Flow-start: Faster and Less Overshoot with Paced Chirps

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Problem: originally L4S/ECN-specific Solution: delay-based

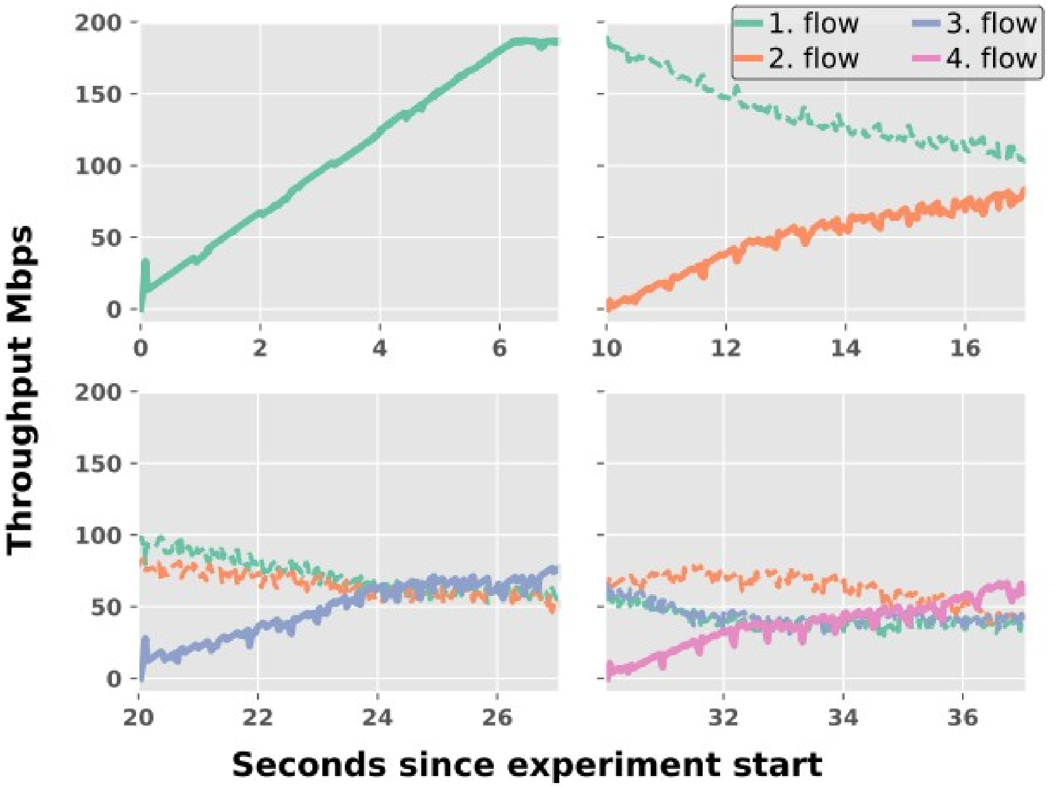
- Original problem
  - DCTCP's ECN marking prob. higher[1] than Classic drop
  - A flow pushing into existing traffic exits slow start earlier
- Solution
  - TCP Prague intended for public Internet
  - Unlike DCTCP, cannot assume ECN support at bottleneck
    - even if new flow experiences ECN marking
    - as available capacity increases, could reveal a non-ECN b'neck
  - Must use delay-sensing, with ECN only to improve precision

