QUIC Throughput and Fairness over Dual Connectivity

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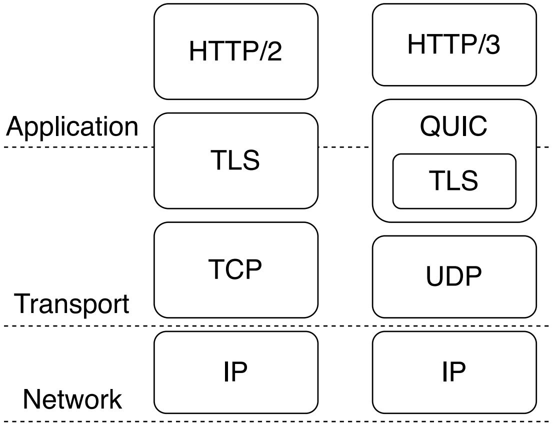
Proc. IEEE MASCOTS workshop, Nov. 2020

QUIC

- New transport protocol
  - Introduced 2013 by Google
  - Continued by IETF to become HTTP/3
- Multi-layer
  - Reliable in userspace over UDP
  - Rapid deployment
  - 0-RTT
  - Per-stream flow control



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- Multi-layer
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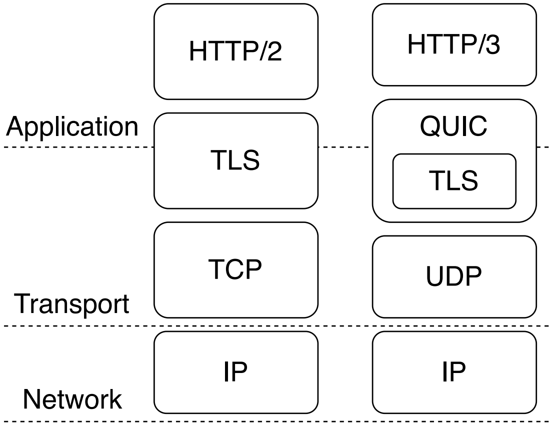
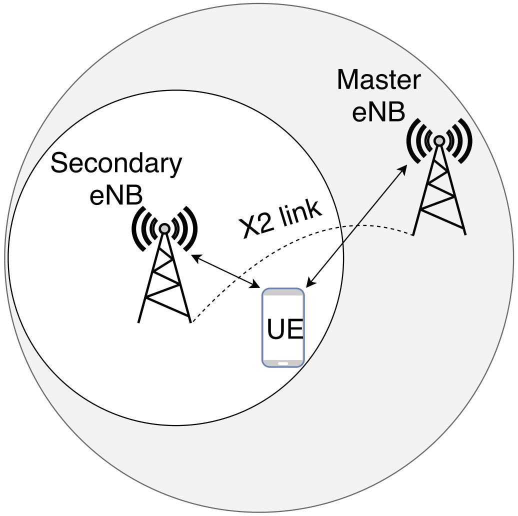
  - Rapid deployment
  - 0-RTT
  - Per-stream flow control
- Widespread adoption
  - Used by Google, YouTube, Facebook, and more…



Dual Connectivity

- Multi-connectivity technique
- Accelerating transition to 5G
- Multiple future uses
  - Throughput
  - Reliability



Dual Connectivity

- Multi-connectivity technique
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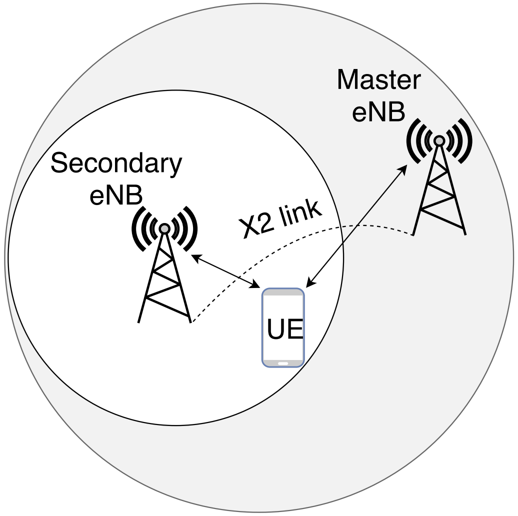
  - Throughput
  - Reliability
- Splits traffic at link layer in PDCP sublayer



Multipath

Application	
Multipath TCP	
IP	IP
PDCP	PDCP
RLC	RLC
MAC	MAC
Physical	Physical

Dual Connectivity

Application	
TCP	
IP	
PDCP	
RLC	RLC
MAC	MAC
Physical	Physical

Carrier Aggregation

Application	
TCP	
IP	
PDCP	
RLC	
MAC	
Physical	Physical

Motivation

- Dual Connectivity invisible to QUIC and TCP
  - Jitter, reordering can significantly impact performance

