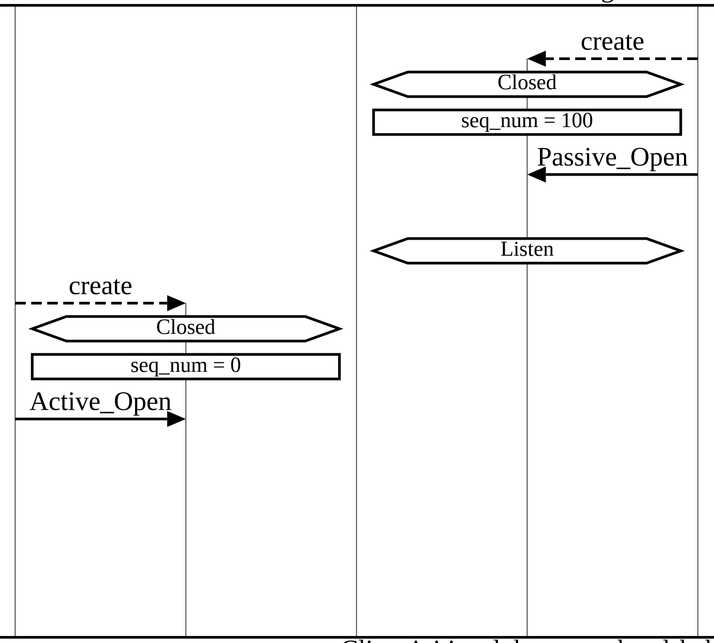
TCP - Transmission Control Protocol (TCP Congestion Avoidance)

Client Node		Internet	Server Node		EventHelix.com/EventStudio 1.0
Client		Net	Server		
Client App	Client Socket	Network	Server Socket	Server App	24-Mar-02 11:30 (Page 1)

LEG: About TCP Congestion Avoidance

We have already seen that TCP connection starts up in slow start mode, geometrically increasing the congestion window (cwnd) until it crosses the slow start threshold (ssthresh). Once cwnd is greater that ssthresh, TCP enters the congestion avoidance mode of operation. In this mode, the primary objective is to maintain high throughput without causing congestion. If TCP detects segment loss, it assumes that congestion has been detected over the internet. As a corrective action, TCP reduces its data flow rate by reducing cwnd. After reducing cwnd, TCP goes back to slow start.



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

Client Application creates Socket

The socket is created in the Closed state

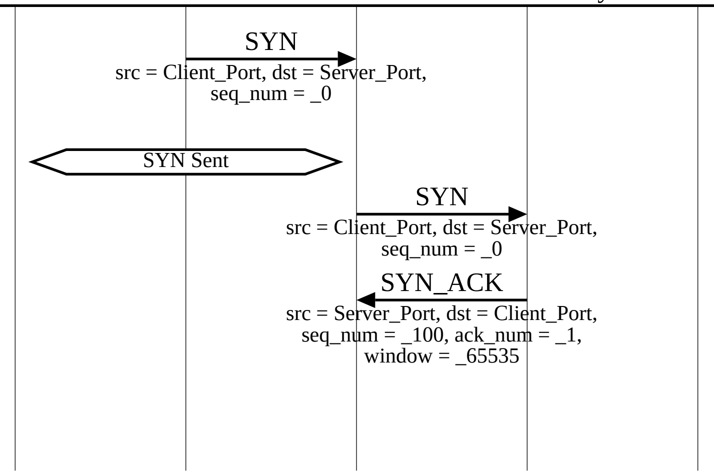
Initial sequence number is set to 0

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.

