Analysis of the phenomenon of several slow start phases in TCP

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Burstiness of TCP during slow start

• Causes:
  – The fast window increase (one packet per ACK)
  – The ACK-clock based transmission

The source transmits at twice the available bandwidth (case of no Delay ACK)

• Result:
  – In case of small buffers in routers, an early buffer overflow and an underestimation of the available bandwidth
The model

Burst rate = $2\mu$

Burst rate = $\mu$

Input of the bottleneck

Output of the bottleneck

Buffer occupancy

Time

$nT$  $(n+1)T$  $(n+2)T$
The overflow window $W_B$

Due to these bursts, $B$ overflows at a window [Lakshman et al. 1997, Barakat et al. 1999]

$$W_B = 2^{n_B - 1} + B$$

$$2^{n_B - 2} < B \leq 2^{n_B - 1}$$

And losses are detected at a window $W_D = \min(W_{th}, 2W_B)$
Double slow start phenomenon


- For $W_{th} = (B + \mu T)/2 < W_B \iff B < \mu T/3$
Triple slow start phenomenon

Although $W_D/2 < W_B$, three consecutive slow start phases are seen in some simulations.

- **Cause**: Packets stored in the receiver buffer at the beginning of the second slow start phase.

- **Explanation**: Different window evolution during the second slow start phase and thus different $W_B$.

- **Consequence**: Further deterioration in performance.
Analysis of triple slow start

Methodology
A detailed analysis of the window evolution and the buffer occupancy during the second slow start phase

Second slow start

We distinguish four consecutive phases

1- The window is multiplied by 1.5 every $T$
2- A burst of packets of size $2^{n_B-1} - B + 2$
3- The window is multiplied by 1.5 every $T$
4 - Normal slow start: The window is multiplied by two every $T$
Results

• Losses cannot appear before phase 4.
• In phase 4, losses cannot appear if \( B > \mu T/7 \).
• For \( B < \mu T/7 \), a sufficient condition for losses

\[
\left( 2^{n_B - 1} - B + 2 \right) \left\lfloor 2(1.5)^n - 1 \right\rfloor > 2B - 1
\]

where \( n \) is the smallest integer number satisfying

\[
\left( 2^{n_B - 1} - B + 2 \right) \left\lfloor (1.5)^{n+1} - 1 \right\rfloor > B + 1
\]
Periodicity of the phenomenon

While increasing $B$ from 0 to $\mu T/7$, the losses during the second slow start phase appear and disappear in a periodic manner causing an oscillation in the throughput

$\mu$ simulator

$\mu=1.5$ Mbps

$T=560$ ms

MSS = 512 bytes
Results

TCP congestion window vs. Time

Conclusions:

• Slow start has different behavior when some packets are stored in the receiver buffer