
University of Pittsburgh
ECE 1150: Computer Networks
The Transport Layer
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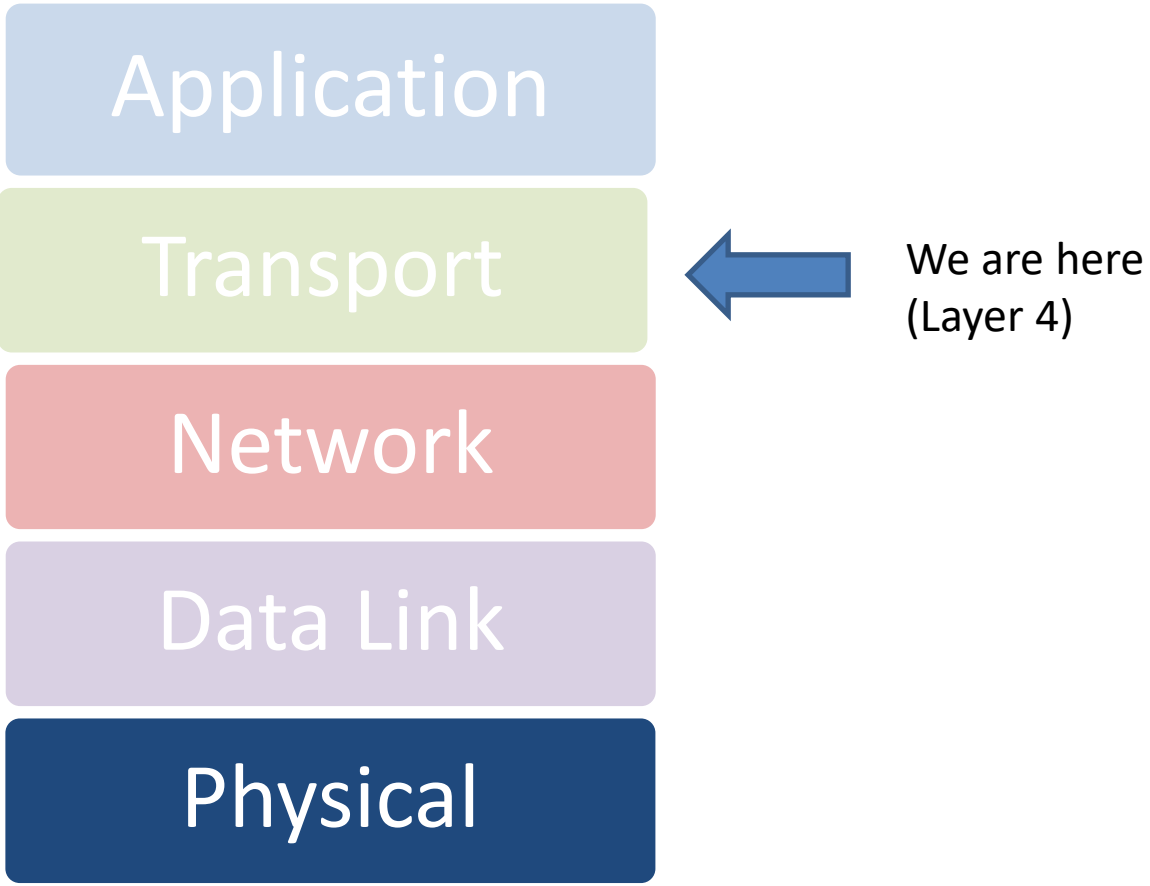
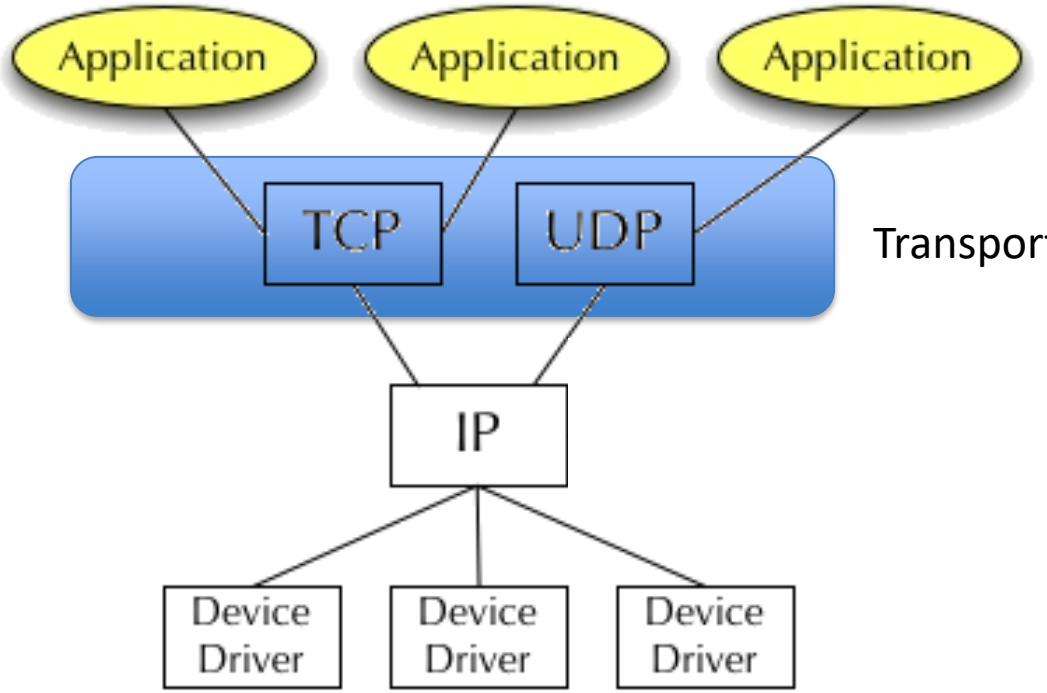
This Unit

- Transport layer



Transport Layer

- Two types:
  - TCP: Transport control protocol (reliable)
  - UDP: User Datagram protocol (easy)

