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Evaluation of MPTCP with BBR Performance on Wi-Fi/Cellular networks for Video Streaming

Masayoshi Kondo, Dirceu Cavendish
Daiki Nobayashi, Takeshi Ikenaga

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

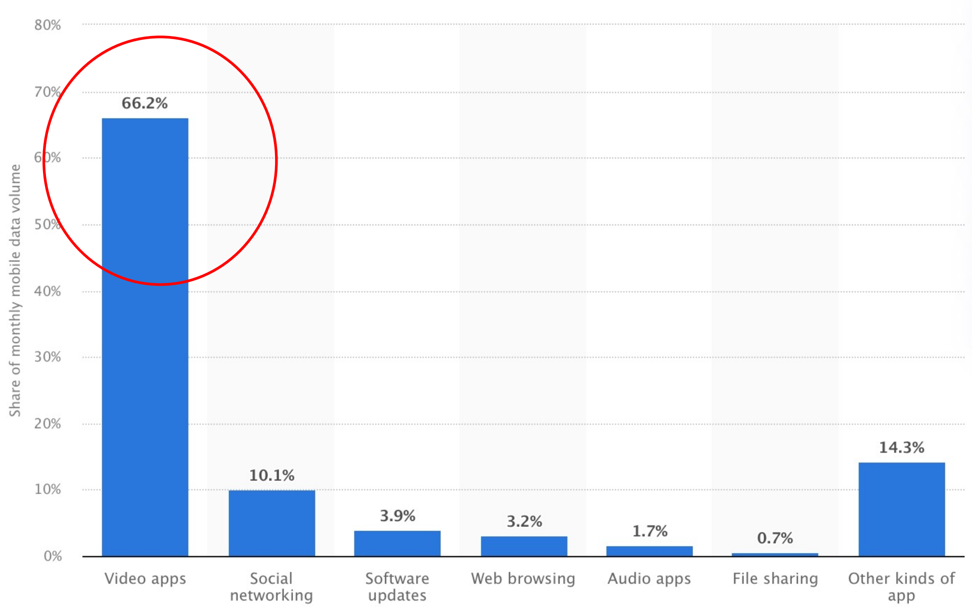
Resume

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

  - Field of Study
    - MPTCP
    - Transport Protocols

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

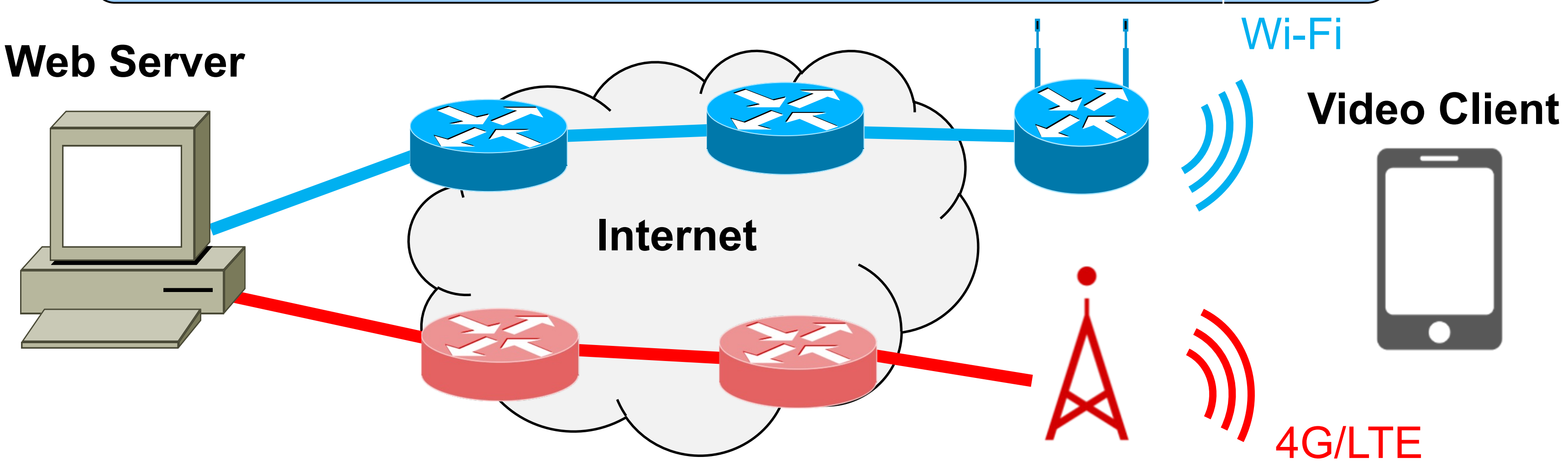
	Rank Change	Category	Downstream	Upstream
1	-	Video Streaming	48.9%	19.4%
2	-	Social Networking	19.3%	16.6%
3	2	Web	13.1%	23.1%
4	-1	Messaging	6.7%	20.4%
5	-	Gaming	4.3%	1.9%
6	-2	Marketplace	4.1%	1.2%
7	2	File Sharing	1.3%	6.6%
8	-1	Cloud	1.1%	6.7%
9	-3	VPN and Security	0.9%	3.9%
10	-	Audio	0.2%	0.2%

*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

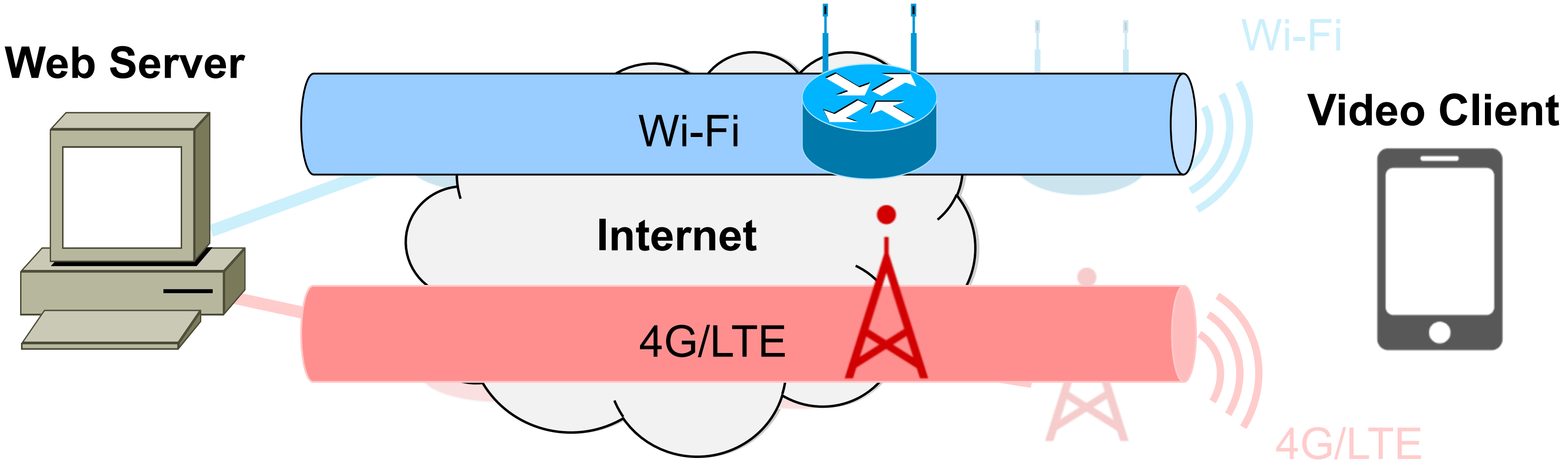
These wireless interfaces can be used simultaneously to enable efficient and redundant communications.



Introduction #3

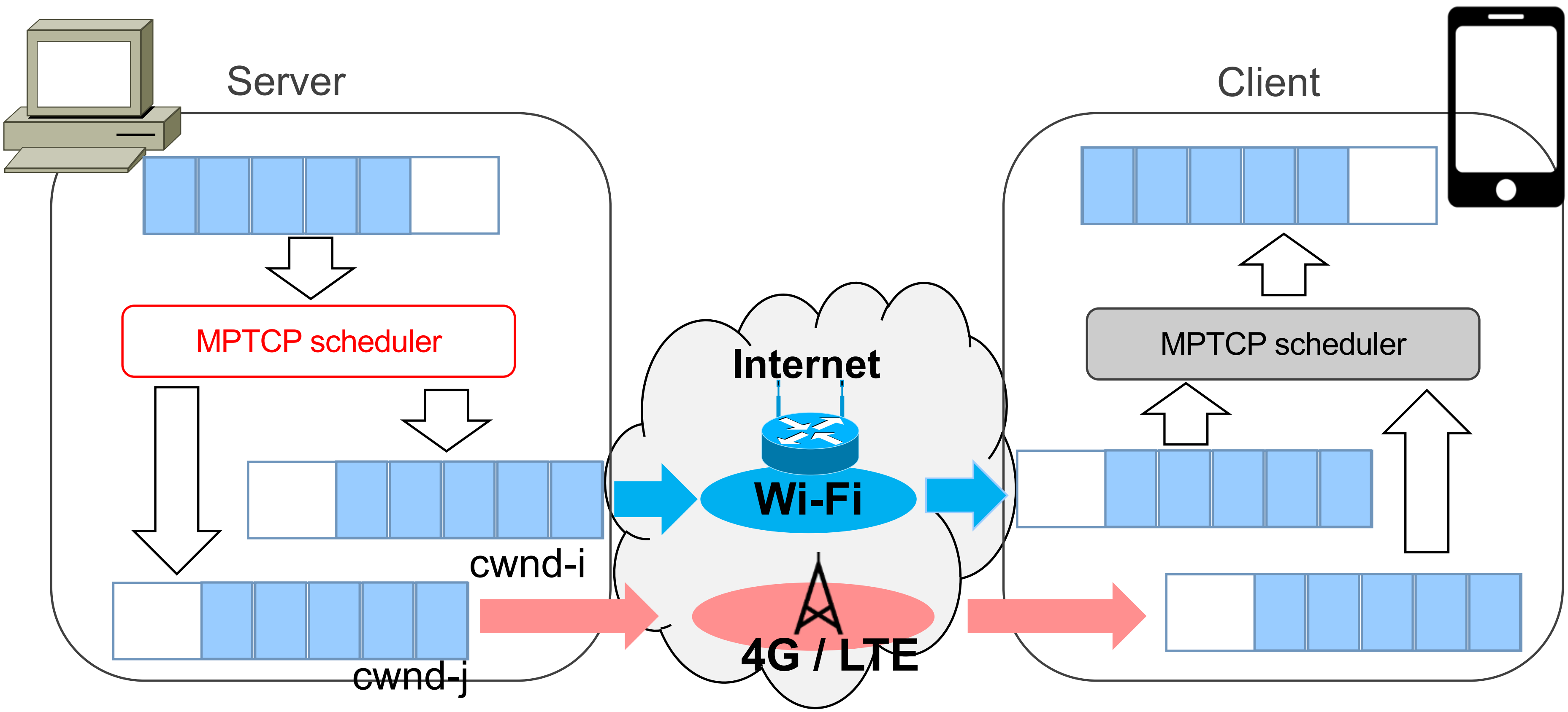
- **Multipath TCP (MPTCP)**
  - use multiple paths simultaneously.
  - can improve throughput for applications
  - can guarantee redundancy

MPTCP can improve TCP performance



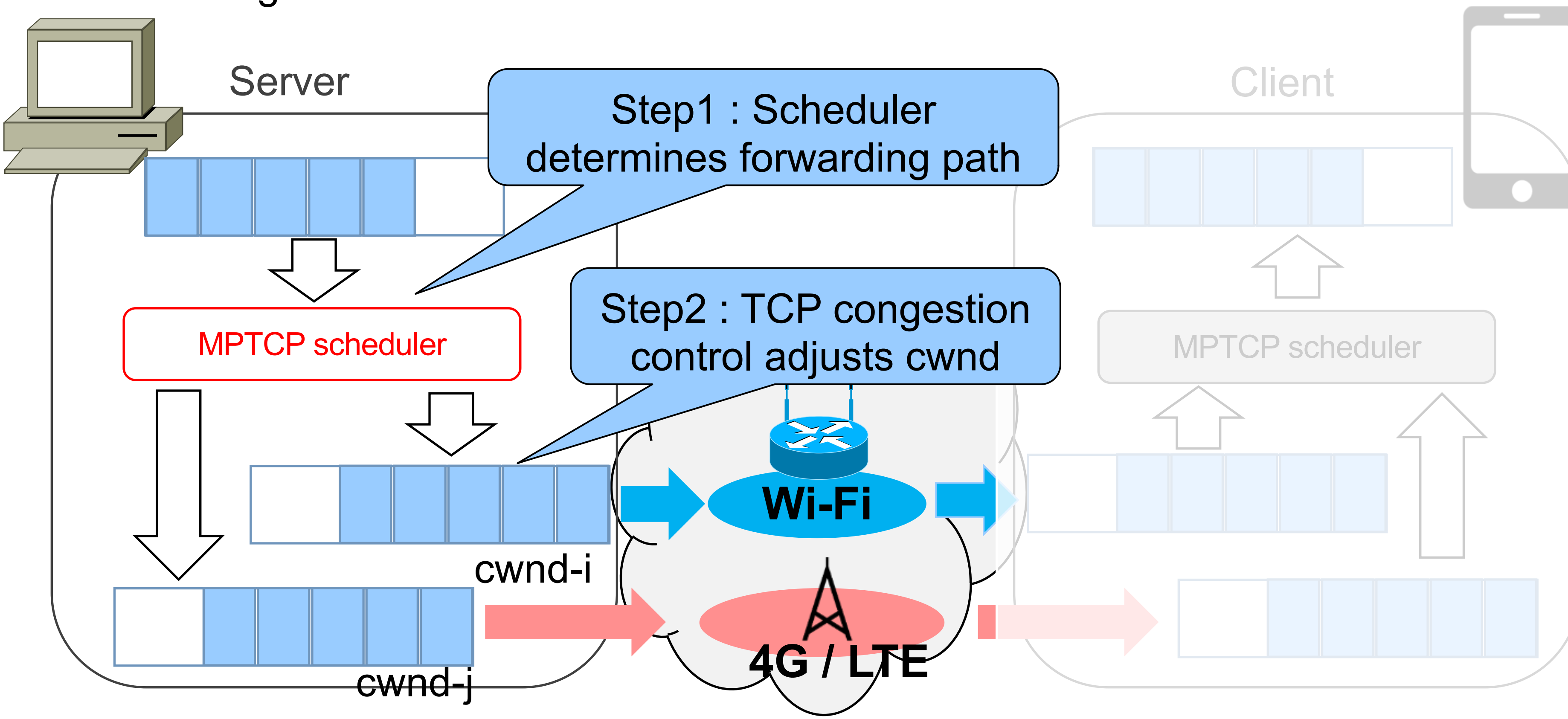
Video streaming over Multipath TCP

- MPTCP performance is determined by:
  - MPTCP scheduler
  - MPTCP congestion control



