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BBR Performance over Variable Delay Paths on Multipath TCP Video Streaming

Masayoshi Kondo, Dirceu Cavendish
Daiki Nobayashi, Takeshi Ikenaga

Kyushu Institute of Technology, Japan
kondo.masayoshi146@mail.kyutech.jp
{nova, ike}@ecs.kyutech.ac.jp

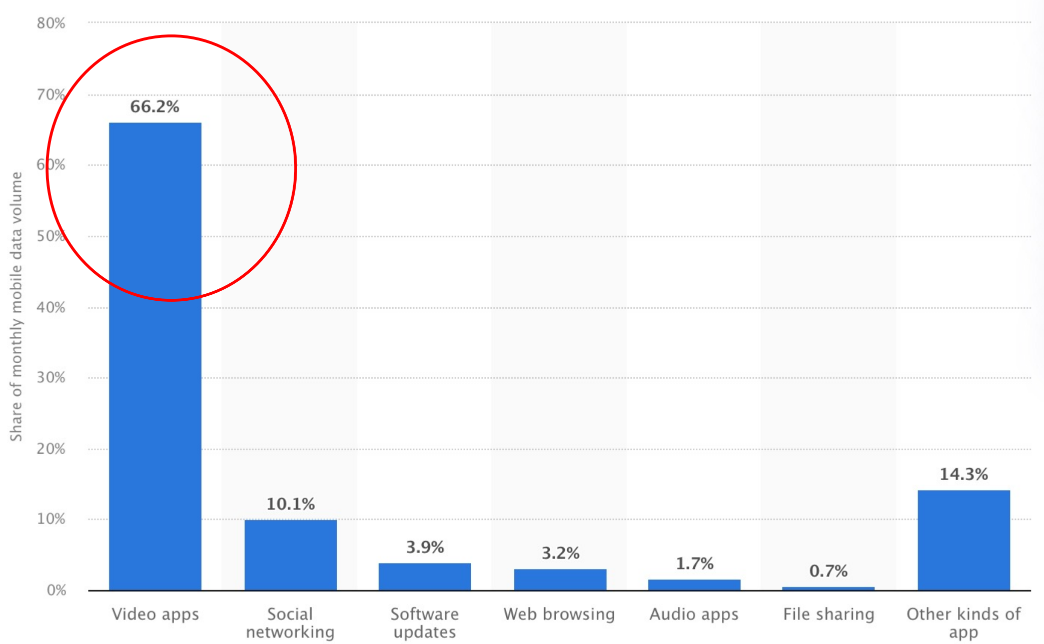
Resume

- Masayoshi Kondo
  - Second-year master's student
  - Kyushu Institute of Technology, Japan
  - kondo.masayoshi146@mail.kytuech.jp

  - Field of Study
    - MPTCP
    - Transport Protocol

Introduction #1

- The demand of video streaming has exploded
  - Mobile video traffic represents a large portion of overall internet traffic.



Distribution of global monthly mobile data volume

GLOBAL APPLICATION CATEGORY TRAFFIC SHARE

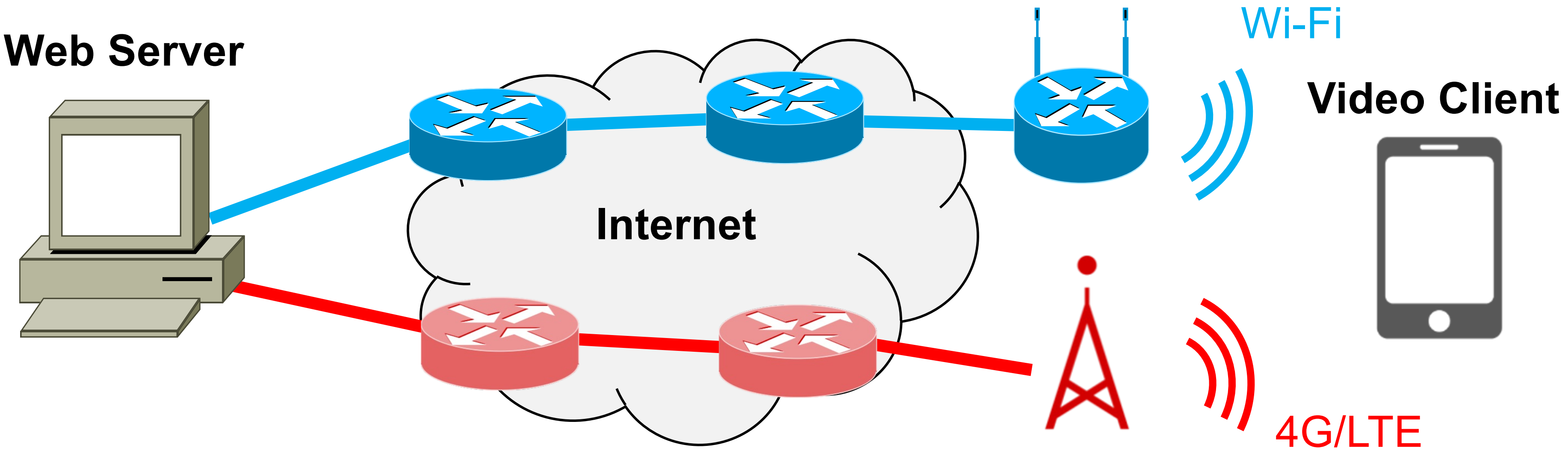
	Rank Change	Category	Downstream	Upstream
1	-	Video Streaming	48.9%	19.4%
2	-	Social Networking	19.3%	16.6%
3	2	Web	13.1%	23.1%
4	-1	Messaging	6.7%	20.4%
5	-	Gaming	4.3%	1.9%
6	-2	Marketplace	4.1%	1.2%
7	2	File Sharing	1.3%	6.6%
8	-1	Cloud	1.1%	6.7%
9	-3	VPN and Security	0.9%	3.9%
10	-	Audio	0.2%	0.2%

*https://www.statista.com/statistics/383715/global-mobile-data-traffic-share/
*https://www.sandvine.com/hubfs/Sandvine_Redesign_2019/Downloads/2021/Phenomena/MIPR%20Q1%202021%2020210510.pdf

Introduction #2

- Video streaming over mobile network
  - High speed and broadband wireless access: 4G/5G/Wi-Fi
  - Mobile devices
    - are becoming more sophisticated and have multiple wireless interfaces.
    - switching between multiple interfaces dynamically

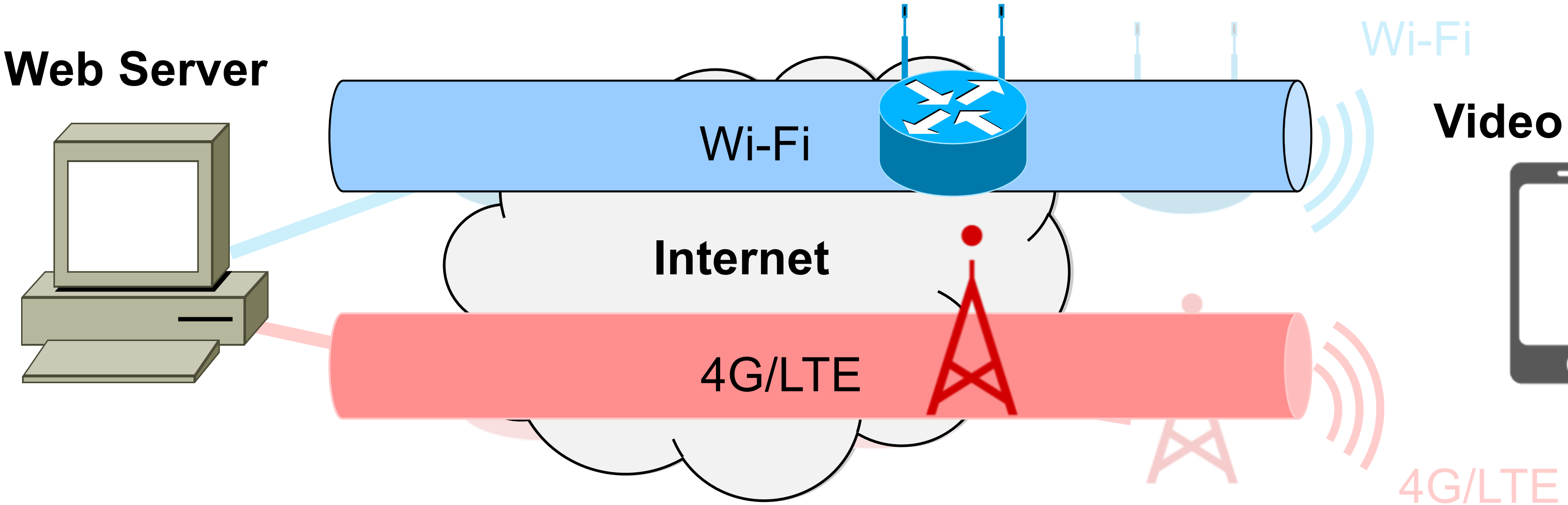
These wireless interfaces can be used simultaneously to enable efficient and redundant communications.



