The Impact of IP Network Impairments on Optimal Play-out Buffer Size Requirements in Video Streaming

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Motivation

- **There is a rapidly increasing demand to stream video on the internet.**
- **According to the latest Total Audience Report[1], online video streaming viewers are rising at an astonishing rate of 60% per month.**
- Video streaming websites such as YouTube, Hulu and MSN video keep offering thousands of easily accessible videos to end users.
- Primarily, this rapid demand is due to two reasons:
  - Watching real-time video is more enjoyable than having to wait for the entire media file to download.
  - Viewers don't have to waste memory space on hard drive.

[1]http://www.nielsen.com/content/dam/corporate/us/en/reports-downloads/2014%20Reports/total-audience-report-december-2014.pdf

Problem Definition

- Regardless of the significant convenience of streaming compared to having to first download videos, **user satisfaction when performing video streaming remains a great uncertainty**.
- **A research shows that on the Internet, about 13% of home and 40% of business streaming sessions suffer various types of quality degradation**[2].
- During network congestion, queues can build up inside the routers that cause delays (**Link Delay**) or the dropping of network packets (**Packet Loss**).
  - When this happens, TCP congestion control will decrease the transmission rate.
  - Since video streaming demands a smooth and flexible sending rate, this bandwidth variation and can damage video quality.

[2]Delving into Internet streaming media delivery: A quality and resource utilization perspective

Problem Definition contd.

- **How does this affect the viewers?**
  - Higher numbers of interruptions in the video (re-buffer events)
  - Longer start-up delays
  - Longer re-buffering delays
    (This is the time taken to start-up the playback after an interruption)
- **How we can get an idea about the impact of such network impairments (delay and packet loss) on the transport quality of video streaming?**
- **By using above problems to give us performance metrics:**
  - Start-up delay
  - Number of Re-buffers
  - Re-buffering delay

Existing Solutions

- Streaming Switching
  - Allows changing the streamed bitrate depending on the detection of congestion.
- Client side Play-out Buffering
  - A play-out buffer uses some current bandwidth to prefetch packets for protection against any future rate reductions.
  - *Focus of our study, which is explained further in the next slide.*

Client Side Play-out Buffering

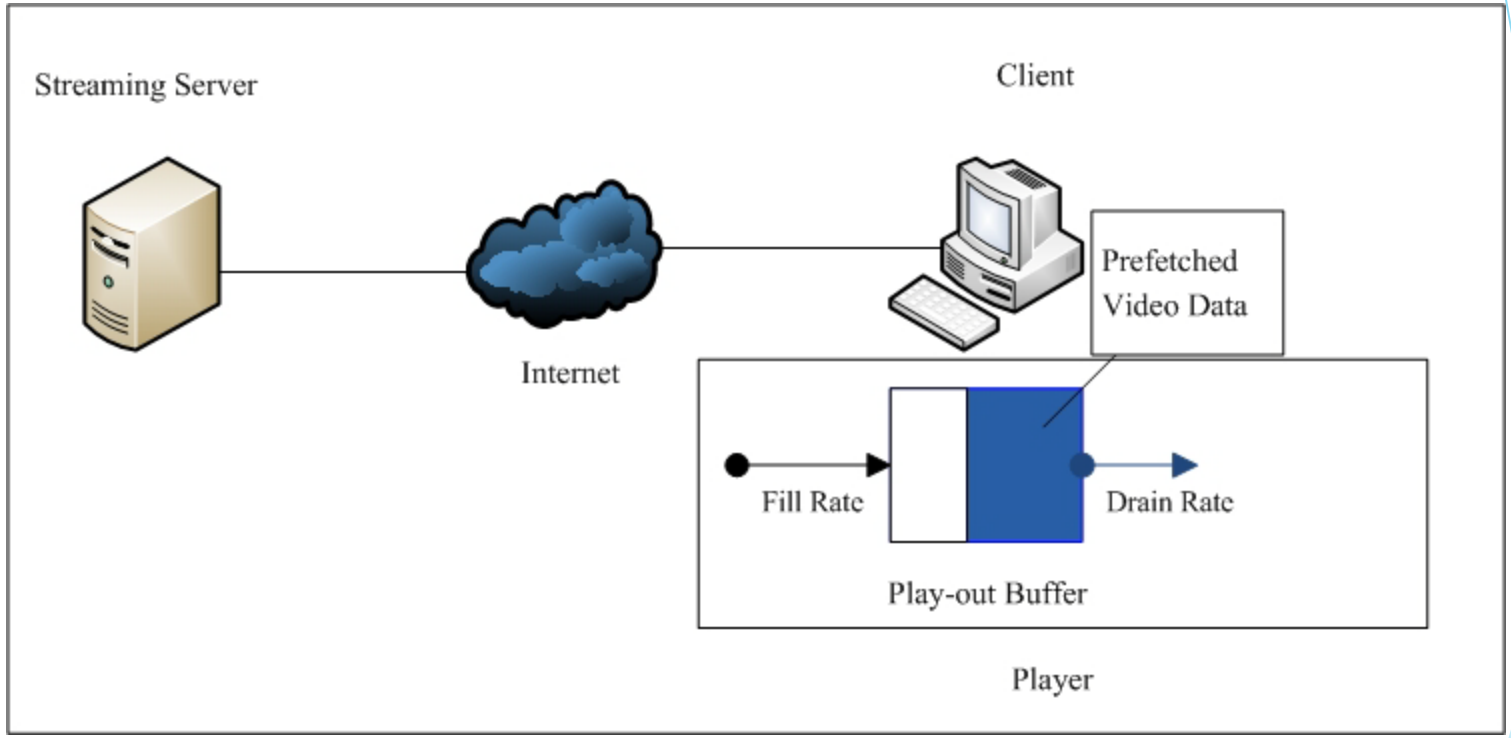


Figure 1: Role of the play-out buffer

Research Questions

- What is the optimal play-out buffer size (which can reasonably protect the video quality) under different link delay and loss rates?
- Is it affected by the video contents (specifically the degree of motion: fast or slow)?
- How the optimal buffer size is changing when the delay and loss rate is increasing?

Definition of Buffer Optimality

- We aim to find the play-out buffer sizes that provide ideal values for the following metrics:
  - Number of re-buffers (interrupts) in the video
  - Start-up delay
  - Re-buffering delay
- Optimal values used in our study:
  - Number of Re-buffers: 0
  - Start-up delay: Less than or equal to 2 seconds[3]
  - Re-buffer delay: Less than 1% of the video duration can be taken as tolerable
  - *Their data set consists of more than 23 million video playbacks from 6.7 million unique viewers who watched an aggregate of 216 million minutes of 102 thousand videos over 10 days.*

[3]Video Stream Quality Impacts Viewer Behavior: Inferring Causality Using Quasi-Experimental Designs

Definition of Buffer Optimality contd.

- Optimal Buffer Size one (OBS_1): The play-out buffer size that causes no re-buffers (ideal value of the first metric) is taken as an optimal buffer while reporting the behavior of the second metric (start-up delay), mentioning whether it resides within its ideal range (less than or equal to 2 seconds) or not. If not, the observed value is compared to the ideal range.

- Optimal Buffer Size two (OBS_2): The play-out buffer size that provides the ideal value for the second metric (start-up delay) is taken as the optimal buffer while reporting the behaviors of the other two metrics, mentioning whether they reside within their ideal target ranges or not. If not, the observed values compared to the ideal ranges are also given.

