UDP & TCP

Fundamentos de Redes

Mestrado Integrado em
Engenharia de Computadores e Telemática
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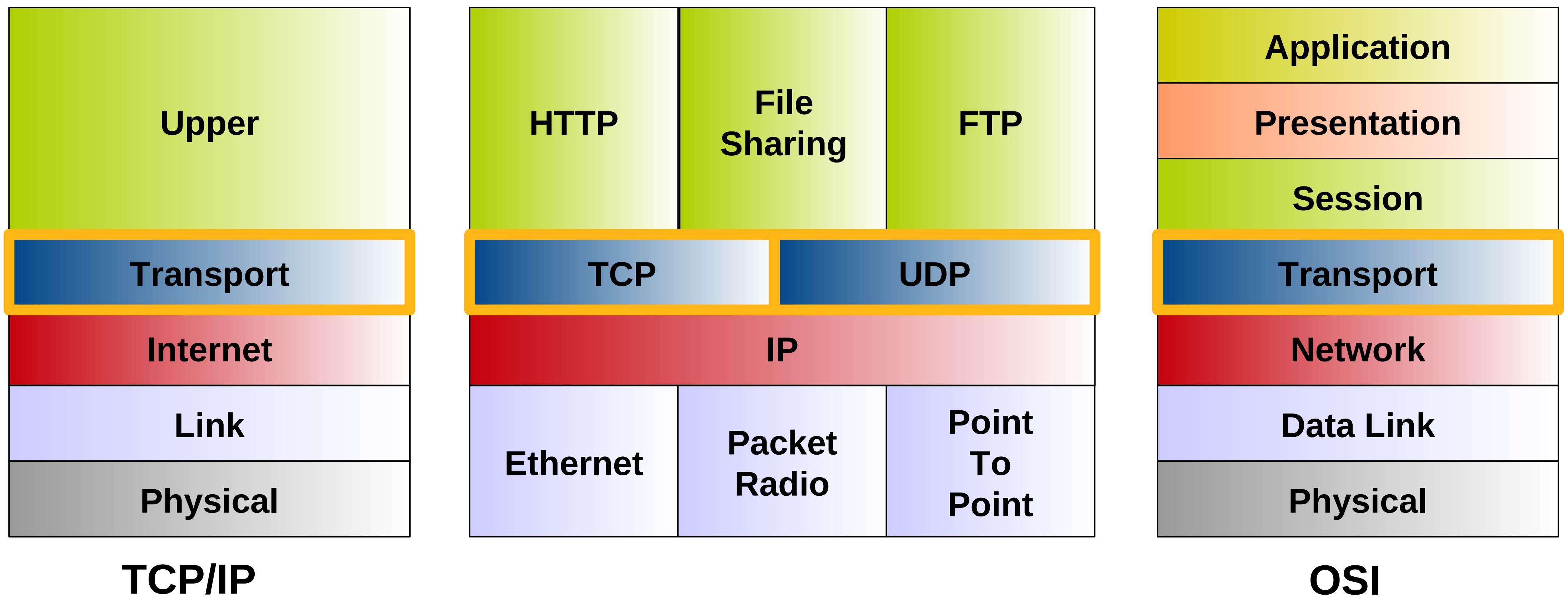
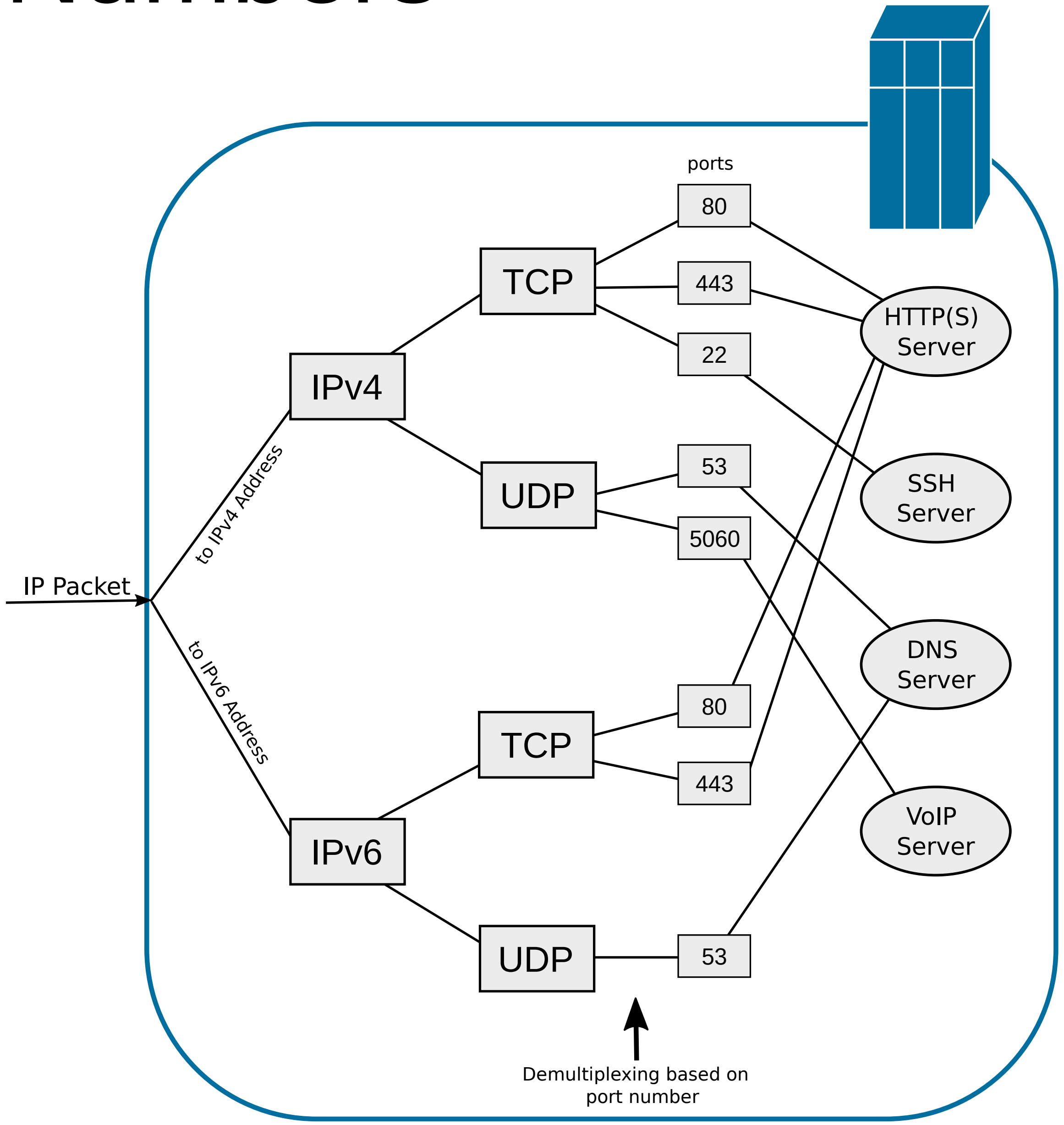
TCP/IP Reference Models



