TCP Congestion Control (Contd.) Critiques & Advanced Techniques

CPSC 433/533, Spring 2021
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Administrivia

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- **Project 1 grades out**
  - Output logs for the tests we ran have been provided
  - We will **not** reveal the actual test cases (code)

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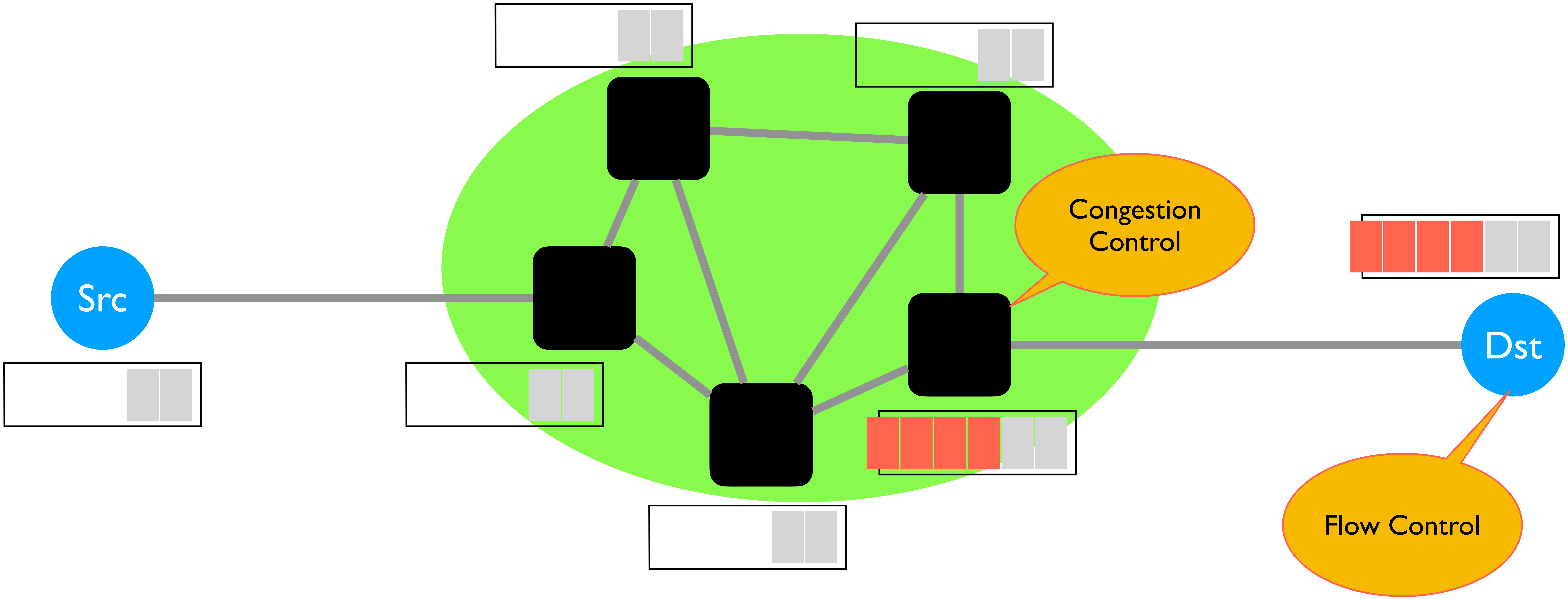
  - Output logs for the tests we ran have been provided
  - We will **not** reveal the actual test cases (code)
- **Midterm drawing close!**
  - We will have a review session next week
  - Be clear on concepts; clarify during OH if you don't understand them!
  - There are some topics that are covered in lectures & not in book, and vice versa
    - Only tested on things taught in class

How does TCP deal with buffer limits?



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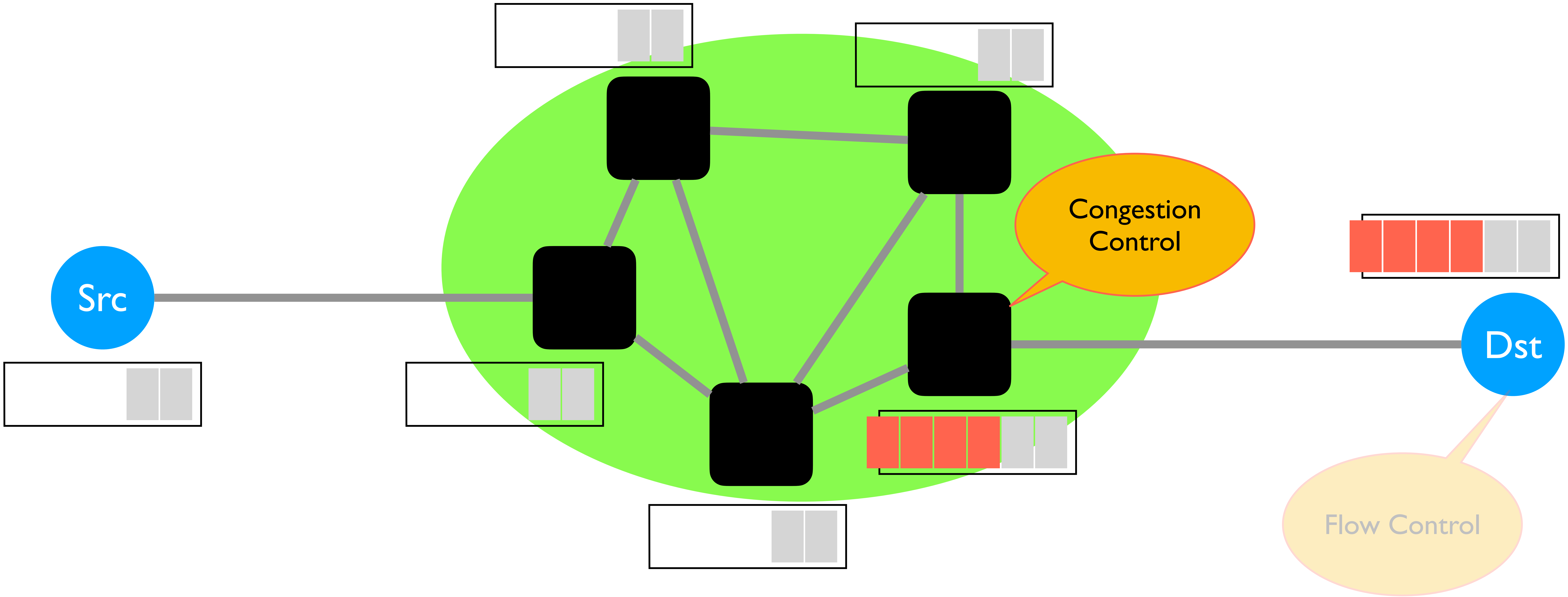

Congestion: Two Basic Questions

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Losses: dupACKs, timeouts

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  - To address three issues:
    - Finding available bottleneck bandwidth
    - Adjusting to bandwidth variations
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Slow Start

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AIMD

TCP Congestion Control Details

Implementation

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- **State at sender**
  - CWND (initialized to a small constant)
  - ssthresh (initialized to a large constant)

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- **State at sender**
  - CWND (initialized to a small constant)
  - ssthresh (initialized to a large constant)
- **Events:**
  - ACK (new data)
  - dupACK (duplicate ACK for old data)
  - Timeout

Event: ACK (new data)

- **If CWND < ssthresh**
  - CWND += 1

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CWND packets per RTT
Hence after each RTT with no packet drops:
CWND = 2 x CWND

Event: ACK (new data)

- **If CWND < ssthresh**
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- **Else:**
  - CWND += 1/CWND

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Event: ACK (new data)

- **If CWND < ssthresh**
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Slow Start Phase

- **Else:**
  - CWND += 1/CWND

Congestion Avoidance Phase
(Additive Increase)

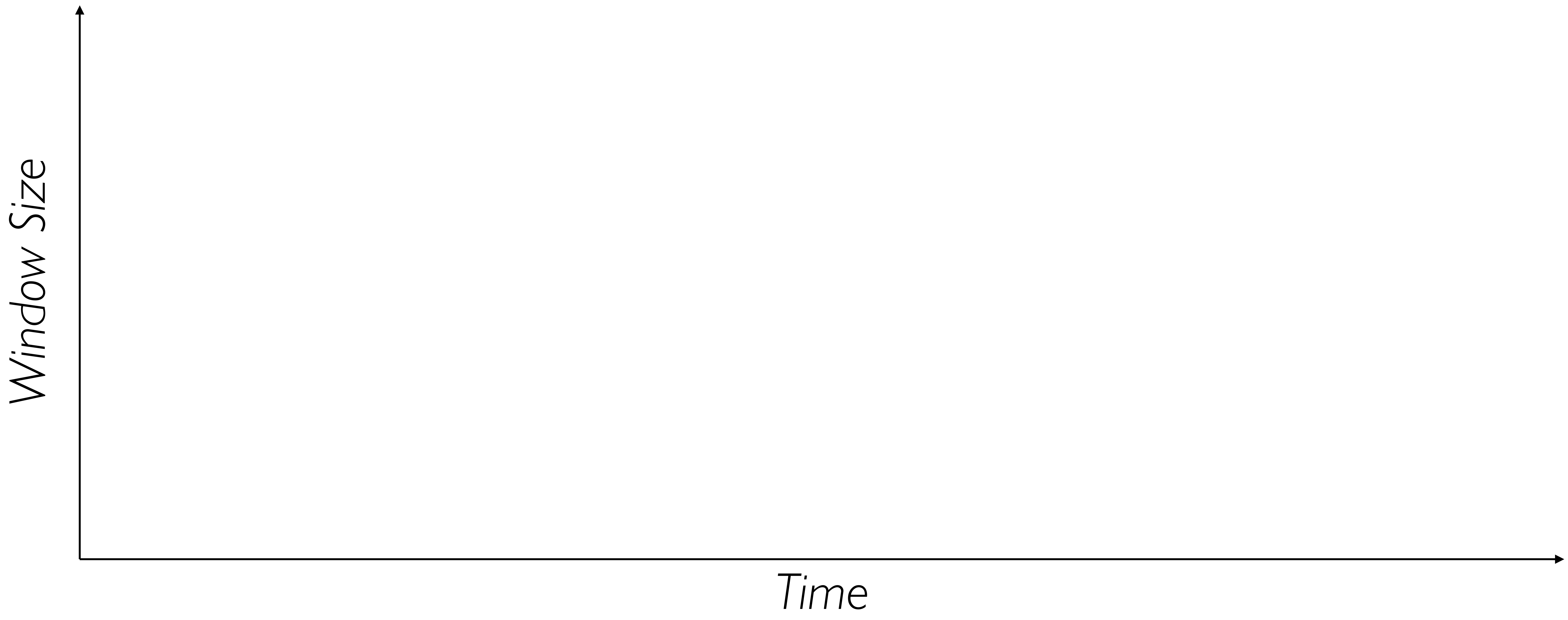
Event: Timeout

- **On timeout**
  - ssthresh ← CWND/2
  - CWND ← 1

Event: dupACK

- **dupACKcount++**
- **If dupACKcount = 3 /* Fast retransmit */**
  - ssthresh ← CWND/2
  - CWND ← CWND/2

Example



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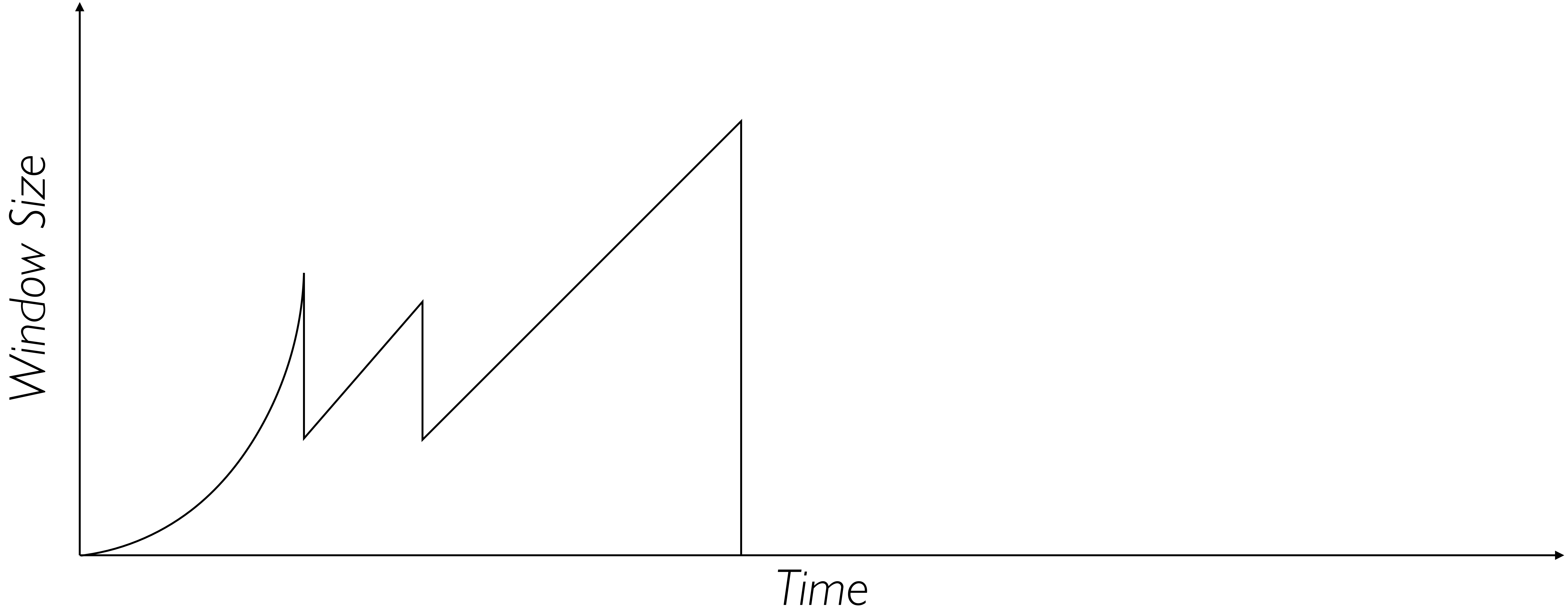

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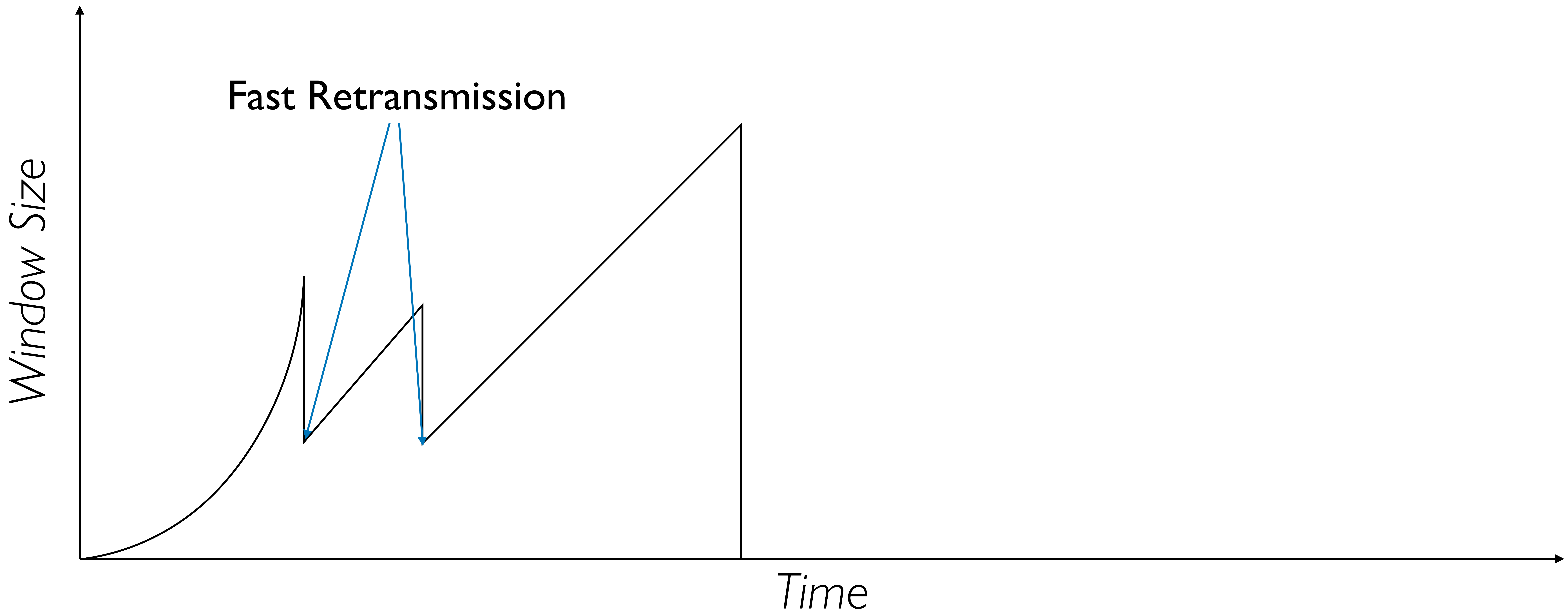

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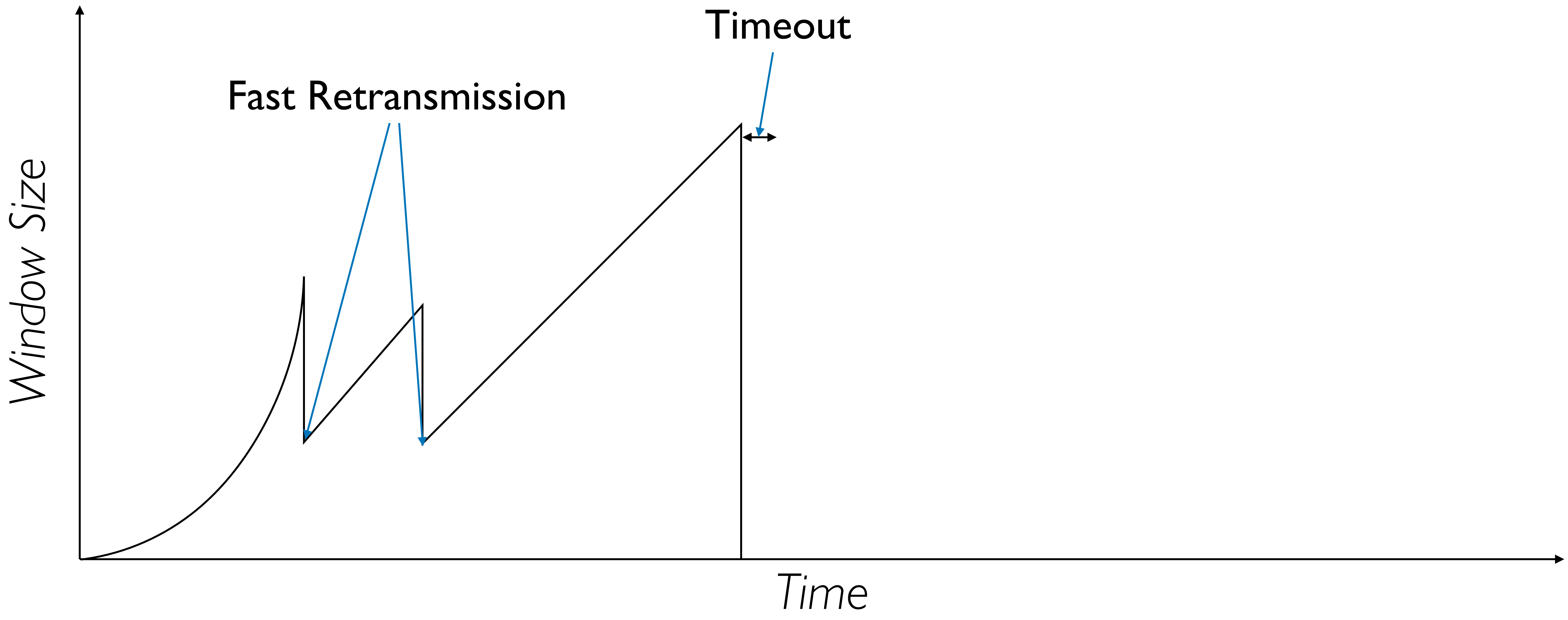

