Cloud Gaming: A QoE Study of Fast-paced Single-player and Multiplayer Gaming

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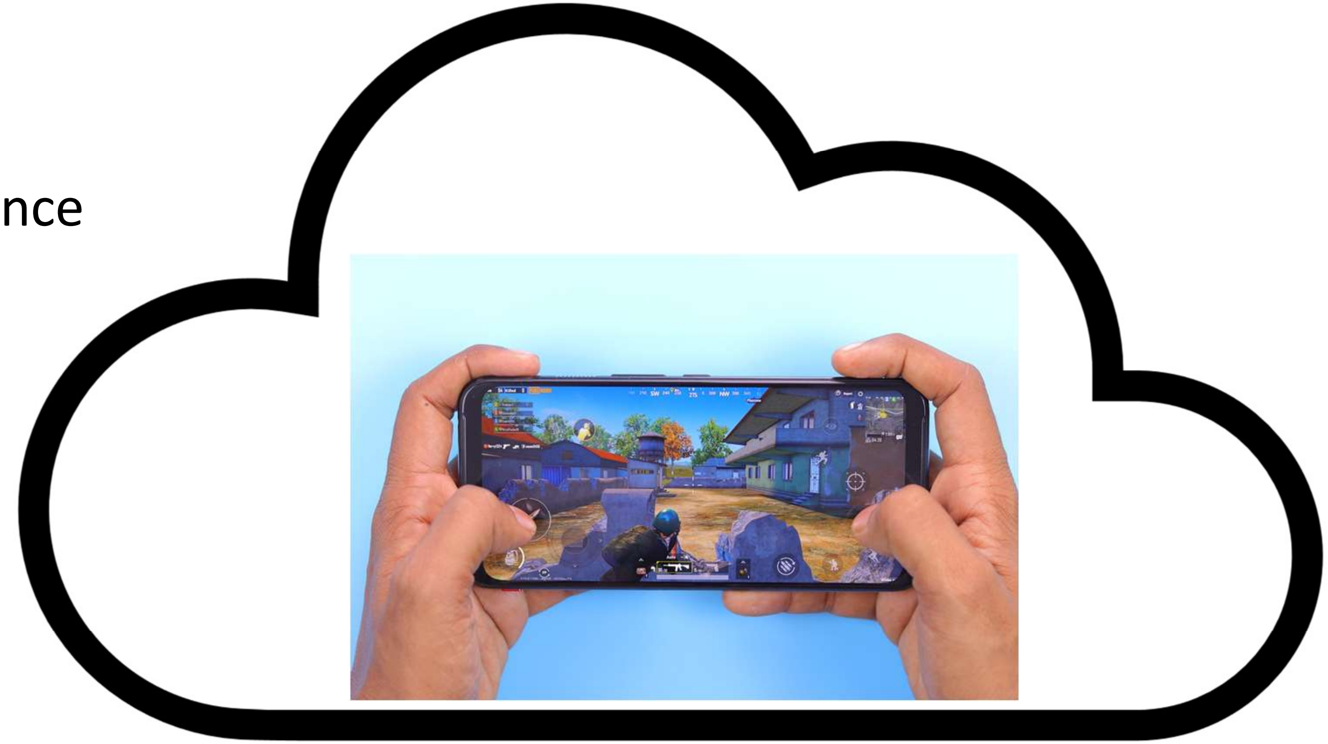
Cloud Gaming

- Quality of Service
- Quality of Experience
- User-based tests



Why Cloud Gaming

- High performance
- Cheaper devices
- Larger customer base

Contributions

- QoE and In-game performance
- User-based tests

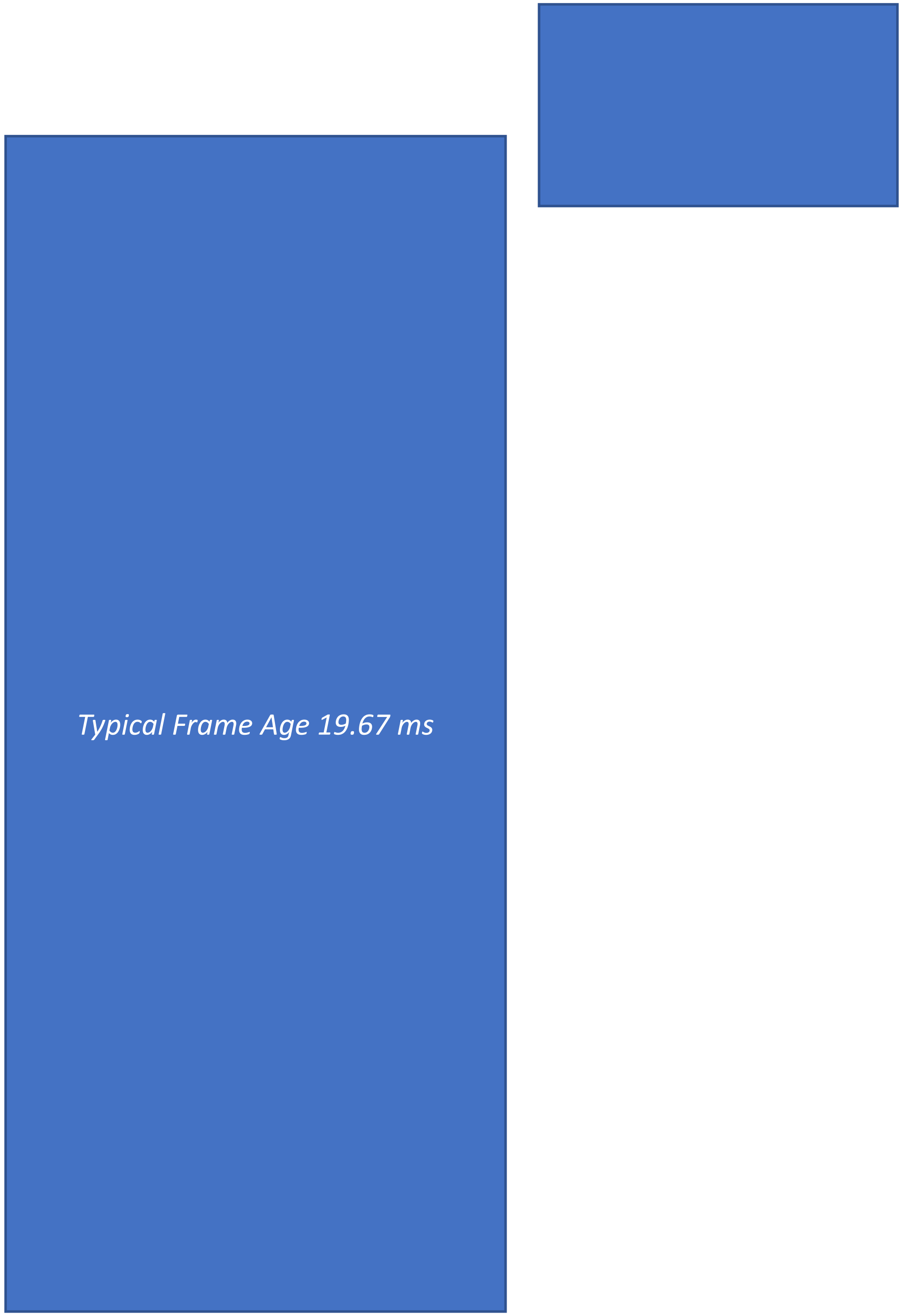
Contributions

- QoE and In-game performance
- User-based tests
- Frame Age
  - Spikes
  - Backlogs