- Understanding two "new" technologies together
  - Dual Connectivity parameters
  - Network conditions (bandwidth, delay, loss)

Contributions

- First performance evaluation of QUIC and Dual Connectivity
  - Throughput
  - Fairness

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- Comparison with TCP counterparts
  - 2 QUIC implementations (aioquic, ngtcp2)
  - NewReno and CUBIC
  - LTE bandwidth trace

Contributions

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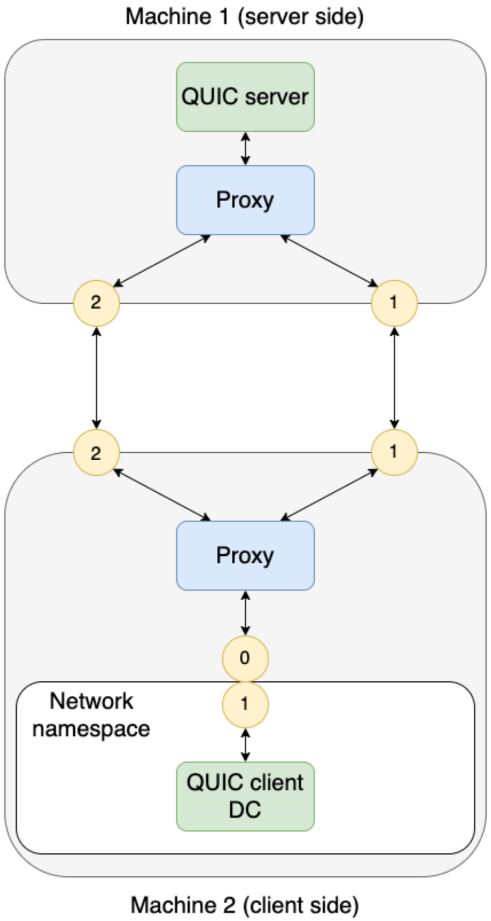
- Insights for network operators

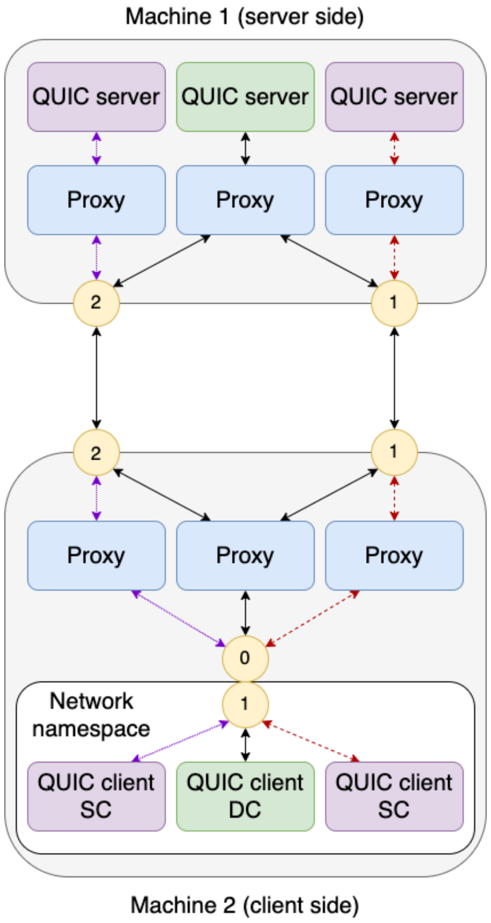
Testbed throughput

- Two machines, 2 interfaces each
- PDCP proxy



Testbed fairness

- 3 QUIC servers/clients
  - 1 Dual Connectivity
  - 2 Single Connectivity



Testbed fairness

- 3 QUIC servers/clients
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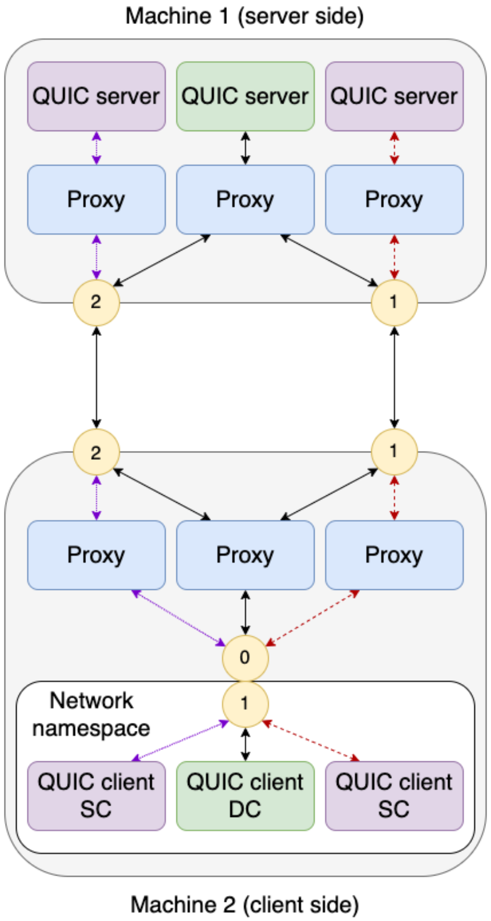
- Jain's fairness index (JFI)