Video streaming over Multipath TCP

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



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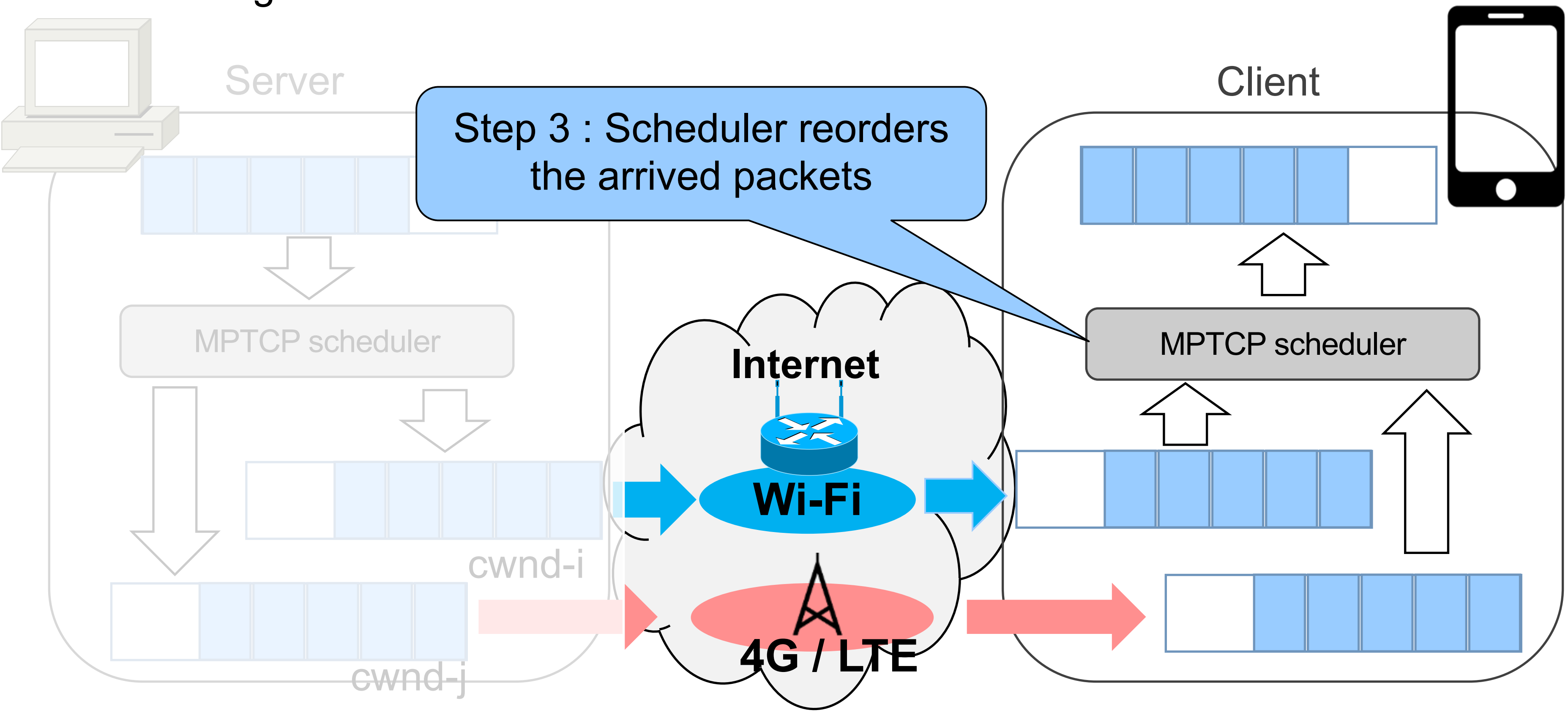
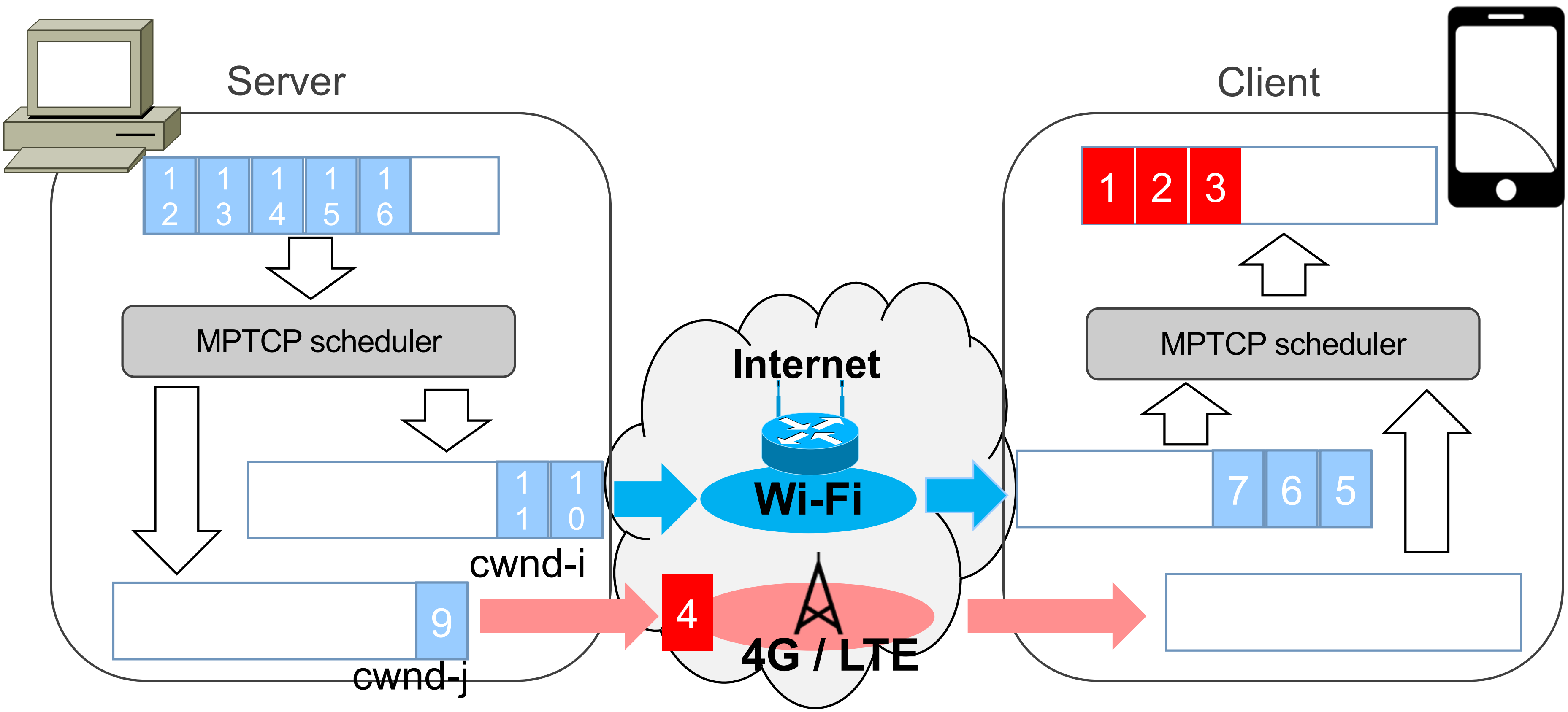


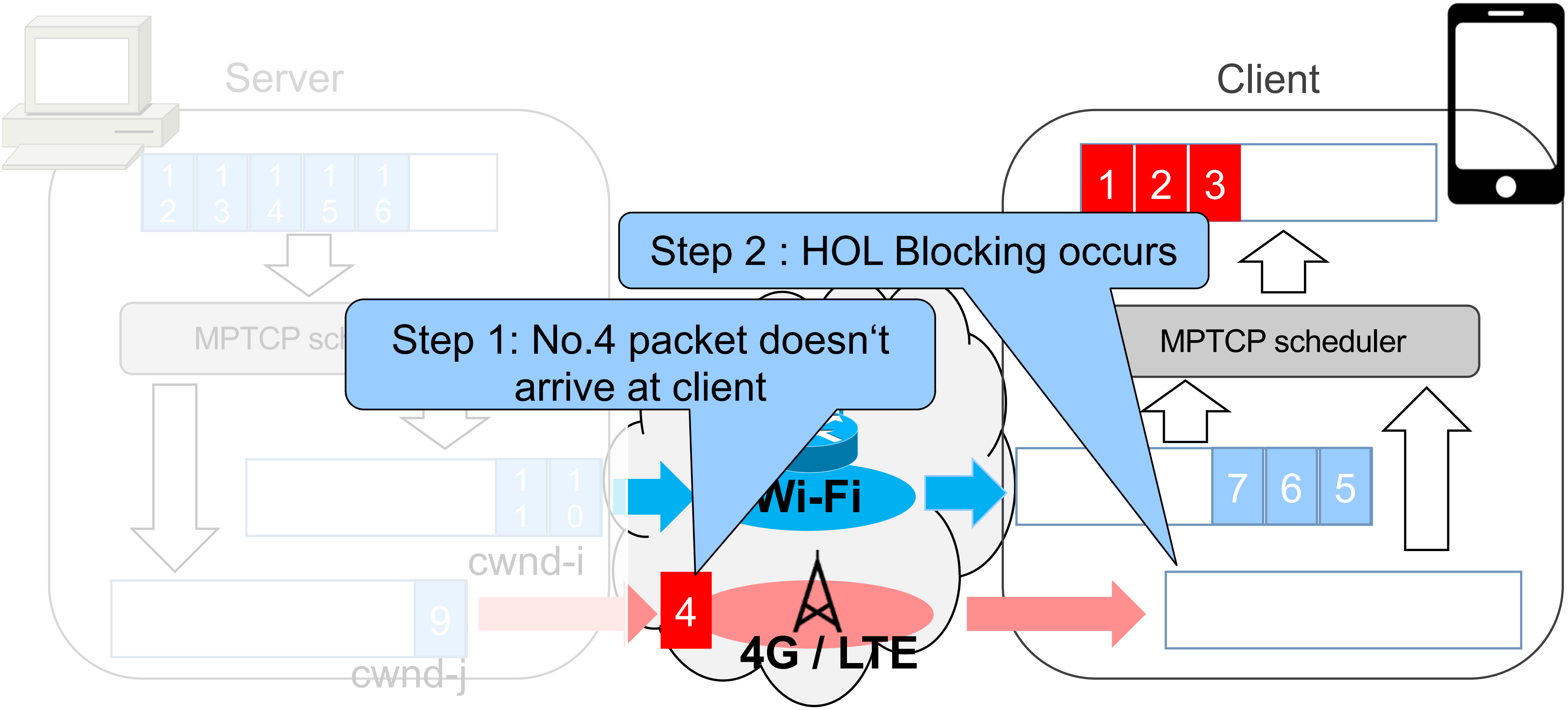
Head of Line Blocking

- 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 discarded at the receiver.



Head of Line Blocking

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



BBR congestion control

- Bottleneck Bandwidth and Round-trip propagation time (BBR)
  - Available on Linux kernel 4.9 or later since Google announced in September 2016.
  - New congestion control without Loss-based algorithm.
  - BBR constantly monitors throughput and RTT, adjusting data transmission rate while understanding the relationship between the amount of transmission data and RTT.

Objective

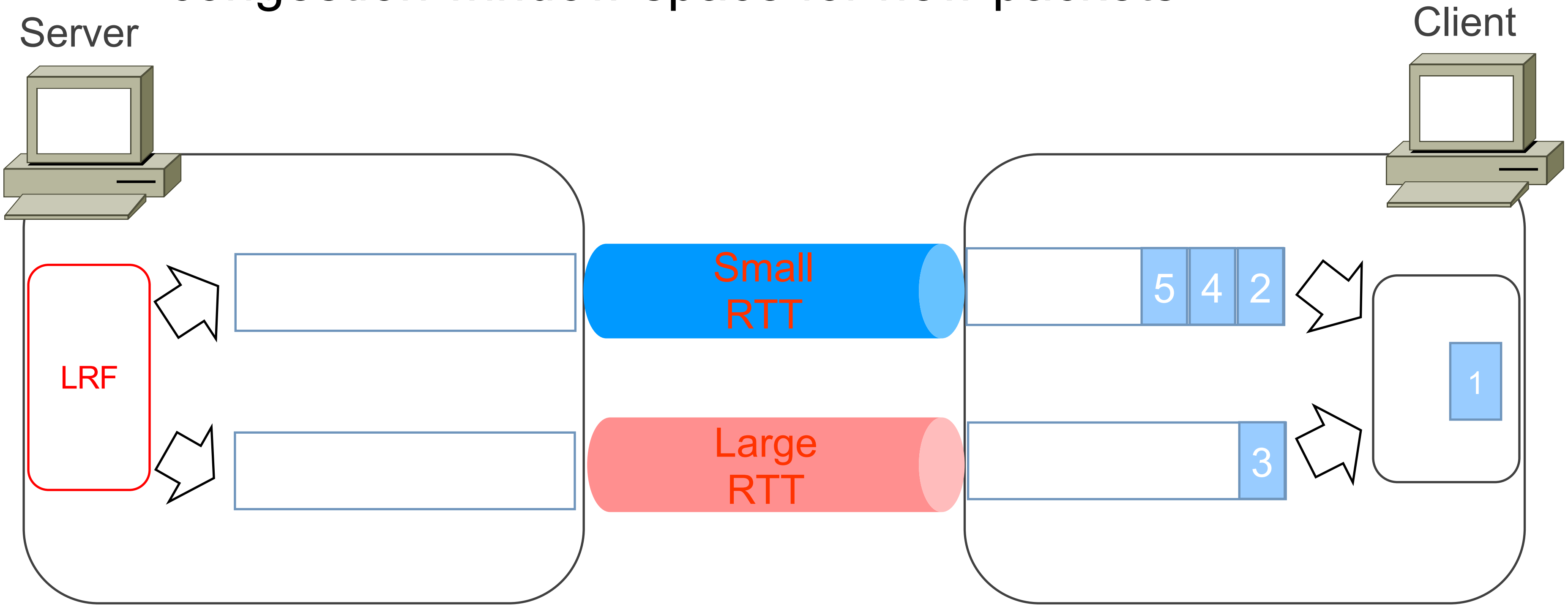
- Important factors in video streaming over MPTCP
  - Determination of a path to forward packets for MPTCP scheduler.
  - Congestion control of each sub-flow.
- We experimented with various combinations of conventional and proposed schedulers and MPTCP congestion control.
- We evaluated MPTCP video streaming with BBR

MPTCP 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)

LRF scheduler

- 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



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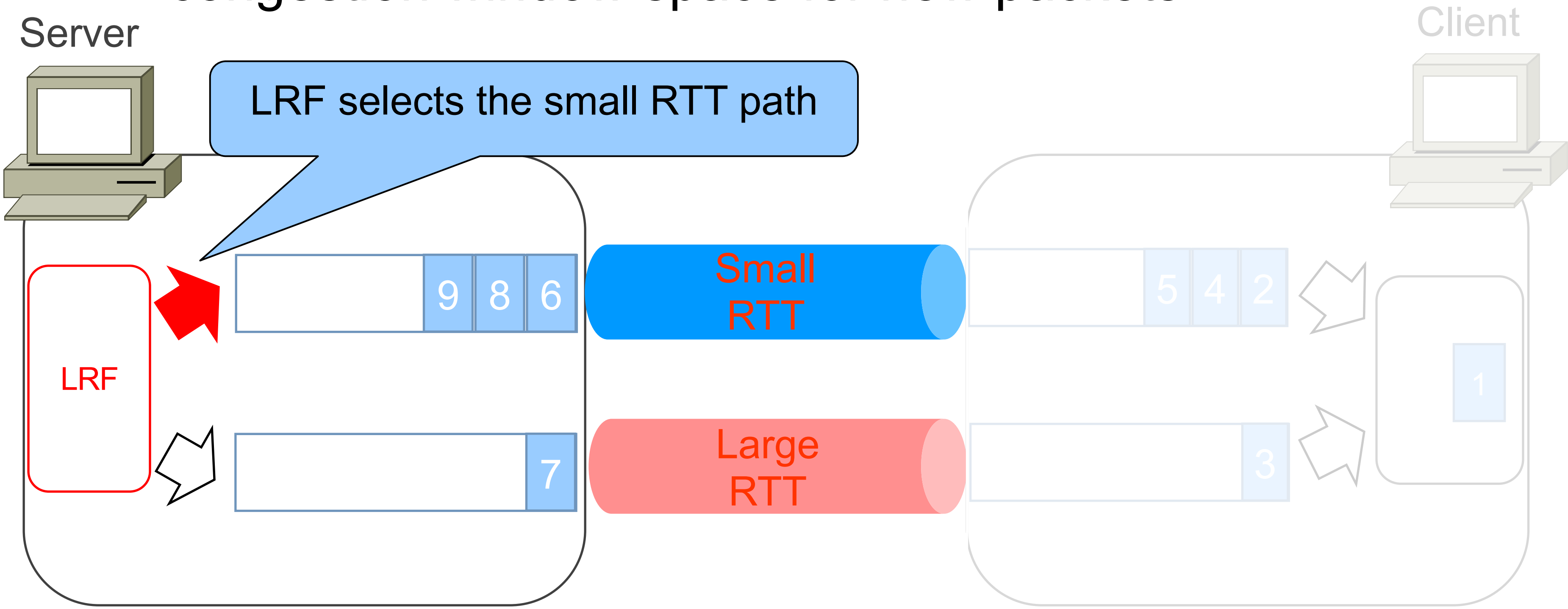
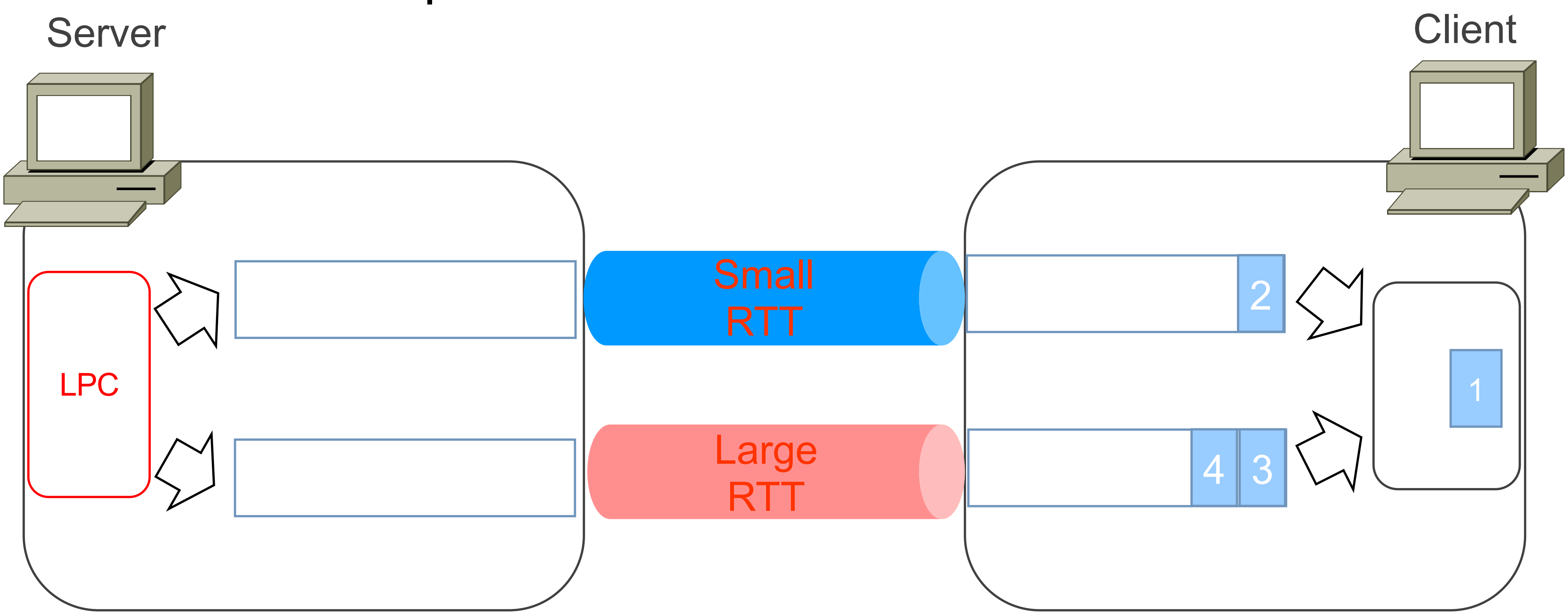


