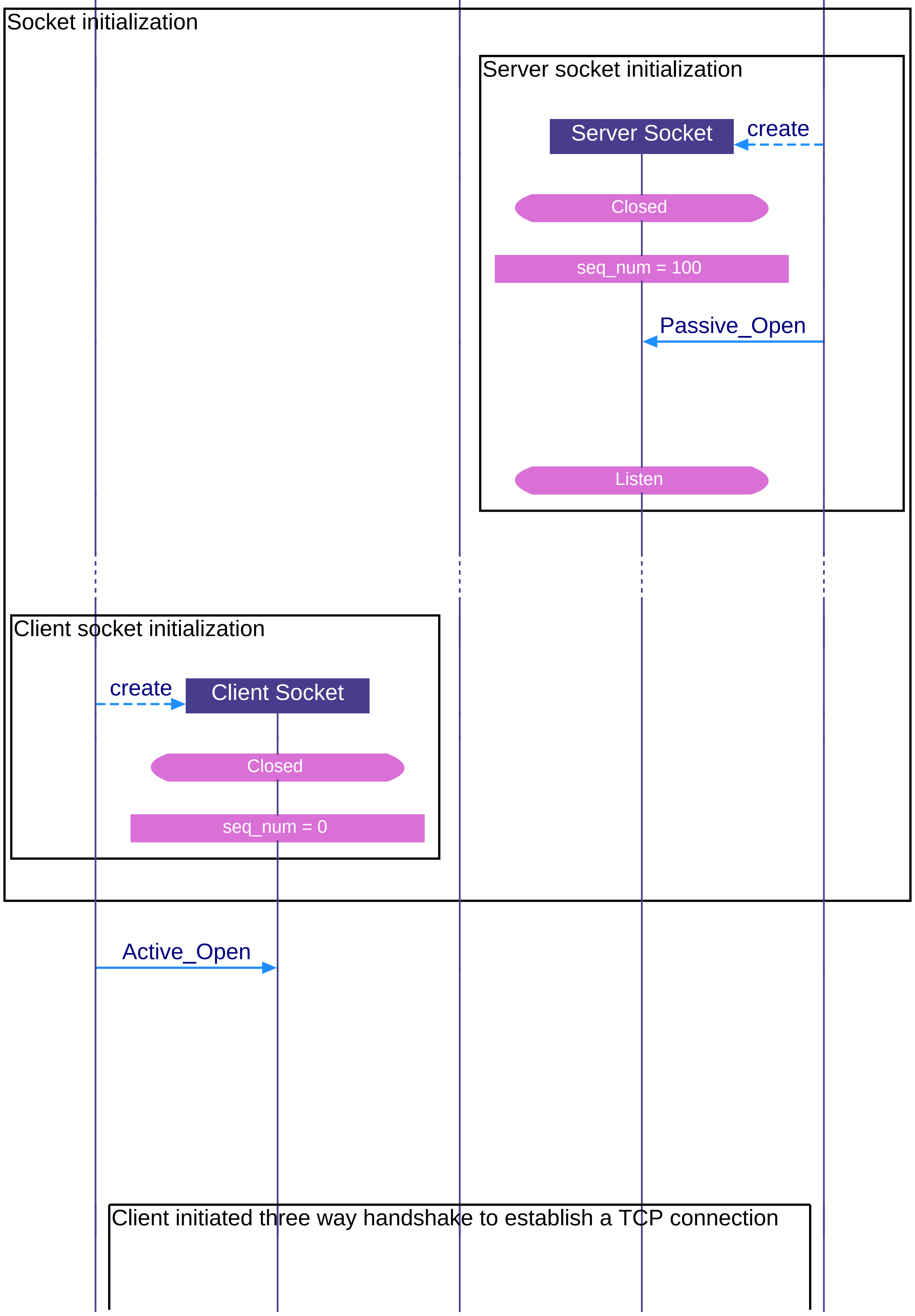
TCP - Transmission Control Protocol (TCP Slow Start)

Client Node		Internet	Server Node		EventStudio System Designer 6
Client		Net	Server		25-May-13 15:32 (Page 1)
Client App		Network		Server App	

This sequence diagram was generated with EventStudio System Designer (http://www.EventHelix.com/EventStudio).

TCP is an end to end protocol which operates over the heterogeneous Internet. TCP has no advance knowledge of the network characteristics, thus it has to adjust its behavior according to the current state of the network. TCP has built in support for congestion control. Congestion control ensures that TCP does not pump data at a rate higher than what the network can handle.

In this sequence diagram we will analyse "Slow start", an important part of the congestion control mechanisms built right into TCP. As the name suggests, "Slow Start" starts slowly, increasing its window size as it gains confidence about the networks throughput.



