Stochastic forecasts achieve high throughput and low delay over cellular networks

Winstein, K., Sivaraman, A., and Balakrishnan, H.,
Proc. of the 10th USENIX Conf. on NSDI, pp. 459-472, 2013

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Outlines

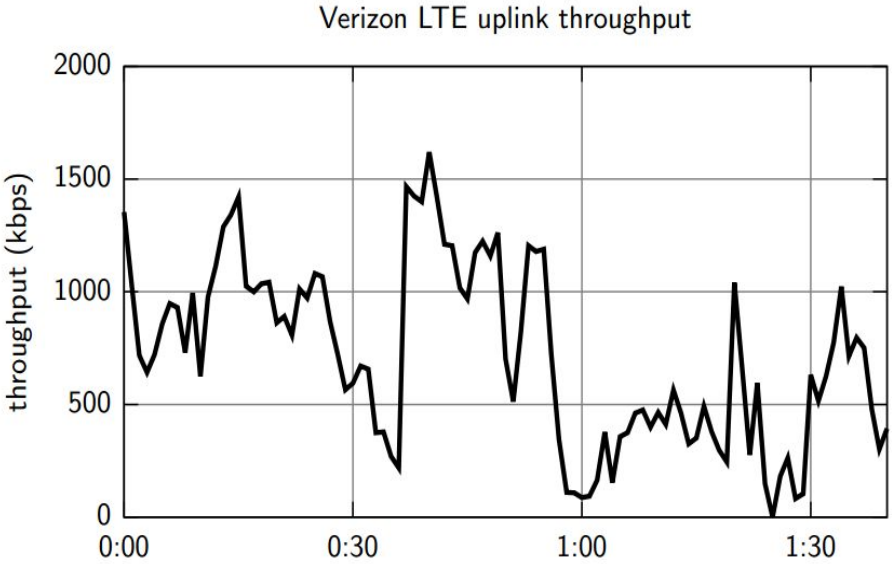
- Introduction
- Sprout Algorithm
- Experimental Testbed
- Evaluation
- Discussion

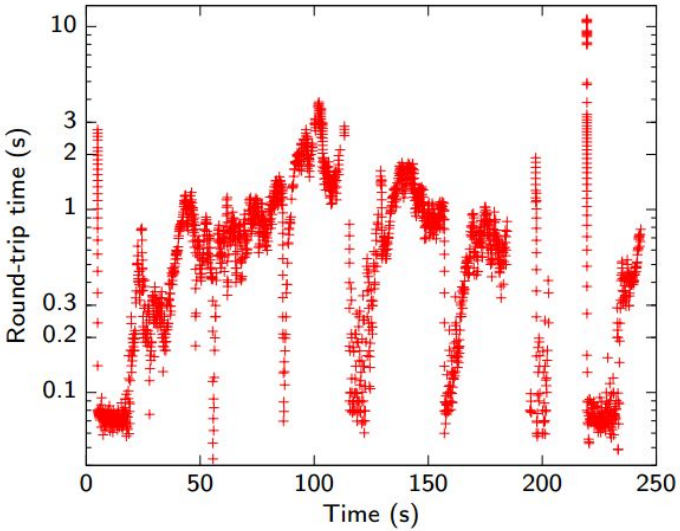
Paper Goals

- Design a protocol to cope with dramatic changes in link quality
- Maximize throughput and avoid delays while also not under-utilizing link
- Handle link outages without over buffering, and recovering gracefully

Cellular Links are not stable

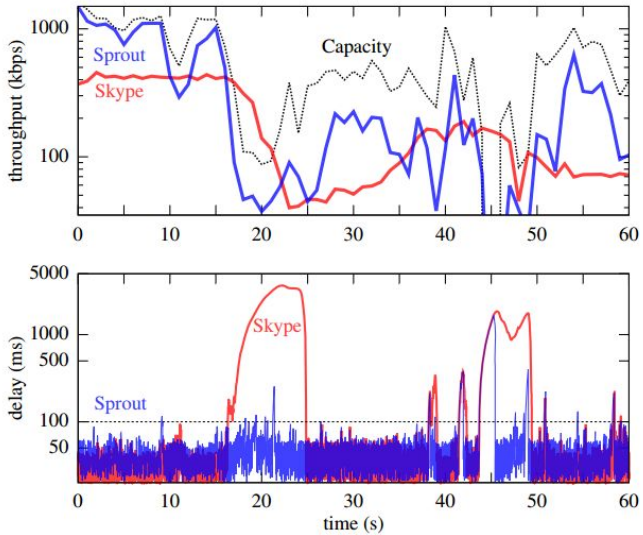
- Rapidly varying link rates
- Multi-second outages in either direction