Introduction #3

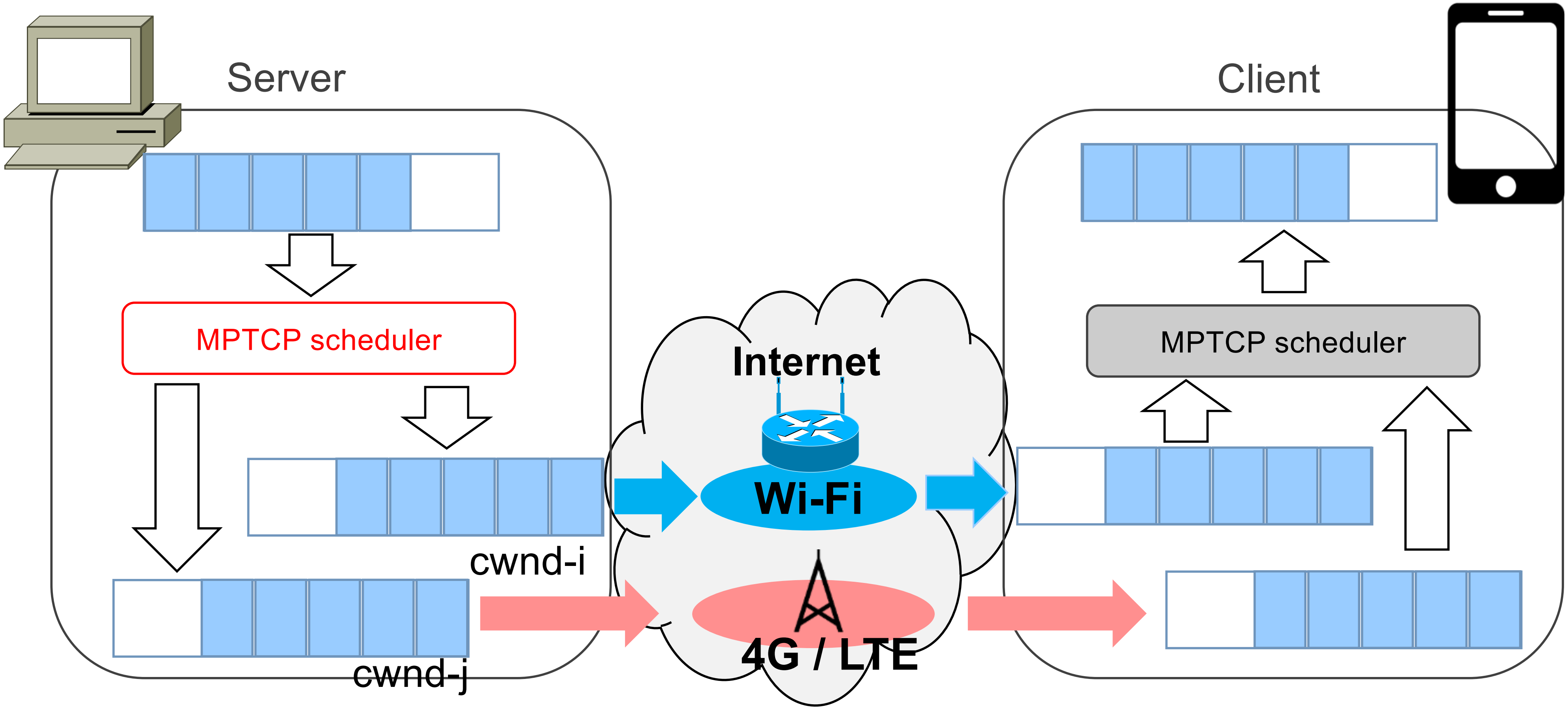
- Multipath TCP (MPTCP)
  - using multiple paths simultaneously.
  - can improve the throughput for applications
  - can guarantee redundancy

MPTCP can improve TCP performance



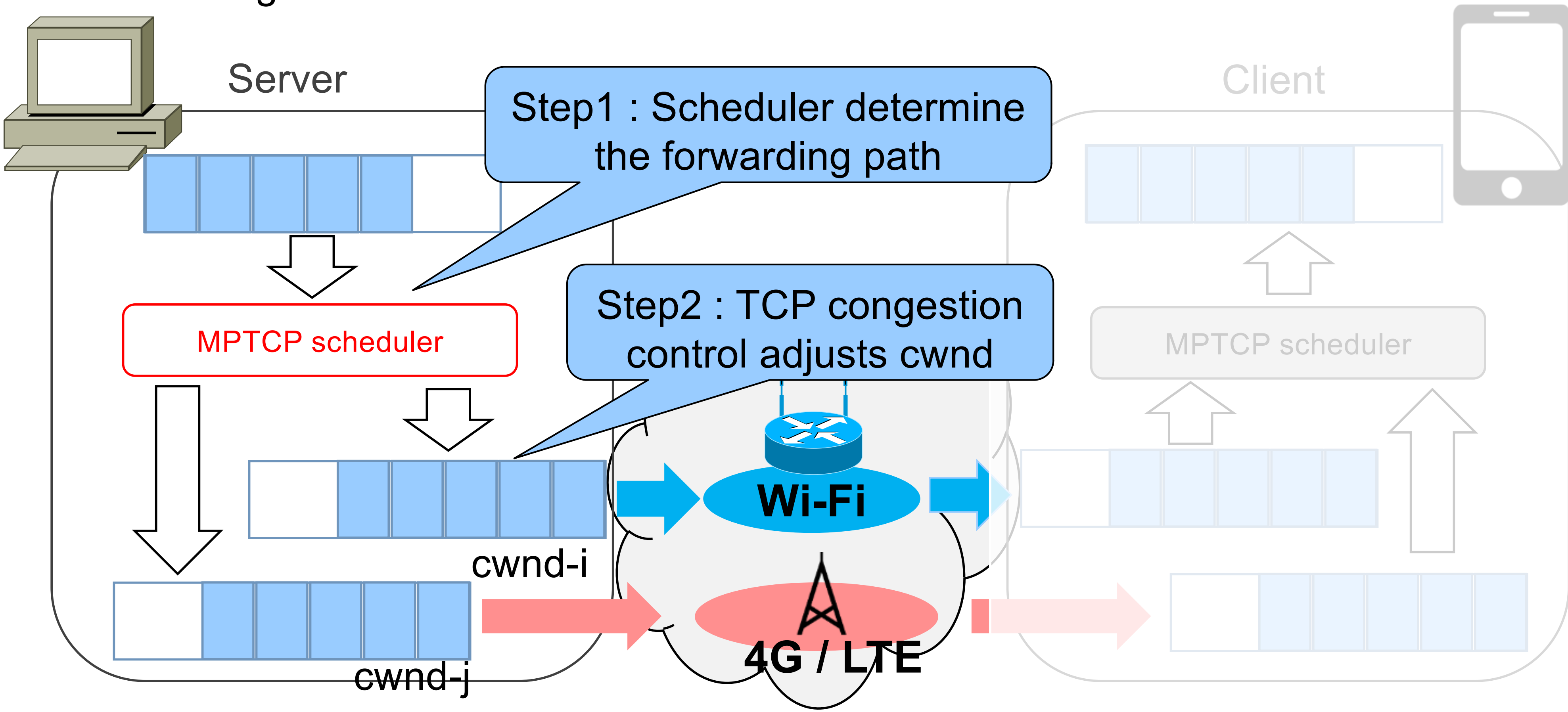
Video streaming over MPTCP #1

- MPTCP performance is determined by two things
  - MPTCP scheduler
  - MPTCP congestion control



Video streaming over MPTCP #2

- MPTCP scheduler
  - determines a path to forward packets
- MPTCP congestion control
  - adjusts congestion window (cwnd) size as well as conventional TCP congestion controls



Video streaming over MPTCP #3

- MPTCP scheduler
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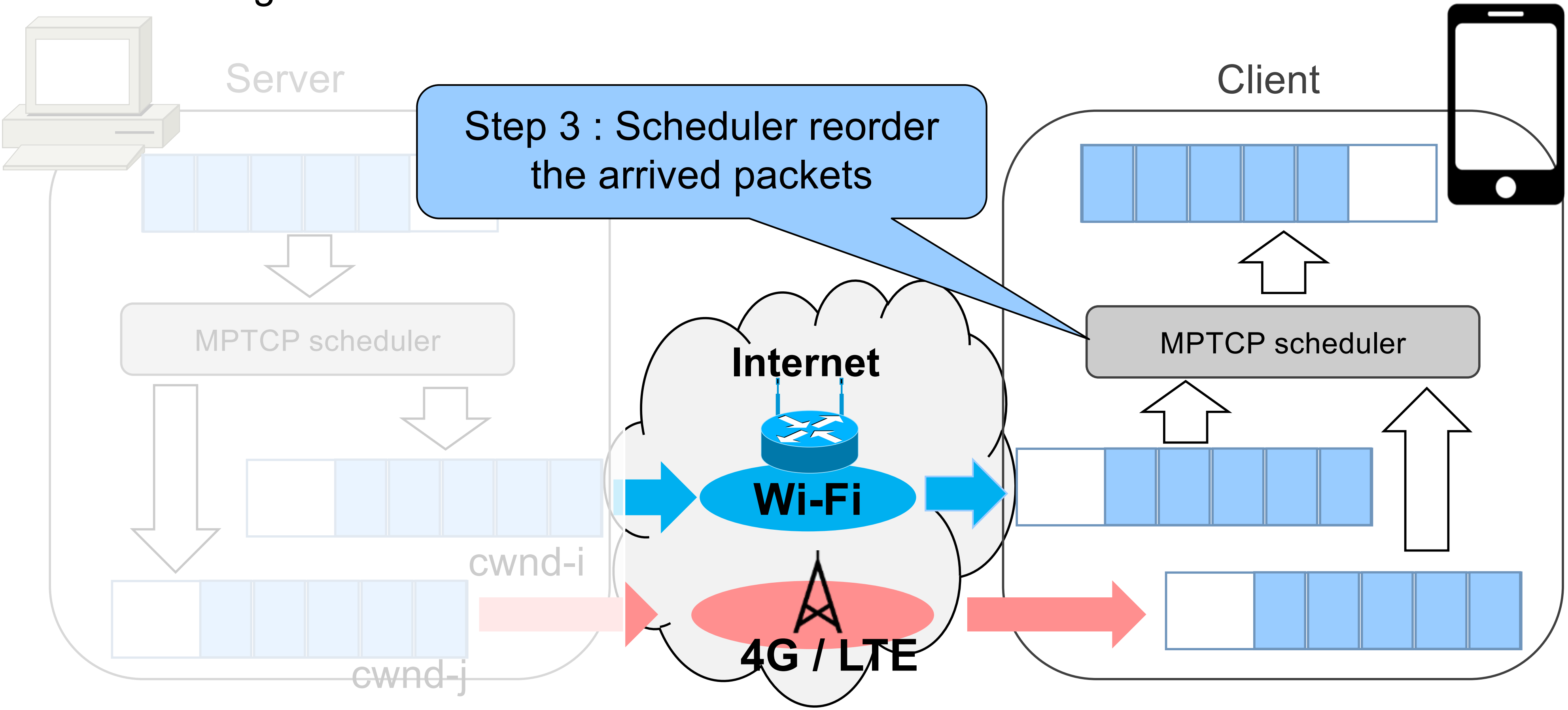
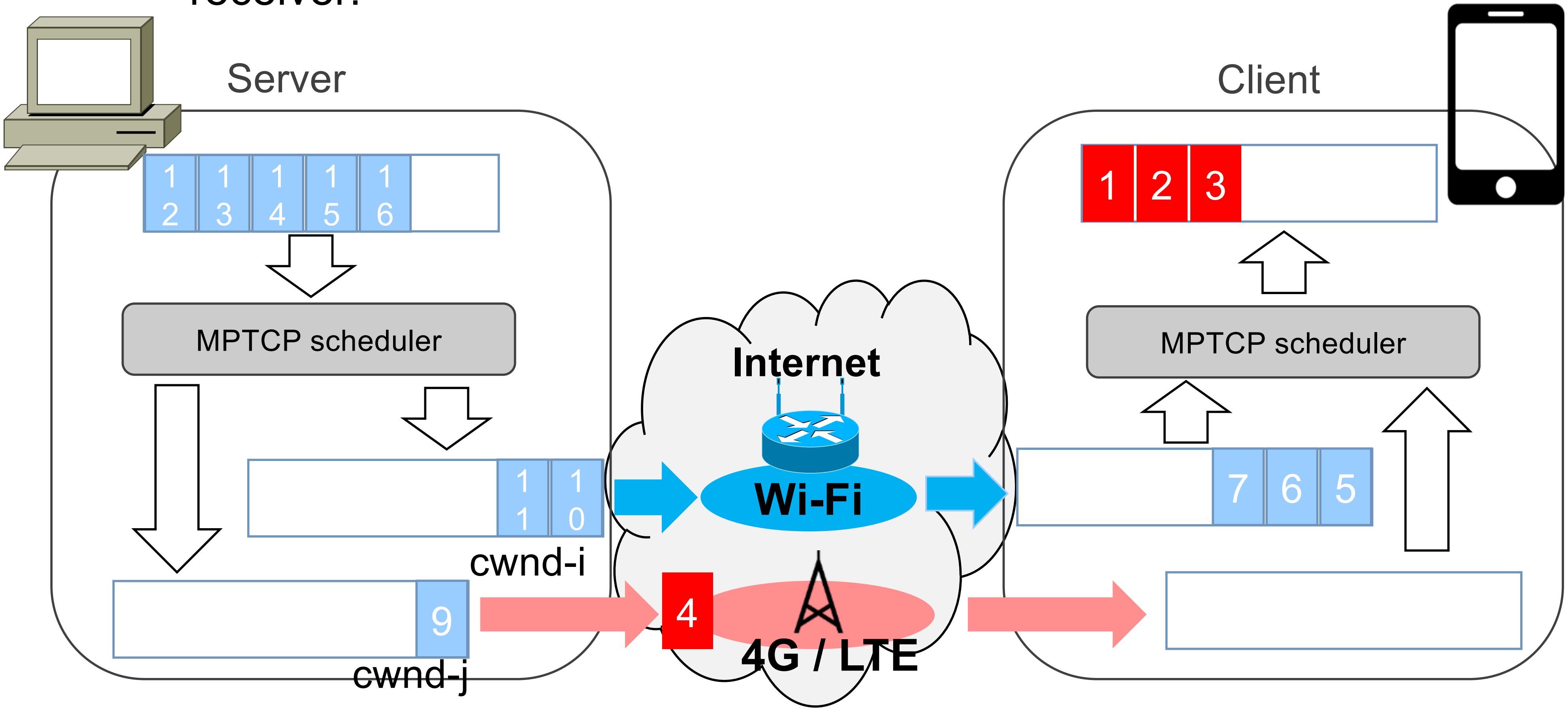


