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Path Schedulers Performance on Cellular/Wi-Fi Multipath Video Streaming

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Resume

- Masayoshi Kondo
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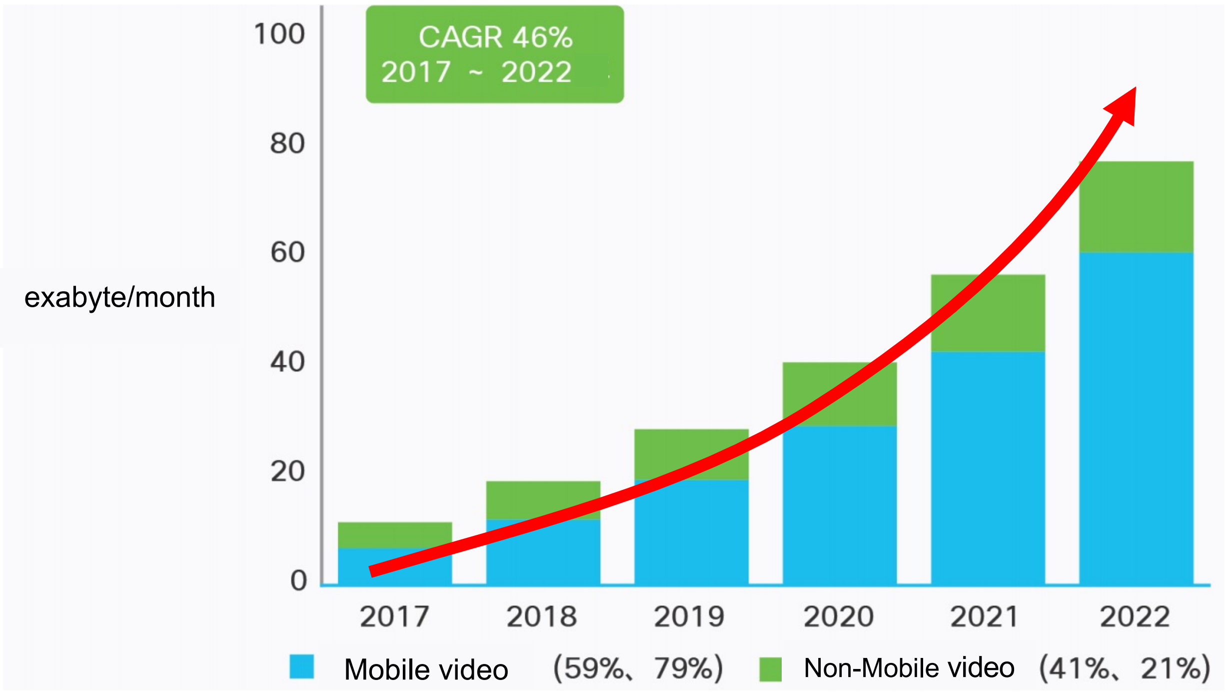
  - Field of Study
    - MPTCP
    - Transport Protocol

Introduction #1

- Mobile video traffic is increasing year by year.
  - The demand of video streaming has exploded

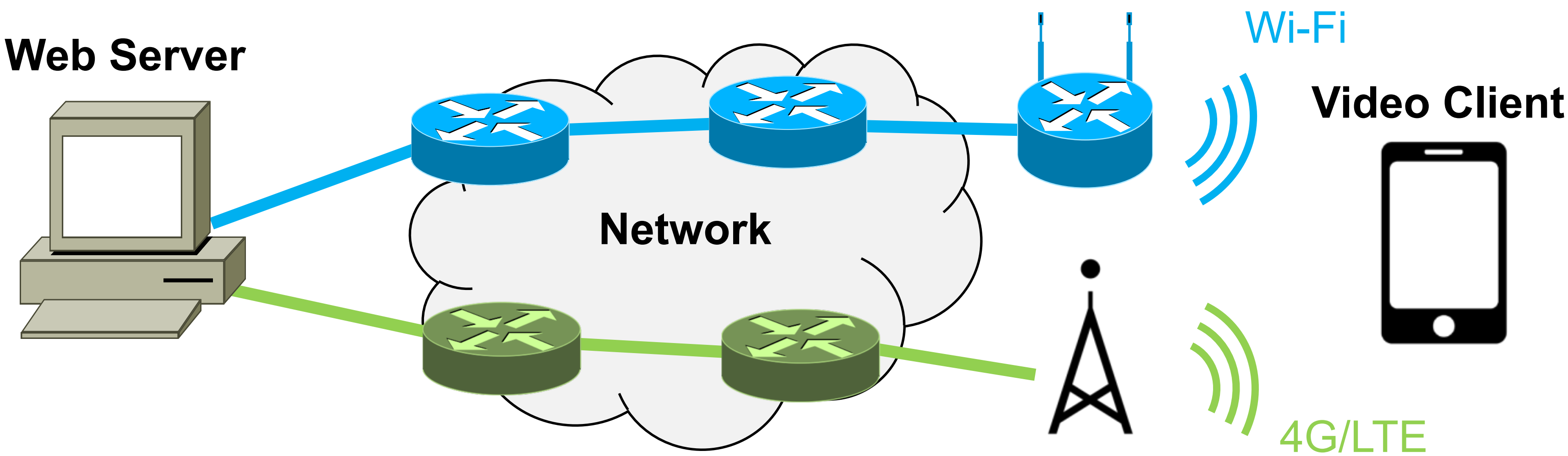


https://www.cisco.com/c/ja_jp/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html

Introduction #2

- Video streaming over mobile network
  - High speed and broadband wireless access: 4G/5G/Wi-Fi
  - Mobile devices have multiple high speed wireless communication interfaces

It is effective to use multiple interfaces for reliable and high quality communication

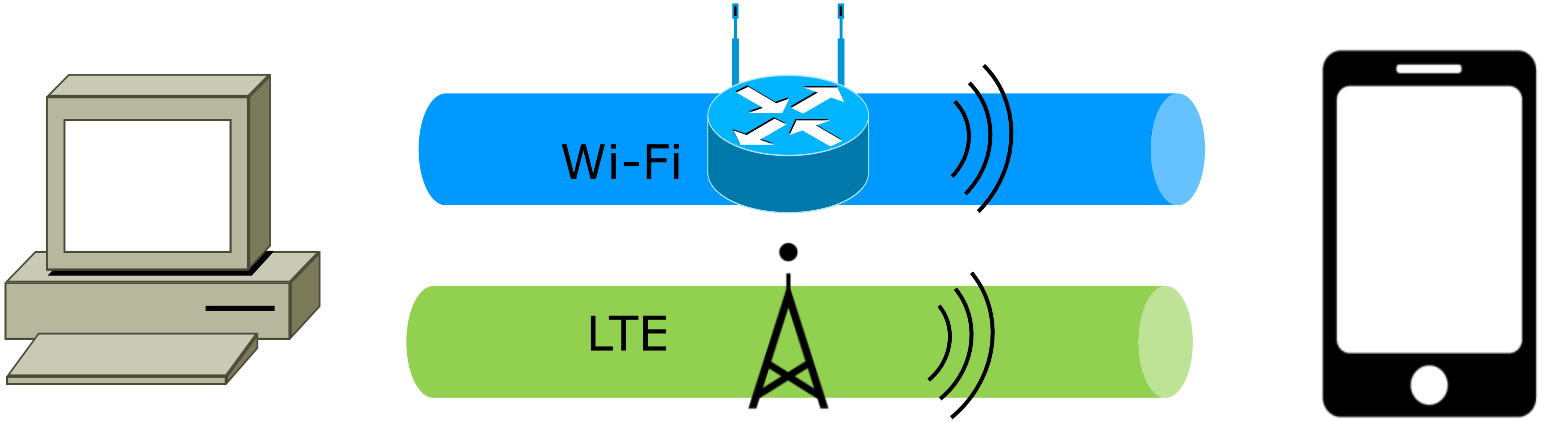


Introduction #3

◆Multipath TCP (MPTCP)

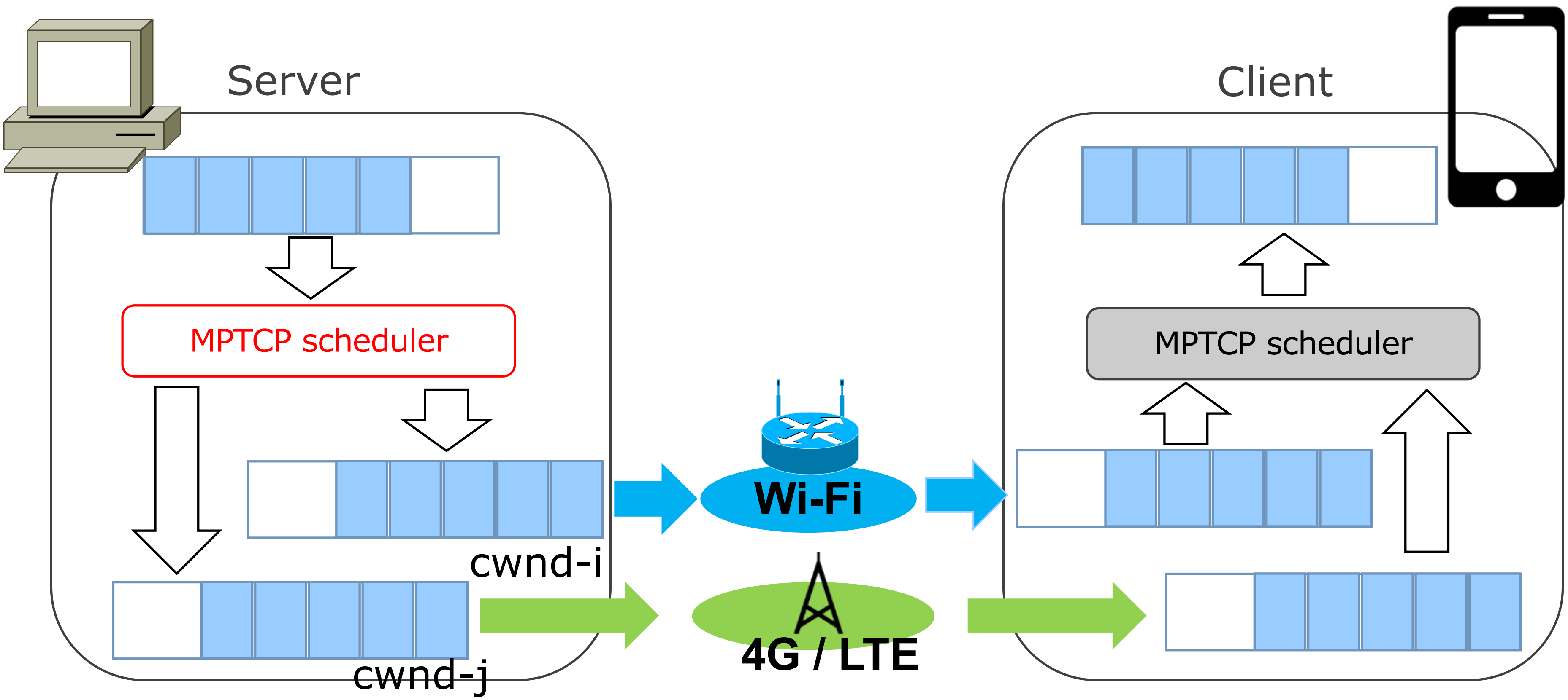
- It is possible to communicate using multiple paths simultaneously.

- MPTCP can improve the throughput for applications
- MPTCP can guarantee redundancy by providing multiple paths



