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A Measurement Study on Multi-path TCP with Multiple Cellular Carriers on High Speed Rails

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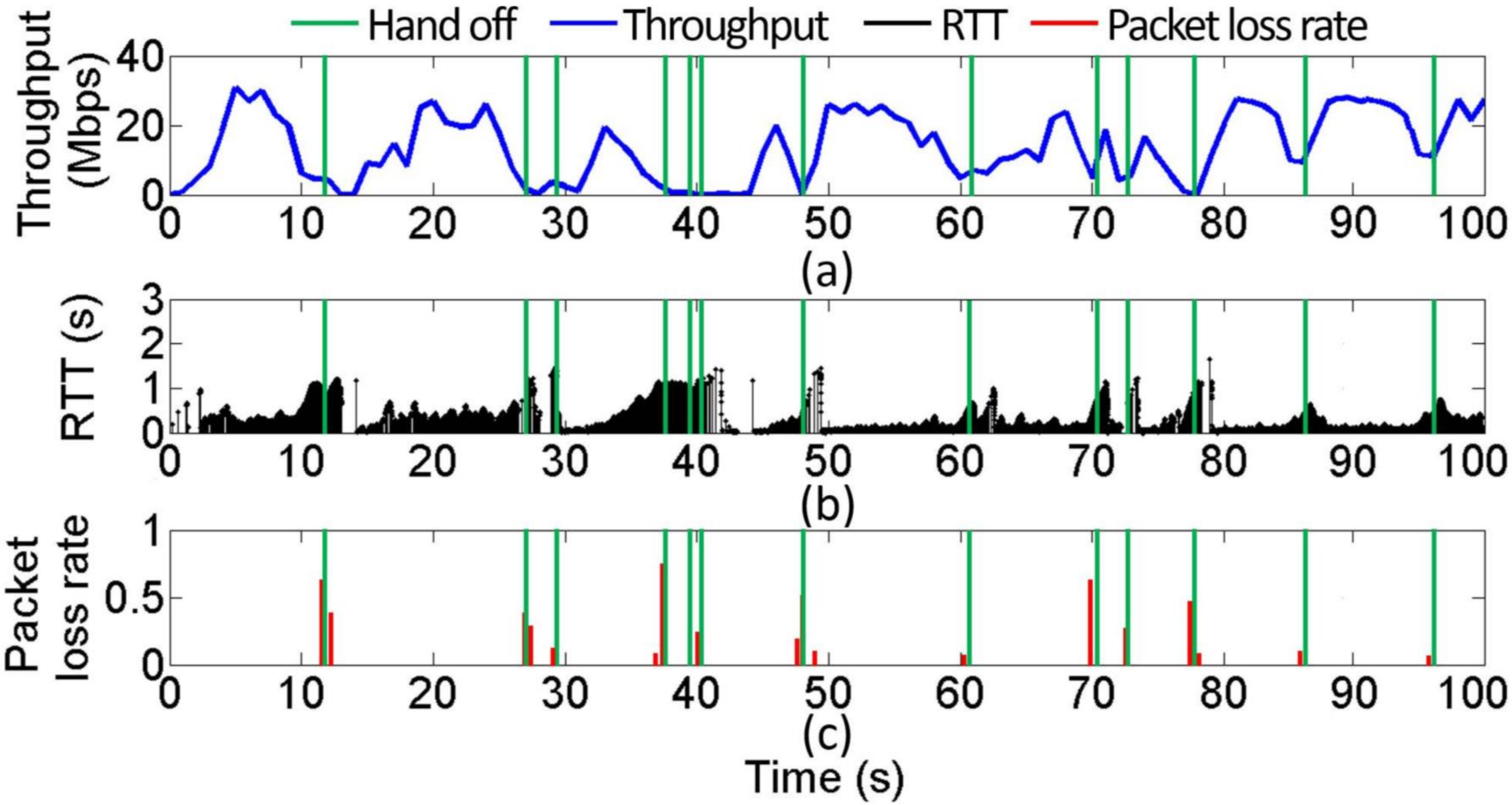
High Speed Rails (HSRs)

38,000 km	66%	310 km/h	1.7 billion	30%	30,000 km
Length	China	Speed	Passenger	Growing	2020

High speed mobility 😄 VS ☹

Increasing need for acceptable quality of network services

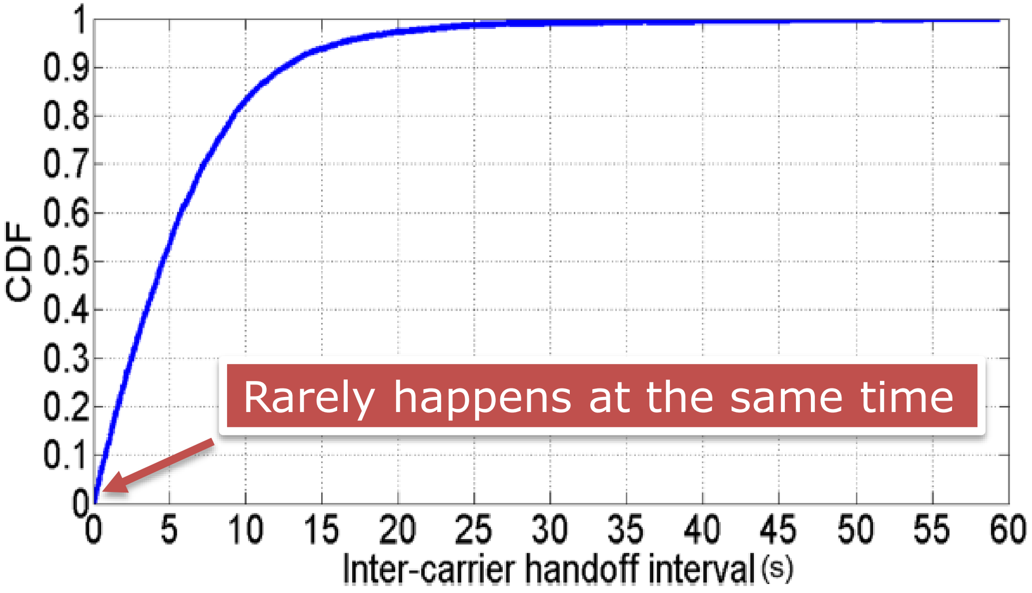
Single-Path Degradation on HSRs



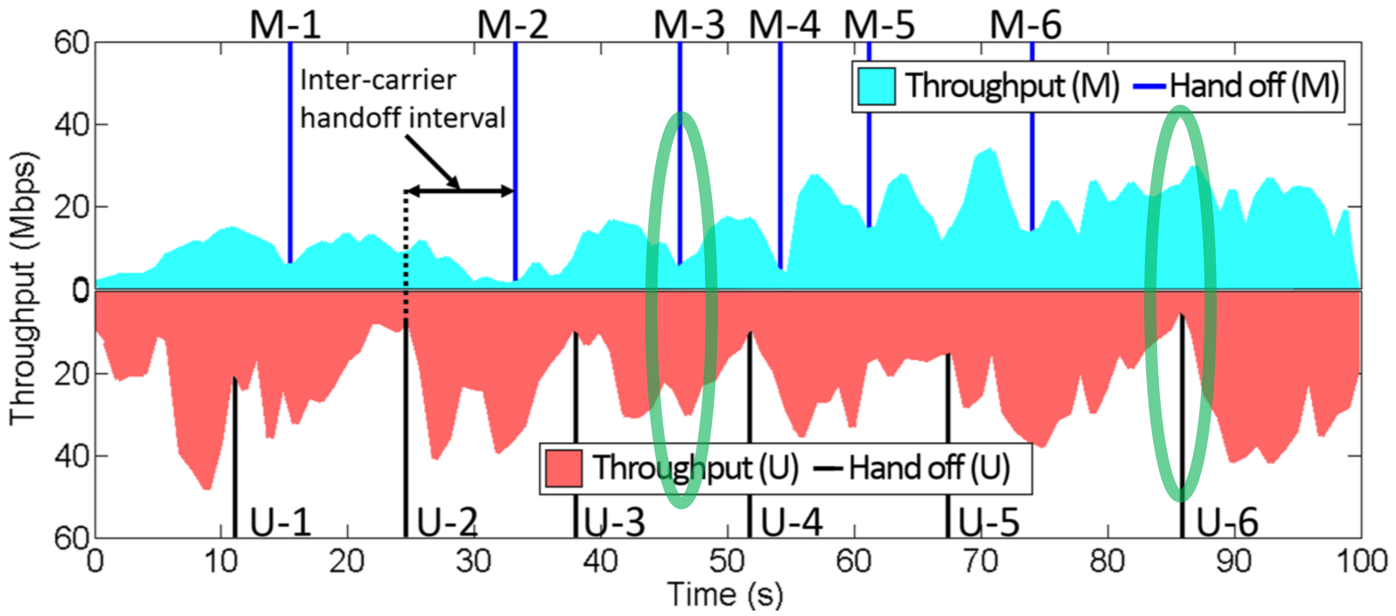
Frequent handoff is the main cause of performance degradation [Li, INFOCOM15] [Li, TON17]