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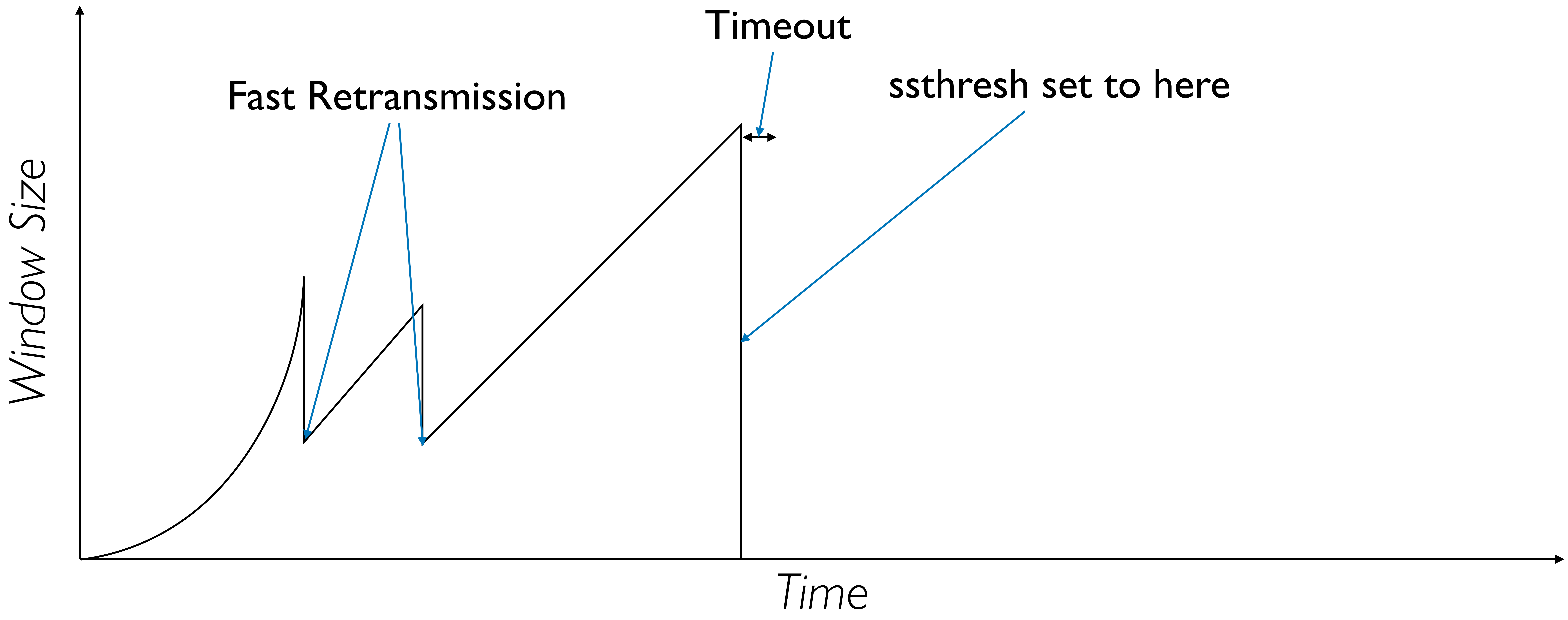
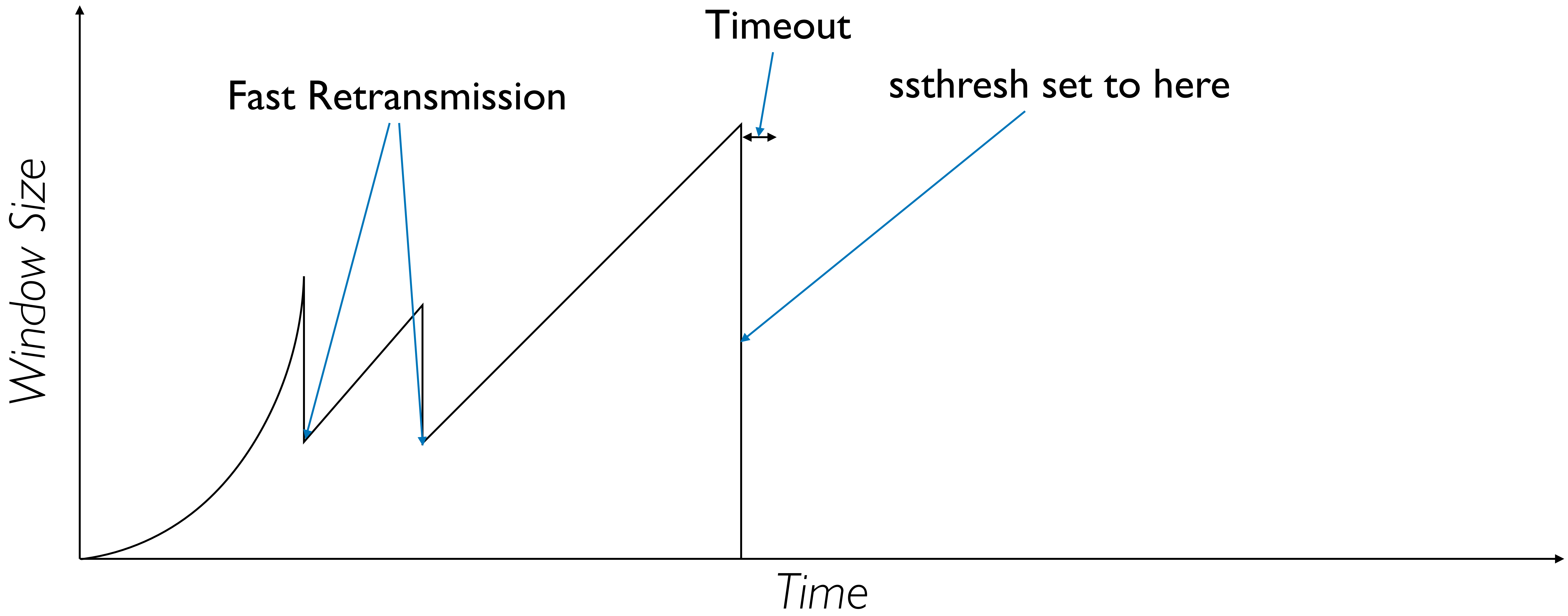

Timeout
ssthresh set to here
Fast Retransmission
Window Size
Time

Example



Slow Start restart: Go back to CWND=1, but take advantage of knowing the previous value of CWND

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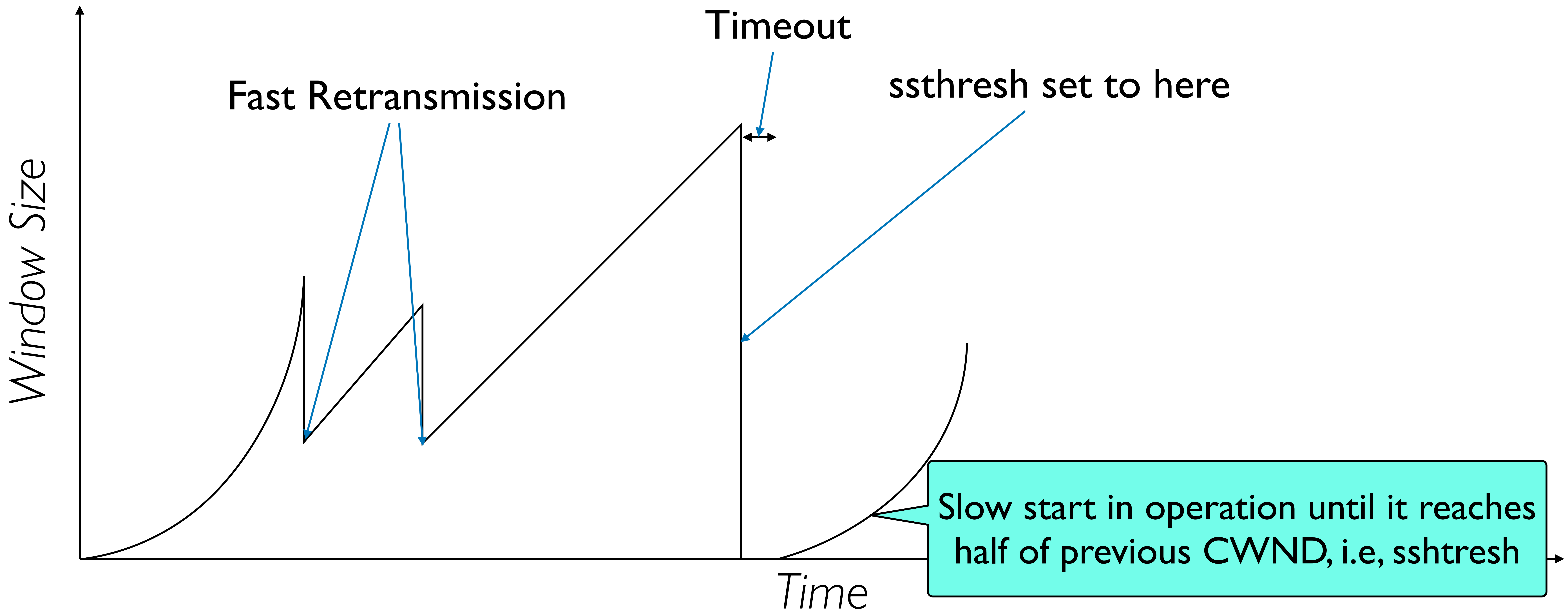

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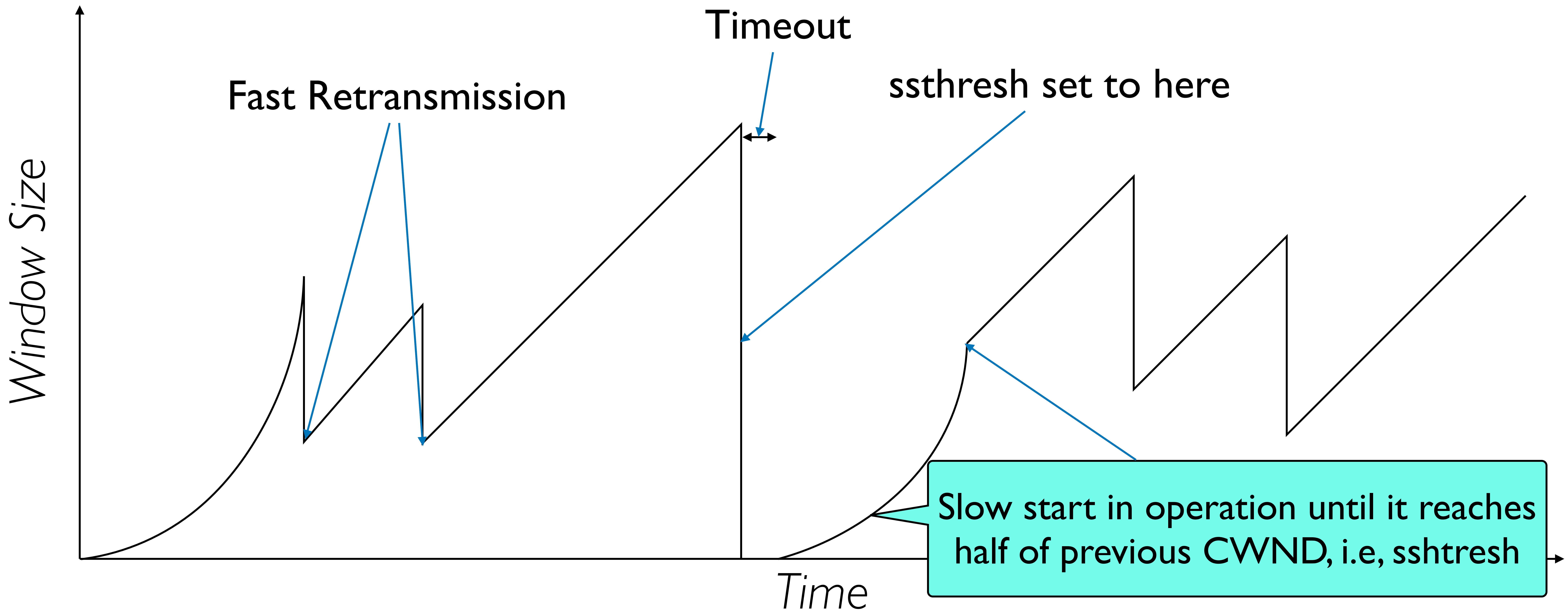

Slow Start restart: Go back to CWND=1, but take advantage of knowing the previous value of CWND

One Final Phase: Fast Recovery

- **The problem: congestion avoidance too slow in recovering from an isolated loss**

Example

- **Consider a TCP connection with:**
  - CWND = 10 packets
  - Last ACK was for packet # 101
    - i.e., receiver expecting next packet to have sequence number 101
- **10 packets [101, 102, 103, ..., 110] are in flight**
  - Packet 101 is dropped
  - What ACKs do they generate?
  - And how does the sender respond?

Timeline

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- ACK 101 (due to 102) cwnd=10 dupACK#1 (no xmit)

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- ACK 111 (due to 101) ← only now can we transmit new packets

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- Plus no packets in flight so ACK "clocking" (to increase CWND) stalls for another RTT

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- **If dupACKcount = 3**
  - ssthresh = CWND / 2
  - CWND = ssthresh + 3

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- **If dupACKcount = 3**
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  - CWND = CWND + 1 for each additional duplicate ACK

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  - ssthresh = CWND / 2
  - CWND = ssthresh + 3
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- **Exit fast recovery after receiving new ACK**
  - Set CWND = ssthresh

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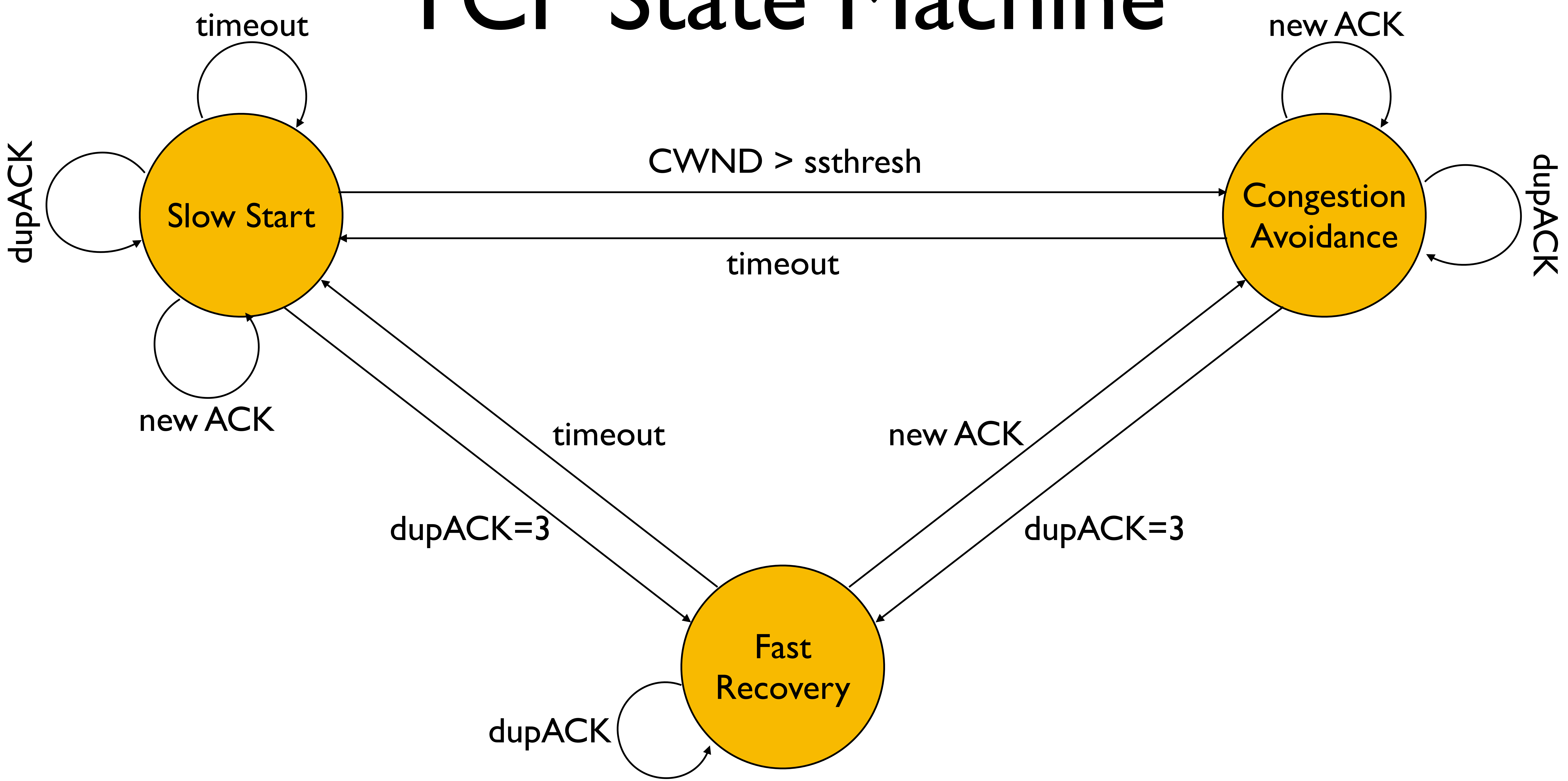
- ACK 112 (due to 111) cwnd=5 + 1/5 ← back in congestion avoidance

