An experimental study of the learnability of congestion control

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Designing congestion-control protocols today

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- Formulate a mental model of the target network
- Decide on the protocol's goal
- Design a protocol to achieve this goal
- Can either be implicit or explicit

But, the model is always wrong!

- Lost throughput due to stochastic loss
- Bufferbloat when queues are incorrectly sized
- Incast in datacenters

Our work

- Can we formalize this design process ...

Our work

- Can we formalize this design process ...
- and quantify the consequences of model mismatch?

Contributions

- Formalize learnability in the context of congestion control
- Use it to answer:
  - Do we need to know the link speed exactly?
  - What is the cost of backwards compatibility?
  - Do we need to know the topology exactly?

Approach

- Specify a *training scenario*.
  - Topology
  - Locations of senders and receiver
  - Application workload
  - Buffer size and queuing discipline
- Specify an *objective function*.
- Synthesize protocol automatically.
- Evaluate on a *testing scenario* inside ns-2

Automated protocol synthesis

- Find best protocol, given an imperfect network model
- The problem is hard to solve in general
- Rely on Remy[1] to produce congestion-control protocols.

[1] KW and Hari Balakrishnan, **TCP ex Machina: Computer-Generated Congestion Control**, *SIGCOMM 2013*

Caveats and non-goals

- Very simple, controlled experiments
- Results could change with better protocol-design tools
- Not trying to understand Remy's internals

Is using Remy reasonable?

- Training scenario:

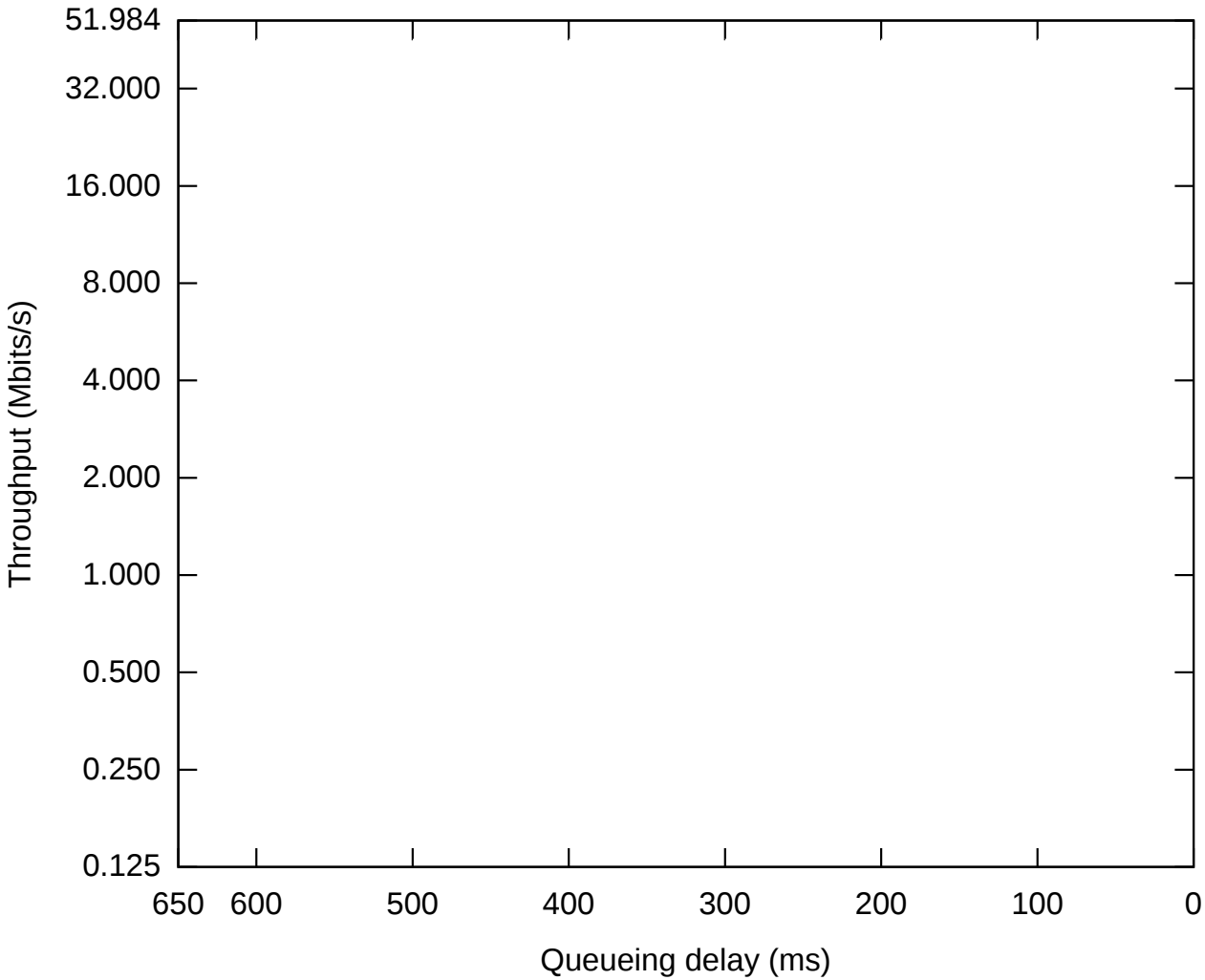
Link speed	32 Mbits/sec
Minimum RTT	150 ms
Topology	Dumbbell
Number of senders	2
Workload	1 sec ON/OFF times
Buffer size	5 BDP
Objective function	$\sum$ log(throughput) - log(delay)

- Testing scenario identical to training scenario

Is using Remy reasonable?

- A hypothetical centralized scheme (CEN)
  - Every time a sender turns ON/OFF, solve $\sum$ log (throughput)
  - Set each sender's rate using obtained solution
  - Zero queuing delay

Is using Remy reasonable?



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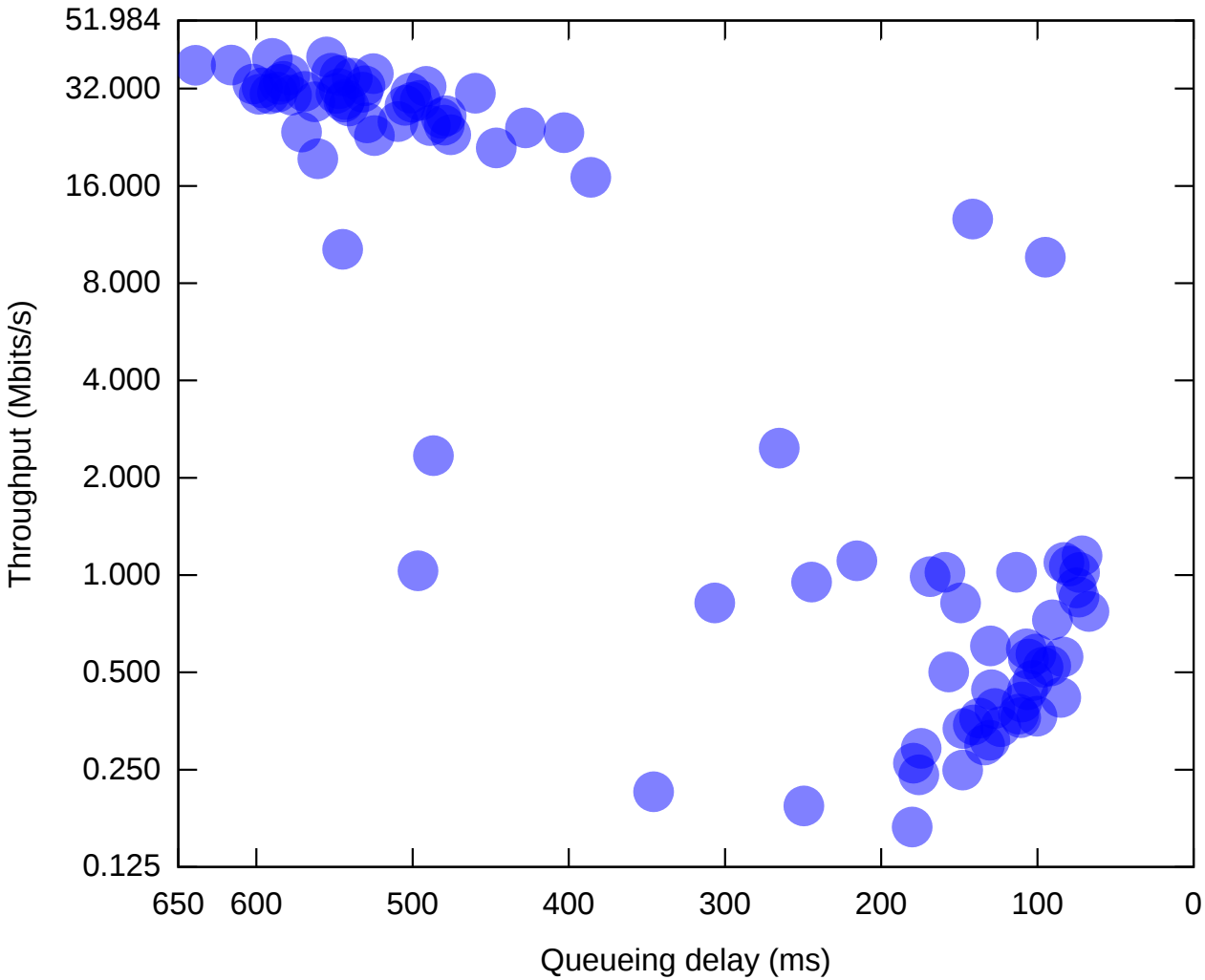

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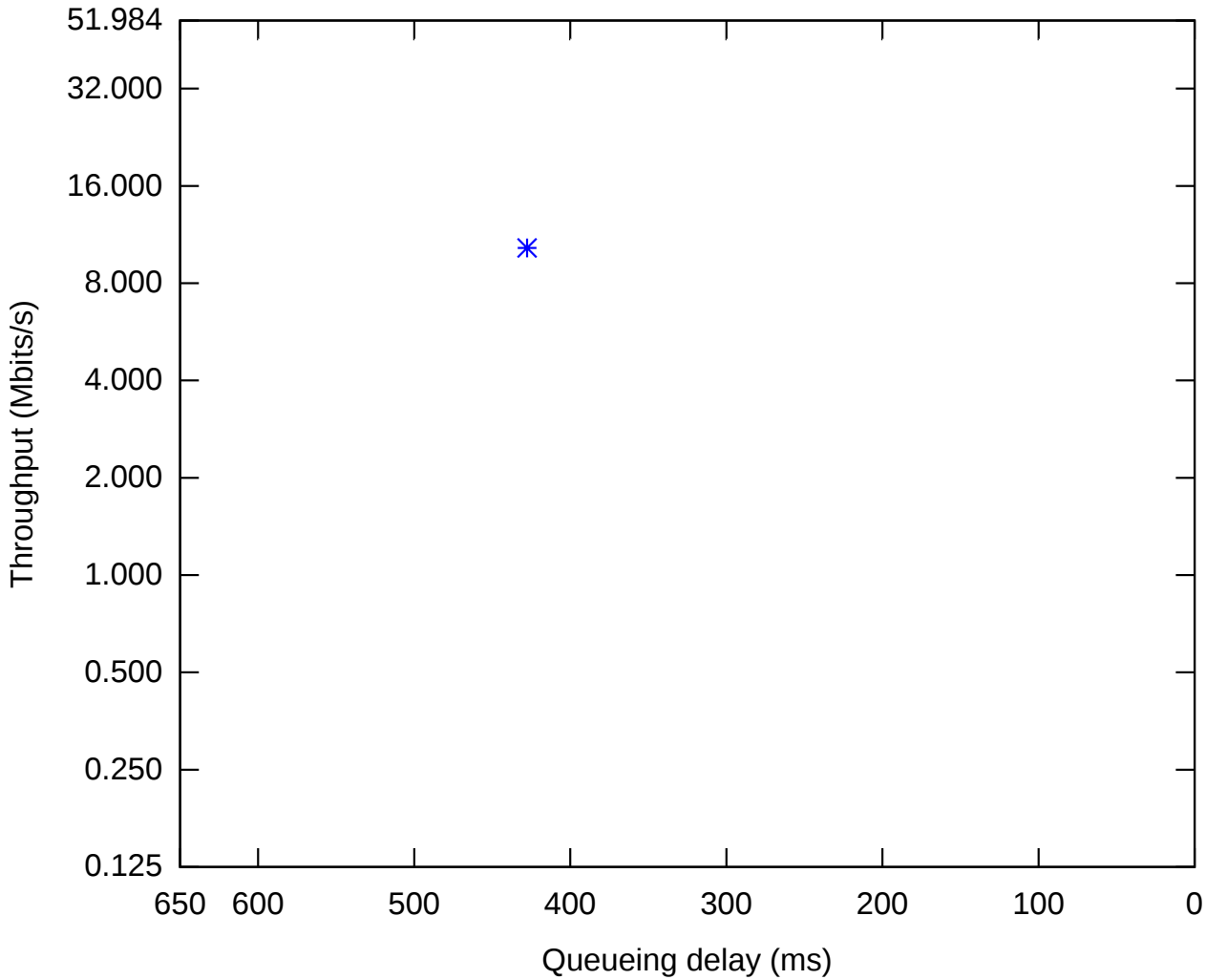

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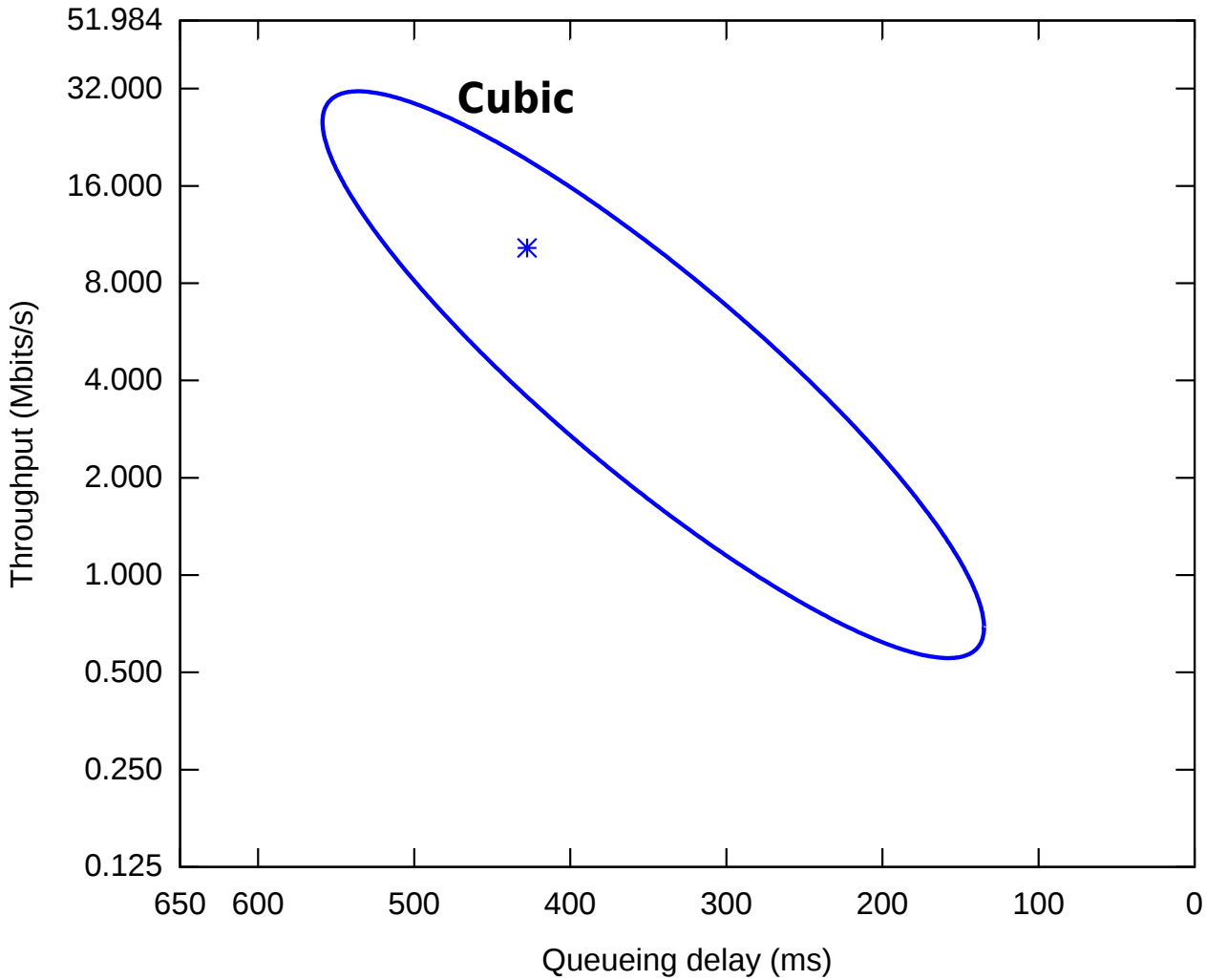

