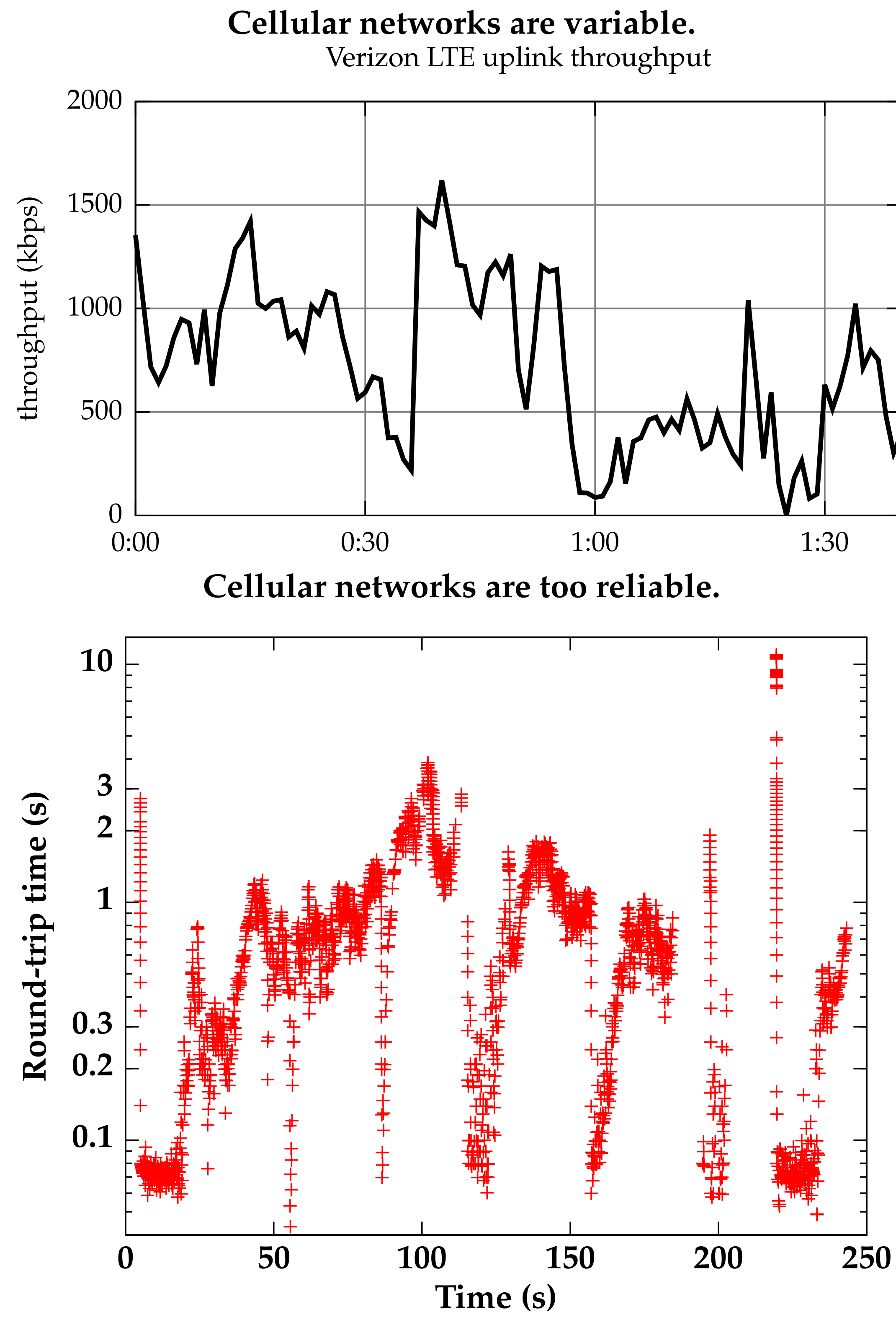


Sprout: Stochastic Forecasts Achieve High Throughput and Low Delay over Cellular Networks

