# Chirping for Congestion Control - Implementation Feasibility

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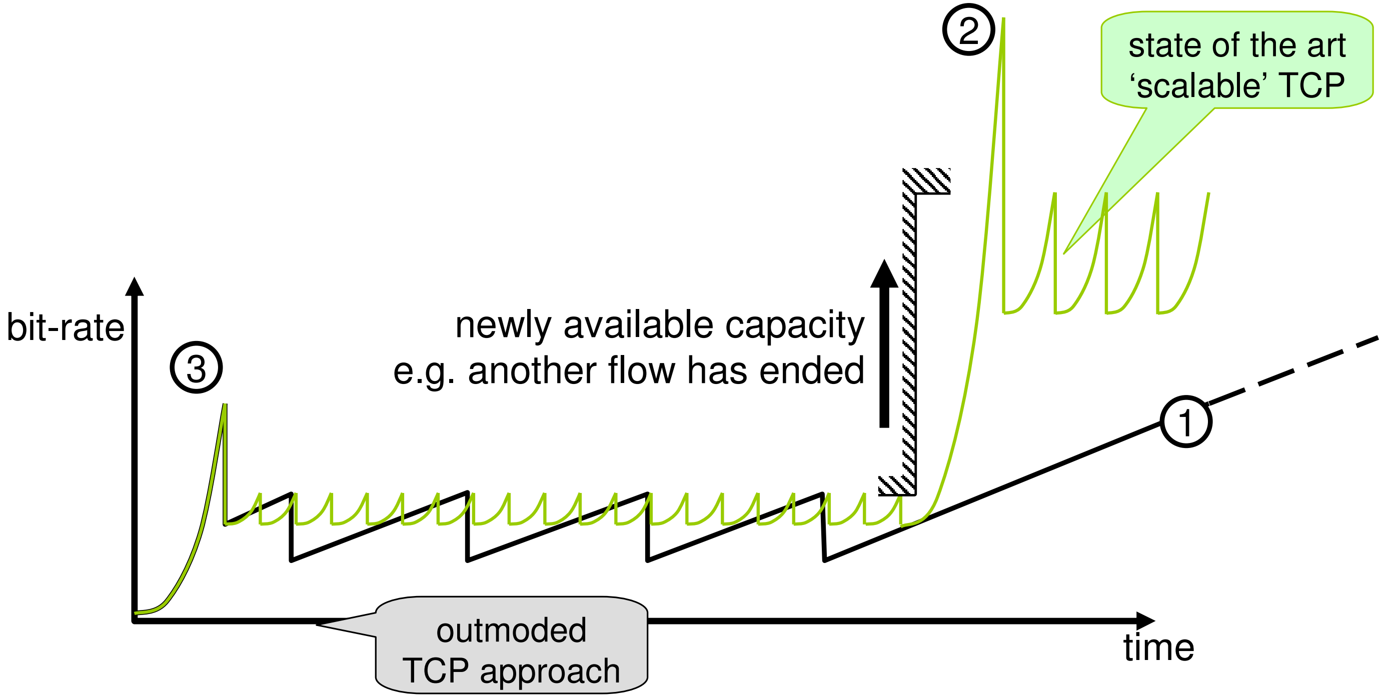
# Overview

- Motivation
- Chirping as a Building Block for Congestion Control
- A Chirping Implementation in the Linux Kernel
- Preliminary Results
- Conclusion and Outlook

# Motivation

## Scaling Problem

1. Original TCP acquires new bandwidth too slowly
2. State-of-the-art approaches overshoot instead
3. Overshoot causes a lot unnecessary congestion




→ Chirping can provide fast feedback information for appropriate congestion control!

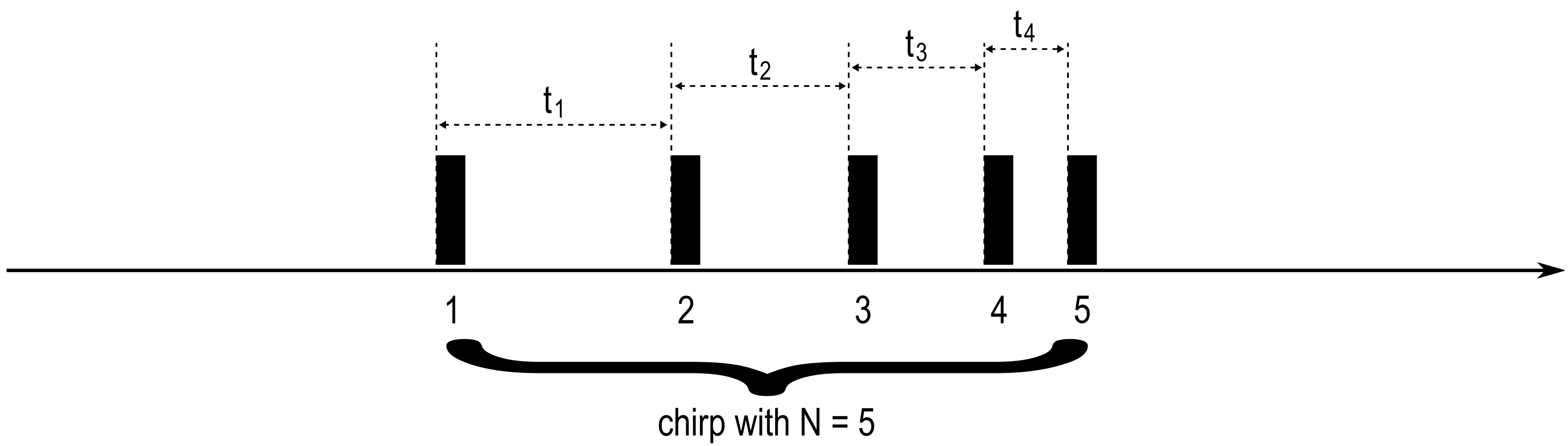
→ But is an implementation of chirping in an real OS feasible?

# Chirping

## *Principle*

**Chirp:** A group of several packets with decreasing inter-packet gaps and increasing rate

– Proposed by pathChirp bandwidth estimation tool [1]




- Bandwidth estimation based on self-induced congestion
- Feedback for monitoring of one-way delay

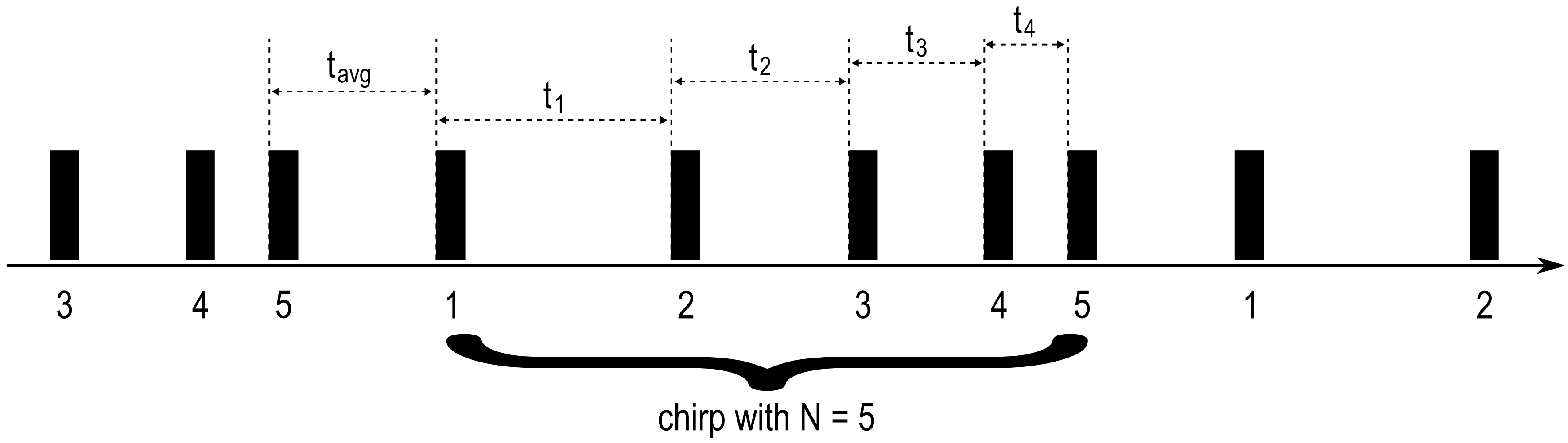
[1] V. Ribeiro, R. Riedi, R. Baraniuk, J. Navratil and L. Cottrell. "pathChirp: Efficient Available Bandwidth Estimation for Network Paths". Passive and Active Measurement Workshop 2003

