STUDY GROUP

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Outline

- A First Look at Disconnection-Centric TCP Performance on High-Speed Railways
  - Background
  - Experiment Design
  - Result
  - Conclusion
- Multi-Radio Selective Band Locking for Railway Communications Reliability Enhancement: An Experimental Approach
  - Background
  - System Architecture
  - Result
  - Conclusion

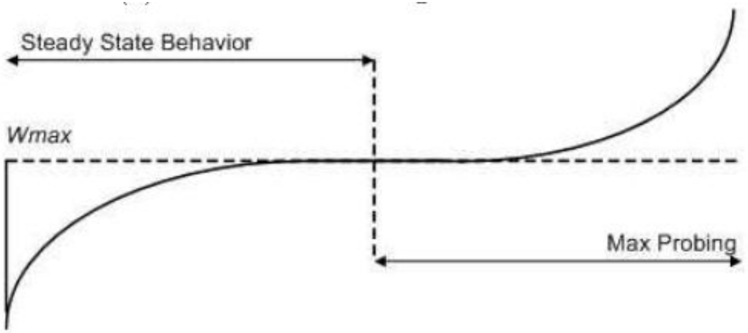
A First Look at Disconnection-Centric TCP Performance on High-Speed Railways

Background

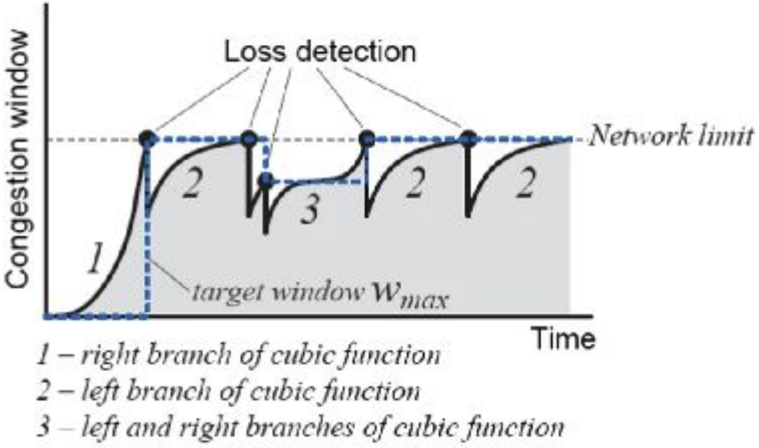
- The impact of high mobility on TCP performance in HSR
- Analyze the impact of LTE disconnection on upper-layer data transmission
- Investigate the root causes of TCP stall in HSR networking environment

Congestion Control Algorithms - CUBIC

- CUBIC
    - Base on packet loss



(b) CUBIC window growth function.



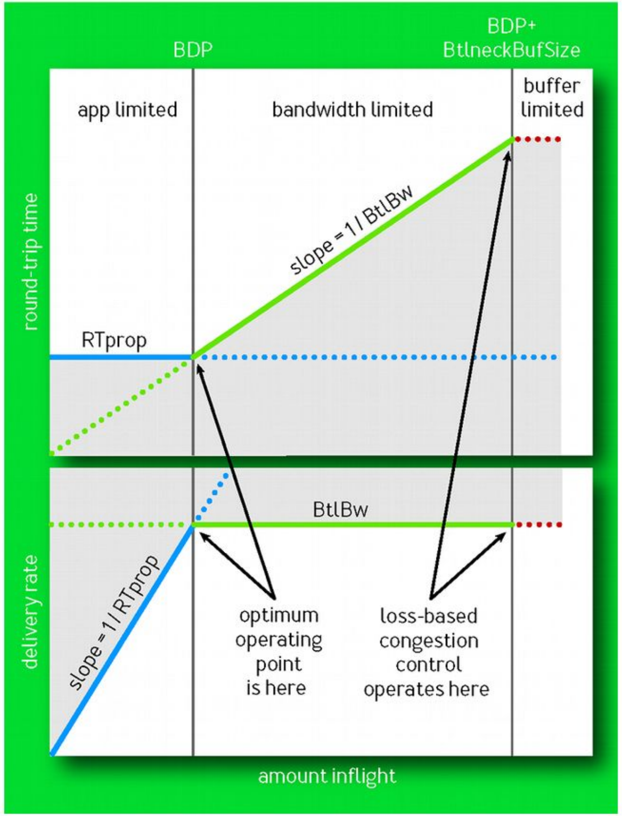
1. mpCUBIC: A CUBIC-like Congestion Control Algorithm for Multipath TCP - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Cwnd-behavior-in-CUBIC-TCP-14_fig1_341995073 [accessed 13 Sep, 2023]
2. Ha, S., Rhee, I., & Xu, L. (2008). CUBIC: A New TCP-Friendly High-Speed TCP Variant. SIGOPS Oper. Syst. Rev., 42(5), 64–74. https://doi.org/10.1145/1400097.1400105

