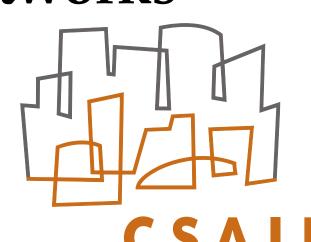
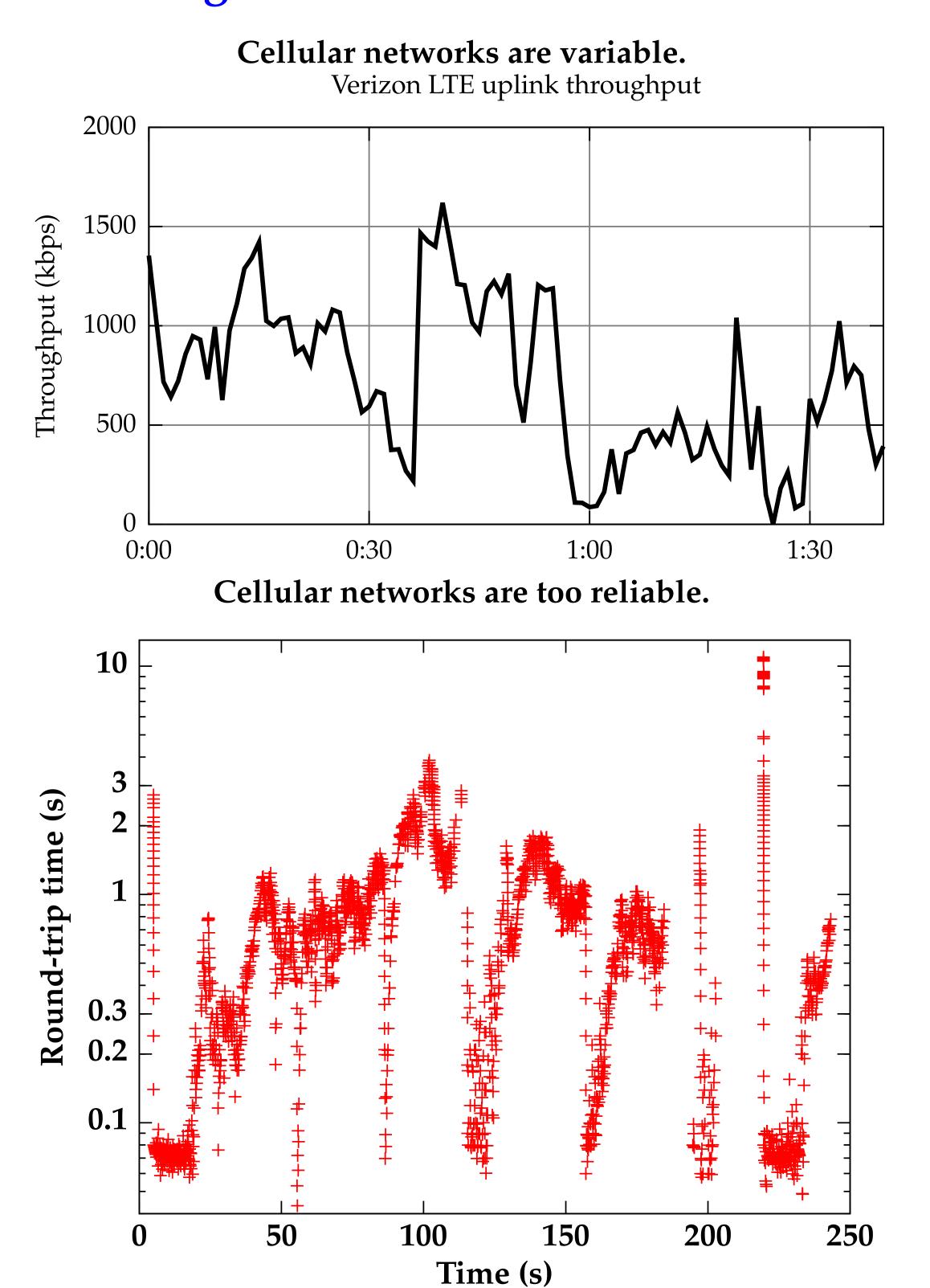
Sprout: Stochastic Forecasts Achieve High Throughput and Low Delay over Cellular Networks