# Chirping

## *A Building Block for Congestion Control*

**Chirping for Congestion Control:** Continuous transmission of data packets as chirps

– proposed by RAPID congestion control [2]




- Average rate $r_{avg}$ should equal intended sending rate of congestion control
- Actual per-packet rates are lower and higher than $r_{avg}$

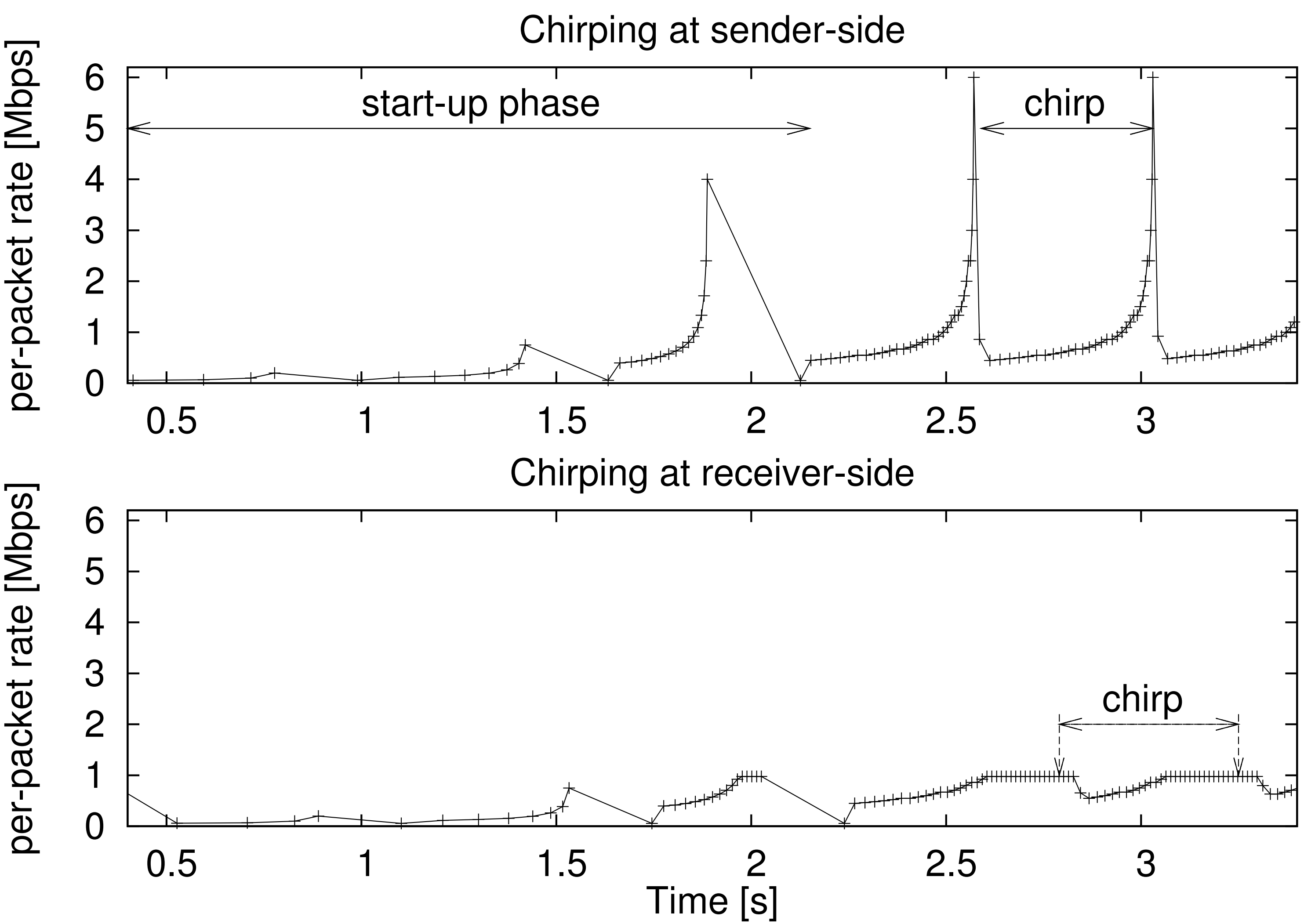
  → Probing for a wide range of possible sending rates but still limited impact of probing on other flows

[2] V. Konda and J. Kaur. "RAPID: Shrinking the Congestion-Control Timescale". In IEEE INFOCOM 2009

# Chirping

## *Preliminary Results*

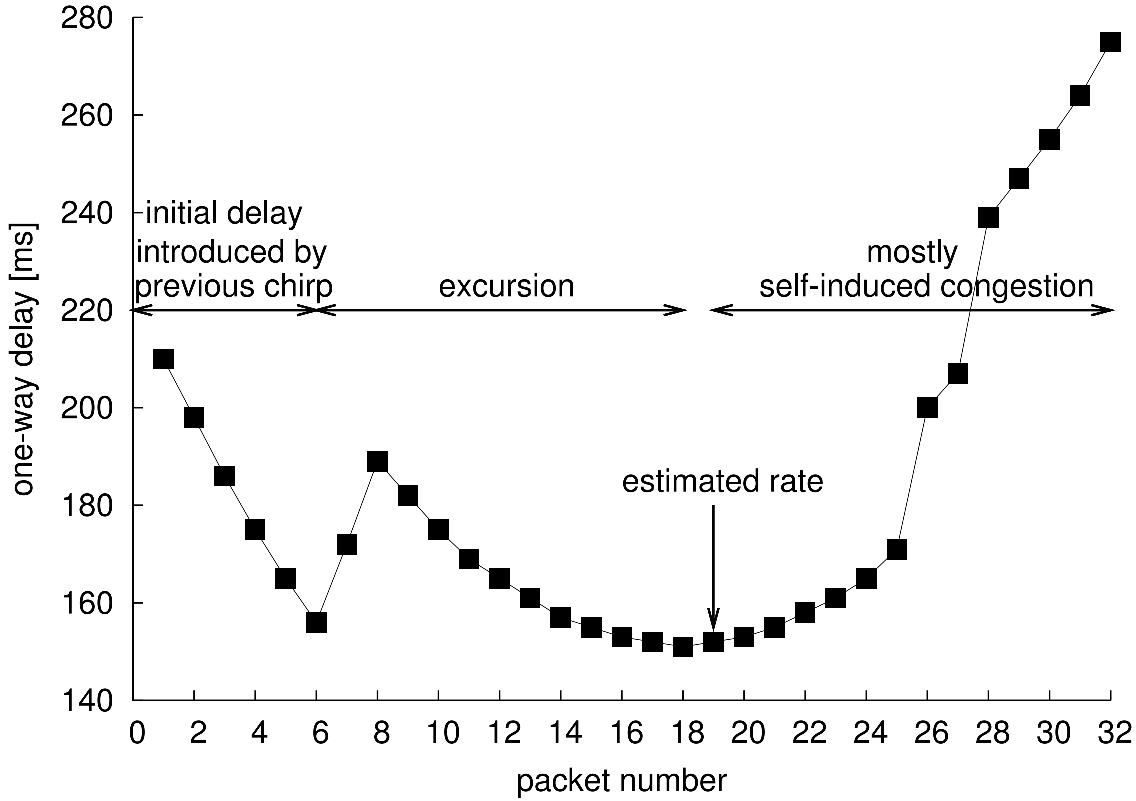
Per-Packet rate of one chirping connection on 1Mbit/s bottleneck link



# Chirping

## *Bandwidth Estimation based on relative One-way Delay*

**Bandwidth estimation:** Monitoring of the relative queuing delays




- Growth in queuing delay between packets: $\triangle q_n = q_n - q_{n-1}$

  → Increasing values at the end of reveals available capacity (*self-induced congestion*)