LEG: Client initiates TCP connection

Client initiated three way handshake to establish a TCP connection


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

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

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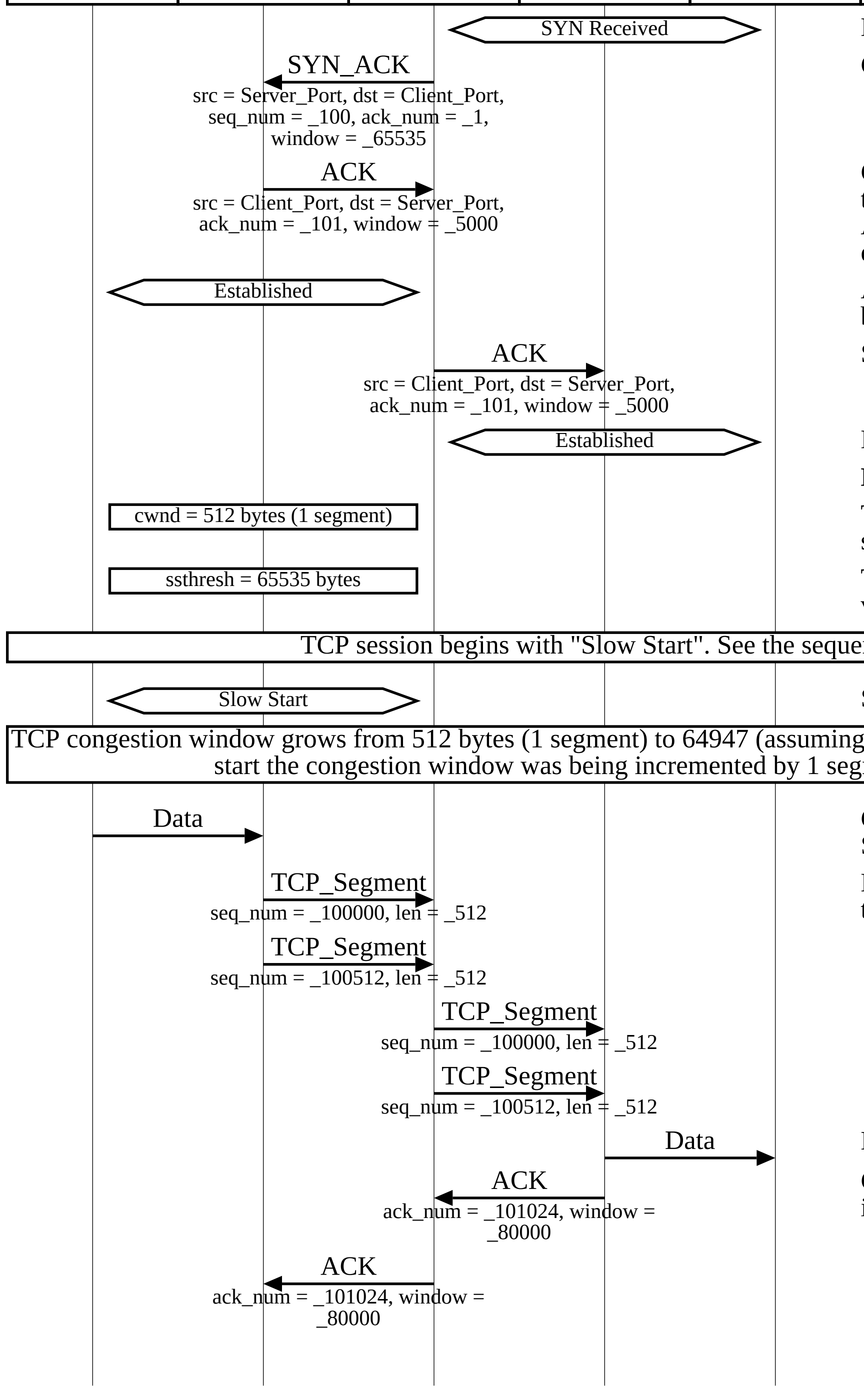
SYN Received
SYN_ACK
src = Server_Port, dst = Client_Port, seq_num = _100, ack_num = _1, window = _65535
ACK
src = Client_Port, dst = Server_Port, ack_num = _101, window = _5000
Established
ACK
src = Client_Port, dst = Server_Port, ack_num = _101, window = _5000
Established
cwnd = 512 bytes (1 segment)
ssthresh = 65535 bytes
Slow Start
Data
TCP_Segment
seq_num = _100000, len = _512
TCP_Segment
seq_num = _100512, len = _512
TCP_Segment
seq_num = _100000, len = _512
TCP_Segment
seq_num = _100512, len = _512
Data
ACK
ack_num = _101024, window = _80000
ACK
ack_num = _101024, window = _80000

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

LEG: TCP Congestion Avoidance Operation

TCP connection begins with a congestion window size of 1 segment

The slow start threshold starts with 64 Kbytes as the threshold value.

