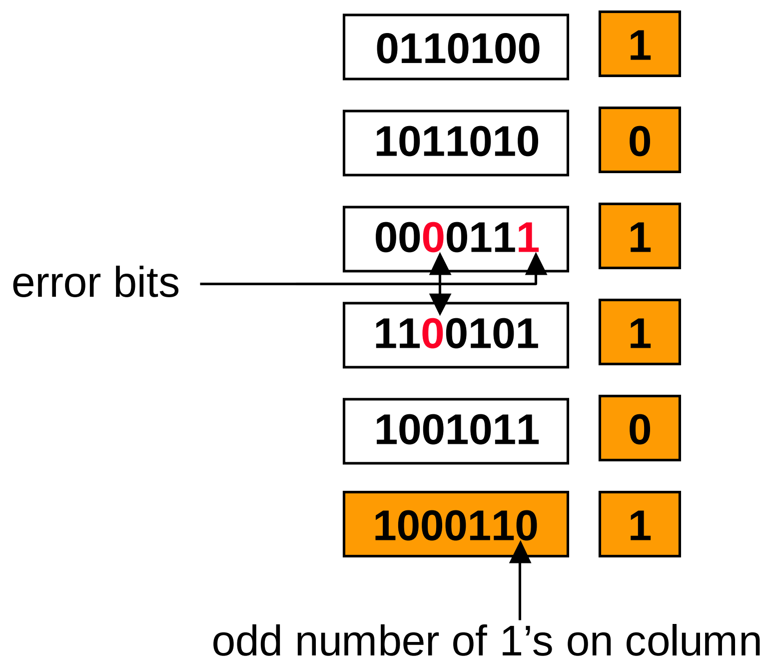
How Many Errors Can you Detect?

- All 2-bit errors
- Example:



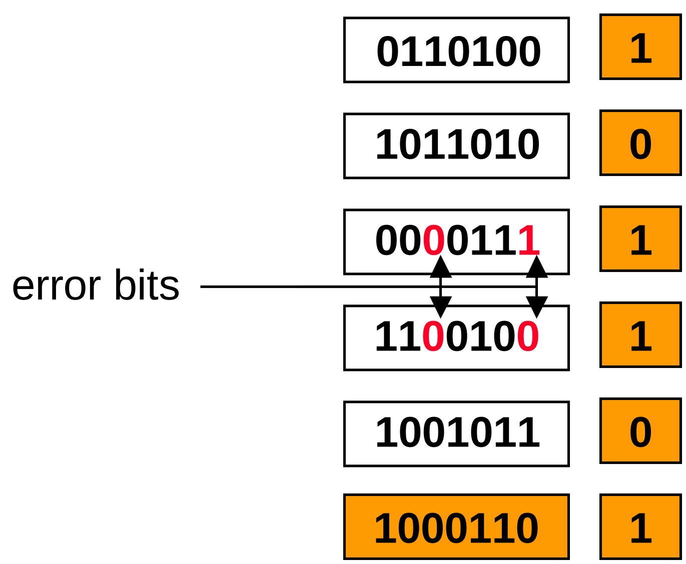
How Many Errors Can you Detect?

- All 3-bit errors
- Example:



How Many Errors Can you Detect?

- Most 4-bit errors
- Example of 4-bit error that is not detected:



How many errors can you correct?