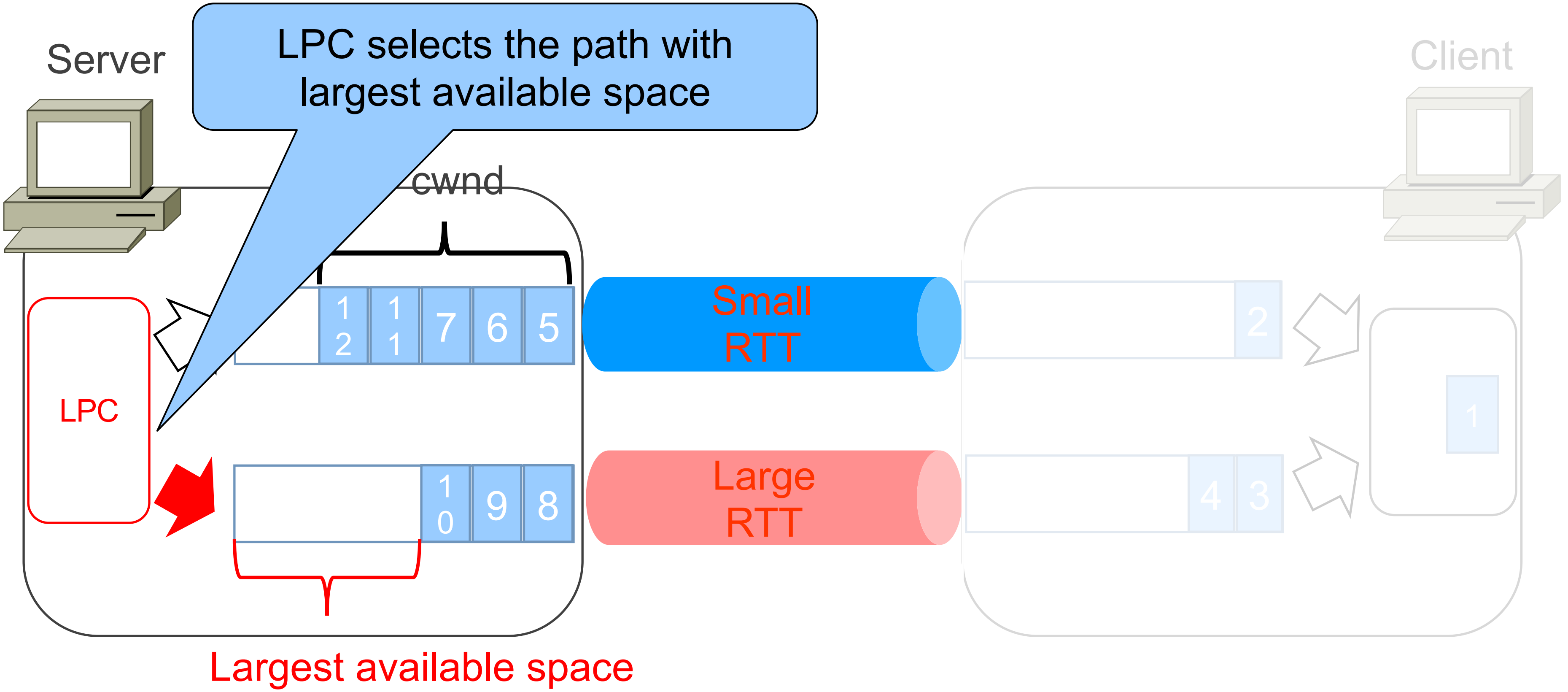
LPC scheduler

- Largest Packet Credits (LPC) scheduler
  - Among the sub-flows with space in their congestion window cwnd, this scheduler selects the one with largest available space



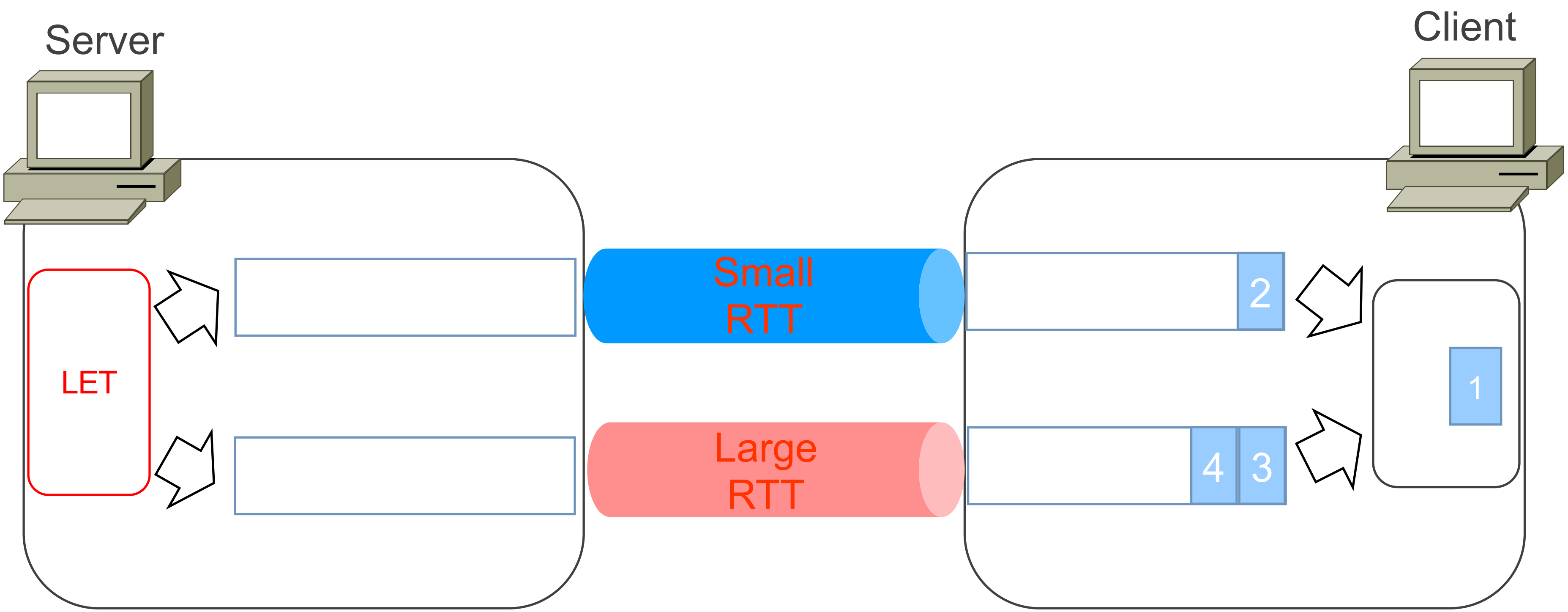
LPC scheduler

- Largest Packet Credits (LPC) scheduler
  - Available space consists of the number of packets allowed by current cwnd size subtracked from the number of packets that have not been acknowledged yet



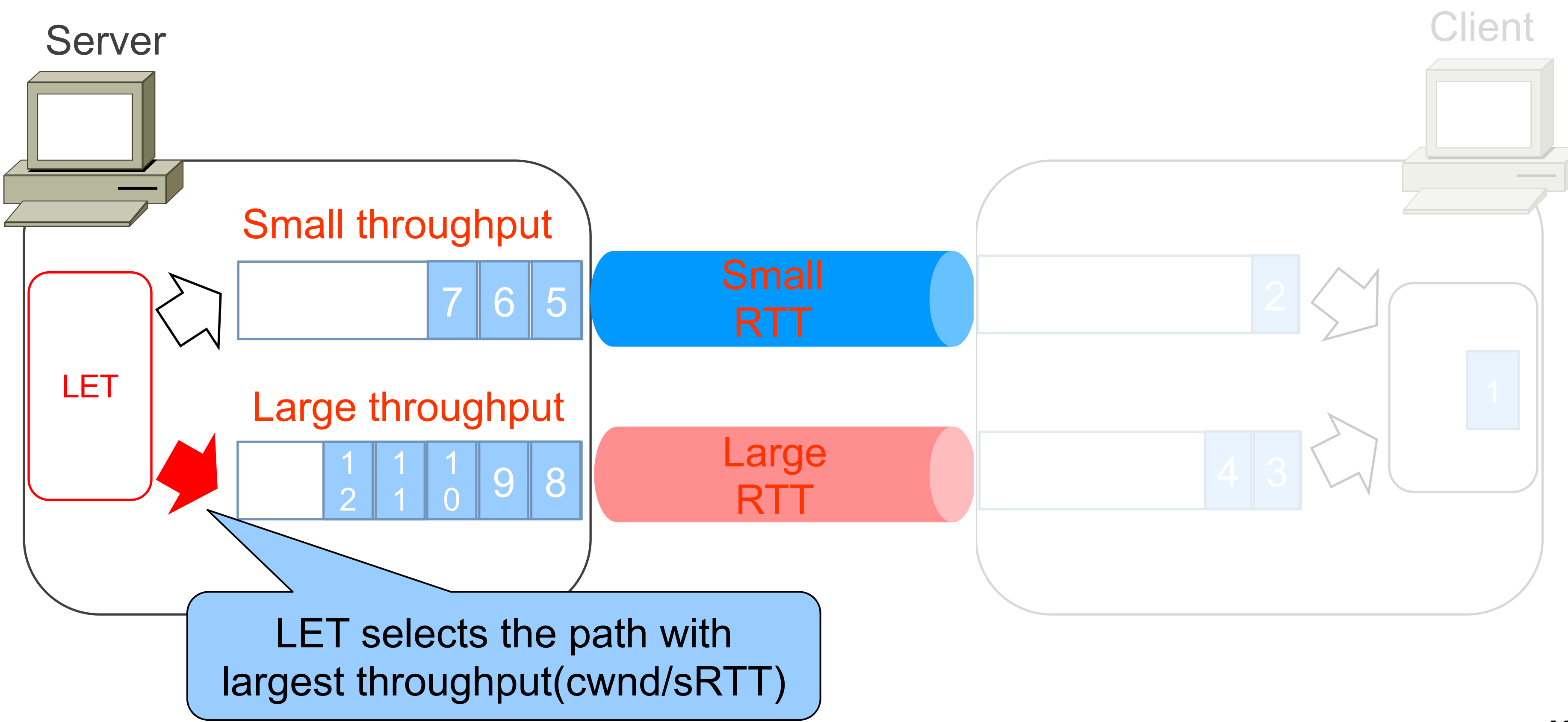
LET scheduler

- Largest Estimated Throughput (LET) scheduler
  - Among the sub-flows with large enough cwnd to accommodate new packets, this scheduler selects the one with largest throughput.



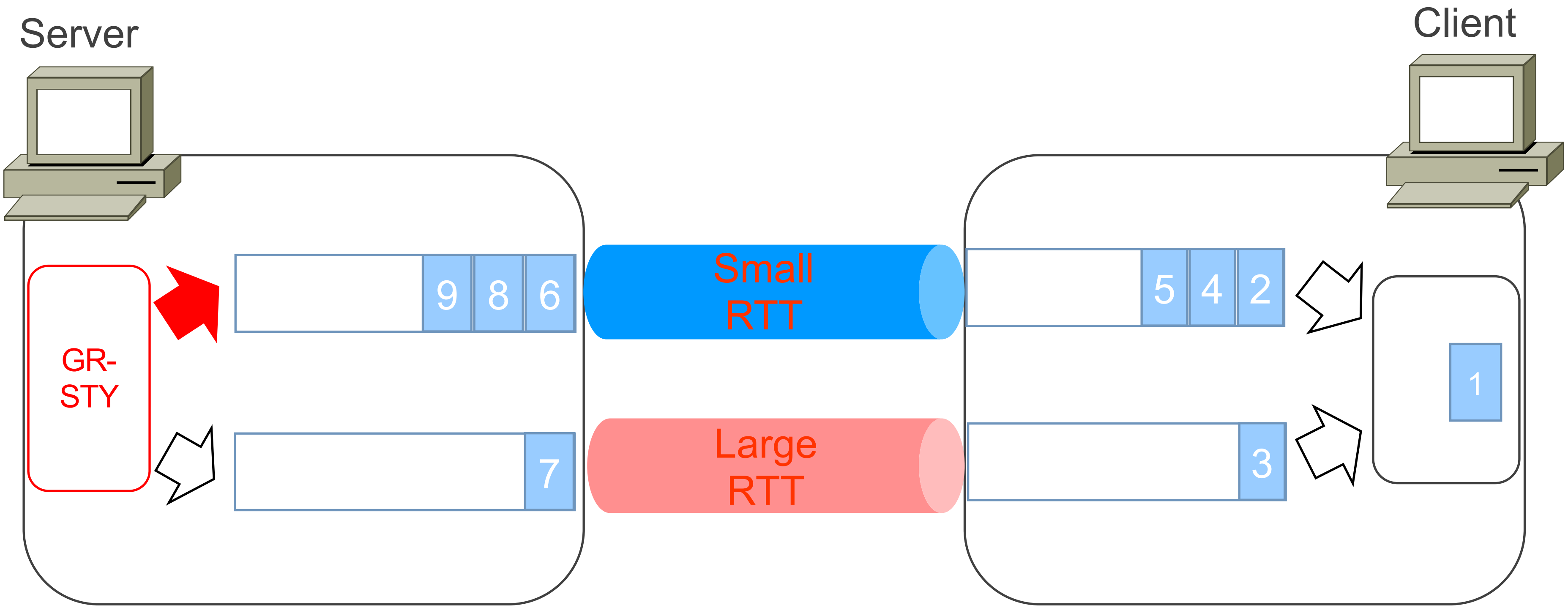
LET scheduler

- Largest Estimated Throughput (LET) scheduler
  - the estimated throughput in each sub-flow as cwnd/sRTT



GR-STY scheduler

- Greedy Sticky (GR-STY) scheduler
  - selects the path with smallest RTT as same as LRF
  - But, once a path is selected, GR-STY stays on a path for as long as there is available window space