Congestion Control Algorithms - BBR

- BBR
    - Base on RTT

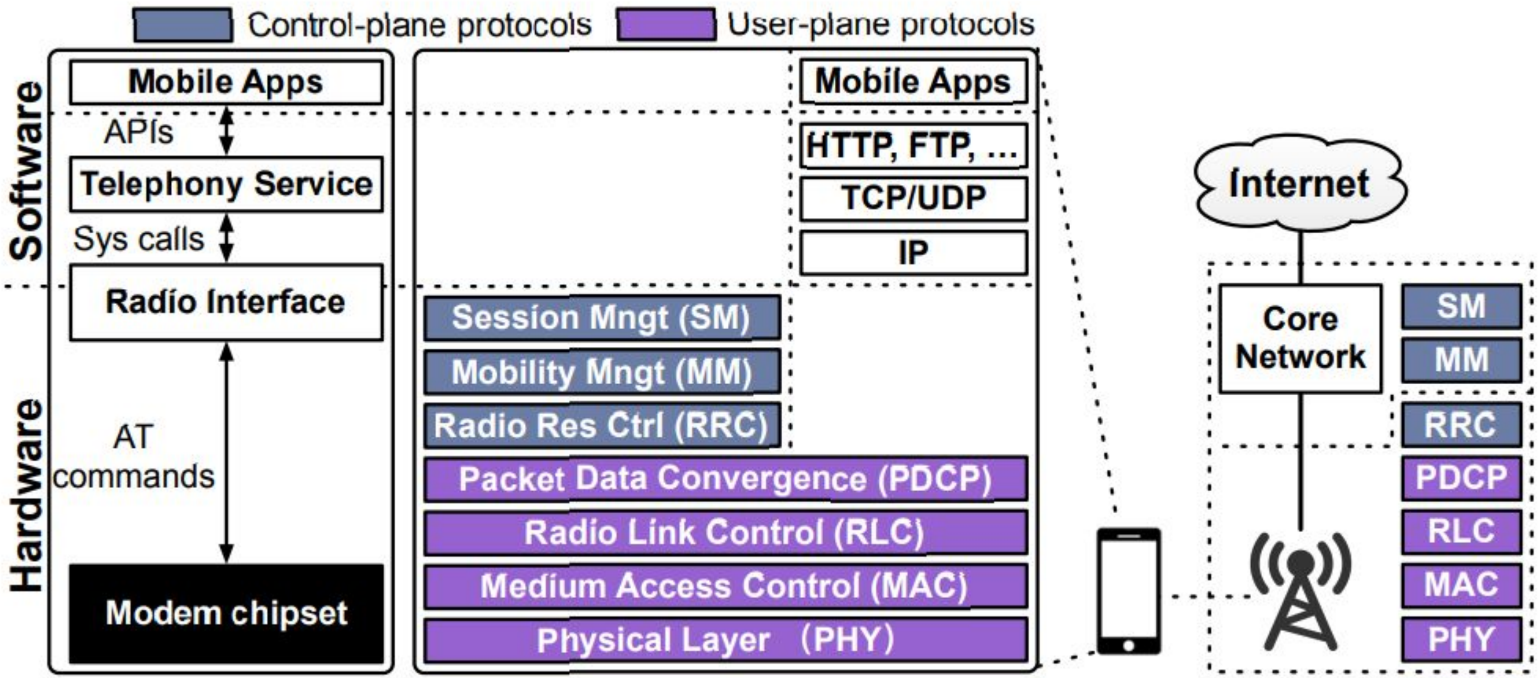
$$\widehat{RTprop} = RTprop + \min(\eta_t) = \min(RTT_t) \quad \forall t \in [T - W_R, T]$$

$$\widehat{BtlBw} = \max(deliveryRate_t) \quad \forall t \in [T - W_B, T]$$



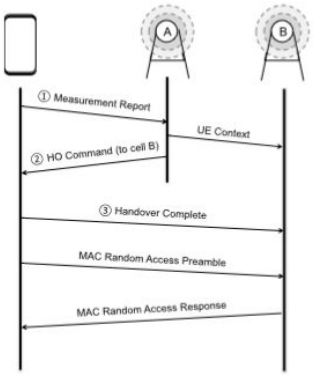
Cardwell, N., Cheng, Y., Gunn, C. S., Yeganeh, S. H., & Jacobson, V. (2016). BBR: Congestion-Based Congestion Control. ACM Queue, 14, September-October, 20–53. http://queue.acm.org/detail.cfm?id=3022184

Network architecture & Protocol stack



Yuanjie Li, Chunyi Peng, Zhehui Zhang, Zhaowei Tan, Haotian Deng, Jinghao Zhao, Qianru Li, Yunqi Guo, Kai Ling, Boyan Ding, Hewu Li, and Songwu Lu. 2021. Experience: a five-year retrospective of MobileInsight. In Proceedings of the 27th Annual International Conference on Mobile Computing and Networking (MobiCom '21). Association for Computing Machinery, New York, NY, USA, 28–41. https://doi.org/10.1145/3447993.3448138

LTE Disconnection Taxonomy



Successful Handover (HO)

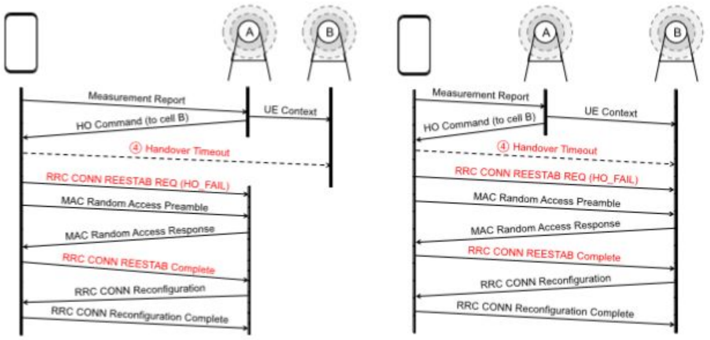
① Tells the serving cell that an event regarding signal strength has happened, e.g. a neighboring cell has stronger signal than the current serving cell.

② An RRC connection reconfiguration request containing the target cell ID.

③ An RRC connection reconfiguration complete message.

④ A timer expires after several unsuccessful random access attempts.

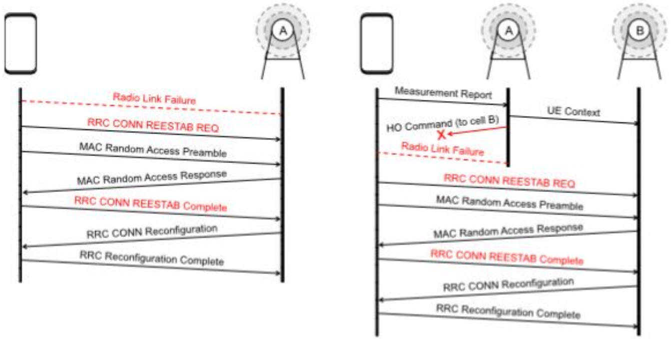
⑤ The cell rejects the request because it does not hold the UE's context, or it has discarded it.



