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Hybrid Slow Start for High-Bandwidth and Long-Distance Networks

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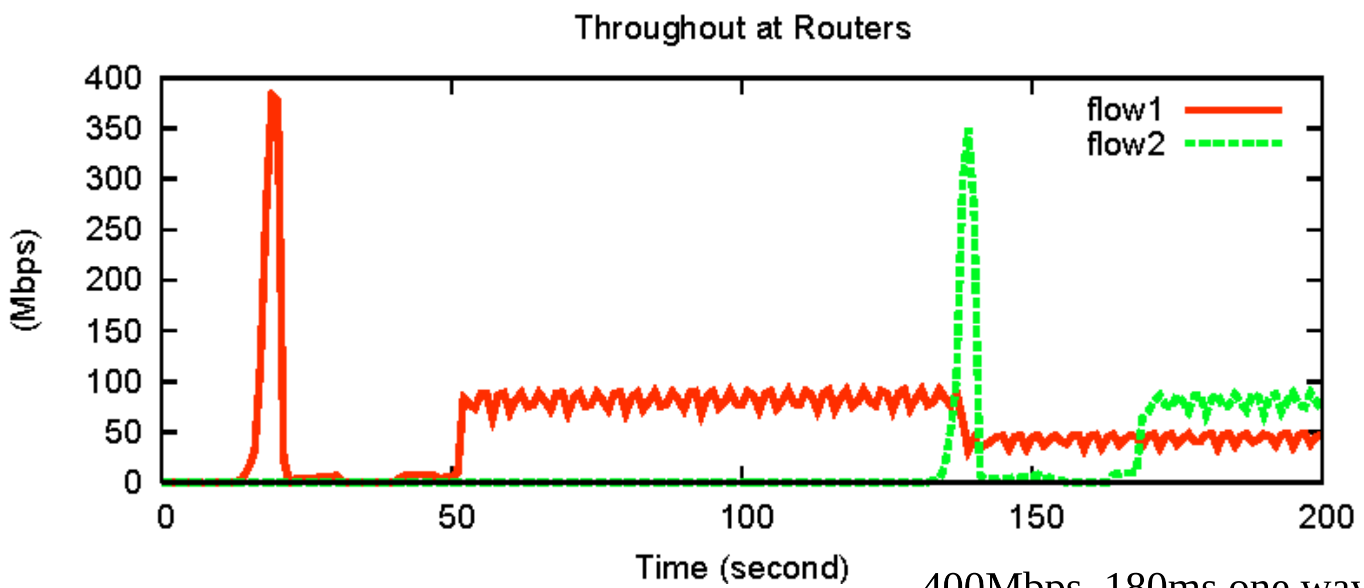
Slow Start on a High BDP path



400Mbps, 180ms one way delay, and 100% BDP buffer

- Slow Start
  - Pros: Slow Start probes an available bandwidth very fast (exponentially)
  - Cons: # of packet drops can be well beyond BDP, so it is more problematic for high bandwidth and long distance network

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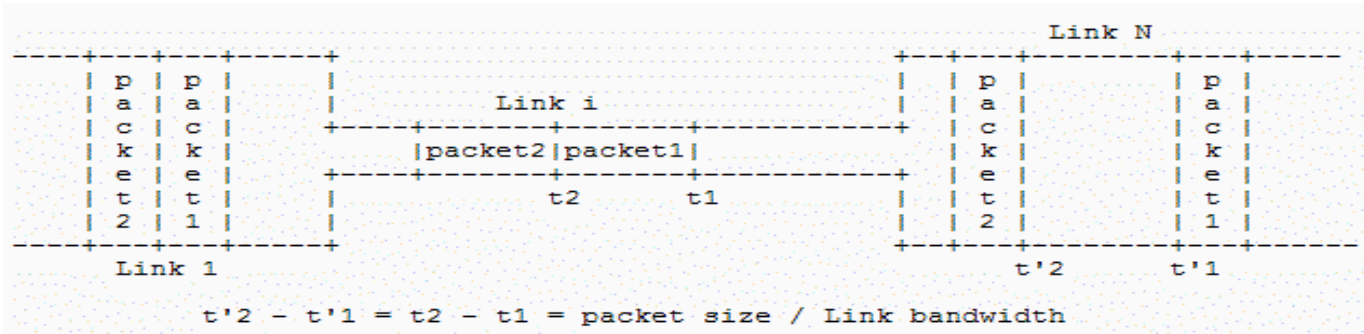
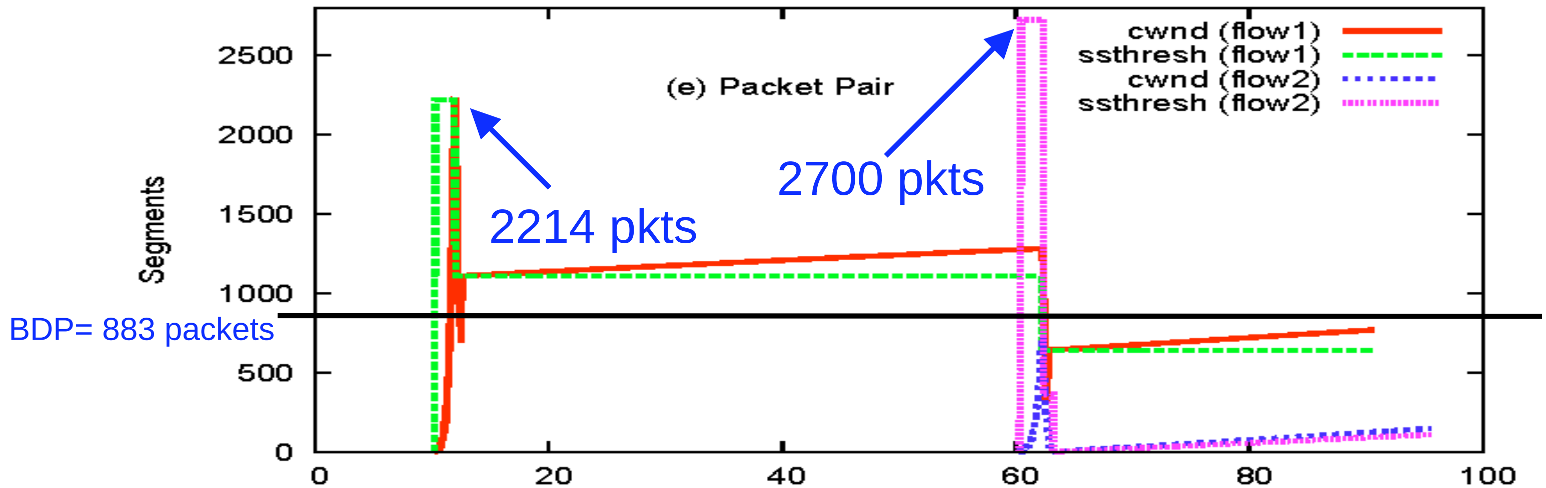
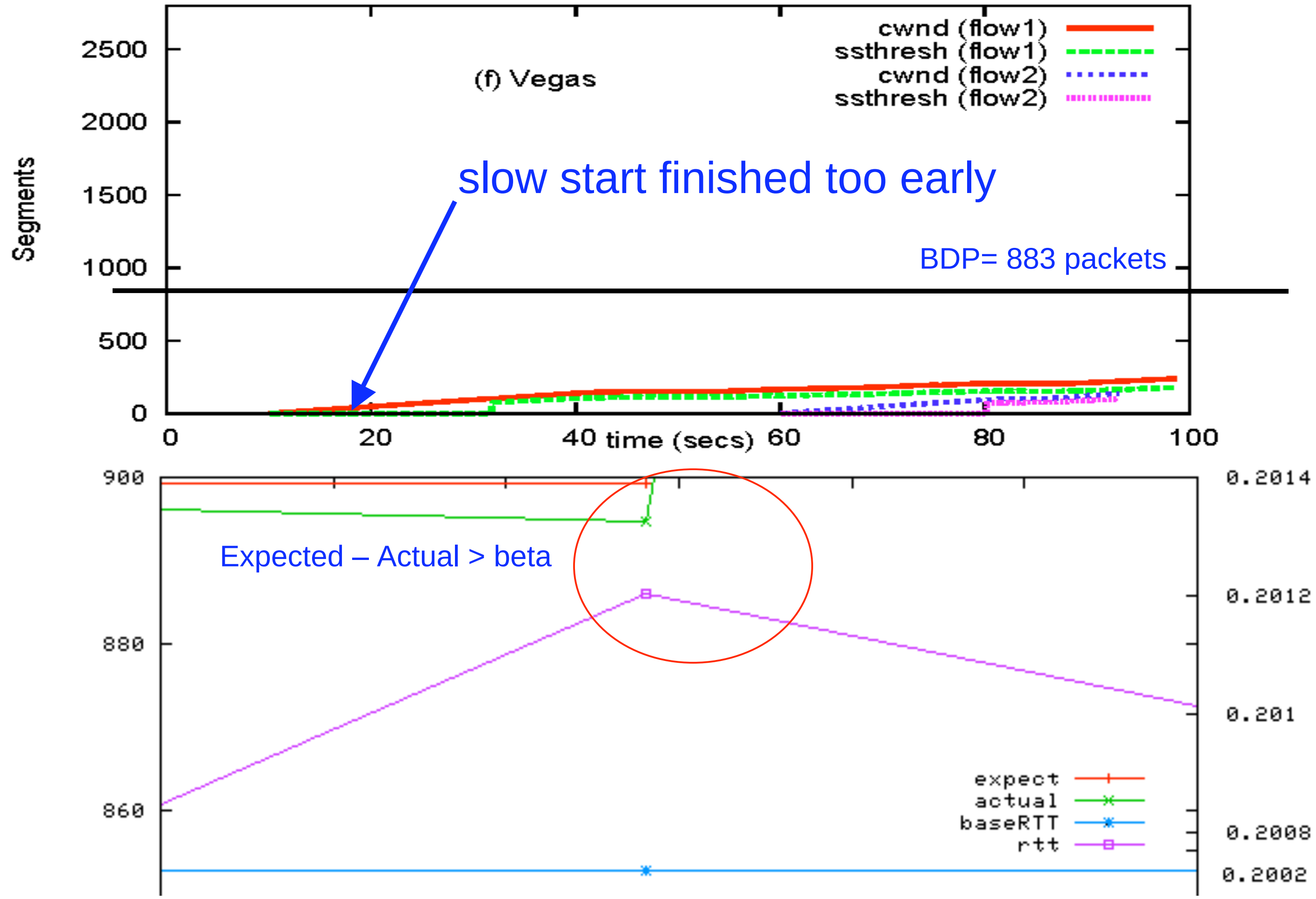
Packet Pair based slow start