Parameters

- DC batch size
- DC ratio (batch split)
- Bandwidth ratio
  - With and without matching DC ratio
- Delay ratio
  - Low and high delay
- Random loss
  - With and without packet duplication

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DC ratio 5:1

80 packets -> 20 packets -> …

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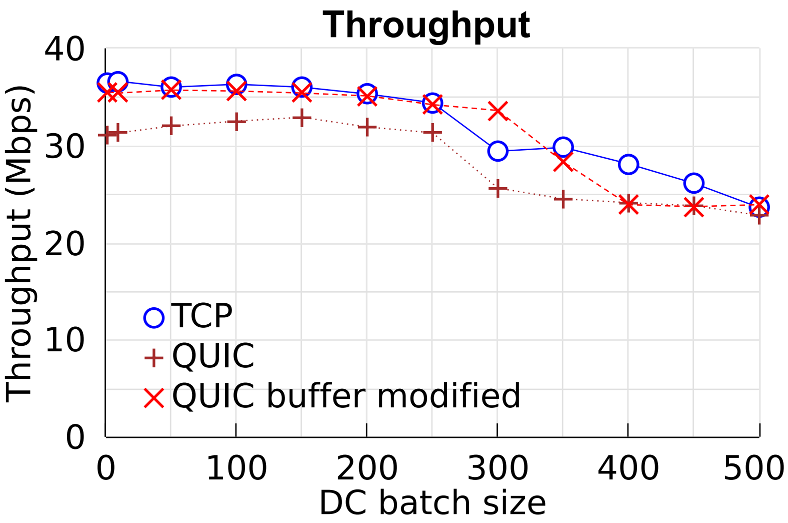

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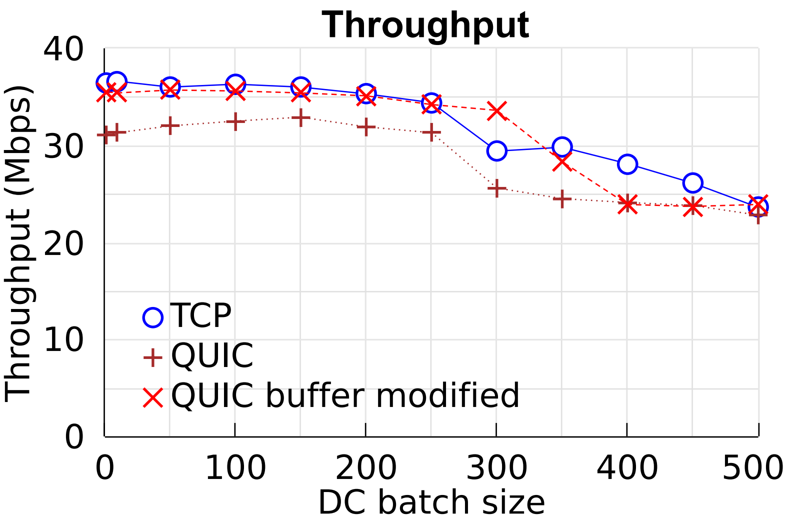