Server Application creates a Socket

The Socket is created in Closed state

Server sets the initial sequence number to 100

Server application has initiated a passive open. In this mode, the socket does not attempt to establish a TCP connection. The socket listens for TCP connection request from clients

Socket transitions to the Listen state

Server awaits client socket connections.

Client Application creates Socket

The socket is created in the Closed state

Initial sequence number is set to 0

Application wishes to communicate with a destination server using a TCP connection. The application opens a socket for the connection in active mode. In this mode, a TCP connection will be attempted with the server.
Typically, the client will use a well known port number to communicate with the remote Server. For example, HTTP uses port 80.

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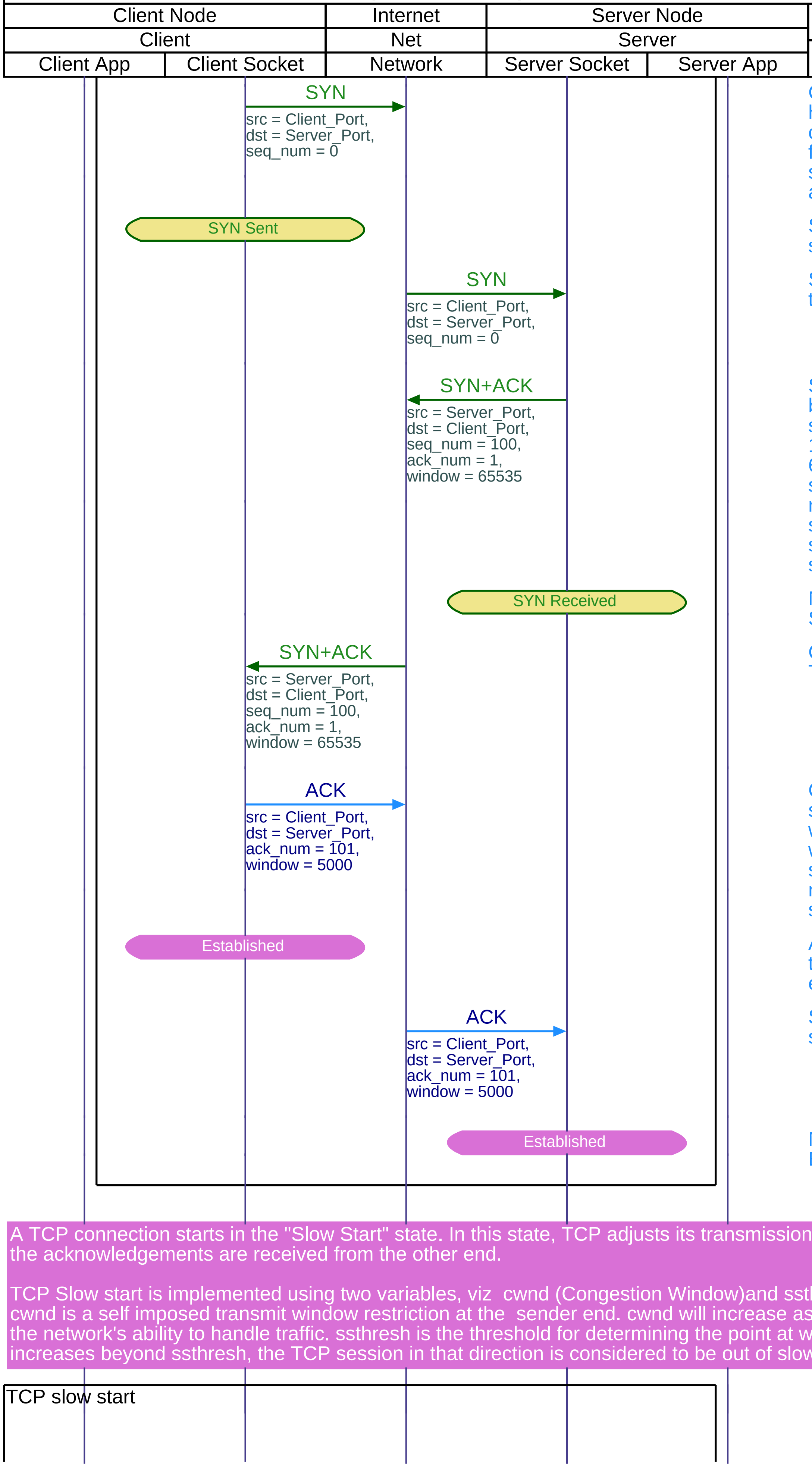