TCP session begins with "Slow Start". See the sequence diagram on slow start for details

Since cwnd < ssthresh, TCP state is slow start

TCP congestion window grows from 512 bytes (1 segment) to 64947 (assuming no segment losses are detected during slow start). During slow start the congestion window was being incremented by 1 segment for every TCP Ack from the other end.

Client Application sends data for transmission over the TCP Socket

Data is split into TCP Segments. The segments are sent over the Internet

Data is forwarded to the server side application

Client acknowledges the last block and also signals an increase in receiver window to 80000

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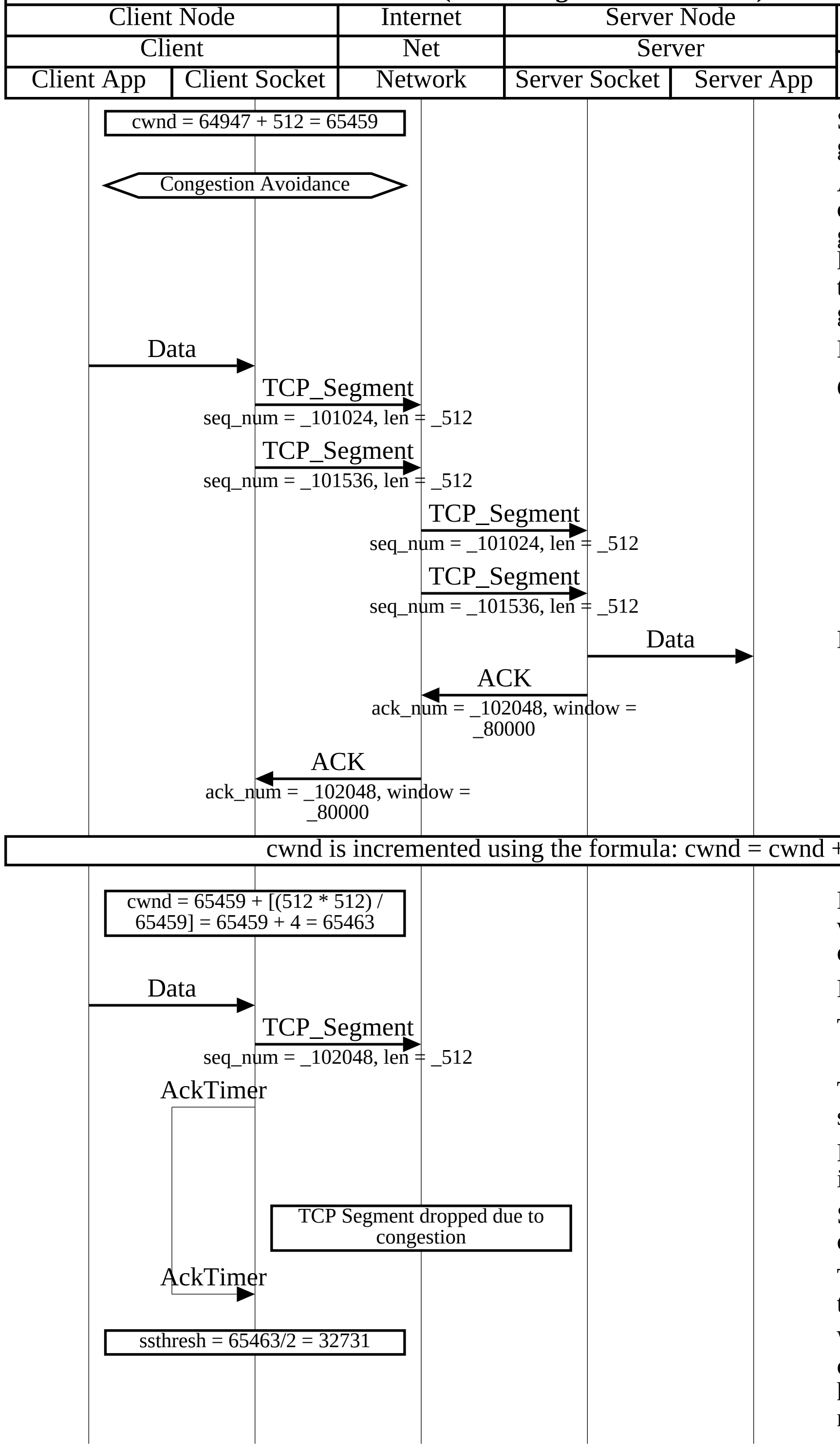
Client Node
Internet
Server Node
Client
Net
Server
Client App
Client Socket
Network
Server Socket
Server App
cwnd = 64947 + 512 = 65459
Congestion Avoidance
Data
TCP_Segment
seq_num = _101024, len = _512
TCP_Segment
seq_num = _101536, len = _512
TCP_Segment
seq_num = _101024, len = _512
TCP_Segment
seq_num = _101536, len = _512
Data
ACK
ack_num = _102048, window = _80000
ACK
ack_num = _102048, window = _80000
cwnd = 65459 + [(512 * 512) / 65459] = 65459 + 4 = 65463
Data
TCP_Segment
seq_num = _102048, len = _512
AckTimer
TCP Segment dropped due to congestion
AckTimer
ssthresh = 65463/2 = 32731