Head of Line Blocking #1

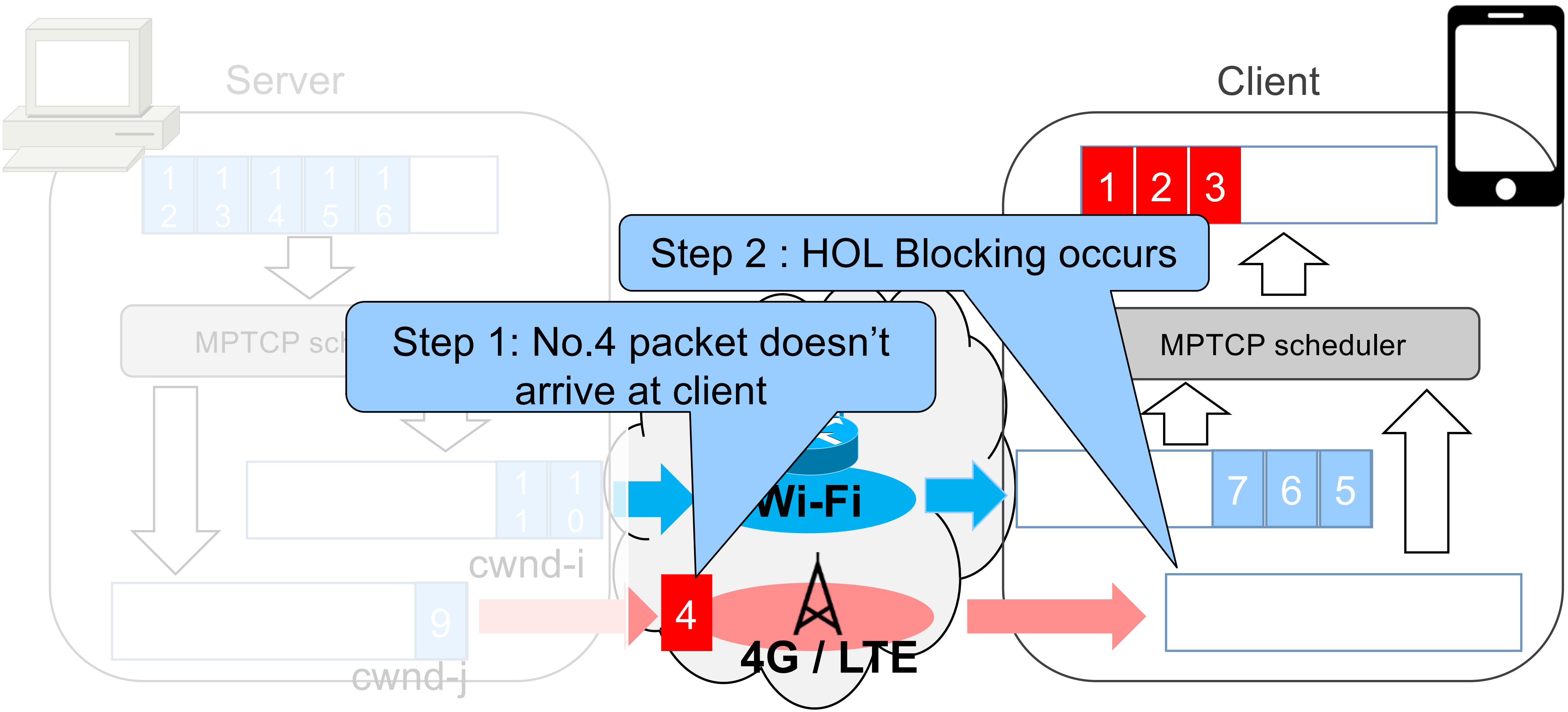
◆ Head of Line Blocking(HOL blocking)

- HOL blocking occurs when data already delivered at the receiver is waiting for additional packets that are blocked at another sub-flow, potentially causing incomplete or late frames to be discard at the receiver.



Head of Line Blocking #2

- At the receiver, video frames cannot be recovered due to HOL blocking, resulting in poor video quality.



MPTCP Congestion Control #1

◆MPTCP Congestion Control

determine congestion window size independently for each subflow.

◆CUBIC

- Loss-based algorithm as default TCP of the Linux operating system.
- Use the cubic function to adjust cwnd.

◆BBR

- New delay-based congestion control algorithm
- constantly monitoring throughput and RTT,
  also adjust the data transmission rate while understanding the relationship between the amount of transmission data and RTT.
- At the end of Bandwidth Delay Product (BDP) estimation period of 10s, cwnd is reduced to 4 packets and estimation is started again after 200ms.
- These steps are repeated to update BDP as required by the state of the transport path characteristics.

◆Important factors in video streaming over MPTCP

- Determination of a path to forward packets for MPTCP Scheduler
- MPTCP Congestion Control for each sub-flow

Previous Research

We proposed various schedulers to improve video quality and evaluated them in combination with various congestion control.

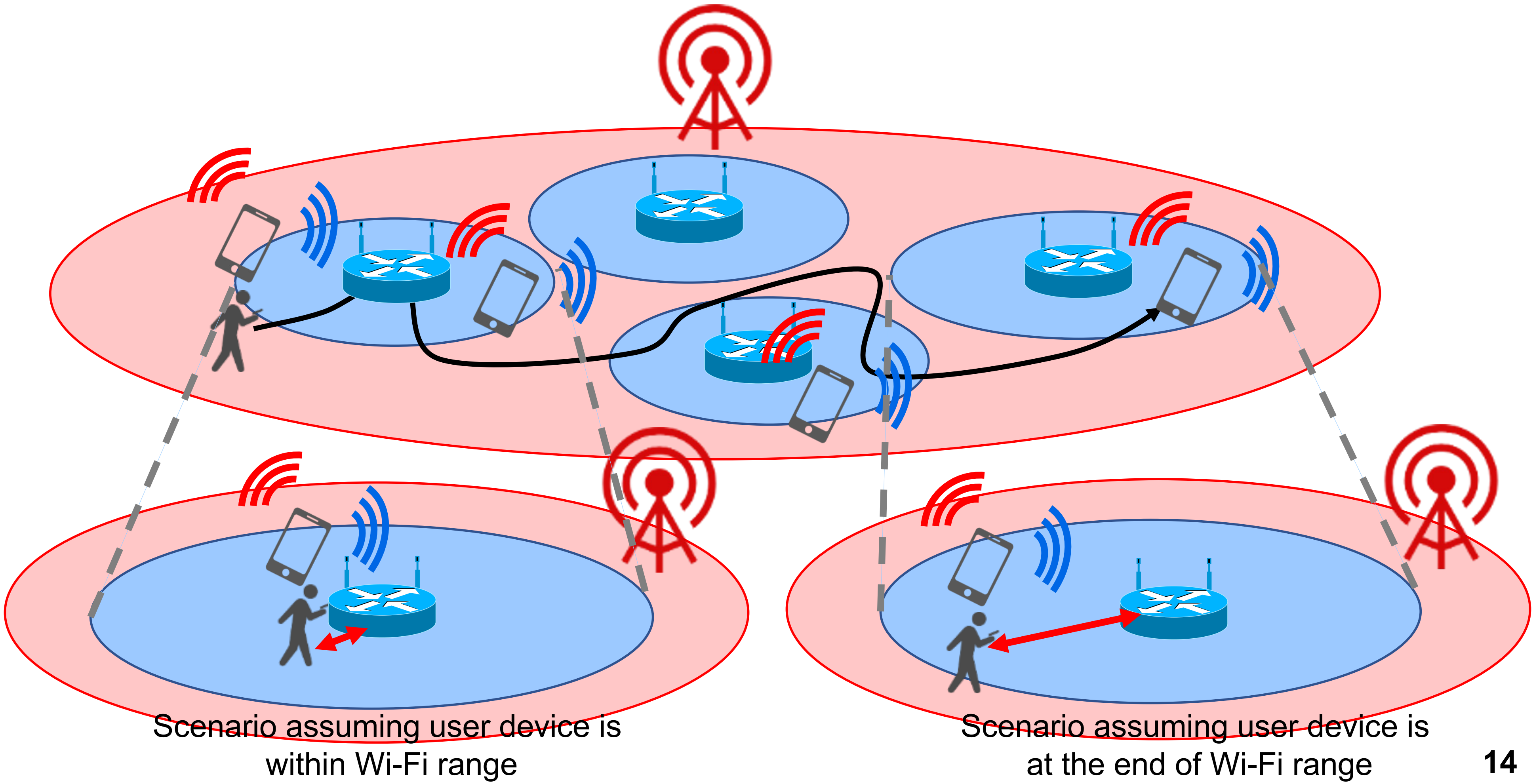
Previous Research: MPTCP Proposed Schedulers

- Default Scheduler (Linux implementation)
  - Low RTT First (LRF)
    selects the path with smaller RTT
- Proposed schedulers
  - Throughput-based
    - Largest Packet Credits (LPC)
    - Largest Estimated Throughput (LET)
  - Reducing sub-flow switching-based
    - Greedy Sticky (GR-STY)
    - Throughput Sticky (TP-STY)
    - Throughput RTT Sticky (TR-STY)

Previous Research: Variable Delay Paths on MPTCP Video Streaming

◆ The reason for dynamically varying packet loss on Wi-Fi path.