TCP State Machine



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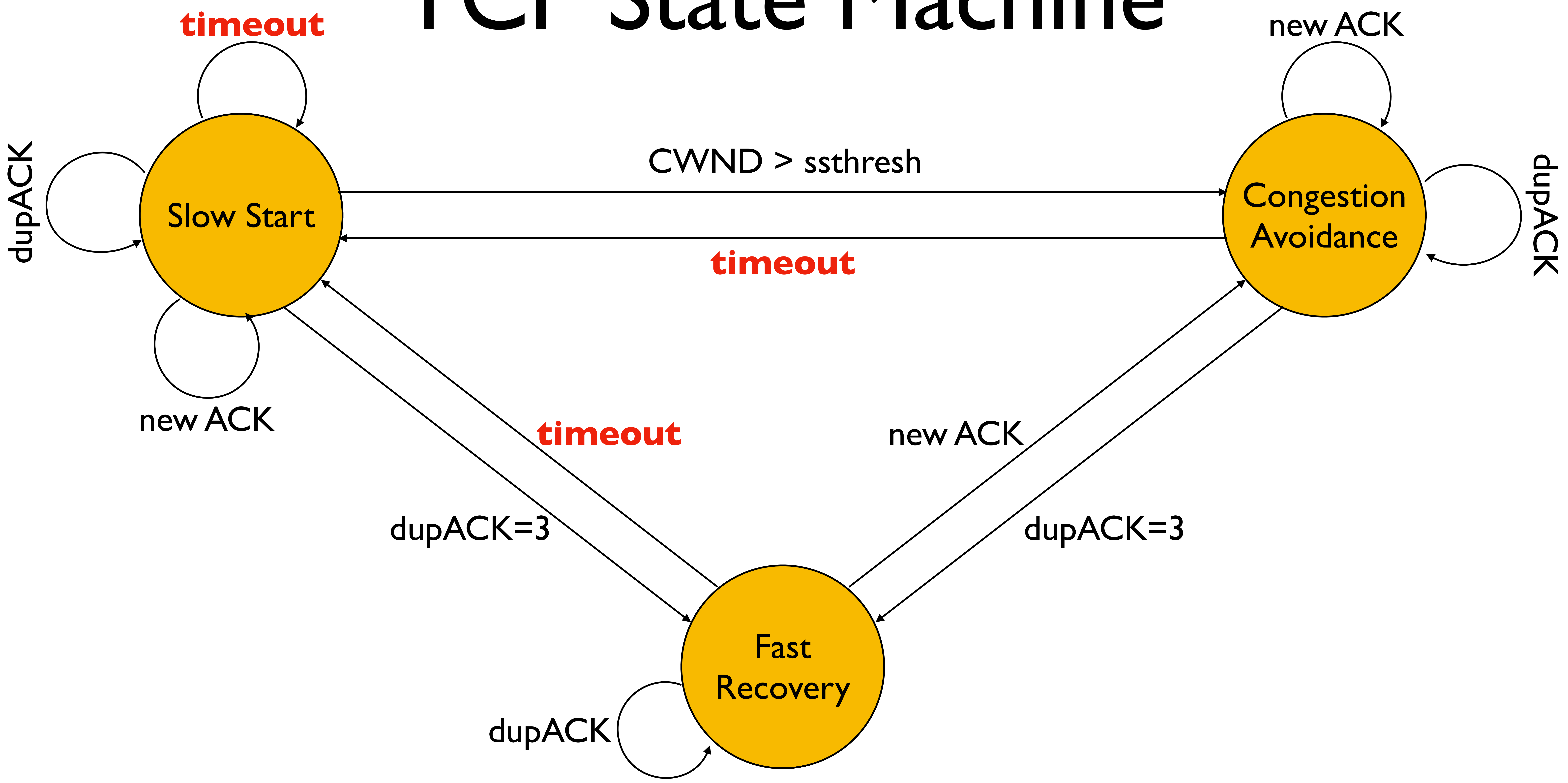

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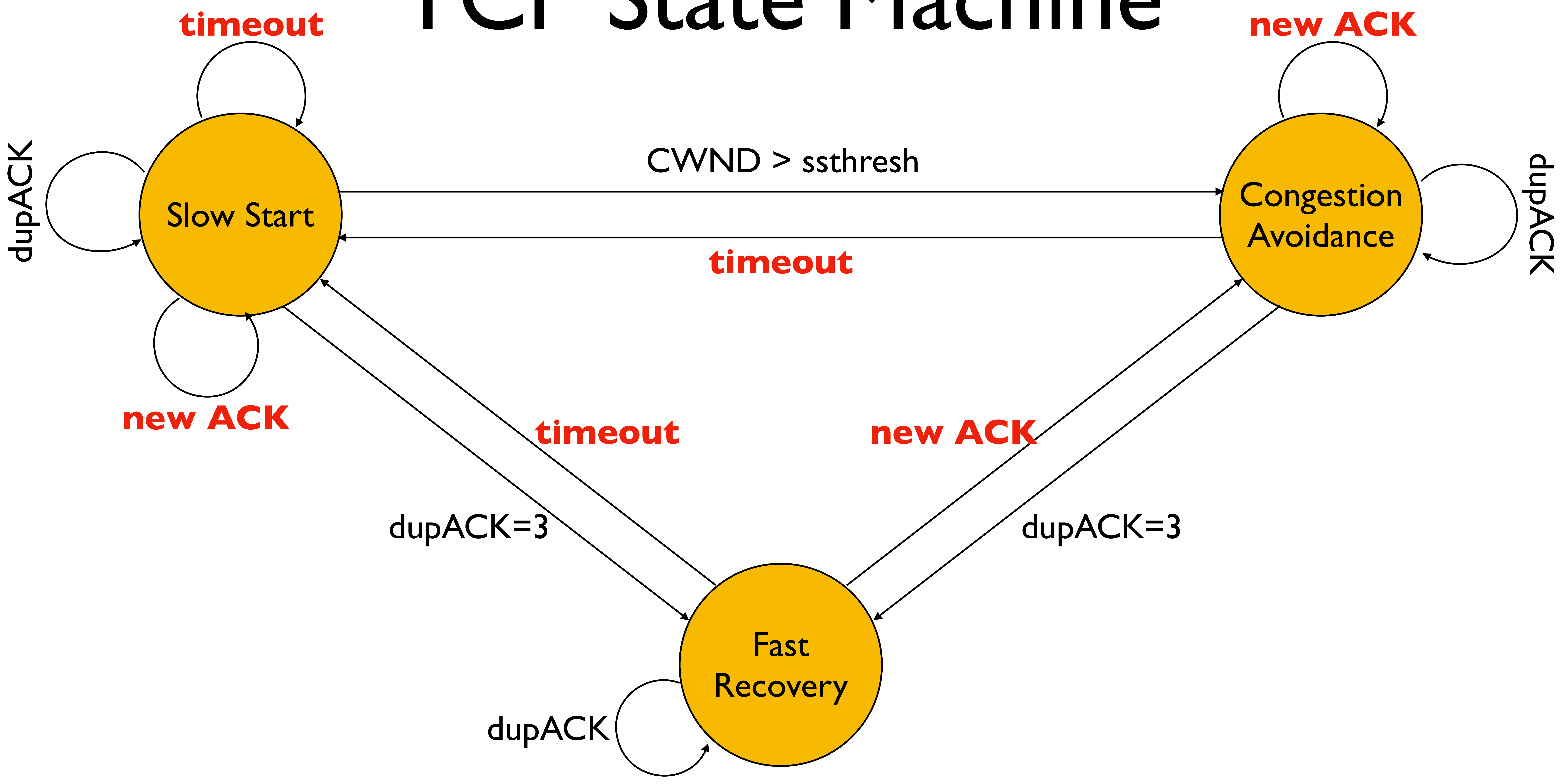

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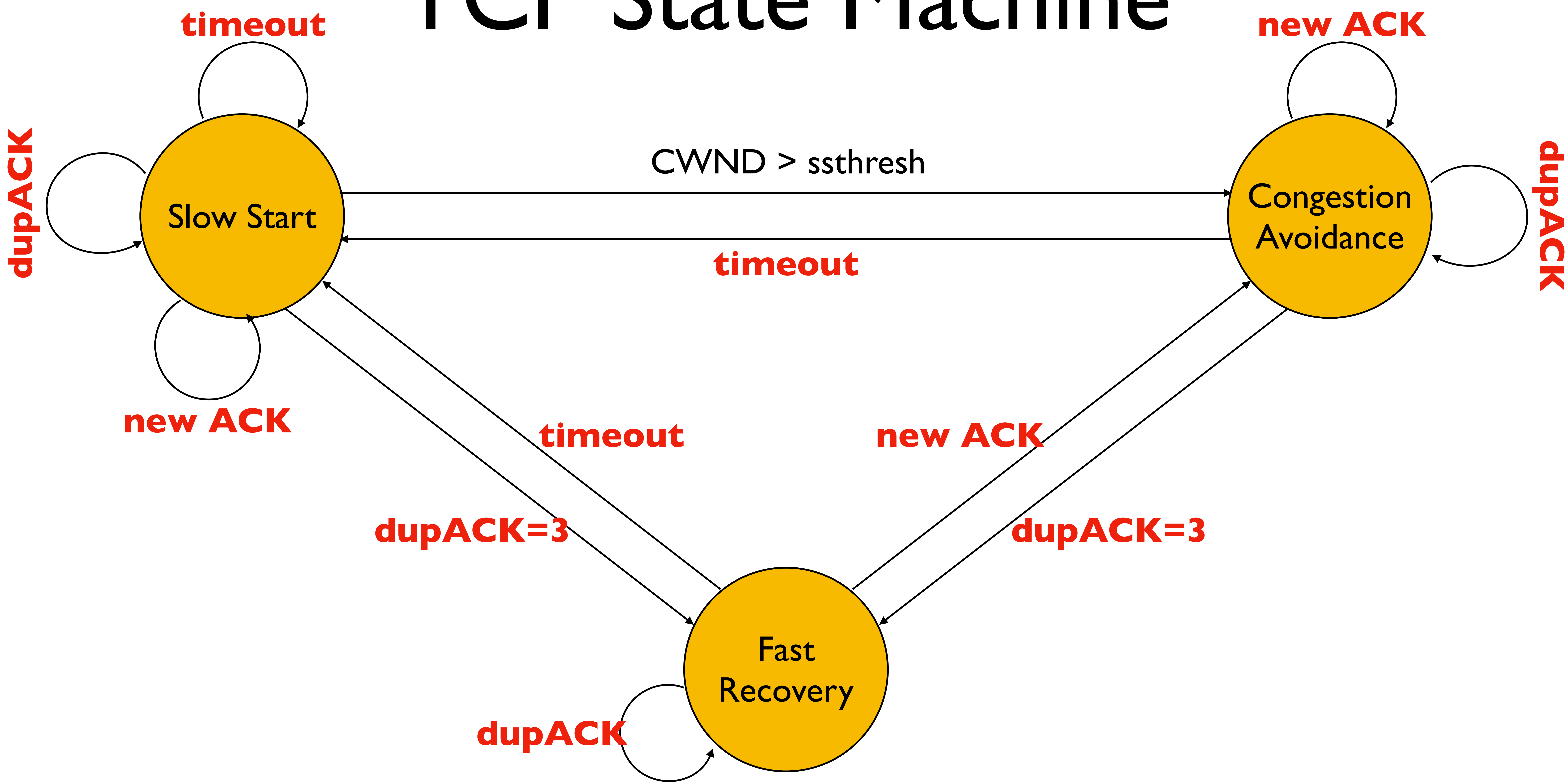

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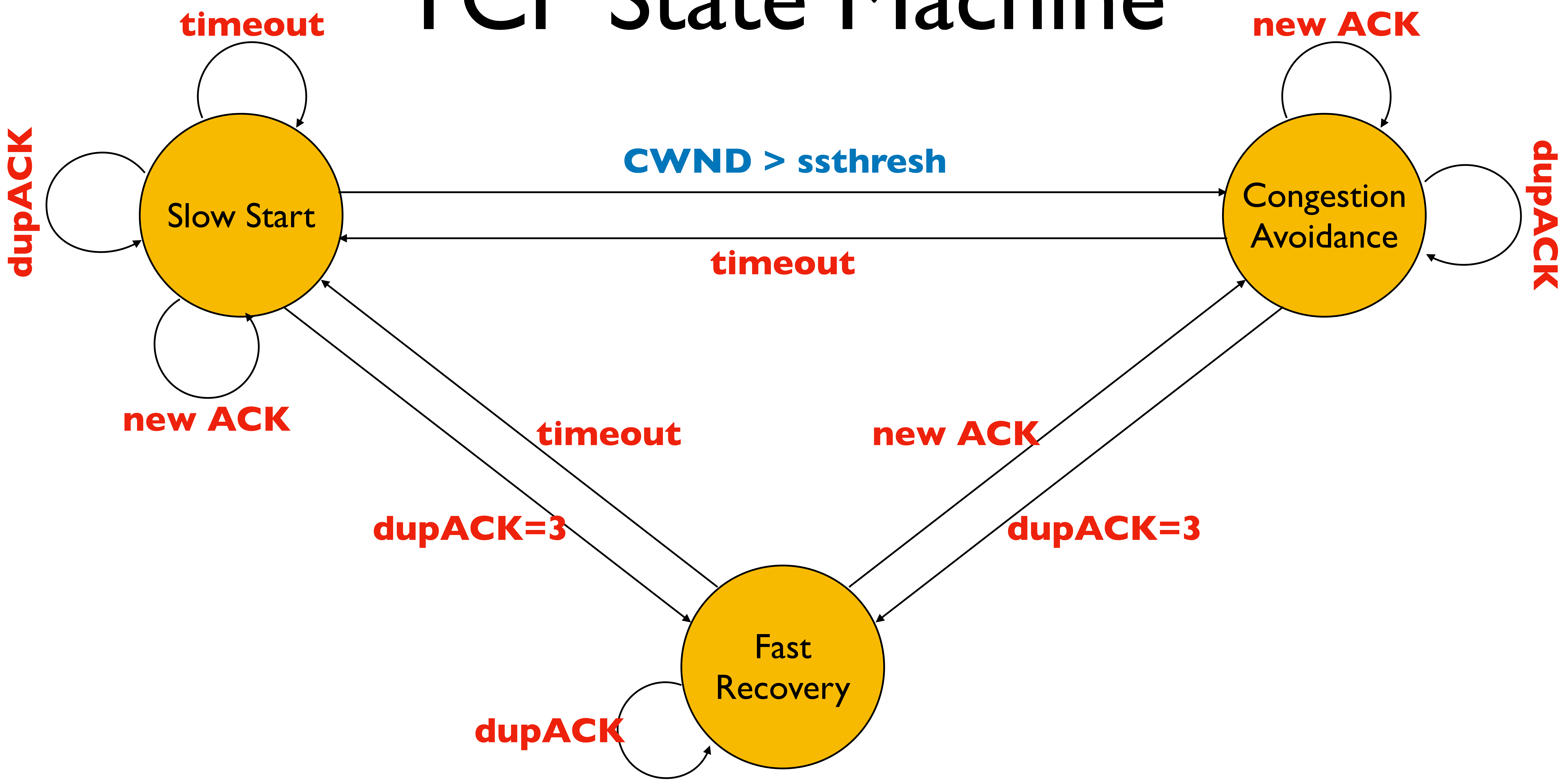

TCP Flavors

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  - CWND=1 on triple dupACK

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    Our Default Assumption
- **TCP SACK**
  - Incorporates selective acknowledgements

Taking Stock

- The concepts underlying TCP are simple
  - Acknowledgements
  - Timers
  - Sliding Windows
  - Buffer Management
  - Sequence Numbers

Taking Stock

- The concepts underlying TCP are simple
- But tricky in the details
  - How do we set timers
  - What is the seqno for an ACK only packet
  - What happens if the advertised window = 0
  - What if the advertised window is 1/2 an MSS
  - Should receiver acknowledge packets right away
  - What if the application generates data in units of 0.1 MSS
  - What happens if I get a duplicate SYN? Or an RST while I'm in FIN_WAIT?
  - *etc., etc., etc.*

Taking Stock

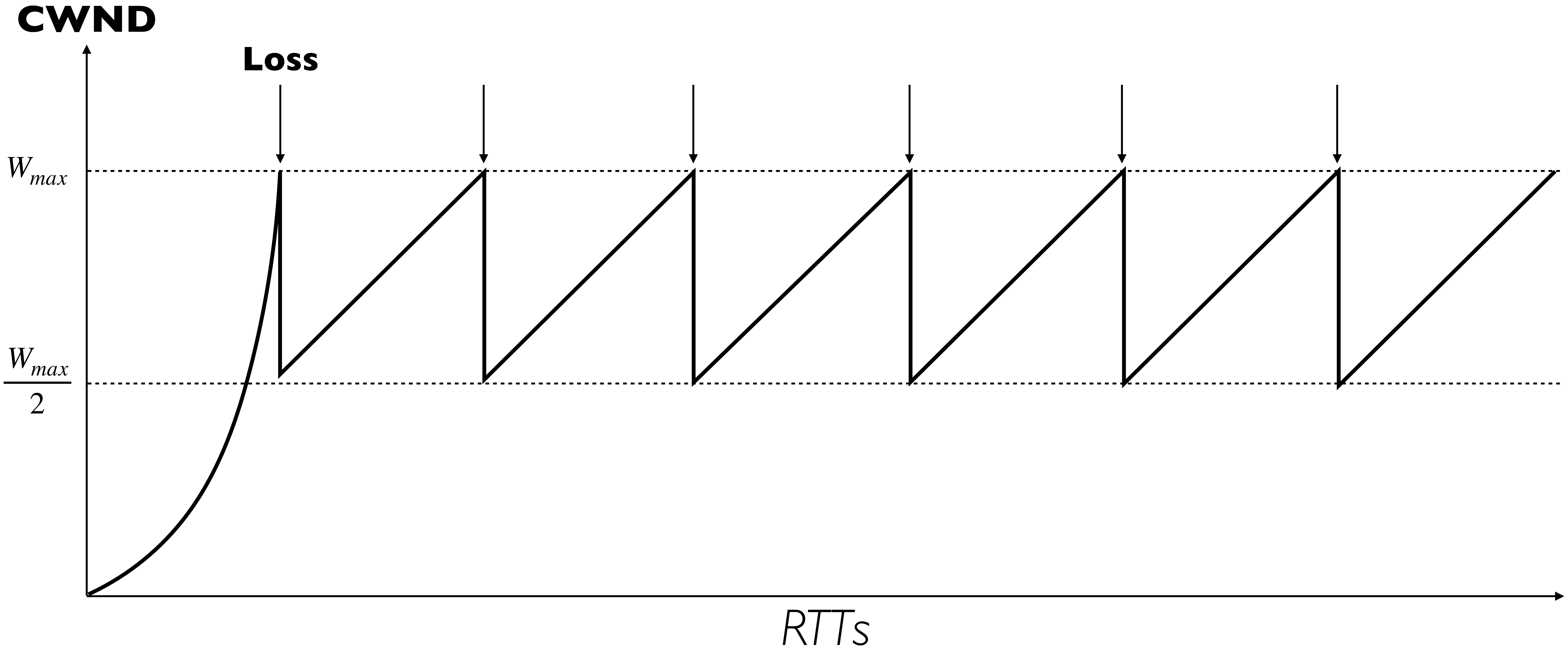
- The concepts underlying TCP are simple
- But tricky in the details
- Do the details matter?