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Problem setting



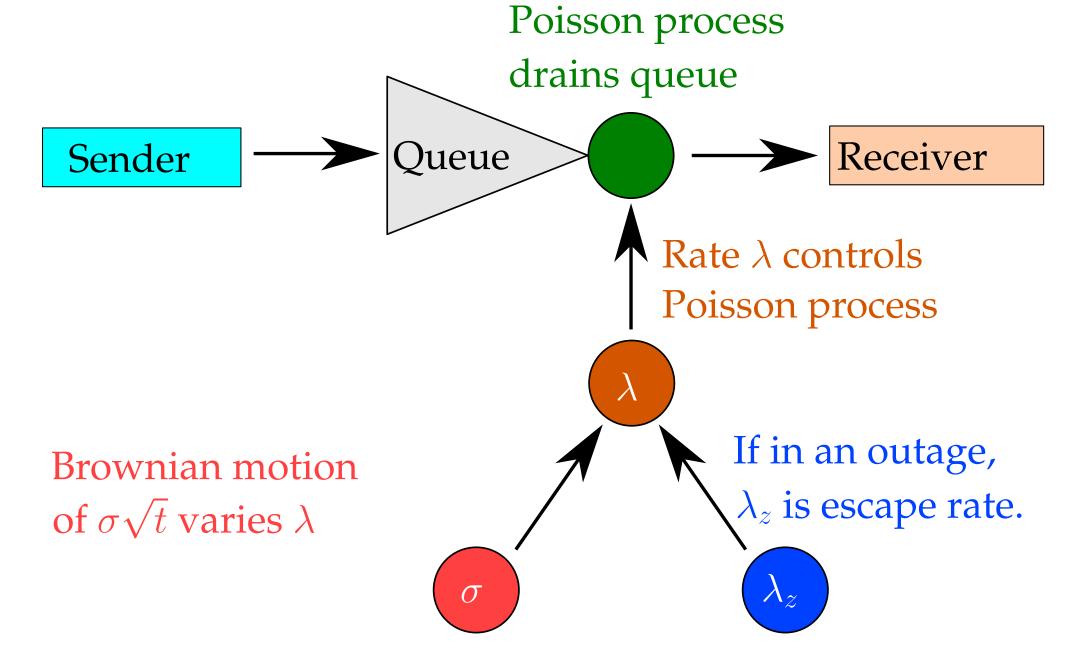
Interactive apps perform poorly because they are reactive.