- Video streaming in mobile networks changes the packet loss rate of the Wi-Fi path as the Mobile devices moves.



Previous Research：
Combination of scheduler and congestion control

- We have proposed various schedulers to improve video quality.
- We also evaluated the combination of the proposed scheduler and congestion control in a variable packet loss environment.

We have confirmed that

- the video quality varies with the combination of scheduler and congestion control [1].
- **BBR video quality does not degrade** in environments with variable packet loss [2].

- [1] M. Kondo et al., “Path Schedulers Performance on Cellular/Wi-Fi Multipath Video Streaming,” IARIA 13th International Conference on Evolving Internet, pp. 10-15, July 2021.
- [2] M. Kondo et al., “Evaluation of MPTCP with BBR Performance on Wi-Fi/Cellular networks for Video Streaming,” IARIA 14th International Conference on Evolving Internet, pp. 6-11, May 2022.

Previous Research： Combination of scheduler and congestion control

- We have proposed various schedulers to improve video quality.
- We also evaluated the combination of the proposed scheduler and congestion control in a variable packet loss environment.

But, since BBR is a BDP based algorithm,
In an environment with variable delay, **video quality can be degraded**.

- the video quality varies with the combination of scheduler and congestion control [1].
- **BBR video quality does not degrade** in environments with variable packet loss [2].

- [1] M. Kondo et al., "Path Schedulers Performance on Cellular/Wi-Fi Multipath Video Streaming," IARIA 13th International Conference on Evolving Internet, pp. 10-15, July 2021.
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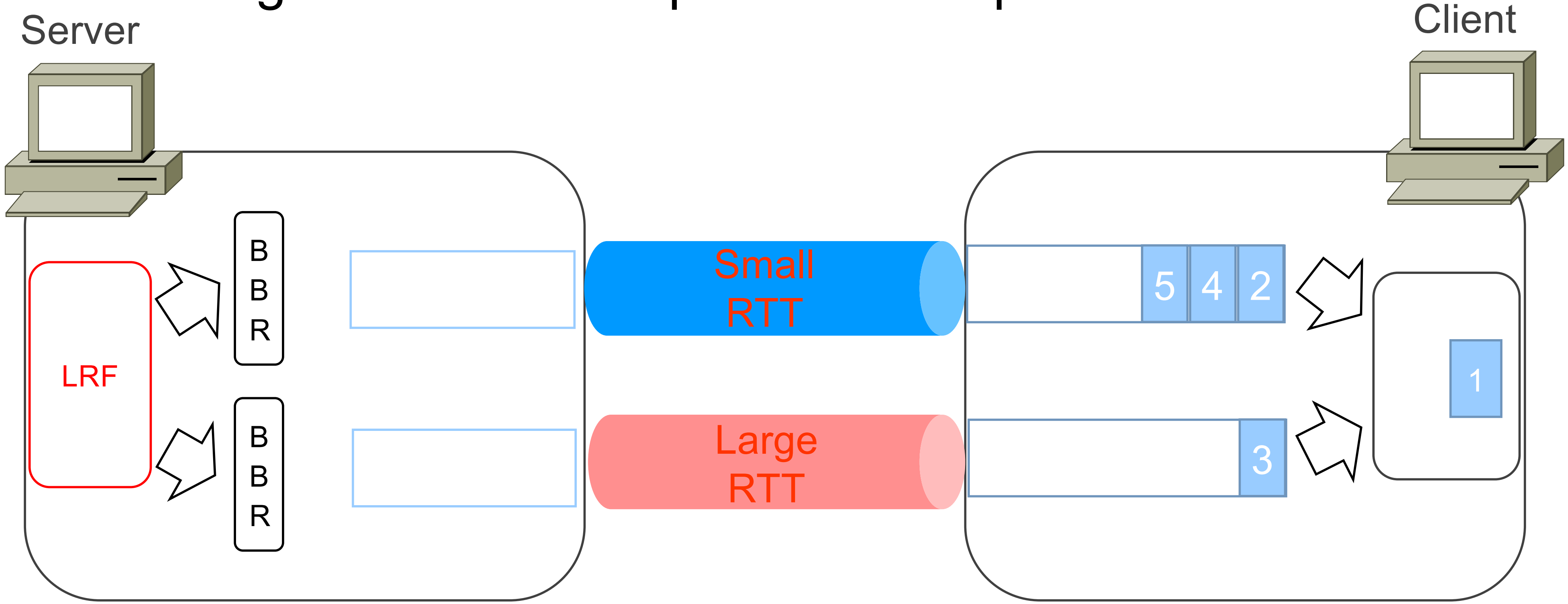
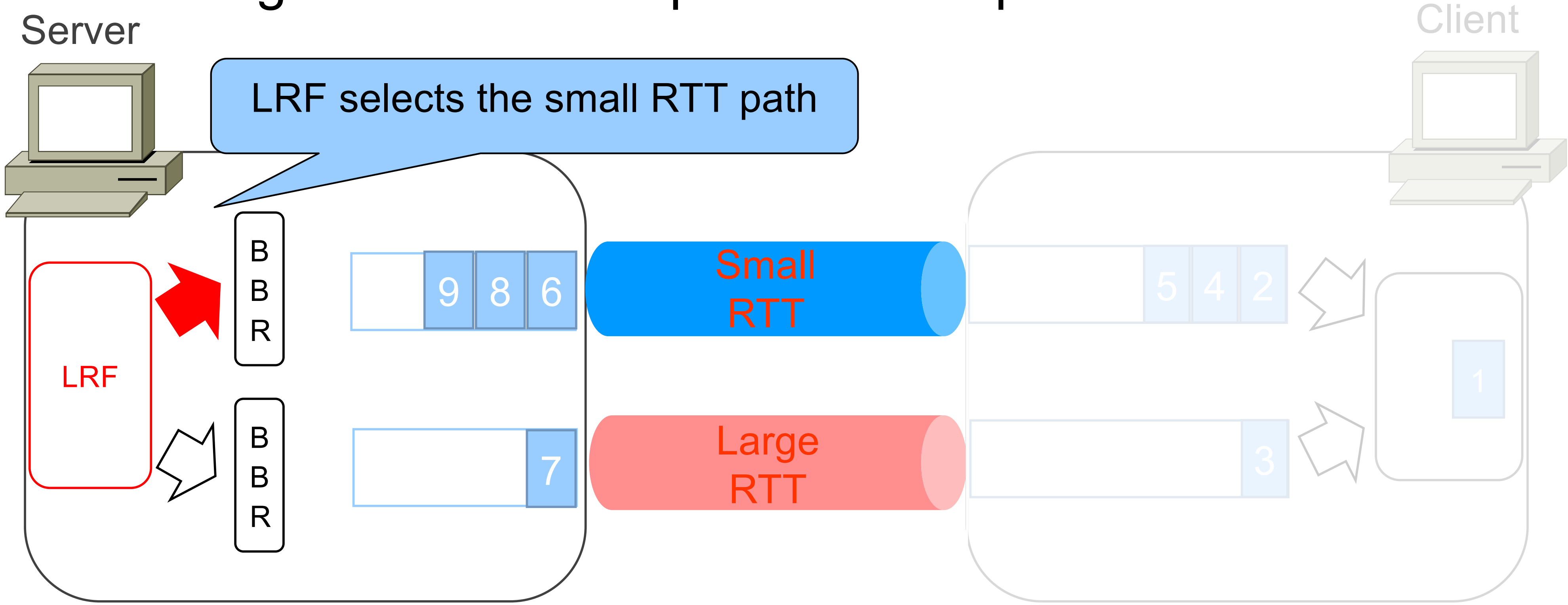
MPTCP with TCP BBR #1

- Low RTT First (LRF) scheduler
  - MPTCP default scheduler (Linux implementation)
  - selects the path with smallest RTT among paths with congestion window space for new packets.



MPTCP with TCP BBR #2

- Low RTT First (LRF) scheduler
  - MPTCP default scheduler (Linux implementation)
  - selects the path with smallest RTT among paths with congestion window space for new packets.



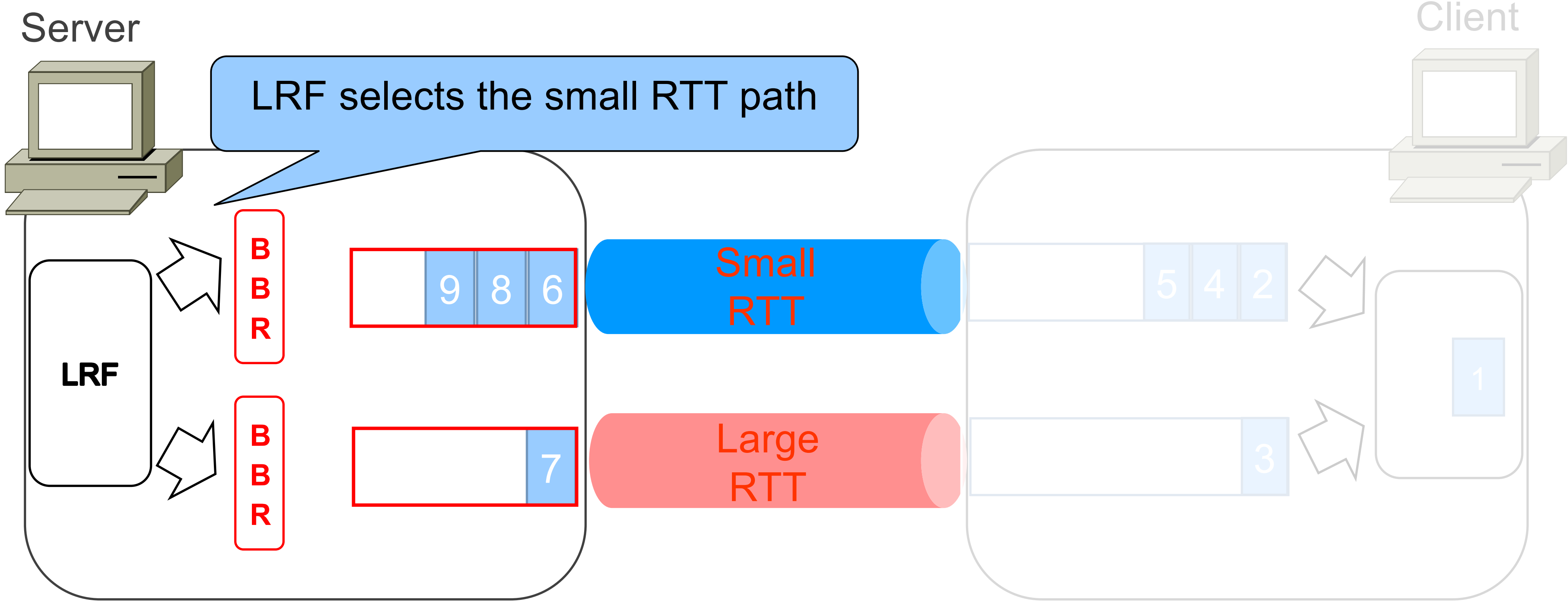
MPTCP with TCP BBR #3

◆TCP BBR

- adjust cwnd based on BDP.
- increases cwnd on routes with large delay.