Rest of Today's Lecture

- Critically examining TCP
- Advanced techniques

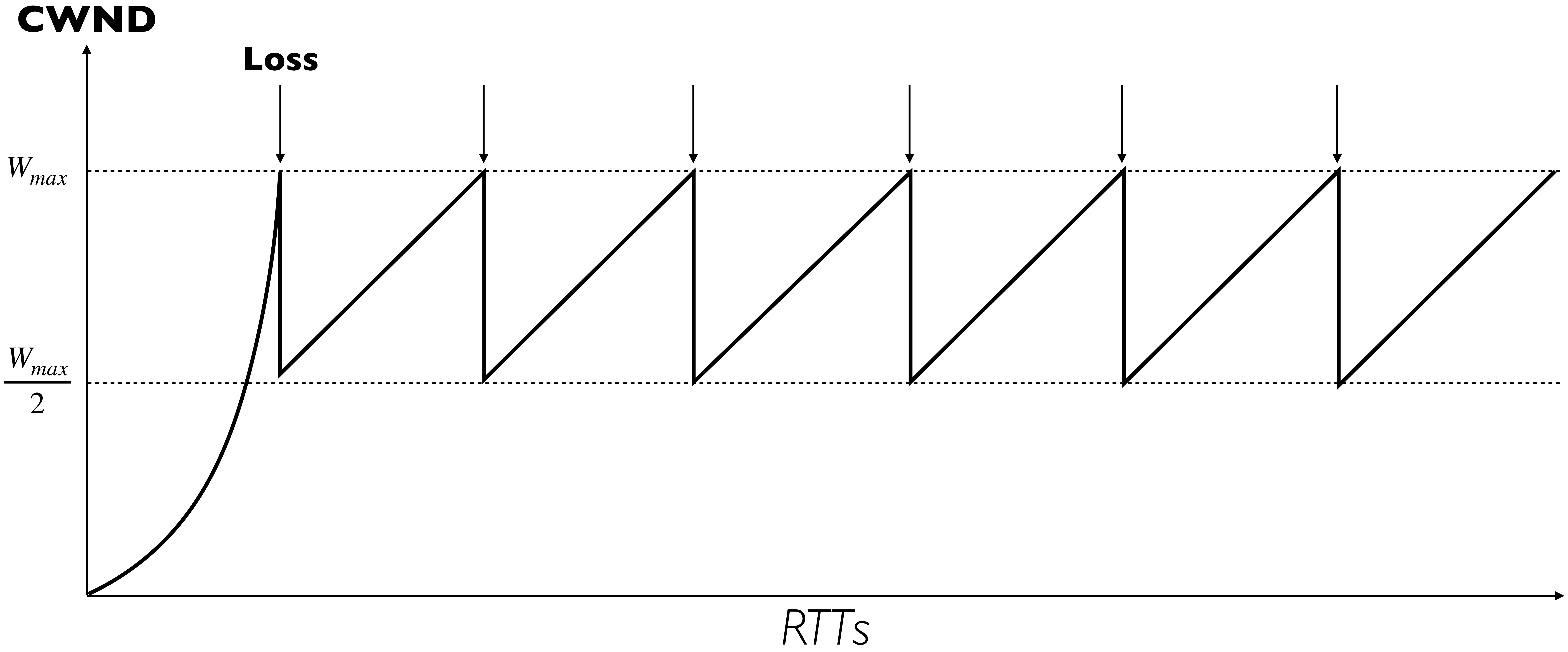
TCP Throughput Equation

A Simple Model for TCP Throughput



A Simple Model for TCP Throughput

Throughput = Window Size / RTT



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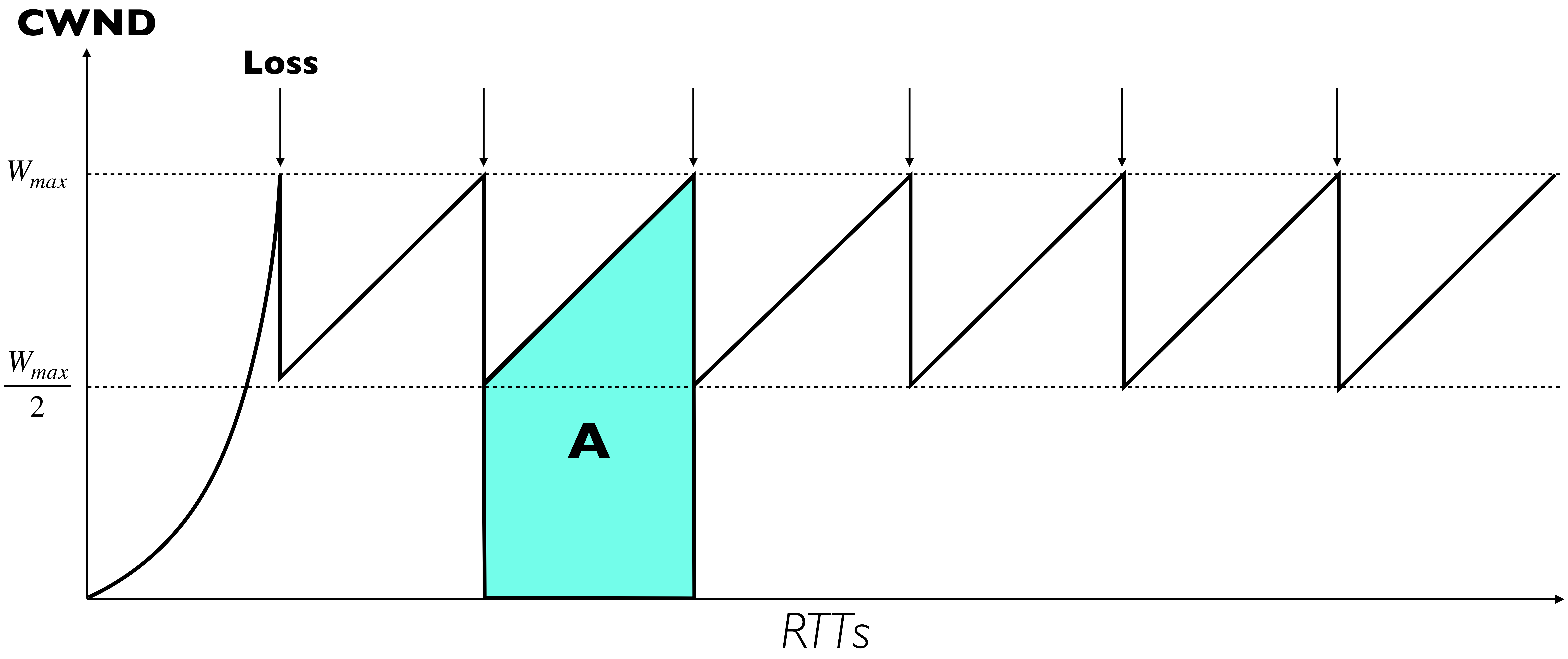

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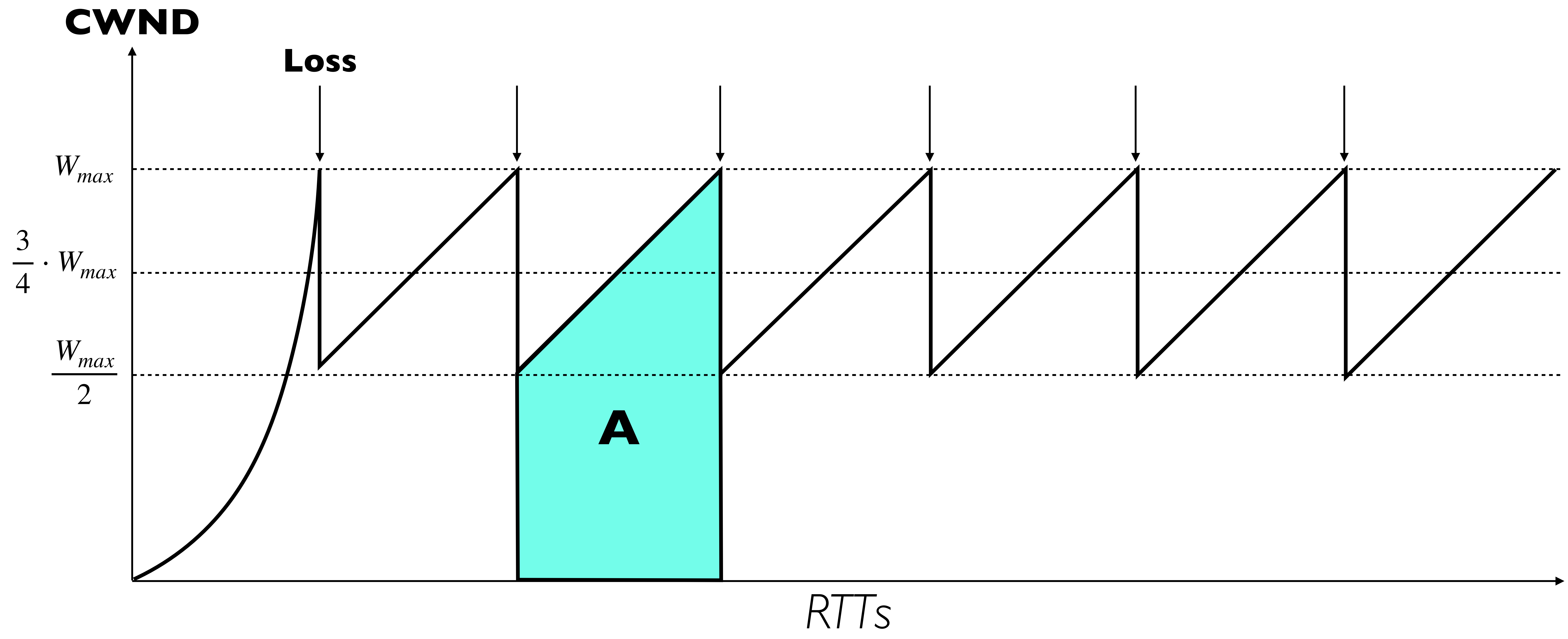

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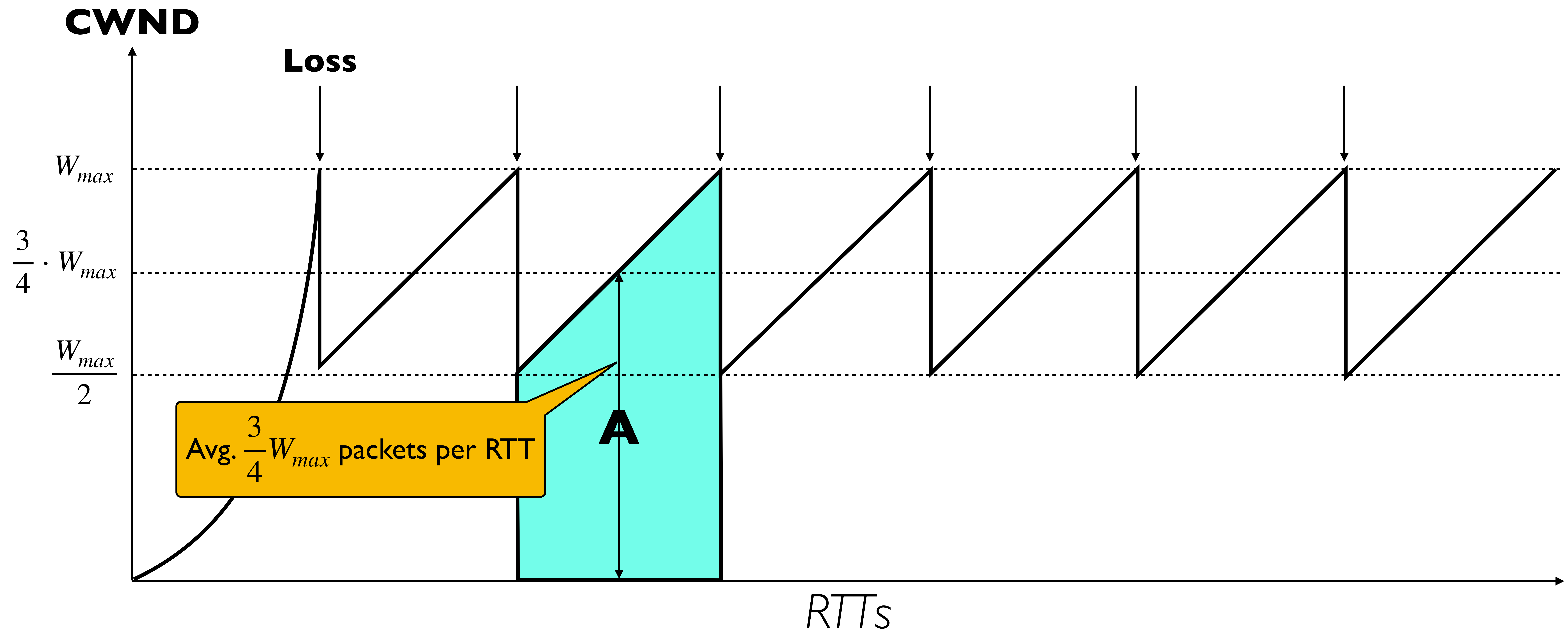

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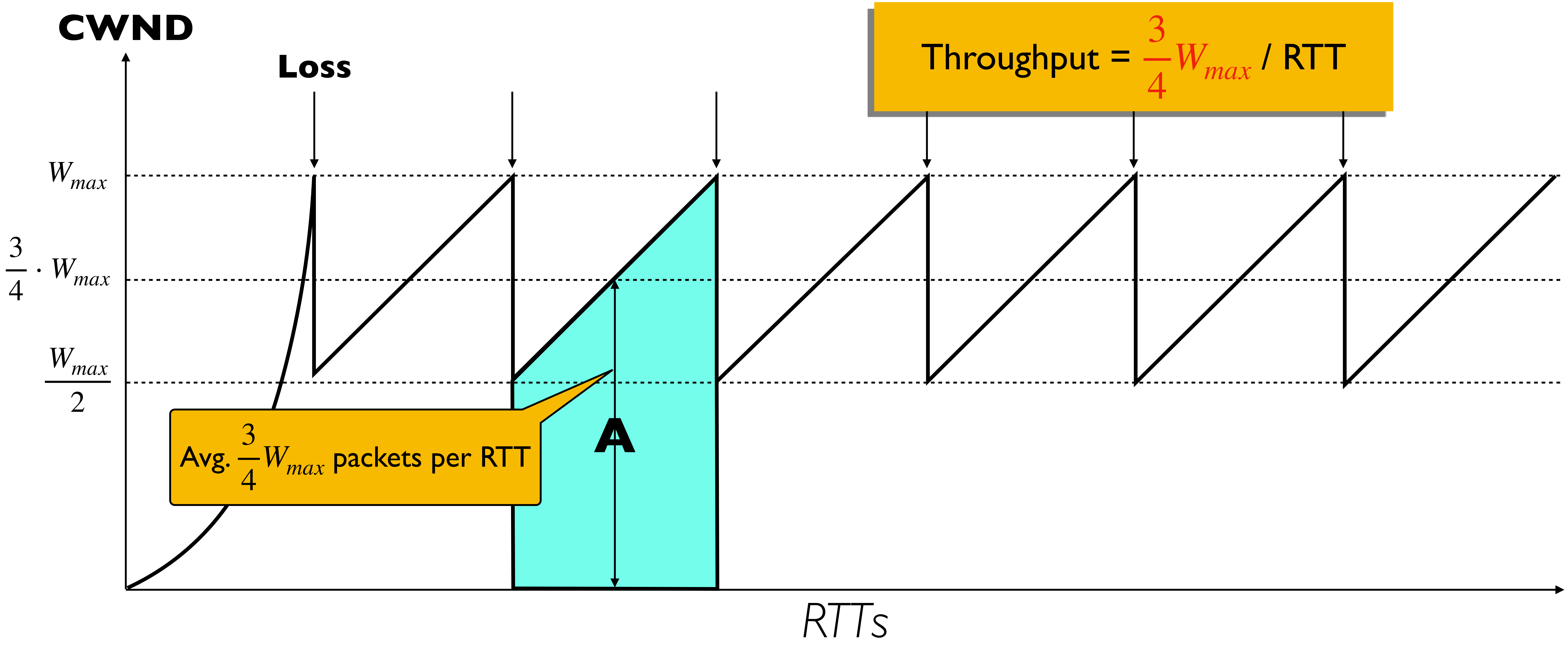

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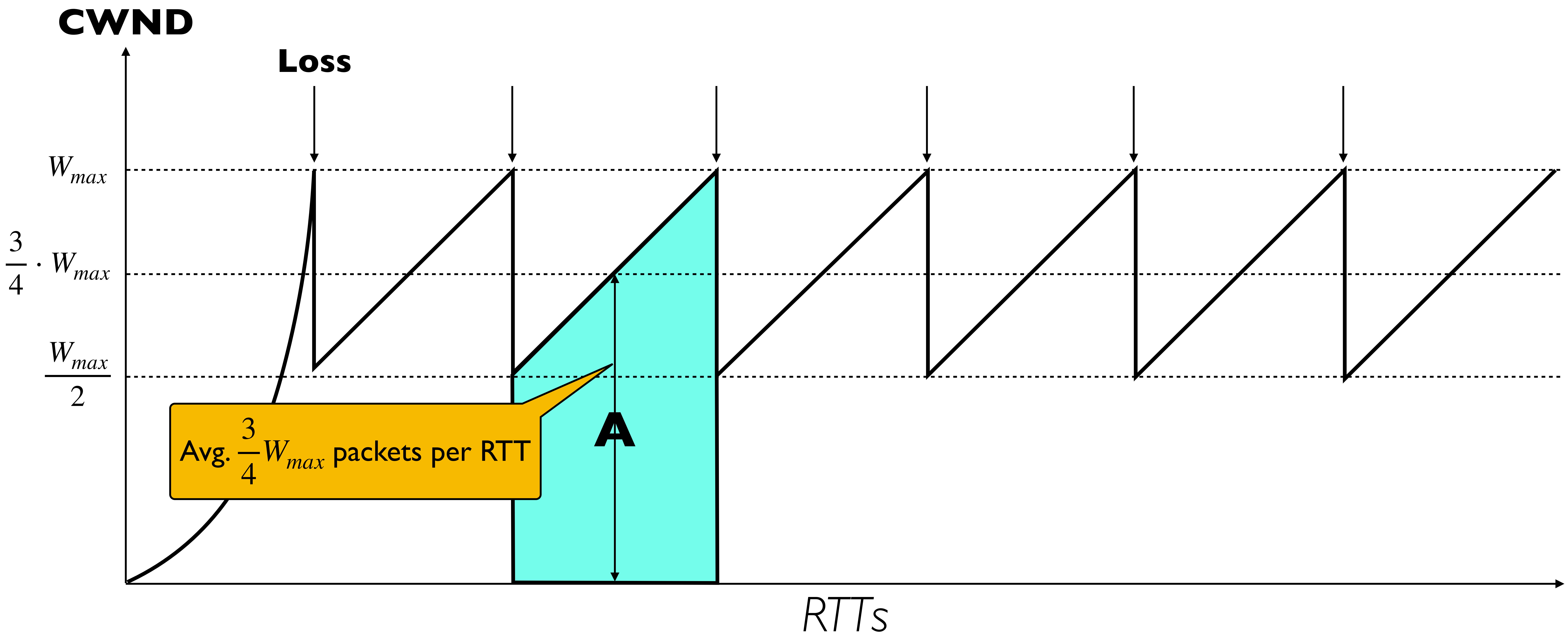

