Flow-start: Faster and Less Overshoot with Paced Chirping

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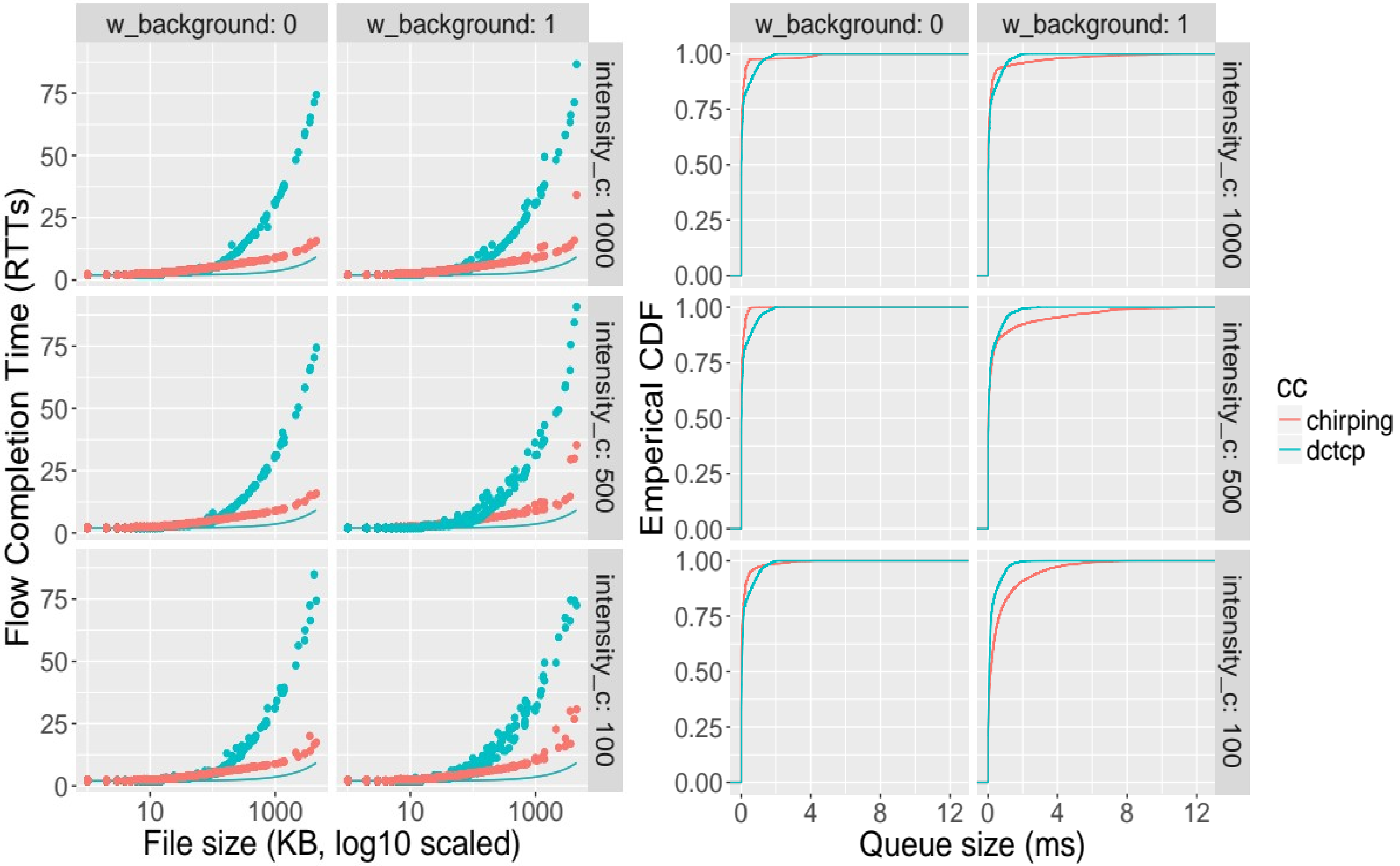
The Slow-Start Dilemma

- The more a flow accelerates
- The greater the overshoot of queuing delay
    - before the sender can notice one round trip later

- This is the received wisdom from slow-start in TCP
    - but it's a general dilemma for any capacity-seeking e2e transport:
- It's possible to sense when to stop earlier, using delay
    - but then it takes longer to converge (e.g. hybrid slow-start)

- Paced Chirping escapes this dilemma

Flow completion time and queue spike plots



- Intensity is mean flow inter-arrival time (Exp. distributed) [ms]

Applicability

- Solely delay-based, to be applicable to the Internet
  - cannot rely on special logic (AQM, ECN, etc.) at every possible bottleneck
- Most interesting where Q delay already ultra-low
  ('cos adds max 2-3ms[1] pulses to queuing delay already present):
  - low latency with congestion control like DCTCP
    isolated from Classic TCP, e.g.
    - Data Centre[2]
    - Internet with L4S DualQ Coupled AQM @bottleneck
- These are the environments we're interested in
  - but from limited testing it seems applicable to the general Internet too
  - try it for your environment – open sourced