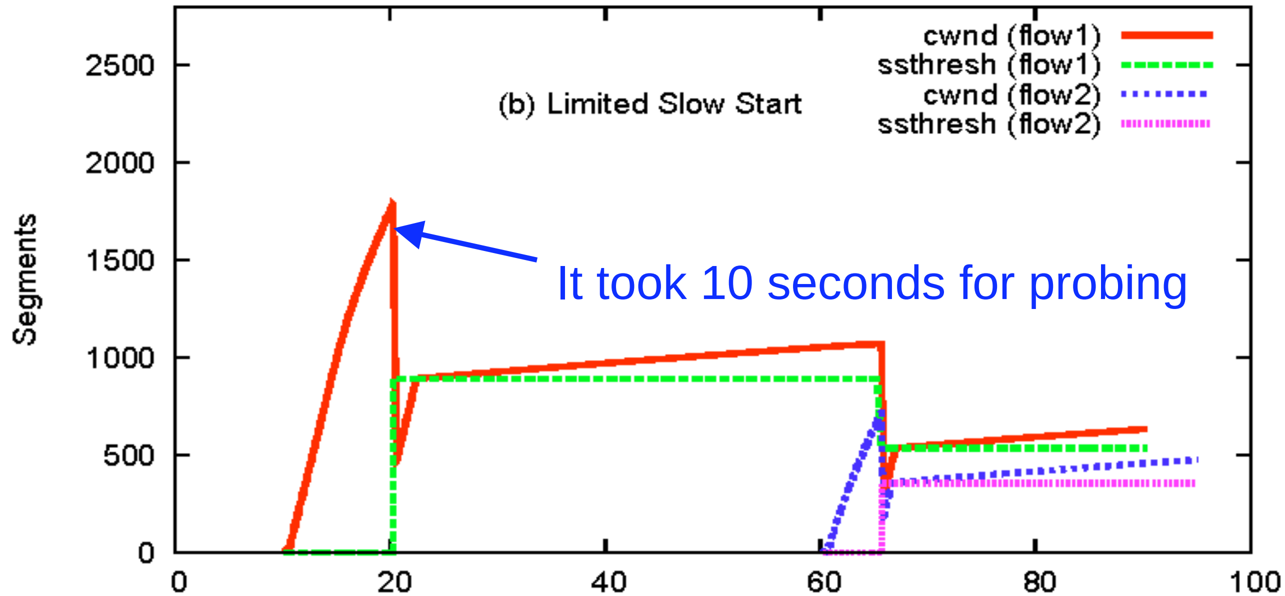
- Frequent over-estimation of bottleneck capacity
- Multiple flows can get the same answers. It can overshoot up to N*C (N: #flows, C: capacity)

Modified slow start of Vegas



- Temporary queue build-up leads to a premature termination of slow start

Limited Slow Start (Exp. RFC 3742)

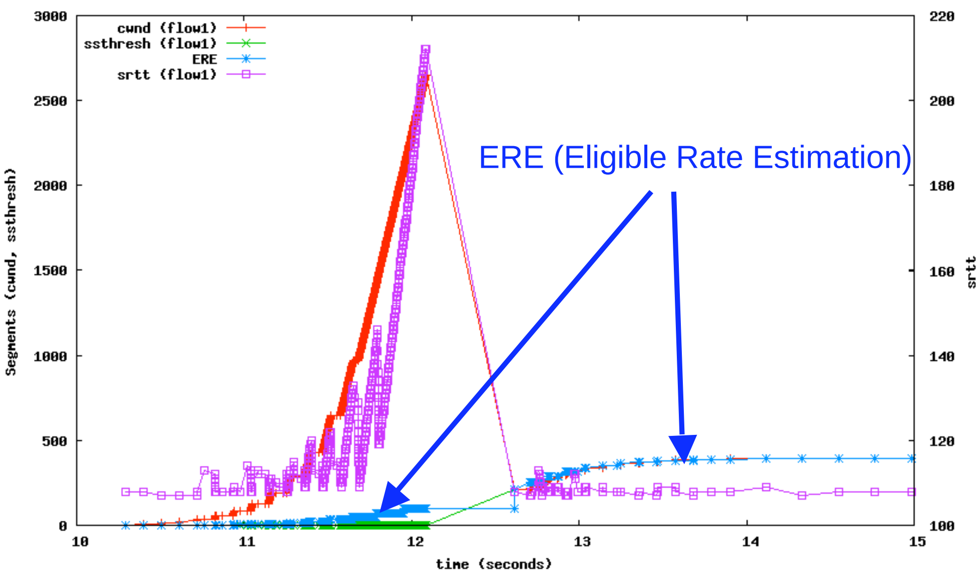


- Algorithm during slow start
  - If (cwnd <= max_ssthresh) cwnd +=MSS
  - Else K = int(cwnd/0.5*max_ssthresh)
  - cwnd += int(MSS/K)
- RFC recommends max_ssthresh=100 for most of cases. But this still suffers for a large BDP path

Adaptive Start

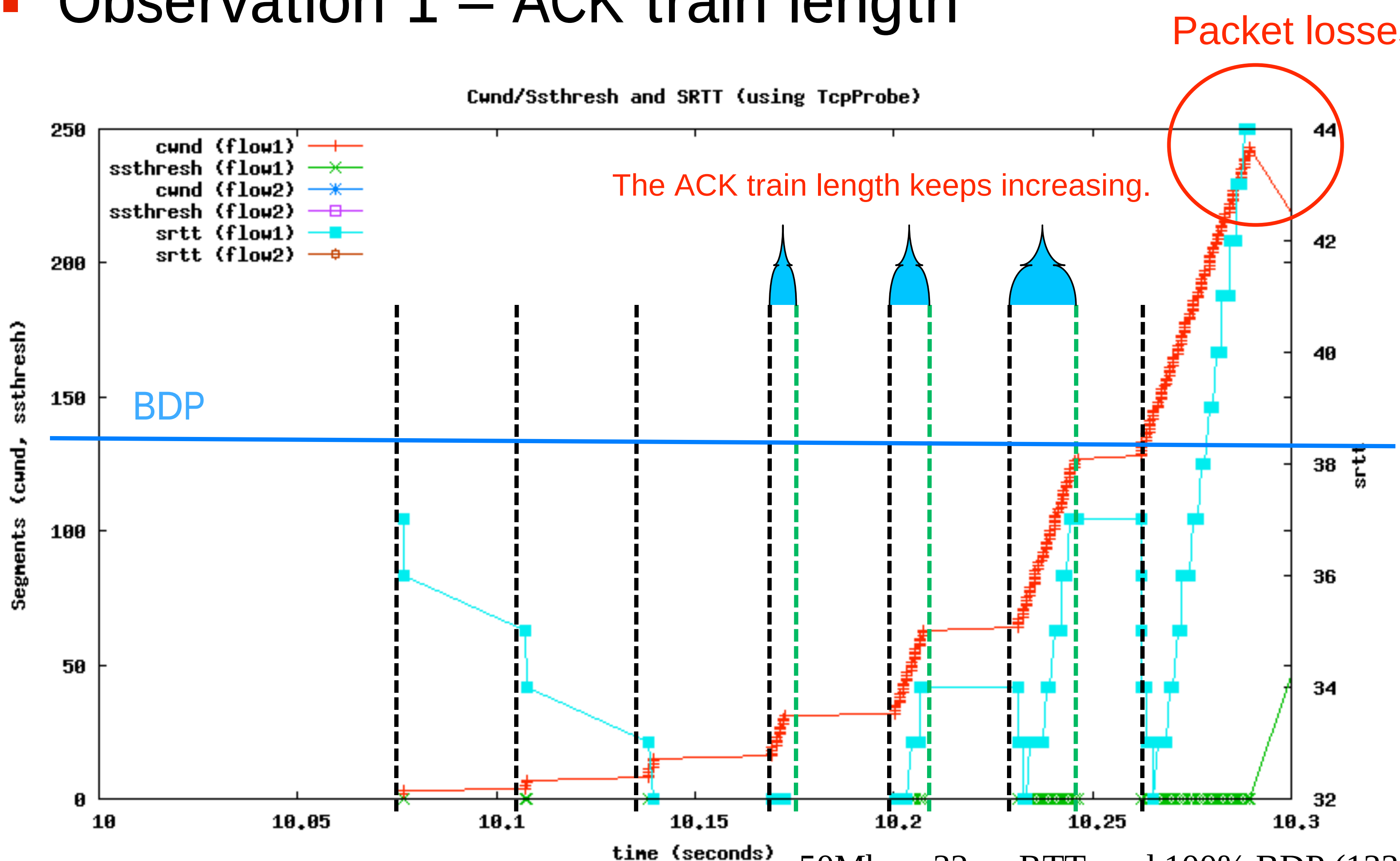
```
if ( DUPACKS are received)
  switch to congestion avoidance phase;
else (ACK is received)
  if (ssthresh < (ERE*RTT_min)/seg_size)
    ssthresh=(ERE*RTT_min)/seg_size; /*reset ssthresh*/
  endif
  if (cwnd >= ssthresh) /*linear increase
  phase*/
    increase cwnd by 1/cwnd;
  else if cwnd < ssthresh) /*exponentially
  increase phase*/
    increase cwnd by 1;
  endif
endif.
```

