CS4700/CS5700 Fundamentals of Computer Networks

Lecture 13: Reliability

Slides used with permissions from Edward W. Knightly, T. S. Eugene Ng, Ion Stoica, Hui Zhang

Overview

- Goal: transmit correct information
- Problem: bits can get corrupted
  - Electrical interference, thermal noise
- Problem: packets can be lost

- Solution
  - Detect errors
  - Recover from errors
    - Correct errors
    - Retransmission

Outline

- Revisit error detection
- Reliable Transmission

Naïve approach

- Send a message twice
- Compare two copies at the receiver
  - If different, some errors exist

- How many bits of error can you detect?

- What is the overhead?

Error Detection

- Problem: detect bit errors in packets (frames)
- Solution: add extra 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)
  - Hamming Codes

Parity

- Even parity
  - Add a parity bit to 7 bits of data to make an even number of 1's

0110100
1011010

- How many bits of error can be detected by a parity bit?
- What's the overhead?

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Data	Parity bit
0110100	**1**
1011010	**0**

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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

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0010110

1110101

1001011

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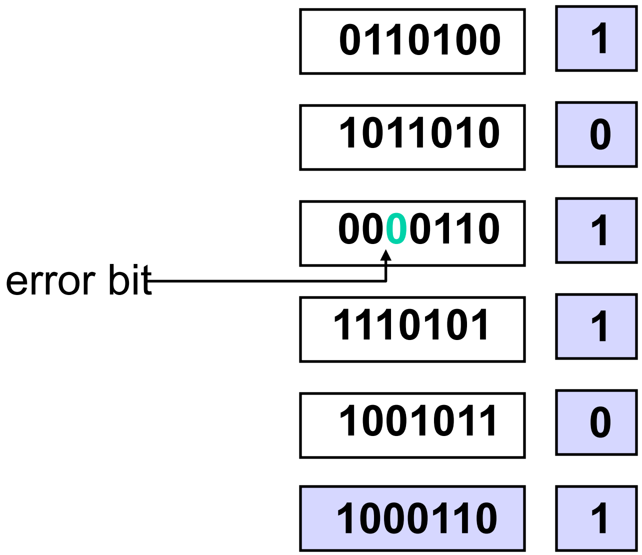
How Many Errors Can you Detect?

- All 1-bit errors
- Example:



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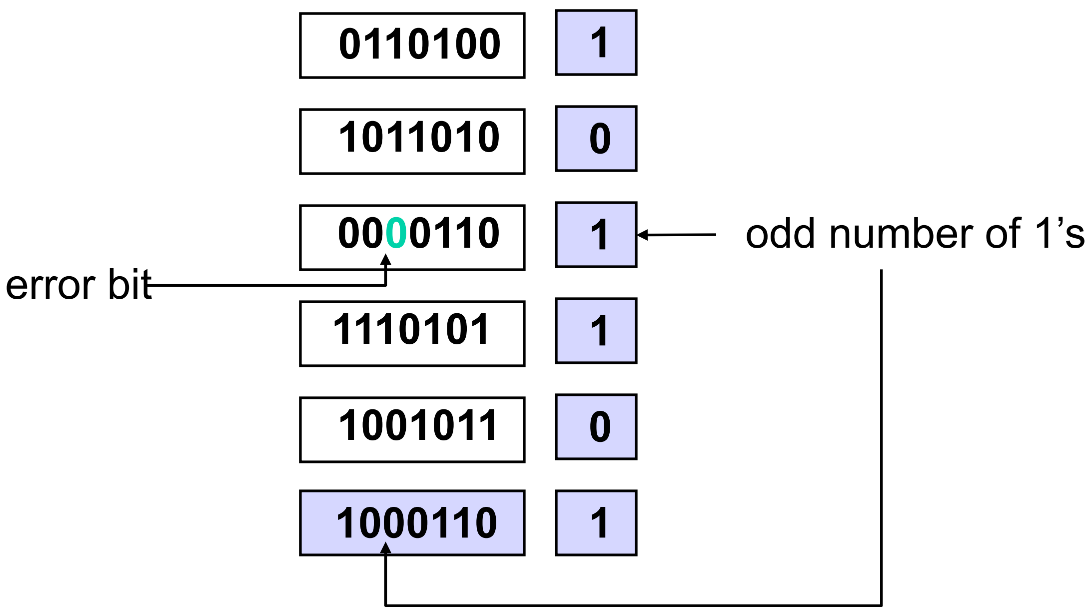
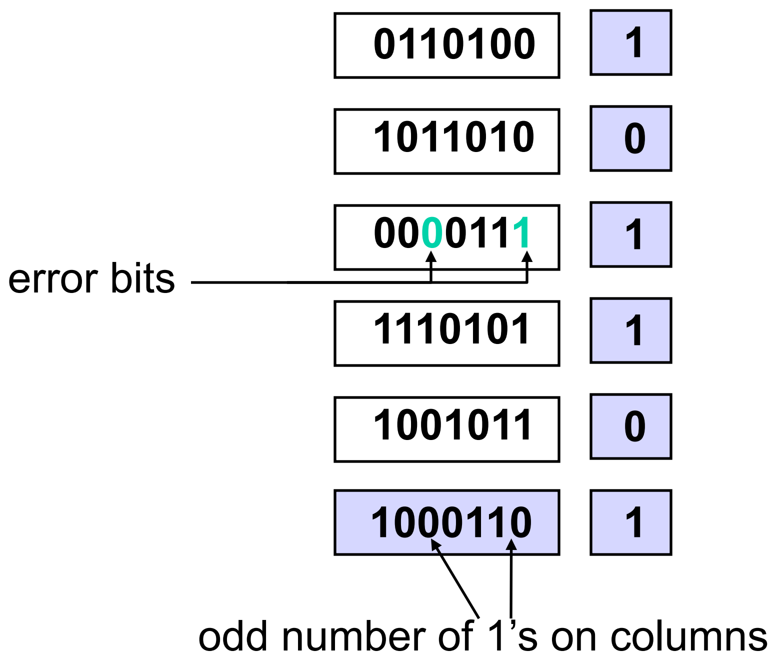