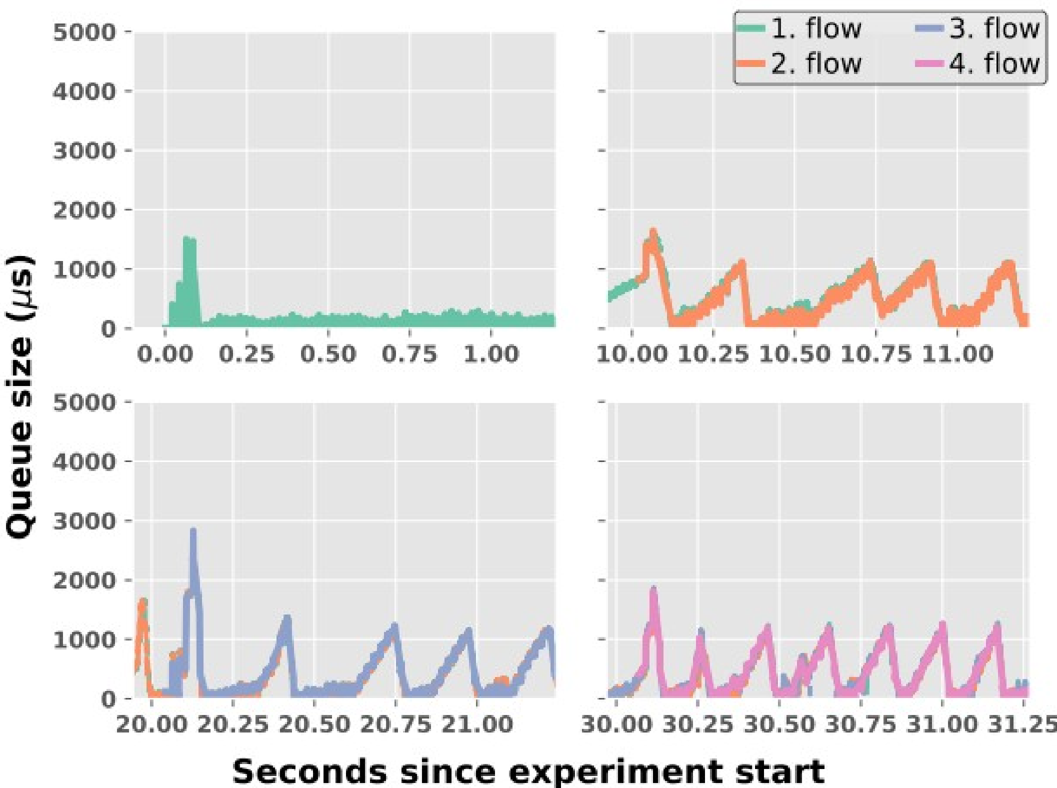
[1] Deliberate: 2 marks per RTT in steady state (control scales to any rate)

L4S: Low Latency Low Loss
Scalable throughput
ECN: Explicit Congestion Notification