- Problem
  - ERE increases very slowly



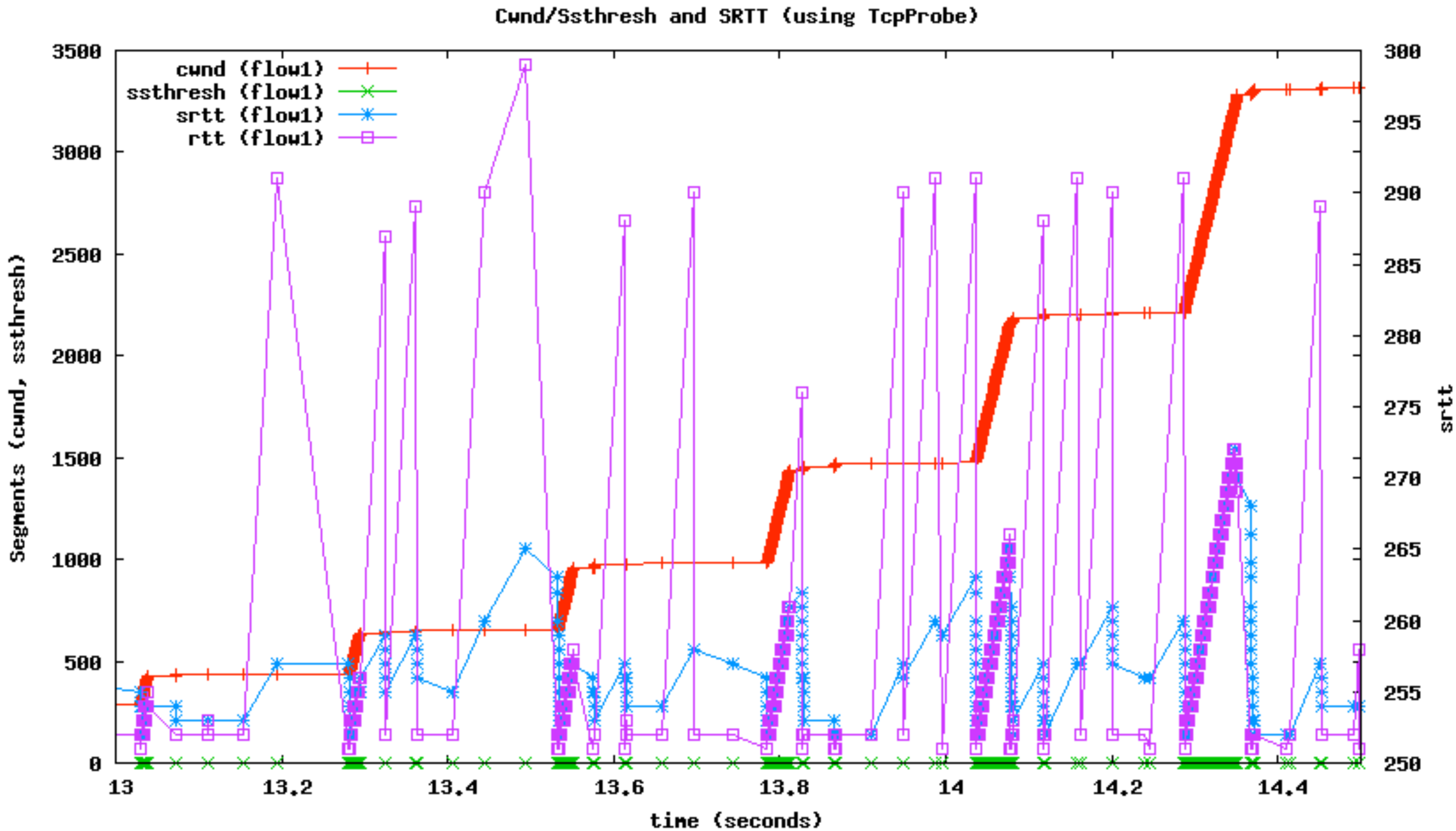
What really happens during Slow Start?

- Observation 1 – ACK train length

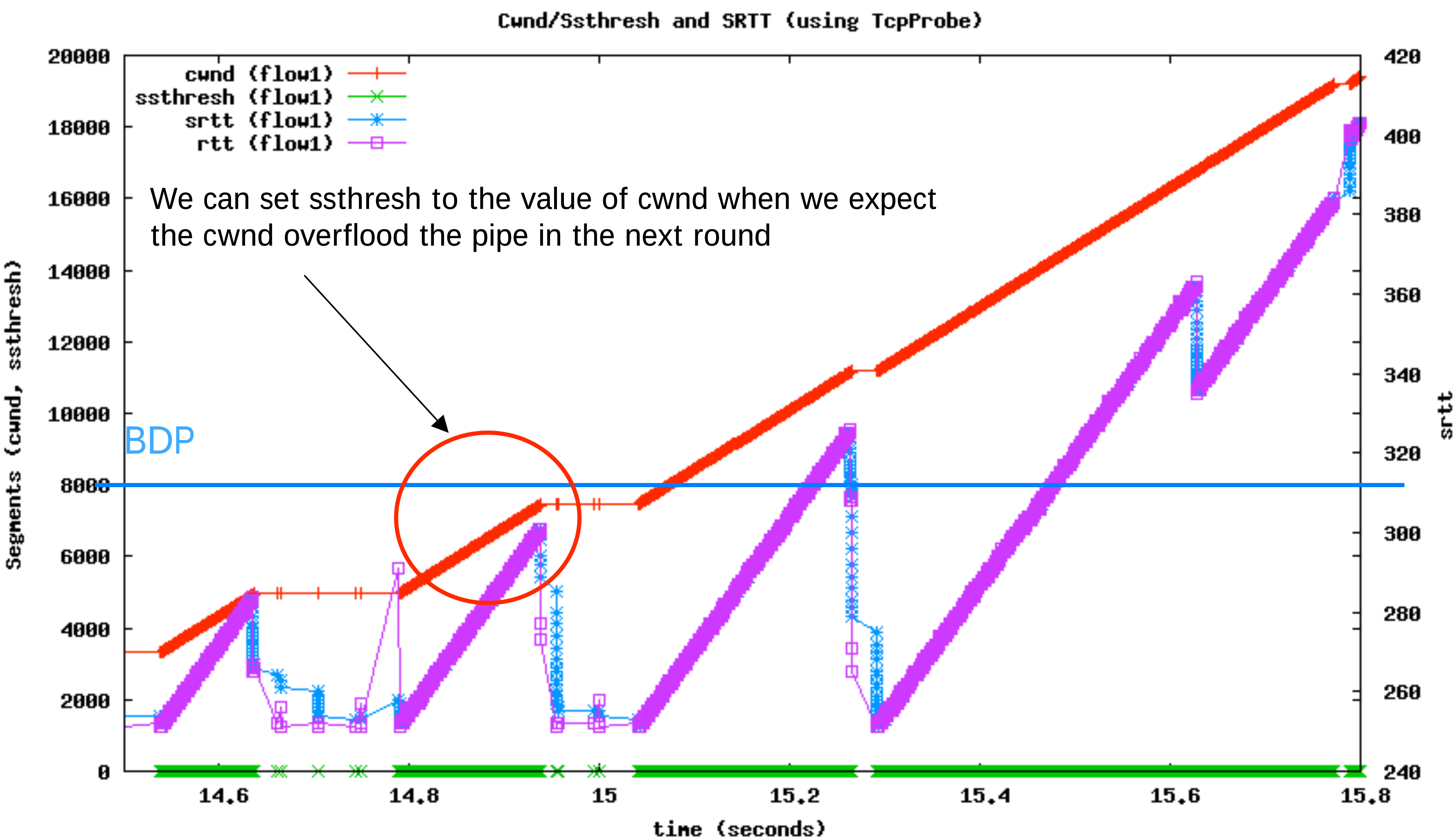


50Mbps, 32ms RTT, and 100% BDP (133pkts)