To serving cell

To (target) new cell

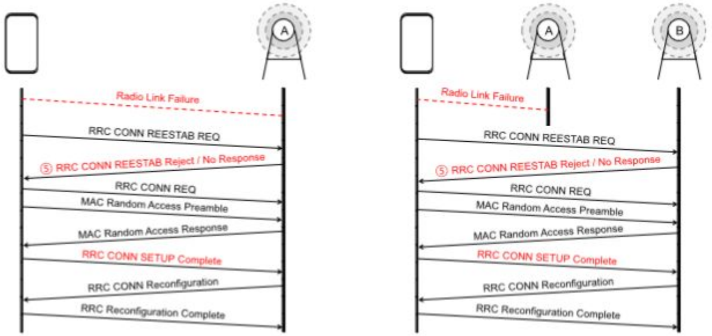
Handover Failure and Recovery (HOF Recovery)



To serving cell

To (target) new cell

Radio Link Failure and Recovery (RLF Recovery)



To serving cell

To new cell

Non-access Stratum Recovery (NAS Recovery)

Experiment Design

1. Flow Size: fixed duration(150 secs) or fix-sized(64 KB)
2. TCP Variants Comparison: CUBIC and BBR
3. TCP-LTE Interaction: Packet-level TCP traces, and use MobileInsight collect handover and disconnection events.

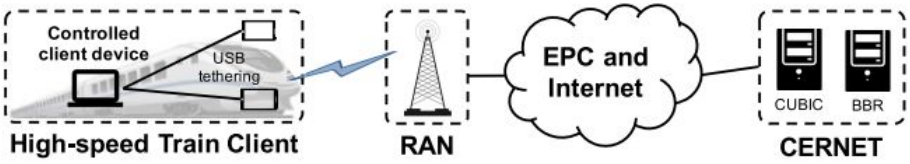
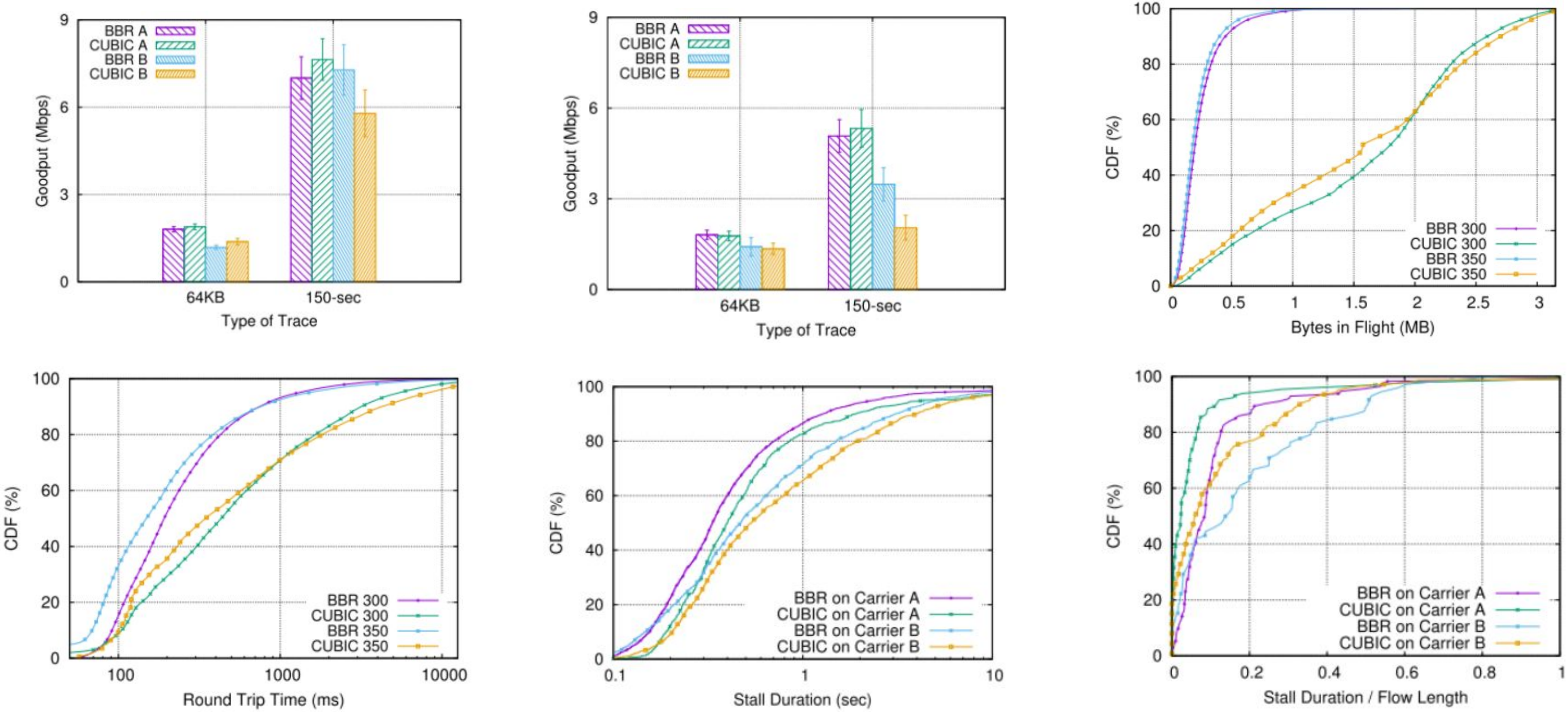


