TCP Congestion Control

Congestion Window

- TCP uses **different policies** to handle the congestion in the network.
- **size of the send window is controlled** by the receiver using the value of *rwnd*
- **receive window is never overflowed** with the received bytes (no end congestion).

Congestion Window

- TCP needs to worry about congestion in middle. I**ntermediate buffers** in the routers, do become congested.

- A router may **receive data from more than one sender.**

- no congestion at the other end, but there may be **congestion in the middle**.

Congestion Window

- TCP needs to worry about congestion - worsening the congestion, and finally the collapse of the communication.

- TCP cannot send small segments either – underutilizing bandwidth

- TCP needs to define policies that **accelerate the data transmission** when there is no congestion and **decelerate the transmission** when congestion is detected.

Congestion Window

- TCP uses another variable called ***congestion window, cwnd,*** whose size is controlled by the congestion situation in the network.

- The ***cwnd variable and the rwnd variable*** together define the size of the send window in TCP.

Actual send window size = minimum (*rwnd, cwnd)*

Congestion Detection

- The TCP sender uses the occurrence of two events as signs of congestion in the network:

✓ **time-out event**

✓ **receiving three duplicate ACKs.**

1. Time-out event

- sender does not receive an ACK for a segment or a group of segments before the time-out occurs

Congestion Detection

2. Receiving Three Duplicate Acks

- TCP receiver sends a duplicate ACK, it is the sign that a segment has been delayed

- sending three duplicate ACKs is the sign of a missing segment, which can be due to congestion in the network.

- congestion in the case of three duplicate ACKs can be less severe than in the case of time-out

Congestion Detection

- **Taho and Reno TCP**
- earlier version of TCP, called Taho TCP, treated both events (time-out and three duplicate ACKs) similarly

- but the later version of TCP, called Reno TCP, treats these two signs differently.

Congestion Detection

- **Strong Congestion** – no ACKs results into timeout
- **Weak Congestion** - receiving of three duplicate ACKs

Congestion Policies

- TCP's general policy for handling congestion is based on three algorithms:

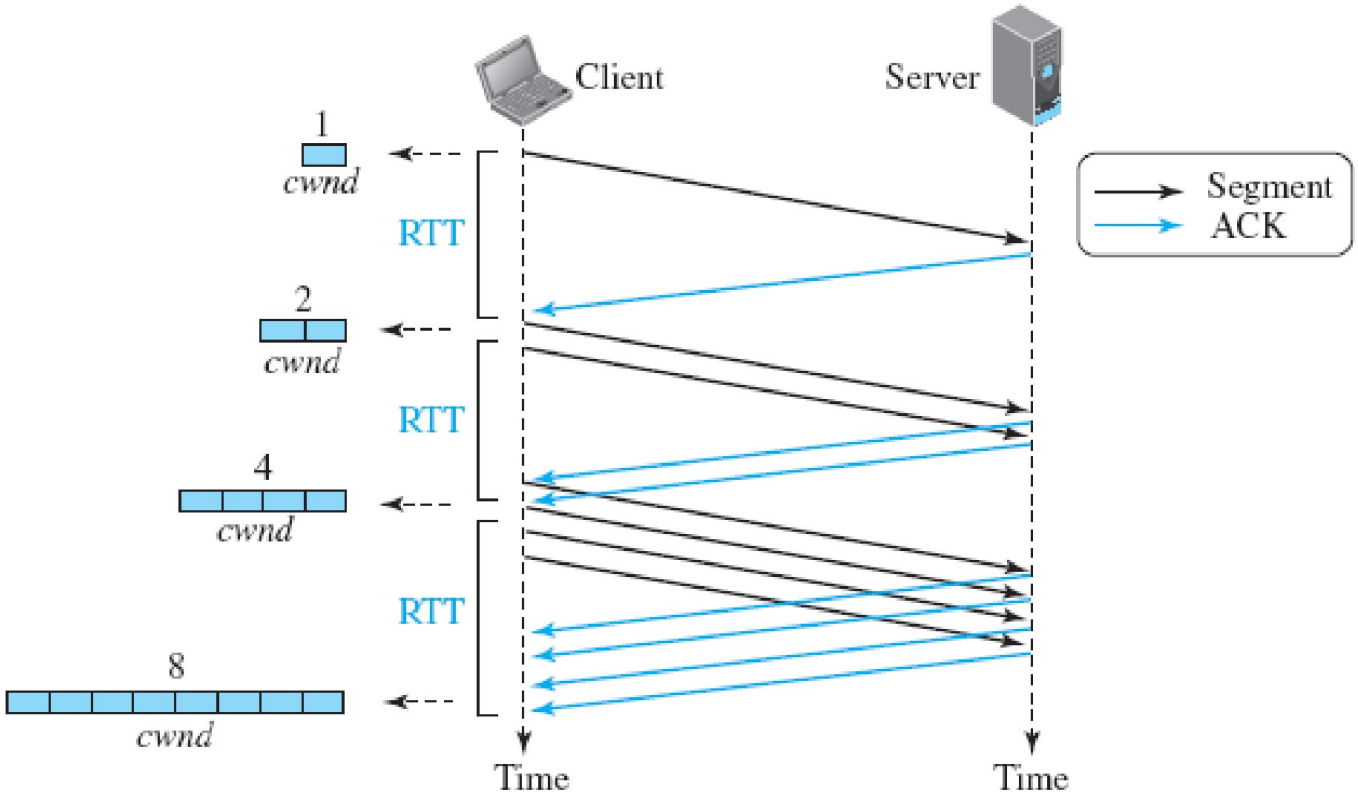
✓ slow start : Exponential Increase
✓ congestion avoidance : Additive Increase
✓ fast recovery