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Problem setting



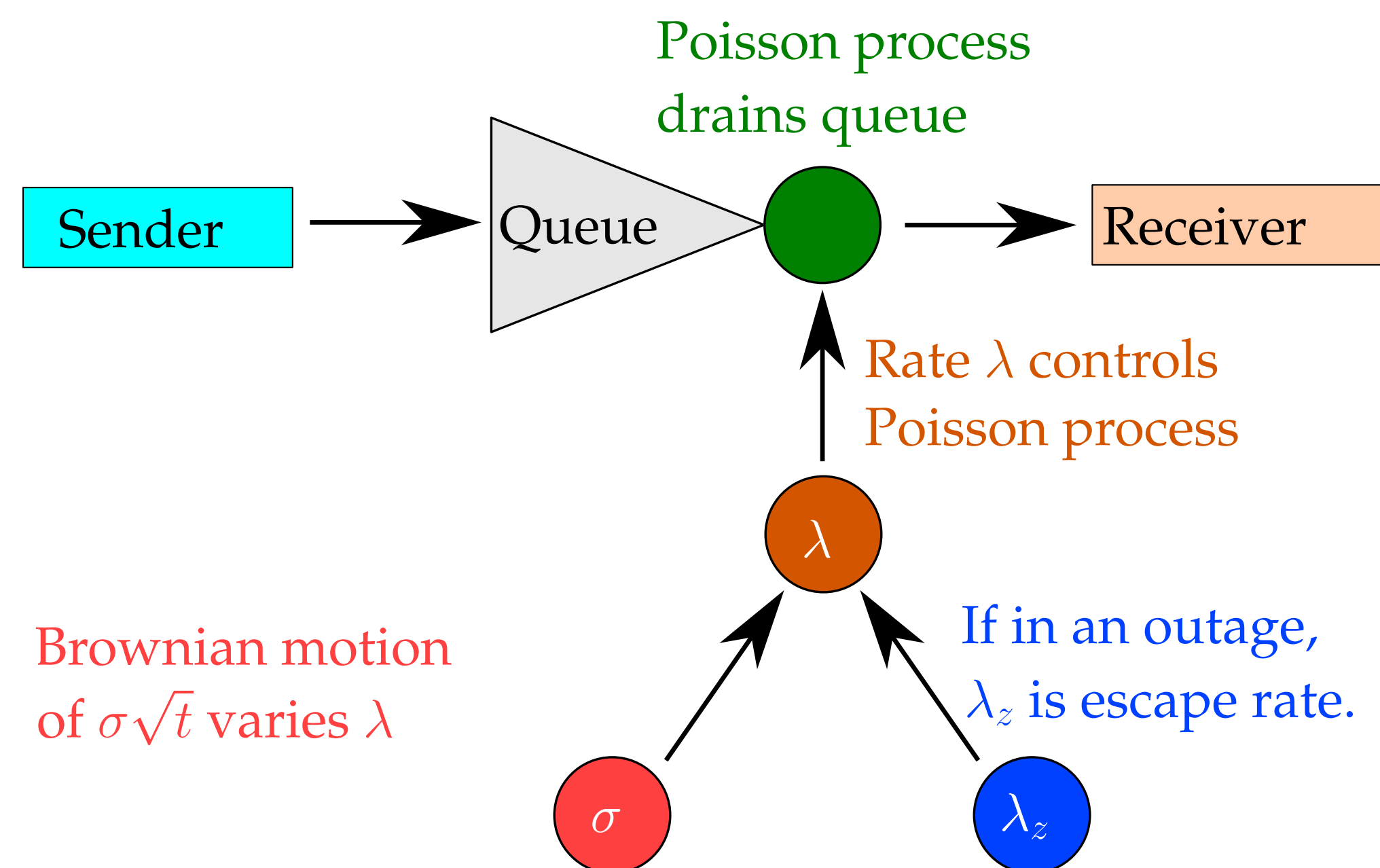
Interactive apps perform poorly because they are reactive.

