TCP Extra Information

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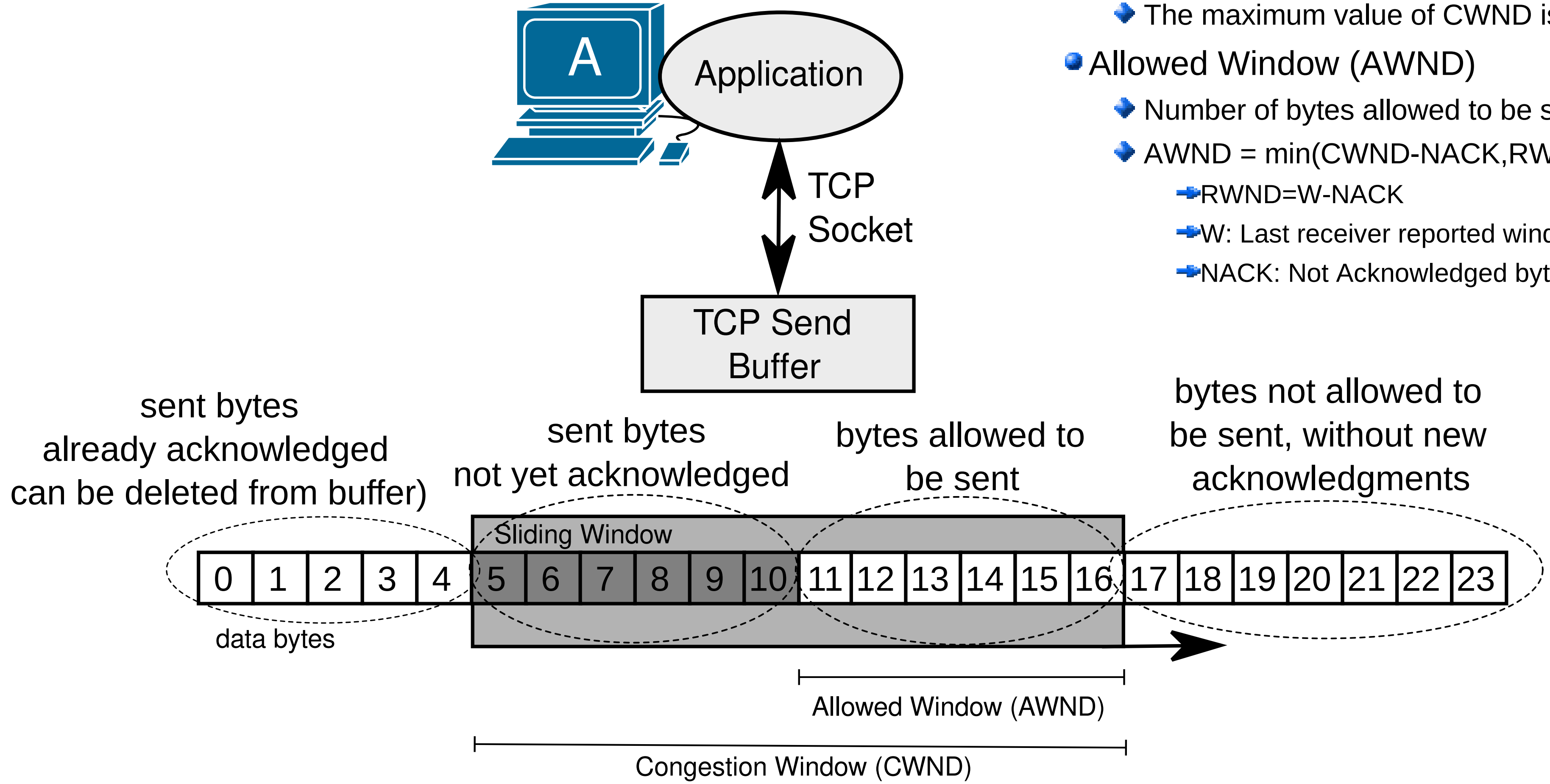
TCP Congestion Control

- Uses a sliding window to determine the number of packets/bytes the sender is allowed to transmit.