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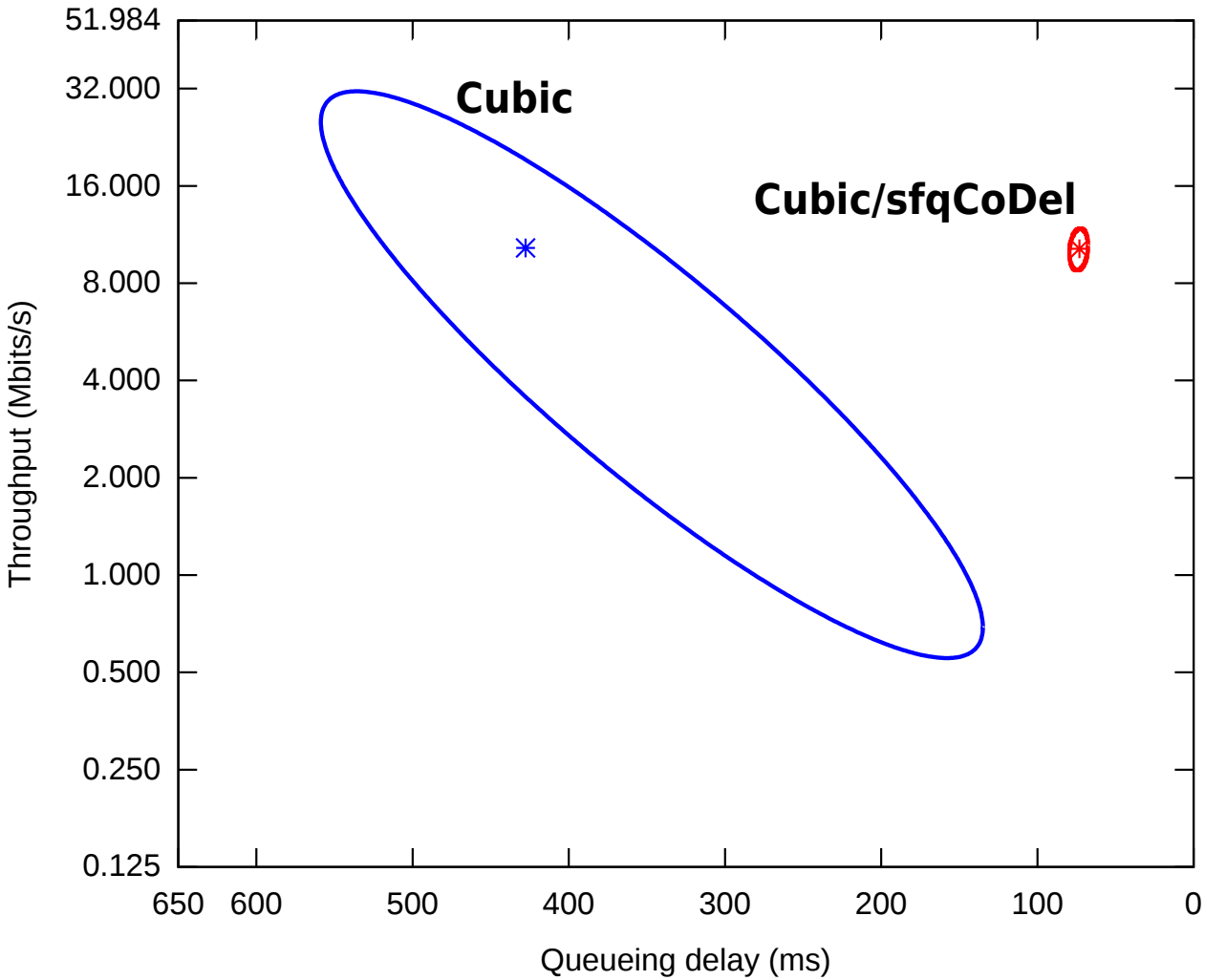

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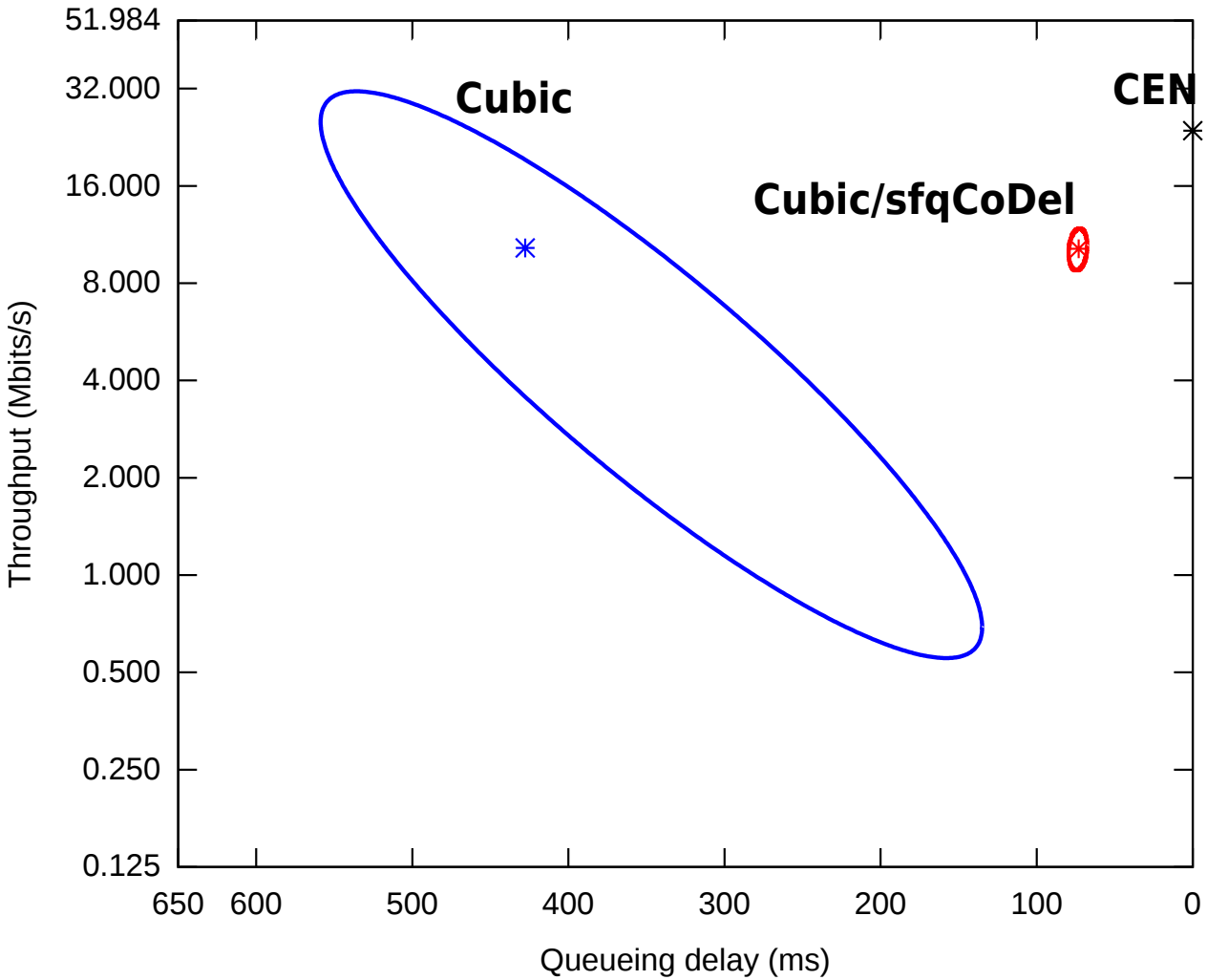

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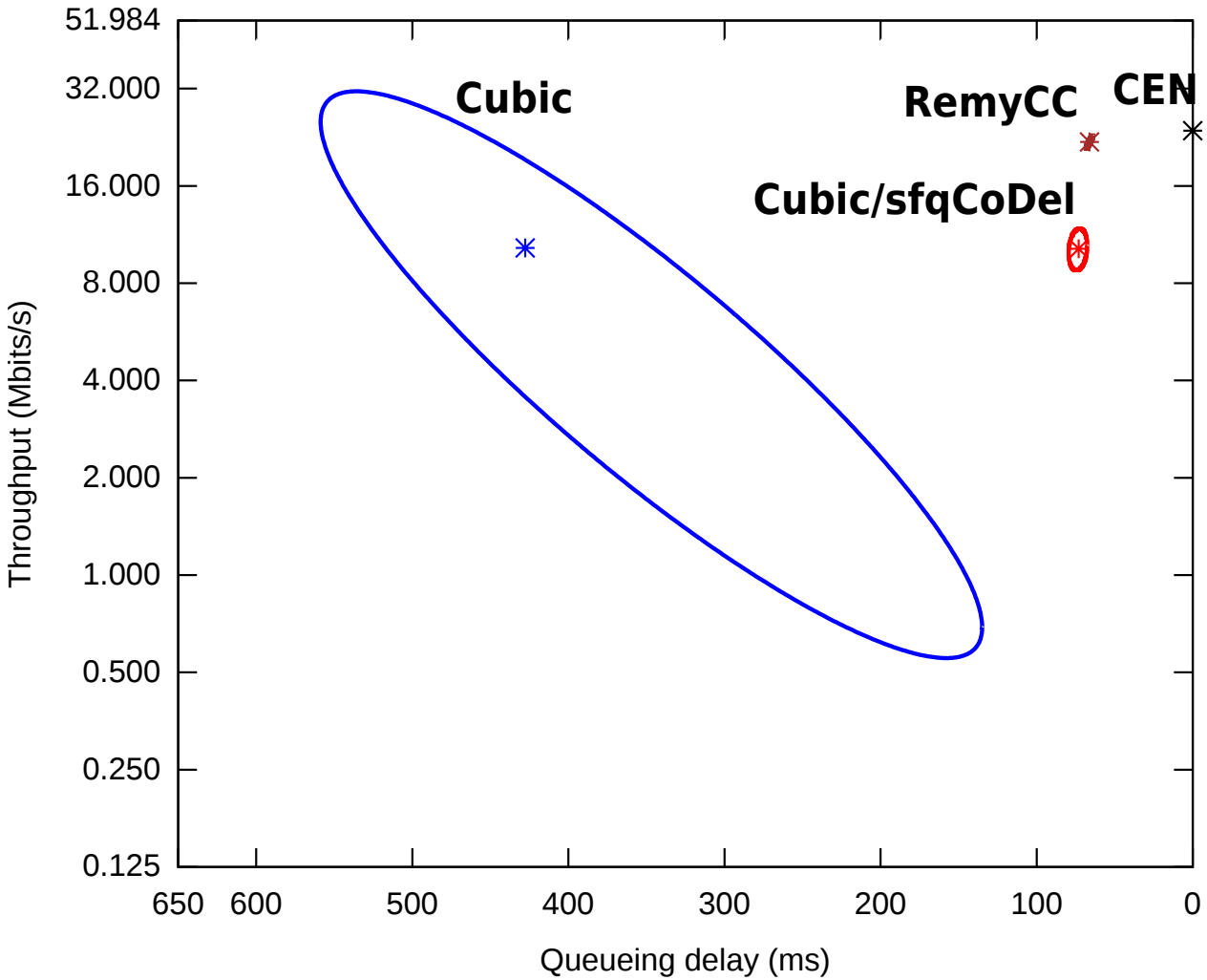

The cost of generality, or forwards-compatibility

RemyCC	**Link rates**	**RTT**	**Senders**	ON/OFF time	Topology
1000x	1–1000 Mbps	150 ms	2	1 sec	Dumbbell
100x	3.2–320 Mbps	150 ms	2	1 sec	Dumbbell
10x	10–100 Mbps	150 ms	2	1 sec	Dumbbell
2x	22–44 Mbps	150 ms	2	1 sec	Dumbbell

Table : Training scenarios for forwards-compatibility experiment

Link rates	**RTT**	**Senders**	ON/OFF time	Topology
1–1000 Mbps	150 ms	2	1 sec	Dumbbell

Table : Testing scenarios for forwards-compatibility experiment

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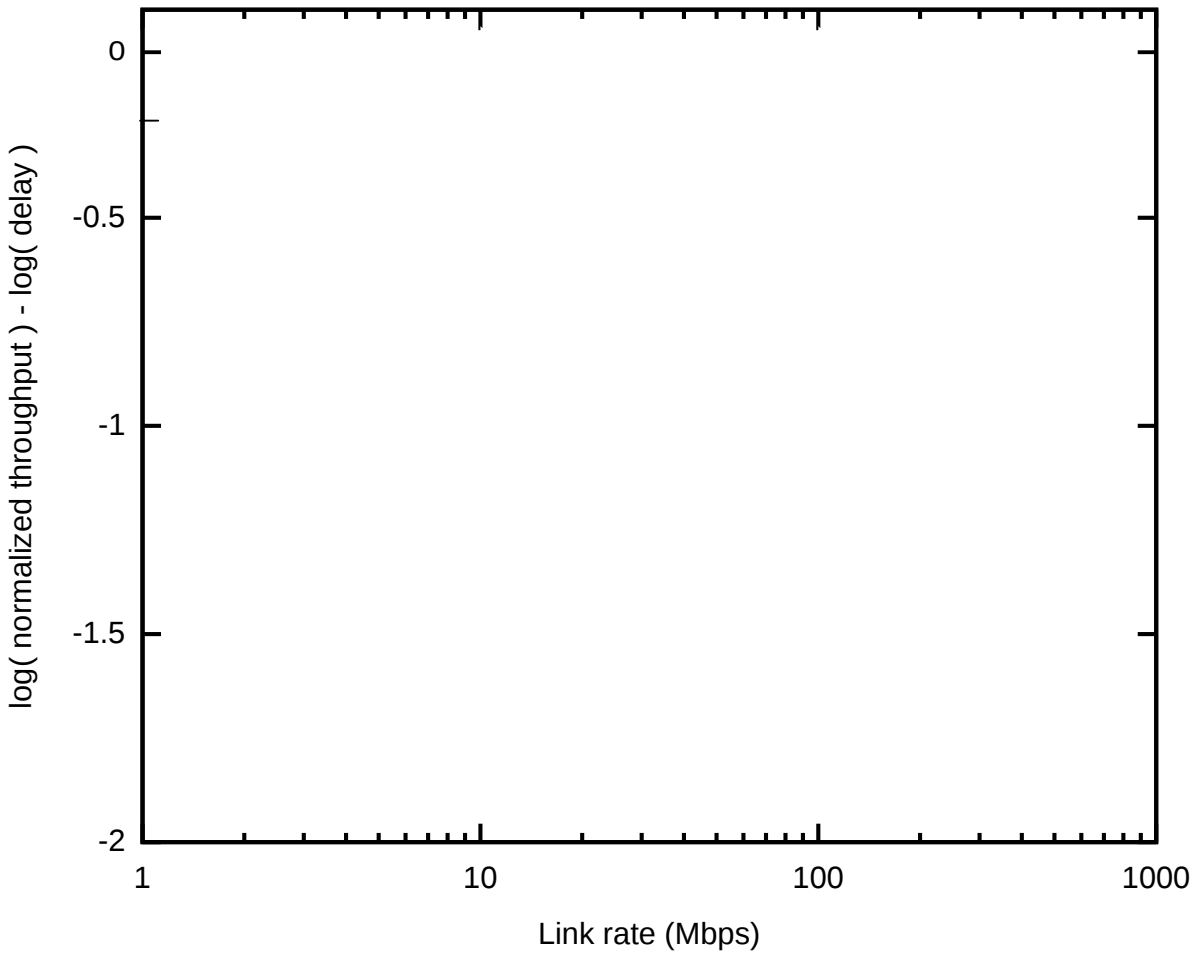