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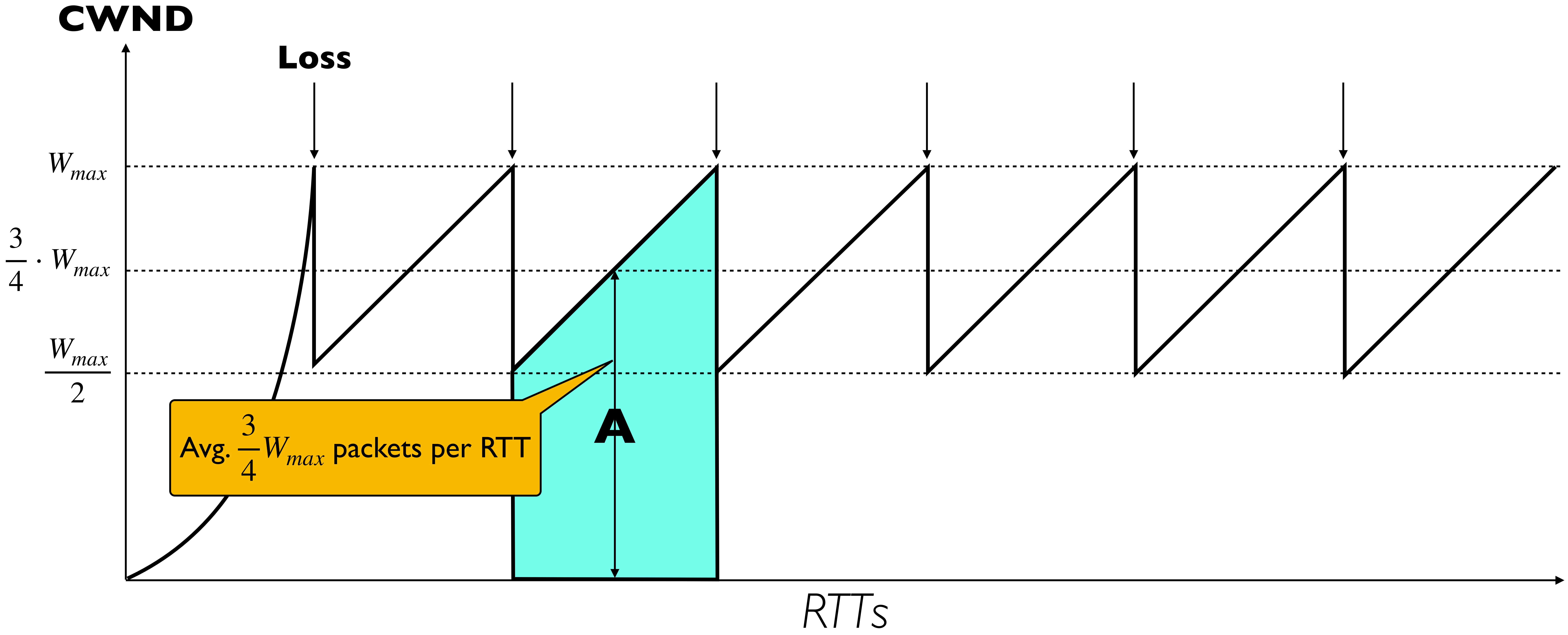

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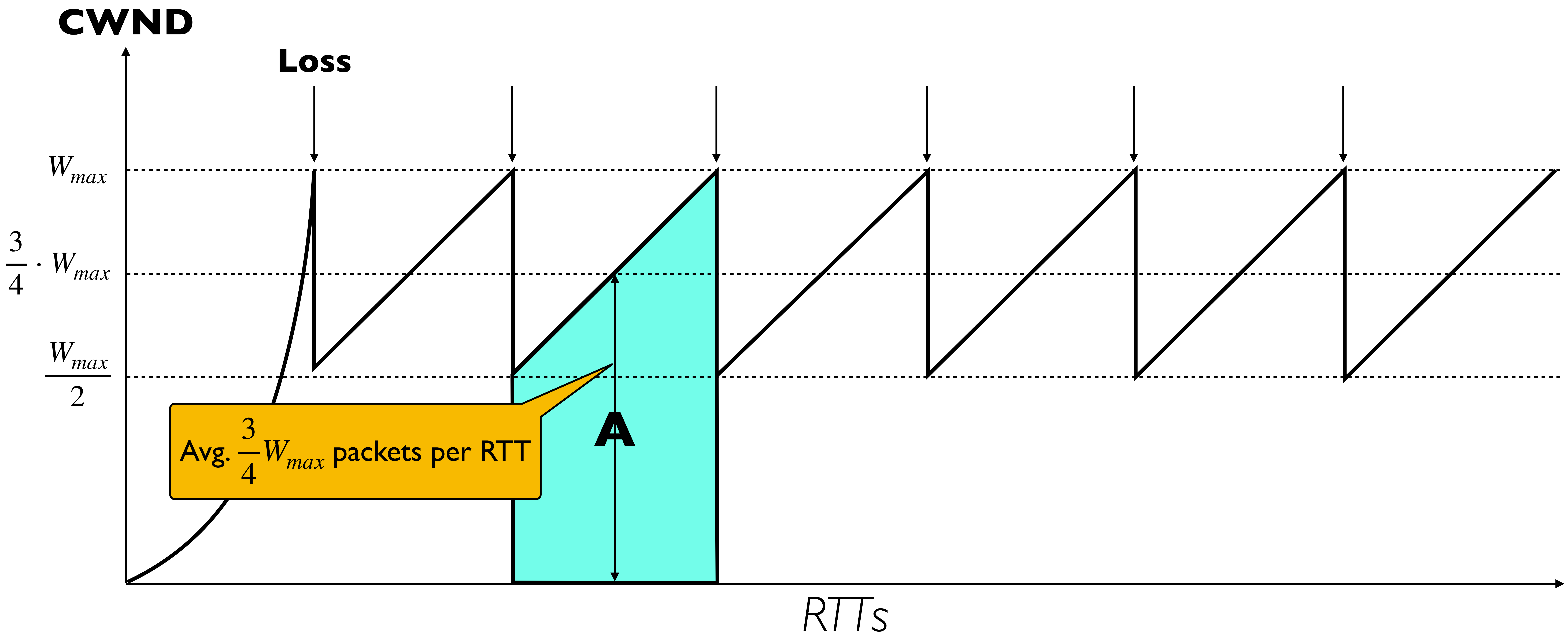

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If one packet dropped every A packets, what is the probability of packet drops?

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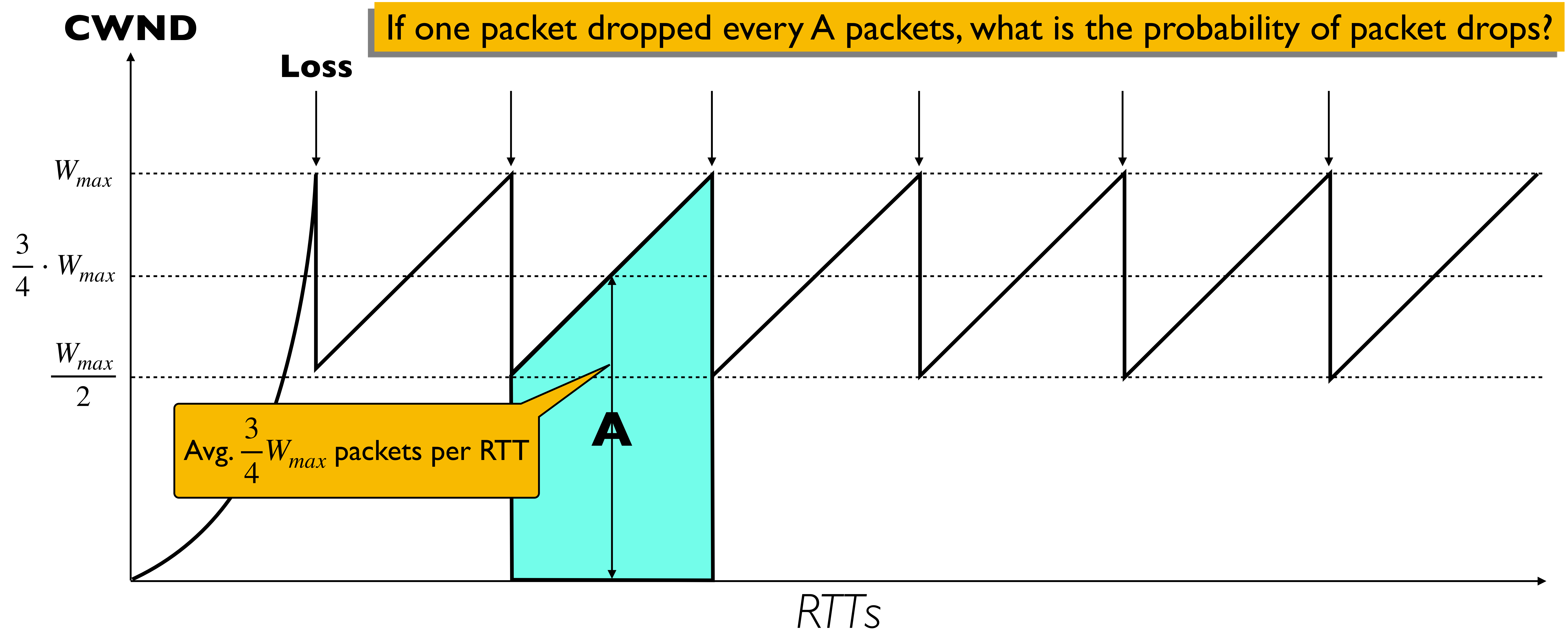

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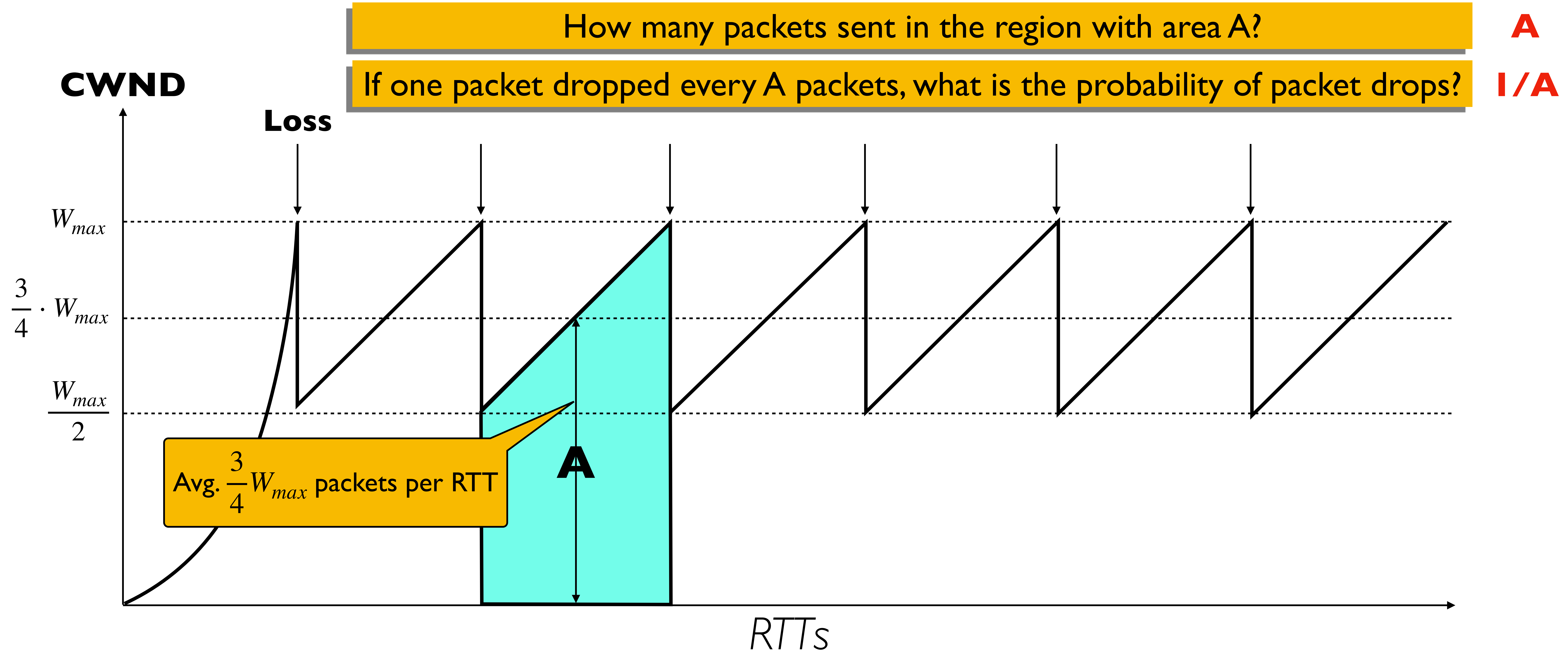

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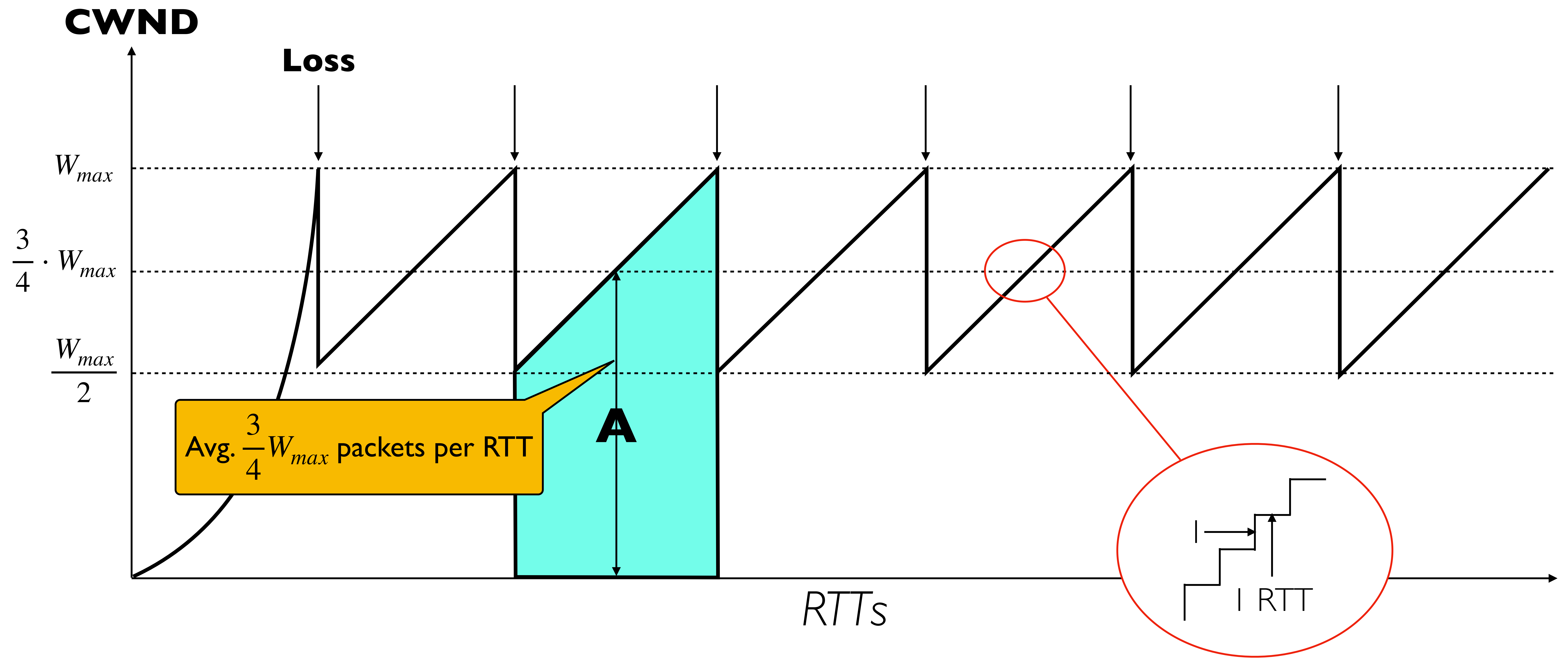

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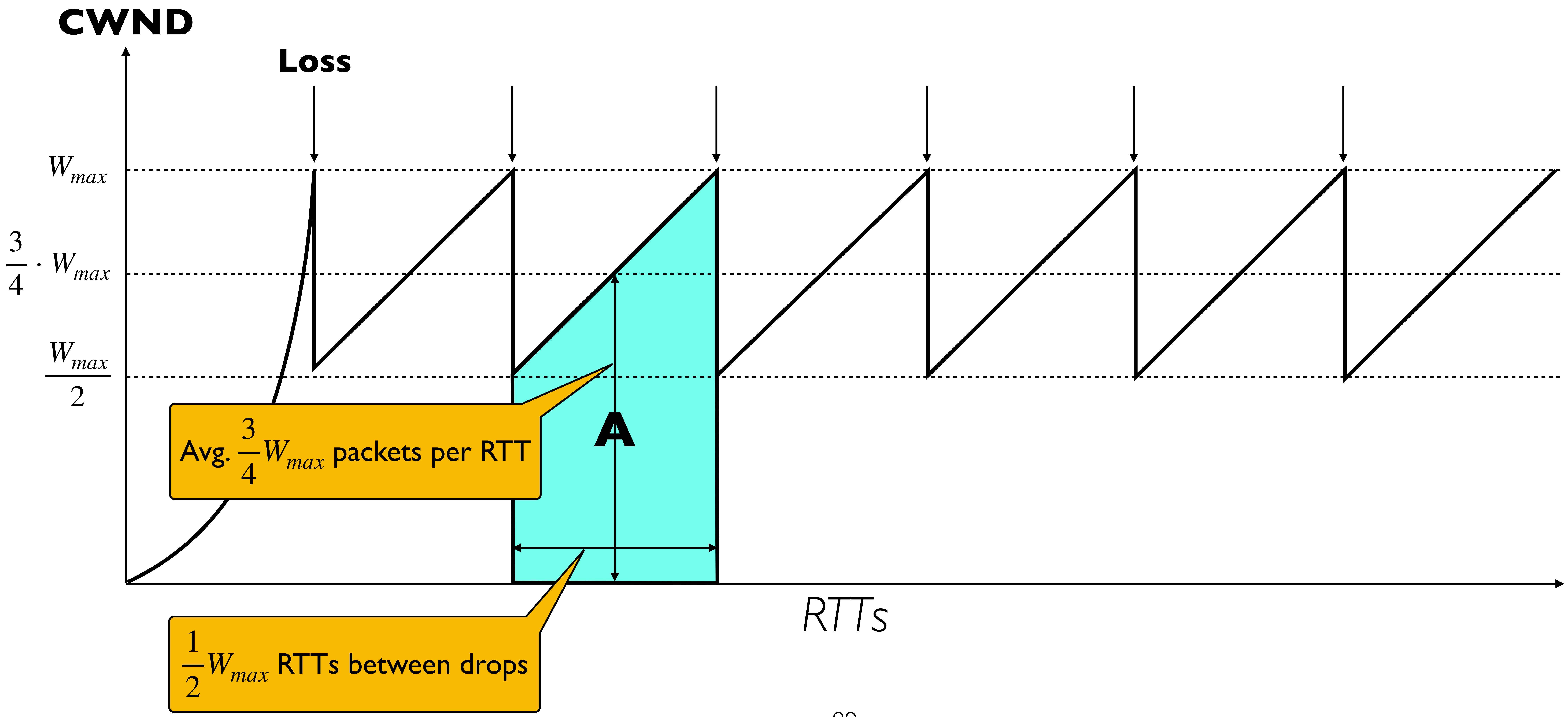