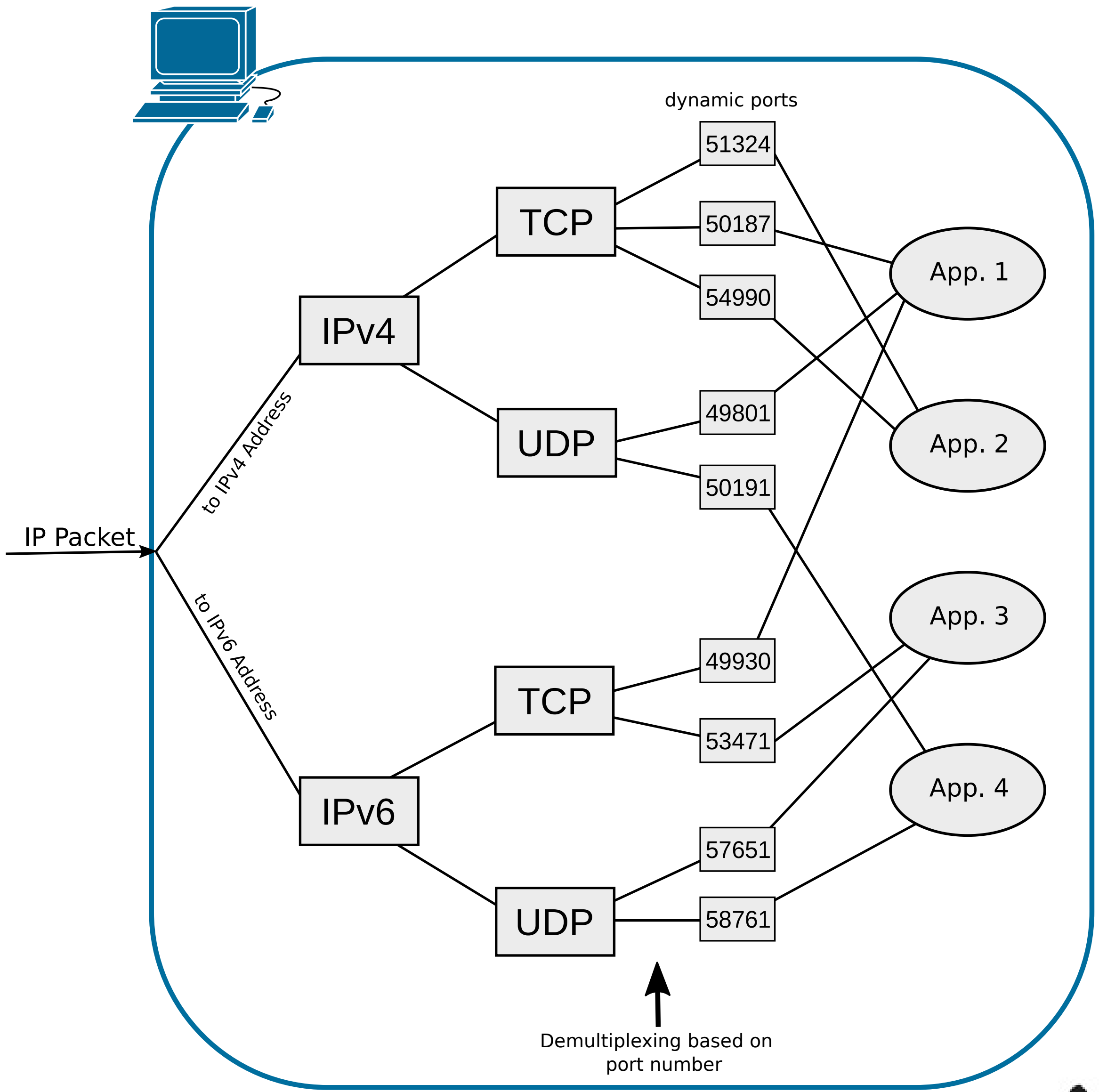
Port Numbers

- The packet destination IP address identifies a target host on the network.
- The transport protocol identifies the type of communication.
- The port number identifies the application running in the target host.
    - Chosen by the application/service.
        - Non-dynamic ports.
    - Each application/service may use more than one port.
    - The OS assures the assignment of different port numbers to each application.



Ephemeral/Dynamic Ports

- Ephemeral/Dynamic ports are used to identify a client application in a client-server communication.
- The Internet Assigned Numbers Authority (IANA) suggests the range 49152 to 65535.
- Randomly assigned by OS.



Well Known Port Numbers

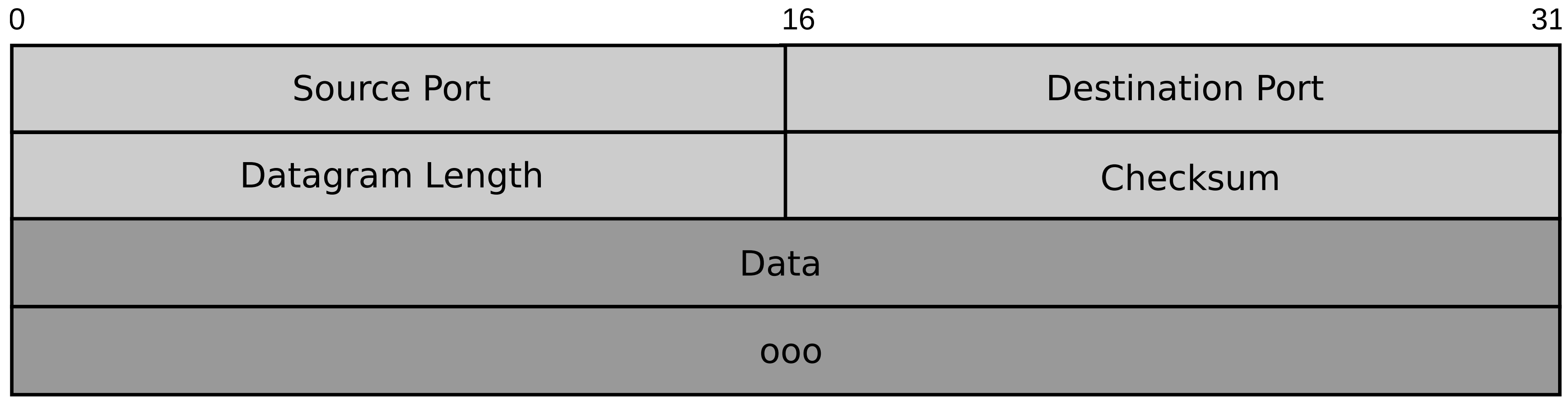
Decimal	Keyword	Protocol	Description
20	FTP-DATA	TCP	File Transfer Protocol (dados)
21	FTP-CONTROL	TCP	File Transfer Protocol (controlo)
22	SSH	TCP	Secure Shell (SSH) service
25	SMTP	TCP	Simple Mail Transport Protocol
67,68	BOOTP	UDP	Bootstrap Protocol (DHCP)
53	DNS	UDP/TCP	Domain Name System
69	TFTP	UDP	Trivial File Transfer Protocol
80	HTTP	TCP	Hypertext Transfer Protocol

- Many Internet IP services were the subject of study by IETF that proposed adequate support protocols.
- For these services, IETF together with the protocol specification proposed also a number (or numbers) to be used by that service at the server side.
- E.g., for protocol HTTP IETF recommends the usage of port 80. Therefore, all Web Browsers use port 80 as default for HTTP accesses.

User Datagram Protocol (UDP)

- Provides a data transport service with the performance characteristics offered by the IP network.
- Provides exchange of data between individual applications, and not only between hosts, with the introduction of a port identifier field.
- Does not provide any mechanism to recover from lost messages.
- Does not provide any mechanism to order received data.
  - Must rely on information at the application level.
- Allows to send data to multiple destinations simultaneously (point-to-multipoint communications).

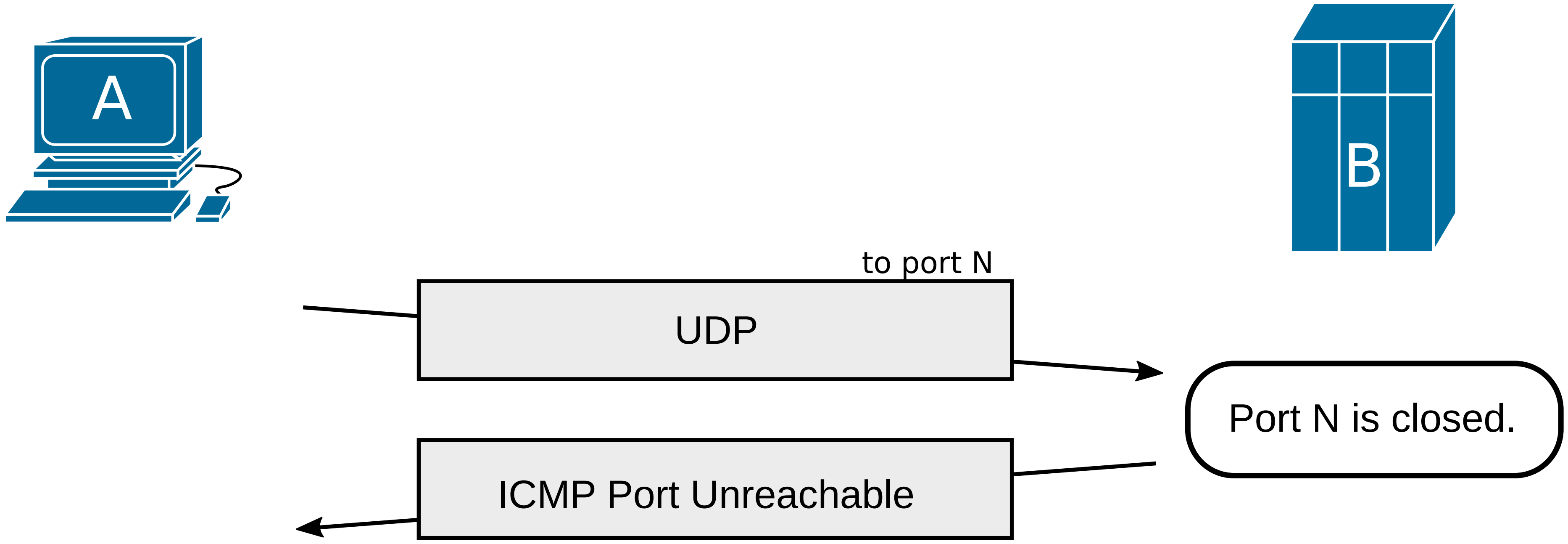
UDP Datagram (Header+Data)



- Source Port (2 bytes): defines the port number assign/chosen by the sender application. This field is optional, if not used should be field with zeros.
- Destination Port (2 bytes): defines the port number assign/chosen by the receiver application.
- Datagram Length (2 bytes): defines the size,in bytes, of the datagram (header+data).
- Checksum (2 bytes): used for data error detection and validation at the end-points. This field is optional, if not used should be field with zeros.
  - The checksum us calculated based on the UDP datagram and a pseudoheader IP (IP protocol identifier, source and destination IP addresses, and length of the IP datagram).
  - Can be used to verify if the end-points are the correct ones.