Benefit from Carrier Complementarity

Making use of the difference in handoff time between carriers



CDF of inter-carrier handoff interval



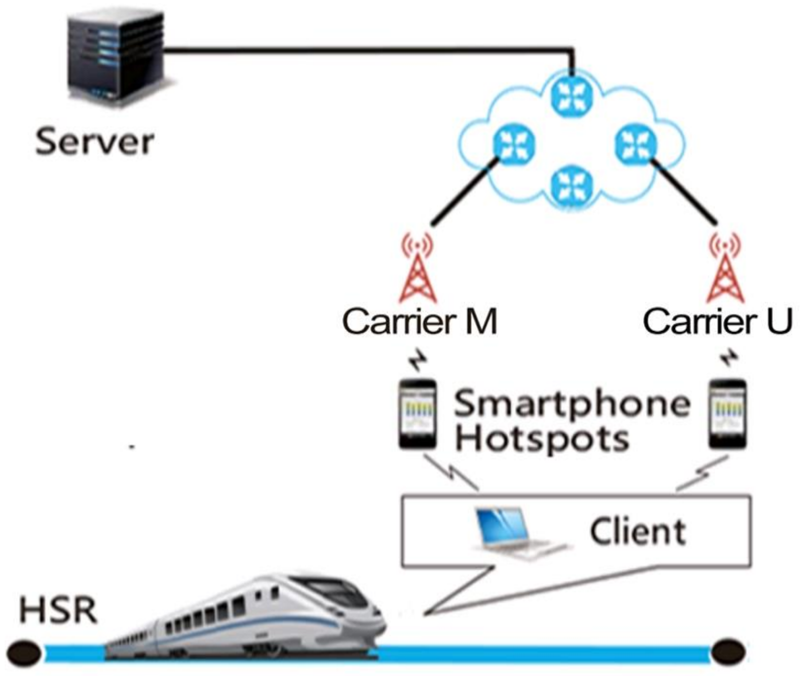
An example of two complementary carriers

To explore potential benefits of using Multi-path TCP (MPTCP)

Measurement Challenges

- Many intertwined factors
  - External: terrain, speed, handoff and network type, etc.
  - Internal: flow size and algorithms (congestion controller or scheduler), etc.
- Location and time bias
  - Same location vs high speed mobility
  - Same time vs flow interference
- Effort and time intensive
  - Many people and much money
  - Massive data traces on various HSR routes

Measurement Methodology

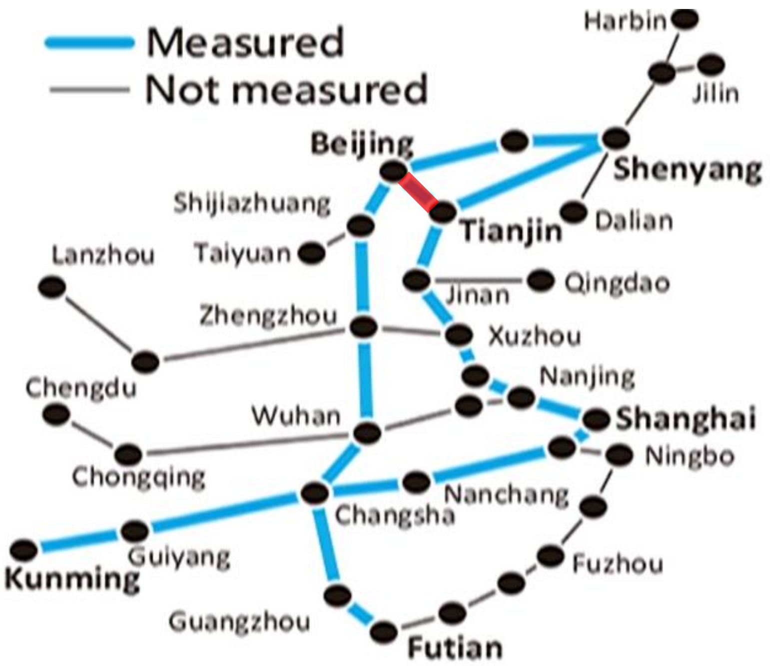


Measurement setup

USB cellular modems, USB WiFi modems accessing smartphone hotspots

MobiNet

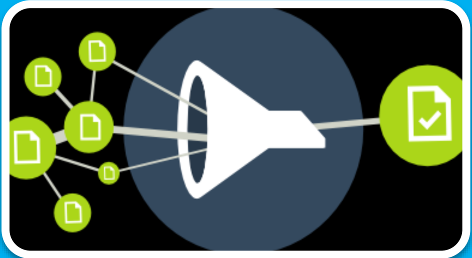
Geographical location, train speed, network type and handoffs



Footprints

Accumulated 82,266 km: 2x Earth Equatorial Circumference

Analysis Method



Filtering data—terrain, speed, handoff and network type

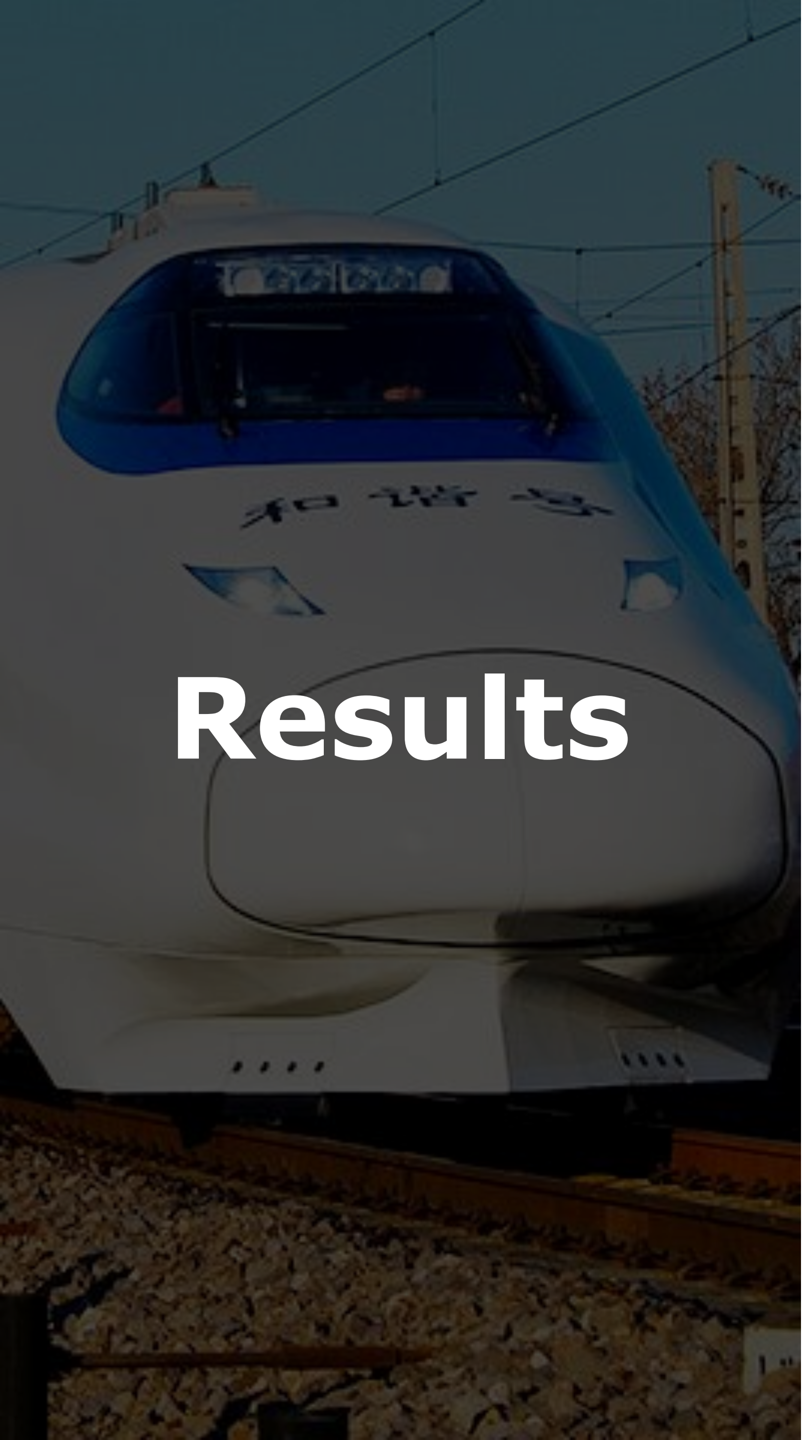
- Only consider data in 4G LTE networks in areas of open plains
- Only consider two cases: static and high speed (280-310km/h)

