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

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# High Speed Rails (HSRs)

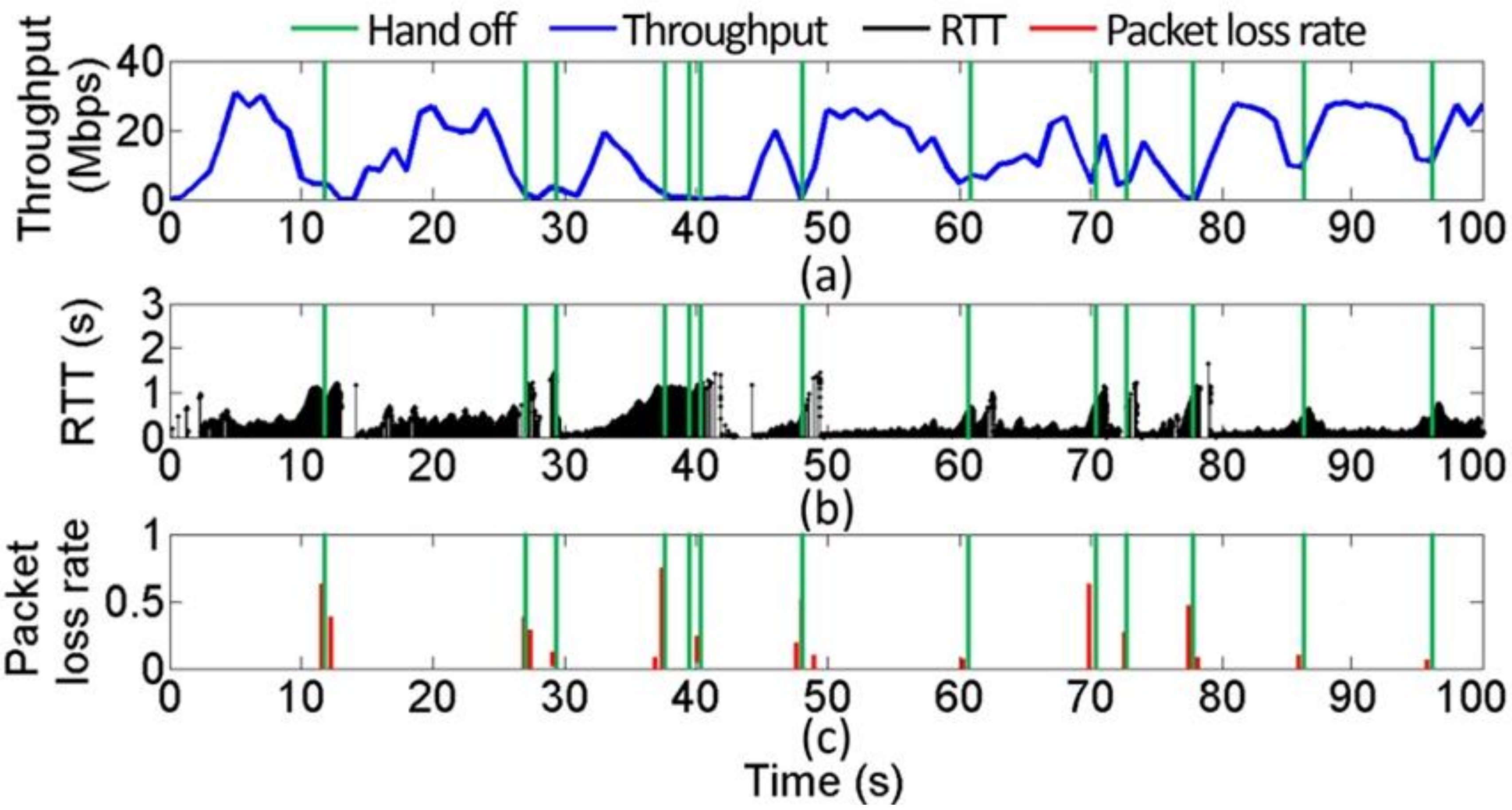
| 38,000 km | 66% | 310 km/h | 1.7 billion | 30% | 30,000 km |
|---|---|---|---|---|---|
| Length | China | Speed | Passenger | Growing | 2020 |




