Adaptive Congestion Control for Unpredictable Cellular Networks

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Verus design goals

1. Track fast channel changes
2. Balance throughput and delay
3. Provide fairness between competing flows

- Verus uses delay feedback
  - Changes only done at the end nodes
  - Proactively avoid congestion
  - Small signaling overhead

Verus design

- No channel prediction/modeling

- Build on TCP concepts:
  - Use slow start
  - Use Multiplicative Decrease (MD) on packet loss
  - Replace Additive Increase (AI) with a step based increase/decrease

Verus in a nutshell

- Learns the **delay profile** of the network
  - Reflects the relationship between delay and sending window
  - Represented as a curve and re-built every **1 second**

- Decide how many packets to send over **5 ms epochs**

- Enforces a delay estimate based on the **delay profile**
  - With a step-based increase/decrease

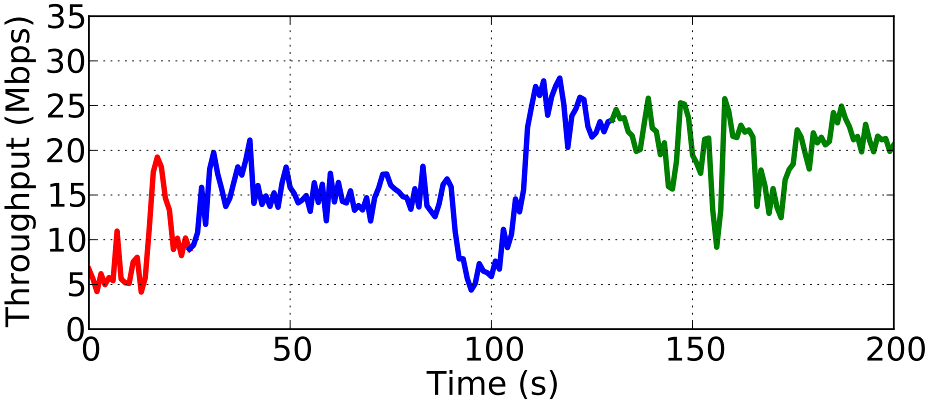
$$W(t+1) = \boxed{f(\underbrace{d(t) \pm \delta(t)}_{\text{Estimated delay } (D_{est})})}\ \text{Delay curve}$$

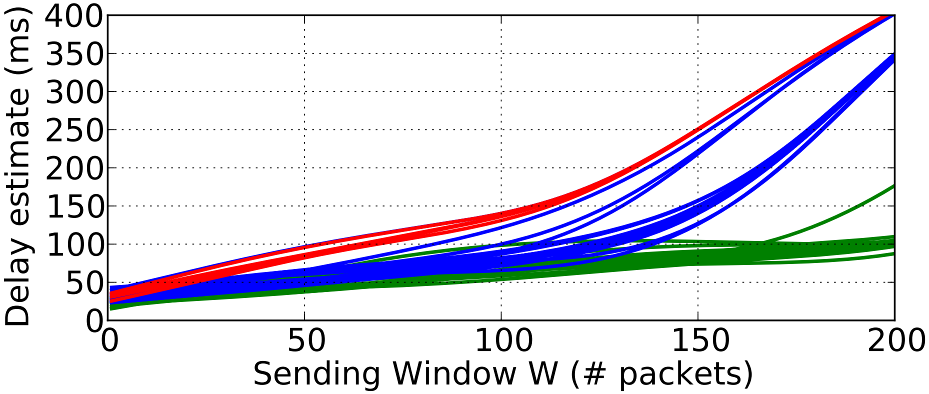
Delay curve concept

- A way to track network changes

- Reflects relationship between sending window and network delay

- Verus dynamically learns the network state
  - Through delay feedback (ACKs)





Tracking fast channel changes

Slow start:

- Every ACK: add a point (W, delay)

Build delay curve:

