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# Performance evaluation of Multipath TCP Video Streaming on LEO Satellite/Cellular Networks

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# About Me



- Yosuke Komatsu
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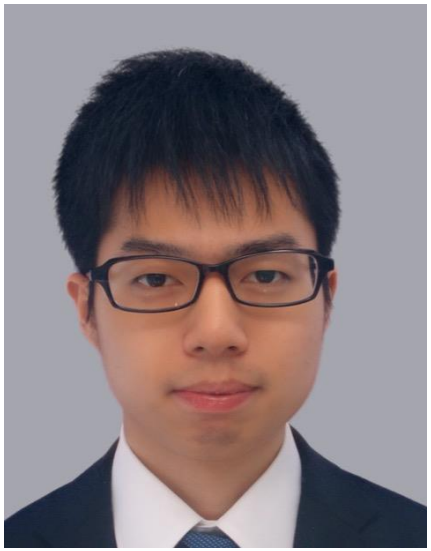
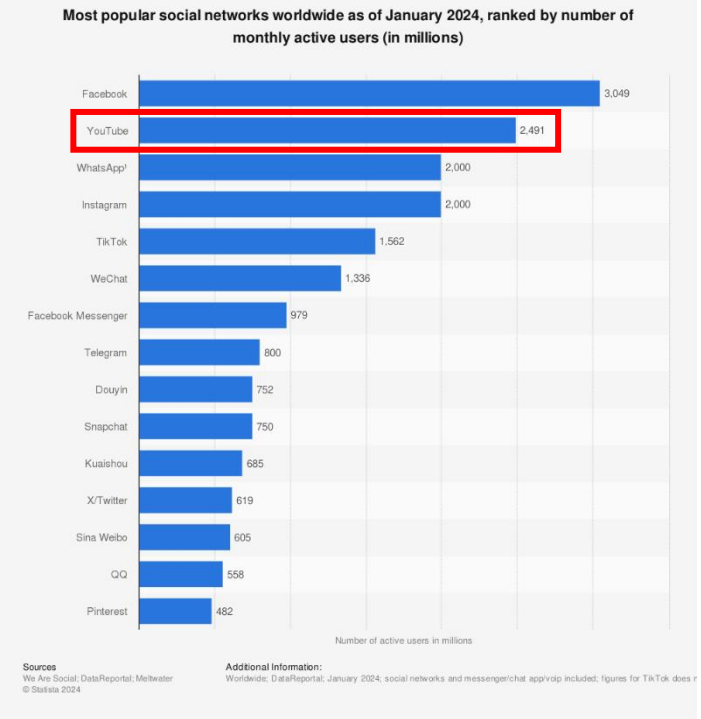
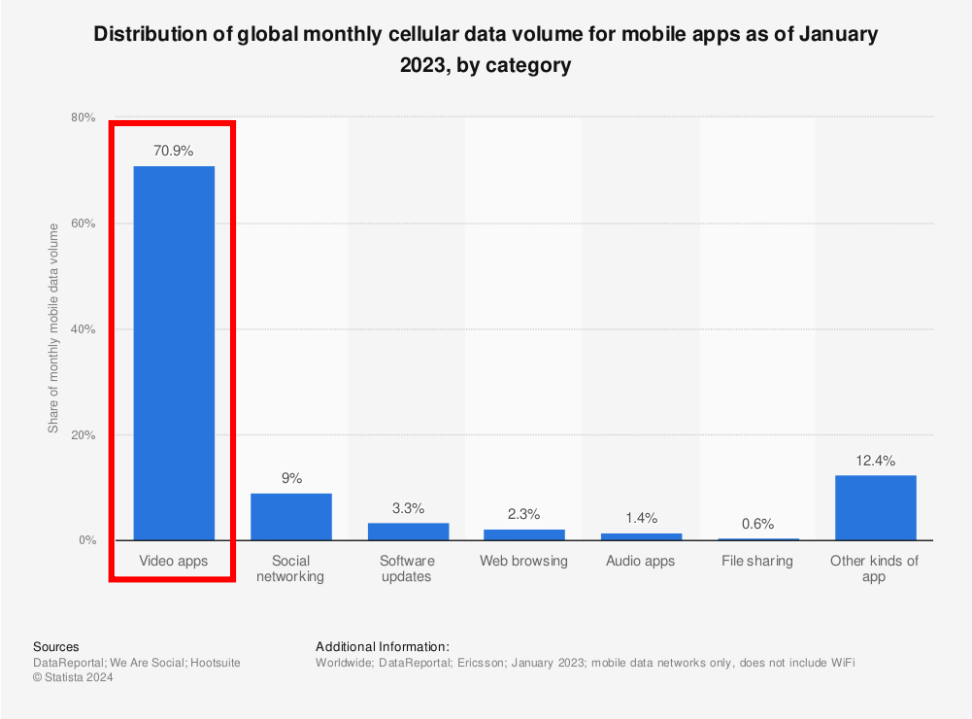


- Field of Study
  - MPTCP
  - Transport Protocol

# About Video Streaming

- Popularity of video streaming and mobile data
  - YouTube has about 2.5 billion monthly active users
  - Video apps account about 70% for mobile data volume




https://www.statista.com/statistics/272014/global-social-networks-ranked-by-number-of-users/

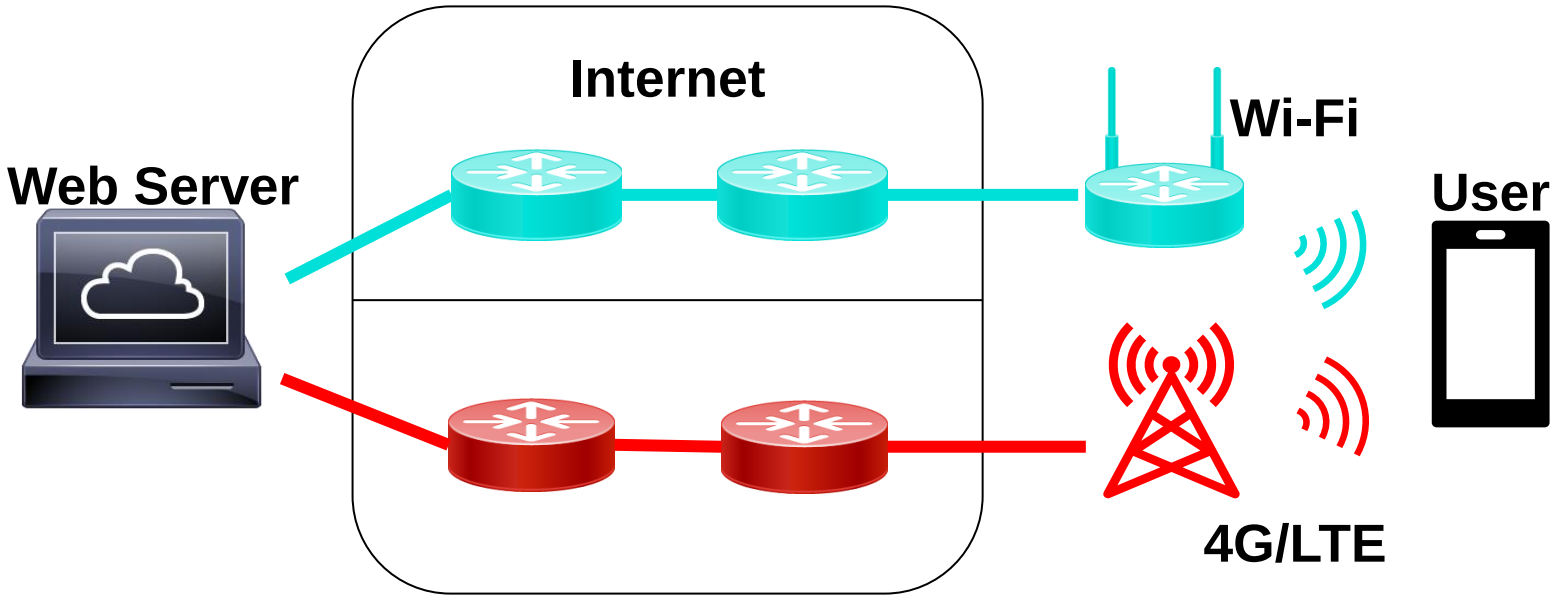
https://www.statista.com/statistics/383715/global-mobile-data-traffic-share/

