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

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Resume

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Field of Study
- MPTCP
- Transport Protocol
Mobile video traffic is increasing year by year.

The demand of video streaming has exploded.

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
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
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

Step 1: Scheduler determines the forwarding path

Step 2: TCP congestion control adjusts cwnd

MPTCP scheduler

4G / LTE

Wi-Fi

Client

Server
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

Step 3: Scheduler reorder the arrived packets
**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, incomplete video frames due to HOL blocking are discarded and degrade the video quality.

**Diagram:**
- Step 1: No.4 packet doesn't arrive at client
- Step 2: HOL Blocking occurs
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.
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
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 subtracted from the number of packets that have not been acknowledged yet.

LPC selects the path with largest available space
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

LET selects the path with largest throughput (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
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.
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.

TP-STY switches the path if the throughput of the new path is larger than that of the current.
**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.

TR-STY switches the path if it has smaller RTT and the throughput of the new path is larger than that of the current.
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

<table>
<thead>
<tr>
<th>Setting</th>
<th>Value</th>
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<tbody>
<tr>
<td>Video size</td>
<td>409 Mbytes</td>
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<tr>
<td>Video Rate</td>
<td>5.24 Mb/s</td>
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<tr>
<td>Playout time</td>
<td>10mins 24s</td>
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<tr>
<td>Encoding</td>
<td>MPEG-4</td>
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<tr>
<td>Video Codec</td>
<td>H.264/AVC</td>
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<tr>
<td>Audio Codec</td>
<td>MPEG-4 AAC</td>
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Table 2: MPTCP Settings

<table>
<thead>
<tr>
<th>MPTCP Schedulers</th>
<th>LRF (default)</th>
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<tbody>
<tr>
<td>LPC, LET</td>
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<td>GR-STY, TP-STY, TR-STY</td>
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</table>

<table>
<thead>
<tr>
<th>MPTCP Variants</th>
<th>Uncoupled</th>
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<td></td>
<td>Cubic</td>
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<tr>
<td></td>
<td>Compound</td>
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<td>OLIA</td>
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<tr>
<td></td>
<td>BALIA</td>
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</tbody>
</table>
Experimental Scenarios

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

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Path</th>
<th>Delay</th>
<th>Packet Loss</th>
<th>RTT</th>
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</thead>
<tbody>
<tr>
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<td>0%</td>
<td>RTT 80ms</td>
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<tr>
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<td>Wi-Fi</td>
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<td></td>
<td>RTT 40ms</td>
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<tr>
<td>B</td>
<td>LTE</td>
<td>0ms</td>
<td>0%</td>
<td>RTT 80ms</td>
</tr>
<tr>
<td></td>
<td>Wi-Fi</td>
<td>30ms</td>
<td></td>
<td>RTT 60ms</td>
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<tr>
<td>C</td>
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<td>0ms</td>
<td>0%</td>
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## Scenarios A

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

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**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

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<td>0%</td>
<td>RTT 80ms</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>scenarios</th>
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<th>Packet loss</th>
<th>RTT</th>
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<tbody>
<tr>
<td>A</td>
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<td>RTT 80ms RTT 40ms</td>
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<td>B</td>
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<td>0%</td>
<td>RTT 80ms RTT 60ms</td>
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<td>LTE</td>
<td>0ms</td>
<td>0%</td>
<td>RTT 80ms</td>
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</table>
Performance evaluation index

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

<table>
<thead>
<tr>
<th>Buffer underflow [times]</th>
<th>LRF</th>
<th>LET</th>
<th>LPC</th>
<th>GR-STY</th>
<th>TP-STY</th>
<th>TR-STY</th>
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Picture discard

<table>
<thead>
<tr>
<th>Picture discard [times]</th>
<th>LRF</th>
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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.
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 à 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 Graphs]

Throughput LTE

Throughput Wi-Fi

Scheduler variants:
- Cubic
- Compound
- LIA
- OLIA
- BALIA
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

<table>
<thead>
<tr>
<th>Scheduler Variant</th>
<th>Cubic</th>
<th>Compound</th>
<th>LIA</th>
<th>OLIA</th>
<th>BALIA</th>
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<tbody>
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Picture discard

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</table>
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.
Scenario E: video performance

◆ Path properties
  - Wi-Fi: RTT=80ms Loss= 6%
  - LTE: RTT= 80ms Loss = 0%

◆ In scenario E, Video performance is excellent
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 1.6 times
  - LET is 2.2 times
Results: evaluation

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

- Picture discard for LRF
- Picture discard for LET
- Picture discard for LPC
- Picture discard for GR-STY
- Picture discard for TP-STY
- Picture discard for TR-STY
Results: evaluation

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

Cubic

- LRF
- LET
- LPC
- GR-STY
- TP-STY
- TR-STY

Graphs showing picture discard times for Cubic scenario with GR-STY highlighted.

Compound

- LRF
- LET
- LPC
- GR-STY
- TP-STY
- TR-STY

Graphs showing picture discard times for Compound scenario with GR-STY highlighted.

LIA

- LRF
- LET
- LPC
- GR-STY
- TP-STY
- TR-STY

Graphs showing picture discard times for LIA scenario with GR-STY highlighted.

OLIA

- LRF
- LET
- LPC
- GR-STY
- TP-STY
- TR-STY

Graphs showing picture discard times for OLIA scenario with GR-STY highlighted.

BALIA

- LRF
- LET
- LPC
- GR-STY
- TP-STY
- TR-STY

Graphs showing picture discard times for BALIA scenario with GR-STY highlighted.
Results: evaluation

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

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

- Even though good performance of OLIA and BALIA in D and E,
  But bad performance of OLIA and BALIA
Results: evaluation

- Cubic has the best performance in all scenarios
The best video streaming quality in the combination of *Cubic* and *GR-STY*

We recommend that Cubic and GR-STY combination
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.