**High speed mobility** VS

**Increasing need for acceptable quality of network services**

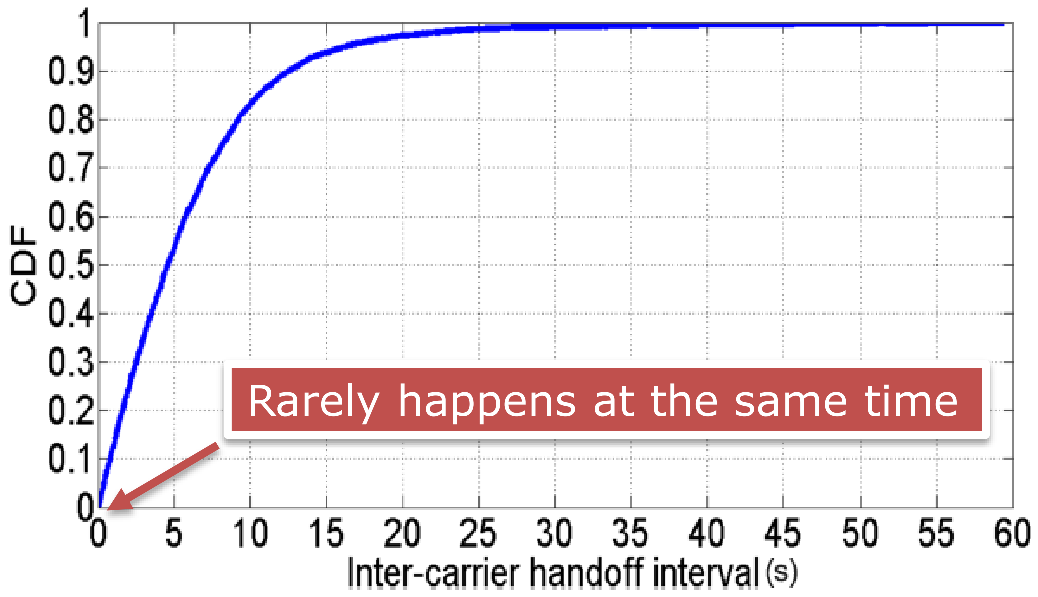
# Single-Path Transmission on HSRs



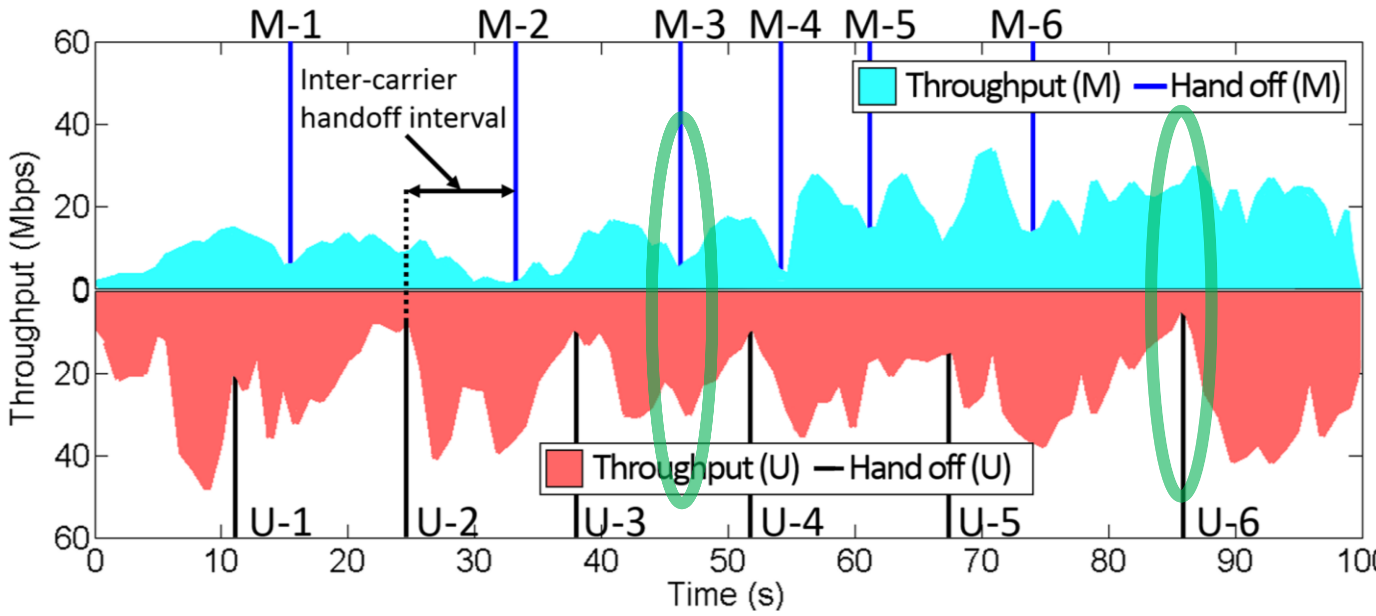

**Frequent handoff** is the main cause of performance degradation [Li, INFOCOM15] [Li, TON17]

# Motivation of Using Multi-path Transmission

Making use of the difference in handoff time between carriers




CDF of inter-carrier handoff interval



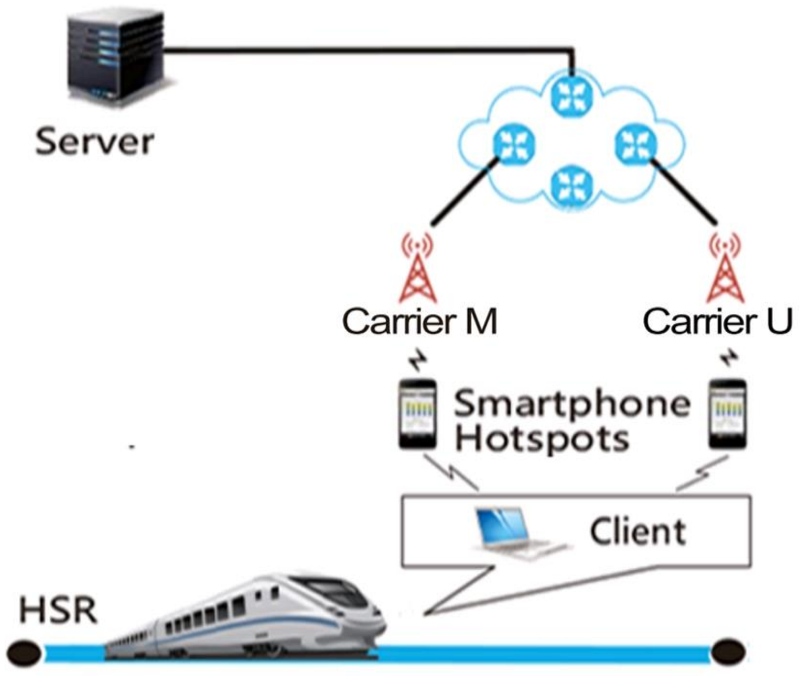

An example of difference in handoff time between two carriers

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

# 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

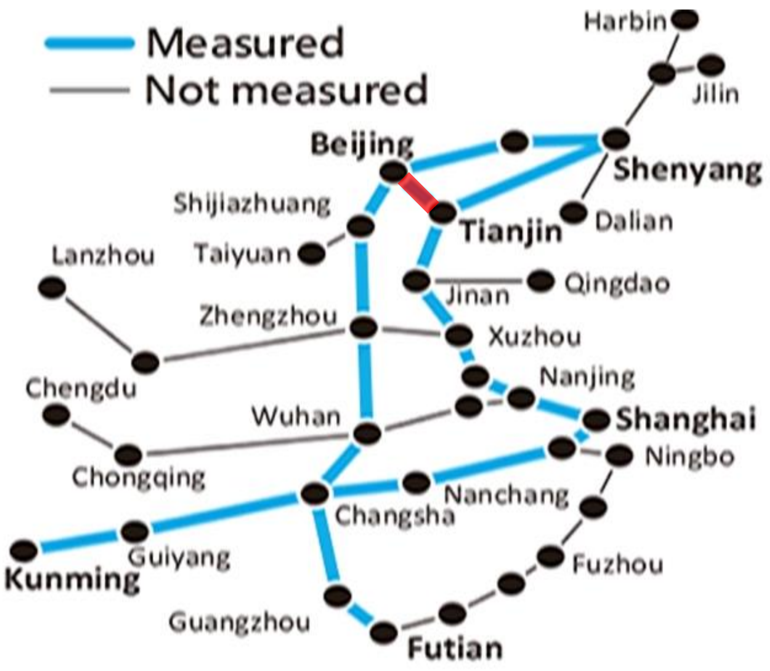



Measurement setup

**USB cellular modems,  USB WiFi modems accessing smartphone hotspots**


MobiNet

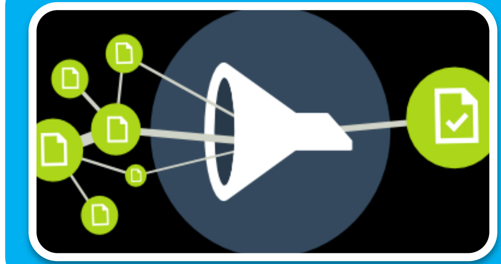
**Geographical location, train speed, network type and handoffs**




Footprints

**Accumulated 82,266 km: 2x Earth Equatorial Circumference**

# Analysis Method



## Filtering data—terrain, speed, handoff and network type

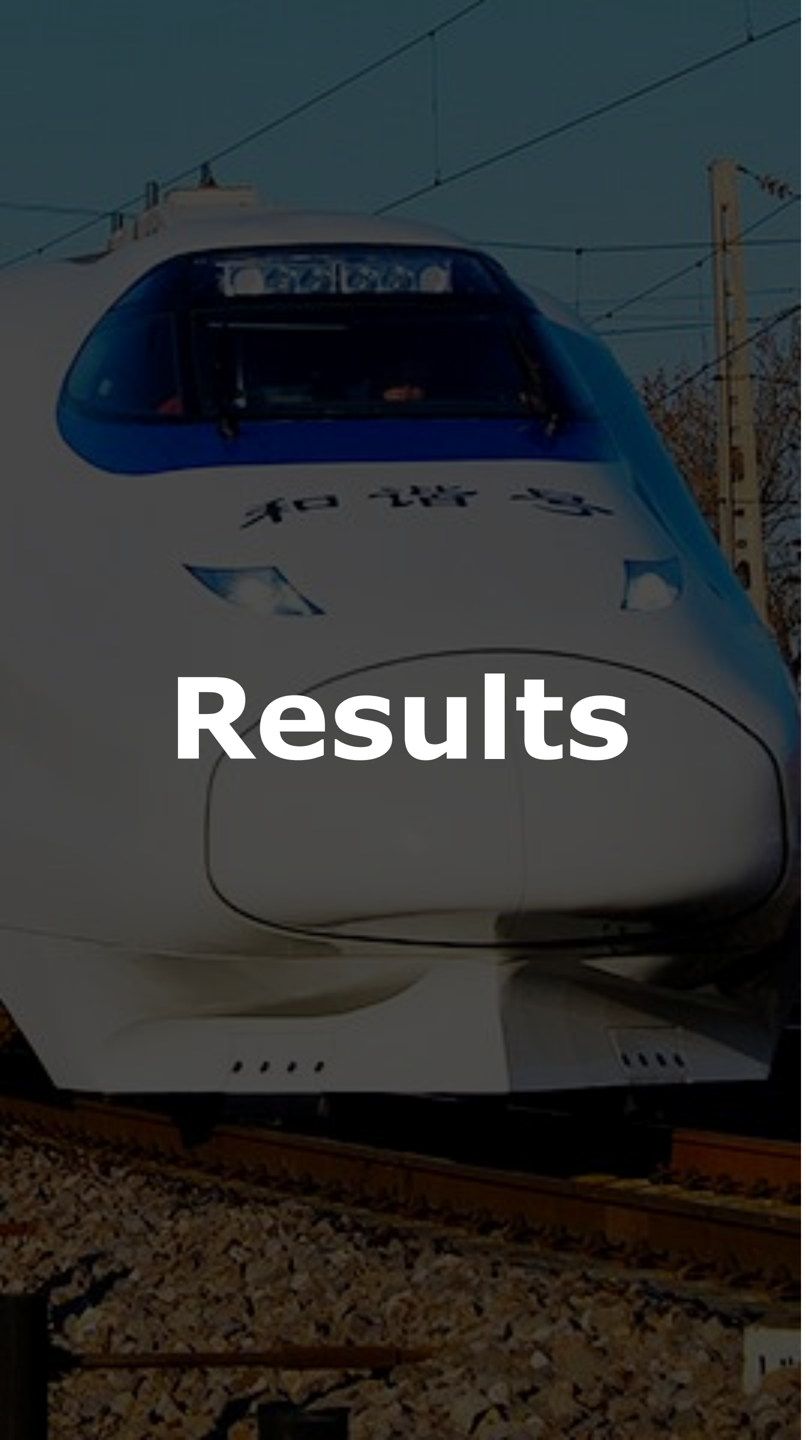
- Only consider data in 4G LTE networks in areas of open plains
- Only consider two cases: static and high speed (280-310km/h)

## 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

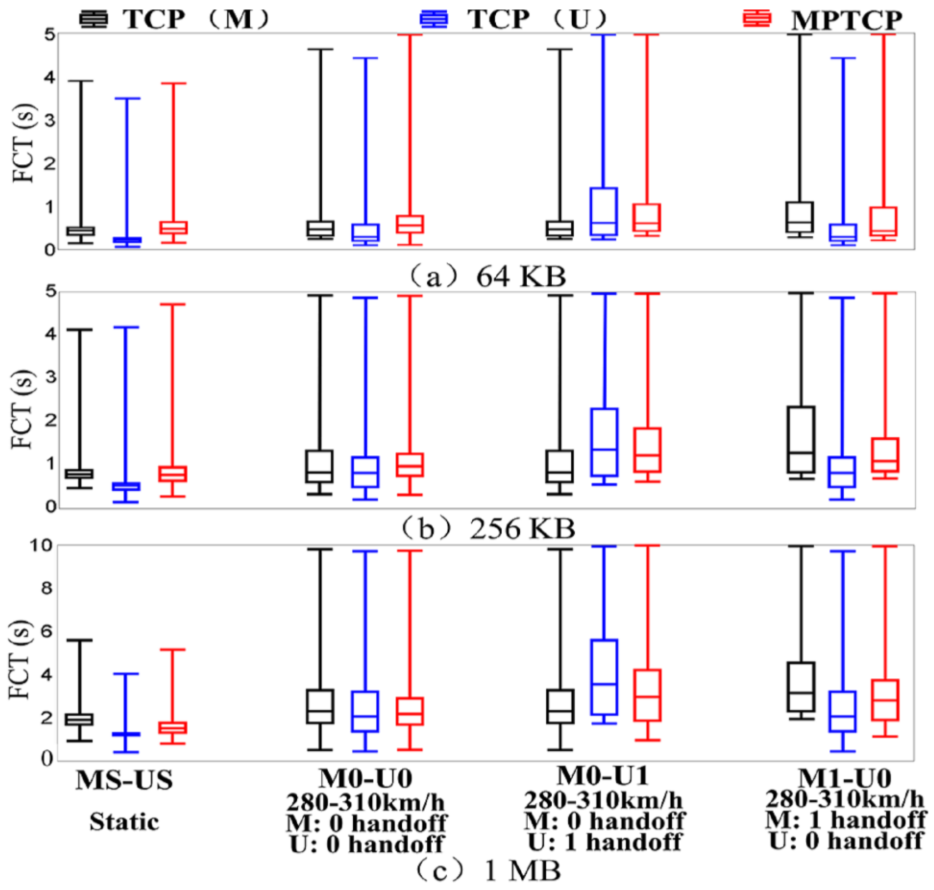
- Robustness: If MPTCP outperforms **either** of the two single TCPs
- Efficiency: If MPTCP outperforms **both** single TCPs