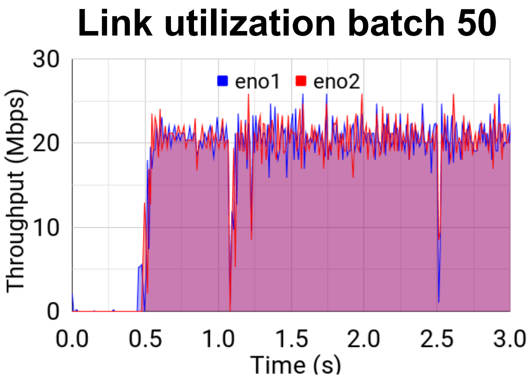

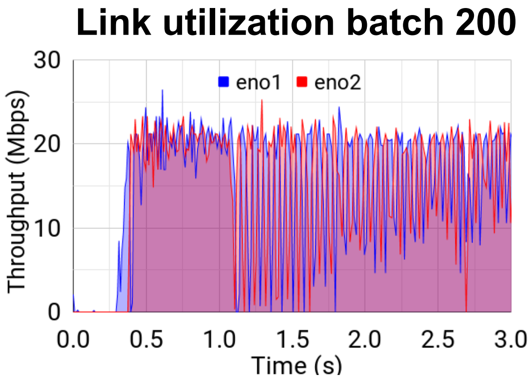

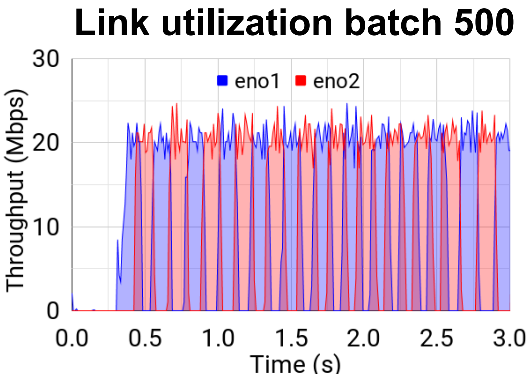

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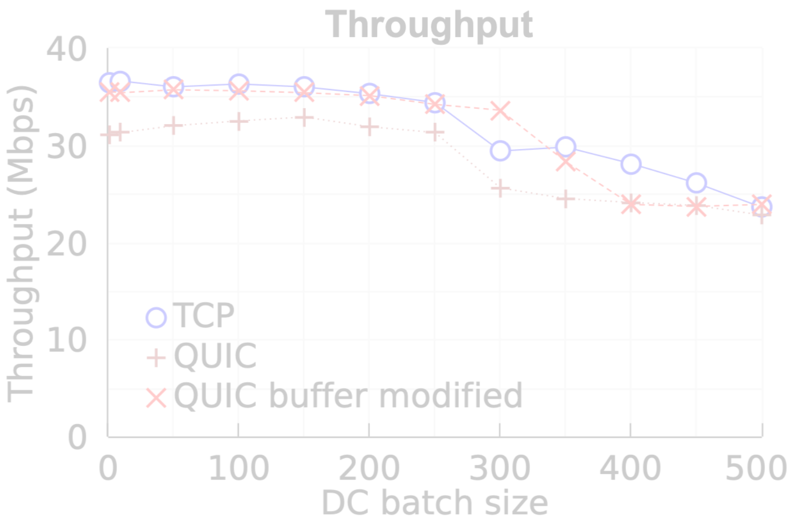
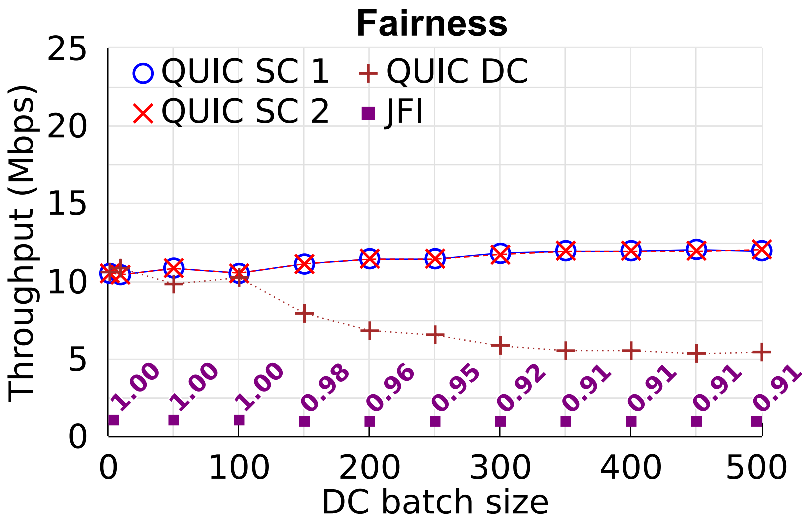
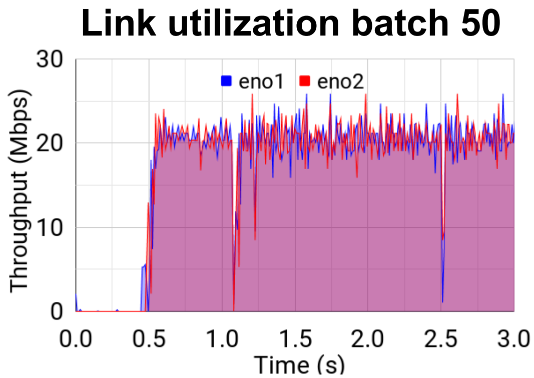
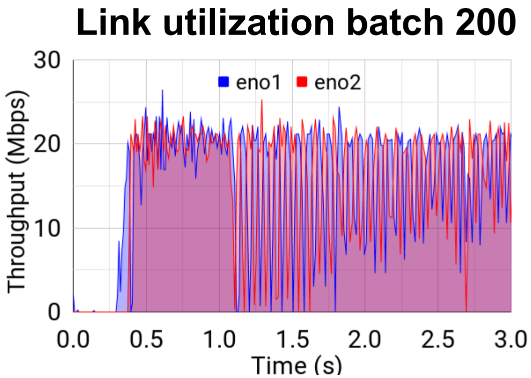
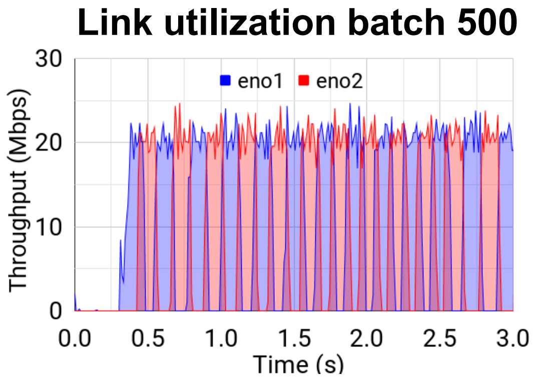