Transport Protocols Today

- Deal with rate variations reactively.
- Slow to decrease their transmission rates
- Don’t fully utilize capacity

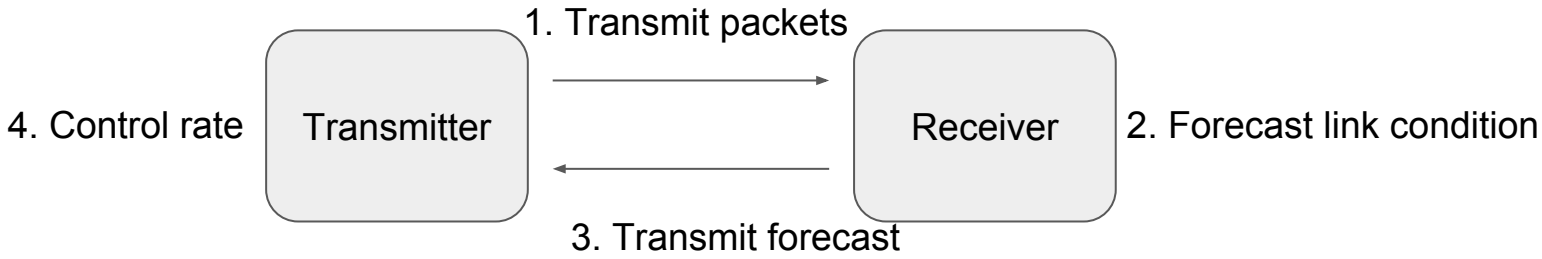


Cellular Links

- Mobile base station runs users’ queues in round robin fashion
- End-to-end delay tends to be self-inflicted
- Traditional bandwidth delay product buffering breaks down
- Active Queue Management schemes are difficult to configure

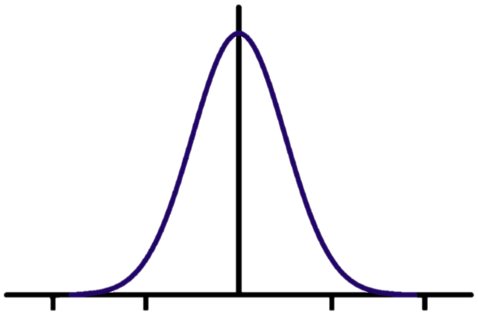
Sprout Algorithm Overview

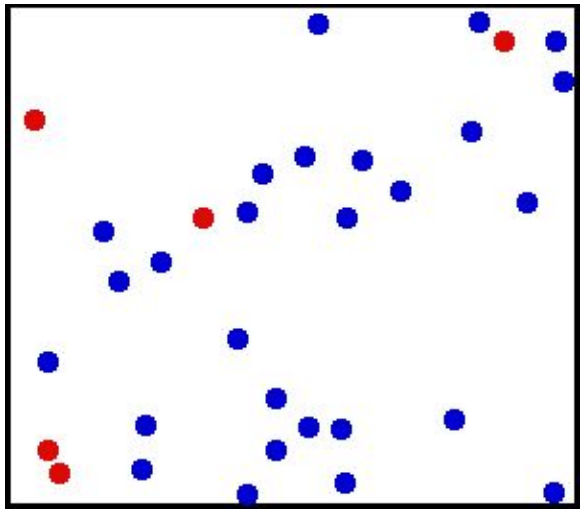
- Goal
  - Achieving highest possible throughput, while preventing packets from waiting too long in a network queue