# Results

## Mice Flows

# File Completion Time (FCT)




FCT of mice flows (<1 MB)

**M: Carrier M U: Carrier U**

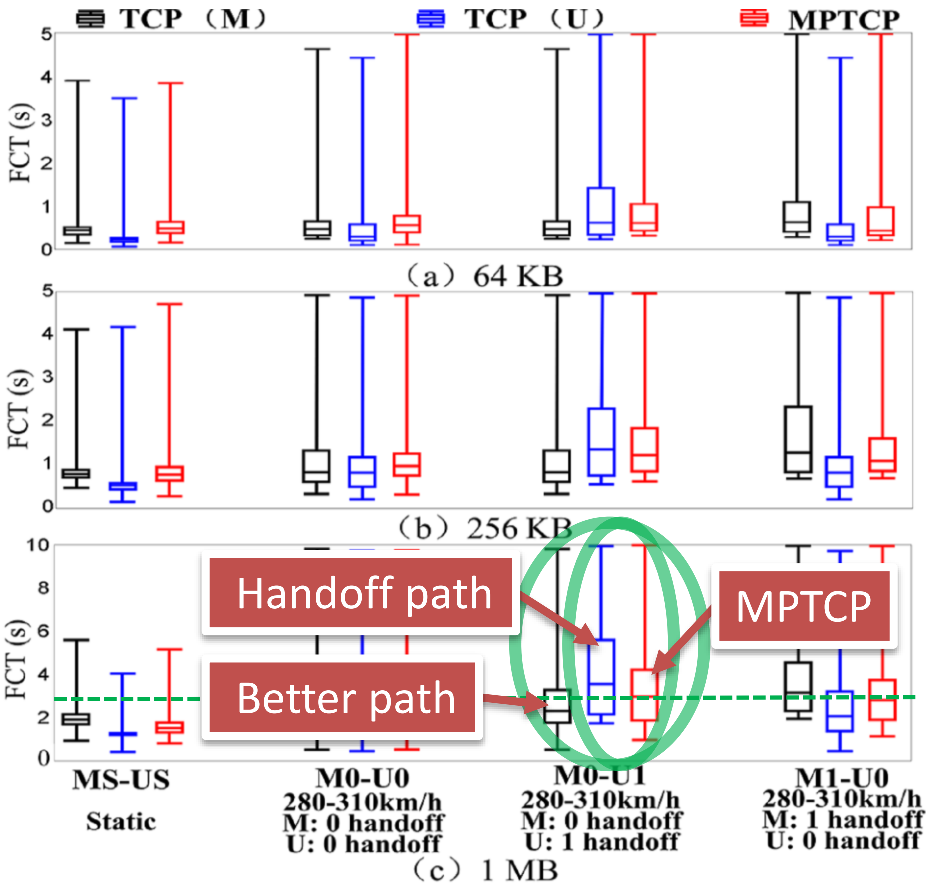
| | Speed (km/h) | MPTCP | | TCP flow (M) | TCP flow (U) |
|---|---|---|---|---|---|
| | | Sub-flow (M) | Sub-flow (U) | | |
| **MS-US** | 0 | 0 handoff | 0 handoff | 0 handoff | 0 handoff |
| **M0-U0** | 280-310 | 0 handoff | 0 handoff | 0 handoff | 0 handoff |
| **M0-U1** | 280-310 | 0 handoff | 1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

# File Completion Time (FCT)

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Robustness

Efficiency

**Cannot achieve advantage over TCP in efficiency**

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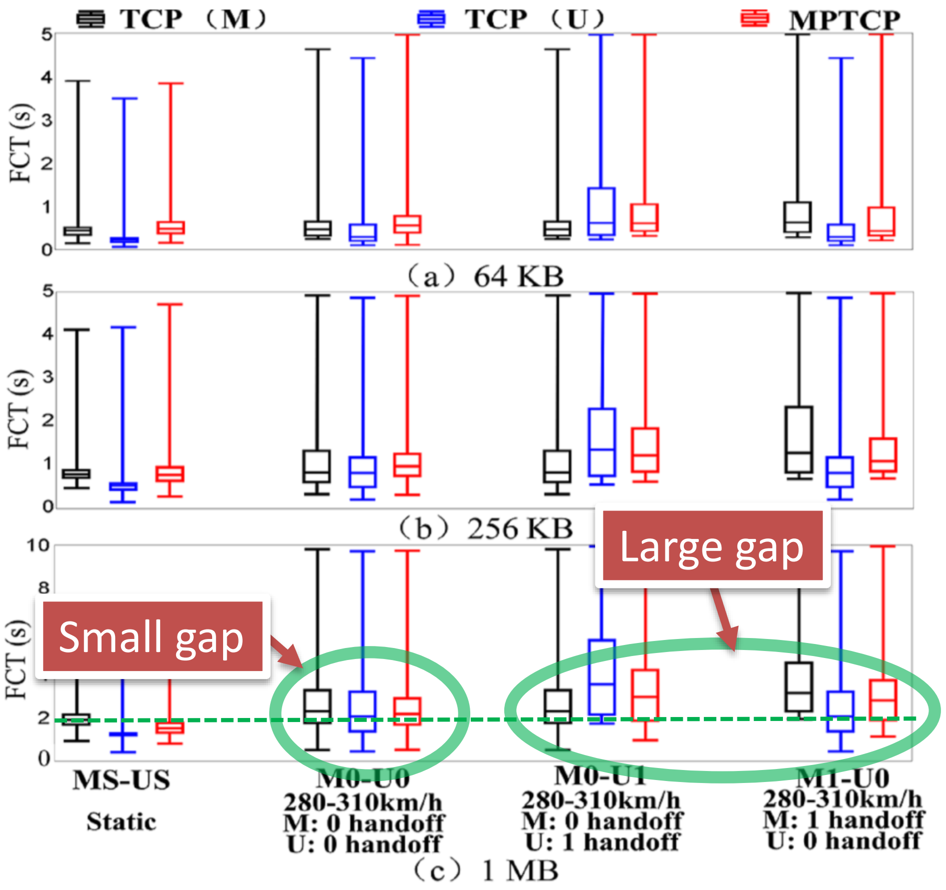


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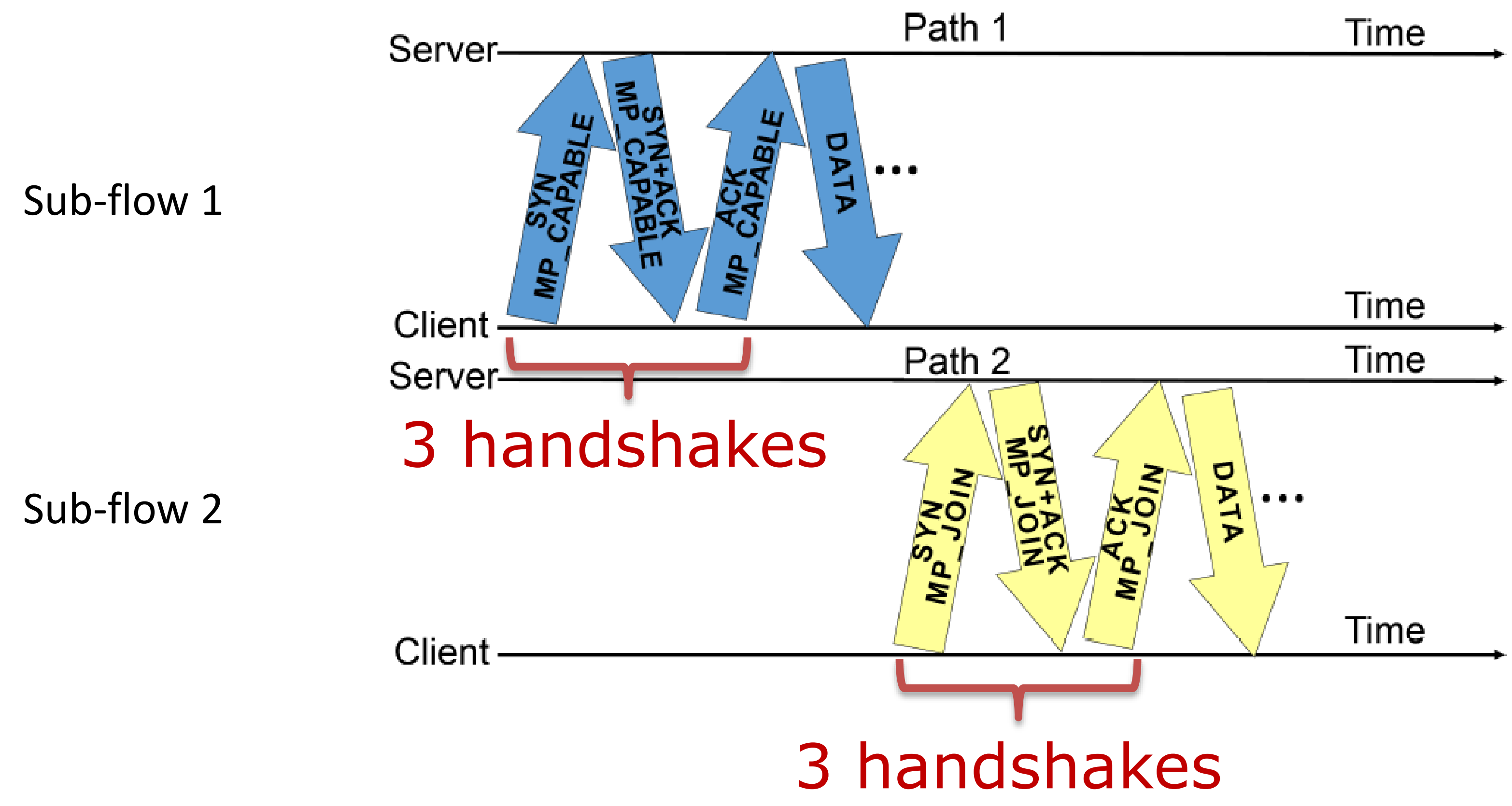
**Handoff leads to efficiency reduction**