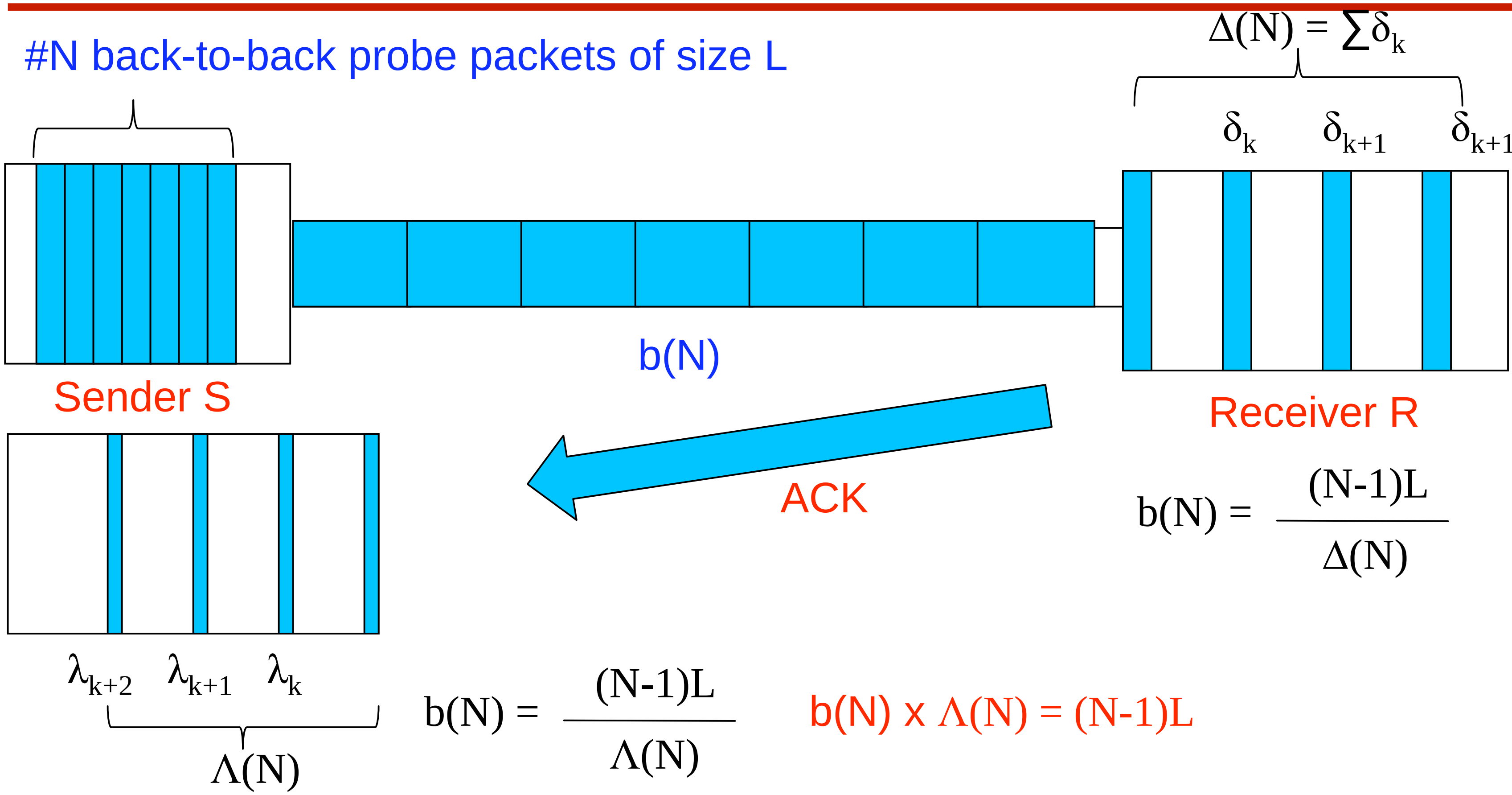
Detailed look on the ACK train (1)



Detailed look on ACK train length (2)



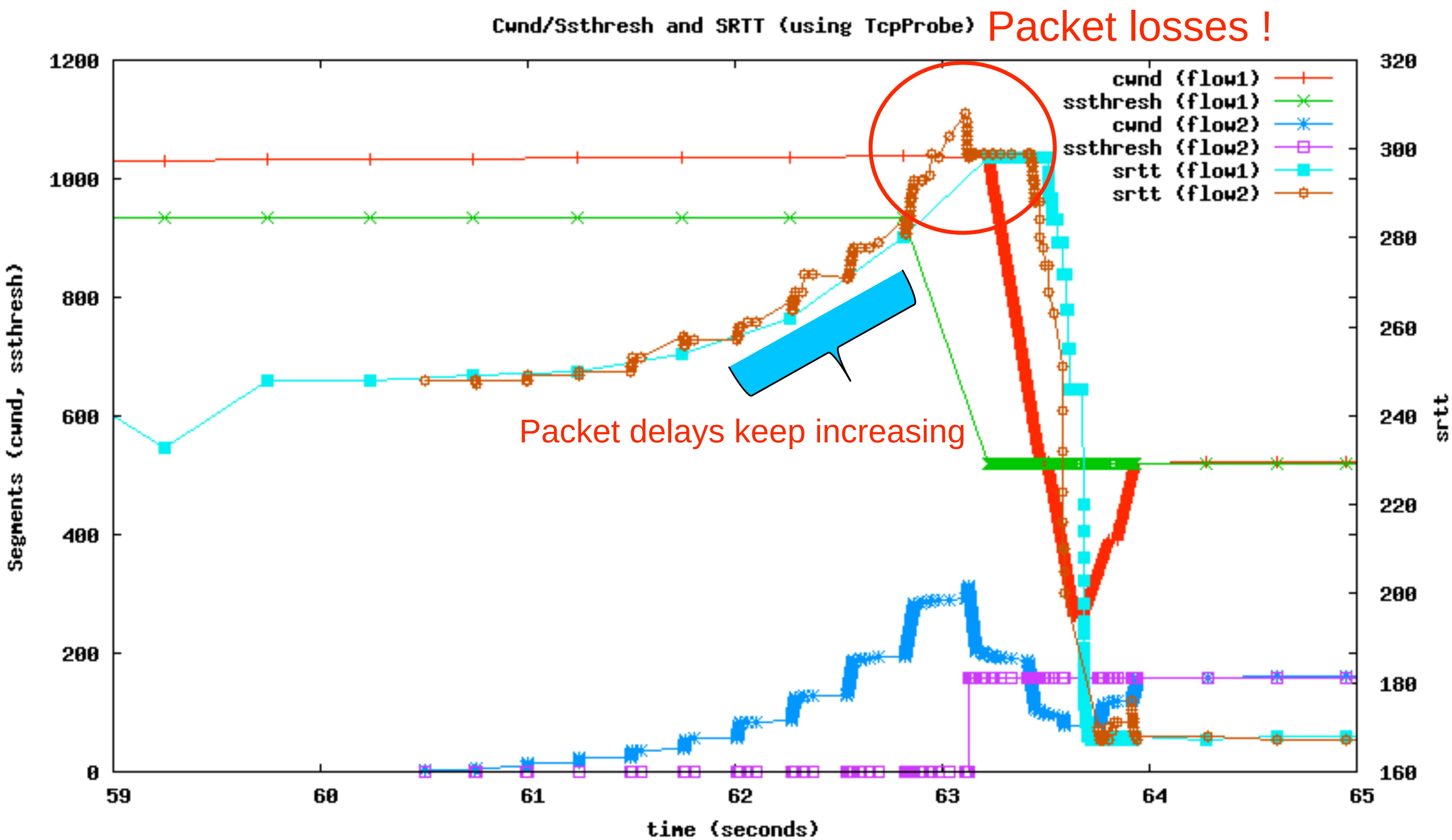
Hybrid Slow Start – ACK train length



- Without knowing (N-1)L and b(N), we can use Λ(N) to infer whether the packets in flight approaching the BDP of a path
- TCP sender doesn't need a high-resolution clock as the TCP sender needs only a rough estimation of ACK train

What really happens during Slow Start?