Client Node
Internet
Server Node
Client
Net
Server
Client App
Client Socket
Network
Server Socket
Server App
SYN
src = Client_Port, dst = Server_Port, seq_num = 0
SYN Sent
SYN
src = Client_Port, dst = Server_Port, seq_num = 0
SYN+ACK
src = Server_Port, dst = Client_Port, seq_num = 100, ack_num = 1, window = 65535
SYN Received
SYN+ACK
src = Server_Port, dst = Client_Port, seq_num = 100, ack_num = 1, window = 65535
ACK
src = Client_Port, dst = Server_Port, ack_num = 101, window = 5000
Established
ACK
src = Client_Port, dst = Server_Port, ack_num = 101, window = 5000
Established
TCP slow start

Client sets the SYN bit in the TCP header to request a TCP connection. The sequence number field is set to 0. Since the SYN bit is set, this sequence number is used as the initial sequence number

Socket transitions to the SYN Sent state

SYN TCP segment is received by the server

Server sets the SYN and the ACK bits in the TCP header. Server sends its initial sequence number as 100. Server also sets its window to 65535 bytes. i.e. Server has buffer space for 65535 bytes of data. Also note that the ack sequence numer is set to 1. This signifies that the server expects a next byte sequence number of 1

Now the server transitions to the SYN Received state

Client receives the "SYN+ACK" TCP segment

Client now acknowledges the first segment, thus completing the three way handshake. The receive window is set to 5000. Ack sequence number is set to 101, this means that the next expected sequence number is 101.

At this point, the client assumes that the TCP connection has been established

Server receives the TCP ACK segment

Now the server too moves to the Established state

A TCP connection starts in the "Slow Start" state. In this state, TCP adjusts its transmission rate based on the rate at which the acknowledgements are received from the other end.

TCP Slow start is implemented using two variables, viz cwnd (Congestion Window)and ssthresh (Slow Start Threshold). cwnd is a self imposed transmit window restriction at the sender end. cwnd will increase as TCP gains more confidence on the network's ability to handle traffic. ssthresh is the threshold for determining the point at which TCP exits slow start. If cwnd increases beyond ssthresh, the TCP session in that direction is considered to be out of slow start phase

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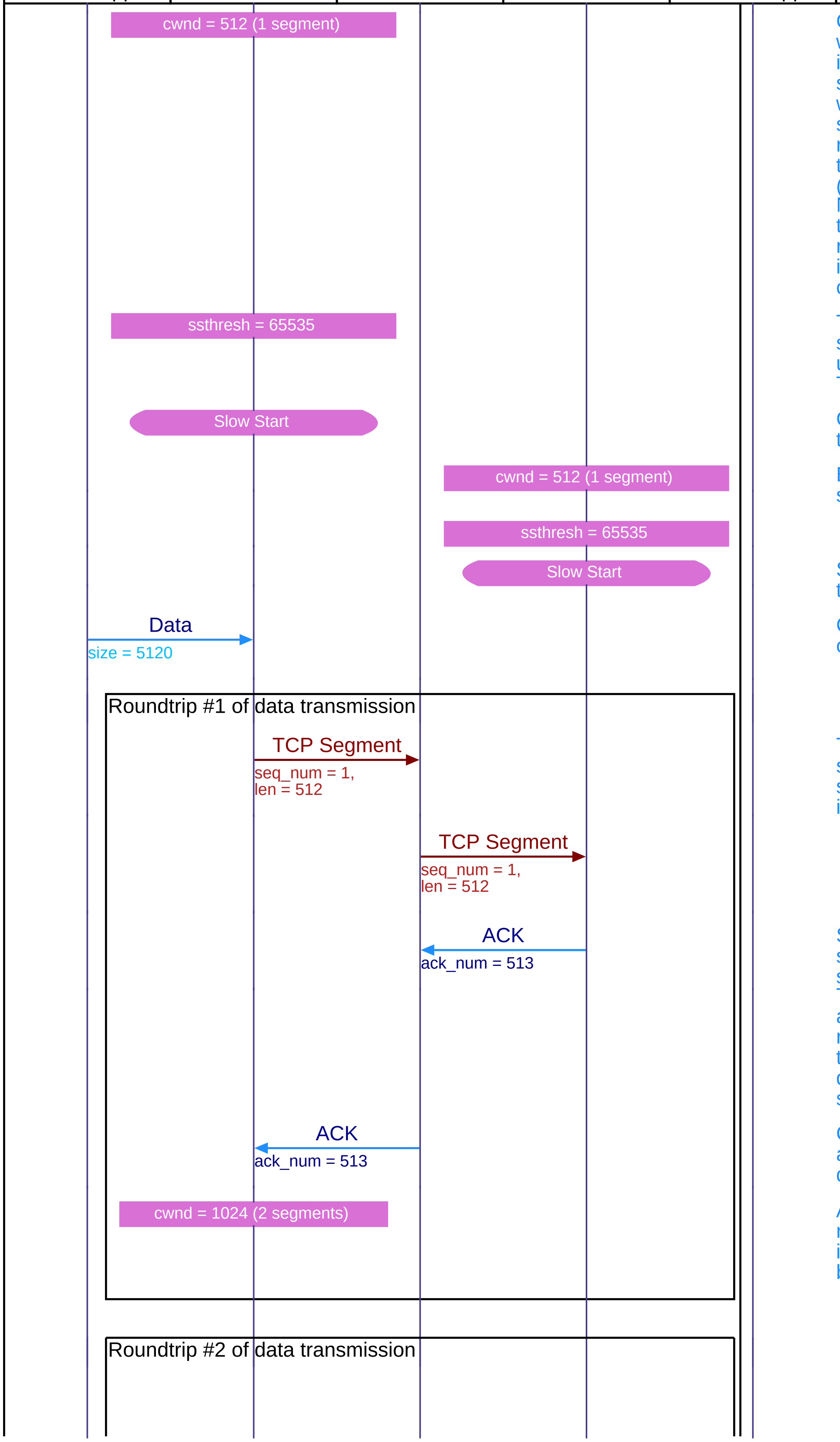