UDP Closed Port

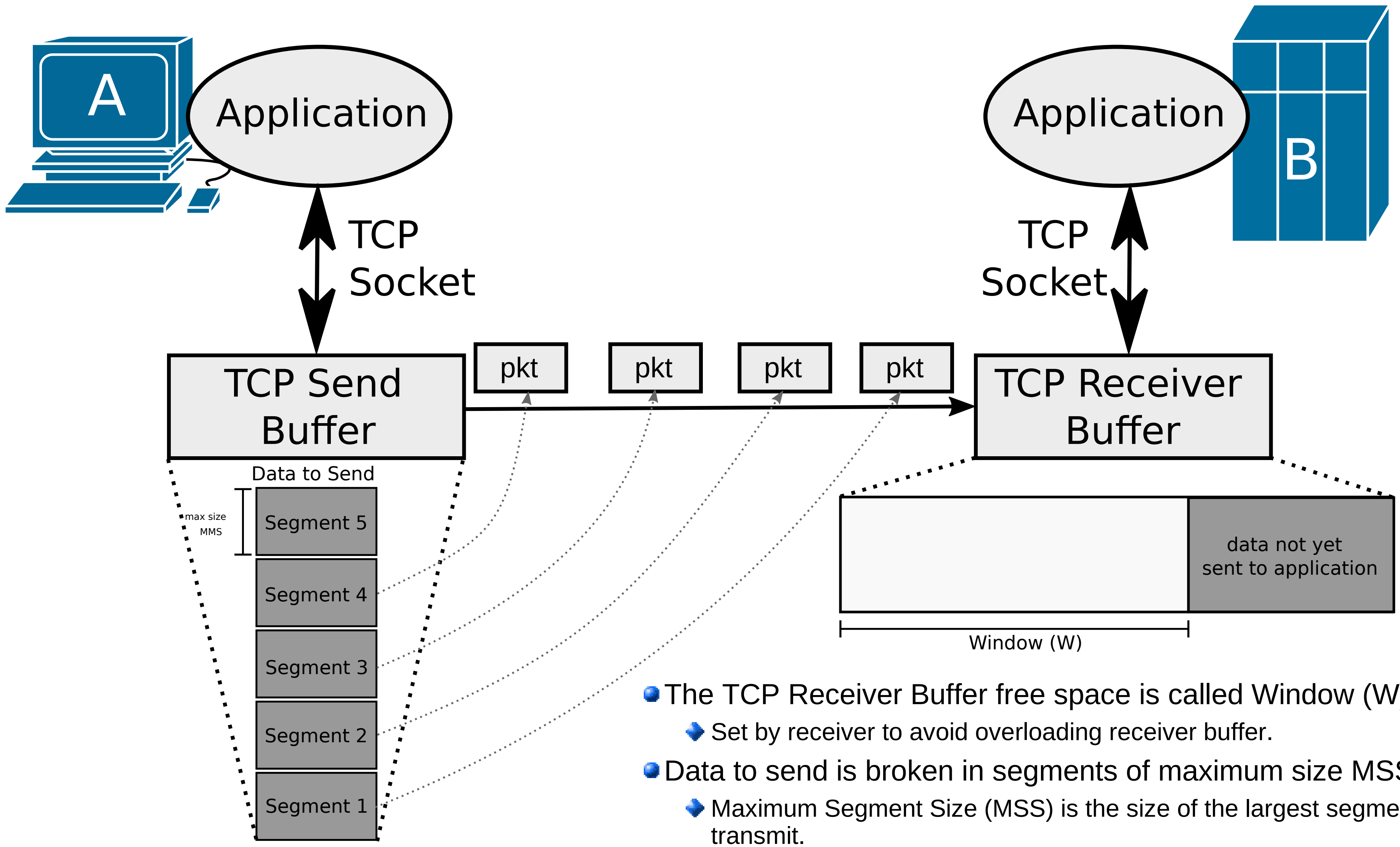
- When an UDP packet arrives to a host, but the UDP port is not open (no application listening):
  - The host responds with a packet ICMP *port unreachable*.



Transmission Control Protocol (TCP)

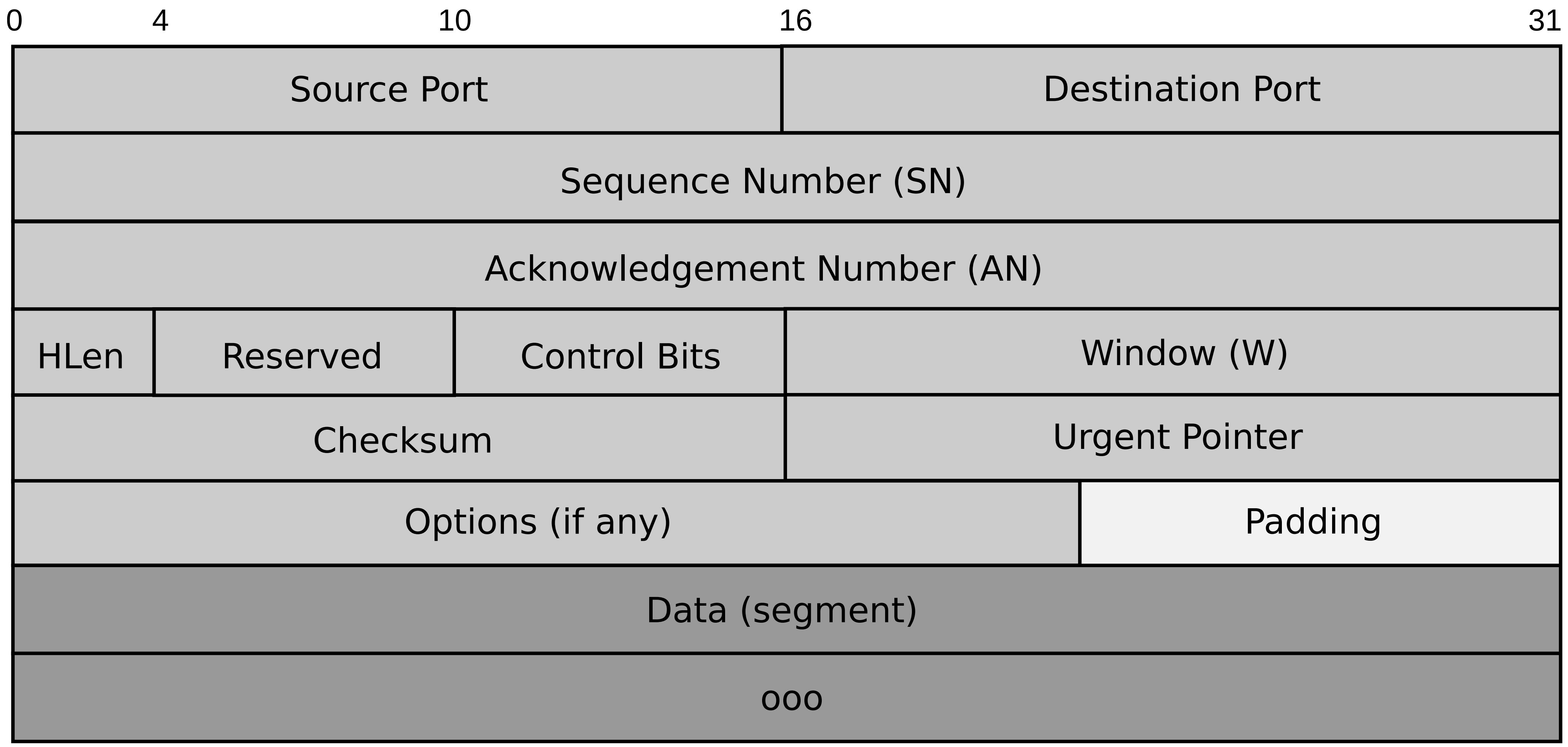
- Provides a reliable data transport service.
  - Data is received by the destination application without any losses and in order.
- Is connection-oriented protocol.
  - End-points establish a logical channel, to which are assigned applications' identifiers and the memory resources required to have a reliable transmission of data.
  - This connection is called Session.
- It is bi-directional.
  - Both end-points can send and receive data using the same logical channel.
- Traditional TCP supports only point-to-point connections.
  - See: Multipath TCP on last slide.
- Provides mechanisms to establish and terminate the connection.
- Network congestion and/or temporary lack of connectivity result in variable delays and consequent losses of packets (at transit or by timeout).
  - TCP includes algorithm that allows to efficiently react in this scenario.

TCP Buffers and Receiver Window



- The TCP Receiver Buffer free space is called Window (W).
  - Set by receiver to avoid overloading receiver buffer.
- Data to send is broken in segments of maximum size MSS.
  - Maximum Segment Size (MSS) is the size of the largest segment that a sender can transmit.
  - Defined by local configuration.
- The sender has an estimation of the available space at the receiver buffer (RWND) given by the reported remote buffer space (W) minus the already sent bytes not yet acknowledged (NACK).

