Validation and Evaluation of HyStart++ for Linux

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TCP Slow Start

Goal:

- quickly discover available capacity.
- TCP congestion window approximately doubles for each RTT

Problem:

exponential growth can overshoot.

Need a signal to exit slow start

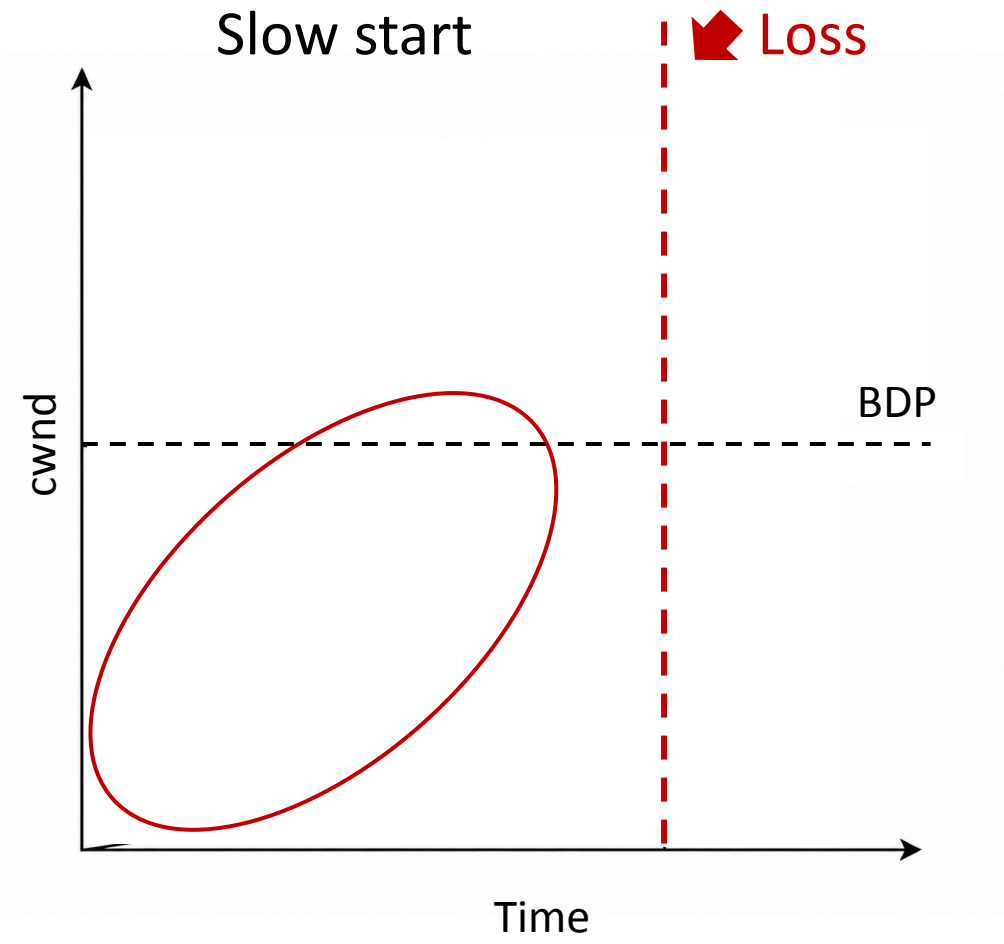
Traditional TCP → Loss → Too late

HyStart → RTT & Ack behavior → Linux default

Too Early →

Limitation

- RTT variation can look like congestion



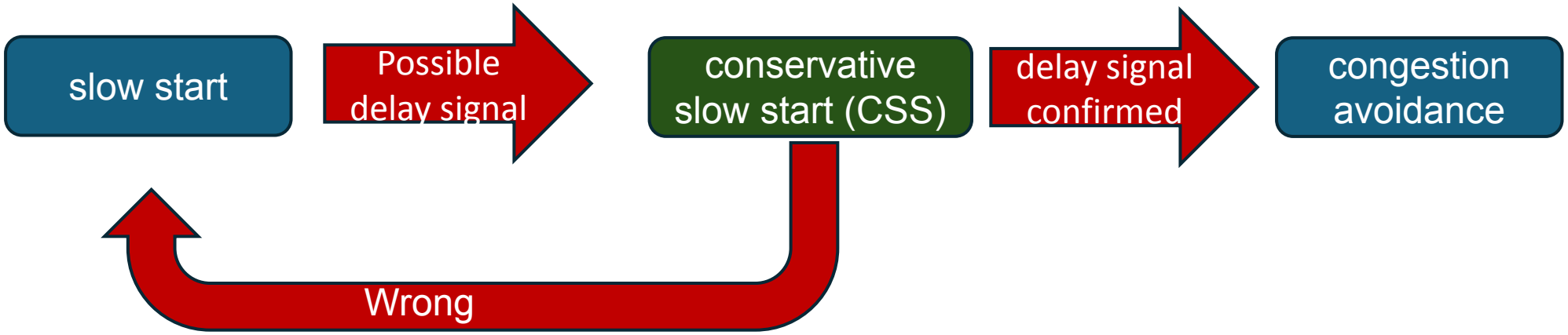
HyStart++

Conservative slow start (CSS): Growth is reduced, not stopped

Exit slow start | Enter congestion avoidance

HyStart

HyStart++



IETF RFC 9406, HyStart++: Modified Slow Start for TCP, May 2023.

