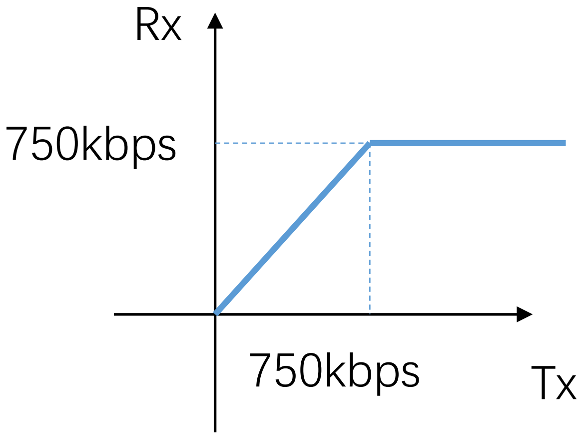
CS120: Computer Networks

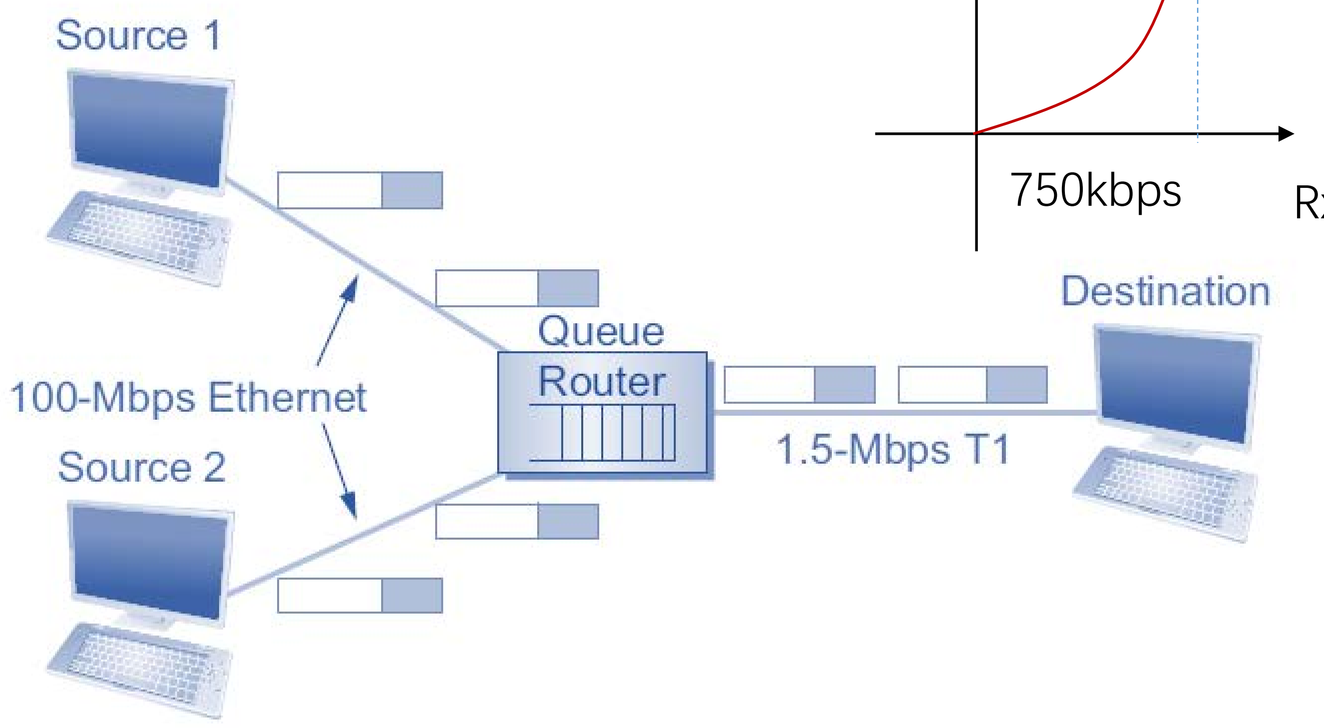
Lecture 17. Congestion Control 1

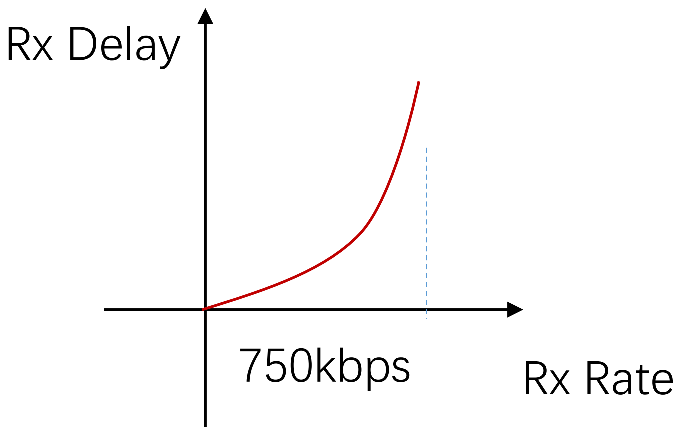
Zhice Yang

Congestion in Network



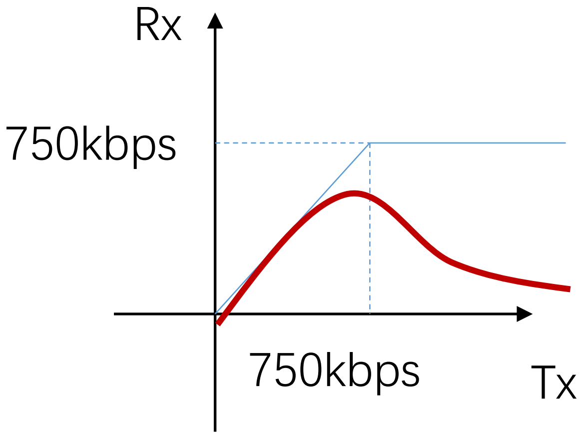
Ideal Case: Infinite Router buffer

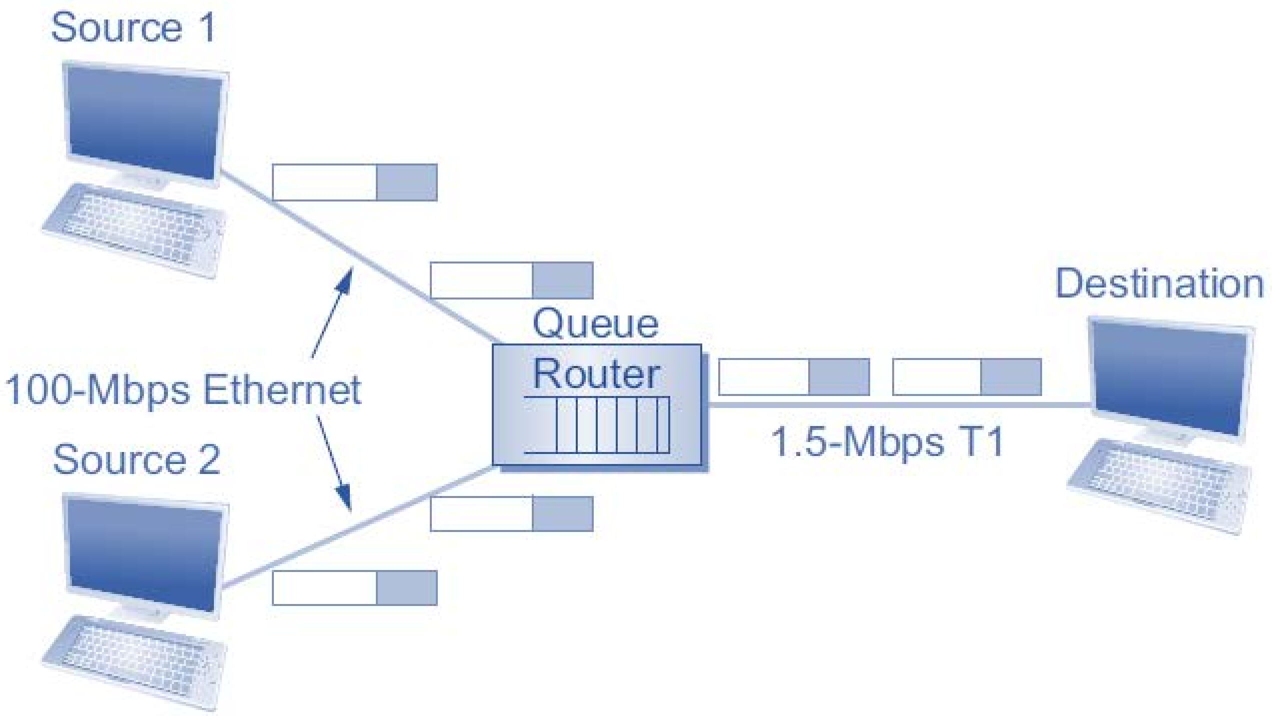




Impact: Network Delay

Congestion in Network





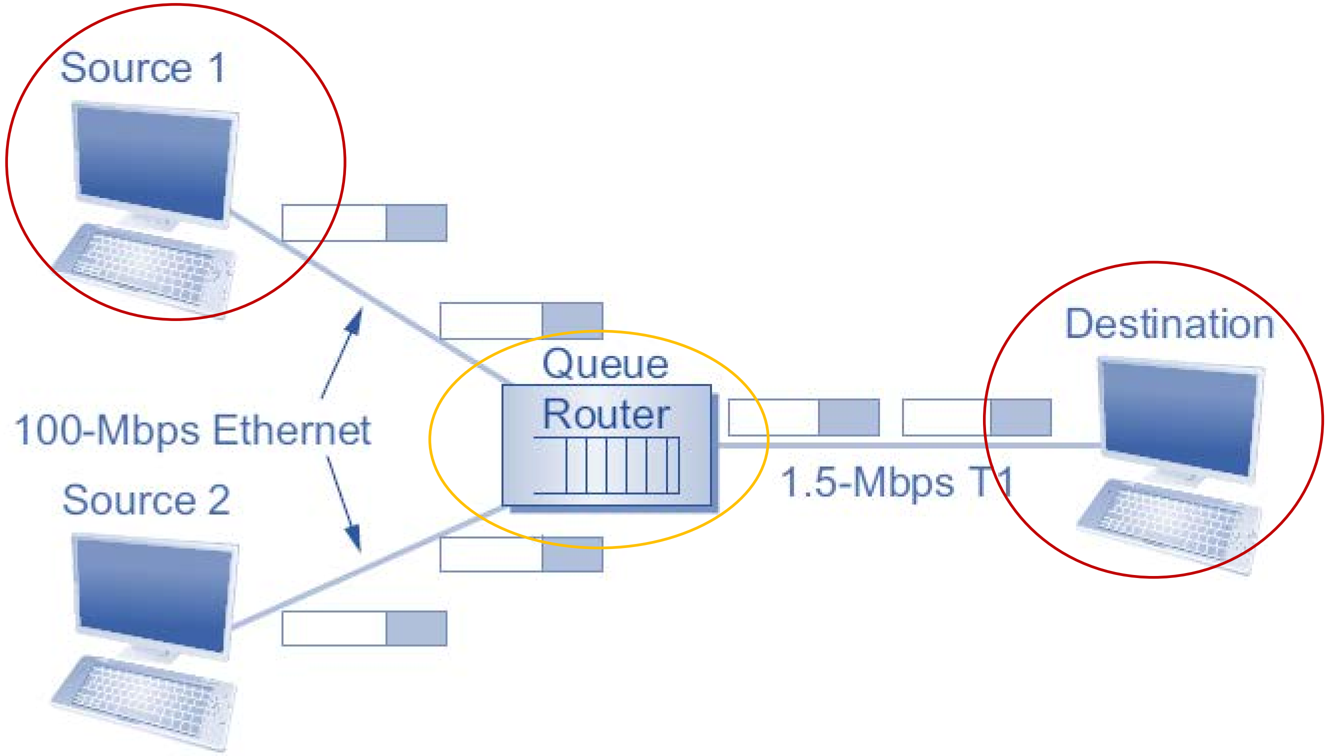
Actual Case: Finite Router buffer

- Packets can be lost (dropped at router) due to full buffers
- Sender does not know when packet has been dropped, retransmissions might be unnecessary

Impact: Retransmissions waste network capacity

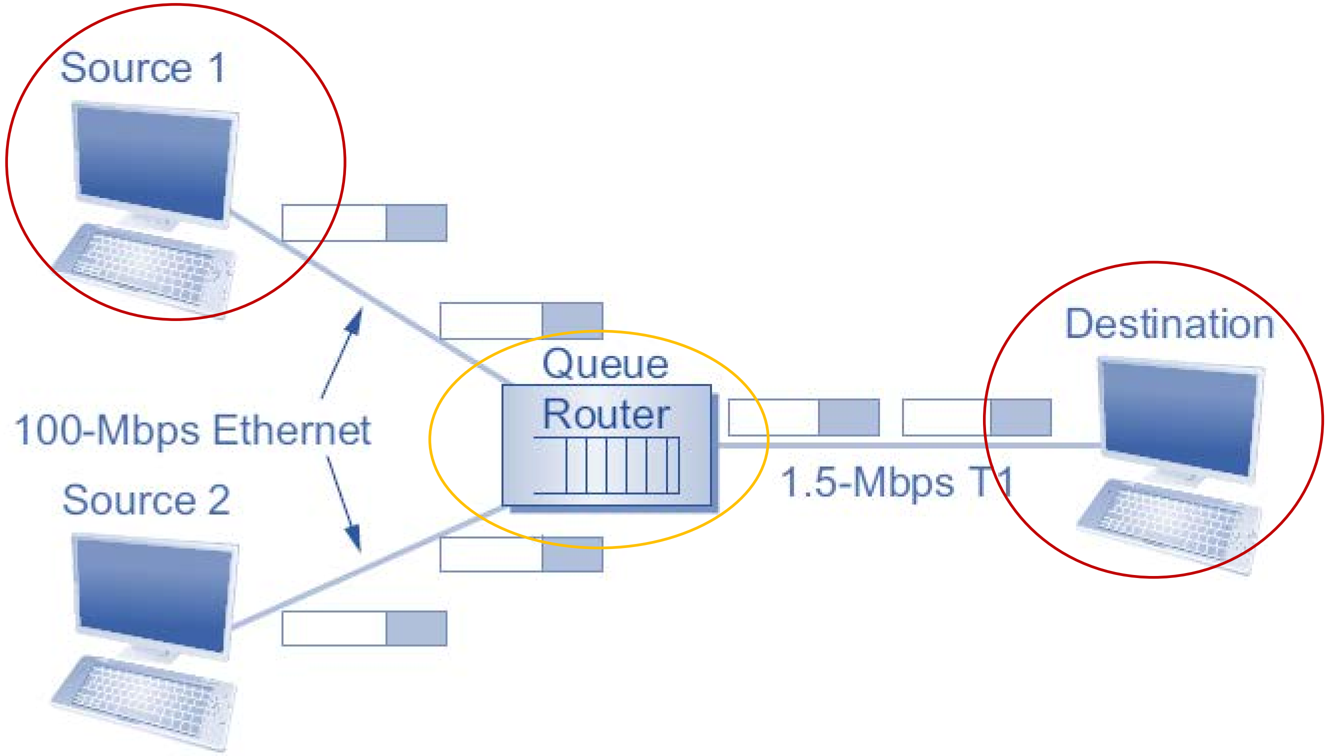
Two Places to Handle Network Congestion

- End hosts
- Routers



Two Places to Handle Network Congestion

- ➢End hosts
- • Routers



Congestion Control

- Host-based Congestion Control
  - Packet Loss
    - AIMD
    - Slow Start
    - Fast Retransmission
    - Fast Recovery