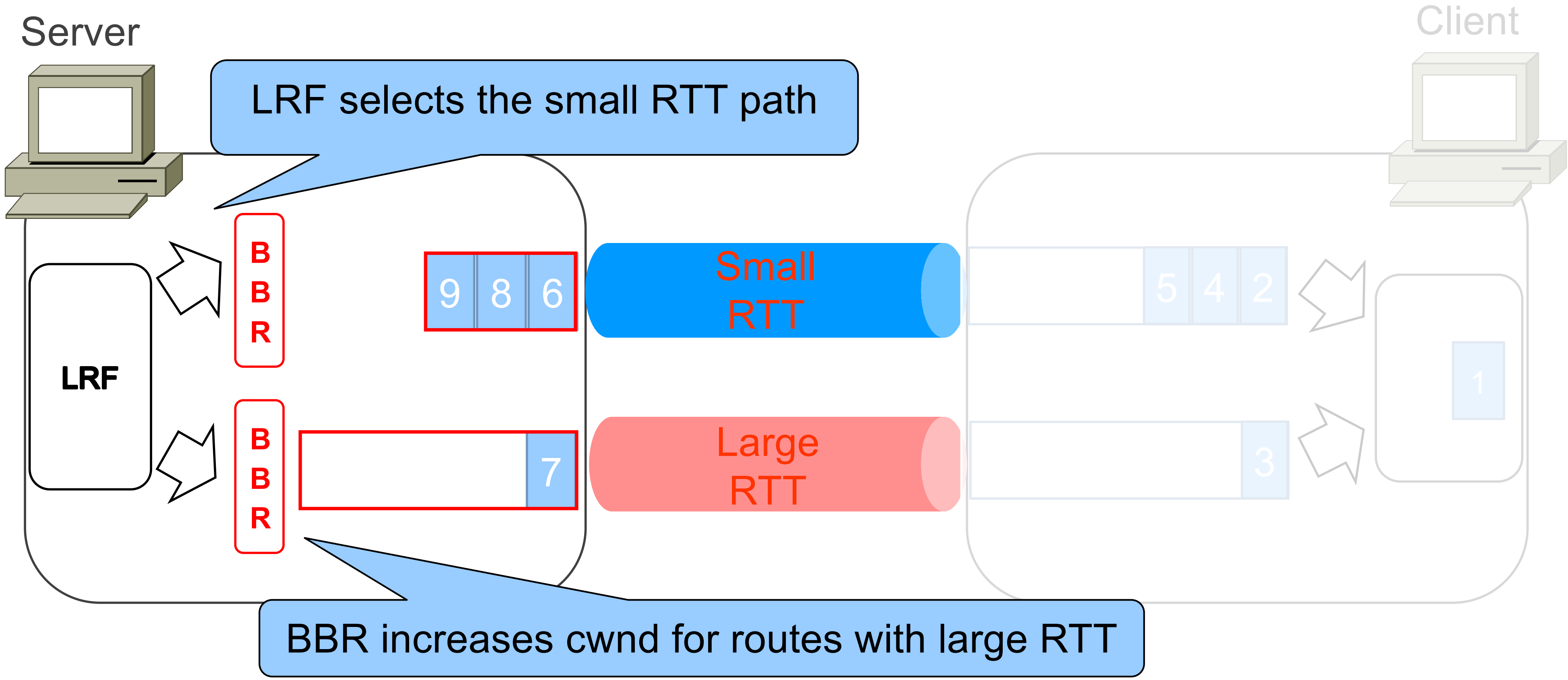
BDP

$BW \times RTprop$



MPTCP with TCP BBR #4

- Combination of LRF scheduler and BBR
  - This combination can degrade video quality due to poor scheduling.

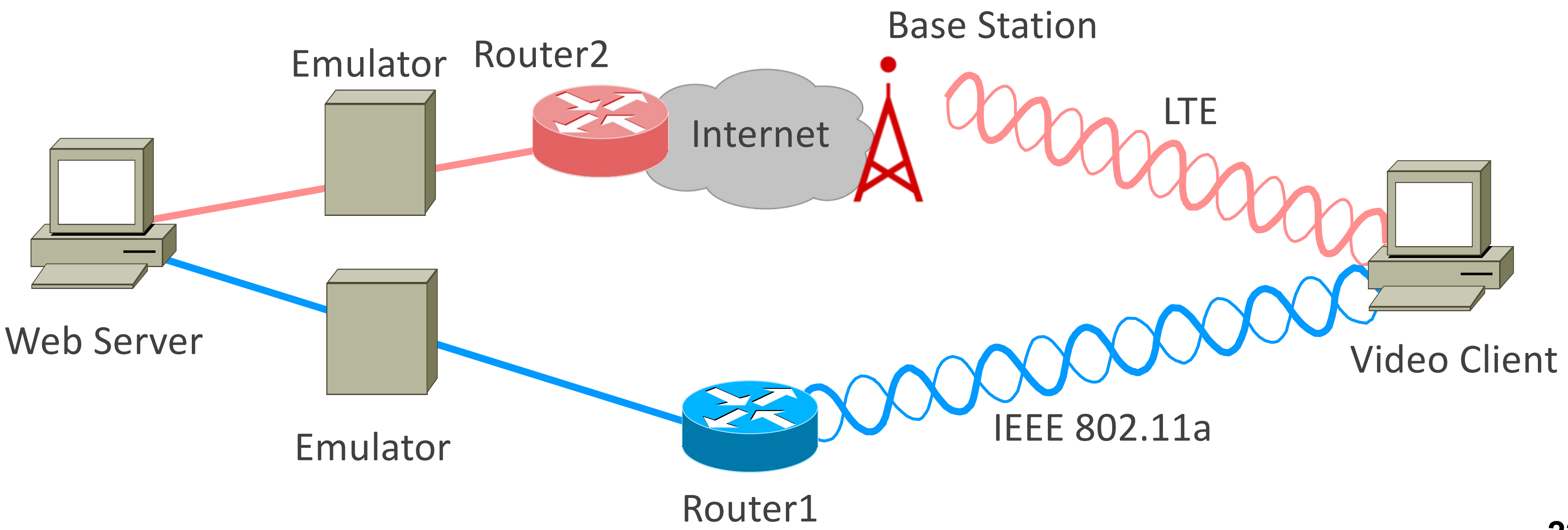


Objective

- Video streaming over MPTCP with TCP BBR
  - This combination can degrade video quality due to poor scheduling.
- We combine the LRF scheduler with CUBIC and BBR to evaluate their performance in a delay-varying environment.
- We evaluate MPTCP video streaming with BBR

Experimental Environment

- HTTP apache video server is connected to two routers
- VLC video client is connected to LTE base station and router1.
- We set emulator between server and router1, router2
- Since the bandwidth of IEEE 802.11a is sufficiently large for the bit rate of video, we have adopted 802.11a as the wireless LAN interface.



Video/network Settings

Table 1: Video Settings

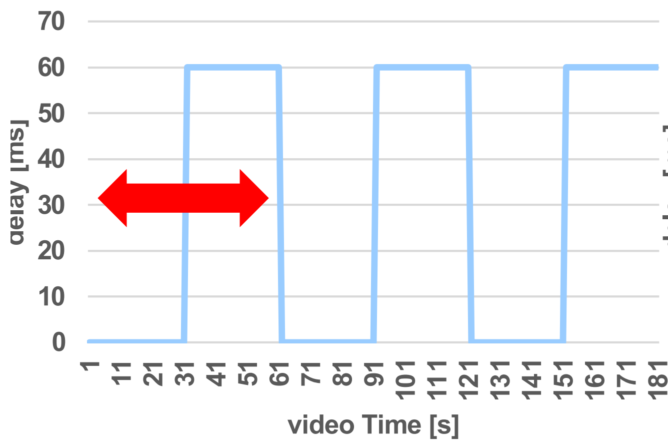
Video size	113 MBytes
Video Rate	5.24 Mb/s
Playout time	3 mins
Encoding	MPEG-4
Video Codec	H264 AVC
Audio Codec	MPEG-4 AAC

Table 2: MPTCP Settings

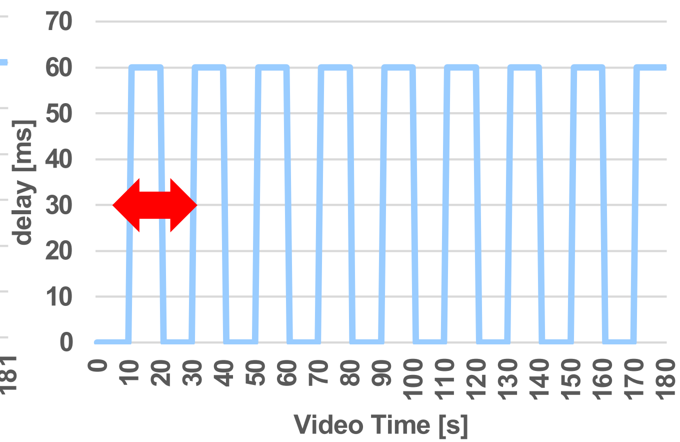
MPTCP Schedulers	LRF(default)
MPTCP Variants	CUBIC, BBR

Experimental Scenarios

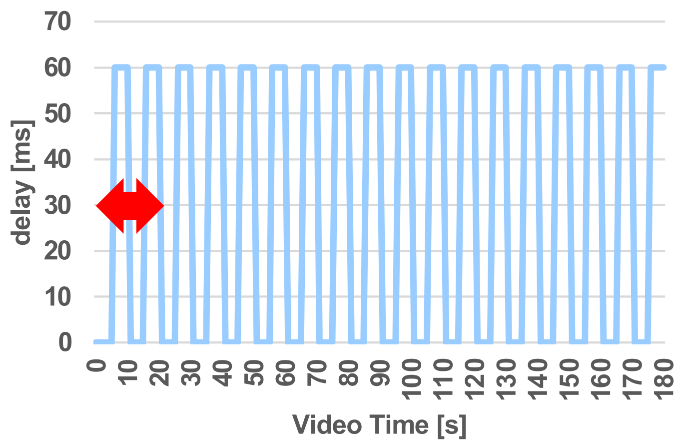
- We use network emulator
  - We set variable delay for Wi-Fi path only.
- We set up our scenario based on the BBR's BDP estimation period (10s).
  - Scenario A： A delay cycle is <u>longer</u> than the estimation period.
  - Scenario B： A delay cycle is the <u>same</u> as the estimated period.
  - Scenario C：A delay cycle is <u>shorter</u> than the estimated period.