Sprout's goal

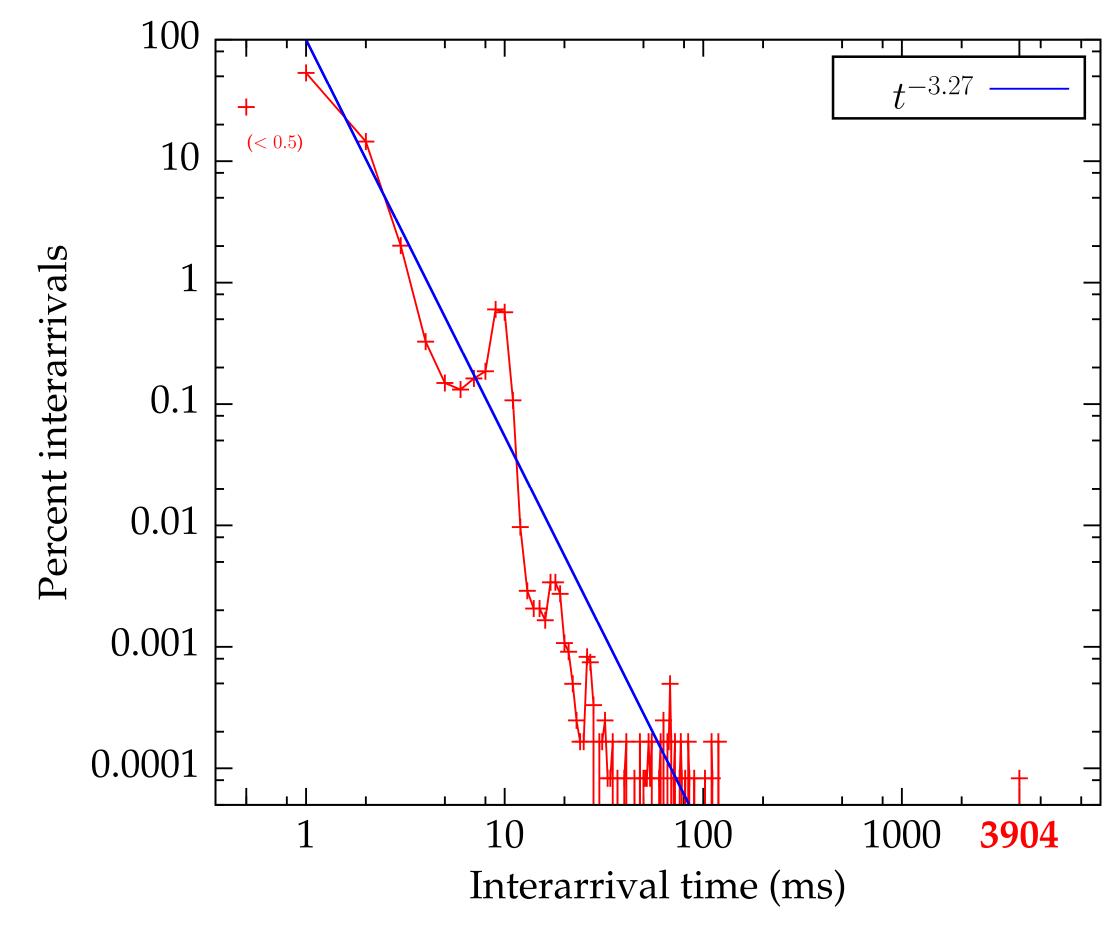
Maximize throughput subject to a bounded risk of delay exceeding 100 ms.

How it works

- Inference: Infer probability distribution of link speeds from packet arrivals.
- Prediction: Predict future link speed.
- Control: Send as much as possible, but ensuring a 95 % chance that all packets are delivered within 100 ms.



Inference



At the receiver:

- Maintain a probability distribution over link rates.
- Model receiver's arrivals as a Poisson process with a time-varying rate λ .
- Observe number of bytes k that arrived in a tick of duration τ .
- ullet Compute the likelihood L(x) that a Poisson process with rate λ generated kbytes.

$$L(x) = \frac{(x.\tau)^k}{k!} exp(-x.\tau) \tag{1}$$

• Update current probability distribution using L(x)

$$F(x) = Pr_{old}(\lambda = x) * L(x)$$
(2)

• Normalize the new probabilities F(x), so that they sum to unity.