Sprout's goal

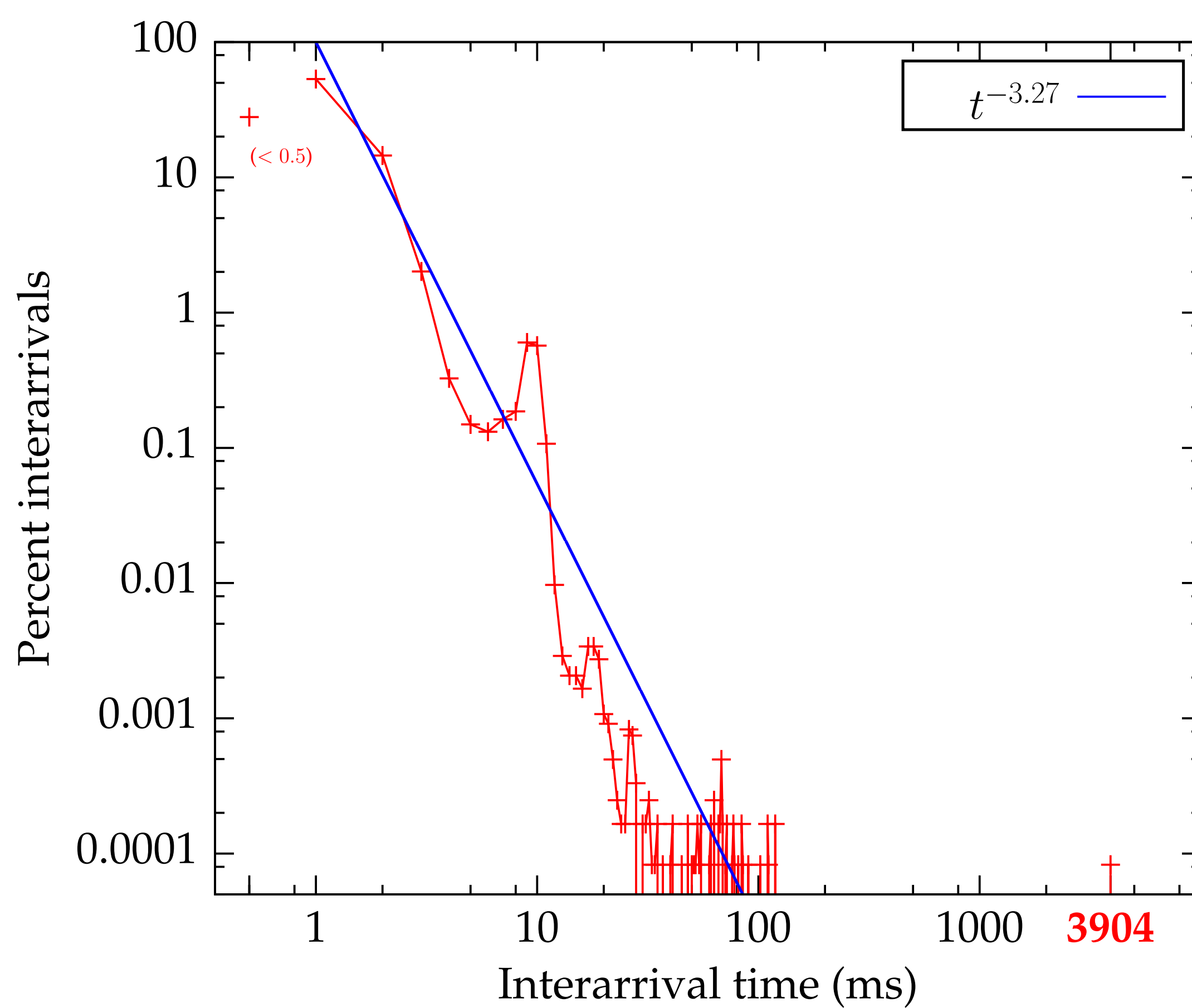
Maximize throughput subject to a bounded risk of delay exceeding 100 ms.