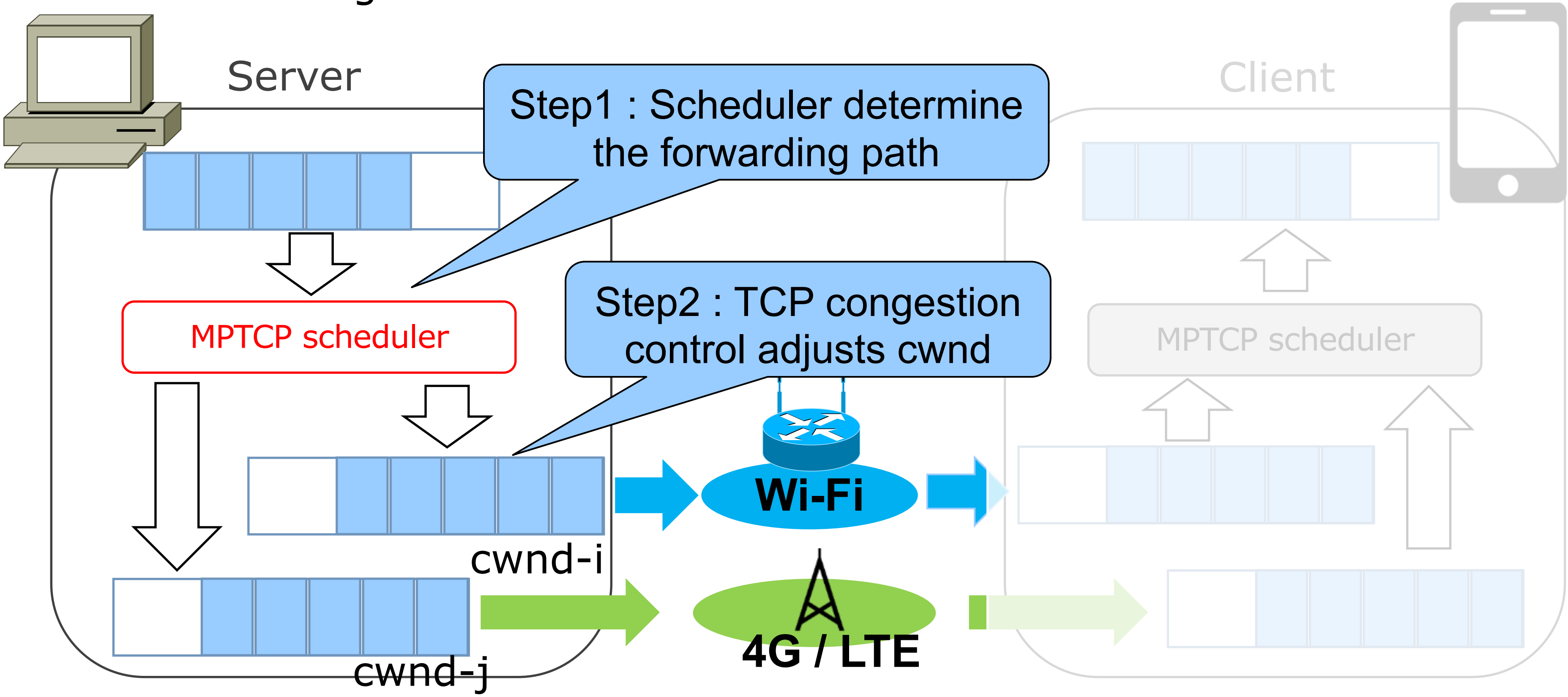
Video streaming over Multipath TCP

- The performance of MPTCP is determined by two important functions
  - 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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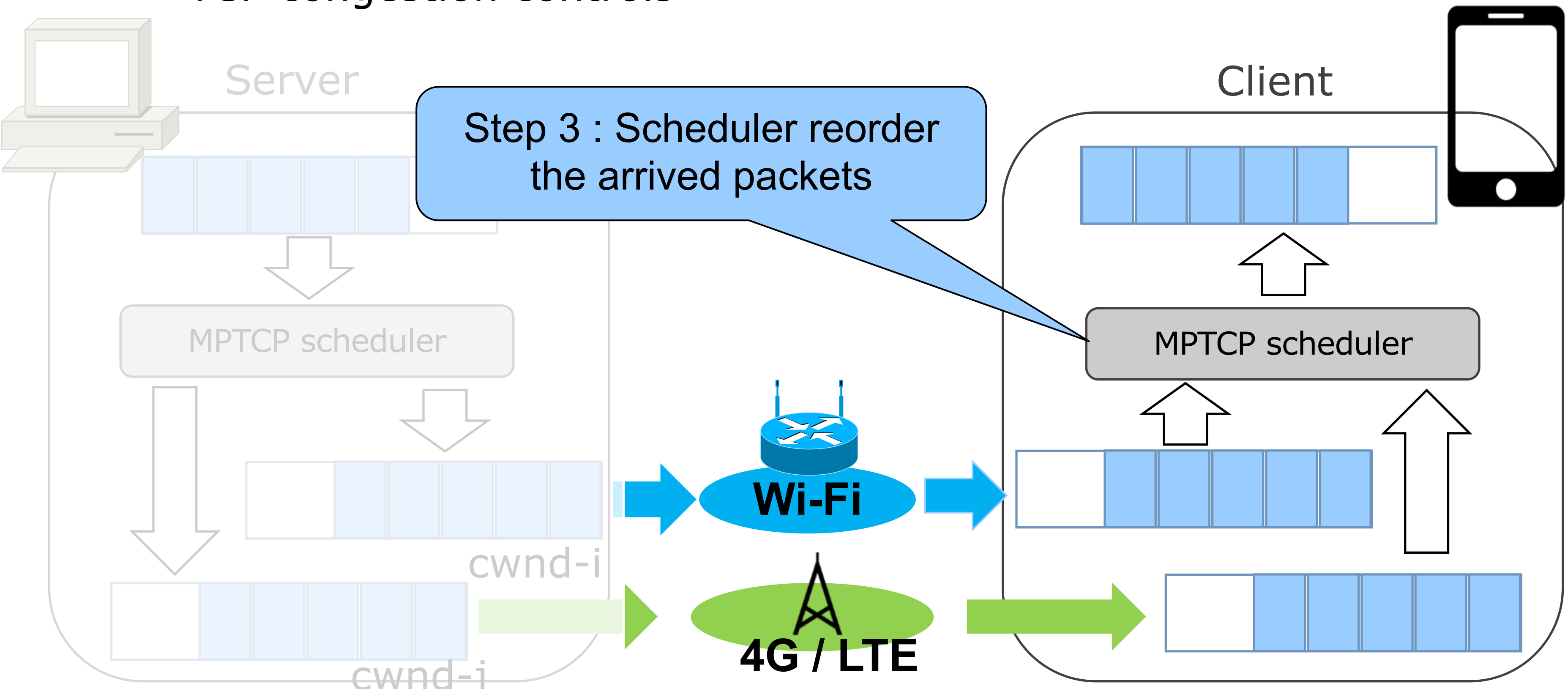
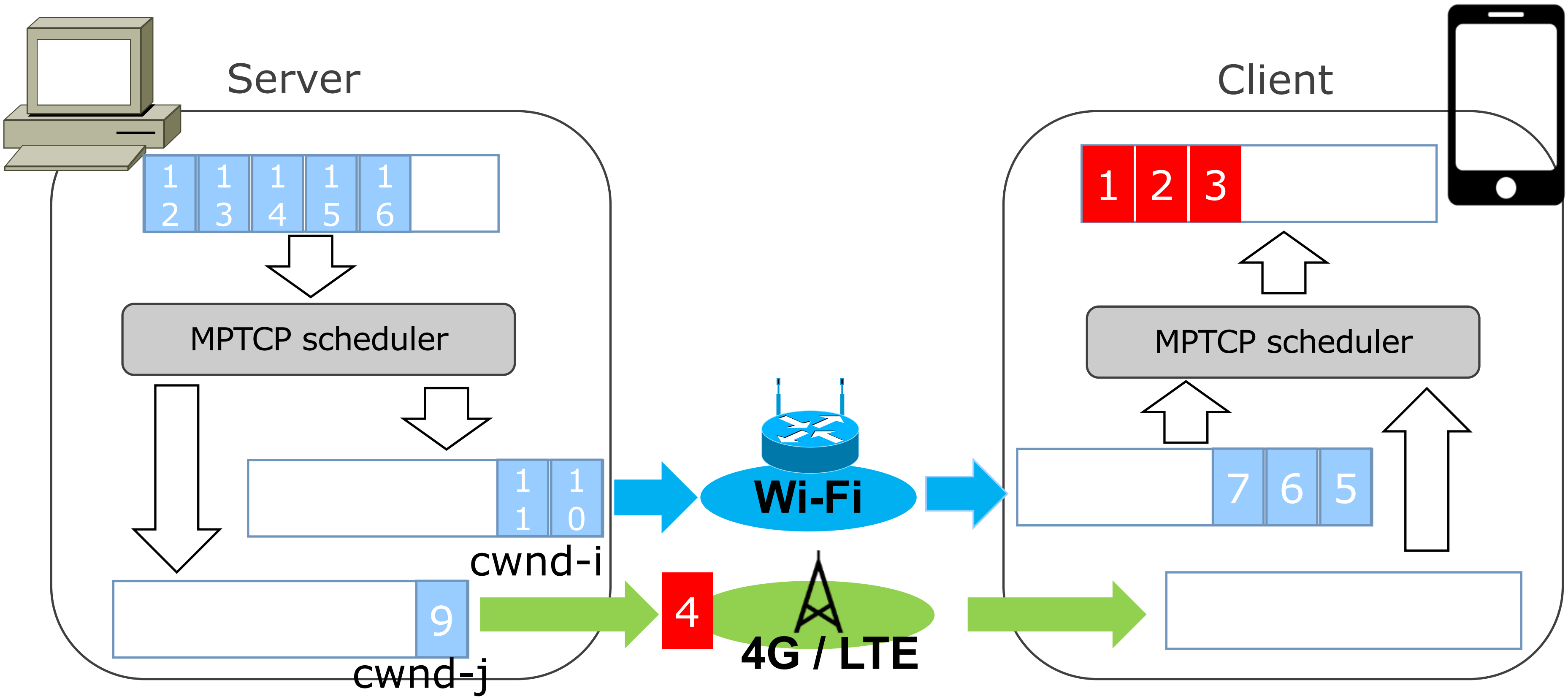


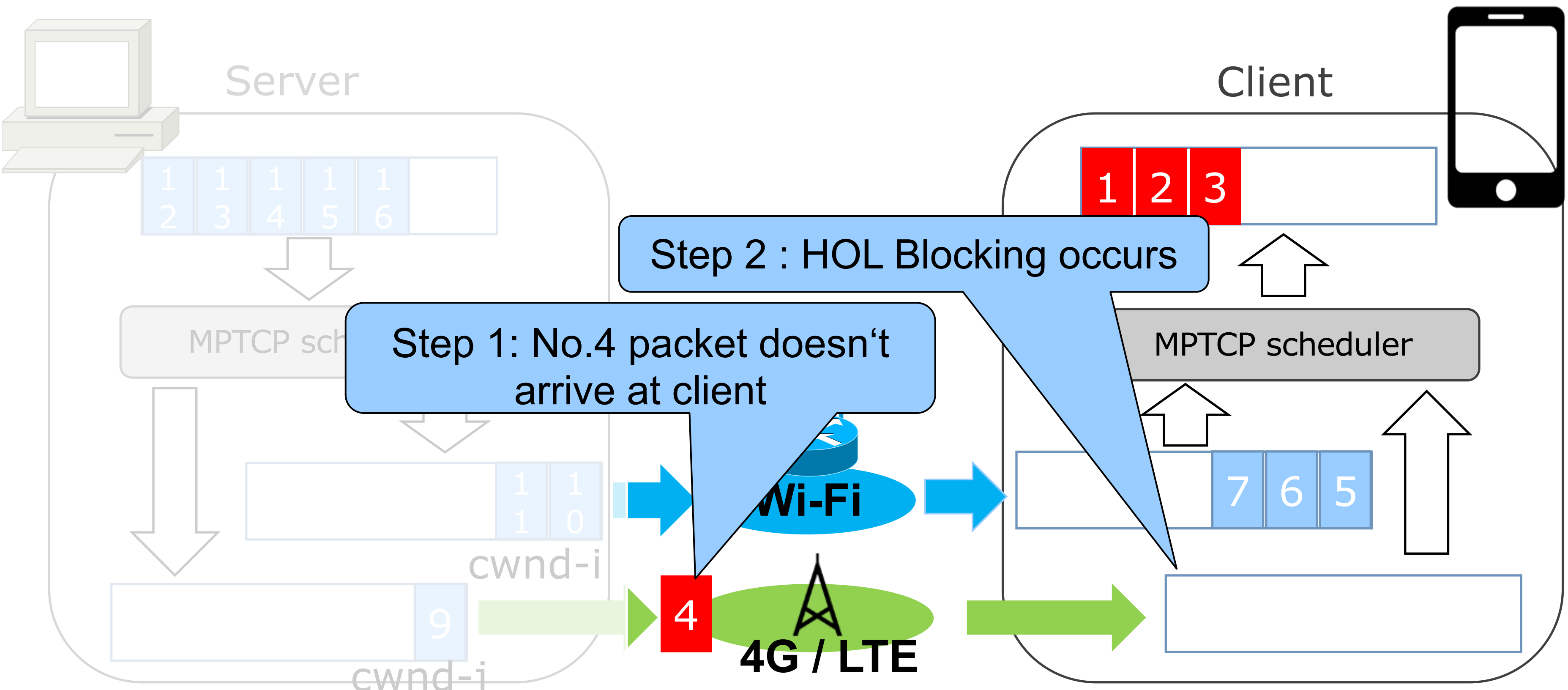
Head of Line Blocking

- 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 discard at the receiver.



Head of Line Blocking

- At the receiver, incomplete video frames due to HOL blocking are discarded and degrade the video quality.



Objective

- Important factors in video streaming over MPTCP
  - Determination of a path to forward packets for MPTCP scheduler
  - Congestion control for each sub-flow

- We combine the conventional and proposed schedulers with various congestion controls of MPTCP in experiments.

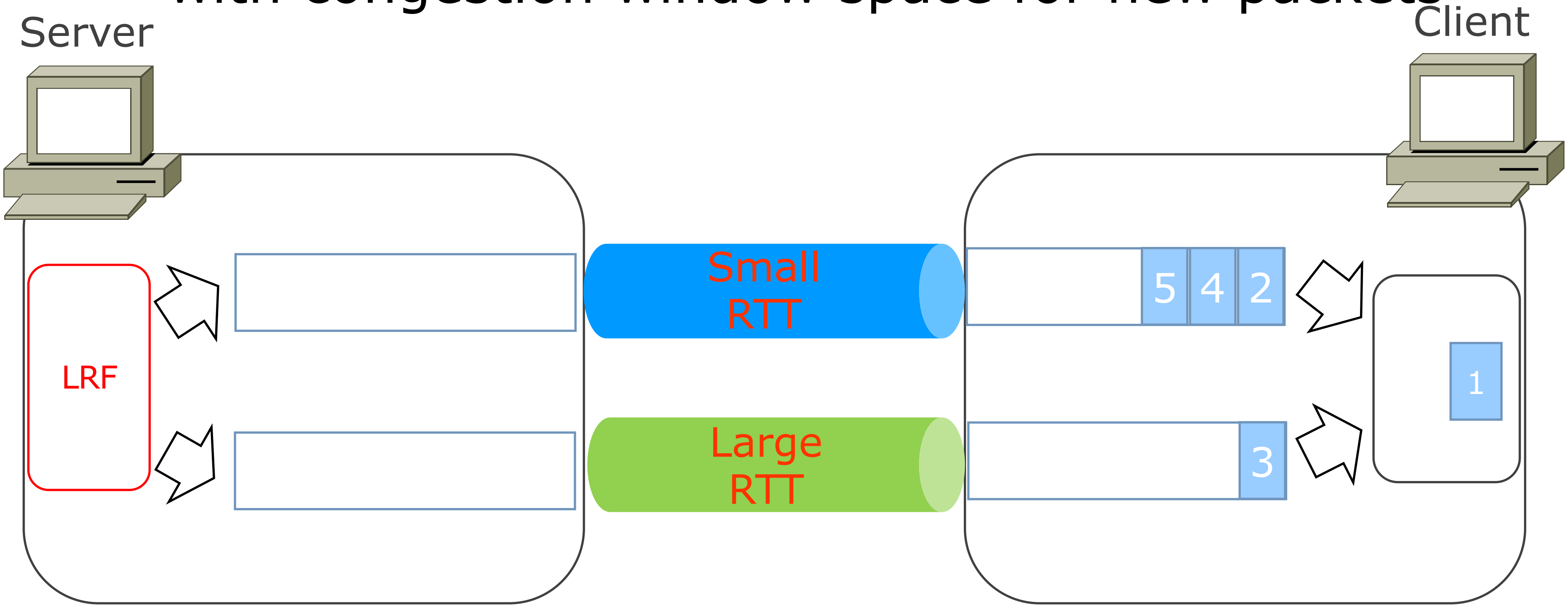
- We consider the optimal combination for MPTCP video streaming

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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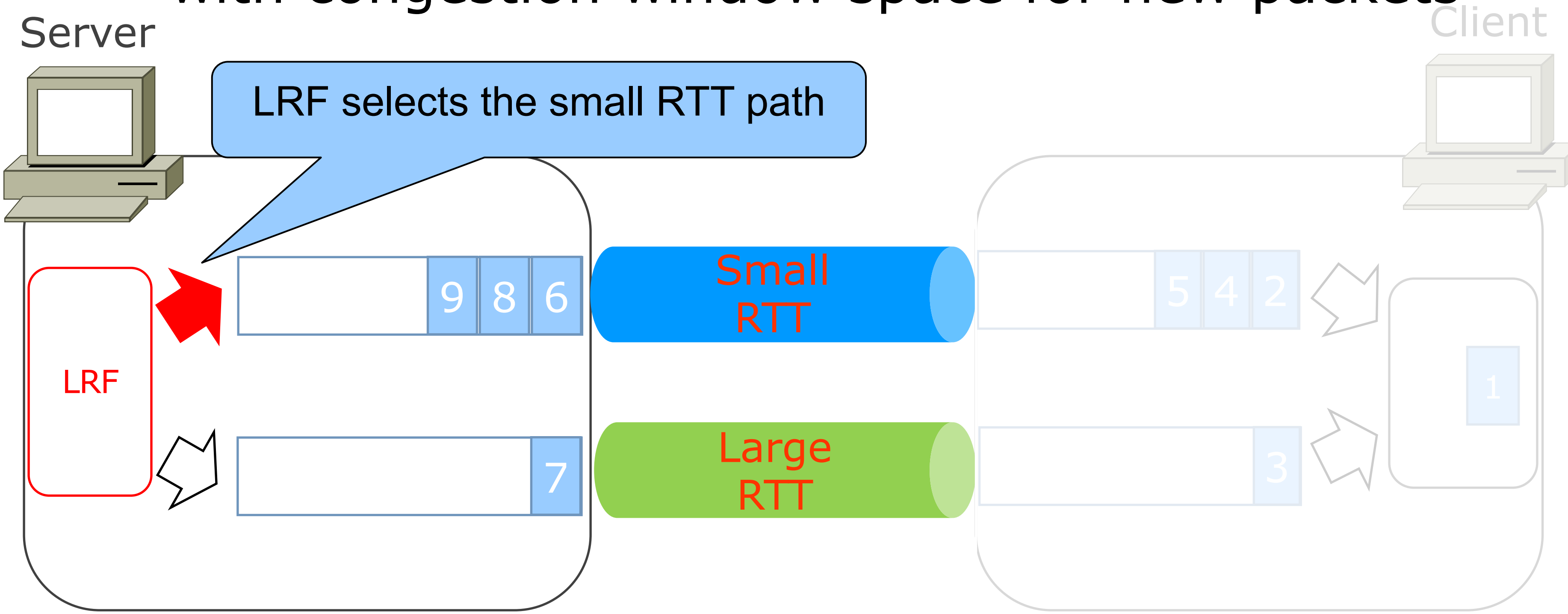
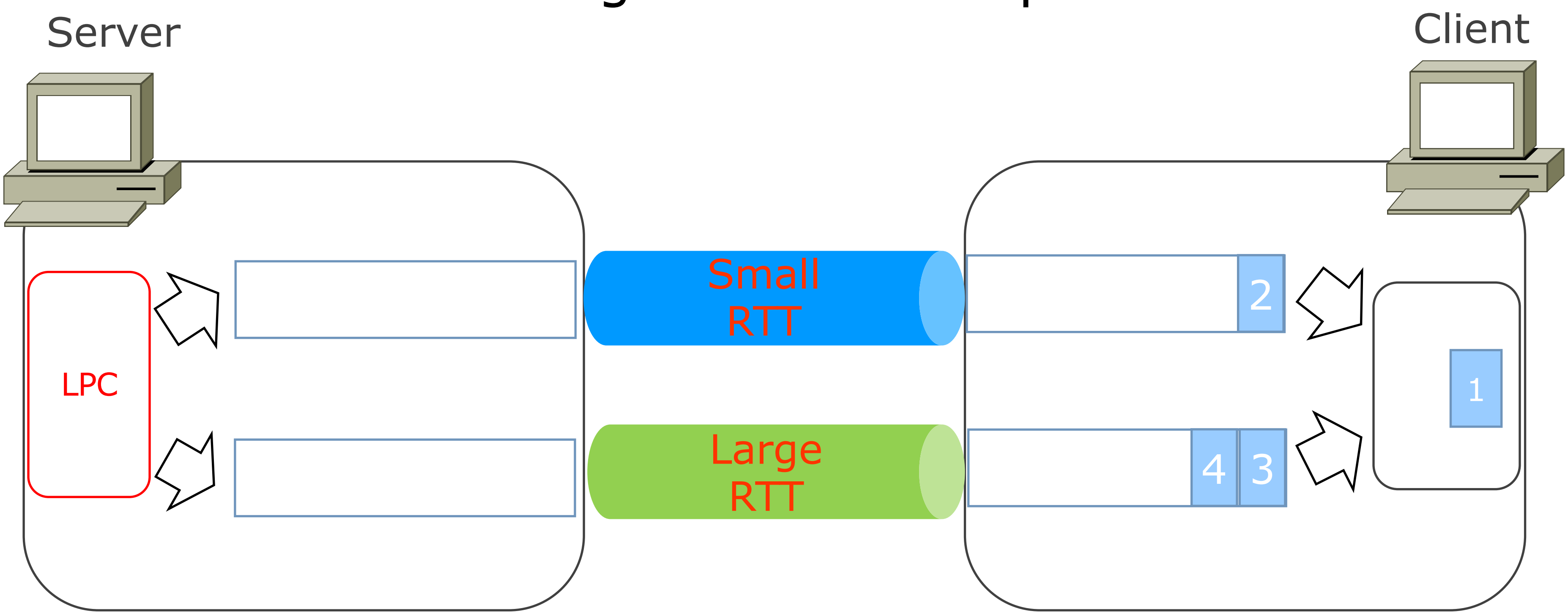