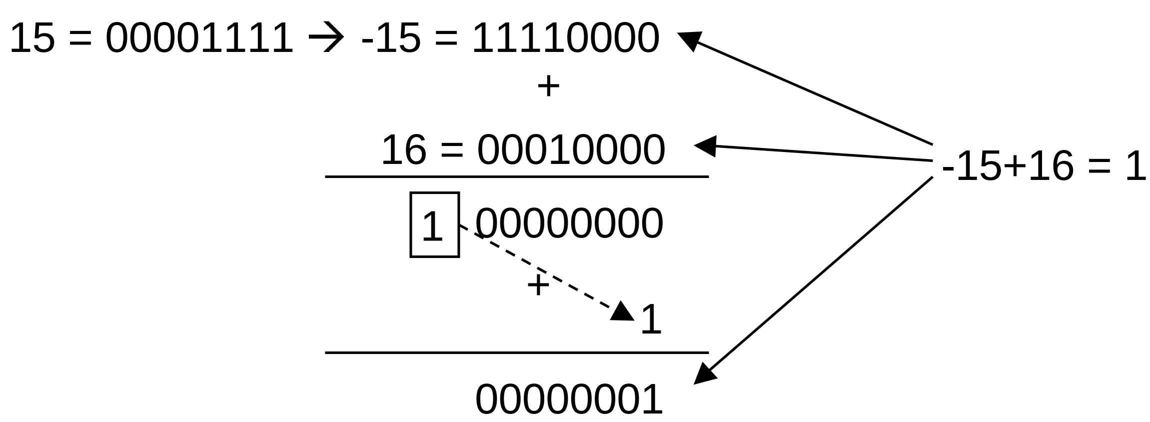
istoica@cs.berkeley.edu

Checksum

- Sender: add all words of a packet and append the result (checksum) to the packet
- Receiver: add all words of a packet and compare the result with the checksum
- Can detect all 1-bit errors
- Example: Internet checksum
  - Use 1's complement addition

1’s Complement Revisited

- Negative number –x is x with all bits inverted
- When two numbers are added, the carry-on is added to the result
- Example: -15 + 16; assume 8-bit representation



Cyclic Redundancy Check (CRC)

Represent a (n+1)-bit message by an n-degree polynomial M(x)

- E.g., 10101101 → $M(x) = x^7 + x^5 + x^3 + x^2 + x^0$

Choose a divisor k-degree polynomial C(x)

Compute reminder R(x) of $M(x)*x^k$ / C(x), and then compute T(x) = $M(x)*x^k$ - R(x)

- T(x) is divisible by C(x)
- First n coefficients of T(x) represent M(x)

Sender:

- Compute and send T(x), i.e., the coefficients of T(x)

Receiver:

- Let T'(x) be the (n+k)-degree polynomial generated from the received message
- If C(x) divides T'(x) → no errors; otherwise errors

Some Polynomial Arithmetic Modulo 2 Properties

- If C(x) divides B(x), then degree(B(x)) >= degree(C(x))
- Subtracting C(x) from B(x) reduces to perform an XOR on each pair of matching coefficients of C(x) and B(x)
  - E.g.:

$$B(x) = x^7 + x^5 + x^3 + x^2 + x^0 \rightarrow 10101101$$

$$C(x) = x^3 + x^1 + x^0 \rightarrow 00001011$$

$$B(x) - C(x) = x^7 + x^5 + x^2 + x^1 \rightarrow 10100110$$

Computing T(x)

- Compute the reminder R(x) of M(x)*x^k / C(x)
- T(x) = M(x)*x^k - R(x)
- Example: send packet 110111, assume C(x) = 101
  - k = 2, M(x)*x^K → 11011100
  - Compute R(x)

```
101) 11011100
     101
      111
      101
       101
       101
          100
          101
            1  <-- R(x)
```

  - T(x) = M(x)*x^k - R(x) → 11011100 xor 1 = 11011101

CRC Properties

- Detect all single-bit errors if coefficients of x^k and x^0 of C(x) are one
- Detect all double-bit errors, if C(x) has a factor with at least three terms
- Detect all number of odd errors, if C(x) contains factor (x+1)
- Detect all burst of errors smaller than k bits

Overview

- Error detection
- Reliable transmission

Reliable Transmission

- Problem: obtain correct information once errors are detected
- Solutions:
  - Use error correction codes (can you give an example of error detection code that can also correct errors?)
  - Use retransmission (we'll do this in details)
- Algorithmic challenges:
  - Achieve high link utilization, and low overhead