- Congestion Window (CWND)
  - Set by sender to avoid overloading network.
  - The maximum value of CWND is RWND.
- Allowed Window (AWND)
  - Number of bytes allowed to be sent.
  - AWND = min(CWND-NACK,RWND)
    - RWND=W-NACK
    - W: Last receiver reported window.
    - NACK: Not Acknowledged bytes.

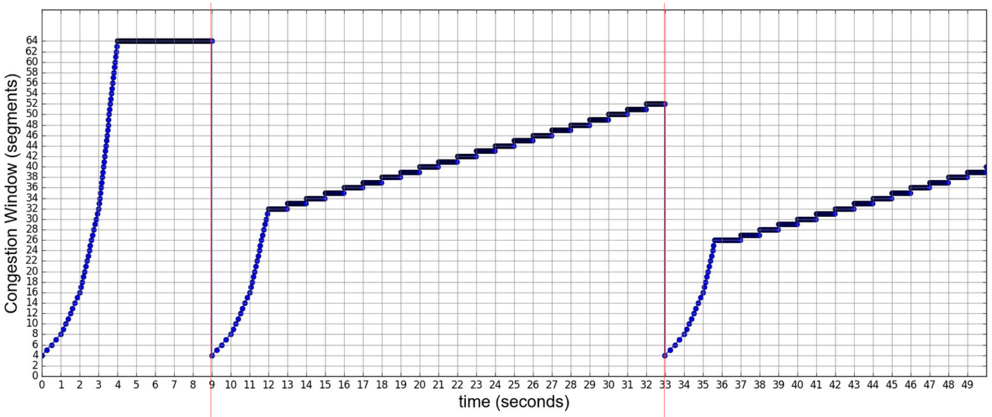


Other TCP Algorithms

- NewReno (1996)
  - Allows for partial ACK.
  - When a loss occurs, CWND is defined as β*CWND, with β=0.5. When a ACK arrives, CWND is updated as CWND=CWND+α, with α=1 MMS.
  - Used by default in Windows and supported by Mac OS X.
    - Used in Windows XP and earlier.
    - After Windows Vista, Compound TCP can also be enabled.
- CUBIC (2005)
  - Uses a cubic function to control the CWND.
  - Used by Linux (kernel 2.6.19 and later) and supported by Mac OS X.
- Compound TCP (2006)
  - Adapts its behavior by use of a scalable delay-based component. T
    - Increases throughput more quickly in the congestion avoidance phase.
  - The AWND depend on the RTT measurements from successfully acknowledged packets.
  - Windows OS supports it as an option.
- Low Extra Delay Background Transport (LEDBAT)
  - Delay-based congestion control algorithm that uses all the available bandwidth while limiting the increase in delay. Measures one-way delay.
  - Supported by Windows 10 and latest versions of Mac OS X.