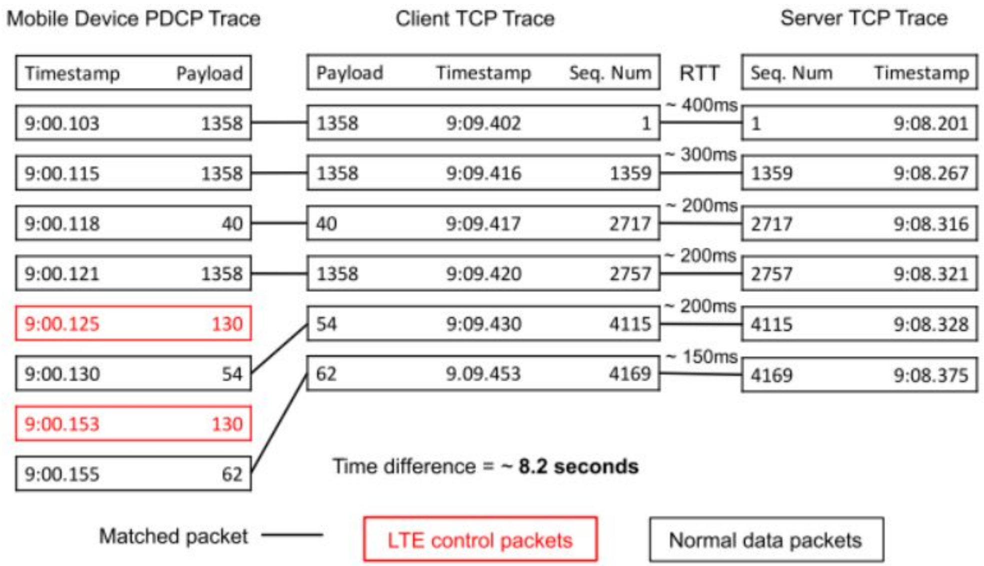
Fig. 1. Our experimental testbed collects data from a dedicated laptop-phone suite.

Result


BBR A
CUBIC A
BBR B
CUBIC B
Goodput (Mbps)
64KB
150-sec
Type of Trace
BBR A
CUBIC A
BBR B
CUBIC B
Goodput (Mbps)
64KB
150-sec
Type of Trace
CDF (%)
Bytes in Flight (MB)
BBR 300
CUBIC 300
BBR 350
CUBIC 350
CDF (%)
Round Trip Time (ms)
BBR 300
CUBIC 300
BBR 350
CUBIC 350
CDF (%)
Stall Duration (sec)
BBR on Carrier A
CUBIC on Carrier A
BBR on Carrier B
CUBIC on Carrier B
CDF (%)
Stall Duration / Flow Length
BBR on Carrier A
CUBIC on Carrier A
BBR on Carrier B
CUBIC on Carrier B

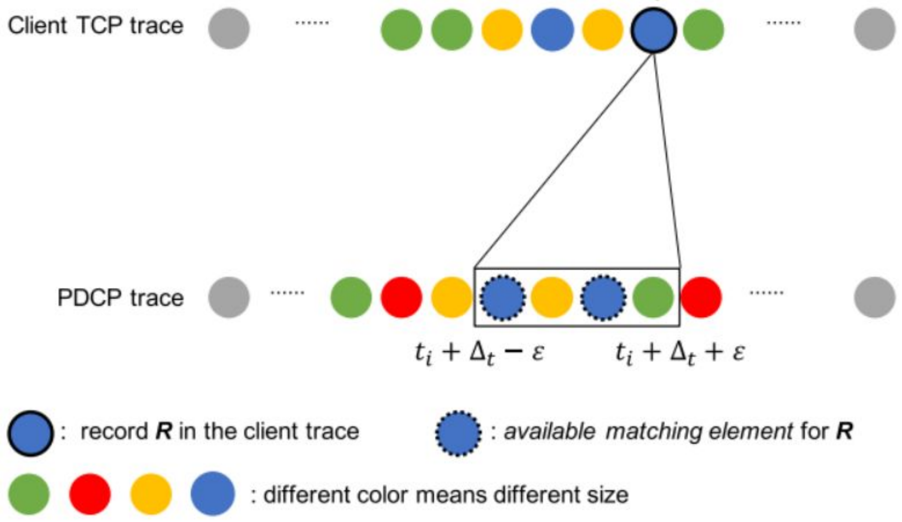
TCP Stall and LTE Disconnection Alignment

1. They fist align timestamps from server and mobile device.
   - They align the device timestamps base on the assumption that the clock misalignment between those devices remain constant during the testing period
   - Use TCP sequence number and timestamp to obtain packet-level alignment