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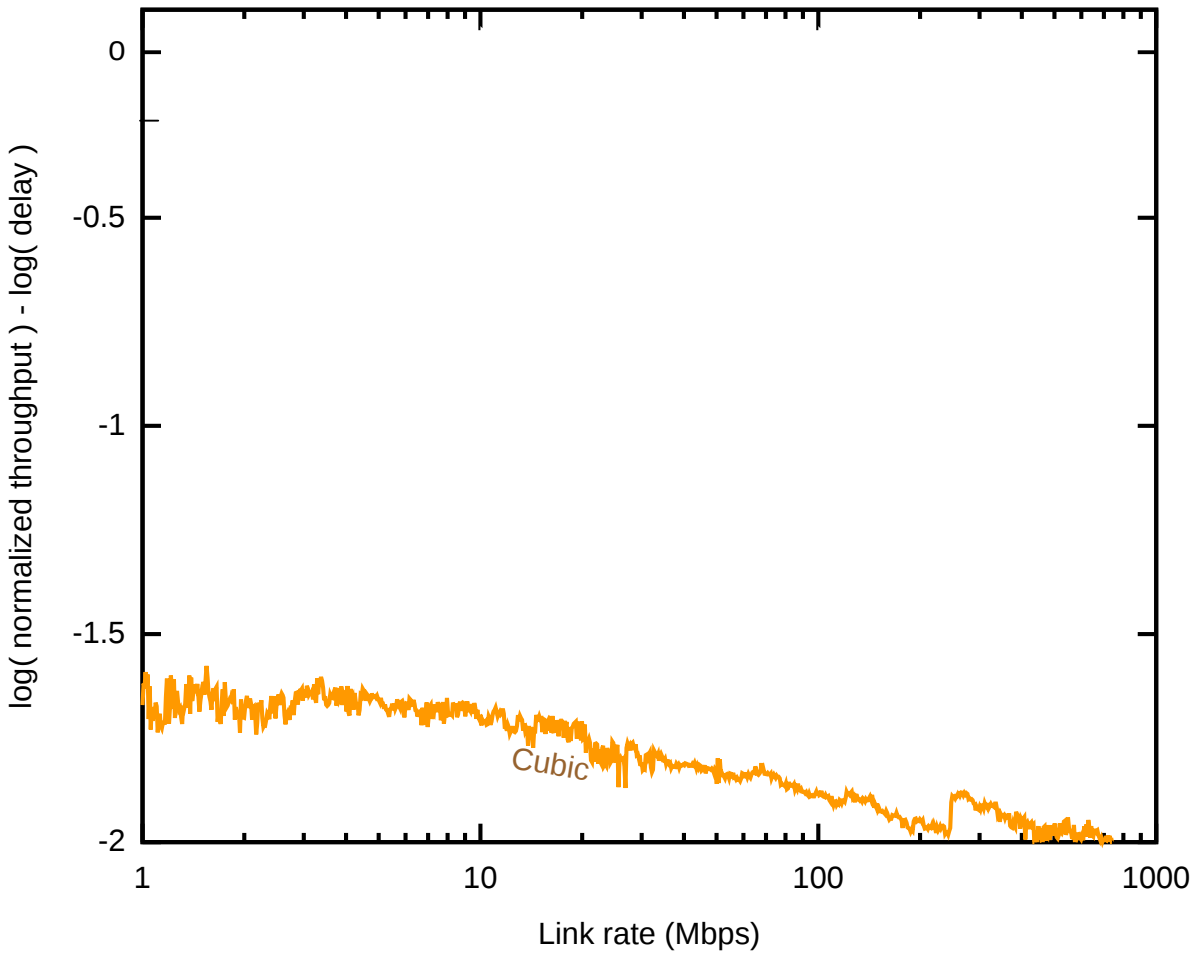

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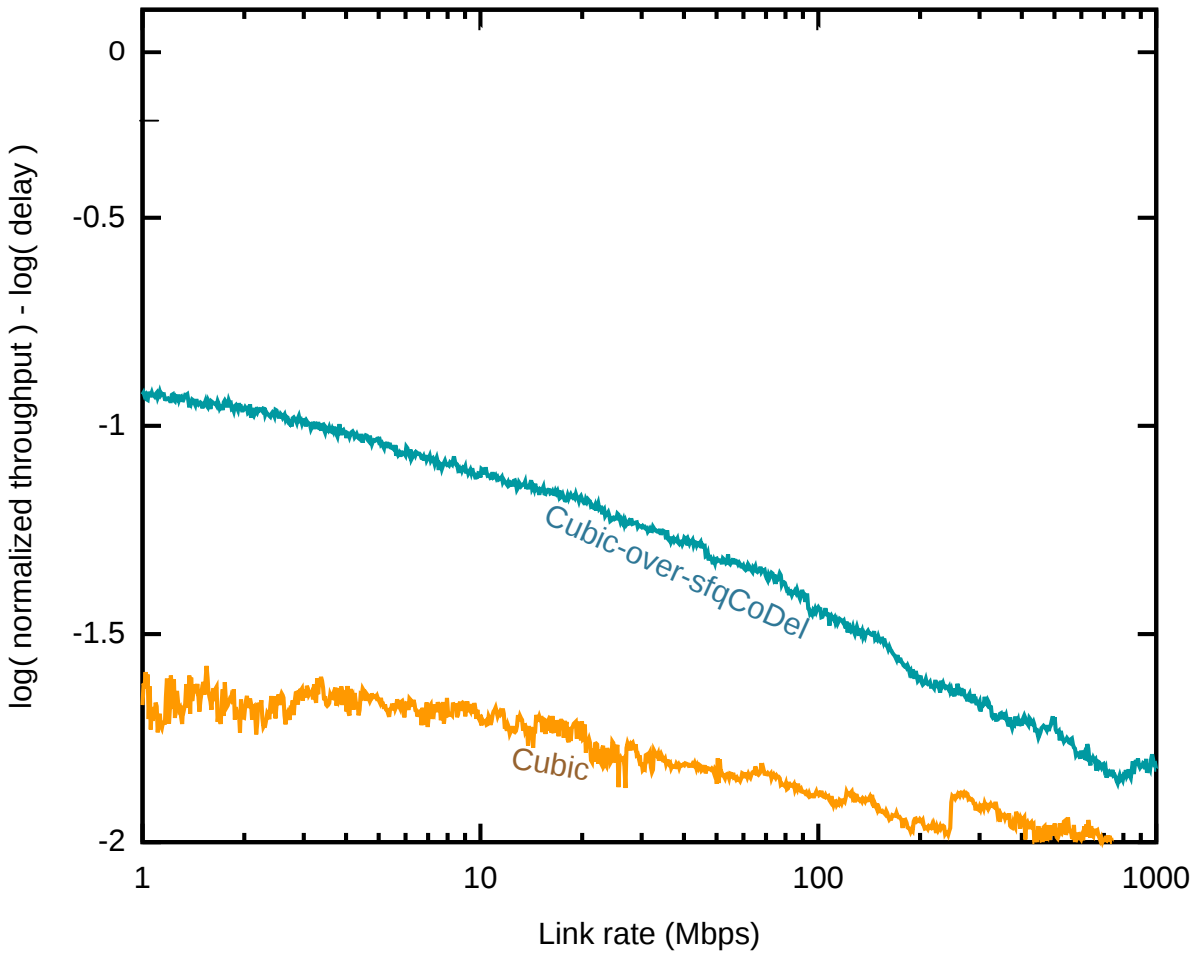

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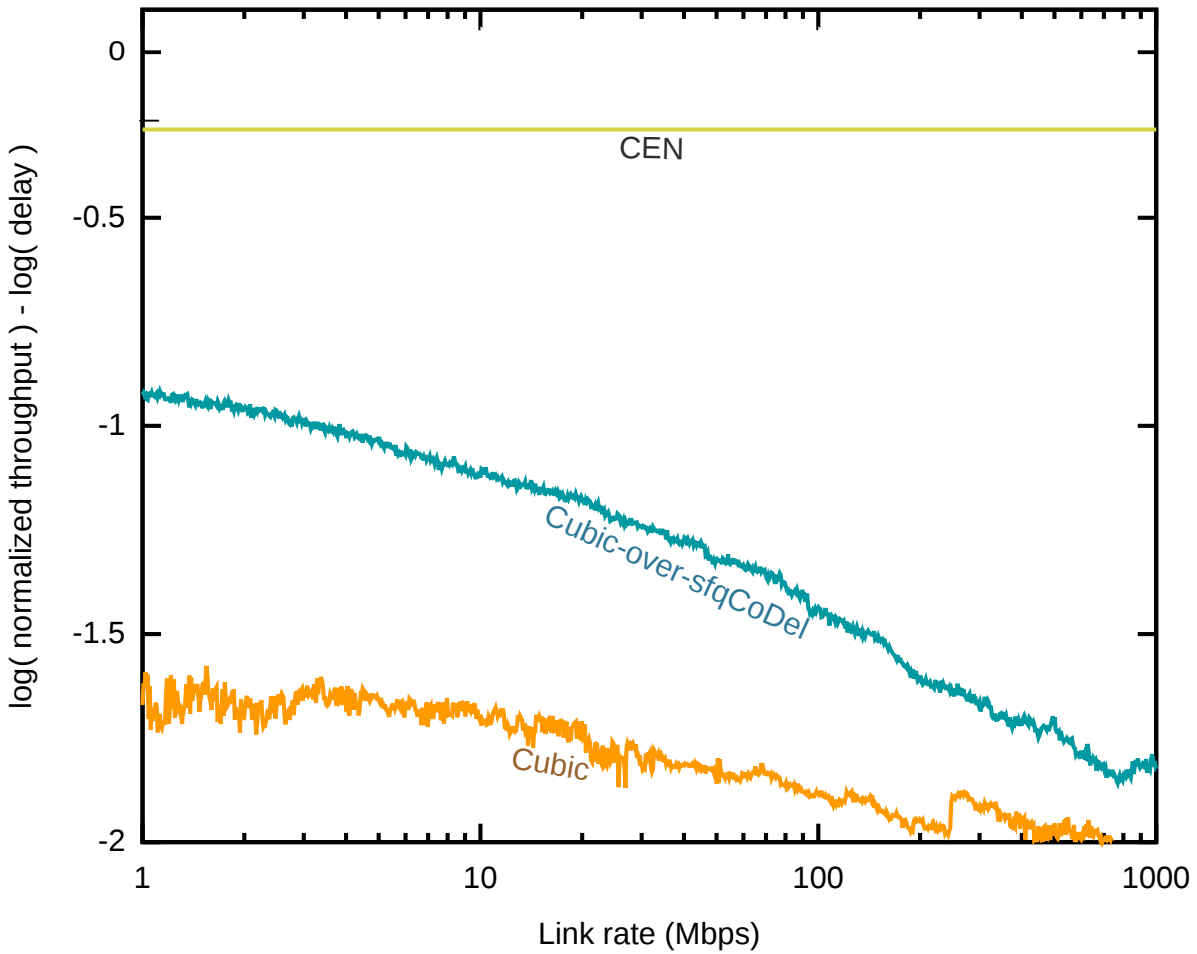

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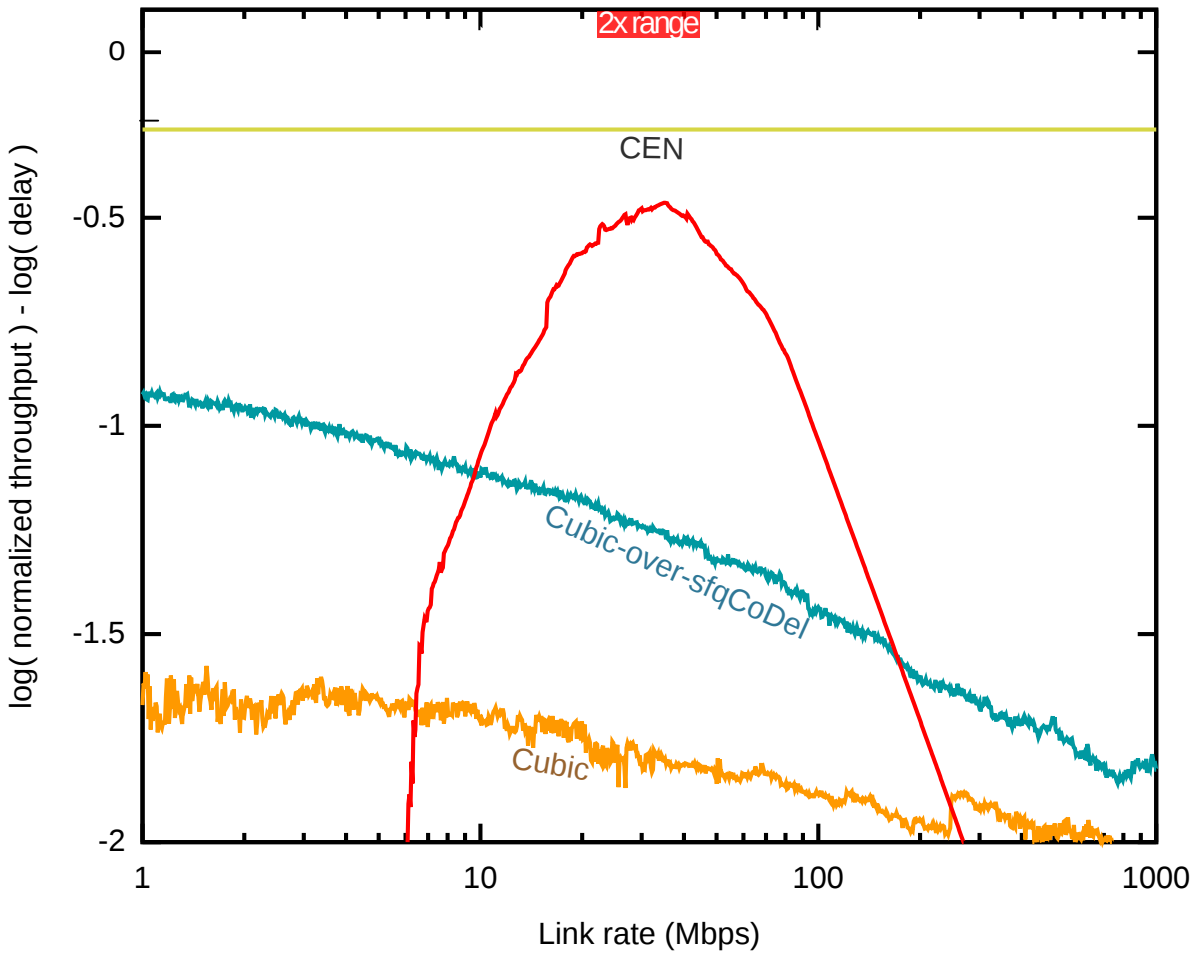