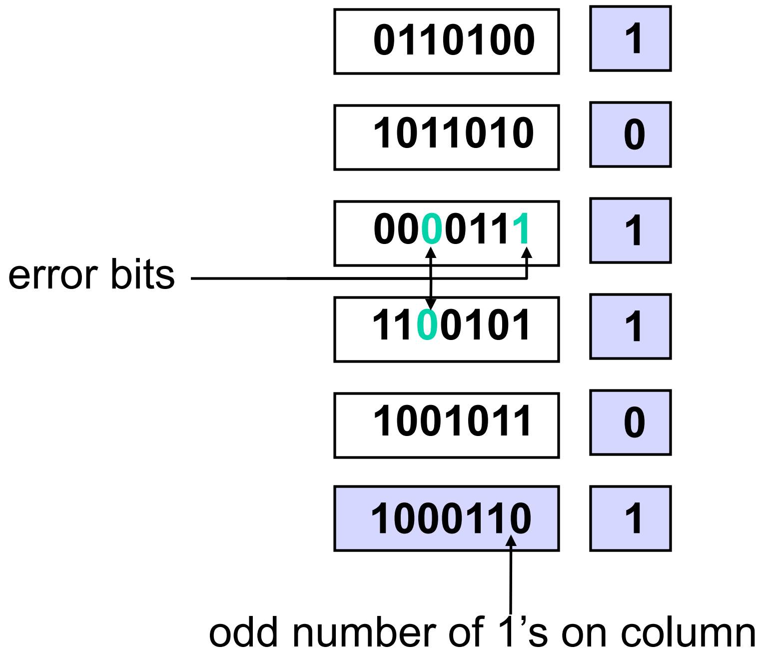
How Many Errors Can you Detect?

- All 2-bit errors
- Example:



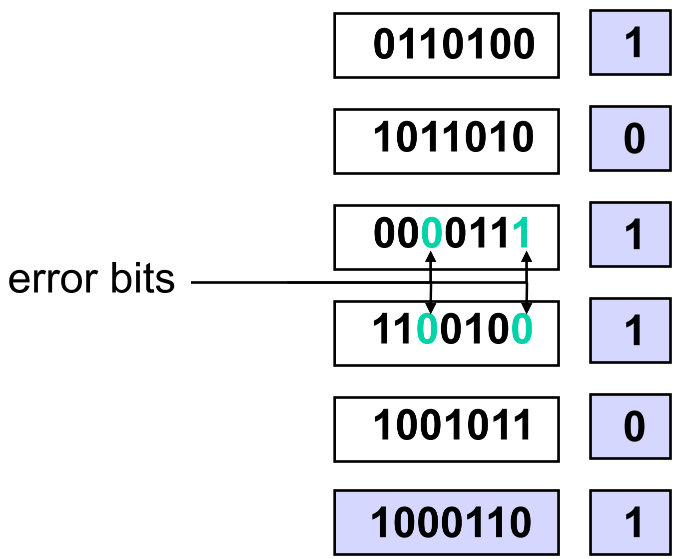
How Many Errors Can you Detect?

- 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?

Checksum

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

1's Complement

- 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

15 = 00001111 → -15 = 11110000
+
16 = 00010000

1's Complement

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```
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                        +
                 16 = 00010000
              ___________________
               [1] 00000000
```

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```
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                          +
                16 = 00010000
            ---------------------
                1  00000000
                      +        1
            ---------------------
                   00000001
```

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```
15 = 00001111 → -15 = 11110000
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                 16 = 00010000
                ----------------
                  [1] 00000000
                      +       1
                ----------------
                      00000001
```

-15+16 = 1

Internet Checksum Implementation

```
u_short cksum(u_short *buf, int count)
{
        register u_long sum = 0;
        while (count--)
        {
                sum += *buf++;
                if (sum & 0xFFFF0000)
                {
                        /* carry occurred, so wrap around */
                        sum &= 0xFFFF;
                        sum++;
                }
        }
        return ~(sum & 0xFFFF);
}
```

Properties

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- What's the overhead?
- Why use this algorithm?
  - Link layer typically has stronger error detection
  - Most Internet protocol processing in the early days (70's 80's) was done in software with slow CPUs, argued for a simple algorithm
  - Seems to be OK in practice

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- What's the overhead?
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  - Link layer typically has stronger error detection
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  - Seems to be OK in practice
- What about the end-to-end argument?

Example of checksum calculation

- If data is

```
1001 1101 0010 1101 1100 0011 1101 0101
```

- Convert to 16-bit words, then add, carry, and invert

```
    1001 1101 0010 1101
    1100 0011 1101 0101
    -------------------
 [1] 0110 0001 0000 0010   Sum
                      1   Carry
    -------------------
    0110 0001 0000 0011   Final sum