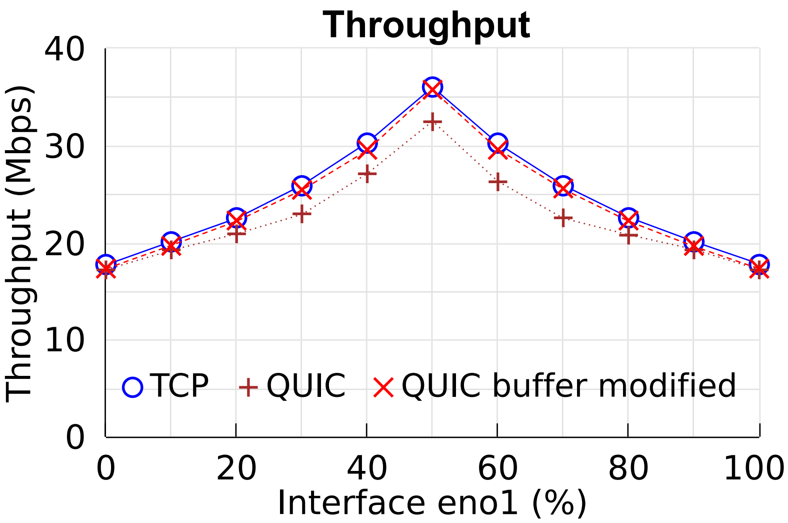








DC ratio (batch split)



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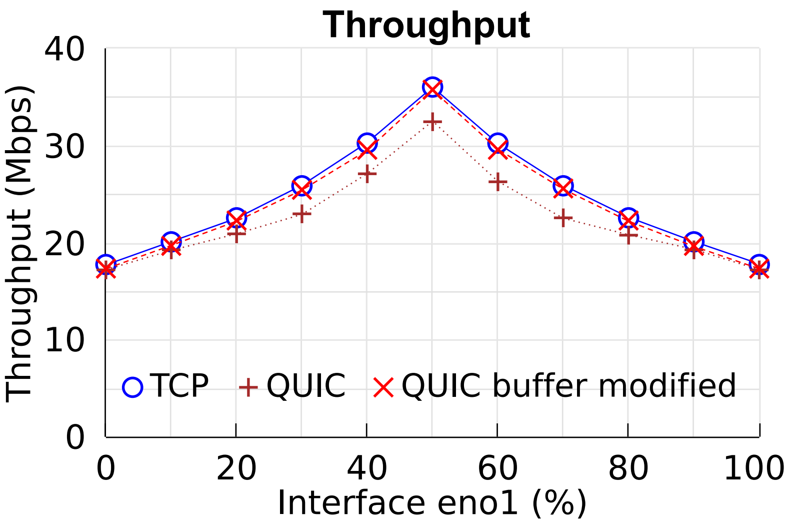