Paper Roadmap

1. RFC Flowchart
What HyStart++ is intended to do

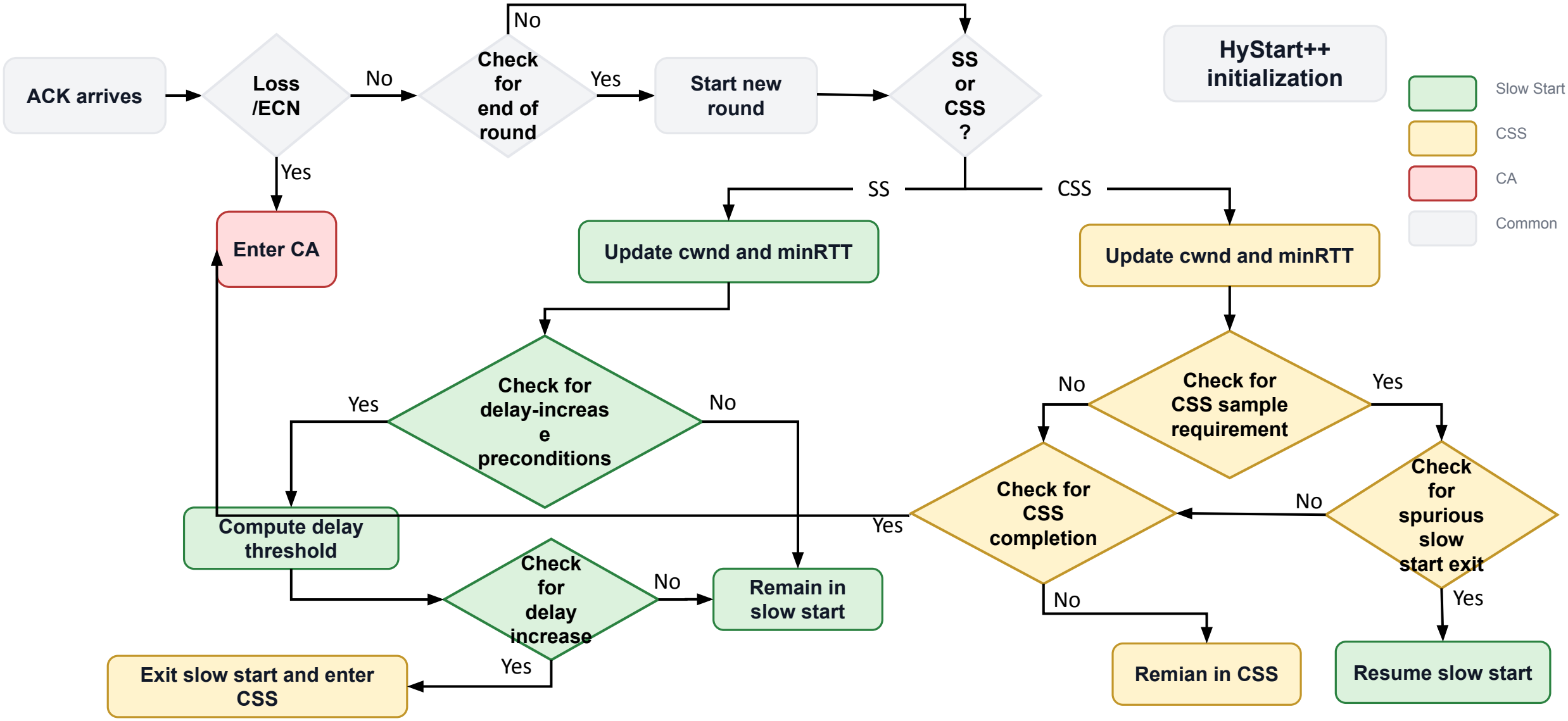
2. Linux Paths
Where that behavior appears

3. Validation Summary
Match

4. Evaluation
Controlled + GEO testbeds

5. Conclusion and future works

HyStart++ RFC (9406)