    1001 1110 1111 1100   Internet checksum
```

Overview

- Revisit error detection
- ➢ Reliable transmission

Retransmission

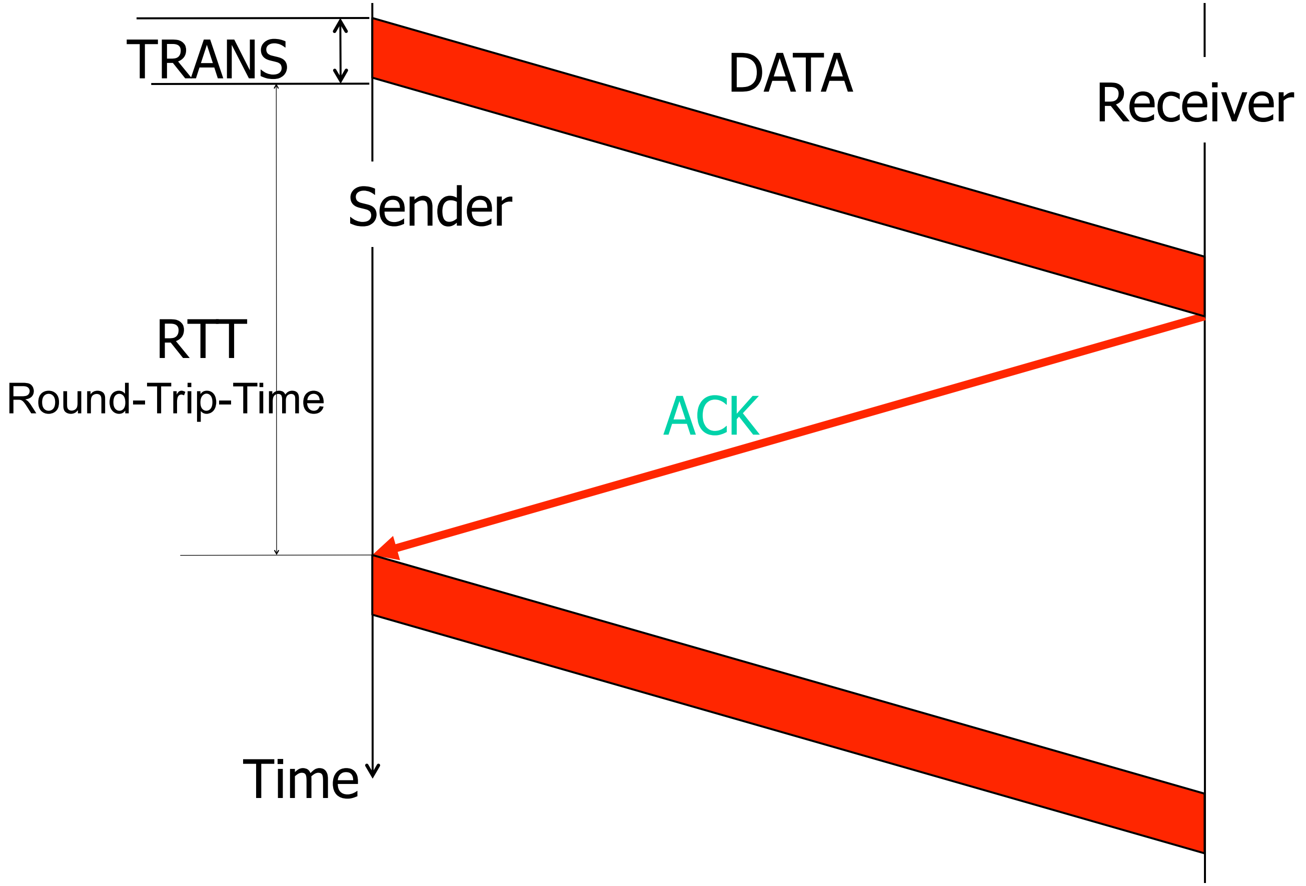
- Problem: obtain correct information once errors are detected
- Retransmission is one popular approach
- Algorithmic challenges
  - Achieve high link utilization, and low overhead

Reliable Transfer

- Retransmit missing packets
  - Numbering of packets and ACKs
- Do this efficiently
  - Keep transmitting whenever possible
  - Detect missing ACKs and retransmit quickly
- Two schemes
  - Stop & Wait
  - Sliding Window
    - Go-back-n and Selective Repeat variants

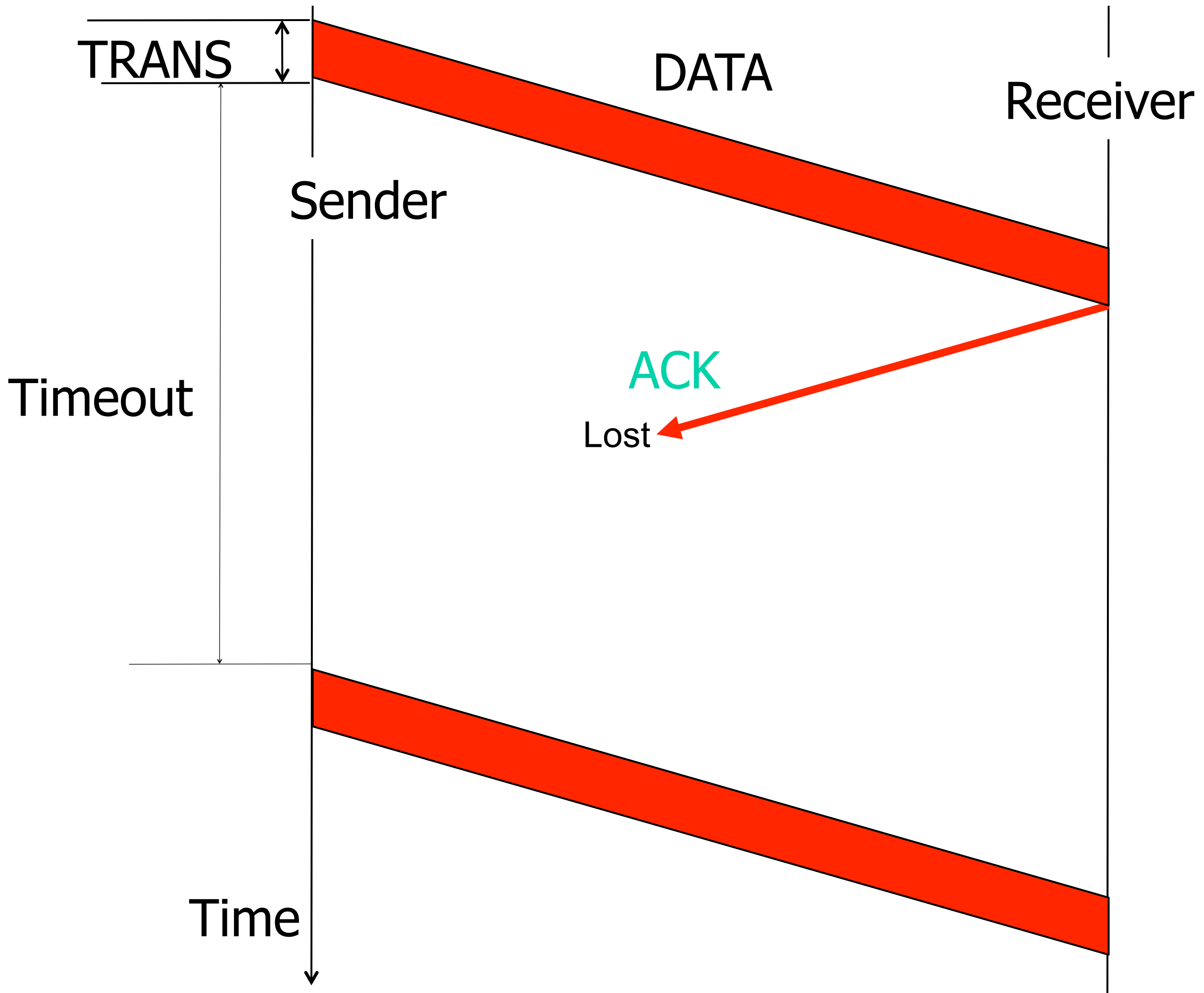
Stop & Wait