Network Path Model

- Doubly-Stochastic process
  - Poisson process
  - Brownian Motion



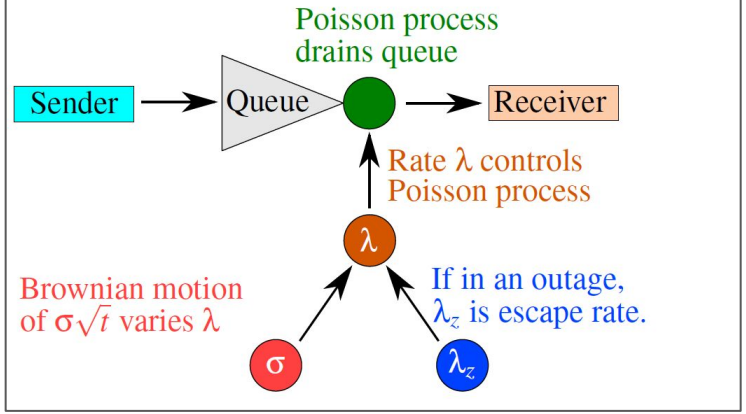


Network Path Model (Cont'd)

- λ of Poisson process (arrival rate)
  - λ is discretized into 256 level
  - λ changes according Brownian motion with noise power σ (random walk to nearby levels)
  - Update interval: 20 ms

- Outage escape rate to model "sticky" property
  - If λ = 0, it tends to stay at outage (Exponential distribution λ_z)

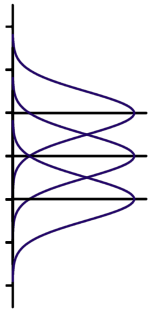
Figure 3: Sprout's model of the network path. A Sprout session maintains this model separately in each direction.



Update λ Distribution

1. Evolves λ by
   - Applying Brownian motion for λ level ≠ 0
   - Applying both Brownian motion and outage escape rate bias for λ level = 0

Time	0	20	40
Level 0	1/256	0.01	0.03
Level 1	1/256	0.02	0.01
...	...	...	...
Level 255	1/256	0.01	0.02



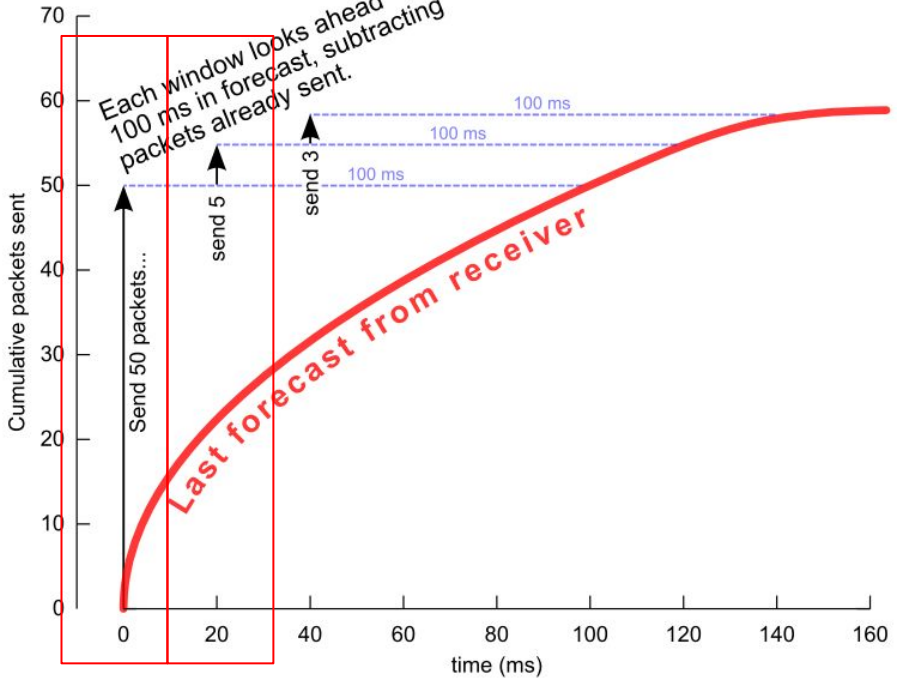
2. Observes the received bytes (k) to further update distribution of λ

$$F(x) \leftarrow \mathbb{P}_{\text{old}}(\lambda = x)\frac{(x \cdot \tau)^k}{k!}\exp[-x \cdot \tau]$$