# Mobile network and Video Streaming



- Video Streaming over mobile network
  - Various broadband wireless access: 4G/5G/Wi-Fi
  - Mobile devices have multiple wireless interfaces
  - Interfaces are changed dynamically depending on coverage situation

- The simultaneous use of these interfaces can increase efficiency and stability of communication

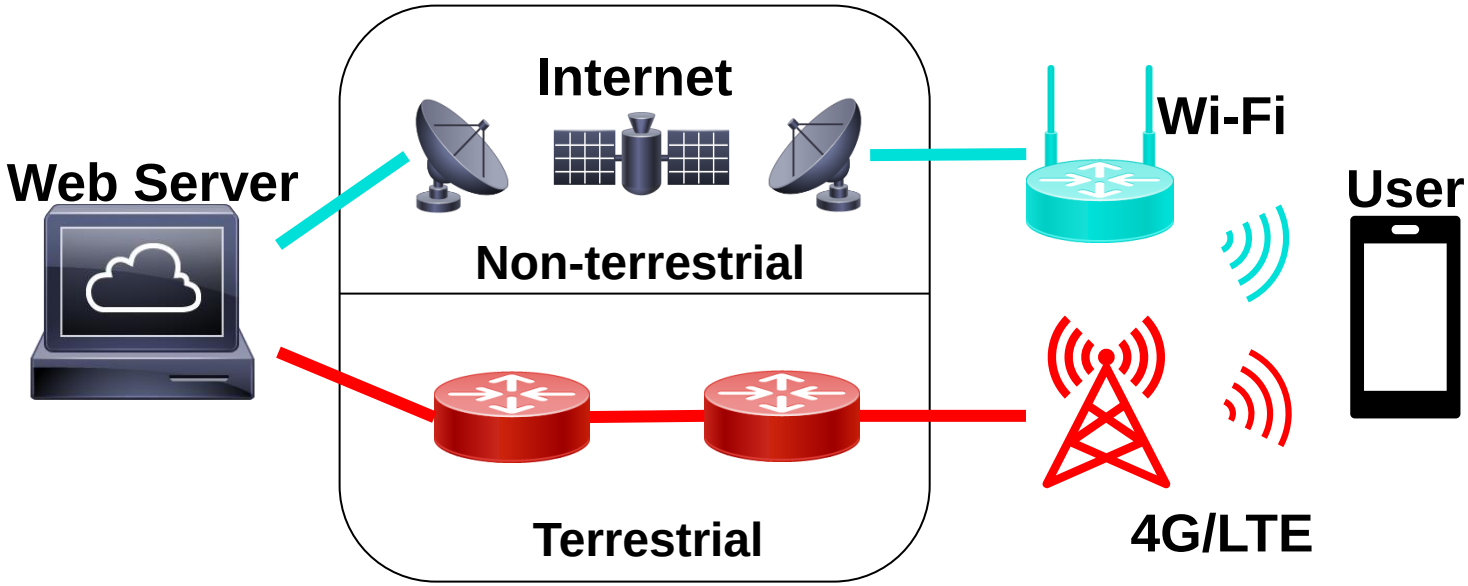


# Making use of Non-terrestrial network



- LEO satellite communication (ex. Starlink)
  - Provides high throughput and short delay
  - Enables coverage on remote locations, where it is difficult to provide communication infrastructure

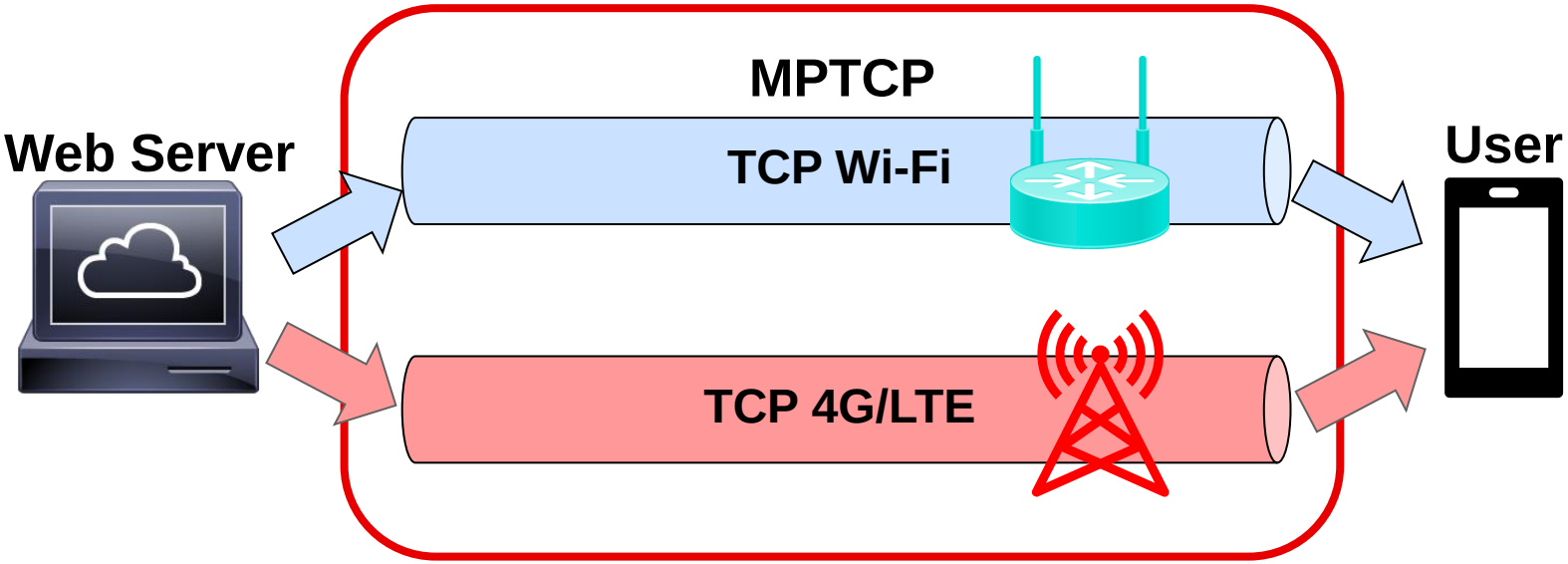
- Expected synergy between cellular and LEO satellite network