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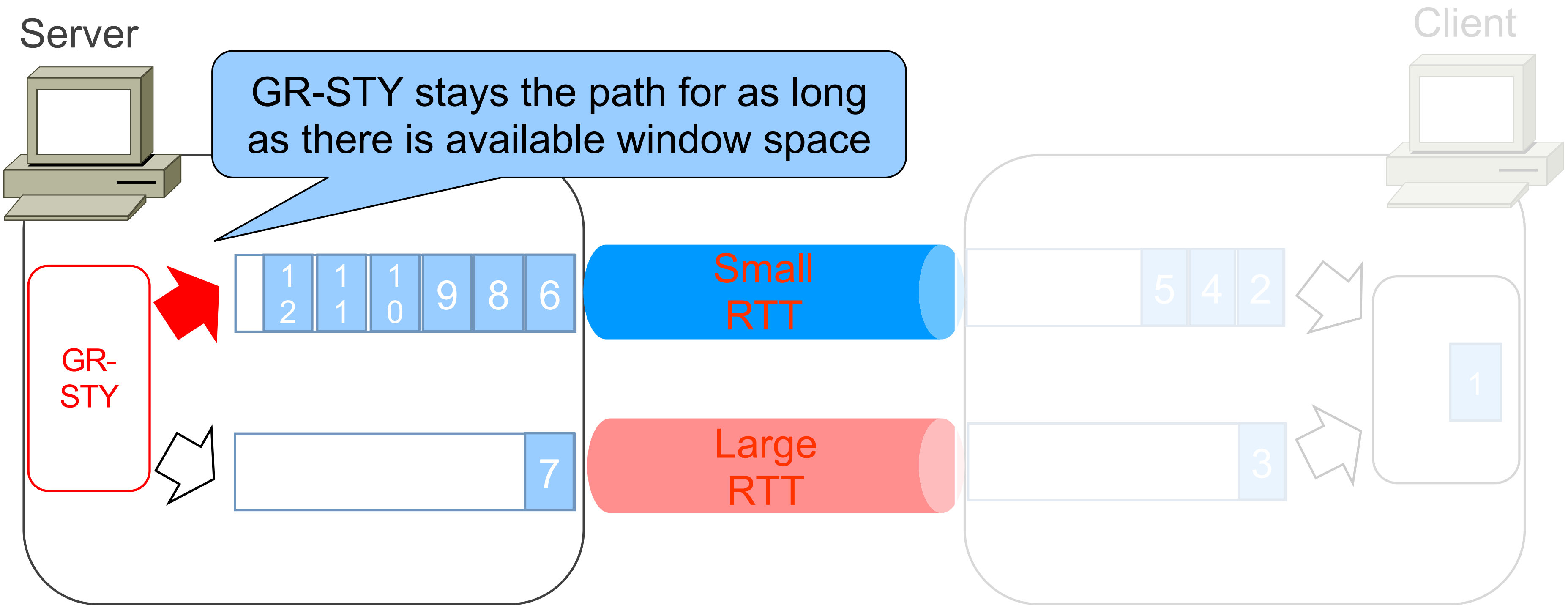
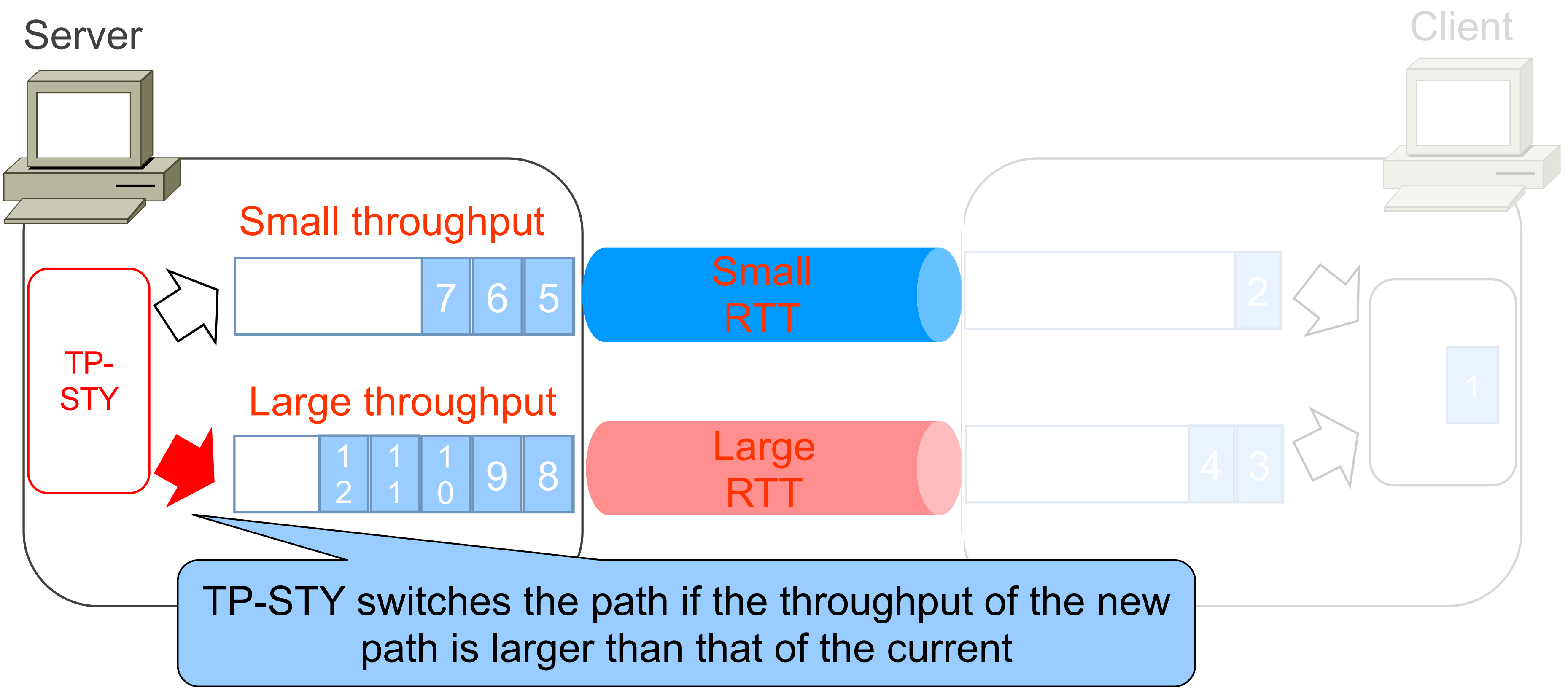


TP-STY scheduler

◆Throughput Sticky (TP-STY) scheduler

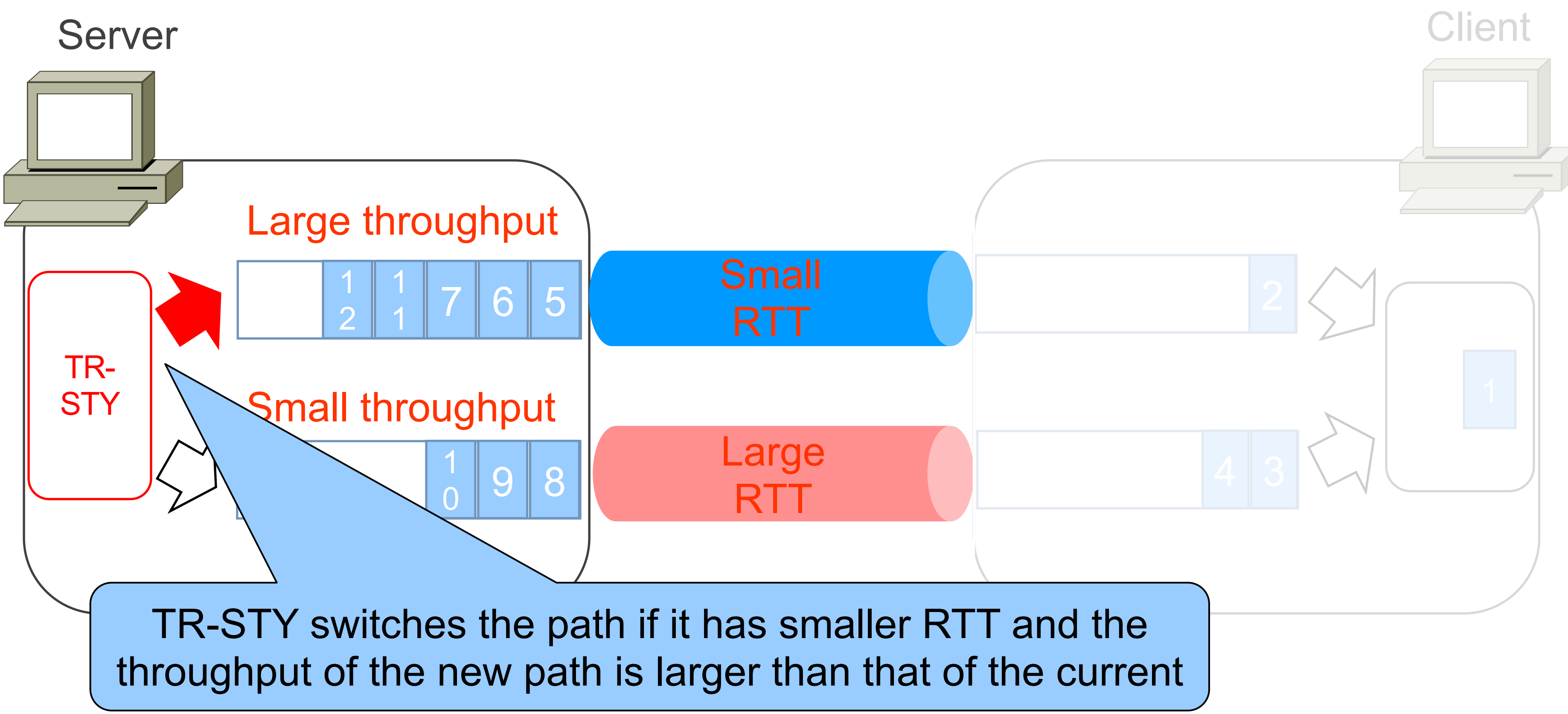
- selects the path with smallest RTT as same as LRF
- A new path is selected only if the throughput of the new path is larger than the throughput of the currently selected path



TR-STY scheduler

Throughput RTT Sticky (TR-STY) scheduler

- selects the path with smallest RTT, similar to LRF
- But, in addition to TP-STY, TR-STY switches paths only if the new path has smaller RTT than the current one



MPTCP Congestion Control

- Uncoupled congestion controls

  determine congestion window size independently for each subflow
  - BBR
    - Use two metrics, RTprop (round-trip propagation time) and BtlBw (bottleneck bandwidth), to adjust congestion window size.
  - Cubic
    - Loss-based algorithm, Linux standard.
    - Use the cubic function to adjust cwnd.
  - Compound
    - Loss-based and delay-based algorithm.
    - Determine the window size by the sum of dwnd and cwnd.
- Coupled congestion controls

  determine the congestion window size by considering the entire connection.
  - Linked Increase Algorithm(LIA)
  - Opportunistic Linked Increase Algorithm(OLIA)
  - Balanced Linked Adaptation Algorithm(BALIA)

Coupled Congestion Control

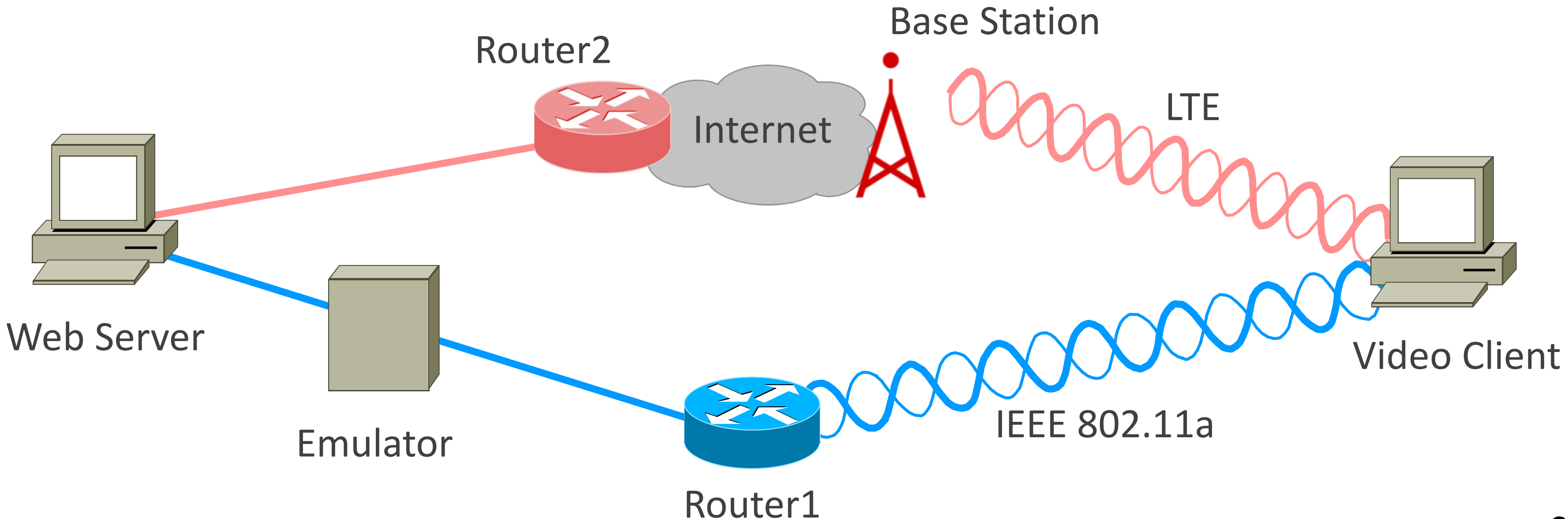
- Linked Increase Algorithm(LIA)
  - Loss-based algorithm with traffic load balancing of multiple paths
  - New Reno is used in each sub-flow, and the congestion window size increase / decrease method (AIMD: Additive increase multiplicative decrease) is adopted.
  - Load balancing is performed by increasing cwnd for paths with low RTT and decreasing cwnd for paths with large RTT.
- Opportunistic Linked Increase Algorithm(OLIA)
  - Loss-based algorithm with TCP friendliness
  - Estimate the number of bytes sent between the last two packet losses and adjust the congestion window size.
- Balanced Linked Adaptation Algorithm(BALIA)
  - Loss-based algorithm with TCP friendliness and responsiveness

Performance Evaluation

- We analyze video performance vis-à-vis TCP variants and path schedulers
- We utilize experiments to evaluate the video performance for various combinations of TCP and schedulers

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
- 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

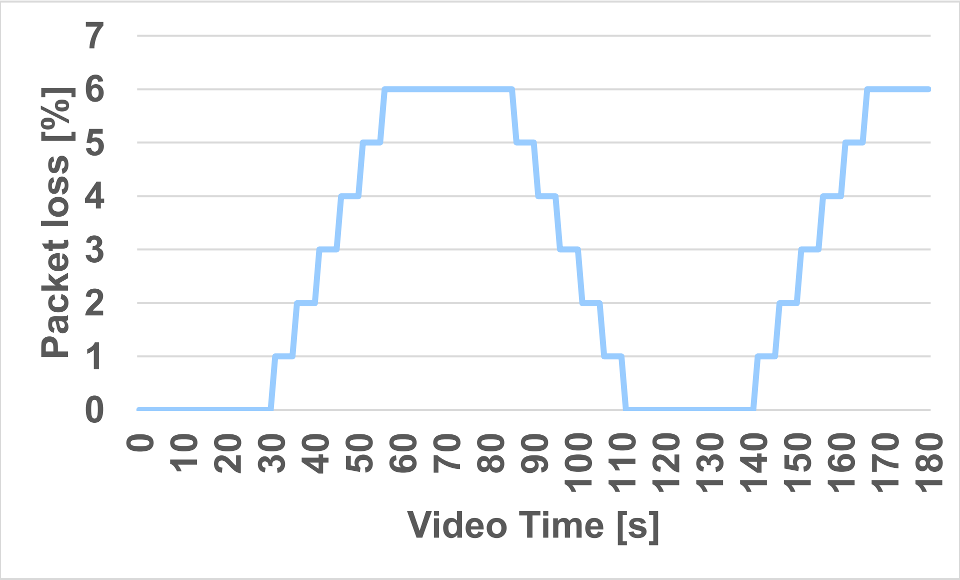
Video size	113 MBytes
Video Rate	5.24 Mb/s
Playout time	3 mins
Encoding	MPEG-4
Video Codec	H264 AVC
Audio Codec	MPEG-4 AAC

Table 2: MPTCP Settings

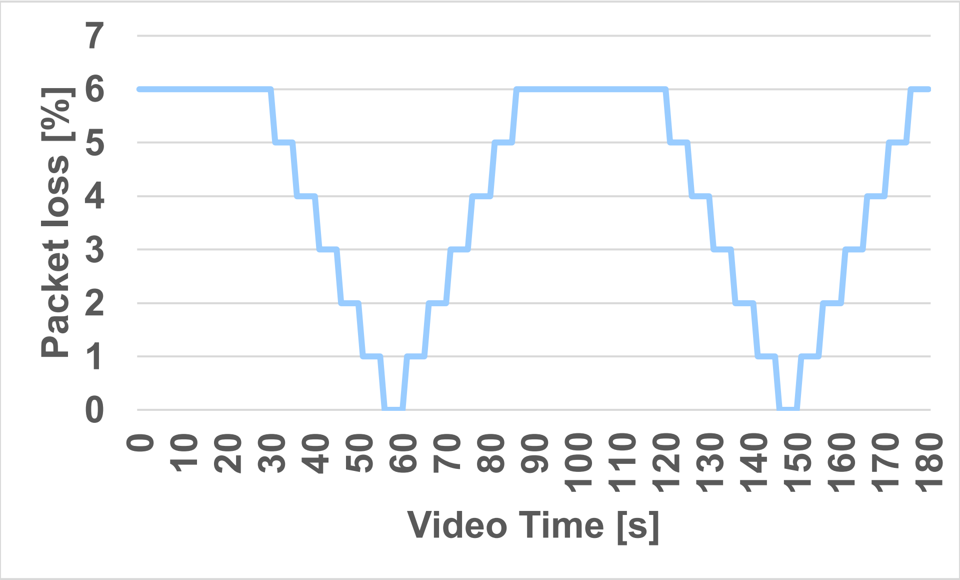
MPTCP Schedulers	LRF(default) LPC, LET GR-STY, TP-STY, TR-STY
MPTCP Variants	• Uncoupled • BBR • Cubic • Compound • Coupled • LIA • OLIA • BALIA

Experimental Scenarios #1

- We use network emulator
  - We set delay and dynamically packet loss for Wi-Fi path only