# Chirping Implementation in the Linux Kernel

## *Overview*

1. Feedback for one-way delay measurement:
   - Protocol extensions needed
   - Different solutions for deployment proposed
2. Rate estimation:

   Algorithm to evaluate the feedback information of one chirp based on pathChirp [1]
3. Rate adaption:
   - Congestion control algorithm evolves the average sending rate of the next chirp (using the available capacity estimated by a previous chirp)
   - CWND should also be updated to a value that allows the intended number of packets to be sent in one RTT
4. Inter-packet gap calculation:
   - Determined by the chosen average sending rate
   - Own algorithm in order to simplify kernel implementation to integer arithmetic

[1] V. Ribeiro, R. Riedi, R. Baraniuk, J. Navratil and L. Cottrell. "pathChirp: Efficient Available Bandwidth Estimation for Network Paths". Passive and Active Measurement Workshop 2003

# Chirping Implementation in the Linux Kernel

## *Sender-side Delay Measurement based on TCP Timestamps*

One-way delay measurement based on TCP Timestamp Option

```
+--------+--------+----------------------+----------------------+
|Kind=8  |   10   |    TS Value (TSval)  |TS Echo Reply (TSecr)|
+--------+--------+----------------------+----------------------+
    1        1               4                       4
```

→ Option header includes echoed timestamp of data packet and ACK timestamp

### Challenges

- TCP Timestamp Option does not ensure certain resolution
- Feedback needs to be assigned to one specific packet in a chirp (delayed ACKs?)
- Additional processing delay in the network stack

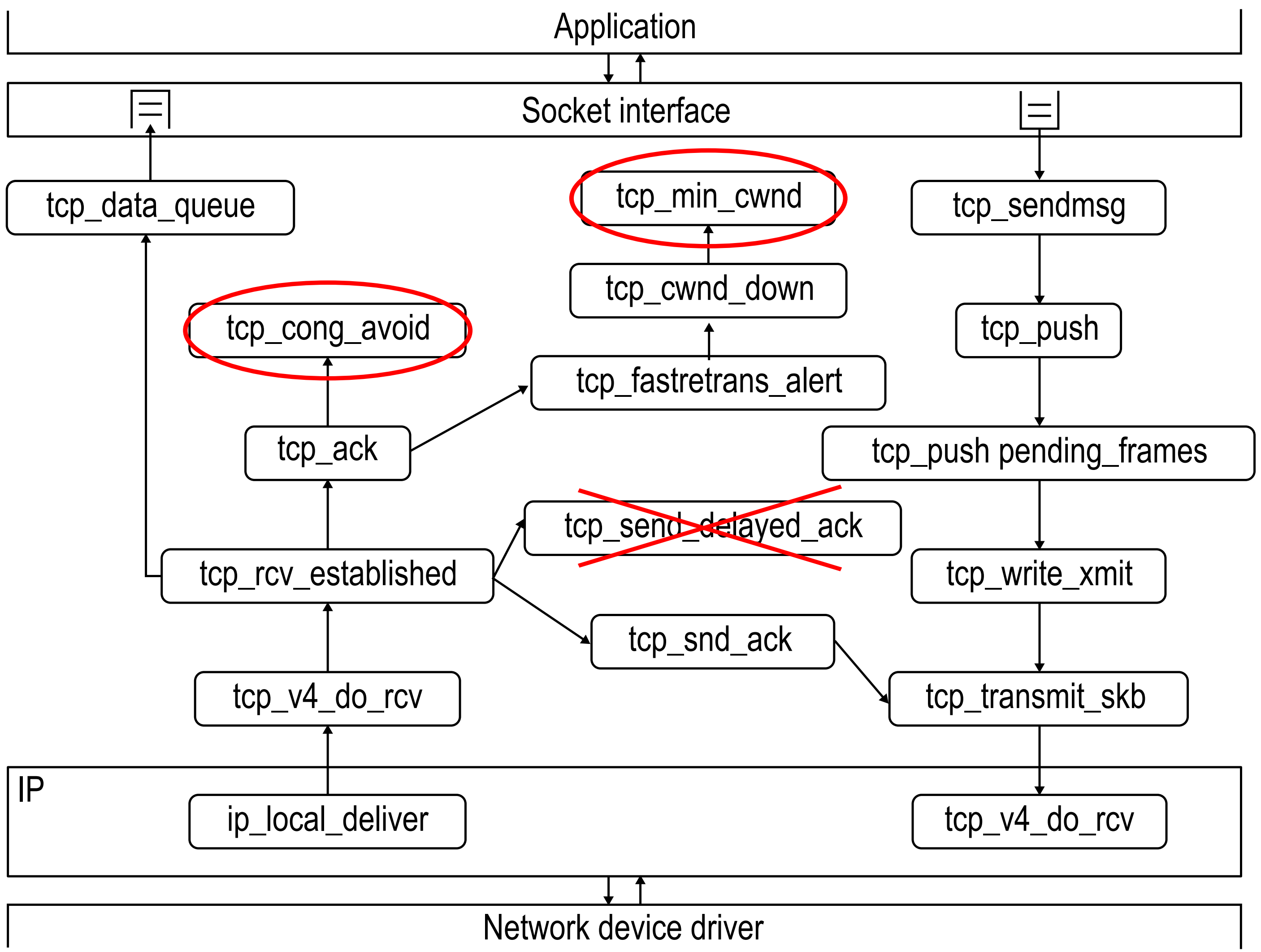
### Proposed Solutions

- Negotiation about the TCP receiver behaviour
- Chirp ID attached to packet header instead of state at sender
- Hardware time-stamping at send-out of data packet and ACK to improve accuracy
- Improved accuracy by use of the actual sending time gaps

# Chirping Implementation in the Linux Kernel

## *Implementation Structure*

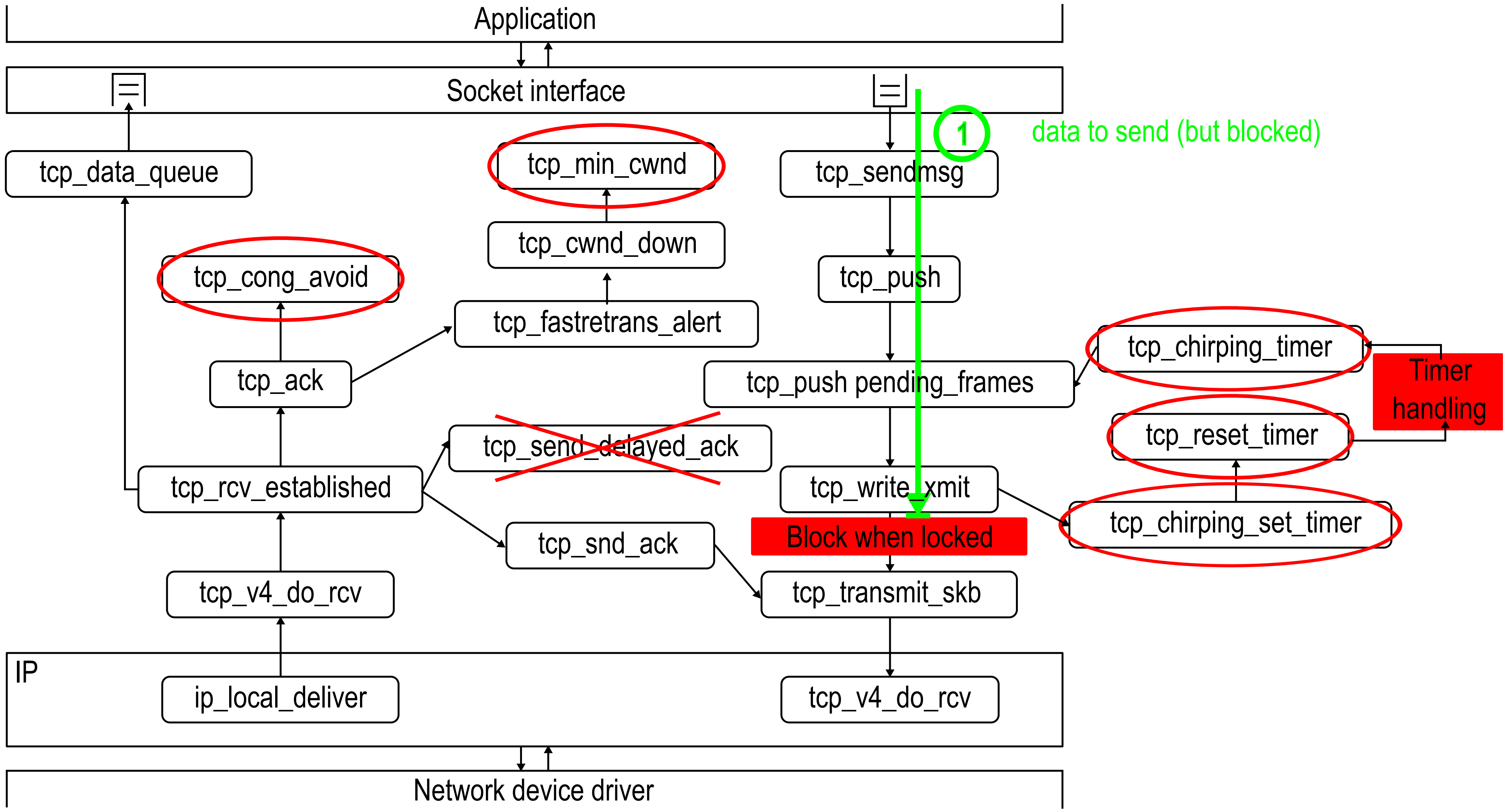
→ Extended congestion control kernel module interface and TCP timer for send-out timing