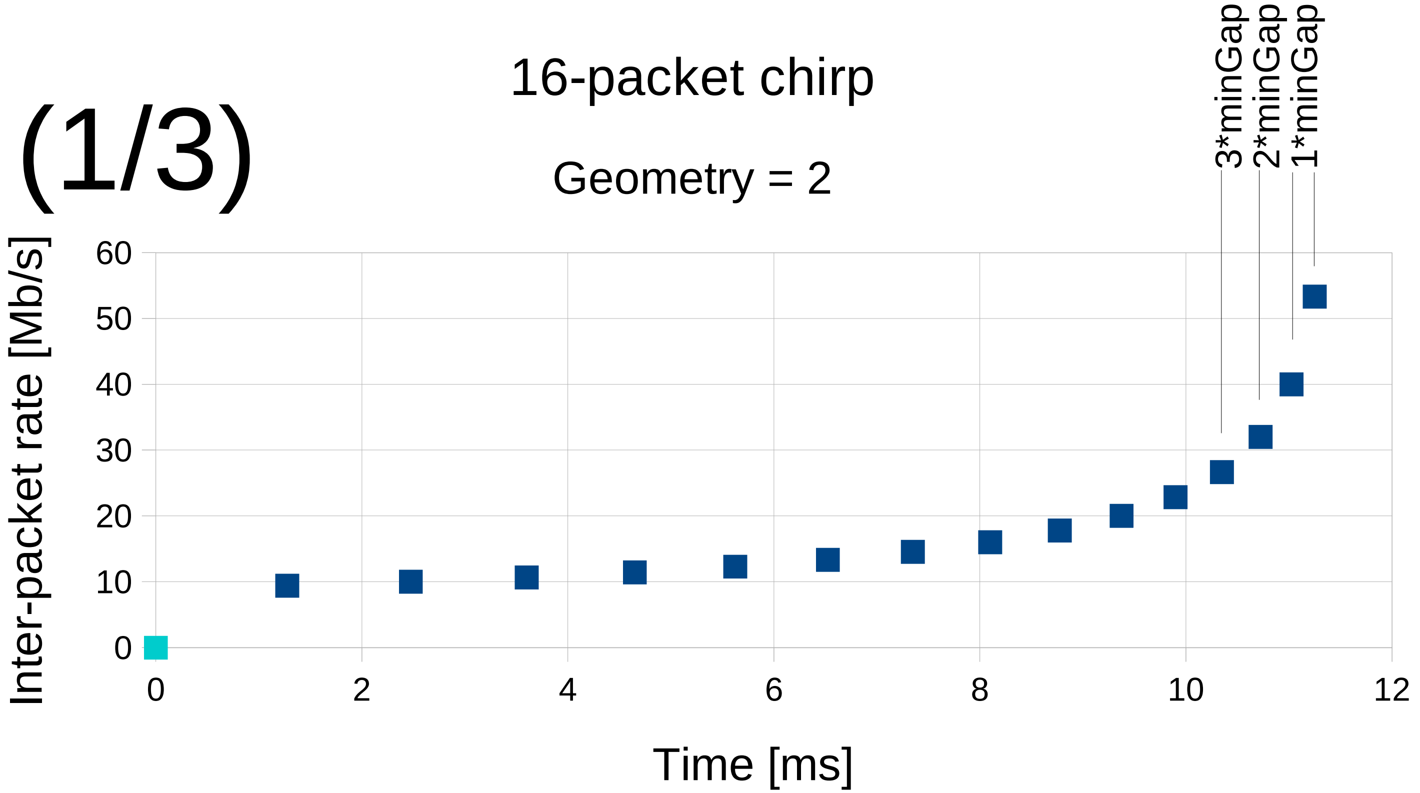
AQM: Active Queue Management
ECN: Explicit Congestion Notification
DCTCP: Data Centre TCP
L4S: Low Latency Low Loss Scalable throughput

[1] Over a 20ms base RTT path at 120Mb/s
[2] Can use shallow buffers without loss

Caveats

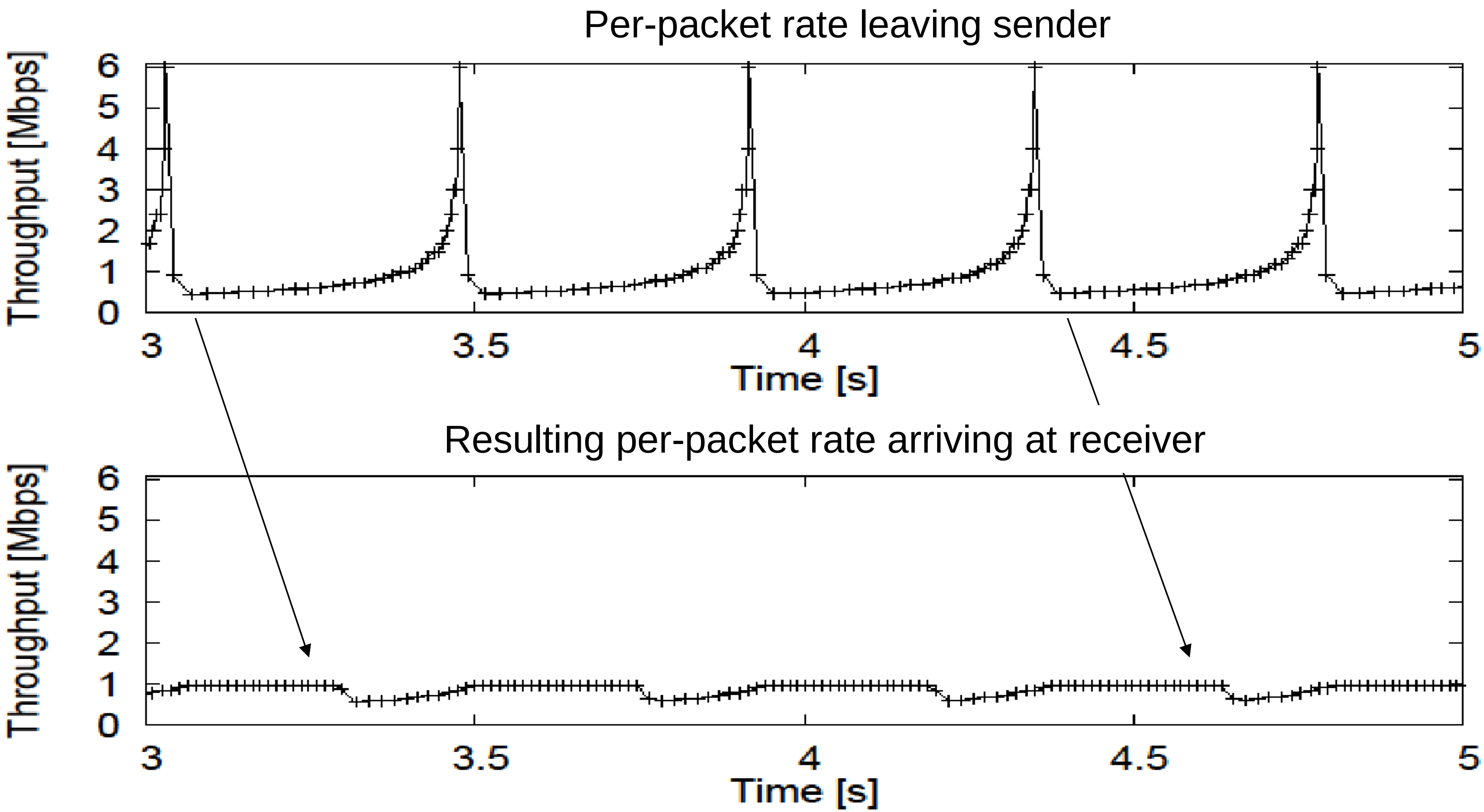
- This is research, not production-ready
- We've focused on proving the concept
- Many open issues for investigation / solution
  - Listed at end, but main ones are:
    1) Delayed ACKs & ACK thinning
    2) Bursty MACs and schedulers