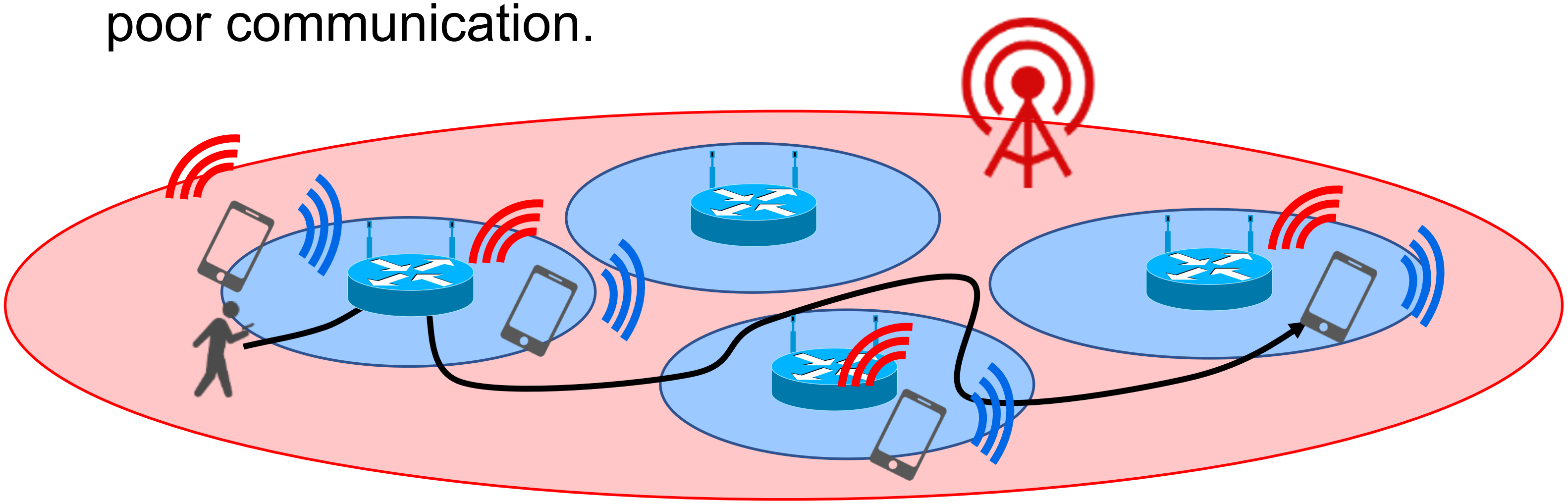
Scenario A



Scenario B

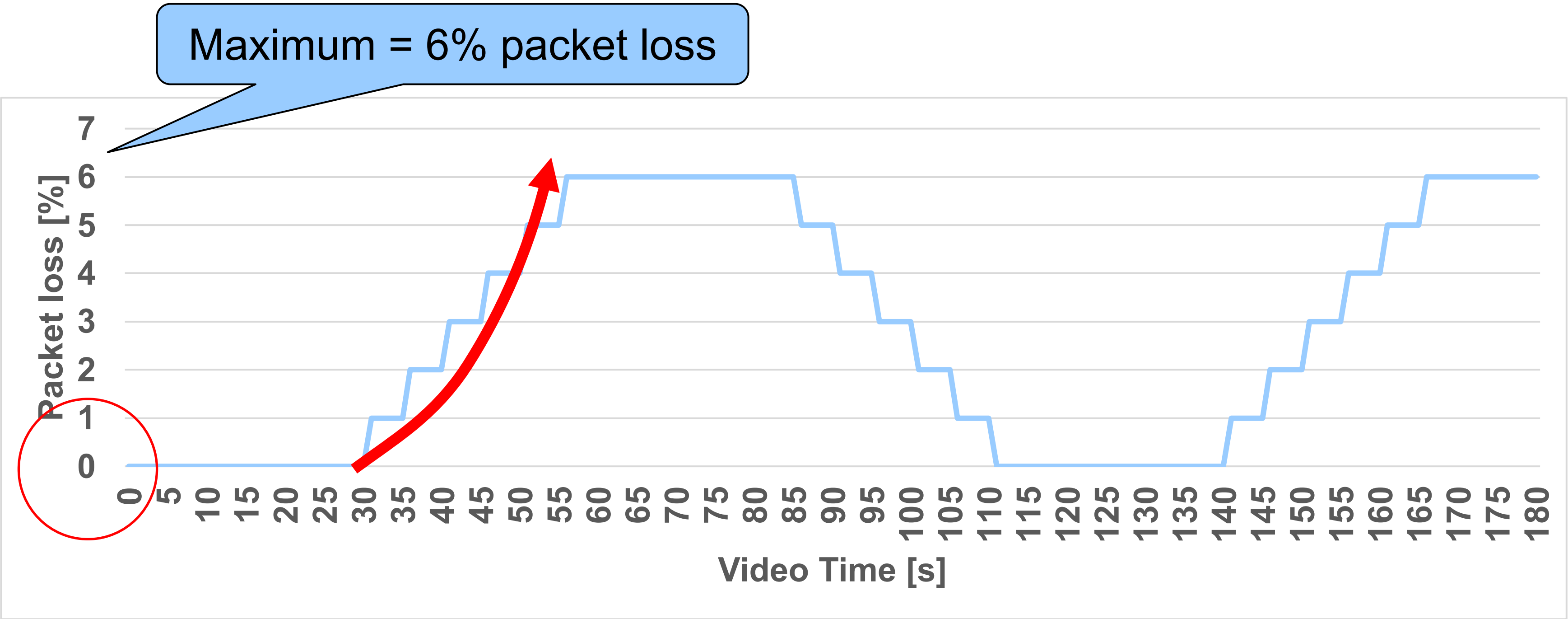
Experimental Scenarios #2

- 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 device moves.
  - Scenario A
    assumes that user device is within Wi-Fi range and has relatively good communication.
  - Scenario B
    assumes that user device is at the end of Wi-Fi range and has a poor communication.



Experimental Scenarios #3

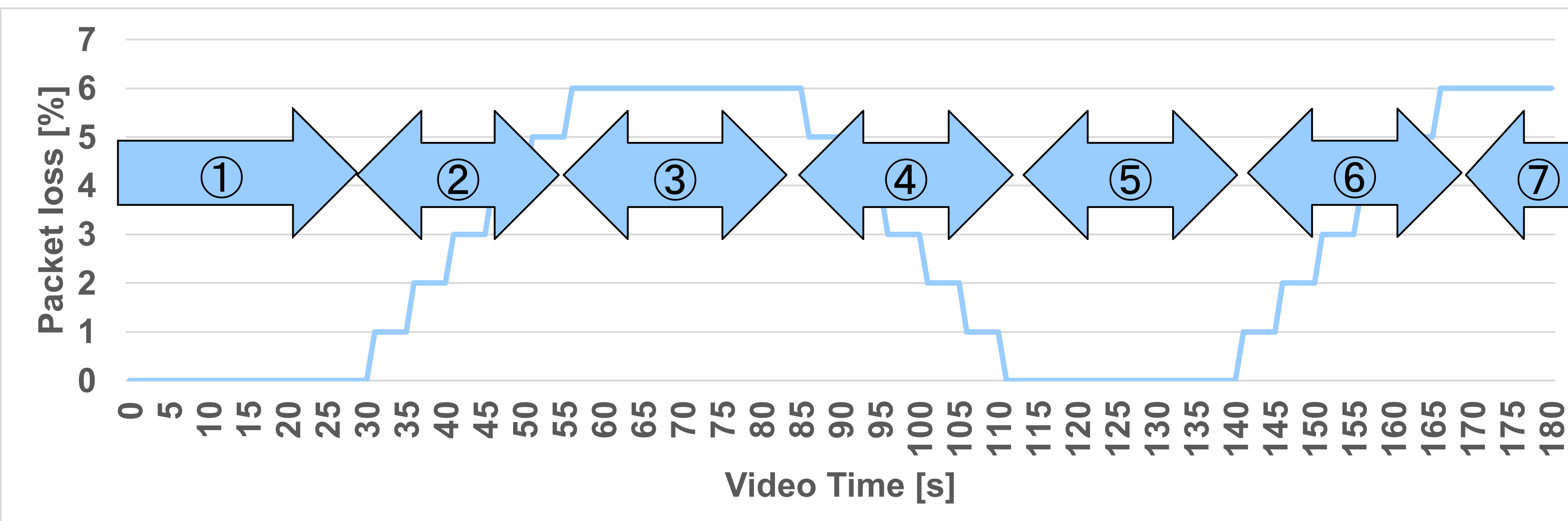
- Scenario A
  - Packets loss ratio starts from **0%.**
  - We set to increase by 1% every 5 seconds for 180 seconds, with a maximum of 6%
  - Packet loss rate rises to 6% twice during video playback.



Scenario A

Experimental Scenarios #3

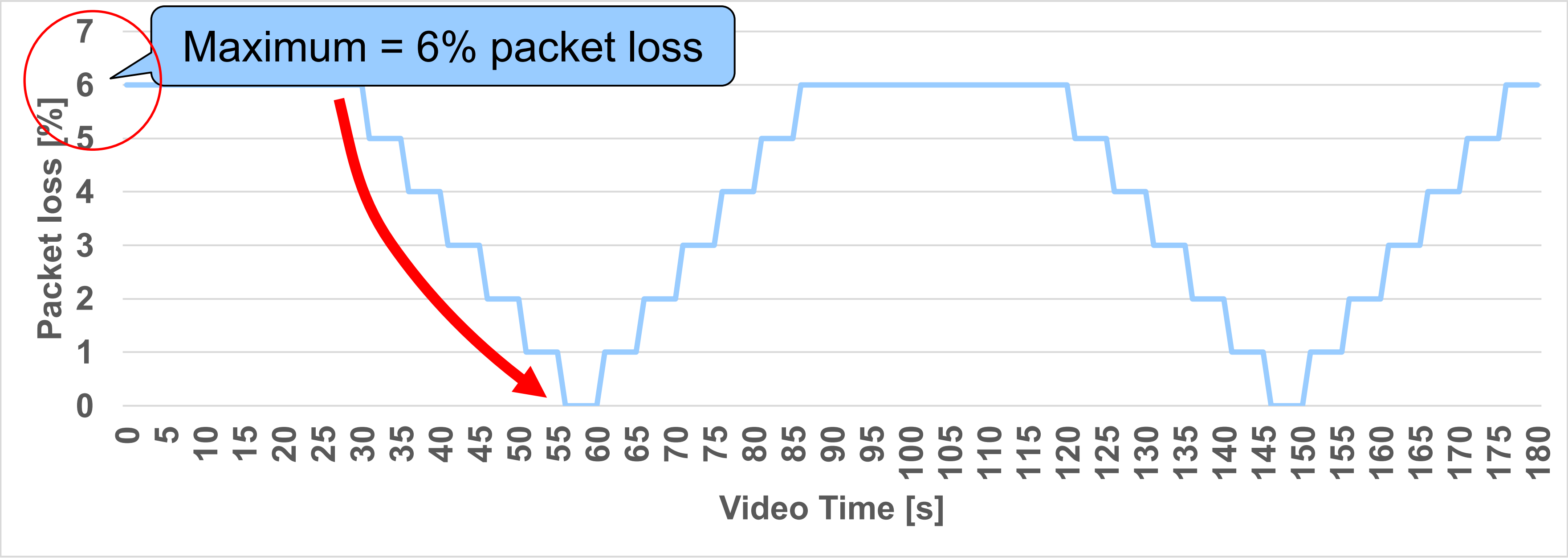
Time	Packet Loss
①0s – 30s	0%
②31s – 55s	1% - 5%
③56s – 85s	6%
④86s – 110s	5% - 1%
⑤111s – 140s	0%
⑥141s – 165s	1% - 5%
⑦165s – 180s	6%



Scenario A

Experimental Scenarios #4

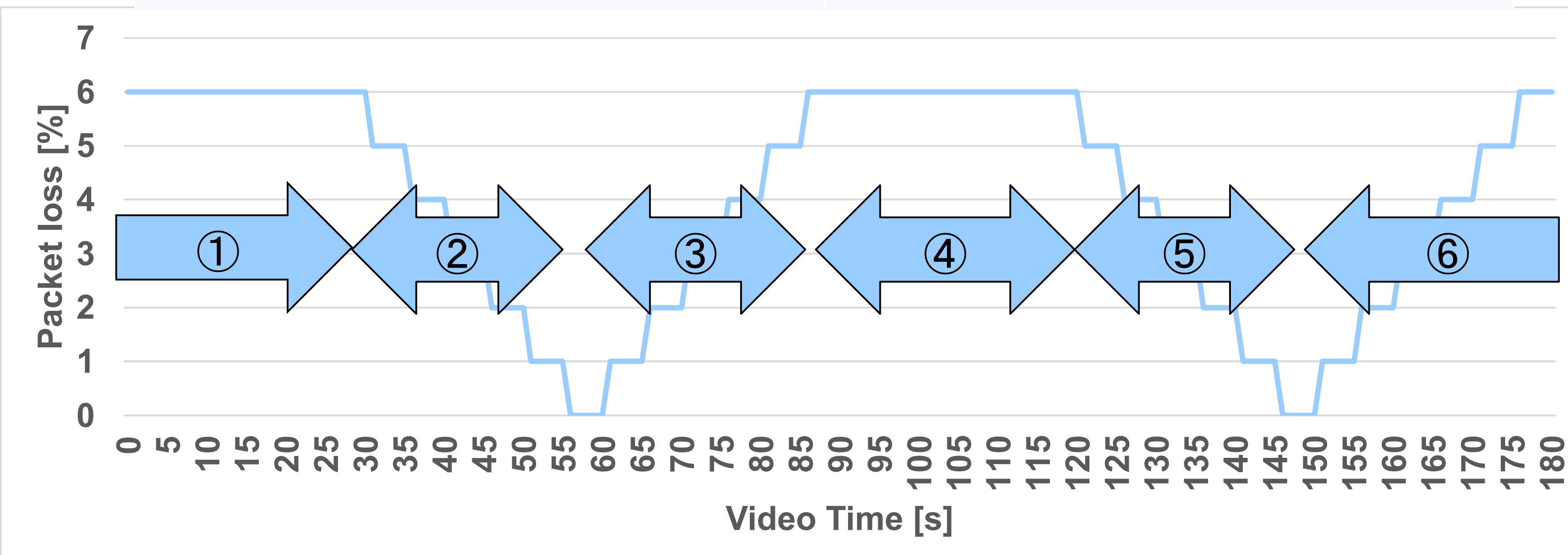
- Scenario B
  - Packets loss ratio starts from **6%**.
  - We set to decrease by 1% every 5 seconds for 180 seconds, with a minimum of 0%
  - Packet loss rate rises to 6% three times during video playback.



Scenario B

Experimental Scenarios #4

Time	Packet Loss
①0s – 30s	6%
②31s – 60s	5% - 0%
③61s – 90s	0% - 5%
④91s – 120s	6%
⑤121s – 150s	5% - 0%
⑥151s – 180s	0% - 5%



Scenario A

Experimental Scenarios #5

- We set up four scenarios in Scenario A and B with modified RTT for the Wi-Fi path only.

scenarios	path	delay	Packet loss pattern	RTT
A1	LTE Wi-Fi	0ms 20ms	Scenario A	RTT 80ms RTT 40ms
A2	LTE Wi-Fi	0ms 30ms	Scenario A	RTT 80ms RTT 60ms
B1	LTE Wi-Fi	0ms 20ms	Scenario B	RTT 80ms RTT 40ms
B2	LTE Wi-Fi	0ms 30ms	Scenario B	RTT 80ms RTT 60ms

Scenarios A1 and A2

- Scenario A1 baseline with scenario A packet loss, where Wi-Fi path of low RTT is predominantly used.
- Scenario A2 is a slightly larger Wi-Fi path delay causes cellular path to be used.

scenarios	path	delay	Packet loss pattern	RTT
A1	LTE Wi-Fi	0ms **20ms**	Scenario A	RTT 80ms **RTT 40ms**
A2	LTE Wi-F	0ms **30ms**	Scenario A	RTT 80ms **RTT 60ms**
B1	[illegible]	[illegible]	…o B	RTT 80ms RTT 40ms
B2	LTE Wi-Fi	0ms 30ms	Scenario B	RTT 80ms RTT 60ms

Scenario A1 with small RTT

Scenarios B1 and B2

- Scenario B1 with scenario B packet loss, where a Wi-Fi link with **low delay faces a heavier loss scenario** representing user situation at which device is at the end of Wi-Fi range.
- Scenario B2 is a Wi-Fi path delay large enough to have cellular path predominantly being used.

scenarios	path	delay	Packet loss pattern	RTT
A1	LTE Wi-Fi	0ms 20ms		ms ms
A2	LTE Wi-Fi	0ms 30ms		ms RTT 60ms
B1	LTE Wi-Fi	0ms **20ms**	Scenario B	RTT 80ms **RTT 40ms**
B2	LTE Wi-Fi	0ms **30ms**	Scenario B	RTT 80ms **RTT 60ms**

Scenario B loss pattern is heavier loss scenario because of starting packet loss 6%.