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 .
- Compute the likelihood $L(x)$ that a Poisson process with rate λ generated k bytes.

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

- Update current probability distribution using $L(x)$

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

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

Prediction

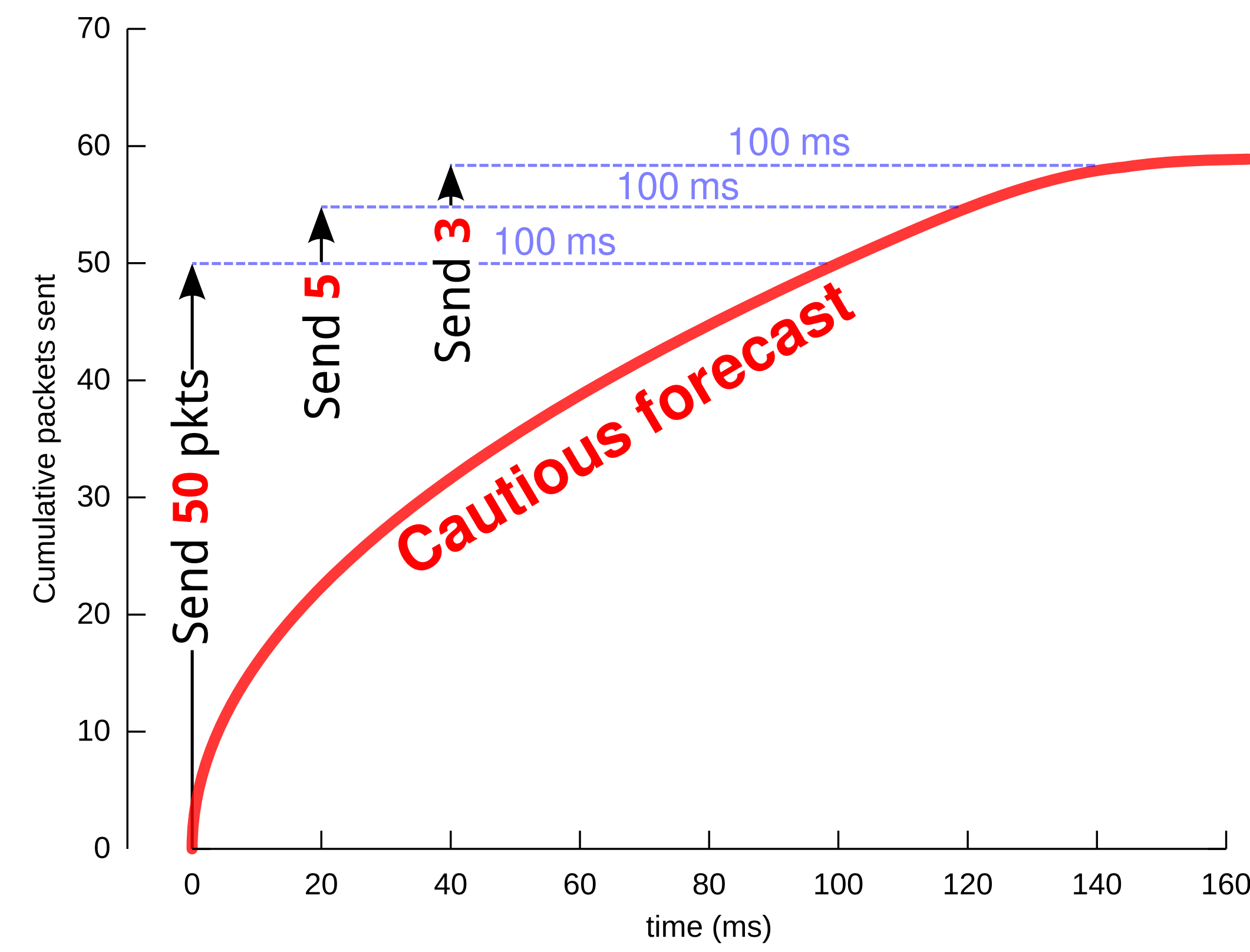
At the receiver:

- 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:

- Determine the cumulative number of bytes delivered 100 ms into the future.
- Subtract number of bytes already in queue.
- Remaining bytes are "safe" to send.