Approach (1/3)



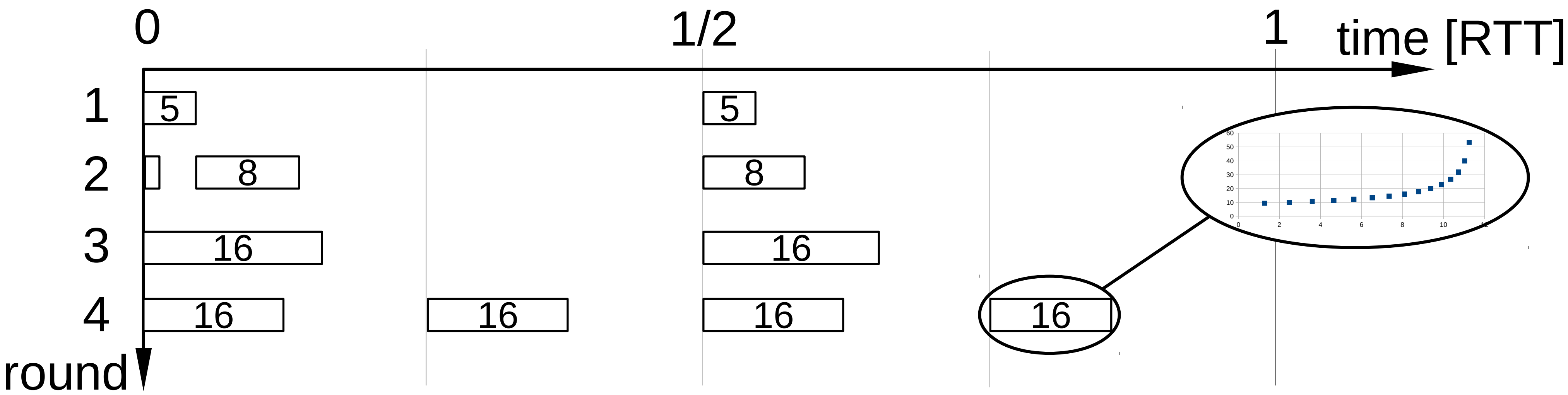
- Packet chirps
  - continually pulse queue by a few packets, then relax
- Samples available (and max) capacity
  - available: rate where ACKs spread from sent pattern (see next slide) (after filtering noise within chirp)
  - max: ACK rate of last 2 packets
- Maximizes ratio of capacity-information-rate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

Using chirps to measure available capacity



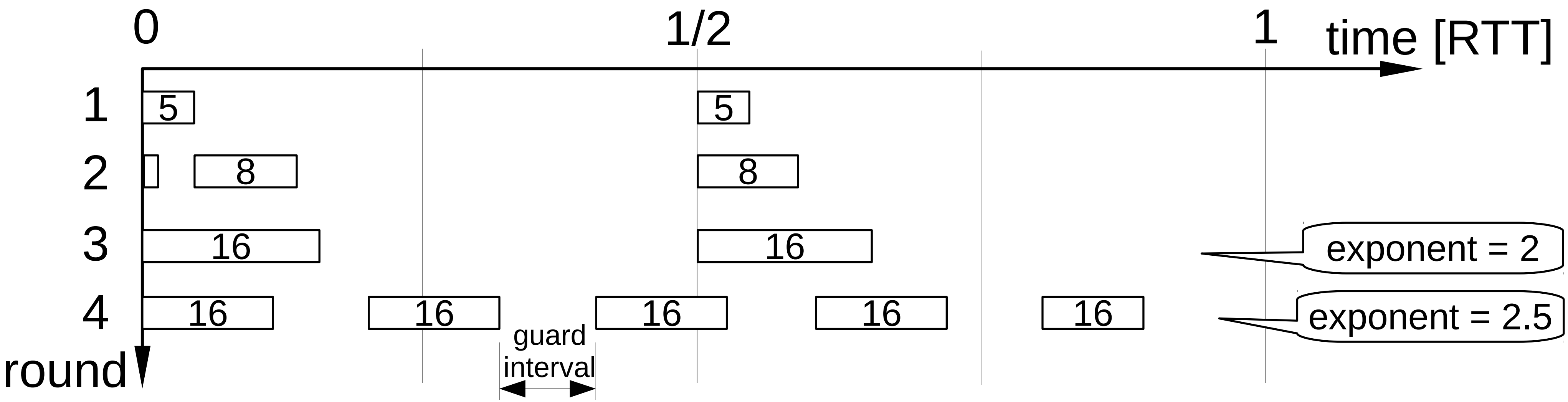
- This example measures constant available capacity
  - Code to interpret chirps filters noise to measure varying available capacity