Comparison between MPTCP and TCP

- Same flow size/duration, at the same train speed, with similar handoff frequency, in the same carrier network
- Stable MPTCP kernel implementation v0.91: www.multipath-tcp.org

Decision Making

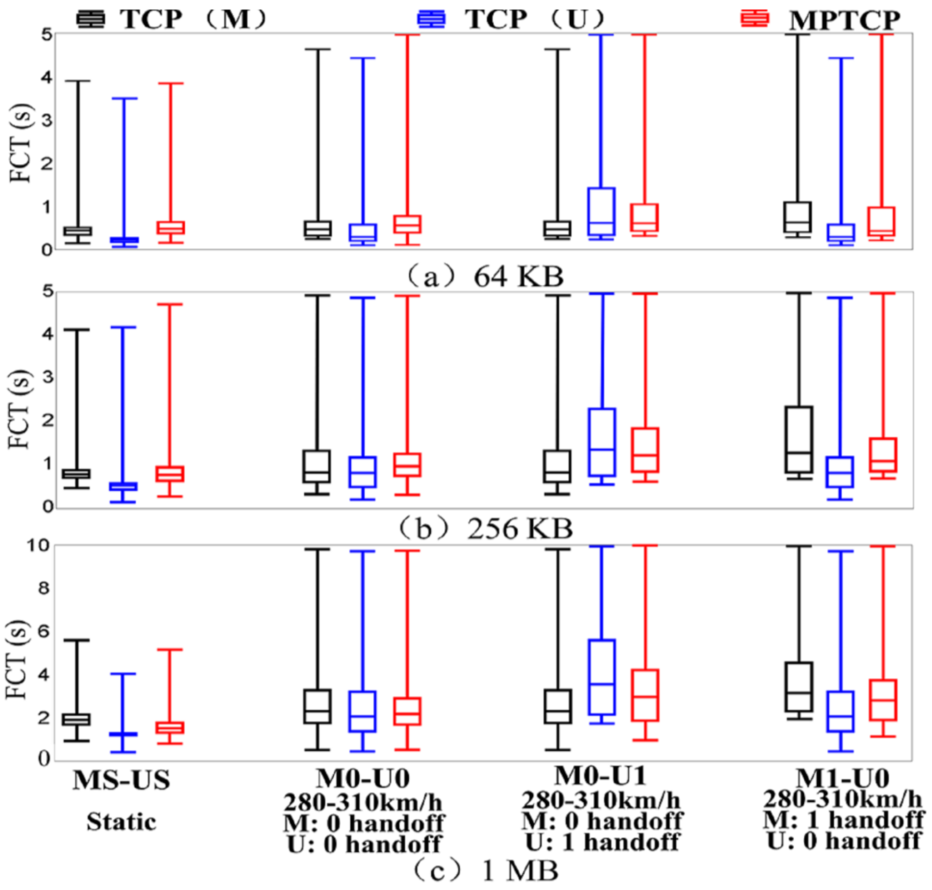
- Robustness: If MPTCP outperforms **either** of the two single TCPs
- Efficiency: If MPTCP outperforms **both** single TCPs



Results

Mice Flows

File Completion Time (FCT)



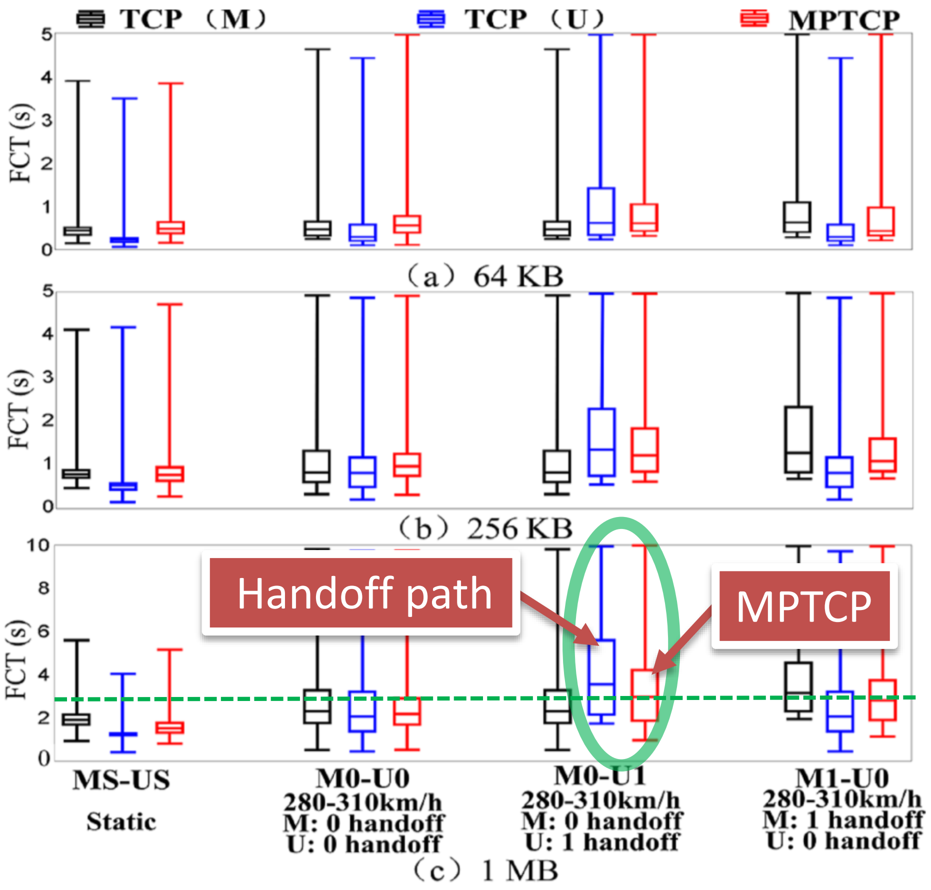
FCT of mice flows (<1 MB)

M: Carrier M   U: Carrier U

	Speed (km/h)	MPTCP		TCP flow (M)	TCP flow (U)
		Sub-flow (M)	Sub-flow (U)		
MS-US	0	0 handoff	0 handoff	0 handoff	0 handoff
M0-U0	280-310	0 handoff	0 handoff	0 handoff	0 handoff
M0-U1	280-310	0 handoff	1 handoff	0 handoff	1 handoff
M1-U0	280-310	1 handoff	0 handoff	1 handoff	0 handoff

TCP (M): single-path TCP using Carrier M
TCP (U): single-path TCP using Carrier U
MPTCP: dual-path MPTCP using Carrier M and Carrier U, simultaneously

Performance of Mice Flows



FCT of mice flows (<1 MB)