# Multipath TCP #1



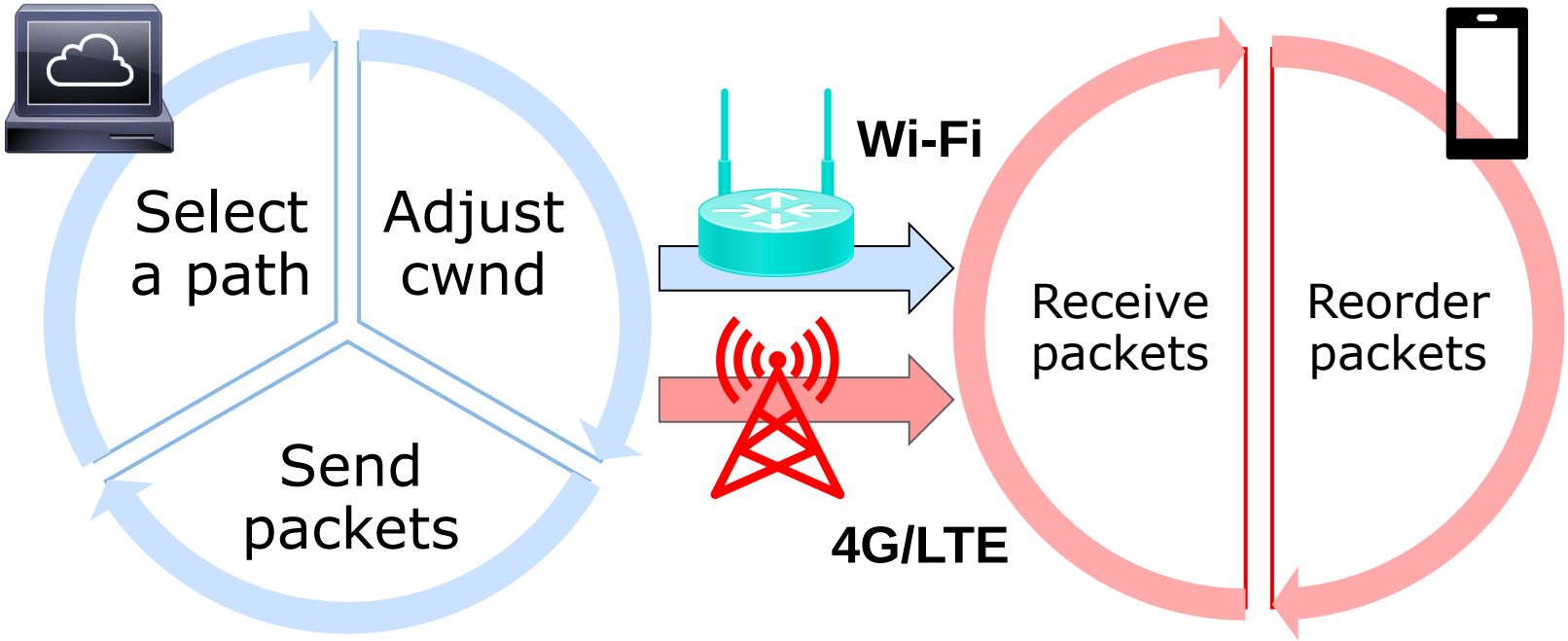
- Multipath TCP (MPTCP)
  - Uses multiple paths simultaneously
  - Enables improvement on:
    - throughput for applications
    - stability of communication



# Multipath TCP #2

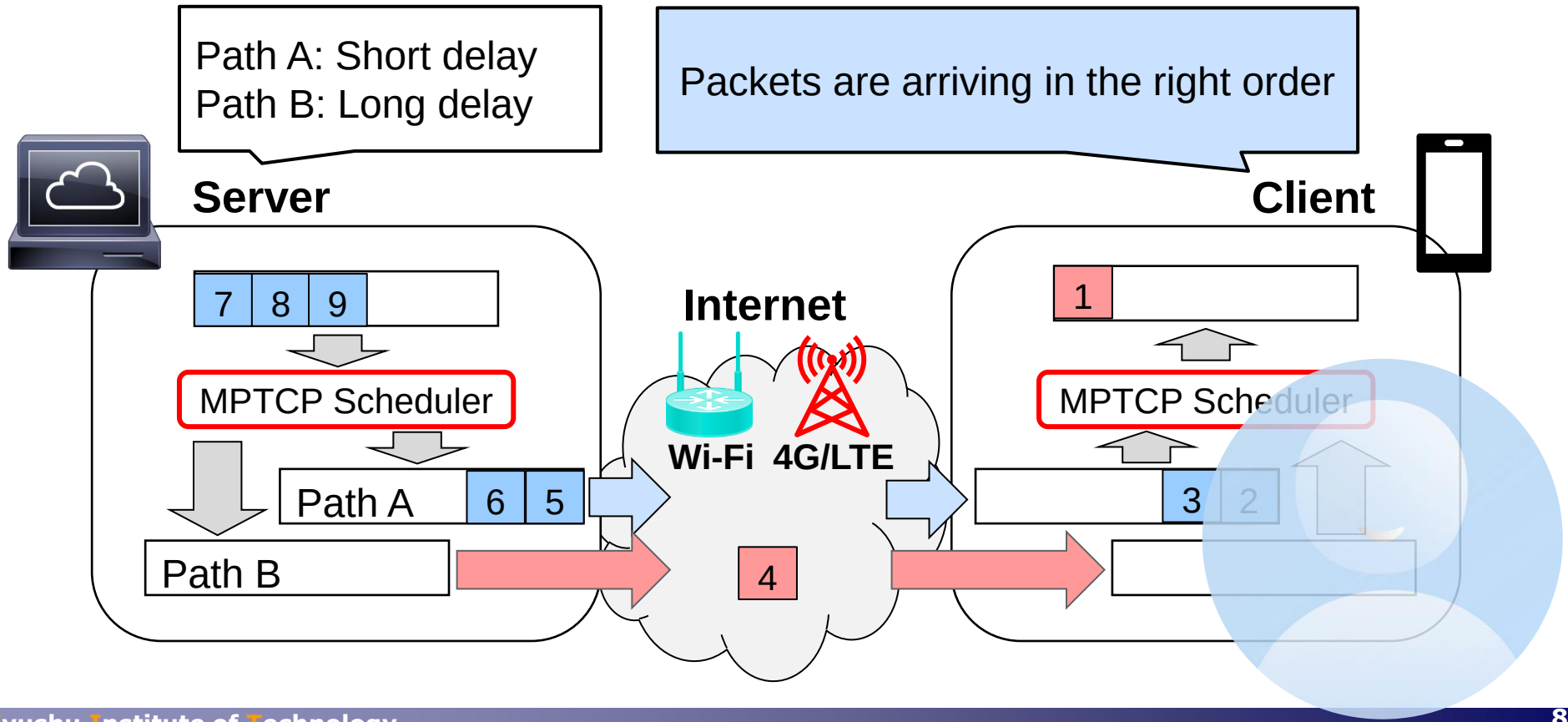


- MPTCP scheduler
  - Determination a path to forward packets
- MPTCP congestion control
  - Adjusts congestion window (cwnd) size as well as conventional TCP congestion controls