Latency, Bandwidth, Round-Trip Time

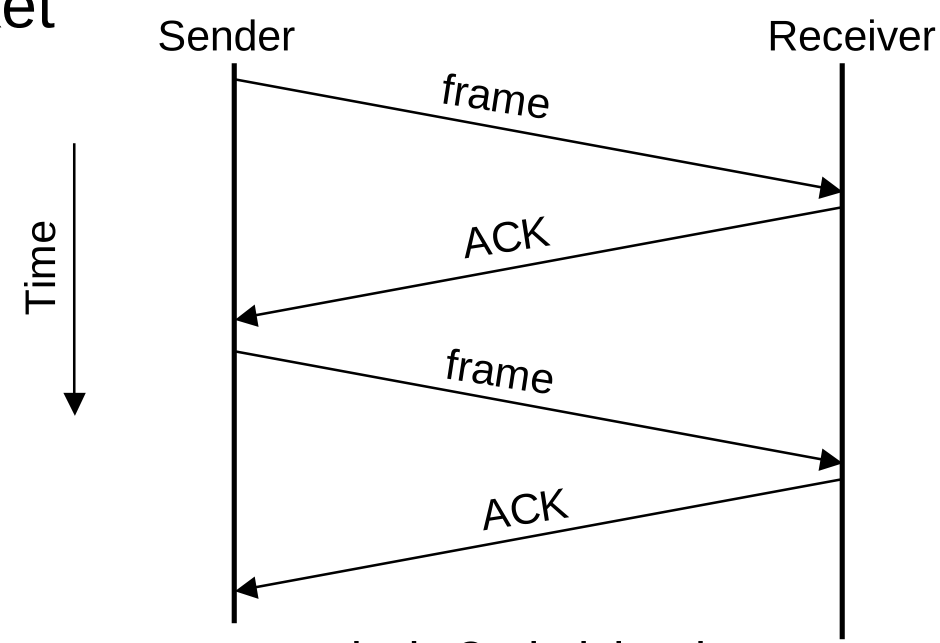
- Latency = propagation + transmit + queue
  - Propagation: time it takes the signal to propagate along the link
  - Transmit: time it takes to transmit the packet = (packet_size)/(link_bandwidth)
  - Queue: time for which the packet waits into the adapter at the sender before being transmitted
- Note: next we'll assume short packets, i.e, transmit term can be neglected !
- Round-Trip Time (RTT) = time it takes to a packet to travel from sender to destination and back
  - RTT = one-way latency from sender to receiver + one-way latency from receiver to sender