Approach (2/3): paced chirps



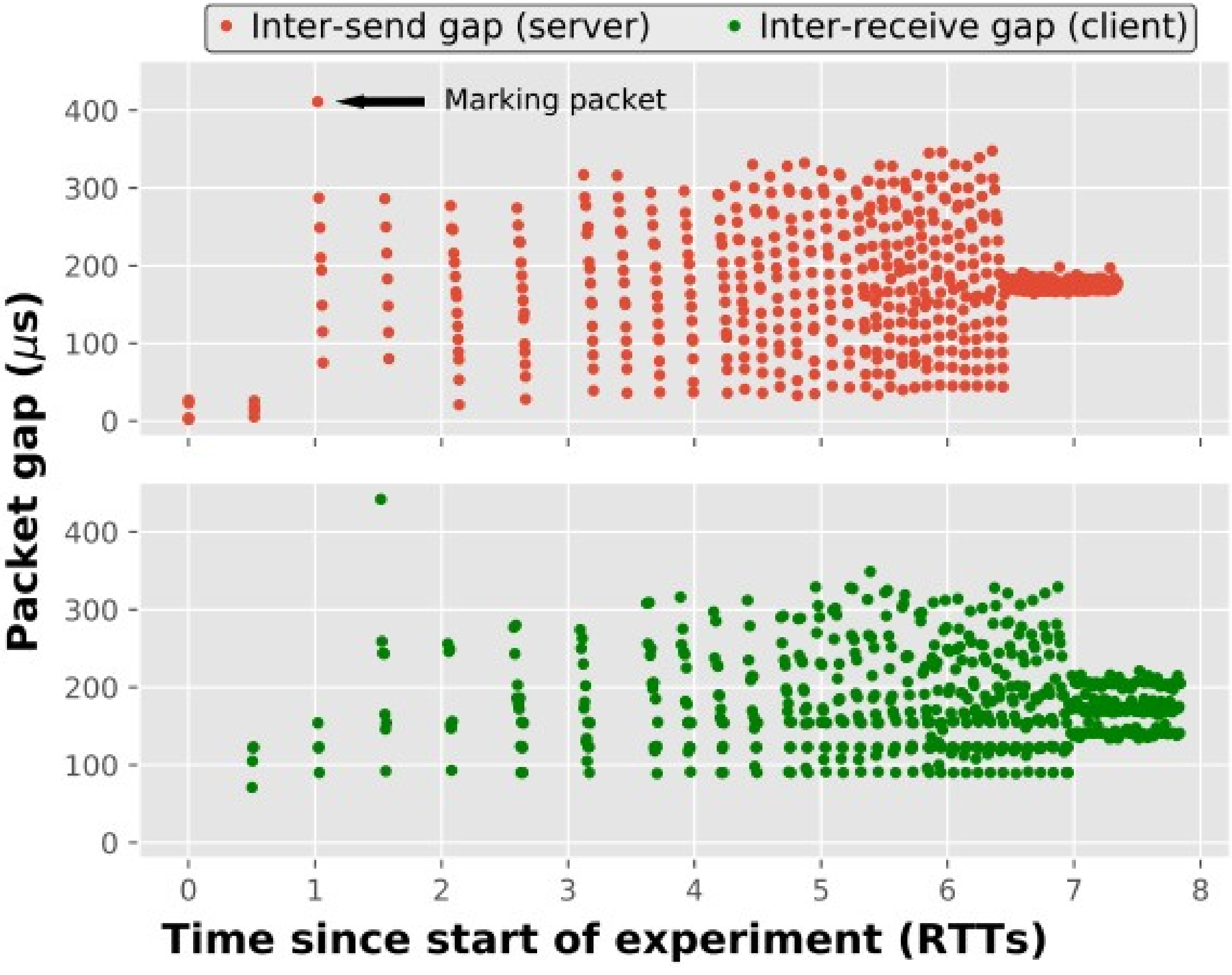
- Avg rate of each chirp depends on EWMA of available capacity measured in previous rounds
- Noisy, but increasingly frequent measurements
- **Queue delay solely depends on chirp geometry**
- Notice, chirp length reduces
  - as available capacity measured in last round increases

Approach (3/3): adaptive gain



- Growth in #chirps per RTT depends on a gain variable
  - the more stable the measurements, the more gain increases (squeeze guard interval)
- Push-in a little harder than available capacity grows:
  - other flows yield
  - goal: activity-triggered link scheduler expands per-user capacity
- **Still, queue delay solely depends on chirp geometry, not gain**
- When to shift from paced chirps to ACK clocking?
  - when chirps fill the round trip
  - or …? (to be determined, perhaps using ECN for extra precision?)