Our Experimental Set-up

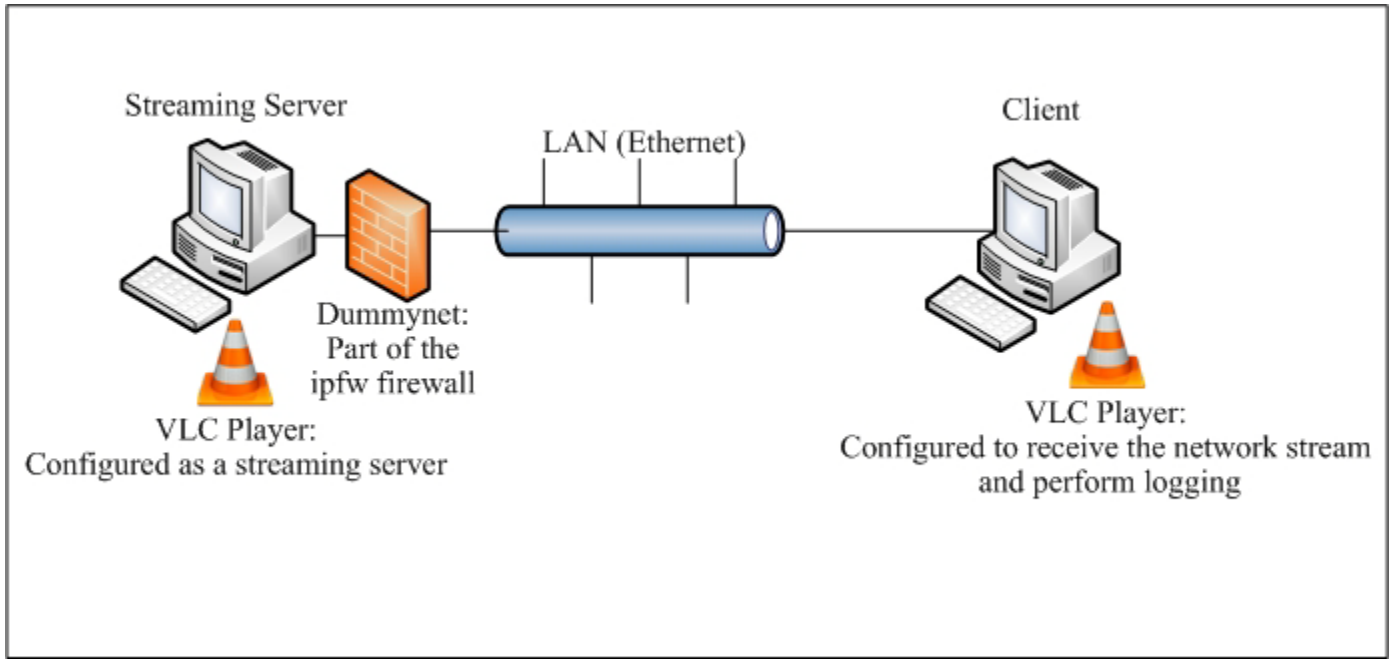


Figure 2: Experimental Test Bed

Tested Network Configurations

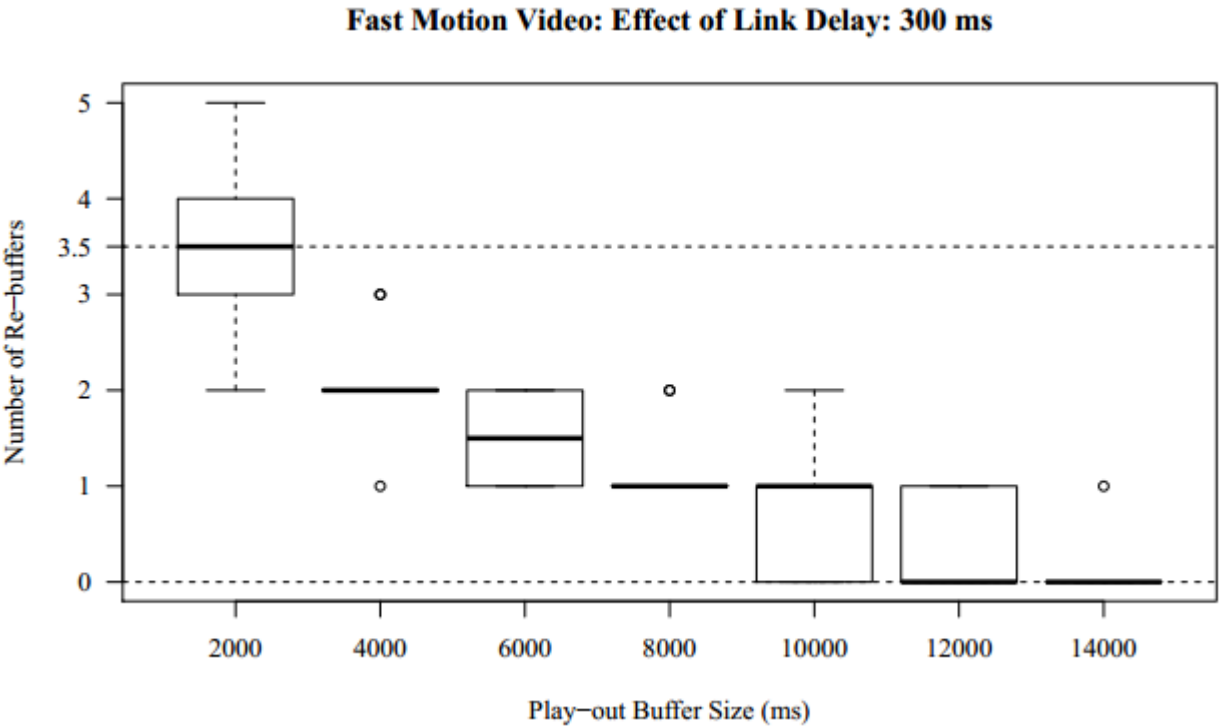
- Bandwidth:
- The 2014 Internet Service Provider Survey of Statistics New Zealand[4] states that download speeds of over two-thirds of the connections in the country are in the range of 8-24 Mbps, and upload speeds of almost half of the connections are in the range of 1.5-10 Mbps.
- **Download BW: 16 Mbps Upload BW: 5.75 Mbps**
- Packet Loss Rates:
- Stanford researchers have defined the quality levels for packet loss as in[5].
- **0-0.1%** excellent, **0.1-1%** = good, **1-2.5%** = acceptable, 2.5-5% = poor, 5%-12% = very poor, and greater than 12% = bad
- Link Delay:
- For real-time multimedia [6]defines the one way delay of: **(0-150) milliseconds** as Good, **(150-300) milliseconds** as Acceptable and values greater than 300 milliseconds as Poor.

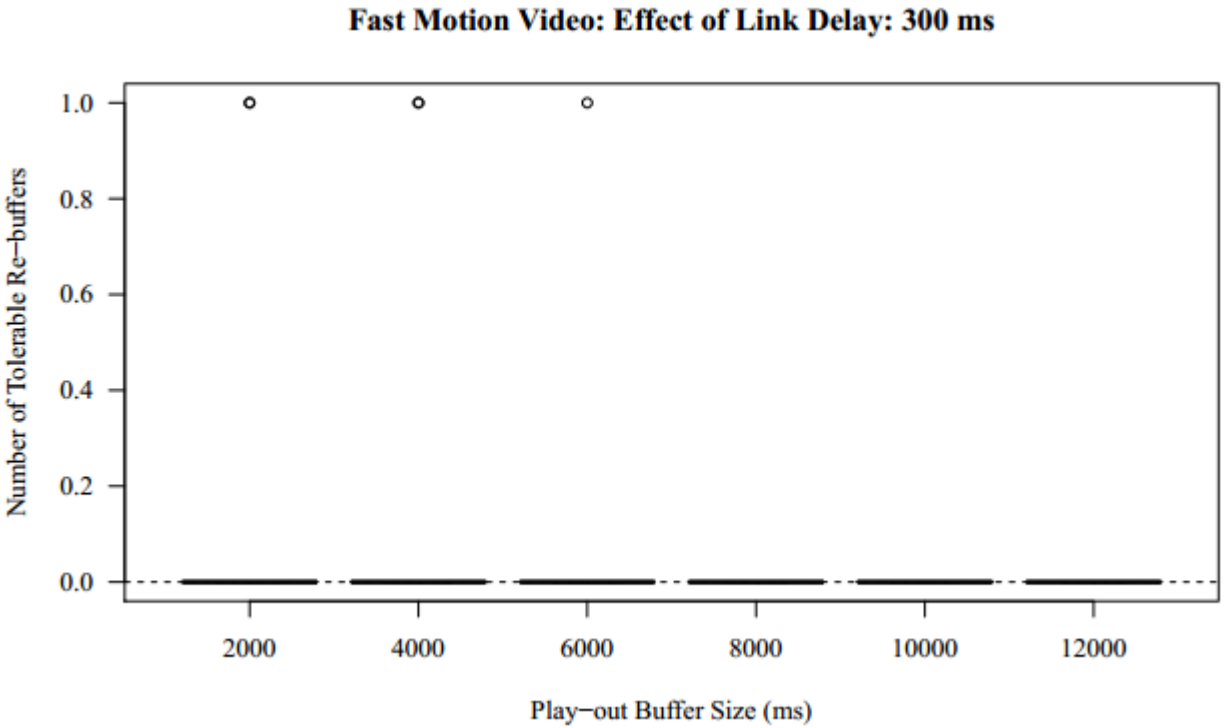
Properties of the Tested Videos

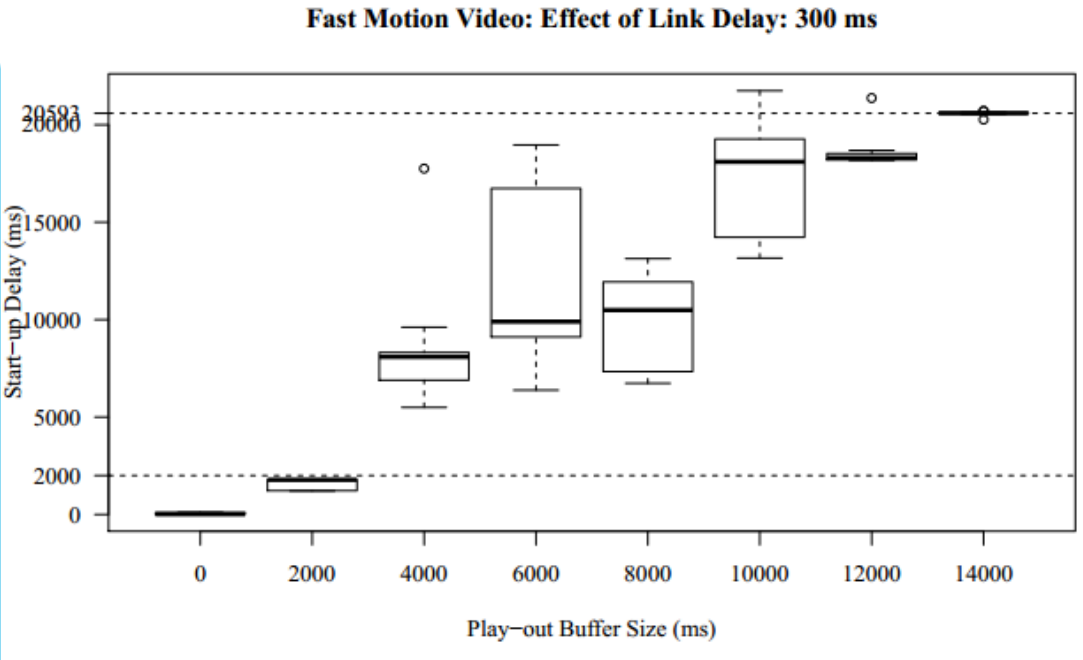
- Fast Motion Video: (https://www.youtube.com/watch?v=LZ3BLcBz9Ls)
  - Format: .mp4
  - Length: 3 minutes
  - Frame Size: 1280x720
  - Frame Rate: 29 fps
  - Send Bit Rate: 2047 Kbps
- Slow Motion Video: (https://www.youtube.com/watch?v=YH7uhgPD0gY)
  - Format: .mp4
  - Length: 2 minutes and 23 seconds
  - Frame Size: 1280x720
  - Frame Rate: 23 fps
  - Send Bit Rate: 1404 Kbps