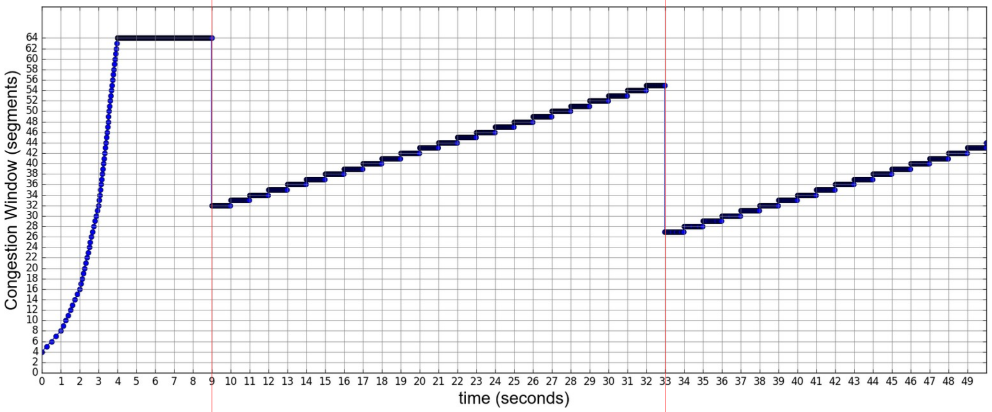
TCP Algorithms Comparison

- Tahoe

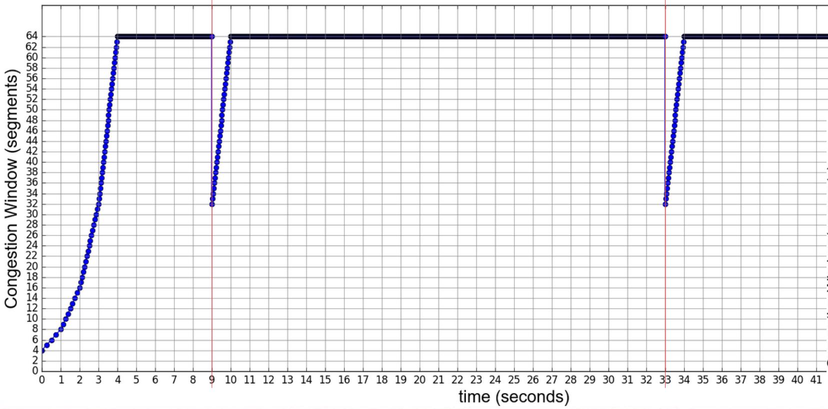


- Behavior and performance depends greatly on traffic and losses patterns, and end-points' behaviors
- In these examples:
    - Using a traffic pattern that sends a number of packets equal to the CWND, in one second interval, equally spaced over the interval.
    - Last packet of interval 8s-9s and 32s-33s are lost.
    - ACWD is 64, and initial CWND is 4 MSS (segments).
    - Receiver sends one ACK per packet.
    - Each dot represents a received ACK.
    - Tahoe sends 1585 packets, Reno 2017 packets and NewReno 2938 packets.