Prediction

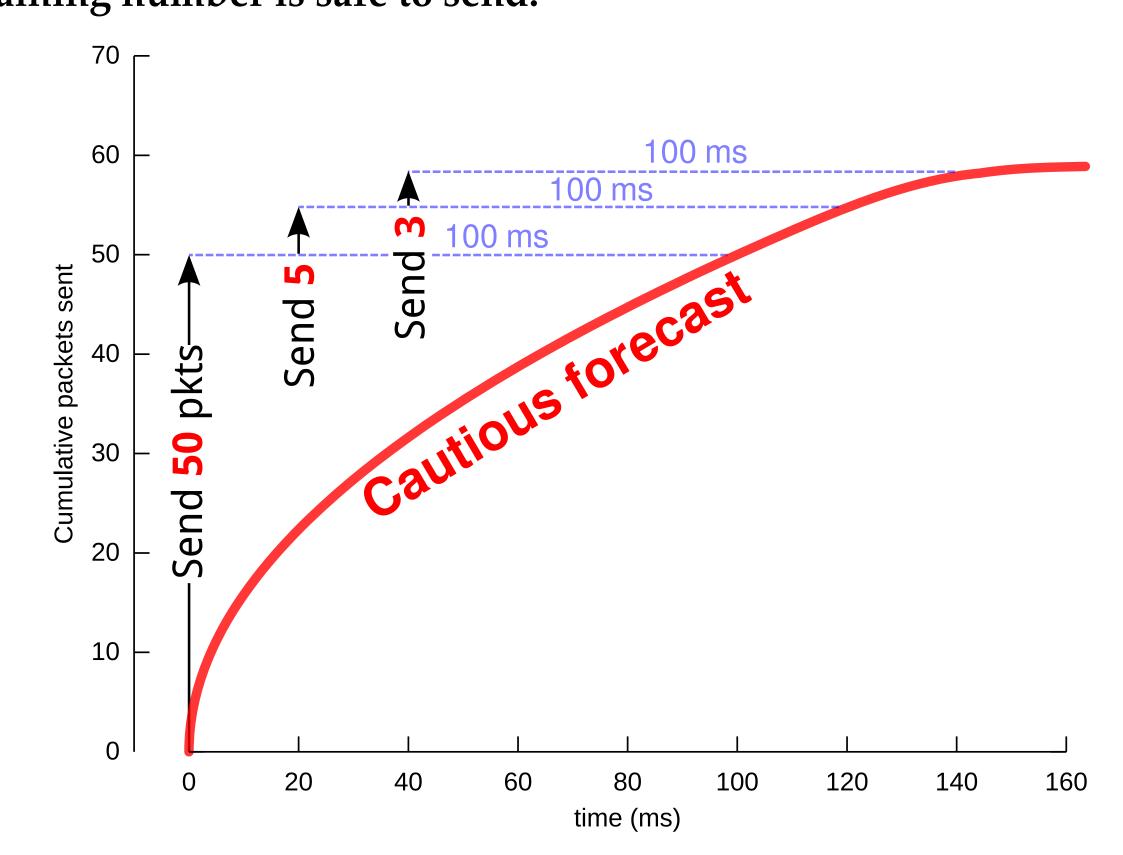
At the receiver:

- Model evolution of link rates as Brownian motion with constant volatility σ .
- Explicitly model outages, using outage escape rate λ_z .
- Cautious forecast: Find the 5th percentile of the cumulative number of packet deliveries for a certain number of ticks in the future.
- Send back forecast to sender.
- Almost all steps are precalculated.

Control

At the sender:

- Use the forecast to determine the cumulative number of packets delivered 100 ms into the future.
- Subtract number of packets already in queue.
- Remaining number is safe to send.