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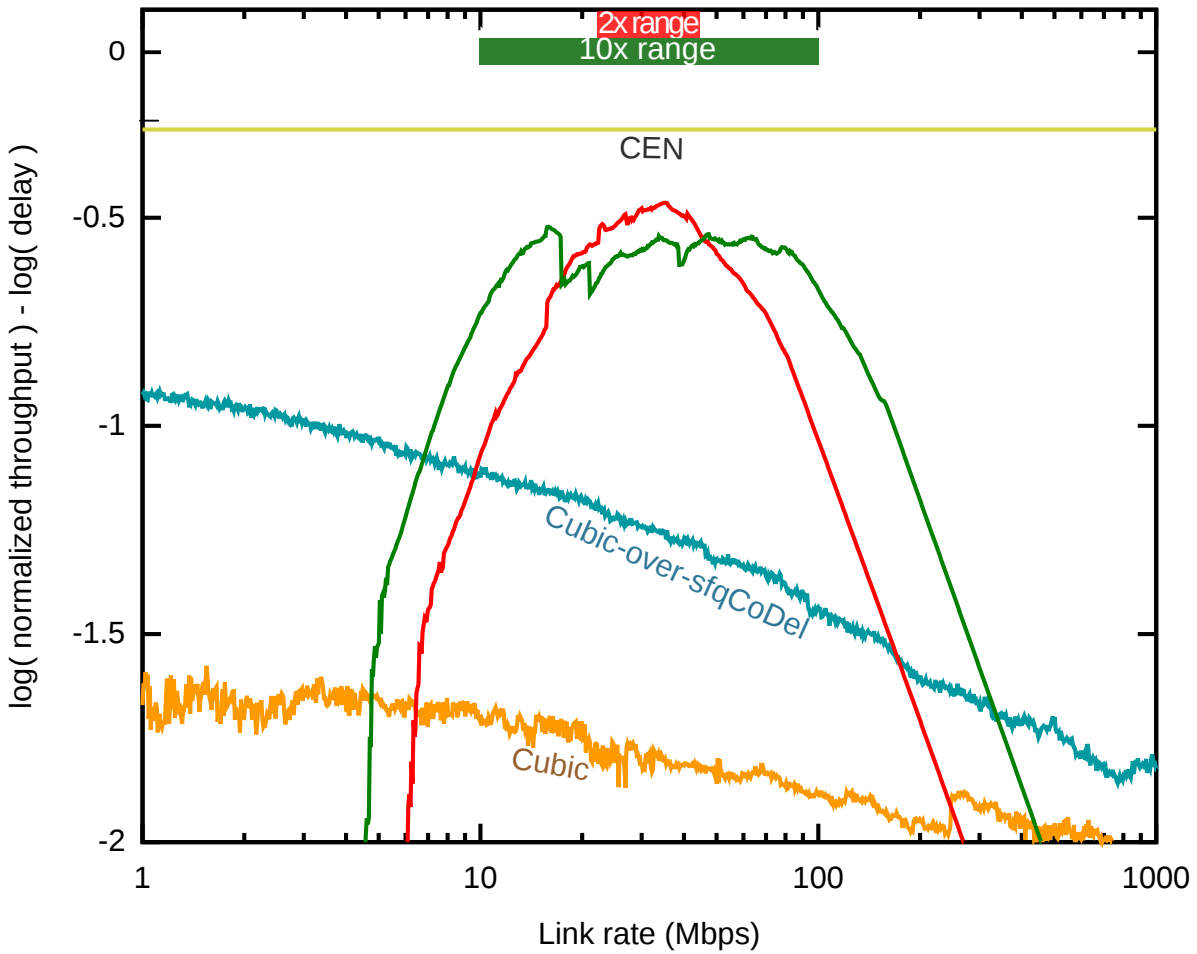

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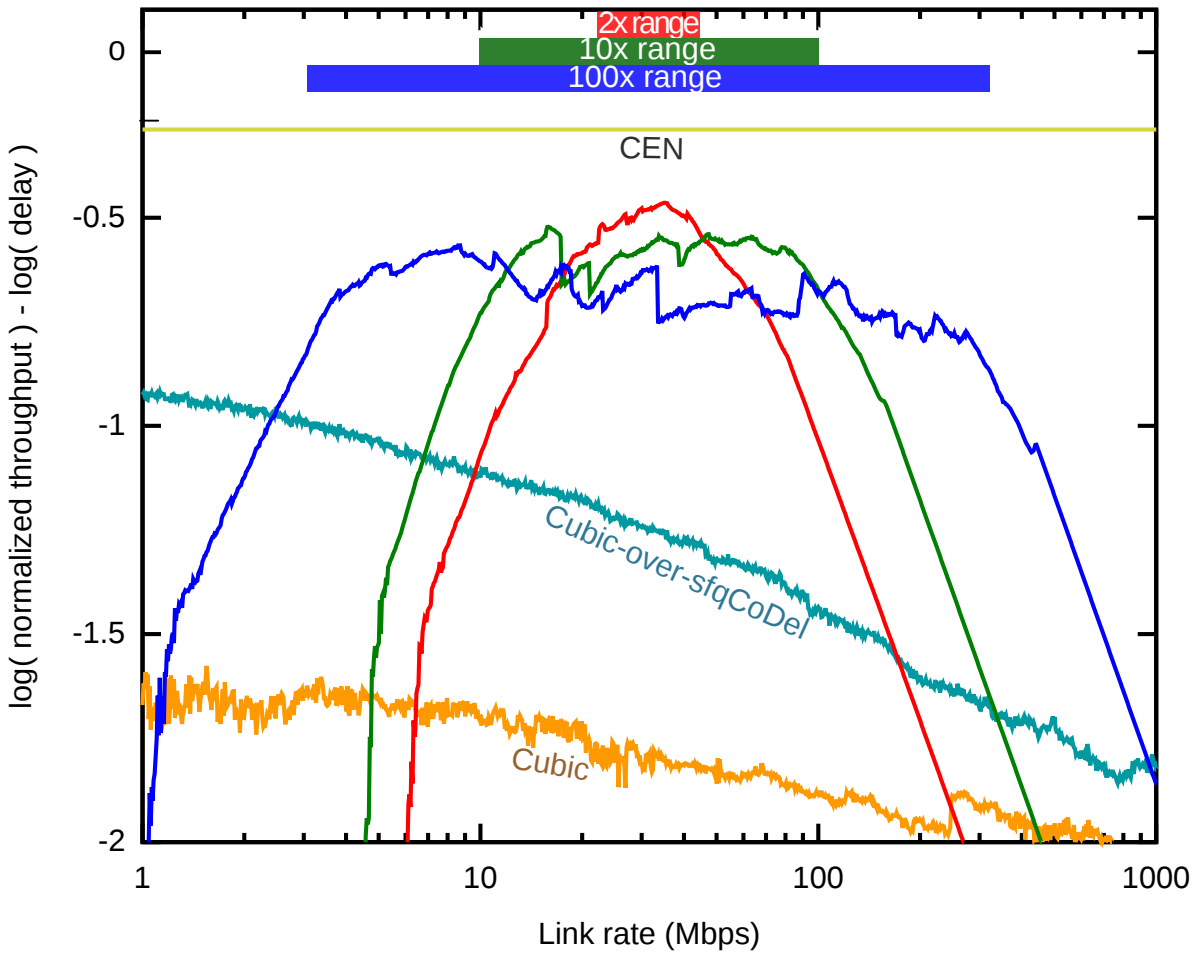

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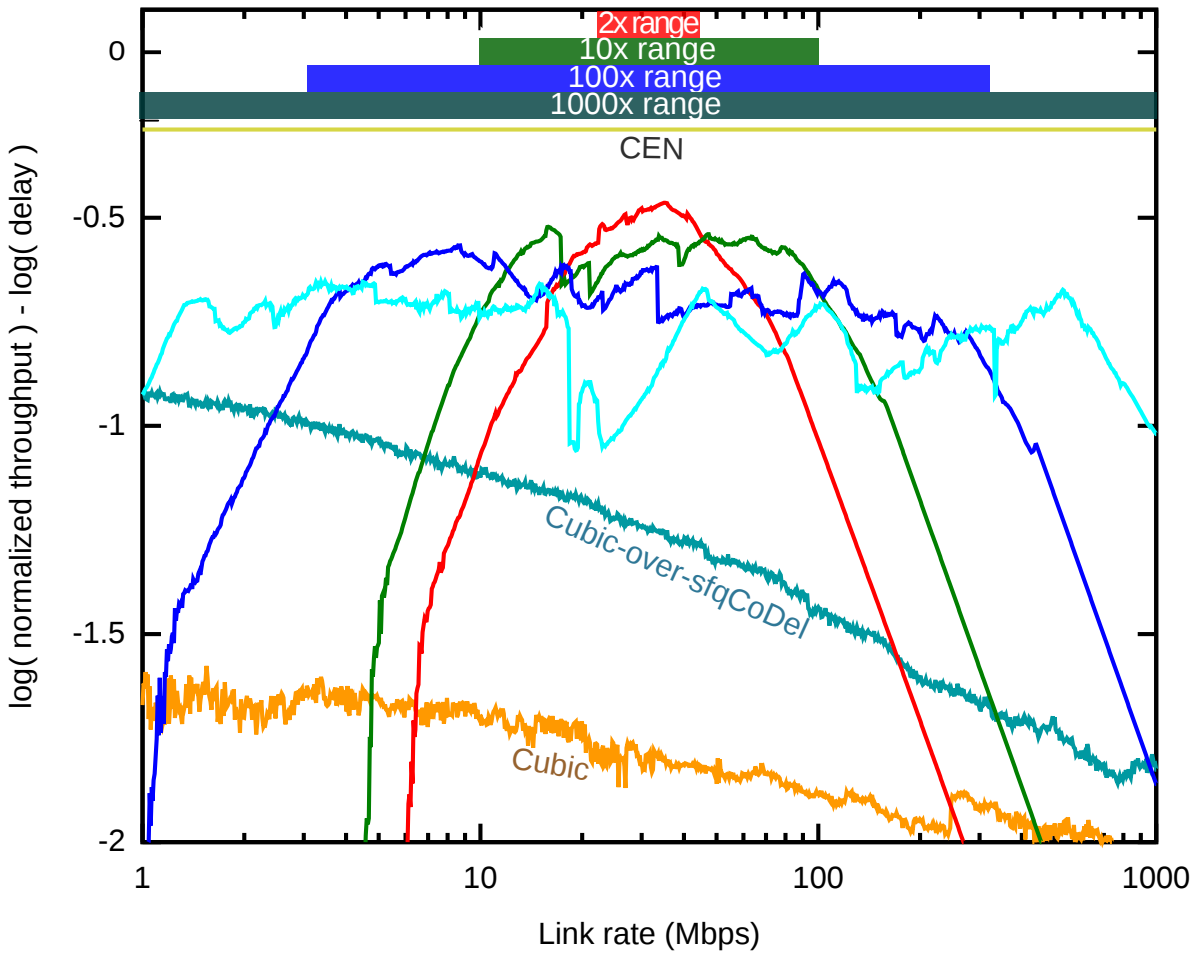


Can we design a RemyCC that is TCP aware?

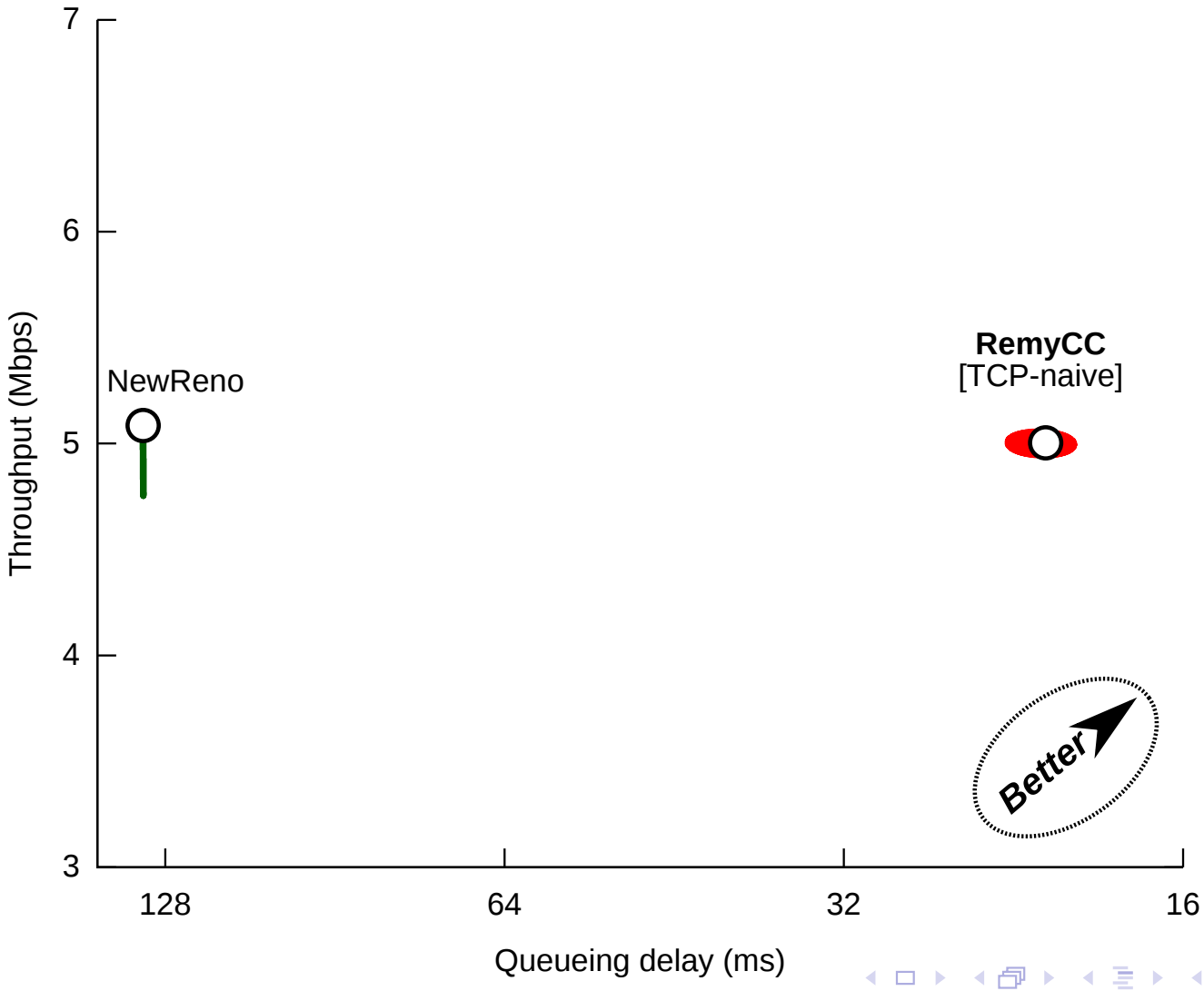
RemyCC	**Link rates**	**RTT**	**Senders**	ON/OFF time	Topology
TCP-aware	9–11 Mbps	100 ms	2 Remy 1 Remy, 1 AIMD	5 sec ON/OFF 5 sec ON, 10 ms OFF	Dumbbell
TCP-naive	9–11 Mbps	100 ms	2 Remy	5 sec ON/OFF 5 sec ON, 10 ms OFF	Dumbbell

Table : Training scenarios

Link rates	**RTT**	**Senders**	ON/OFF time	Topology
10 Mbps	100 ms	2 TCP-aware	5 sec ON, 10 ms OFF	Dumbbell
10 Mbps	100 ms	2 TCP-naive	5 sec ON, 10 ms OFF	Dumbbell
10 Mbps	100 ms	TCP-aware, AIMD	5 sec ON, 10 ms OFF	Dumbbell
10 Mbps	100 ms	TCP-naive, AIMD	5 sec ON, 10 ms OFF	Dumbbell
10 Mbps	100 ms	2 AIMD	5 sec ON, 10 ms OFF	Dumbbell