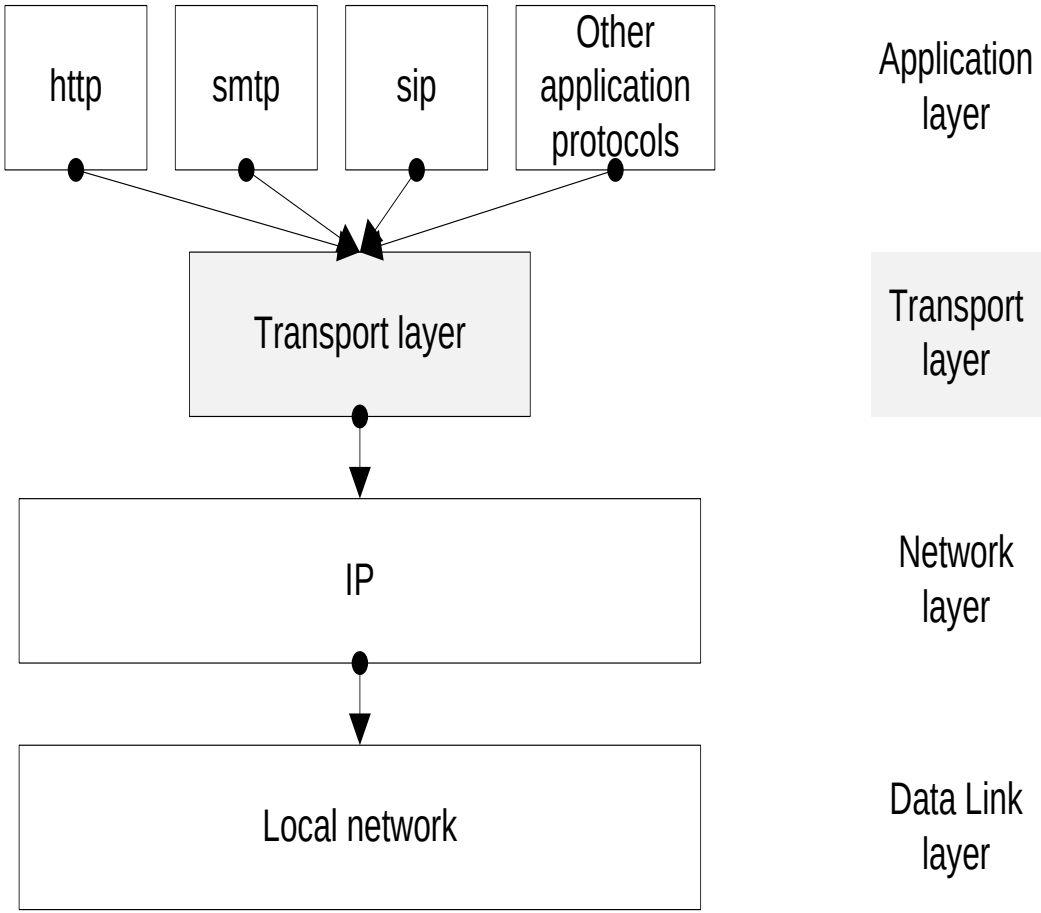


Transport Layer – layer 4

Schematic of TCP/IP Operation

TCP Functions

- Therefore TCP has to perform many tasks
  1. Segmentation
  2. Reliability
  3. Flow-control
  4. Multiplexing for applications
  5. Connection establishment



TCP Functions - Segmentation

- TCP allows IP to transfer arbitrarily large data blocks
- However, the maximum packet size in network layer is 65,536 bytes
  - What happens if the application wants to send a file of size 5 Mega bytes?

TCP Functions - Segmentation

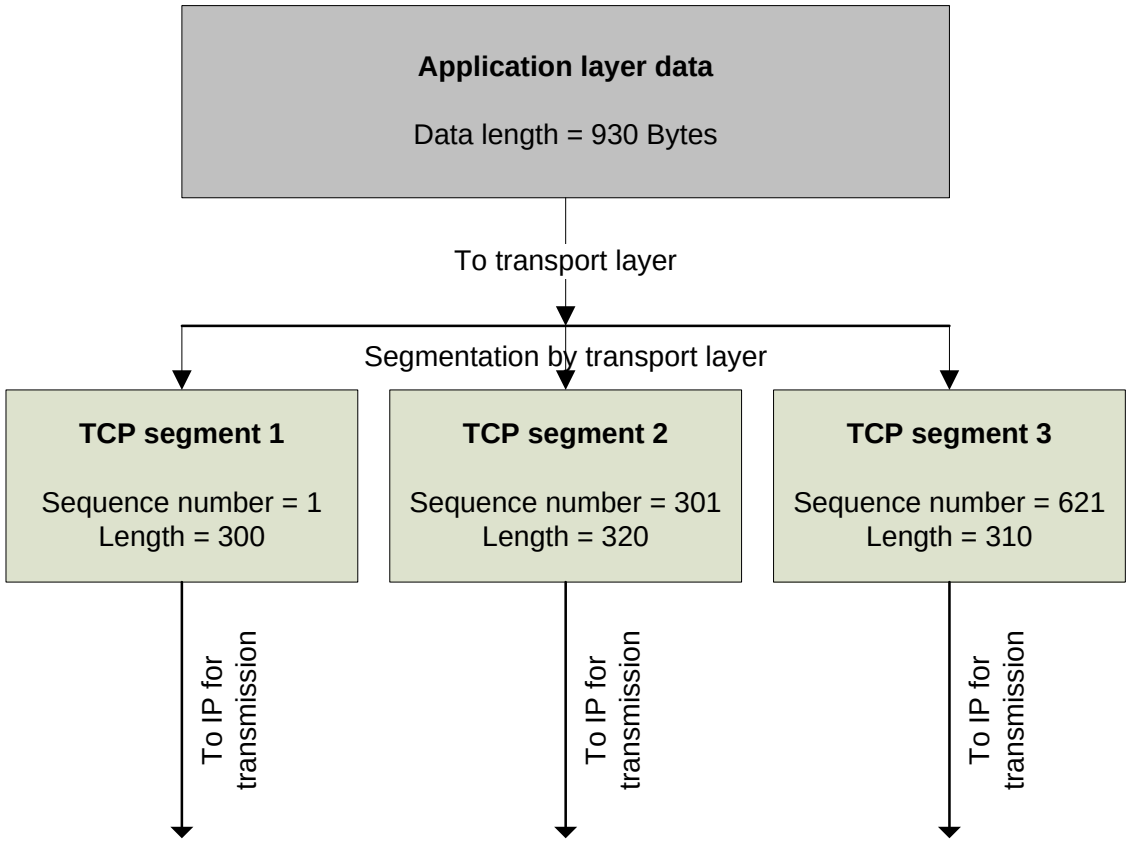
TCP does segmentation

- At the sender**, break files into smaller blocks** (called segments or datagrams)