Decision Making

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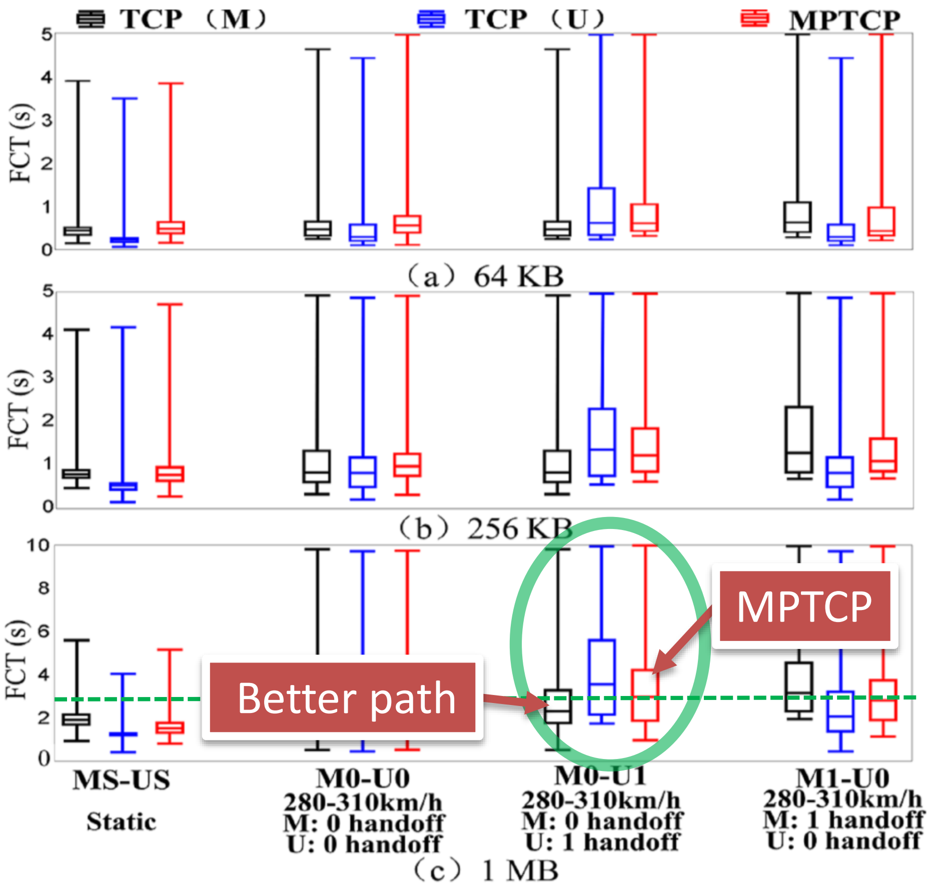
Robustness

Efficiency

Performance of Mice Flows



FCT of mice flows (<1 MB)

Decision Making

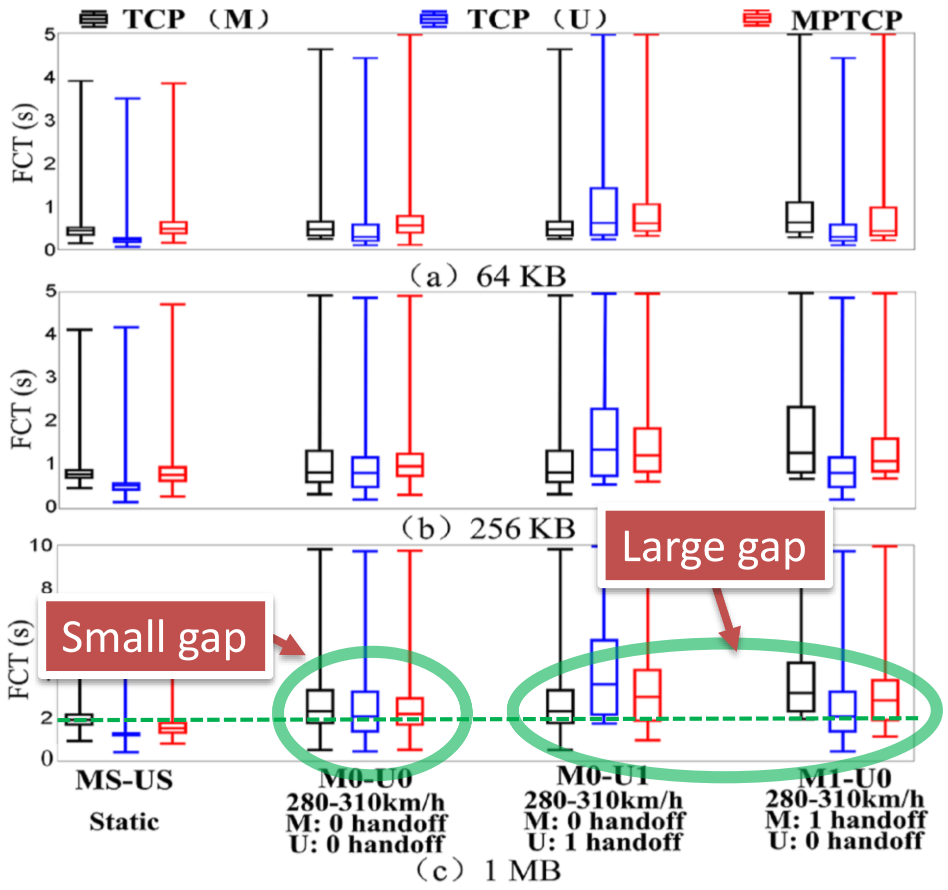
- Robust: If MPTCP outperforms **either** of the two single TCPs
- Efficient: If MPTCP outperforms **both** single TCPs

Robustness

Efficiency

Cannot achieve advantage over TCP in efficiency

Performance of Mice Flows



FCT of mice flows (<1 MB)

Decision Making

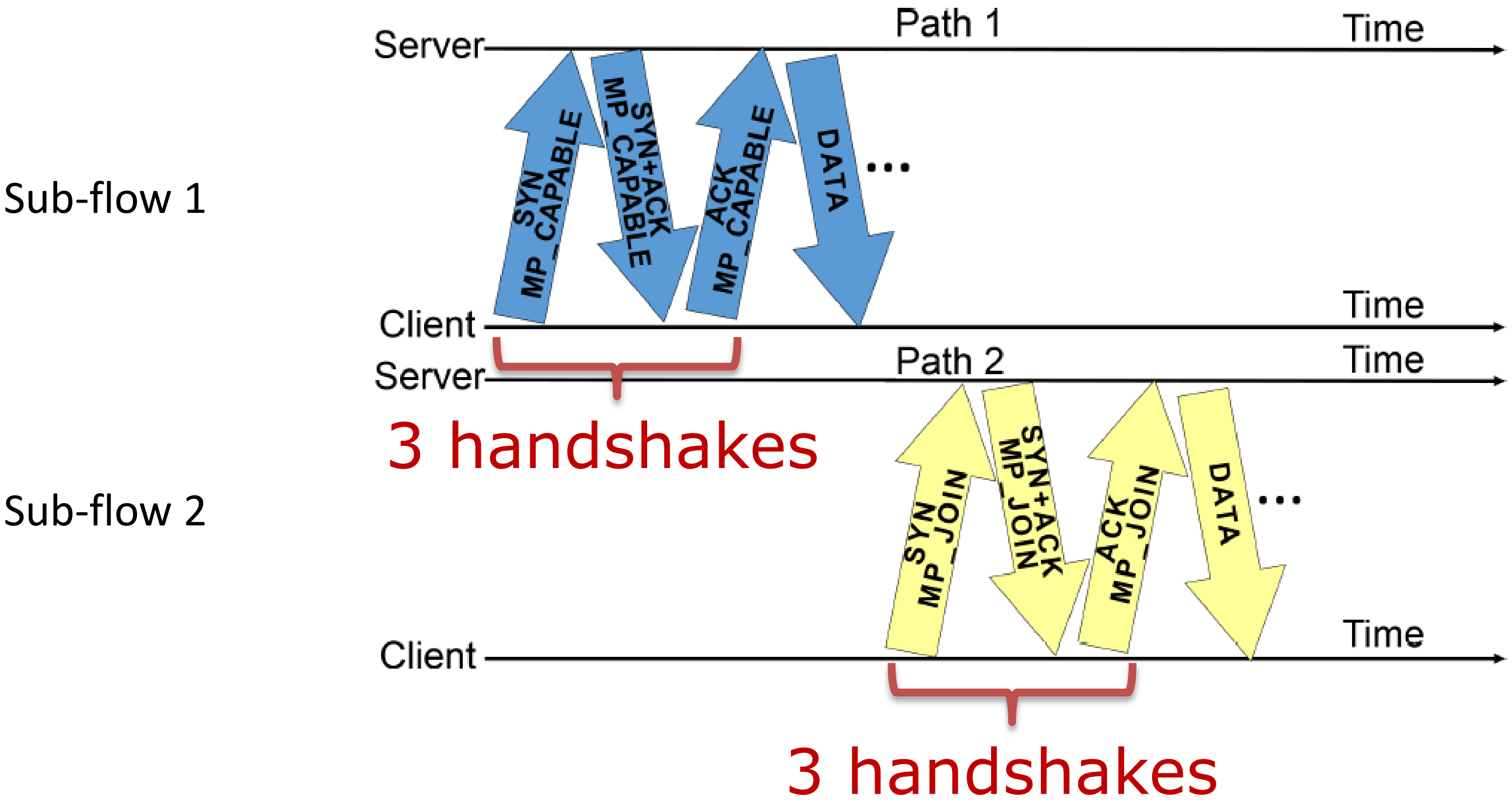
- Robust: If MPTCP outperforms **either** of the two single TCPs
- Efficient: If MPTCP outperforms **both** single TCPs