Table : Testing scenarios

RemyCC competing against itself



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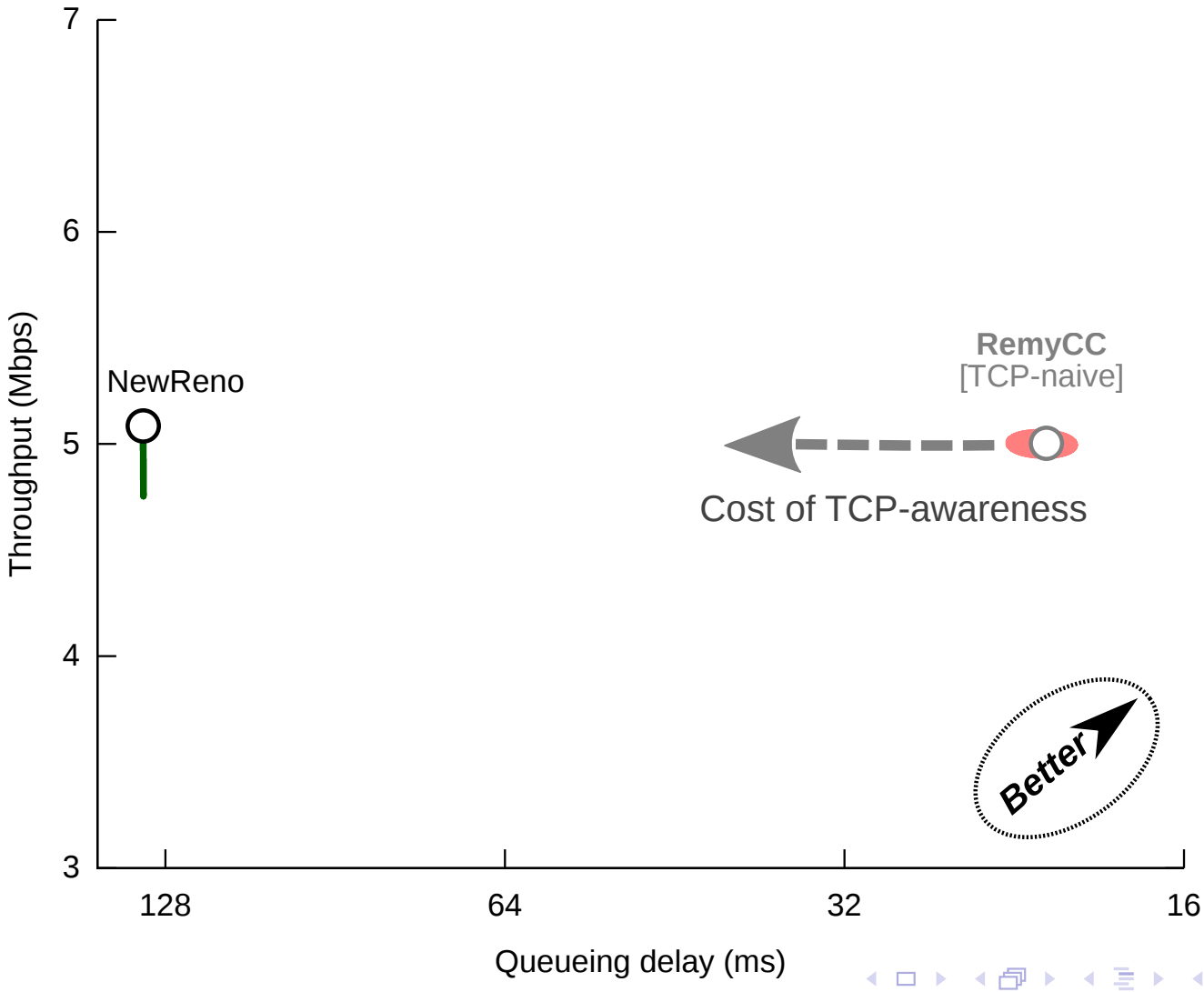

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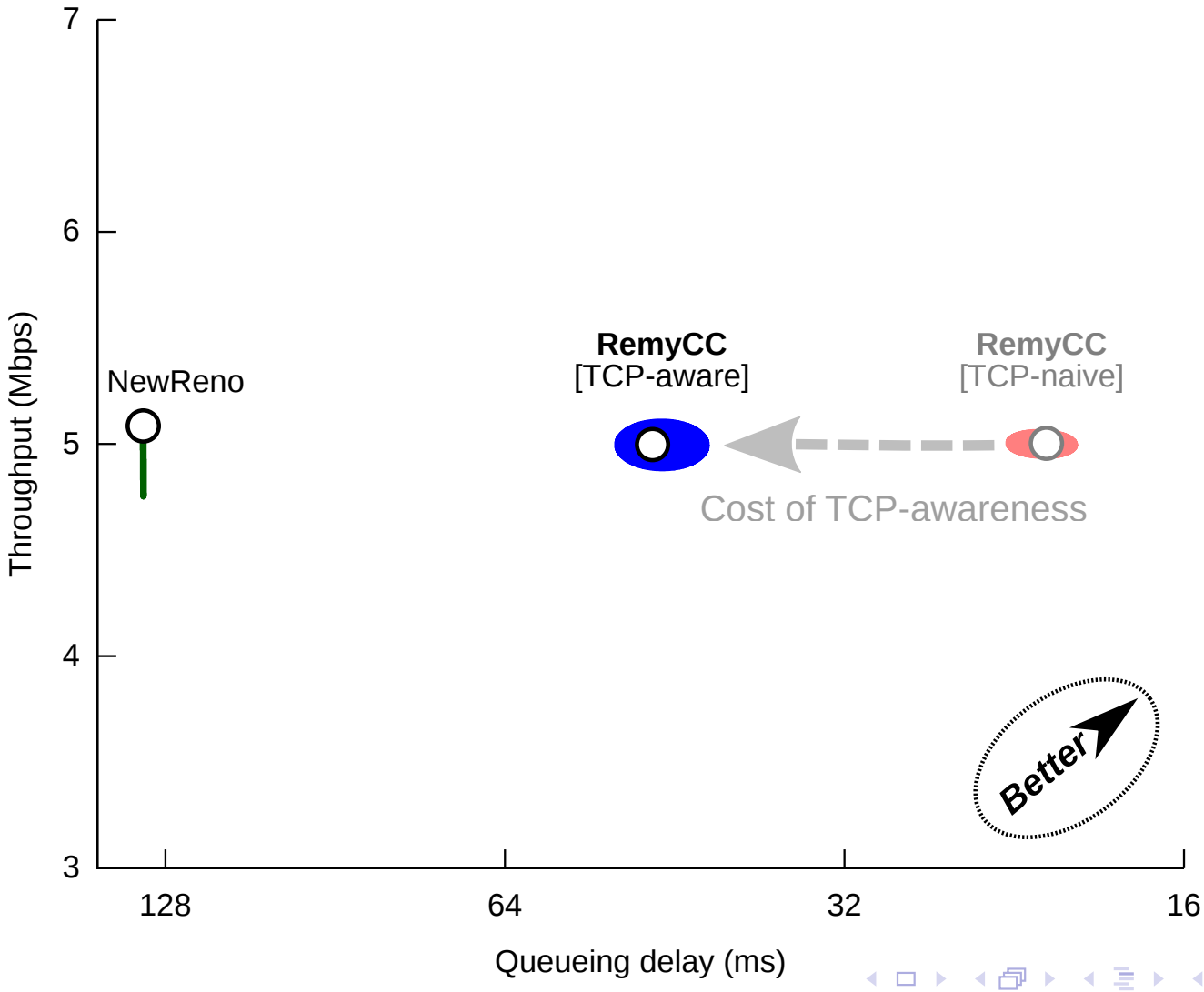
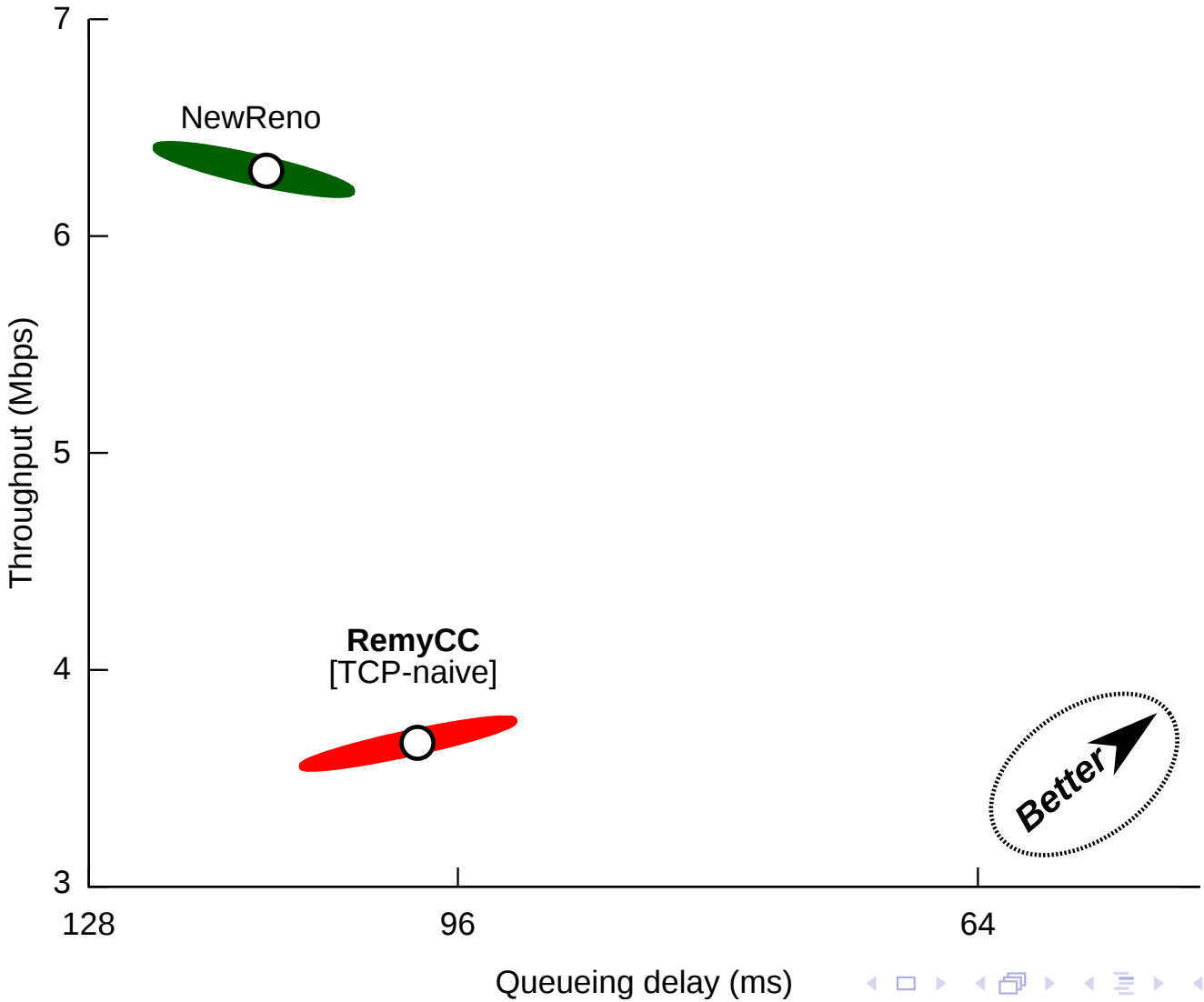


RemyCC competing against TCP NewReno



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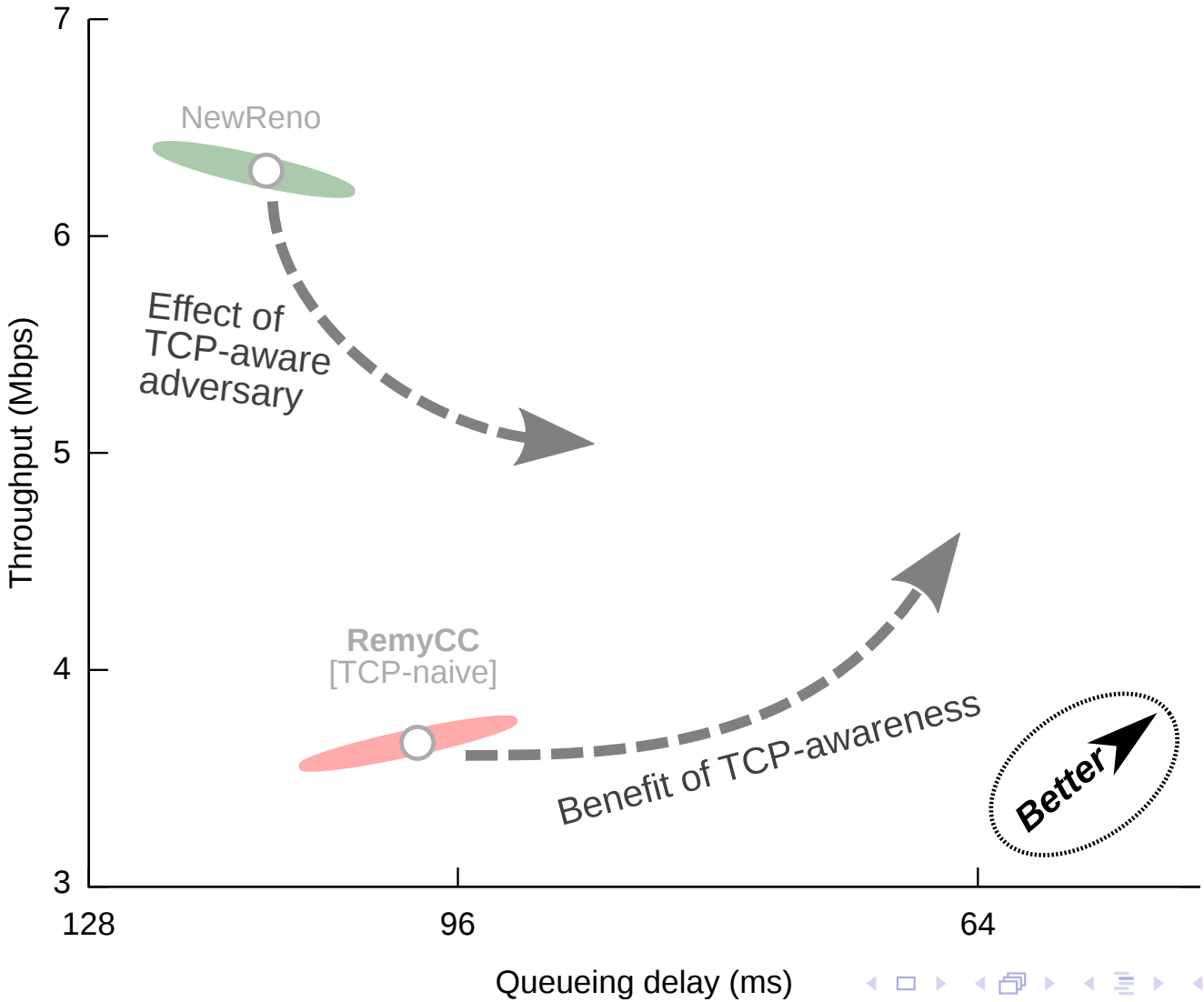