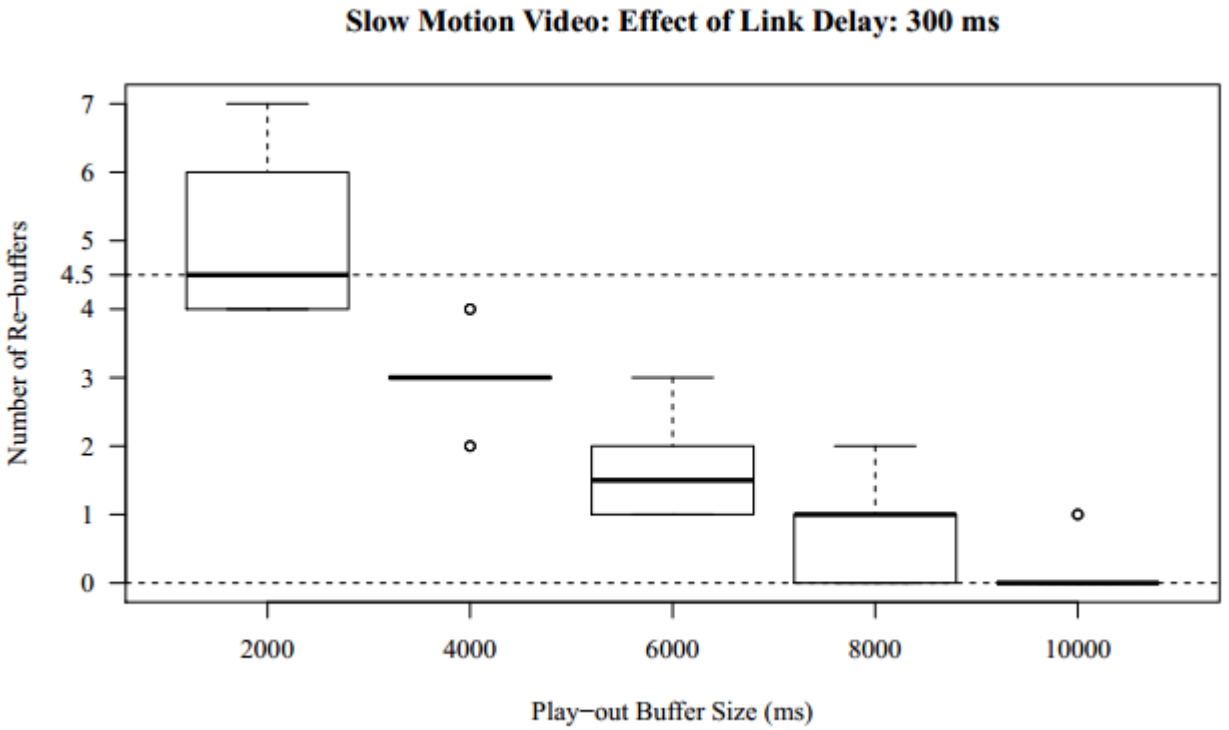
Testing Methodology

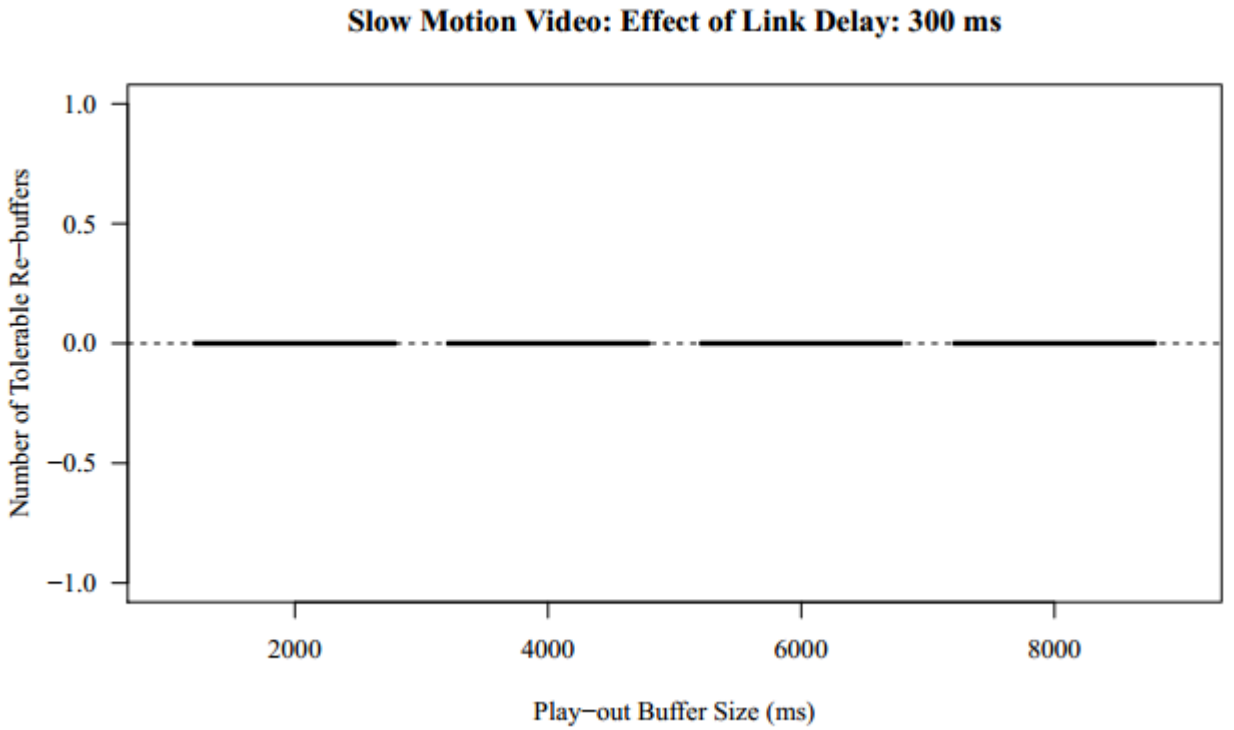
- For each selected link delay or packet loss rate, we started streaming of video data with no play-out buffering.
- Then we progressively increased the buffer size by intervals of 2 seconds, until we obtain the most appropriate buffer sizes for OBS_2 and OBS_1.
- All results were obtained by repeating each video streaming test 10 times for a given buffer size.

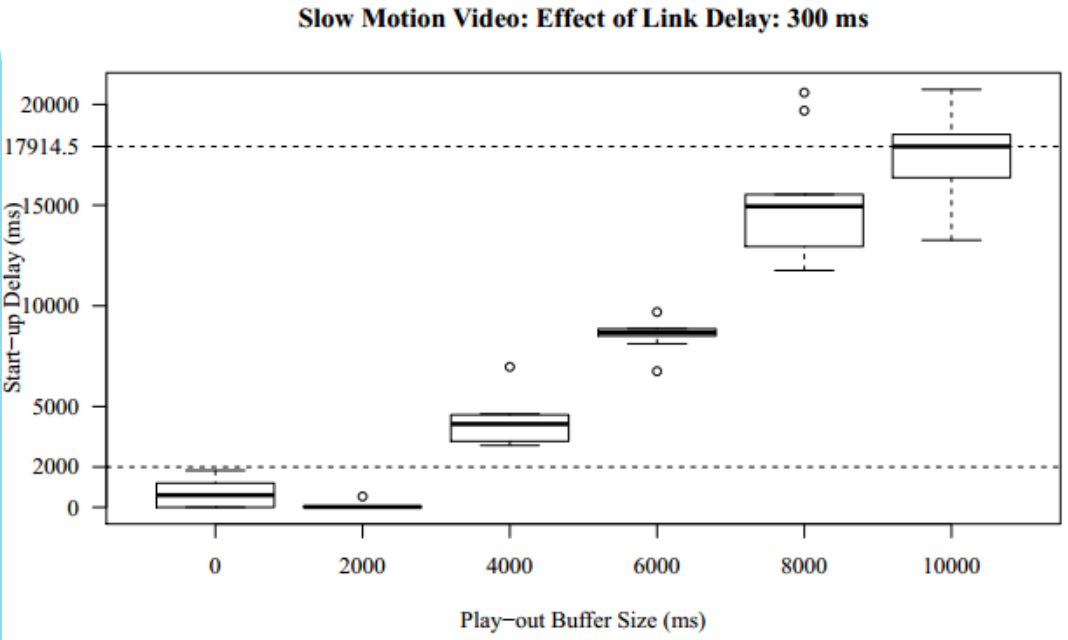

Fast Motion Video: Effect of Link Delay: 300 ms
Number of Re−buffers
0
1
2
3
3.5
4
5
2000
4000
6000
8000
10000
12000
14000
Play−out Buffer Size (ms)

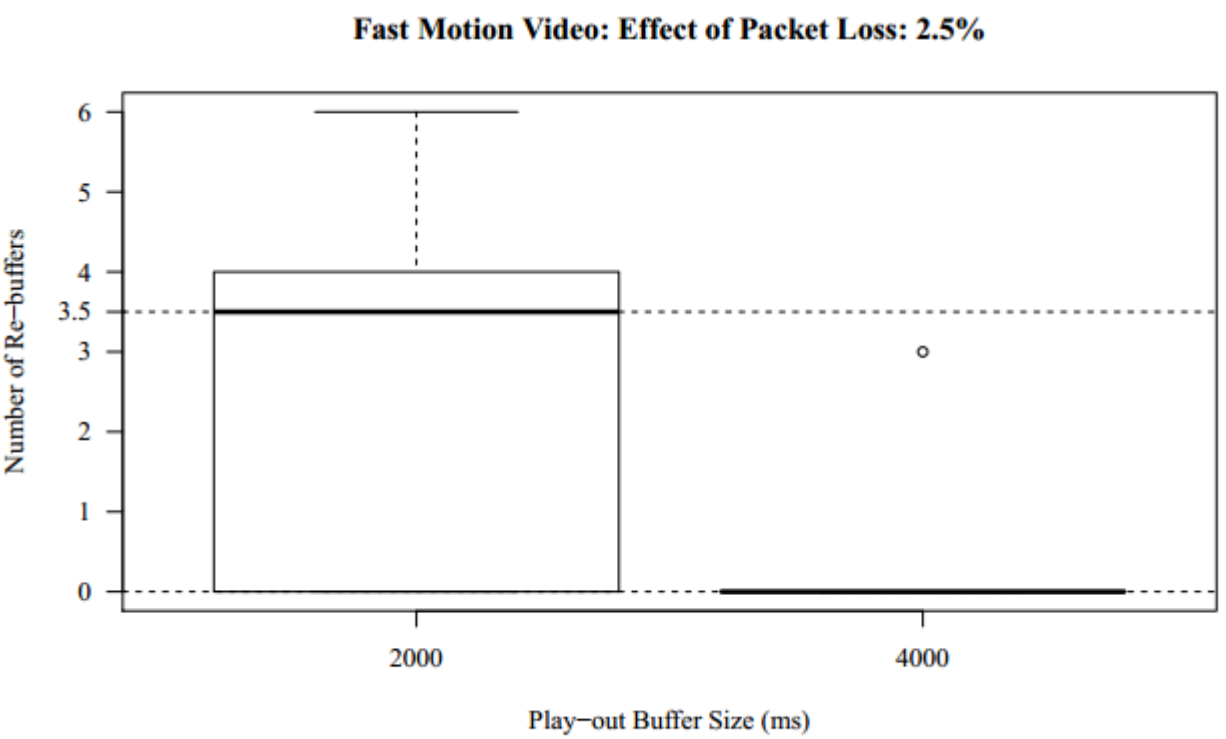

Fast Motion Video: Effect of Link Delay: 300 ms
Number of Tolerable Re−buffers
0.0
0.2
0.4
0.6
0.8
1.0
2000
4000
6000
8000
10000
12000
Play−out Buffer Size (ms)

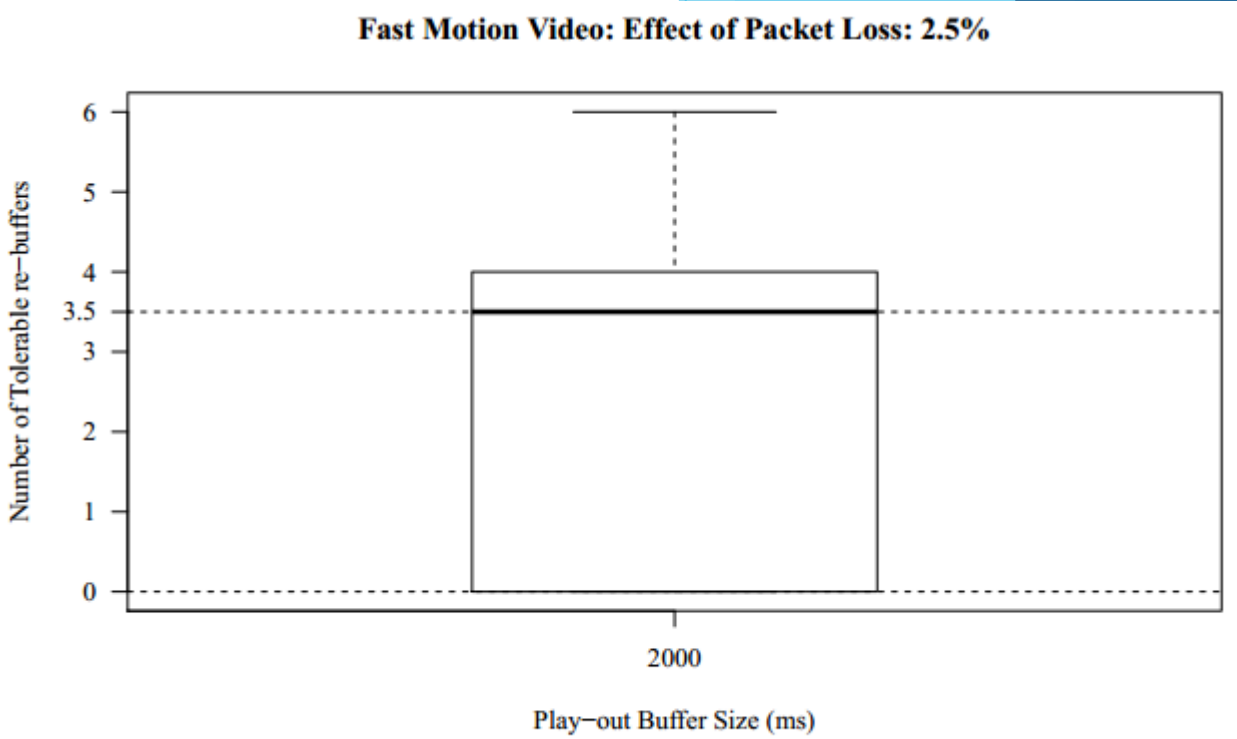

Fast Motion Video: Effect of Link Delay: 300 ms
Start−up Delay (ms)
0
2000
5000
10000
15000
20000
20583
0
2000
4000
6000
8000
10000
12000
14000
Play−out Buffer Size (ms)