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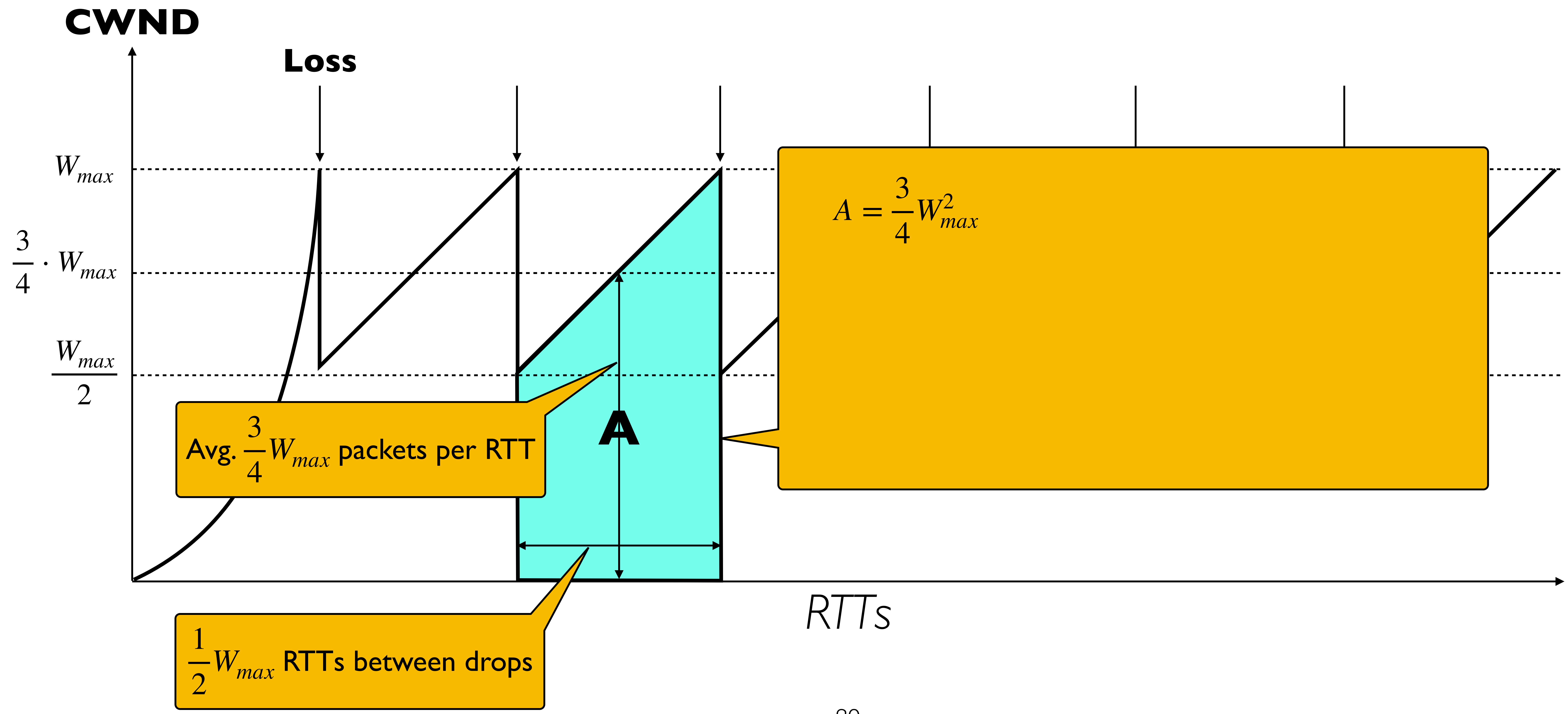

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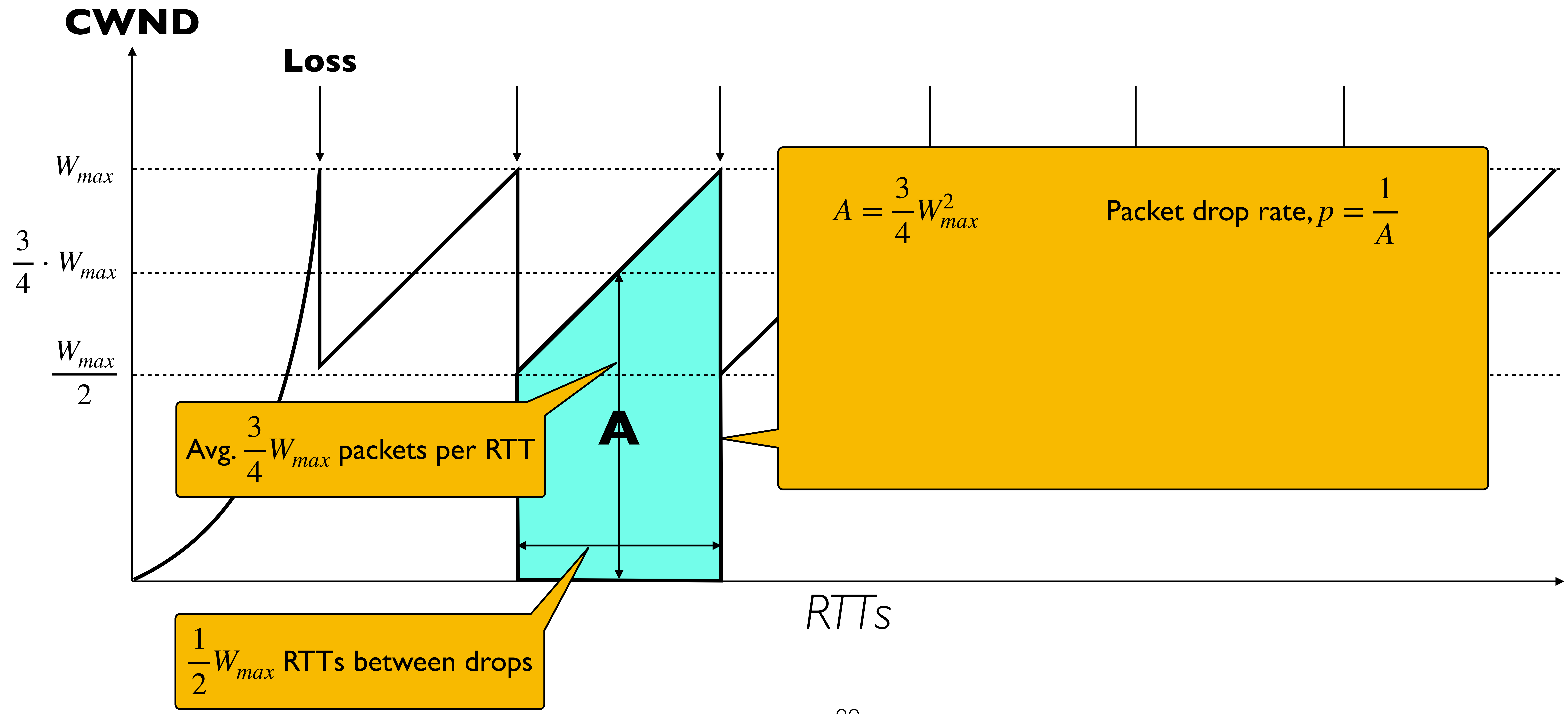

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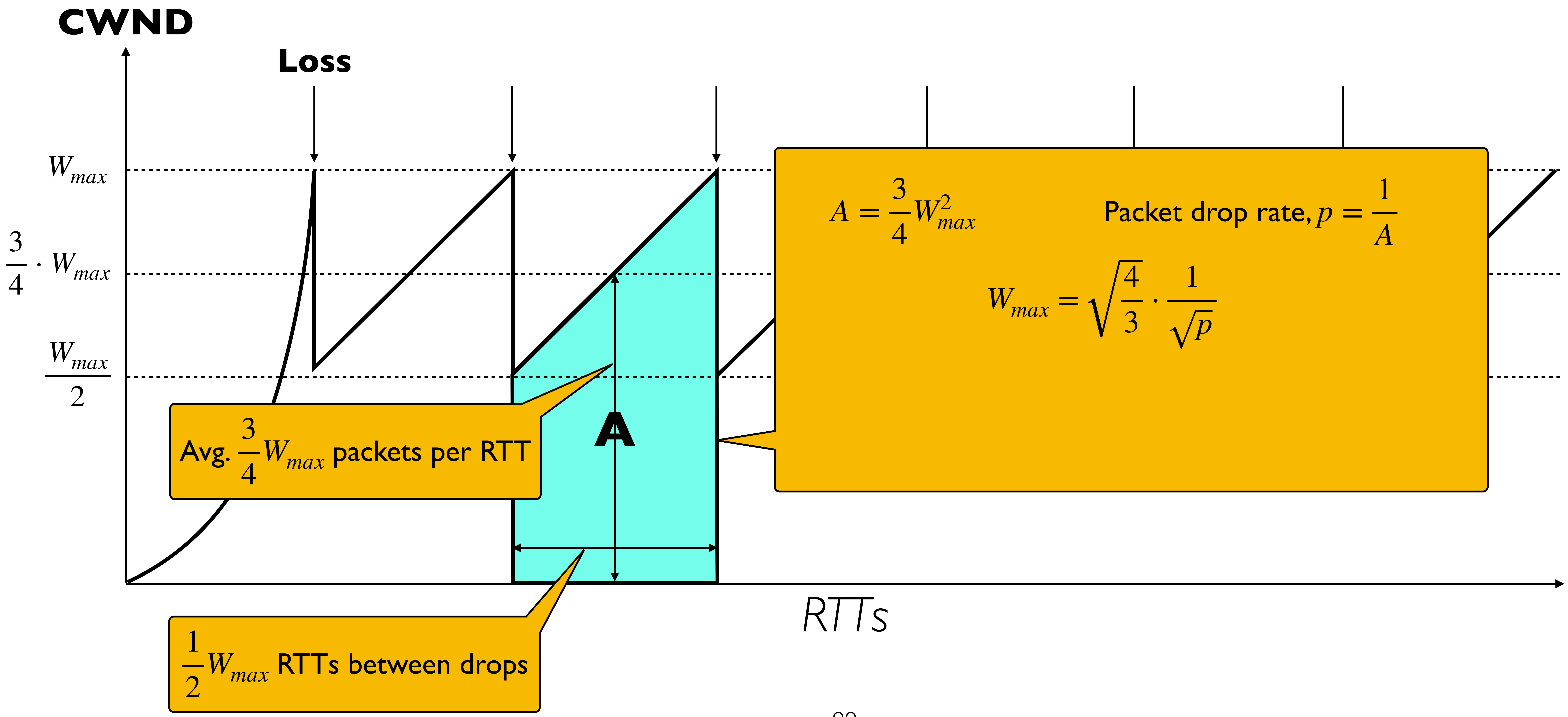

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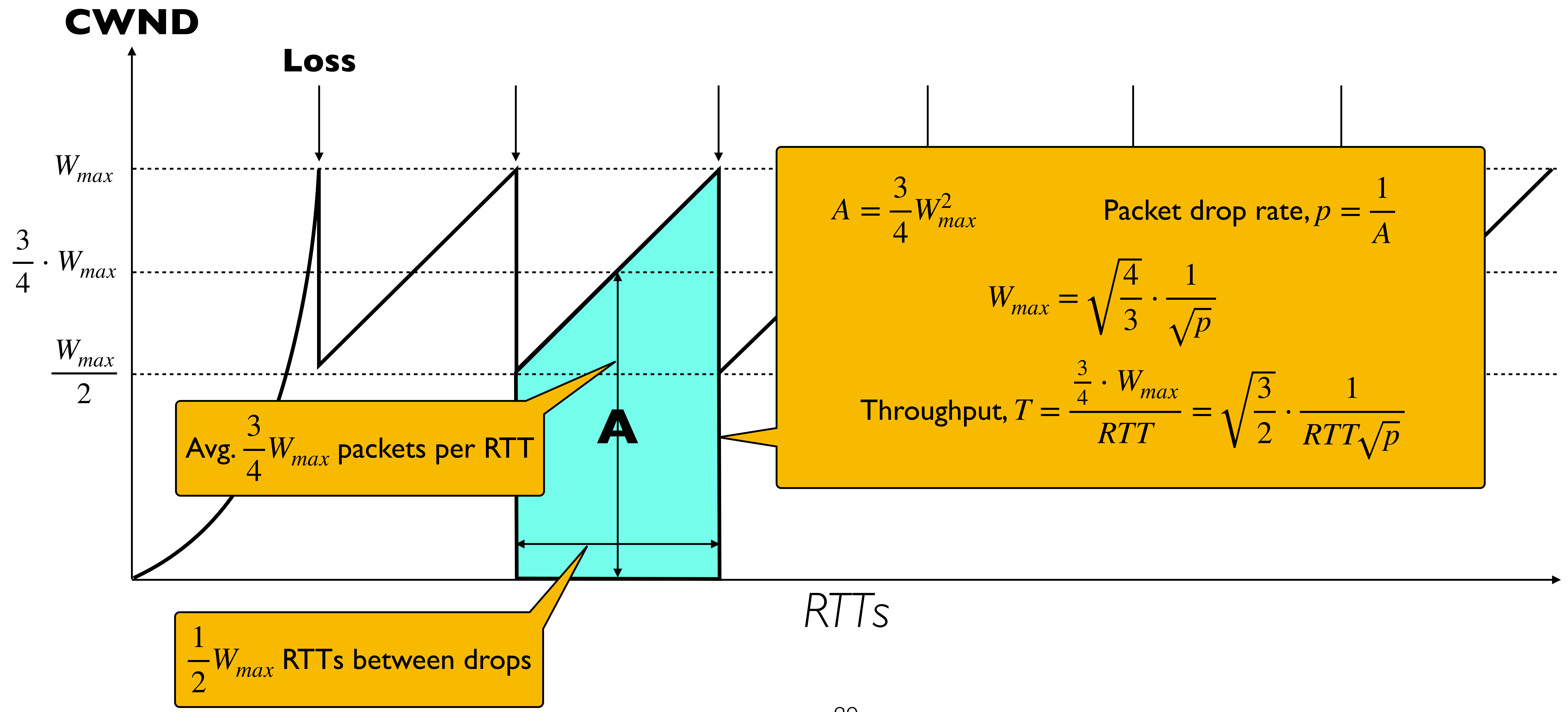

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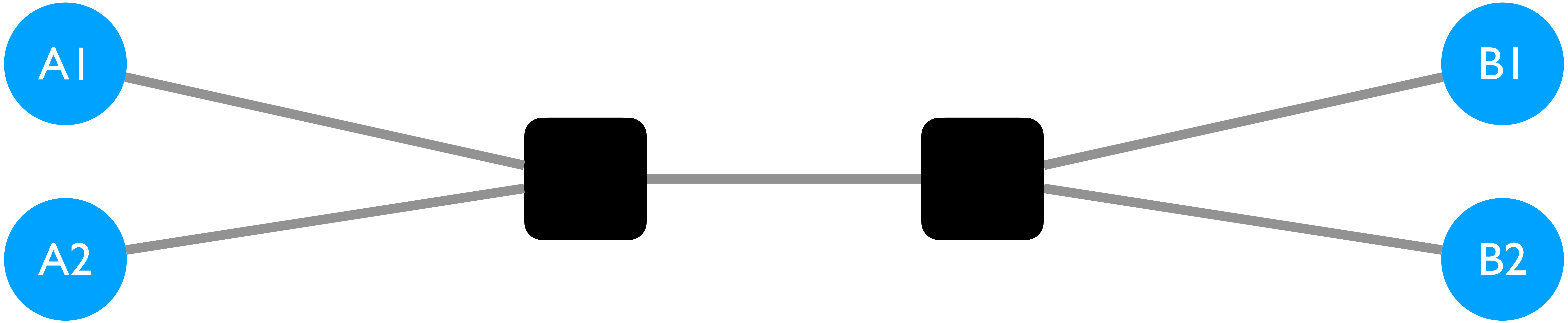

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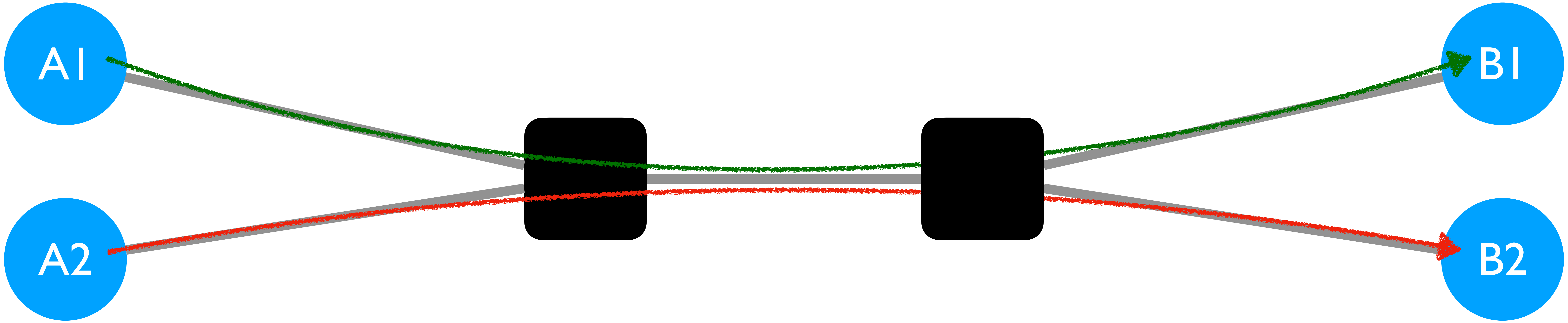

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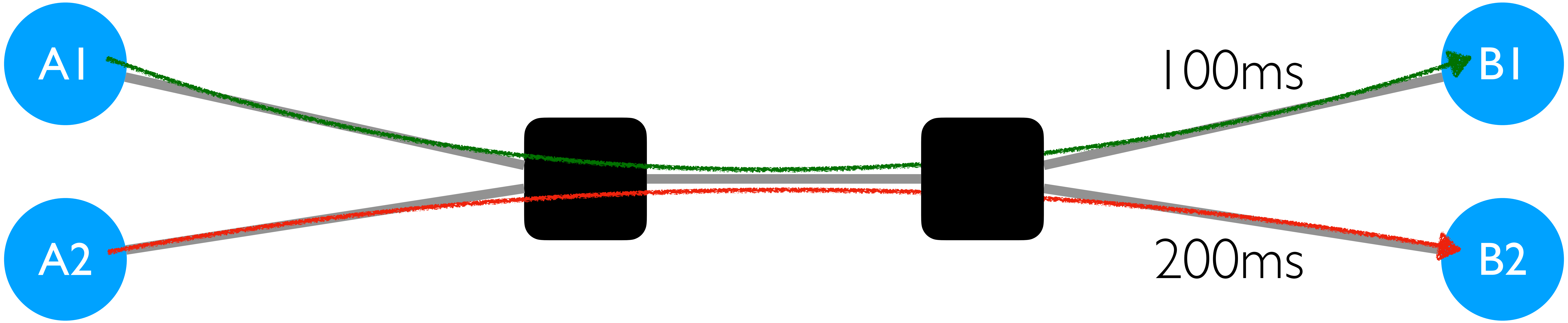