Problem: DCTCP slow start

- Throughput convergence
  - awful
- Queuing Impact
  - excellent



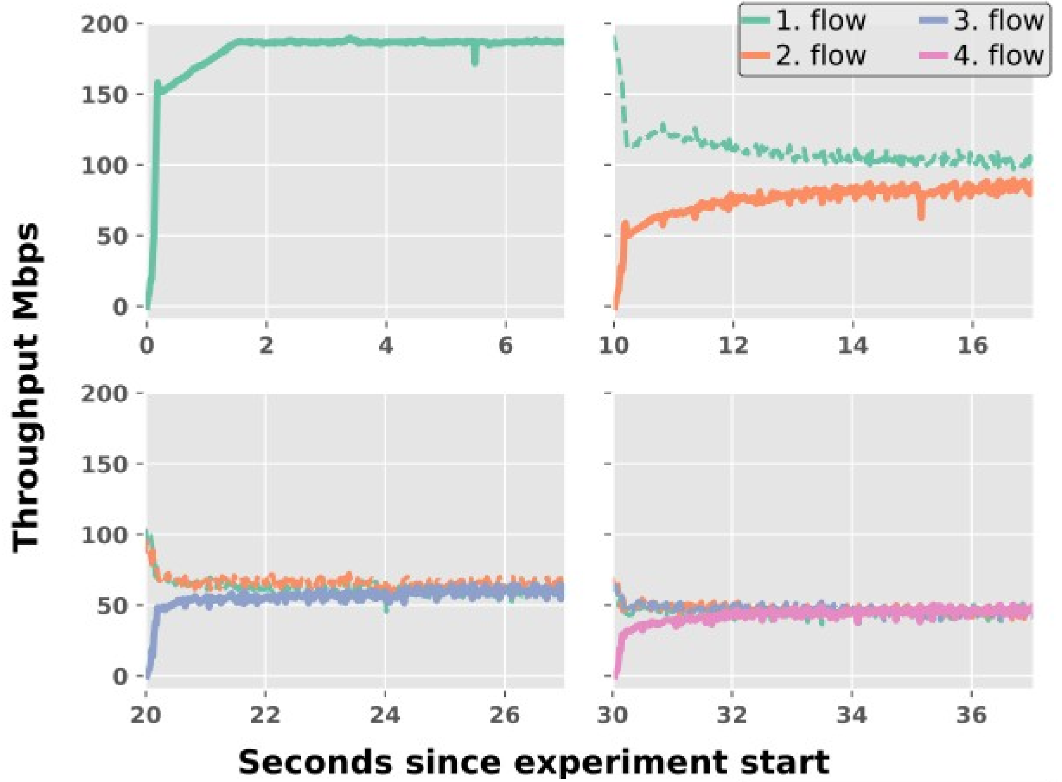


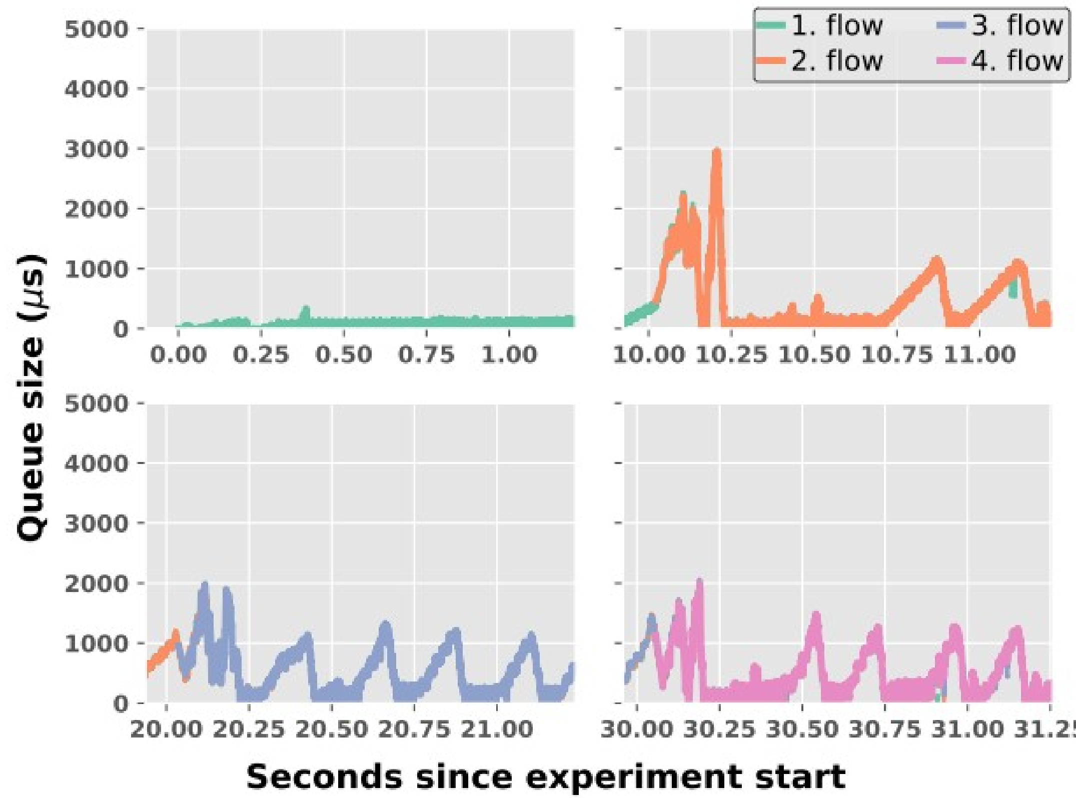
Solution:
Paced Chirping

- Throughput convergence
    - excellent