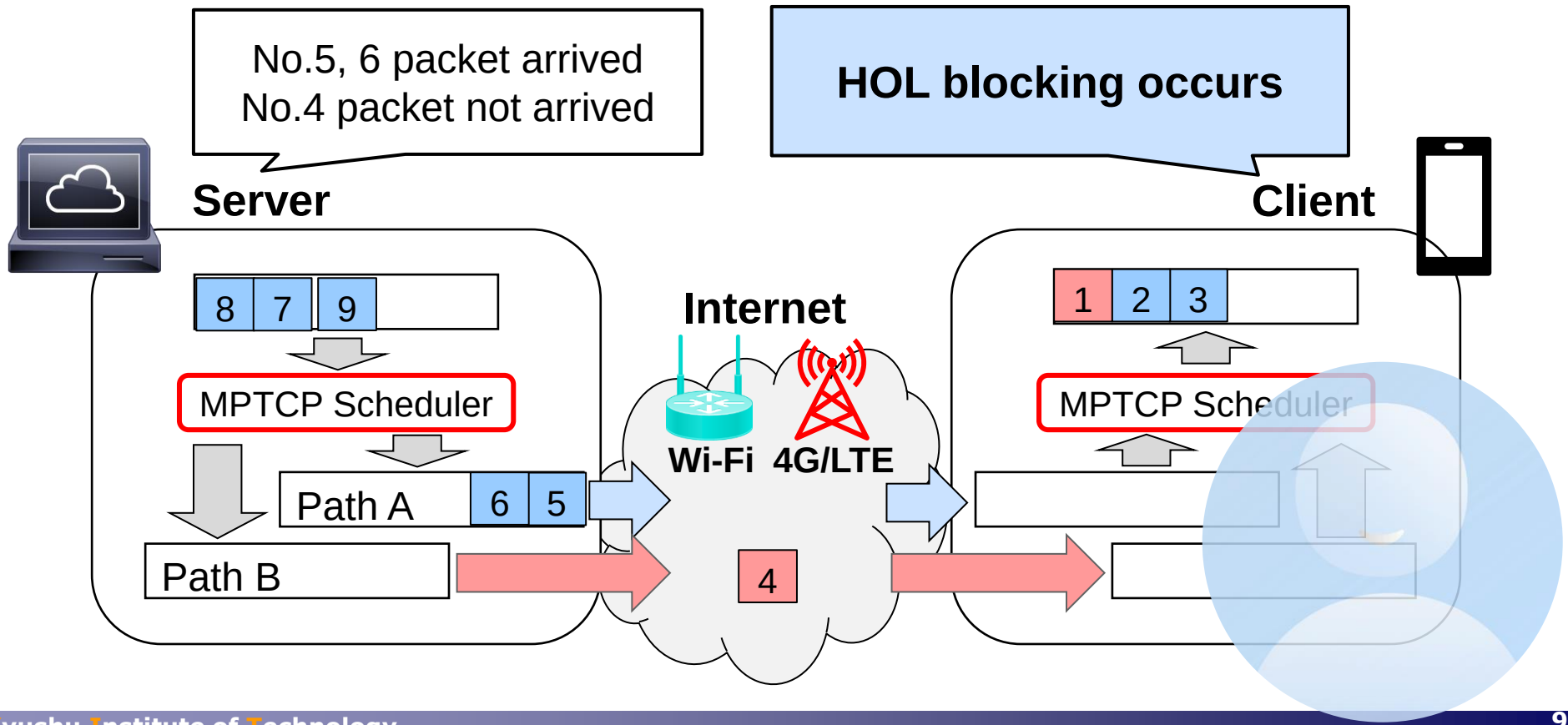
# Multipath TCP #3

- Head of Line Blocking (HOL blocking)
  - HOL blocking can occur by a packet that should have arrived first but is has not arrived at client due to loss or delay fluctuation



# Multipath TCP #4

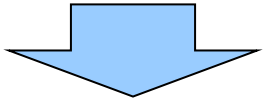
- Head of Line Blocking (HOL blocking)
  - HOL blocking can occur by a packet that should have arrived first but is has not arrived at client due to loss or delay fluctuation



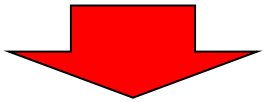
# Purpose of this study



Occurrence of HOL blocking varies in asymmetric paths' characteristics



Proposal is to research MPTCP performance over cellular and LEO satellite mixed network environment



Evaluate video streaming quality over MPTCP with 4G/LTE and Starlink

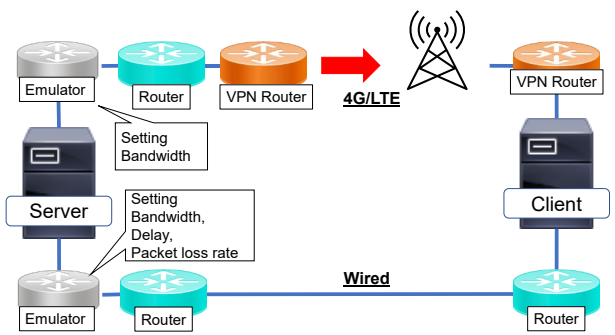
# Experimental Environment



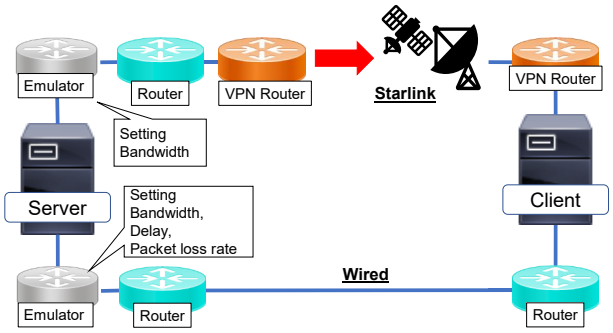
- Server
  - Linux (kernel version 6.1.31)
  - Nginx video server
  - Connected to emulators and routers
- Client
  - Linux (kernel version 6.1.31)
  - Connected to routers and 4G/LTE and/or Starlink

| Video setting | |
|---|---|
| Video size | 118MBytes |
| Video Rate | 5.24Mb/s |
| Playout time | 3 mins |
| Encoding | MPEG-4 |
| Video Codec | H264 AVC |
| Audio Codec | MPEG-4-AAC |