- Send; wait for acknowledgement (ACK); repeat
- If timeout, retransmit

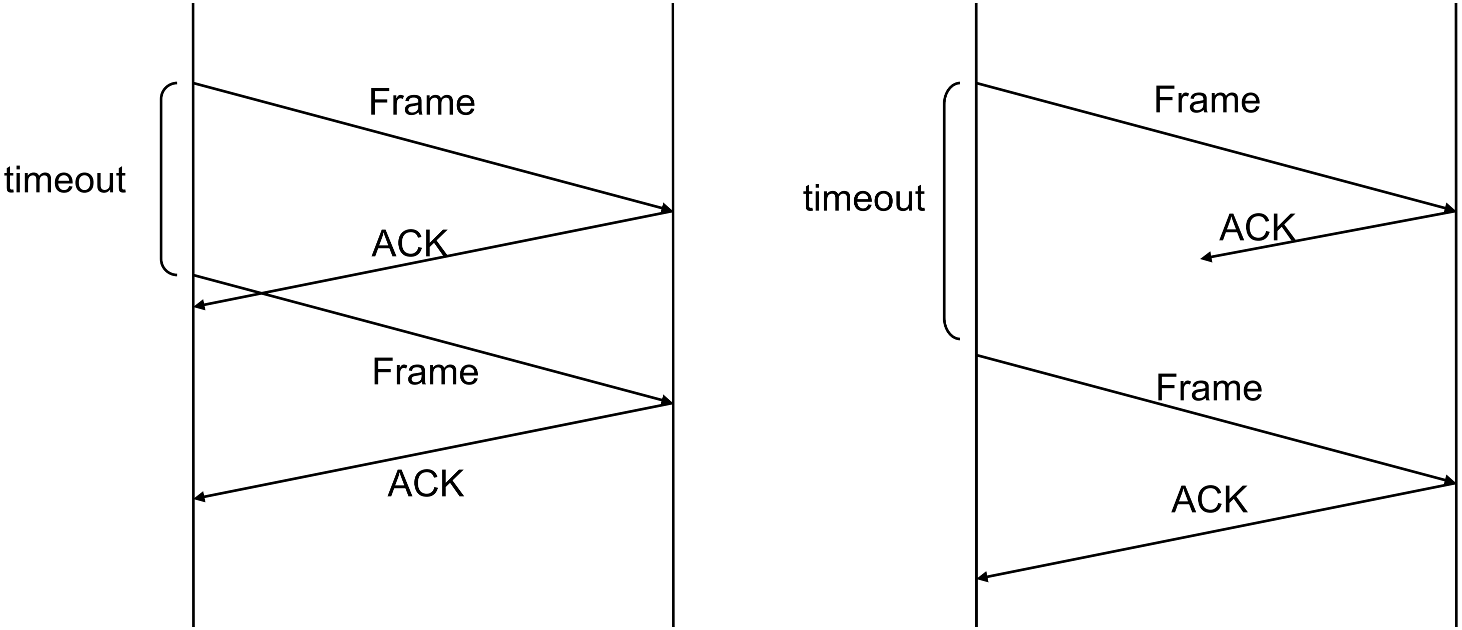


Inefficient if TRANS << RTT

Stop & Wait



Is a Sequence Number Needed?



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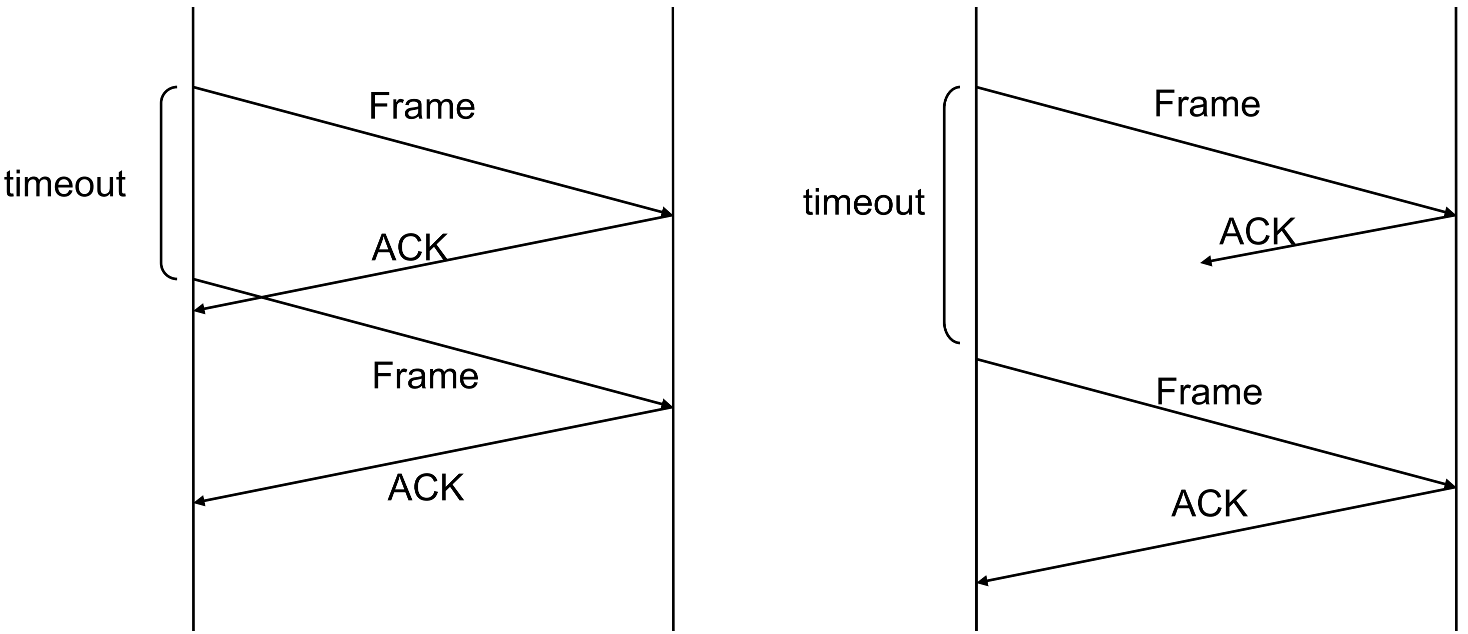

- Need a 1 bit sequence number (i.e. alternate between 0 and 1) to distinguish duplicate frames

Problem with Stop-and-Go

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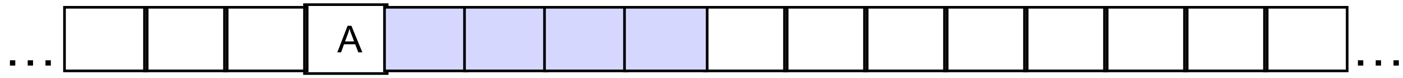
- Lots of time wasted in waiting for acknowledgements

Problem with Stop-and-Go

- Lots of time wasted in waiting for acknowledgements
- What if you have a 10Gbps link and a delay of 10ms?