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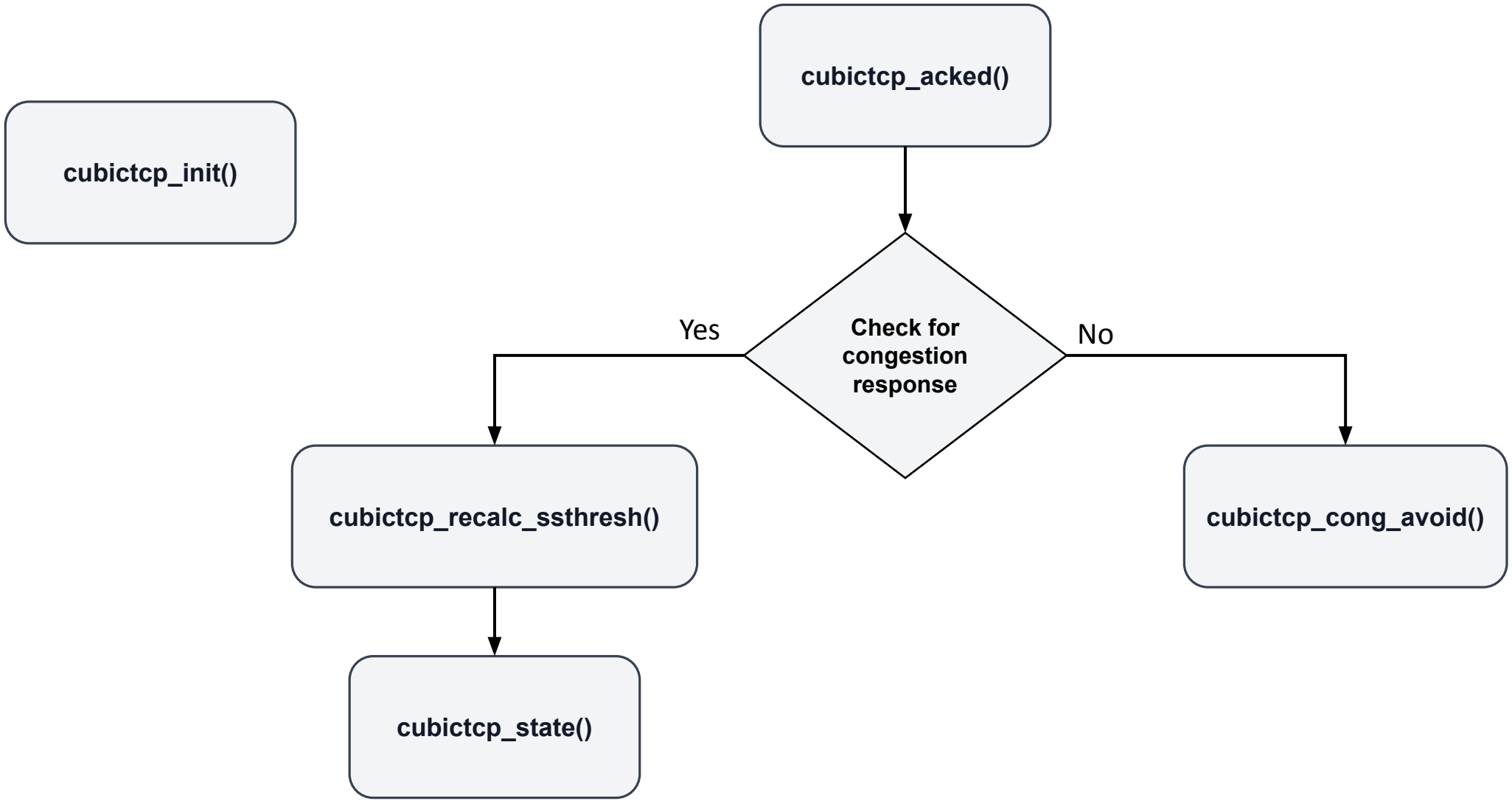
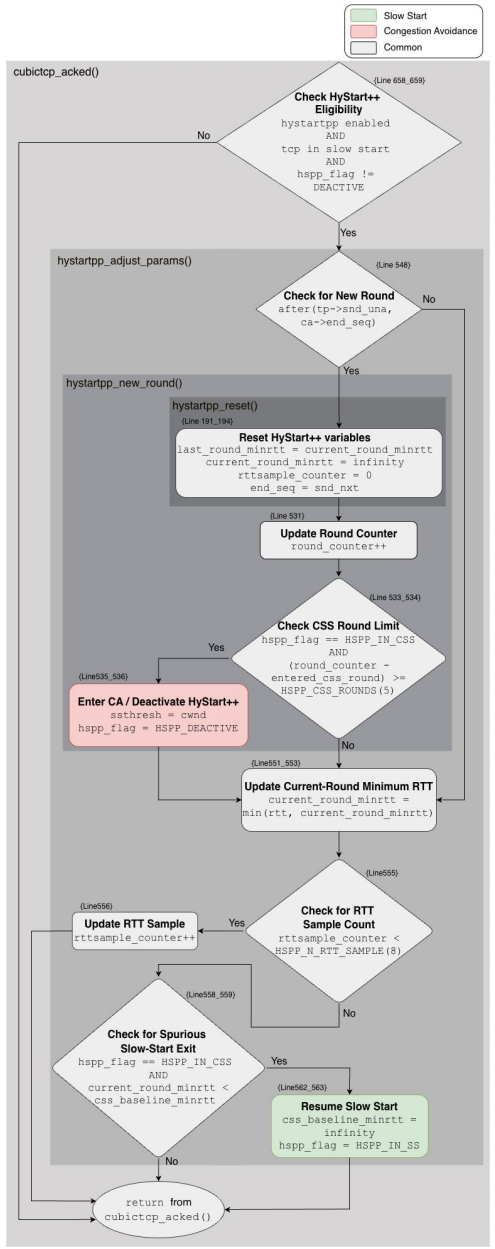
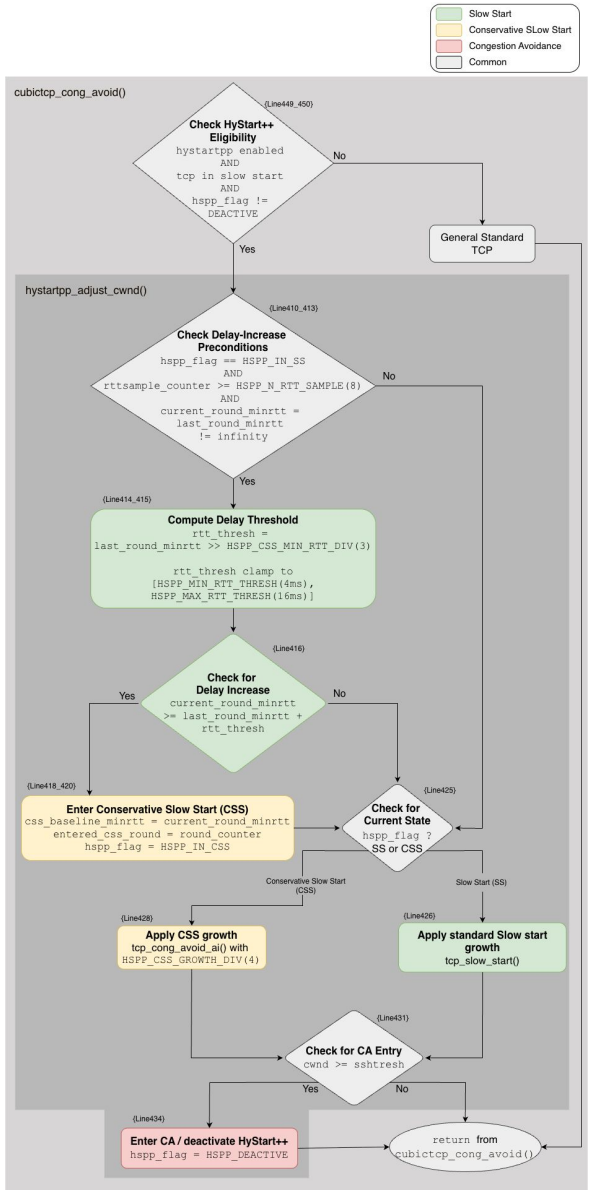
Linux Implementation