- At the receiving end, **re-assemble** these blocks into the file

- A **sequence number** is assigned to each datagram
  - Sequence numbers help **receiver order datagrams** even when received out of order
  - Datagrams may also get **duplicated**
    - Sequence numbers help identify these duplicates

Sequence Numbers



Assume we start with sequence number 1

Sequence number of a TCP segment	=	sequence number of the previous segment + length of previous segment

TCP functions - Segmentation

- Advantages of segmentation
  - **Errors are less** likely in smaller segments
  - **Less retransmission** if error is introduced in a segment
    - When error occurs in one segment, no need to transmit the entire file again. Just retransmit the segment.
  - **Easier for routers** to hold segments in memory
    - Reduce complexities in packet handling
- Disadvantages
  - **More computations** in sending and receiving

TCP Functions - Reliability

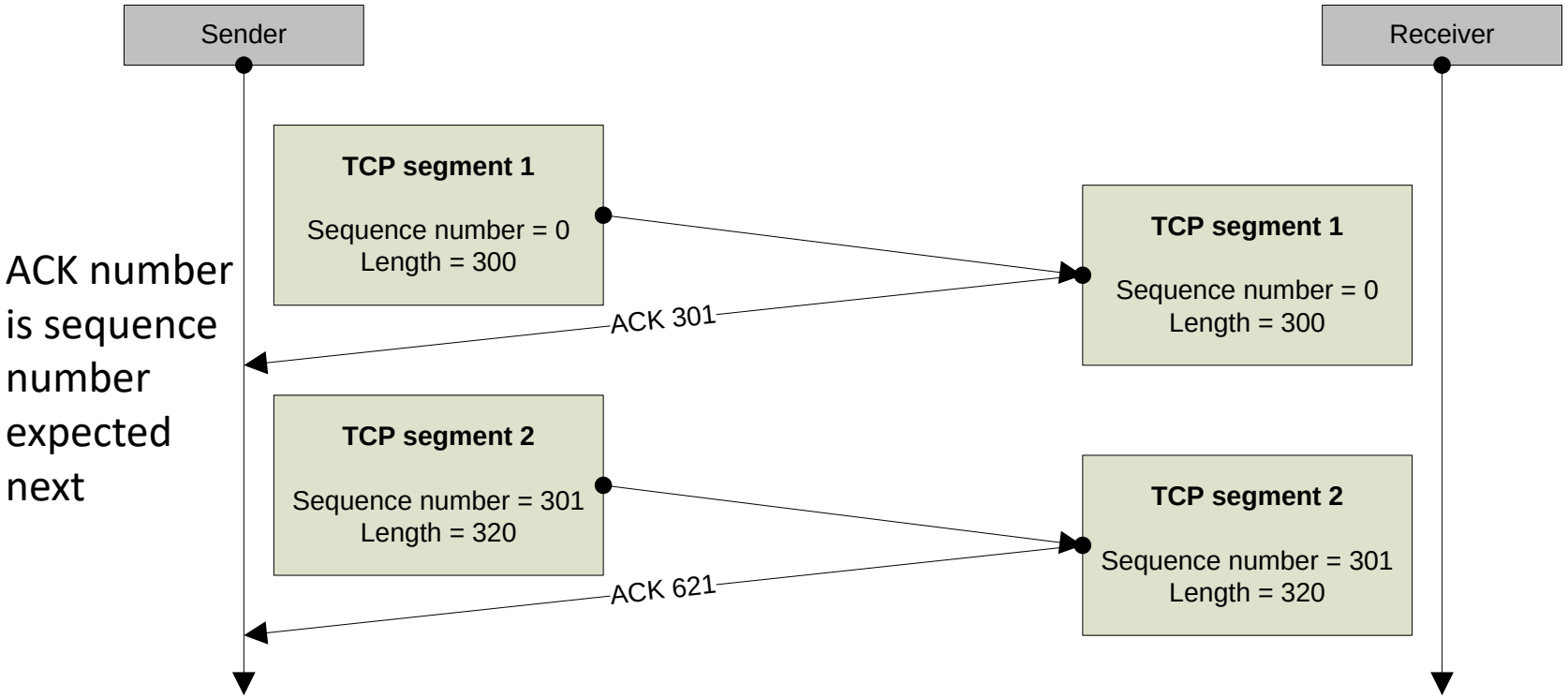
- Datagrams may get damaged during transmission

- **TCP adds a checksum** to detect errors. This checksum is not as robust as CRC.

TCP Functions - Reliability

- **Reliable end-to-end** communication service
- TCP **recovers from network damage** to data
- Basic mechanisms similar to error control at data link layer, but now **applied end-to-end**
  - Receiver sends a positive **acknowledgment (ACK)** if all goes well
  - If the ACK is not received within a **timeout** interval, the sender retransmits the data
- Two techniques: Stop-and-wait & sliding window
- Also used for **flow control**