  - Delay
- Router-based Congestion Control
  - Queuing Discipline

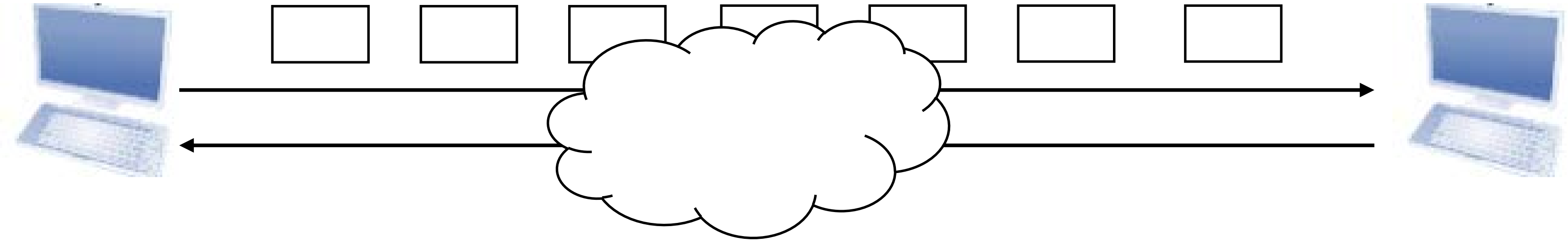
TCP Congestion Control

- Introduced by Van Jacobson through his Ph.D. dissertation work in late 1980s
  - 8 years after TCP became operational
- Basic ideas
  - Each host determines network capacity for itself
    - Leverage feedback
- Challenges
  - Determining the available capacity
  - Adjusting to changes in capacity

Simple Case – Steady Capacity

- In the steady state
  - How to measure the network capacity ?
  - How to pace the sender ?

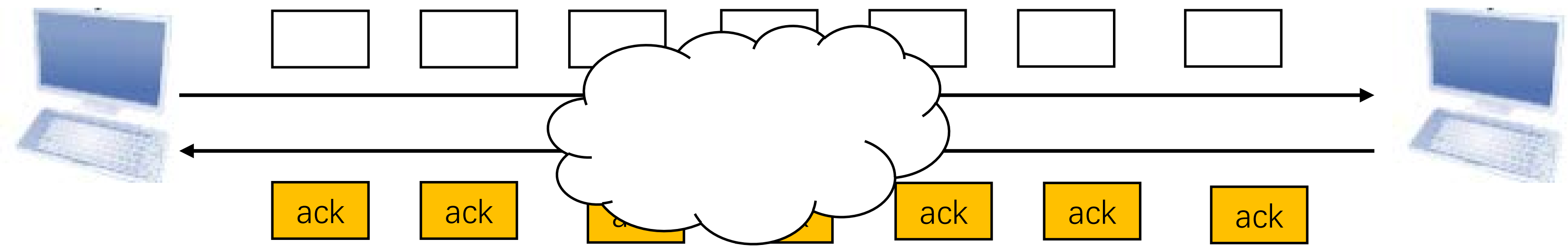
capacity: 7 packets per second (due to congestion)
(physical rate: 100 packets per second)



Simple Case – Steady Capacity

- In the steady state
  - How to measure the network capacity ?
  - How to pace the sender ?

capacity: 7 packets per second (due to congestion)
(physical rate: 100 packets per second)



TCP uses ACKs to estimate the bandwidth and pace the sending, i.e., self-clocking