Client maintains a congestion window (cwnd). Initially the window is set to lower of the maximum TCP segment size and receiver's allowed window size. In most cases the segment size is smaller than receiver window, thus cwnd is set to the maximum TCP segment size (512 in this example)
Note here that cwnd implements a transmitter end flow control. The receiver advertised window implements a receiver enforced flow control.

TCP connections start with ssthresh set to 64K. This variable will be used to determine the point at which TCP exits slow start

Client end TCP connection moves to slow start state

By the same logic, the server also sets cwnd to 512

Server end TCP connection moves to slow start state

Client application sends 5120 bytes of data to the socket

The first TCP segment is sent with a sequence number of 1. This is the sequence number for the first byte in the segment.

Server acknowledges the data segments with the next expected sequence number as 513
TCP typically sends an acknowledgement every two received segments but in this case it times out for another segment and decides to acknowledge the only segment received.

Client receives the acknowledgement for the first TCP data segment

As the TCP session is in slow start, receipt of an acknowledgement increments the congestion window by one 1 segment.

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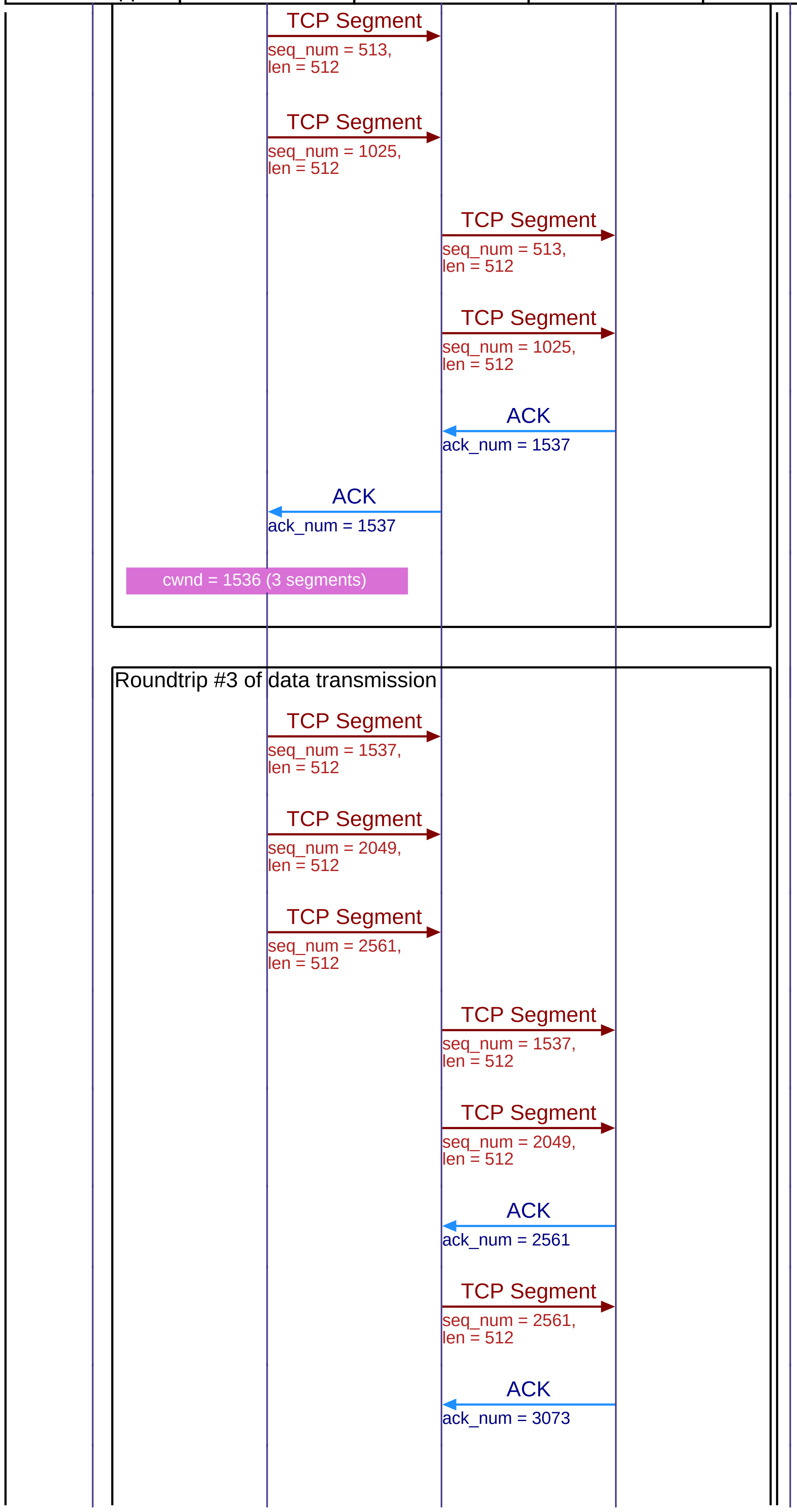