Simple Flow Control Mechanism
Stop - and - Wait

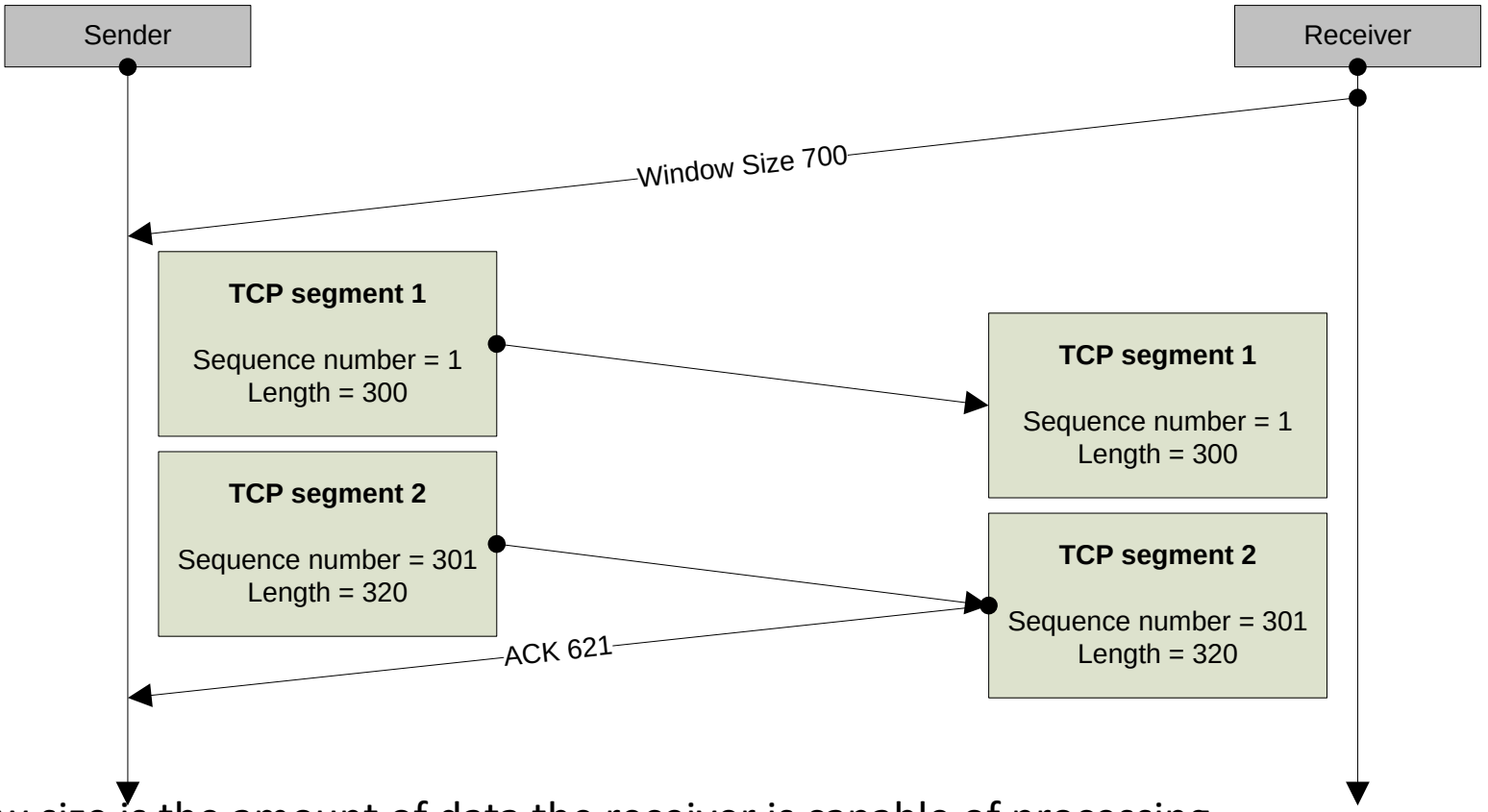


- Flow control mechanism shown here is called stop-and-wait
  - Sender waits for ACK before sending next datagram
    - Very slow

Flow Control - Sliding window

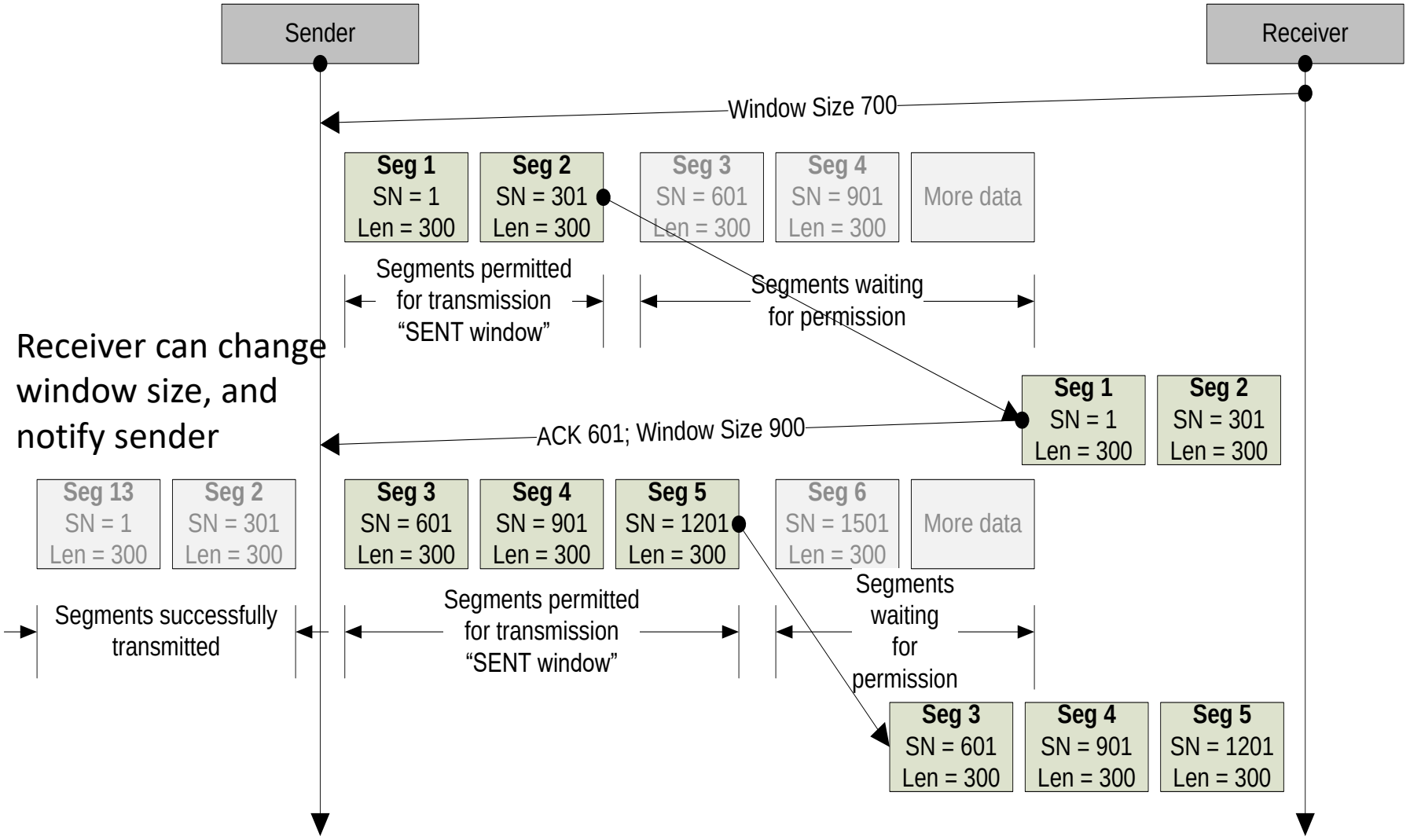
- Flow control: **receiver regulates** the amount of data the sender may send
- Accomplished by specifying a "**window**" with every **ACK**
  - "**Window**" indicates **how many bytes** of data the sender may transmit **before receiving any more ACK**
- Window slides as **receiver acknowledges** packets or modifies window size