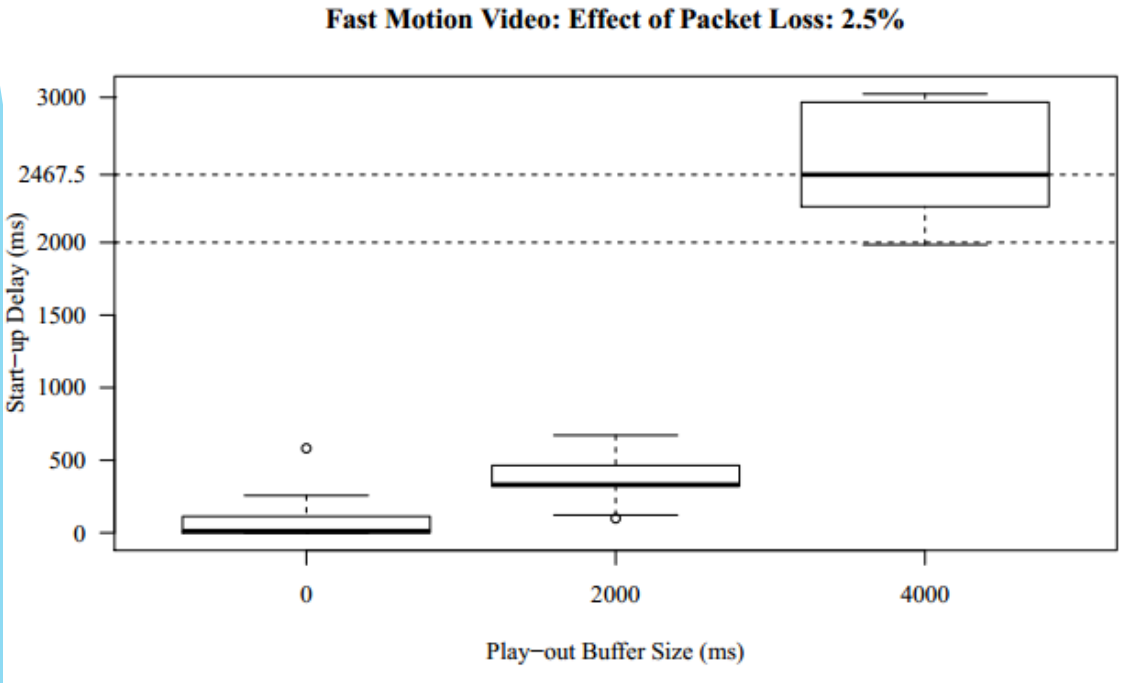

Slow Motion Video: Effect of Link Delay: 300 ms
Number of Re−buffers
0
1
2
3
4
4.5
5
6
7
2000
4000
6000
8000
10000
Play−out Buffer Size (ms)

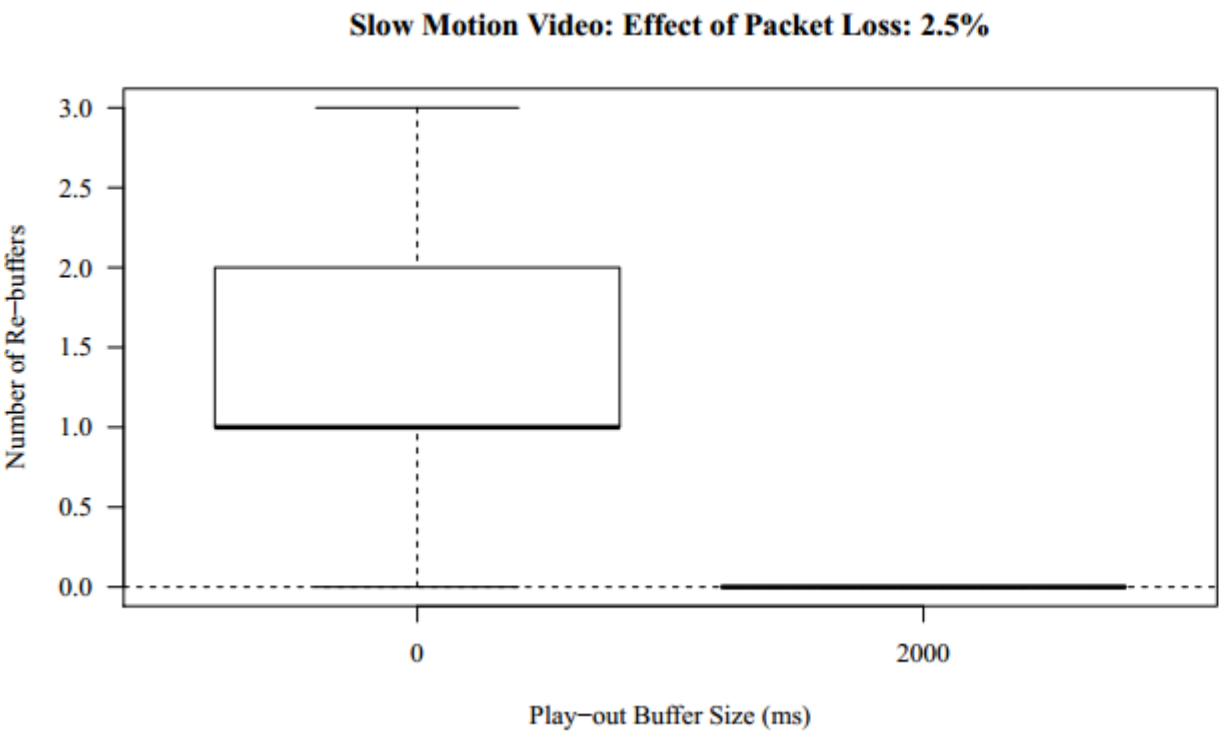

Slow Motion Video: Effect of Link Delay: 300 ms
Number of Tolerable Re−buffers
−1.0
−0.5
0.0
0.5
1.0
2000
4000
6000
8000
Play−out Buffer Size (ms)

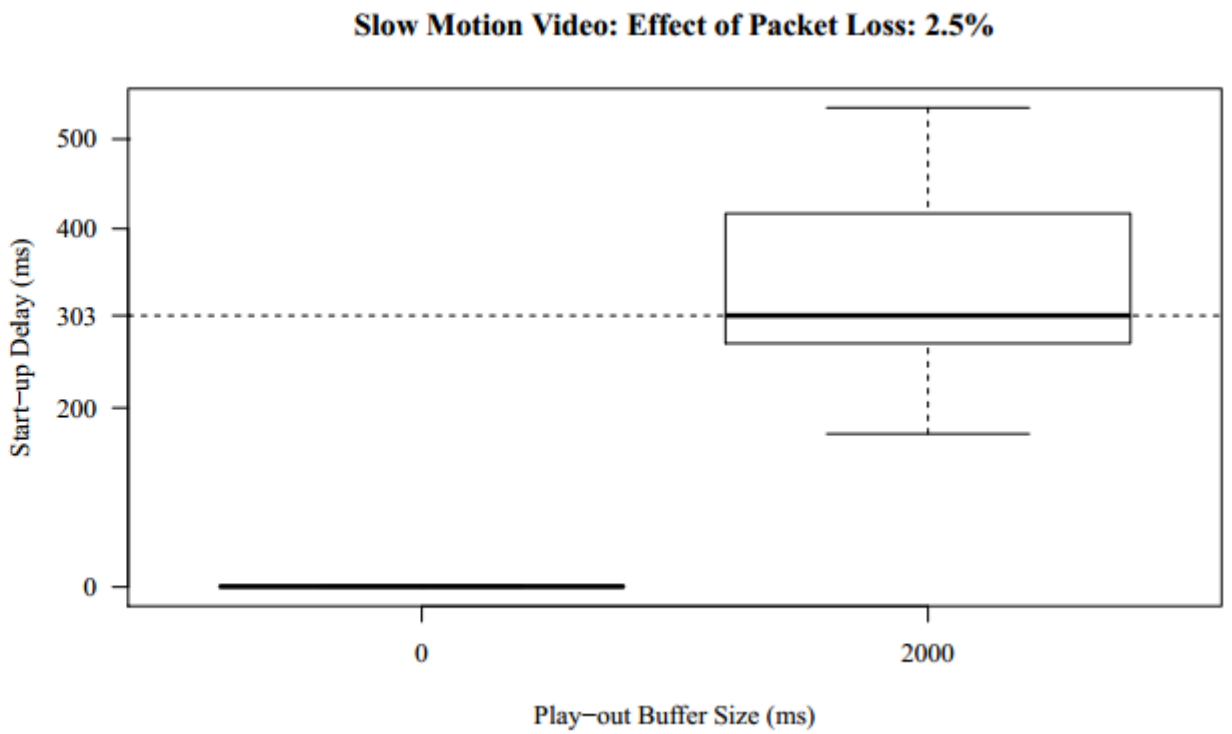

Slow Motion Video: Effect of Link Delay: 300 ms
Start−up Delay (ms)
0
2000
5000
10000
15000
17914.5
20000
0
2000
4000
6000
8000
10000
Play−out Buffer Size (ms)


Fast Motion Video: Effect of Packet Loss: 2.5%
Number of Re−buffers
6
5
4
3.5
3
2
1
0
2000
4000
Play−out Buffer Size (ms)


Fast Motion Video: Effect of Packet Loss: 2.5%
Number of Tolerable re−buffers
6
5
4
3.5
3
2
1
0
2000
Play−out Buffer Size (ms)


Fast Motion Video: Effect of Packet Loss: 2.5%
Start−up Delay (ms)
3000
2467.5
2000
1500
1000
500
0
0
2000
4000
Play−out Buffer Size (ms)


Slow Motion Video: Effect of Packet Loss: 2.5%
Number of Re−buffers
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2000
Play−out Buffer Size (ms)


Slow Motion Video: Effect of Packet Loss: 2.5%
Start−up Delay (ms)
500
400
303
200
0
0
2000
Play−out Buffer Size (ms)

Fast Motion Video				Slow Motion Video			
150ms		300ms		150ms		300ms	
OBS_2	OBS_1	OBS_2	OBS_1	OBS_2	OBS_1	OBS_2	OBS_1
2 seconds With a 90% probability Intolerable re-buffers	**10 seconds** Highly increased non-optimal start-up	**2 seconds** In-tolerable re-buffers	**14 seconds** With a 90% Probability Highly increased non-optimal start-up	**2 seconds** With a 80% Probability Few intolerable re-buffers	**6 seconds** Moderately increased non-optimal start-up	**2 seconds** In-tolerable re-buffers	**10 seconds** With a 90% Probability Highly increased non-optimal start-up

Fast Motion Video				Slow Motion Video	
1.0%		2.5%		1.0%	2.5%
OBS_2	OBS_1	OBS_2	OBS_1	**OBS_2=OBS_1=2 seconds** Optimal start-up	**OBS_2=OBS_1=2 seconds** Optimal start-up
2 seconds Few tolerable re-buffers	**4 seconds** Slightly increased non-optimal start-up	**2 seconds** Few tolerable re-buffers	**4 seconds** With a 90% probability Slightly increased non-optimal start-up		

Fast Motion Video		Slow Motion Video
0.1%		0.1%
OBS_2	OBS_1	**OBS_2=OBS_1=2 seconds** Optimal start-up
2 seconds Few tolerable re-buffers	**4 seconds** Slightly increased non-optimal start-up	