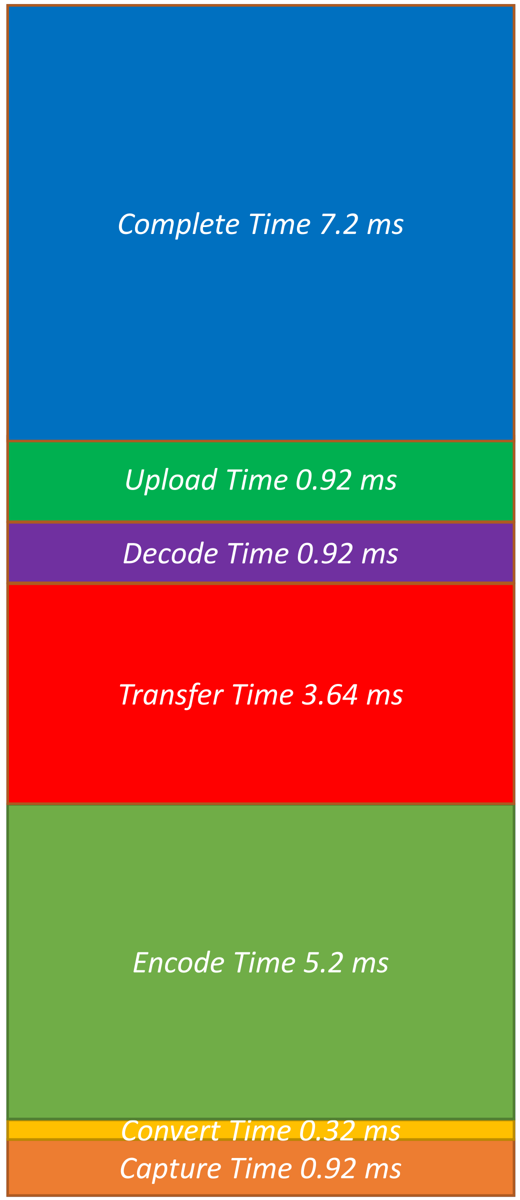
Contributions

- QoE and In-game performance
- User-based tests
- Frame Age
  - Spikes
- Scenario-based analysis
- Correlation
- Regression models

Frame Age



Frame Age


Complete Time 7.2 ms
Upload Time 0.92 ms
Decode Time 0.92 ms
Transfer Time 3.64 ms
Encode Time 5.2 ms
Convert Time 0.32 ms
Capture Time 0.92 ms

Related work (at a glance)

- Effect of Latency
  - Linear degradation

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- QoS Optimization

Related work (at a glance)

- Effect of Latency
  - Linear degradation
- QoS Optimization
- Frame Age

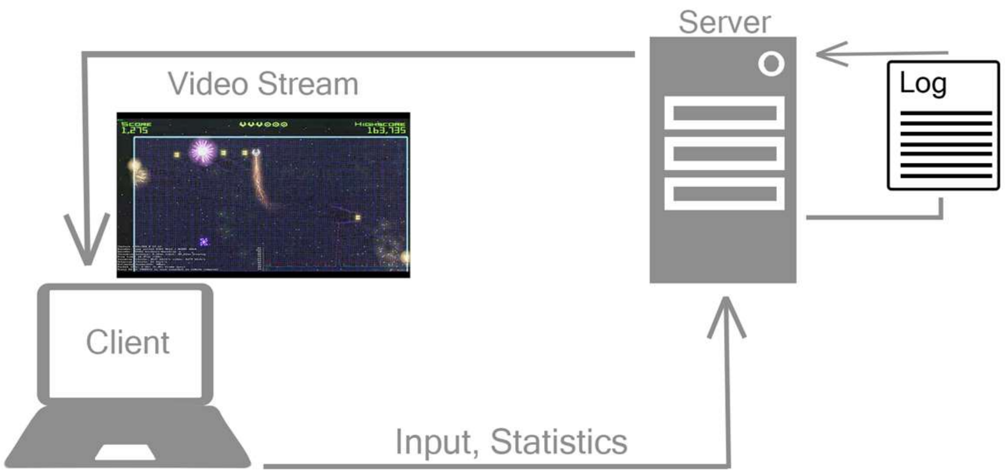
"*whether the average frame age is an effective measure of **user-perceived** QoE …*" [1]

[1] Yates et al., “Timely cloud gaming,” in Proc. IEEE INFOCOM, 2017.

Methodology: Design and metrics

High-level Methodology

- High-power server
- Mid-level client
- Network conditions
  - Artificially controlled



Metrics

```
Frame: 5138, 30379 bytes, k_EStreamFrameEventStart at 91365.17ms
           k_EStreamFrameEventCaptureBegin at 91365.17ms, delta: 0.00ms
           k_EStreamFrameEventCaptureEnd at 91365.80ms, delta: 0.63ms
           k_EStreamFrameEventConvertBegin at 91365.80ms, delta: 0.00ms
           k_EStreamFrameEventConvertEnd at 91366.02ms, delta: 0.21ms
           k_EStreamFrameEventEncodeBegin at 91366.02ms, delta: 0.00ms
           k_EStreamFrameEventEncodeEnd at 91370.84ms, delta: 4.82ms
           k_EStreamFrameEventSend at 91370.85ms, delta: 0.02ms
           k_EStreamFrameEventRecv at 91374.74ms, delta: 3.89ms
           k_EStreamFrameEventDecodeBegin at 91375.08ms, delta: 0.34ms
           k_EStreamFrameEventDecodeEnd at 91375.75ms, delta: 0.67ms
           k_EStreamFrameEventUploadBegin at 91378.33ms, delta: 2.58ms
           k_EStreamFrameEventUploadEnd at 91379.64ms, delta: 1.31ms
           k_EStreamFrameEventComplete at 91386.16ms, delta: 6.52ms
           total frame time: 20.98ms, result = k_EStreamFrameResultDisplayed
NETWORK: Ping: 3.01ms, Server: 14435 Kbit/s, Client: 1828 Kbit/s, Link: 87237 Kbit/s, Packet loss: 0.00%
```

Metrics

Per-second information

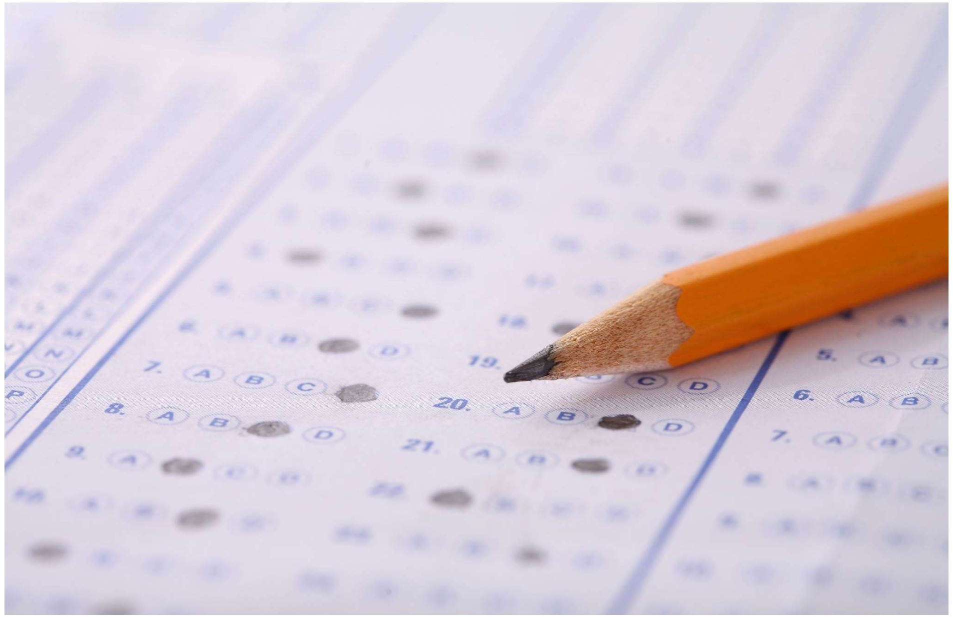
- Latency
- Server bandwidth
- Client bandwidth
- Link bandwidth
- Packet loss