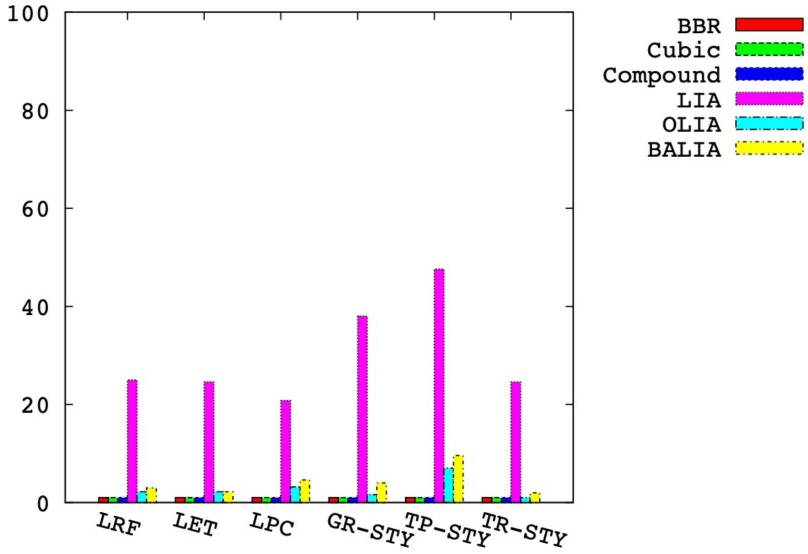
Performance evaluation index

- 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
  - **Total Packets**
    Total number of packets sent during video playback
  - **Retransmit Packets**
    Total number of packets retransmitted during video playback

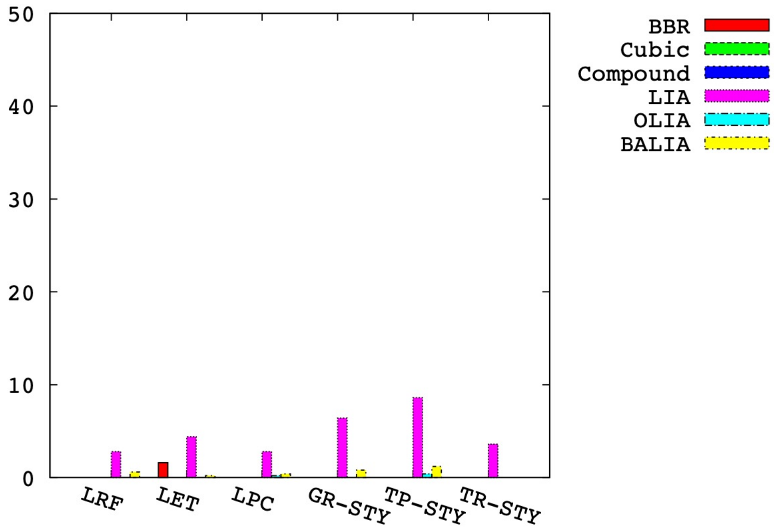
The experiment is conducted **five times** and the average is calculated.

Scenario A1 : video performance

- Path properties
  - packet loss pattern = Scenario A
  - Wi-Fi: RTT= 40ms、LTE: RTT= 80ms
- Figures report on video streaming buffer underflow and picture discard performance
- Except for LIA, the video quality is excellent.



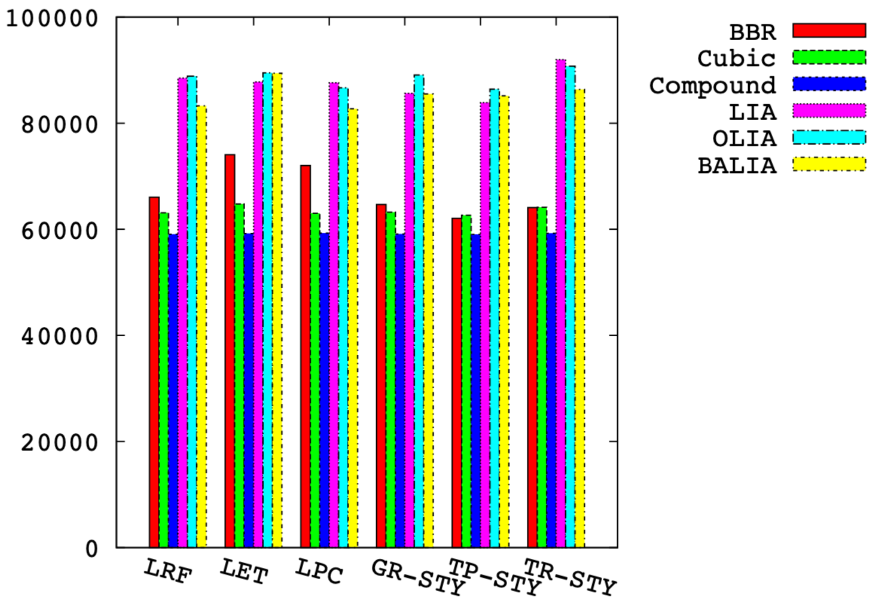
Buffer underflow (times)



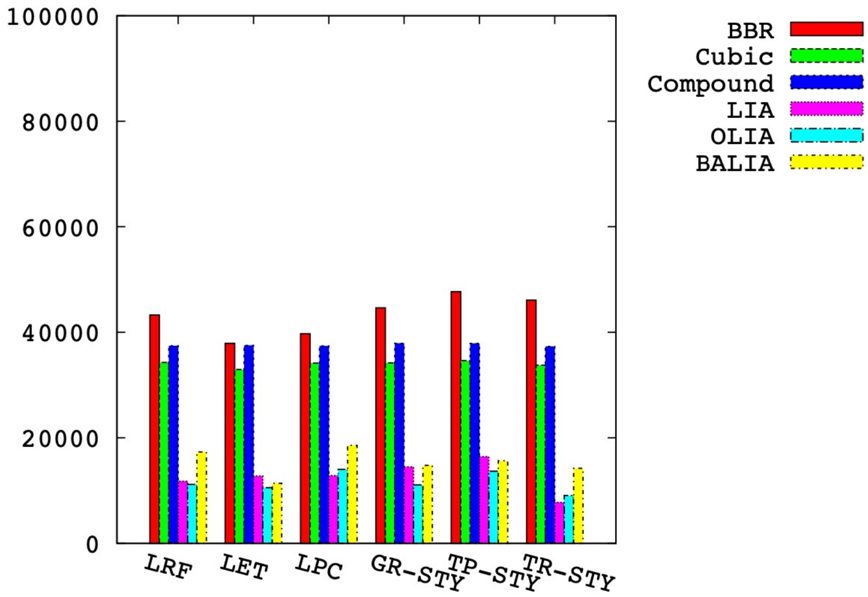
Picture discard (times)

Scenario A1 : Total Packets

- Path properties
  - packet loss pattern = Scenario A
  - Wi-Fi: RTT= 40ms,LTE: RTT= 80ms
- Figures report of LTE and Wi-Fi Total Packets
- We can see that LTE path is most used



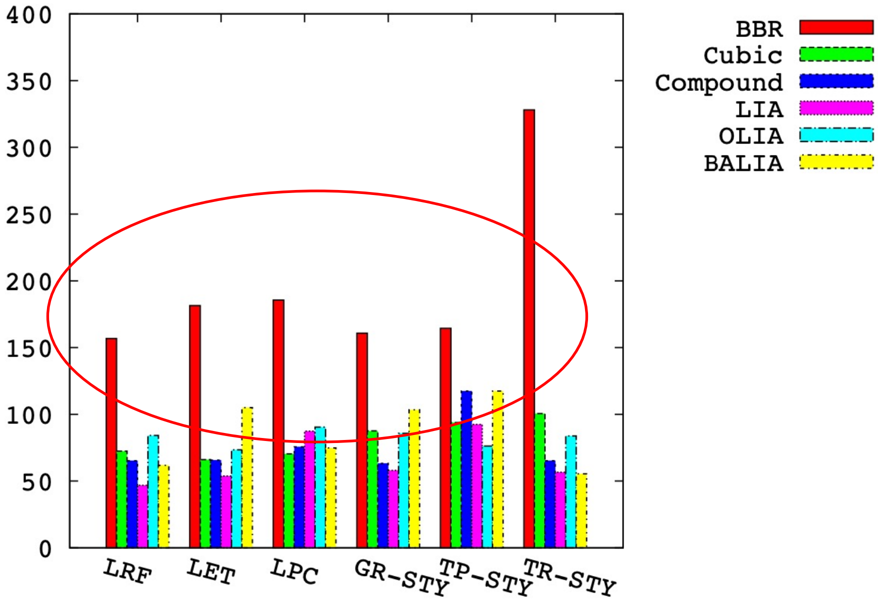
Total packets LTE (number of packets)



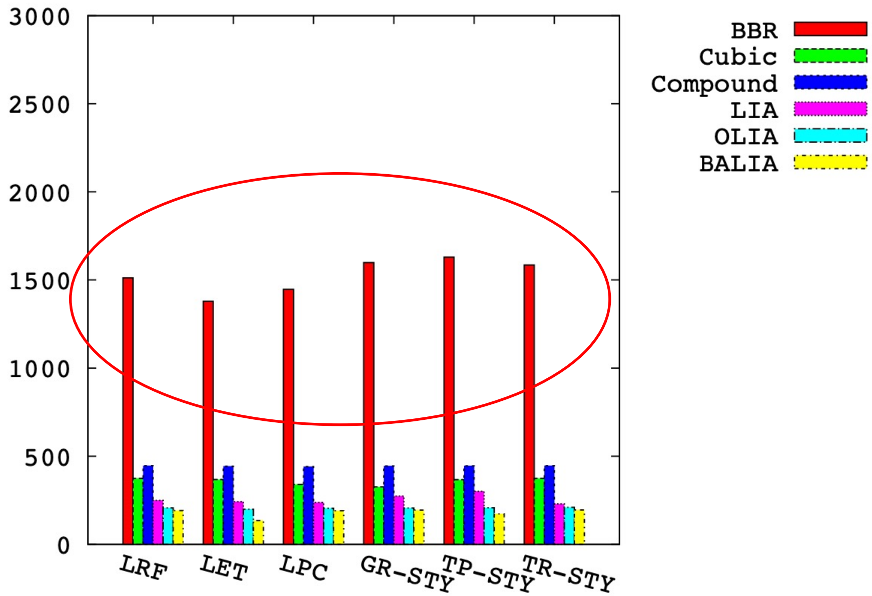
Total packets Wi-Fi (number of packets)

Scenario A1 :Retransmit Packets

- Path properties
  - packet loss pattern = Scenario A
  - Wi-Fi: RTT= 40ms,LTE: RTT= 80ms
- Figures report of LTE and Wi-Fi Retransmit Packets
- We can see that BBR has a high number of retransmissions



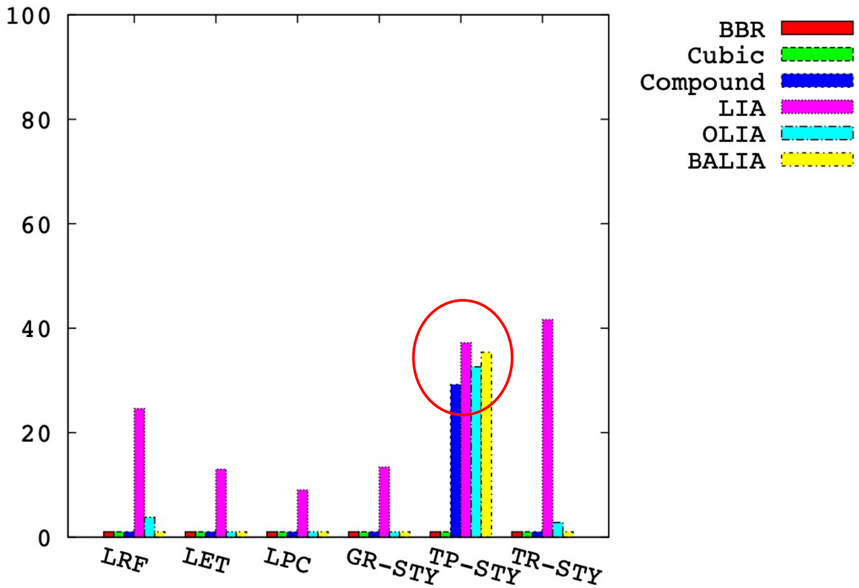
Retransmit packets LTE (number of packets)



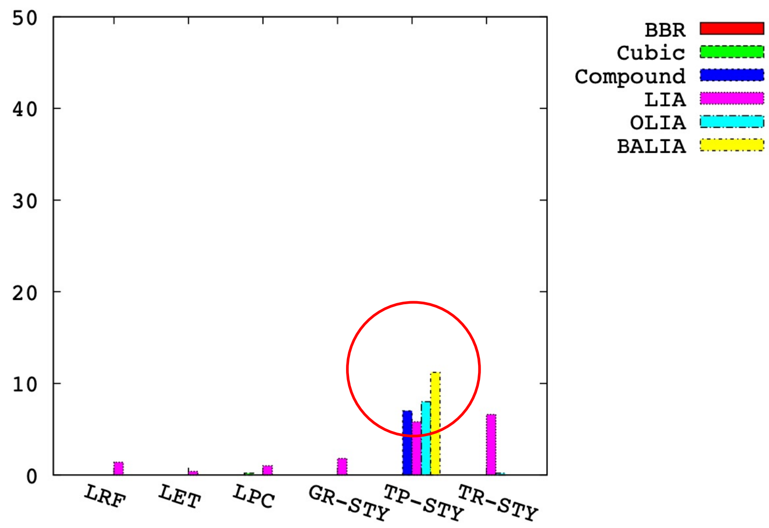
Retransmit packets Wi-Fi (number of packets)

Scenario A2 : video performance

- Path properties
  - packet loss pattern = Scenario A
  - Wi-Fi: RTT= 60ms,LTE: RTT= 80ms
- Compound, OLIA and BALIA have a large buffer underflow and picture discard performance using TP-STY scheduler. LIA variants perform poorly.



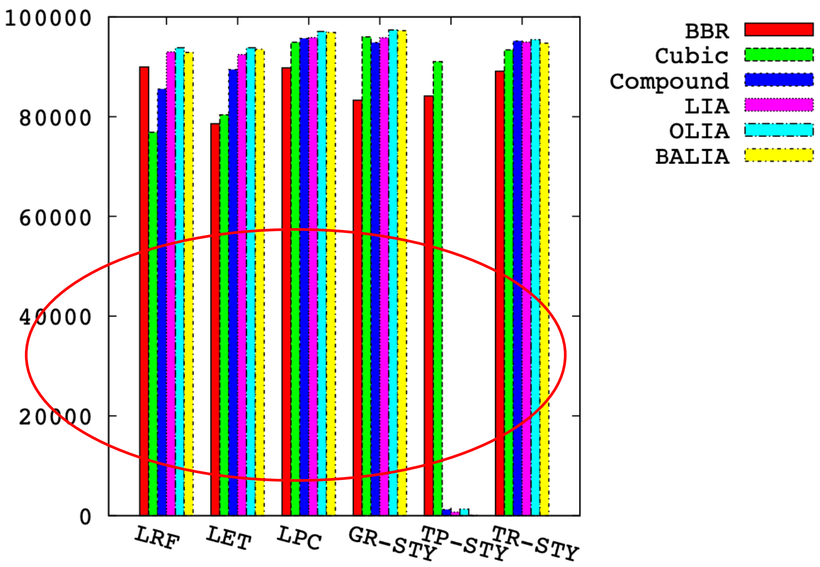
Buffer underflow (times)



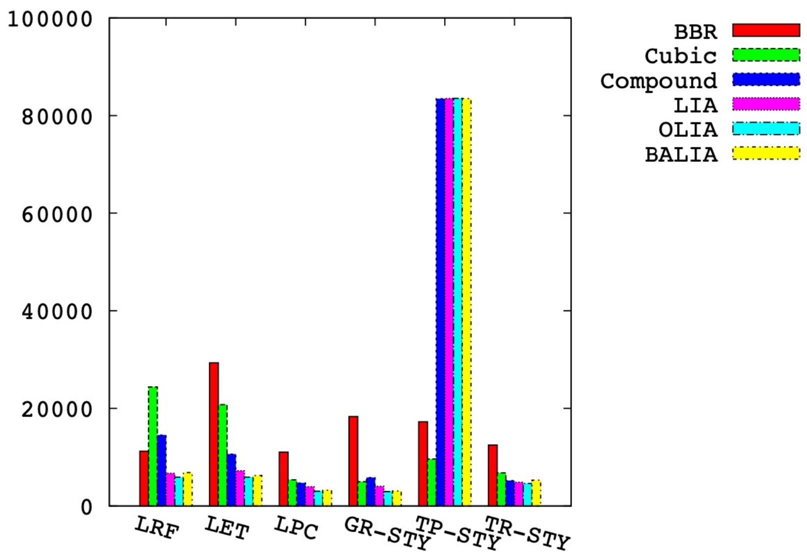
Picture discard (times)

Scenario A2 : Total Packets

- Path properties
  - packet loss pattern = Scenario A
  - Wi-Fi: RTT= 60ms,LTE: RTT= 80ms
- We can see that TCP variants of poor video performance under TP-STY prefers Wi-Fi path to LTE path, even under large Wi-Fi path delay and packet loss