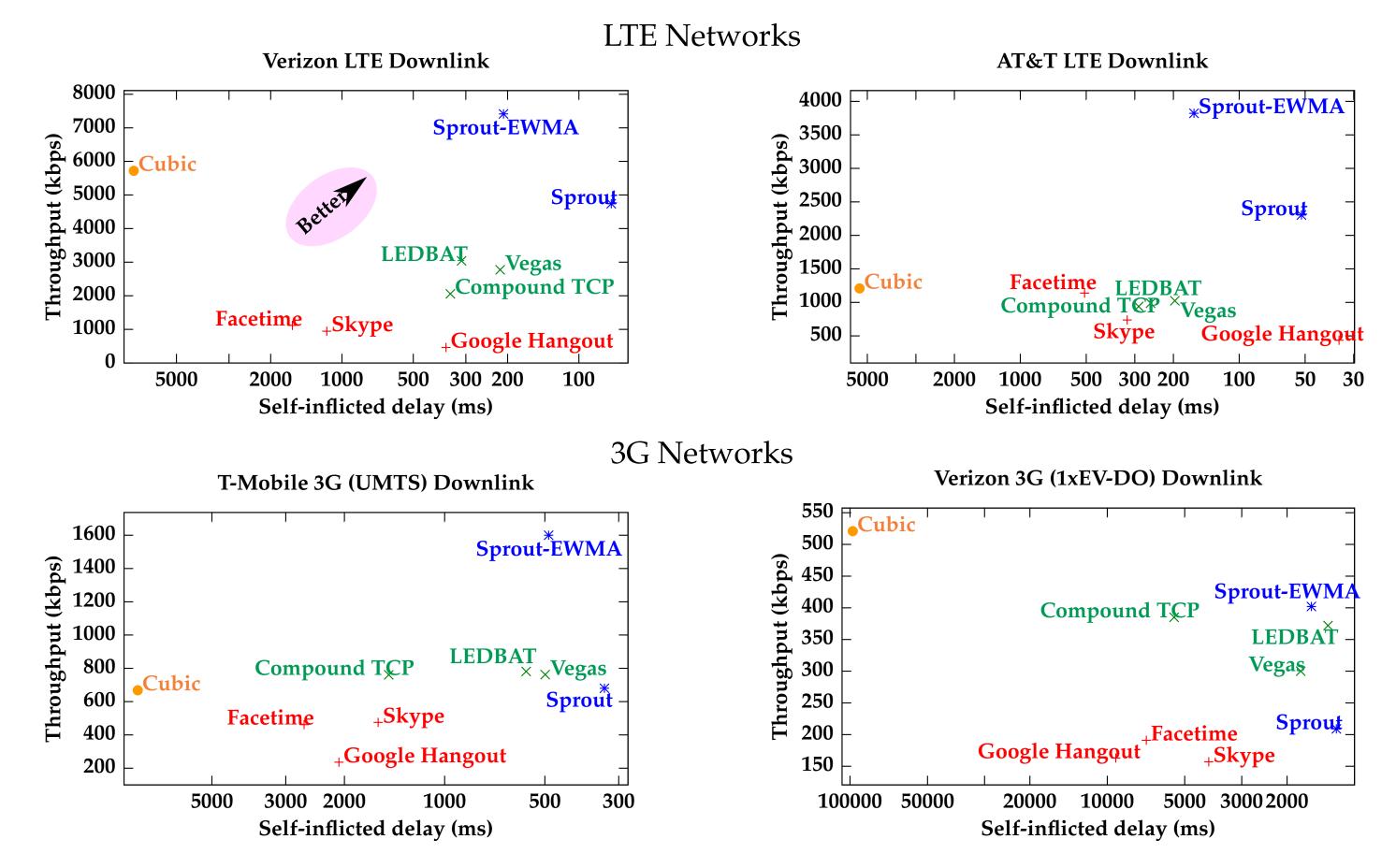
Evaluation

- Saturate a cellular link in both the uplink and downlink directions.
- Playback trace in a trace-driven link emulator.
- Measure total throughput and end-to-end delay for reconstructing 95 % of the signal.
- Also evaluated Sprout-EWMA, a simplified variant of Sprout:
- At the receiver, estimate link rate using a moving average filter.
- -Send link rate estimate to the sender, with no forecast.
- All source code was frozen before data collection.

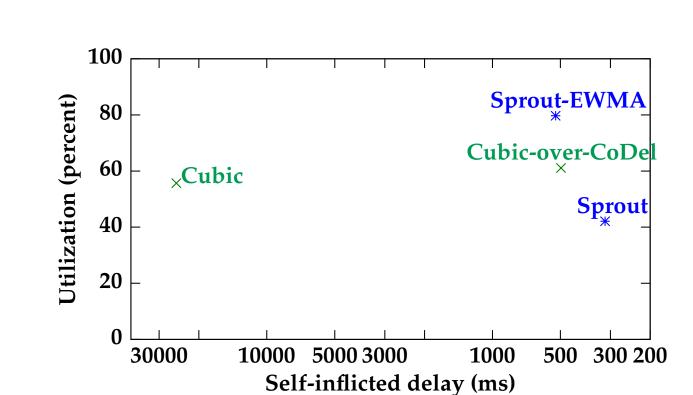
Sprout parameters used in evaluation				
Volatility σ : fixed @	$200 \frac{\mathbf{pkts}/s}{\sqrt{s}}$			
Expected outage time $1/\lambda_z$:	1 s			
Tick length:	20 ms			
Forecast length:	160 ms			
Delay target:	$100 \ ms$			
Risk tolerance:	5%			

Results

Sprout outperforms other end-to-end protocols



Sprout competes with AQM even though it is end-to-end



Sprout, used as a tunnel, successfully isolates competing traffic

	Direct	via Sprout	Benefit
Cubic throughput	8336 kbps	3776 kbps	0.5x (= worse)
Skype throughput	78 kbps	490 kbps	6x
Skype 95% delay	6.0 s	0.17 s	35x