Per-frame information

- Frame size
- Frame age
- Capture time
- Convert time
- Encode time
- Transfer time
- Decode time
- Upload time
- Complete time

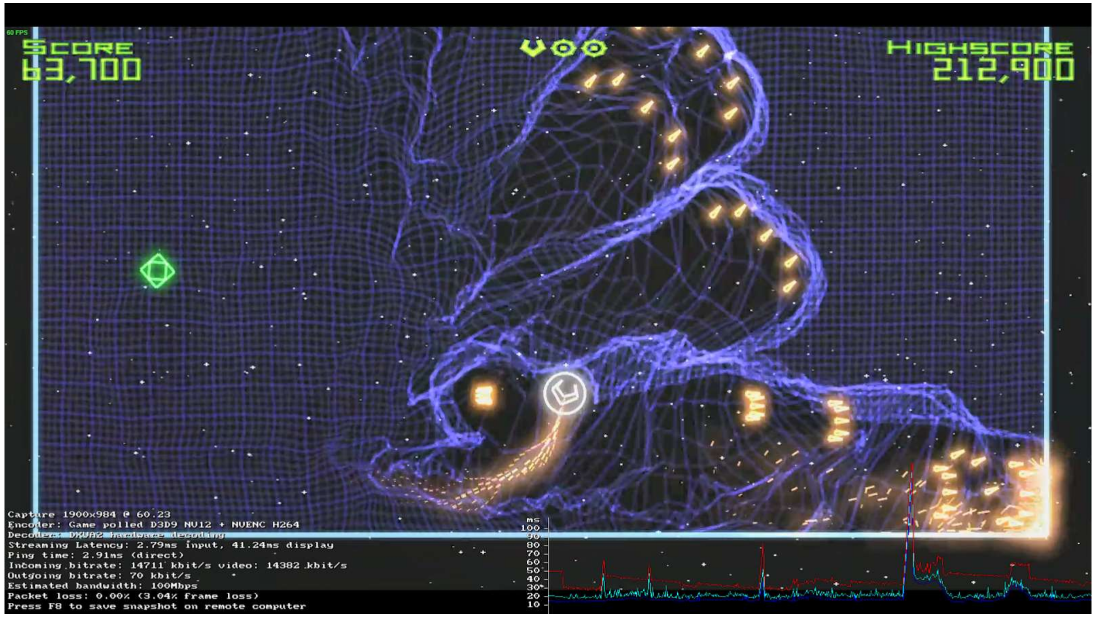
QoE

- Opinion Score
  - 7-point scale
  - Overall opinion
  - Graphical Quality
  - Interactive Quality
- In-game Score
  - Player performance



Single-player

- Geometry Wars
  - 2D Action game
  - Fast-paced



Single-player

25 scenarios

Scenario	Additional Latency	Additional Packet Loss	Comments
BL1	0 ms	0 %	Baseline
L1	25 ms	0 %	Latency 1
L2	50 ms	0 %	Latency 2
L3	75 ms	0 %	Latency 3
L4	100 ms	0 %	Latency 4
L5	125 ms	0 %	Latency 5
L6	150 ms	0 %	Latency 6
L7	175 ms	0 %	Latency 7
L8	200 ms	0 %	Latency 8
P1	0 ms	0.25 %	Packet loss 1
P2	0 ms	0.5 %	Packet loss 2
P3	0 ms	0.75 %	Packet loss 3
P4	0 ms	1.0 %	Packet loss 4
P5	0 ms	1.25 %	Packet loss 5
P6	0 ms	1.5 %	Packet loss 6
P7	0 ms	1.75 %	Packet loss 7
P8	0 ms	2.0 %	Packet loss 8
PL1	100 ms	0.5 %	Packet loss & latency 1
PL2	100 ms	1.0 %	Packet loss & latency 2
PL3	150 ms	1.0 %	Packet loss & latency 3
PL4	200 ms	1.0 %	Packet loss & latency 4
PL5	100 ms	1.5 %	Packet loss & latency 5
PL6	100 ms	2.0 %	Packet loss & latency 6
PL7	50 ms	1.0 %	Packet loss & latency 7
BL2	0 ms	0 %	Baseline 2

Single-player

25 scenarios

- Latency

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Single-player

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- Latency
- Packet loss
- Latency & Packet loss

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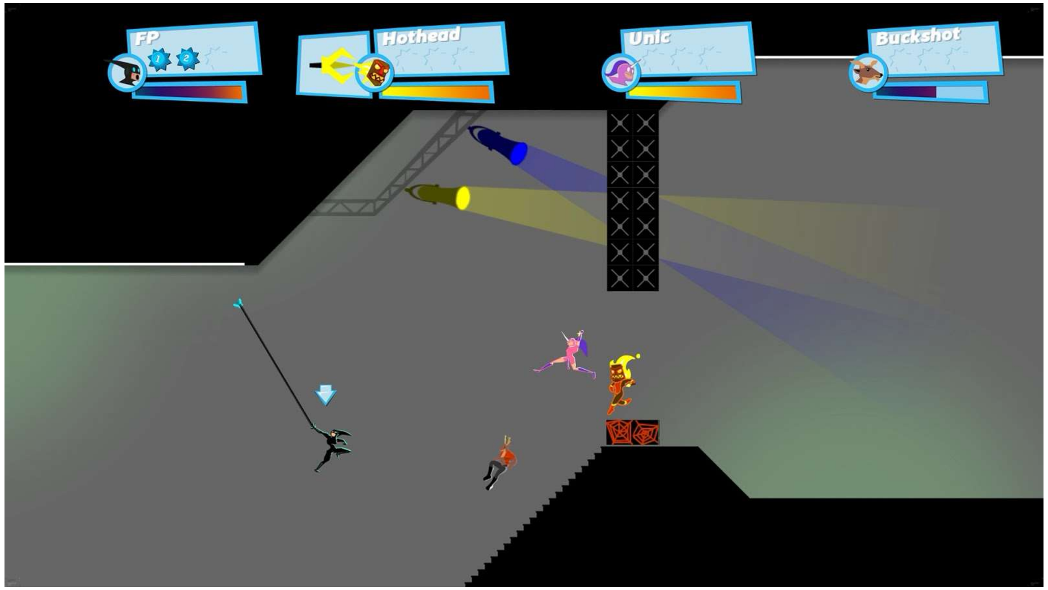
Multiplayer

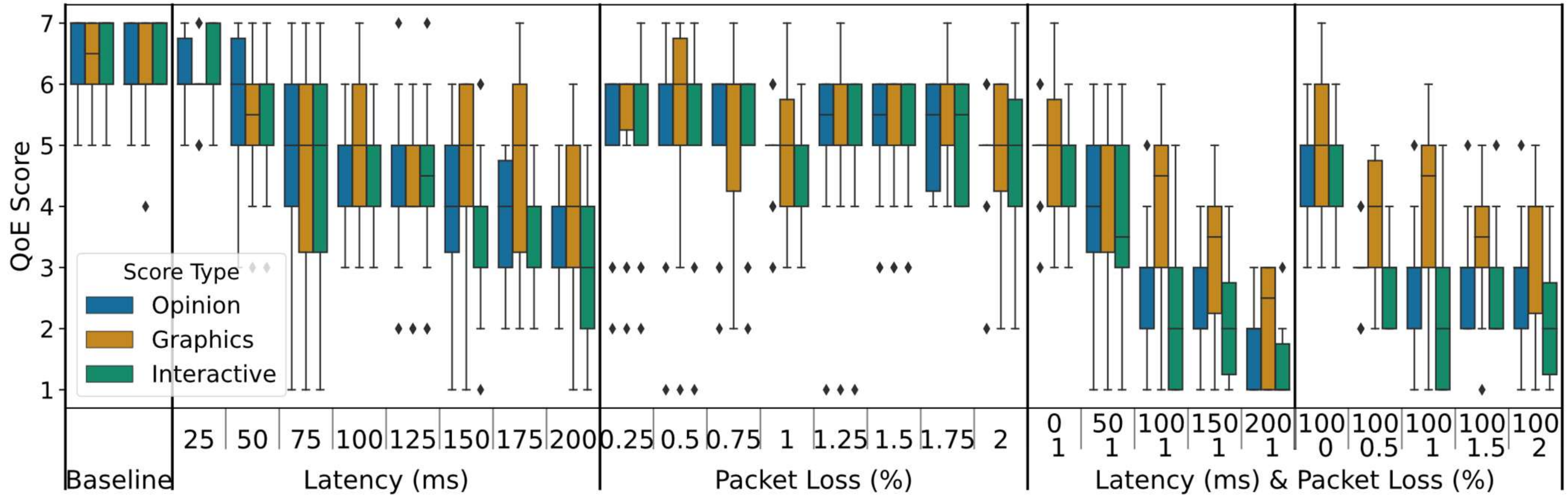
- Two players
- Only latency
- Adaptive latency
  - Skill difference
  - 50 ms
  - $f = x^n$