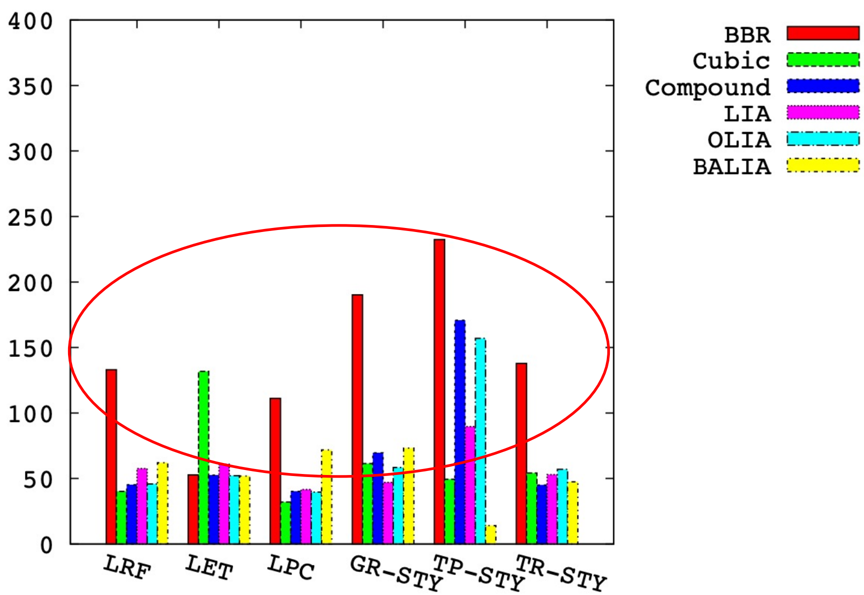
Total packets LTE (number of packets)



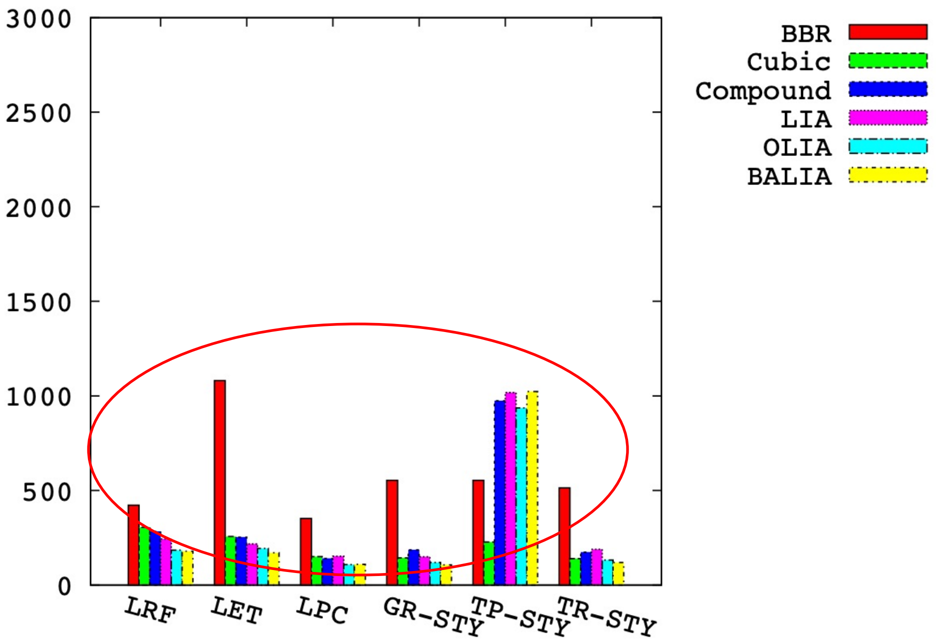
Total packets Wi-Fi (number of packets)

Scenario A2 :Retransmit Packets

- Path properties
  - packet loss pattern = Scenario A
  - Wi-Fi: RTT= 60ms,LTE: RTT= 80ms
- We can see larger retransmissions for BBR than other variants across schedulers except TP- STY on Wi-Fi path.



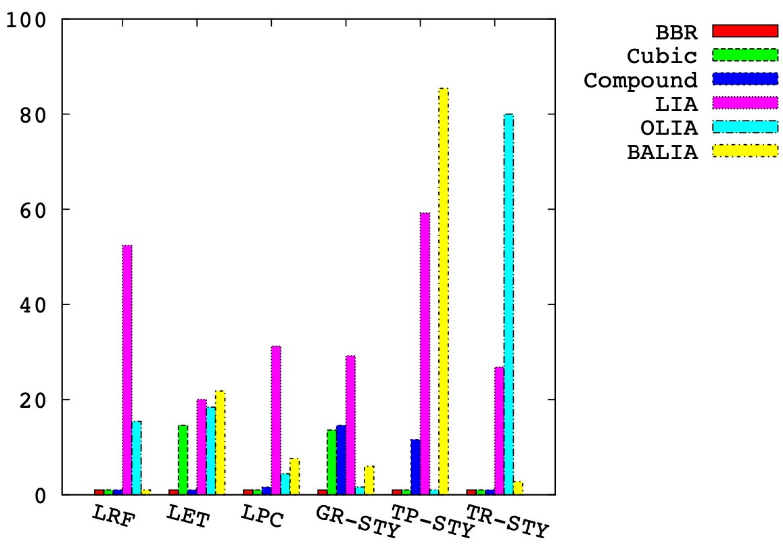
Retransmit packets LTE
(number of packets)



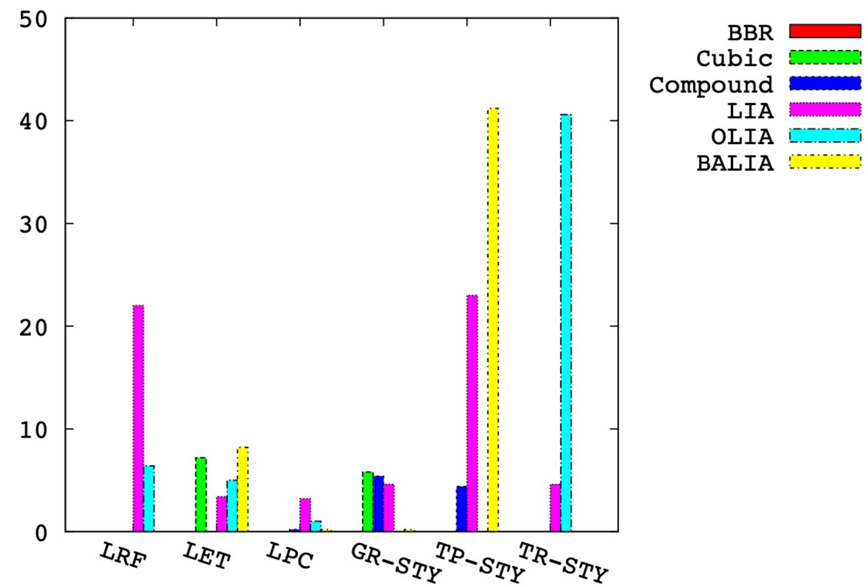
Retransmit packets Wi-Fi
(number of packets)

Scenario B1 : video performance

- Path properties
  - packet loss pattern = Scenario B
  - Wi-Fi: RTT= 40ms,LTE: RTT= 80ms
- We notice a wide variety of performances vis a vis path scheduler/TCP variant combinations. Impressive is the consistent good performance of BBR TCP variant, even across all schedulers.



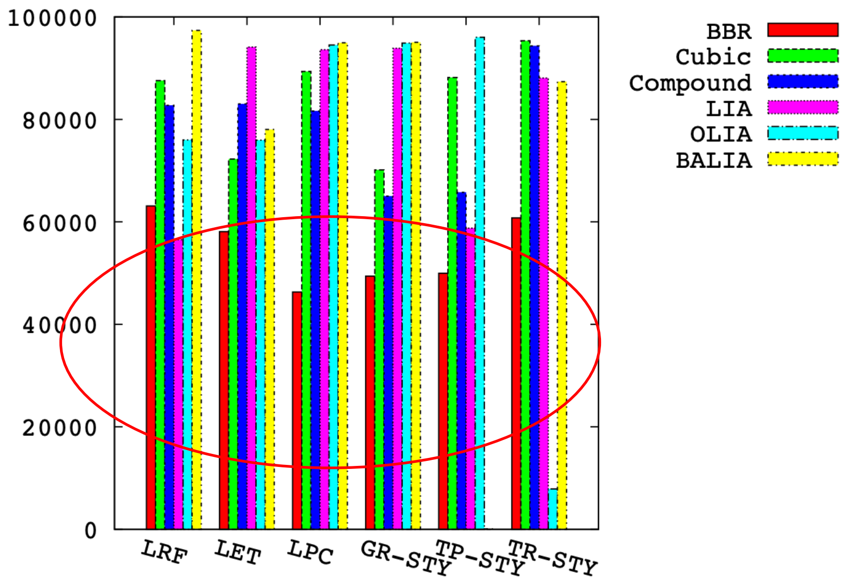
Buffer underflow (times)



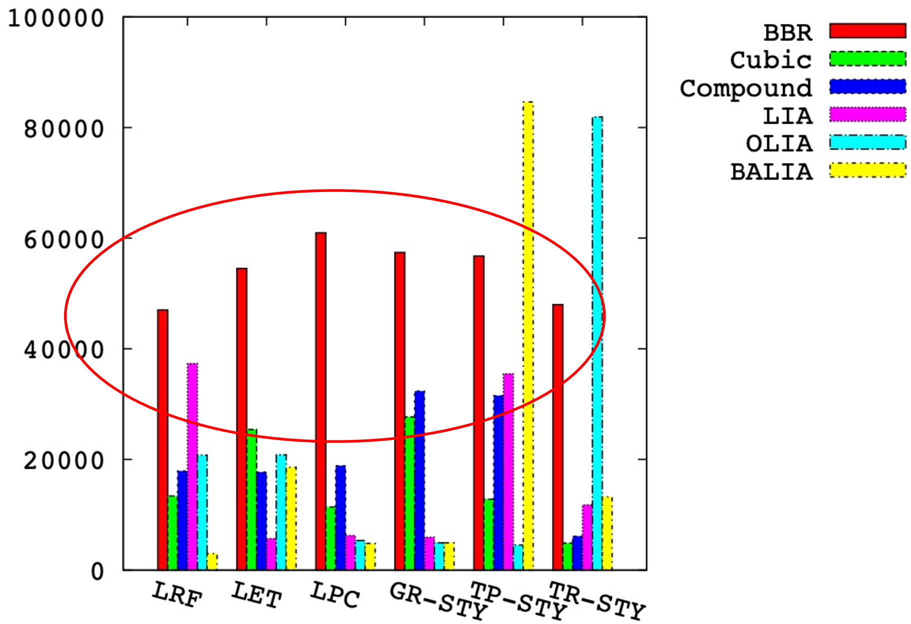
Picture discard (times)

Scenario B1 : Total Packets

- Path properties
  - packet loss pattern = Scenario B
  - Wi-Fi: RTT= 40ms,LTE: RTT= 80ms
- We can see that BBR maintains a better Wi-Fi utilization, striking a balance between LTE and cellular paths across all packet schedulers.



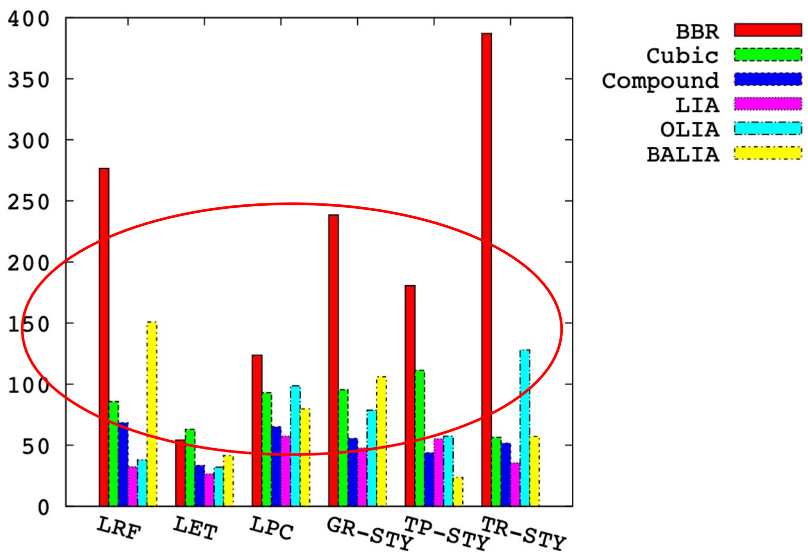
Total packets LTE (number of packets)



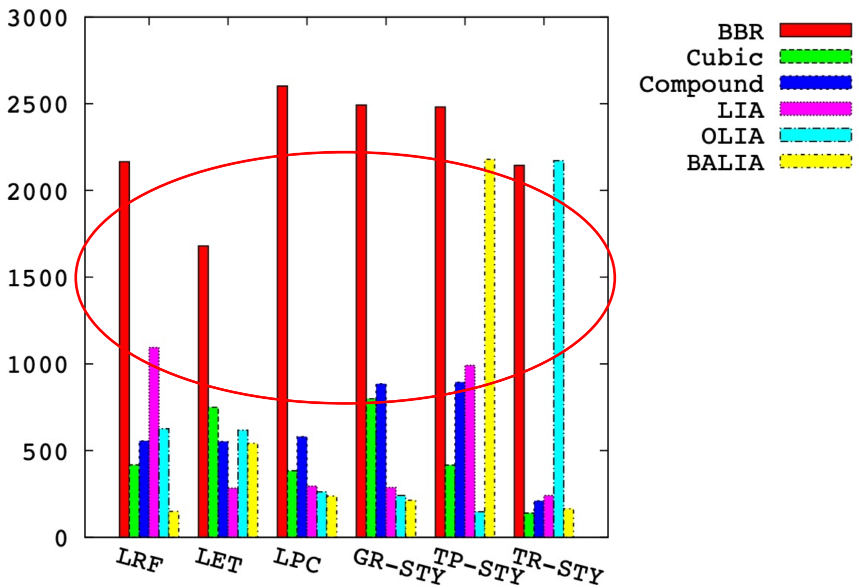
Total packets Wi-Fi (number of packets)

Scenario B1 :Retransmit Packets

- Path properties
  - packet loss pattern = Scenario B
  - Wi-Fi: RTT= 40ms,LTE: RTT= 80ms
- BBR with a significantly larger number of retransmissions across all schedulers than other TCP variants.



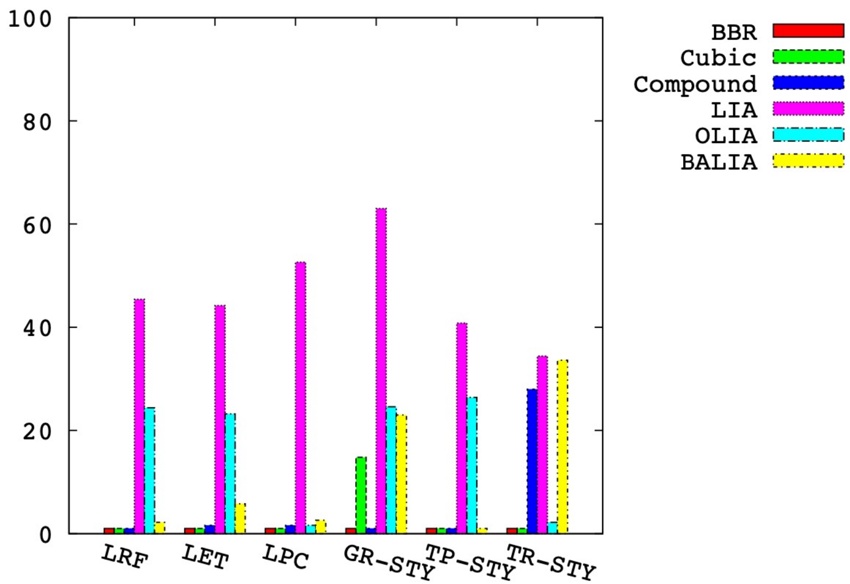
Retransmit packets LTE
(number of packets)



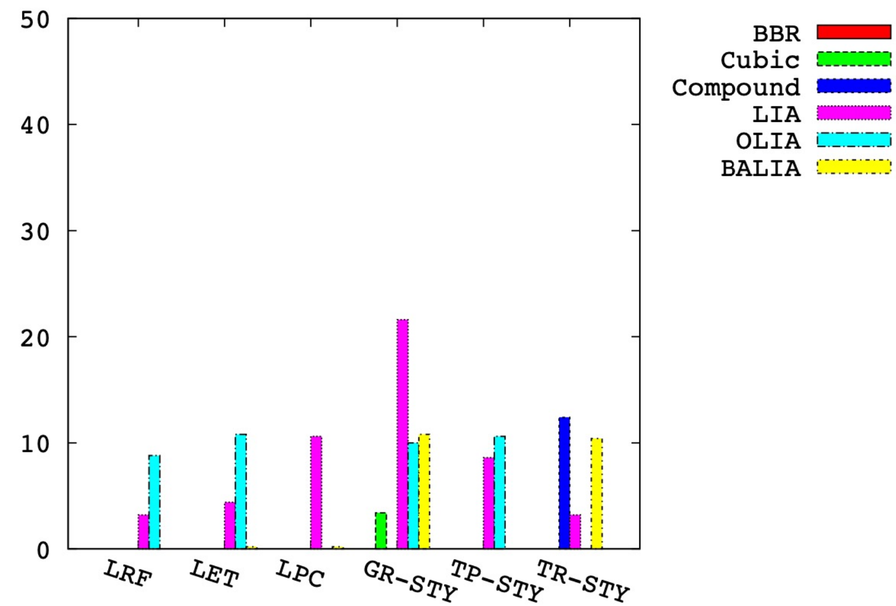
Retransmit packets Wi-Fi
(number of packets)

Scenario B2 : video performance

- Path properties
  - packet loss pattern = Scenario B
  - Wi-Fi: RTT= 40ms,LTE: RTT= 80ms
- Only TCP variants able to deliver good performance across all schedulers is BBR and Cubic.
- LIA variants all deliver large buffer underflow due to their lack of aggressiveness.