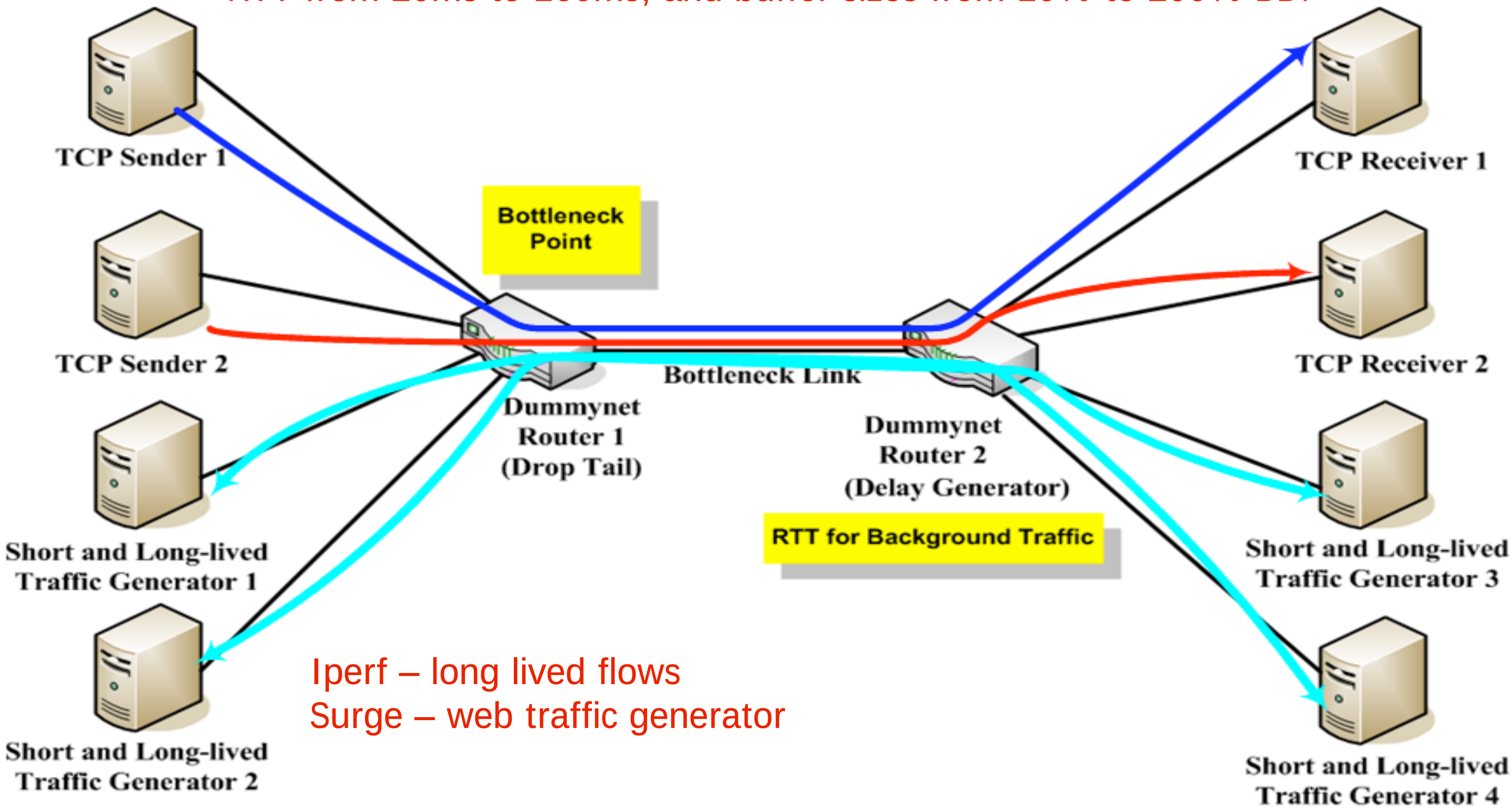
- Observation 2 – increase in packet delays



50Mbps, 166ms RTT, and 100% BDP (553pkts)

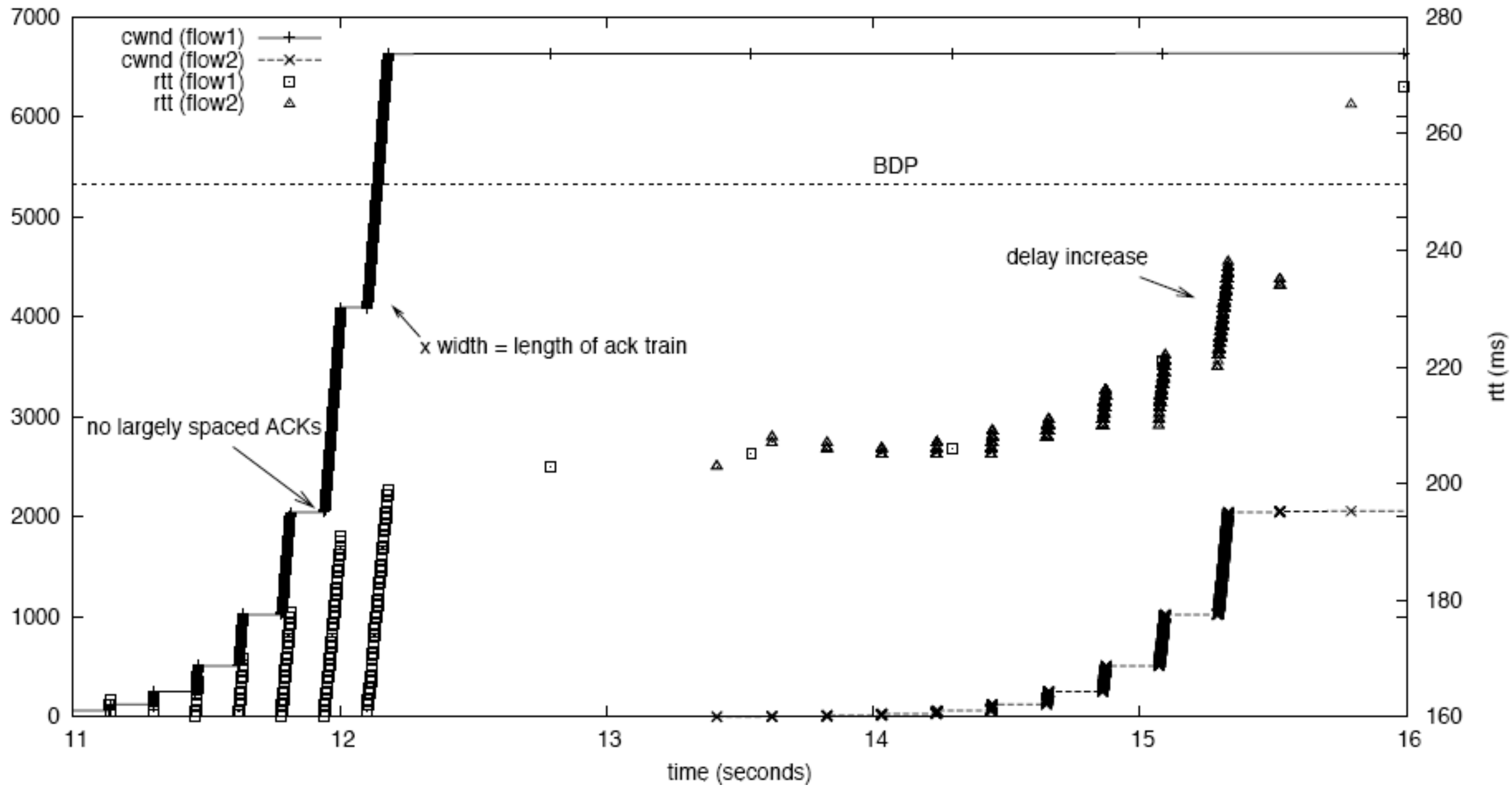
Testbed (Dummynet) Setup

The bottleneck bandwidth varied from 10Mbps to 400Mbps,
RTT from 20ms to 160ms, and buffer sizes from 10% to 200% BDP



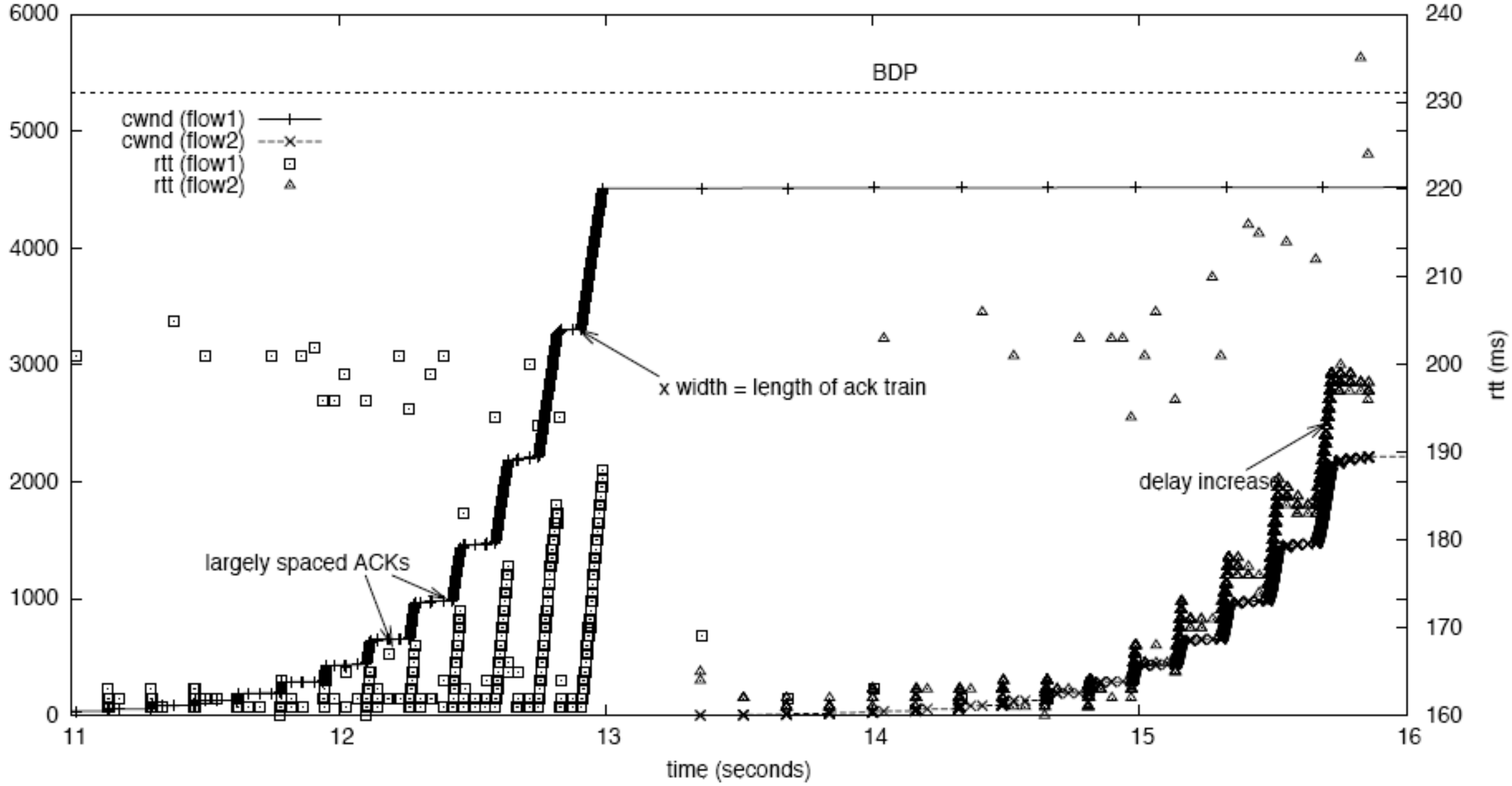
Iperf – long lived flows
Surge – web traffic generator