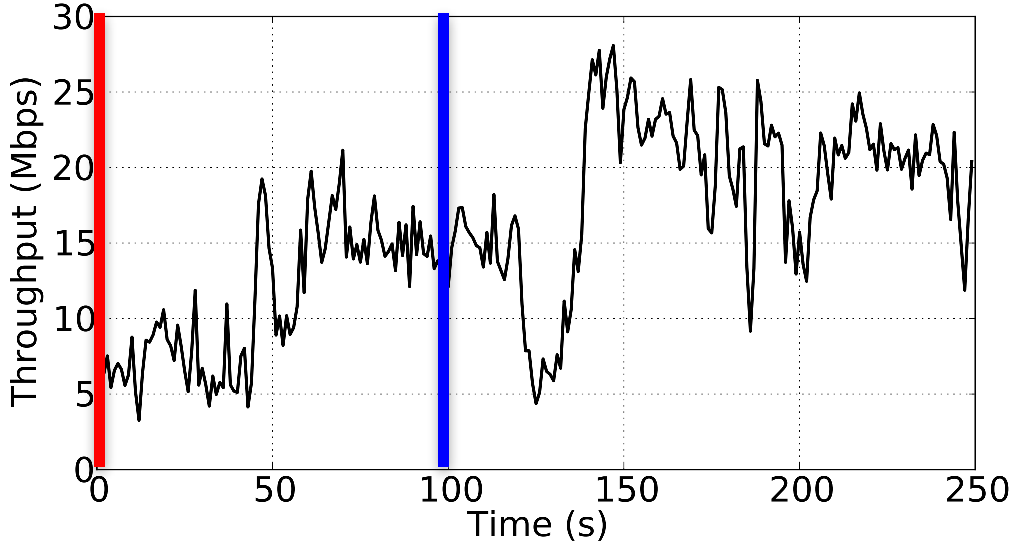
- Cubic spline interpolation

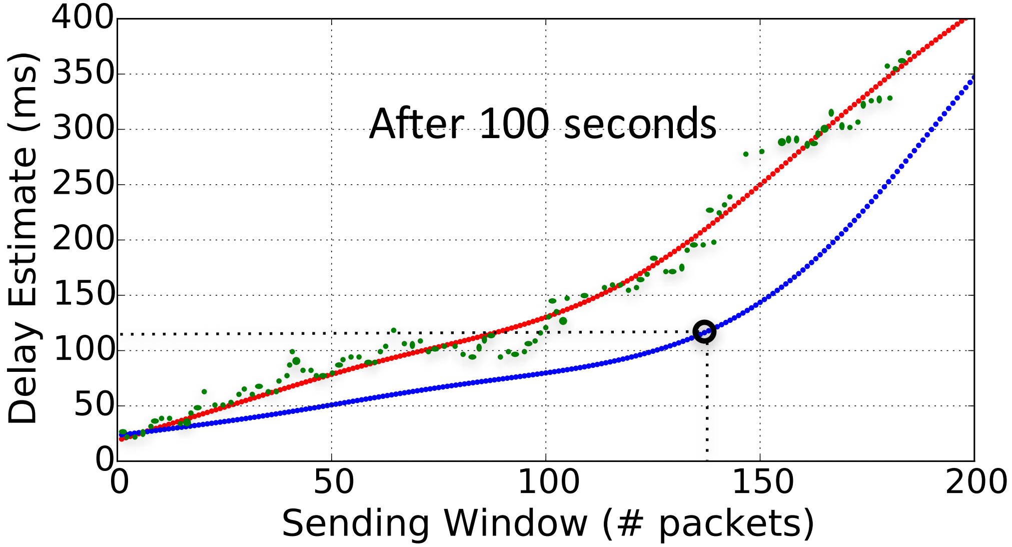
Verus control loop:

- every epoch 5 ms

Rebuild delay curve:

- every 1 second



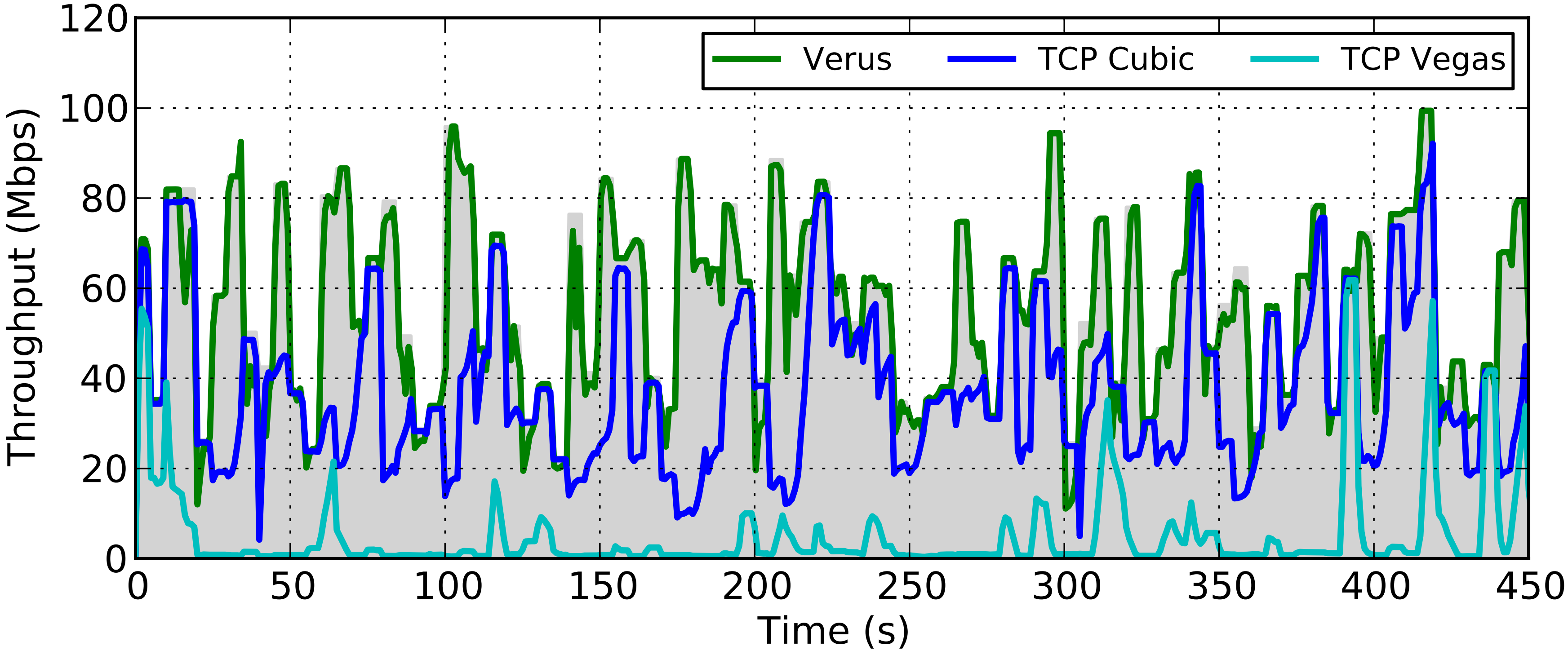


Tracking fast channel changes

Every 5 sec:

Link: 10-100 Mbps

Round trip time: 10-100 ms

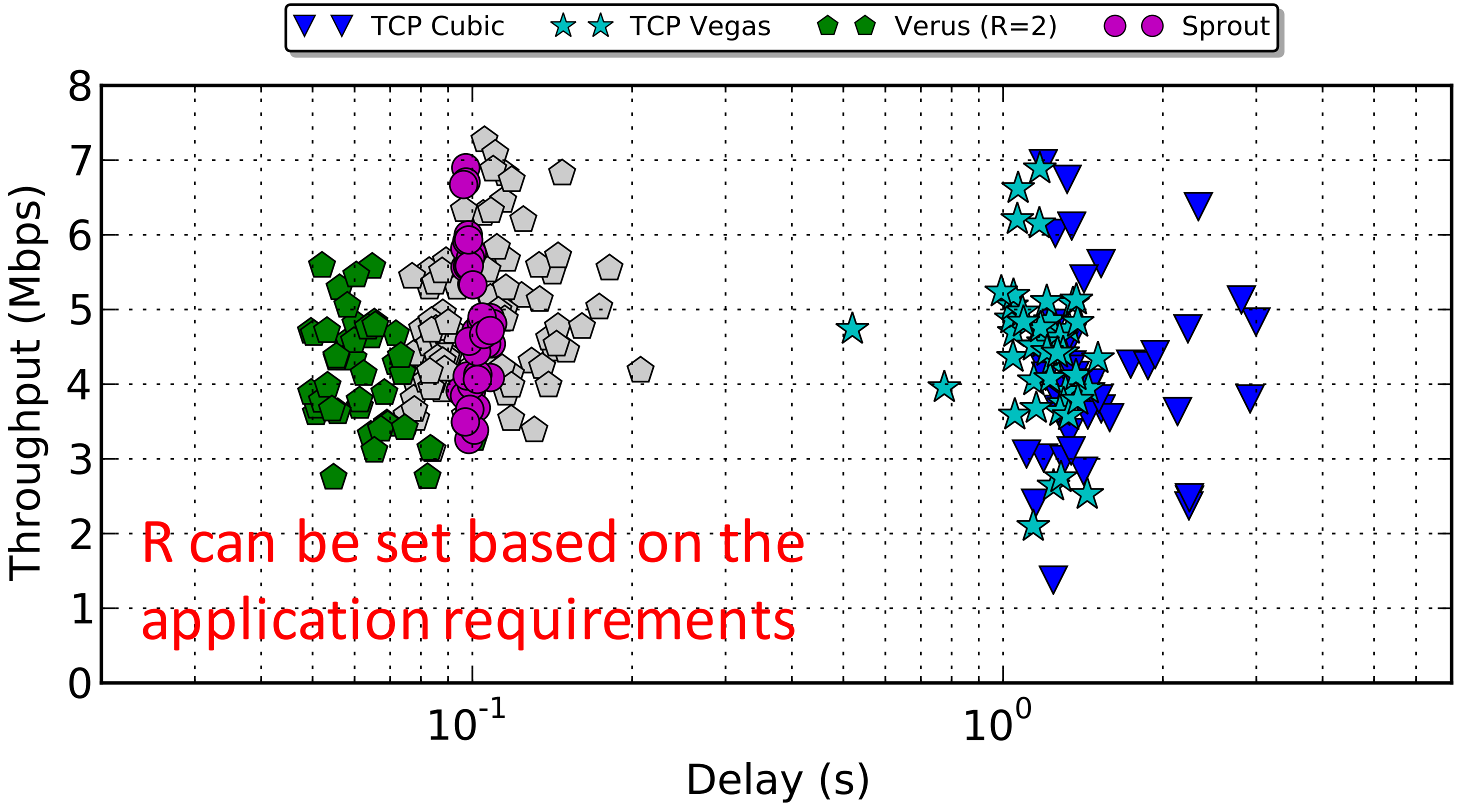


Trade-off between throughput & delay

Tuning parameter (R) defines the ratio between max and min network delay

Experiments over real LTE network:

- Stationary scenario
- 3 phones each running 3 flows
- Repeated 5 times each

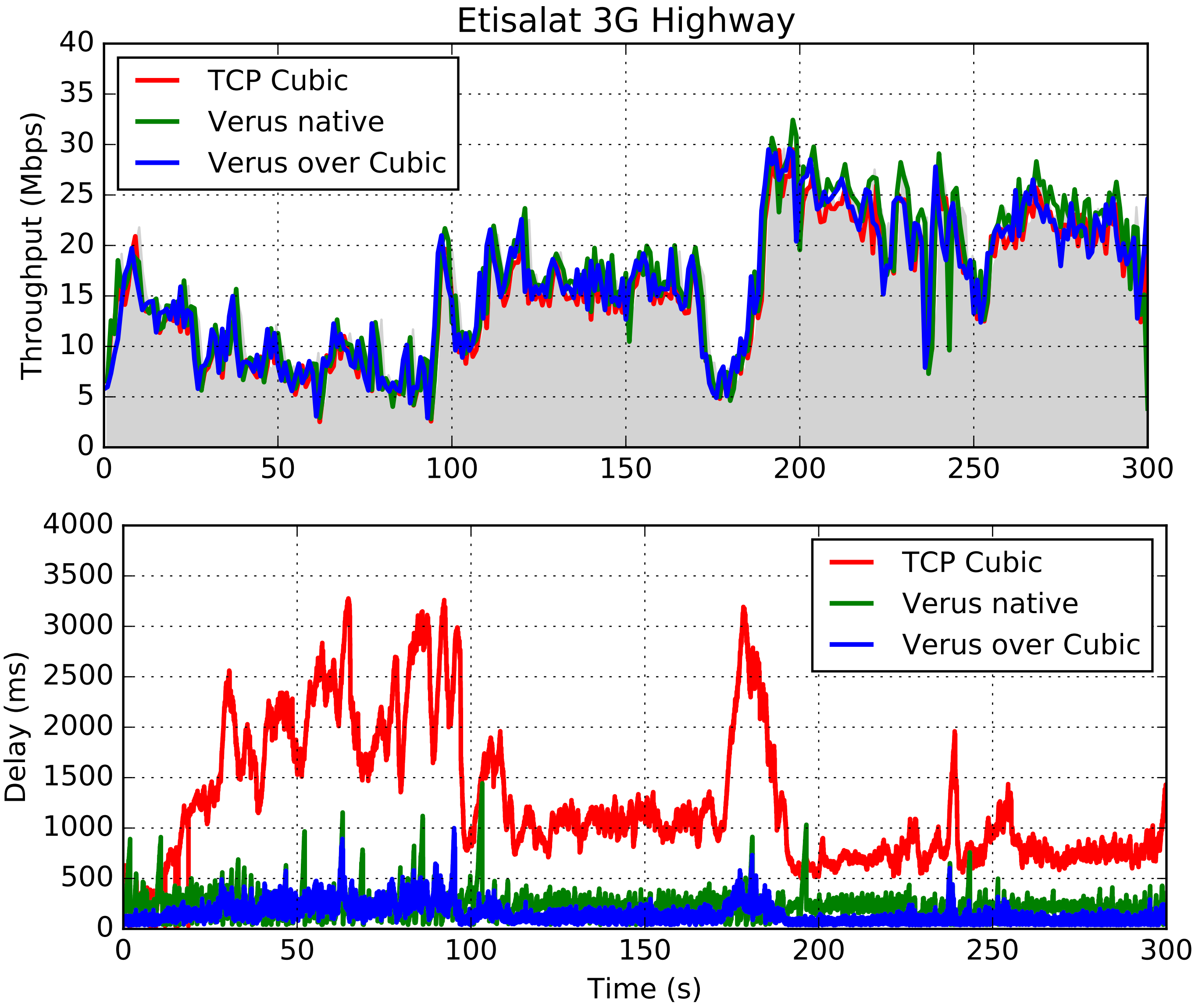


R can be set based on the application requirements

Verus implementations

- Native Verus over UDP
  - http://yzaki.github.io/verus/
- Verus Sockets (ongoing)
  - As CC module in UDT (UDP-based Data Transfer) http://udt.sourceforge.net/index.html
- As an adaptation layer over TCP Cubic
  - https://github.com/yzaki/verus/tree/verus_over_tcp
- As a CC module within Quic (Planned)

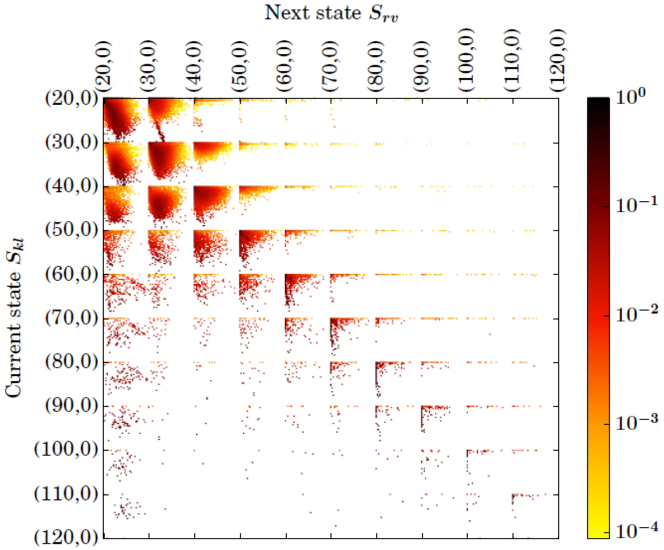
Verus over TCP Cubic



Verus modeling

- Delay based CC protocols are not well understood
  - A generic mathematical description
    - Simplify the understanding of these protocols
    - Prove convergence and stability

- Verus is modeled as a two-dimensional discrete-time Markov chain
  - Focus on highly fluctuating networks
  - Reflect properties of the protocol
  - Achieve similar performance


Next state S_{rv}
(20,0)
(30,0)
(40,0)
(50,0)
(60,0)
(70,0)
(80,0)
(90,0)
(100,0)
(110,0)
(120,0)
Current state S_{kl}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}