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And it shows little about timeouts and retransmissions

TCP

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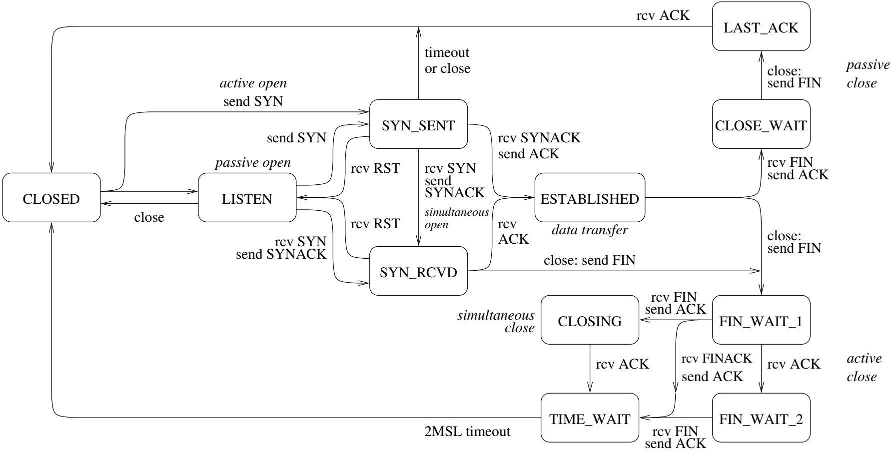

TCP State Diagram

We start (and end) in CLOSED

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And the two closes: active and passive

This state diagram is followed for each end of a connection, i.e., each socket in the socketpair

TCP

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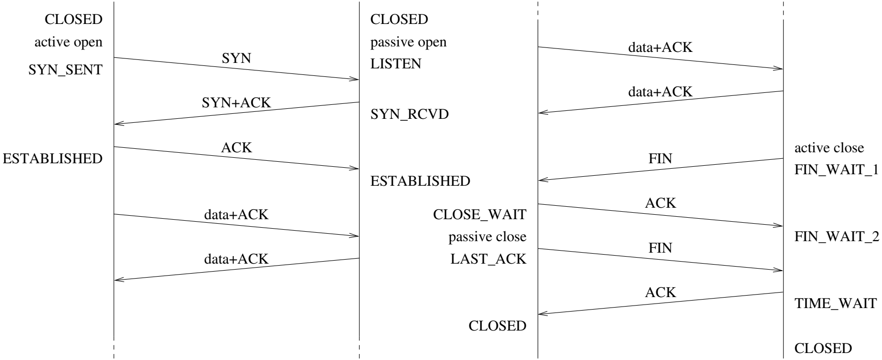

Typical TCP Timeline

The active close is somewhat complicated by the need for reliability

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The TIME_WAIT state (also called 2MSL state) appears before the final close: the active-close end of the connection must remain non-closed until a time period has passed

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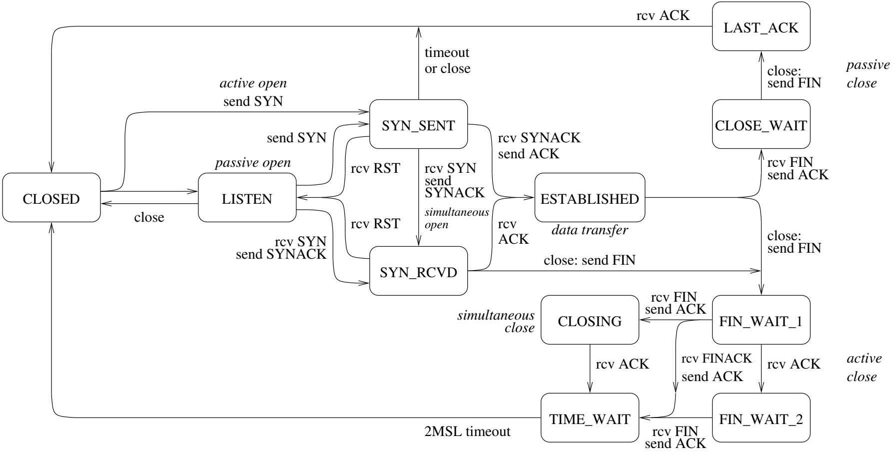

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At this point this end of the connection has received a final ACK and sent its final ACK

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And resent if it didn't get to the other end