3. Normalizes the distribution of λ: $\mathbb{P}_{\text{new}}(\lambda = x) \leftarrow \frac{F(x)}{\sum_i F(i)}$

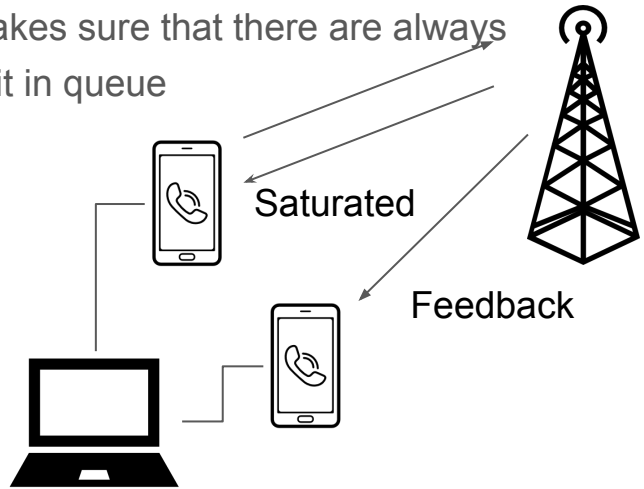
Forecast and Control Packet Delivery Rate

- Predict the link capacity by finding 5th percentile of λ distribution
- Forecast 8 ticks (160 ms)
  - Without the second step
- Transmitter will control the packet transmission based on the forecast and estimated packets in queue



Experimental Testbed - Data Collection

- Devices
  - A laptop to generate data
  - One cell phone for data transmission and another for feedback
- Saturator
  - A program that makes sure that there are always packets to transmit in queue

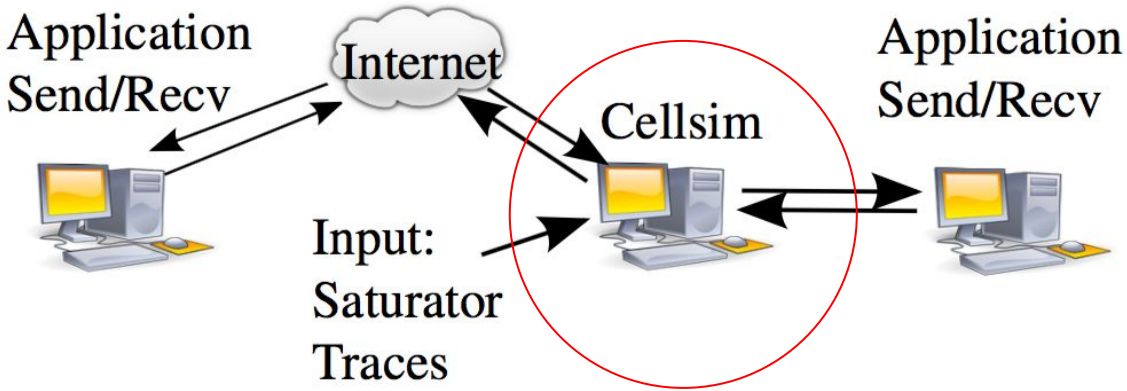


Trace Records

Packet Received Time	Packet Sent Time
1 ms	3 ms
2 ms	6 ms
4 ms	7 ms
...	...

Experimental Testbed - Cellsim

Figure 5: Block diagram of Cellsim



Act as base station

Trace Records

Packet Received Time	Packet Sent Time
1 ms	3 ms
2 ms	6 ms
4 ms	7 ms
...	...