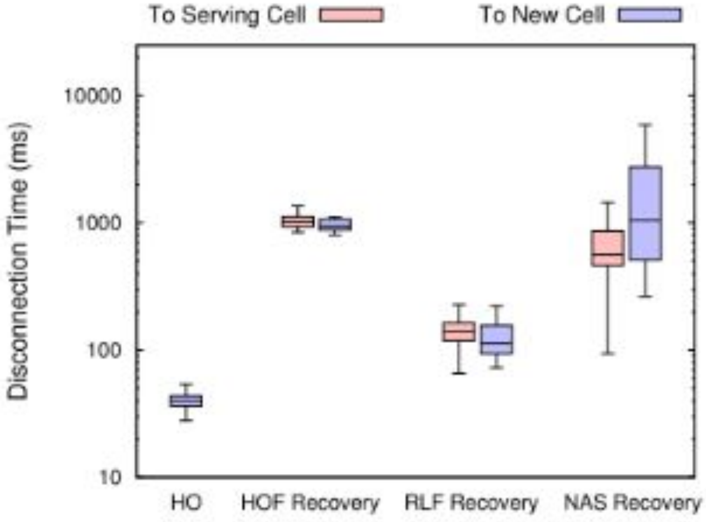


TCP Stall and LTE Disconnection Alignment

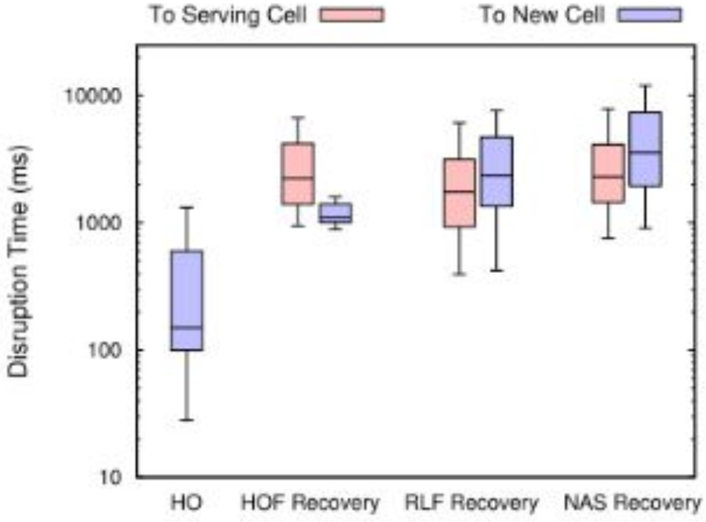
- Then, synchronize LTE event and TCP packet at the client side.
  - PDCP data packet carries the same payload as in TCP/IP packet
  - matching element now includes all the records in Spdcp within [ti + Δt – ε , ti + Δt + ε] that has size of Sizei



Result

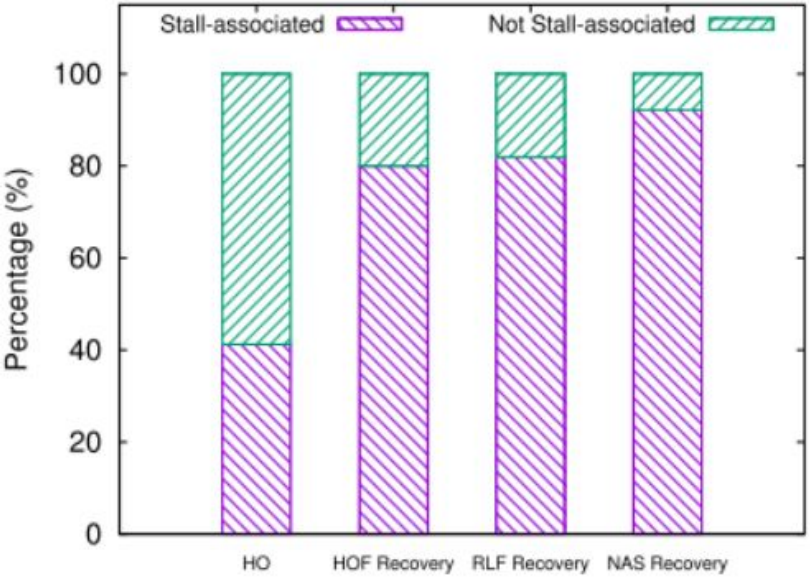


(a) Disconnection time.

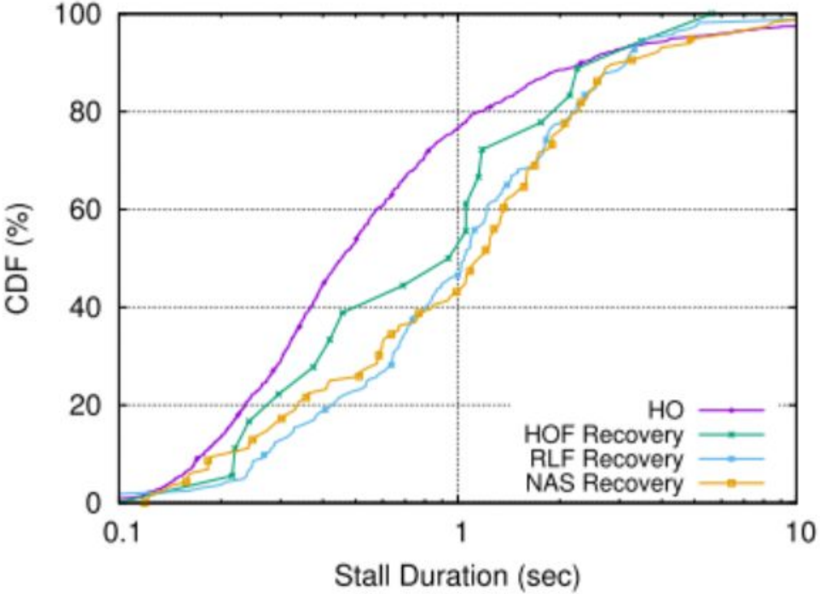


(b) Disruption time.

Result

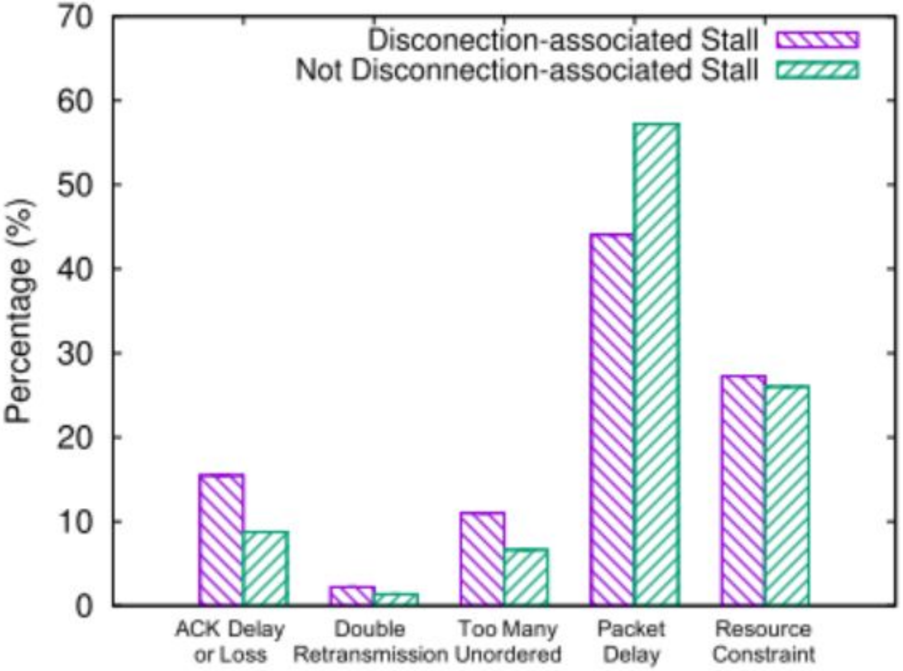


Stall-associated
Not Stall-associated
Percentage (%)
0
20
40
60
80
100
HO
HOF Recovery
RLF Recovery
NAS Recovery