TCP Congestion Control

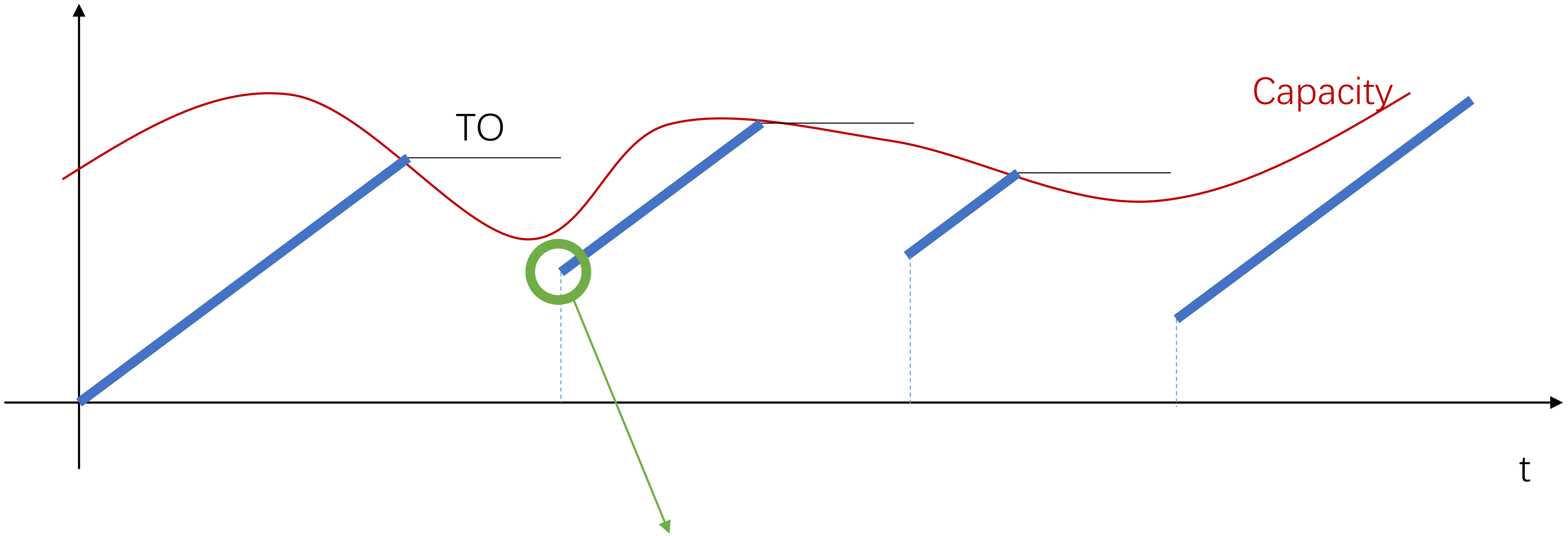
- Objective: Estimate and Adapt to (varying) Network Capacity
- Approach: Adjust Sliding Window according to ACKs
  - MaxWindow = MIN(CongestionWindow, AdvertisedWindow)
  - Decrease CongestionWindow upon detecting congestion
  - Increase CongestionWindow upon lack of congestion
  - **C**ongestion**W**i**nd**ow abbr. cwnd (in unit of MSS)
- Basic Components
  - Additive Increase/Multiplicative Decrease (AIMD)
  - Slow Start
  - Fast Retransmission
  - Fast Recovery
- Other Variants

Additive Increase/Multiplicative Decrease (AIMD)

- Intuition: over-sized window is much worse than an under-sized window
  - Over-sized window: packets dropped and retransmitted
  - Under-sized window: somewhat lower throughput
- Additive Increase
  - If successfully received acks of the last window of data
    - cwnd = cwnd+1
- Multiplicative Decrease
  - If packet loss
    - cwnd = cwnd/2

AIMD

- TCP sawtooth pattern



This is half of the cwnd before **T**ime**O**ut (TO)

Sliding Window in TCP: Adaptive Timeout

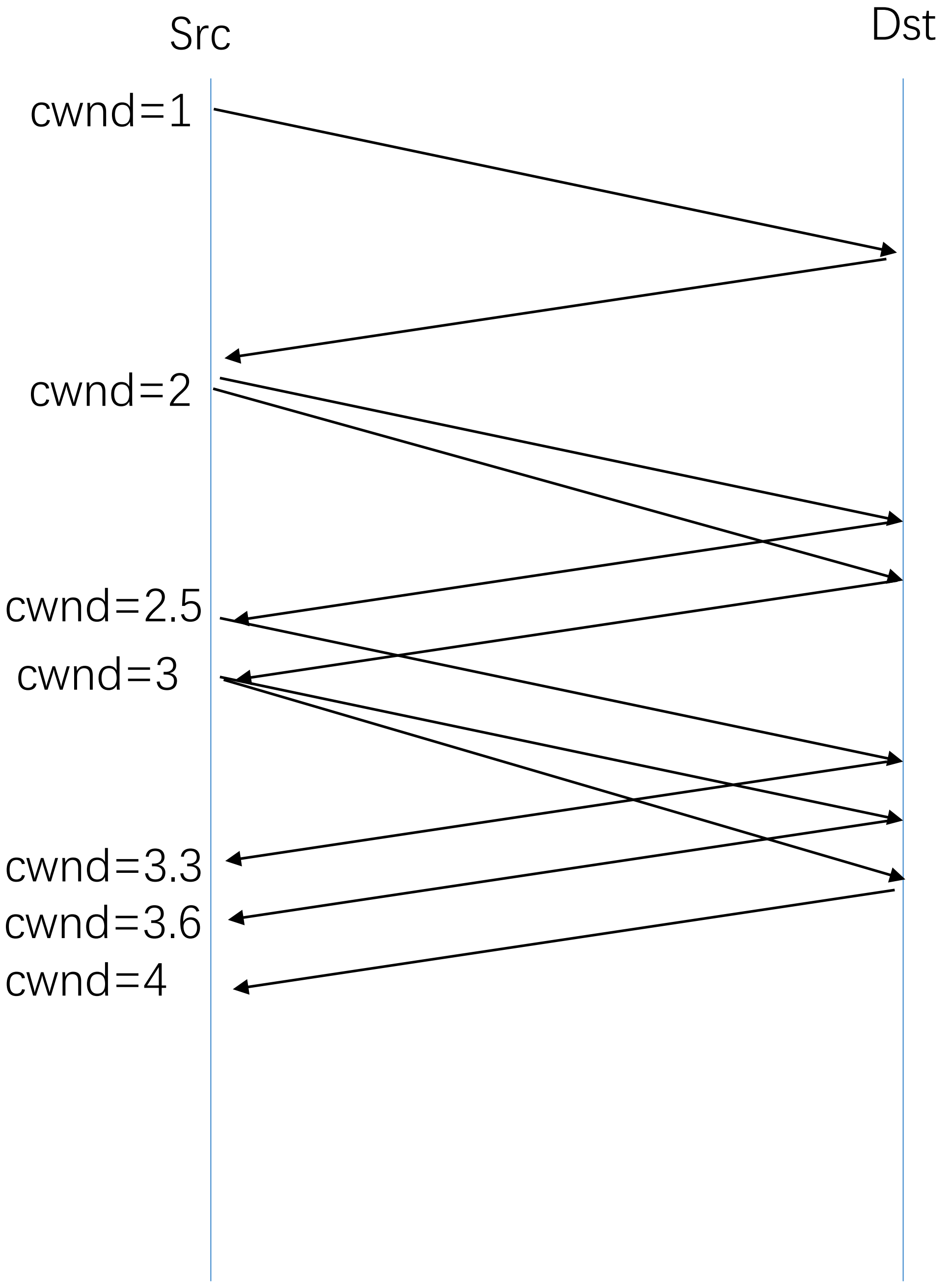
- Jacobson/Karels Algorithm Implementation

Difference = SampleRTT − EstimatedRTT
EstimatedRTT = EstimatedRTT + (δ∗Difference)
Deviation = Deviation + δ∗(|Difference| − Deviation)
TimeOut = μ ∗ EstimatedRTT + φ ∗ Deviation

```
SampleRTT -= (EstimatedRTT >> 3);
EstimatedRTT += SampleRTT;
if (SampleRTT < 0)
      SampleRTT = -SampleRTT;
SampleRTT -= (Deviation >> 3);
Deviation += SampleRTT;
TimeOut = (EstimatedRTT >> 3) + (Deviation >> 1);
```