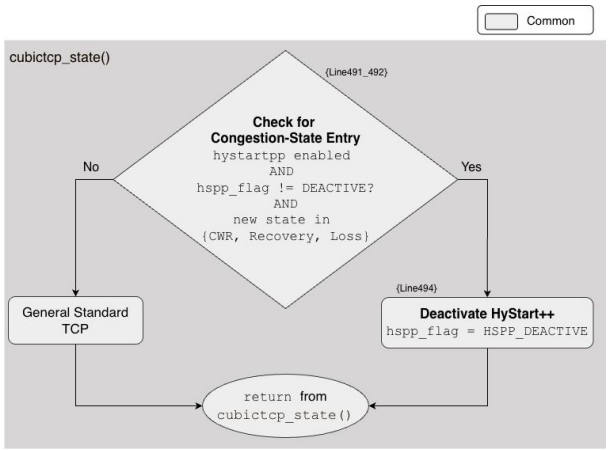


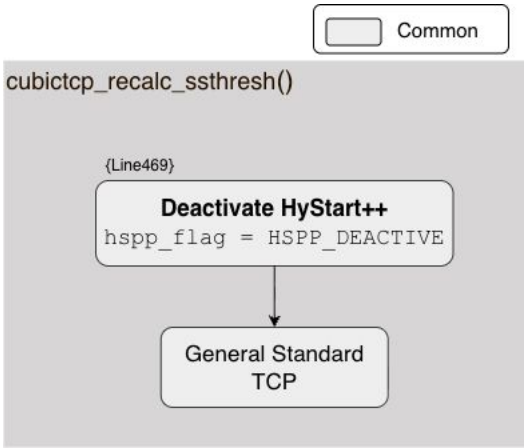
M. Arghavani, HyStartPP: Modified Linux CUBIC Implementation, GitHub, commit c0a089e, 2025.

Linux Implementation









RTT / Rounds

cubictcp_acked() maintains RTT samples, round tracking, rollback to slow start, and exit slow start by completion round in CSS.

cwnd growth

cubictcp_cong_avoid() applies standard slow start or CSS growth and detects CSS entry.

deactivation

state and ssthresh callbacks deactivate HyStart++ after congestion events.