# Chirping Implementation in the Linux Kernel

## Implementation Details

→ Extended congestion control kernel module interface and TCP timer for send-out timing



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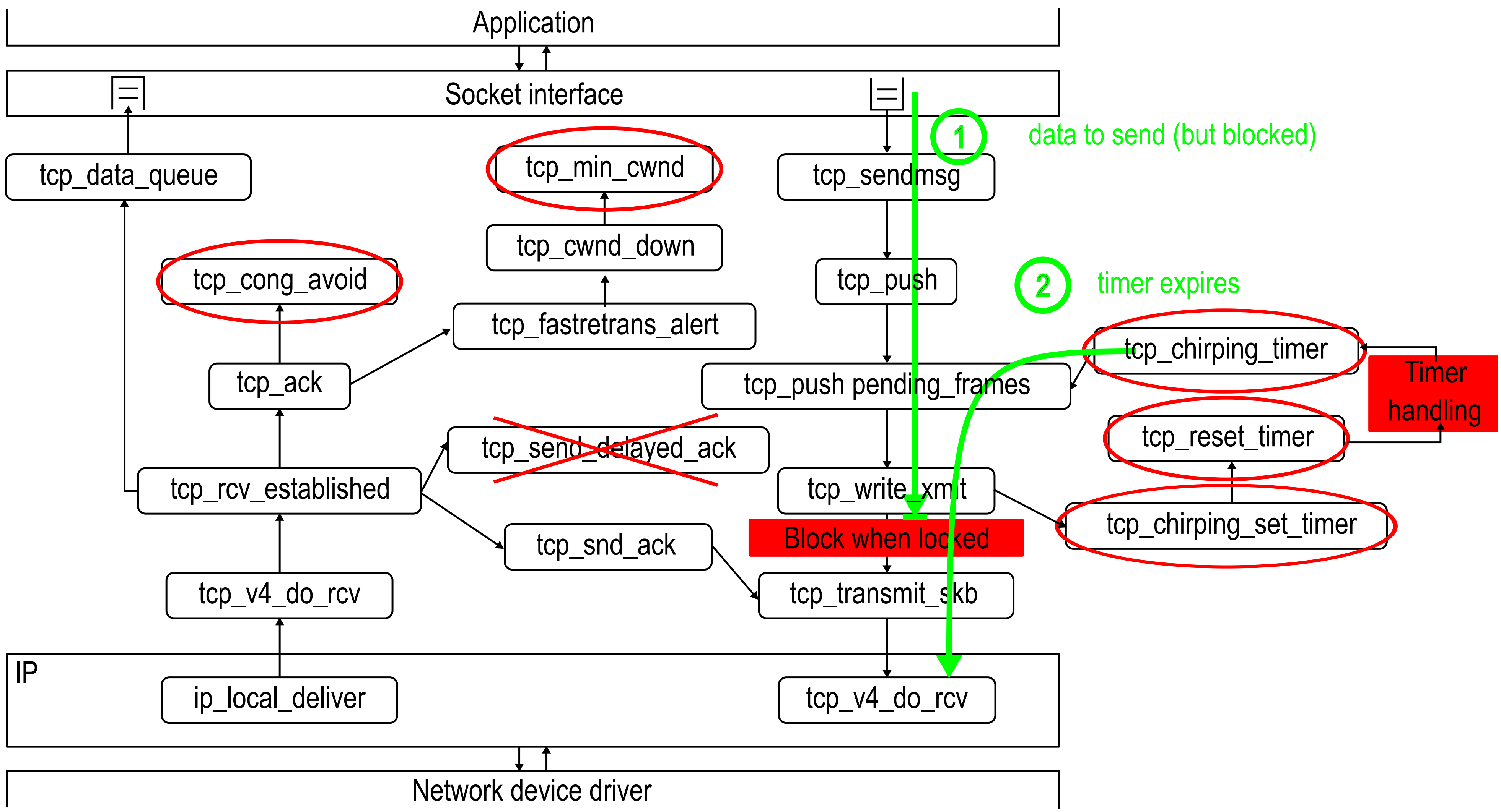

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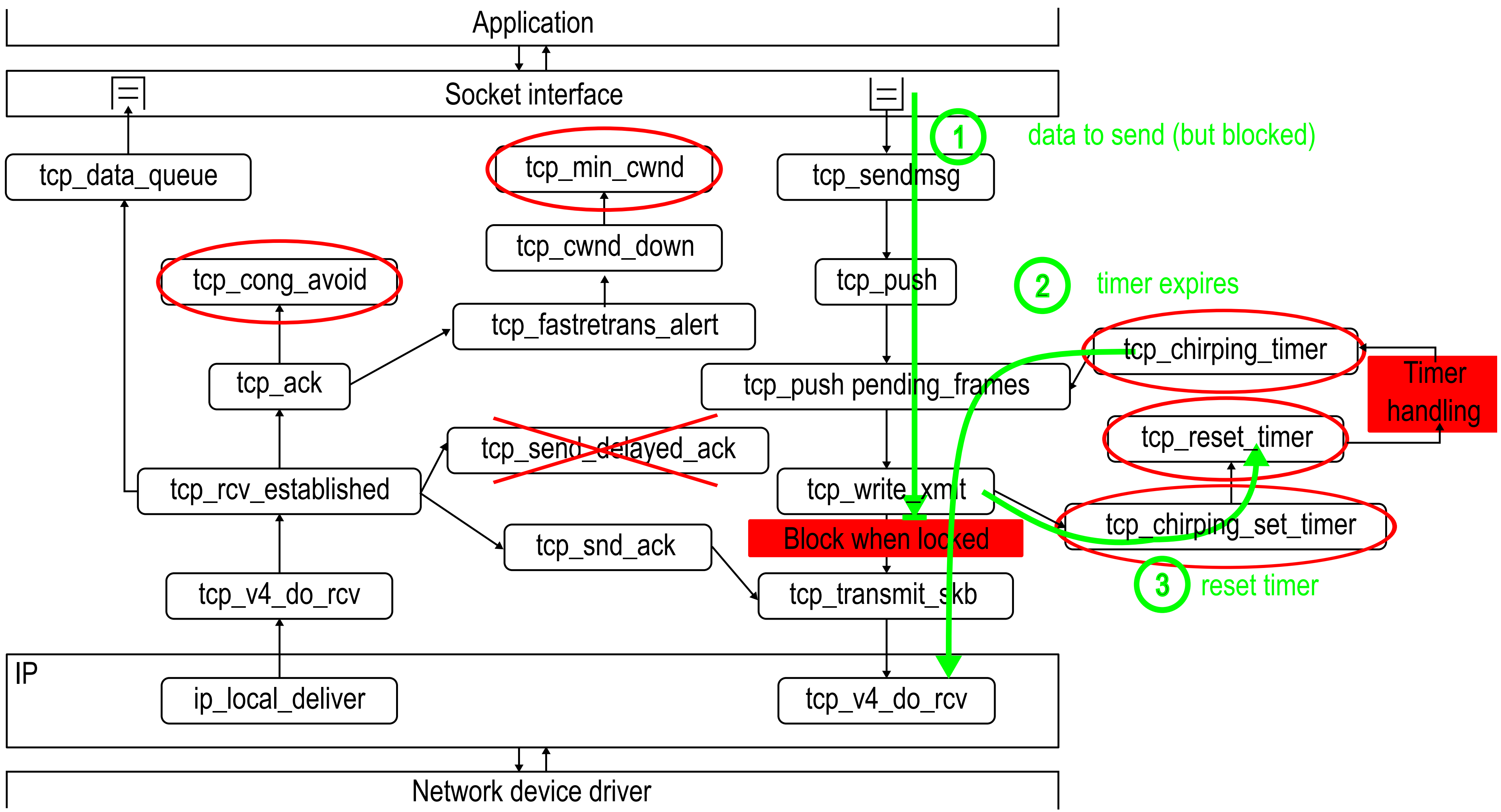