TCP Packet Header (1)

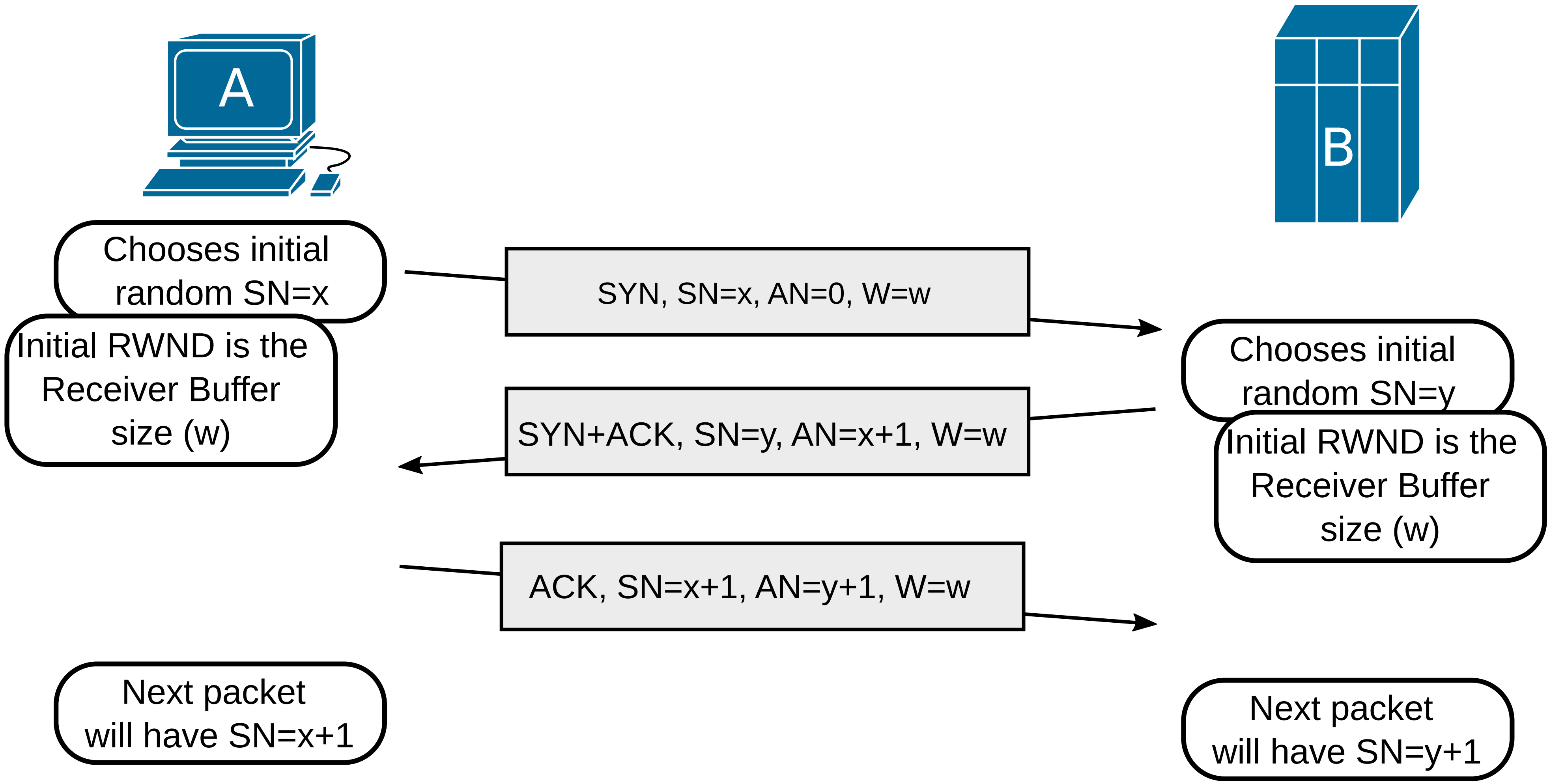


TCP Packet Header (2)

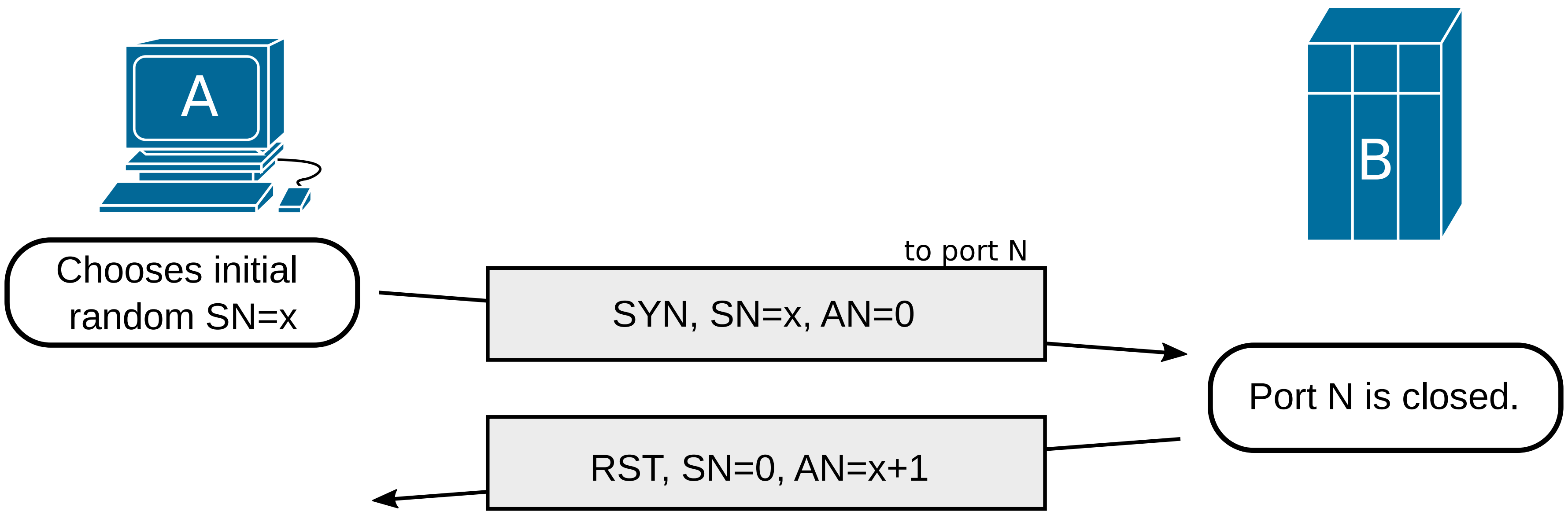
- The TCP Header has a variable length.
  - The field *Options* may contain additional fields.
- *Source Port* and *Destination Port* fields define the respective end-point ports.
- The *Sequence Number* defines the index of the first data byte in this segment.
- The *Acknowledge Number* defines the value of the next sequence number.
  - Acknowledges the good reception of data until byte with index (Acknowledge Number-1)
- *HLen* defines the size of the TCP header in bytes.
  - When *Options* are present, the field *Padding* is used to extend the header size to a multiple of 32 bytes.
- *Window (W)* field defined the number of data bytes the sender of this segment is willing to accept. Free space on the reception buffer.
  - The estimation of the remote receiver free buffer is called Receiver Window (RWND), as is given by the reported remote buffer space (W) minus the already sent bytes not yet acknowledged (NACK).
- *Control Bits* field is a binary set of flags
  - URG: Urgent Pointer is a valid field.
  - ACK: Acknowledgement is a valid field.
  - PSH: Data requires Push (receiver should push immediately data from TCP buffer to application).
  - RST: Connection Reset.
  - SYN: Sincronize Sequence Number.
  - FIN : Source closing connection.
- *Urgent Pointer* field defines the portion of data that should be considered urgent.
  - Not used by modern protocols.
- *Checksum* is used to detect errors.