**Inefficient sub-flow establishment to handoff**

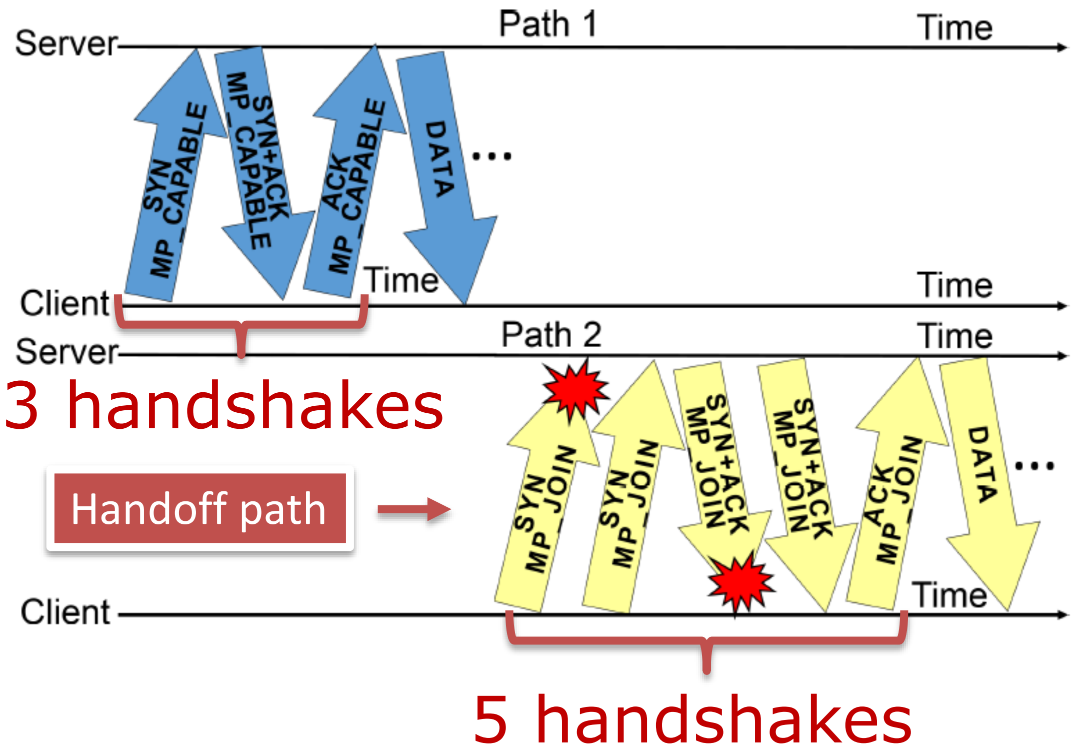
# Sub-flow Establishment

Normal case: neither of two paths suffers a handoff

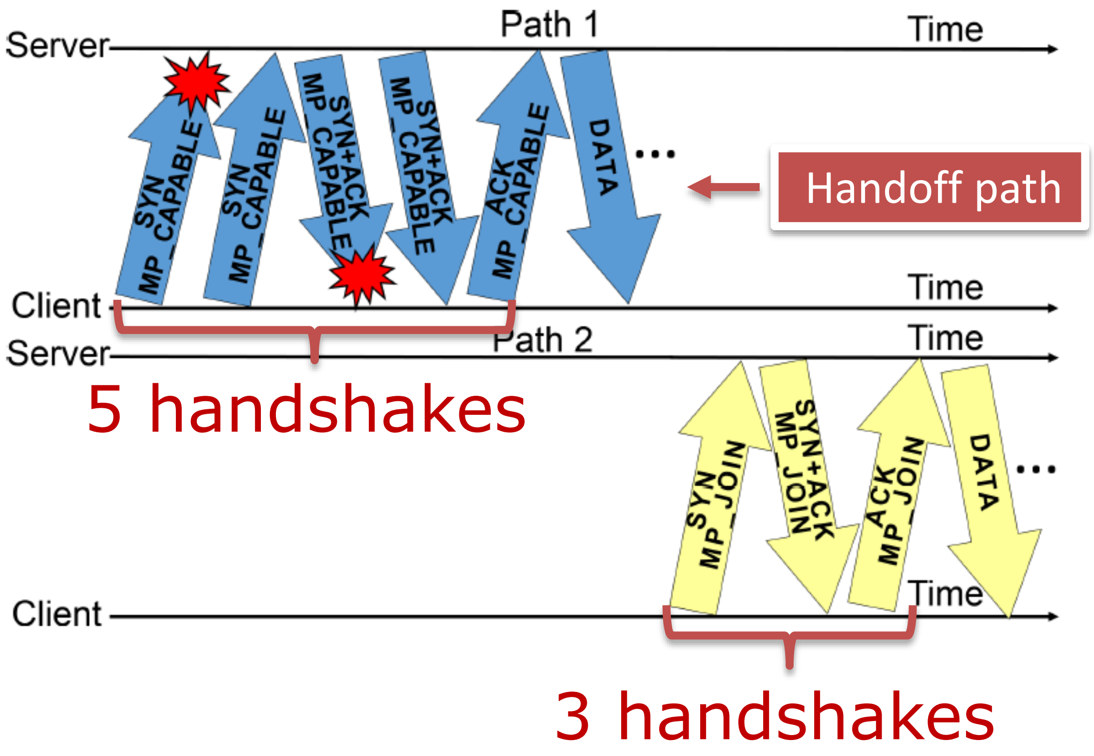


# Sub-flow Establishment

Handoff case: either path suffers a handoff

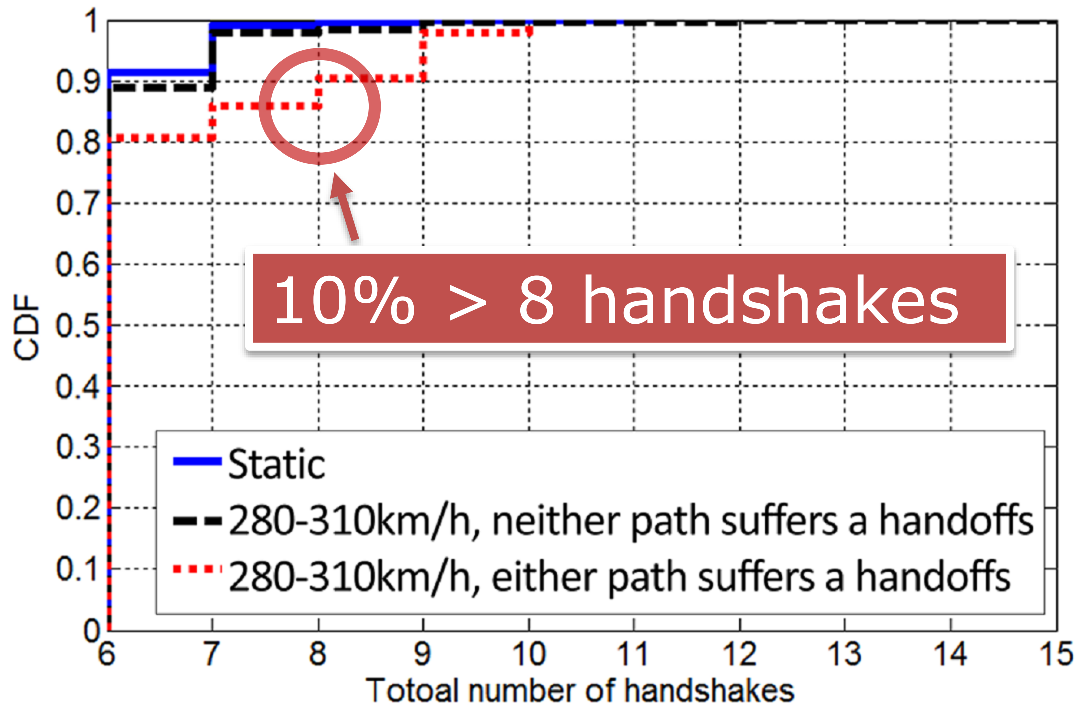



Lucky Case

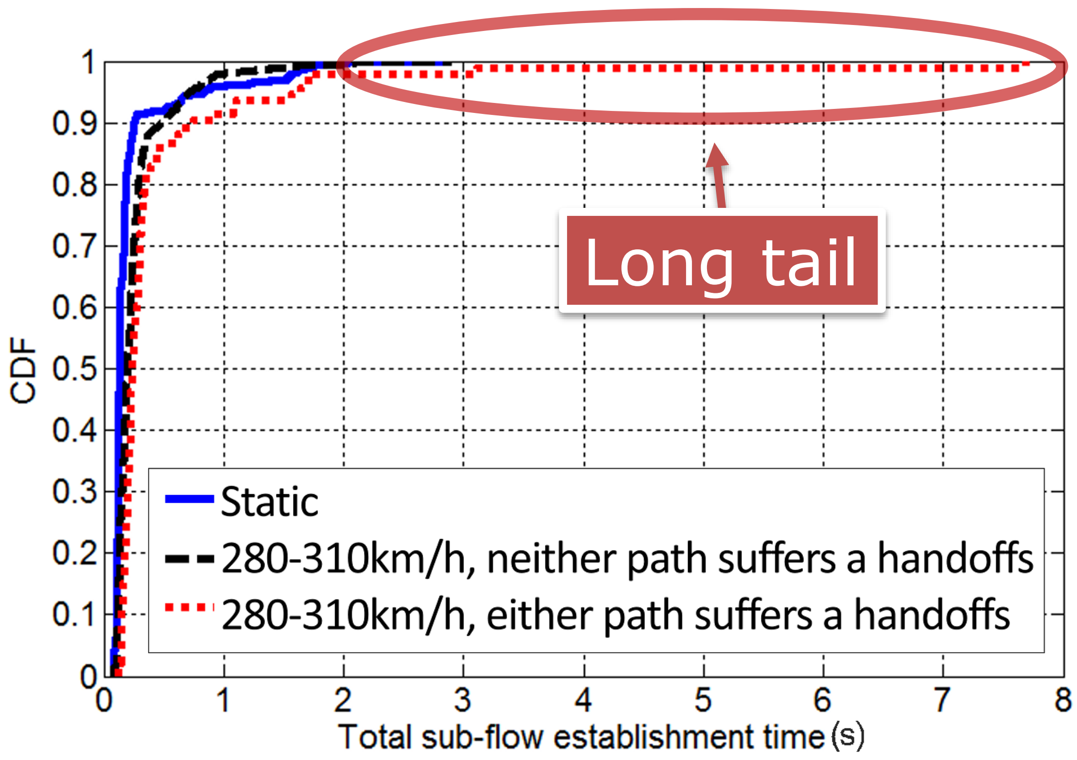



Unlucky Case