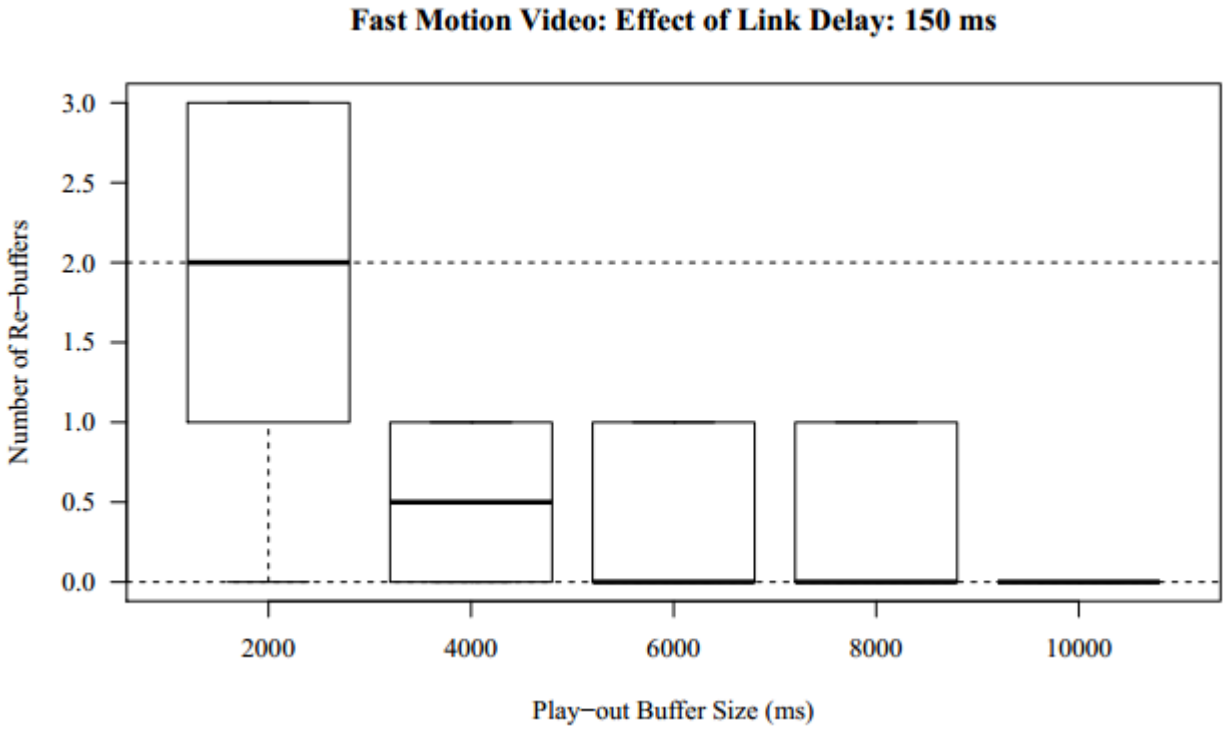
Conclusions

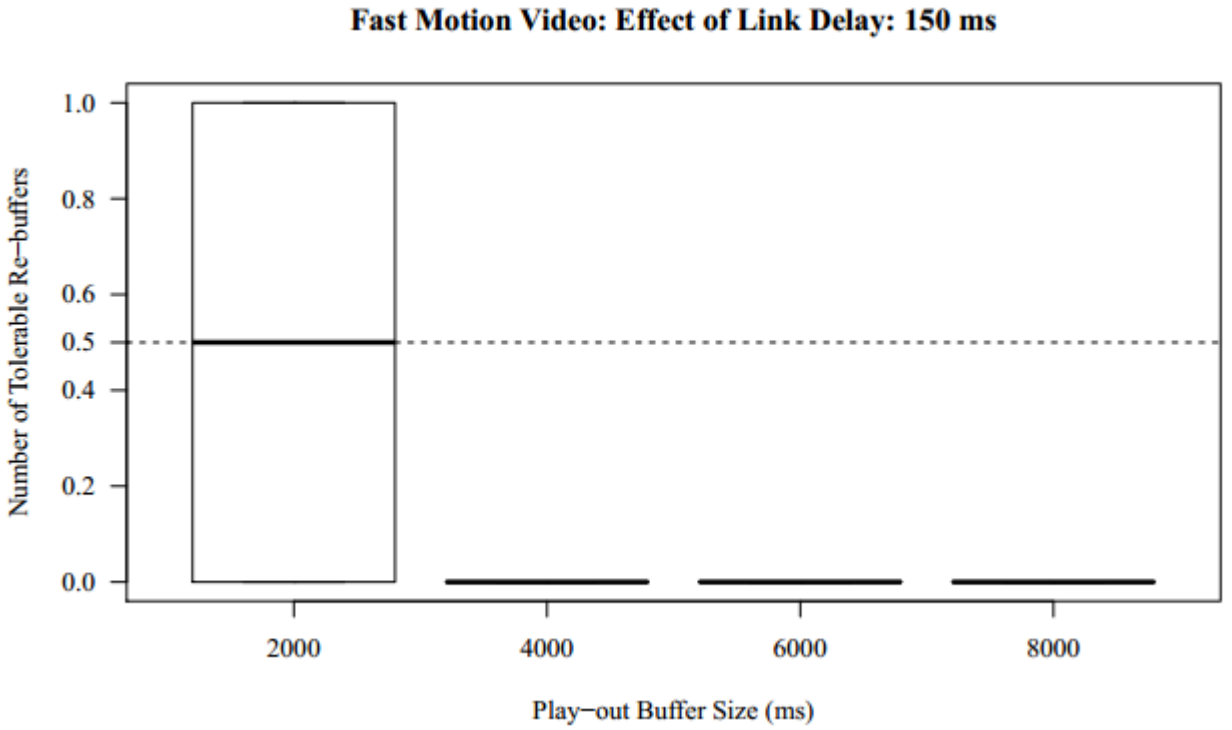
- We show that in the presence of link delay and packet loss, videos with slow motion can be reasonably protected by optimally-sized relatively smaller play-out buffers while, fast motion videos require comparatively larger optimal buffers.
- Similarly OBS_1 is inclined to increase when the link delay increases.
- But we need more data points to be representative.
- Irrespective to the level of link delay or packet loss, a 2 second play-out buffer is very likely to provide an optimal start-up delay for both fast and slow motion videos, based on our chosen model of user broadband.
- These values may depend on the codec and base OS.

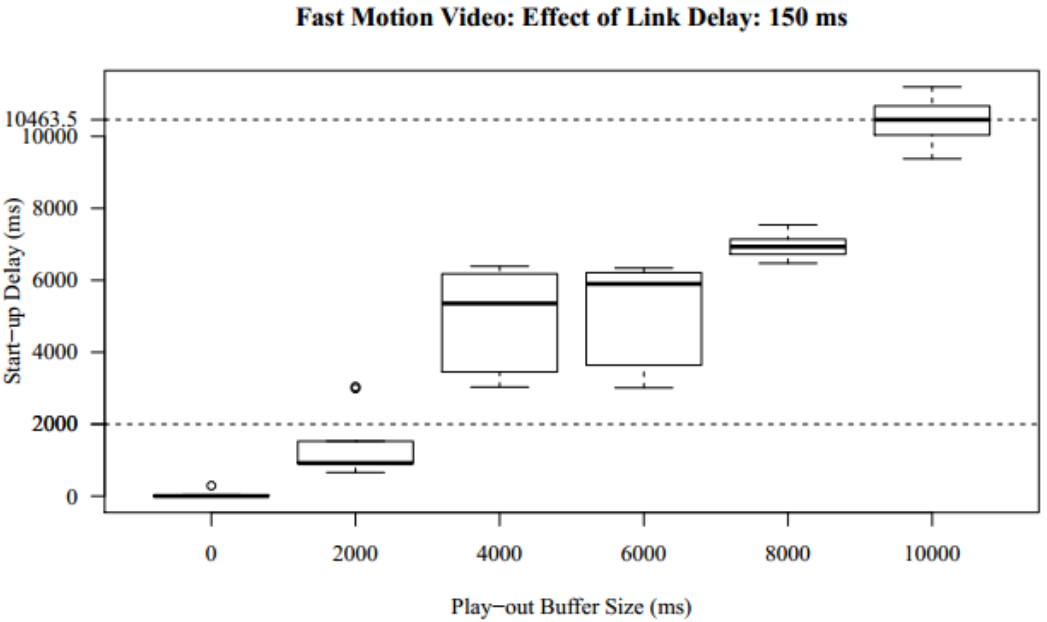
Thank You.!

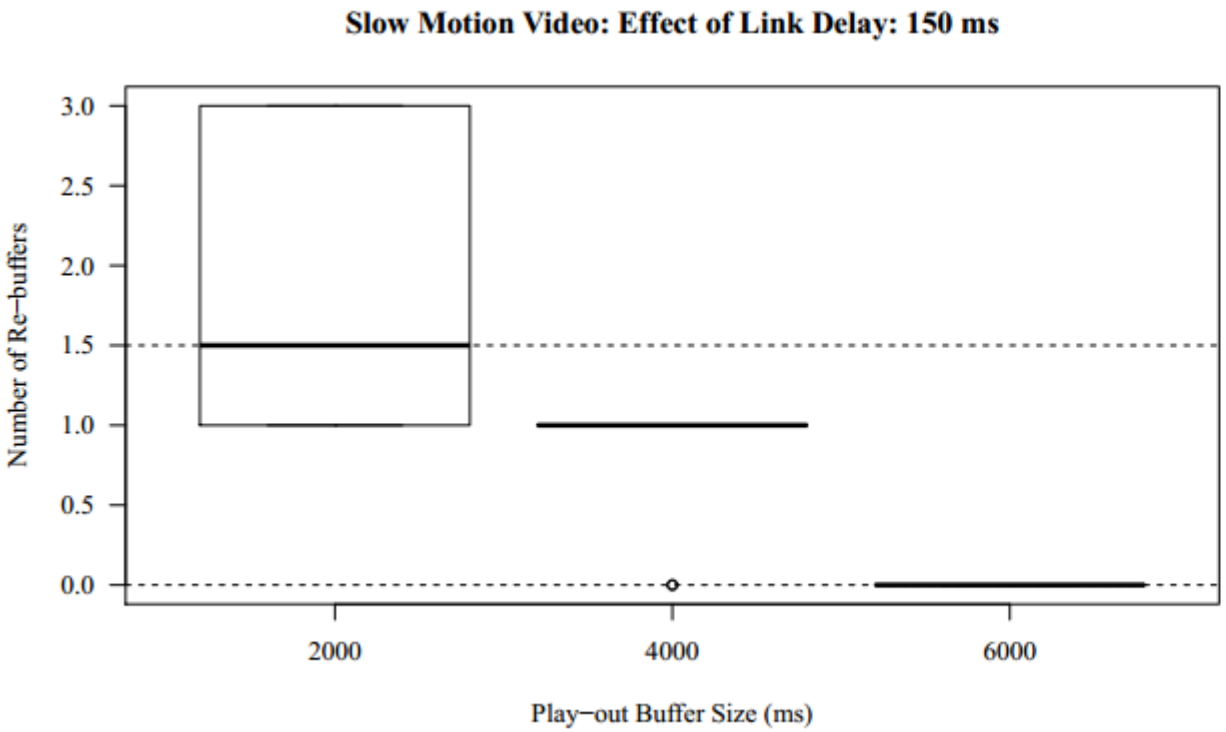
Future Research Directions

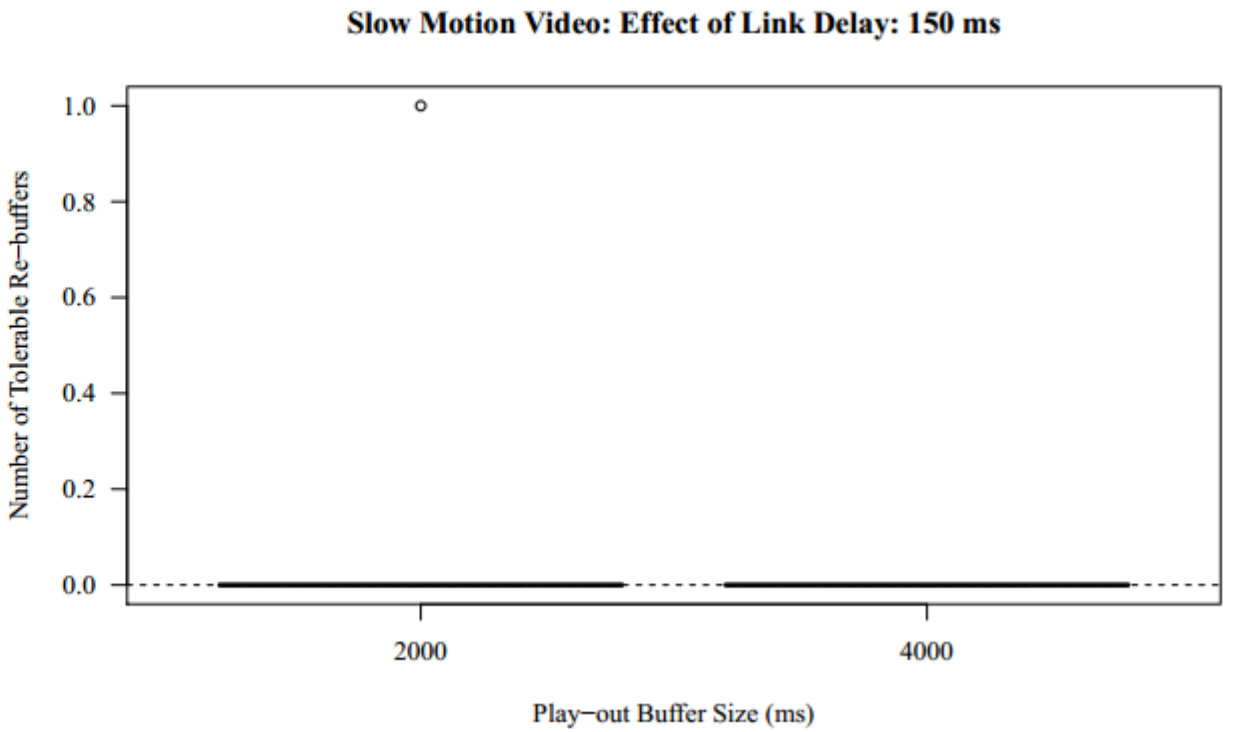
- P2P video streaming
  - What is the most suitable peer selection algorithm?
  - What is the most suitable piece selection algorithm?
- Cloud-assisted video streaming
  - How should a video service provider minimize its operational cost?
  - How much resources (e.g., bandwidth) should be provisioned at each location?
  - How should user requests be directed to different geo-distributed data centers so as to maximize overall user experience?
  - Video service provider should adjust resource provisioning at different regions proactively and place video contents according to the changes of user demands.