  - Need 100Mbit to fill the pipe with data
- If packet size is 1500B (like Ethernet), because you can only send one packet per RTT
  - Throughput = 1500*8bit/(2*10ms) = 600Kbps!
  - A utilization of 0.006%

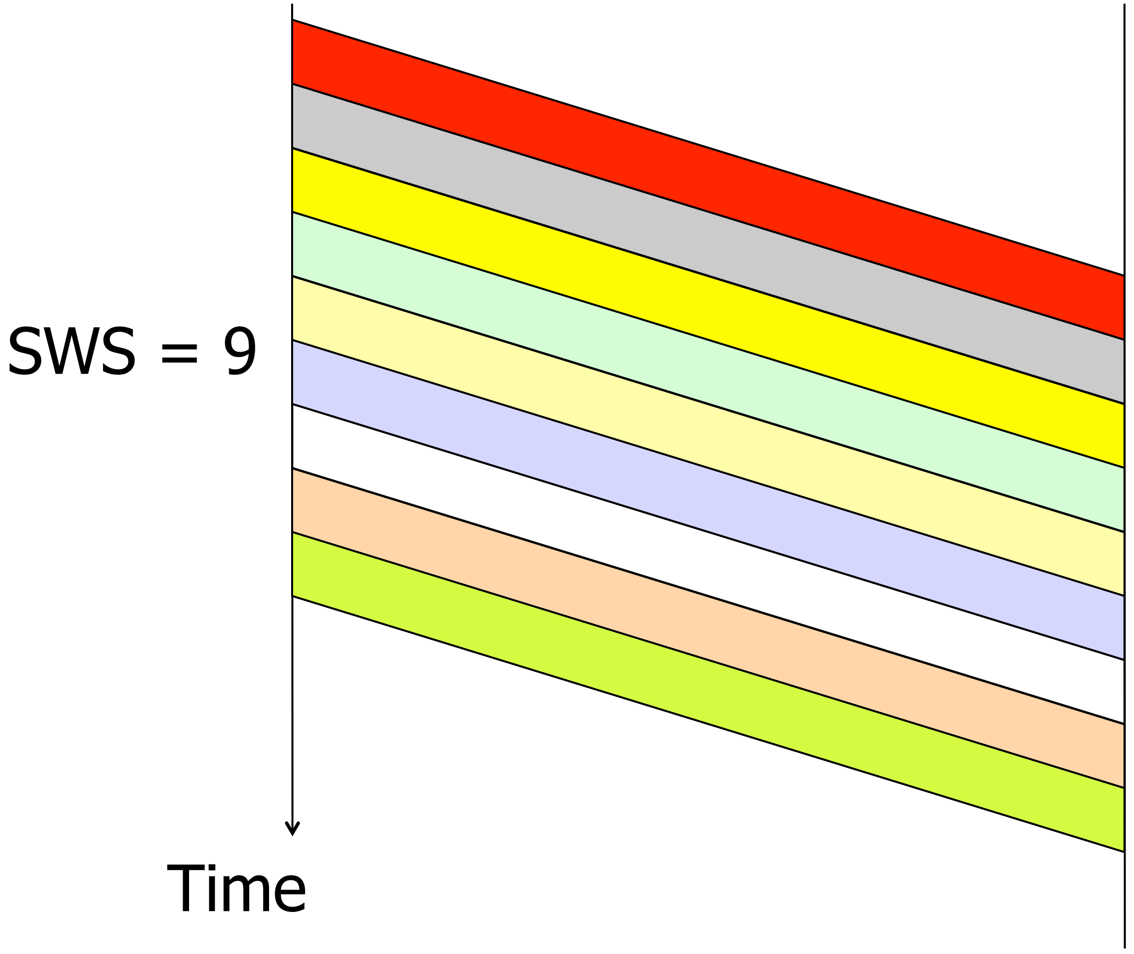
Sliding Window

- *window* = set of adjacent sequence numbers
- The size of the set is the *window size (WS)*
  - Assume it is n
- Let A be the last ack'd packet of sender without gap; then window of sender = {A+1, A+2, …, A+n}
  - Sender window size (SWS)



- Sender can send packets in its window
- Let B be the last received packet without gap by receiver, then window of receiver = {B+1,…, B+n}
  - Receiver window size (RWS)