Winning score	Losing score	x
3	0	1.20
3	1	1.15
3	2	1.10

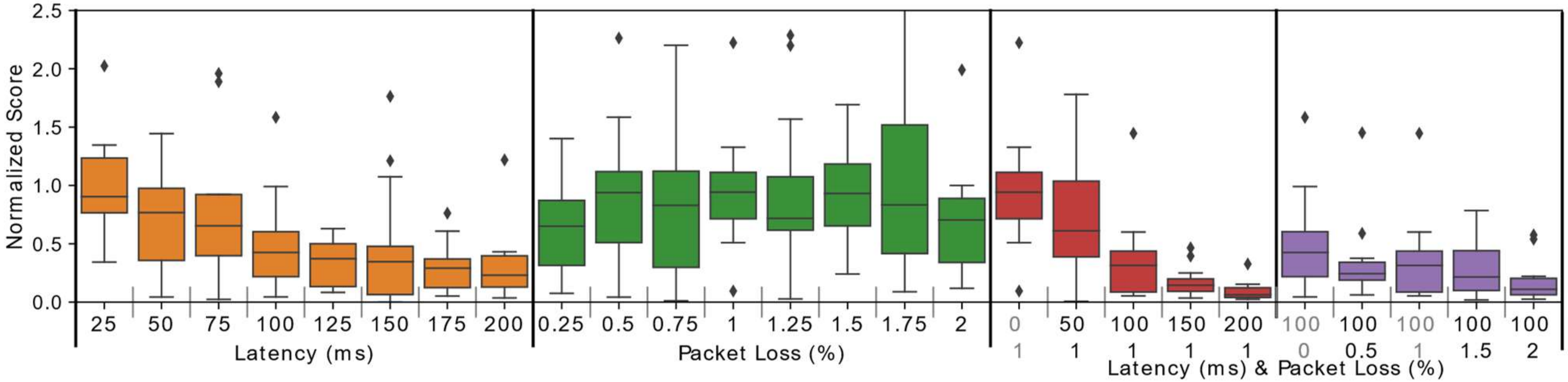
Results

Scenario-based QoE Analysis



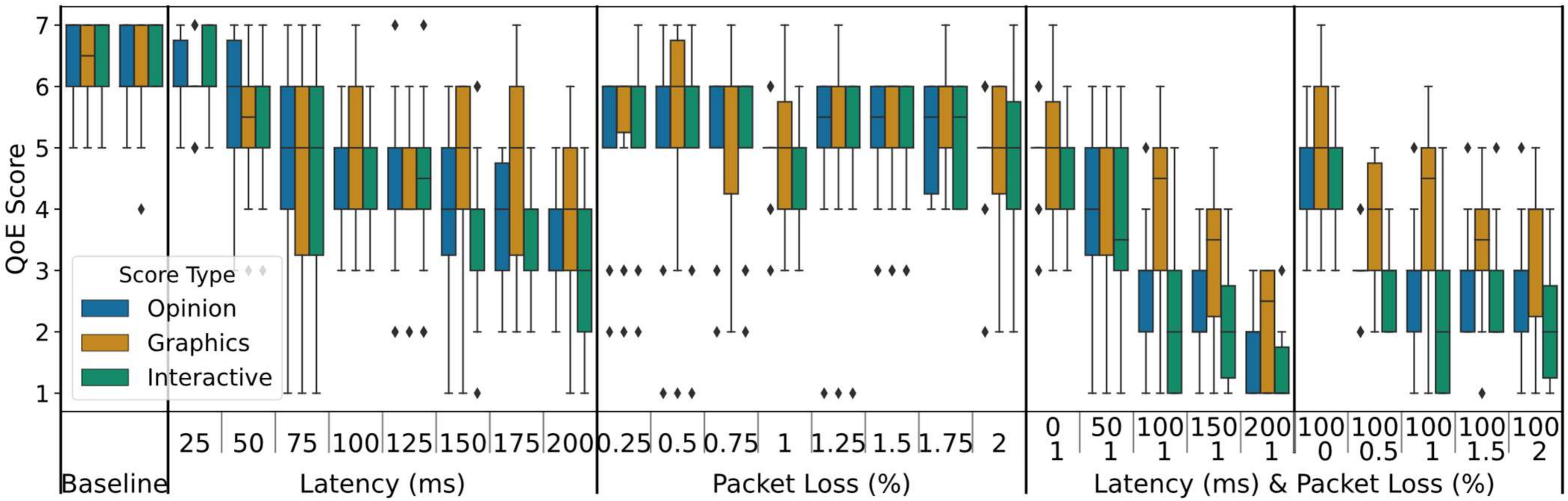
- Downwards trend in QoE
- Higher latency greater negative impact
- Combination gives even greater impact