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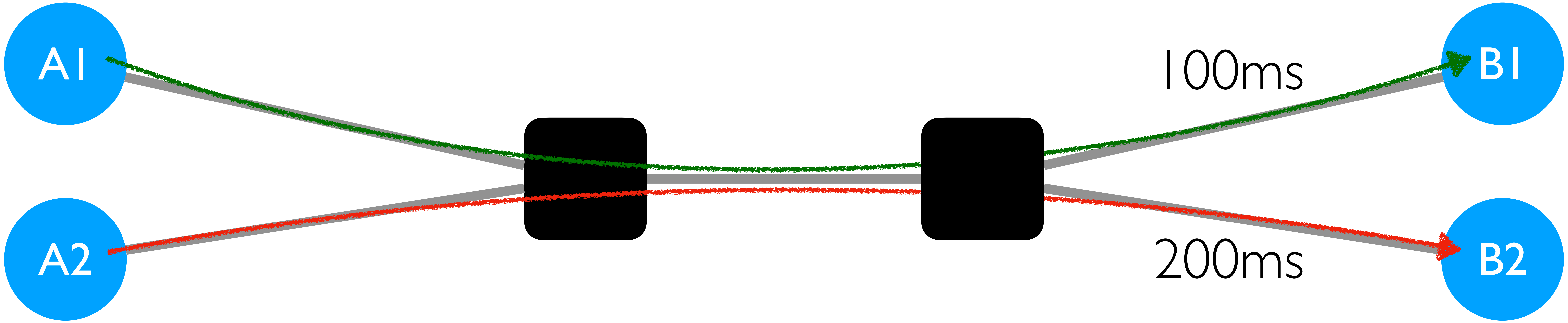

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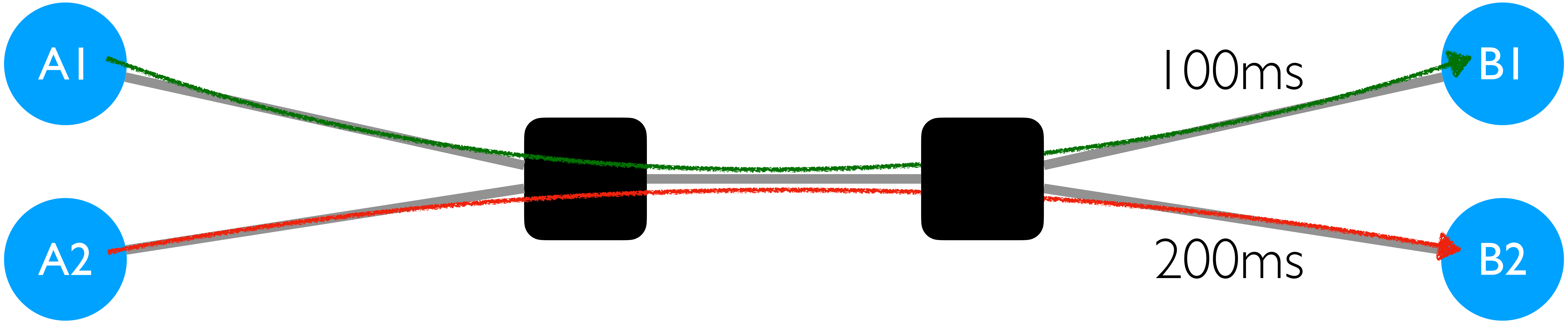

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Other Limitations of TCP Congestion Control

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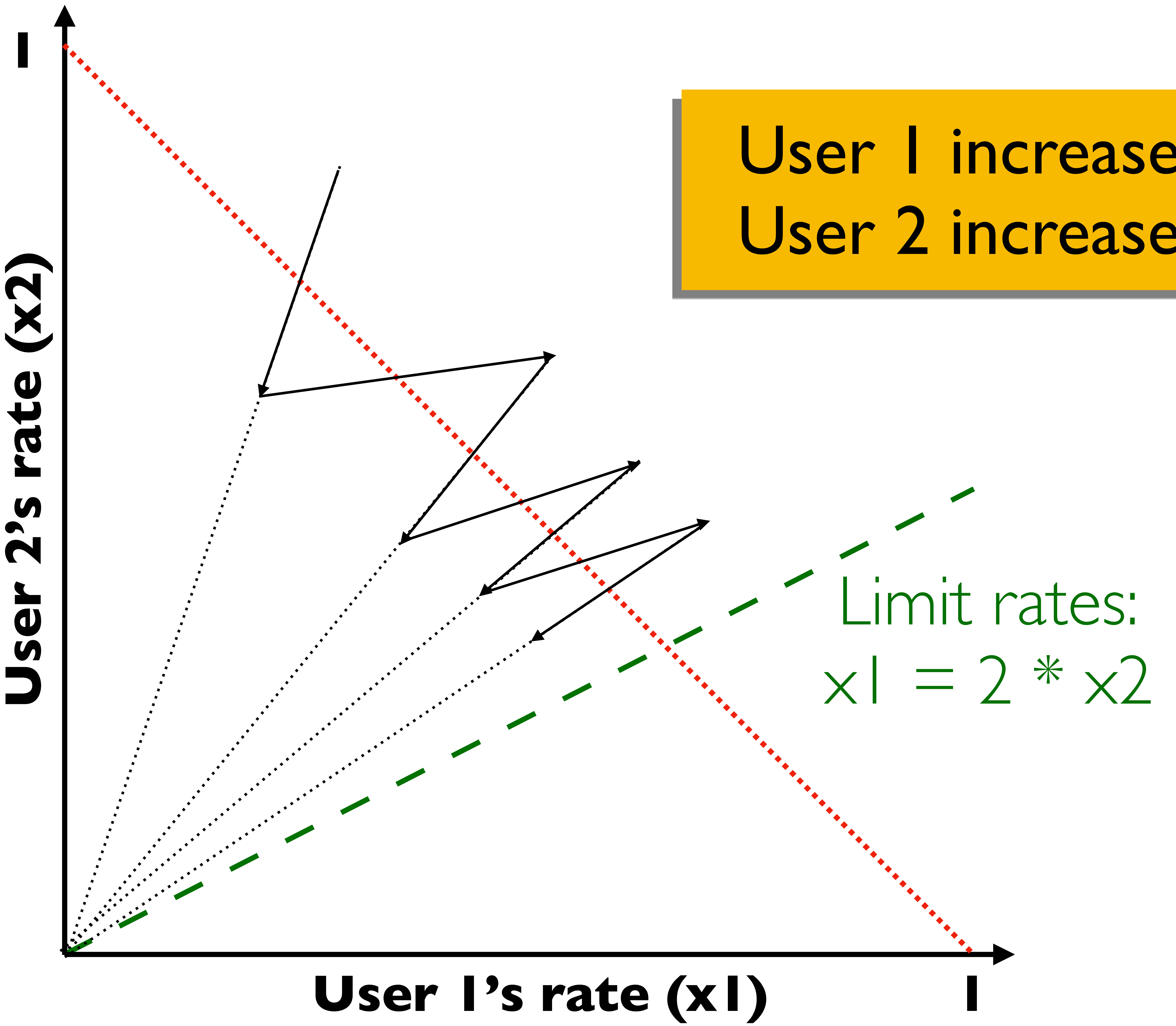
Increasing CWND Faster



User 1 increases by 2 per RTT
User 2 increases by 1 per RTT

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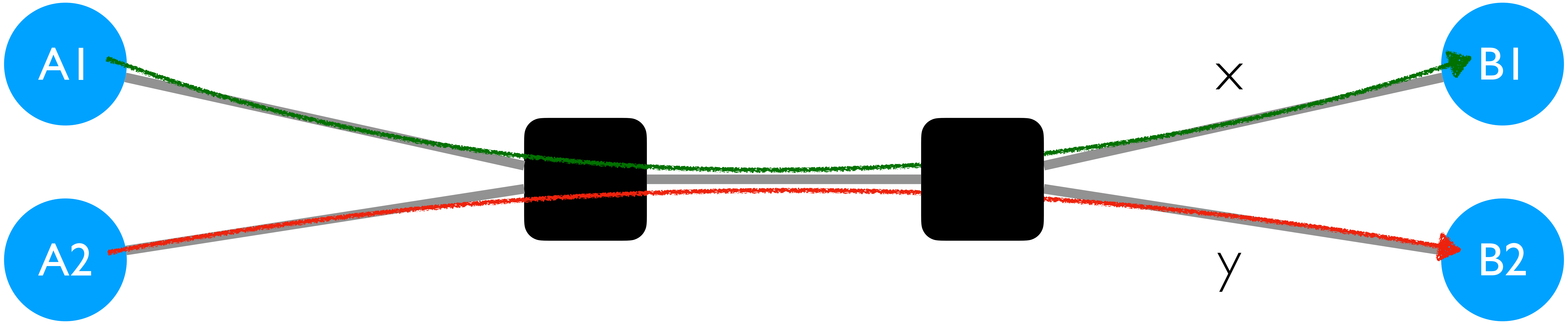

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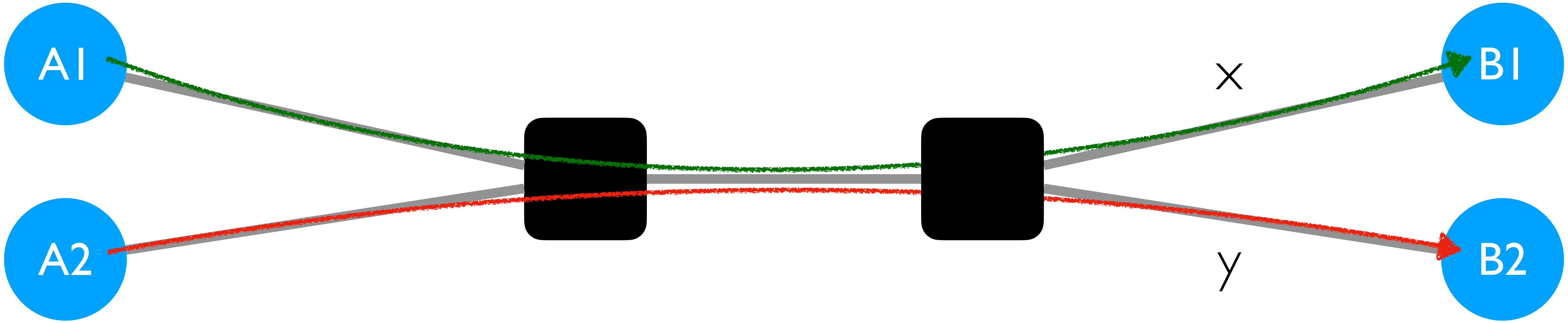

- Assume:

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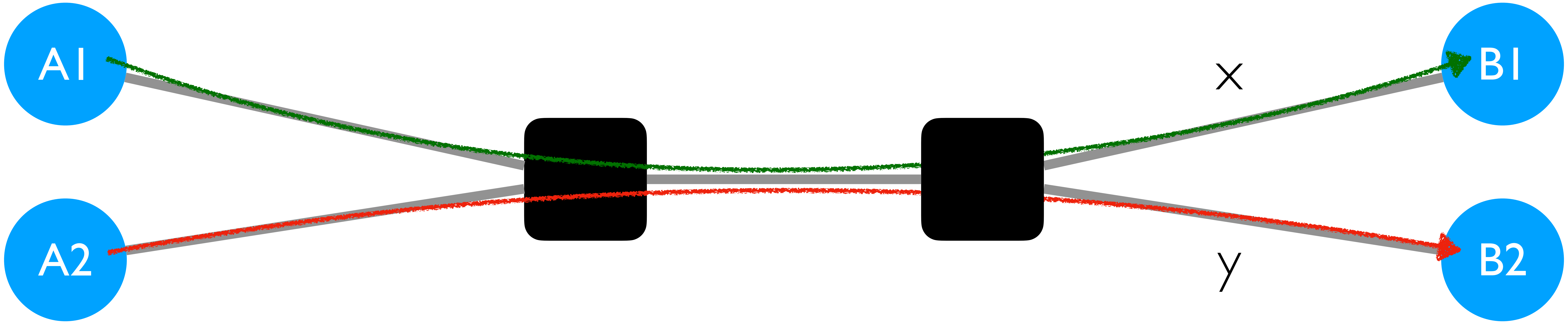

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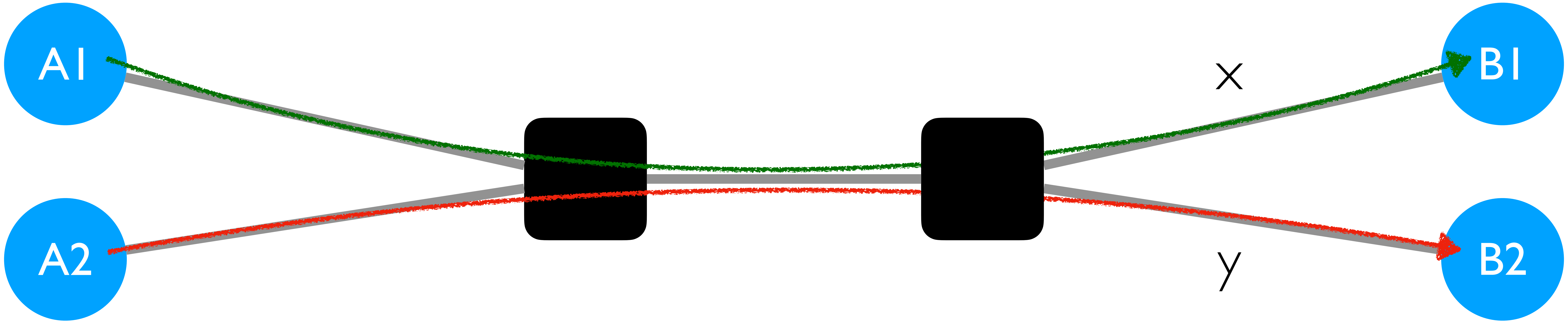

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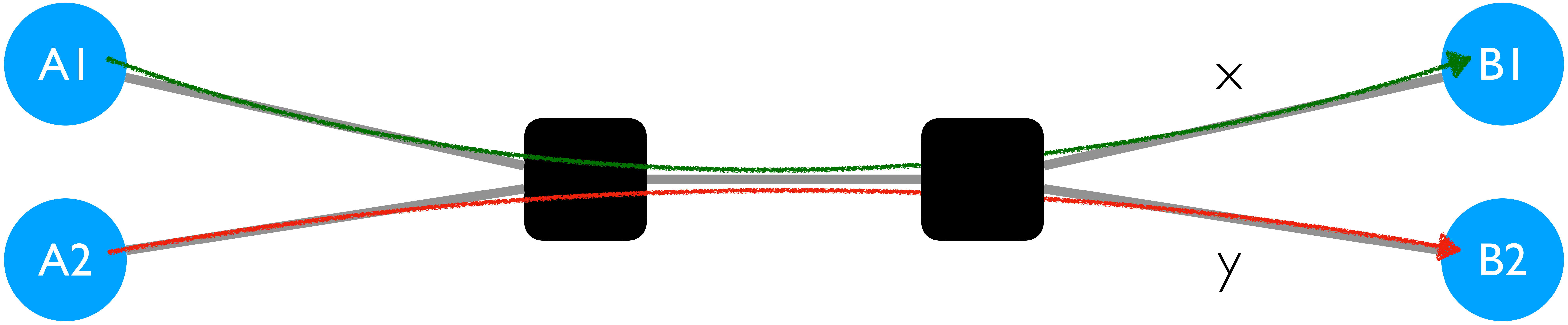

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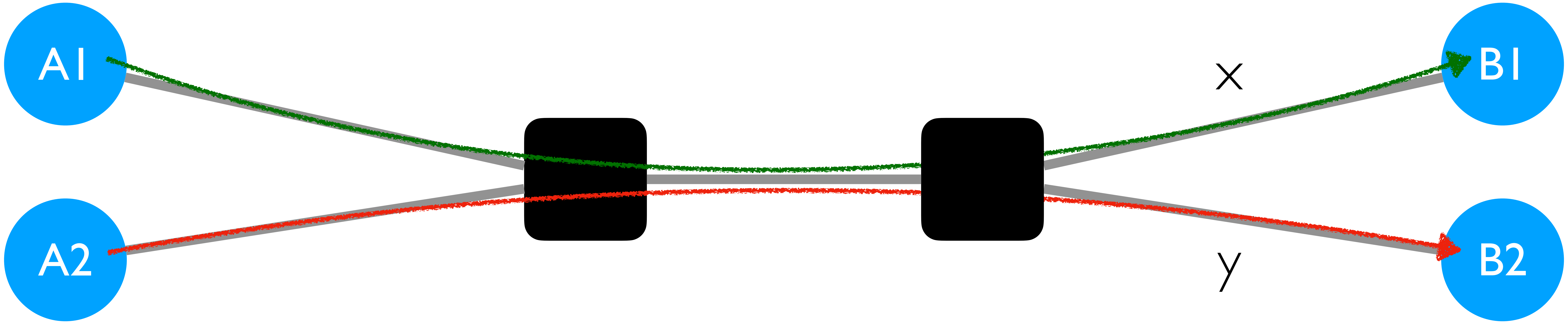

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    - Receiver sends multiple ACKs for same segment
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- Fills up queues leading to high delays
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Could fix many of these with some help from routers!

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  - Detecting congestion

How can routers ensure each flow gets its “fair share”?

Fairness: General Approach

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- What does "fair" mean exactly?