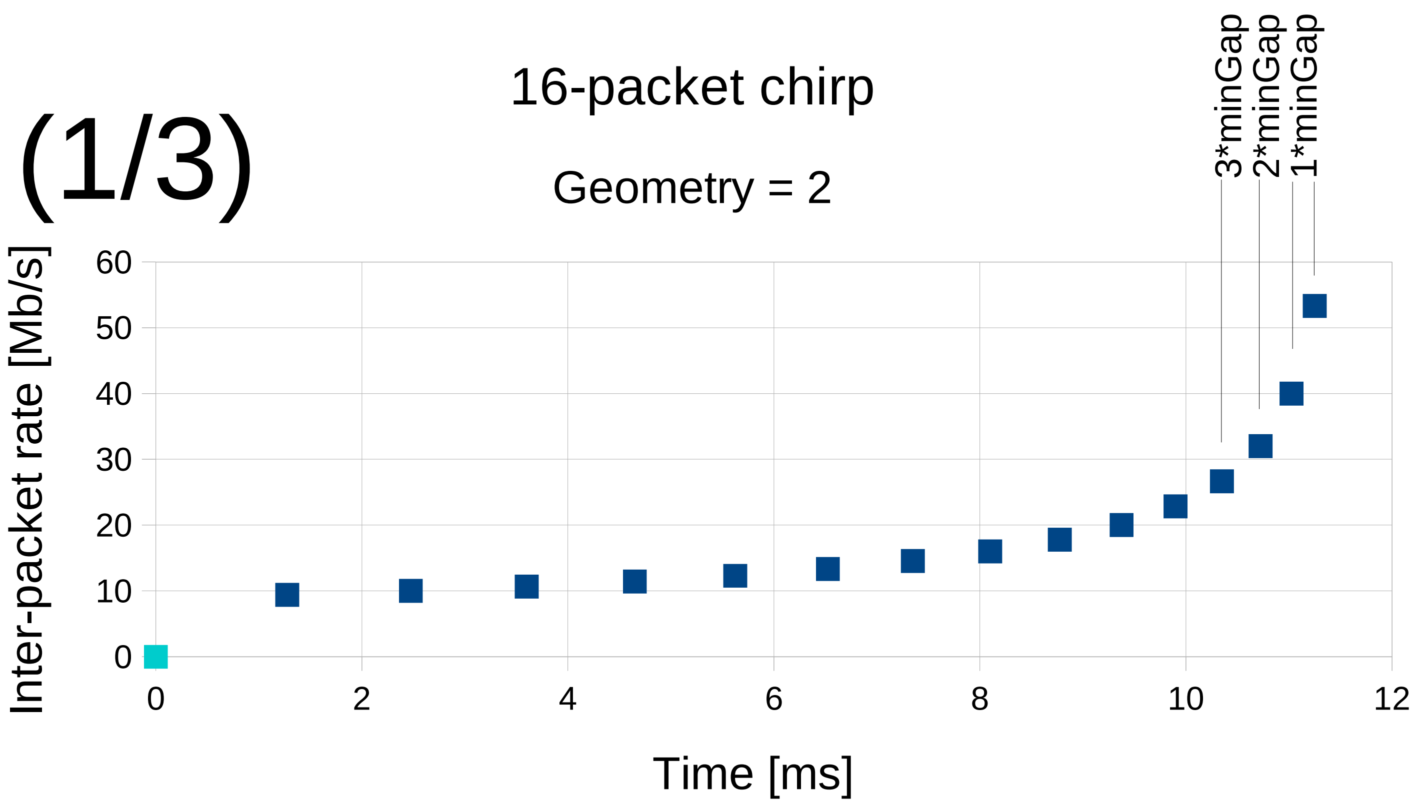
- Queuing Impact
    - excellent

- Implemented
    - kernel module and modified the API to pacing in linux kernel
    - still only one outstanding timer per connection
- But not tested to extremes