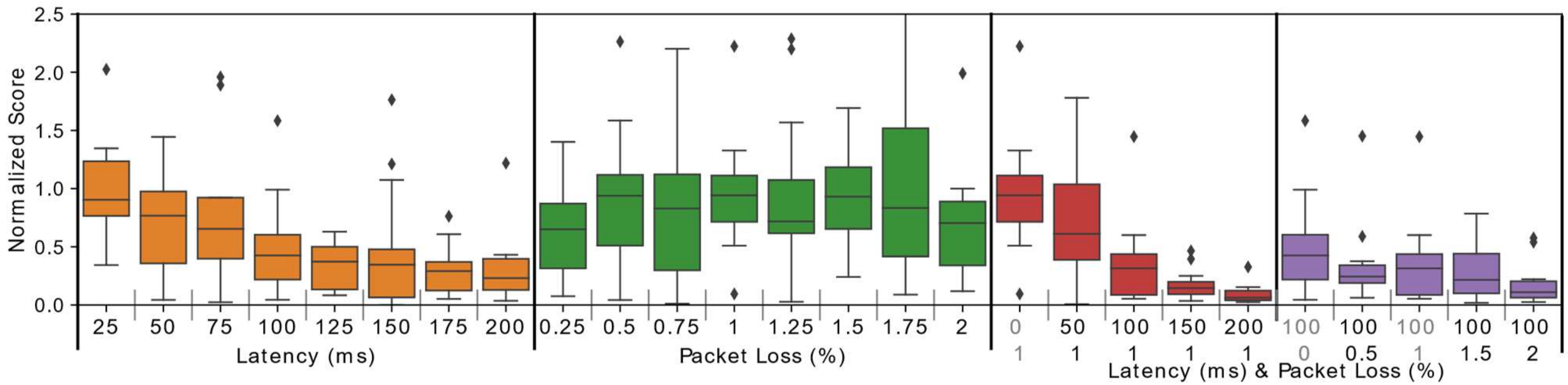
Scenario-based QoE Analysis



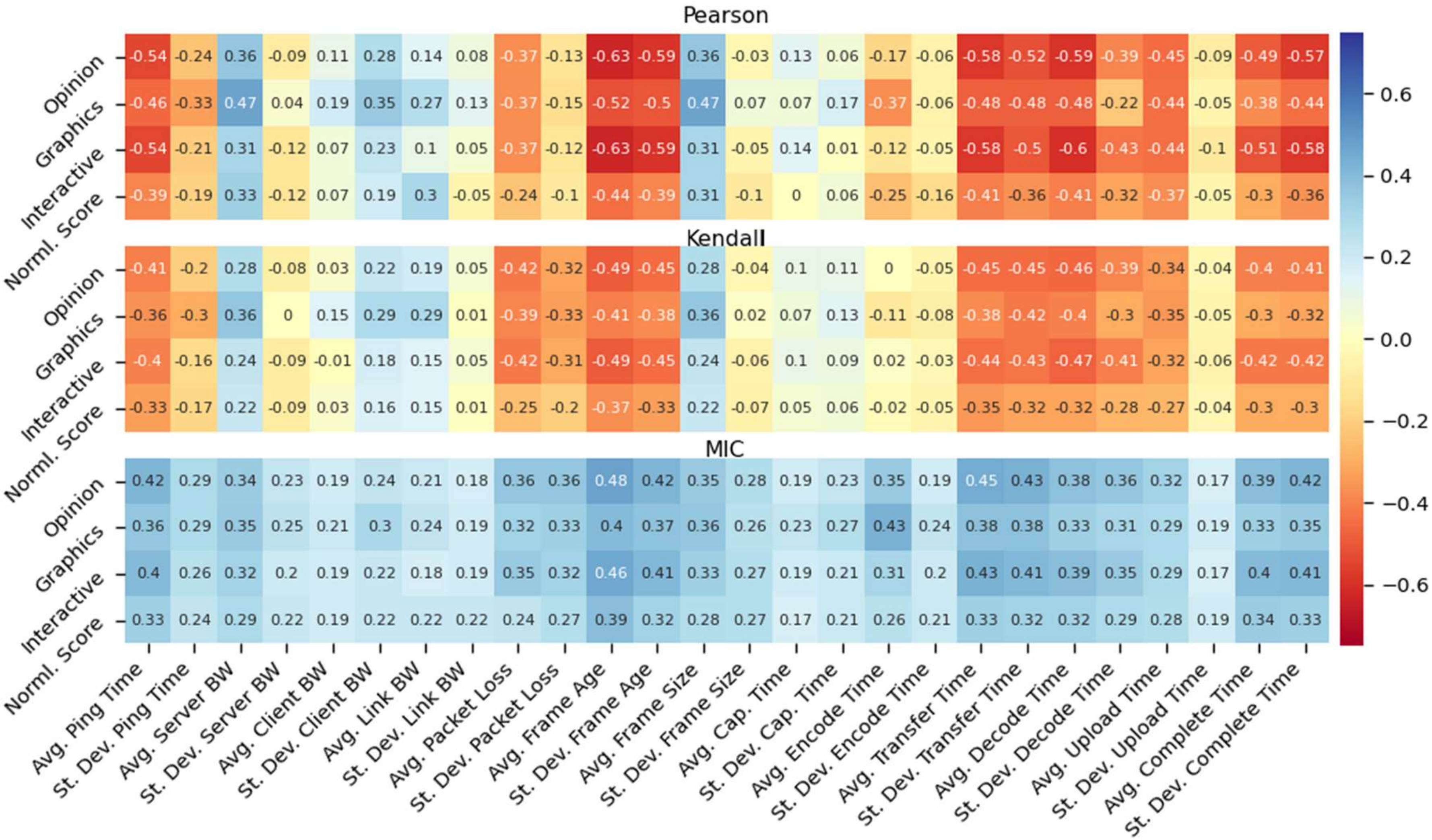
- Downward trend in in-game performance
- Latency greater negative impact

Scenario-based QoE Analysis





QoE modeling using QoE metrics



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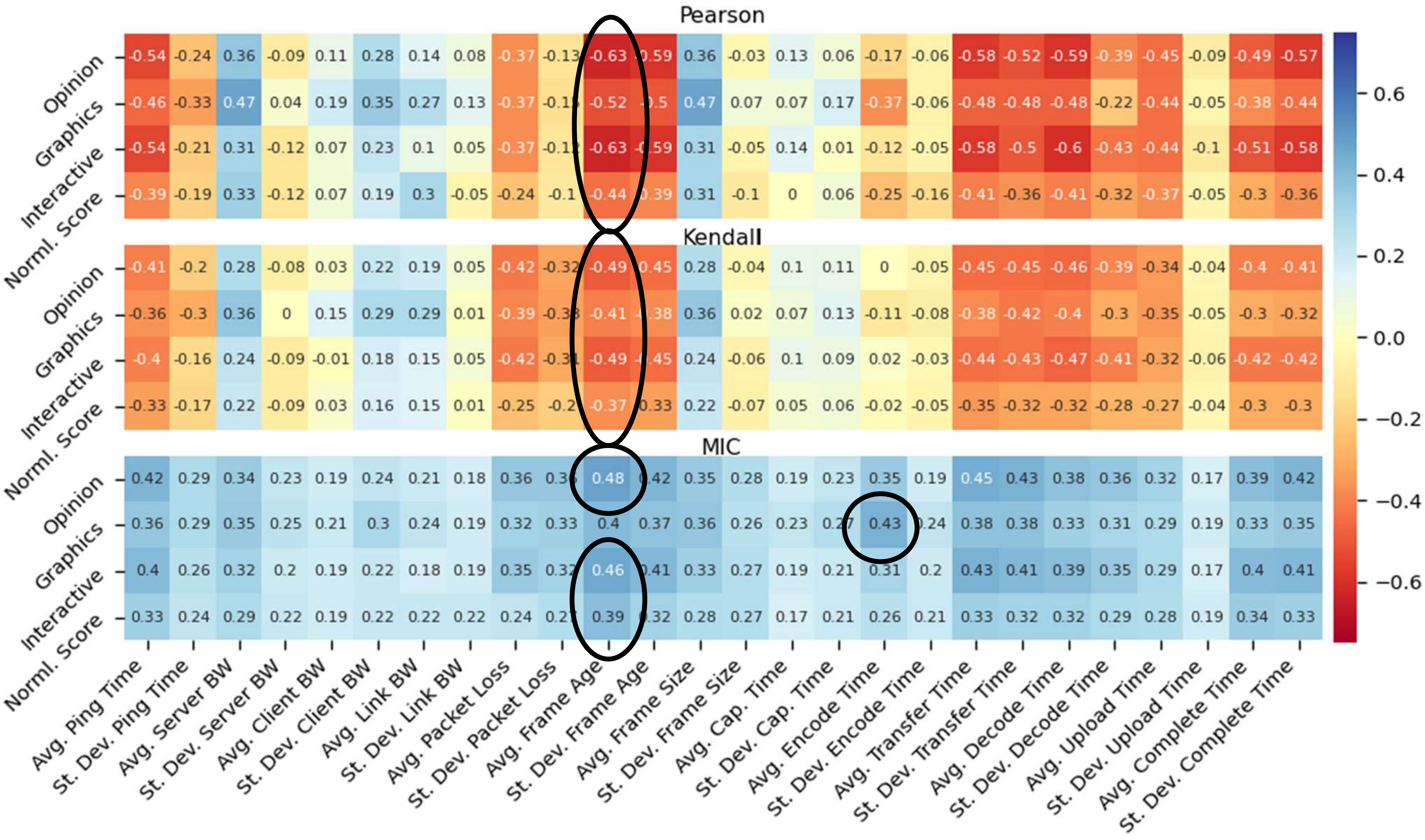
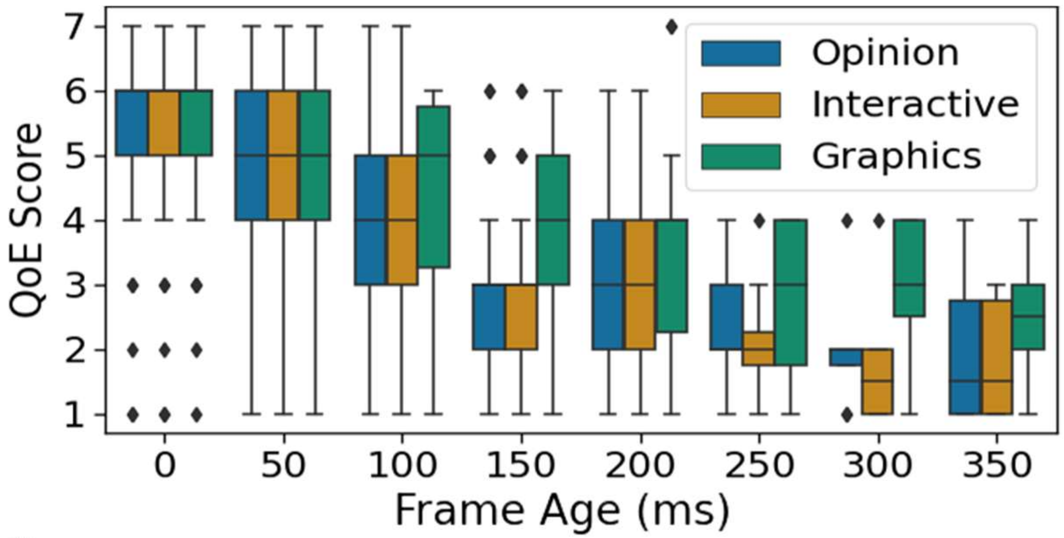
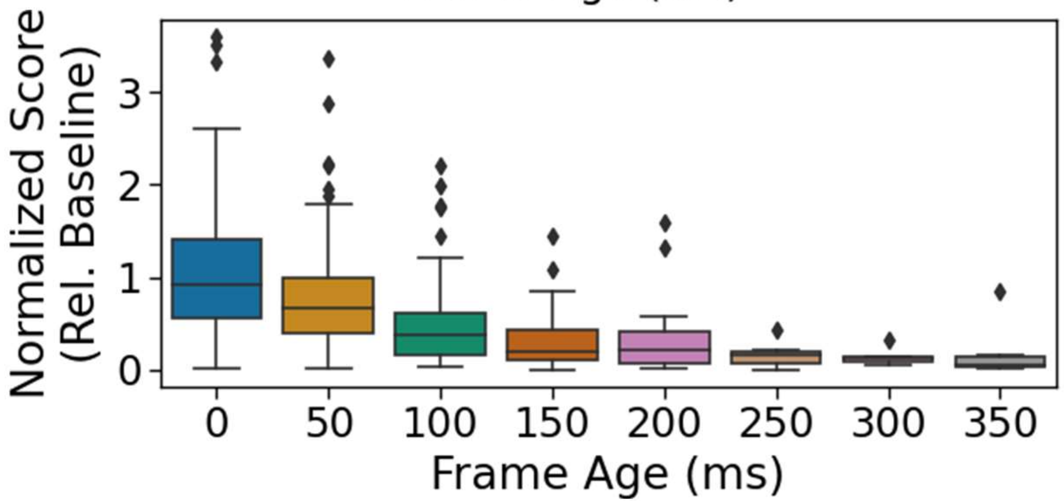