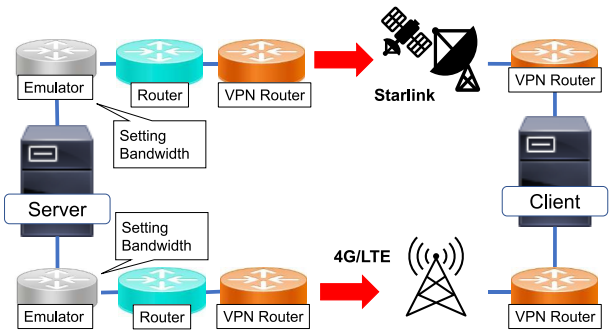
| MPTCP setting | |
|---|---|
| MPTCP scheduler | Default |
| MPTCP Variants | CUBIC, BBR |




Scenario A




Scenario B

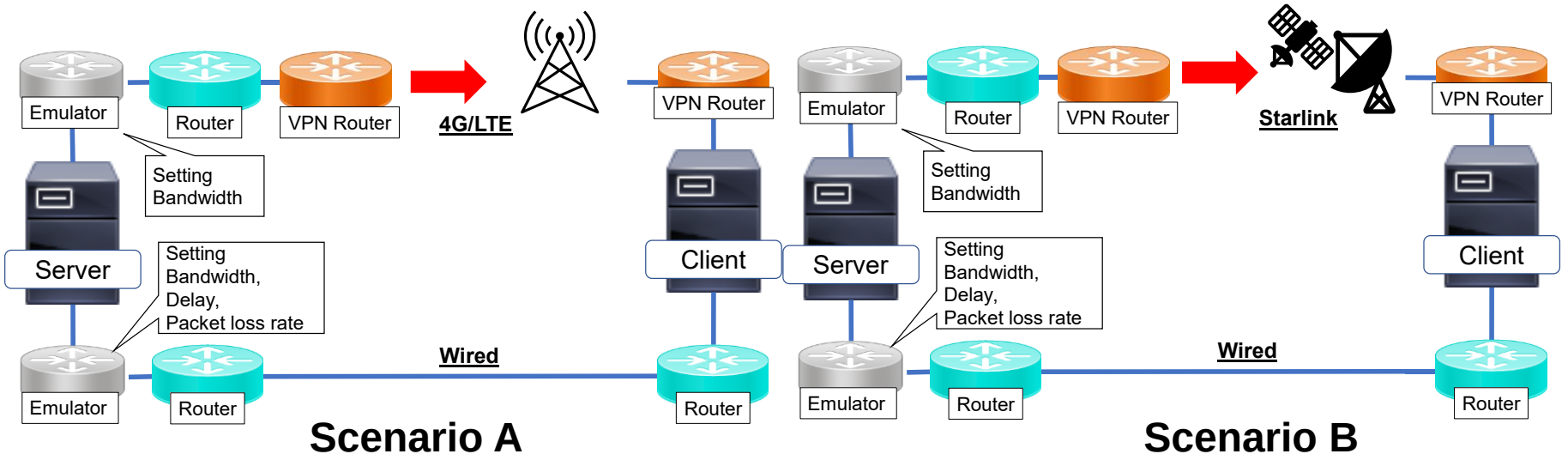



Scenario C

# Experimental Scenarios #1



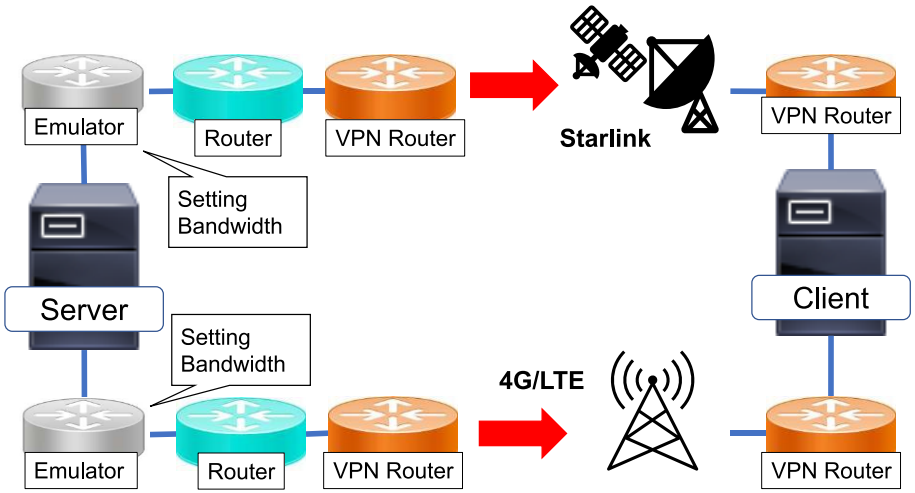
- Scenarios A and B
  - Wired and 4G/LTE or Starlink
  - Five video streaming sessions (trials) were conducted in each TCP variant
- Emulator setting
  - Bandwidth: 3Mb/s
  - Delay: 60ms or 90ms
  - Packet loss rate: 0.5%



# Experimental Scenarios #2



- Scenario C
  - Starlink and 4G/LTE
  - Five video streaming sessions (trials) were conducted in each TCP variant
  - Conducted experiment for two initial flow patterns (Starlink or 4G/LTE)
    - Initial flow…The path to connect to the server first with MPTCP
- Emulator setting
  - Bandwidth: 3Mb/s




Scenario C

# Performance evaluation metrics



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

Picture discard, Buffer underflow and Retransmission average over five trials.

cwnd dynamics of a sample (first) trial

# Scenario A Results#1



- Emulator setting
  - Bandwidth: 3Mb/s
  - Delay: 60ms or 90ms
  - Packet loss rate: 0.5%

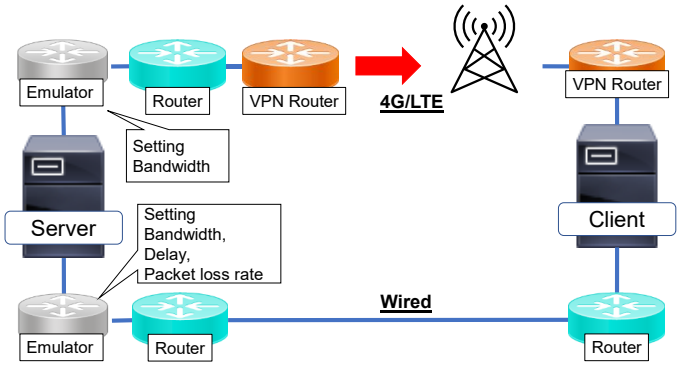
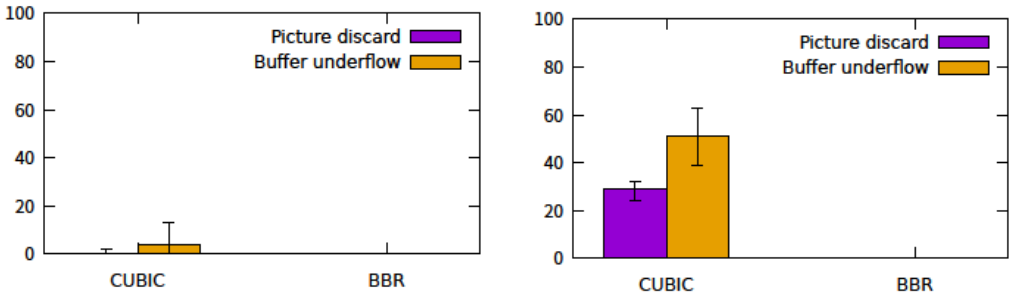