Scenario A



Scenario B



Scenario C

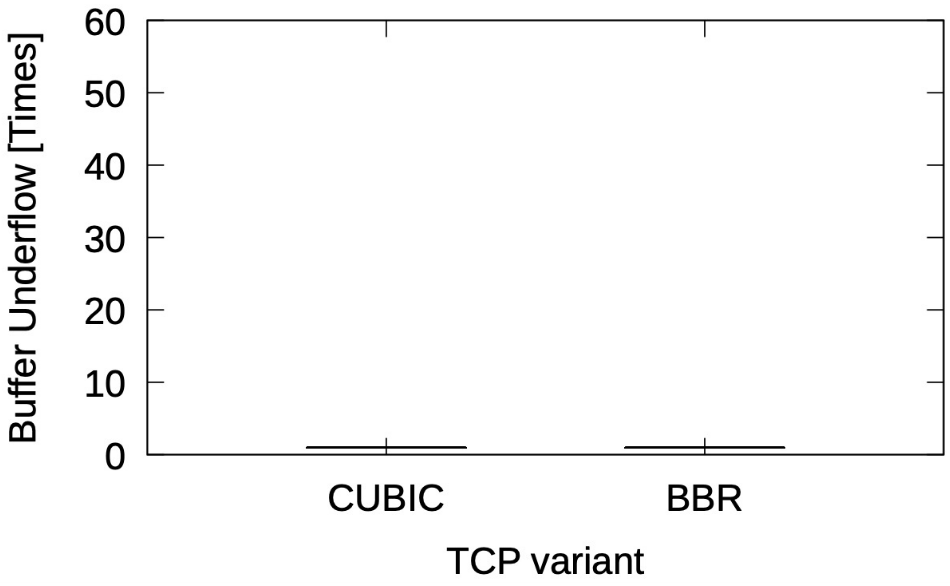
Performance evaluation index

- Video Performance
  - **Picture discard**
    Number of frames discarded by the video decoder
  - **Buffer underflow**
    Number of buffer underflow events ad video client buffer
- Transmission Performance
  - **Throughput**
  - **cwnd each sub-flow**

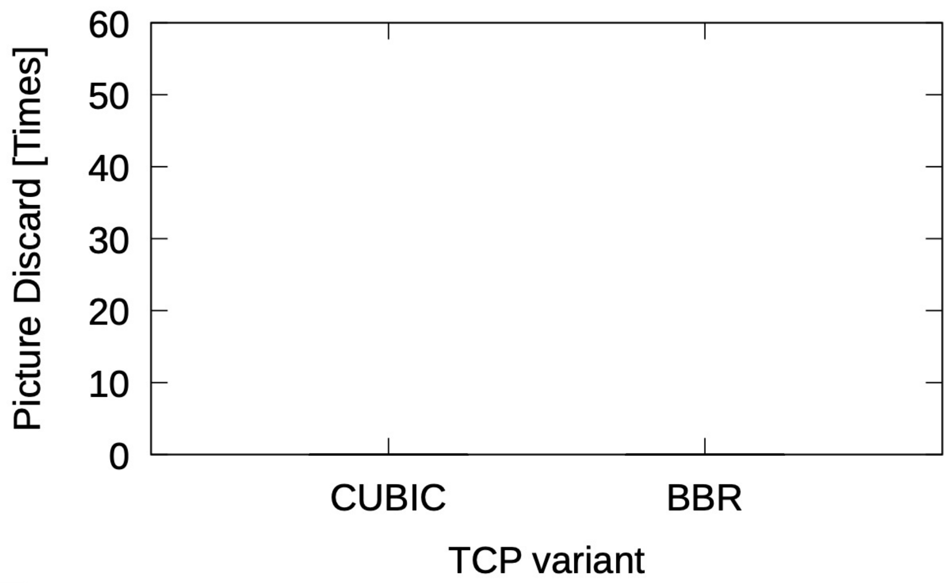
The experiment is conducted **five times** and the average is calculated.

Scenario A : Video Performance

- Path properties
  - Wi-Fi : BW = 3Mbps, RTT = 2 – 120ms (delay cycle 60s)
  - LTE : BW = 3Mbps, RTT = 80ms
- Figures report on video streaming buffer underflow and picture discard performance.
- Video performance is excellent for both CUBIC and BBR.



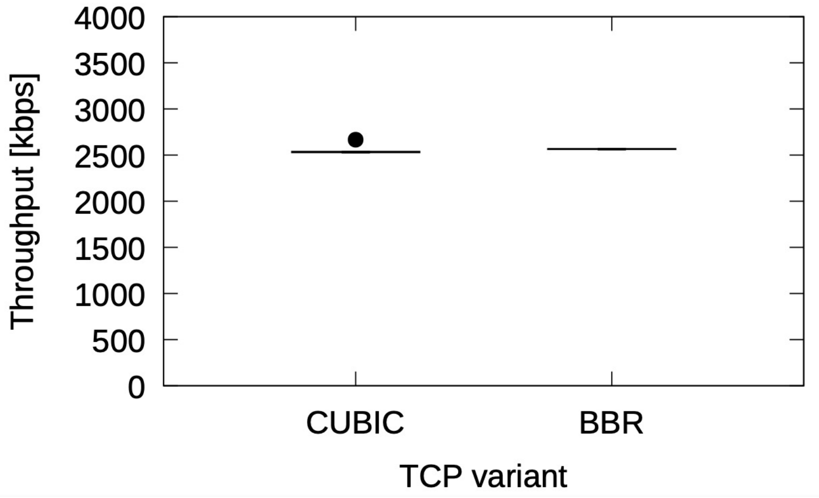
A-1 : Buffer underflow (times)



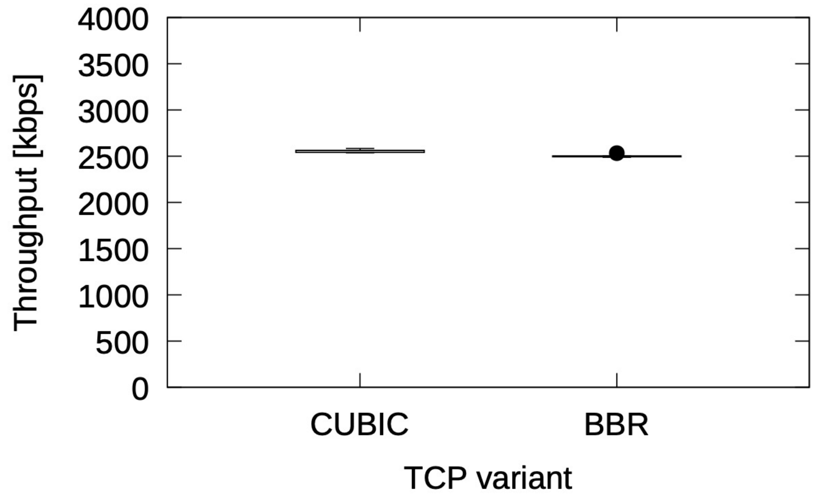
A-2 : Picture discard (times)

Scenario A : Transmission Performance #1

- We can see CUBIC and BBR use 2500kbps for both Wi-Fi and LTE path.



A-3 : Throughput LTE



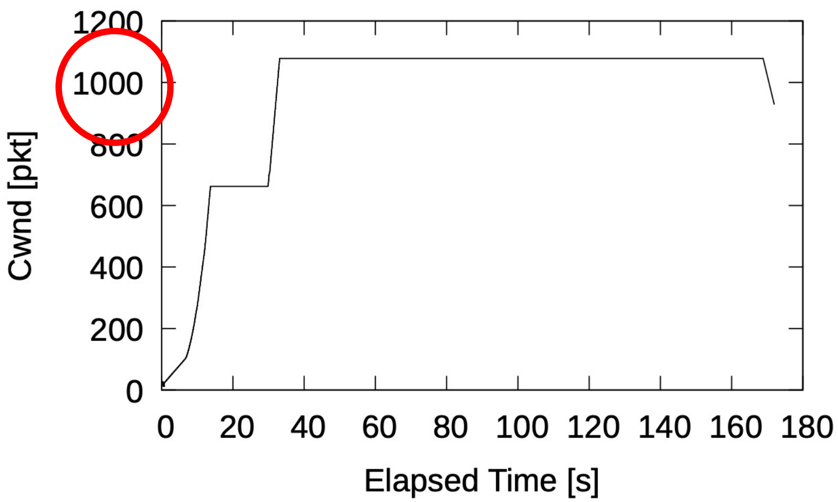
A-4 : Throughput Wi-Fi

A-5 : CUBIC cwnd Wi-Fi

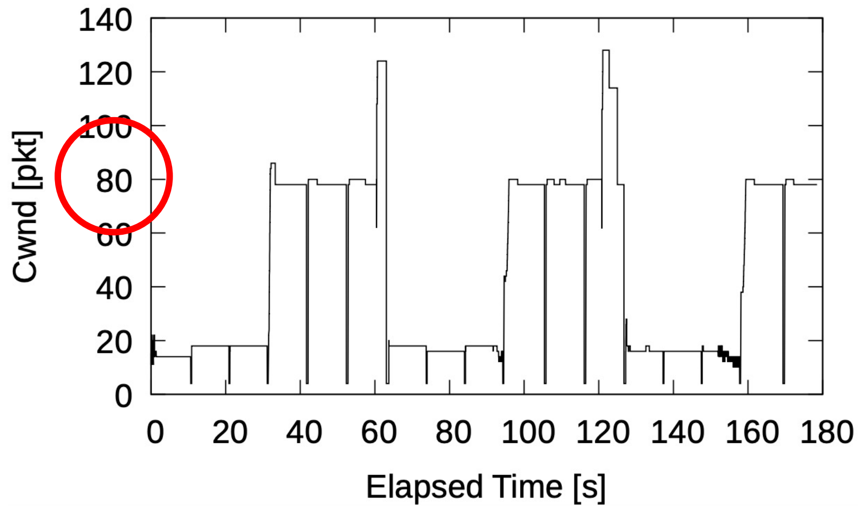
A-6 : BBR cwnd Wi-Fi

Scenario A：Transmission Performance #2

- CUBIC
  - which, being a loss-based variant, is insensitive to delay variations.
- BBR
  - We can see that BBR enforces a much reduced Wi-Fi cwnd than CUBIC, still delivering excellent video performance.
  - BBR cwnd size tracks nicely delay cycles.