Max-Min Fairness

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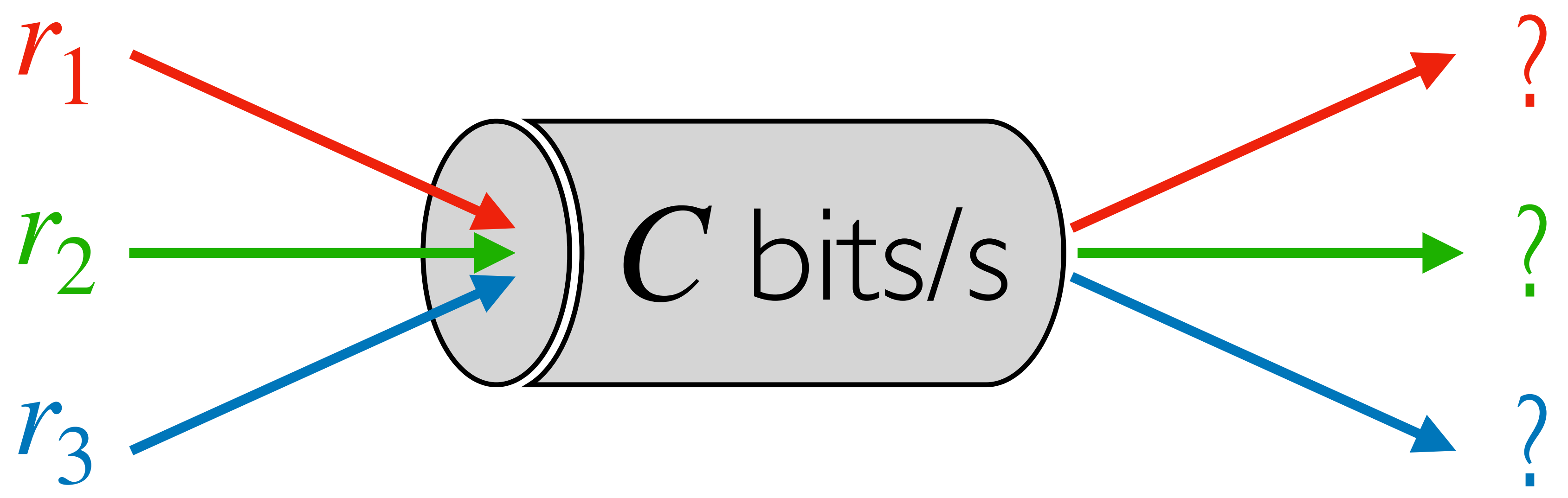
- Given a set of bandwidth demands r_i and total bandwidth C, max-min bandwidth allocations are:

$$a_i = min(f, r_i)$$

where f is the unique value such that $\sum_i a_i = C$



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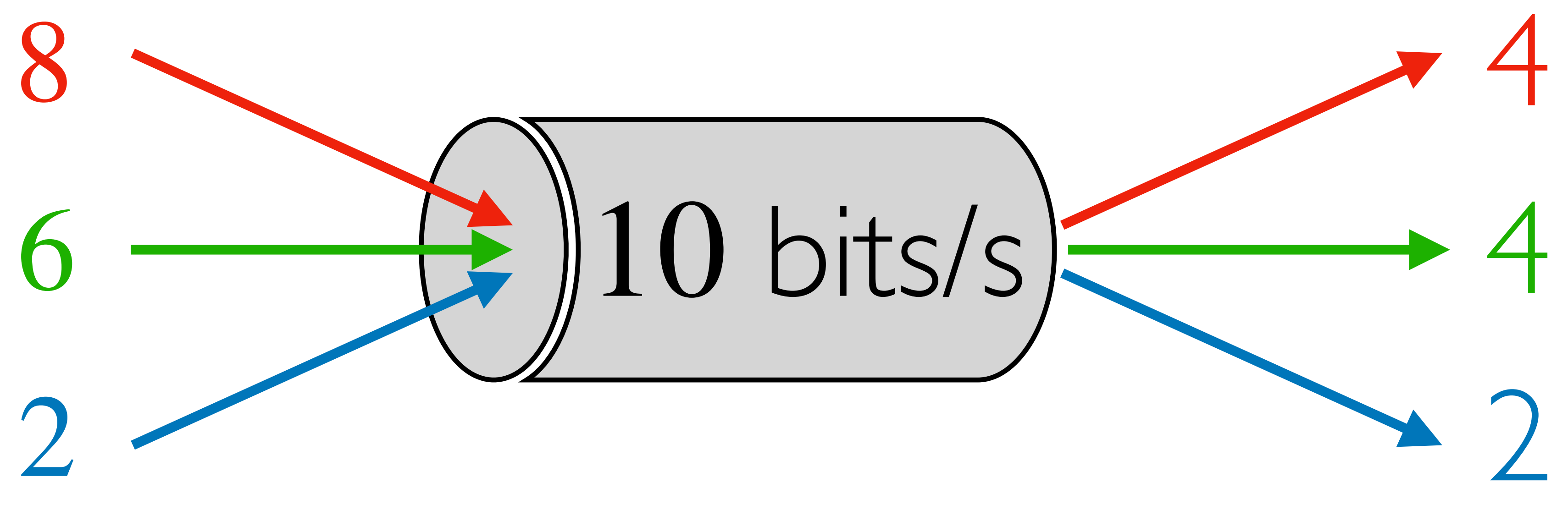

$f = 4:$
$\min(8,4) = 4$
$\min(6,4) = 4$
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- Can you do this in practice?
- No, packets cannot be preempted
- But we can approximate it
  - This is what “fair queueing” routers do

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- Then service packets in the increasing order of their deadlines

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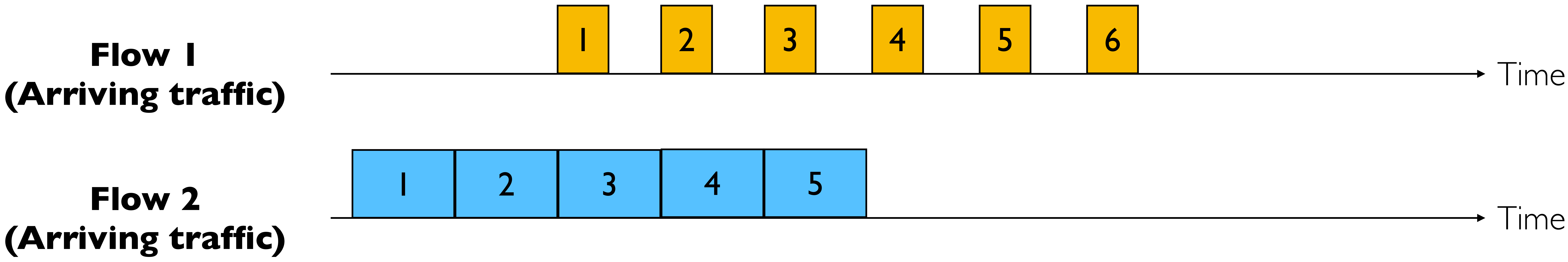
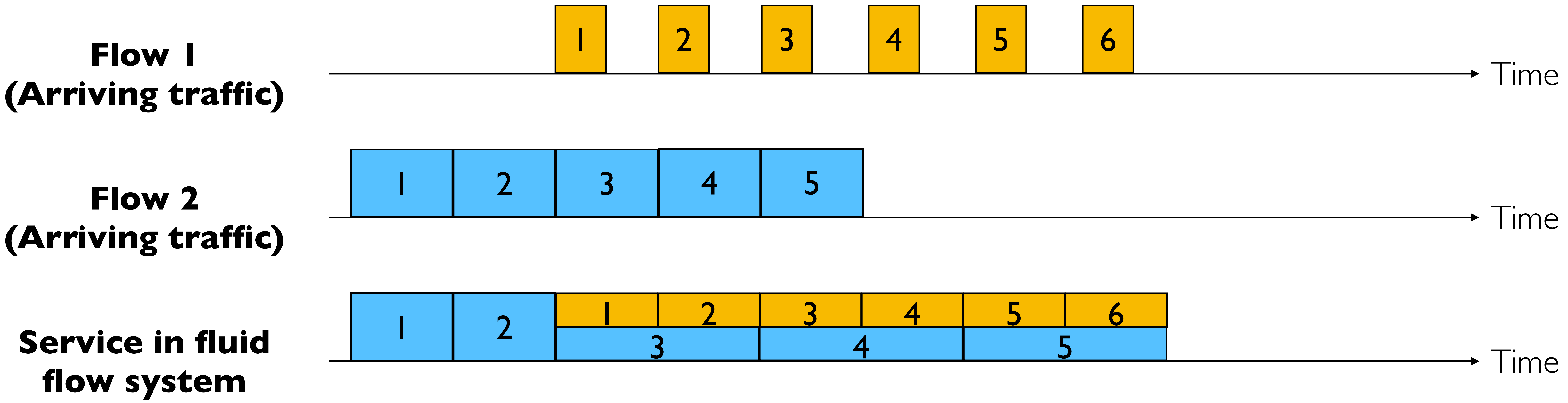


Flow 1
(Arriving traffic)
1
2
3
4
5
6
Time
Flow 2
(Arriving traffic)
1
2
3
4
5
Time

Example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Service in fluid flow system
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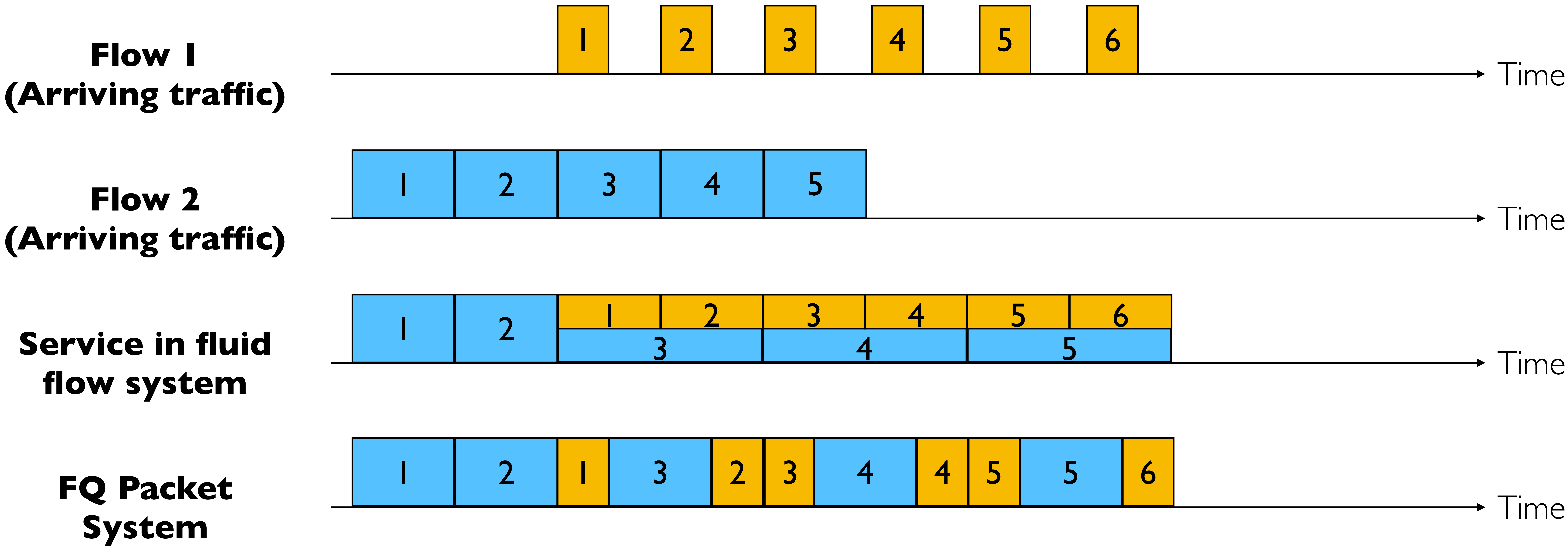
Example



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- **Weighted** fair queuing (WFQ): assign different flows different shares

- Today, some form of WFQ implemented in almost all routers
  - Not the case in the 1980-90's, when CC was being developed
  - Mostly used to isolate traffic at larger granularities (e.g., per-prefix)

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- Disadvantages
  - More complex than FIFO: per flow queue/state, additional per-packet book-keeping

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    - Why should you get twice the bandwidth
- **What if your flow goes over 4 congested hops, and mine goes only over 1?**
    - Why shouldn't you be penalized for using more scarce bandwidth?
- **And what is a flow anyway?**
    - TCP connection?
    - Source-destination pair?
    - Source?

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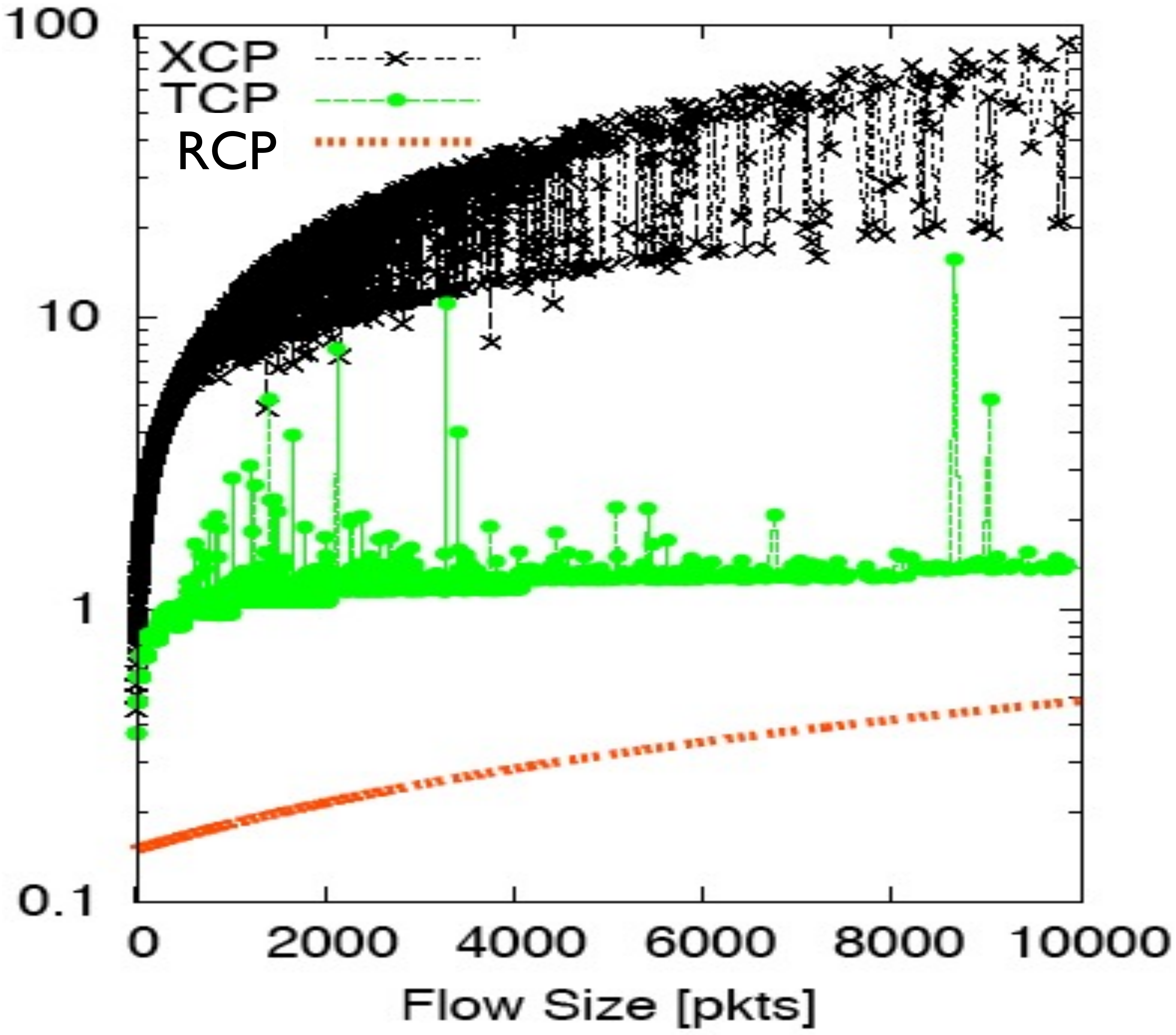
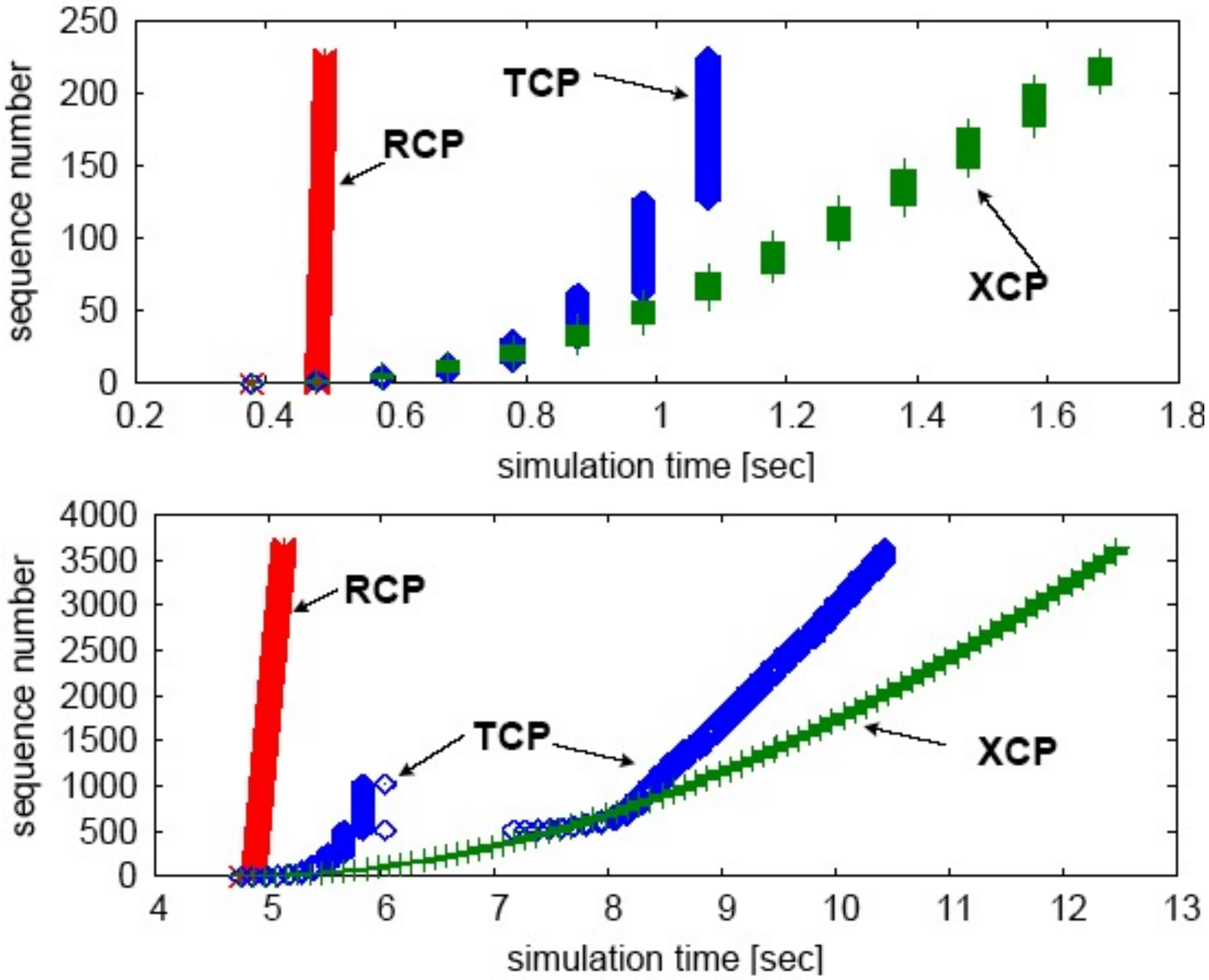
    - Hopefully (still need some policing of end-systems!)
- *Basic idea behind the "Rate Control Protocol" (RCP) from Dukkipati et. al. '07*

Flow Completion Time: TCP vs. RCP (Ignore XCP)

Flow Duration (seconds) vs. Flow Size



Why the Improvement?



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- **Congestion semantics can be exactly like that of drop**
  - i.e., end-system reacts as though it saw a drop
- **Advantages:**
  - Don't confuse corruption with congestion; recovery with rate adjustment
  - Can serve as an early indicator of congestion to avoid delays
  - Easy (easier) to incrementally deploy
    - Today: defined in RFC 3168 using **ToS/DSCP** bits in the IP header

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- Use ECN as congestion markers
- Whenever I get an ECN bit set, I have to pay $$
- Now there's no debate over what a flow is, or what fair is…
- Idea started by Frank Kelly at Cambridge
  - "Optimal" solution, backed by much math
  - Great idea: simple, elegant, effective
  - Unclear that it will impact practice

Recap

Recap

- TCP
  - Somewhat hacky
  - But practical/deployable
  - Good enough for Internet traffic
  - Needs of datacenters might change status quo (future lecture)