Establishement of a TCP Connection

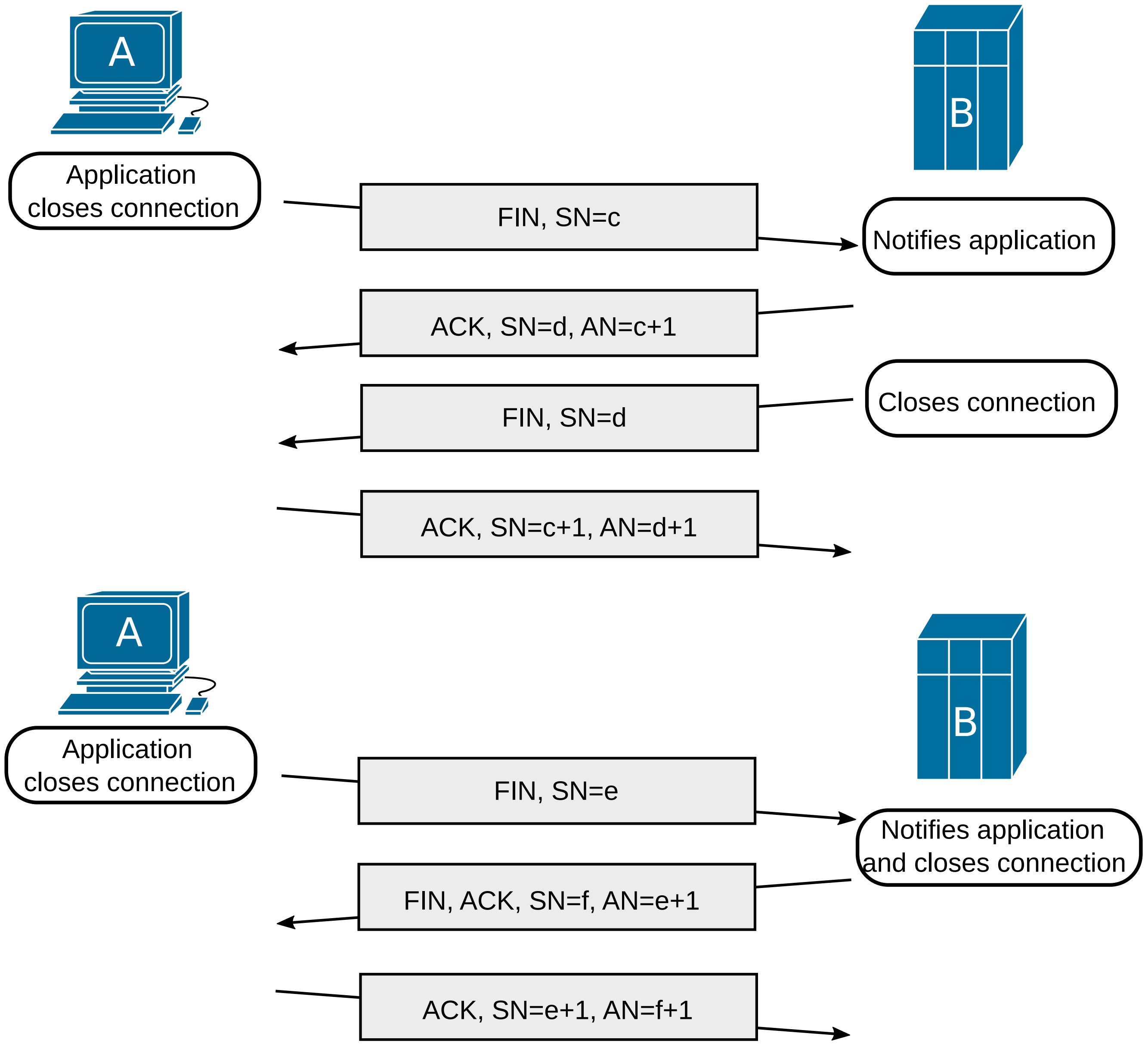
- 3-Way Handshake.
  - Synchronizes the both end-points initial *Sequence Numbers* (SYN), and acknowledges it (ACK flag).


A
B
Chooses initial random SN=x
Initial RWND is the Receiver Buffer size (w)
SYN, SN=x, AN=0, W=w
Chooses initial random SN=y
Initial RWND is the Receiver Buffer size (w)
SYN+ACK, SN=y, AN=x+1, W=w
ACK, SN=x+1, AN=y+1, W=w
Next packet will have SN=x+1
Next packet will have SN=y+1

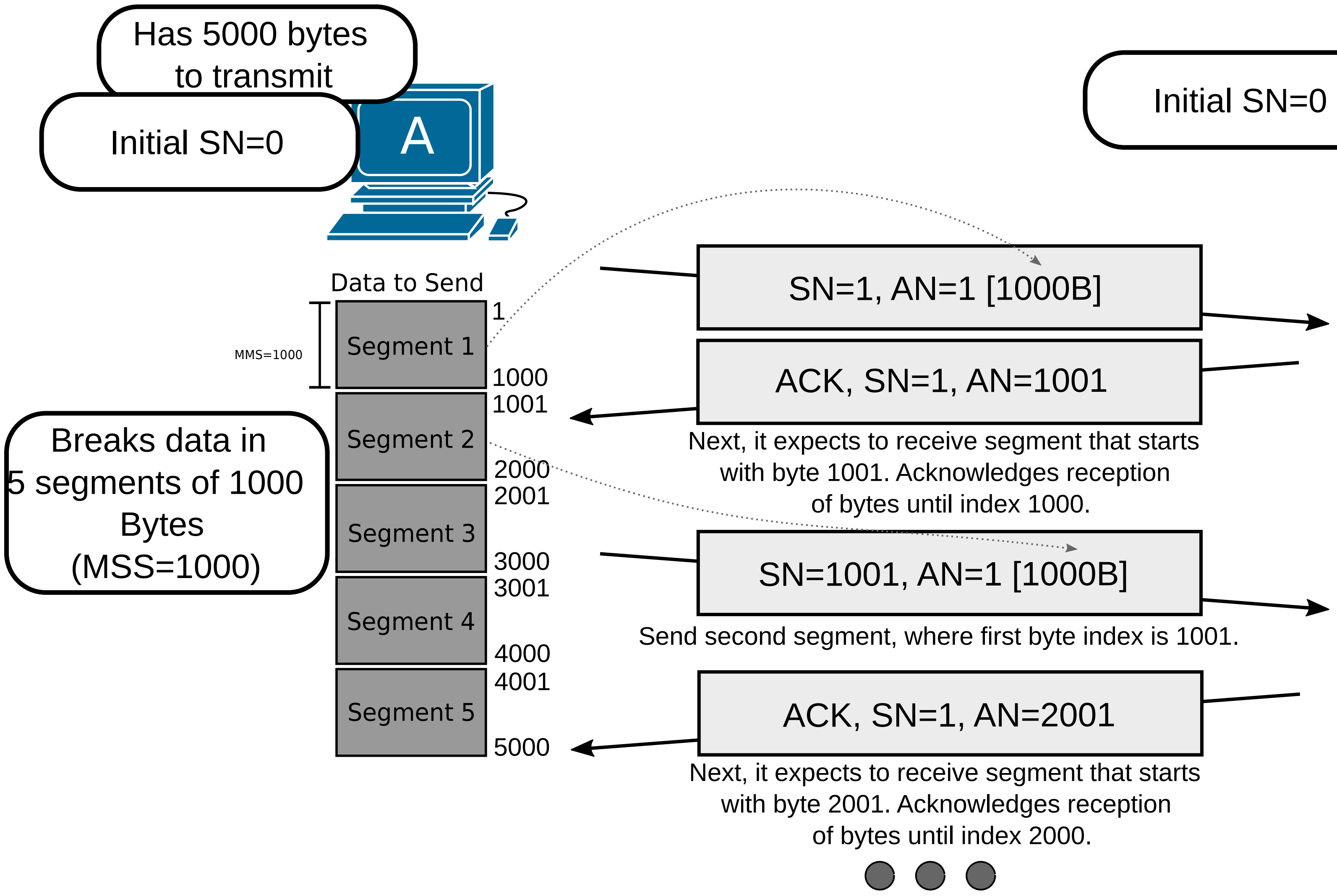
Establishement of a TCP Connection to a Closed Port