TCP Flow Control with Window Size



- Window size is the amount of data the receiver is capable of processing
- Receiver begins by announcing the window size
- ACK 621: means that all data up to byte 620 is received correctly

Sliding Window

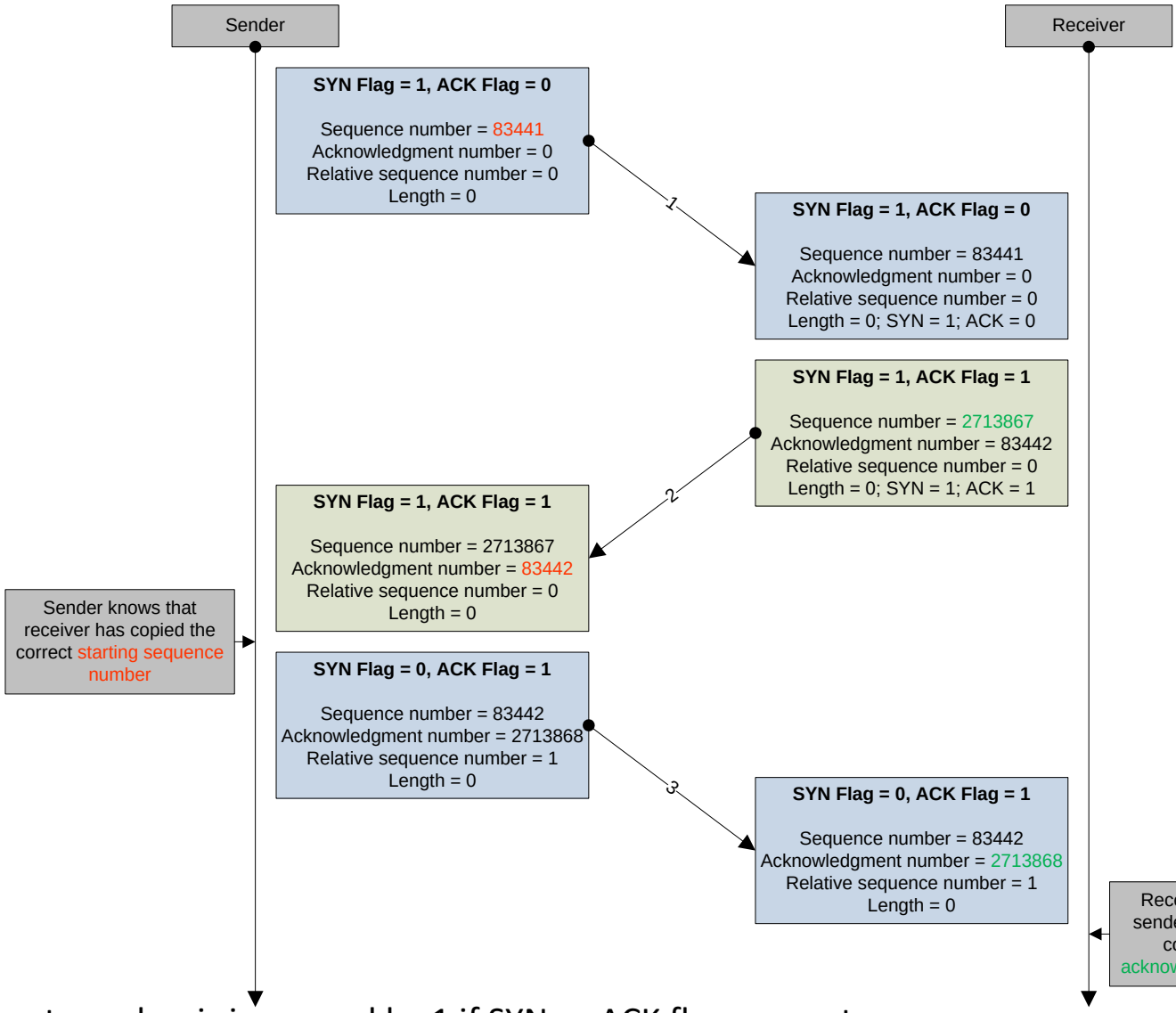


TCP Functions – Connection Establishment

- Sequence numbers are core part of TCP
- It is not a good idea to reuse the same sequence numbers in succession
  - Creates problems in detecting duplicates
- Hence, before communication starts, sender and receiver **negotiate** the **initial sequence numbers to use in TCP connection**
  - **Called 3-Way Handshake, which is made to establish a connection**

3-Way Handshake

1. Sender generates Initial Sequence Number (ISN). E.g. ISN = 83441.
2. Receiver ACKs this reception by putting the (**ACK =**sender ISN +1), and **inserts its own Rx ISN**.
3. When the sender receives the ACK, it also knows the ISN of the Rx, it then sends an ACK