Age-based QoE Analysis

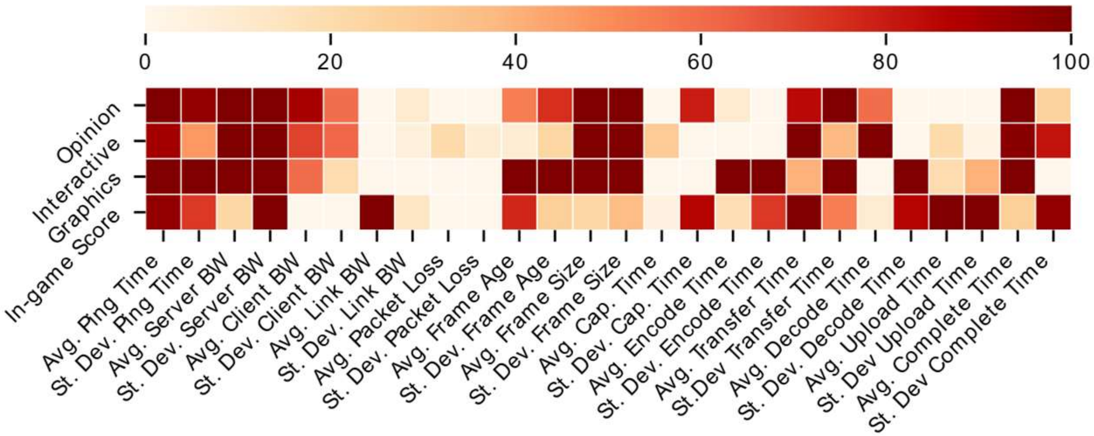
- Impact of frame age
  - Impacts graphics less
- Good QoS proxy for QoE





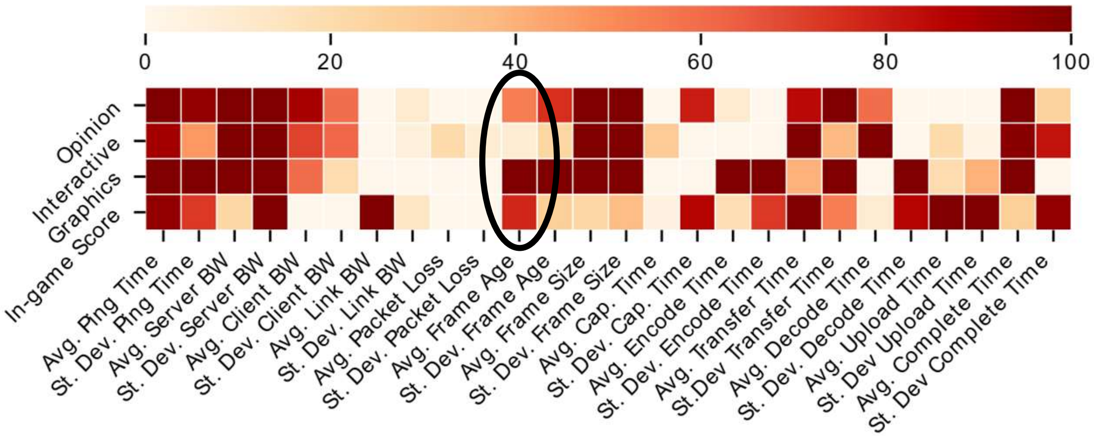
Model-based parameter selection

- Multivariate regression
- Best subset regression
  - Mallow's C_p
  - Most used variable