# Sub-flow Establishment

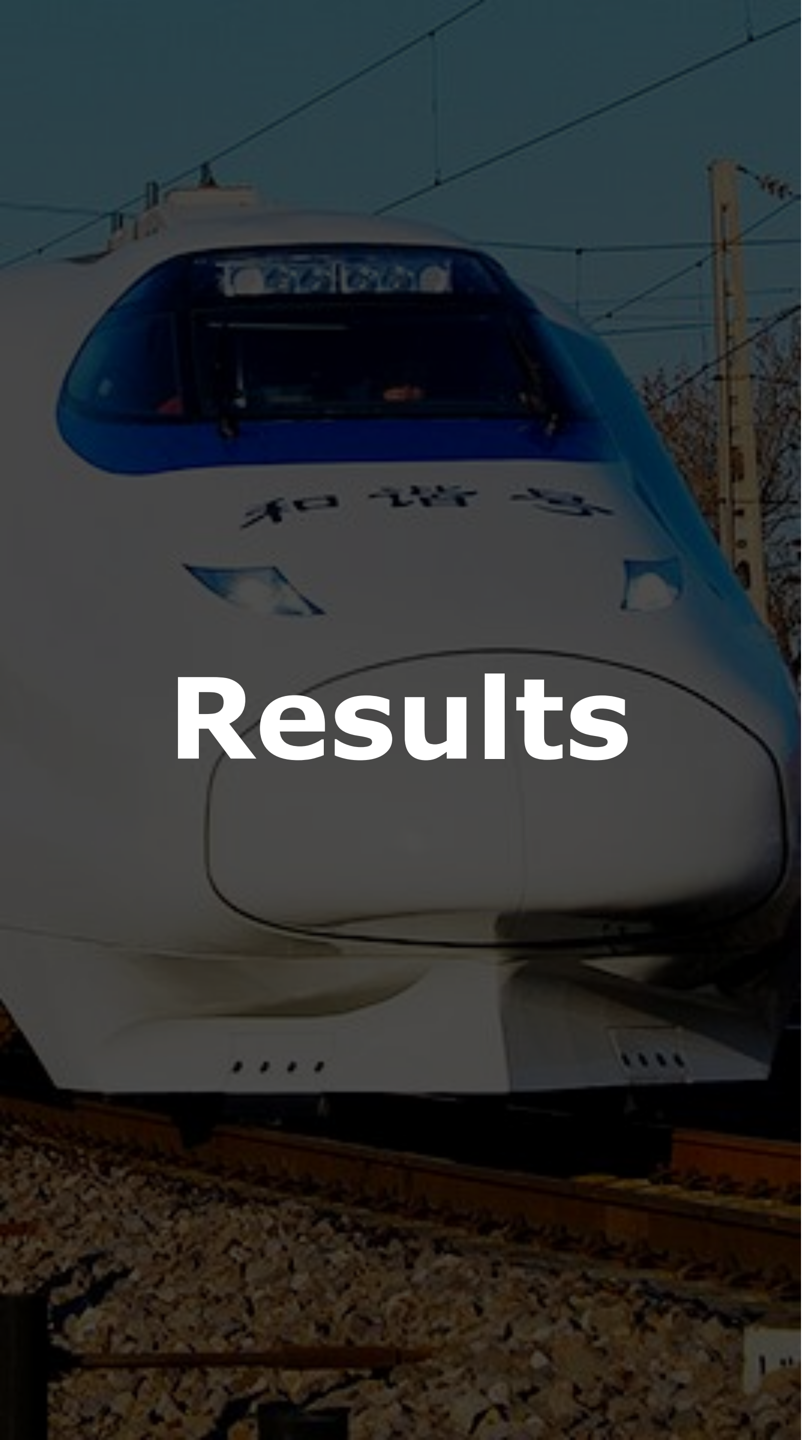



CDF of total number of handshakes




CDF of Sub-flow establishment time

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




# Results

# Elephant Flows

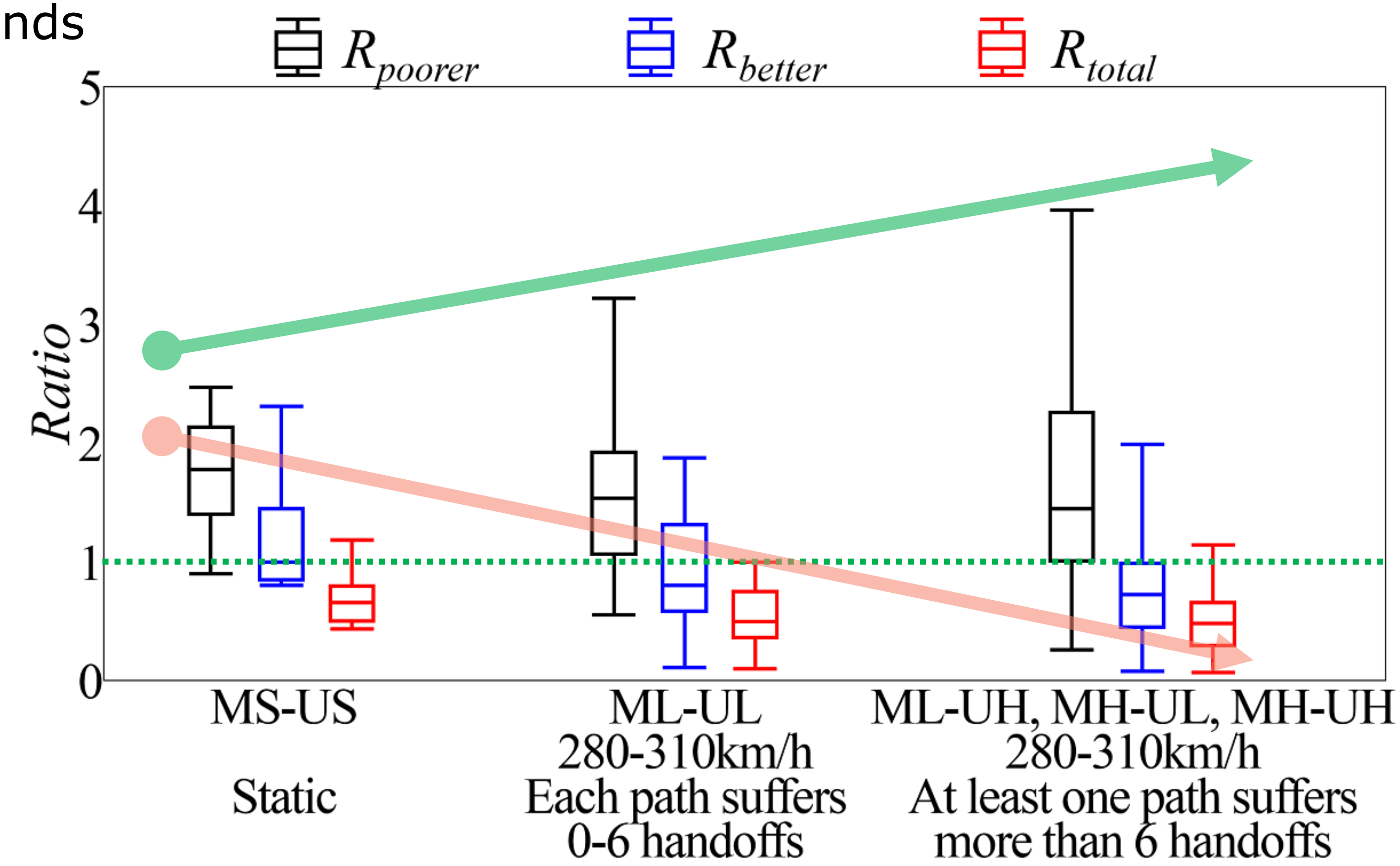
# Elephant Flows

- 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

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




- Results remain constant, but reasons are different!