- Receiver can accept out of sequence packets, if in window

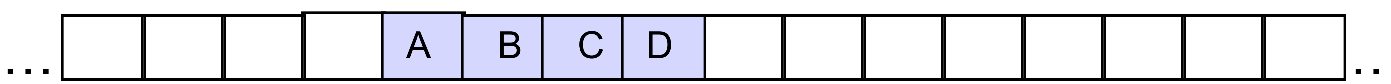
Example



Basic Timeout and Acknowledgement

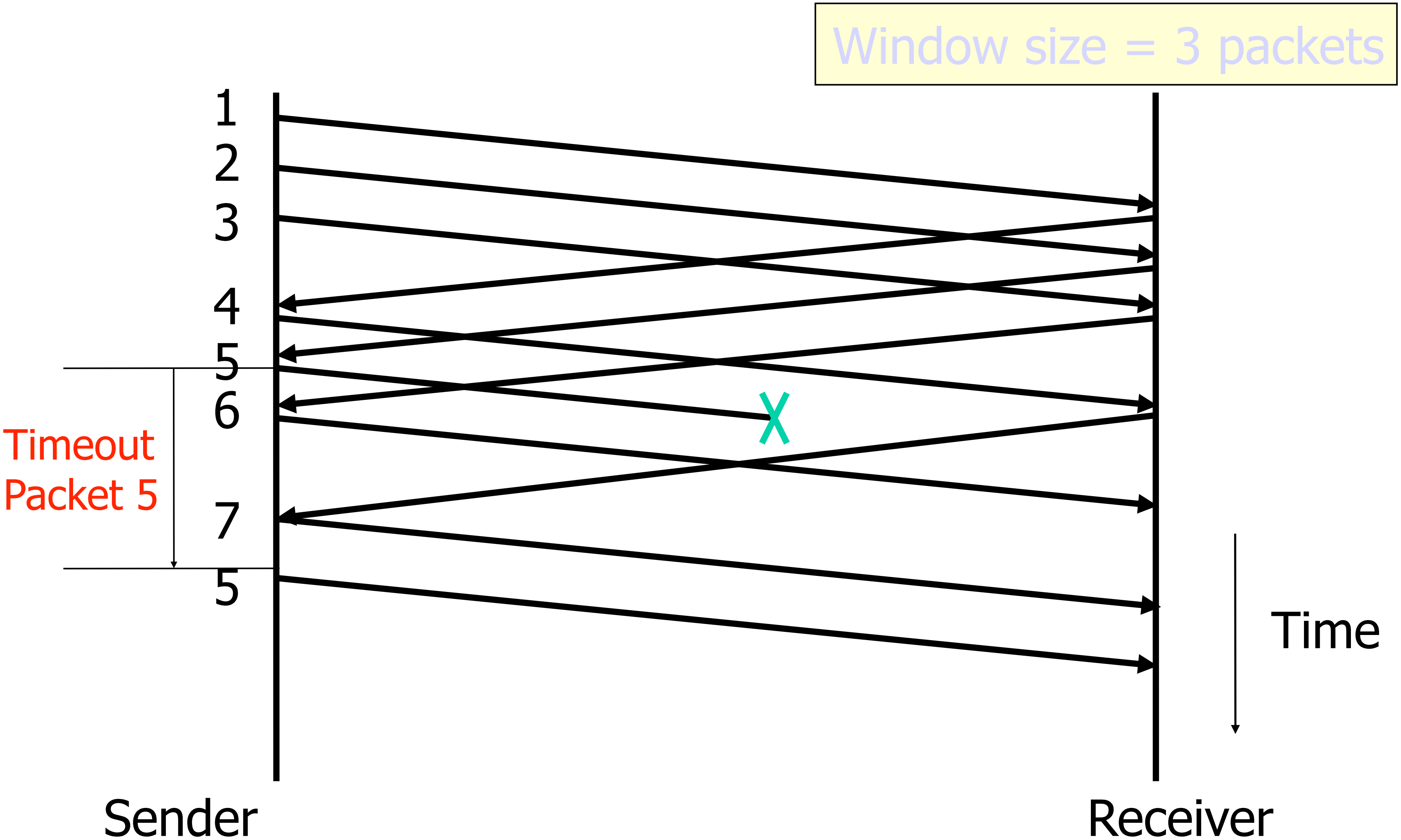
- Every packet k transmitted is associated with a timeout
- If by timeout(k), the ack for k has not yet been received, the sender retransmits k

- Basic acknowledgement scheme
  - Receiver sends ack for packet k when all packets with sequence numbers <= k have been received
  - An ack k means every packet up to k has been received

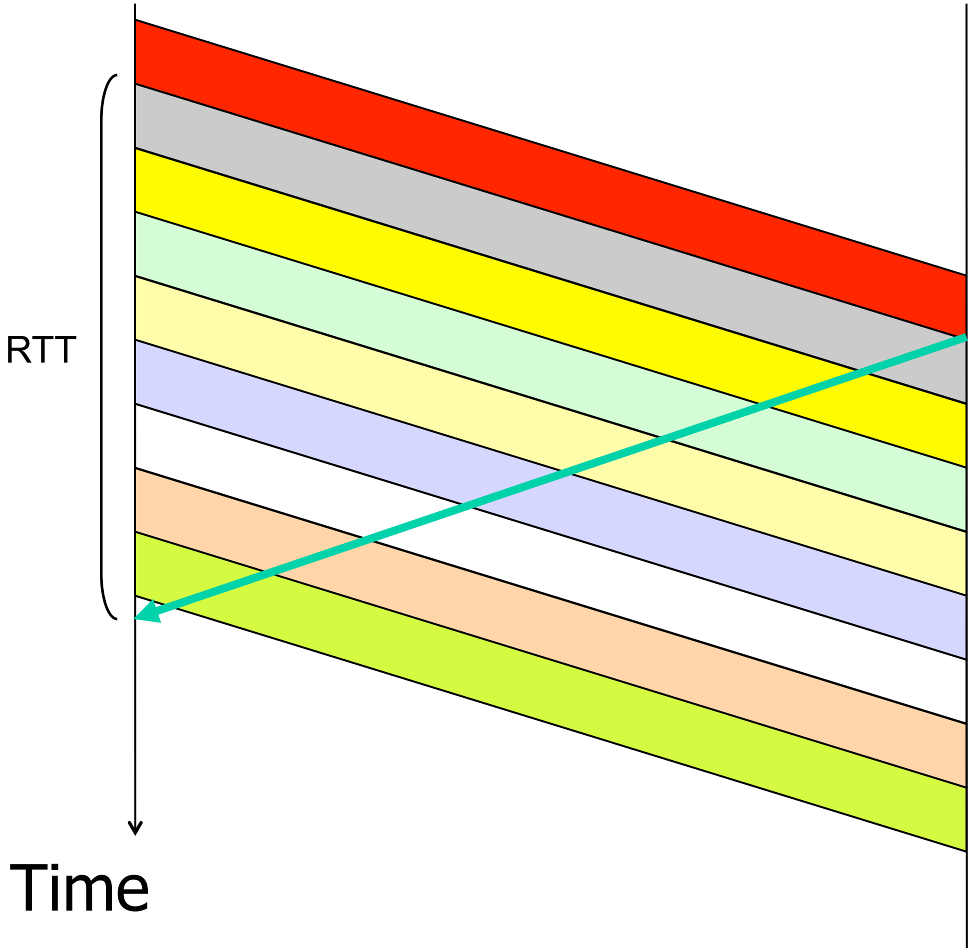


  - Suppose packets B, C, D have been received, but receiver is still waiting for A. No ack is sent when receiving B,C,D. But as soon as A arrives, an ack for D is sent by the receiver, and the receiver window slides