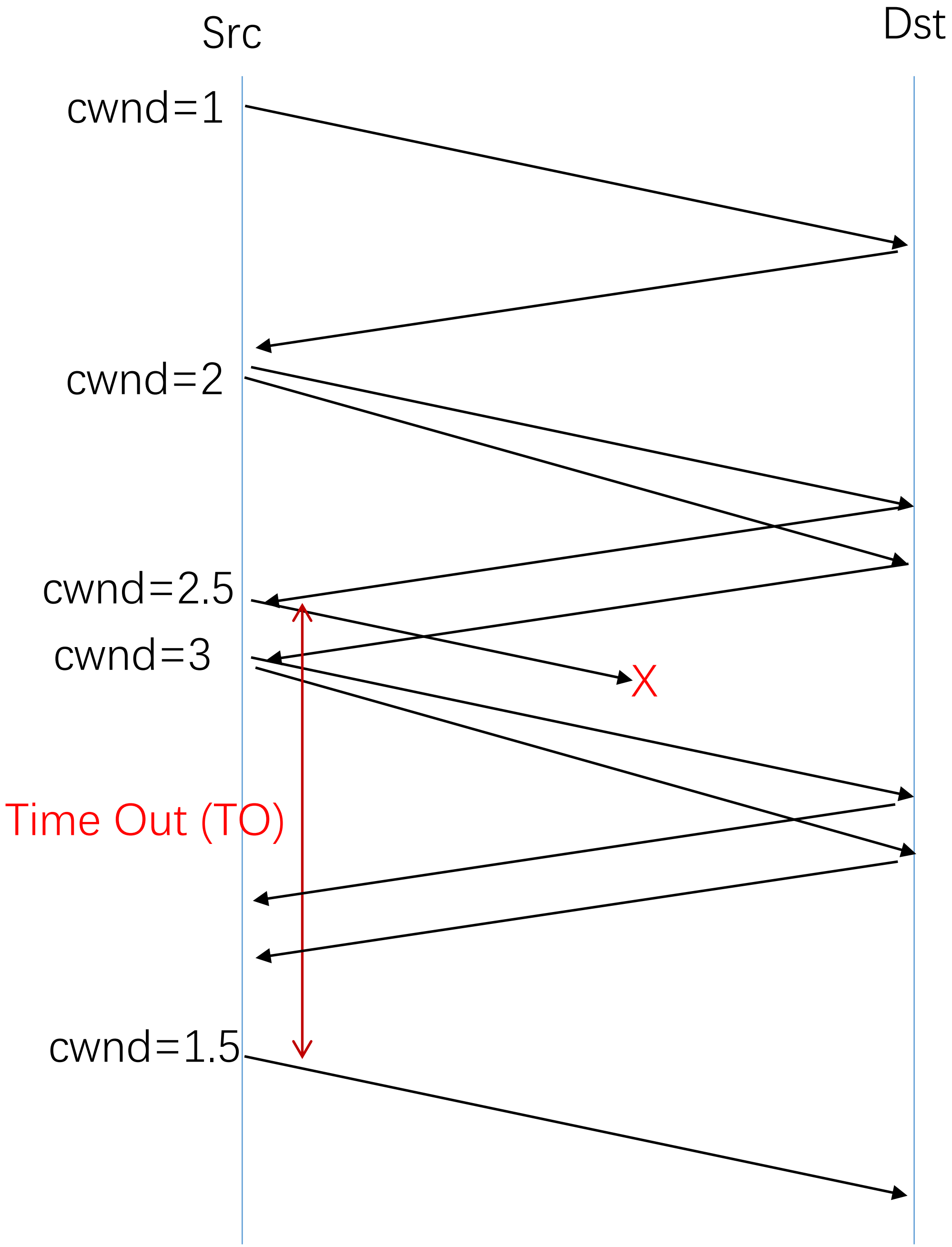
AIMD

- Additive Increase
  - Increment = 1/cwnd
  - cwnd += Increment



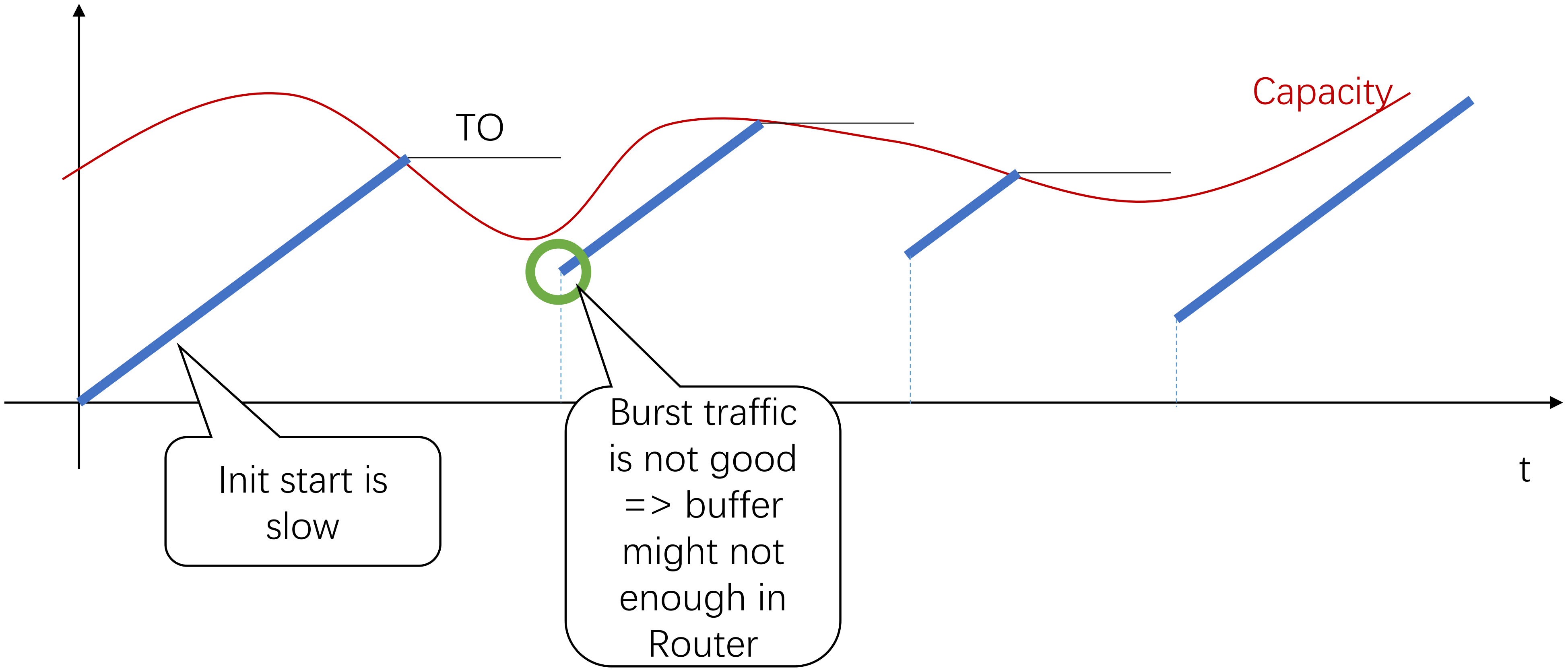
AIMD

- Multiplicative Decrease
  - cwnd = cwnd /2



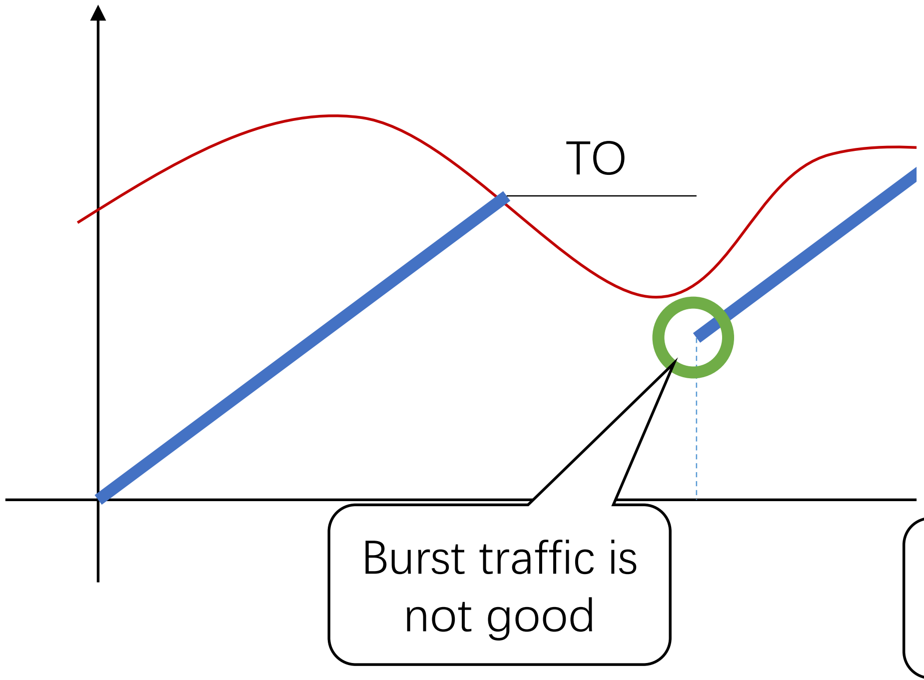
AIMD

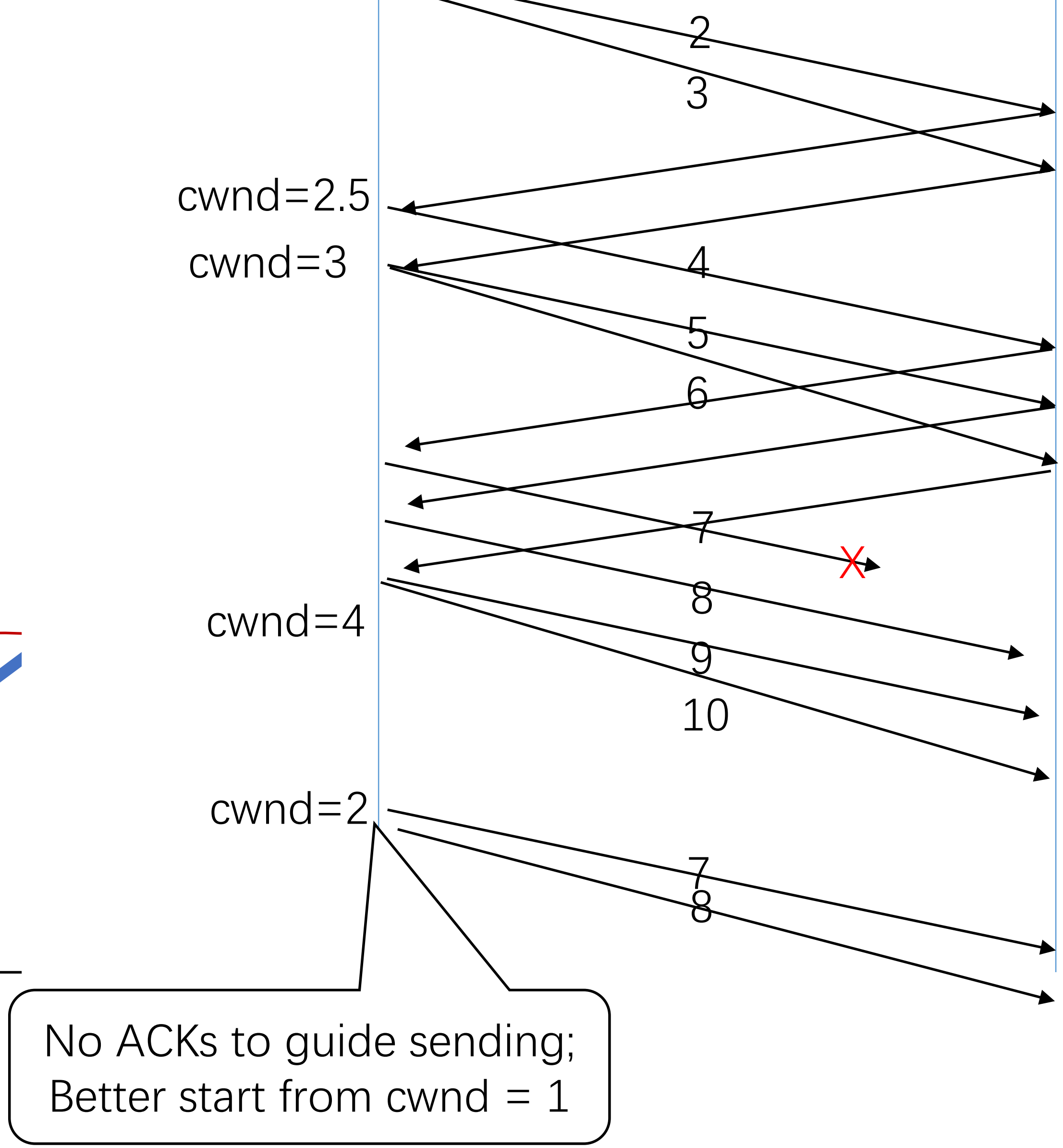
- TCP sawtooth pattern



AIMD

- TCP sawtooth pattern



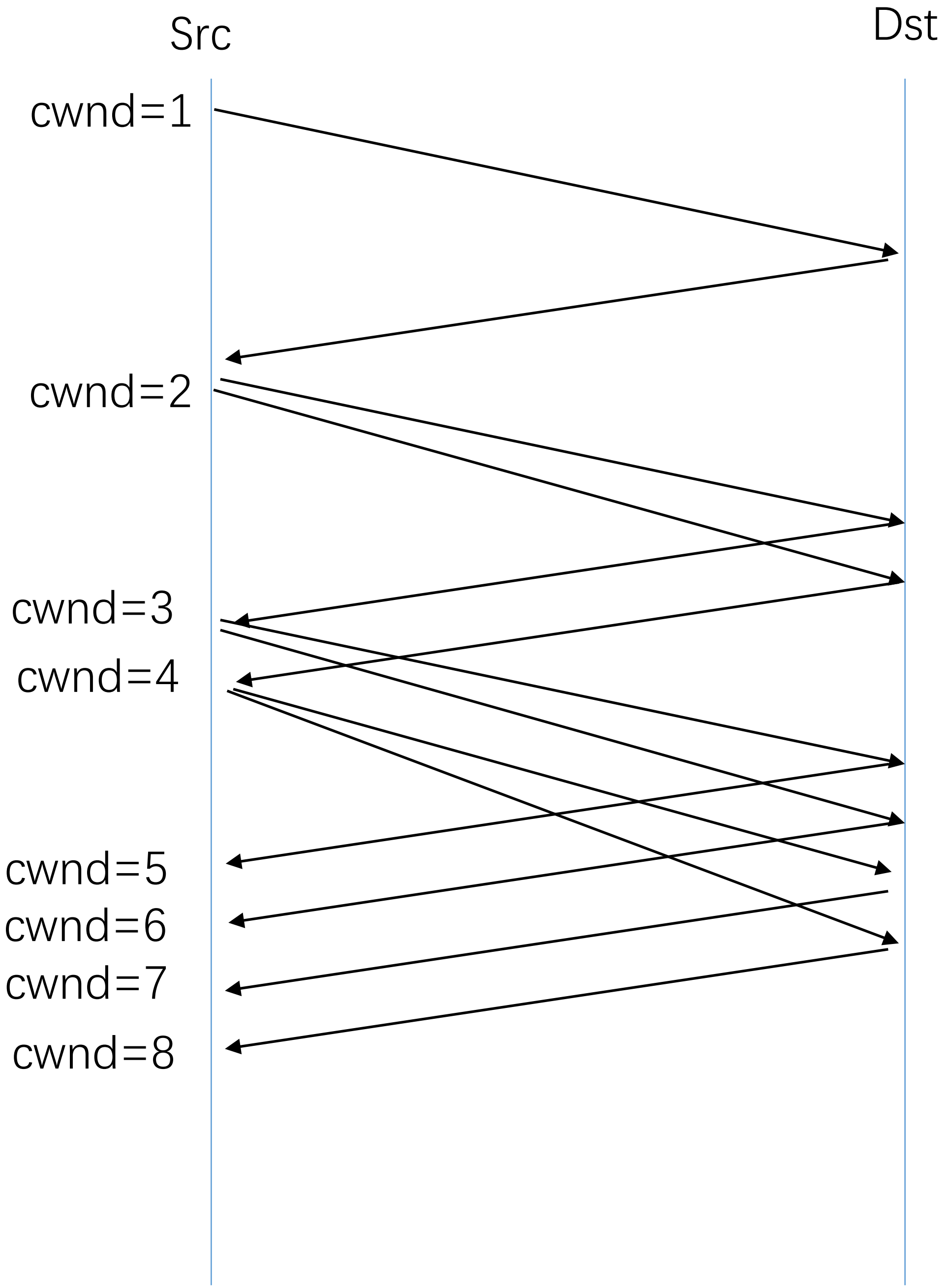


Slow Start

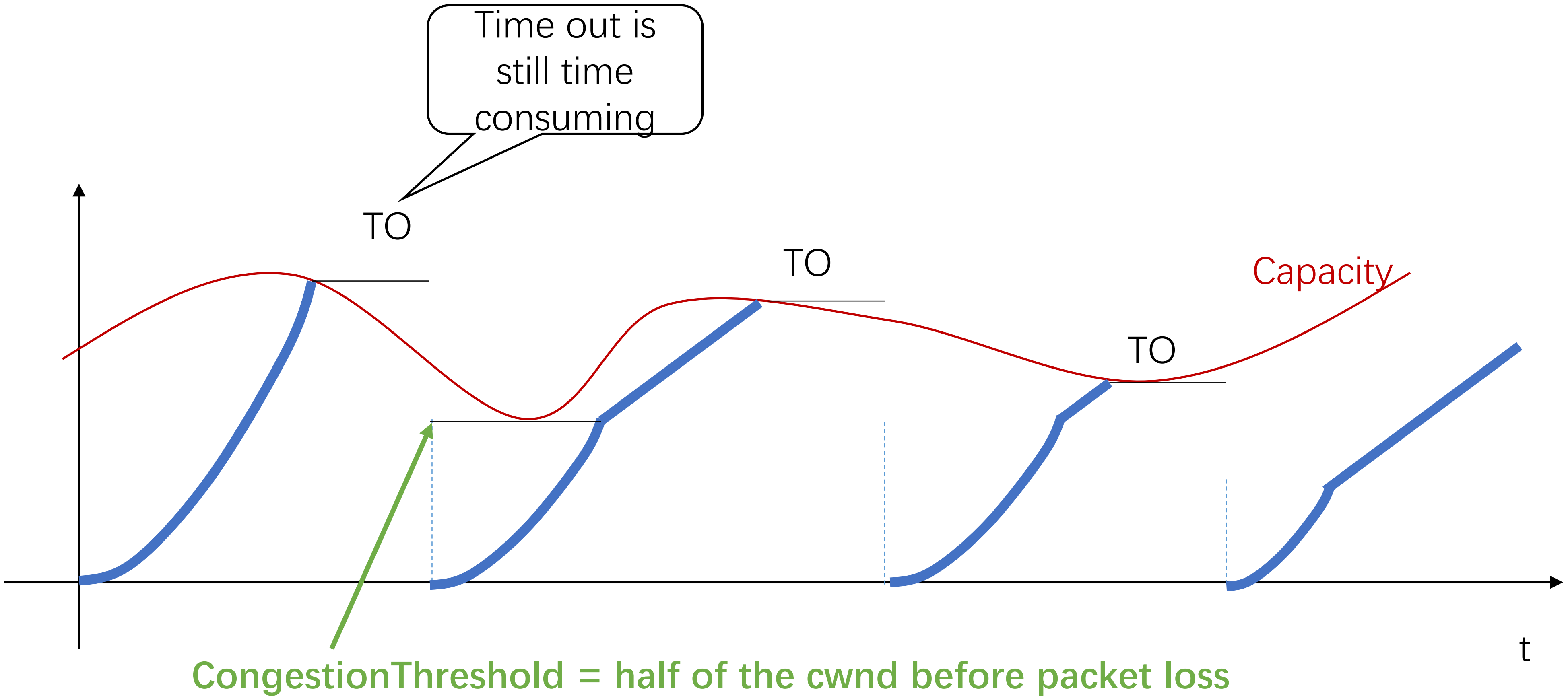
- Intuition: speed up additive Increase when TCP start
- Why “Slow Start”
  - “Slow Start” is not slow compared with additive Increase
  - “Slow Start” is slow compared with sending a whole window’s worth of data (original TCP)
- Double CongestionWindow per round-trip time
  - If successfully received one ack
    - cwnd = cwnd +1
    - Until cwnd == **CongestionThreshold**
      - CongestionThreshold = half of the cwnd before packet loss
  - Then do Additive Increase