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Functionality Match

RFC behavior RFC	RFC flowchart state	Linux implementation function
Initialize minimum RTT values and round boundary	**Initialize HyStart++ Variables**	cubictcp_init(), hystartpp_reset()
Start a new round and reset per-round measurements	**Check for End of Round; Start New Round**	cubictcp_acked(), hystartpp_adjust_params(), hystartpp_new_round(), hystartpp_reset()
Update current-round RTT measurements	**Update cwnd and minRTT** (RTT-update portion)	cubictcp_acked(), hystartpp_adjust_params()
Detect delay increase and enter CSS	**Check for Delay-Increase Preconditions; Compute Delay Threshold; Check for Delay Increase; Remain in Slow Start; Exit Slow Start and Enter CSS**	cubictcp_cong_avoid(), hystartpp_adjust_cwnd()
Apply slow start and CSS growth	**Check for Current State; Update cwnd and minRTT** (cwnd-update portion)	cubictcp_cong_avoid(), hystartpp_adjust_cwnd(), tcp_slow_start(), tcp_cong_avoid_ai()
Return from CSS after a spurious slow start exit	**Check for CSS Sample Requirement; Check for Spurious Slow-Start Exit; Resume Slow Start**	cubictcp_acked(), hystartpp_adjust_params()
Complete CSS and enter congestion avoidance	**Check for CSS Completion; Remain in CSS; Enter Congestion Avoidance**	cubictcp_acked(), hystartpp_adjust_params(), hystartpp_new_round()
Handle loss or ECN during slow start or CSS	**Check for Congestion Signal; Enter Congestion Avoidance**	cubictcp_state(), cubictcp_recalc_ssthresh()
Restrict HyStart++ to the initial slow start	**Enter Congestion Avoidance**	cubictcp_init(), hystartpp_new_round(), hystartpp_adjust_cwnd(), cubictcp_state(), cubictcp_recalc_ssthresh()

Functionality Match

RFC behavior RFC	Status	Comments
Initialize minimum RTT values and round boundary		
Start a new round and reset per-round measurements		
Update current-round RTT measurements		
Detect delay increase and enter CSS		
Apply slow start and CSS growth		
Return from CSS after a spurious slow start exit		
Complete CSS and enter congestion avoidance		
Handle loss or ECN during slow start or CSS		
Restrict HyStart++ to the initial slow start		

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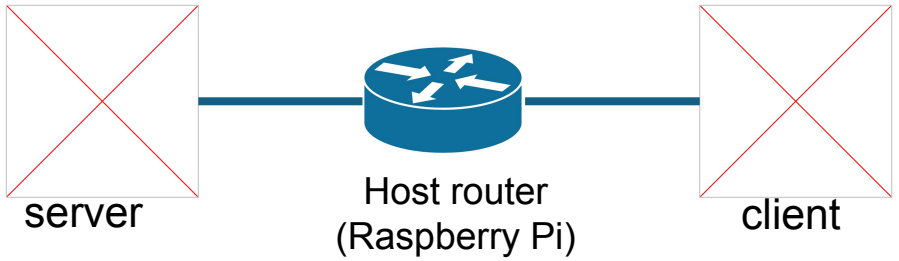
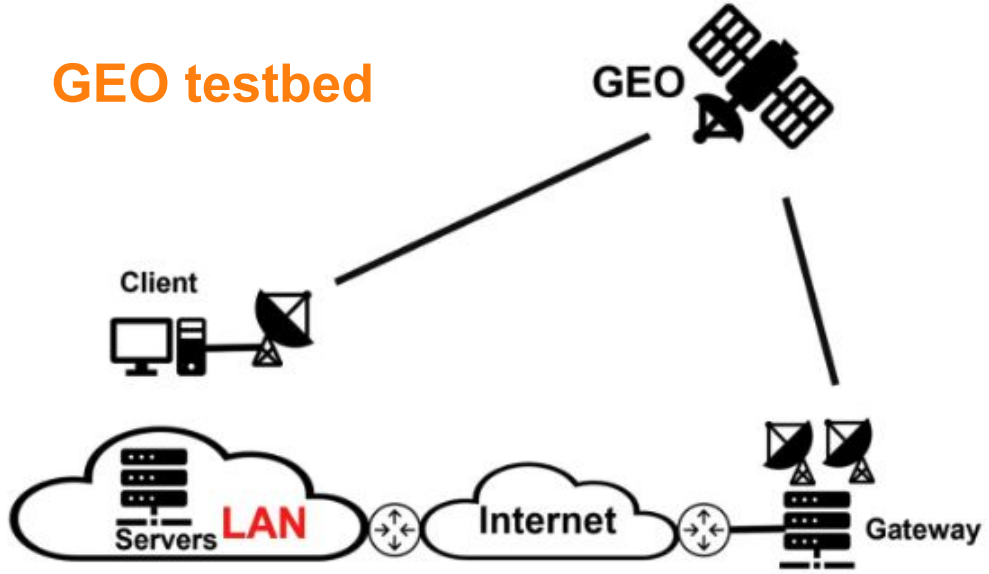
Evaluation Testbeds

Controlled testbed



Factor	Value
Algorithm	Traditional, HyStart, HyStart++
Rate	50, 100, 150 Mb/s
Base RTT	25, 100, 400 ms
Queue	1, 2, 4 X BDP
Jitter	RTT/4, RTT/2, RTT
Duration	10 seconds
Runs	30 per config; 2,430 per algorithm