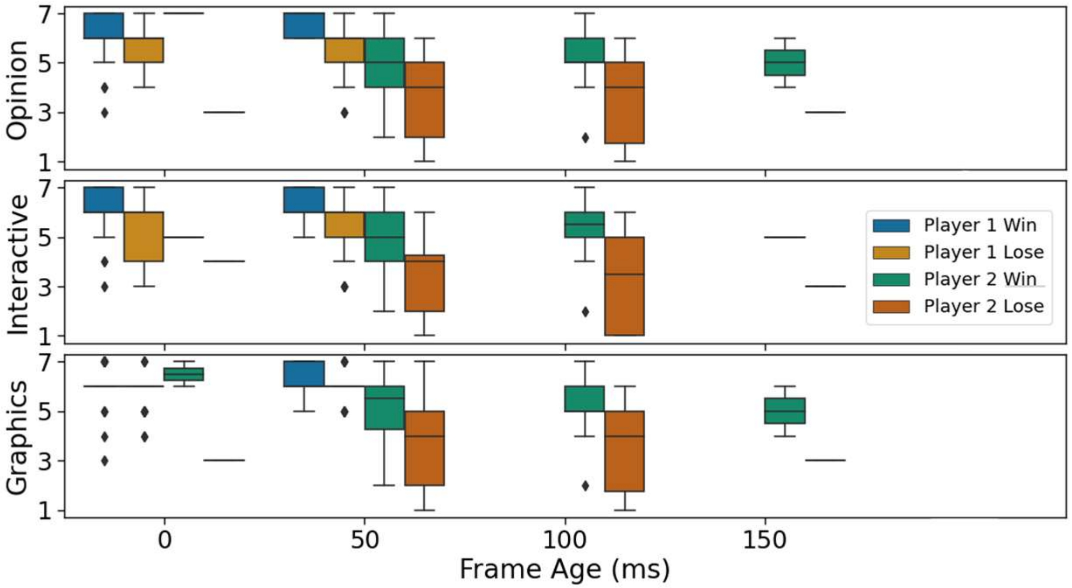
Model-based parameter selection

- Multivariate regression
- Best subset regression
  - Mallow's C_p
  - Most used variable
- Frame age not most used
- Complementing information



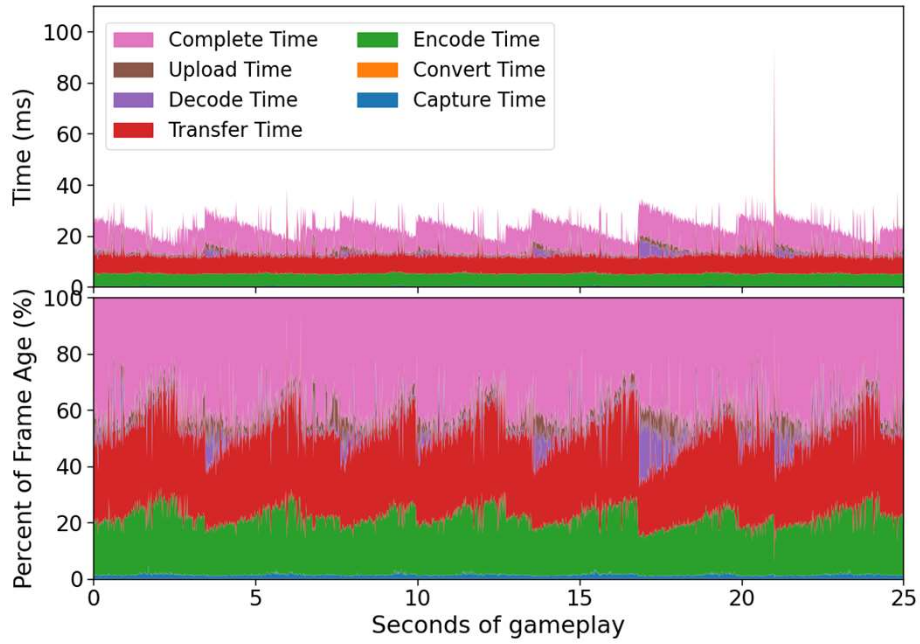
Multiplayer results & impact of wins/losses

- QoE depending on Win/Loss
- Clear impact of winning
  - Even graphics
- Correlation between performance and opinion



Frame-by-Frame Analysis

- Frame age breakdown
  - Complete time
  - Transfer time
  - Encode time



Frame-by-Frame Analysis

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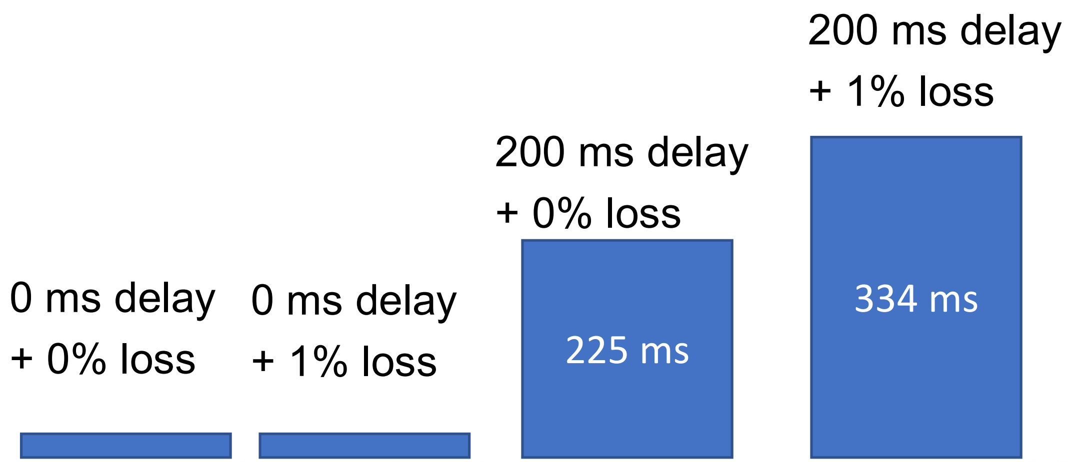
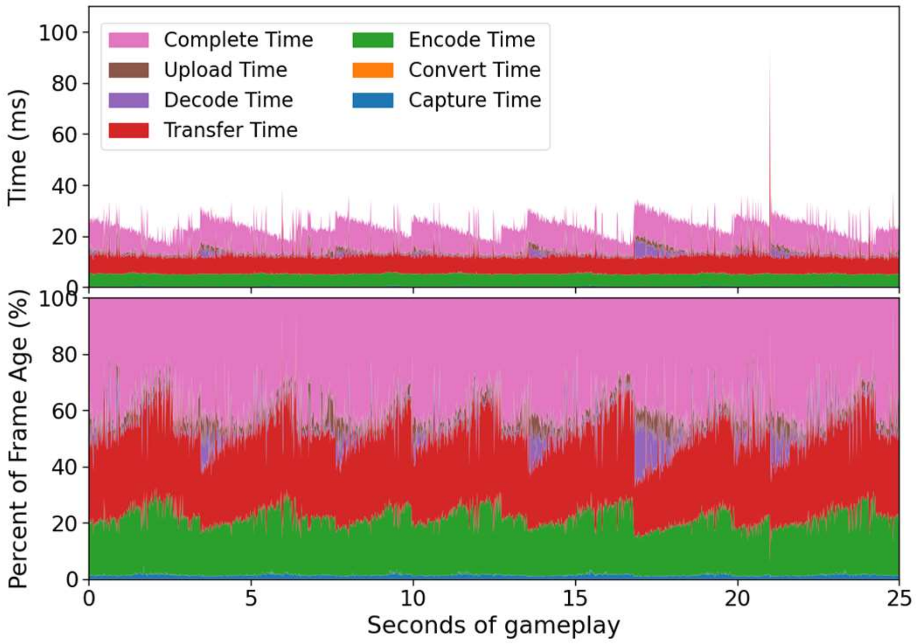


	Low-low	Low-high	High-low	High-high
Capture	0.78 (0.26)	0.73 (0.21)	0.77 (0.26)	0.77 (0.24)
Convert	0.39 (2.68)	0.37 (2.68)	0.29 (0.09)	0.28 (0.08)
Encode	5.10 (0.28)	5.11 (0.18)	4.86 (0.17)	4.88 (0.20)
Transfer	3.47 (3.69)	3.44 (3.40)	204.81(3.78)	211.35(35.61)
Decode	2.66 (3.40)	1.74 (3.32)	2.01 (2.86)	7.89 (7.70)
Upload	1.62 (0.40)	1.16 (0.58)	1.29 (0.68)	2.02 (0.47)
Complete	10.41 (2.81)	9.75 (2.70)	10.05(2.81)	71.03(122.34)
Other	1.78 (1.18)	1.82 (1.35)	1.54 (1.71)	35.74 (66.68)
Frame age	26.21(6.84)	24.14(6.97)	225.60(6.21)	334.18 (120.15)