Example with Errors



Efficiency



SWS = 9, i.e. 9 packets in one RTT instead of 1

→ Can be fully efficient as long as WS is large enough

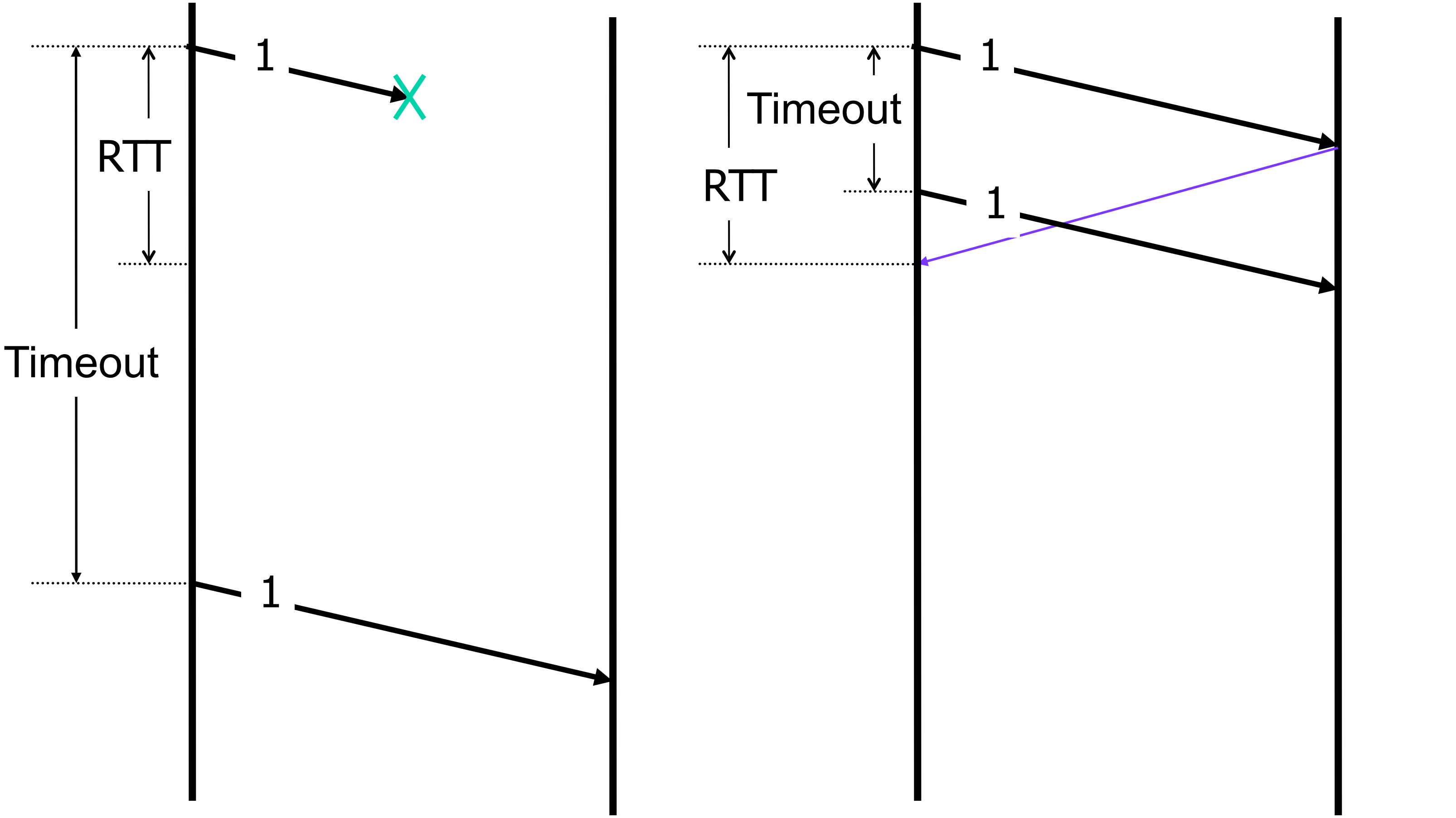
Observations

- With sliding windows, it is possible to fully utilize a link, provided the window size is large enough. Throughput is ~ (n/RTT)
  - Stop & Wait is like n = 1.
- Sender has to buffer all unacknowledged packets, because they may require retransmission
- Receiver may be able to accept out-of-order packets, but only up to its buffer limits

Setting Timers

- The sender needs to set retransmission timers in order to know when to retransmit a packet that may have been lost
- How long to set the timer for?
  - Too short: may retransmit before data or ACK has arrived, creating duplicates
  - Too long: if a packet is lost, will take a long time to recover (inefficient)

Timing Illustration



Timeout too long → inefficiency

Timeout too short → duplicate packets

Adaptive Timers

- The amount of time the sender should wait is about the round-trip time (RTT) between the sender and receiver
- For link-layer networks (LANs), this value is essentially known
- For multi-hop WANS, rarely known
- Must work in both environments, so protocol should adapt to the path behavior
- E.g. TCP timeouts are adaptive, will discuss later in the course