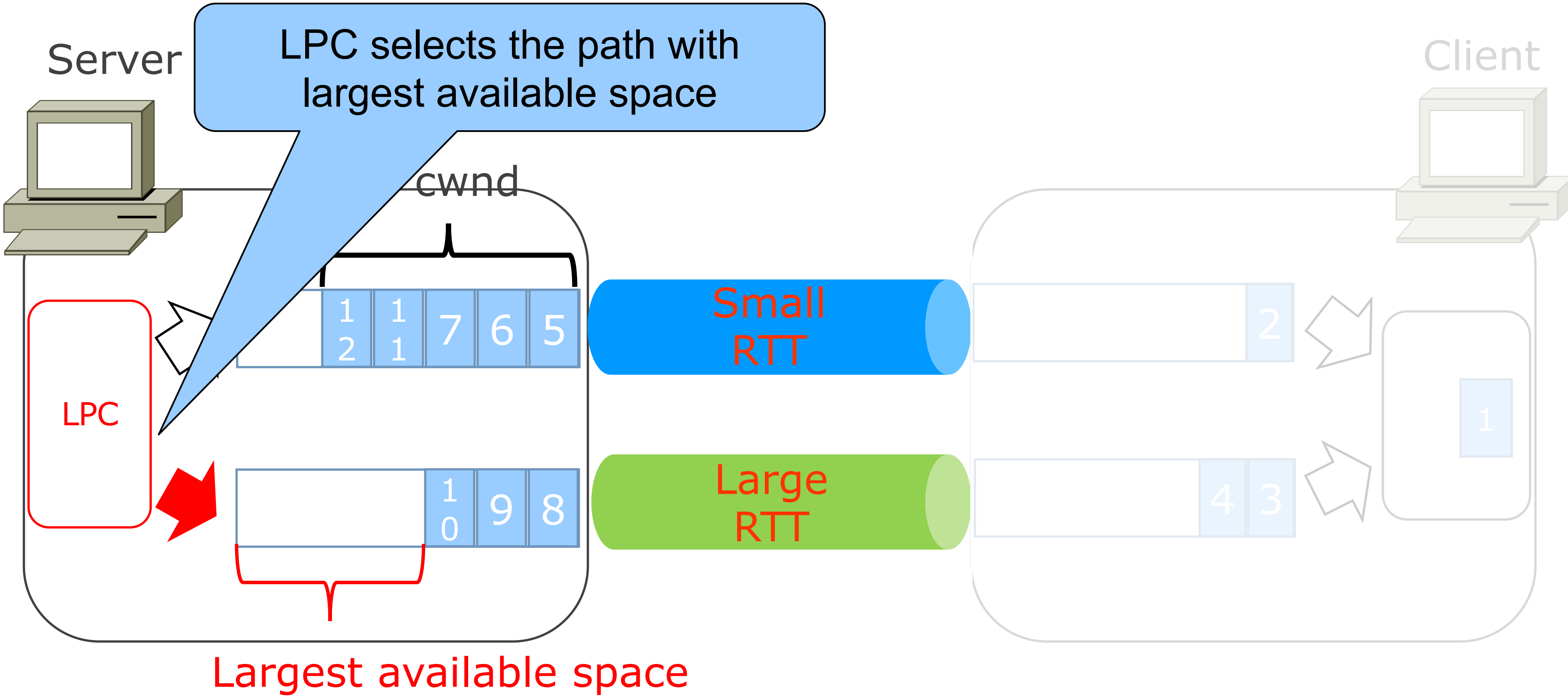
LPC scheduler

- 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



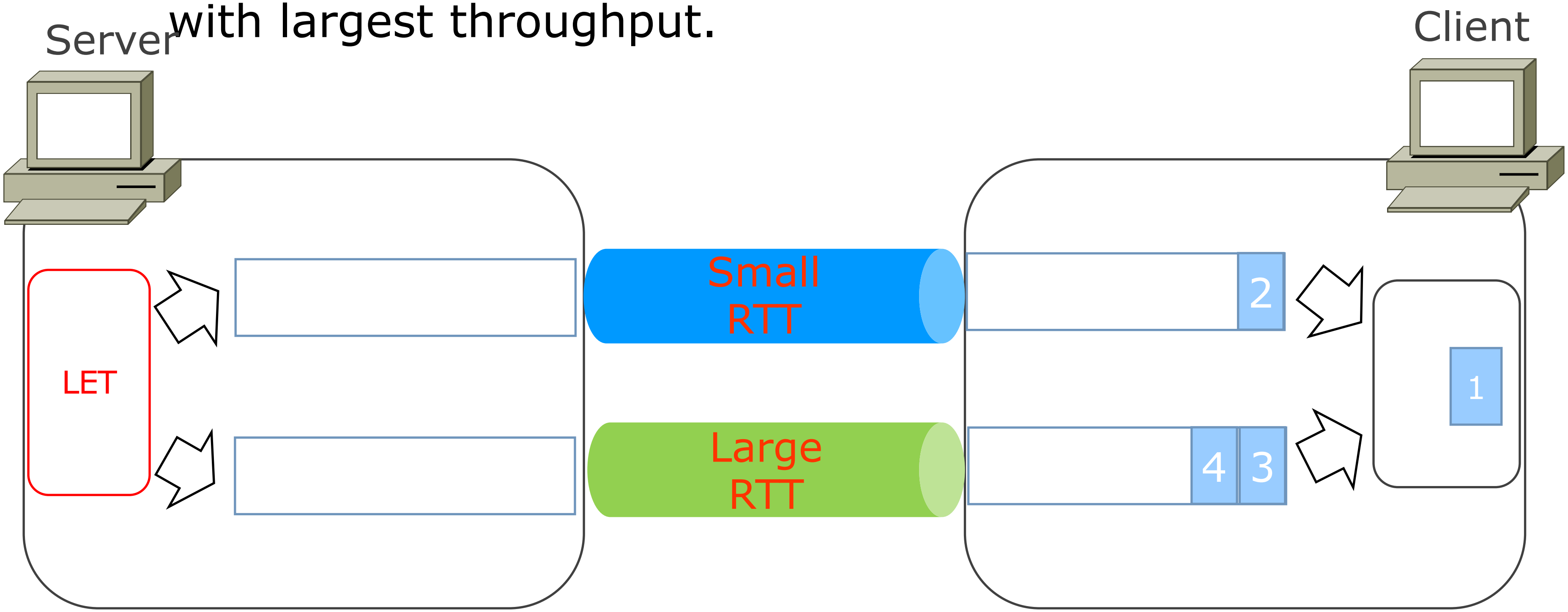
LPC scheduler

- 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



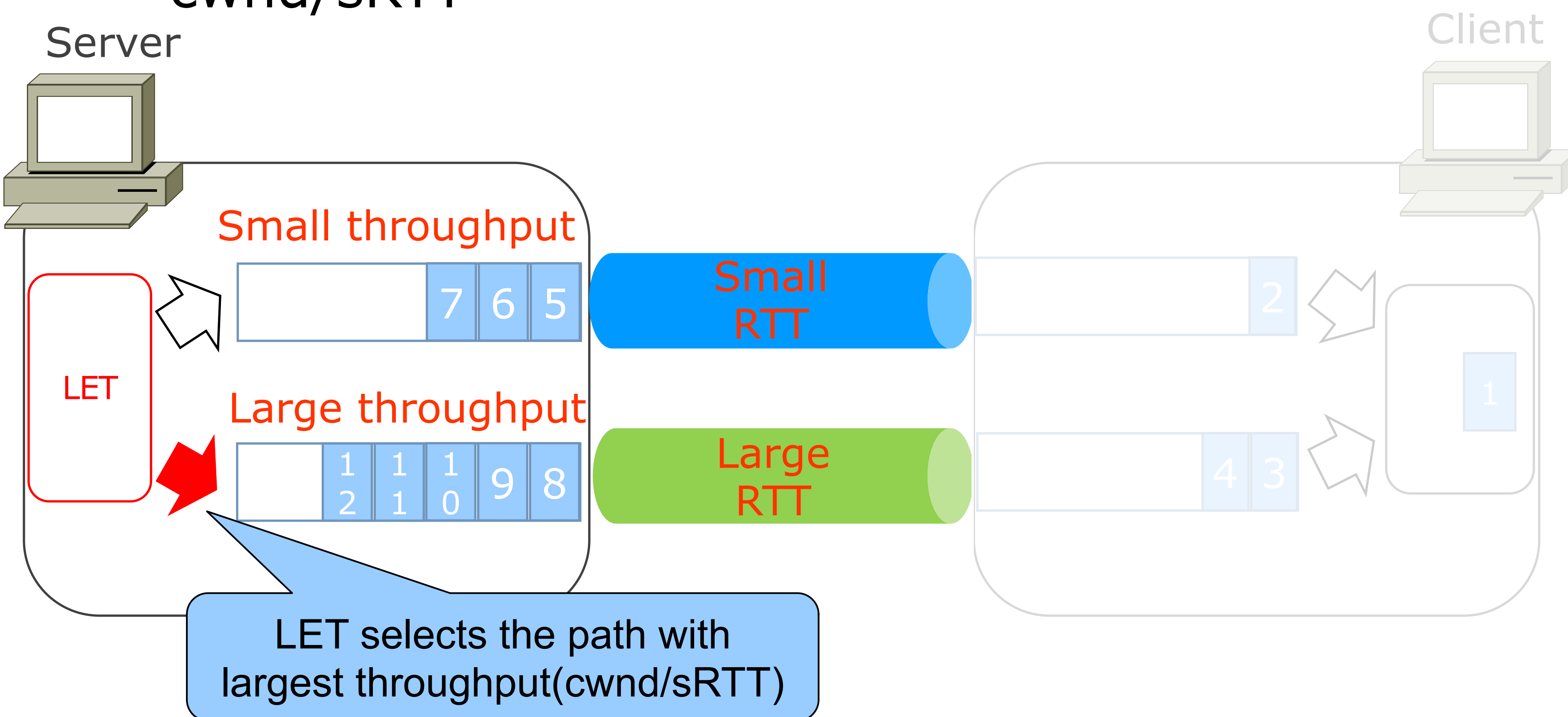
LET scheduler

- 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.