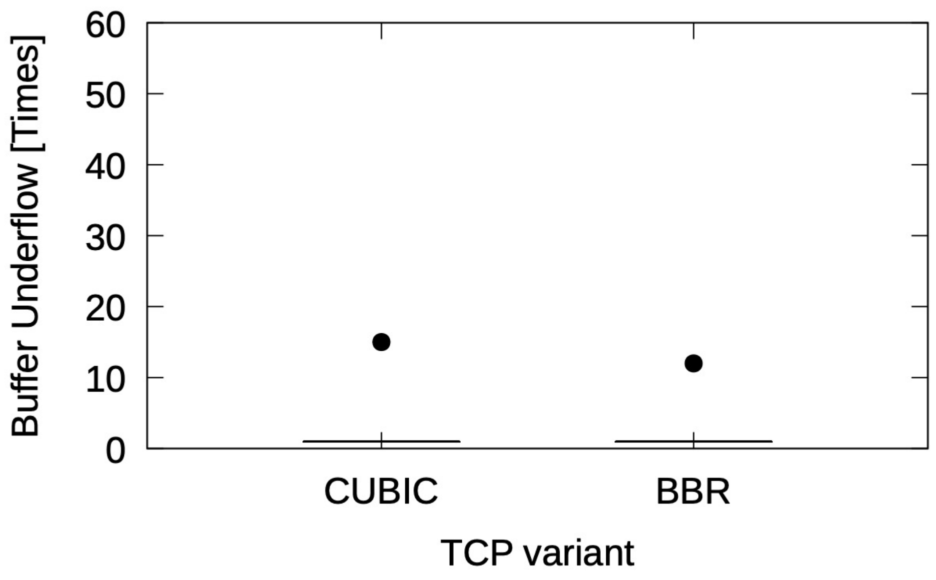
A-5 : CUBIC cwnd Wi-Fi



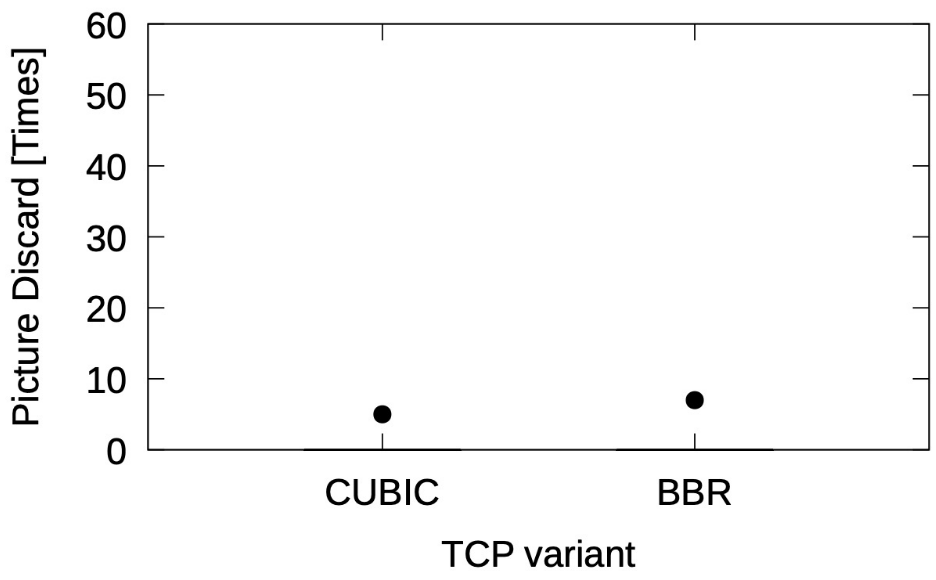
A-6 : BBR cwnd Wi-Fi

Scenario B : Video Performance

- Path properties
  - Wi-Fi : BW = 3Mbps, RTT = 2 – 120ms (delay cycle 20s)
  - LTE : BW = 3Mbps, RTT = 80ms
- Video performance degrades for both TCP variants, with BBR delivering less buffer underflows and more picture discards than CUBIC.



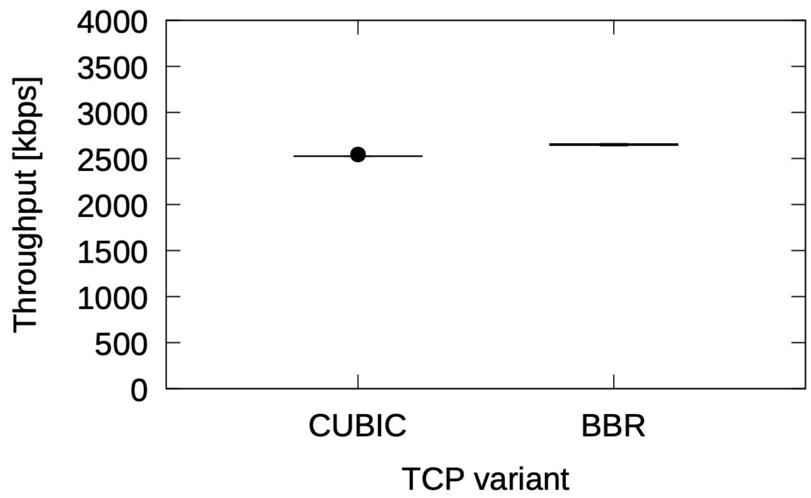
B-1 : Buffer underflow (times)



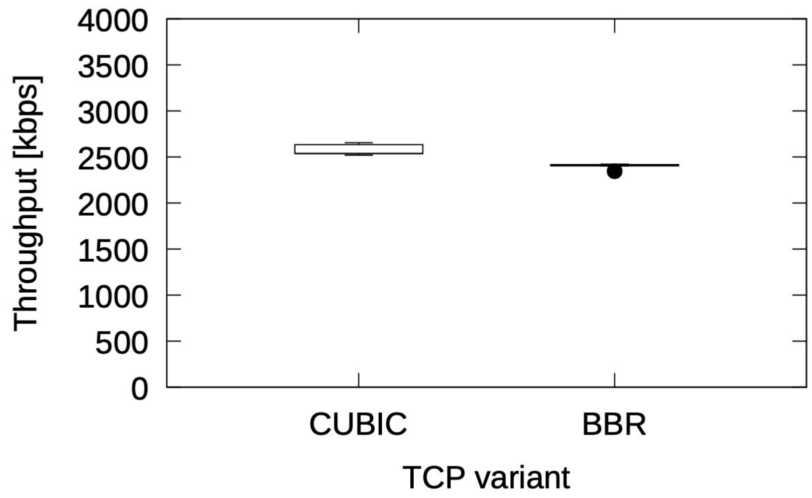
B-2 : Picture discard (times)

Scenario B : Transmission Performance #1

- We can see CUBIC and BBR use 2500kbps for both Wi-Fi



B-3 : Throughput LTE



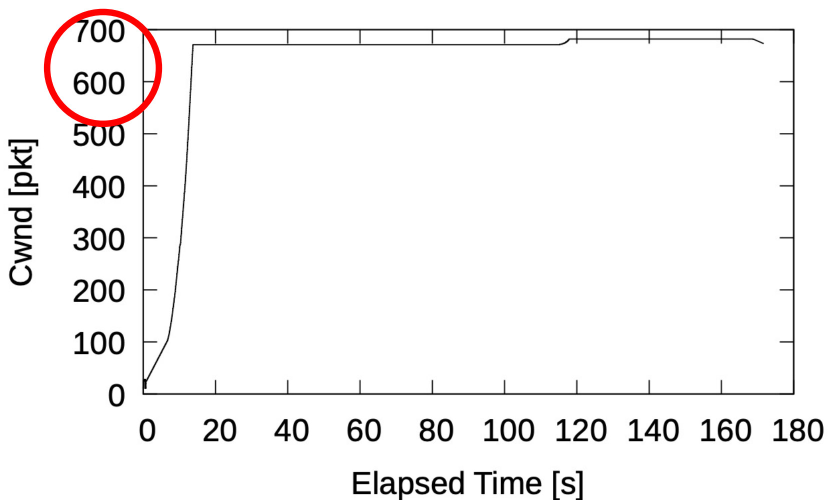
B-4 : Throughput Wi-Fi

B-5 : CUBIC cwnd Wi-Fi

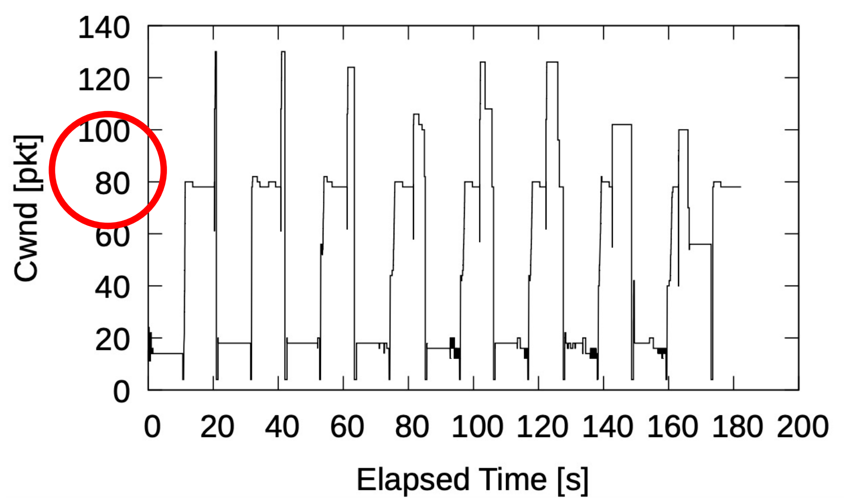
B-6 : BBR cwnd Wi-Fi

Scenario B : Transmission Performance #2

- CUBIC
  - which, being a loss-based variant, is insensitive to delay variations.
- BBR
  - enforces a much reduced Wi-Fi cwnd than CUBIC, still tracking delay cycles nicely.