Fig.A-1

- BBR has good performance
- CUBIC is affected by Wired side delay, but it depends on the length of it

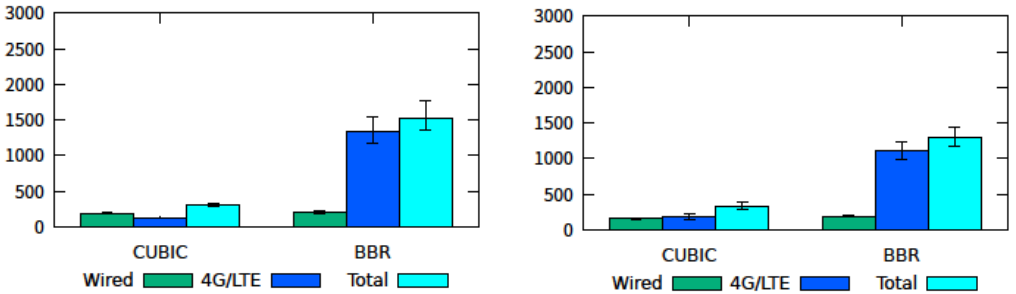



(a) 60ms (b) 90ms

Fig.A-1 Picture discard and buffer underflow.

Fig.A-2

- BBR has many retransmitted packets, mostly towards 4G/LTE
- No significant change due to delay time




(a) 60ms (b) 90ms

Fig.A-2 Retransmission.

# Scenario A Results#2



- Emulator setting
  - Bandwidth: 3Mb/s
  - Delay: 60ms or 90ms
  - Packet loss rate: 0.5%

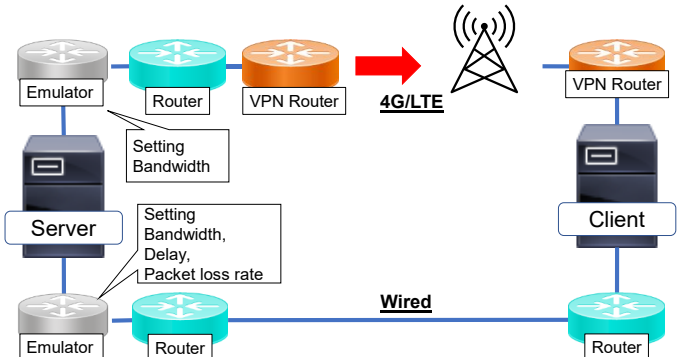
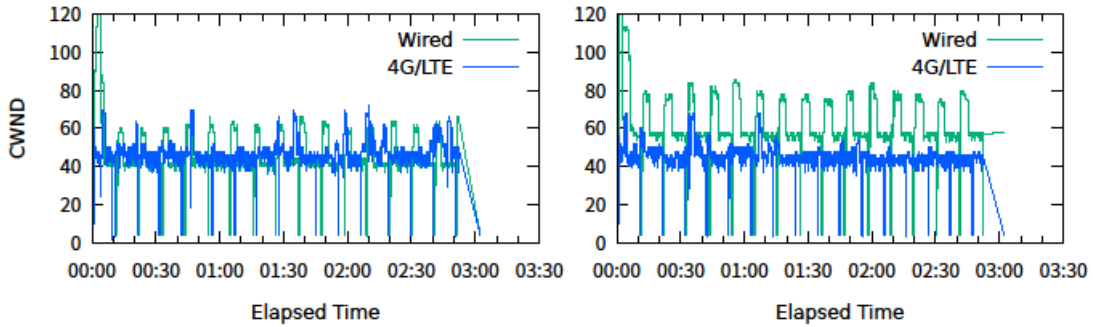


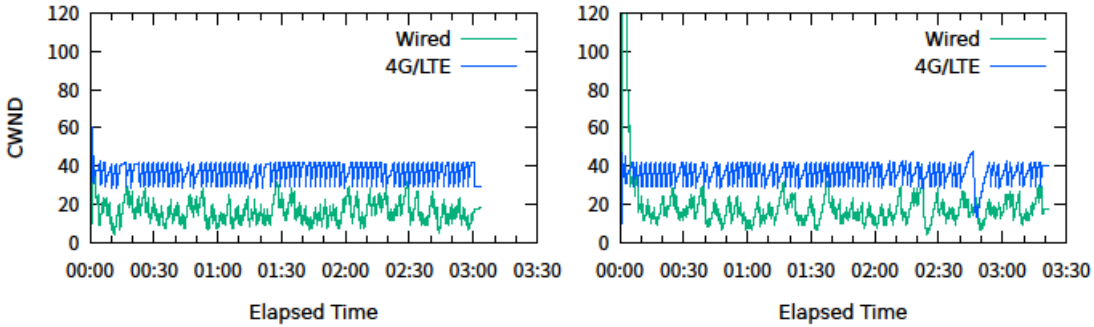

Fig.A-3 (BBR)
- cwnd on both paths is used fairly




(a) 60ms (b) 90ms

Fig.A-3 BBR cwnd.

Fig.A-4 (CUBIC)
- cwnd for 4G/LTE remains around 40, but it is lower on the Wired side
- When delay is 90 ms, data could not be sent during 3 minutes




(a) 60ms (b) 90ms

Fig.A-4 CUBIC cwnd.

# Scenario B Results#1



- Emulator setting
  - Bandwidth: 3Mb/s
  - Delay: 60ms or 90ms
  - Packet loss rate: 0.5%

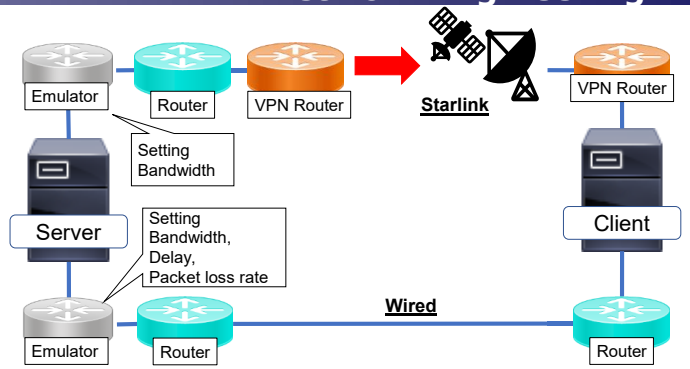
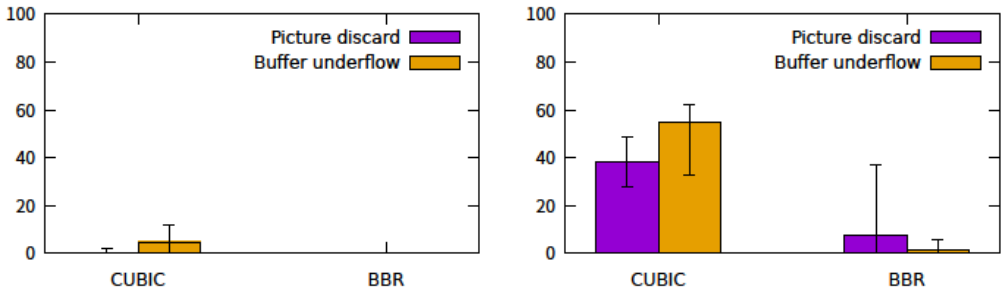



