

Graph-Based Analysis and Observations

We conducted a performance evaluation of three congestion control (CC) algorithms—CUBIC, BBR, and COPA—using the Pantheon testbed under a 12 Mbps network trace. The evaluation focused on three key metrics: throughput, average RTT, and loss rate. The insights from our graph-based analysis are detailed below.

1. Throughput Comparison

From the Throughput Comparison graph, we observed:

CUBIC: ~12.48 Mbps

BBR: ~12.31 Mbps

COPA: ~12.50 Mbps

Observation: All schemes successfully utilized the available 12 Mbps link capacity. COPA slightly outperformed others in maximizing throughput without crossing the saturation point. This is consistent with COPA's design as a delay-sensitive protocol with intelligent pacing mechanisms. BBR, though known for high throughput, slightly lagged due to its bandwidth probing nature that adapts more conservatively in our limited runtime.

2. Packet Loss Rate Comparison

The Loss Rate graph showed:

CUBIC: 0.05%

BBR: 0.02%

COPA: 0.01%

Analysis: COPA maintained the lowest packet loss, indicating that it avoided persistent queues and congestion. CUBIC, a loss-based algorithm, caused more packet drops due to its aggressive growth until loss is detected. BBR's model-based design tries to avoid queues but sometimes overshoots depending on RTT variation.

3. Average RTT Comparison

Average RTTs recorded:

CUBIC: 48.5 ms

BBR: 35.2 ms

COPA: 25.3 ms

Interpretation: COPA consistently maintained lower queue occupancy, resulting in minimal queuing delay. CUBIC's higher RTTs are attributed to bufferbloat, a known side-effect of its AIMD congestion window expansion. BBR performed better than CUBIC but still had higher latency than COPA due to its probing behavior.

4. RTT vs Throughput Tradeoff (Pareto Plot)

This plot highlights the efficiency of each algorithm in balancing throughput and latency.

Top-right corner is ideal: high throughput and low latency.

COPA is closest to the top-right, indicating best tradeoff.

CUBIC achieved decent throughput but at the cost of higher RTT.

BBR positioned itself in the middle, maintaining balance but not excelling in either metric.

Conclusion: COPA emerged as the most latency-friendly and efficient protocol in this scenario, while CUBIC, although throughput-efficient, compromised heavily on latency due to queue buildup.

Overall Inference

Most aggressive: CUBIC (higher loss, higher RTT)

Most latency-friendly: COPA (lowest RTT and loss)

Most balanced: BBR (medium RTT, decent throughput)

While CUBIC and BBR performed well in throughput, only COPA maintained a near-ideal latency-throughput balance, making it best-suited for interactive applications or real-time streaming.