Slow Start

- If successfully received one ack
  - cwnd = cwnd +1

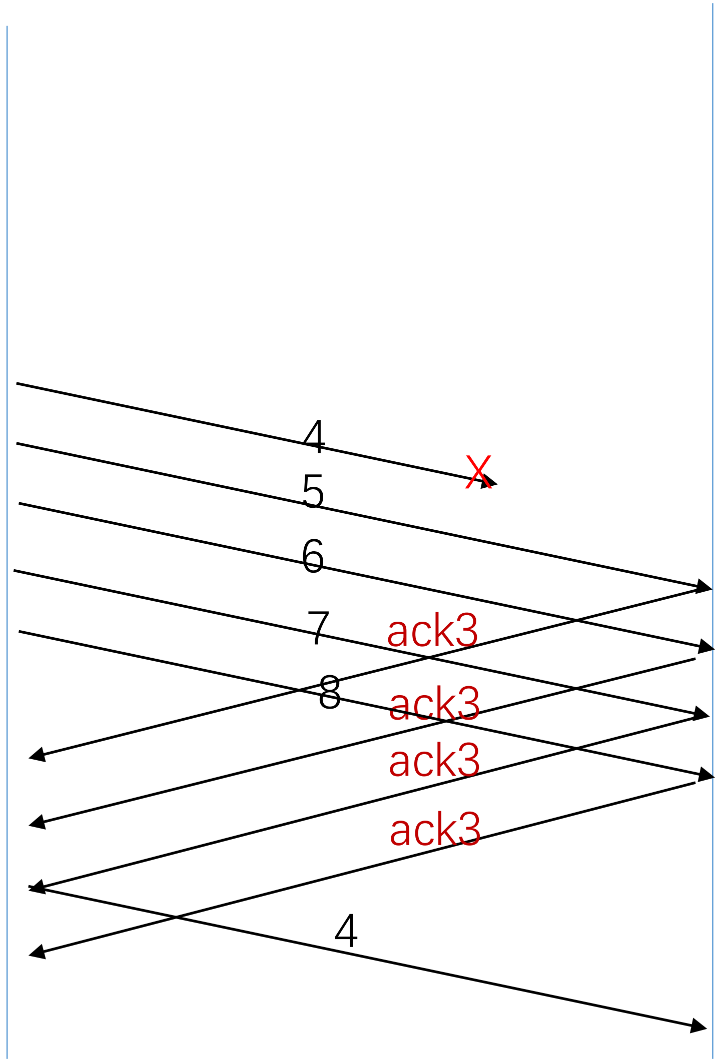


Slow Start


Time out is still time consuming
TO
TO
TO
Capacity
t
CongestionThreshold = half of the cwnd before packet loss

Fast Retransmission

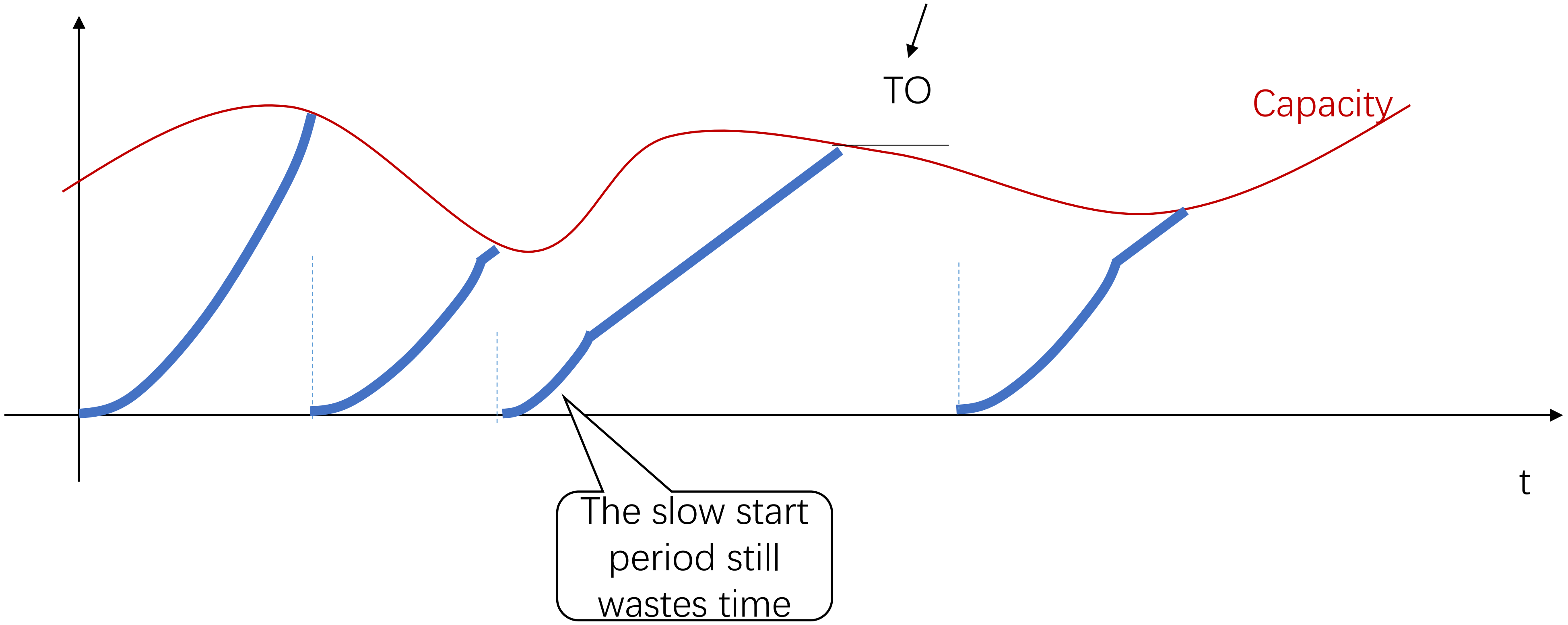
- Intuition: use duplicate ACK to indicate packet loss
- Approach:
  - Receiver replies every TCP segment with acknum = next byte expected
  - Transmitter resends a segment after 3 duplicate acks
    - 3 duplicate acks => possible packet loss
- Throughput Gain: 20%



Fast Retransmission

Timeout still exists

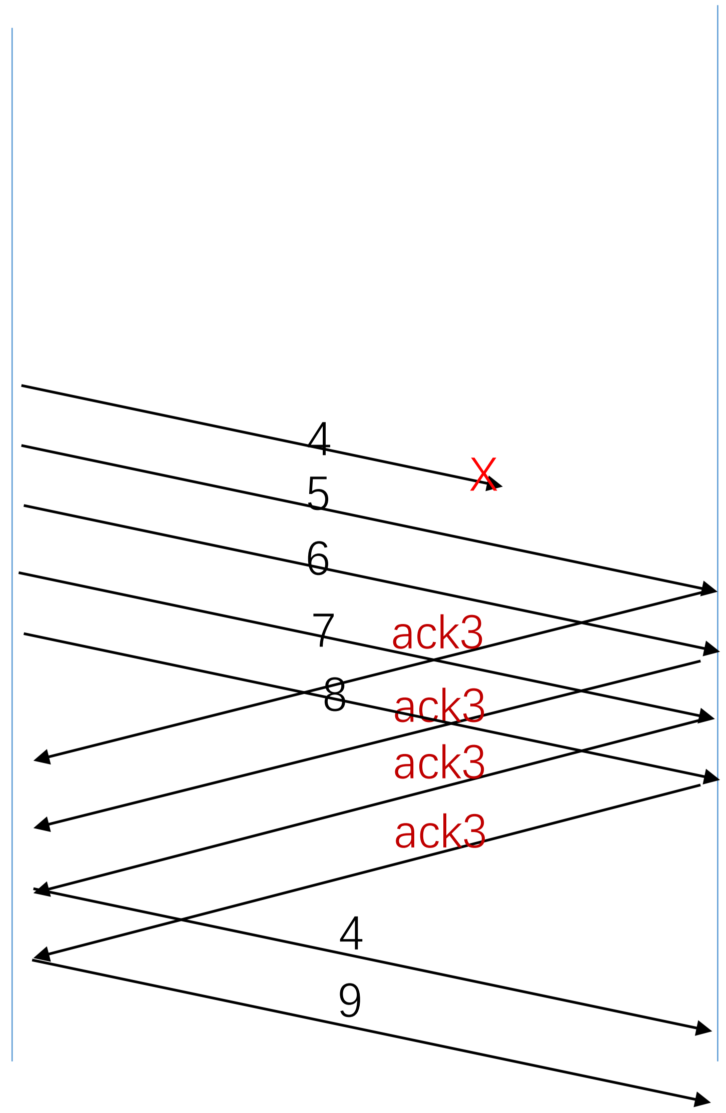
- Too many packet loss
- Window may be too small to generate enough duplicate acks