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A TCP connection is required stay in TIME_WAIT for twice the MSL

This is in case the final ACK (of the final FIN) was lost and needs to be retransmitted

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And while in this wait state if a new process tries to make a connection using the same ports it will be denied: the old connection is still active. We don’t want to deliver late packets to the new process

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In this sense the TCP connection and the process using it are quite separate entities

TCP

Teardown

When an application exits, the OS sends FINs on behalf of the application for all currently open connections. This makes sure everything is tidied up nicely (even if the programmer didn't)

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If a host is shut down normally, rather than crashing, the operating system will (should!) send FINs for all currently open connections

It really should do the `TIME_WAIT`, but often implementations don't bother as this would hold up the shutdown

TCP Strategies

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It is possible to implement TCP like this, but performance would be poor

So a typical TCP implementation will be a bit more smart on its use of ACKs: we have already mentioned delaying an ACK to let it piggyback on a returning data segment

TCP Strategies

That is just first of many strategies a TCP implementation can employ while still following the TCP protocol

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We shall look at a few basic strategies, starting with more detail on the advertised window

TCP Strategies

Advertised Window

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The space left depends on

- how fast the sender is sending the data
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If the data arrives faster than it is read, the buffer will fill up

TCP Strategies

Advertised Window

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A sliding window describes the range of bytes in the stream the sender can transmit next

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The sender recomputes the space available in the receiver every time it receives an ACK

TCP Strategies

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As more ACKs are received, the window *closes* as the left edge advances

TCP Strategies

Advertised Window

As the application reads data, the window *opens* as the right edge advances

TCP Strategies

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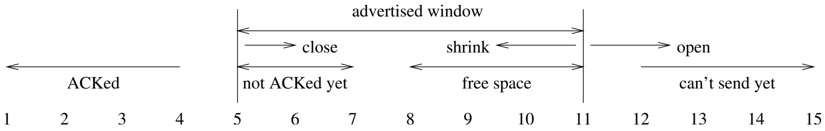
Rarely, the window can *shrink* (right edge recedes), perhaps if the buffer shrinks due to the memory being needed elsewhere

TCP Strategies

Advertised Window

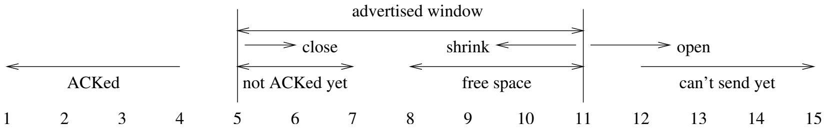


TCP sliding window

This is from the point of view of the sending end of a connection;

TCP Strategies

Advertised Window

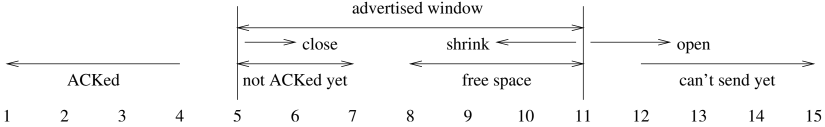


TCP sliding window

The situation is that we have just sent a segment with bytes 5-7; then received an ACK of 5 with a window of 7;

TCP Strategies

Advertised Window

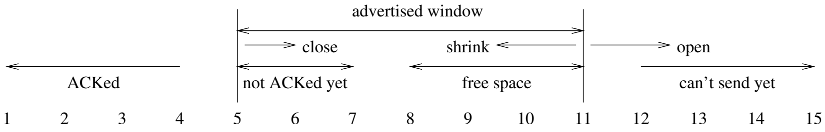


TCP sliding window

Bytes to the left of the window (1-4) have been ACKed and are safe in the destination;

TCP Strategies

Advertised Window

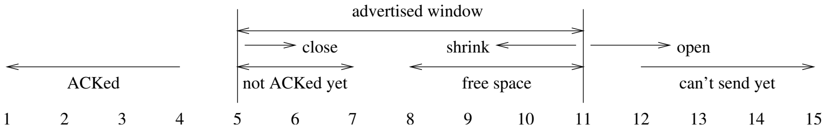


TCP sliding window

The advertised window tells us there is space for 7 bytes in the destination: bytes to the right (12 onwards) cannot be sent yet as the destination has nowhere to put them;