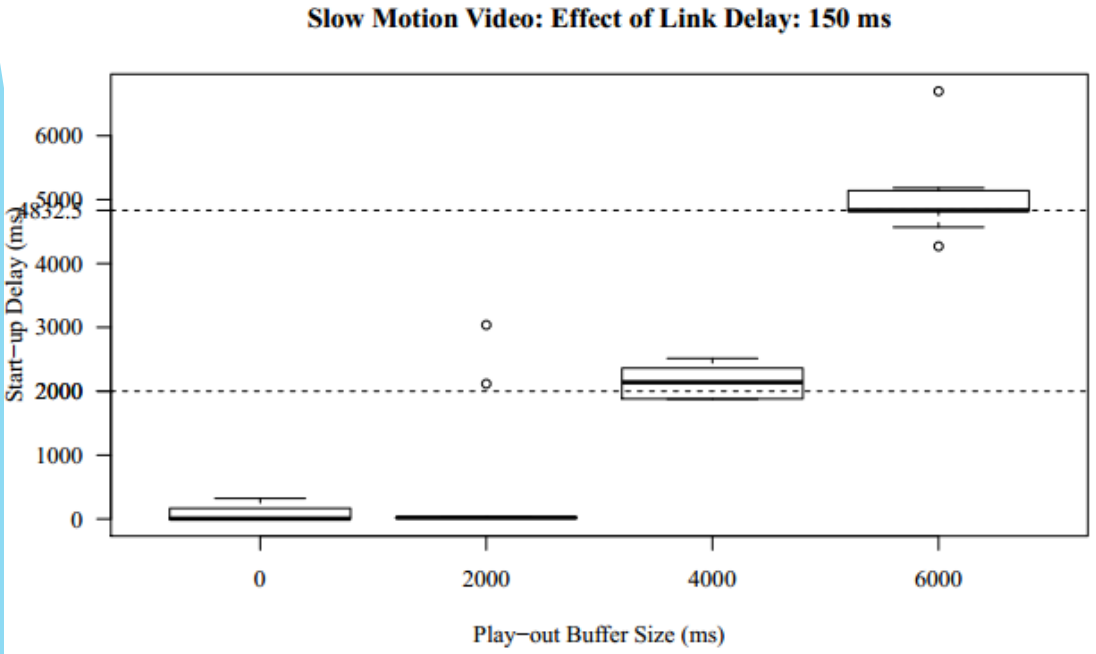

Fast Motion Video: Effect of Link Delay: 150 ms
Number of Re−buffers
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2000
4000
6000
8000
10000
Play−out Buffer Size (ms)

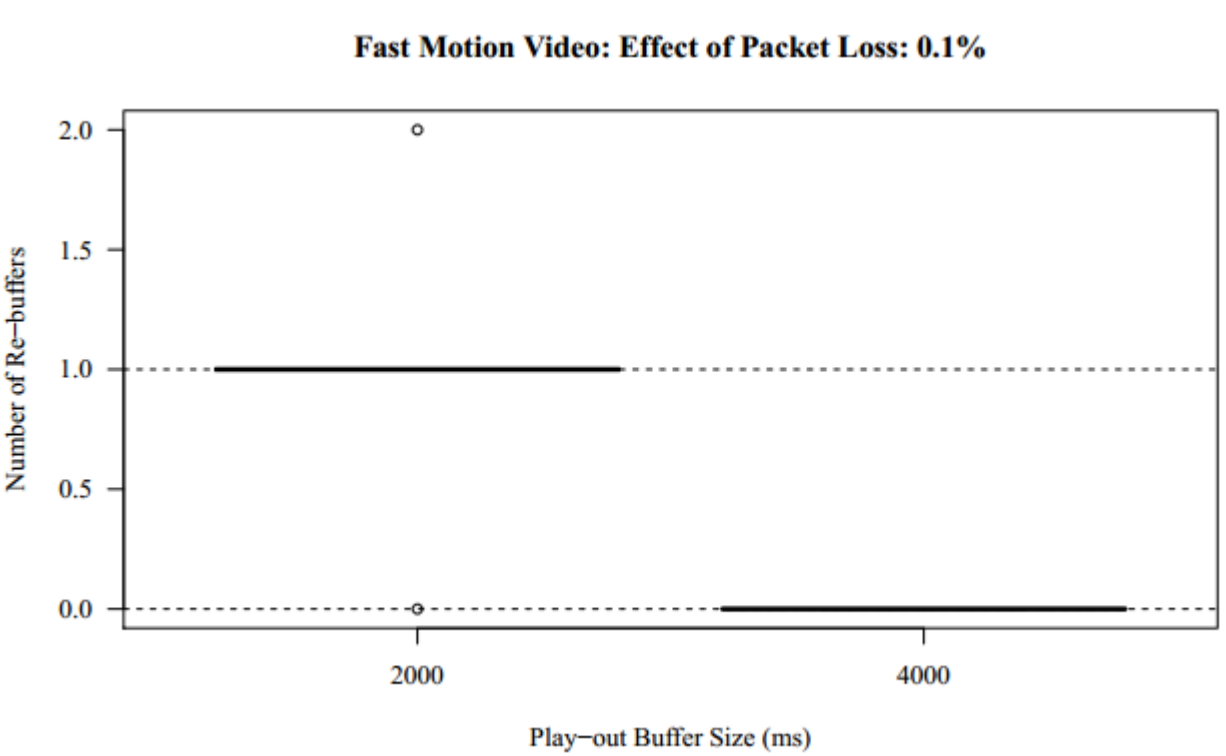

Fast Motion Video: Effect of Link Delay: 150 ms
Number of Tolerable Re−buffers
1.0
0.8
0.6
0.5
0.4
0.2
0.0
2000
4000
6000
8000
Play−out Buffer Size (ms)

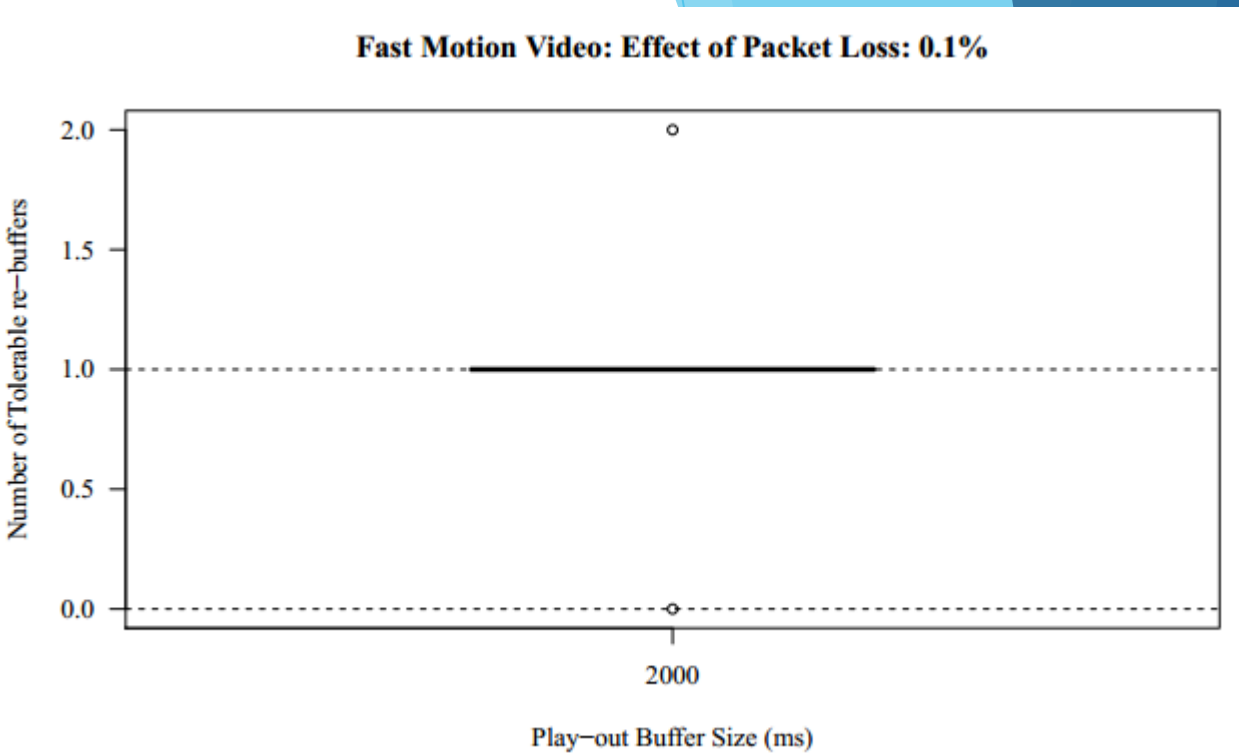

Fast Motion Video: Effect of Link Delay: 150 ms
Start−up Delay (ms)
10463.5
10000
8000
6000
4000
2000
0
0
2000
4000
6000
8000
10000
Play−out Buffer Size (ms)

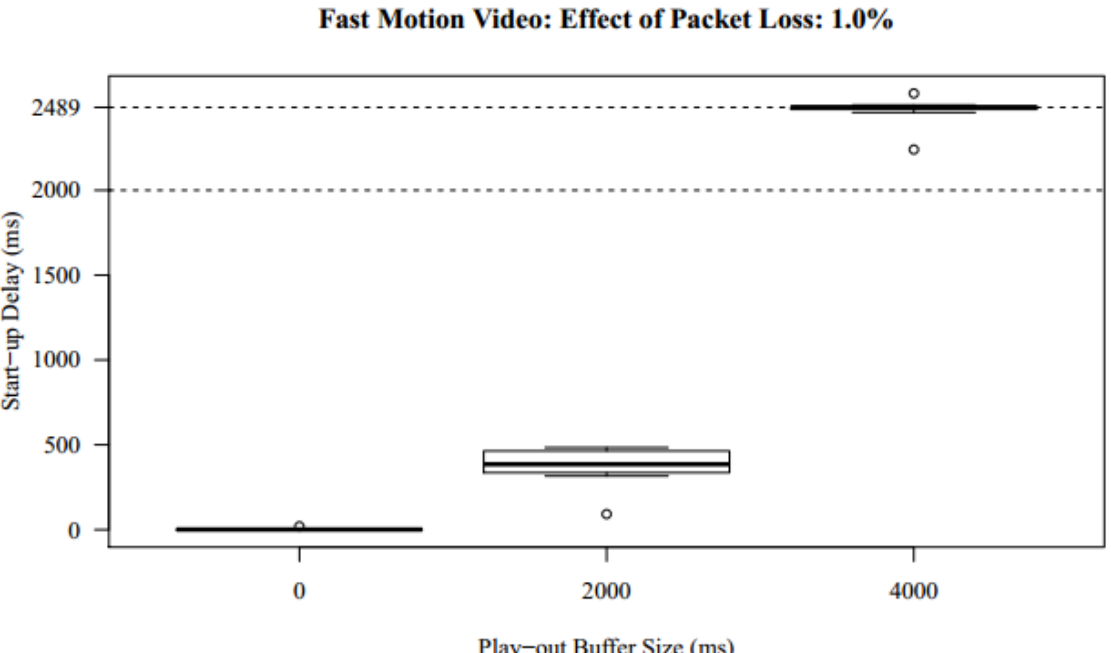

Slow Motion Video: Effect of Link Delay: 150 ms
Number of Re−buffers
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2000
4000
6000
Play−out Buffer Size (ms)