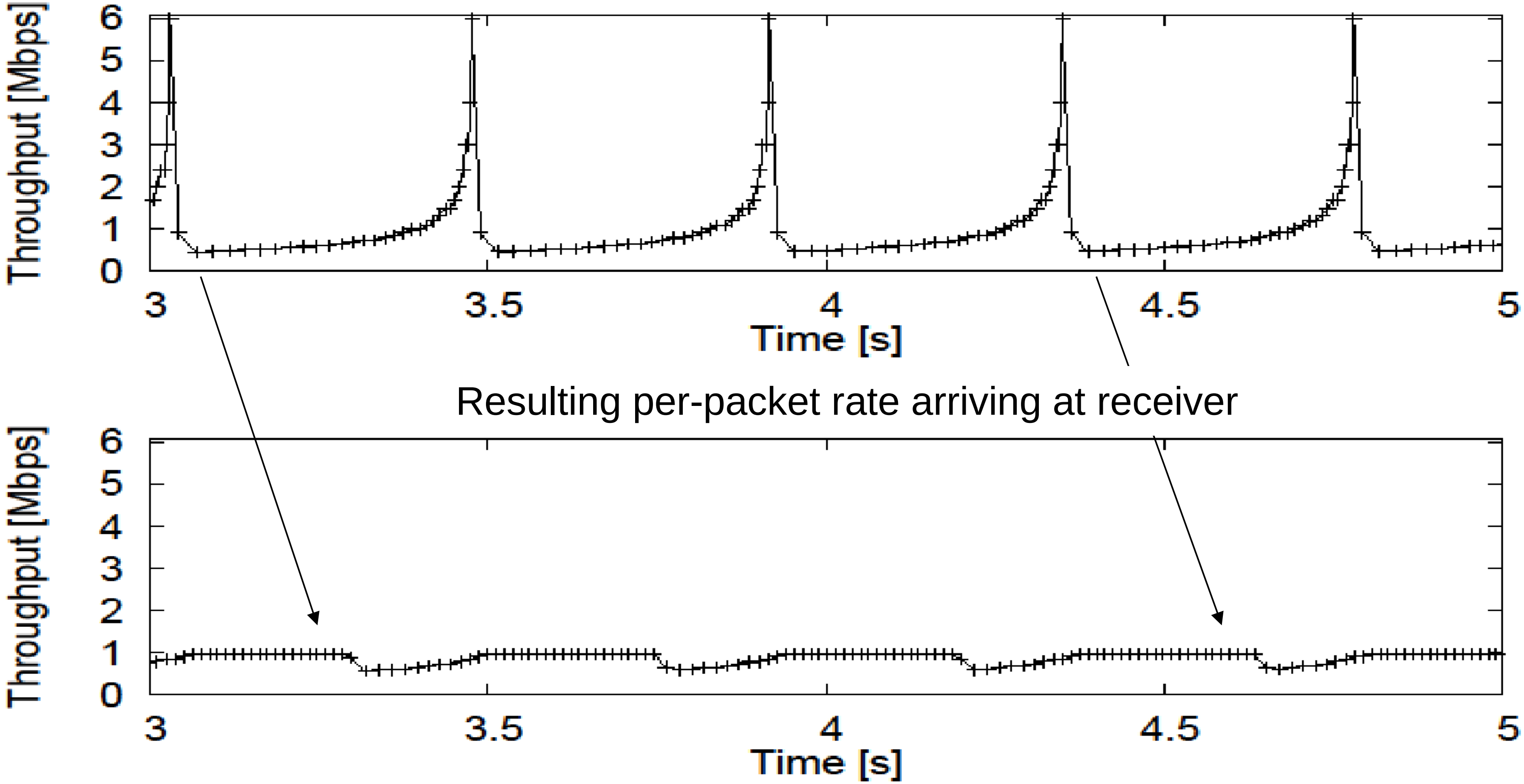
Approach (1/3)



- Packet chirps
    - continually pulse queue by a few packets, then relax
- Samples available (and max) capacity
    - available: rate where ACKs spread from sent pattern (after filtering noise within chirp)
    - max: ACK rate of last 2 packets
- Maximizes ratio of capacity-information-rate to harm (queue delay)
    - run each (per chirp) meaasurement through EWMA

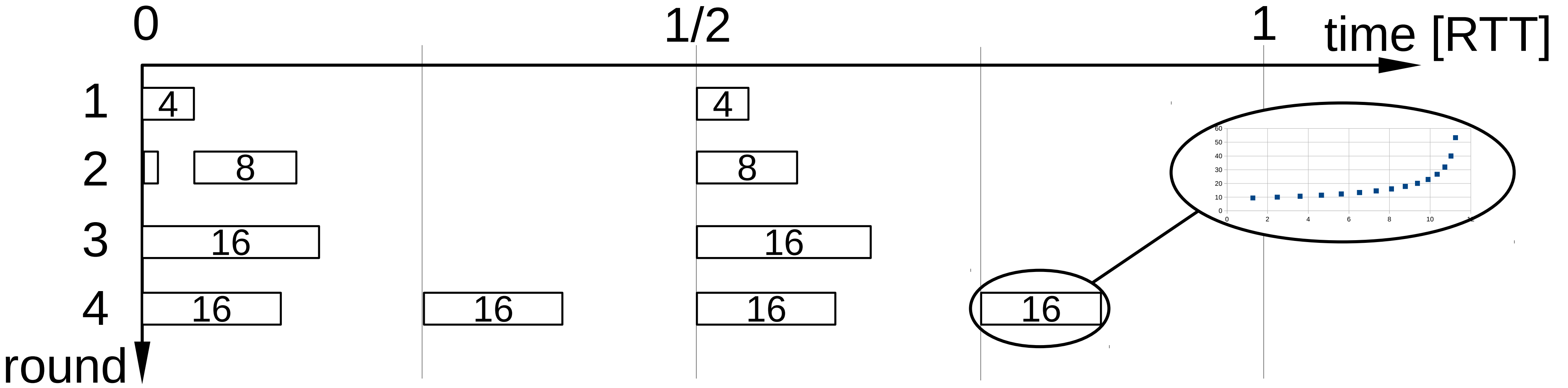
Using chirps to measure available capacity