Hybrid Slow Start with quick ACKs (Linux 2.4 receivers)



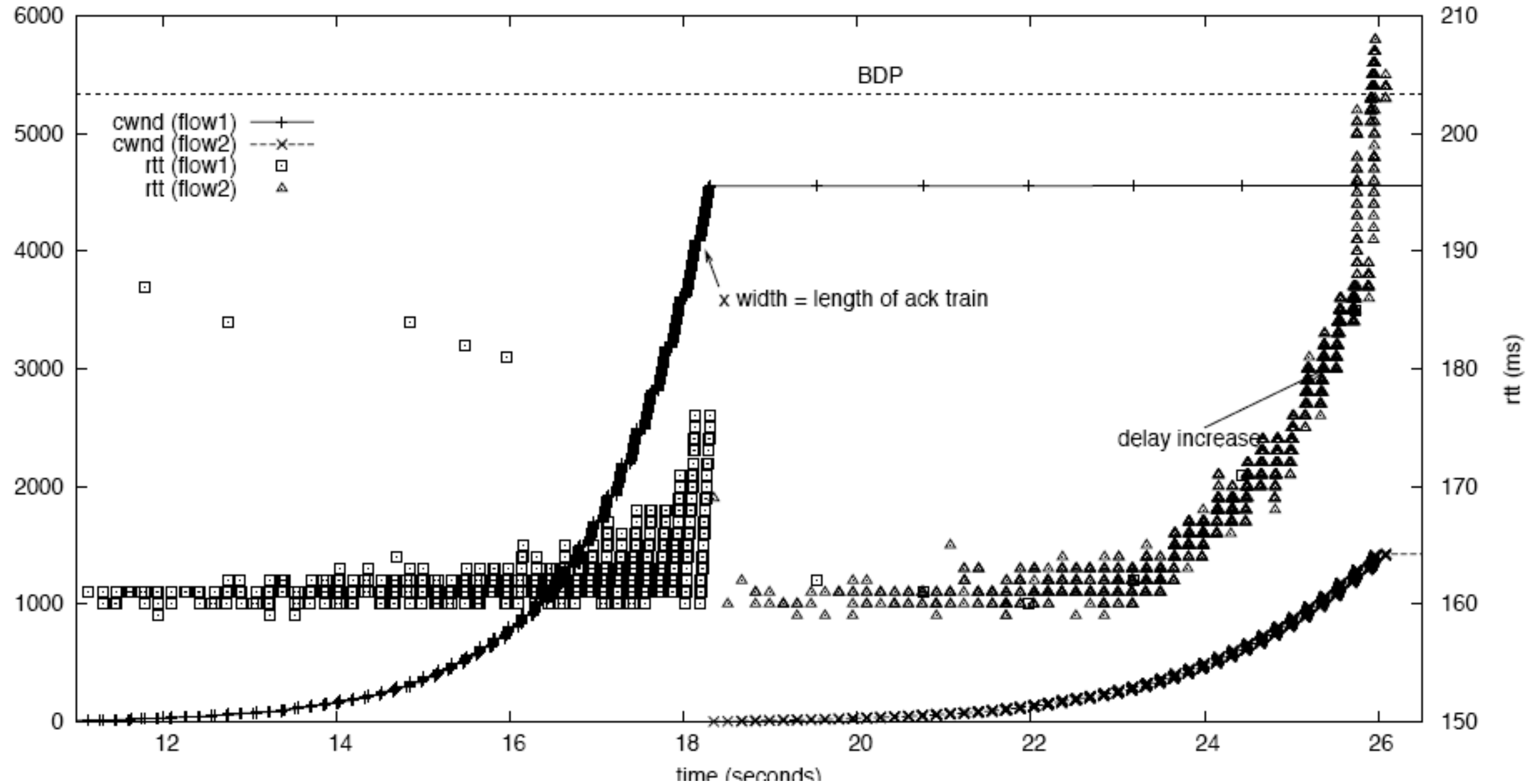
Two TCP-SACK flows with Hybrid Slow Start.
400Mbps, 160ms RTT, and 100% BDP (5333packets)

Hybrid Slow Start with quick and delayed ACKs (Linux 2.6 receivers)



Two TCP-SACK flows with Hybrid Slow Start.
400Mbps, 160ms RTT, and 100% BDP (5333packets)

Hybrid Slow Start with delayed ACKs (Windows and FreeBSD)

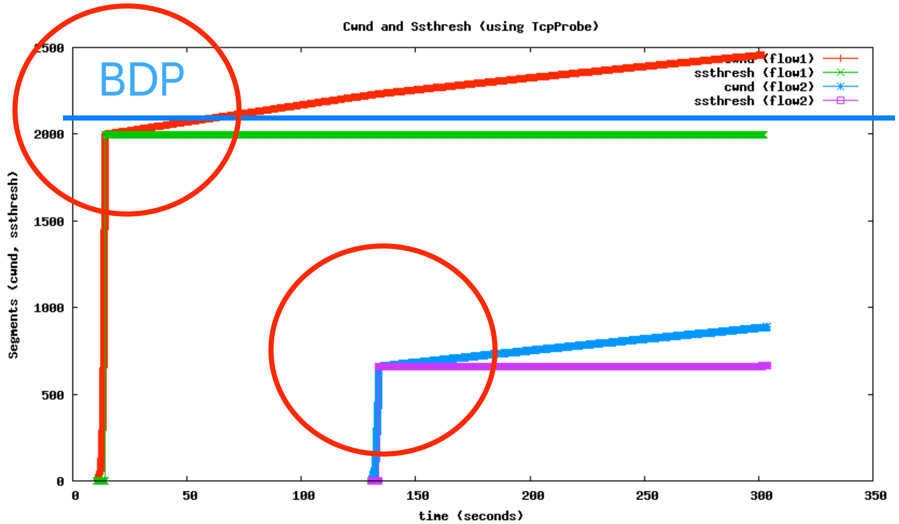


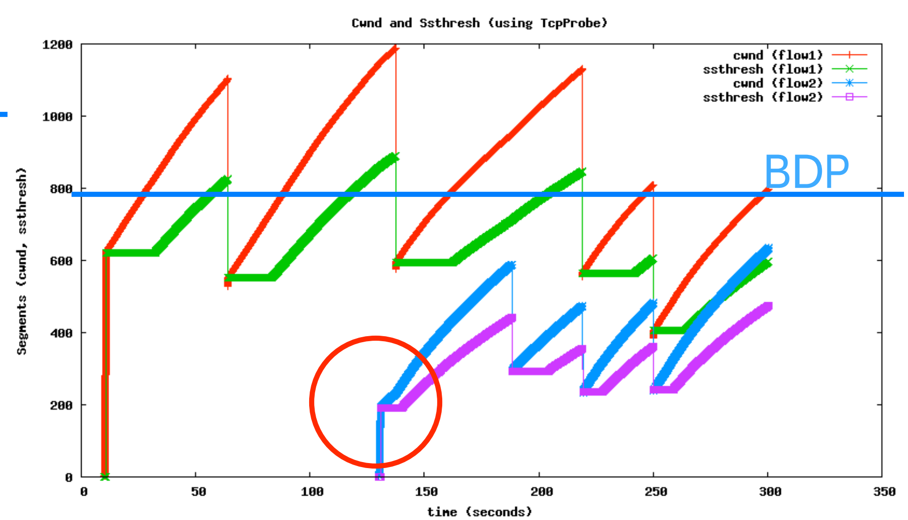
Two TCP-SACK flows with Hybrid Slow Start.
400Mbps, 160ms RTT, and 100% BDP (5333packets)