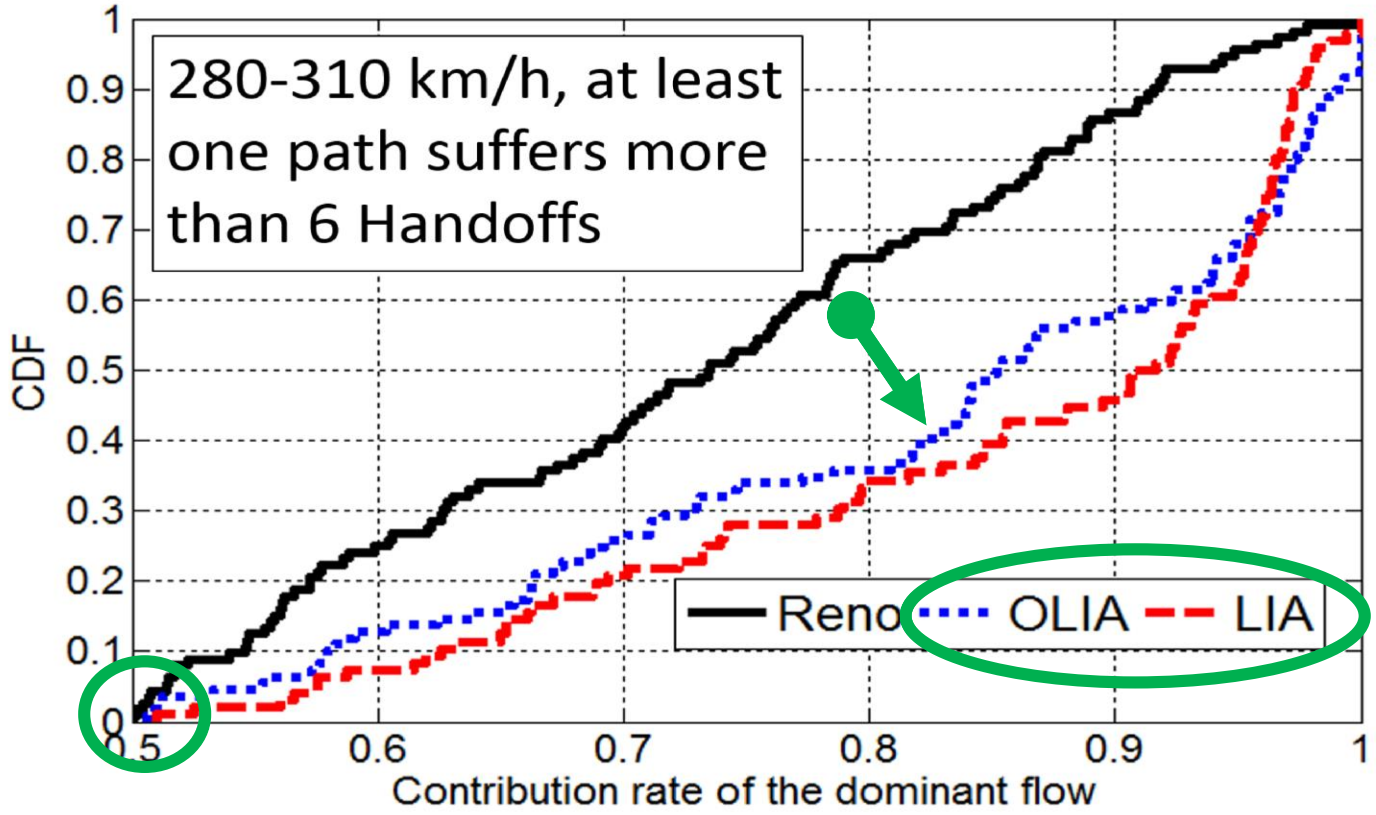
**Poor adaptability of congestion control and scheduling to frequent handoffs**

# 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

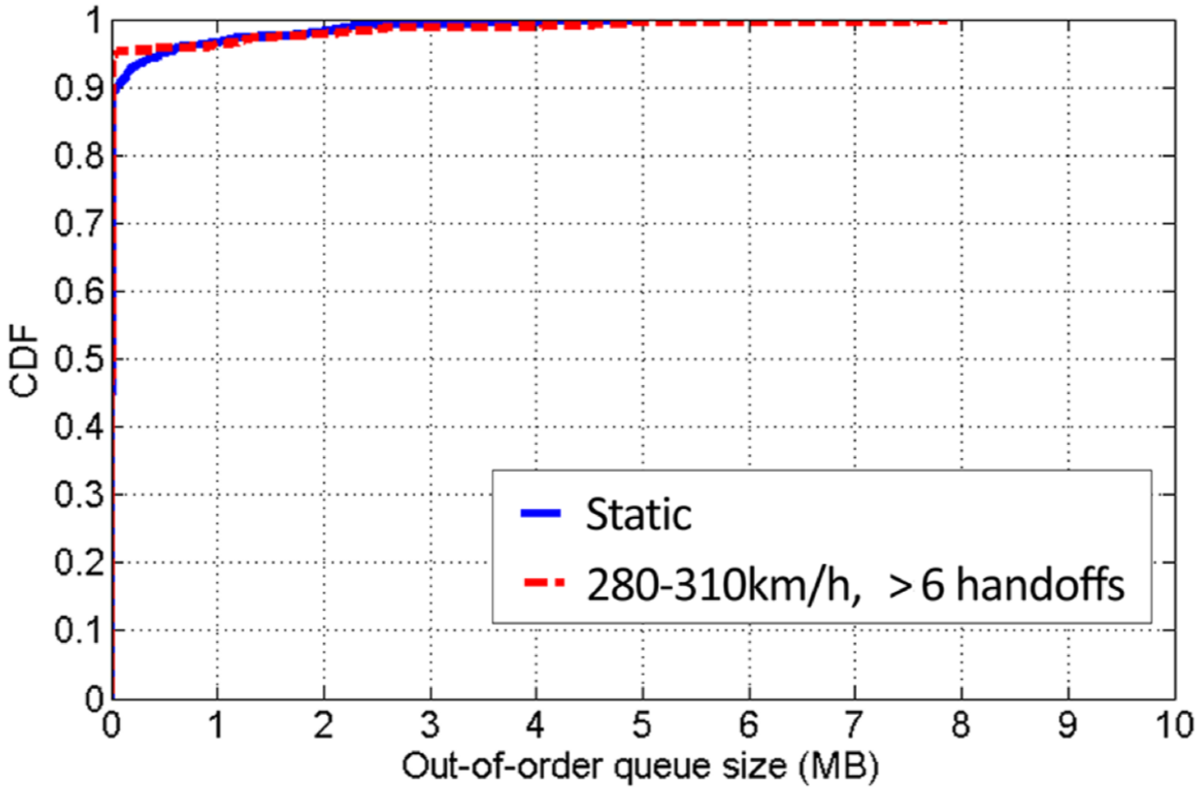
- Packet loss causes window drops
- Window distribution imbalance leads to traffic distribution imbalance
- **Coupled** congestion controllers
  - LIA [Raiciu et.al, RFC 6356]
  - OLIA [Khalili et.al, IETF draft]
  - Transfer traffic from a congested path to a less congested one