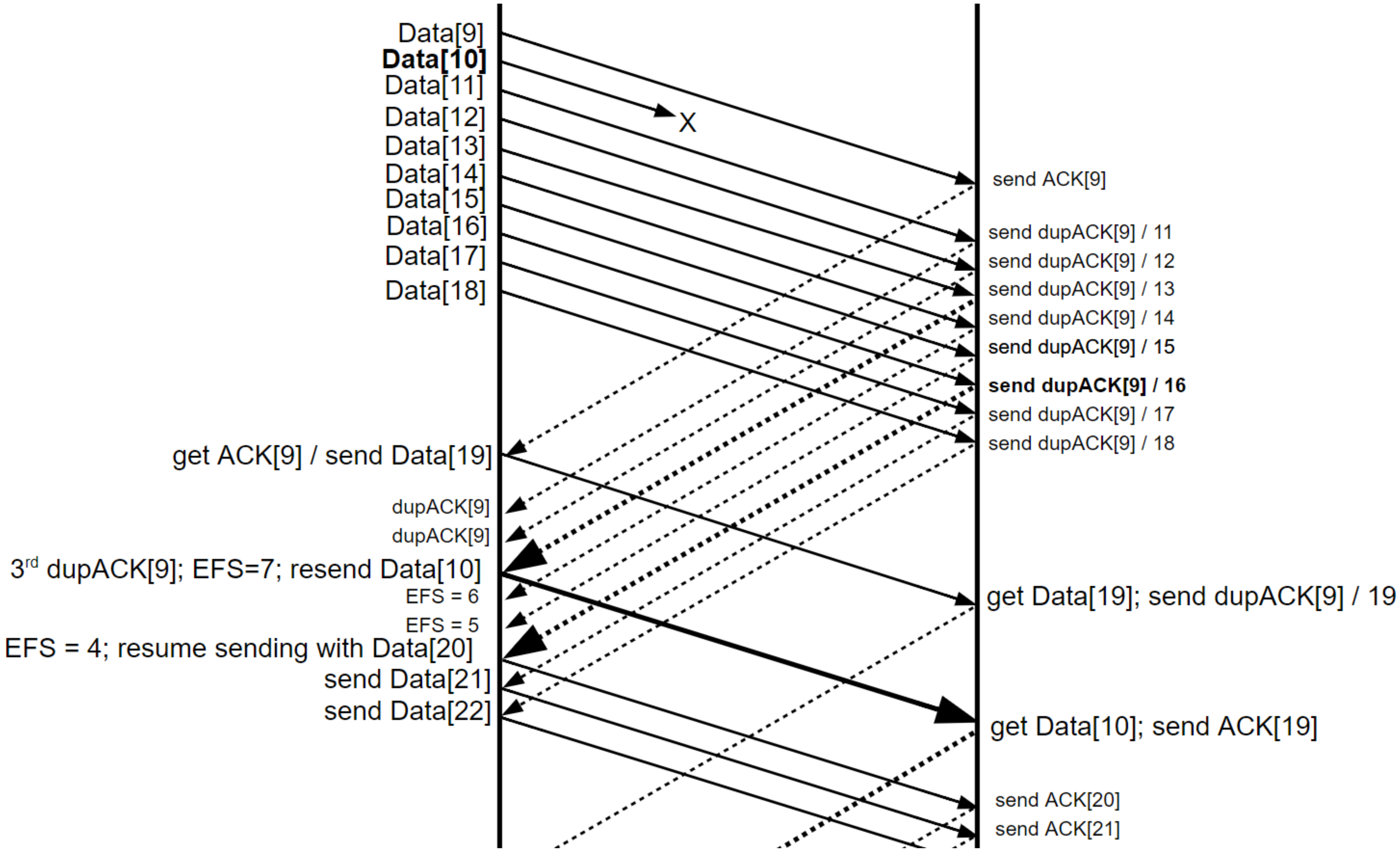
TCP Tahoe

Fast Recovery

- Intuition:
  - Flying acks can be used as clock
    - No need to start from window size 1

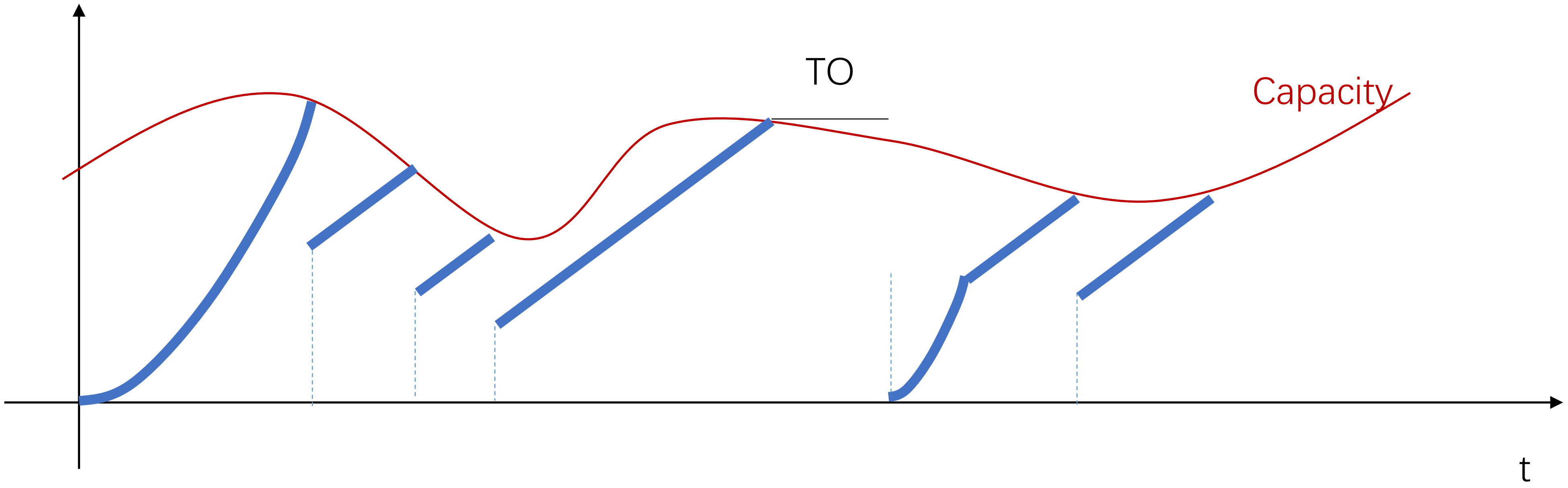


Fast Recovery



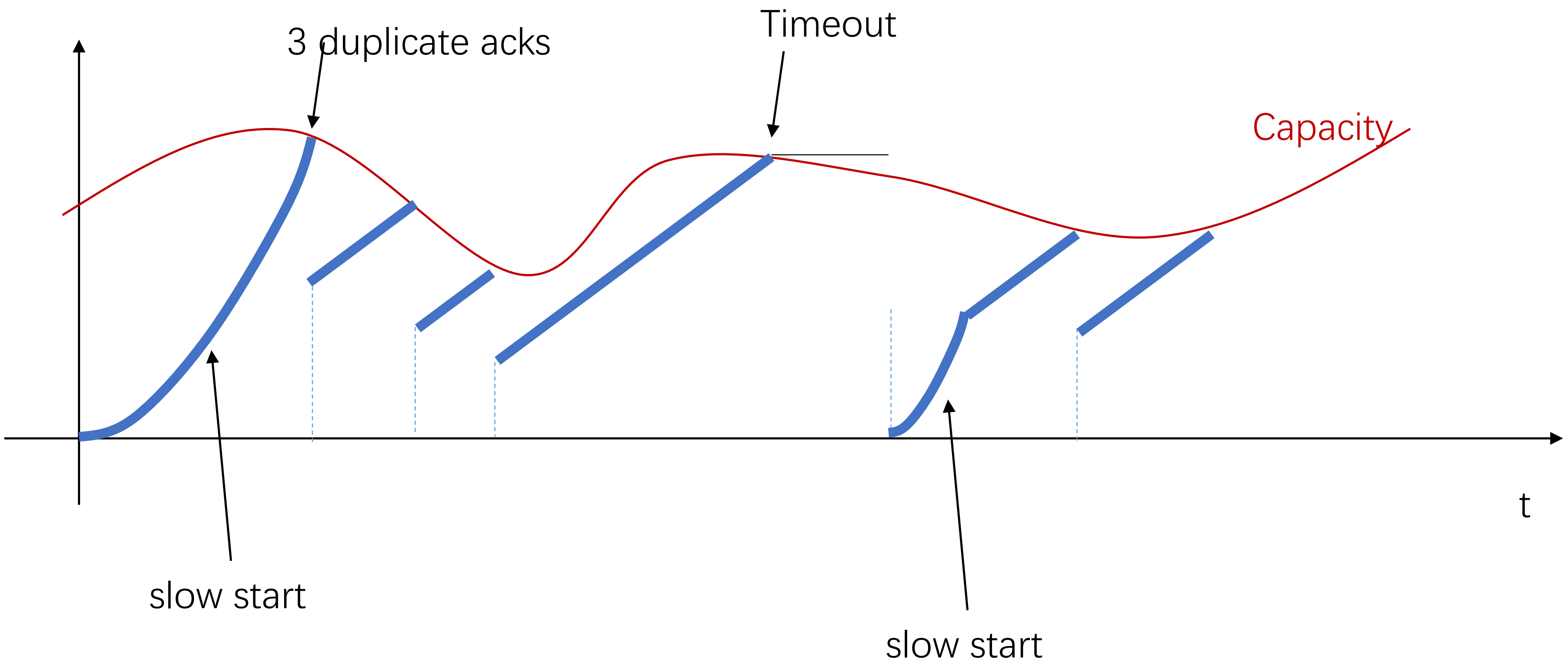
Refer to http://intronetworks.cs.luc.edu/current/html/reno.html