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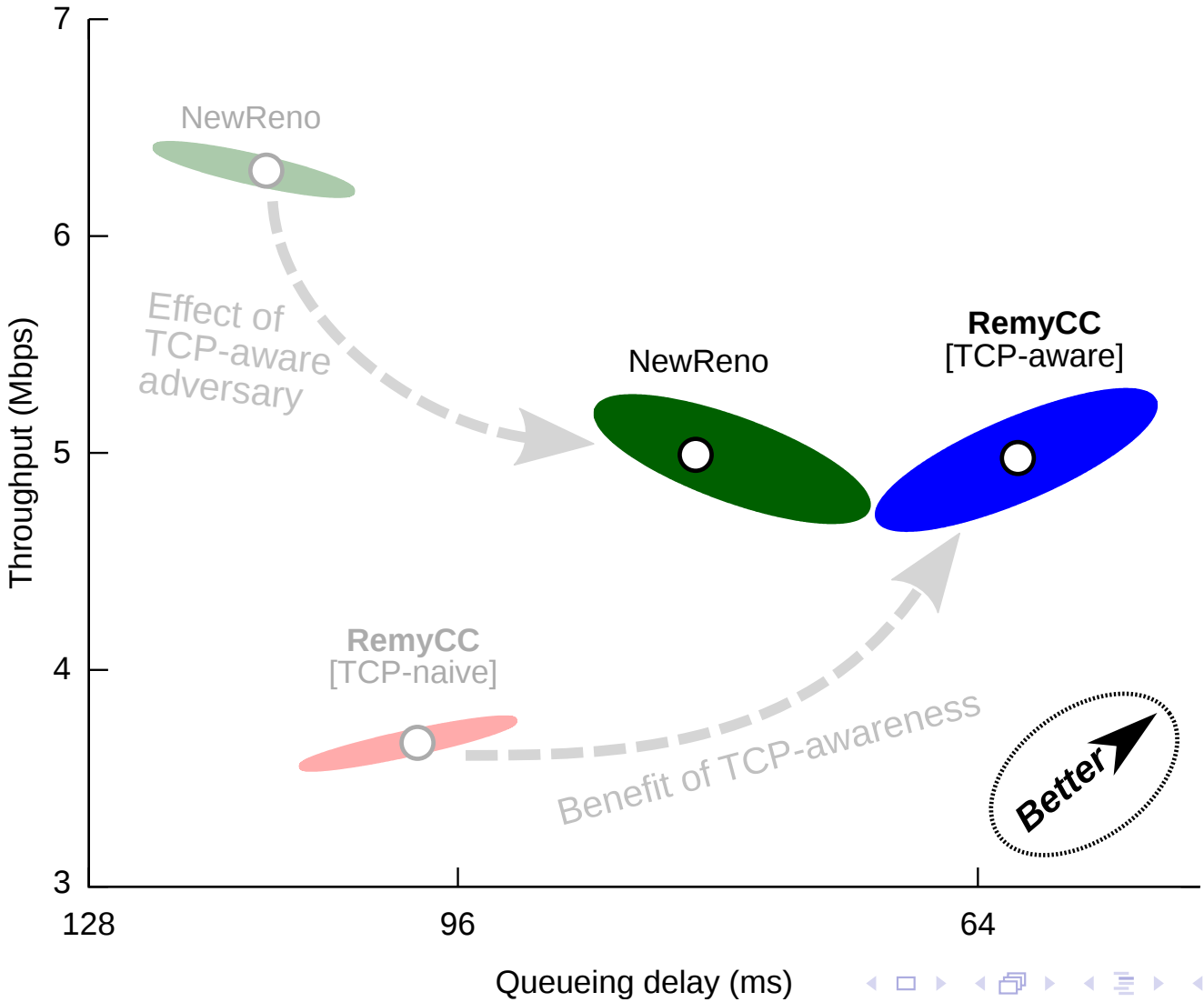
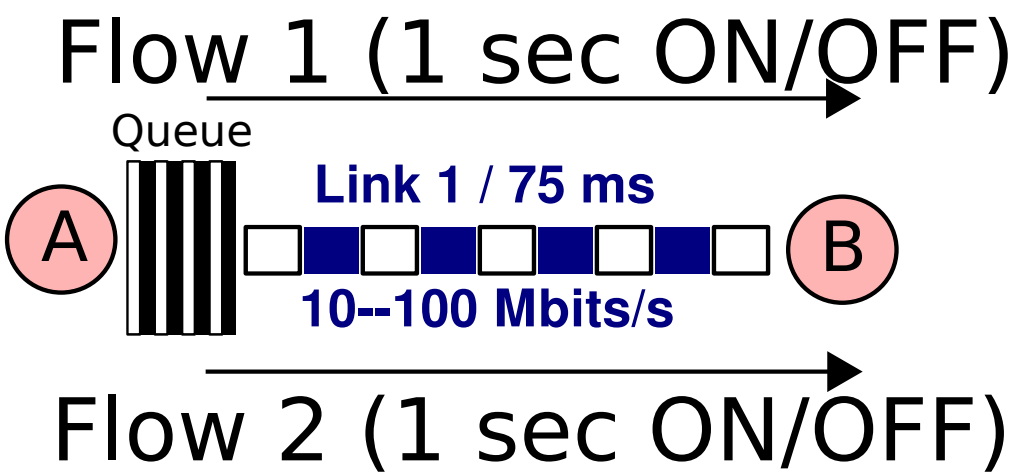


When the model is wrong about the topology

One bottleneck



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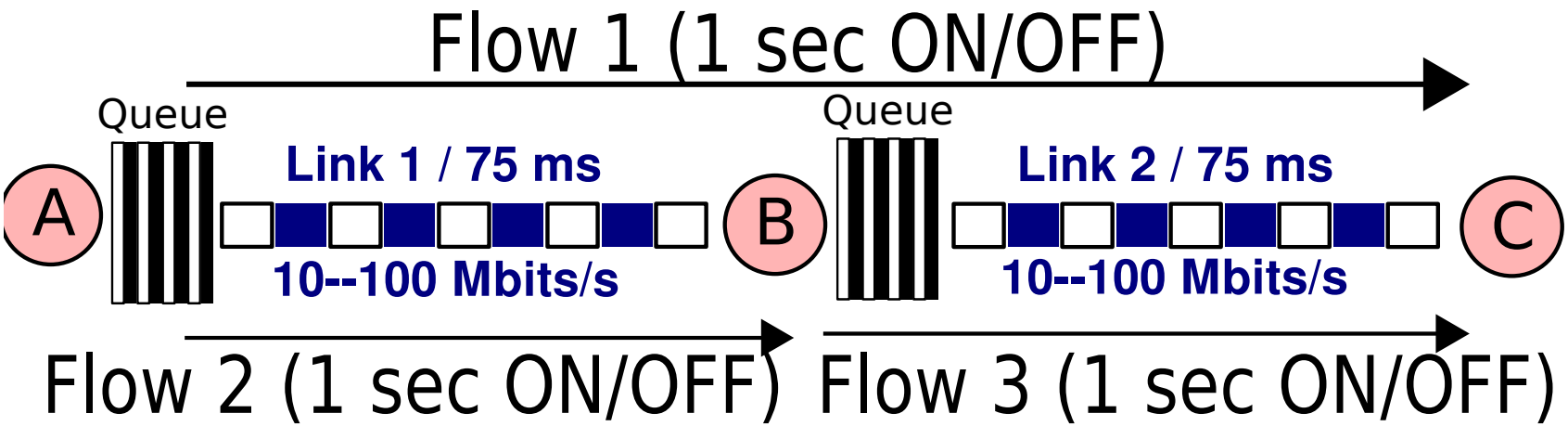
Two bottlenecks



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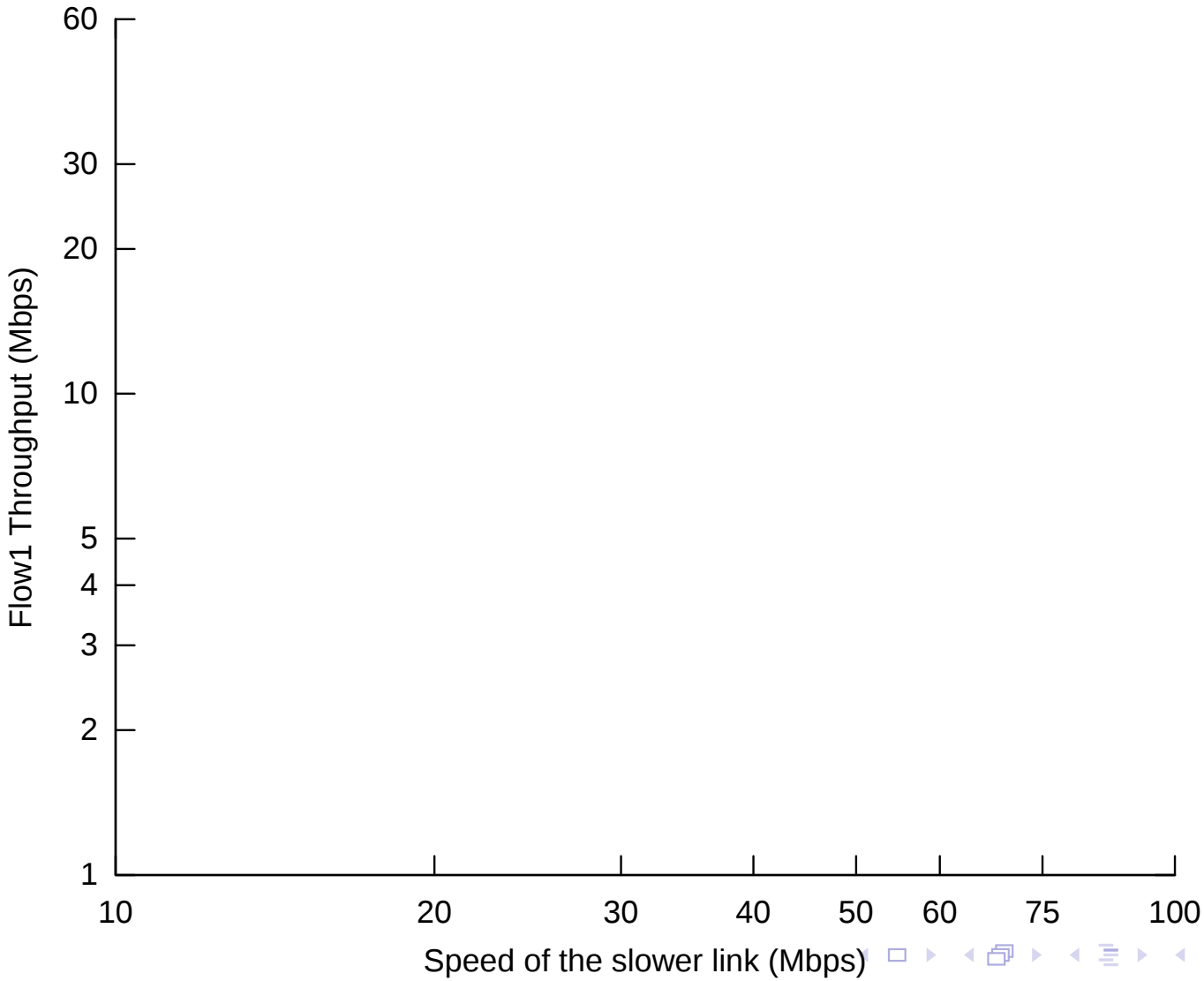

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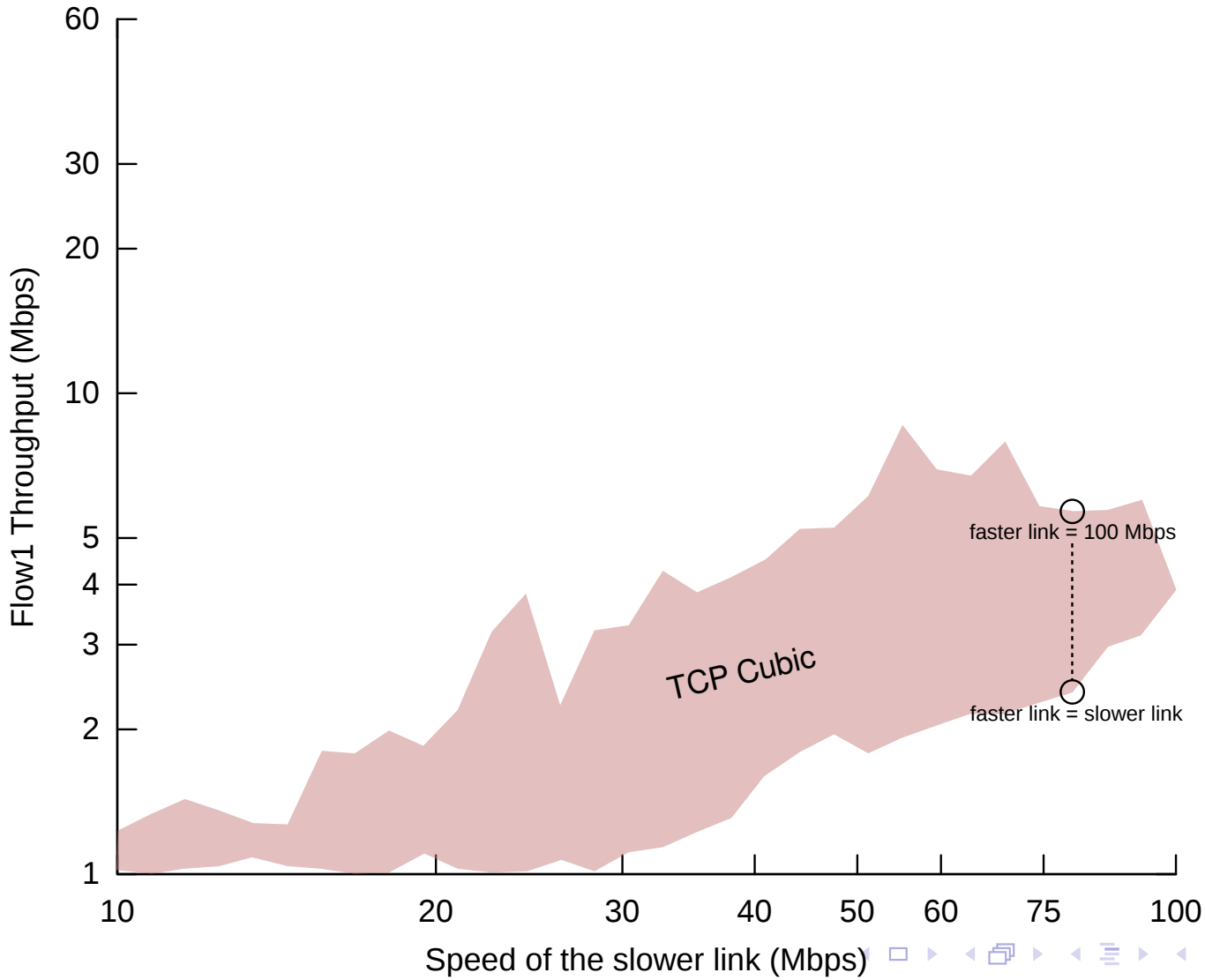

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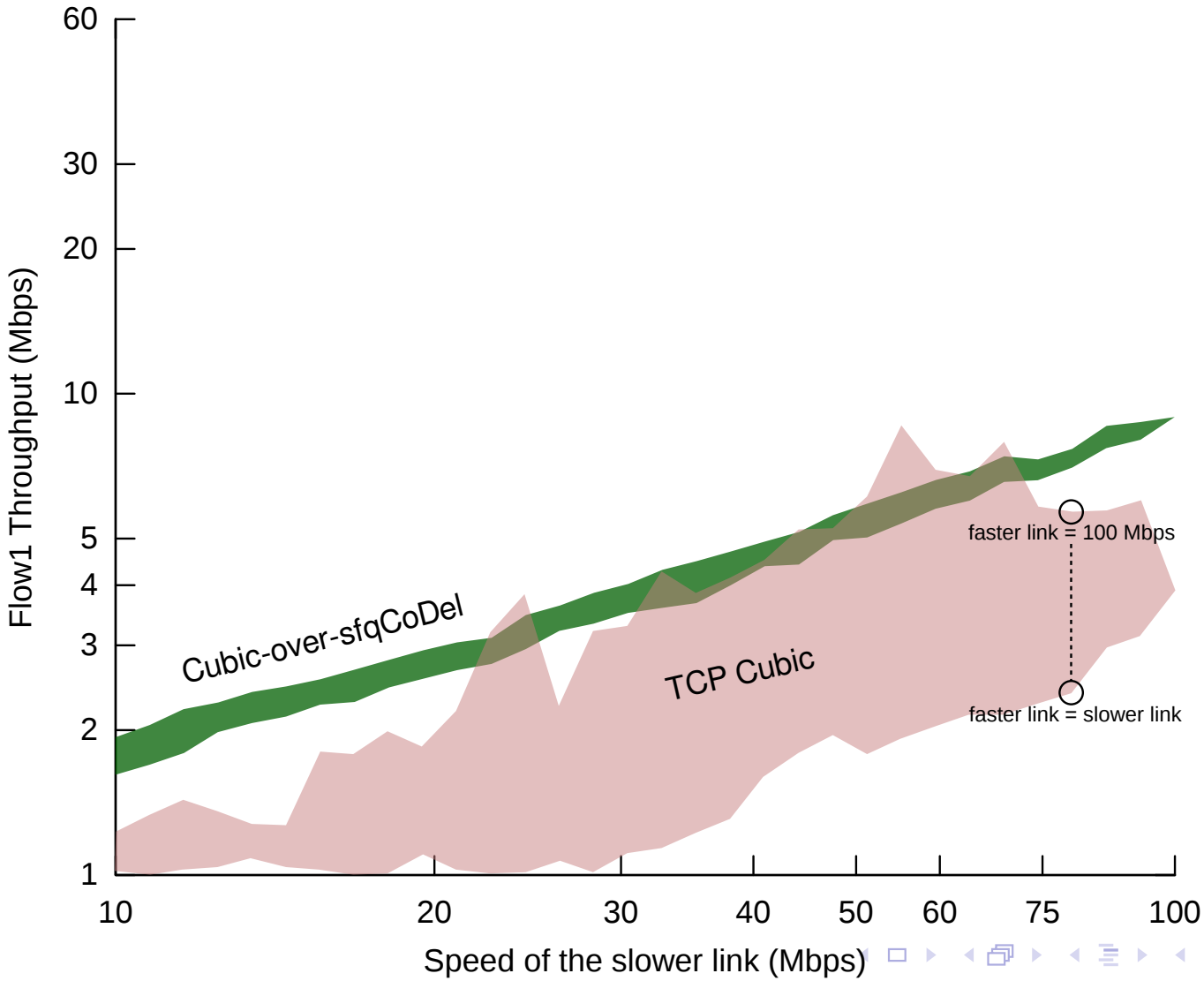