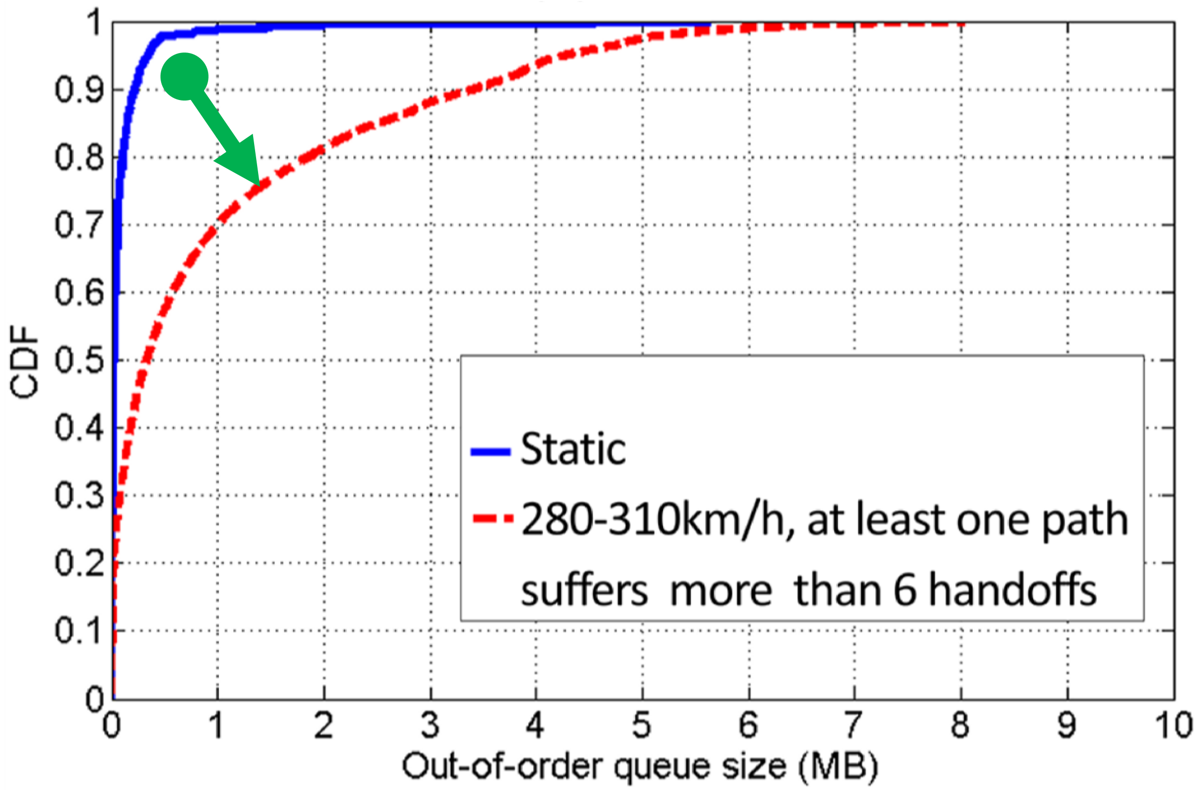

*More details please refer to the paper.

# Scheduling: Out of Order Problem

- Out-of-order queue size rises



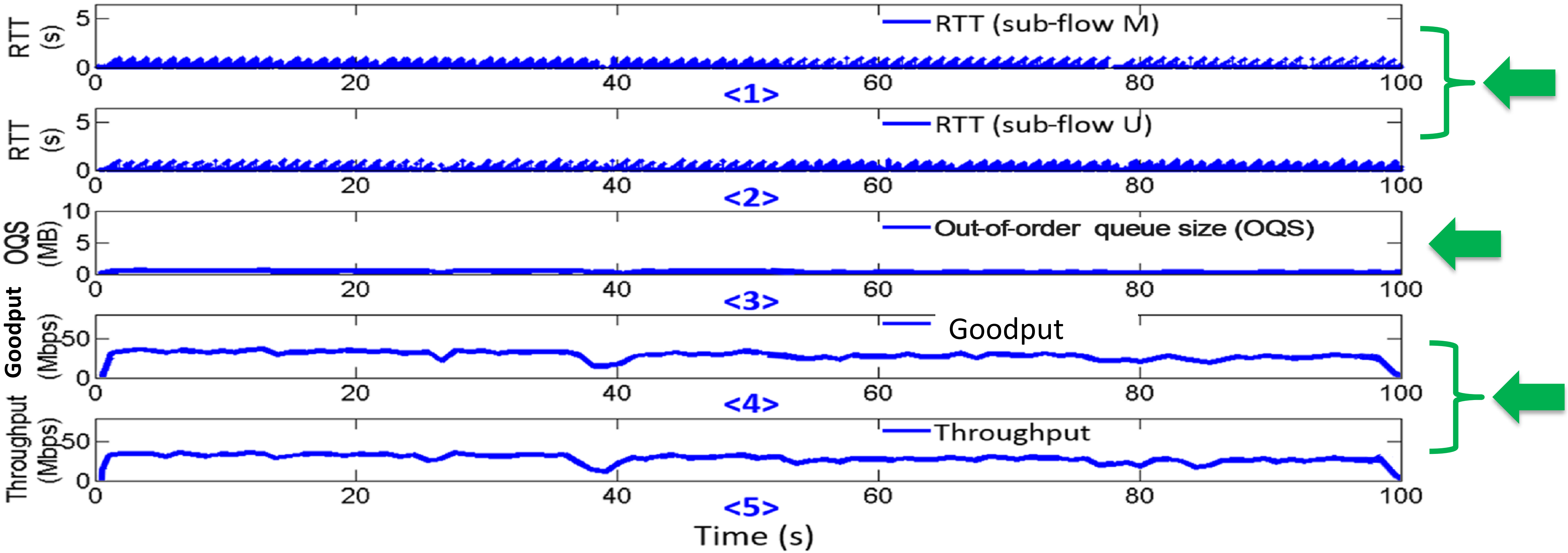

(a) TCP




(b) MPTCP

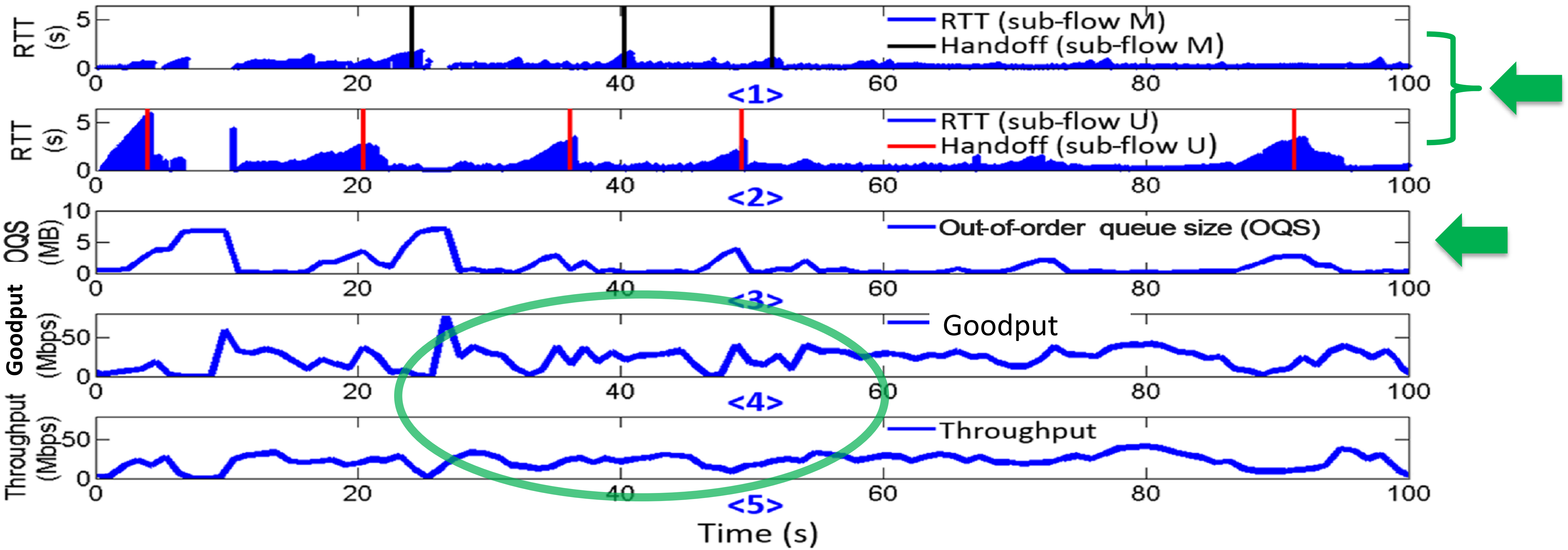
# Static Cases

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



# High Speed Mobility Cases

- Out-of-order problem due to RTT spikes during handoffs




MPTCP's efficiency of congestion control and scheduling is low in HSRs

# Conclusion and Takeaways

- MPTCP on HSRS
  - Significant advantage in **robustness**
  - **Efficiency** of MPTCP is far from satisfactory
- Poor adaptability to frequent handoffs
- State of the art
  - Sub-flow establishment [Nguyen, IETFdraft16] [Szilagyi, PIMRC17] [Barre, IETFdraft18]
  - Scheduling [Guo, Mobicom17] [Shi, ATC18]
  - Congestion control [Sinky, TWC16]
- Handoff pattern detection and prediction
  - Establish new sub-flows outside a predicted handoff
  - Retransmit lost packet of handoff path via others
  - Coupled CC that is not loss-based. Or just apply uncoupled!