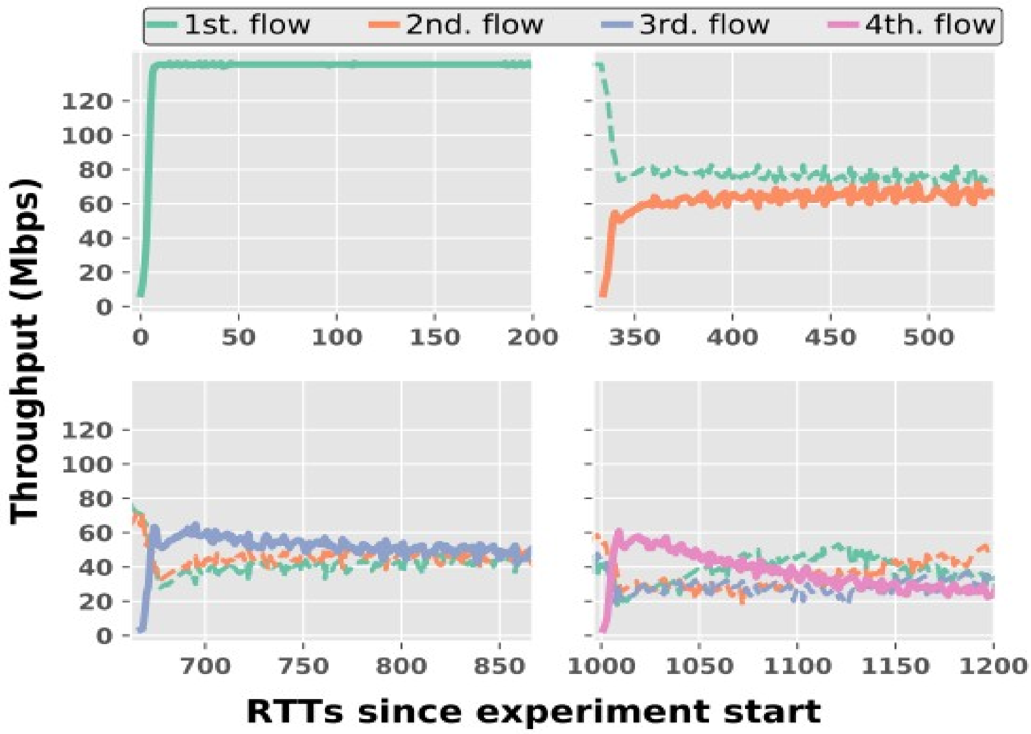
A Whole Short Flow

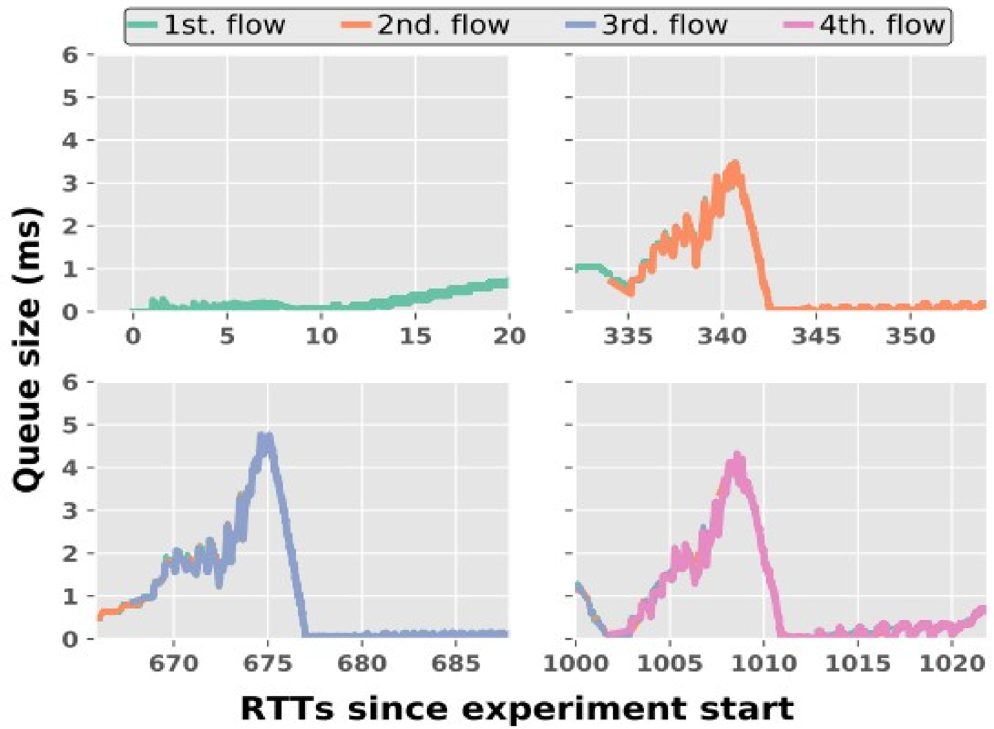


- Inter-receive gap measured at sender using ACKS

Outcome

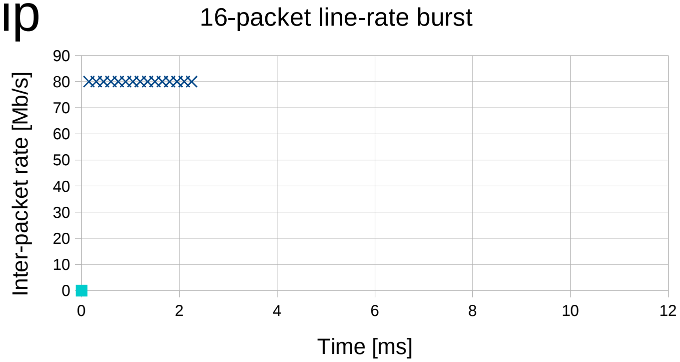
- Fast convergence
- Low queueing delay



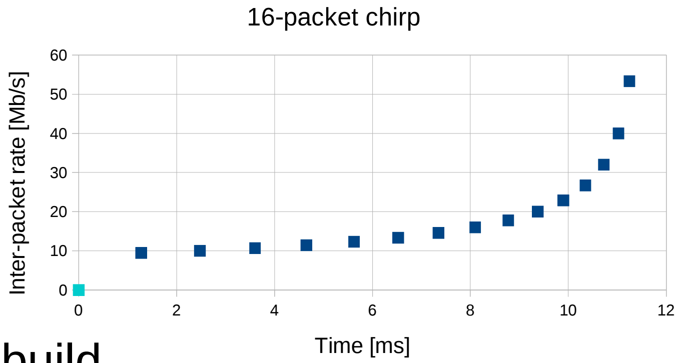


Discussion

- Slow Start vs. Pacing – 2 extremes:
  - sending 2 pkts per ACK is a great way to build a queue
  - pacing at constant rate, increasing each round trip
    - if slightly below capacity:
      a great way to get no info about capacity at all
    - if slightly above capacity:
      a great way to build a huge queue