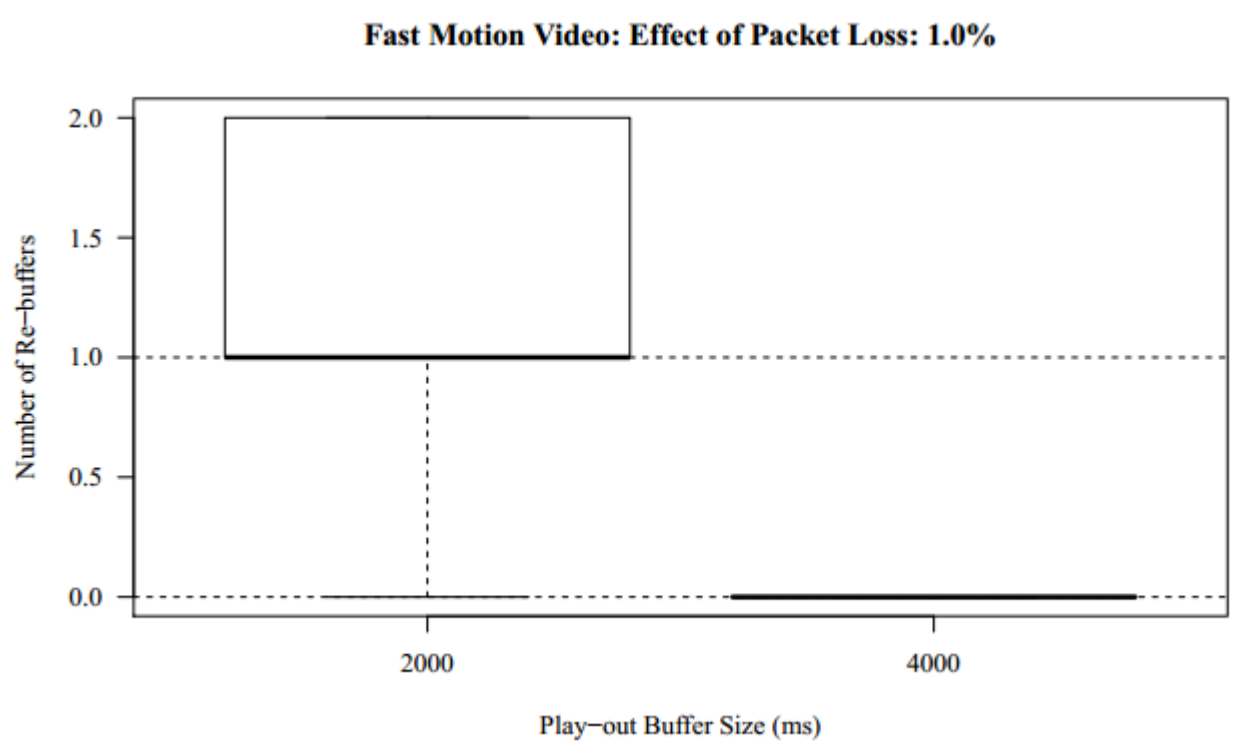

Slow Motion Video: Effect of Link Delay: 150 ms
Number of Tolerable Re−buffers
1.0
0.8
0.6
0.4
0.2
0.0
2000
4000
Play−out Buffer Size (ms)

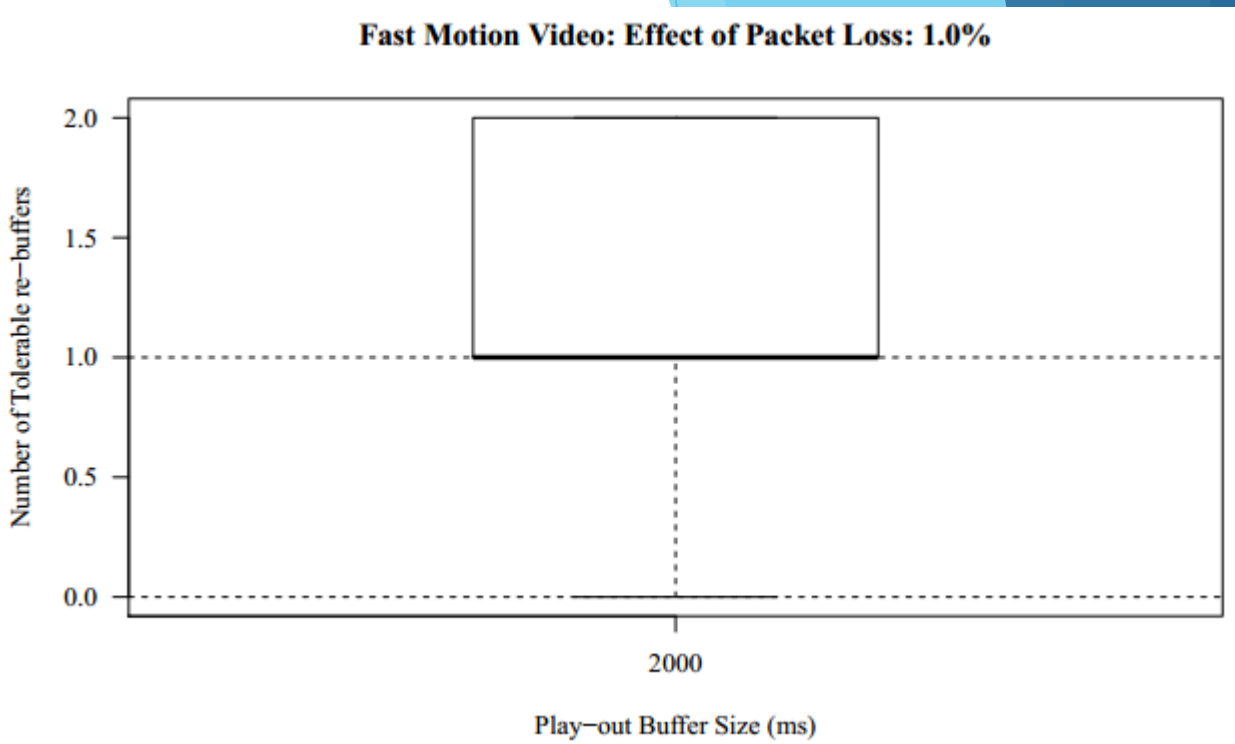

Slow Motion Video: Effect of Link Delay: 150 ms
Start−up Delay (ms)
6000
5000
4832.5
4000
3000
2000
1000
0
0
2000
4000
6000
Play−out Buffer Size (ms)

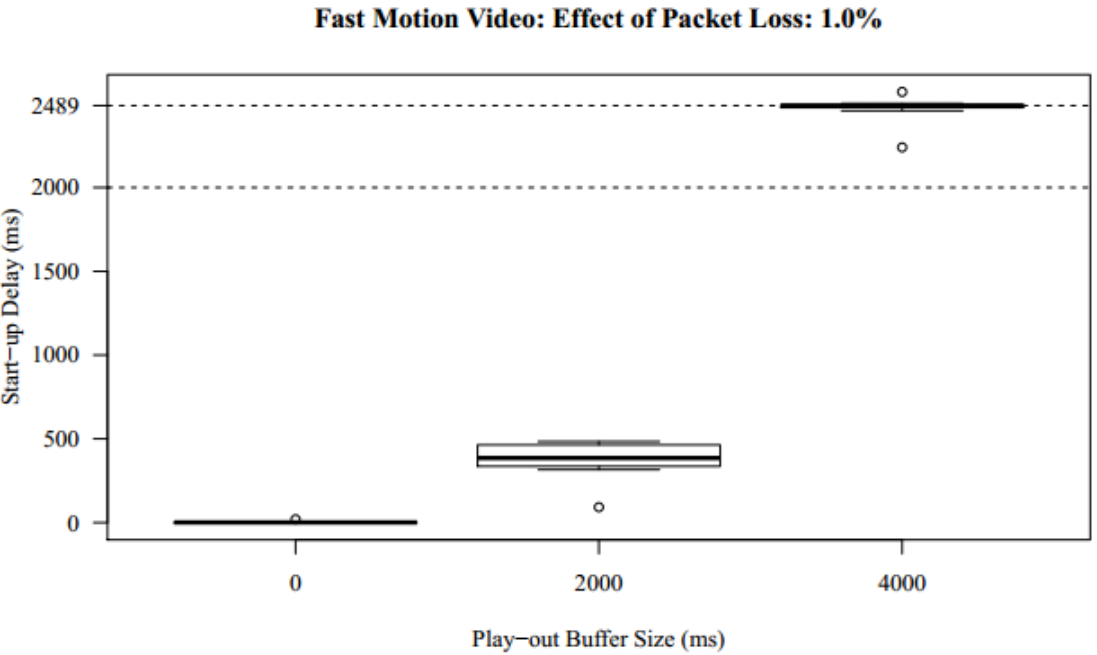

Fast Motion Video: Effect of Packet Loss: 0.1%
Number of Re−buffers
2.0
1.5
1.0
0.5
0.0
2000
4000
Play−out Buffer Size (ms)

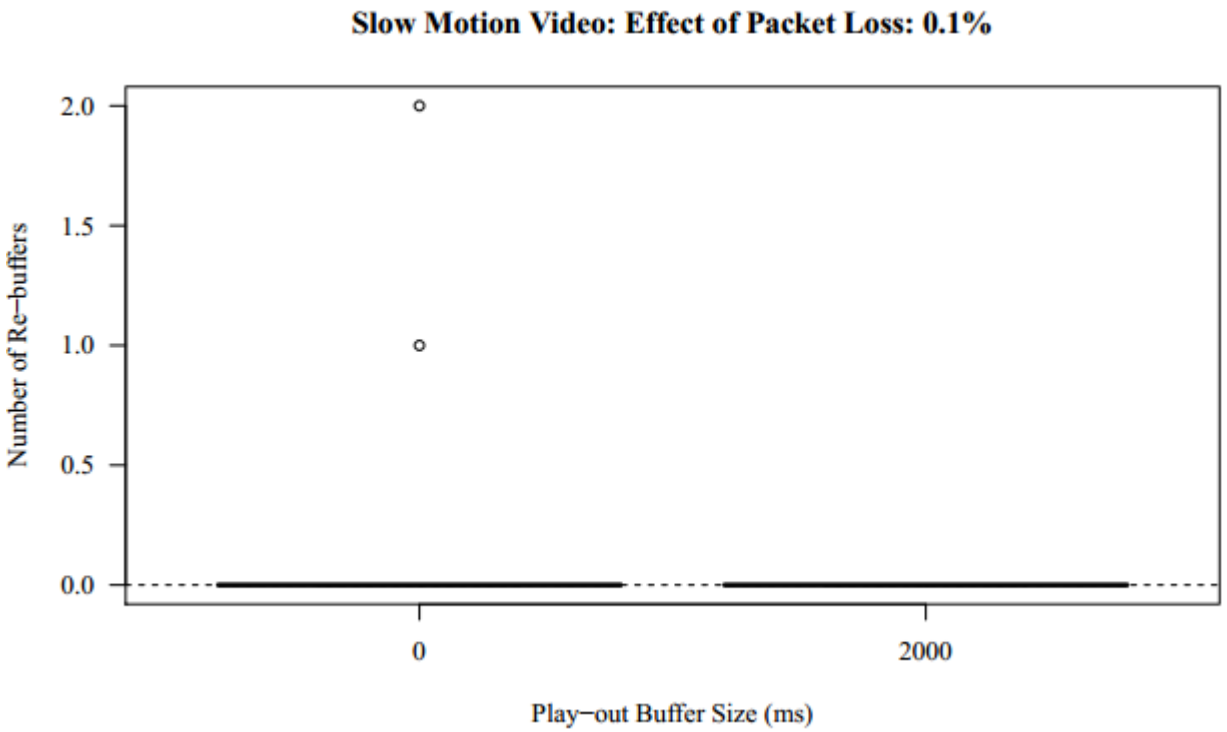

Fast Motion Video: Effect of Packet Loss: 0.1%
Number of Tolerable re−buffers
2.0
1.5
1.0
0.5
0.0
2000
Play−out Buffer Size (ms)