Handoff leads to efficiency reduction

Inefficient sub-flow establishment

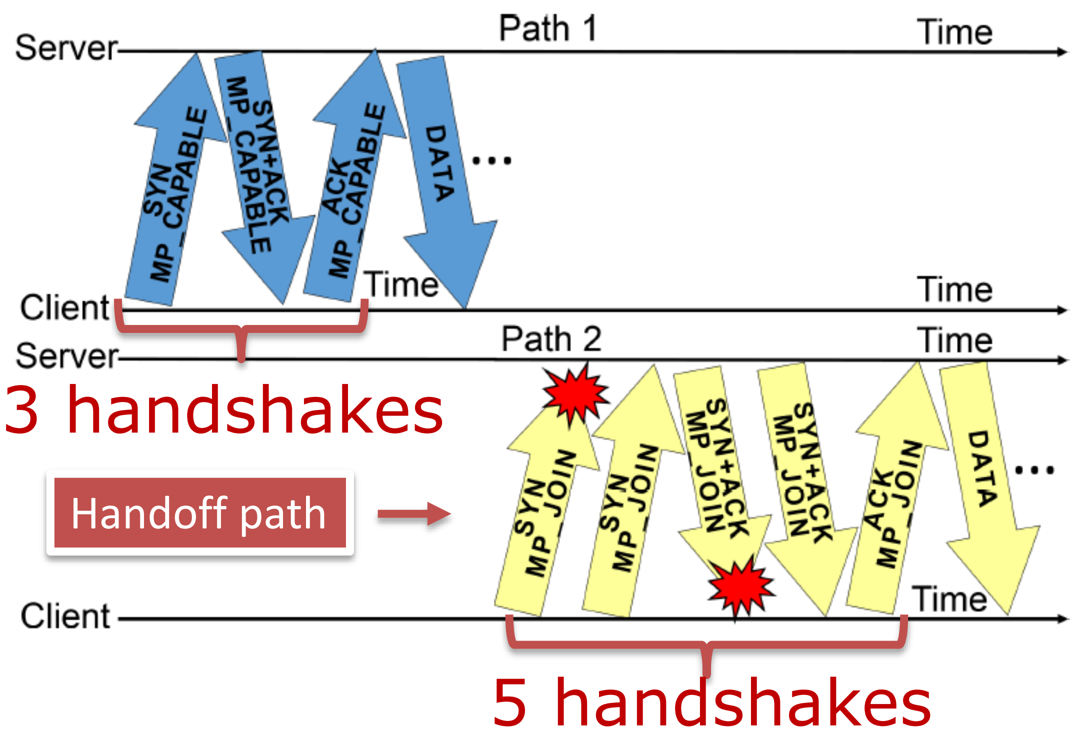
Sub-flow Establishment: Normal Case

Neither of two paths suffers a handoff

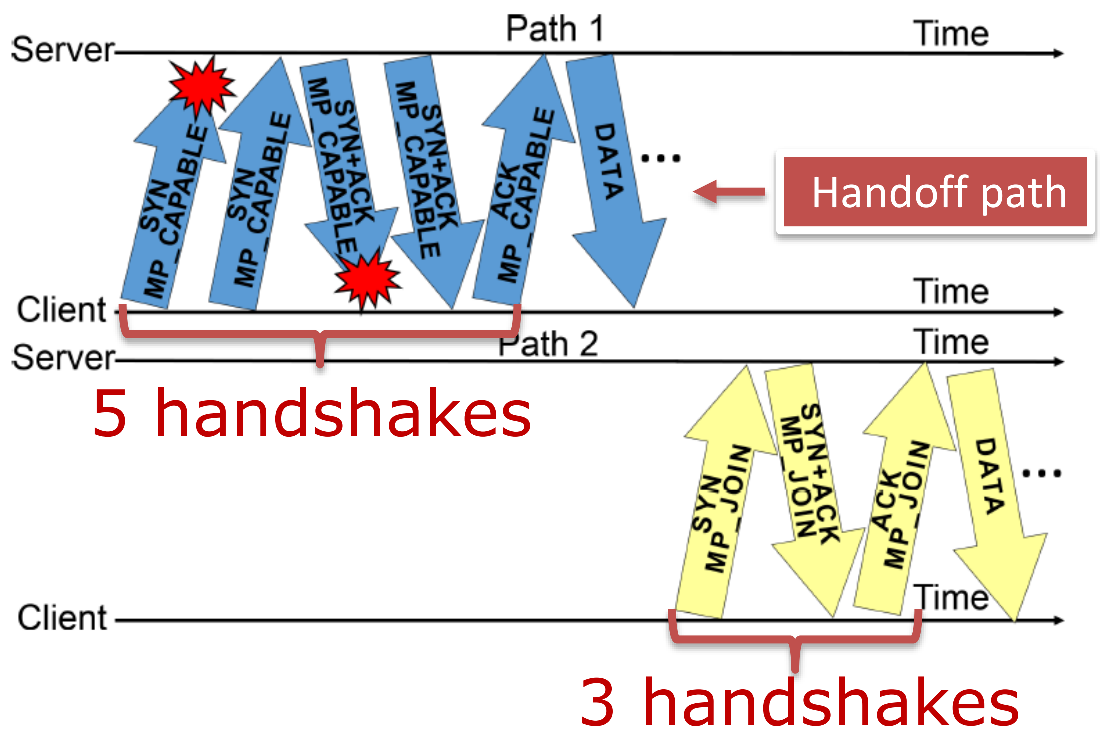


Sub-flow Establishment: Handoff Case

Either of two paths suffers a handoff

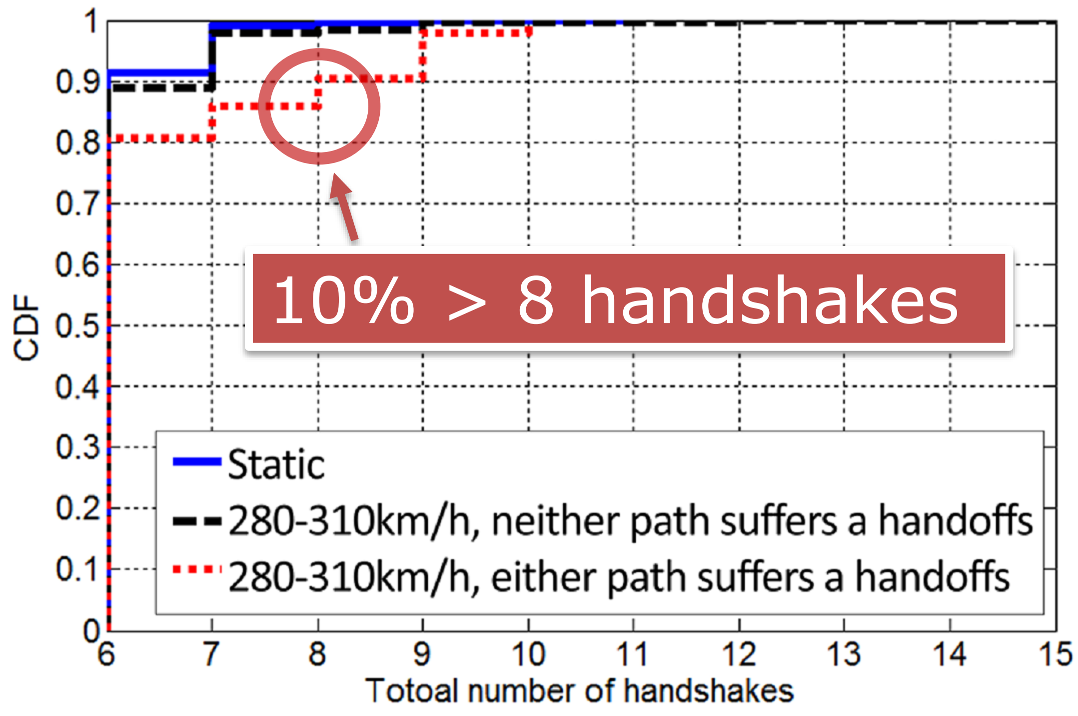


Lucky Case

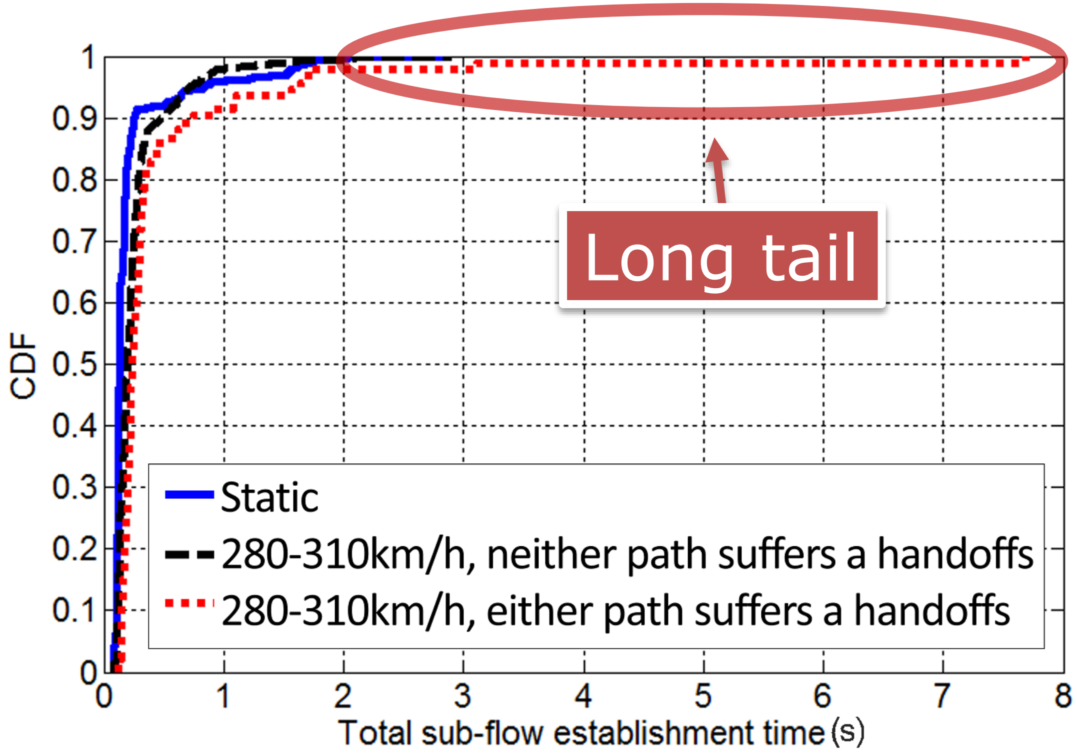