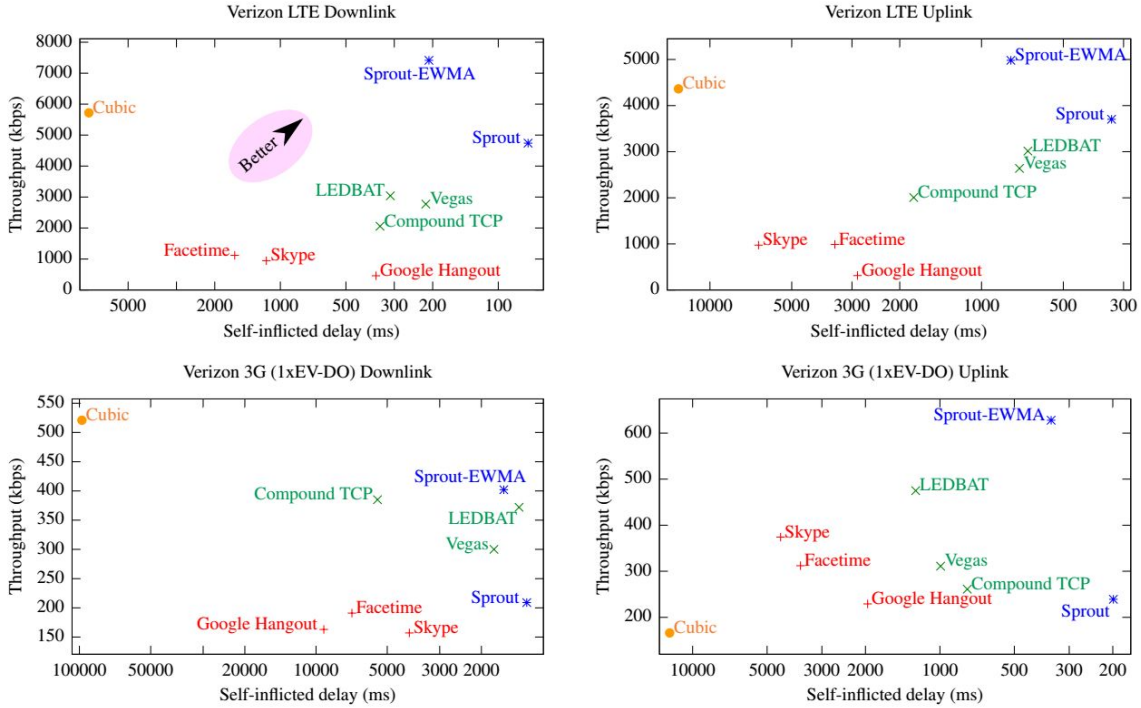
Sprout Exponentially Weighted Moving Average

- Used to compare benefits of Sprout's forecasting
- Still uses packet arrival times
- Doesn't do inference, but passes values to exponentially-weighted moving average (EWMA) function.
- Mostly results in higher throughput and delay compared to Sprout