Note: Acknowledgment number is increased by 1 if SYN or ACK flags are set

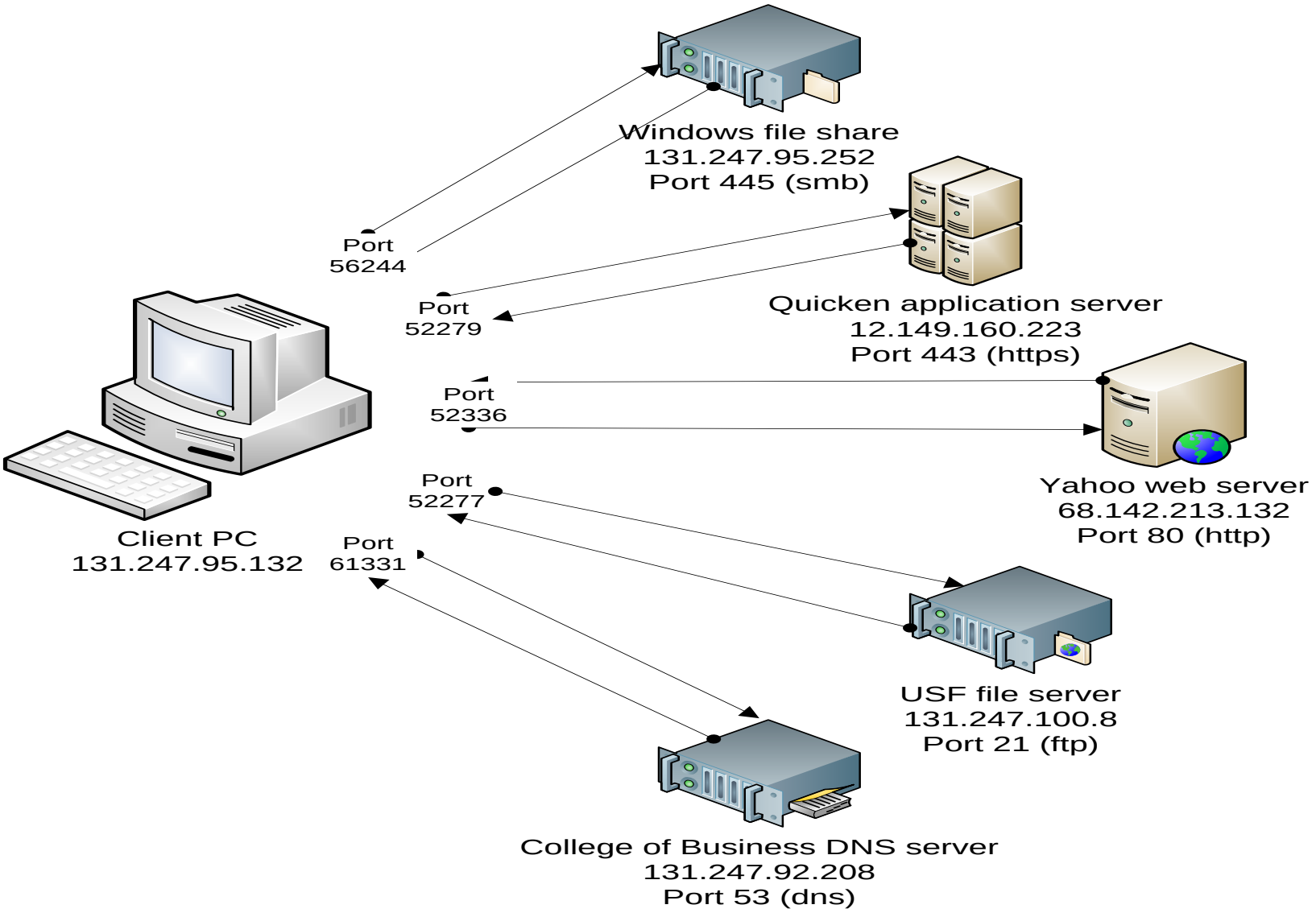
Connection Establishment with 3-Way Handshake

- Three way handshake
  1. Sender generate a random initial sequence number (ISN) and sends it to destination
  2. Destination generates a random initial sequence number and sends it along with the acknowledgment to sender
  3. Sender acknowledge

TCP Functions - Multiplexing

- Transport layer performs **application multiplexing**
  - Allowing multiple applications to use the same network interface card.
- This is accomplished by **assigning different port numbers** to different applications within a host
  - Each **application** that needs a network connection (each browser tab) is assigned a **port number**
  - Port number is 16 bits
- An IP address and port address together is called a **socket**

Port addresses and multiplexing



TCP Port Assignment

- On the **sender** side, the **operating system** assigns one of the free ports to an application that requires network connectivity

- How do you know what port to connect to on the receiver side?
  - On what port is the web server listening?
  - Standard ports
    - Assigned by IANA: Internet Assigned Numbers Authority
  - Common ports: https://www.utilizewindows.com/list-of-common-network-port-numbers/
    - 80 : http
    - 443: SSL (https)
    - 53: DNS
    - 23: Telnet

Viewing Ports Usage With Netstat Command

- Netstat: Utility provided by OS to view port usage

```
C:\>netstat -n

Active Connections

  Proto  Local Address          Foreign Address        State
  TCP    127.0.0.1:5354         127.0.0.1:46133        ESTABLISHED
  TCP    127.0.0.1:46133        127.0.0.1:5354         ESTABLISHED
  TCP    192.168.1.5:46122      192.168.1.153:445      ESTABLISHED
  TCP    192.168.1.5:46149      74.125.67.138:443      CLOSE_WAIT
  TCP    192.168.1.5:46151      74.125.45.104:80       CLOSE_WAIT
  TCP    192.168.1.5:51117      131.247.80.160:143     ESTABLISHED
  TCP    192.168.1.5:51124      131.247.80.160:143     ESTABLISHED
  TCP    192.168.1.5:51292      131.247.16.141:22      ESTABLISHED
  TCP    192.168.1.5:51369      131.247.80.29:445      SYN_SENT
```

Foreign address: IP addresses the local device is connected to

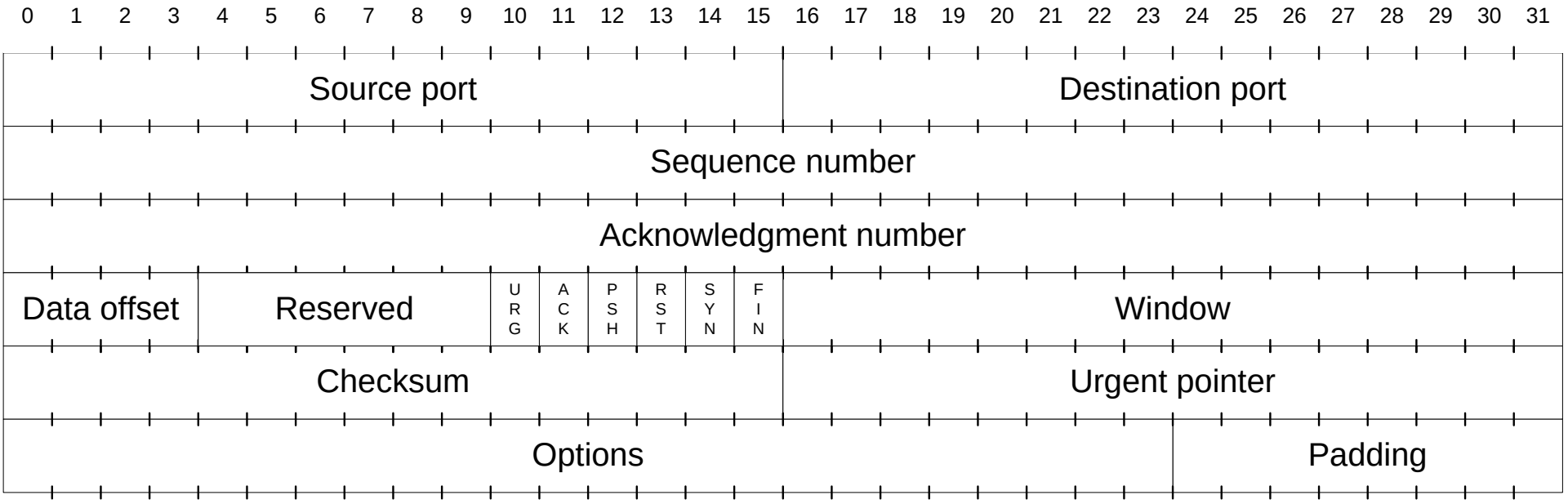
CLOSE_WAIT: Wait to request of terminating connection