Per-packet rate leaving sender



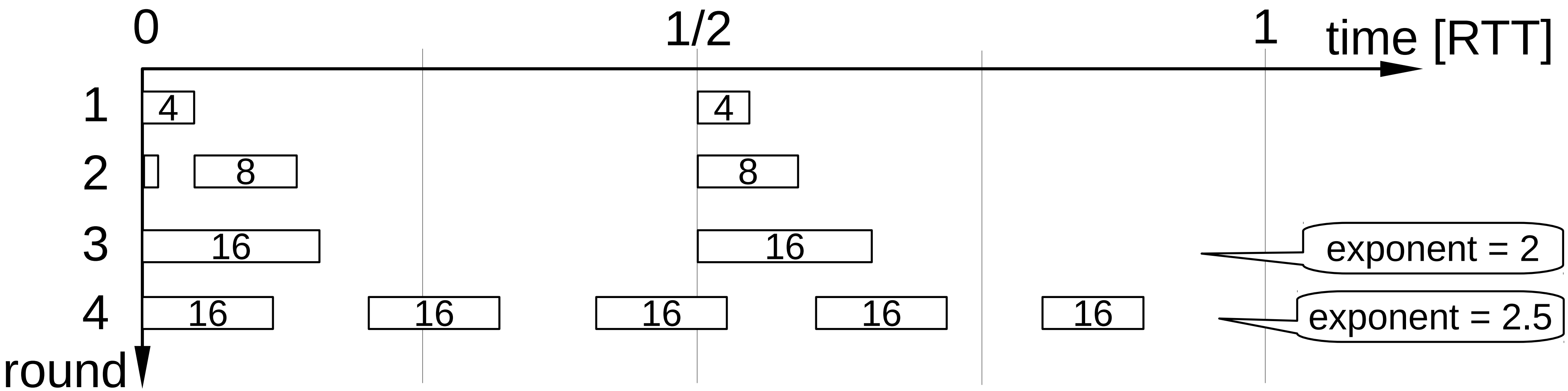
- This example measures constant available capacity
  - Code to interpret chirps filters noise to measure varying available capacity

Approach (2/3): paced chirps



- Avg rate of each chirp depends on EWMA of available capacity measured in previous rounds
- Noisy, but increasingly frequent measurements
- Queue delay solely depends on chirp geometry
- Notice, chirp length reduces
  - as available capacity measured in last round increases

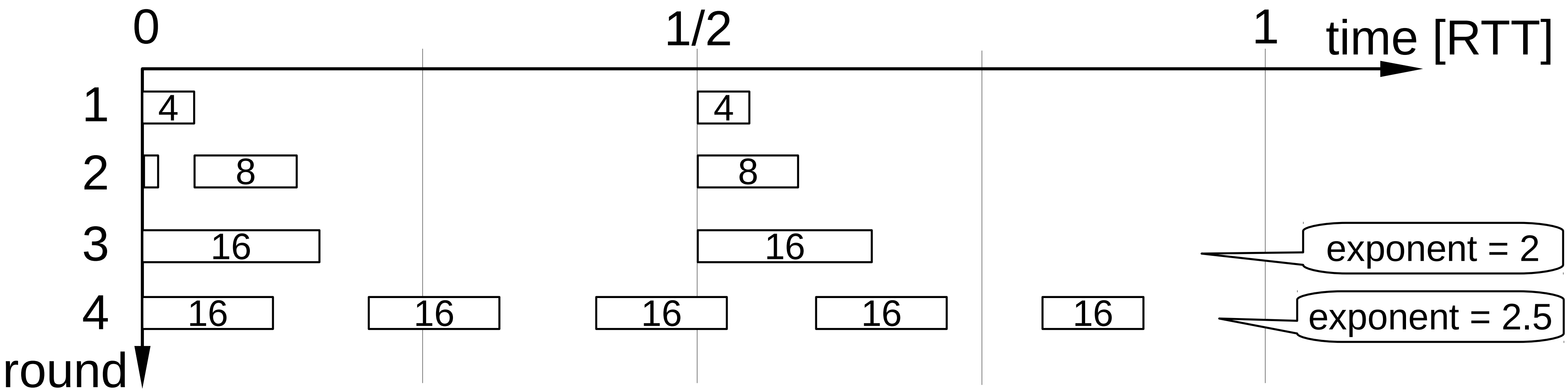
Approach (3/3): adaptive gain



- Growth in #chirps per RTT depends on a gain variable
  - vary gain dependent on stability of available capacity samples
- Push-in a little harder than available capacity grows:
  - other flows yield
  - activity-triggered link scheduler expands per-user capacity
- When shift from paced chirps to ACK clocking?
  - when chirps fill the round trip
  - or …? (to be determined, perhaps using ECN for extra precision?)