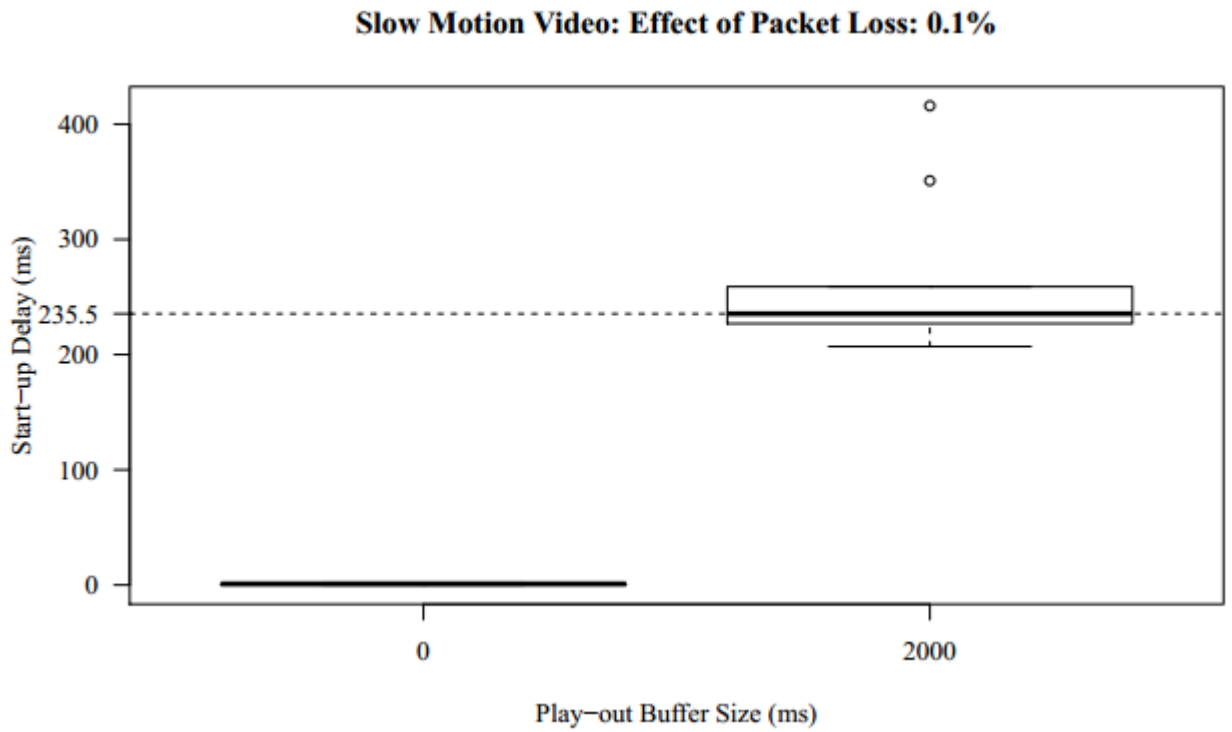

Fast Motion Video: Effect of Packet Loss: 1.0%
Start−up Delay (ms)
2489
2000
1500
1000
500
0
0
2000
4000
Play−out Buffer Size (ms)

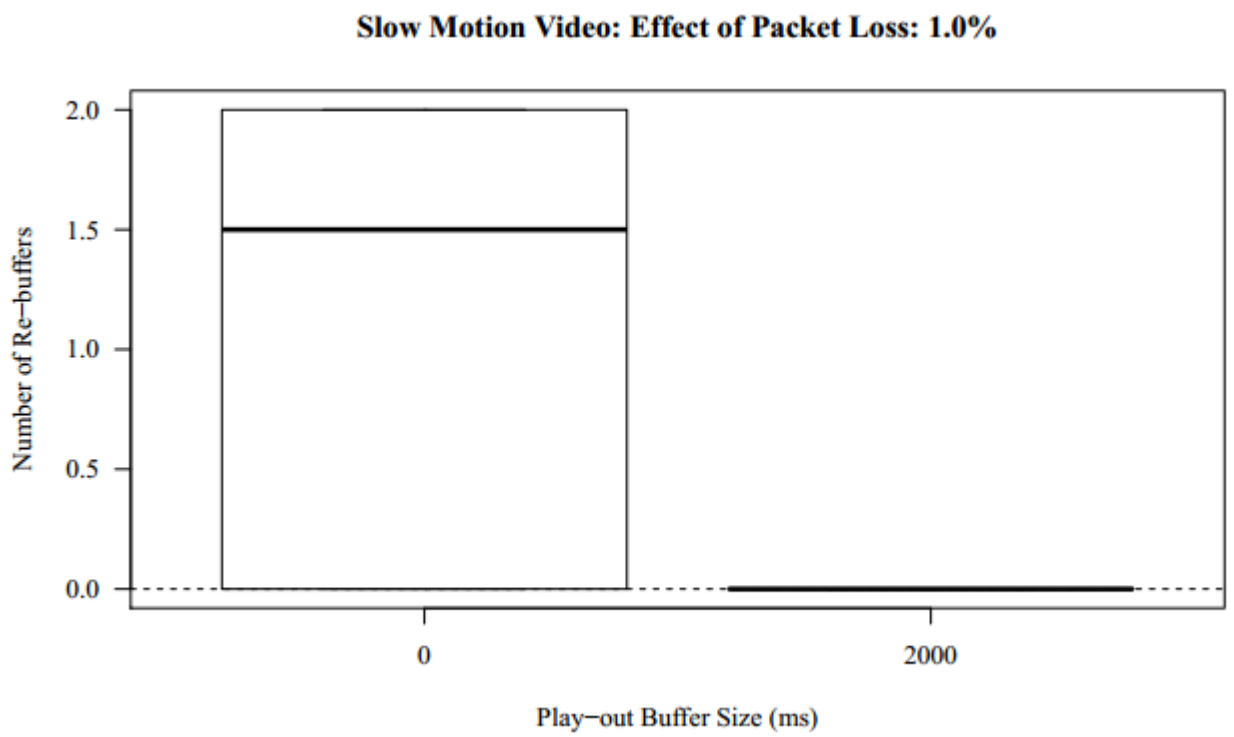

Fast Motion Video: Effect of Packet Loss: 1.0%
Number of Re−buffers
2.0
1.5
1.0
0.5
0.0
2000
4000
Play−out Buffer Size (ms)

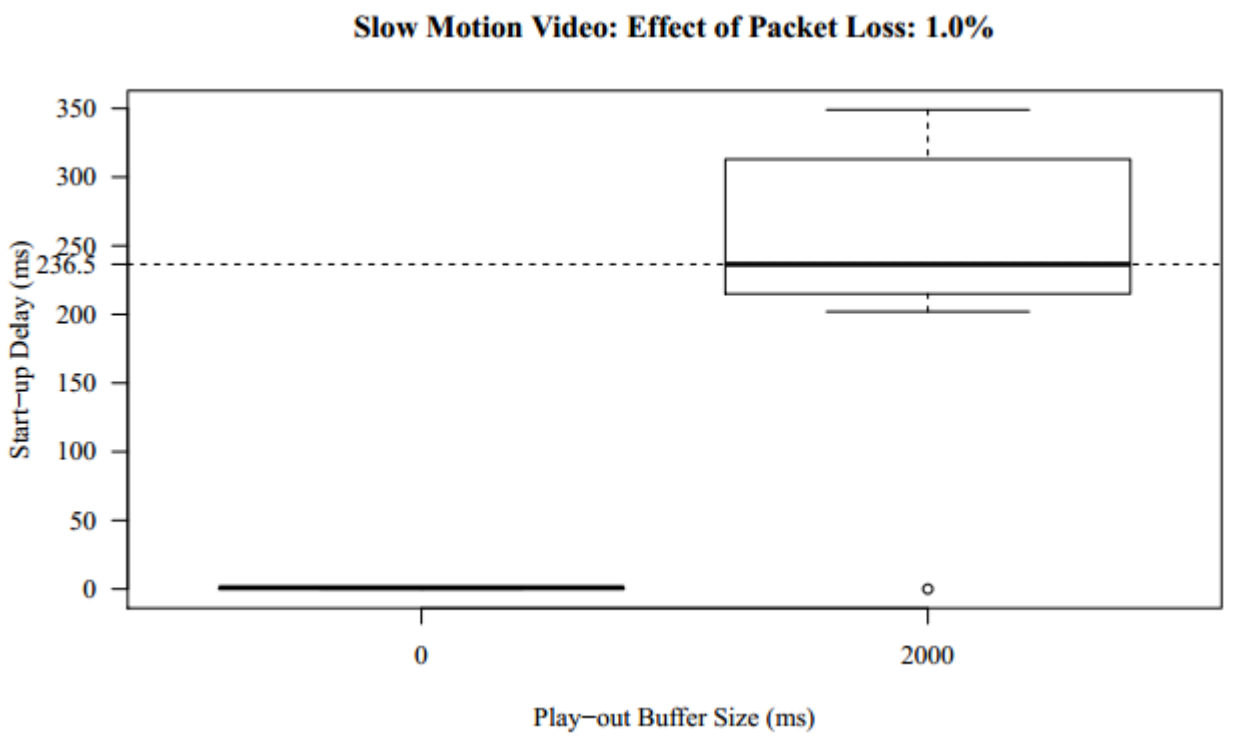

Fast Motion Video: Effect of Packet Loss: 1.0%
Number of Tolerable re−buffers
2.0
1.5
1.0
0.5
0.0
2000
Play−out Buffer Size (ms)


Fast Motion Video: Effect of Packet Loss: 1.0%
Start−up Delay (ms)
2489
2000
1500
1000
500
0
0
2000
4000
Play−out Buffer Size (ms)


Slow Motion Video: Effect of Packet Loss: 0.1%
Number of Re−buffers
2.0
1.5
1.0
0.5
0.0
0
2000
Play−out Buffer Size (ms)


Slow Motion Video: Effect of Packet Loss: 0.1%
Start−up Delay (ms)
400
300
235.5
200
100
0
0
2000
Play−out Buffer Size (ms)


Slow Motion Video: Effect of Packet Loss: 1.0%
Number of Re−buffers
2.0
1.5
1.0
0.5
0.0
0
2000
Play−out Buffer Size (ms)


Slow Motion Video: Effect of Packet Loss: 1.0%
Start−up Delay (ms)
350
300
250
236.5
200
150
100
50
0
0
2000
Play−out Buffer Size (ms)