Ports on local device

Ports on remote servers

https://en.wikipedia.org/wiki/Transmission_Control_Protocol

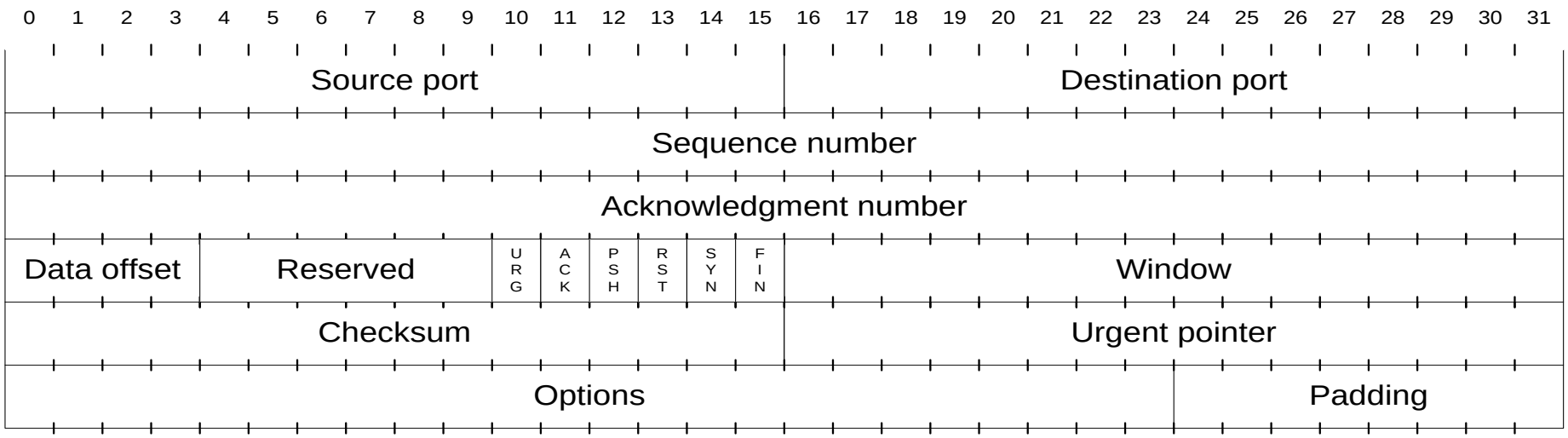
TCP Header



Note: Each tick mark represents a bit position

TCP Header Fields

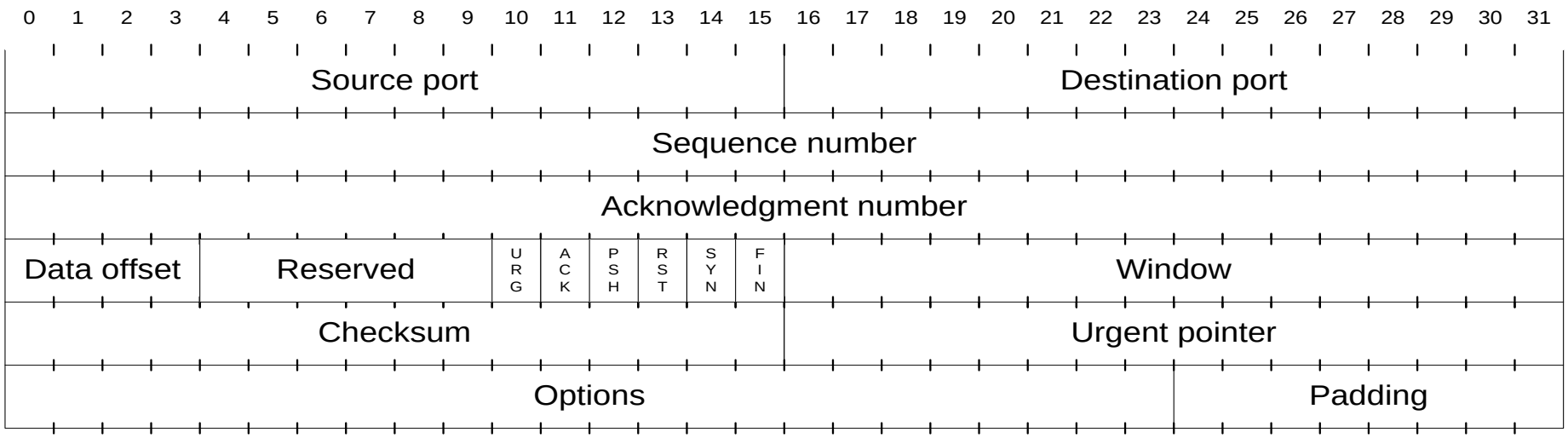
- Port addresses have 16 bits
  - 2^{16} = 65,536 ports possible per host
  - If computing resources are available, a single computer running TCP can support 65,536 simultaneous network connections