Closing a TCP Connection



Data Delivery Acknowledgment

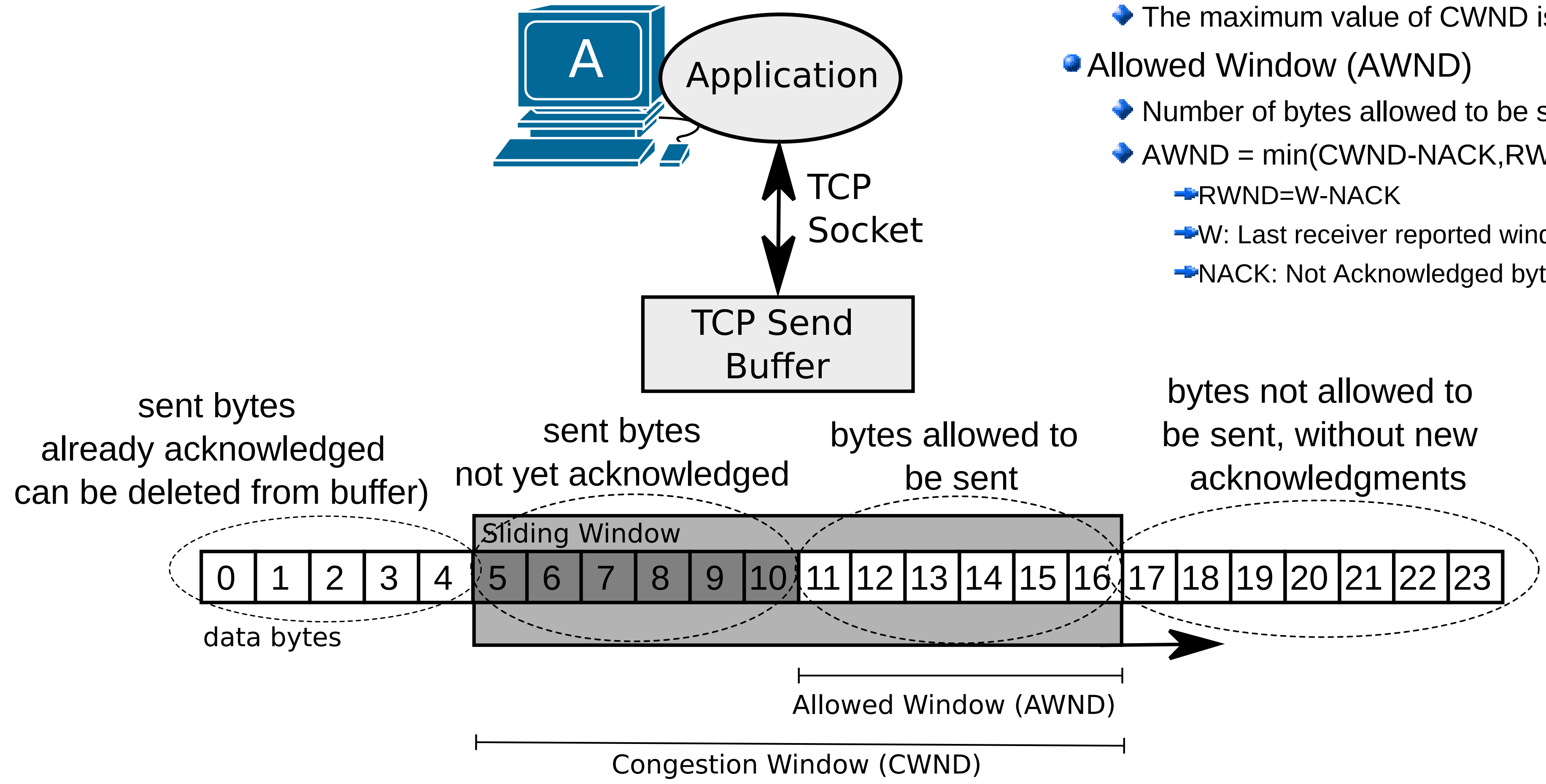

Has 5000 bytes to transmit
Initial SN=0
A
Initial SN=0
B
Data to Send
MMS=1000
Segment 1
Segment 2
Segment 3
Segment 4
Segment 5
1
1000
1001
2000
2001
3000
3001
4000
4001
5000
Breaks data in 5 segments of 1000 Bytes (MSS=1000)
SN=1, AN=1 [1000B]
ACK, SN=1, AN=1001
Next, it expects to receive segment that starts with byte 1001. Acknowledges reception of bytes until index 1000.
SN=1001, AN=1 [1000B]
Send second segment, where first byte index is 1001.
ACK, SN=1, AN=2001
Next, it expects to receive segment that starts with byte 2001. Acknowledges reception of bytes until index 2000.

- Sender can (usually) send more than one packet before receiving the ACK.
  - Depends on the congestion window (next slide).
- Both end-points can send data.
  - A packet with a data segment, can acknowledge the reception of data a segment received from the other end-point.

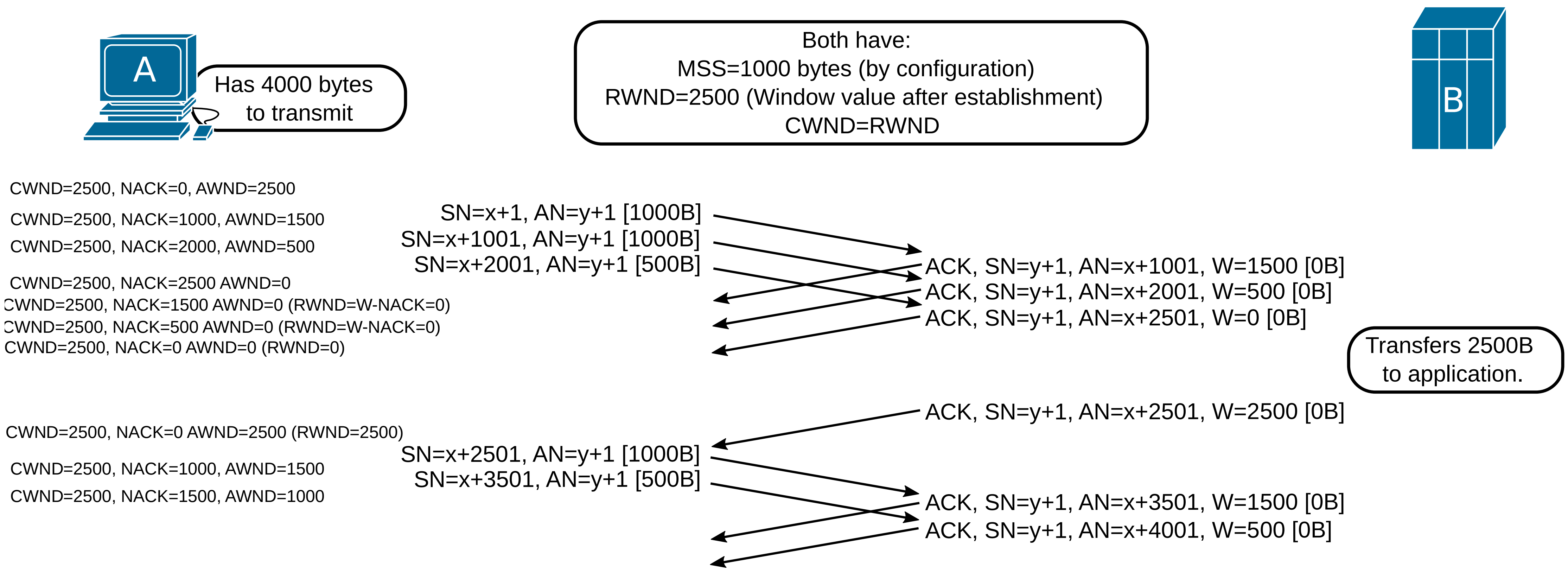
TCP Congestion Control (1)

- 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.



TCP Congestion Control (2)