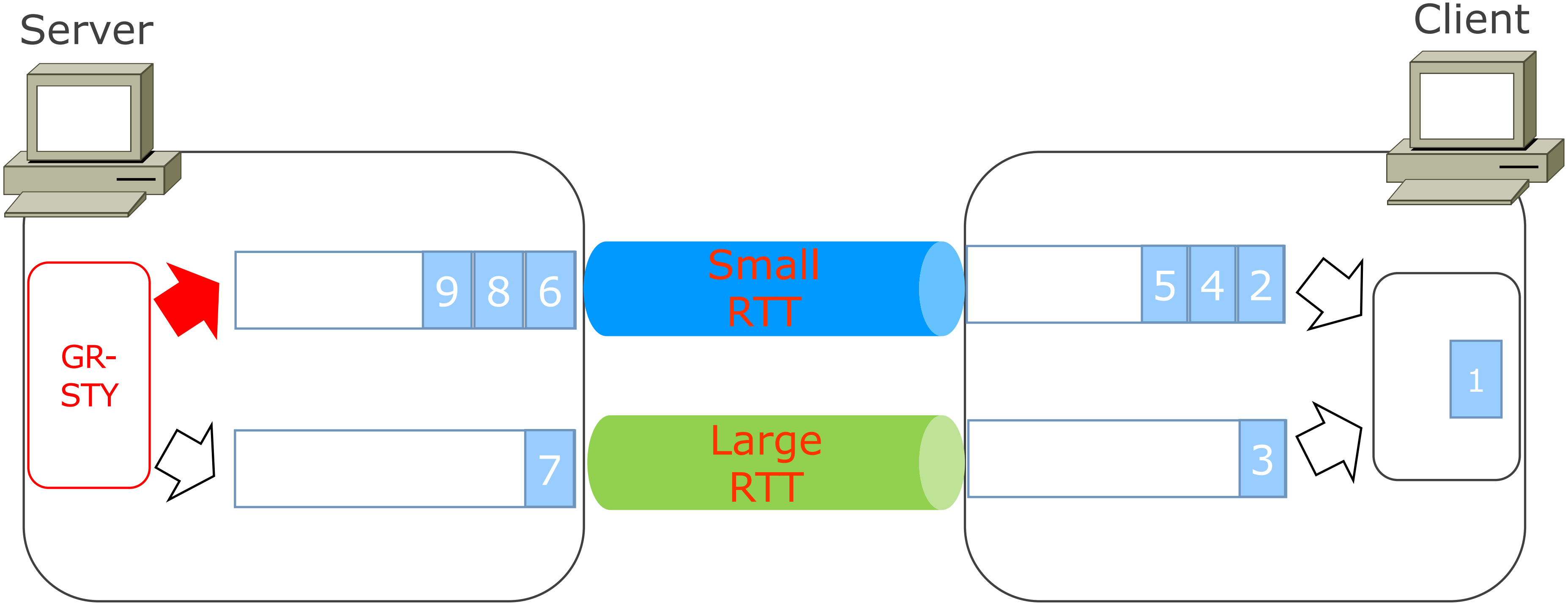
LET scheduler

- Largest Estimated Throughput (LET) scheduler
  - the estimated throughput is 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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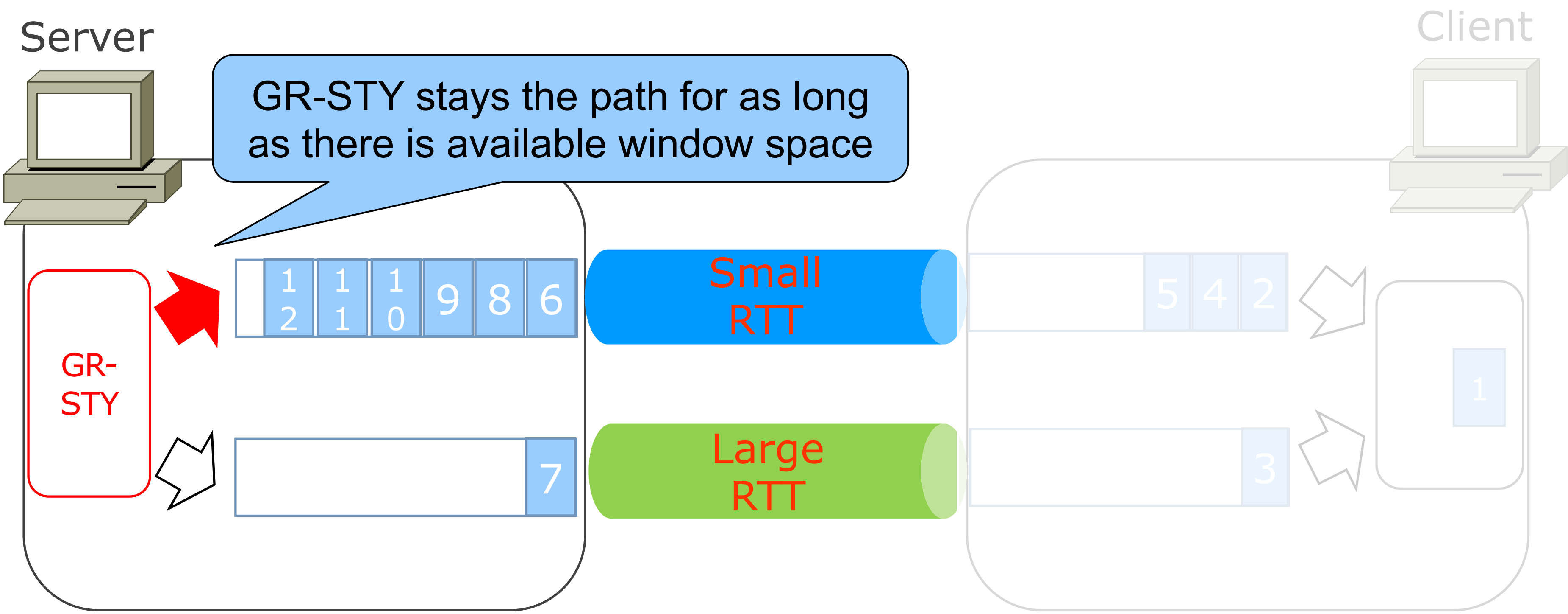
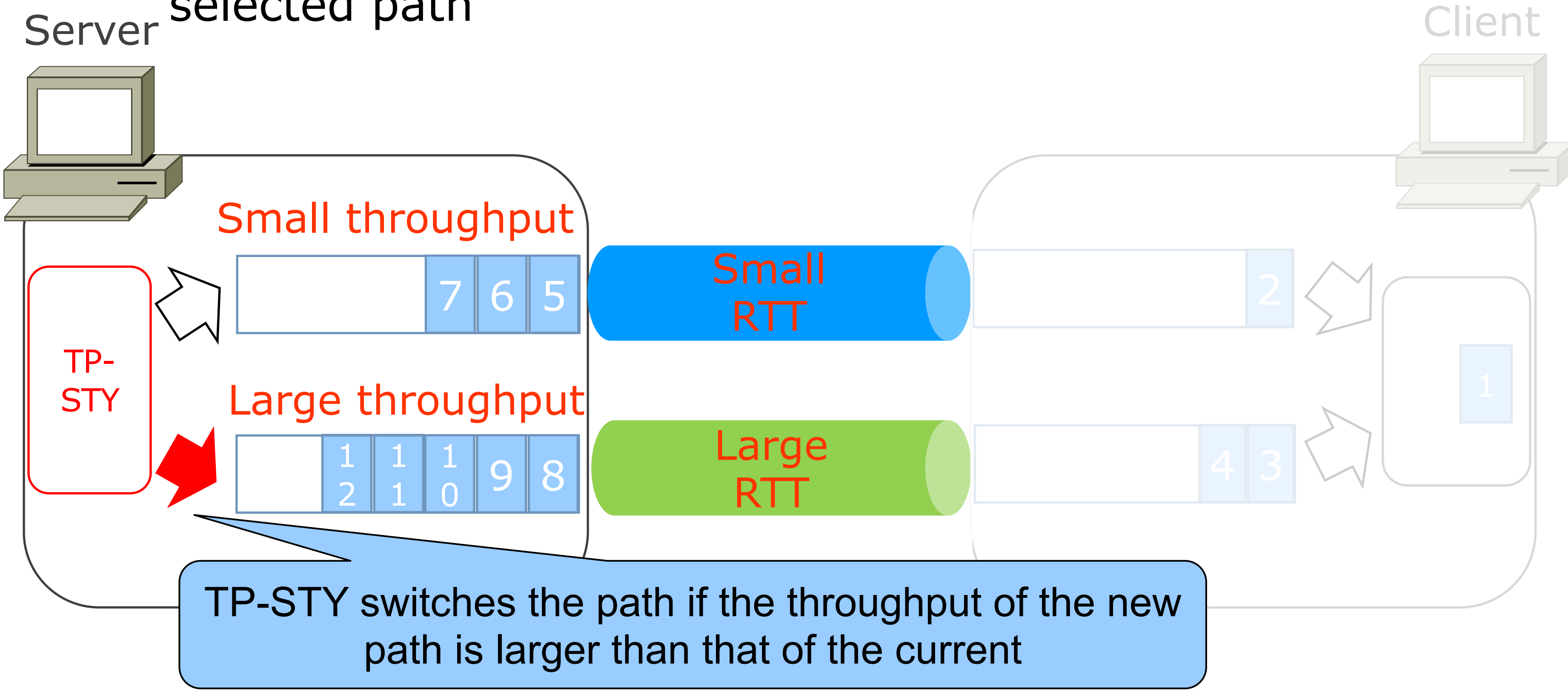


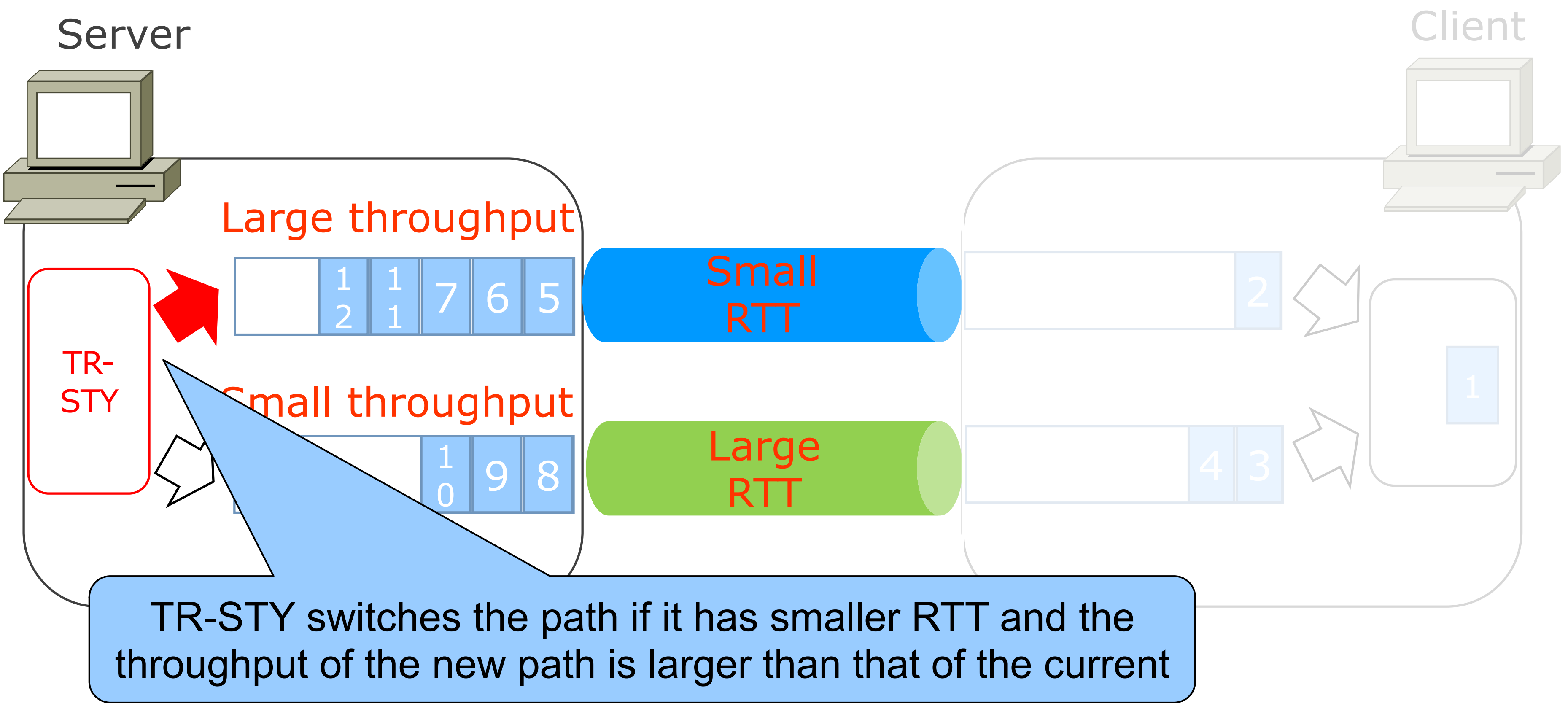
TP-STY scheduler

- Throughput Sticky (TP-STY) scheduler
  - selects the path with smallest RTT as same as LRF
  - But, 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 as same as LRF
  - But, in addition to TP-STY, TR-STY switches the new path has smaller RTT than the current one



MPTCP Congestion Control

- Uncoupled congestion controls
  - determine congestion window size independently for each subflow
  - 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

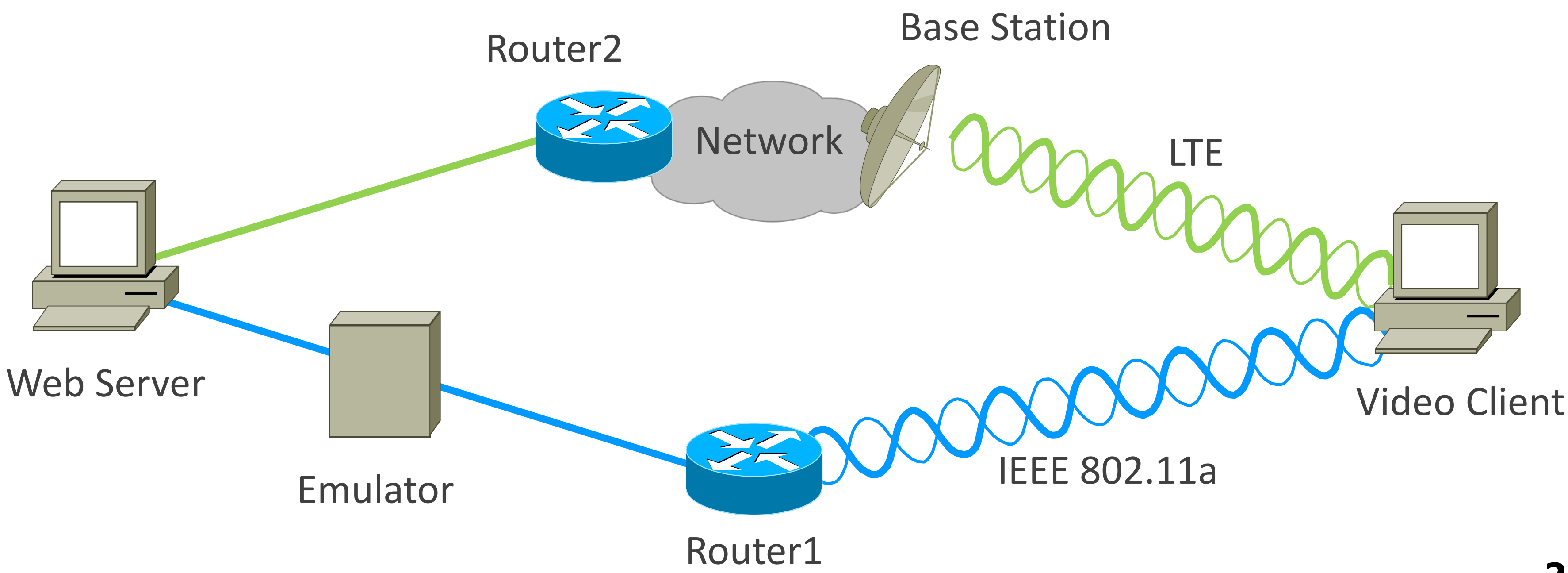
Performance Evaluation

- We analyze video performance vis-à-vis TCP variants and path schedulers

- We utilize verification 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



Video/network Settings

Table 1: Video Settings

Video size	409 Mbytes
Video Rate	5.24 Mb/s
Playout time	10mins 24s
Encoding	MPEG-4
Video Codec	H.264/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
	    • Cubic
	    • Compound
	• Coupled
	    • LIA
	    • OLIA
	    • BALIA

Experimental Scenarios

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

scenarios	path	delay	Packet loss	RTT
A	LTE Wi-Fi	0ms 20ms	0%	RTT 80ms RTT 40ms
B	LTE Wi-Fi	0ms 30ms	0%	RTT 80ms RTT 60ms
C	LTE Wi-Fi	0ms 30ms	0% 6%	RTT 80ms RTT 60ms
D	LTE Wi-Fi	0ms 40ms	0%	RTT 80ms
E	LTE Wi-Fi	0ms 40ms	0% 6%	RTT 80ms

Scenarios A

- Scenario A is baseline scenario, where Wi-Fi path is good quality

scenarios	path	delay	Packet loss	RTT
A	LTE Wi-Fi	0ms 20ms	0%	RTT 80ms RTT 40ms
B	LTE [illegible]	[illegible]ms [illegible]	0%	RTT 80ms RTT 60ms
C	[illegible] Wi-Fi	[illegible] 30ms	[illegible] 6%	RTT 80ms RTT 60ms
D	LTE Wi-Fi	0ms 40ms	0%	RTT 80ms
E	LTE Wi-Fi	0ms 40ms	0% 6%	RTT 80ms

Scenario A with small RTT

Scenarios B and C

- Scenario B is a slightly larger Wi-Fi path delay
- Scenario C is a Wi-Fi link with medium delay suffers a 6% packet loss degradation

scenarios	path	delay	Packet loss	RTT
A	LTE Wi-Fi	0ms 20ms	0%	RTT 80ms RTT 40ms
B	LTE Wi-Fi	0ms 30ms	0%	RTT 80ms RTT 60ms
C	LTE Wi-Fi	0ms 30ms	0% 6%	RTT 80ms RTT 60ms
D	LTE	ms	0%	RTT 80ms
E	Wi-Fi	40ms	0%	T 80ms

Scenario B with middle RTT
Scenario C with middle RTT and 6% packet loss

Scenarios D and E

- Scenario D is a Wi-Fi path delay large enough
- Scenario E is a Wi-Fi link with large delay also suffers a 6% packet loss degradation

scenarios	path	delay	Packet loss	RTT
A	LTE Wi-Fi	0ms 20ms	0%	RTT 80ms RTT 40ms
B	LTE [illegible]	0ms [illegible]	[illegible]	RTT 80ms [illegible] 60ms
C	[illegible] Wi-Fi	[illegible] [illegible]ms	[illegible] 6%	RTT 80ms RTT 60ms
D	LTE Wi-Fi	0ms 40ms	0%	RTT 80ms
E	LTE Wi-Fi	0ms 40ms	0% 6%	RTT 80ms

Scenario D with large RTT
Scenario E with large RTT and 6% packet loss

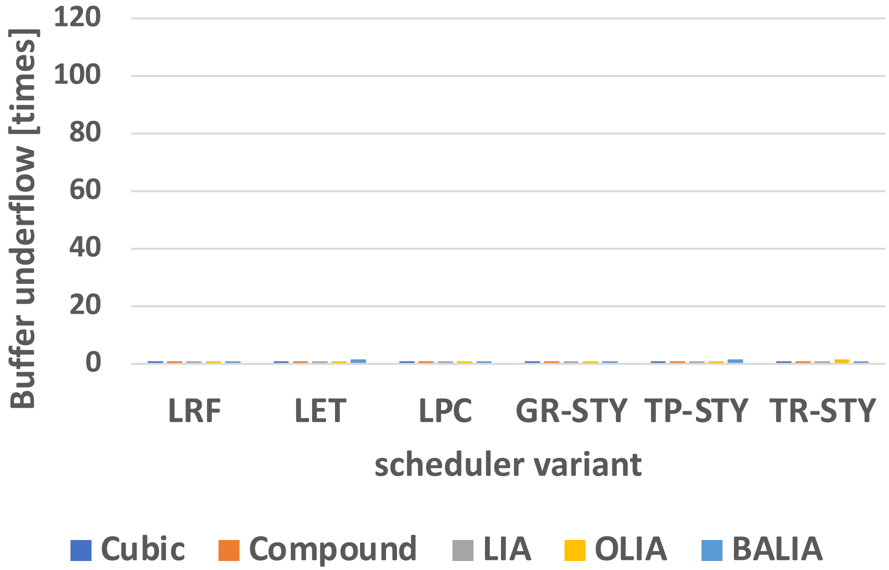
Performance evaluation index

- Video Performance
  - Picture discard
    - Number of frames discarded by the video decoder
  - Buffer underflow
    - Number of buffer underflow events ad video client buffer

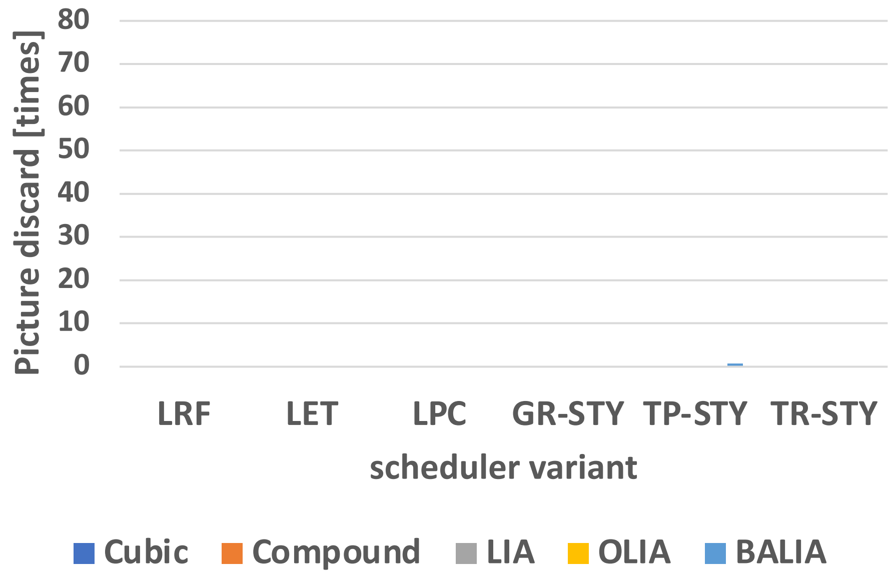
- The number of trials is 5 and the average value is calculated.