# Chirping Implementation in the Linux Kernel

## *Open Issues*

- Timer-based sent-up does not use ACK-clocking

  $\rightarrow$ Addition interupt processing burden

  $\rightarrow$ Could be solved by the use of hardware timers in future
- Timer resolution has to be high enough to serve high-speed links (hrtimers in the Linux kernel provide nanosecond resolution)

### Futher improvements

- Fully based on inter-packet time gaps instead of rate
- N should be an the integer power of 2

  $\rightarrow$ Initiallly hard-coded to N = 32 (=$2^5$)
- Algorithm for Inter-packet gap Calculation
  - Harmonic progression of rates by linear decrease of inter-packet gaps:

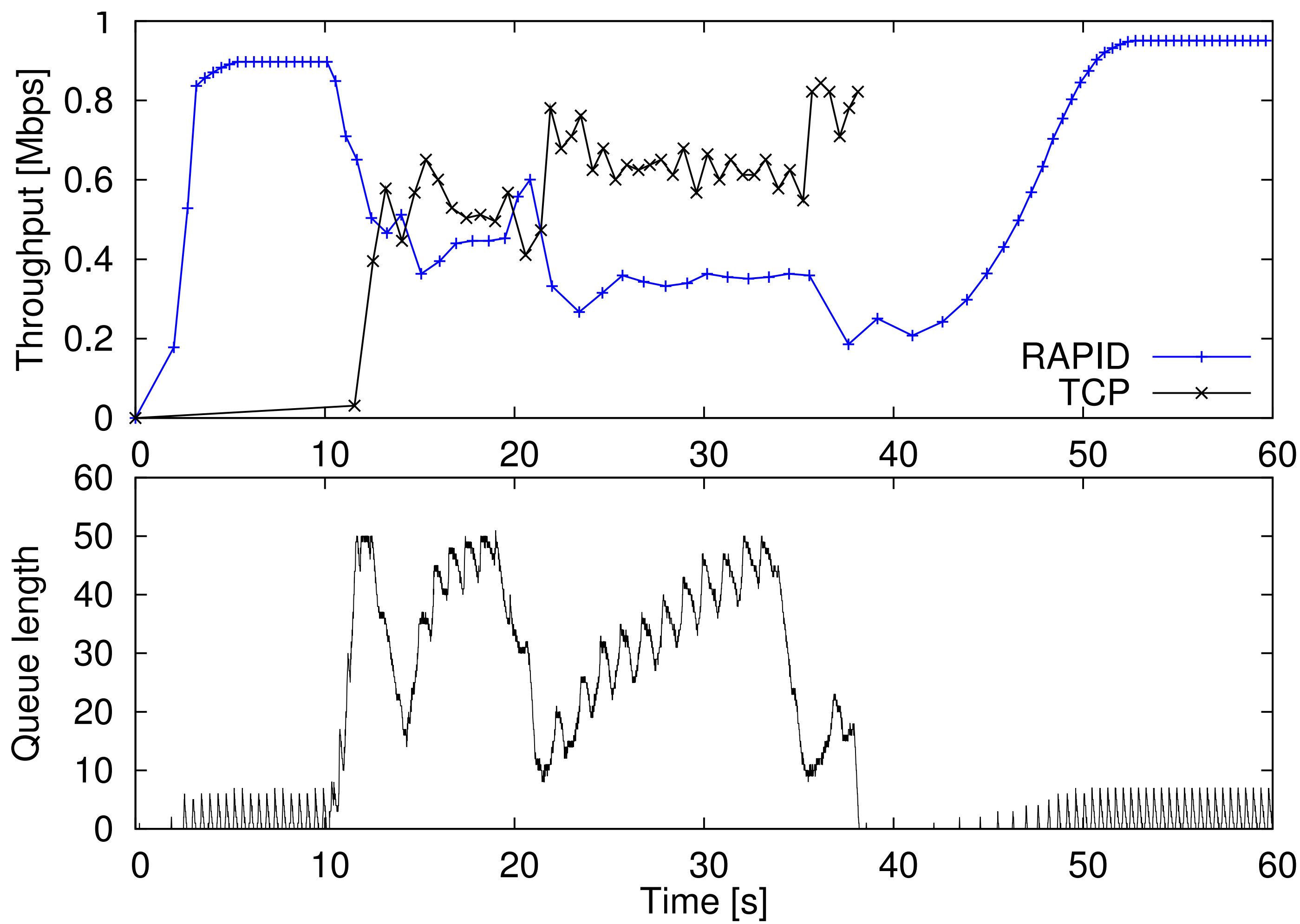
    $gap_i = gap_{i-1} - gap_{step}$ with $gap_{step} = (2 * gap_{avg}) / N$

  $\rightarrow$ Implementation with integer arithmetic

# Preliminary Results

## *RAPID Congestion Control*

For convergence to equalized rate: $r_{avg} = r_{avg} + \frac{l}{\tau}(ABest - r_{avg})$ $\quad l = \frac{N * P}{r_{avg}}$