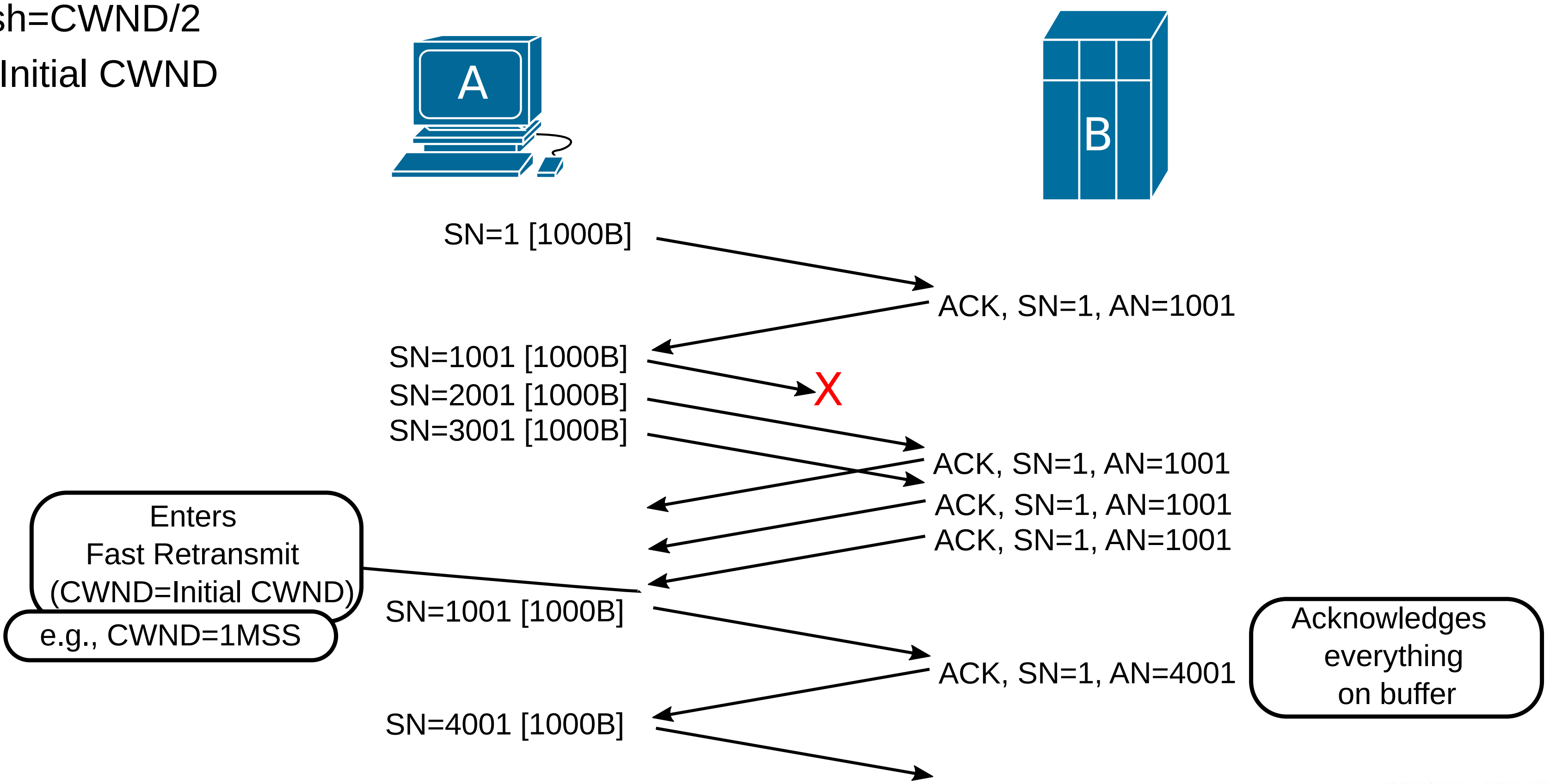

A
Has 4000 bytes to transmit
Both have:
MSS=1000 bytes (by configuration)
RWND=2500 (Window value after establishment)
CWND=RWND
B
CWND=2500, NACK=0, AWND=2500
CWND=2500, NACK=1000, AWND=1500
CWND=2500, NACK=2000, AWND=500
CWND=2500, NACK=2500 AWND=0
CWND=2500, NACK=1500 AWND=0 (RWND=W-NACK=0)
CWND=2500, NACK=500 AWND=0 (RWND=W-NACK=0)
CWND=2500, NACK=0 AWND=0 (RWND=0)
SN=x+1, AN=y+1 [1000B]
SN=x+1001, AN=y+1 [1000B]
SN=x+2001, AN=y+1 [500B]
ACK, SN=y+1, AN=x+1001, W=1500 [0B]
ACK, SN=y+1, AN=x+2001, W=500 [0B]
ACK, SN=y+1, AN=x+2501, W=0 [0B]
Transfers 2500B to application.
ACK, SN=y+1, AN=x+2501, W=2500 [0B]
CWND=2500, NACK=0 AWND=2500 (RWND=2500)
CWND=2500, NACK=1000, AWND=1500
CWND=2500, NACK=1500, AWND=1000
SN=x+2501, AN=y+1 [1000B]
SN=x+3501, AN=y+1 [500B]
ACK, SN=y+1, AN=x+3501, W=1500 [0B]
ACK, SN=y+1, AN=x+4001, W=500 [0B]

TCP Congestion Control (3)

- A packet with a data segment is considered lost when:
  - Timeout: After some time no ACK is received for that data segment
  - With Fast Retransmit/Recovery: After 3 or more duplicate ACKs are received for the previous data segment.
- When a packet is lost, TCP automatically decreases transmission rate to adapt to network conditions.
  - i.e., Decreases CWND size.
- When data delivery is acknowledged, TCP increases transmission rate.
  - i.e., Increases CWND size.
- The way the CWND size varies depend on the TCP Algorithms used:
  - Tahoe (Original TCP, 1988) uses:
    - Fast Retransmit, Slow Start, and Congestion Avoidance.
  - Reno (1990) uses:
    - Uses Fast Recovery, and Congestion Avoidance.
- At the beginning, the initial CWND value is usually 2, 3, 4, or 10 MSS and then the terminal starts the *Slow Start* with SSThresh=RWND*.*

TPC Fast Retransmit

- A segment is considered lost if 3 or more duplicate ACKs are received for the previous data segment.
  - Faster detection than waiting for a timeout.
  - Requires receiver to work.
- TCP retransmits immediately the lost segment.
- The TCP algorithm enters Slow-Start, with:
  - SSThresh=CWND/2
  - CWND=Initial CWND

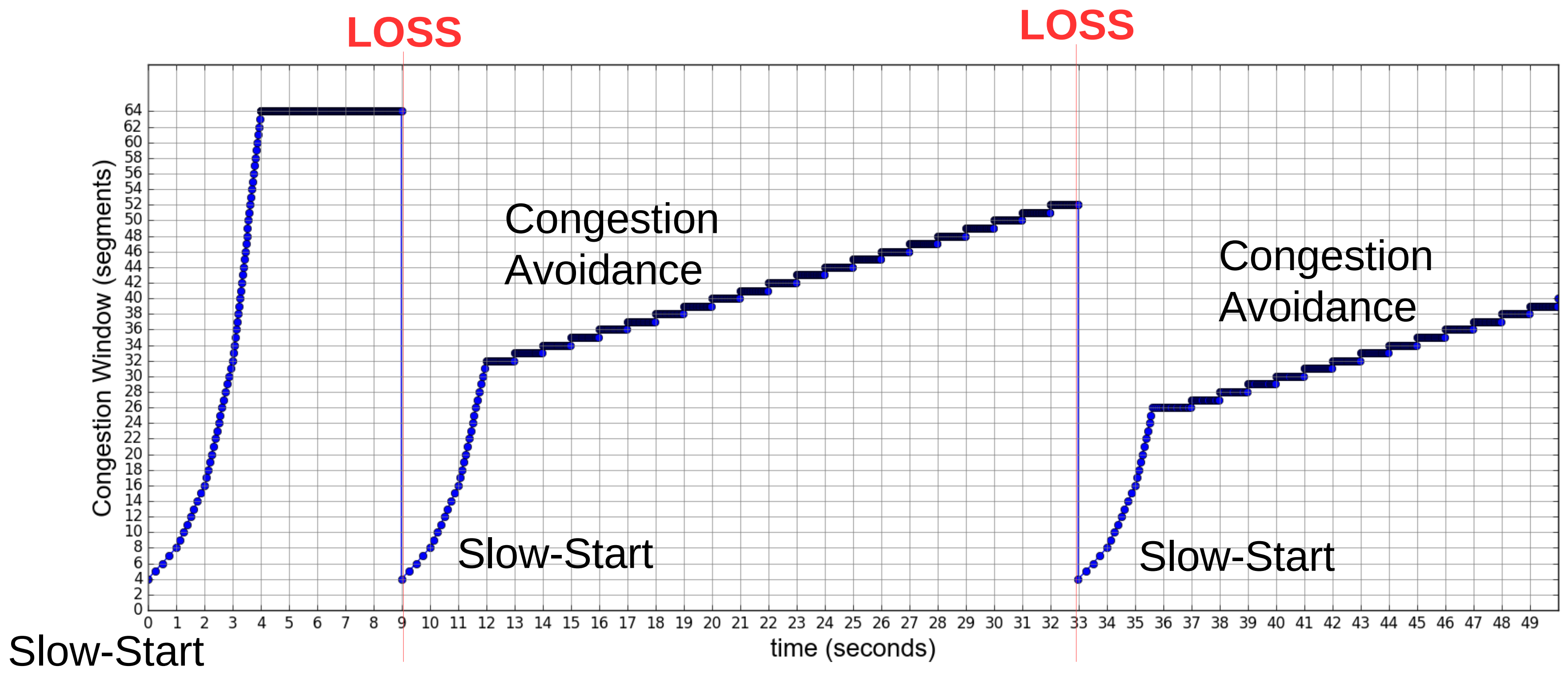


TCP Slow-Start

- At the beginning, the initial CWND value is usually 2, 3, 4, or 10 MSS and the terminal starts the *Slow Start* with SSThresh=RWND*.*
- CWND size grows very fast while smaller than the predefined threshold (CWND<SSThresh).
    - When a ACK arrives the CWND is updated: CWND=CWND+N,
        - N is the number of bytes acknowledged in the ACK.
        - Results that the window size (approximately) doubles each round-trip time.
            - Exponential growth.
        - Continues until a loss occurs or CWND reaches RWND.
- When a loss occurs, SSThresh is defined as CWND/2 and Slow-Start begins again from its initial CWND.
- Once the CWND reaches the SSThresh, it changes to congestion avoidance algorithm.
    - Linear growth.