- Line-rate Burst vs. Chirp
  - chirp measures available capacity (and max)
  - ACK-rate from a burst only measures max capacity



- Intuition
  - chirp fits increasing amount between existing pkts,
    and measures its ACK-rate when a queue started to build
  - burst squeezes as much as possible between existing packets,
    and its ACK-rate measures how fast the resulting queue drained

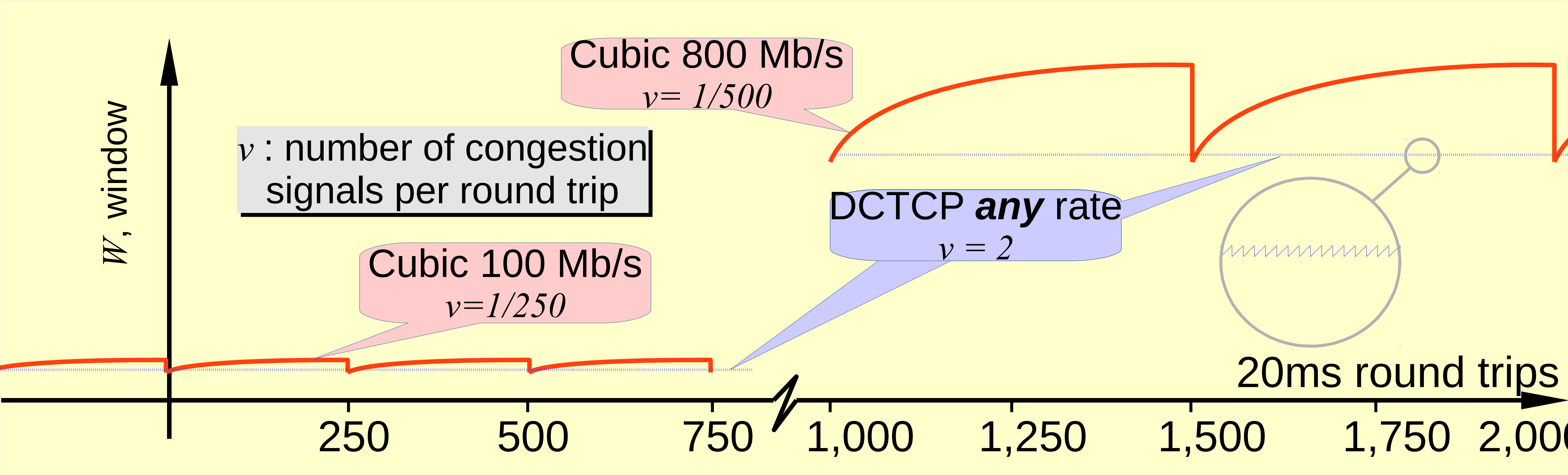
Where Paced Chirping Fits (1/2)

- No need to chirp during stable periods of congestion avoidance
  - each chirp is a signal for the sender, but noise for other flows
    - chirping elephants just confuse mice
  - using ACK clock reduces timer burden on servers
    (large majority of packets are sent in steady state)

- So, goal of paced chirping: “Do one thing and do it well”
  - reach smooth transition to closed loop (ACK-clocking, ECN, etc.)

Where Paced Chirping Fits (2/2)

- A building block, to replace all the instances of open loop capacity seeking:
  - flow start
  - re-start after idle
  - when congestion avoidance goes open-loop,
    e.g. another flow ends, radio capacity increases
- Future work: with Scalable CC, e.g. TCP Prague, DCTCP, etc.
  - after **2 round trips** without ECN-marks
  - start paced chirps to rapidly find new operating point
- Infeasible with unscalable CC, e.g. **500-1000 round trips** for Cubic @800Mb/s



Much 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
  - Delayed ACKs & ACK thinning
  - Handling loss, reordering during slow start
  - TFO when RTT estimate is stale in the first RTT
  - Apply the idea from QUIC where a stretch ACK lists arrival times

Design Contributions (1/2)

- Queue is independent of scale
  - depends solely on geometry of chirp, not on pkts per RTT
- Achieved by the guard interval betw. each chirp
  - if estimate of available capacity were perfect
    - back-to-back chirps should build a few pkts of Q, then relax it
  - guard interval allows for error in the estimation
    - the more consistent available capacity measurements are
    - the faster the guard-interval can shrink
    - and the faster the congestion window can grow

Design Contributions (2/2)

- Paced chirping is continually crafting the packets it sends
  - around its measurements in previous rounds
  - while allowing for the possibility of change and error
- It is simultaneously
  - evolving its estimate of available capacity
  - sending packets at a spread of rates around this
  - sampling at multiple points across each round trip time
  - pushing back possible competing traffic
  - tracking variability of its measurements
  - reducing its guard interval accordingly
  - and therefore increasing its window
- Paced chirping shrinks the measurement-response loop
  - it makes flow-start closed-loop

Contributions to Experimentation

- Open sourced
  - github.com/JoakimMisund/PacedChirping
- Implementation in Linux
  - based on internal pacing in 4.13 kernel (earliest with internal pacing)
  - added kernel support for list of inter-packet times
  - paced chirping kernel module
- Advice on how to suppress certain kernel assumptions
  - disabled kernel pacing rate calculation
  - made it possible to hide CE marks from the TCP stack
- Published initial evaluation
  - "Rapid Acceleration in TCP Prague", Masters Thesis of Joakim Misund (University of Oslo) (May 2018).