Since TCP is in slow start, every ack leads to the window growing by one segment.

At this point cwnd (=65459) > ssthresh (=65535) thus TCP changes state to congestion avoidance. Now TCP window growth will be much more conservative. If no segment or ack losses are detected, the congestion window will grow no more than one segment per roundtrip. (Compare this with geometric growth of 1 segment per TCP ack in slow start)

More data is received from the client application

Client data is split into TCP segments

Data is forwarded to the server application

cwnd is incremented using the formula: cwnd = cwnd + (segment_size segment_size) / cwnd)

Now TCP is in congestion avoidance mode, so the TCP window advances very slowly. Here the window increased by only 4 bytes.

Data to be sent to server

TCP session sends out the data as a single segment

TCP session starts a ack timer, awaiting the TCP ack for this segment.

Note: The above timer is started for every segment. The timer is not shown at other places as it played role in our analysis

Some node in the Internet drops the TCP segment due to congestion

TCP times out for a TCP ACK from the other end. This will be treated as a sign of congestion by TCP

When TCP detects congestion, it stores half of the current congestion window in ssthresh variable. In this case, ssthresh has been reduced from 65535 to 32731. This signifies that TCP now has less confidence on the network's ability to support big

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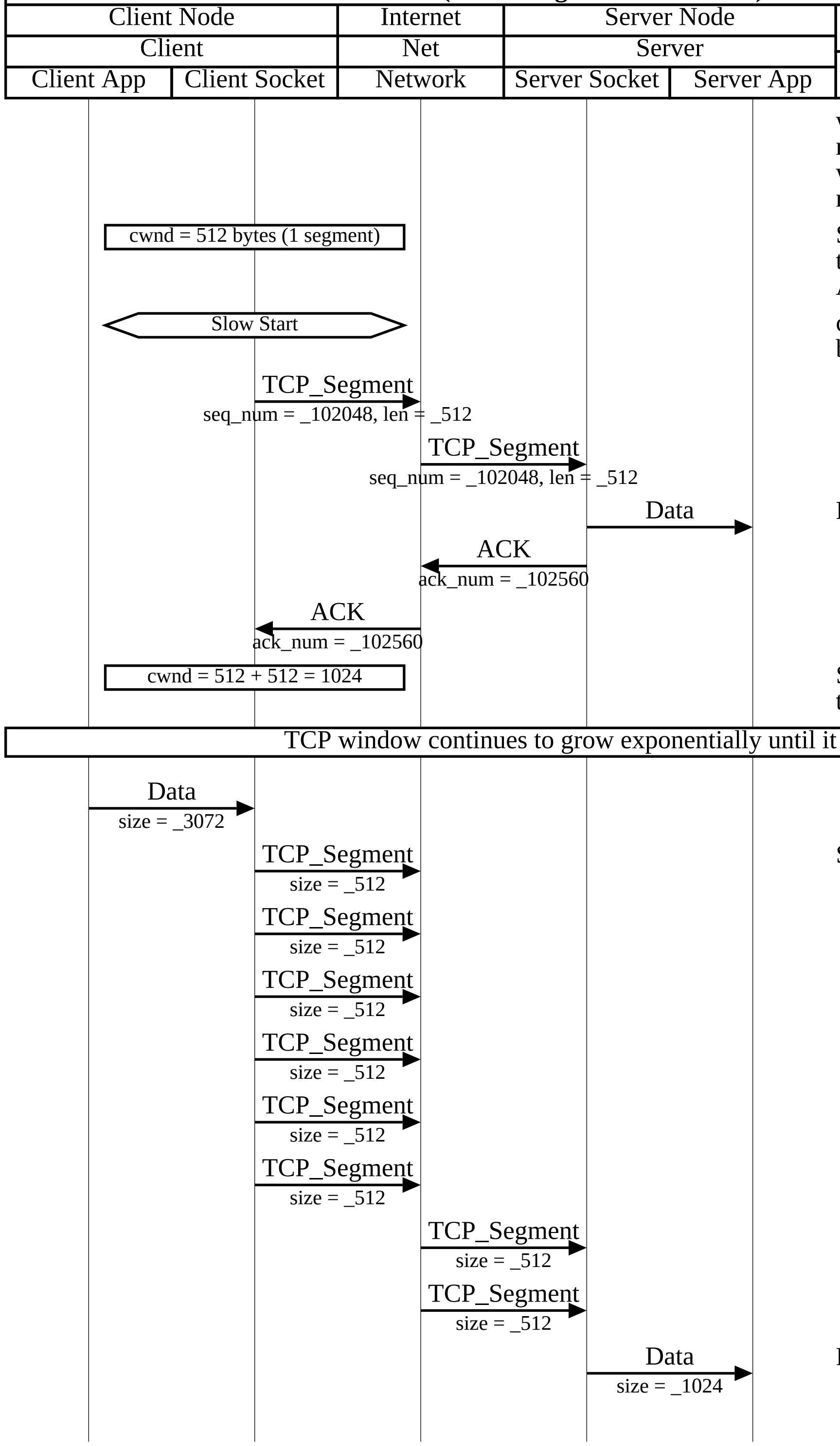

window sizes. Thus if the window size falls due to congestion, rapid window size increases will be carried out only until the window reaches 32731. Once this lowered ssthresh value is reached, window growth will be much slower.

Since current congestion has been detected by timeout, TCP takes the drastic action of reducing the congestion window to 1. As you can see, this will have a big impact on the throughput.

cwnd (=1) is now lower than ssthresh (=32731) so TCP goes back to slow start.

Data is finally given to the server application

Since TCP is in slow start, a TCP acknowledgement results in the window growing by one segment

TCP window continues to grow exponentially until it reaches the ssthresh (=32731) value.