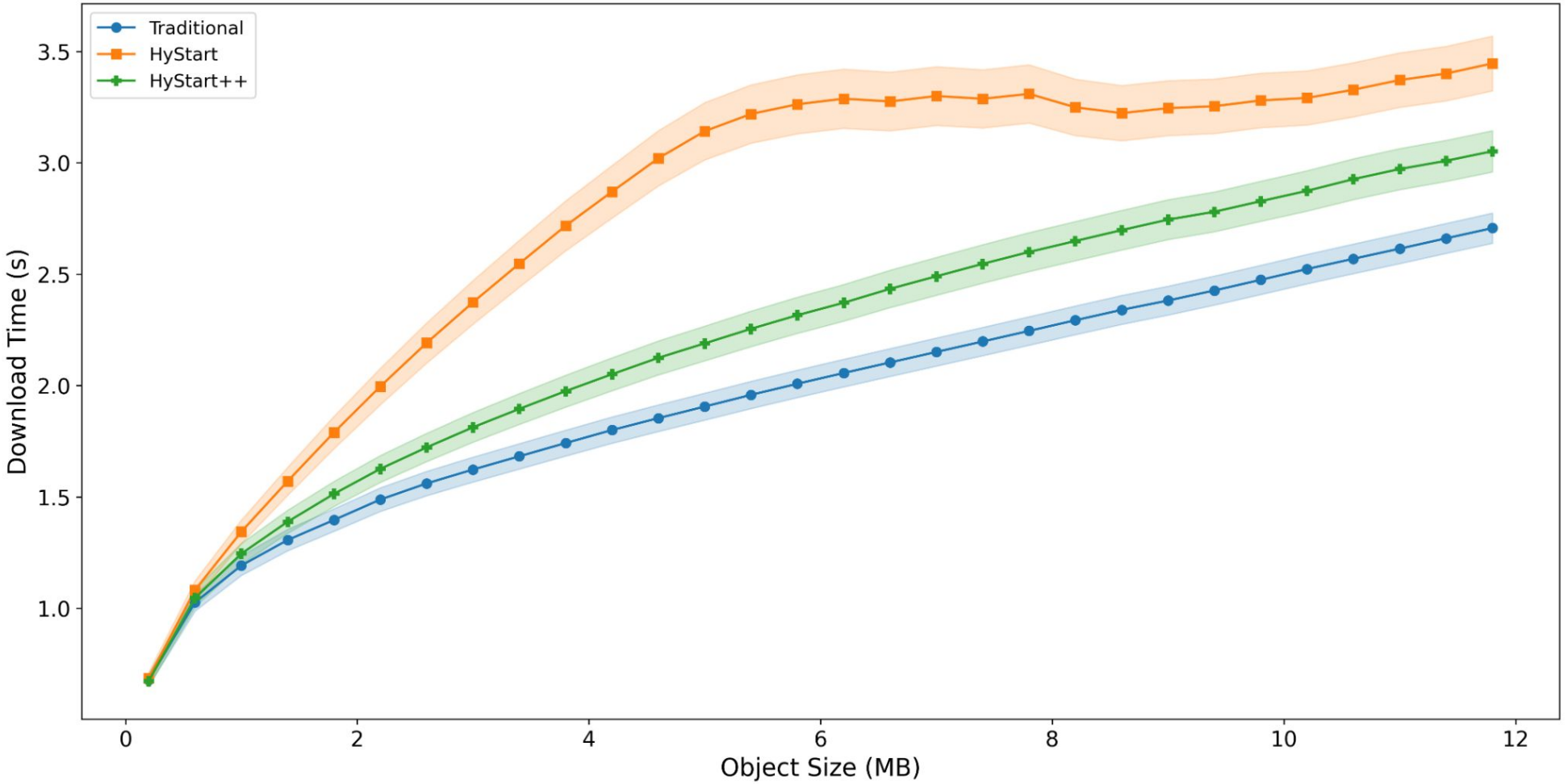
GEO testbed



Factor	Value
Algorithm	Traditional, HyStart, HyStart++
Duration	45 seconds
Schedule	24 hours
Runs	161 per algorithm