Note: Each tick mark represents a bit position

TCP Header Fields

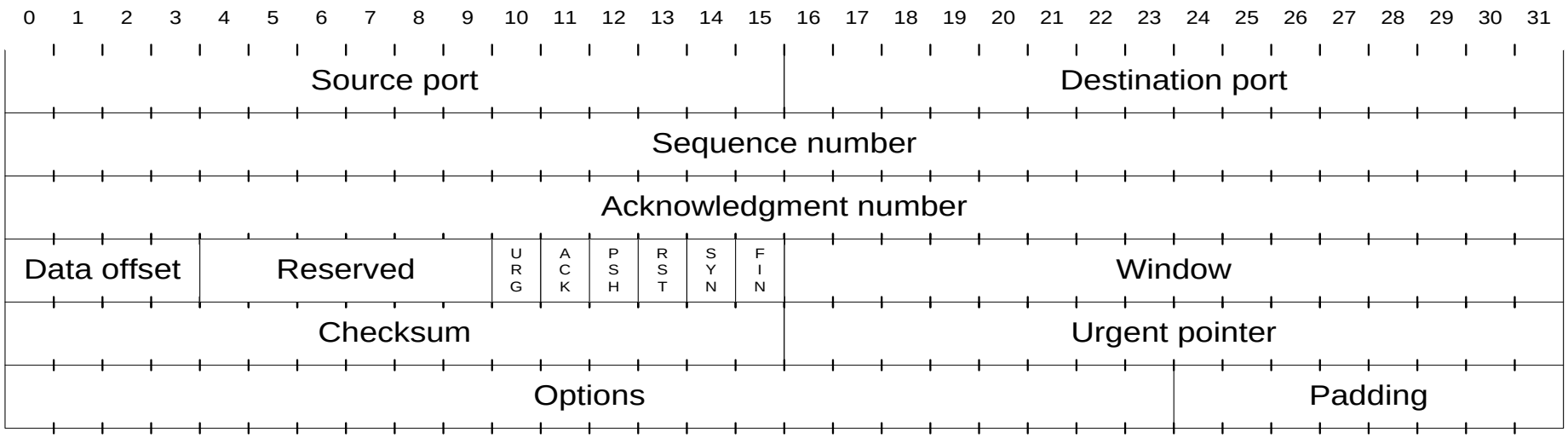
- Sequence and acknowledgment numbers have 32 bits
  - **Sequence number** is the sequence number of the **first data byte** in the datagram
  - Acknowledgments are cumulative
    - **ACK 1079** implies that all data till byte number **1078** have been received correctly



Note: Each tick mark represents a bit position

TCP Header Fields

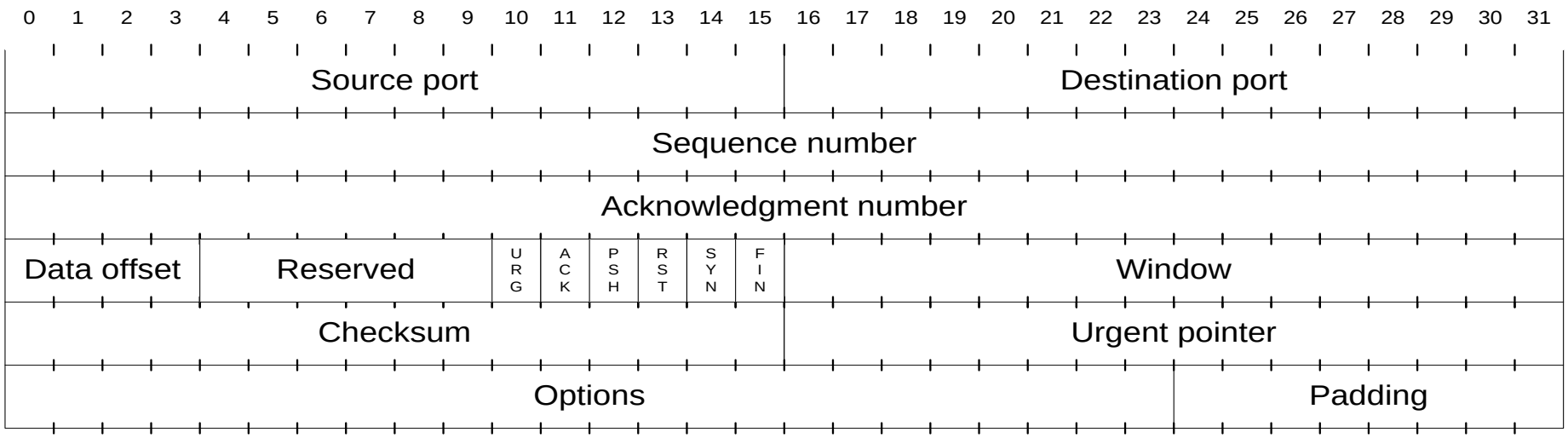
- Control fields
  - **ACK: 1 implies that the value of the acknowledgment field is meaningful**
  - **SYN: 1 implies that the segment is trying to synchronize sequence numbers**
  - RST: Reset the connection



Note: Each tick mark represents a bit position

TCP Header Fields

- Window size: Number of data octets the sender of this information is willing to accept beyond the ACK number field
- Checksum: For error detection
- Urgent pointer: Indicates that data must be processed immediately (earlier applications).

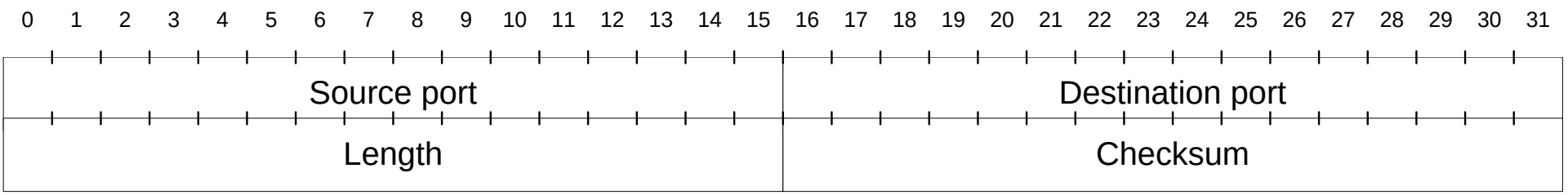


Note: Each tick mark represents a bit position

User Datagram Protocol (UDP)

- Defined in RFC 768 (1980)
- Many applications do not need TCP, such as
  - Applications sending very small amounts of data
  - Prefer speed to reliability (voice)
- In these cases, if we can avoid TCP, we **eliminate the overhead** of keeping track of sequence numbers, window sizes etc.
- With UDP: **No retransmissions**, **no sequence number validation, no window size defined**.

UDP Header



Note: Each tick mark represents a bit position

Checksum: similar to TCP, but often not used in computer-intensive applications such as video streaming

Length: of the datagram

Transport layer protocols

TCP service:

- Connection-oriented: setup required between client and server processes (3-way handshake)
- Reliable transport between sending and receiving process
- Flow control: sender won't overwhelm receiver

UDP service:

- **Unreliable data transfer** between sending and receiving process
- Faster transmission
- **Does not** provide: connection setup, reliability, flow control

Summary

- Segmentation
  - Need sequence numbers
- Flow control by sliding window
- Port numbers for application multiplexing
- TCP connection establishment through three-way handshake to agree on the initial sequence numbers
- UDP vs TCP