Fig.B-1

- BBR performance is better than CUBIC
- but sometimes BBR shows bad performance similar to CUBIC in the case of delay 90 ms

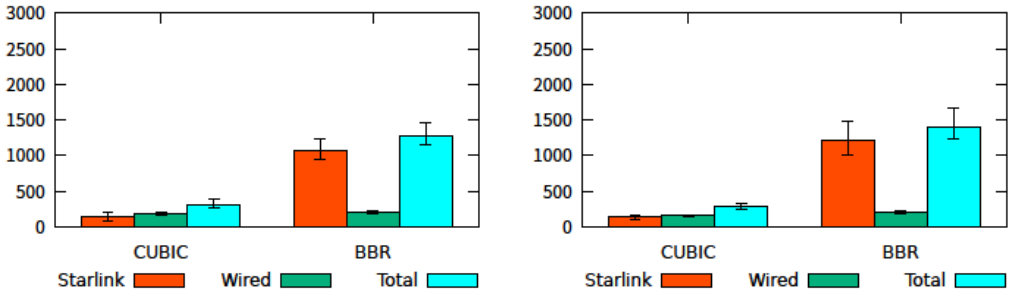



(a) 60ms (b) 90ms

Fig.B-1 Picture discard and buffer underflow.

Fig.B-2

- BBR has many retransmitted packets, mostly towards Starlink
- No significant change due to delay time




(a) 60ms (b) 90ms

Fig.B-2 Retransmission.

# Scenario B Results#2



- Emulator setting
  - Bandwidth: 3Mb/s
  - Delay: 60ms or 90ms
  - Packet loss rate: 0.5%

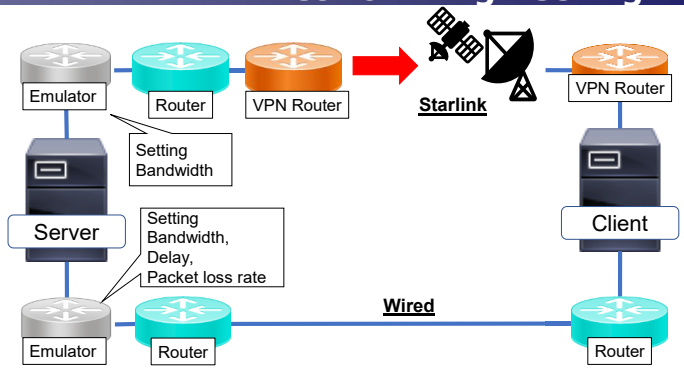
Fig.B-3 (BBR)

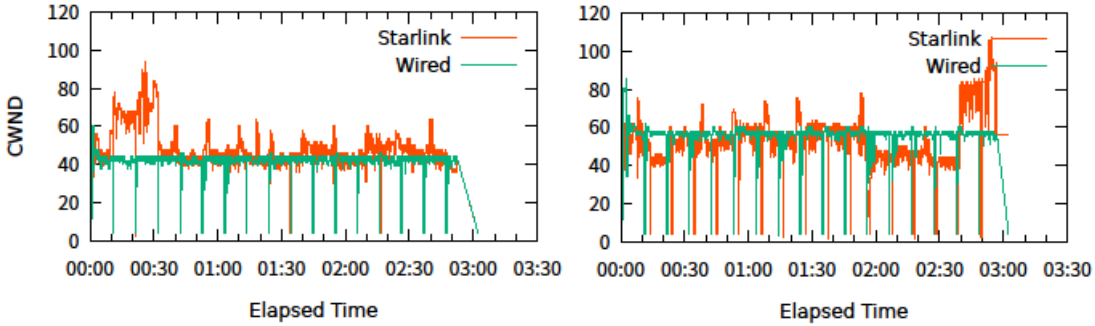
- cwnd for Starlink shows occasional fluctuations

Fig.B-4 (CUBIC)

- cwnd for Starlink shows occasional fluctuations
- When the delay is 90 ms, data could not be sent during 3 minutes

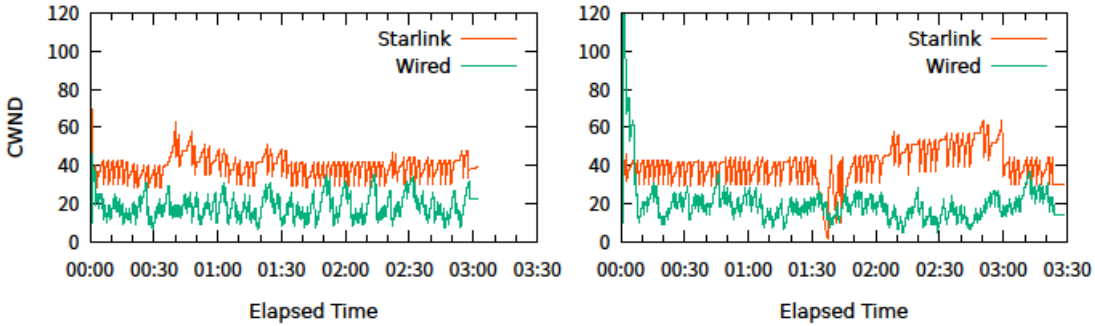
Starlink cwnd may be influenced during transmission and reception between satellite and dish




(a) 60ms (b) 90ms

Fig.B-3 BBR cwnd.




(a) 60ms (b) 90ms

Fig.B-4 CUBIC cwnd.