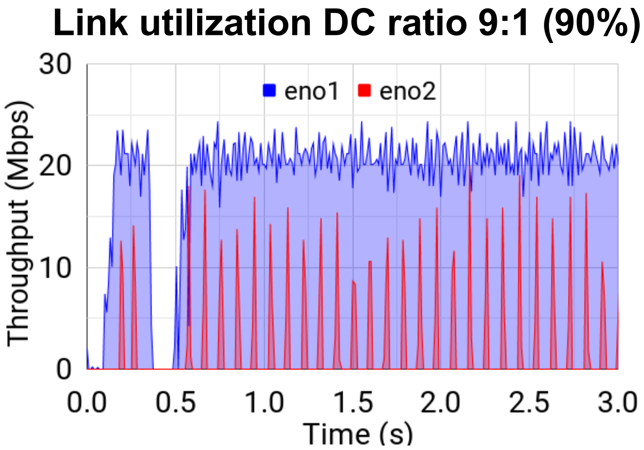

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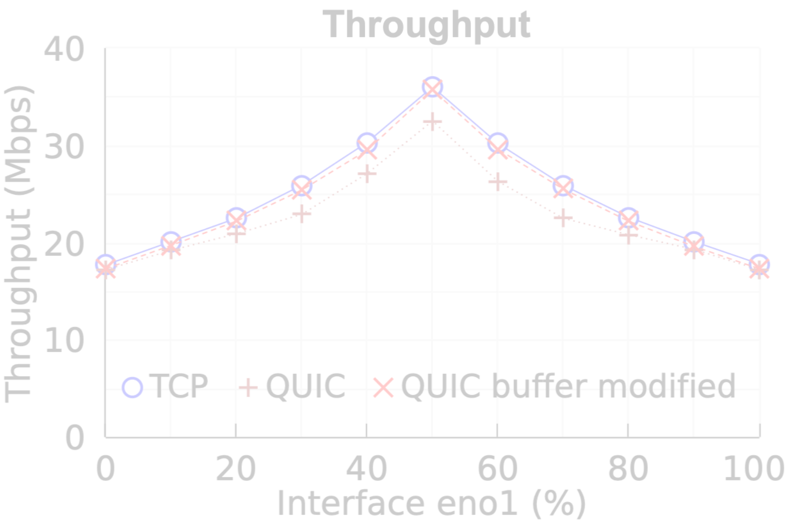
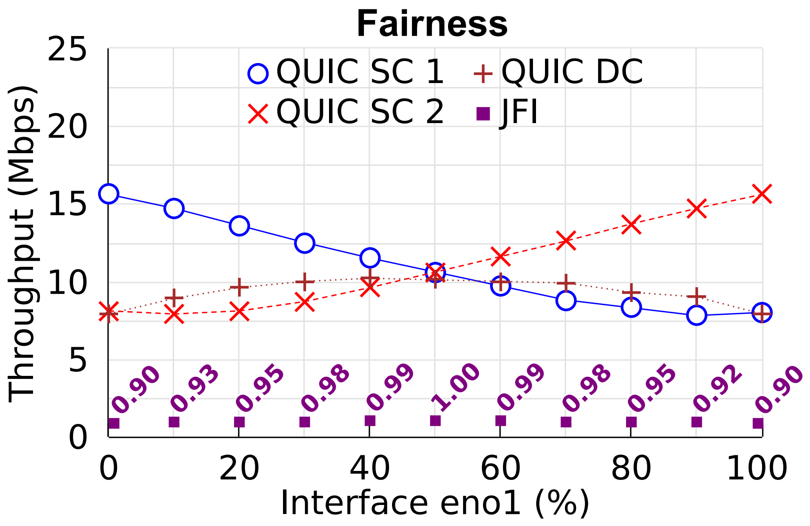
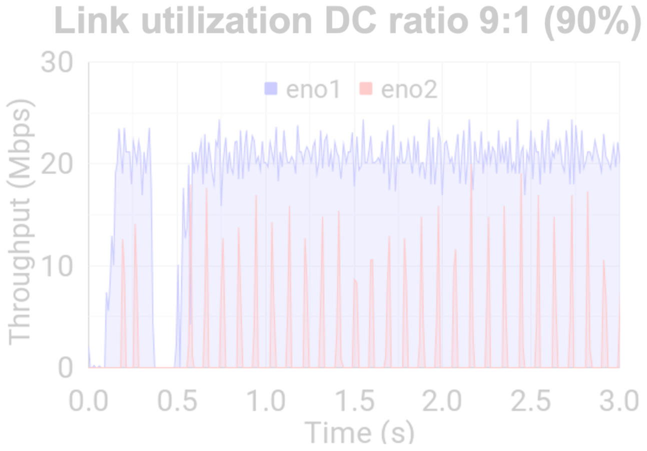
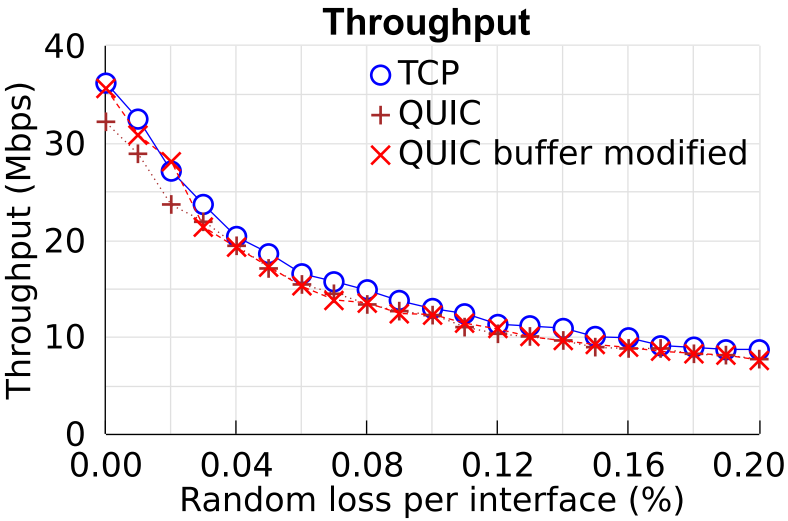