Since the congestion window has increased to 2, TCP can now send two segments without waiting for an ack

Receiver generates a TCP ACK on receiving the two segments

Receipt for ack again moves the congestion window

Now three segments can be sent without waiting for an ack

Network delivers the three segments to the destination server

TCP acknowledges receipt of two segments

TCP times for another segment and acknowledges the only pending segment

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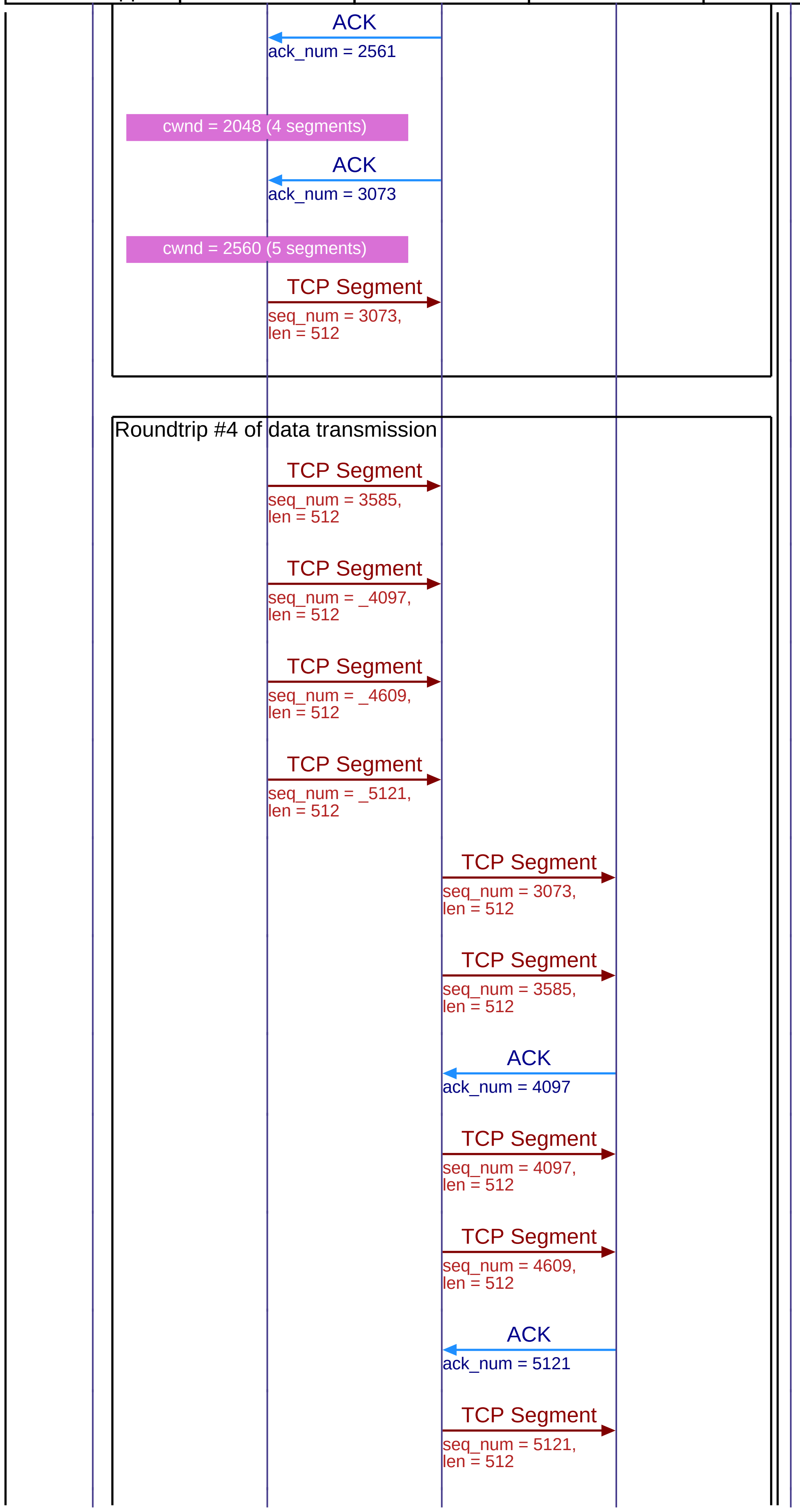