Still, queue delay solely depends on chirp geometry, not gain

Approach (3/3): adaptive gain



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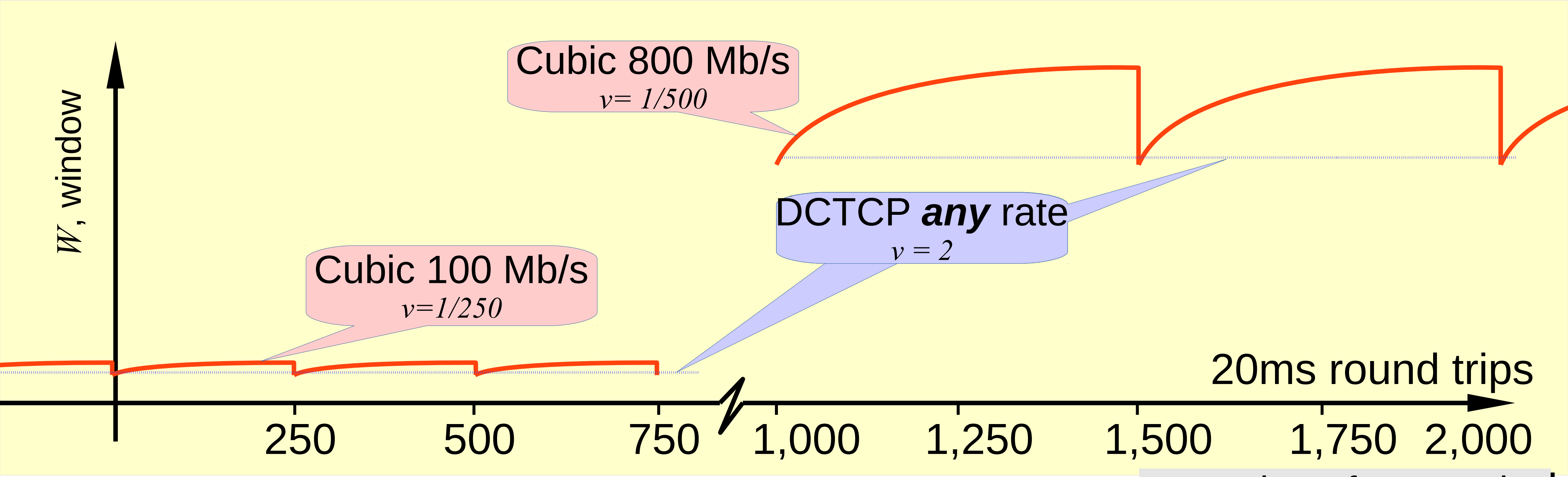
Caveats

- Delayed ACKs & ACK thinning
    - we need rcvr to suppress delayed ACKs during SS
    - Linux rcvr quickacks during SS - detected heuristically
        - but our modified start-up phase confuses its heuristics
    - sender could request quickacks with a 1-bit option
  - Could put arrival times in ACKs (as in QUIC)
- Bursty MACs and schedulers
    - Our initial experiments are with simple Ethernet
    - Shared upstream links (LTE, DOCISIS, GPON) all time-slotted
    - Averaging within chirps designed to cope, but may need tweaking
    - EWMA designed to cope with numerous noisy measurements

Closing the loop

- Paced chirps: not just for slow-start
  - for whenever the closed loop signal is lost
- With Scalable CC, e.g. TCP Prague, DCTCP, etc.
  - after **1 round trip** without marks
  - start paced chirps to rapidly find new operating point



- Takes a lot longer with an unscalable CC
  - e.g. **500-1000 round trips** for Cubic at 800Mb/s

v : number of congestion signals per round trip

Why two phases?