Evaluation

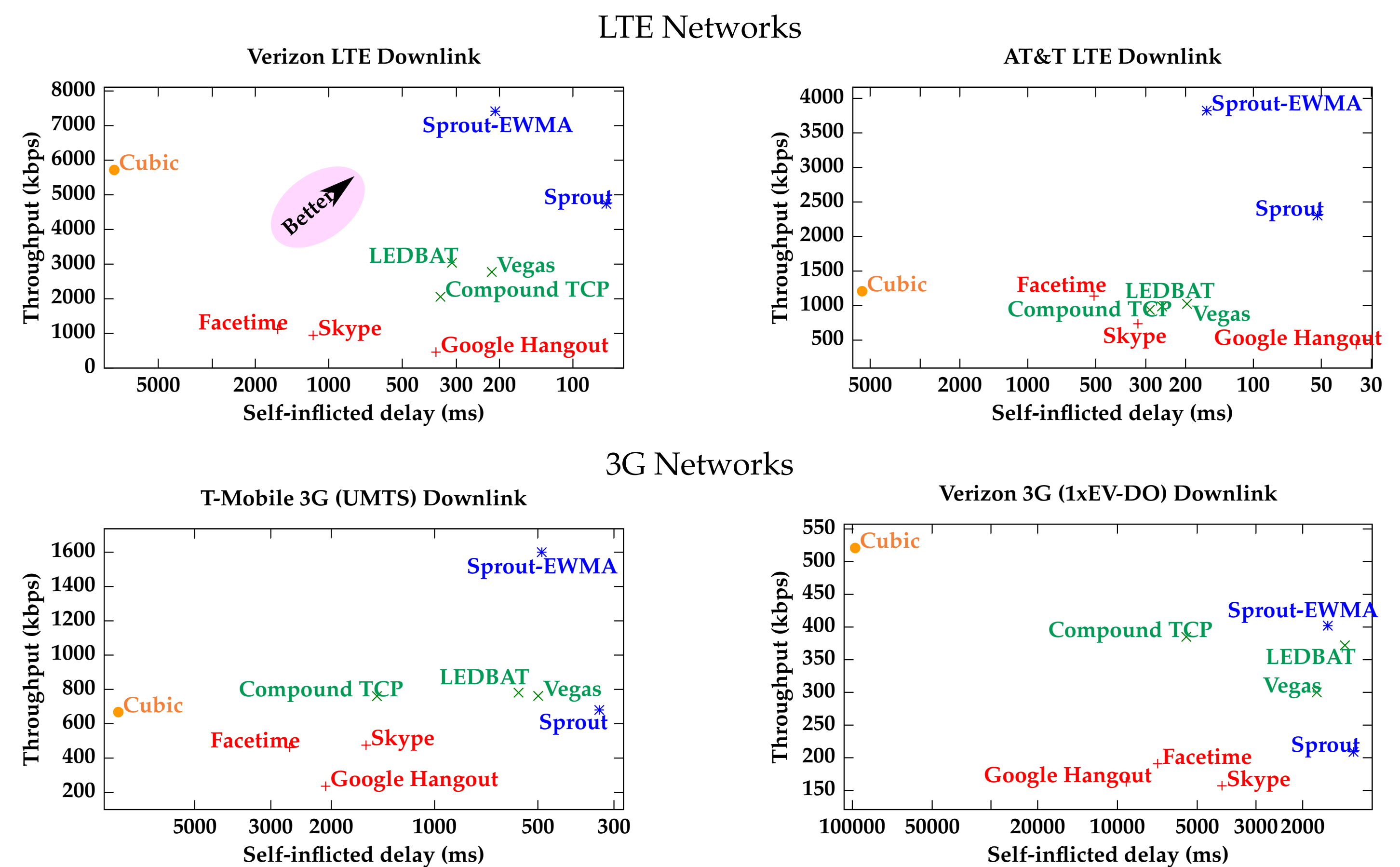
- Saturate a cellular link in both the uplink and downlink directions.
- Playback trace in a trace-driven link emulator.
- Measure total throughput and end-to-end delay for reconstructing 95 % of the signal.
- Also evaluated Sprout-EWMA, a simplified variant of Sprout:
 - At the receiver, estimate link 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