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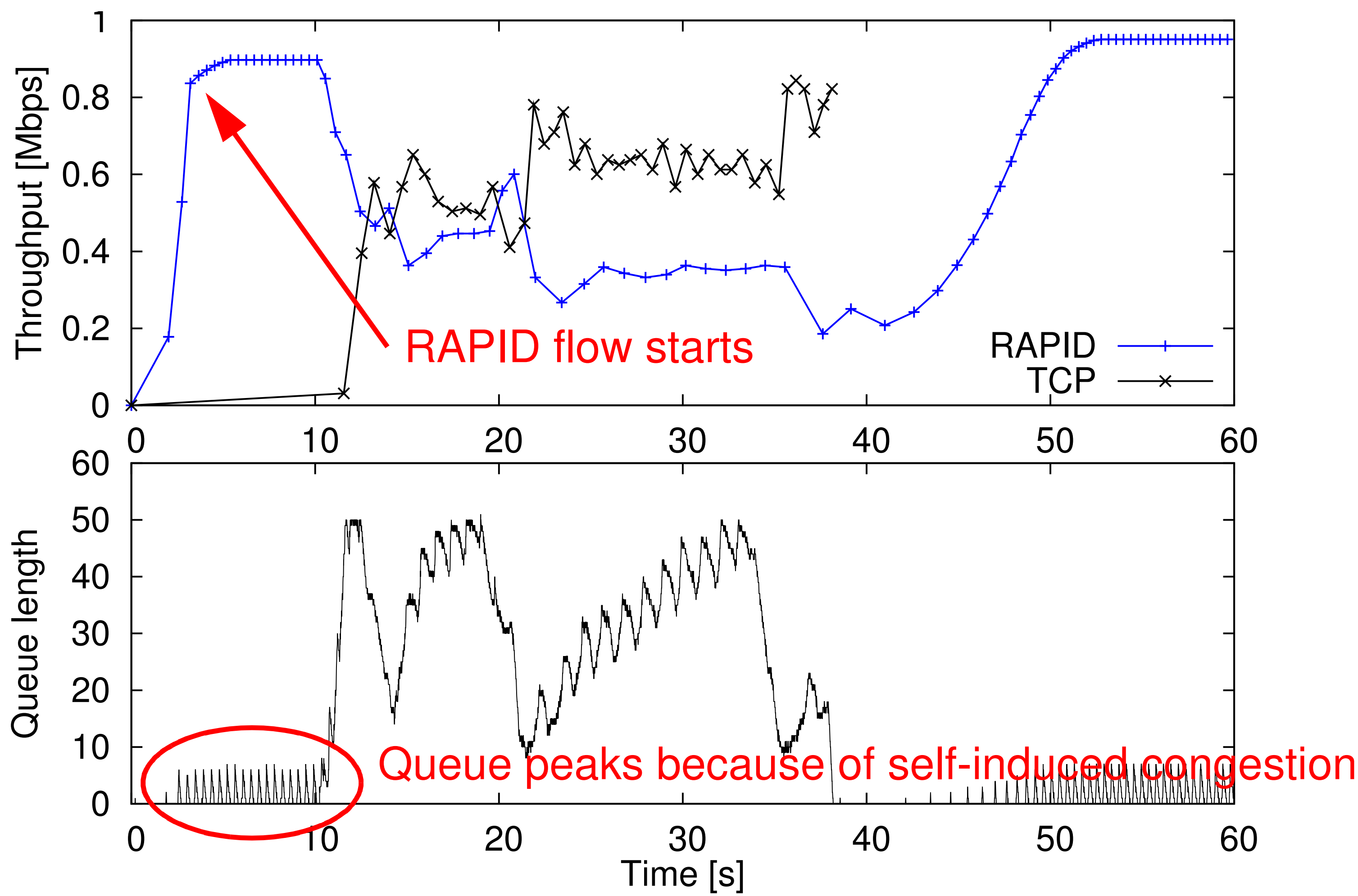

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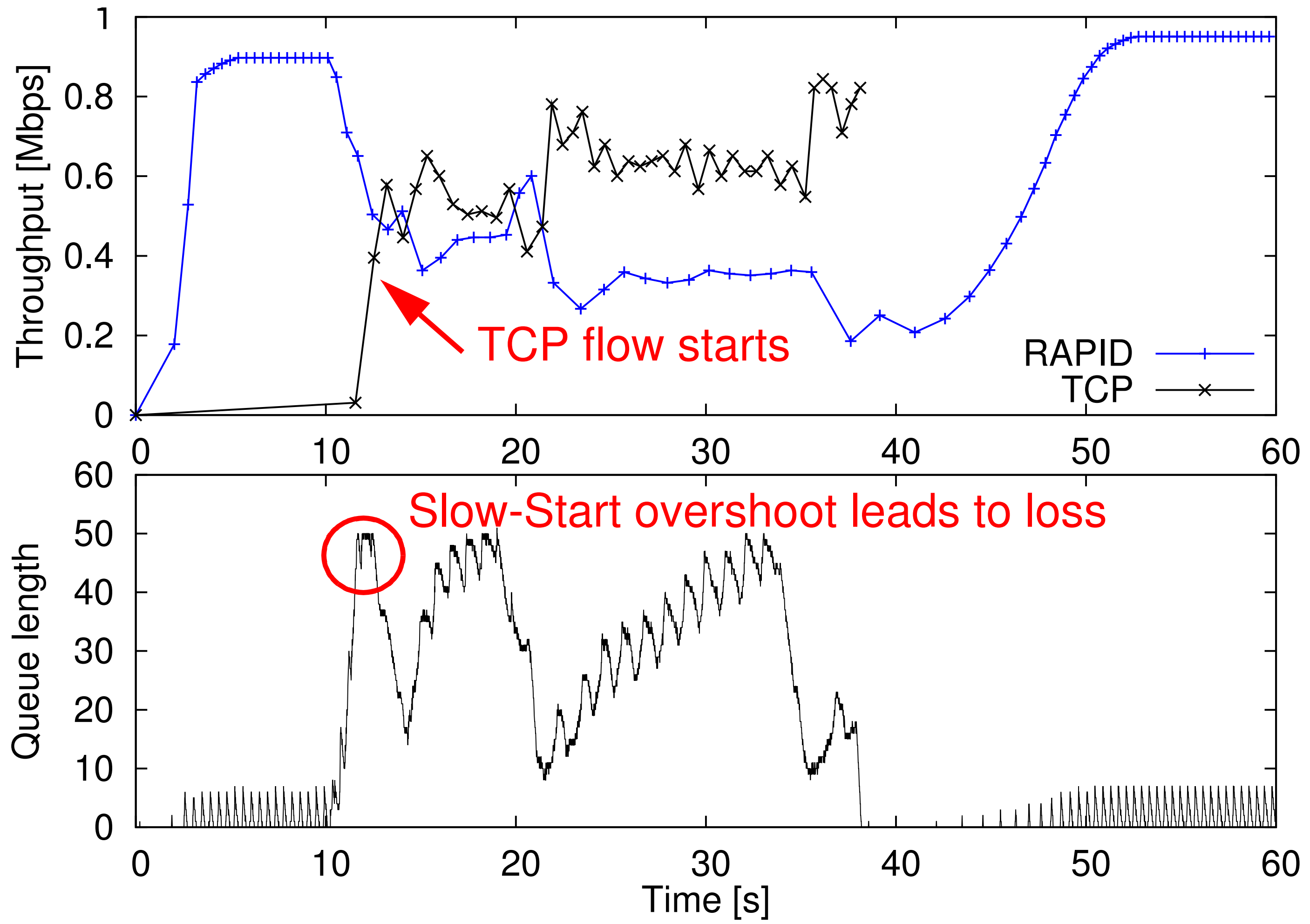

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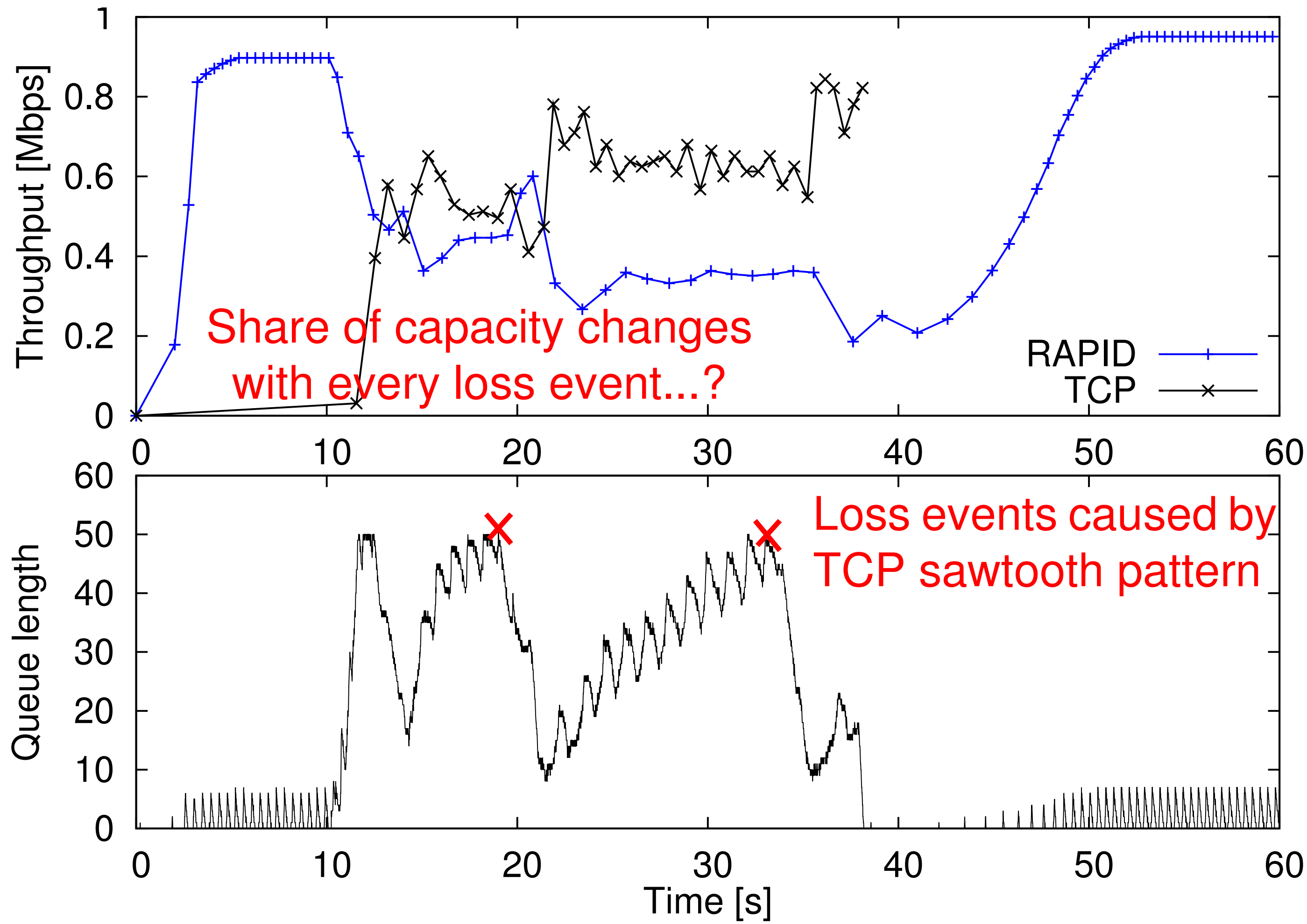