1) Start-up:
    - paced chirping
2) Steady state:
    - regular congestion avoidance, preferably scalable
      (e.g. DCTCP, TCP Prague, Relentless, Scalable TCP)

- Benefit of not chirping in steady state
    - using ACK clock reduces timer burden on servers
      (large majority of packets are sent in steady state)
    - cuts out noise
      (each chirp is a signal for the sender, but noise for other flows)

Further Work Needed

- Research
  - Termination condition – when to stop pushing in
  - Improving noise filtering & precision of chirps
    - esp. for bursty MACs: LTE/5G, DOCSIS, GPON
  - Exploiting ECN if available
  - Initial avg. gap for a wide range of possible networks
  - Evaluation over much wider range of conditions & iterate design
    - much lower/higher BDP, hi as well as lo stat. mux. bottlenecks, etc.
- Engineering
  - handling loss, reordering during slow start
  - TFO when RTT estimate is stale in the first RTT
  - mimic QUIC's ACKS listing arrival times in other protocols

Summary

- TCP slow-start is mimicked in most transport protocols
    - an open loop phase characterized by arbitrary numbers
- Paced chirping
    - closes the open loop – frequent startup information
    - queue delay solely depends on geometry of each chirp, not pace of chirps
    - maximizes ratio: (capacity-information-rate / harm)
- Initial research
    - much more testing and development to do

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Q&A

and

Spare Slides

Measuring Available Capacity using Chirps

- Find inter-packet gap where path delay starts to persistently increase

1) Record each inter-packet path delay increase

   $\Delta q_n = q_n - q_{n-1}$

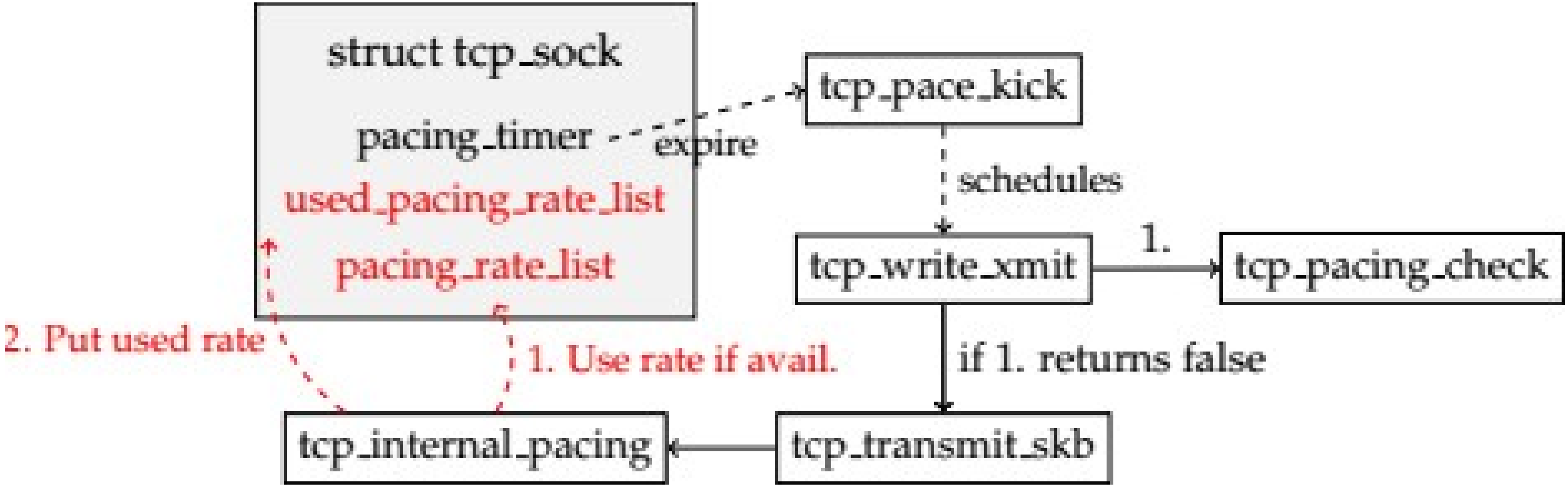
   where $q = ts_{rcv} - ts_{snd}$; ts are timestamps; and n is the packet number

2) Ideally one-way delay: timestamp each packet:
   - when sent (not when scheduled to send)
   - when received
     - in practice use when ACK rec'd (round trip delay)

3) Filter out noise. Simple example filter:
   - only count an increasing trend of more than L packets

     to count as an increase $\Delta q > \frac{max_{i=1}^{n}(\Delta q_i)}{F}$
   - default: $L=5, F=1.5$

Linux Pacing Framework



modifications in red

Linux kernel
Structure to set up per-packet rates