Slow Start: Exponential Increase

- congestion window (***cwnd***) starts with one maximum segment size (MSS) ,but it increases one MSS each time an acknowledgment arrives.

- assume that ***rwnd*** is much larger than ***cwnd,*** so that the sender window size always equals ***cwnd***.

Figure 24.29 *Slow start, exponential increase*



Slow Start: Exponential Increase

- **If an ACK arrives, *cwnd = cwnd + 1.***

Start	$\rightarrow$	$cwnd = 1 \rightarrow 2^0$
After 1 RTT	$\rightarrow$	$cwnd = cwnd + 1 = 1 + 1 = 2 \rightarrow 2^1$
After 2 RTT	$\rightarrow$	$cwnd = cwnd + 2 = 2 + 2 = 4 \rightarrow 2^2$
After 3 RTT	$\rightarrow$	$cwnd = cwnd + 4 = 4 + 4 = 8 \rightarrow 2^3$

Slow Start: Exponential Increase

- In the slow-start algorithm, the size of the congestion window increases exponentially until it reaches a threshold.

- **ssthresh (slow-start threshold).**

- if two segments are acknowledged cumulatively, the size of the cwnd increases by only 1, not 2.

- The growth is still exponential, but it is not a power of 2. With one ACK for every two segments, it is a power of 1.5.

Congestion Avoidance: Additive Increase

- continue with the slow-start algorithm, the size of the congestion window increases exponentially.

- Avoid congestion before it happens – control the size of congestion window.

- **congestion avoidance -** which increases the cwnd additively instead of exponentially.