CDF (%)
0
20
40
60
80
100
0.1
1
10
Stall Duration (sec)
HO
HOF Recovery
RLF Recovery
NAS Recovery

Result



Disconection-associated Stall
Not Disconnection-associated Stall
Percentage (%)
70
60
50
40
30
20
10
0
ACK Delay or Loss
Double Retransmission
Too Many Unordered
Packet Delay
Resource Constraint

Conclusion

- BBR performs reasonably well by preserving its key advantages (compared to CUBIC) such as being robust to random losses and incurring a smaller amount of bytes-in-flight, and thus is more friendly to carrier and train speed diversity

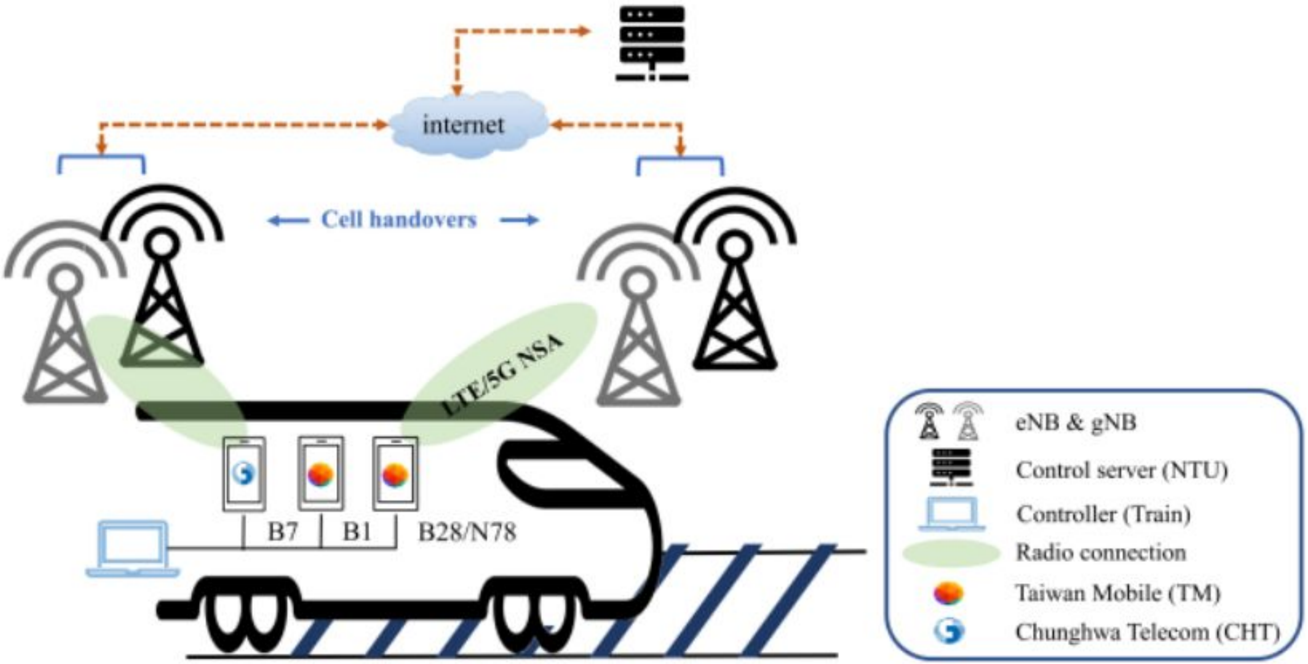
- LTE disconnection has a strong impact on TCP stall in terms of both occurrence and duration, and it is highly desirable to avoid disconnections other than successful handover

Multi-Radio Selective Band Locking for Railway Communications Reliability Enhancement: An Experimental Approach

Background

This research aim to find the methods to reduce the affect cause by unnecessary handovers in the train-to-ground communication