Automatic Repeat Request (ARQ) Algorithms

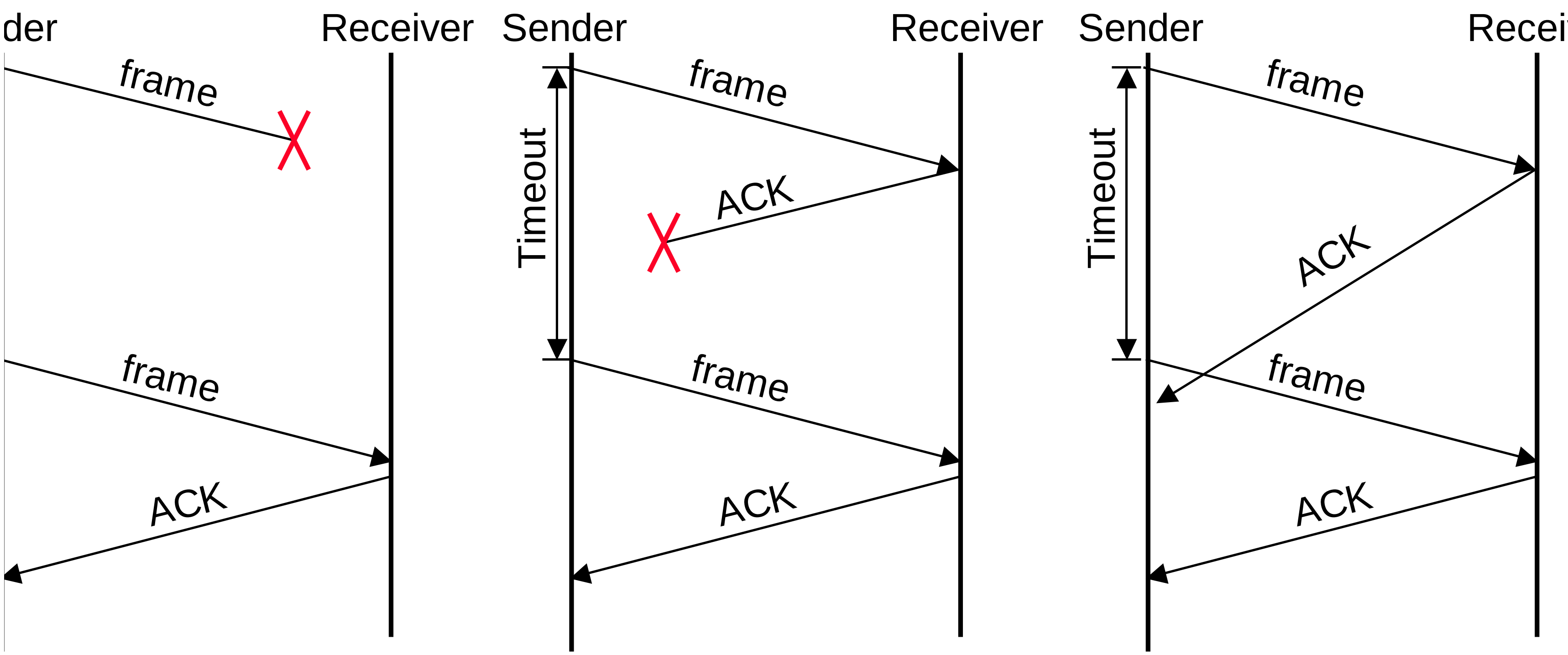
- Use two basic techniques:
  - Acknowledgements (ACKs)
  - Timeouts
- Two examples:
  - Stop-and-go
  - Sliding window

Stop-and-Go

- Receiver: send an acknowledge (ACK) back to the sender upon receiving a packet (frame)
- Sender: excepting first packet, send a packet only upon receiving the ACK for the previous packet



What Can Go Wrong?



Frame lost → resent it on Timeout

ACK lost → resent packet

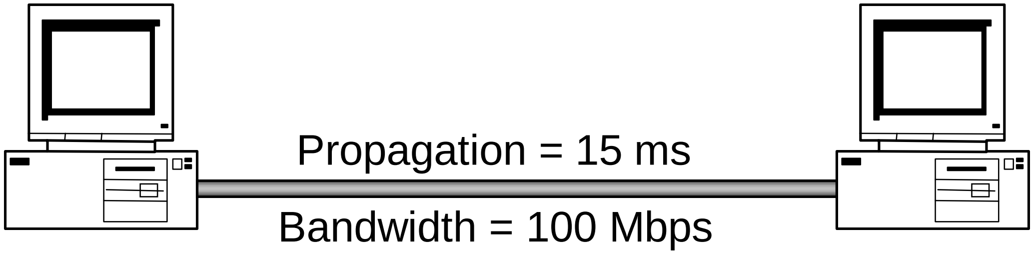
Need a mechanisms to detect duplicate packet