Scenario A : video performance

- Path properties
  - Wi-Fi: RTT=40ms、Loss= 0%
  - LTE: RTT= 80ms、Loss = 0%
- Figures report on video streaming buffer underflow and picture discard performance
- Video performance is excellent



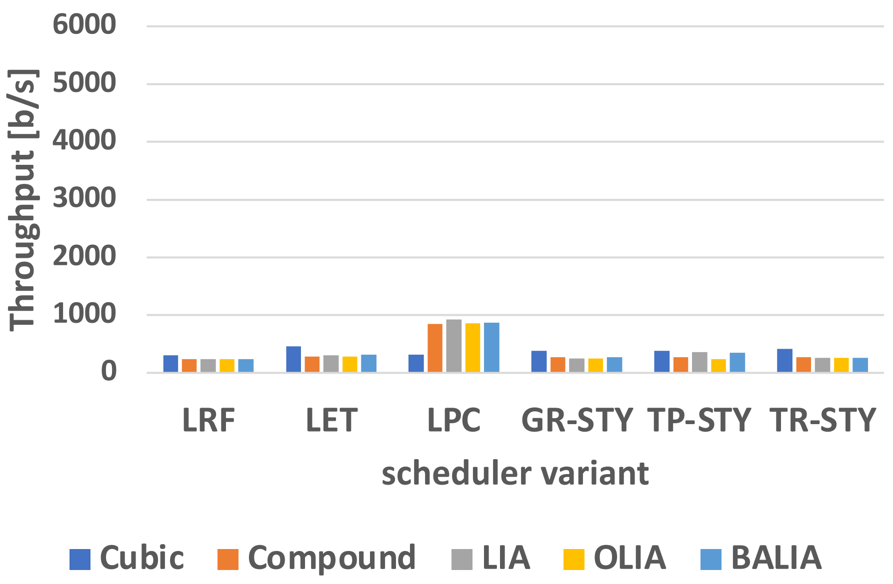
Buffer underflow



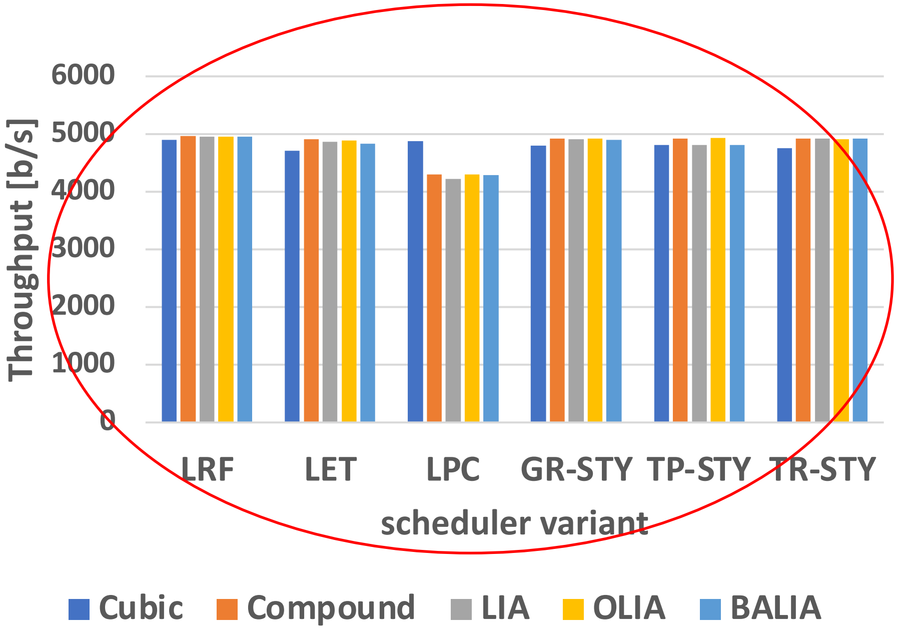
Picture discard

Scenario A : throughput

- Path properties
  - Wi-Fi: RTT=40ms、Loss= 0%
  - LTE: RTT= 80ms、Loss = 0%
- Figures report of LTE and Wi-Fi throughput
- We can see that Wi-Fi path is most used



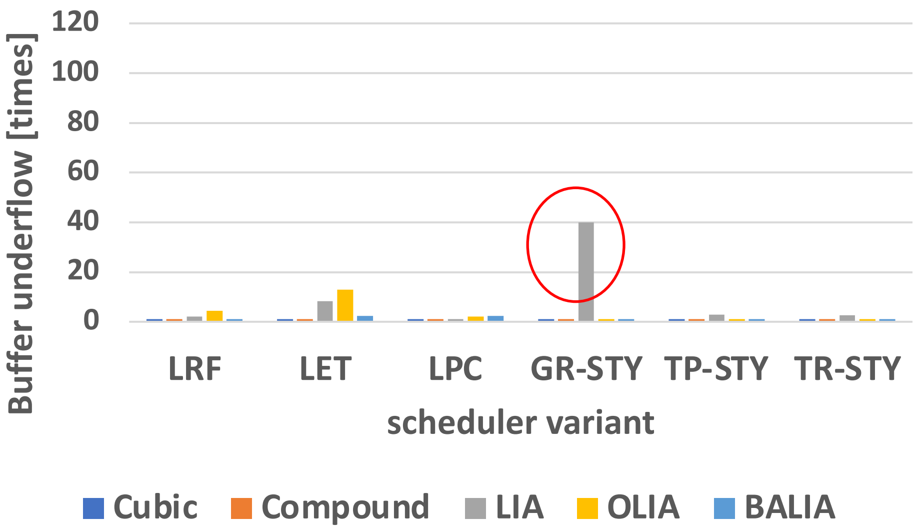
Throughput LTE



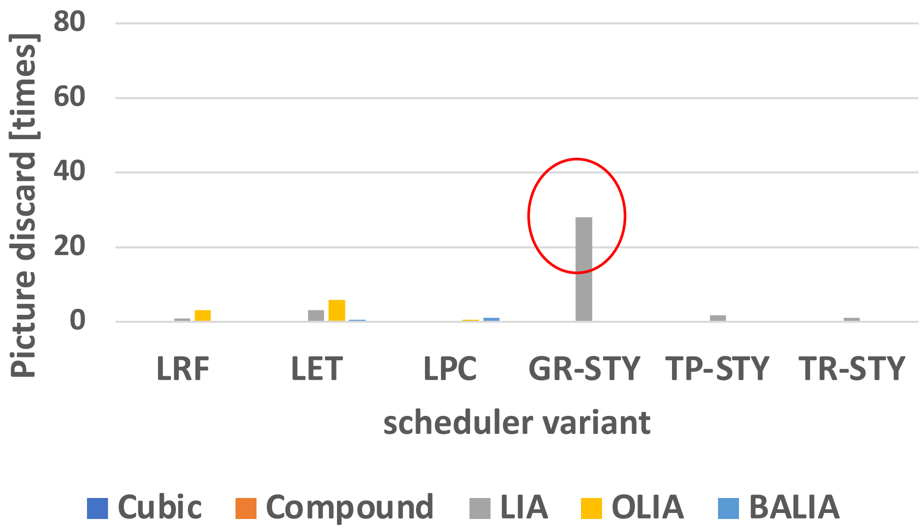
Throughput Wi-Fi

Scenario B : video performance

- Path properties
  - Wi-Fi: RTT=60ms、Loss= 0%
  - LTE: RTT= 80ms、Loss = 0%
- In scenario B, Even though most TCP variant and path scheduler perform well, LIA under GR-STY results in video degradation



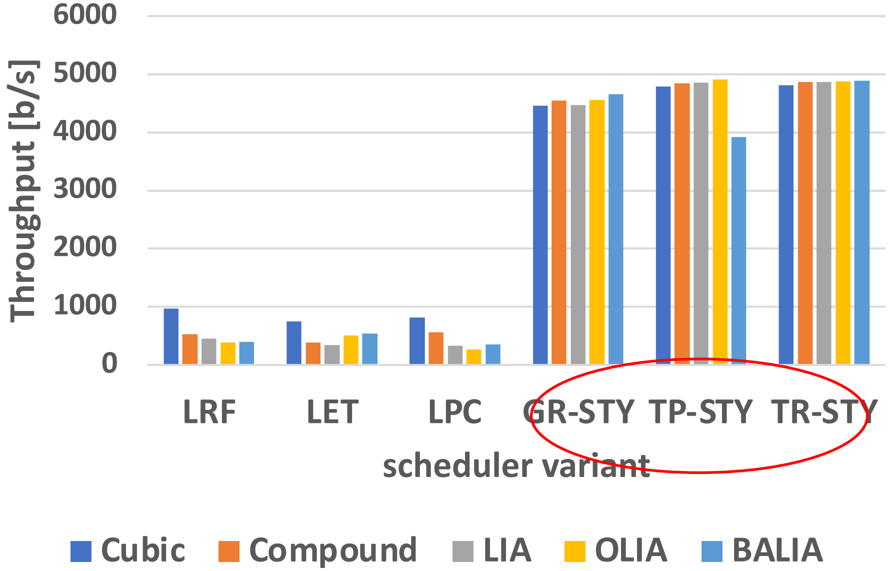
Buffer underflow



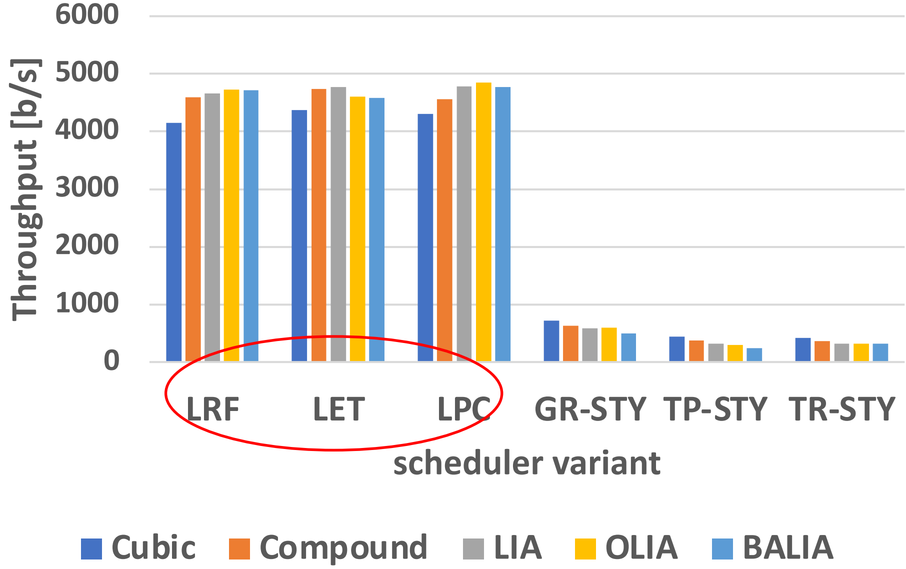
Picture discard

Scenario B：throughput

- Path properties
  - Wi-Fi: RTT=60ms、Loss= 0%
  - LTE: RTT= 80ms、Loss = 0%
- In scenario B, We see that path schedulers drive the usage of one path versus the other, independent of the TCP variant.
- LRF, LET, LPC utilize Wi-Fi path mostly, STY scheduler use LTE path.
- This shows how sensitive path selection is to delay differentials



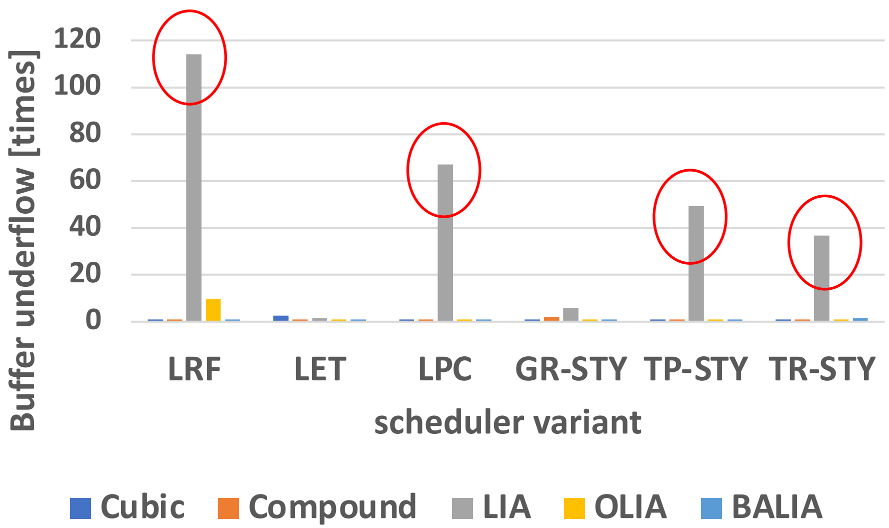
Throughput LTE



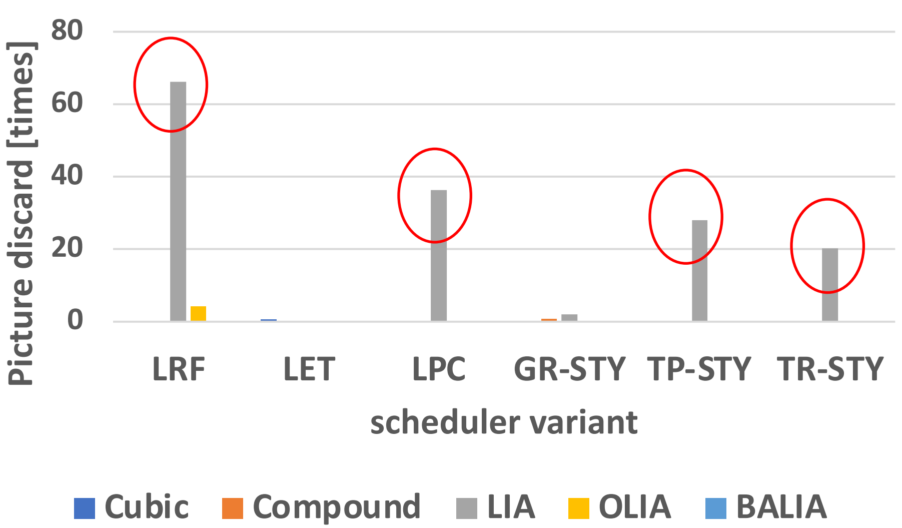
Throughput Wi-Fi

Scenario C : video performance

- Path properties
  - Wi-Fi: RTT=60ms、Loss= 6%
  - LTE: RTT= 80ms、Loss = 0%
- In scenario C, We see that a wide variety of performances vis a vis path scheduler/TCP variant combinations