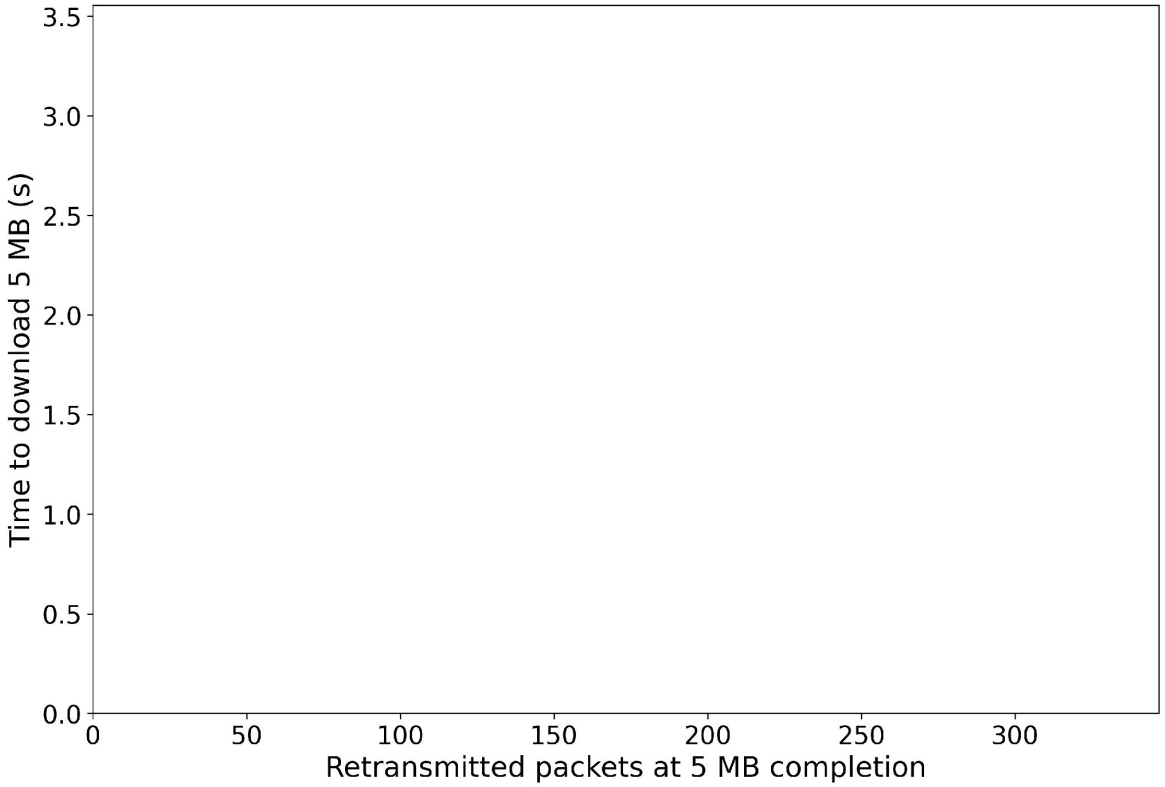
Evaluation Result: Download Time

Controlled dataset

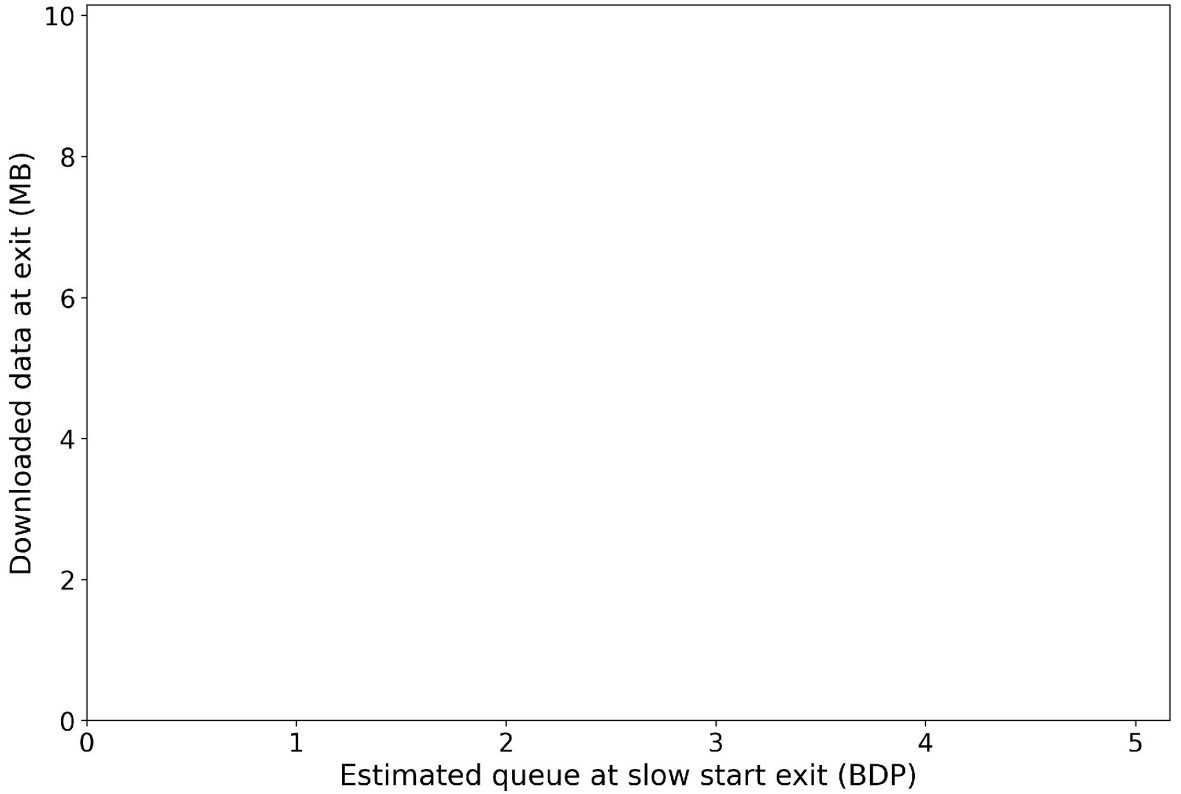


Evaluation Result

Controlled dataset



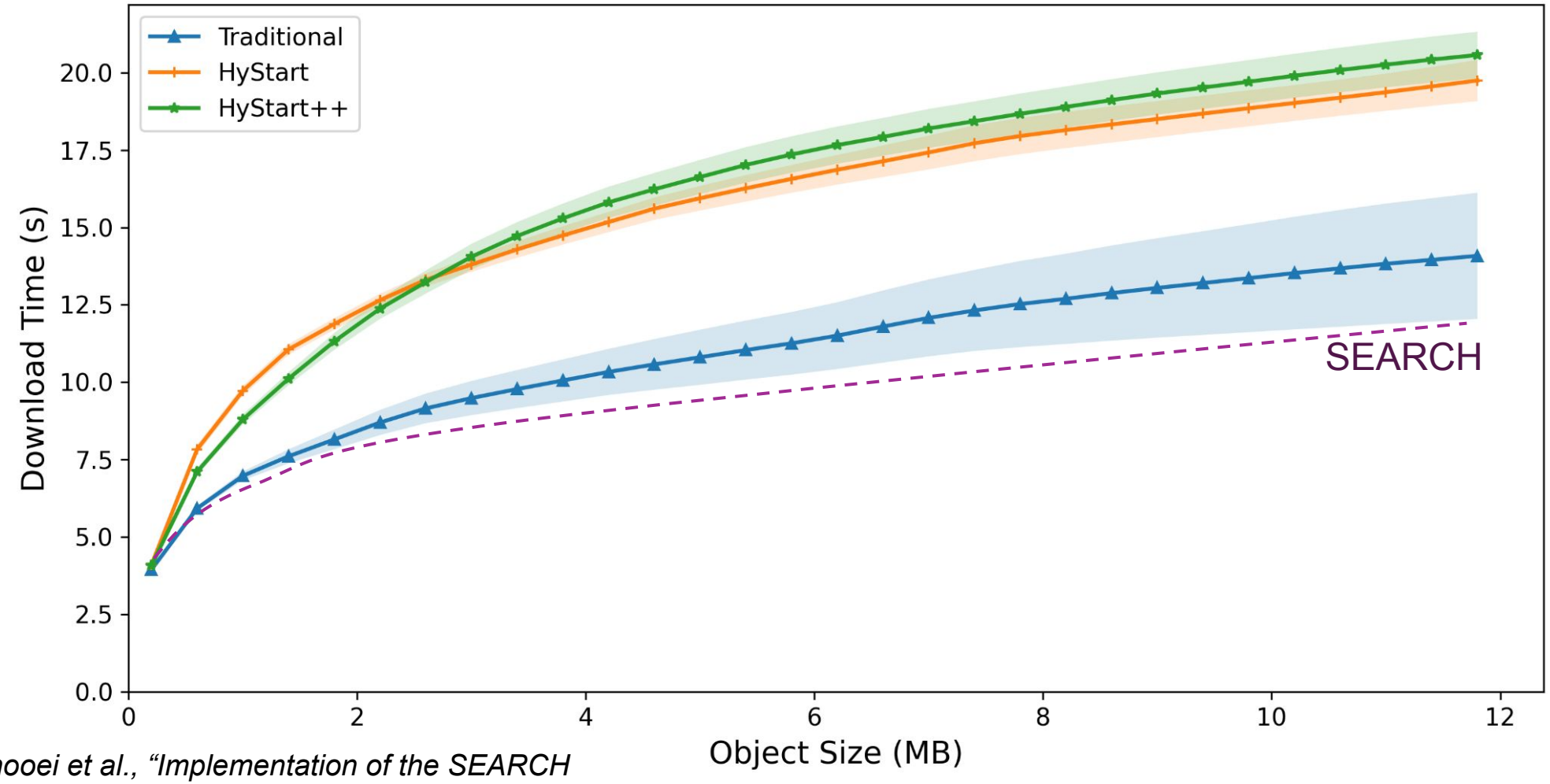
Mean time to download 5 MB versus retransmitted packets at 5 MB completion



Downloaded data and estimated queue occupancy when the slow start exit has happened

Evaluation Result: Download Time

GEO dataset



M. A. Kachooei et al., "Implementation of the SEARCH Slow Start Algorithm in the Linux Kernel," Proc. NetDev 0x18, 2024.

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Conclusion

- Linux HyStart++ faithfully implements the main RFC 9406 behavior:

  Slow Start → CSS → Congestion Avoidance

- CSS reduces premature HyStart exits by probing after the first delay signal.
- HyStart++ is a middle point:

  less conservative than HyStart, less aggressive than traditional slow start

- RTT variation still challenges delay-based exit on wireless/satellite paths.

Future Work

- Tune HyStart++ parameters for high-variation paths:

  CSS duration, CSS growth rate, delay threshold

- Explore delivery/rate-based signals for slow start exit:
  - RTT-confirmed signal
  - Standalone signal

Thank you for your attention!

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