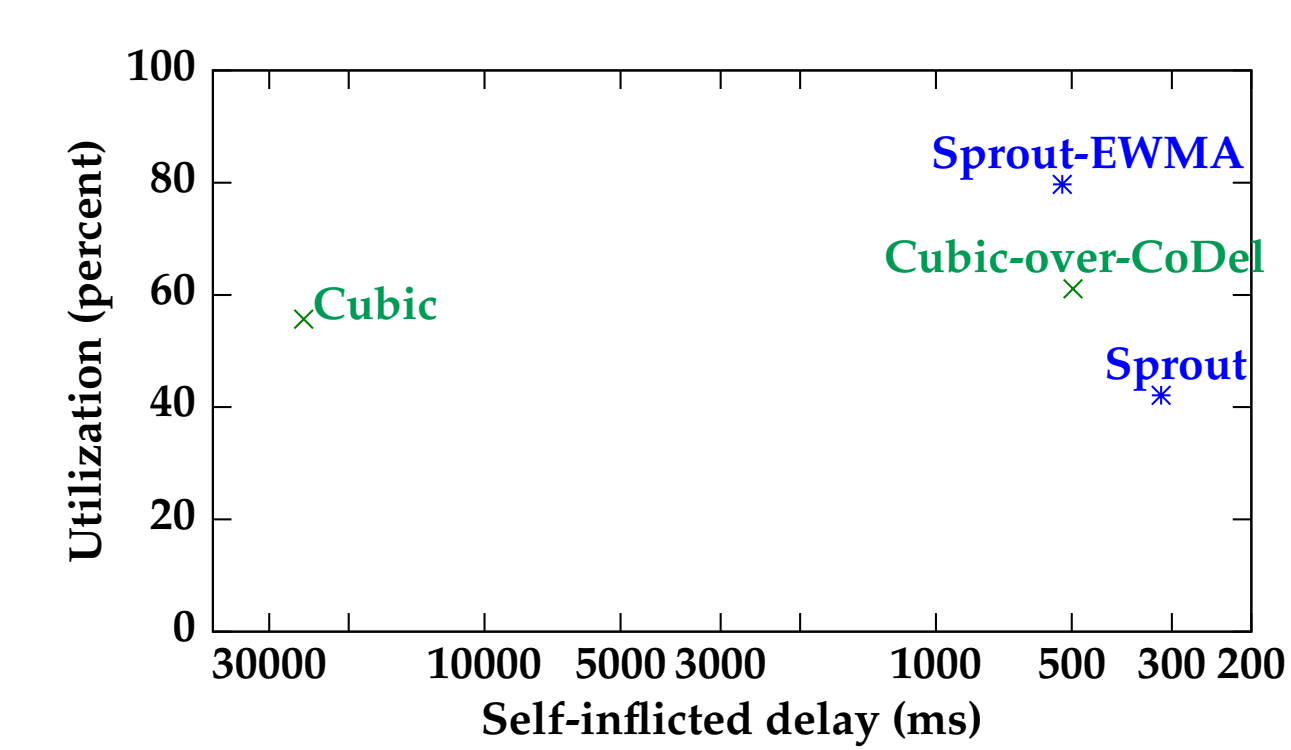
Volatility σ : fixed @	200 $\frac{\text{pkts}}{\sqrt{s}}$
Expected outage time $1/\lambda_z$:	1 s
Tick length:	20 ms
Forecast length:	160 ms
Delay target:	100 ms
Risk tolerance:	5%

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