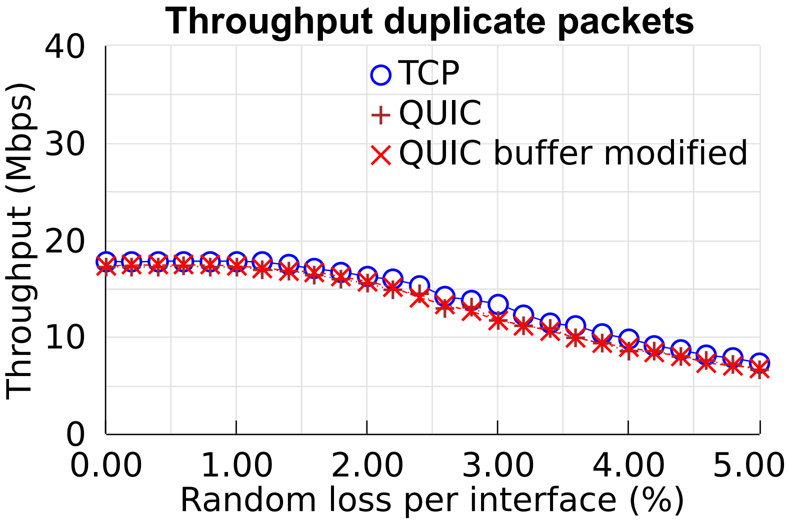




Random loss



Throughput
Throughput (Mbps)
40
30
20
10
0
0.00
0.04
0.08
0.12
0.16
0.20
Random loss per interface (%)
○ TCP
+ QUIC
× QUIC buffer modified



Throughput duplicate packets
Throughput (Mbps)
40
30
20
10
0
0.00
1.00
2.00
3.00
4.00
5.00
Random loss per interface (%)
○ TCP
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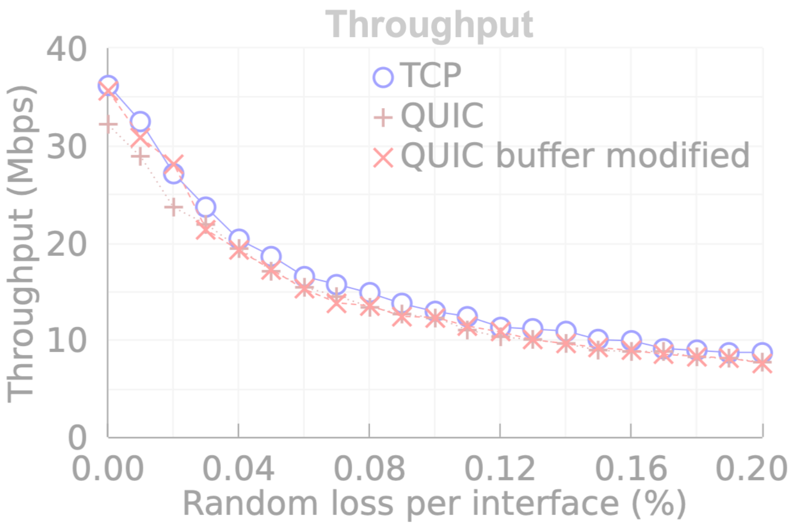
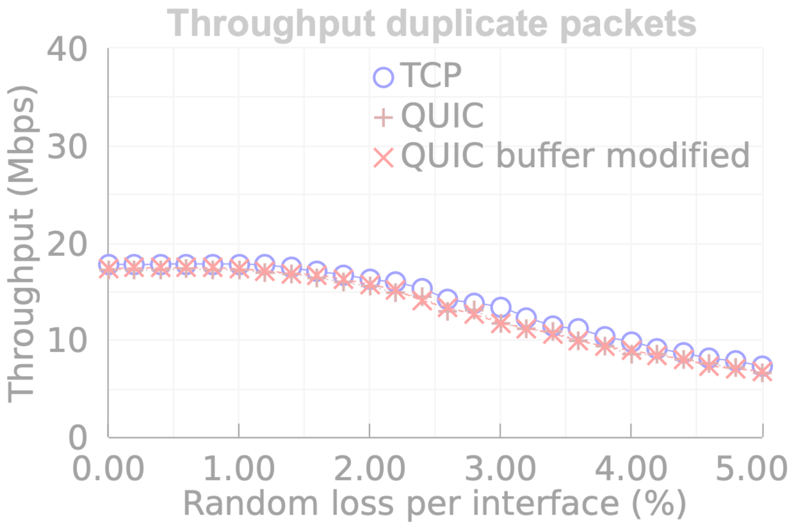
× QUIC buffer modified