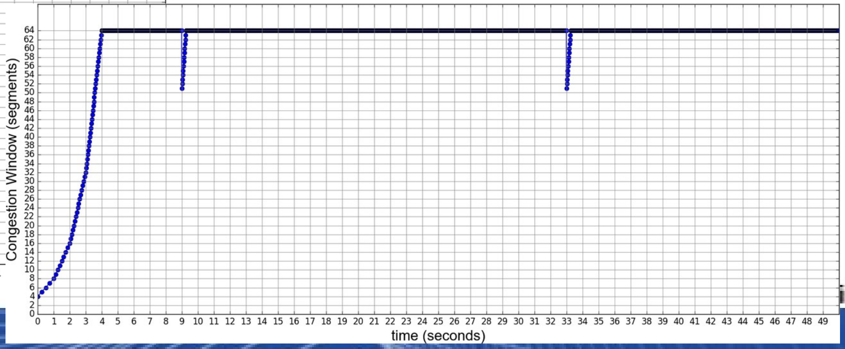
- Reno



- NewReno

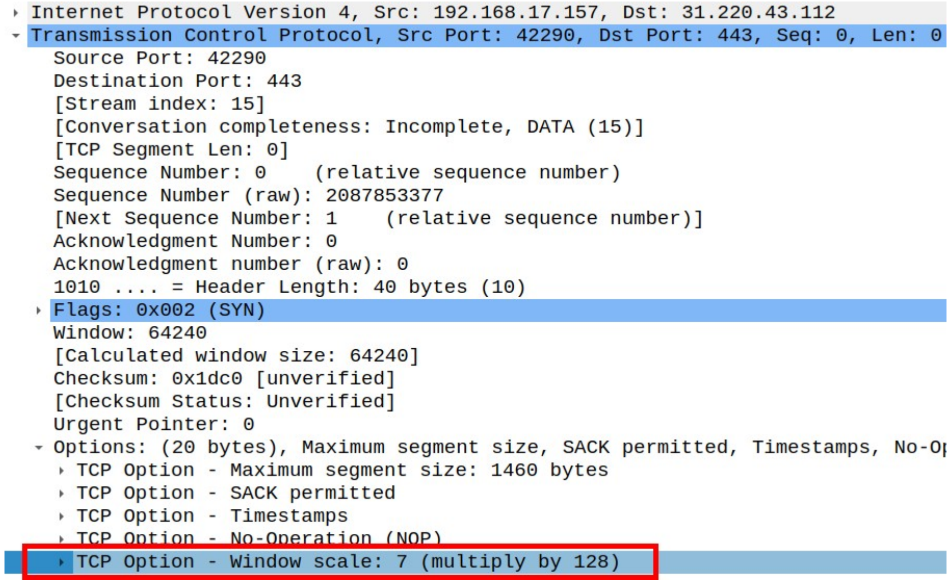


- Cubic

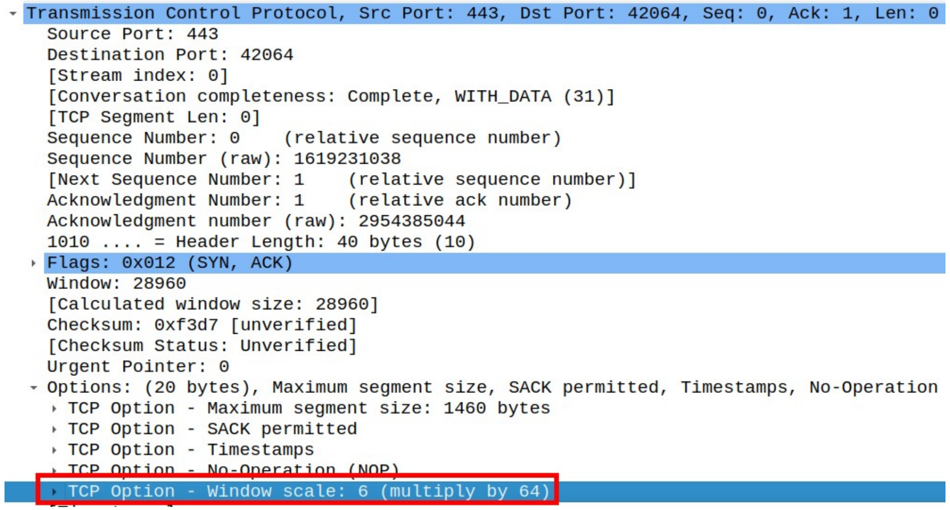


TCP Window Scaling

- Window field has only 16 bits, allows only 65536 bytes as maximum windows.
- Nowadays, devices have much more available memory and networks much more throughput.
- A small Window limits performance.
- The **TCP Window Scale** option was introduced by RFC 7323 in 2014.
  - Commonly used in current OS.
- The TCP Window Scale option defines the (power of 2) exponent that will be multiplied by the standard Window value.
  - Scaled Window Size = Window * 2^ (Window Scale exponent).
  - Sent/defined by each host, independently of the other, in the TCP session establishing packets (with SYN flag).
    - If a host receives a <SYN> packet containing a Window Scale option, it SHOULD send its own Window Scale option in the <SYN,ACK> packet.
  - The maximum scale exponent is limited to 14 for a maximum permissible window size of 1 GiB (2^(14+16)).
    - Common exponent values are 6 (2^6=64), 7 (2^7=128) and 8 (2^8=256).