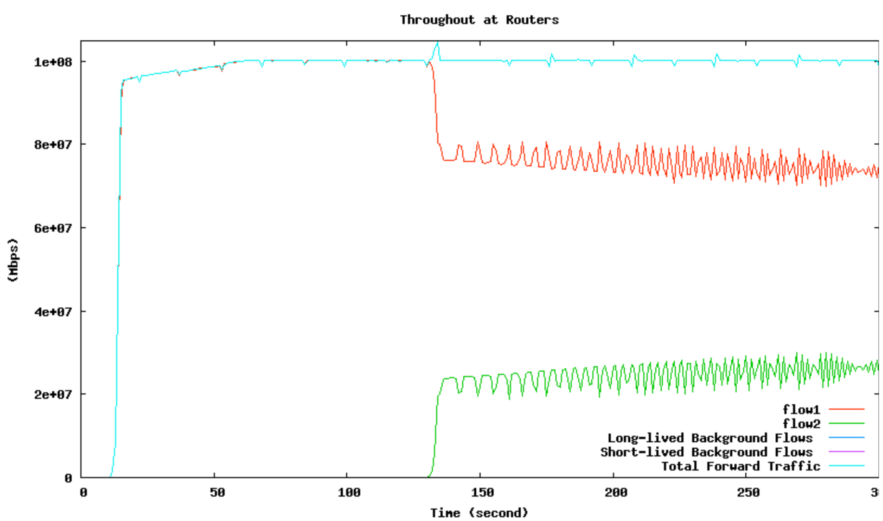
More results with TCP-SACK

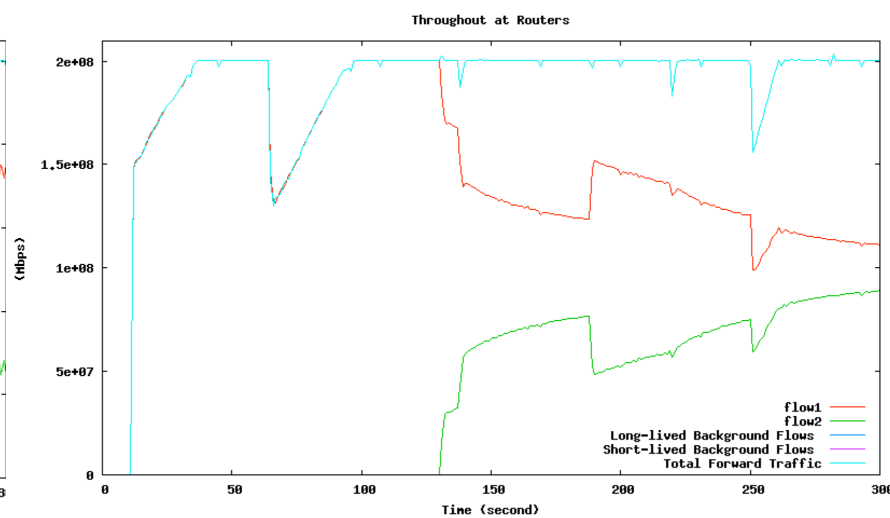
100M-1.0 BDP-250ms RTT – No BK

200M-1.0 BDP-50ms RTT – No BK

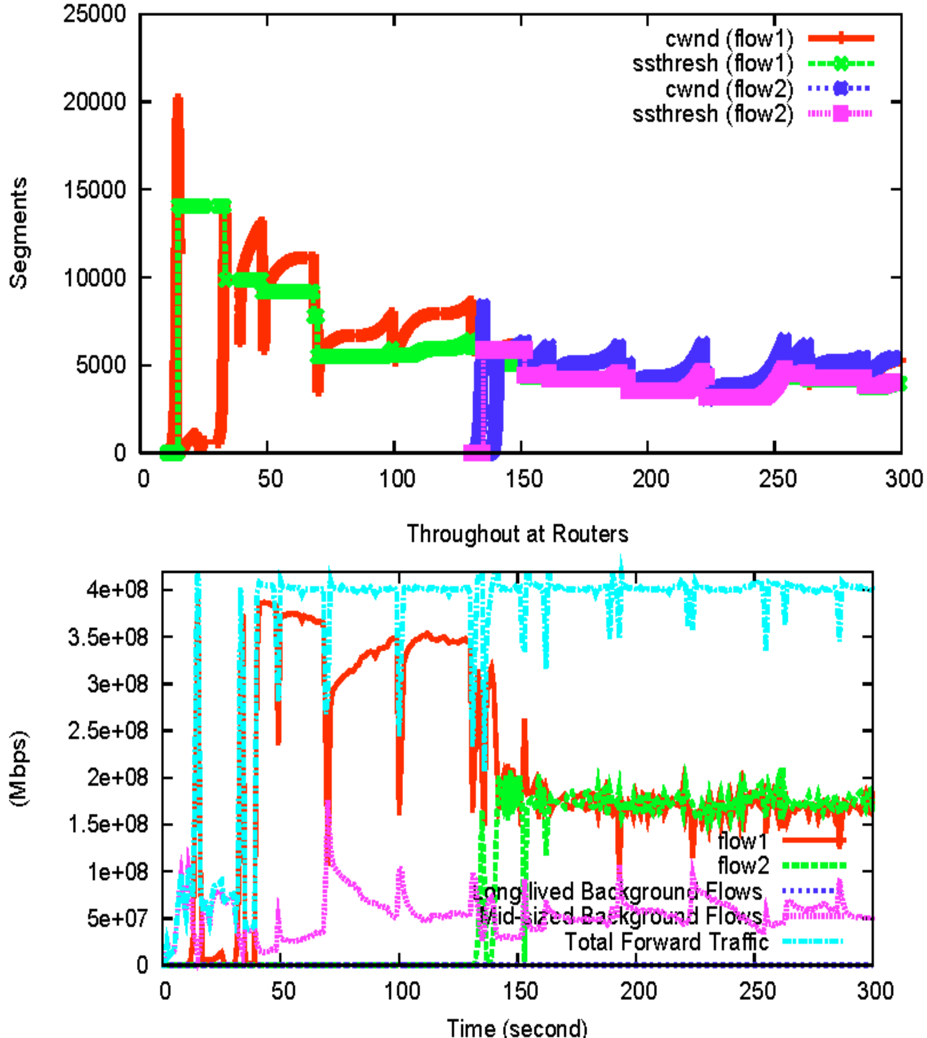




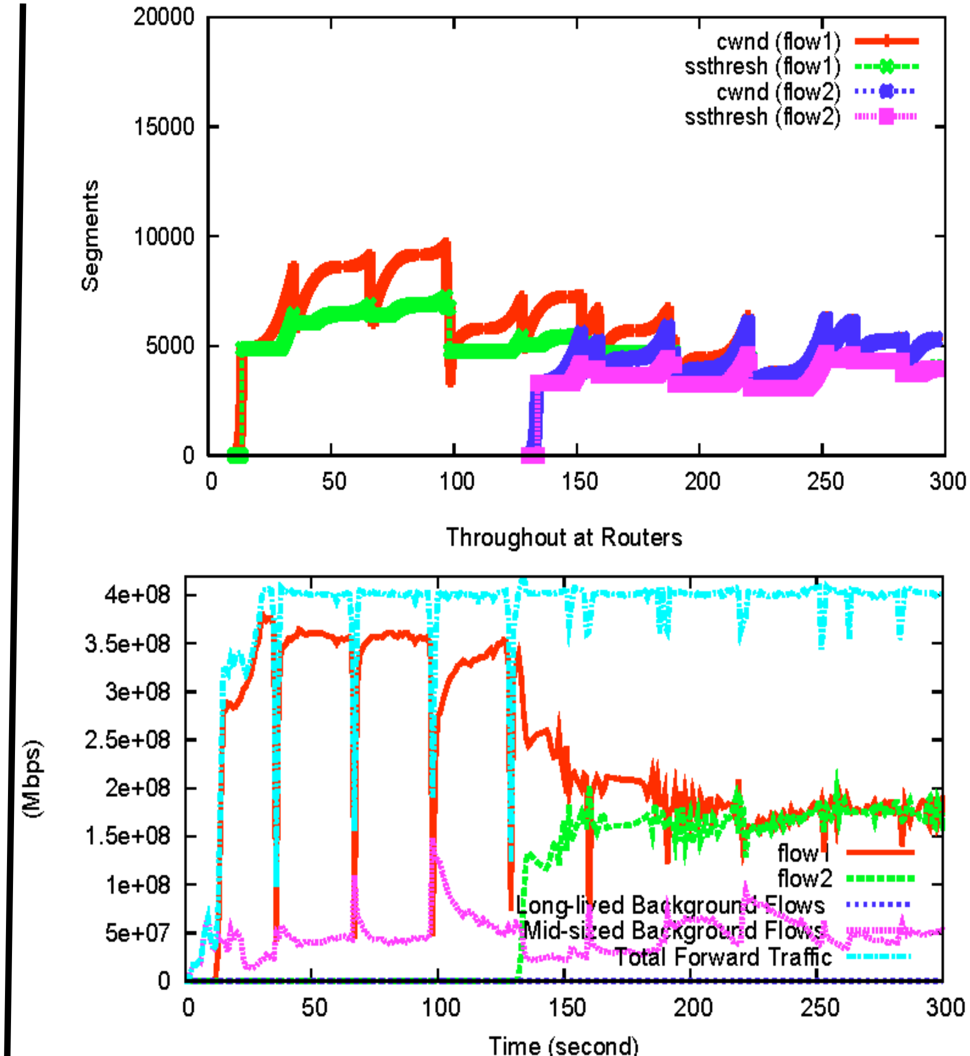




Apply Hybrid Slow Start to CUBIC

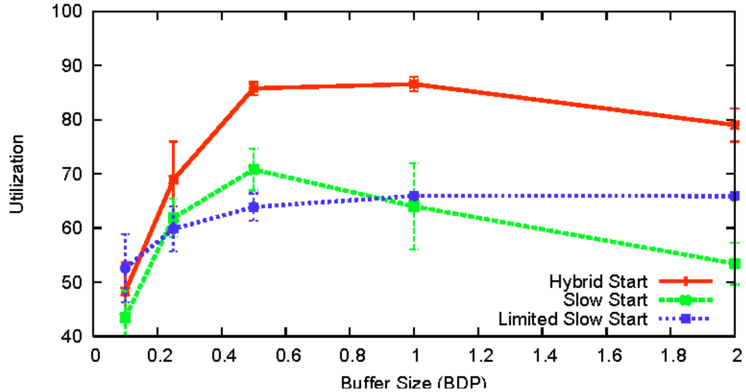


Slow Start

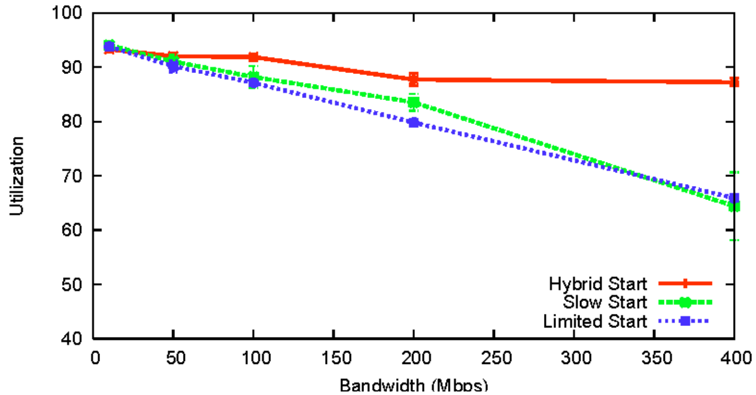


Hybrid Slow Start

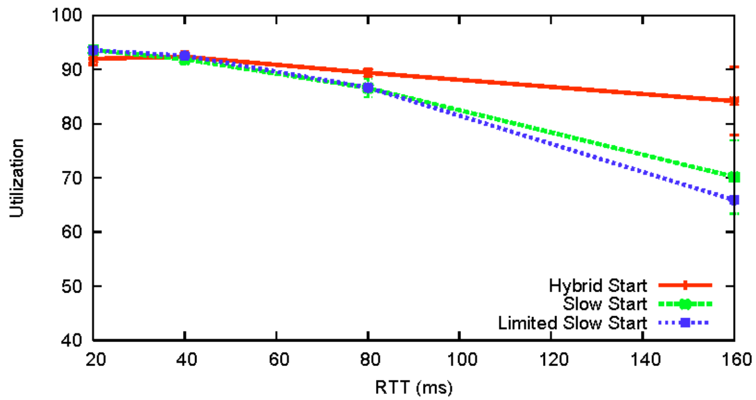
Testing under more diverse settings



Bandwidth: 400Mbps
RTT: 160ms
Buffer size: 10% ~200% BDP

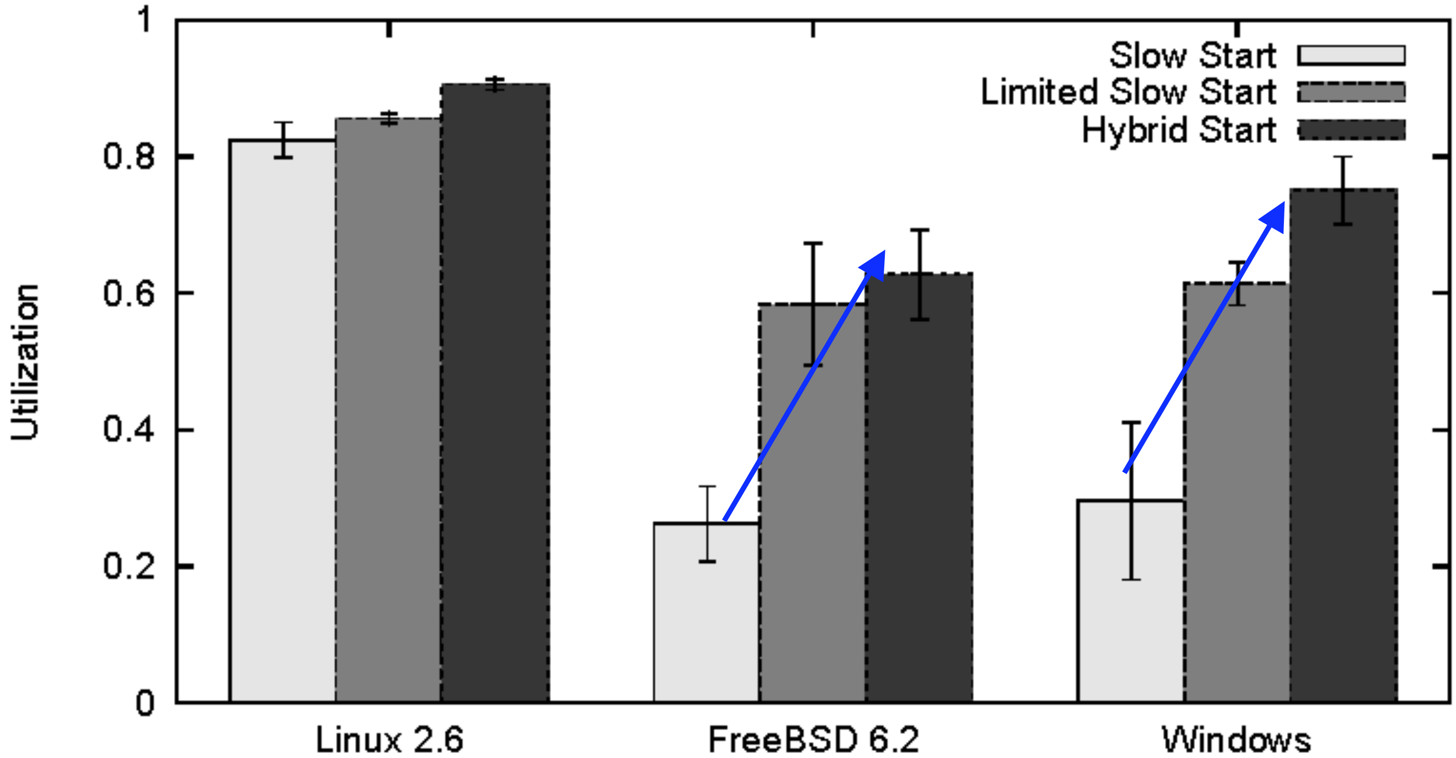


RTT: 160ms
Buffer size: 100% BDP,
Bandwidth: 10Mbps ~ 400Mbps



Bandwidth: 400Mbps
Buffer size: 100% BDP
RTT: 20ms ~ 160ms

Testing with Linux, FreeBSD, and Windows Receivers



Bandwidth: 400Mbps
RTT: 100ms
buffer size: 100% BDP

Conclusion and Future Work

- Using ACK train and delay information significantly improves the efficiency of Slow Start
- Hybrid Slow Start is a small plugin to an existing Slow Start and can be easily integrated with existing TCP congestion control algorithms
- More testing over real production networks and Refinements for handling asymmetric link and congestion on the backward path are our future work

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Q & A

More experimental results (including Internet2 results) will be available at