# Scenario C Results#1



- Emulator setting
  - Bandwidth: 3Mb/s

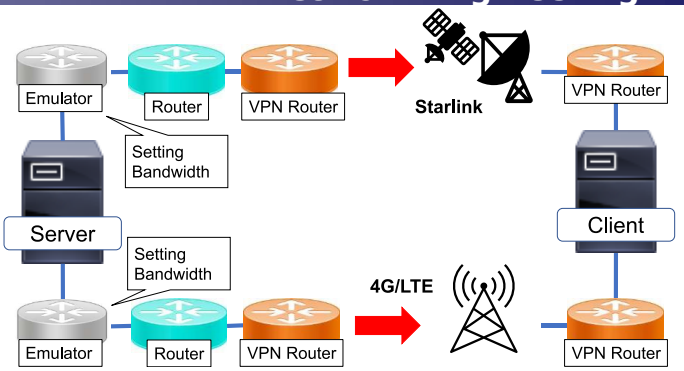
Fig.C-1

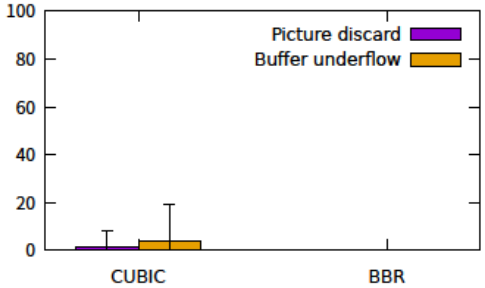
- BBR has good performance
- CUBIC may sometimes have poor performance

Fig.C-2

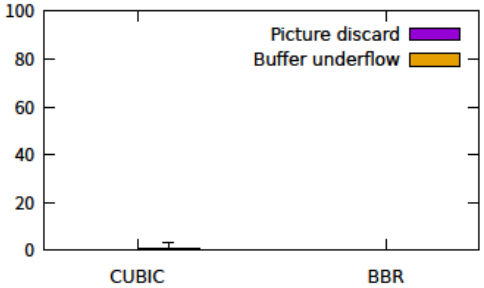
- BBR has many retransmitted packets, which are about the same on both paths

- BBR has the potential to perform well on cellular and LEO satellite network
- Despite of BBR performance as well as CUBIC, the number of retransmissions is large



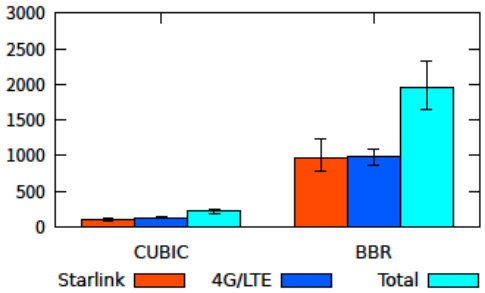




Initial-flow 4G/LTE

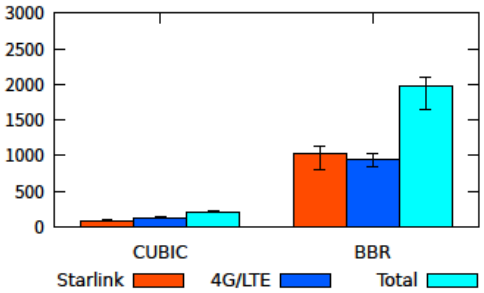



Initial-flow Starlink

Fig.C-1 Picture discard and buffer underflow.




Initial-flow 4G/LTE




Initial-flow Starlink

Fig.C-2 Retransmission.

# Scenario C Results#2



- Emulator setting
  - Bandwidth: 3Mb/s

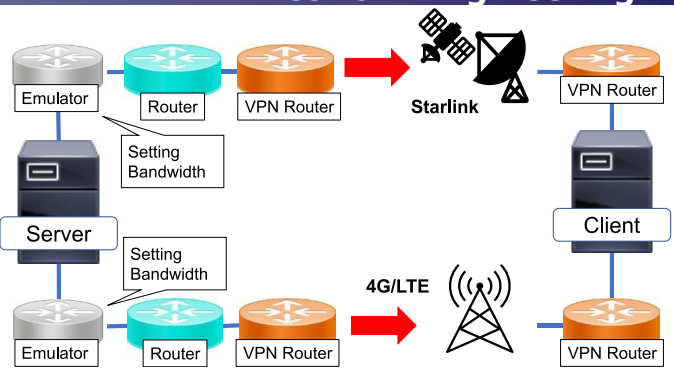
Fig.C-3 (BBR)

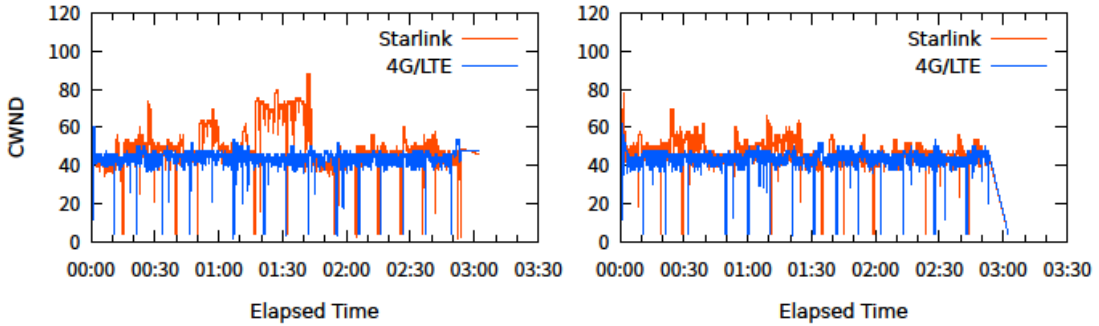
- cwnd on both paths keep above 40 packets
- Starlink cwnd is likely to fluctuate

Fig.C-4 (CUBIC)

- cwnd in both paths keep around 40 packets

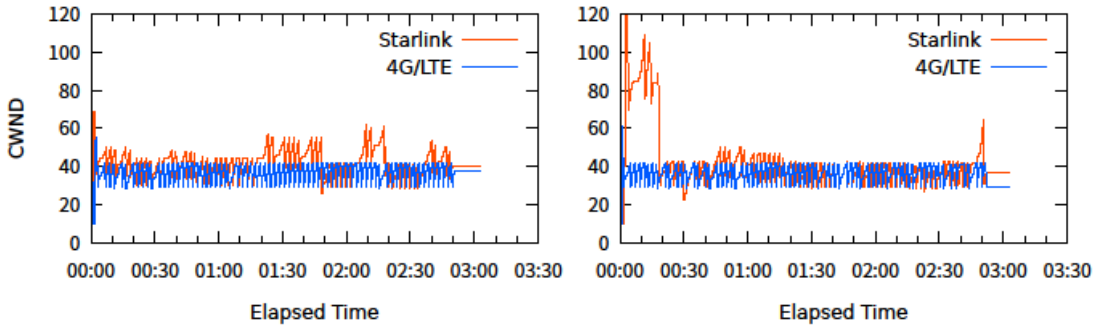
- BBR may handle LEO satellite environment flexibly
- CUBIC tries to keep Starlink cwnd on par with 4G/LTE




Initial-flow 4G/LTE　　Initial-flow Starlink

Fig.C-3 BBR cwnd.




Initial-flow 4G/LTE　　Initial-flow Starlink

Fig.C-4 CUBIC cwnd.

# Conclusion



- The path which has high packet loss rate and long delay causes poor performance of MPTCP video streaming using CUBIC TCP variant

- BBR TCP variant provides good performance for MPTCP video streaming, but retransmitted packets are large
  - Costly in satellite bandwidth due to large retransmissions

- Starlink transmission and reception between satellite and antenna could be affecting performance

- MPTCP with Cellular and LEO satellite multipaths are able to sustain video streaming with good performance.