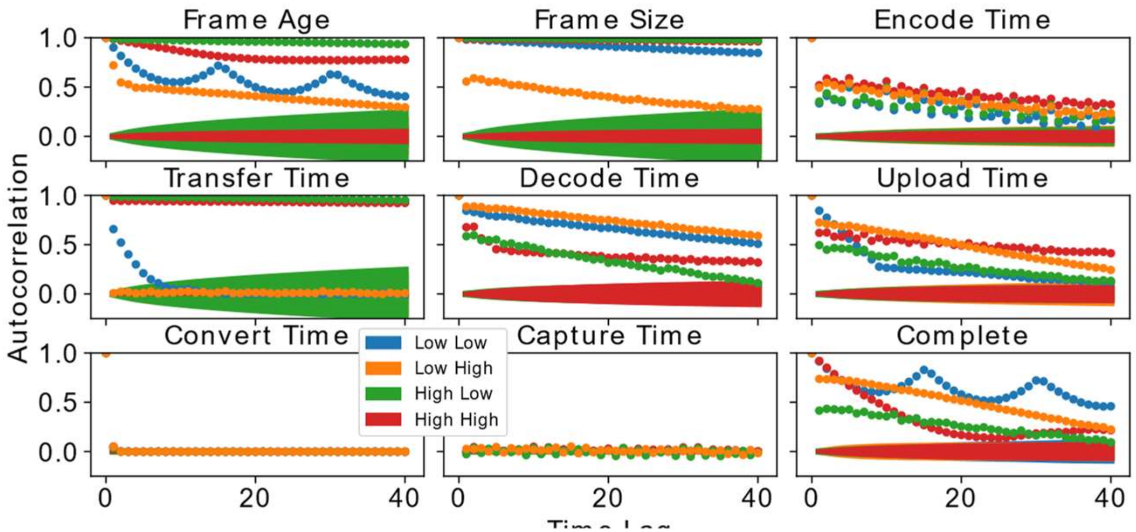
Auto- and cross-correlation analysis

- Periodic pattern
  - Temporal dependencies



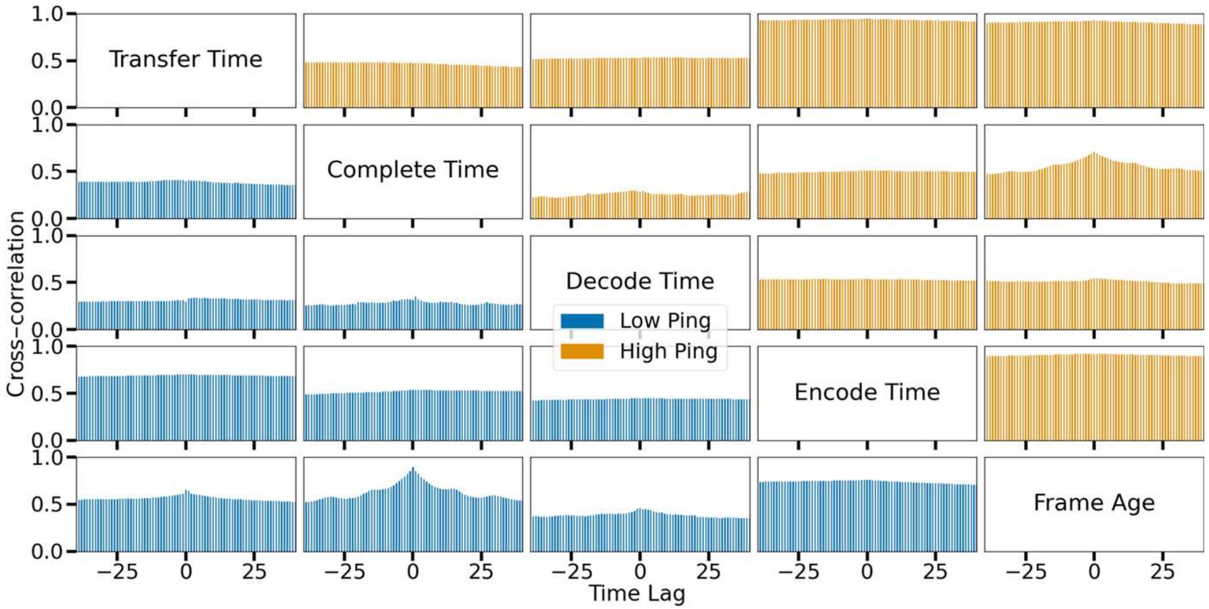
Auto- and cross-correlation analysis

- Periodic pattern
  - Temporal dependencies
- Auto-correlation
  - 1-40 frame lag
- Time dependencies
- Decreases with latency



Auto- and cross-correlation analysis

- Average Cross-correlation
  - Low-low (Blue)
  - High-low (Yellow)
- Spikes
  - Complete time
  - Frame Age



Summary and conclusions

Relationship between QoS and QoE

- **Objective** and easier to collect QoE
- **Subjective** QoE

Importance of frame age

- **Latency** large impact
- **Extended** impact of **spikes**

Paper online!

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ABSTRACT

Cloud computing offers an attractive solution for modern computer games. By moving the increasingly demanding graphical calculations (e.g., generation of real-time video streams) to the cloud, consumers can play games using small, cheap devices. While cloud gaming has many advantages and is increasingly deployed, not much work has been done to understand the underlying factors impacting players' user experience when moving the processing to the cloud. In this paper, we study the impact of the quality of service (QoS) factors most affecting the players' quality of experience (QoE) and in-game performance. In particular, these relationships are studied from multiple perspectives using complementing analysis methods applied on the data collected via instrumented user tests. During the tests, we manipulated the players' network conditions and collected low-level QoS metrics and in-game performance, and after each game, the users answered questions capturing their QoE. New insights are provided using different correlation/auto-correlation/cross-correlation statistics, regression models, and a thorough breakdown of the QoS metric most strongly correlated with the users' QoE. We find that the frame age is the most important QoS metric for predicting in-game performance and QoE, and that spikes in the frame age caused by large frame transfers can have extended negative impact as they can cause processing backlogs. The study emphasizes the need to carefully consider and optimize the parts making up the frame age, including dependencies between the processing steps. By lowering the frame age, more

only obtains user inputs and displays a real-time game video stream generated by one or more cloud servers.

Cloud computing offers an effective way to deliver high-performance services to players who lack the necessary computation resources. In the context of cloud gaming, this approach has positive effects for both players and developers. For example, the reduced need for high-performance computations on the client side allows players to use cheaper devices and improves battery life. Second, since players only need a "thin client", they can use regular home entertainment devices rather than custom-made gaming devices. This significantly extends the pool of customers that game developers can target. Third, the game-specific code would only need to be stored on the server, reducing piracy risks for the developers [28].

Driven by these advantages, there has been a significant increase in the use of cloud gaming services. The global cloud gaming market is set to generate $3.2 Billion by 2023 [4]. However, although this approach has many advantages and is increasingly deployed, not much work has been done to understand the factors impacting the gamer's user experience when processing is moved to the cloud.

In this paper, we study what objective quality of service (QoS) factors best explain the players' quality of experience (QoE) and in-game performance, and how each impacts the player experience. To capture these relationships from multiple perspectives and to allow the use of selected, complementing analysis approaches (taking into account the impact of game, player, and win/loss, for example), we designed a series of user-based tests in which two gamers

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* Illustrative images created using images from pixabay.com