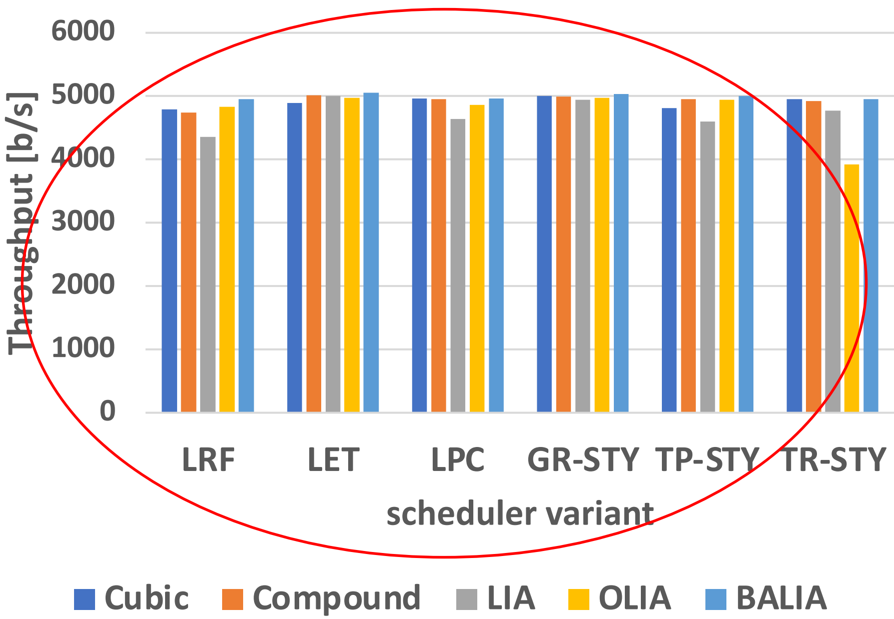
Buffer underflow



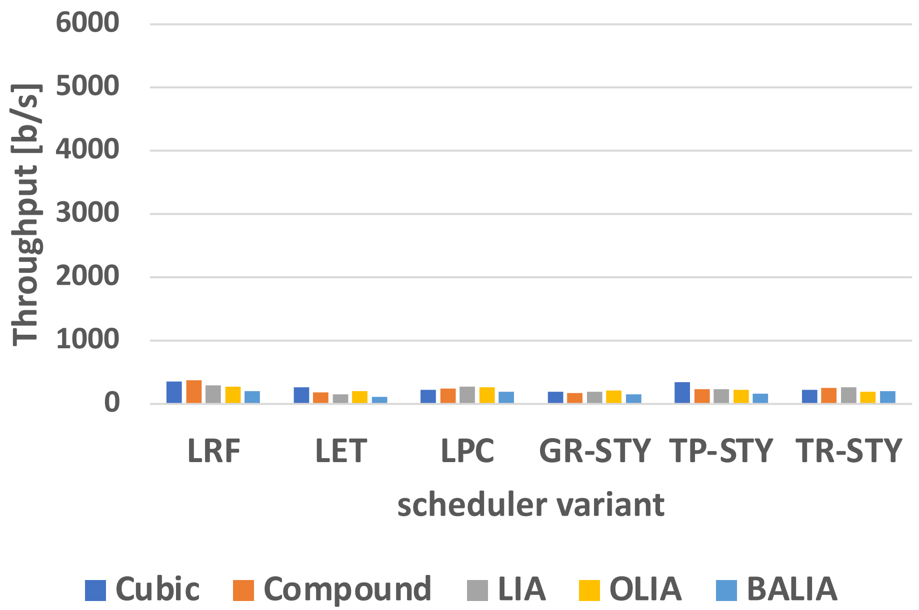
Picture discard

Scenario C : throughput

- Path properties
  - Wi-Fi: RTT=60ms、Loss= 6%
  - LTE: RTT= 80ms、Loss = 0%
- In scenario C, LTE path is mostly used.
- This is because the Wi-Fi path has packet loss, so the window size does not increase, the RTT is large, but the LTE path with low loss is used.



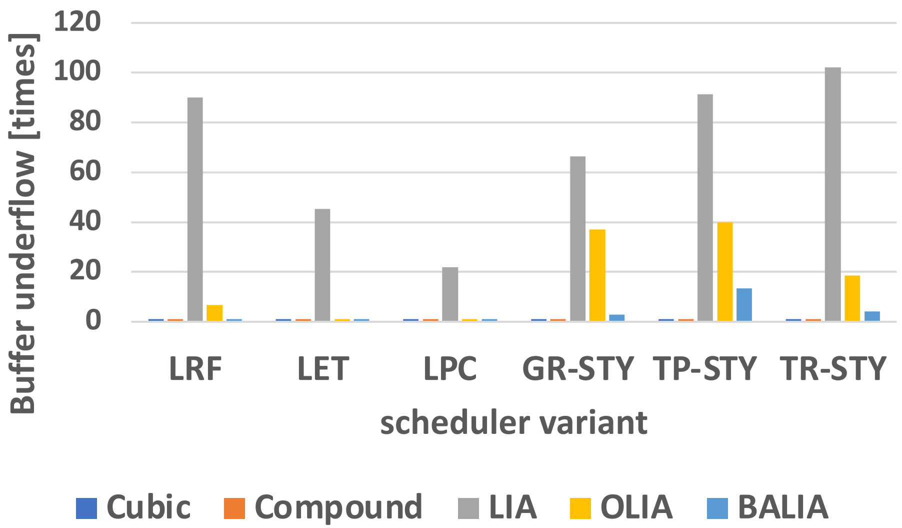
Throughput LTE



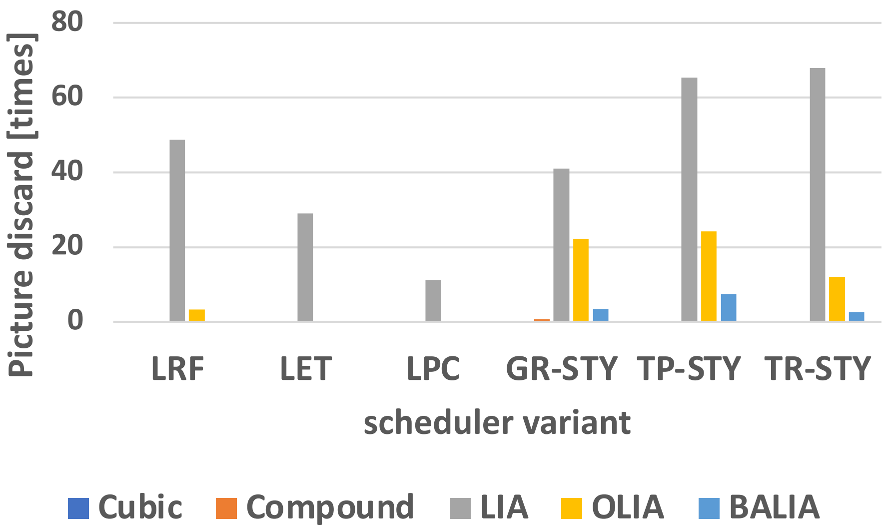
Throughput Wi-Fi

Scenario D : video performance

- Path properties
  - Wi-Fi: RTT=80ms Loss= 0%
  - LTE: RTT= 80ms Loss = 0%
- In scenario D, LIA under all schedulers results in video degradation
- Also, OLIA under STY scheduler results in video degradation



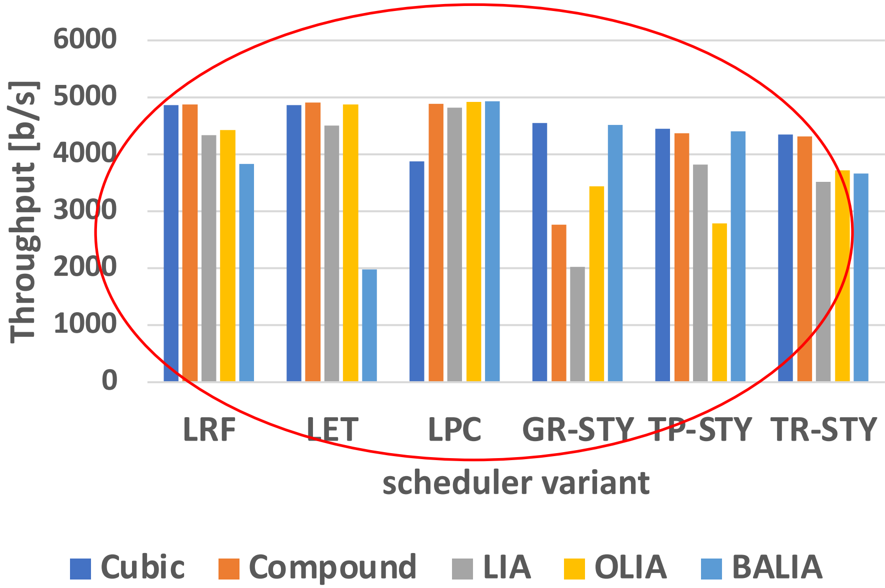
Buffer underflow



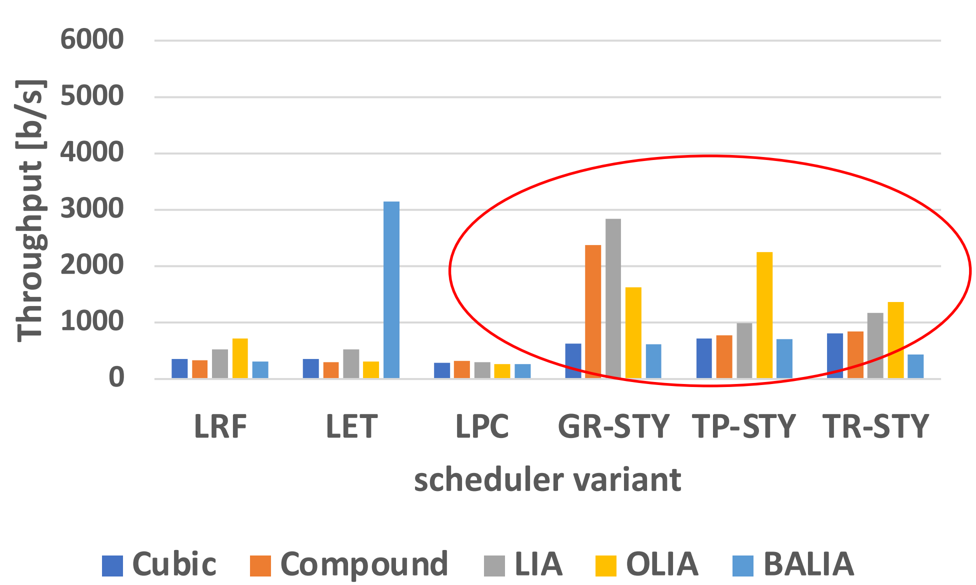
Picture discard

Scenario D : throughput

- Path properties
  - Wi-Fi: RTT=80ms Loss= 0%
  - LTE: RTT= 80ms Loss = 0%
- In scenario D, some video traffic still goes through Wi-Fi path
- If the RTT is similar, the number of path switching will increase and the video quality will degrade due to the occurrence of Head of line Blocking.



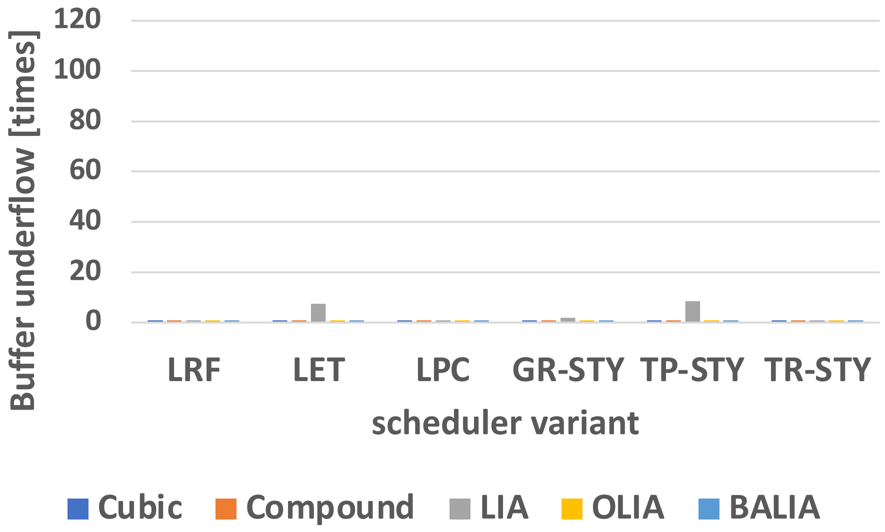
Throughput LTE



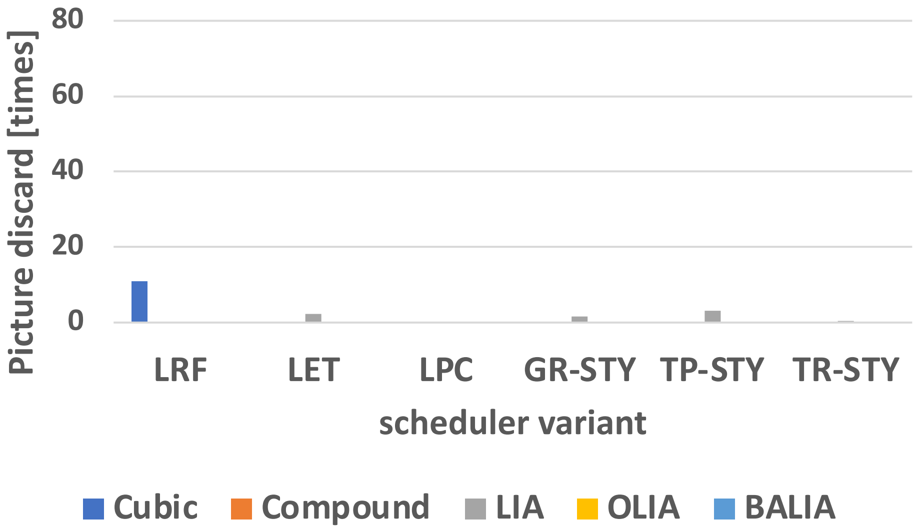
Throughput Wi-Fi

Scenario E : video performance

- Path properties
  - Wi-Fi: RTT=80ms Loss= 6%
  - LTE: RTT= 80ms Loss = 0%
- In scenario E, Video performance is excellent



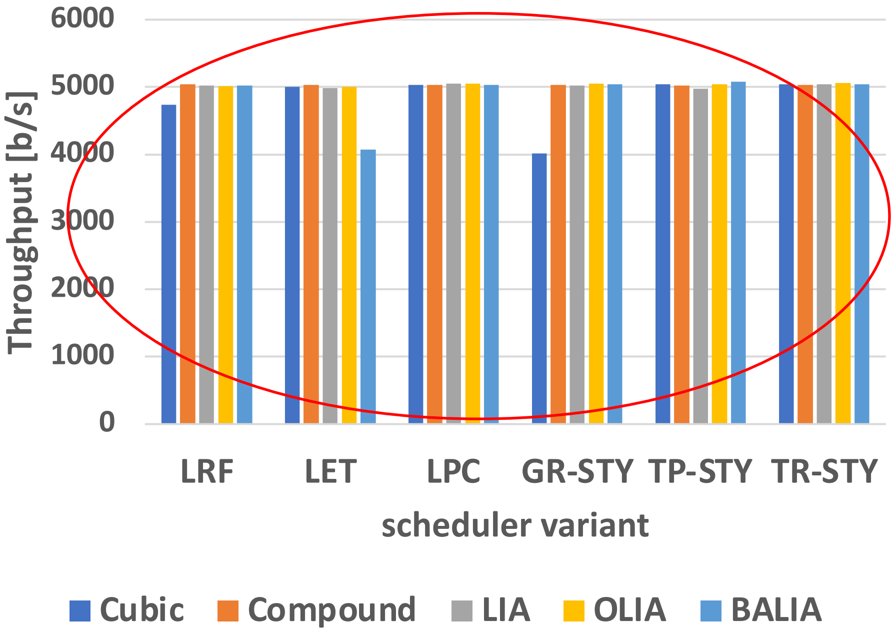
Buffer underflow



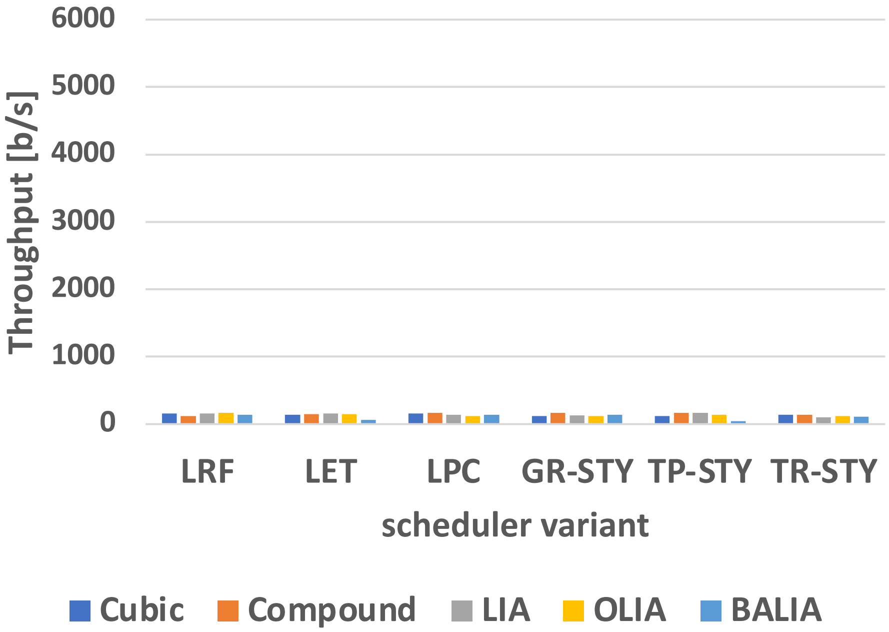
Picture discard

Scenario E : throughput

- Path properties
  - Wi-Fi: RTT=80ms Loss= 6%
  - LTE: RTT= 80ms Loss = 0%
- Even if the RTT is about the same, if there is packet loss in the Wi-Fi path, the window size will not increase and the Wi-Fi path will not be used.