Congestion Avoidance: Additive Increase

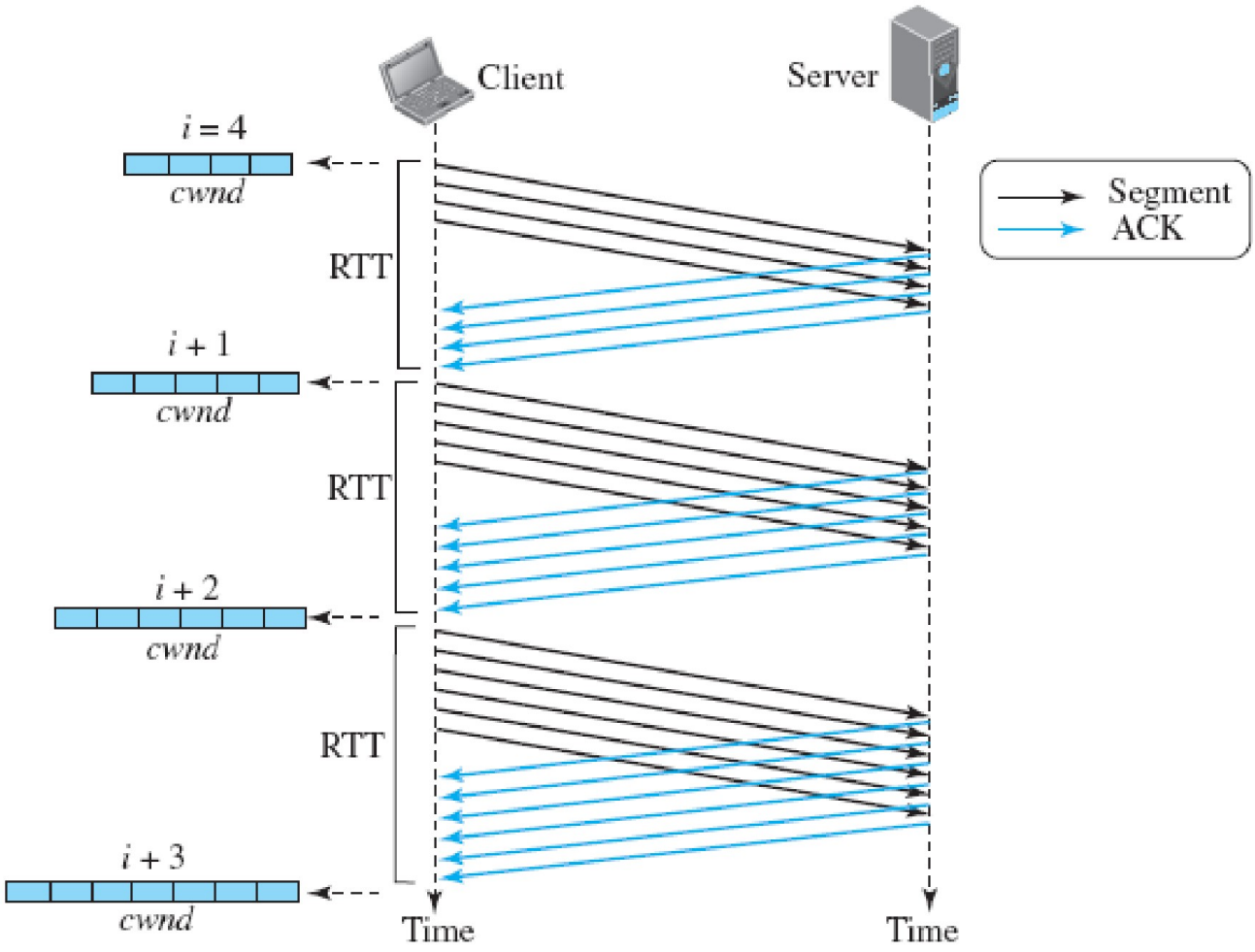
- size of the congestion window reaches the slow-start threshold in the case where

$$cwnd = i,$$

- the slow-start phase stops and the additive phase begins.

- each time the whole “window” of segments is acknowledged, the **size of the congestion window** is increased by **one**.

Figure 24.30 *Congestion avoidance, additive increase*



Congestion Avoidance: Additive Increase

- If an ACK arrives, *cwnd 5 = cwnd 1 (1/cwnd).*

Start	$\rightarrow$	$cwnd = i$
After 1 RTT	$\rightarrow$	$cwnd = i + 1$
After 2 RTT	$\rightarrow$	$cwnd = i + 2$
After 3 RTT	$\rightarrow$	$cwnd = i + 3$

Congestion Avoidance: Additive Increase

- In the congestion-avoidance algorithm, the size of the congestion window increases additively until congestion is detected.