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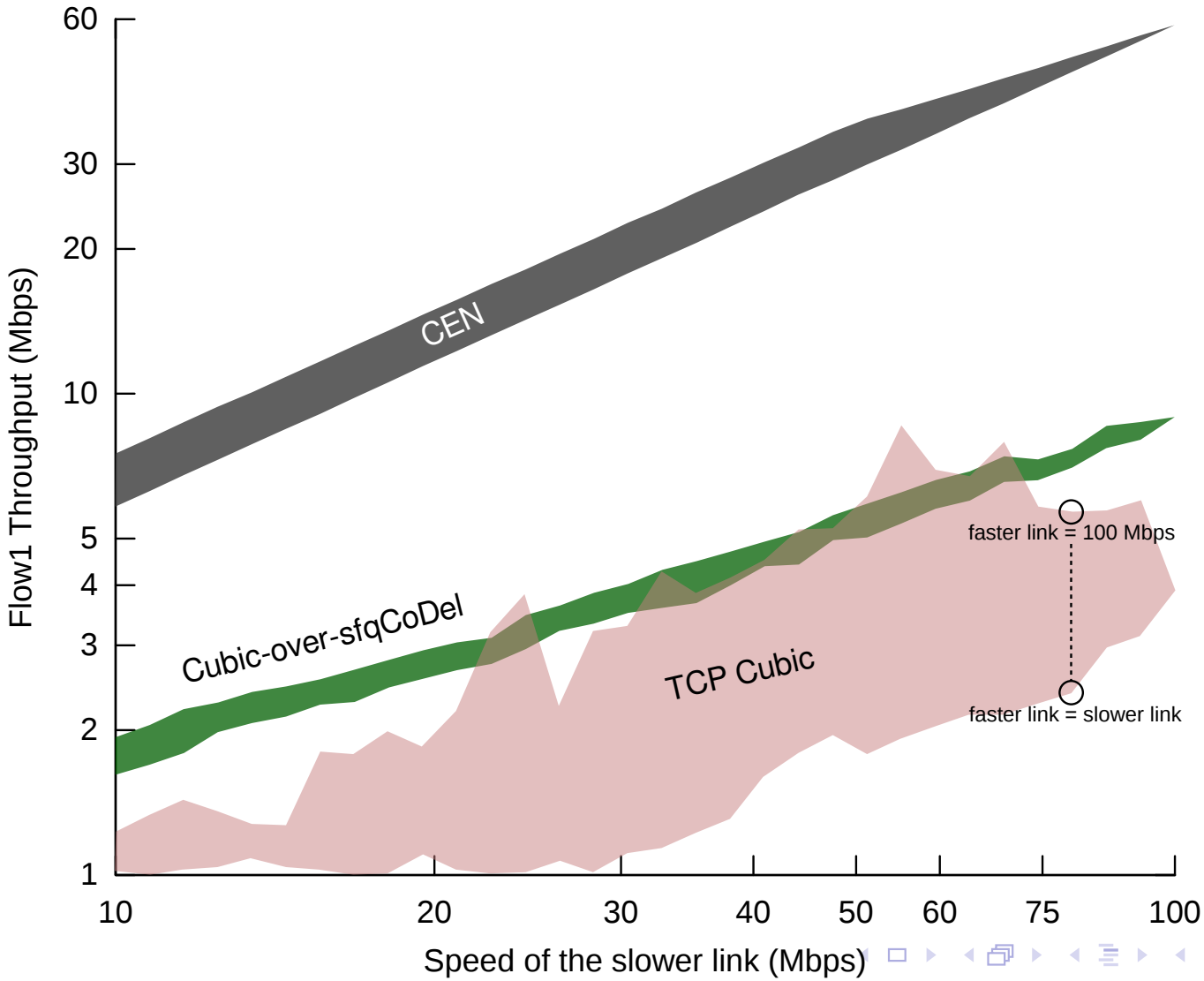

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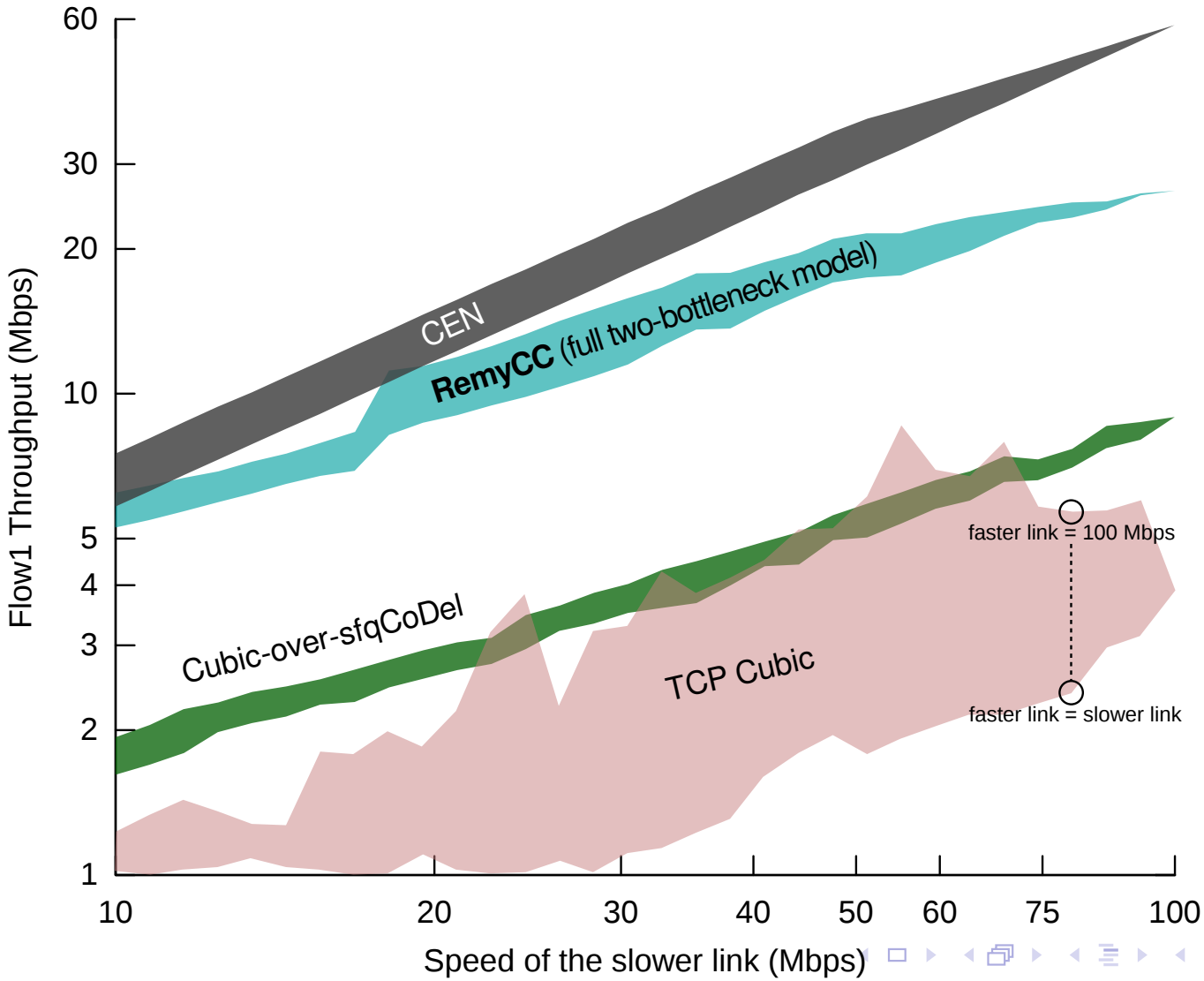

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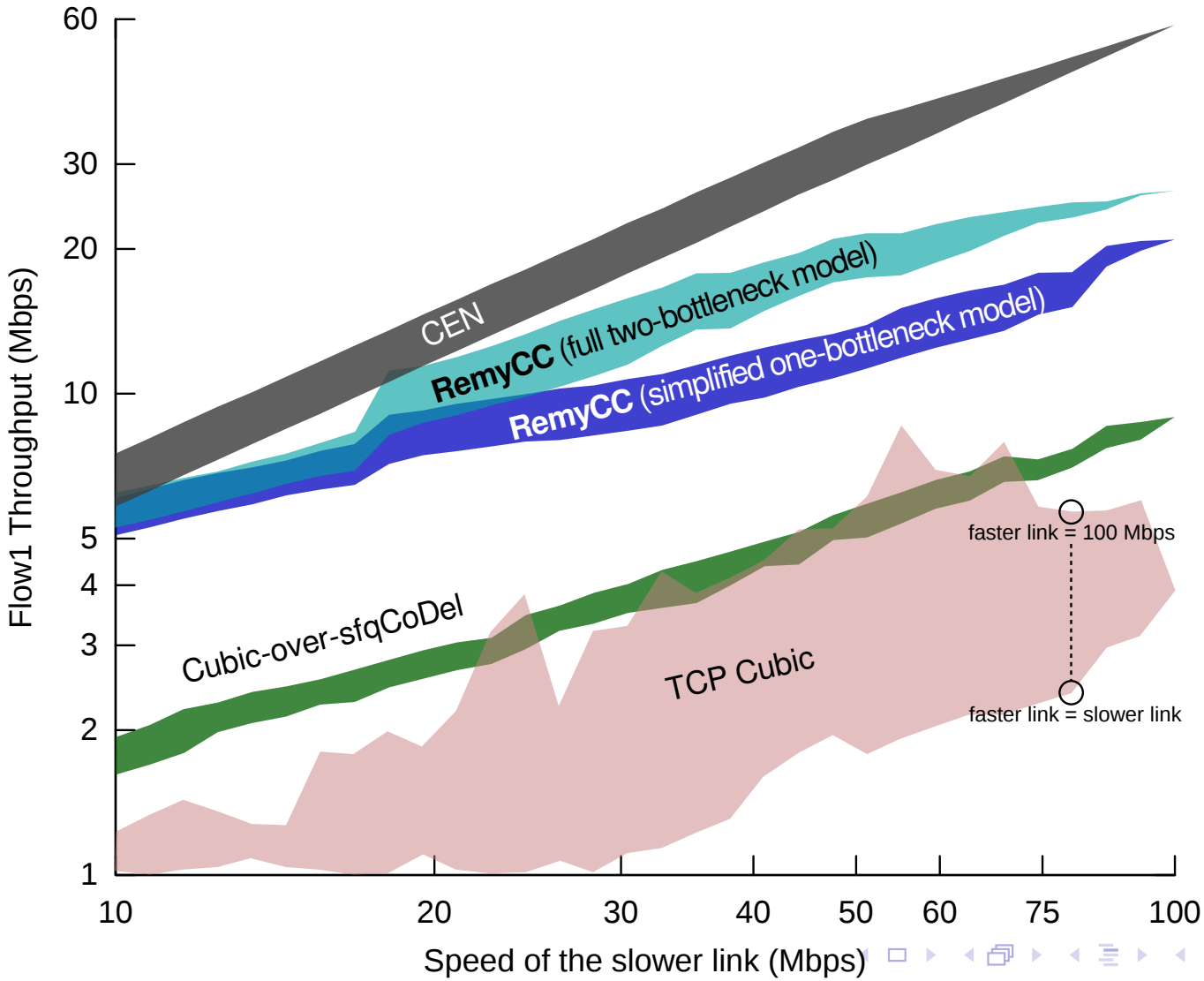


Related Work

- Probably approximately correct learning
- Transfer learning
- Machine-generated congestion control

Limitations and future work

- Generalizability to more complex topologies?
- Better characterization of gap from optimal
- Do results change if we learn in-network behavior as well?
- Model mismatches between simulation and the real world

Backup slides

Can applications with different objectives coexist?

- Tpt. Sender: A throughput-intensive sender

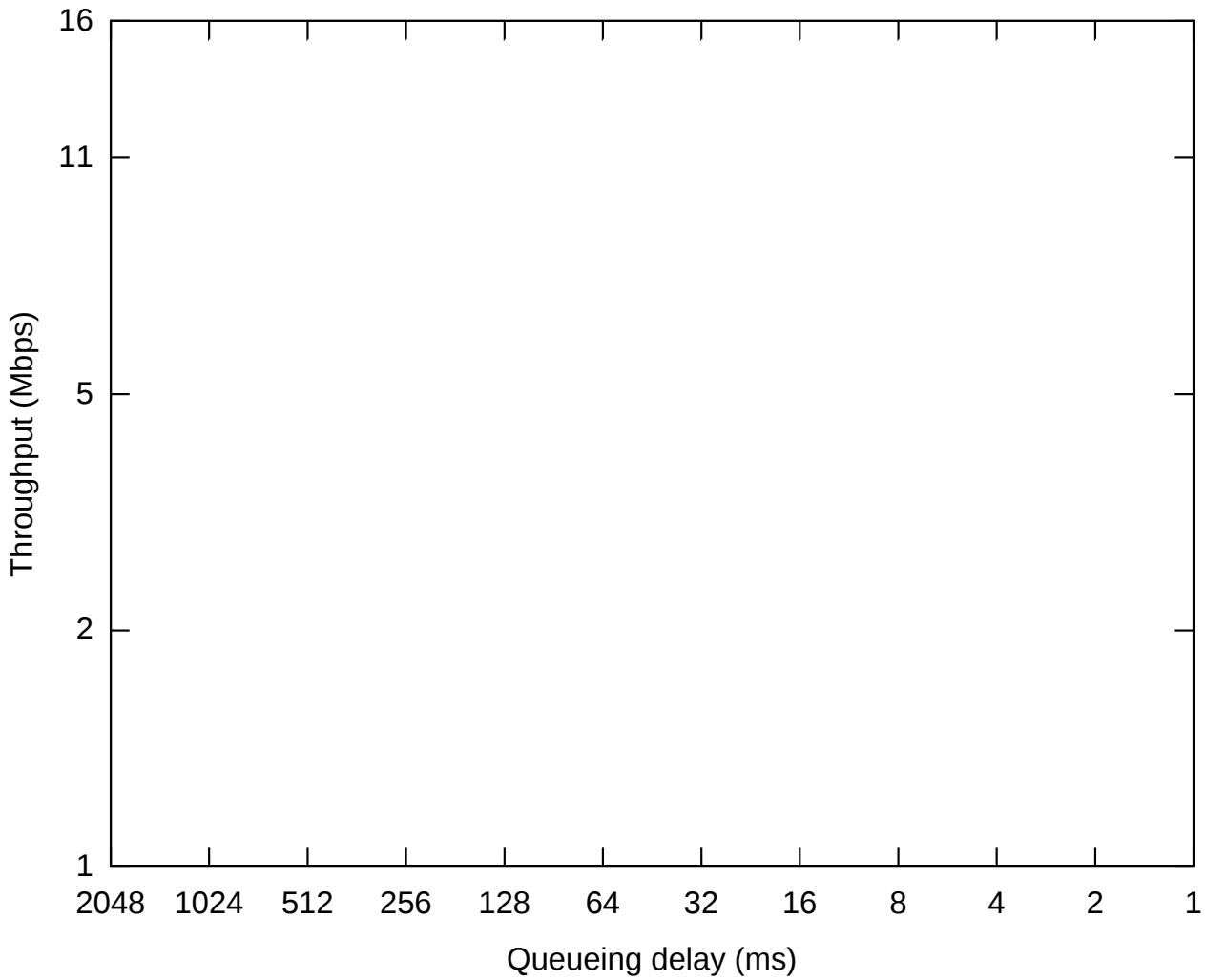
$$log(throughput) - 0.1 * log(delay) \quad (1)$$

- Lat. Sender: A latency-sensitive sender

$$log(throughput) - 10.0 * log(delay) \quad (2)$$

- Running over a FIFO queue

Training for diversity has a cost ...