The TCP acknowlegements again increment cwnd. This time two acks are received, so cwnd will get incremented by 2

Since cwnd has reached 5 segments, TCP is allowed to send 5 segments without waiting for the ack

The 5 segments are received by the destination server

TCP Ack is sent after first two segments

Ack for next two segments

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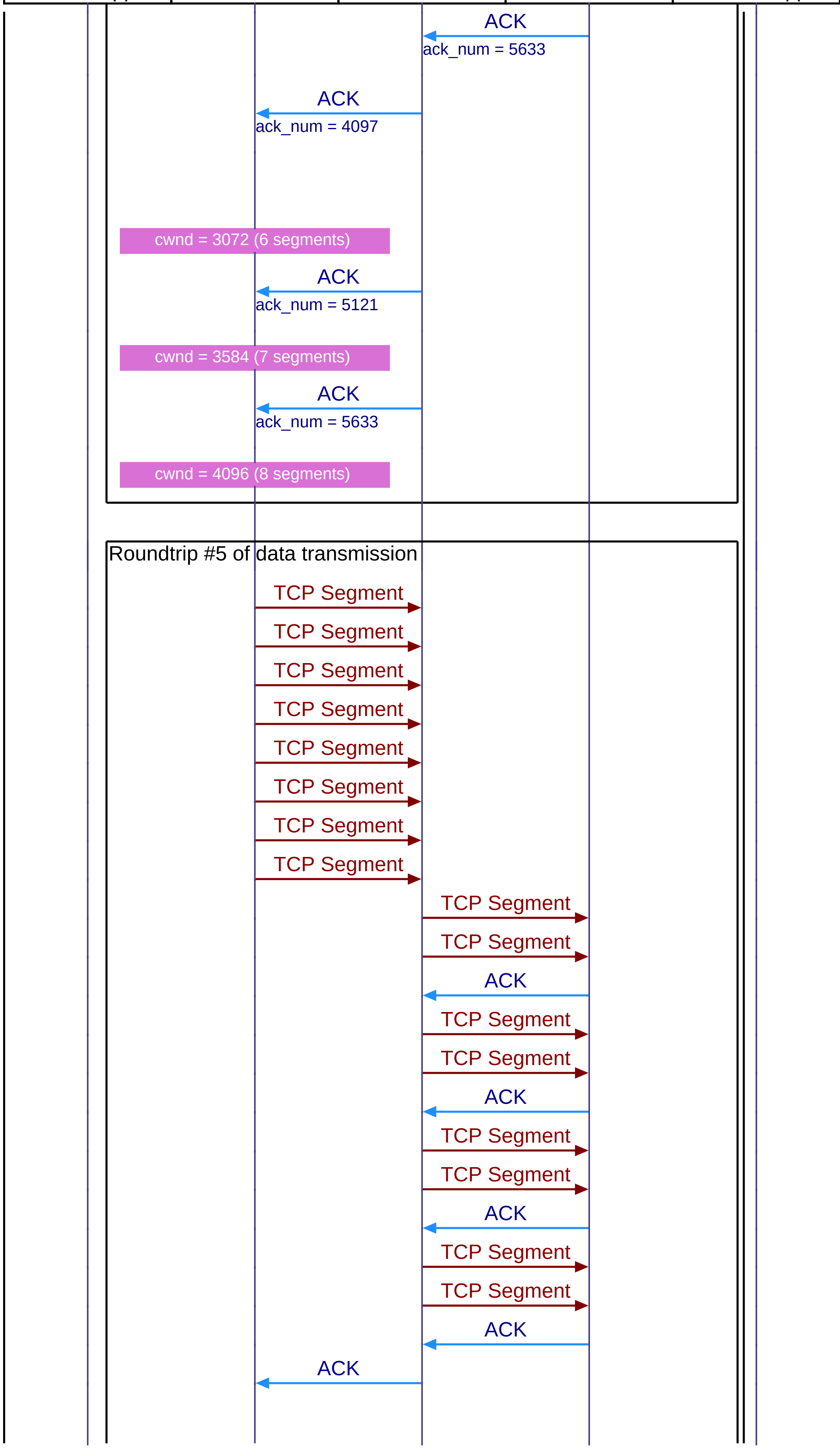

Ack for last segment

Three acknowledgements will be received for the 5 TCP segments. Now the cwnd has almost started increasing geometrically for every round trip between the client and the server.