Unlucky Case

Sub-flow Establishment Time

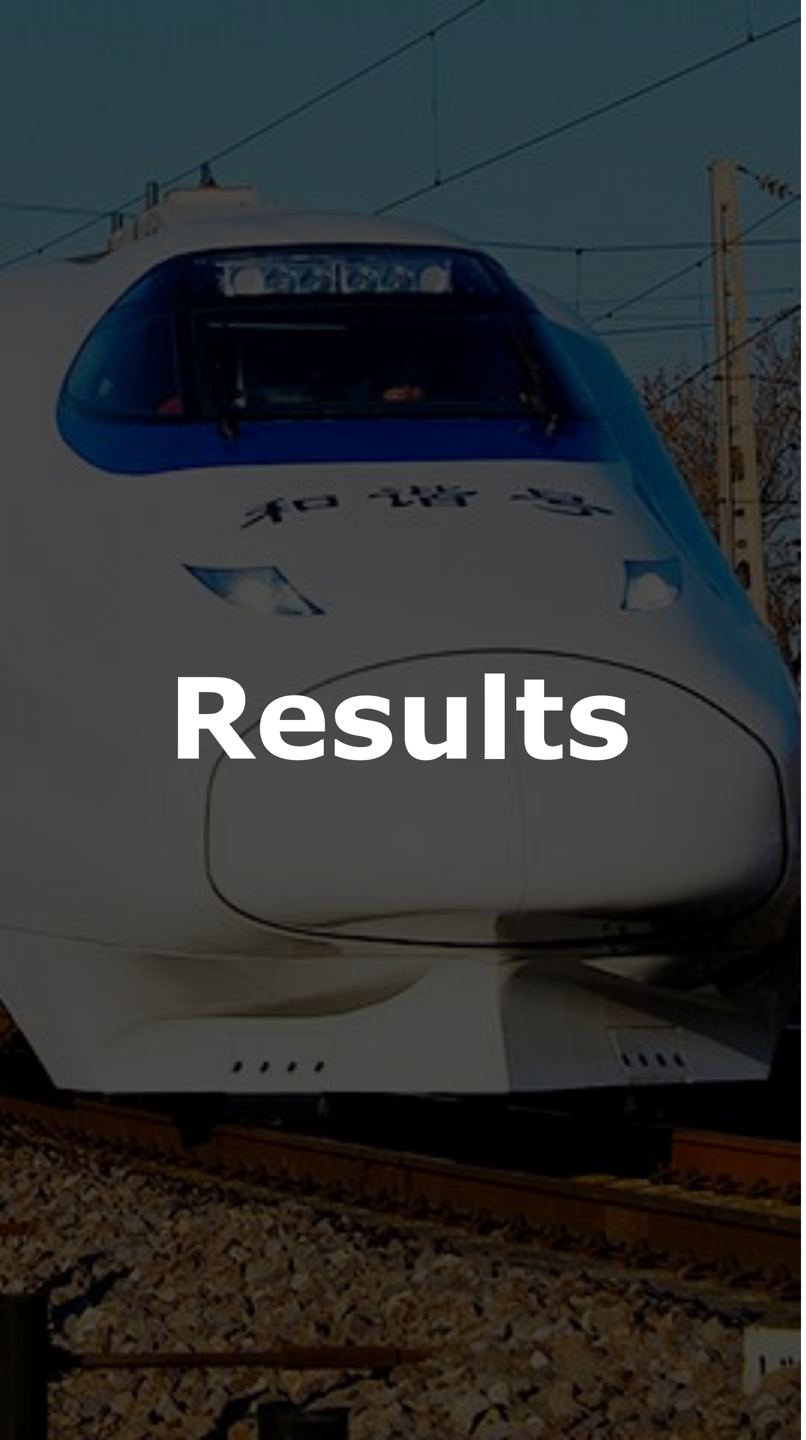


CDF of total number of handshakes



CDF of Sub-flow establishment time

MPTCP’s efficiency of sub-flow establishment is low on HSRs



Results

Elephant Flows

Performance of Elephant Flows

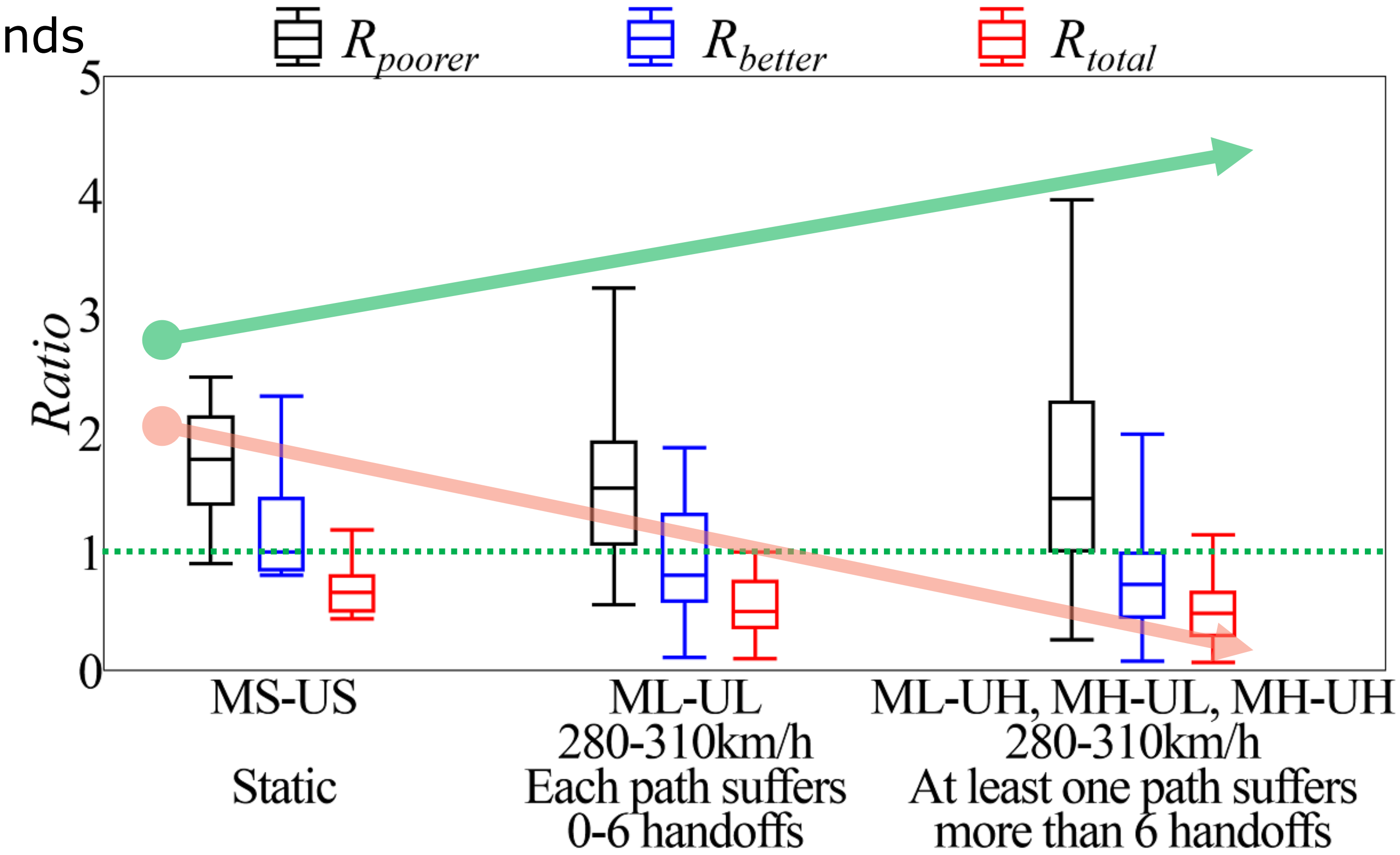
- Metric: average rate during 100 seconds
- Variable: train speed and number of handoffs suffered