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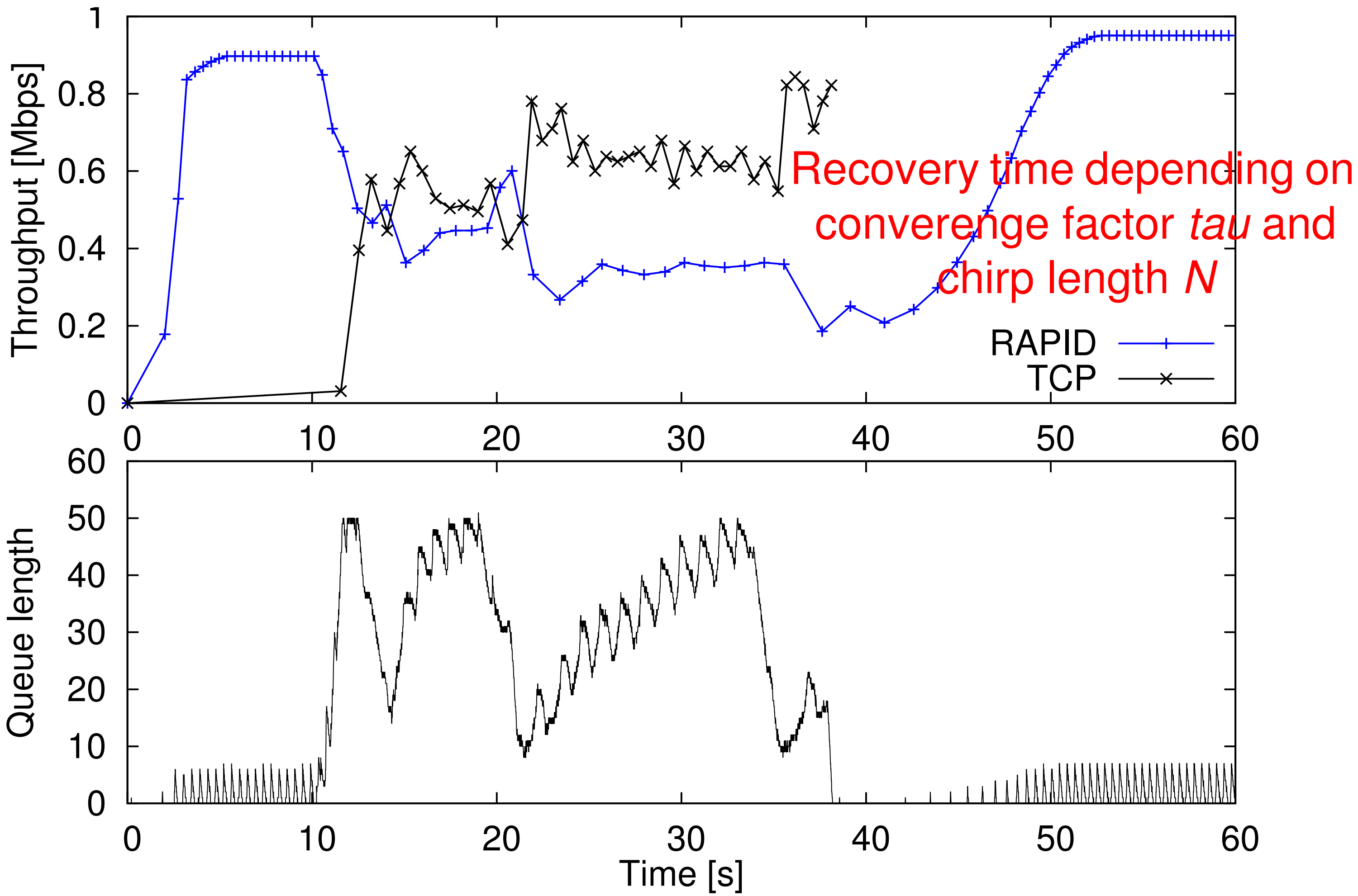


# Preliminary Results

## *Next Steps*

### Design of a robust congestion control based on chirping

- Adaption of chirping parameters to prevailing conditions
- Converenge in capacity sharing also when competing with other protocols
  - RAPID is scavenger protocol: Not designed to take capacity share from loss-based protocols
- Fast feedback chirping information only in addition to other network state information

### Future Work

- Impact of short term probing delays on the queue burstiness
- Influence of a large aggregation of probing chirps on the base queue length

  → Reduced overshoot and respectively reduced maximum queue length
- Accuracy of measurement with a large aggregation of probing chirps
- Adaptation of the chirping parameters e.g. selection of chirp size *N*

  → Higher accuracy of chirping information

# Conclusion and Outlook

- **Implementation** of chirping as a building block for congestion control in Linux
  - Nanosecond resolution provided by kernel hrtimers is sufficient for today's speed
  - Protocol design for feedback needed for one-way delay measurements
- **Structured the problem space** in three independent sub-problems

  rate estimation, rate adaption and adapting chirp parameters
- **Identified challenges** in implementation and deployability
  - Timer-based implementation does not use ACK-clocking and CWND
  - Negotiation about timestamp resolution and receiver behavior (delayed ACKs)
- **Invented solutions** to reduce implementation complexity and improve accuracy
  - Inter-packet gap calculation with linear decrease of inter-packets gaps
  - Hardware timestamping
  - Use of actual sent-out timestamps (instead of pre-set inter-packet gaps)

→ Show feasibilty of chirping within a contineous data stream!

→ Use faster feedback to enable **more scalable rate adaption with minimal overshoot**!

→ Encourge others to build research on rate estimation, rate adaption and adaption of chirping parameters!