ACK delayed → resent pack

Need a bit to differentiate between ACK for current and previous packet

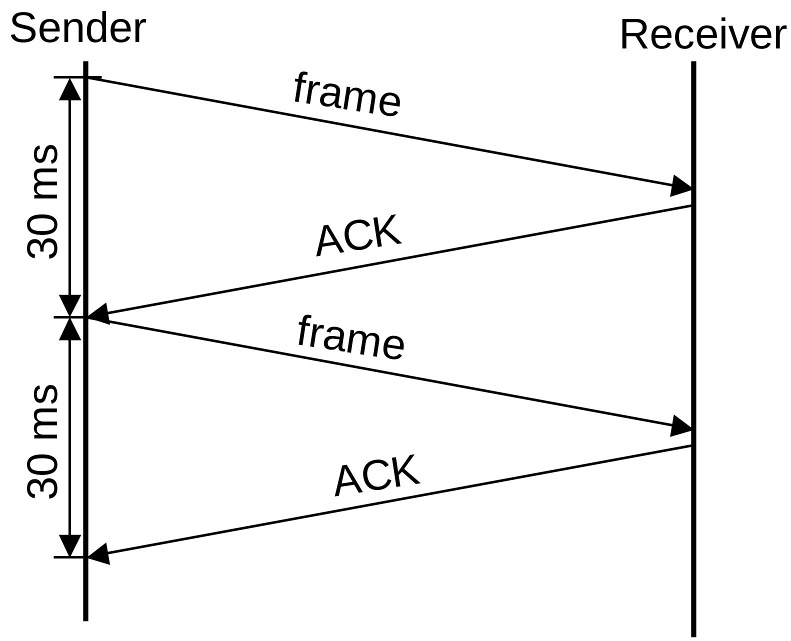
Stop-and-Go Disadvantage

- May lead to inefficient link utilization
- Example: assume
  - One-way propagation = 15 ms
  - Bandwidth = 100 Mbps
  - Packet size = 1000 bytes → transmit = $(8*1000)/10^8$ = 0.08ms
  - Neglect queue delay → Latency = approx. 15 ms; RTT = 30 ms



Stop-and-Go Disadvantage (cont'd)

- Send a message every 30 ms → Throughput = (8*1000)/0.03 = 0.2666 Mbps
- Thus, the protocol uses less than 0.3% of the link capacity!

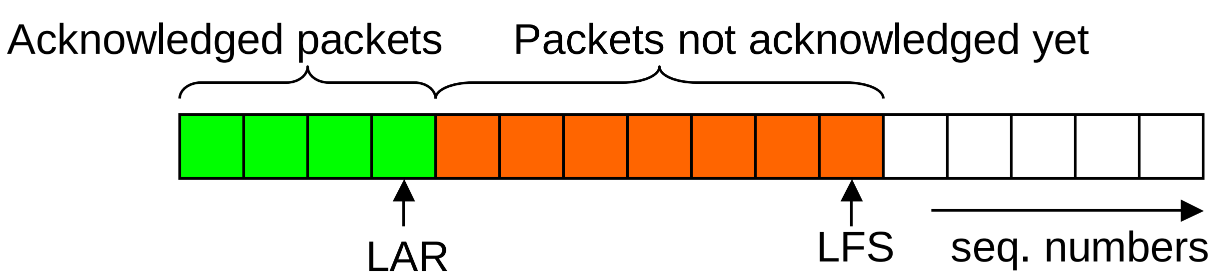


Solution

- Don't wait for the ACK of the previous packet before sending the next one!