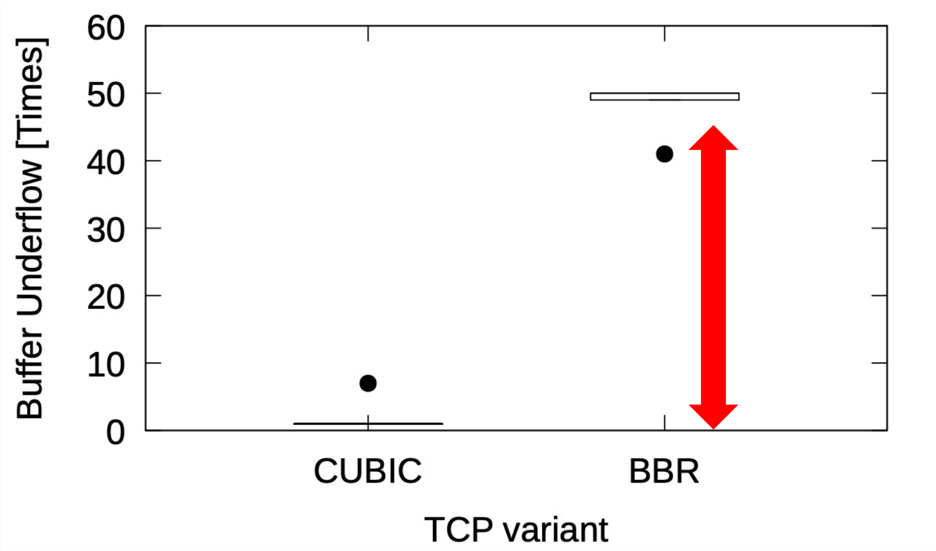
B-5 : CUBIC cwnd Wi-Fi



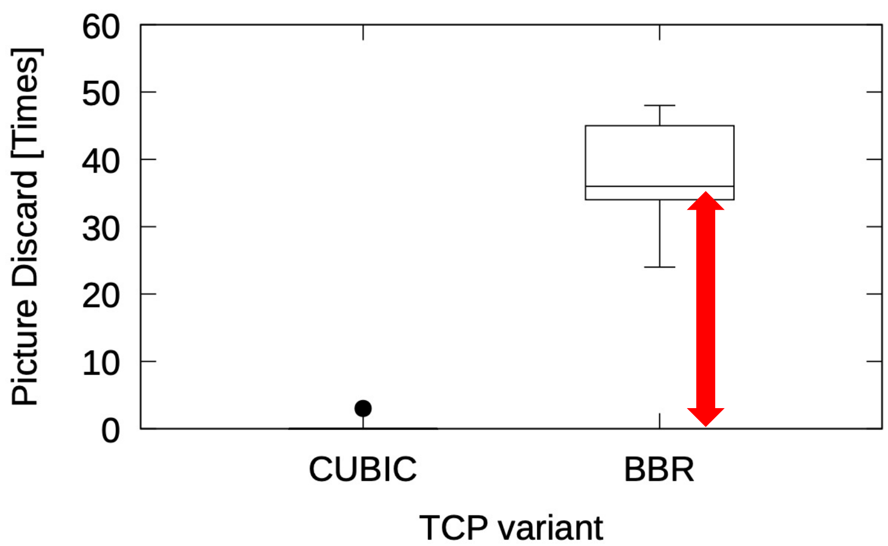
B-6 : BBR cwnd Wi-Fi

Scenario C : Video Performance

- Path properties
  - Wi-Fi : BW = 3Mbps, RTT = 2 – 120ms (delay cycle 10s)
  - LTE : BW = 3Mbps, RTT = 80ms
- Video performance degrades significantly for BBR, whereas CUBIC delivers video performance comparable with previous scenario.



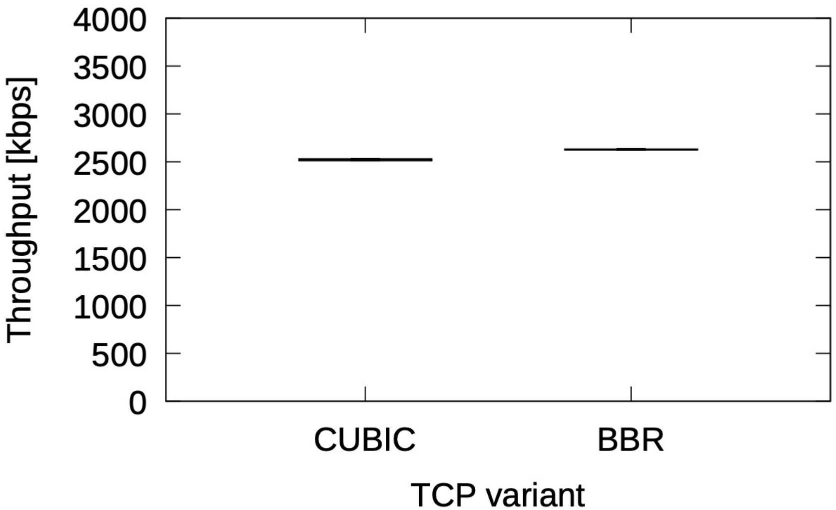
C-1 : Buffer underflow (times)



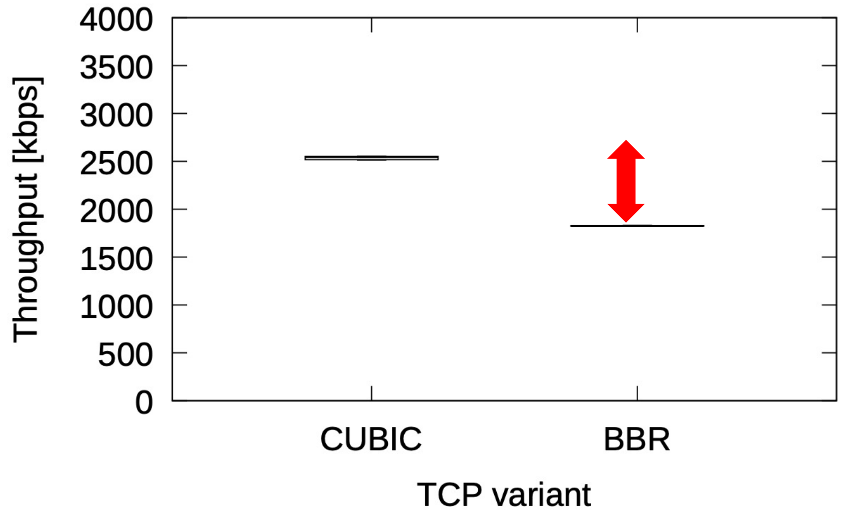
C-2 : Picture discard (times)

Scenario C : Transmission Performance #1

- BBR delivering a much reduced level of Wi-Fi throughput than CUBIC, and not being able to compensate enough with more LTE bandwidth than CUBIC.



C-3 : Throughput LTE



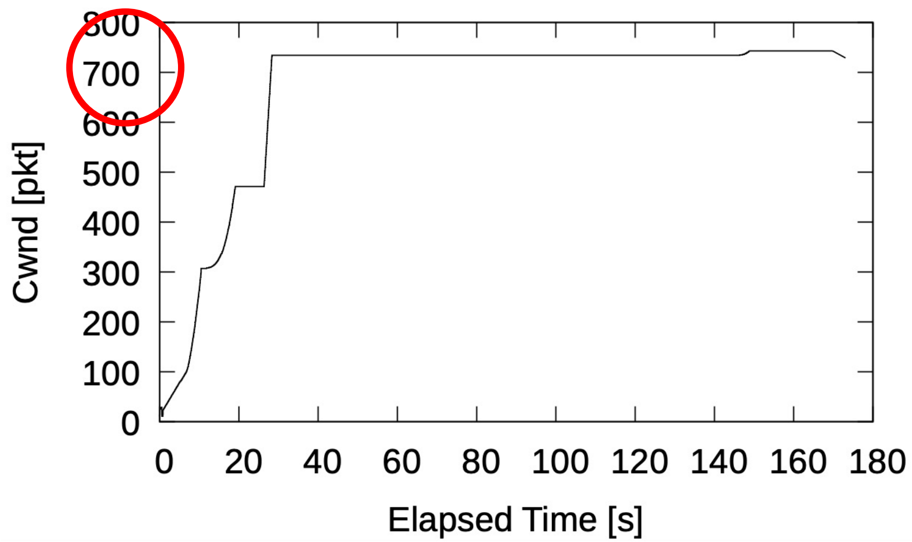
C-4 : Throughput Wi-Fi

C-5 : CUBIC cwnd Wi-Fi

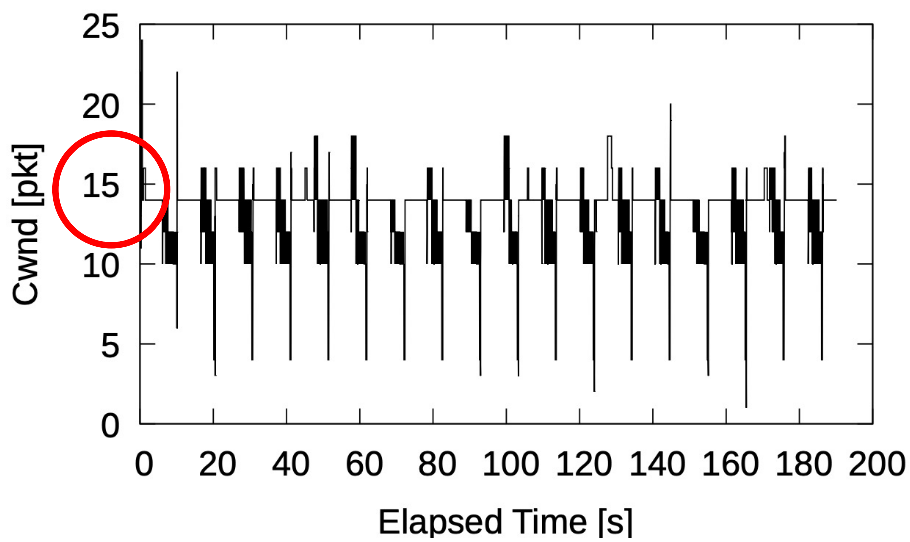
C-6 : BBR cwnd Wi-Fi

Scenario C : Transmission Performance #2

- **CUBIC**
  - which, being a loss-based variant, is insensitive to delay variations.
- **BBR**
  - performance degradation. BBR is no longer able to track delay cycles as before, remaining ”stuck” at a small cwnd of 15 packets.
  - Since the delay cycle in Scenario C is 10s, the estimation is not performed correctly during ProbRTT and cwnd does not increase.



C-5 : CUBIC cwnd Wi-Fi



C-6 : BBR cwnd Wi-Fi

Conclusion

- We evaluated the impact of using a standard scheduler, CUBIC, and BBR on video quality in an environment with variable latency.

- We have shown that on rapidly varying path delay scenario, BBR TCP variant delivers a degraded video streaming performance.

- Under this fast delay variation, BBR remains at a shrunk congestion window situation that effectively reduces considerably the path throughput.

- Therefore, a combined improvement of the scheduler and congestion control algorithm to improve the video quality is a future challenge.