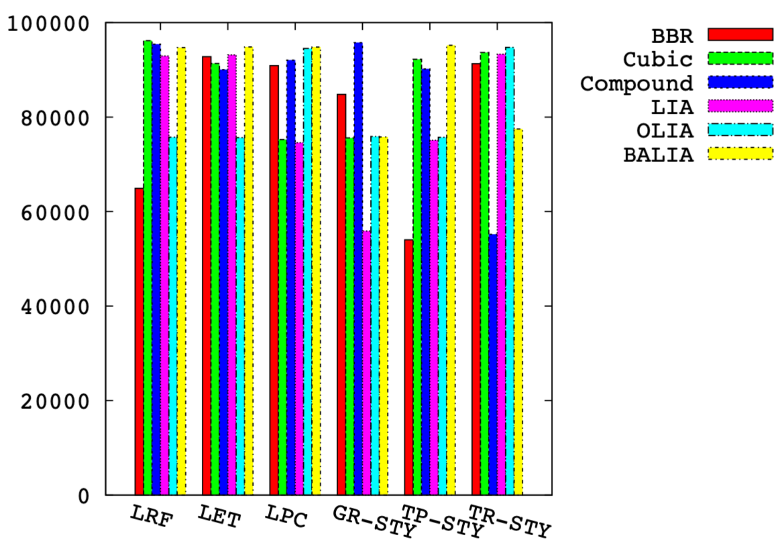
Buffer underflow (times)



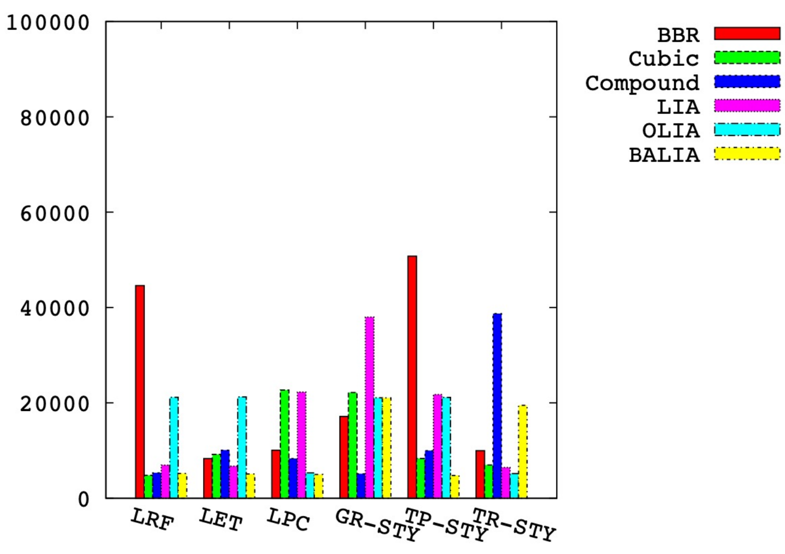
Picture discard (times)

Scenario B2 : Total Packets

- Path properties
  - packet loss pattern = Scenario B
  - Wi-Fi: RTT= 40ms,LTE: RTT= 80ms
- Large LTE path utilization, due to Wi-Fi large delay and heavy packet losses across all TCP variants.



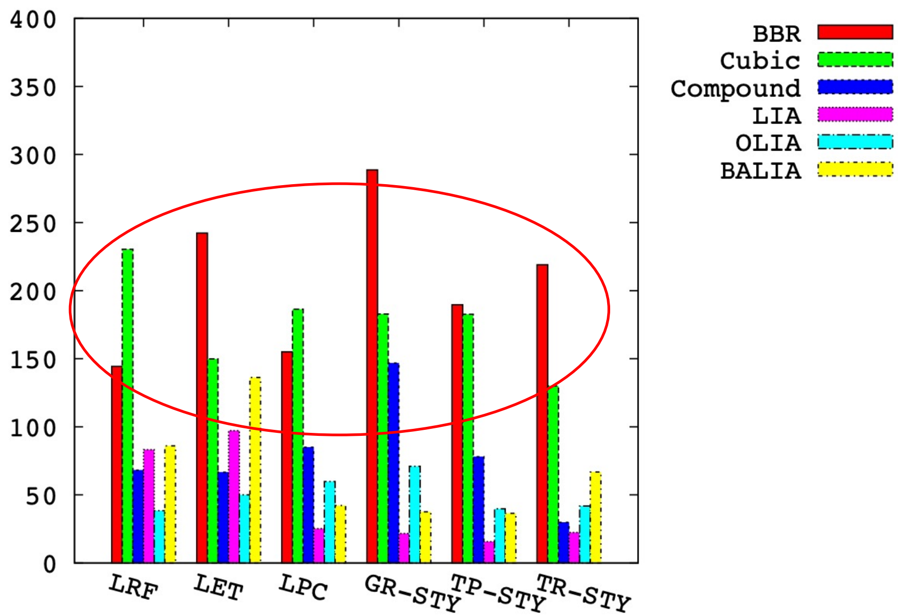
Total packets LTE (number of packets)



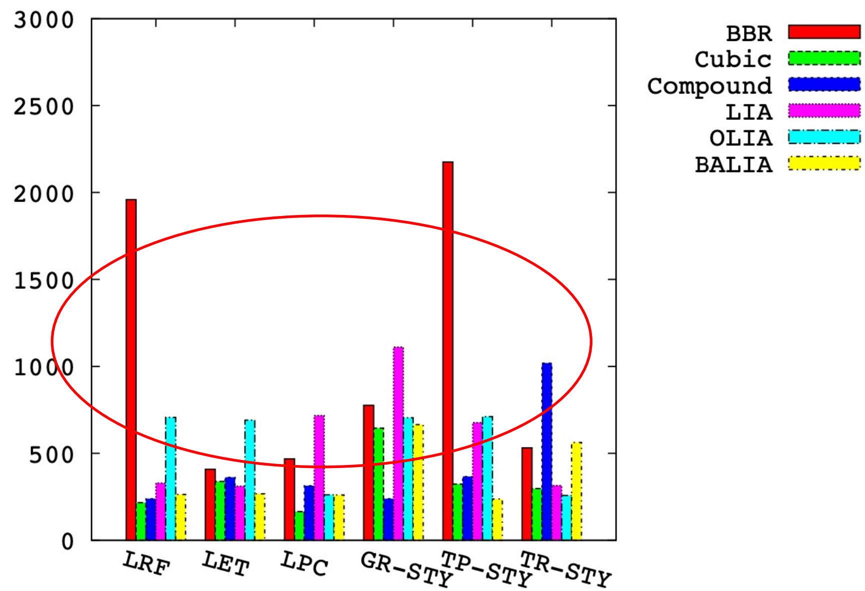
Total packets Wi-Fi (number of packets)

Scenario B2 :Retransmit Packets

- Path properties
  - packet loss pattern = Scenario B
  - Wi-Fi: RTT= 40ms,LTE: RTT= 80ms
- As in scenario B2, BBR retransmits more than the other congestion control variants.



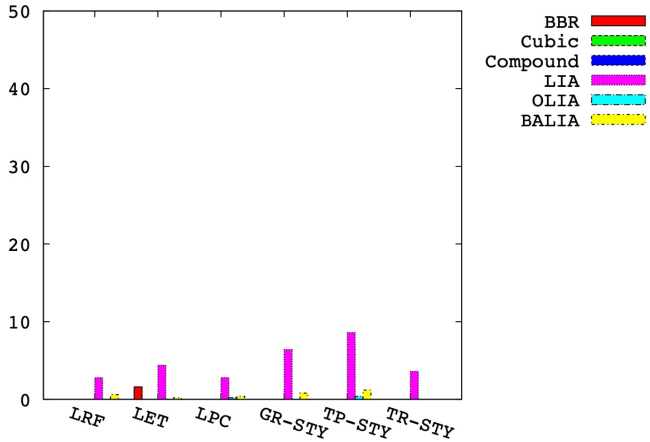
Retransmit packets LTE
(number of packets)



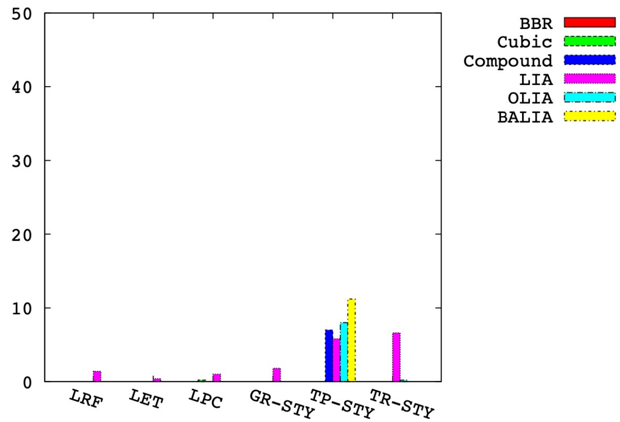
Retransmit packets Wi-Fi
(number of packets)

Results : evaluation

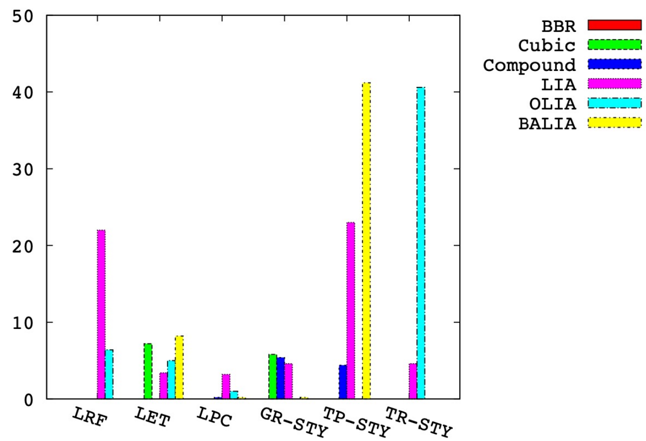
- Picture discard for BBR in all scenario
  - All schedulers with BBR result in good performance



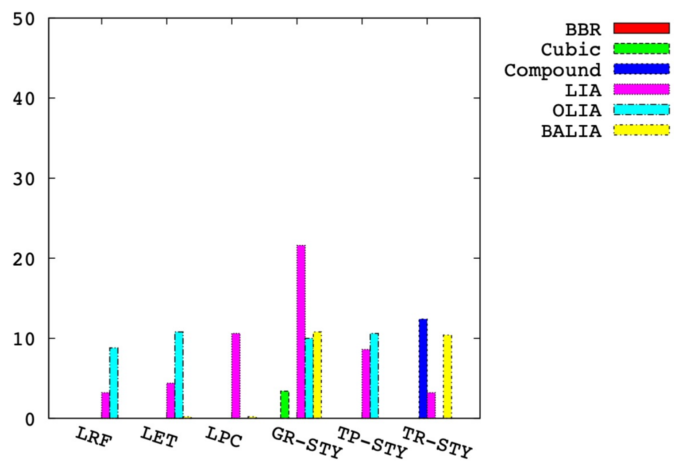
Scenario A1



Scenario A2



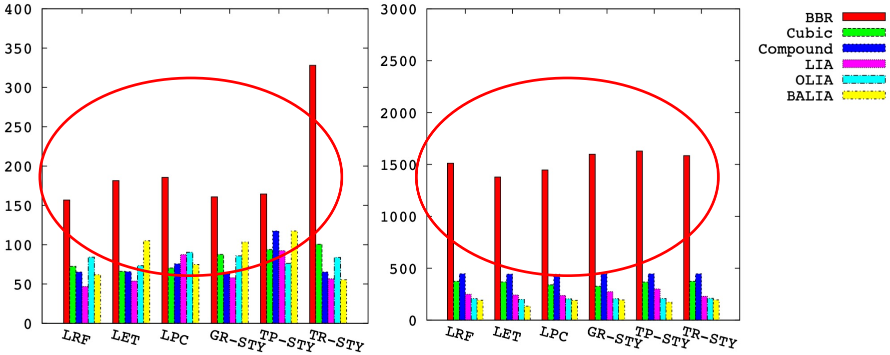
Scenario B1



Scenario B2

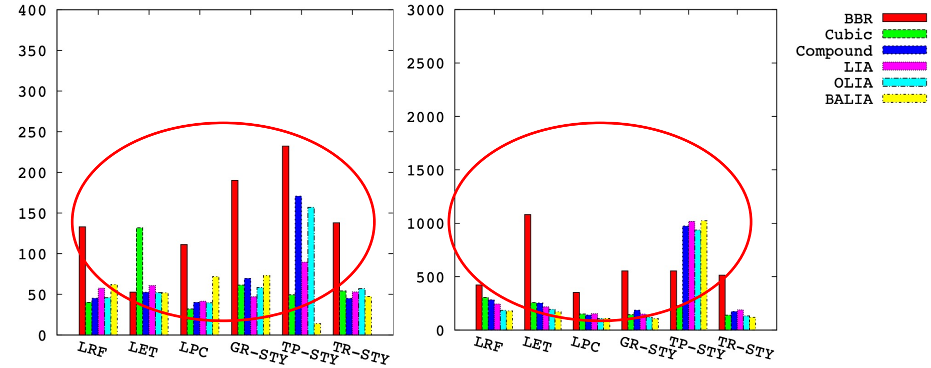
Results ： evaluation

- Retransmit Packets for BBR in all scenario
  - BBR retransmits more than other congestion control variants.



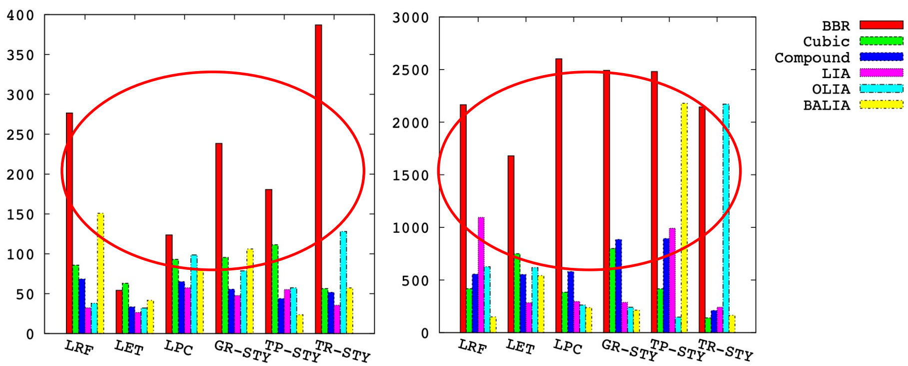
LTE Wi-Fi

Scenario A1



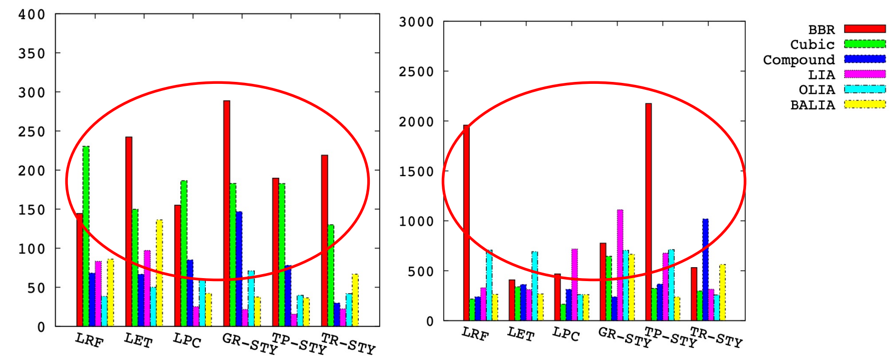
LTE Wi-Fi

Scenario A2



LTE Wi-Fi

Scenario B1



LTE Wi-Fi

Scenario B2

Results : evaluation

- Overall, video quality was good for all schedulers and BBR combinations.

- In all scenarios, BBR retransmits more than the other congestion controls.

Conclusion

- In MPTCP video streaming, Head of Line Blocking occurs due to the difference in communication characteristics of each path, and the video quality is degraded

- Congestion control of each sub-flow and path scheduler are important factors for improving video quality.

- As a result, Video quality was found to be better than other congestion controls for MPTCP video streaming using BBR.

- We are currently investigating the reasons for BBR consistently good streaming performance, despite its large number of retransmissions.