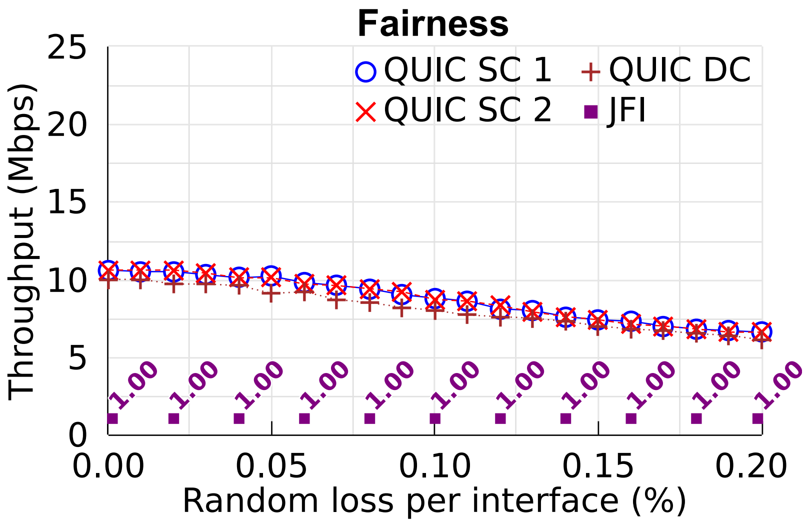
Random loss



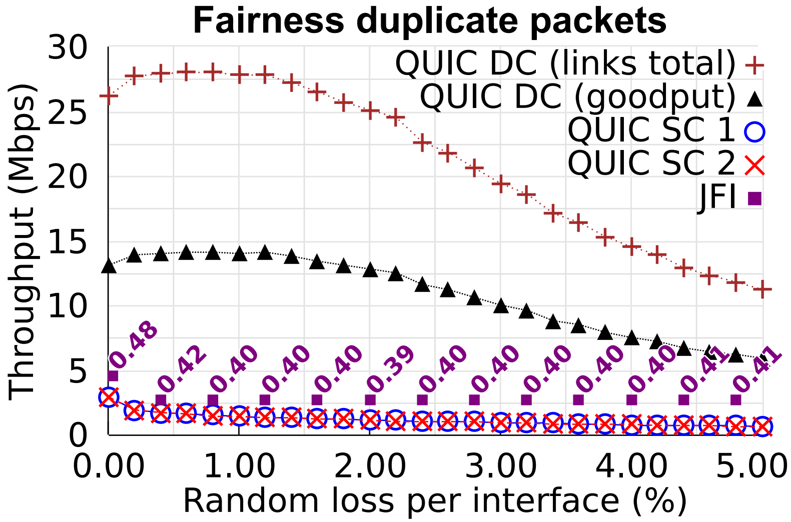
Throughput



Throughput duplicate packets



Fairness



Fairness duplicate packets

QUIC configuration/version

- QUIC implementation
  - Second QUIC implementation more aggressive, achieves higher throughput in general but unfair
  - Differences observed due to execution speed and pacer implementation

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  - Second QUIC implementation more aggressive, achieves higher throughput in general but unfair
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- Little to no differences when using:
  - CUBIC instead of NewReno
  - Trace-based bandwidth variation

Conclusions

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  - If link properties similar and batch size small
  - Otherwise better to turn DC off

Conclusions

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- QUIC performs similarly, but not identical, to TCP over DC

- QUIC can utilize the increased throughput/reliability of DC
  - If link properties similar and batch size small
  - Otherwise better to turn DC off

- Optimal systemwide fairness
  - If symmetric link conditions and not duplicating packets

Thanks for listening!

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