Fast Recovery

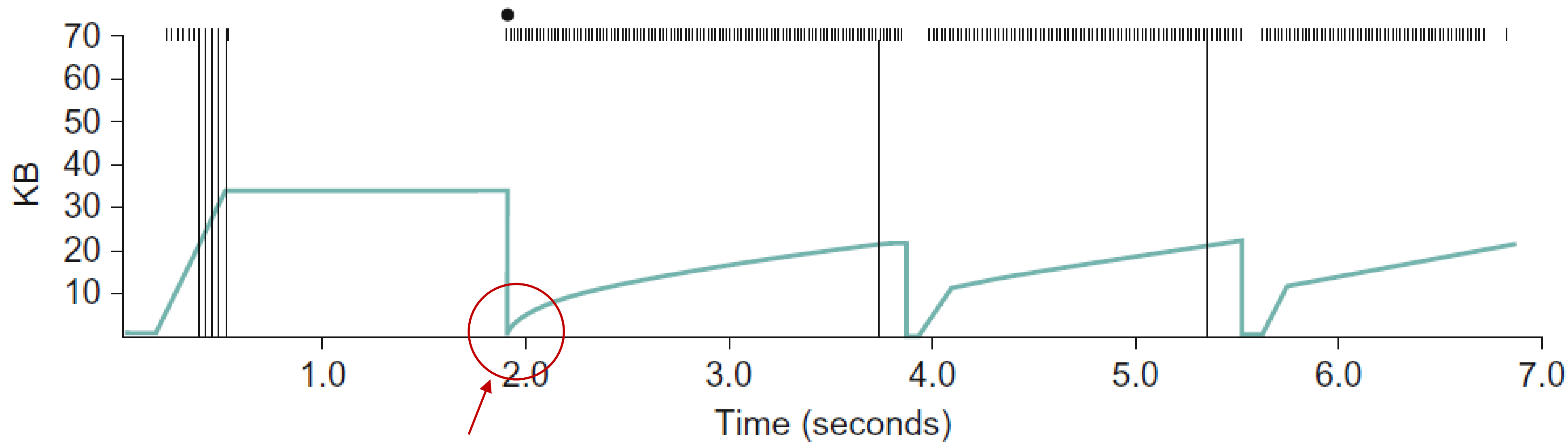


TCP Reno

TCP Reno



Figures in Textbook



Hard to Explain, should be slow start

No Fast Recovery in the Simulation, i.e., TCP Tahoe

TCP Congestion Control

- Objective: Estimate and adapt to (varying) network capacity
- Approach: Adjust Sliding Window
  - MaxWindow = MIN(CongestionWindow, AdvertisedWindow)
  - Decrease CongestionWindow upon detecting congestion
  - Increase CongestionWindow upon lack of congestion
- Basic Components
  - Additive Increase/Multiplicative Decrease (AIMD)
  - Slow Start
  - Fast Retransmission
  - Fast Recovery

➢ Other Variants

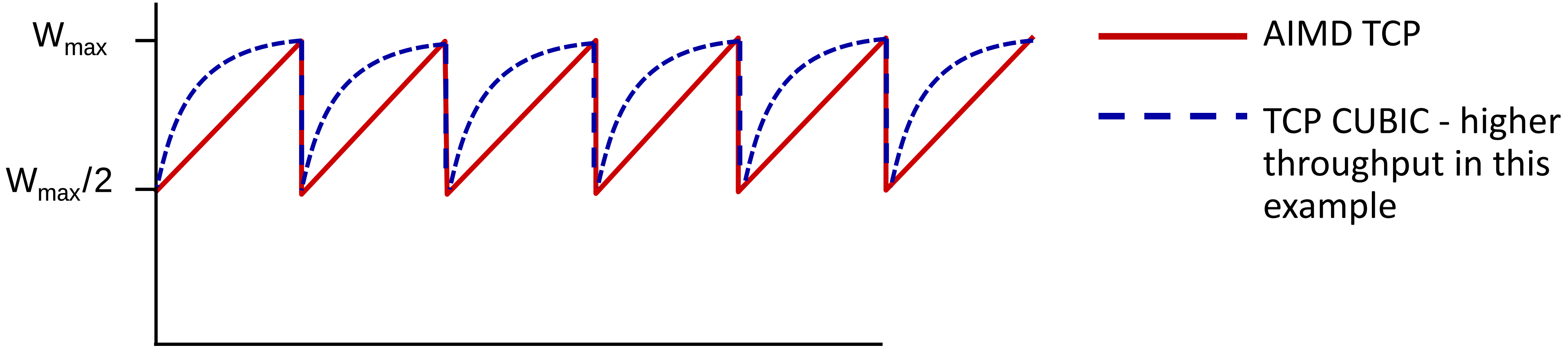
TCP Congestion Control Algorithms

- ref: https://en.wikipedia.org/wiki/TCP_congestion_control

Variant	Feedback	Required changes	Benefits	Fairness
(New)Reno	Loss	-	-	Delay
Vegas	Delay	Sender	Less loss	Proportional
High Speed	Loss	Sender	High bandwidth	
BIC	Loss	Sender	High bandwidth	
CUBIC	Loss	Sender	High bandwidth	
H-TCP	Loss	Sender	High bandwidth	
FAST	Delay	Sender	High bandwidth	Proportional
Compound TCP	Loss/Delay	Sender	High bandwidth	Proportional
Westwood	Loss/Delay	Sender	L	
Jersey	Loss/Delay	Sender	L	
BBR[11]	Delay	Sender	BLVC, Bufferbloat	
CLAMP	Multi-bit signal	Receiver, Routers	V	Max-min
TFRC	Loss	Sender, Receiver	No Retransmission	Minimum delay
XCP	Multi-bit signal	Sender, Receiver, Router	BLFC	Max-min
VCP	2-bit signal	Sender, Receiver, Router	BLF	Proportional
MaxNet	Multi-bit signal	Sender, Receiver, Router	BLFSC	Max-min
JetMax	Multi-bit signal	Sender, Receiver, Router	High bandwidth	Max-min
RED	Loss	Router	Smaller delay	

TCP CUBIC

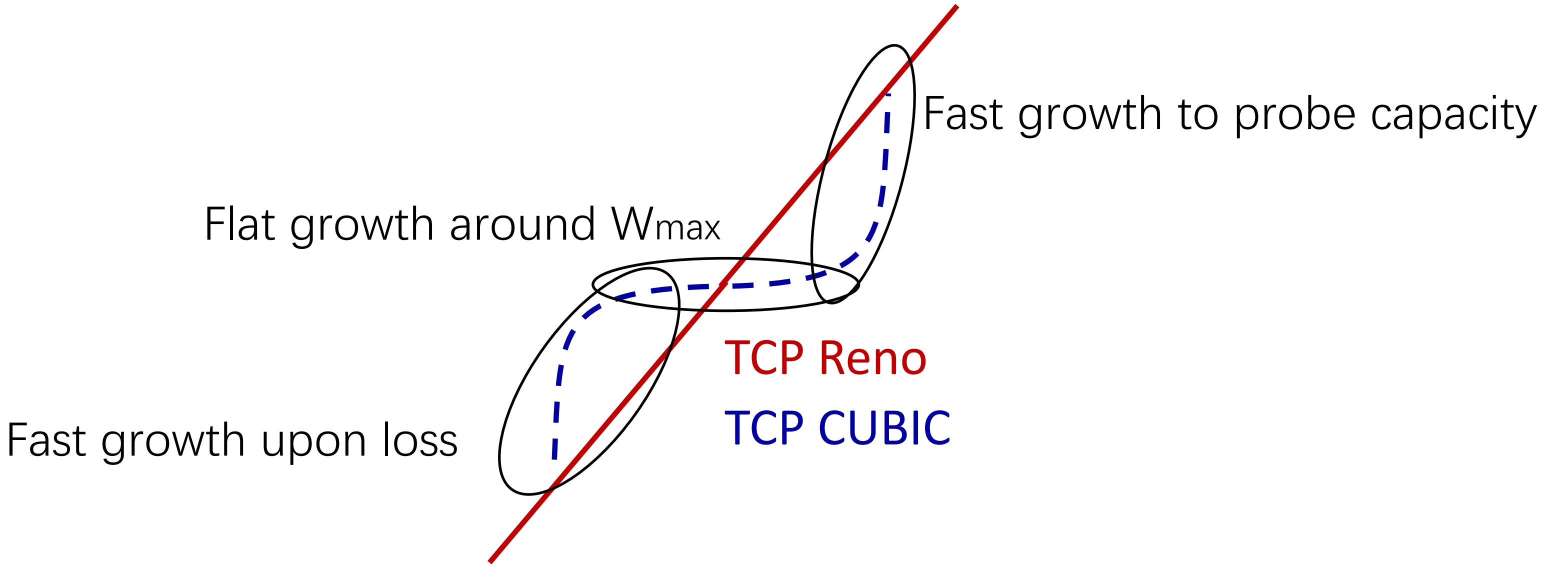
- A better way than AIMD to “probe” for usable bandwidth
  - Intuition: after cutting rate/window in half on loss, initially ramp to W_{max} faster, but then approach W_{max} more slowly



This slide is adapted from http://www-net.cs.umass.edu/kurose_ross/ppt.htm by Kurose Ross

TCP CUBIC

- Why "CUBIC" ?
  - Increase cwnd as a function of the cube of the distance between current time and the estimated time reaching the capacity



Demo

- https://wps.pearsoned.com/ecs_kurose_compnetw_6/216/55463/14198700.cw/index.html

Demo

- Sliding Window code location

  `/net/ipv4/`

  https://elixir.bootlin.com/linux/latest/source/net/ipv4
- Switching Sliding Window Scheme
  - Show current schemes

  ```
  cat /proc/sys/net/ipv4/tcp_congestion_control
  ```
  - Switch congestion control scheme

  ```
  sysctl net.ipv4.tcp_available_congestion_control[=XX]
  ```

Reference

- Textbook 6.3
- http://intronetworks.cs.luc.edu/current/html/reno.html