TCP Strategies

Advertised Window

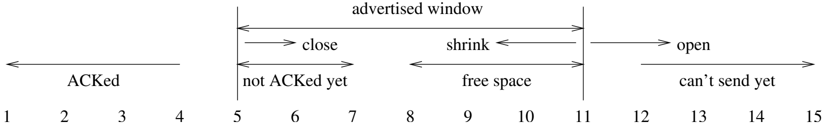


TCP sliding window

Bytes within the window are either not ACKed yet, or represent free space;

TCP Strategies

Advertised Window

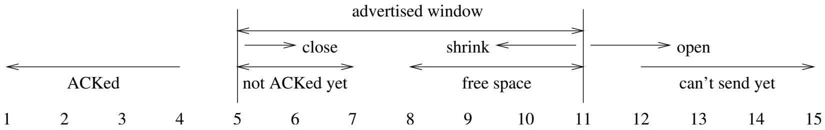


TCP sliding window

unACKed bytes (5-7) are those that have been sent by the sender, possibly received by the destination, and an ACK not yet received by the sender and possibly not yet sent by the receiver;

TCP Strategies

Advertised Window



TCP sliding window

The free space (8-11) is the actual number of bytes that the sender can be sure that can be buffered;

TCP Strategies

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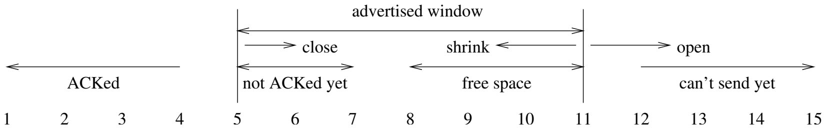
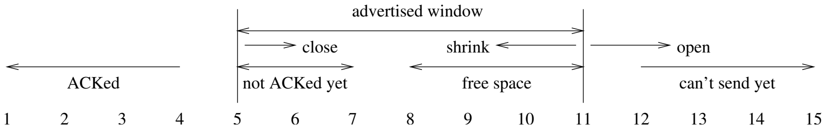


TCP sliding window

The sender can compute this free space as the latest window value minus the number of bytes sent but as yet unACKed;

TCP Strategies

Advertised Window



TCP sliding window

Thus the sender knows the limit on how much more data it can currently send

TCP Strategies

Advertised Window

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Complications arise if this window update gets lost: the *Persist Timer* (see later) is used here

TCP Strategies

Delayed ACKs

The next strategy we have mentioned before

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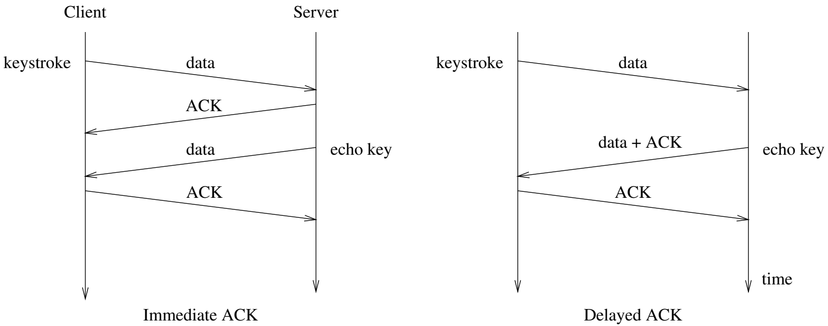
Instead of immediately ACKing every segment, we can slightly delay it and *piggyback* it on returning data

TCP Strategies

Delayed ACKs

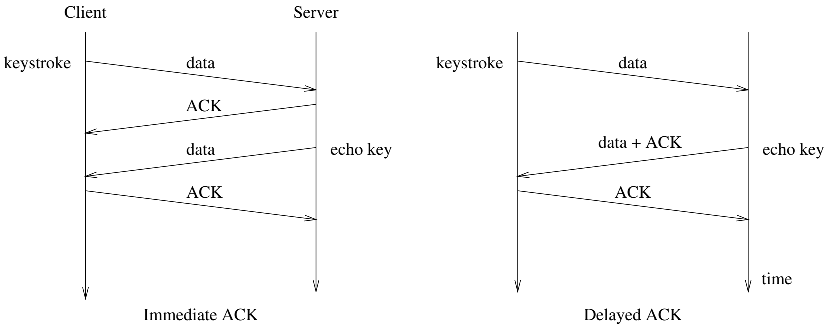


Immediate vs. delayed ACK

For example, when logged in to a remote terminal each keystroke is echoed back to your screen;