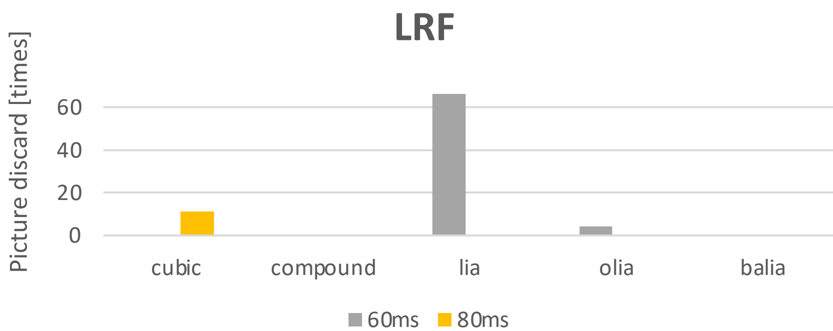
Throughput LTE

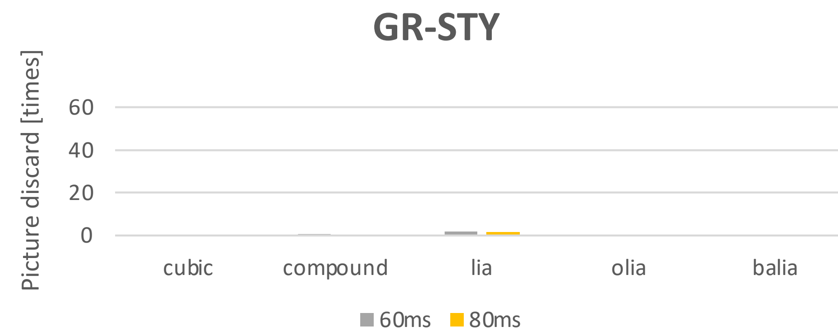


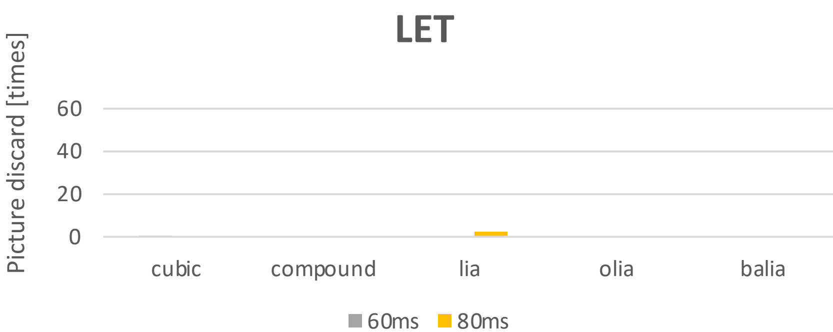
Throughput Wi-Fi

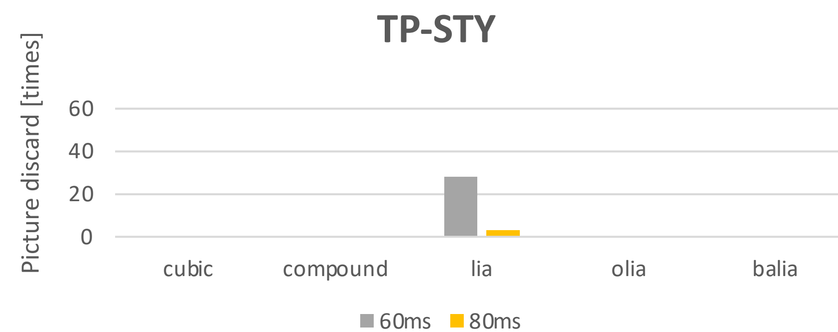
Results : evaluation

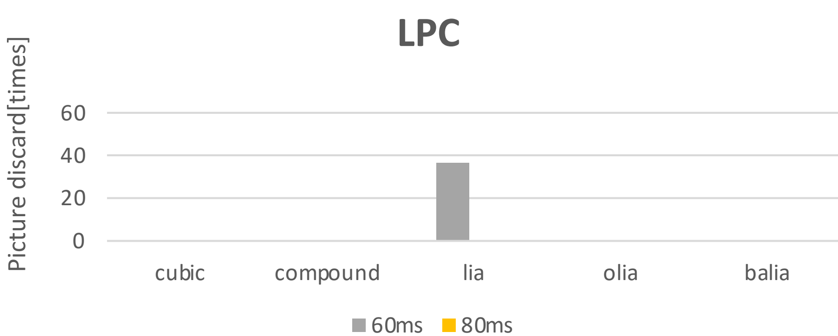
- Picture discard for each scheduler in scenario D and E
  - GR-STY and LET are good performance

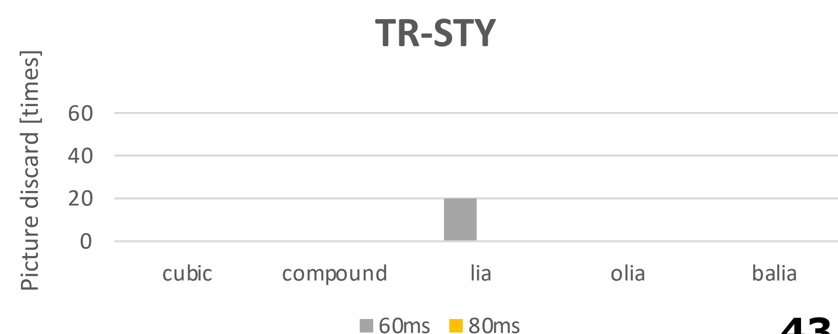






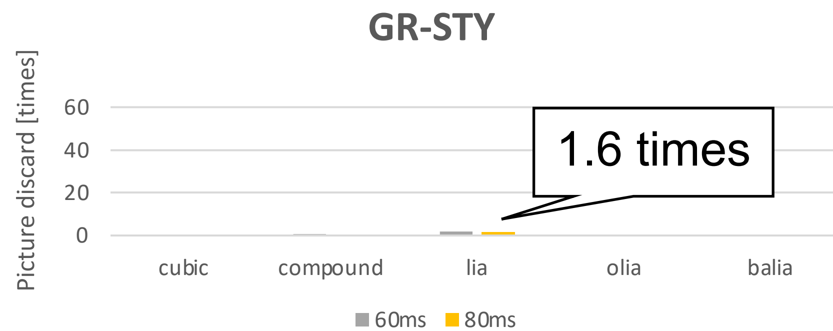


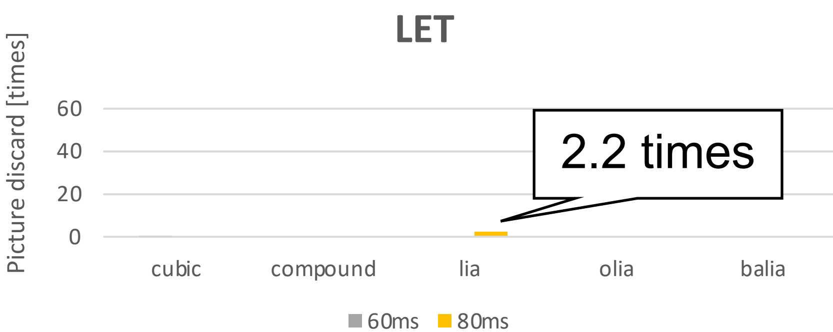


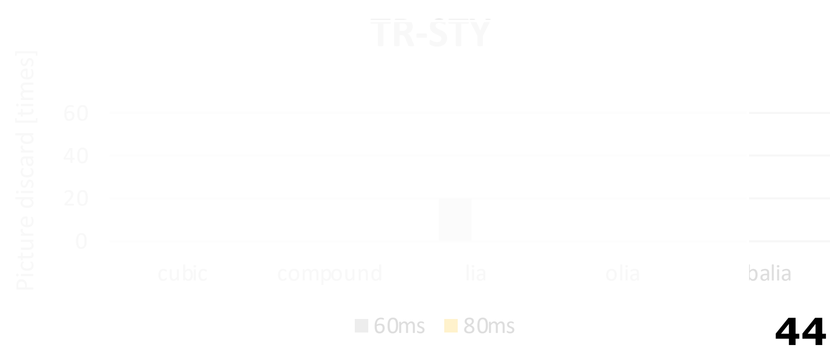


Results : evaluation

- Picture discard for each scheduler in scenario D and E
  - GR-STY is 1.6times
  - LET is 2.2times

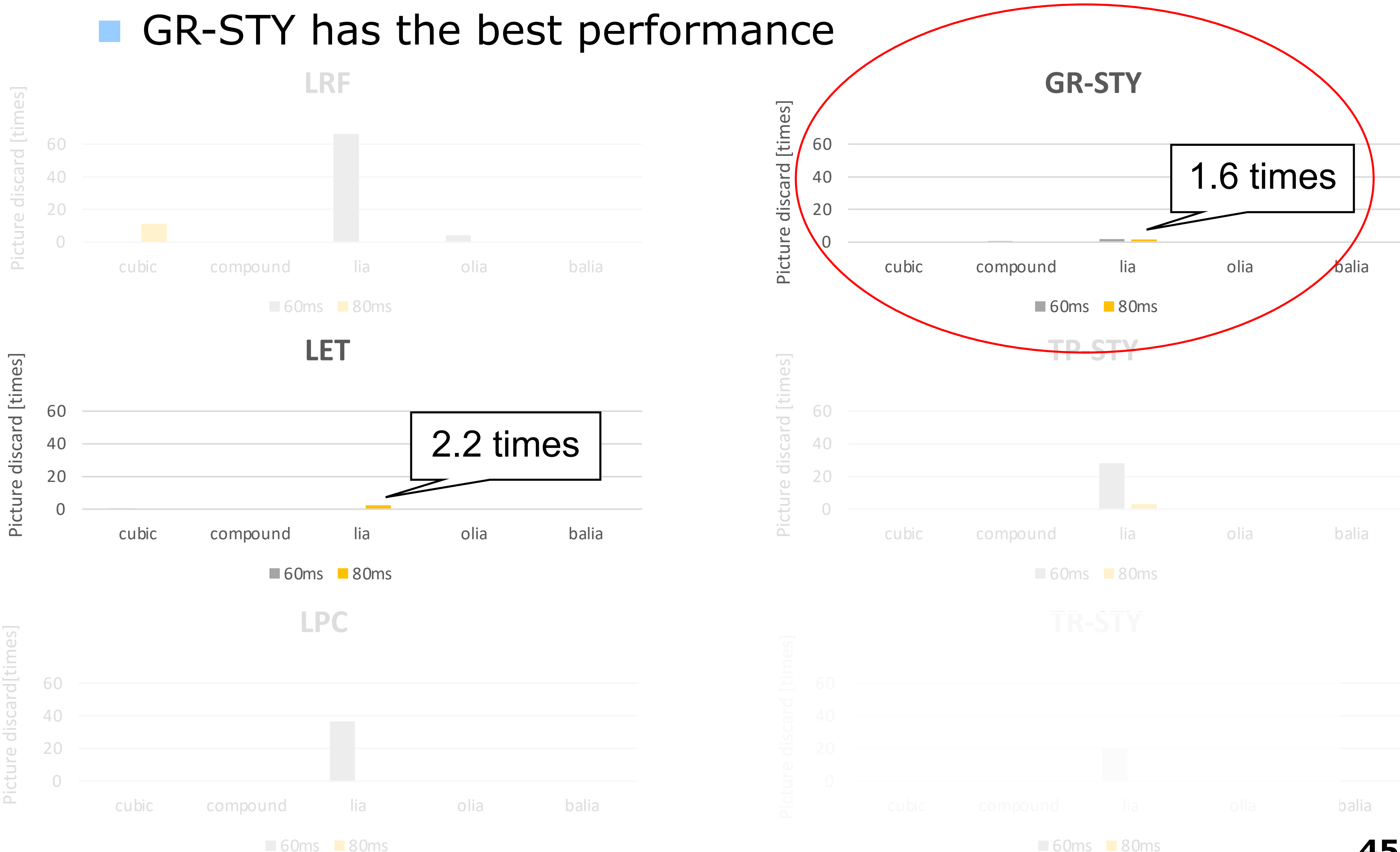






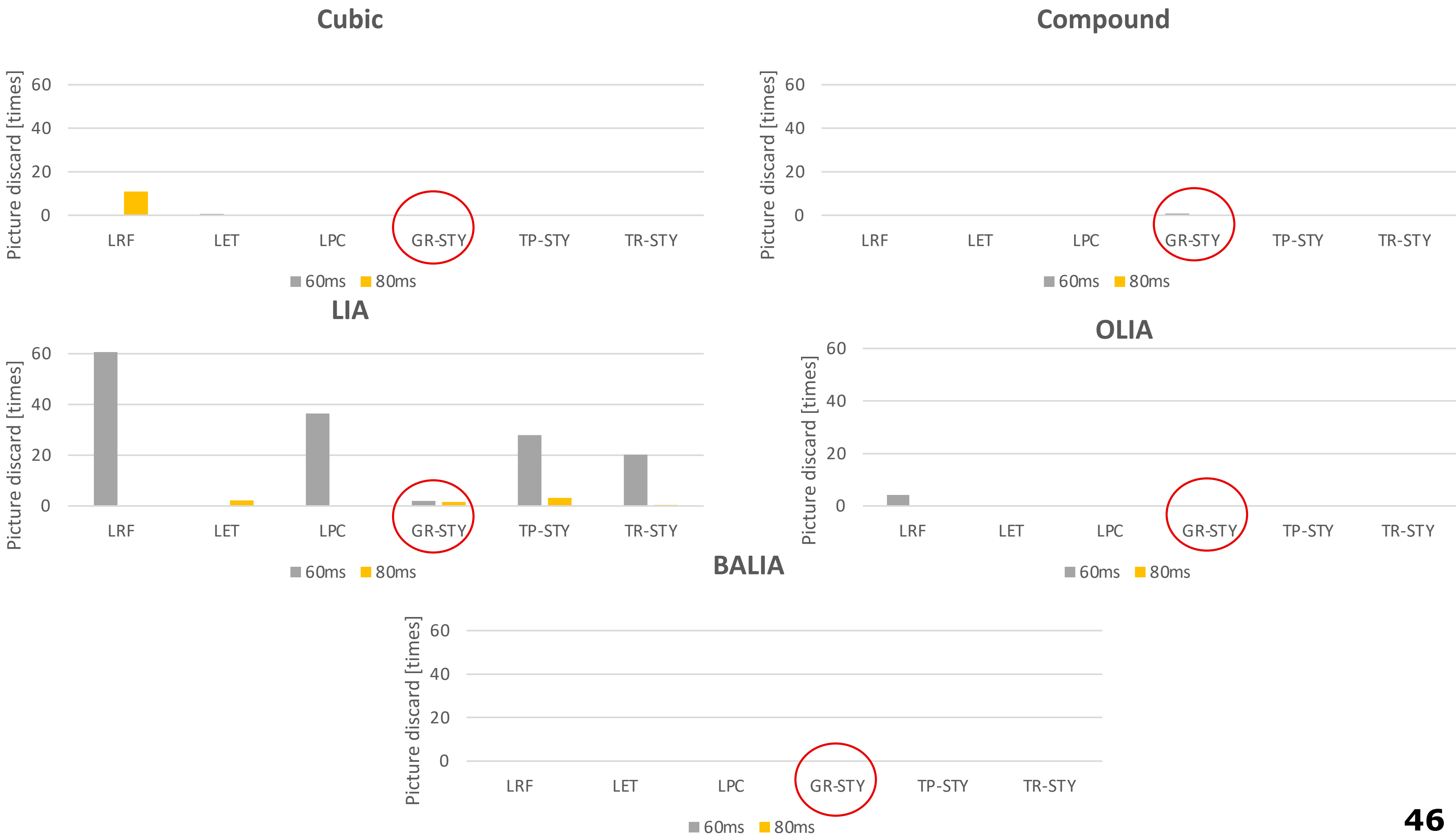
Results : evaluation

- Picture discard for each scheduler in scenario D and E
  - GR-STY has the best performance