$R_{poorer} = \frac{MPTCP}{\min(TCP_i)} > 1$ Robustness

$R_{better} = \frac{MPTCP}{\max(TCP_i)} < 1$ Efficiency

$R_{total} = \frac{MPTCP}{\text{sum}(TCP_i)} < 1$ Aggregation

- Results remain constant, but reasons are different!



Poor adaptability of congestion control and scheduling to frequent handoffs

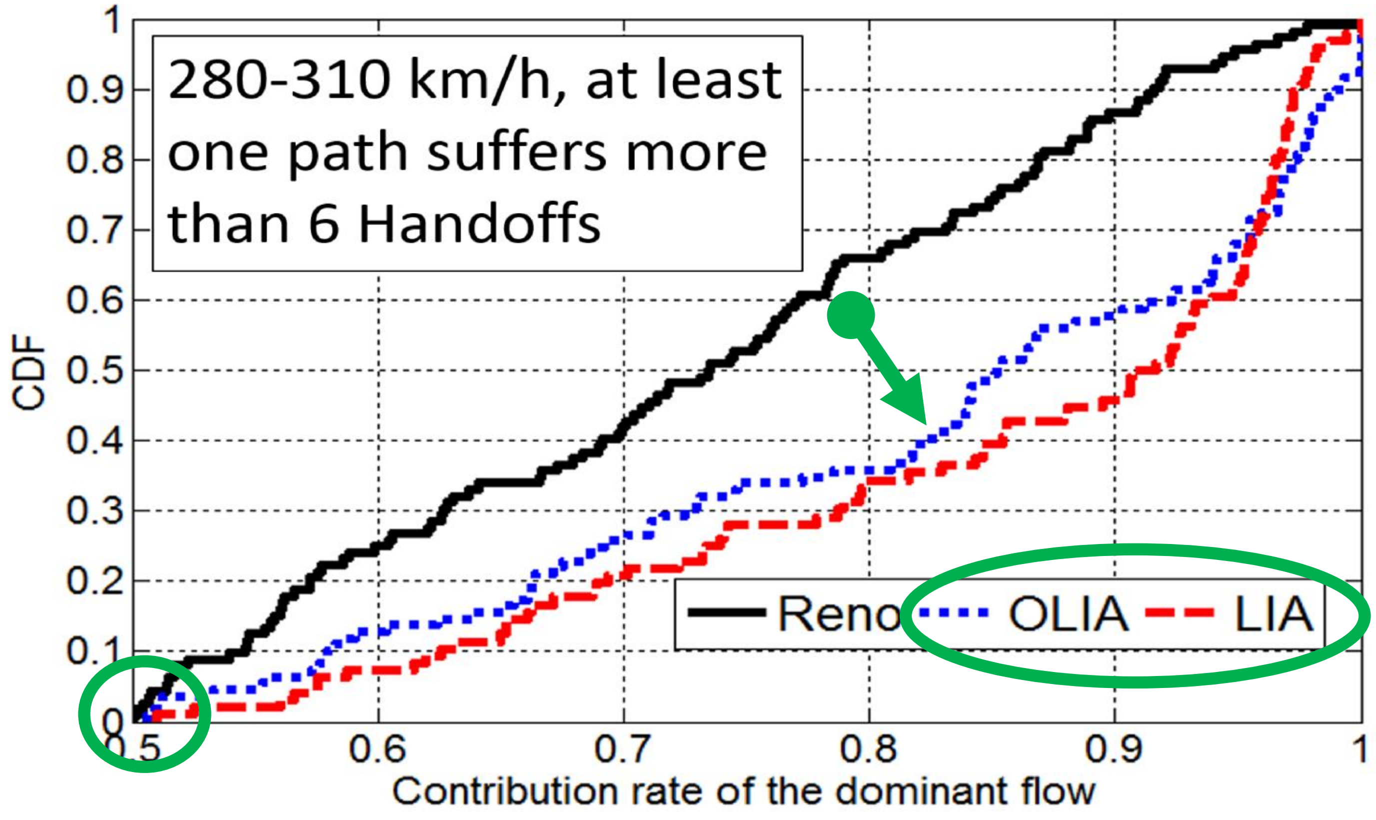
Congestion Control: Traffic Distribution