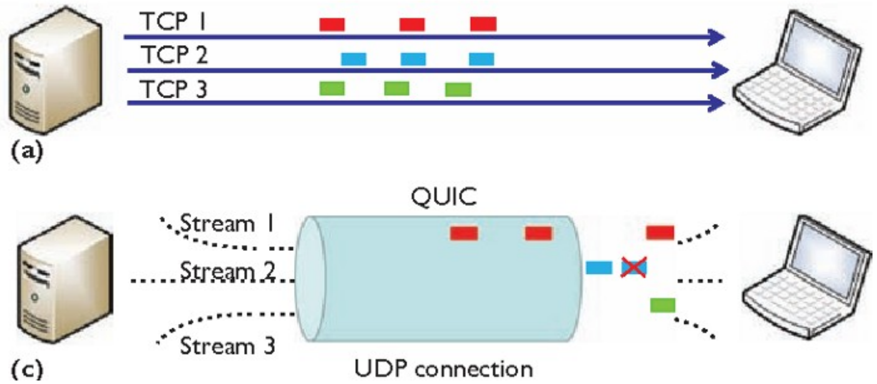


```
▸ Internet Protocol Version 4, Src: 192.168.17.157, Dst: 31.220.43.112
▾ Transmission Control Protocol, Src Port: 42290, Dst Port: 443, Seq: 0, Len: 0
    Source Port: 42290
    Destination Port: 443
    [Stream index: 15]
    [Conversation completeness: Incomplete, DATA (15)]
    [TCP Segment Len: 0]
    Sequence Number: 0    (relative sequence number)
    Sequence Number (raw): 2087853377
    [Next Sequence Number: 1    (relative sequence number)]
    Acknowledgment Number: 0
    Acknowledgment number (raw): 0
    1010 .... = Header Length: 40 bytes (10)
  ▸ Flags: 0x002 (SYN)
    Window: 64240
    [Calculated window size: 64240]
    Checksum: 0x1dc0 [unverified]
    [Checksum Status: Unverified]
    Urgent Pointer: 0
  ▾ Options: (20 bytes), Maximum segment size, SACK permitted, Timestamps, No-Op
    ▸ TCP Option - Maximum segment size: 1460 bytes
    ▸ TCP Option - SACK permitted
    ▸ TCP Option - Timestamps
    ▸ TCP Option - No-Operation (NOP)
    ▸ TCP Option - Window scale: 7 (multiply by 128)
```



```
▾ Transmission Control Protocol, Src Port: 443, Dst Port: 42064, Seq: 0, Ack: 1, Len: 0
    Source Port: 443
    Destination Port: 42064
    [Stream index: 0]
    [Conversation completeness: Complete, WITH_DATA (31)]
    [TCP Segment Len: 0]
    Sequence Number: 0    (relative sequence number)
    Sequence Number (raw): 1619231038
    [Next Sequence Number: 1    (relative sequence number)]
    Acknowledgment Number: 1    (relative ack number)
    Acknowledgment number (raw): 2954385044
    1010 .... = Header Length: 40 bytes (10)
  ▸ Flags: 0x012 (SYN, ACK)
    Window: 28960
    [Calculated window size: 28960]
    Checksum: 0xf3d7 [unverified]
    [Checksum Status: Unverified]
    Urgent Pointer: 0
  ▾ Options: (20 bytes), Maximum segment size, SACK permitted, Timestamps, No-Operation
    ▸ TCP Option - Maximum segment size: 1460 bytes
    ▸ TCP Option - SACK permitted
    ▸ TCP Option - Timestamps
    ▸ TCP Option - No-Operation (NOP)
    ▸ TCP Option - Window scale: 6 (multiply by 64)
```

QUIC



- QUIC was developed and deployed by Google in 2013, but was presented as a standard in 2021 by RFC9000.
- QUIC packets are carried in UDP datagrams to better facilitate deployment in existing systems and networks.
- QUIC handshake combines negotiation of cryptographic (TLS) and transport parameters.
  - Is structured to permit the exchange of application data as soon as possible.
- Provides the necessary feedback to implement reliable delivery and congestion control.
- Application protocols exchange information over a QUIC connection via streams which are ordered sequences of bytes. Two types of streams can be created:
  - Bidirectional streams, which allow both endpoints to send data.
  - Unidirectional streams, which allow a single endpoint to send data.
- Avoids head-of-line blocking across multiple streams.
  - When a packet loss occurs, only streams with data in that packet are blocked waiting for a retransmission to be received, while other streams can continue making progress.
- Two levels of data flow control in QUIC:
  - Stream flow control, which prevents a single stream from consuming the entire receive buffer for a connection by limiting the amount of data that can be sent on each stream.
  - Connection flow control, which prevents senders from exceeding a receiver's buffer capacity for the connection by limiting the total bytes of stream data sent in STREAM frames on all streams.