# Thank You!

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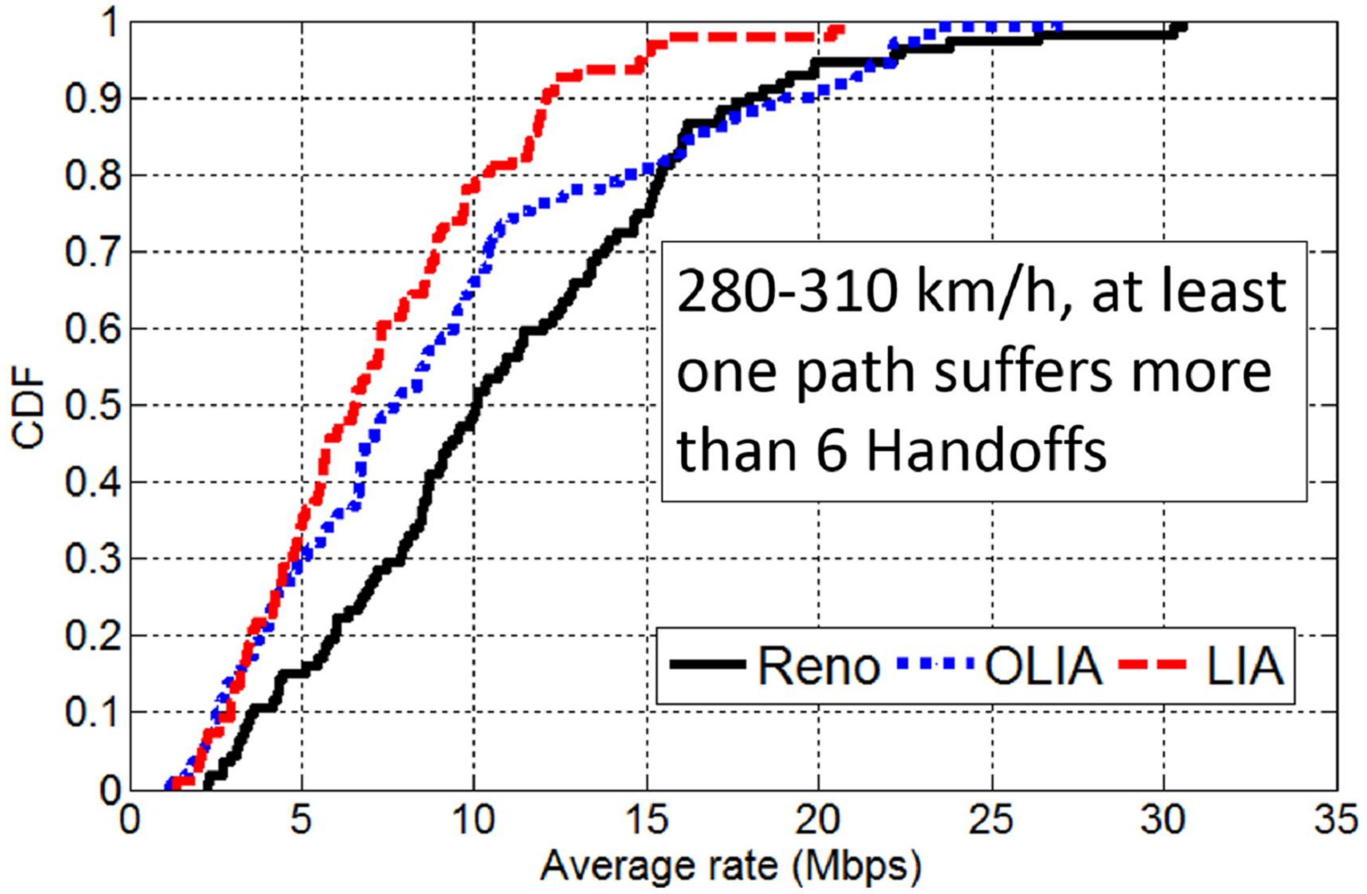
backup

# Congestion Control



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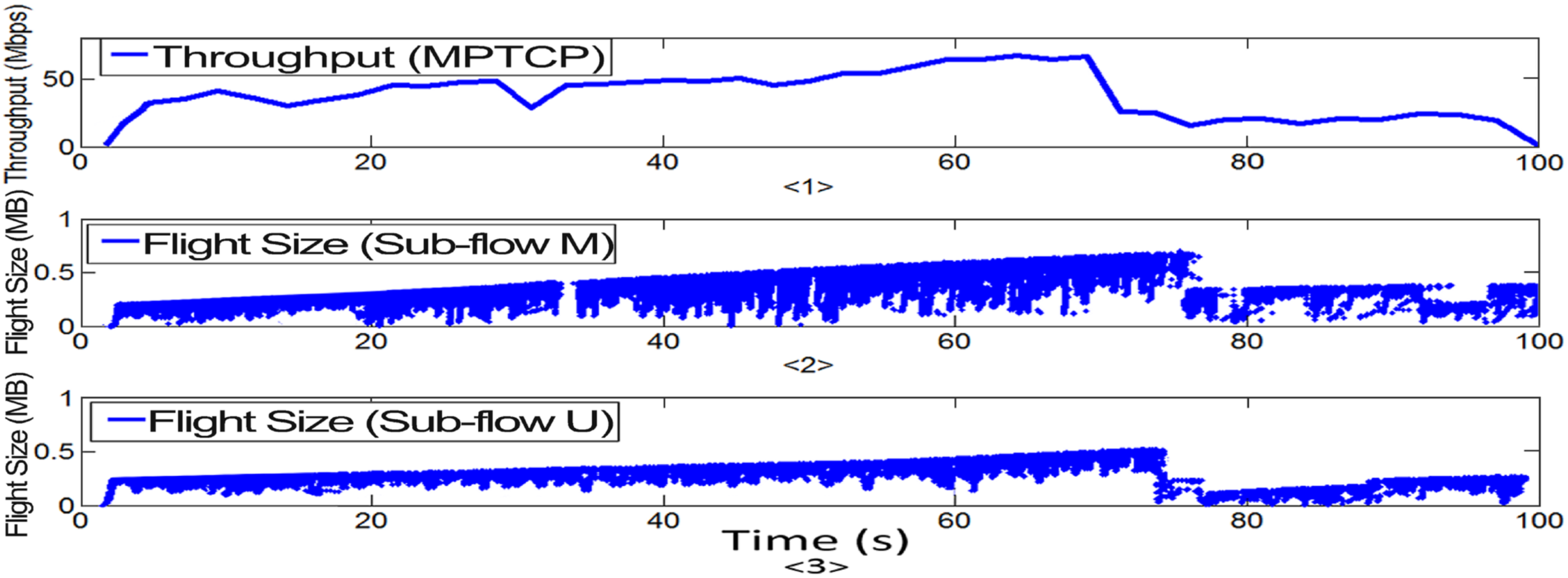
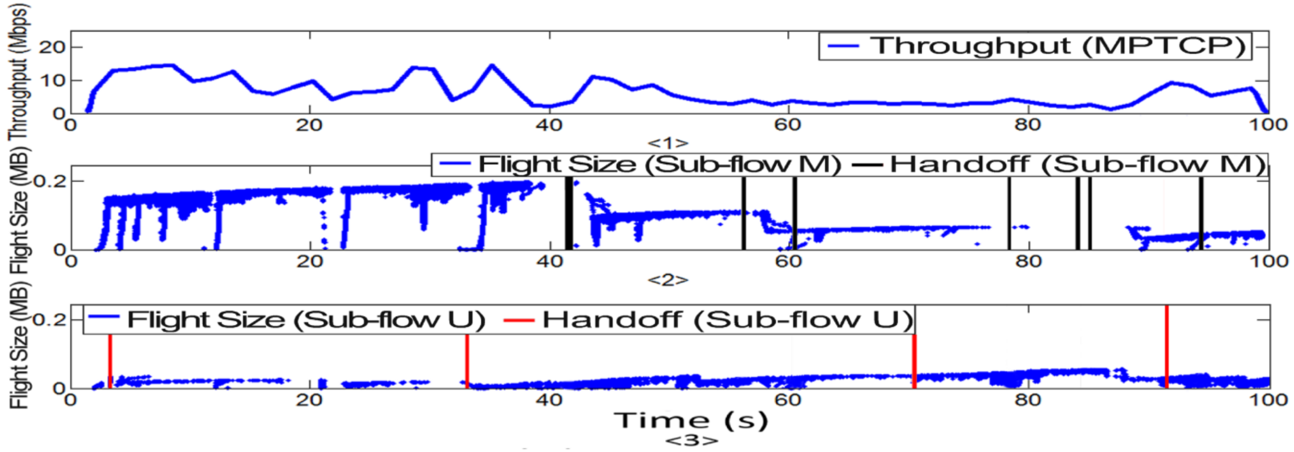
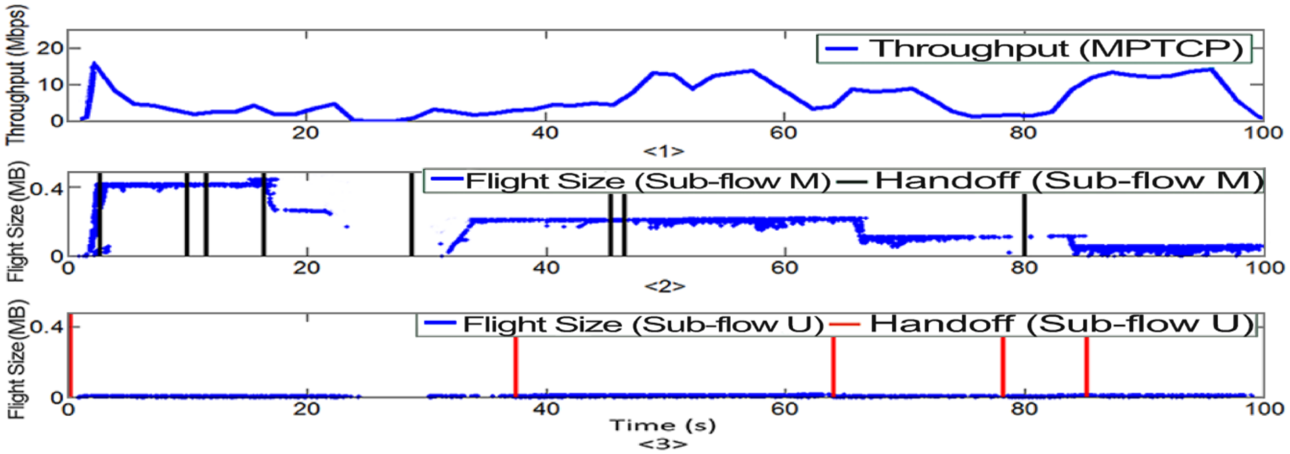



(a) MPTCP Reno (static)

# Congestion Control




(b) MPTCP Reno (high speed)




(c) MPTCP LIA (high speed)