This time 8 TCP segments are sent

Ack for first two segments

Ack for next two segments

Ack for next two segments

Ack for next two segments

Now four acks will be received, thus moving cwnd even more quickly

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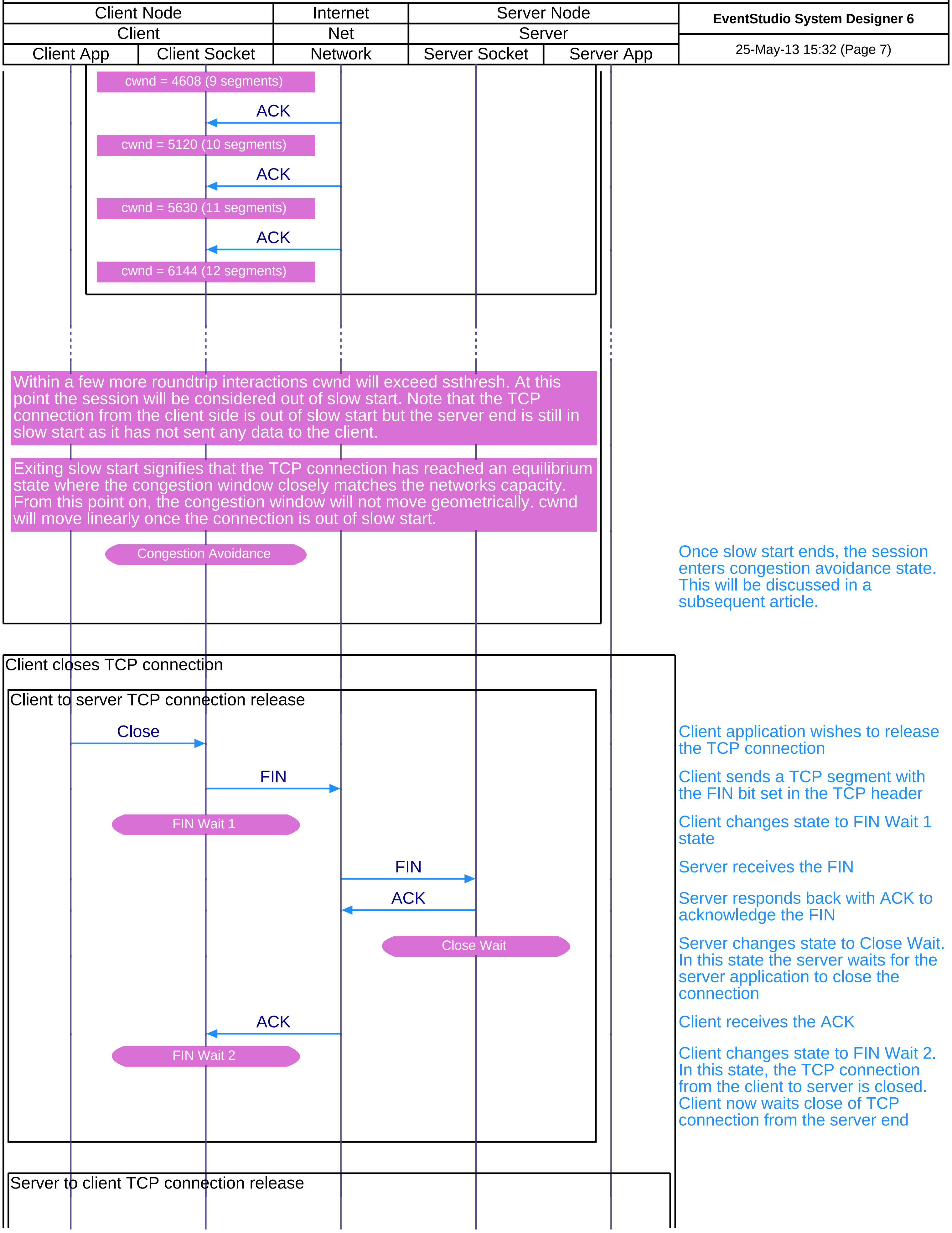

Within a few more roundtrip interactions cwnd will exceed ssthresh. At this point the session will be considered out of slow start. Note that the TCP connection from the client side is out of slow start but the server end is still in slow start as it has not sent any data to the client.

Exiting slow start signifies that the TCP connection has reached an equilibrium state where the congestion window closely matches the networks capacity. From this point on, the congestion window will not move geometrically. cwnd will move linearly once the connection is out of slow start.