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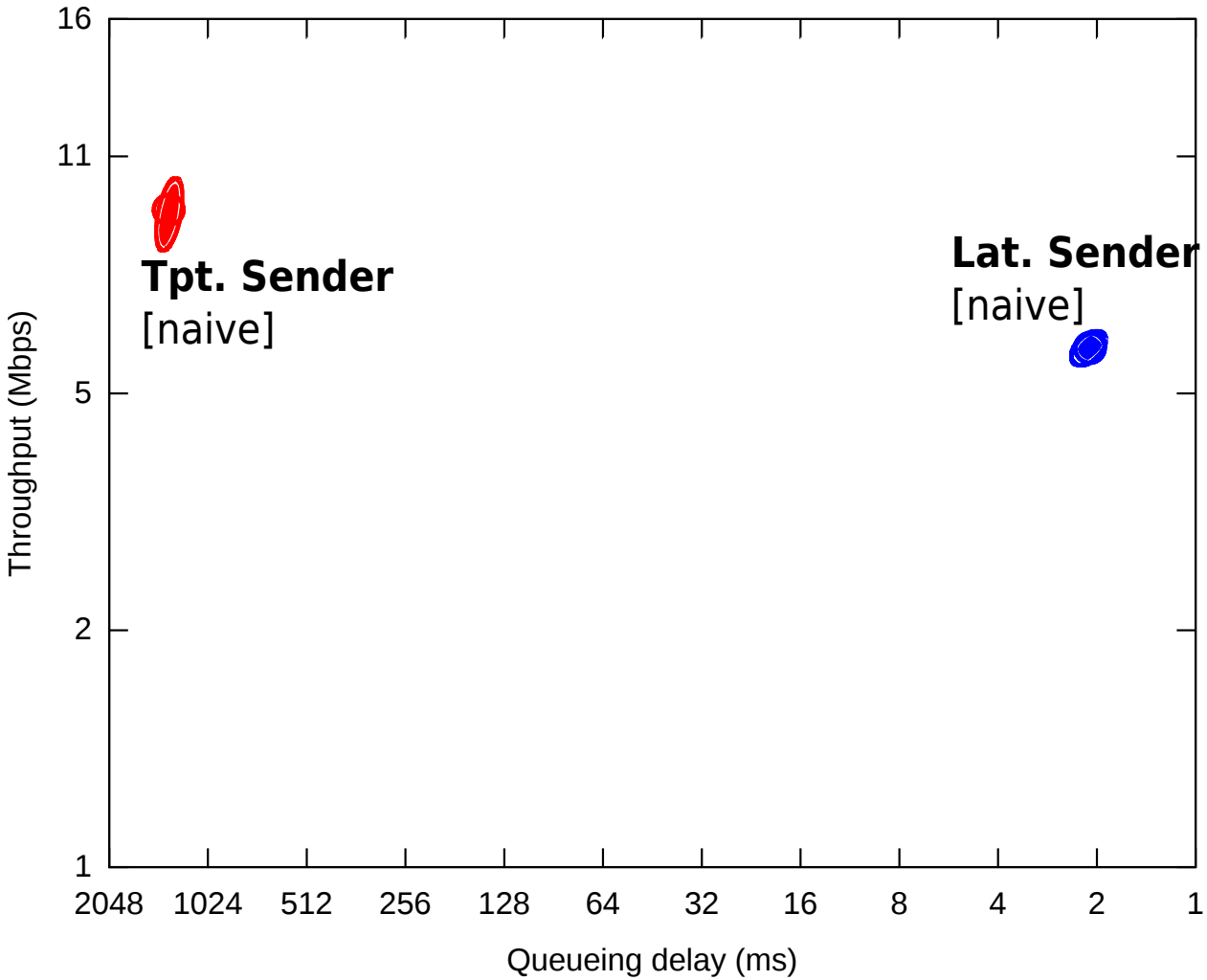

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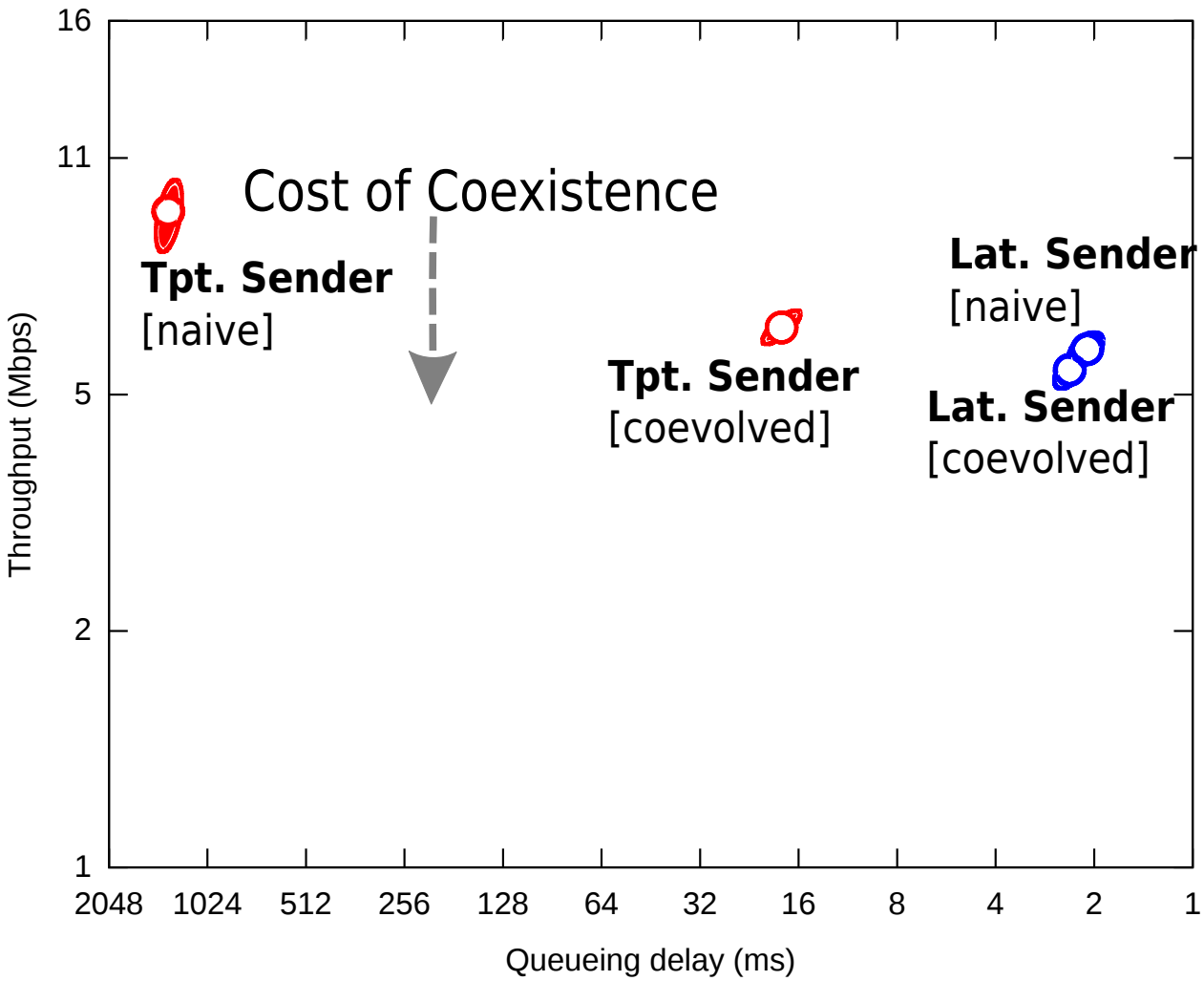

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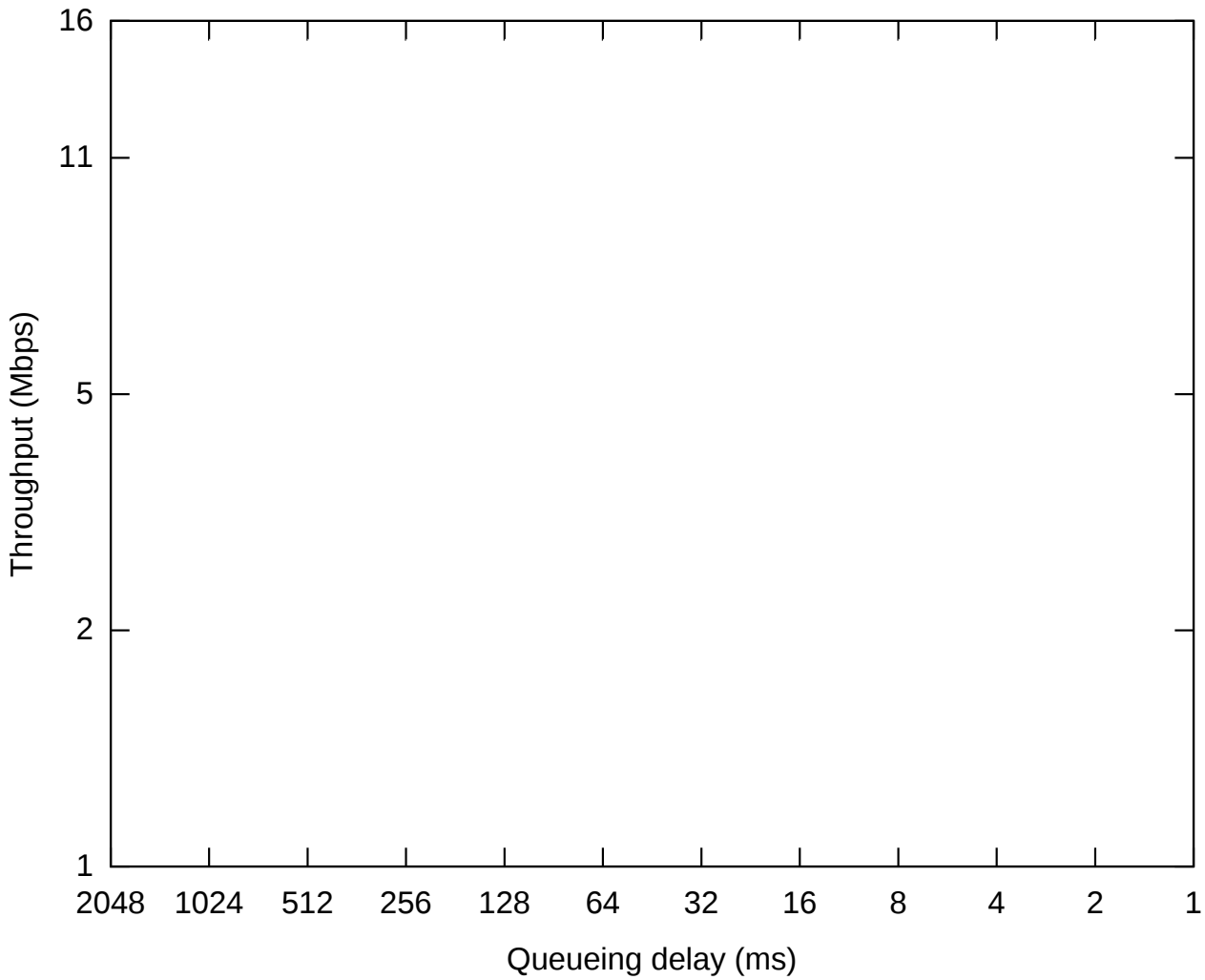

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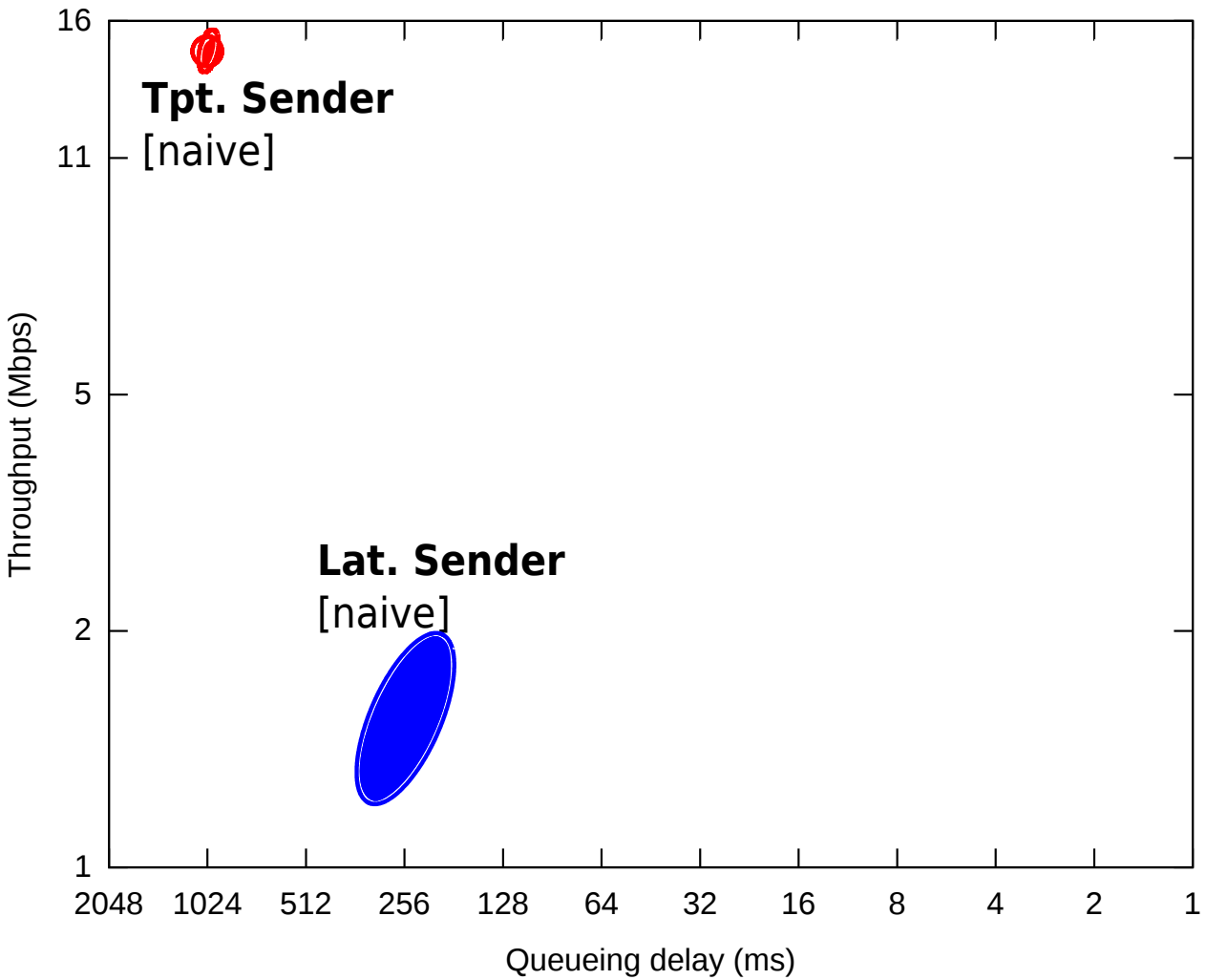

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