TCP Congestion Avoidance

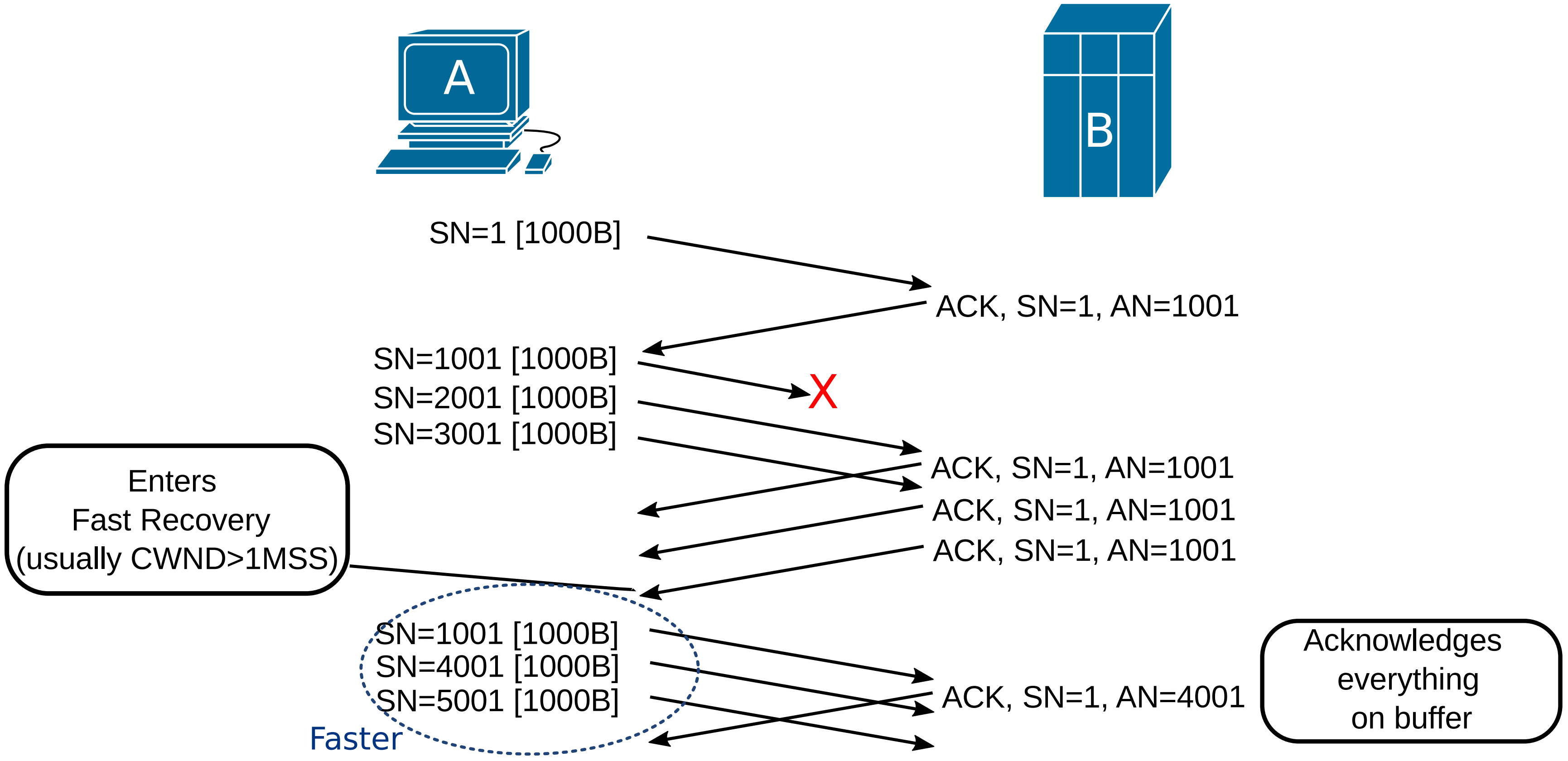
- When a ACK arrives the CWND is updated: CWND=CWND+N/CWND,
  - This results in a linear increase of the CWND.



- RWND is 64, and initial CWND is 4 MSS (segments).
- Initial SSThresh=RWND=64. After first loss: SSThresh=CWND/2=32. After second loss: SSThresh=CWND/2=26.

TPC Fast Recovery

- The same as TPC Fast Retransmit.
- However when a loss occurs enters directly to Congestion Avoidance with:
  - SSThresh=CWND/2
  - CWND=SSThresh
    - Some implementation have: CWND=SSThresh+3*MSS.

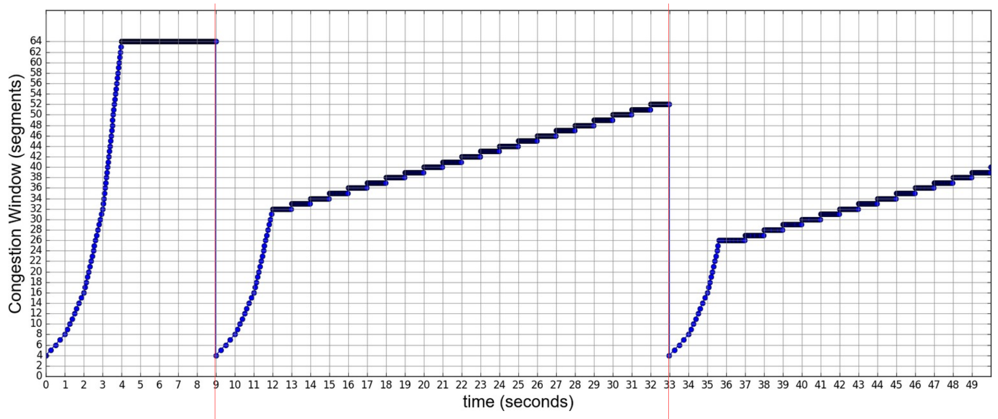


Other TCP Algorithms

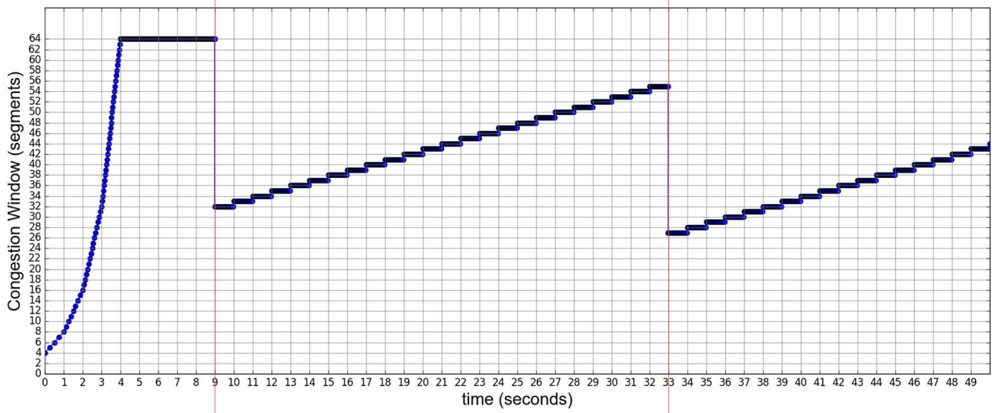
- NewReno (1996)
  - Allows for partial ACK.
  - When a loss occurs, CWND is defined as β*CWND, with β=0.5. When a ACK arrives, CWND is updated as CWND=CWND+α, with α=1 MMS.
  - Used by default in Windows and supported by Mac OS X.
    - Used in Windows XP and earlier.
    - After Windows Vista, Compound 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

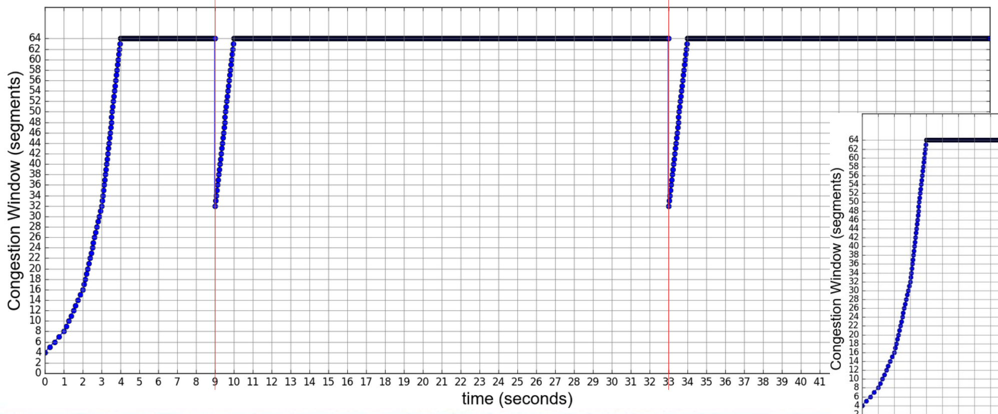
- Tahoe



- Reno

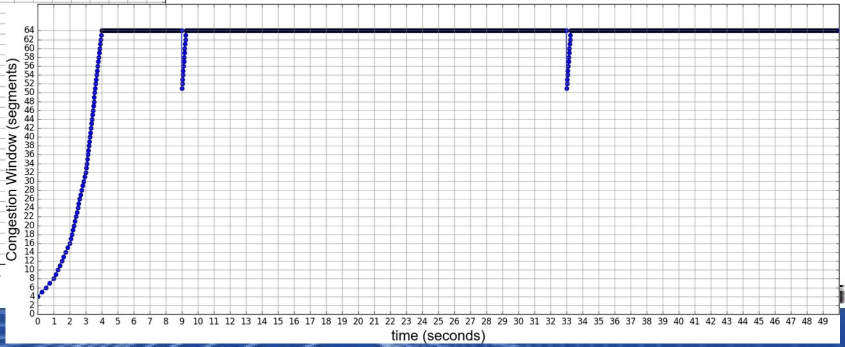


- NewReno



- 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.

- Cubic



Multipath TCP (MPTCP)

- TCP is essentially a single-path protocol.
  - When a TCP connection is established, the transmission is bound to the IP addresses of the two end-points.
  - If one address changes the TCP session will fail.
  - TCP can not load balance segments using more than um TCP session.
    - This load balancing must be done at the application level.
- Multipath TCP allows multiple subflows within a single MPTCP session.
  - A MPTCP session starts with an initial subflow, using the traditional 3-Way Handshake.
  - After the first MPTCP subflow is established, additional subflows can also established similar to the tradional TCP 3-Way Handshake. However, but rather than being a separate session, all subflows are bounded to the same MPTCP session.
  - Data can then be sent over any of the active subflows, using joint *Sequence* and *Acknowledgment Numbers.*
- Apple’s Siri application uses Multipath TCP.