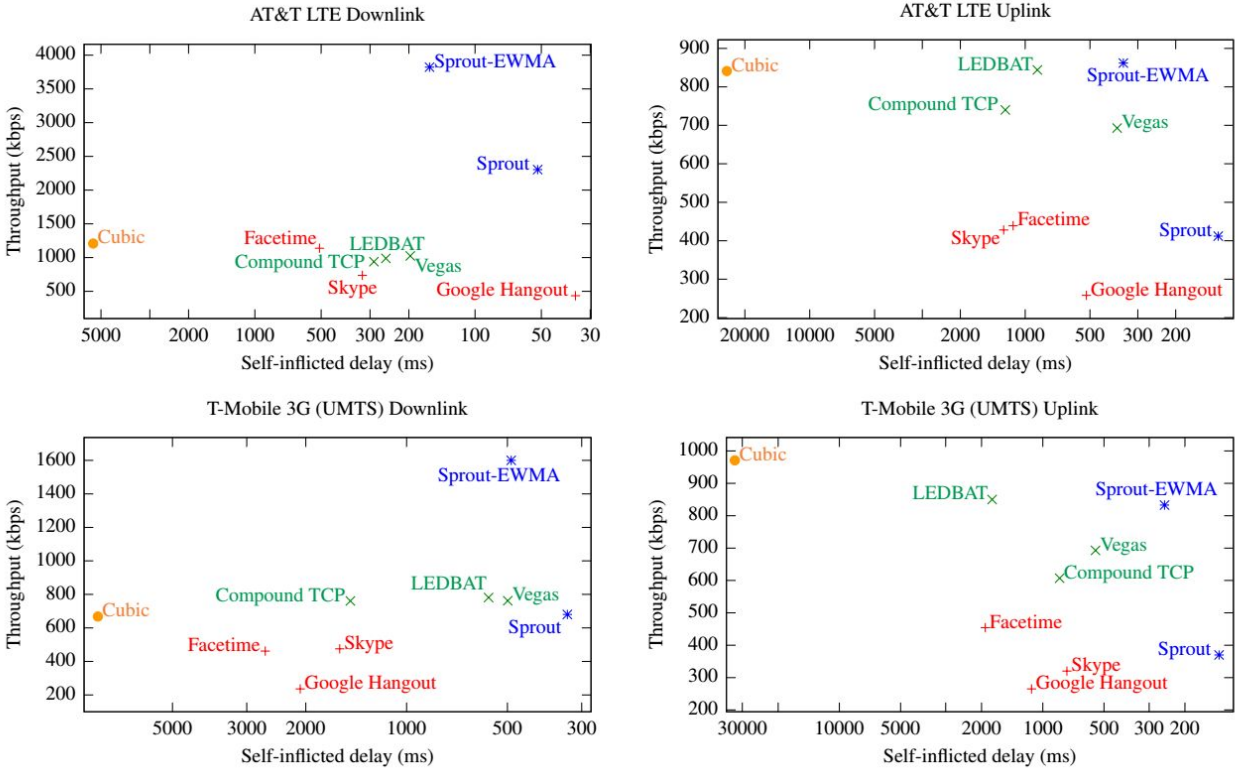
Evaluation Metrics

- Throughput: total bits received / duration of experiment
- Self-inflicted delay: difference in end to end delay between a perfect protocol and the chosen protocol