Once slow start ends, the session enters congestion avoidance state. This will be discussed in a subsequent article.

Client application wishes to release the TCP connection

Client sends a TCP segment with the FIN bit set in the TCP header

Client changes state to FIN Wait 1 state

Server receives the FIN

Server responds back with ACK to acknowledge the FIN

Server changes state to Close Wait. In this state the server waits for the server application to close the connection

Client receives the ACK

Client changes state to FIN Wait 2. In this state, the TCP connection from the client to server is closed. Client now waits close of TCP connection from the server end

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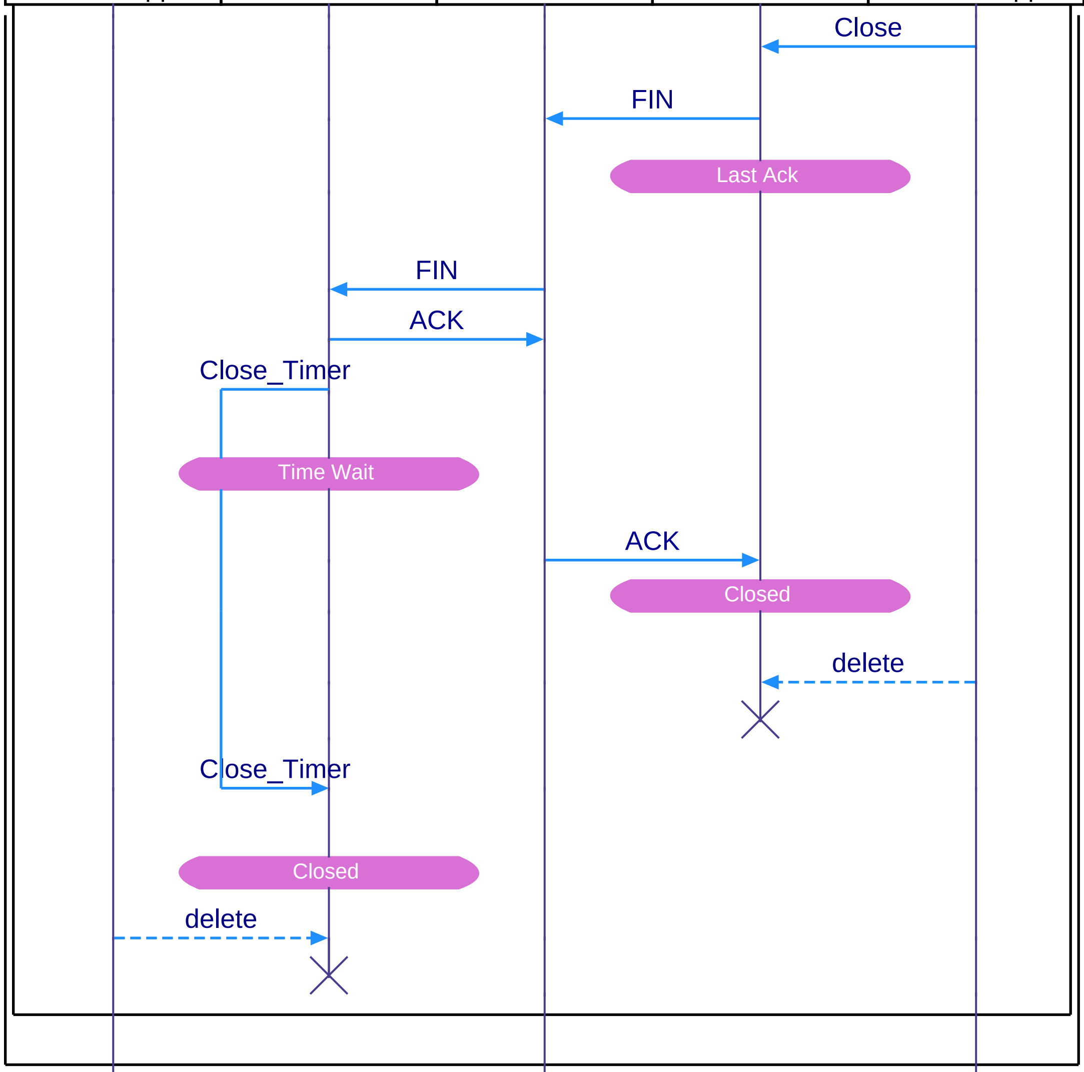

Server application closes the TCP connection

FIN is sent out to the client to close the connection

Server changes state to Last Ack. In this state the last acknowledgement from the client will be received

Client receives FIN

Client sends ACK

Client starts a timer to handle scenarios where the last ack has been lost and server resends FIN

Client waits in Time Wait state to handle a FIN retry

Server receives the ACK

Server moves the connection to closed state

Close timer has expired. Thus the client end connection can be closed too.