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
  - Aims to maximize ratio: (capacity-information-rate / harm)
- Initial research
  - much more testing and development to do

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Q&A

and

Spare Slides

Delayed ACKs & ACK thinning

- Could put arrival times in ACKs (as in QUIC)
- Could introduce a 1-bit option for sender to request quickacks
- Failing either, we need rcvr to suppress delayed ACKs during SS
    - Linux rcvr quickacks during SS
    - but paced chirping confuses its heuristics

Measuring Available Capacity using Chirps

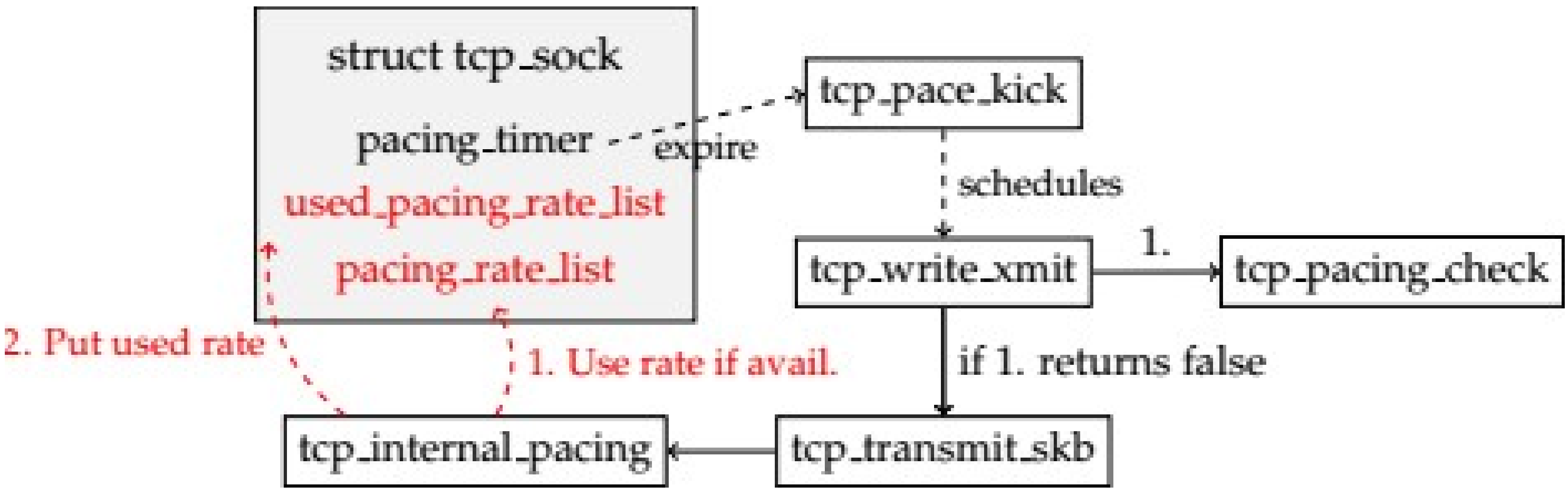
- Find inter-packet gap where path delay starts to persistently increase
  1) Record each inter-packet path delay increase

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

     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

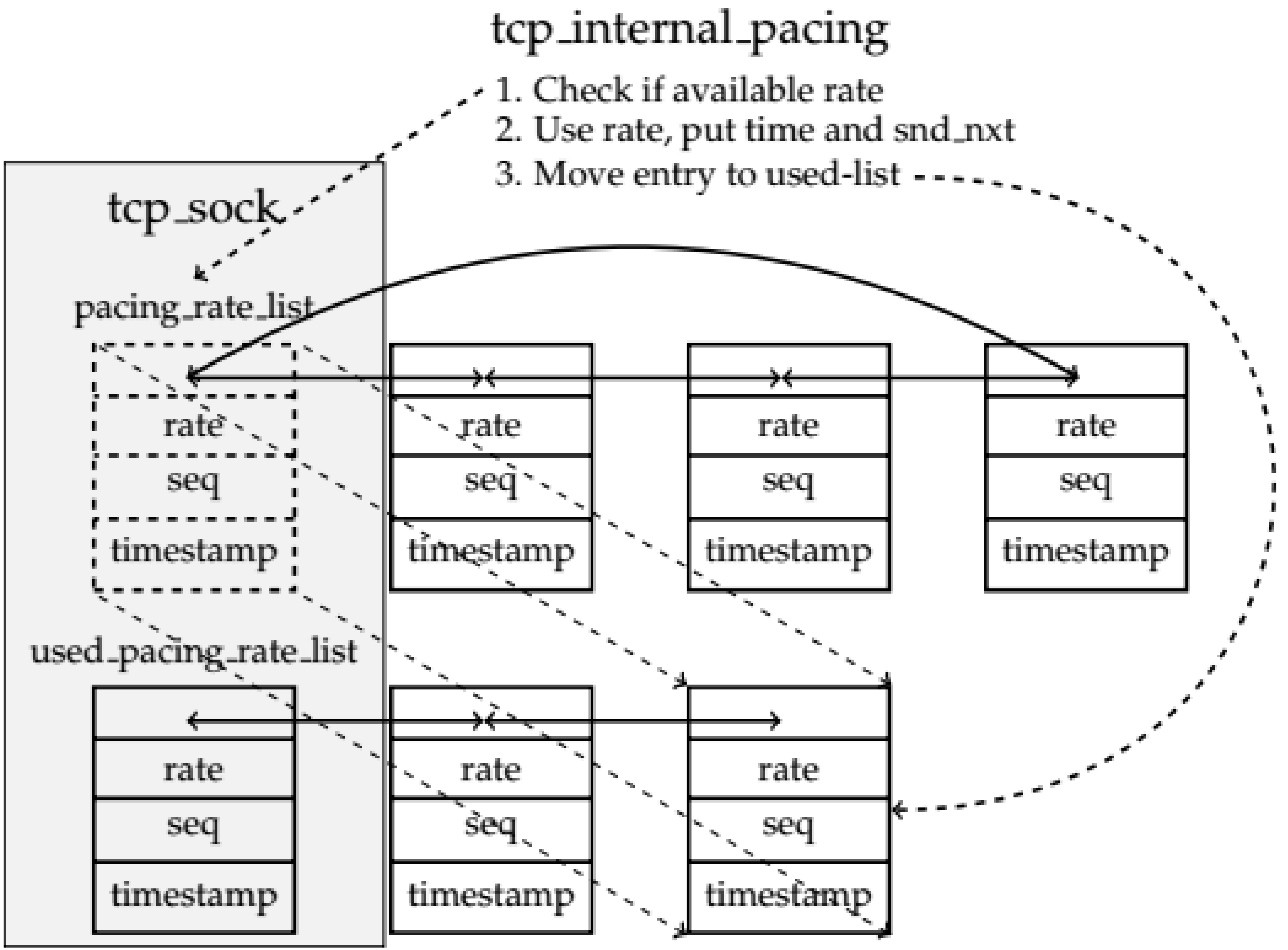
       to count as an increase, $\Delta q > \frac{max_{i=1}^{n}(\Delta q_i)}{F}$
     - default: $L=5, F=1.5$