- Contribution rate of dominant sub-flow to quantify degree of traffic distribution balance

$$D_{balance} = \frac{\max(TCP_i)}{\mathrm{sum}(TCP_i)} \approx 1$$

Balance

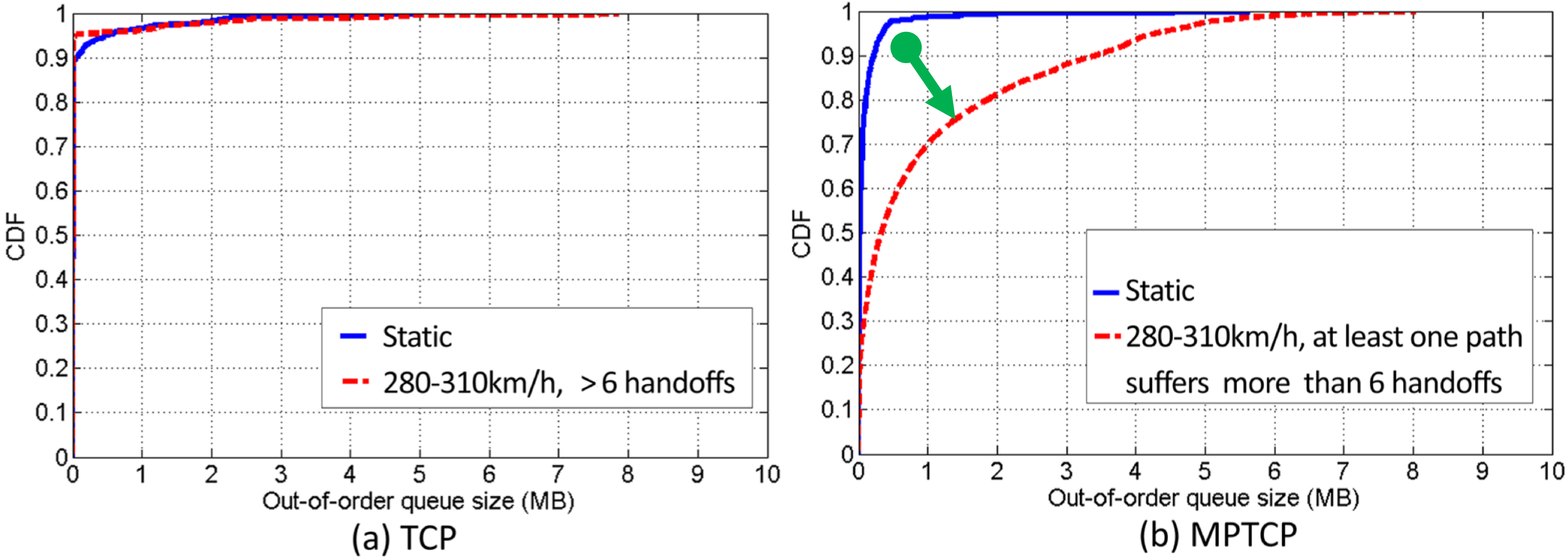
- Packet loss causes window drops
- Window distribution imbalance leads to traffic distribution imbalance
- **Coupled** congestion controllers
  - LIA [Raiciu et.al, RFC 6356]
  - OLIA [Khalili et.al, IETF draft]
  - Transfer traffic from a congested path to a less congested one



*More details please refer to the paper.

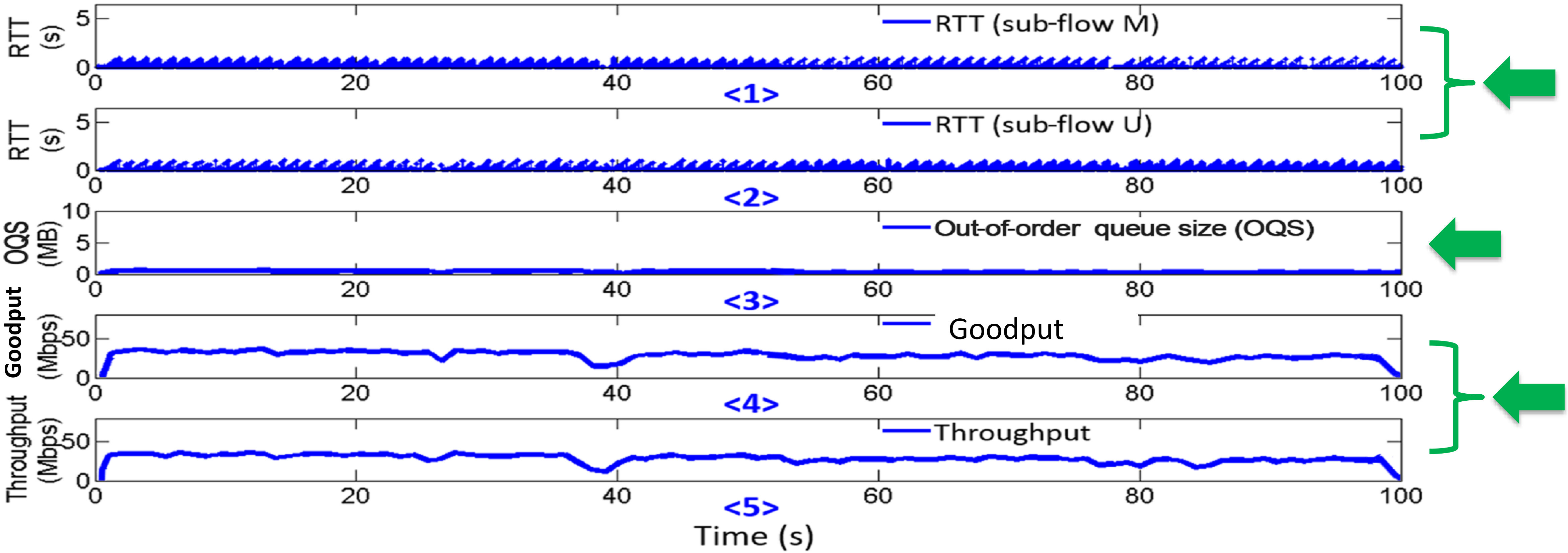
Scheduling: Out of Order Problem

- Out-of-order queue size rises

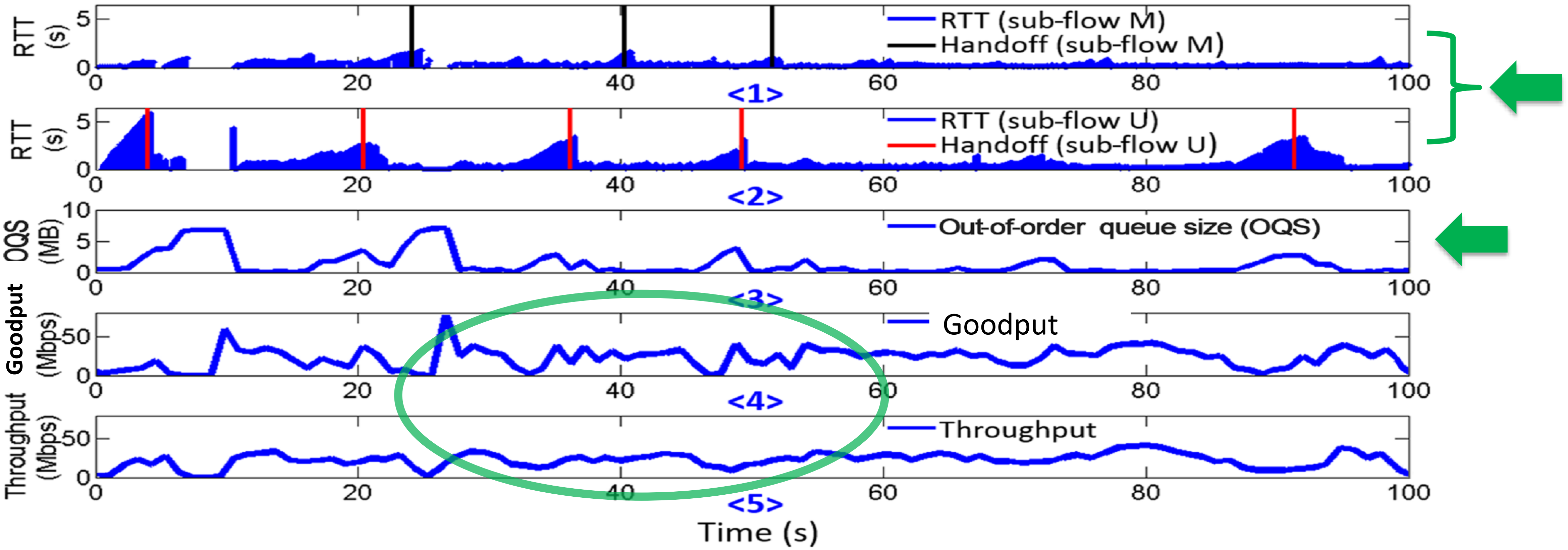


Static Cases

- Out-of-order problem is not serious in static cases



High Speed Mobility Cases



MPTCP’s efficiency of congestion control and scheduling is low on HSRs

Key Takeaways

- **Insights:** reliability enhancement rather than bandwidth aggregation
  - Significant advantage in robustness
  - Efficiency of MPTCP is far from satisfactory
- **Cause:** poor adaptability to frequent handoffs
  - Mice: sub-flow establishment
  - Elephant: scheduling and congestion control
- **Suggestions:** handoff pattern detection and prediction

Thank You!

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Data traces are available at http://www.thucsnet.org/hsrmptcp.html