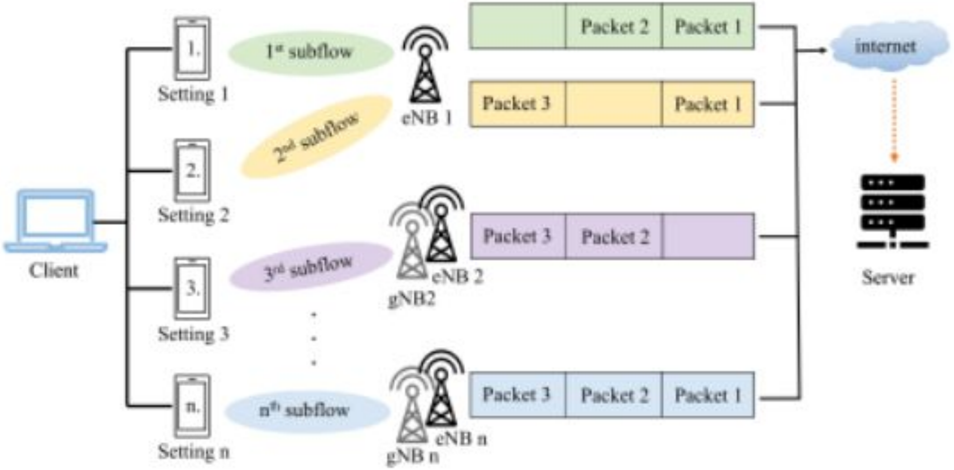
System Architecture



System Design

Duplicate packet transmission

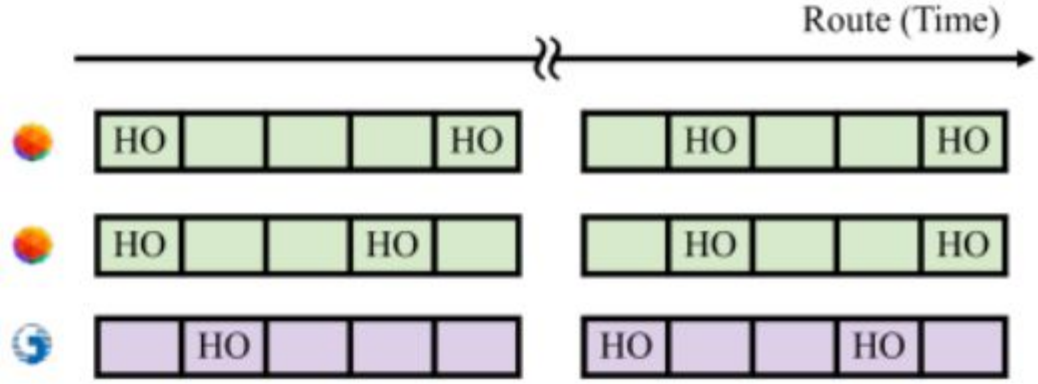
Because the cell phones are band locked, so the controller might link to mutiple BS at the same time. In this way, it can enhance the system's reliability even if some packets are lost, since the duplicated message are successfully transmitted through other interface(cell phone).



System Design

MULTI-RADIO TRANSMISSION FOR HANDOVER SEPARATION

In order to reduce the event, that the handover may be in the nearby timeslot, they add another operator to provide the backup of the service.



System Design

MULTI-RADIO BAND LOCKING

Use band locking for reducing the handover chance. And assume that if the same operator is chosen, the one with limited band support will perform better since the corresponding times of handover is reduced

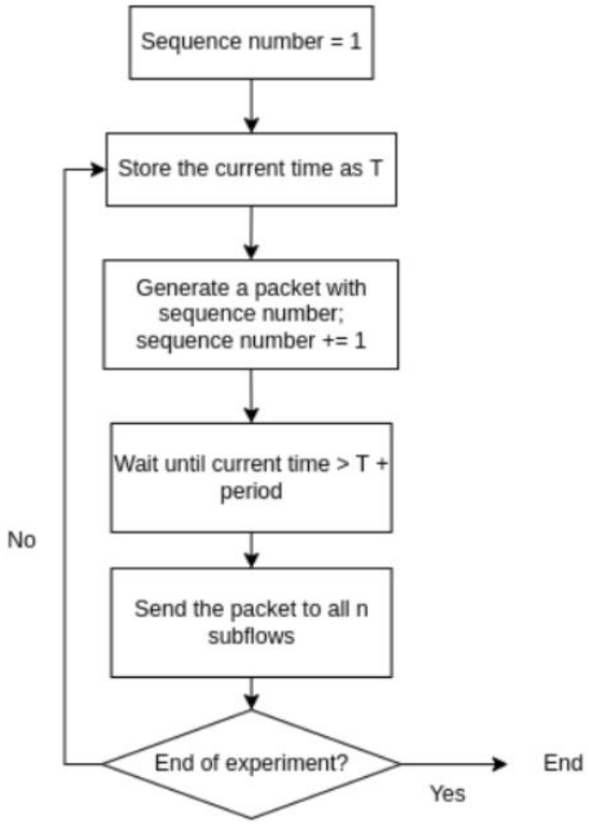
Experimental Methodology

- MRT Route: Xinhai Station to Taipei Zoo Station
- Supported band

Operators	LTE band and frequency (MHz)	NR band and frequency (MHz)
Taiwan Mobile (TM)	B1 (2100) B3 (1800) B28 (700)	N78 (3500)
Chunghwa Telecom (CHT)	B1 (2100) B3 (1800) B7 (2600) B8 (900)	N1 (2100) N78 (3500)