Linux Pacing Framework

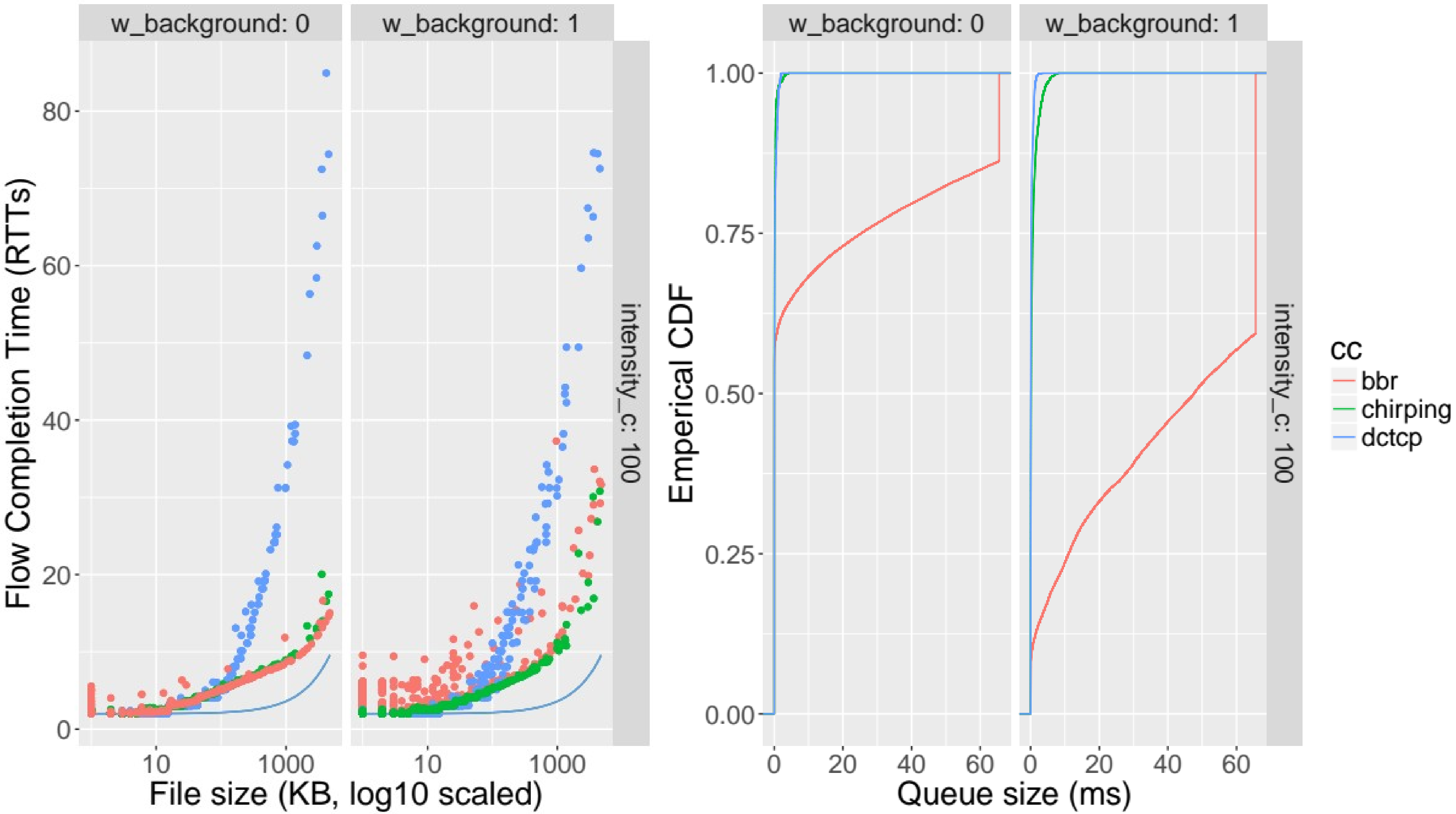


modifications in red

Linux kernel
Structure to set up per-packet rates



Escaping the Slow-start dilemma



- Probably broken version of BBR over v4.13 kernel

Higher intensity;

Paced Chirping needs a better termination condition