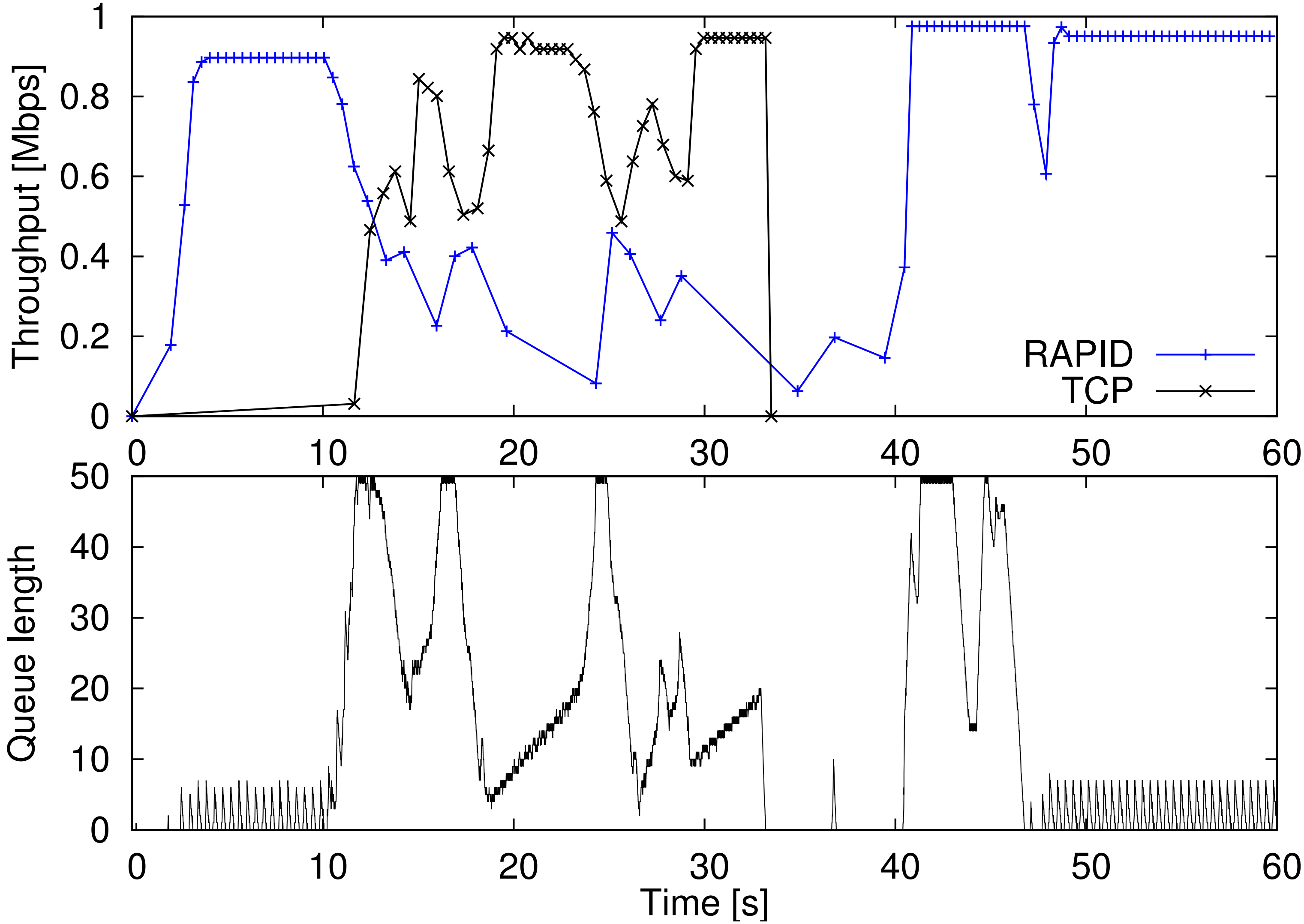
# Thank you for your attention!

# Questions?

# Preliminary Results

## *RAPID Congestion Control*

TCP cross traffic starts at 10s (20Mbit) on 1Mbit/s bottleneck link



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## *Implementation Details*

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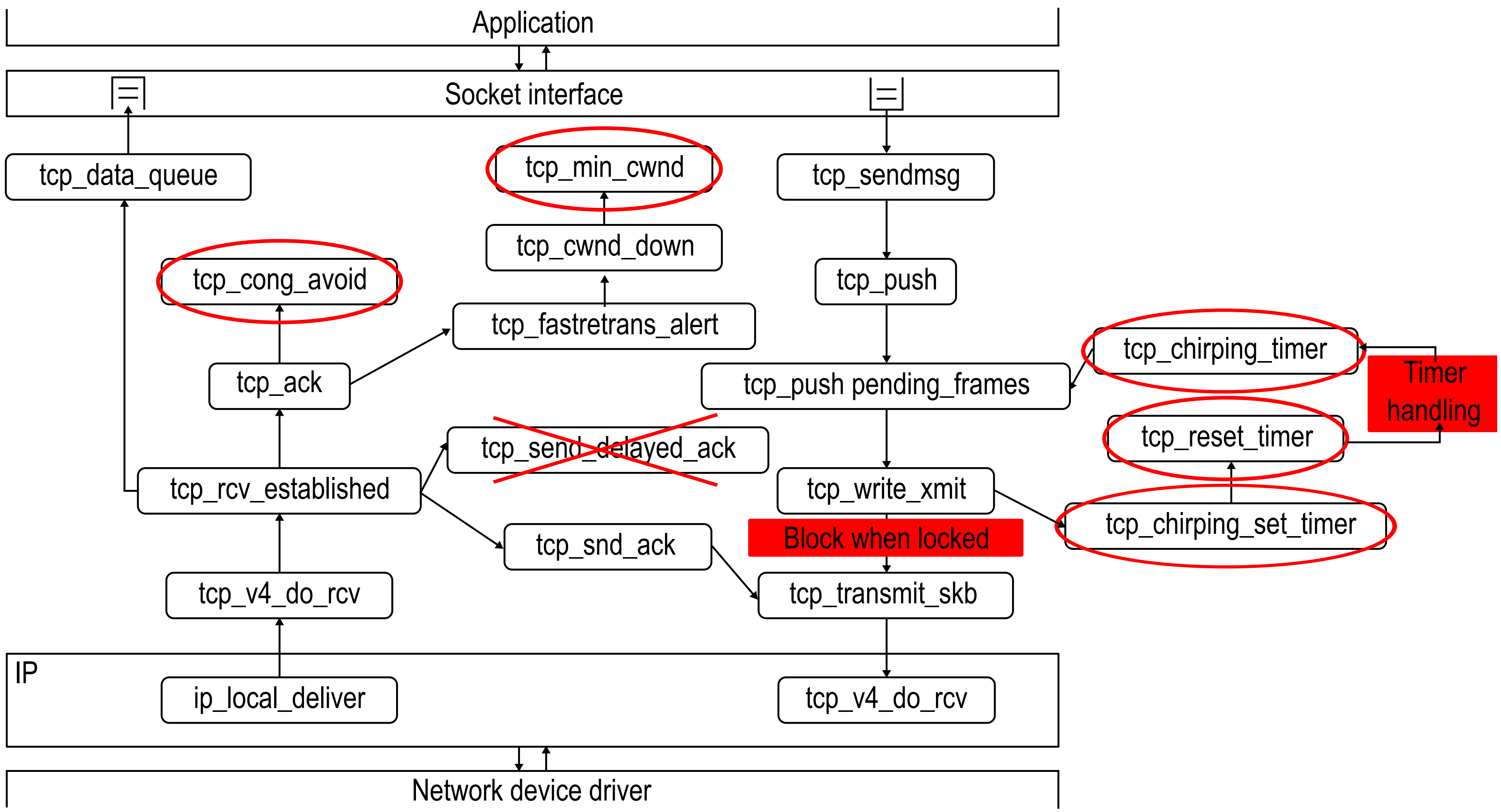

# Chirping Implementation in the Linux Kernel

## *Algorithm for Inter-packet gap Calculation*

- Fully based on inter-packet time gaps instead of rate
- N should be an the integer power of 2

  → Initiallly hard-coded to N = 32 (=$2^5$)
- Harmonic progression of rates

  → Linear decrease of inter-packet gaps: $gap_i = gap_{i-1} - gap_{step}$ with $gap_{step} = (2 * gap_{avg}) / N$
- Implementation with integer arithmetic

$$gap_i = gap_{step} * (N - i + 1) = (2 * gap_{avg}) / N * (N - i + 1) \qquad \text{with } i = 1...N\text{-}1;\ gap_0 = gap_{avg}$$

  – Probing range:1/2 $r_{avg}$ to N/4 $r_{avg}$
  – Maximum rates of harmonic progression not used

→ Slightly lower average rate than the estimated one