TCP Strategies

Delayed ACKs

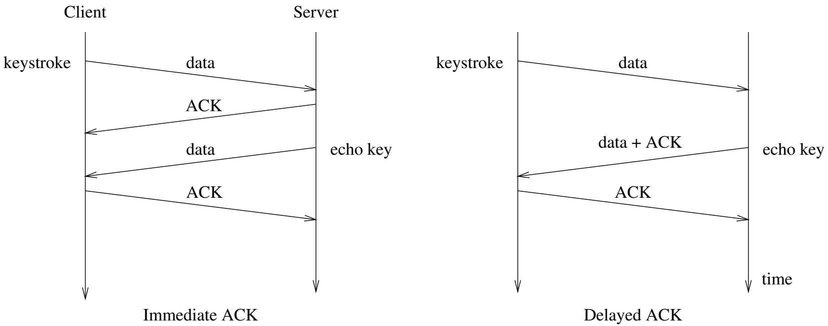


Immediate vs. delayed ACK

An immediate ACK would use four segments;

TCP Strategies

Delayed ACKs



Immediate vs. delayed ACK

A delayed ACK piggybacking on the data for the echoed key uses just three segments

TCP Strategies

Delayed ACKs

As far as the user is concerned, they see the keystroke echo in the same way, with no extra delay, but fewer segments are sent

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It is important to reduce the traffic on a heavily loaded network

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Delayed ACKs

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It is important to reduce the traffic on a heavily loaded network

It also reduces the chance of a lost segment

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By delaying, we might also be able to ACK more than one segment at a time

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This reduces traffic again

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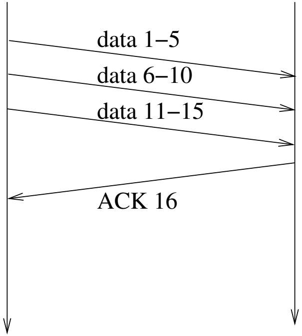
Delayed ACKs



ACKing bytes received

ACKs acknowledge bytes received, not segments

TCP Strategies

Delayed ACKs

So how long to delay an ACK?

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Delayed ACKs

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If too long, the sender might think the segment was lost and resend

If too short, we do not get so many free piggybacks or multiple ACKed segments

A typical implementation will delay for up to 200ms

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Delayed ACKs

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The TCP specification says you should send an ACK for at least every second full-sized segment and you *must not* delay for more than 500ms

This one of the many timers associated with TCP

Each time you receive a data segment the TCP software should set a timer for that segment that expires after 200ms

TCP Strategies

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Not so accurate as per-segment timers, but much easier to implement

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Delayed ACKs

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If you get an out-of-order segment (its sequence number is not the one you are expecting next, e.g., a segment was possibly lost), you *must not* delay, but send an ACK immediately

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Though the other end will wait for three duplicate ACKs just to be sure before resending

TCP Strategies

Nagle

Next strategy: when sending keystrokes (or other small data) over a network there is a lot of wasted bandwidth

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And so on down the layers

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TCP Strategies

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Nagle created a strategy for reducing this

It applies to the sender of the tinygram (client)

TCP Strategies

Nagle

Nagle's Algorithm:

> *a TCP connection can have only one outstanding un-ACKed small segment: no additional small segments can be sent until that ACK has been received*

TCP Strategies

Nagle

Nagle's Algorithm:

> *a TCP connection can have only one outstanding un-ACKed small segment: no additional small segments can be sent until that ACK has been received*

If you are sending tinygrams, only send one and wait until you get its ACK before sending any more

TCP Strategies

Nagle

Nagle's Algorithm:

> *a TCP connection can have only one outstanding un-ACKed small segment: no additional small segments can be sent until that ACK has been received*

If you are sending tinygrams, only send one and wait until you get its ACK before sending any more

Any small segments waiting to be sent should be collected together into a single larger segment that is sent when the ACK is received

TCP Strategies

Nagle

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Variants choose anything from “1 byte” to “any segment shorter than the maximum segment size”

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But that won’t be a constraint until the scale is bigger than a segment, e.g., $2^{10} = 1024$, but $2^{11} = 2048 > 1500$

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When there is congestion, so ACKs return more slowly, fewer tinygrams are sent

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Nagle can be turned off for such cases