Congestion Detection: Multiplicative Decrease

- If congestion occurs, the congestion window size must be decreased.

- guess that congestion has occurred is the need to retransmit a segment
- retransmission can occur in one of two cases:
  - ✓RTO timer times out
  - ✓three duplicate ACKs are received.

Congestion Detection: Multiplicative Decrease

1. **If a time-out occurs, there is a stronger possibility of congestion:**

   A segment has probably been dropped in the network and there is no news about the sent segments.

In this case TCP reacts strongly:

a. It sets the value of the threshold to half of the current window size.

b. It reduces cwnd back to one segment.

c. It starts the slow start phase again.

Congestion Detection: Multiplicative Decrease

2. **If three duplicate ACKs are received, there is a weaker possibility of congestion:**

   A segment may have been dropped but some segments after that have arrived safely since three duplicate ACKs are received - **Fast Recovery**

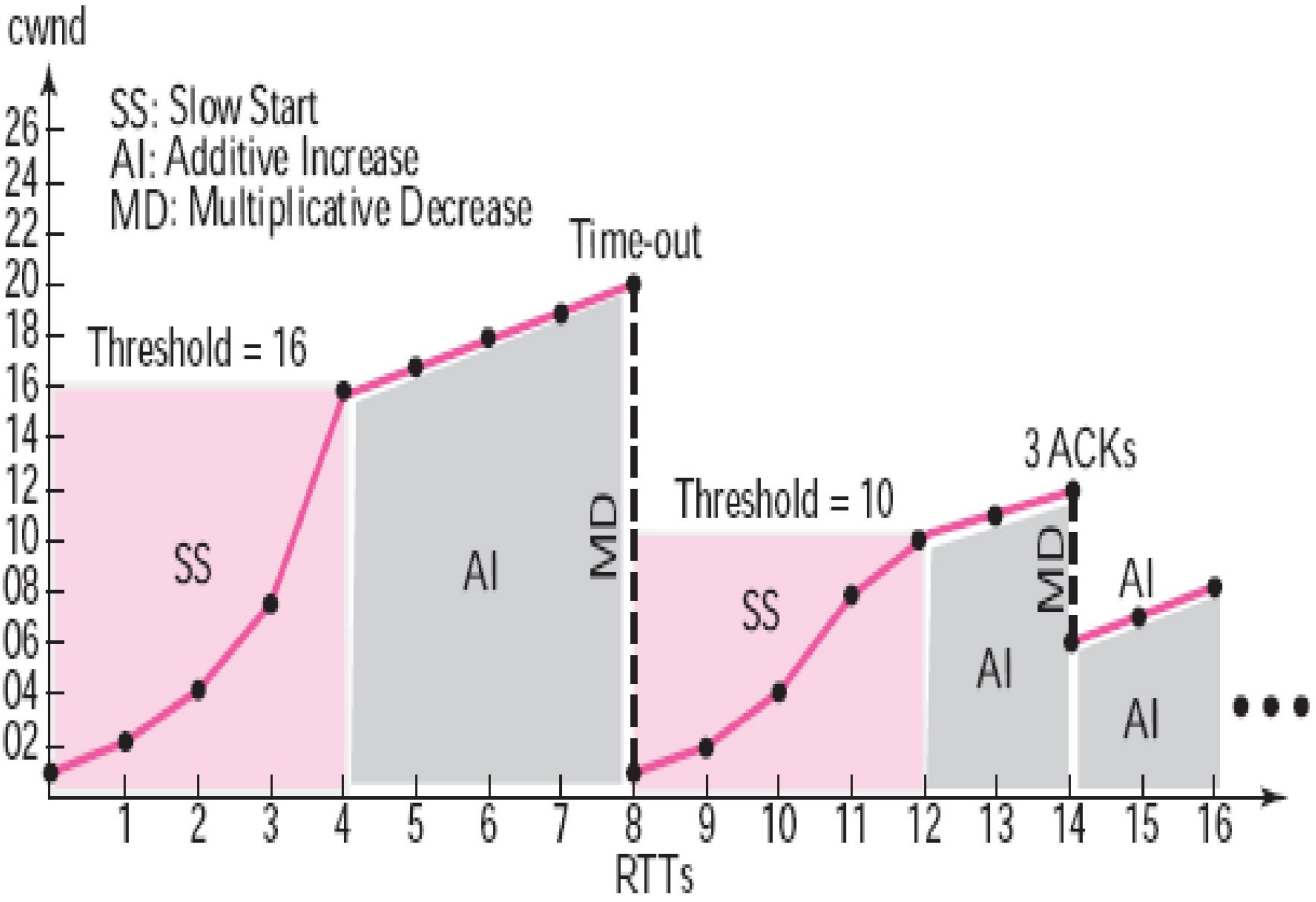
- **In this case, TCP has a weaker reaction as shown below**:

a. It sets the value of the threshold to half of the current window size.

b. It sets cwnd to the value of the threshold

c. It starts the congestion avoidance phase.

Figure 15.37 *Congestion example*



Fast Recovery

- Optional in TCP
- When 3 duplicate ACKs arrive, which is interpreted as light congestion.
- Like congestion avoidance, this algorithm is also additive increase.

TCP Timers

- Retransmission Timer
- Persistence Timer
- Keepalive Timer
- TIME-WAIT Timer

Retransmission Timer

- To retransmit lost segments, TCP employs one retransmission timer (for the whole connection period).
- Handles the retransmission time-out (RTO), the waiting time for an acknowledgment of a segment.
- When TCP sends the segment in front of the sending queue, it starts the timer.
- If the queue is empty, TCP stops the timer; otherwise, TCP restarts the timer.

Persistence Timer

- To deal with a zero-window-size advertisement, TCP needs another timer.
- Receiving TCP announces a window size of zero, sending TCP stop transmitting segments until receiving TCP sends an ACK announcing non zero window size.
- ACK can be lost.
- Sending TCP has not received an acknowledgment and waits for the other TCP to send an acknowledgment advertising the size of the window.
- Both TCPs might continue to wait for each other forever (a deadlock).
- To correct this deadlock, TCP uses a **persistence timer** for each connection

Persistence Timer

- When the sending TCP receives an acknowledgment with a window size of zero, it starts a persistence timer.
- When the persistence timer goes off, the sending TCP sends a special segment called a *probe.*
- This segment contains only 1 byte of new data.
- The probe causes the receiving TCP to resend the acknowledgment.
- value of the persistence timer is set to the value of the retransmission time.
- If no response received, another probe, value of persistence timer is doubled.

Persistence Timer

- Sender continues sending probe and doubling persistence timer until value reaches threshold (usually 60 s).
- After threshold, probe is send every 60 s until window is reopened.

Keepalive Timer

- Used to prevent long idle connection between two TCP.
- Server Resets Keepalive timer each time it hears from client.
- Timeout is usually 2 hours.
- If the server does not hear from the client after 2 hours, it sends a probe segment.
- If there is no response after 10 probes, each of which is 75 s apart, it assumes that the client is down and terminates the connection.

TIME-WAIT Timer

- The TIME-WAIT (2MSL) timer is used during connection termination.
- MSL (Maximum Segment Life) : amount of time any segment can exist in a network before being discarded.
- Common MSL values are 30 seconds, 1 minute, or even 2 minutes
- The 2MSL timer is used when TCP performs an active close and sends the final ACK.
- The connection must stay open for 2 MSL amount of time to allow TCP to resend the final ACK in case the ACK is lost.