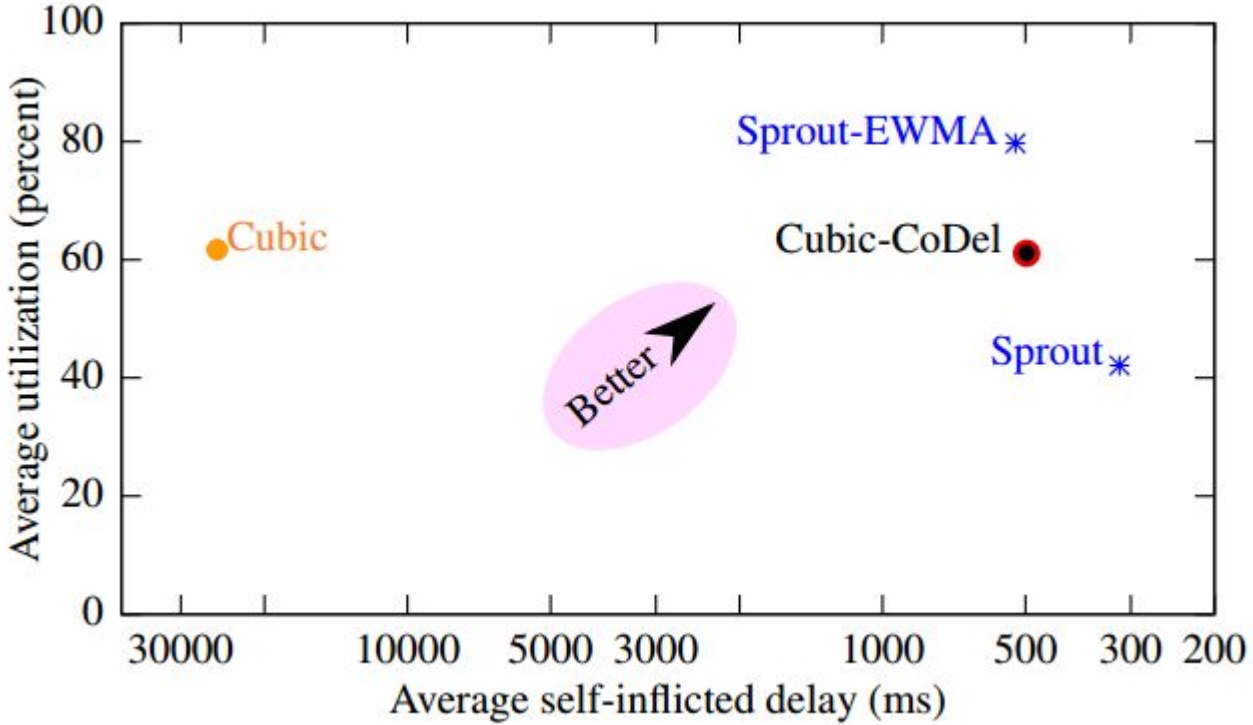
Results Over Different Networks



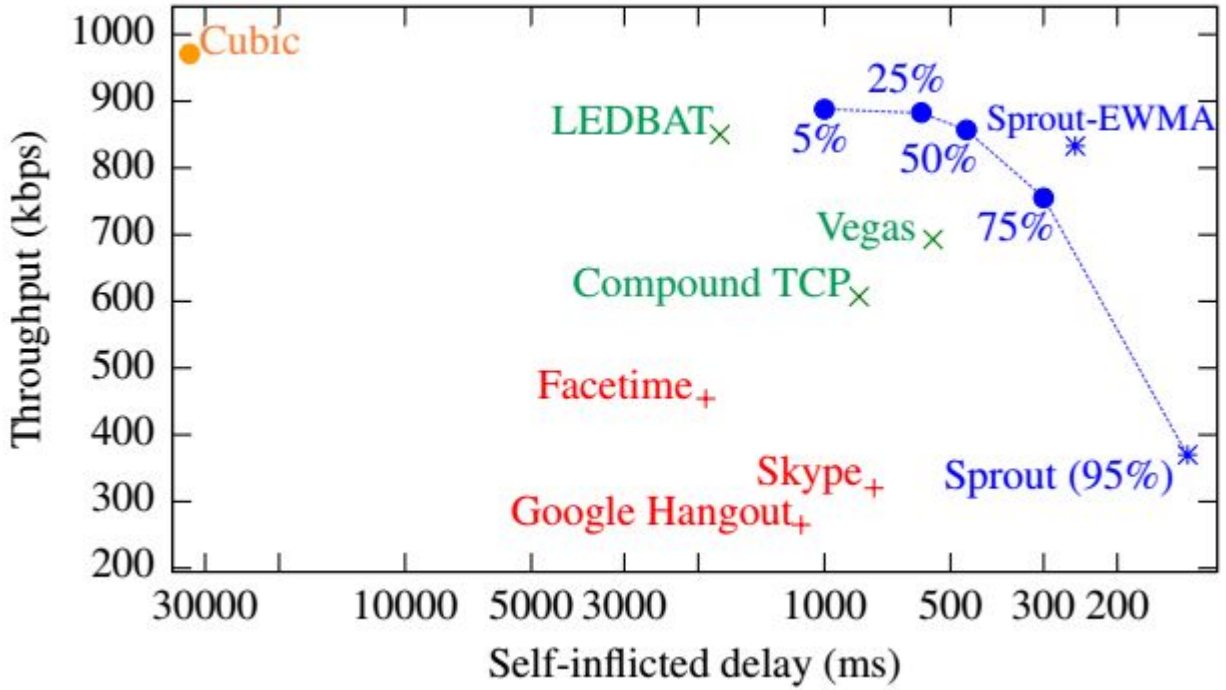
Results Over Different Networks (cont)



Results Compared to AQM



Confidence Parameter Effects



What’s Novel and “aha”?

- Sprout can outperform CoDel
- Adoption of Brownie Motion Model

How to extend or adopt this work?

- Extend
  - Short term performance?
  - Trying different models other than Brownian motion
  - Multiple Sprouts at the same time
  - More traffic scenario should be considered
- Shortcomings
  - Self-similar property may still holds, is Poisson enough?
  - No explicit explanation of why adopting brownian motion