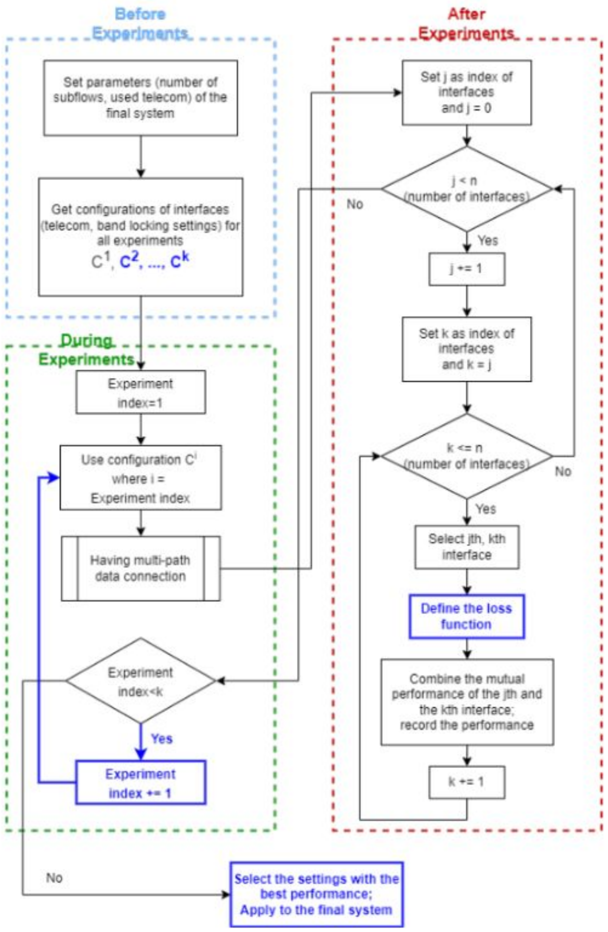
Experimental Methodology

- Tools
  - MobileInsight
  - Tcpdump
- MPUDP socket programming

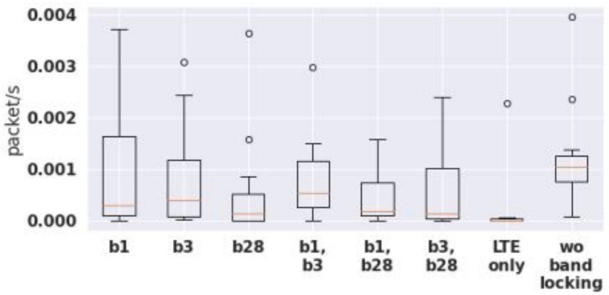


EXPERIMENTAL PROCEDURES

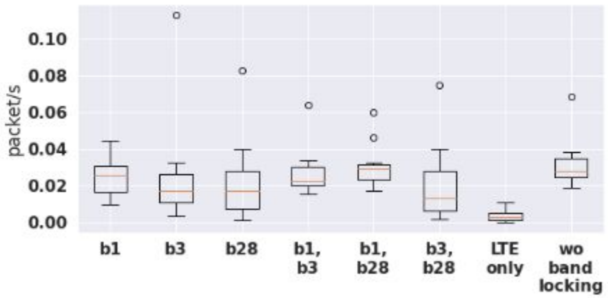
1. Before the Experiment
    - To reduce the experimental times, combinations of LTE are excluded
    - Determine the experimental parameters of the system
2. During the Experiment
    - procedure same as Fig. 8
3. After the Experiment
    - loss function
        - Latency: Because the measurement is in redundant mode, all subflows will send the same packets
        - $$MultiPathDelay(s) = \min_{i \in I_1,\ldots,I_m} Delay_i(s)$$
        - Packet loss: mark the packet loss of each sub-flow and find the one with the lowest packet loss rate.
        - $$MultiPathLoss(s) = \prod_{i \in I_1,\ldots,I_m} Loss_i(s)$$



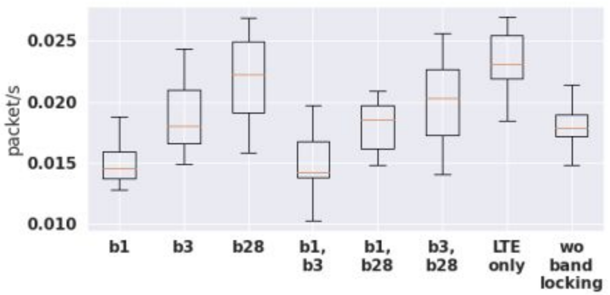
Result



(e) PLR for band locking.



(f) ELR for band locking.

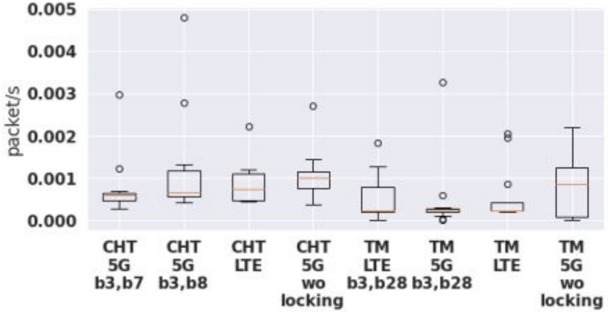


(g) Average latency for band locking.

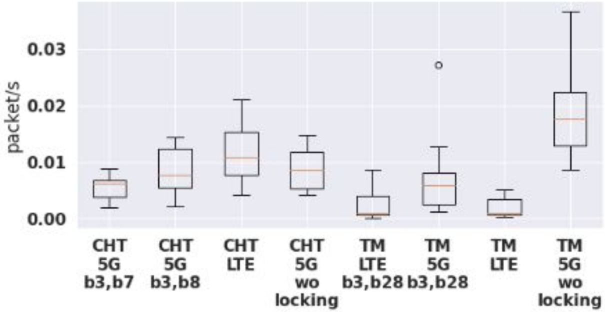
Result

	UL PLR	DL PLR	UL ELR	DL ELR
Baseline(BL): Single path (all band)	2.16×10^{-3}	1.18×10^{-3}	3.20×10^{-2}	1.39×10^{-2}
MPUDP: 5G (all band) & LTE only	2.35×10^{-4}	2.00×10^{-6}	7.74×10^{-4}	8.03×10^{-5}
Compared with BL	-89.10 %	-99.83 %	-97.58 %	-99.42 %
MPUDP & Band locking: 5G B3, B28 & LTE only	1.20×10^{-5}	0	1.46×10^{-4}	8.03×10^{-6}
Compared with MPUDP	-94.87 %	-100 %	-81.09 %	-90.00 %

Result



(e) PLR for band locking.



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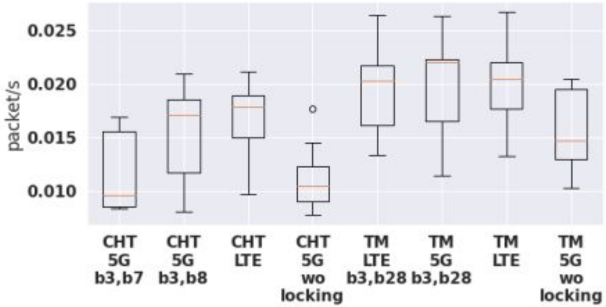

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MPUDP & Band locking: 5G B3, B28 & LTE only	1.20×10^{-5}	0	1.46×10^{-4}	8.03×10^{-6}
Compared with BL	-99.44 %	-100 %	-99.54 %	-99.94 %
MPUDP & diff telecoms: TM (all band) & CHT (all band)	6.69×10^{-5}	3.08×10^{-5}	3.56×10^{-4}	2.26×10^{-5}
Compared with BL	-96.89 %	-97.40 %	-98.89 %	-99.83 %
MPUDP & diff telecom & band locking: CHT (5G B3, B8) & TM (LTE only)	0	0	0	0

Conclusion

- Multi- radio can effectively separate the handover during the train journey.
- Band locking can reduce the handover times and furtherly enhance communication reliability.
- The packet loss performance gain can increase by more than 89.1 % with the proposed method. In our results, we can have zero packet loss if we choose the appropriate combination wisely.

Reference

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- Previous seniors work

QA

Thanks for Listening