Six TCP segments are transmitted in the slow start mode

First part of the data is delivered

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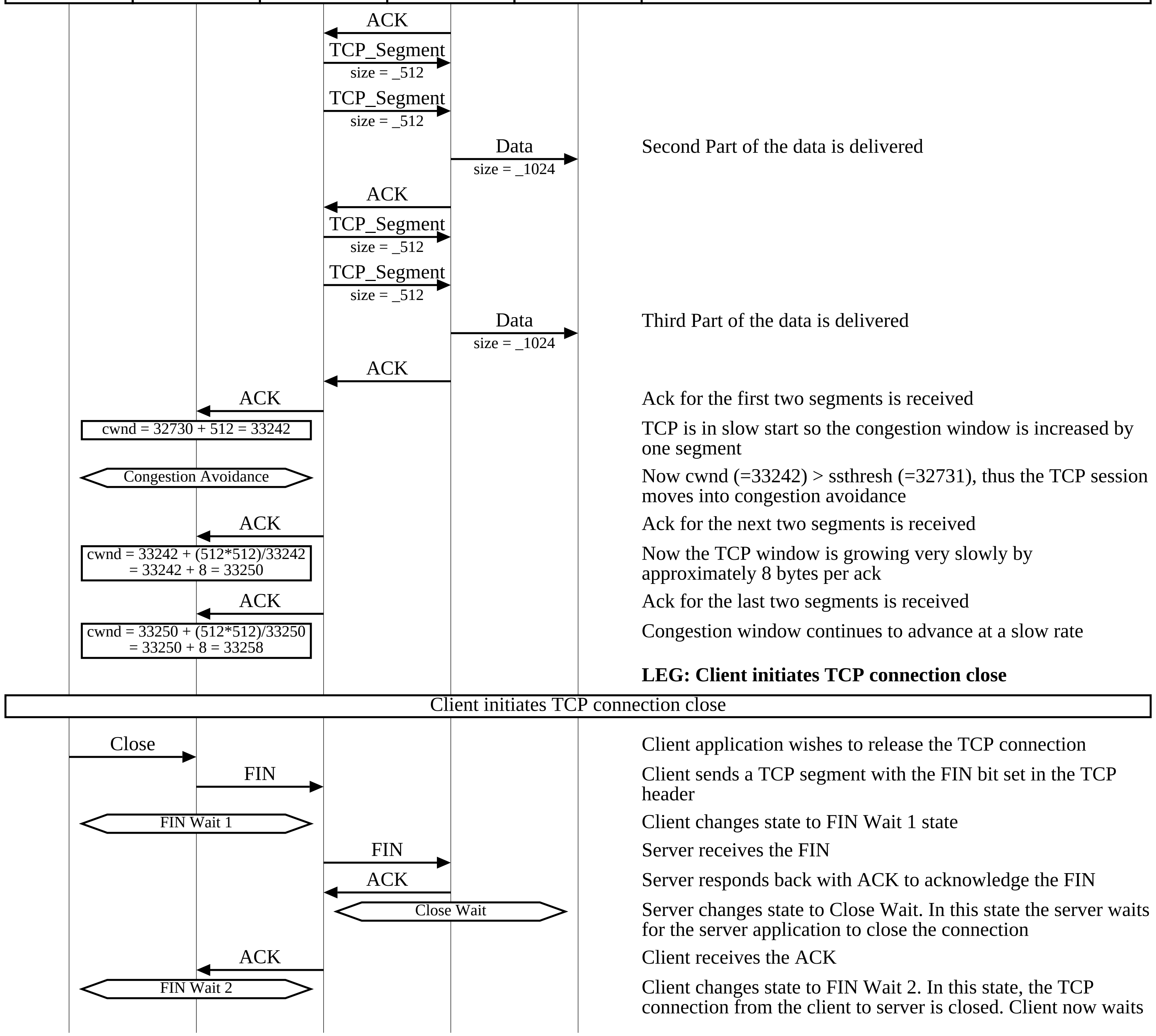

Second Part of the data is delivered

Third Part of the data is delivered

Ack for the first two segments is received

TCP is in slow start so the congestion window is increased by one segment

Now cwnd (=33242) > ssthresh (=32731), thus the TCP session moves into congestion avoidance