http://netsrv.csc.ncsu.edu/twiki/bin/view/Main/SlowStart

Thank you for your participation

Backup Slides

Hybrid Slow Start - Pseudo Codes

Algorithm 1: Hybrid Slow Start

```
Initialization:
low_ssthresh ⟵ 16        nSampling ⟵ 8
At the start of each RTT round:
begin
  if !found and cwnd ≤ ssthresh then
    // Save the start of an RTT round
    roundStart ⟵ lastJiffies ⟵ Jiffies
    lastRTT ⟵ curRTT
    curRTT ⟵ ∞
    samplingCnt ⟵ nSampling
end
On each ACK:
begin
  RTT ⟵ usecs_to_jiffies(RTT_us)
  dMin ⟵ min(dMin, RTT)
  if !found and cwnd ≤ ssthresh then
    // ACK is closely spaced, and the
       train length reaches to T_forward?
    if Jiffies − lastJiffies ≤ msecs_to_jiffies(2)
    then
      lastJiffies ⟵ Jiffies
      if Jiffies − roundStart ≥ dMin/2 then
        found ⟵ 1
    // Samples the delay
    if samplingCnt then
      curRTT ⟵ min(curRTT, RTT)
      samplingCnt ⟵ samplingCnt − 1
    η ⟵ max(2, ⌈lastRTT/16⌉)
    // If the delay increase is over η
    if !samplingCnt and curRTT ≥ lastRTT + η
    then
      found ⟵ 2
    if found and cwnd ≥ low_ssthresh then
      ssthresh ⟵ cwnd
end
Timeout:
begin
  dMin ⟵ ∞        found ⟵ 0
end
```

Internet2 path (NCSU – Japan)

- We tested Hybrid Slow Start over the Internet2 path between NCSU (Linux 2.6.25-rc3) and NICT Japan (Linux 2.6.19) and found that the results are very promising.

Packet losses !