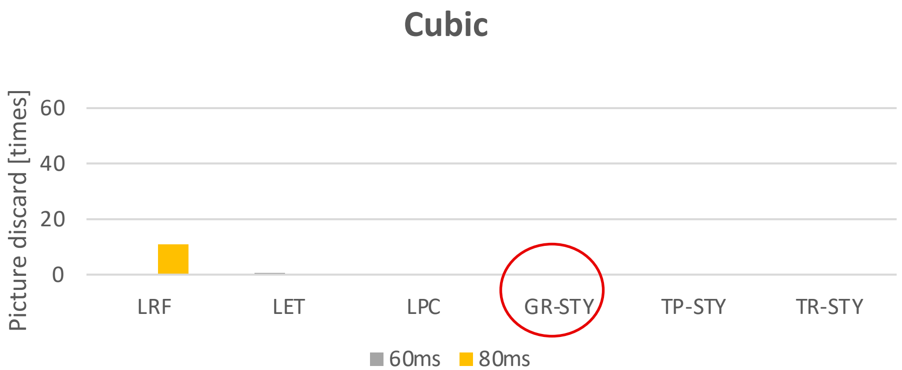
Results : evaluation

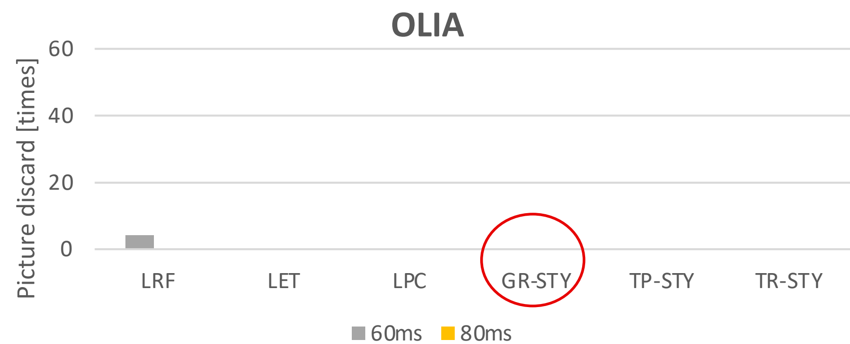
- Picture discard for each congestion control in scenario D and E
  - Focus on GR-STY

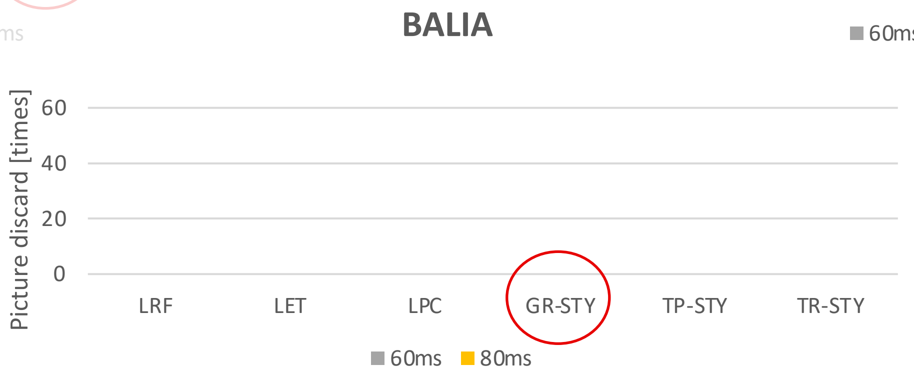


Results : evaluation

- Picture discard for each congestion control in scenario D and E
  - Cubic, OLIA and BALIA have the best performance

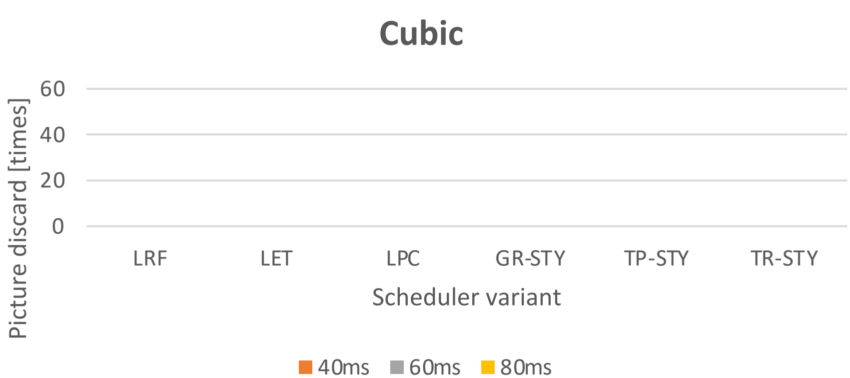


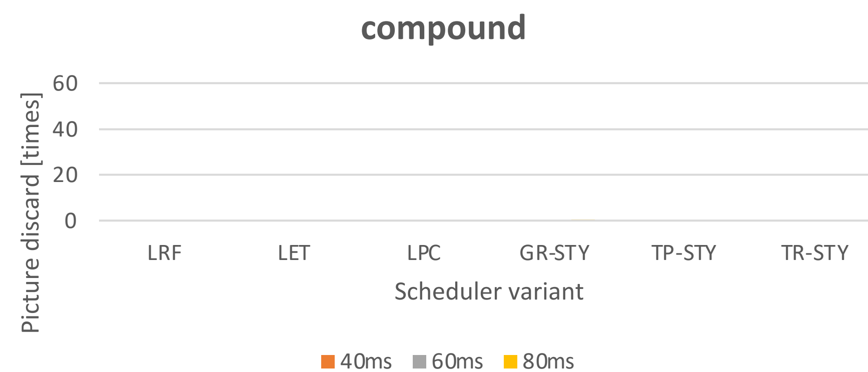


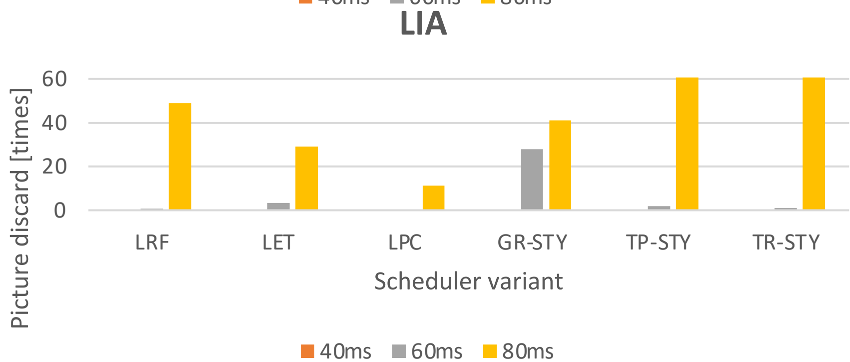


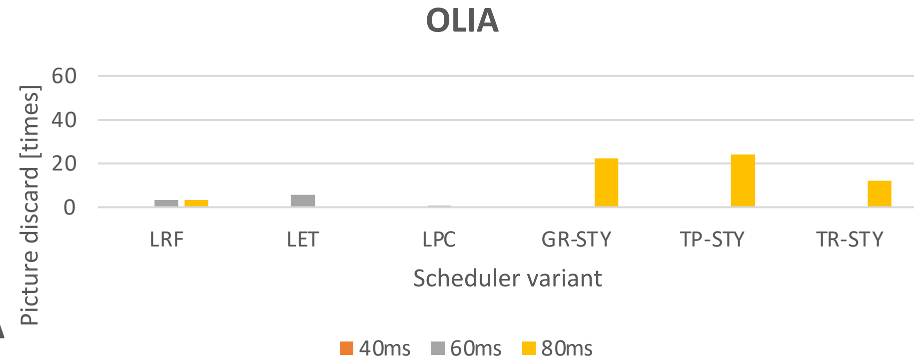
Results : evaluation

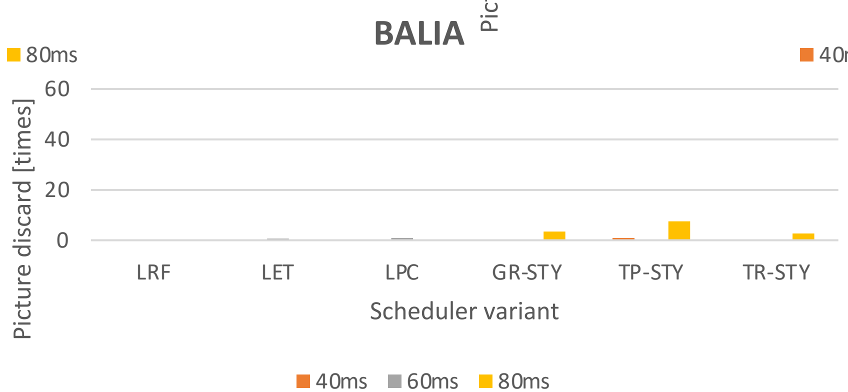
- Picture discard for each congestion control in scenario A, B and C





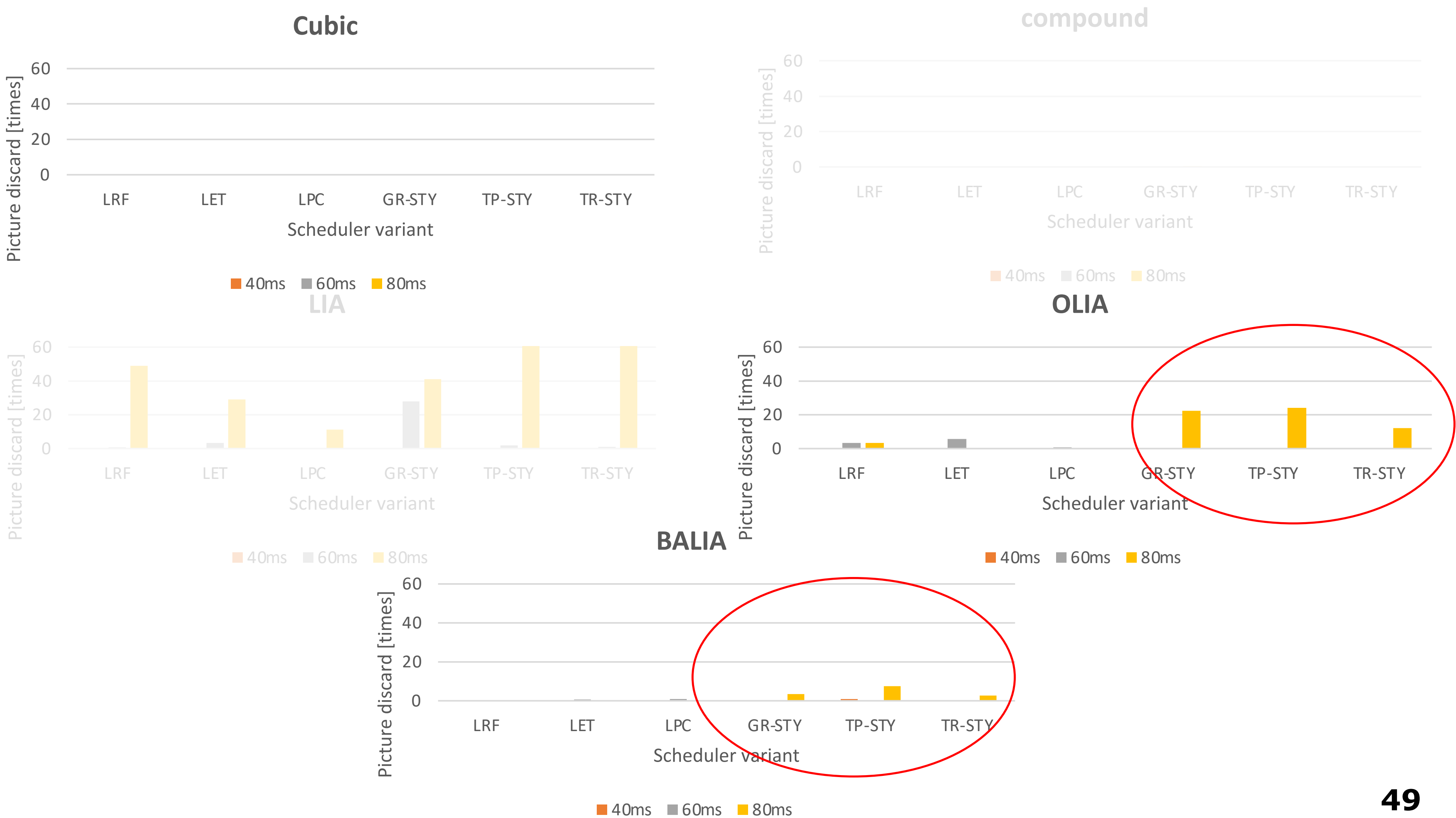






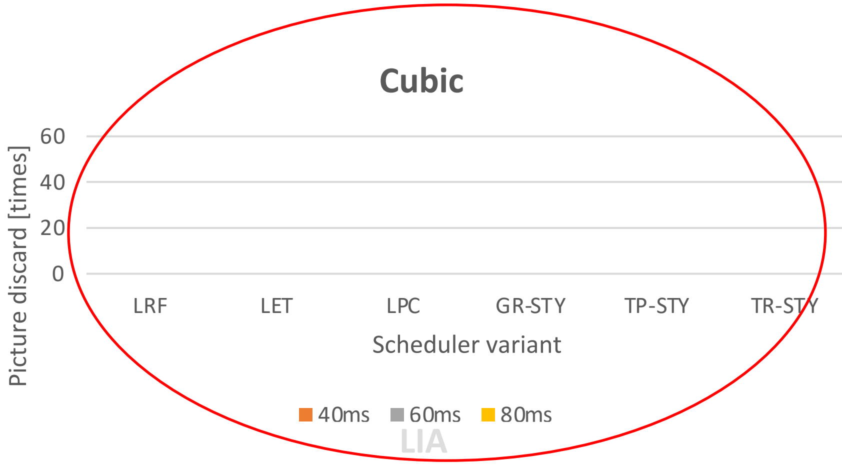
Results : evaluation

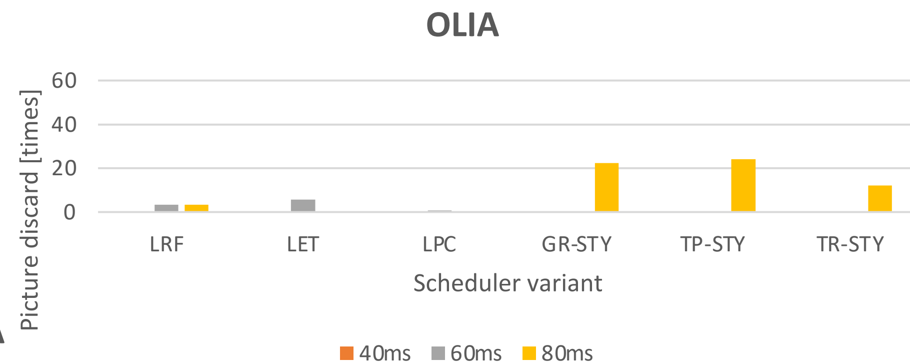
- Even though good performance of OLIA an BALIA in D and E, But bad performance of OLIA and BALIA

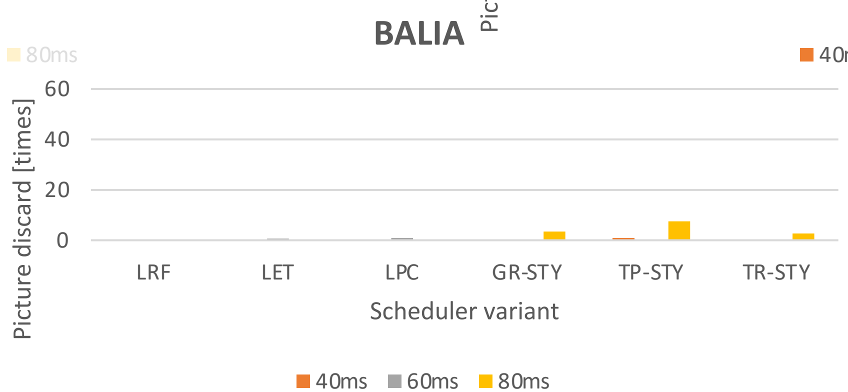


Results : evaluation

- Cubic has the best performance in all scenarios







Results : evaluation

- The best video streaming quality in the combination of Cubic and GR-STY

- We recommend that Cubic and GR-STY combination

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

- As the results, the combination of Cubic and GR-STY schedule is our recommended choice for MPTCP video streaming.