Ack for the next two segments is received

Now the TCP window is growing very slowly by approximately 8 bytes per ack

Ack for the last two segments is received

Congestion window continues to advance at a slow rate

LEG: Client initiates TCP connection close

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

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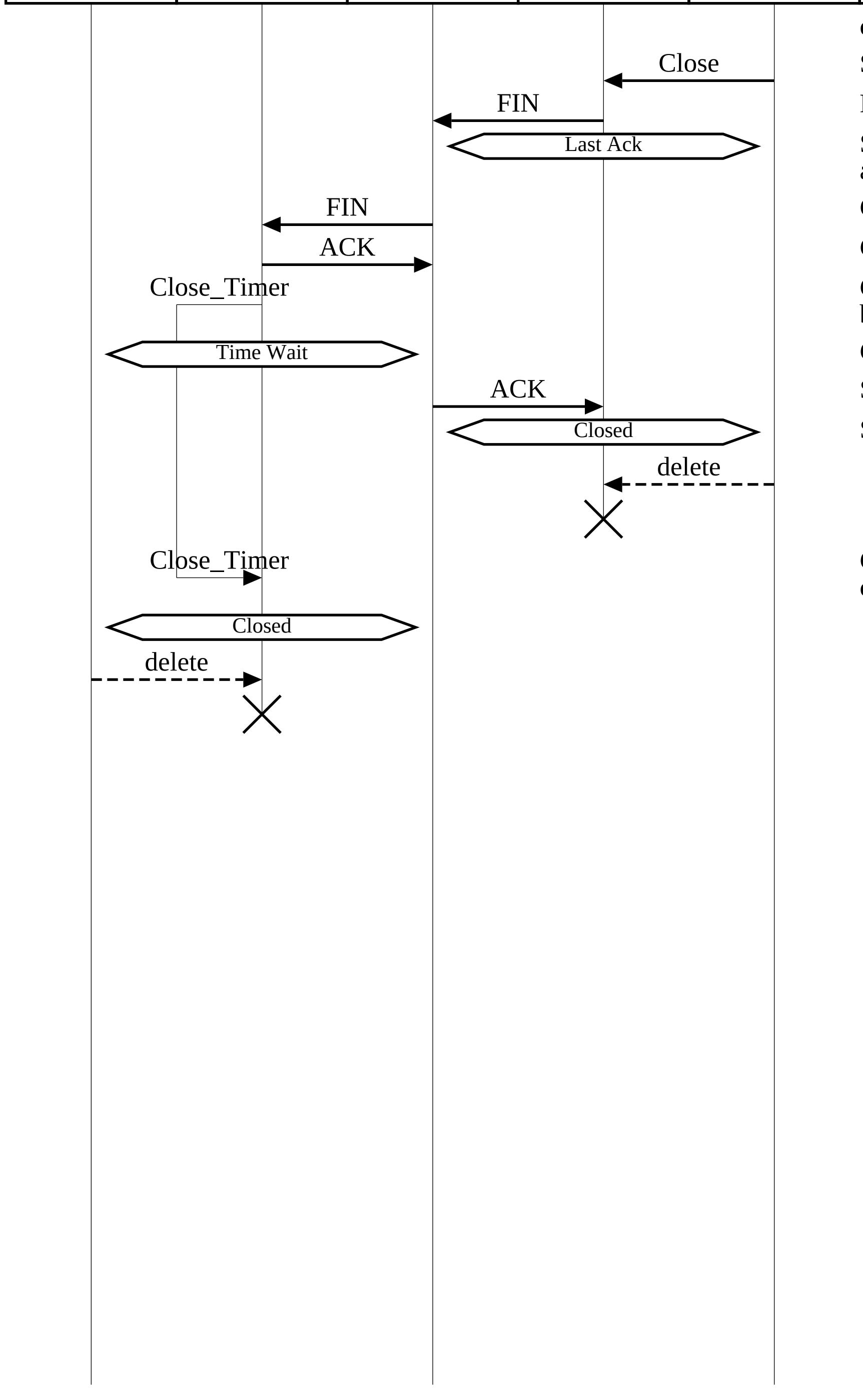

close of TCP connection from the server end

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.