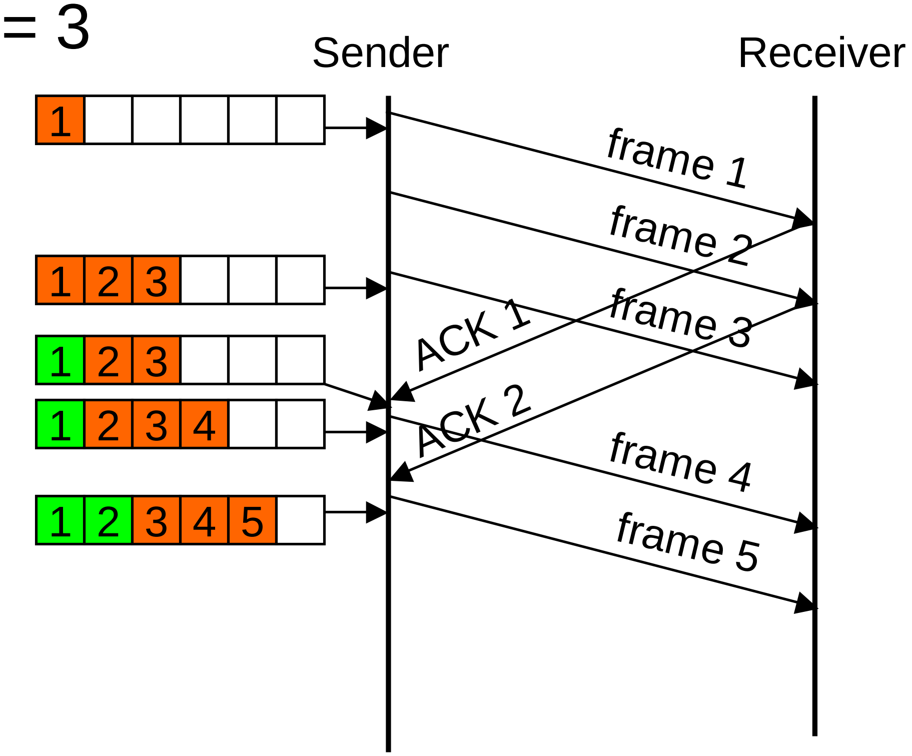
Sliding Window Protocol: Sender

- Each packet has a sequence number
  - Assume infinite sequence numbers for simplicity
- Sender maintains a window of sequence numbers
  - SWS (sender window size) – maximum number of packets that can be sent without receiving an ACK
  - LAR (last ACK received)
  - LFS (last frame sent)



Example

- Assume SWS = 3



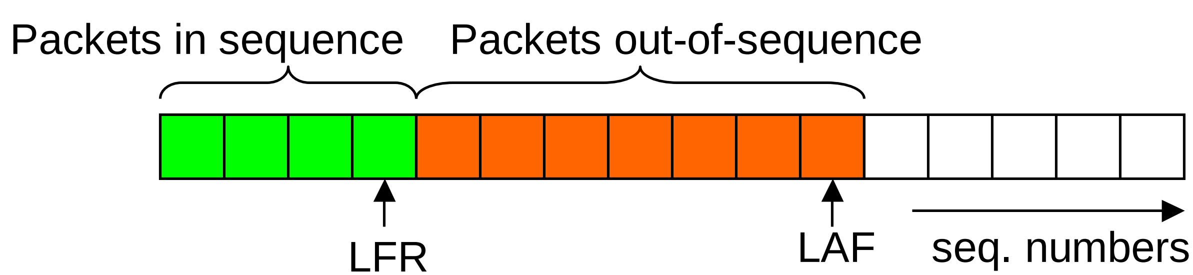
Note: usually ACK contains the sequence number of the first packet in sequence expected by receiver

Sliding Window Protocol: Receiver

- Receiver maintains a window of sequence numbers
  - RWS (receiver window size) – maximum number of out-of-sequence packets that can received
  - LFR (last frame received) – last frame received in sequence
  - LAF (last acceptable frame)
  - LAF – LFR <= RWS

Sliding Window Protocol: Receiver

- Let seqNum be the sequence number of arriving packet
- If (seqNum <= LFR) or (seqNum >= LAF)
  - Discard packet
- Else
  - Accept packet
  - ACK largest sequence number seqNumToAck, such that all packets with sequence numbers <= seqNumToAck were received



Properties of ARQ Protocols

- Reliability
- Increase link utilization (only for sliding window protocols)
- Flow control: a sender cannot send at a rate greater than the rate at which the receiver can consume the packets
- Packet order
  - In the case the Sliding Window Protocol the size of receiver window (RWS) → specifies how many out-of-order packets can be stored at the receiver

Summary

- There are two steps required to transmit frames (packets) reliable
  - Detect when packets experience errors or are lost (we'll talk more about packet loss in the context of TCP)
    - Two-dimensional parity
    - Checksum
    - Cyclic Redundancy Check (CRC)
  - Use packet retransmission to recover from errors
    - Stop-and-go
    - Sliding window protocol