

# FoVR: Attention-based VR Streaming through Bandwidth-limited Wireless Networks

**Songzhou Yang**<sup>\*</sup>, Yuan He<sup>†</sup>, Xiaolong Zheng<sup>‡</sup>

<sup>\*</sup><sup>†</sup>School of Software and BNRist, Tsinghua University

<sup>‡</sup>School of Computer Science, Beijing University of Posts and Telecommunications



# Virtual Reality (VR)



The number of Virtual Reality devices will reach 39.9 millions by 2020 according to Bloomberg

# VR 360 Videos



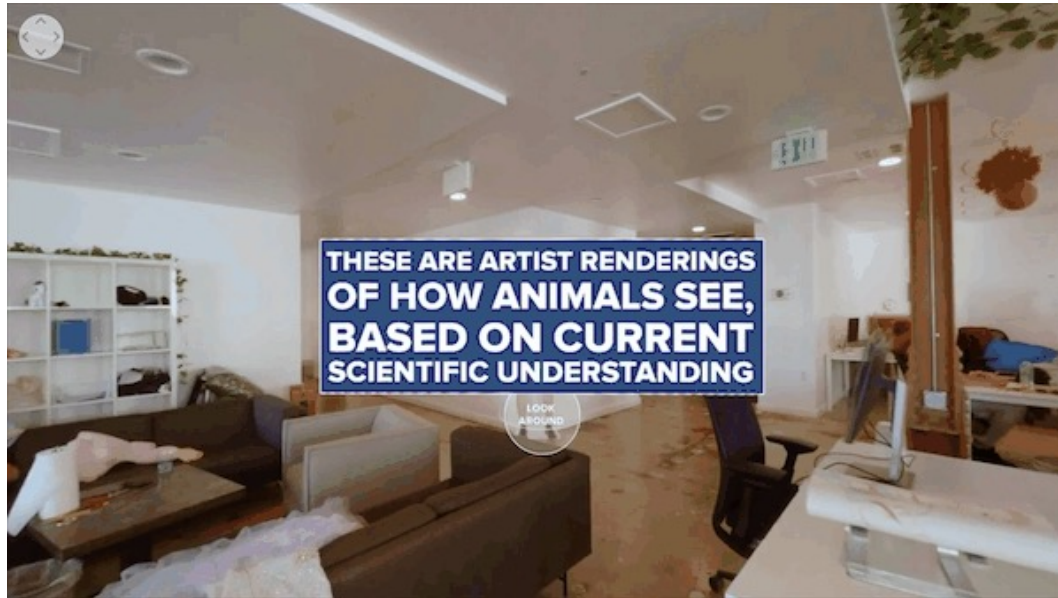
Huawei report that VR 360 Videos are in a dominant position with a 99.37% proportion in VR content types

However, ...



Video will stall when the bandwidth cannot meet requirements

# Video quality suffers as well



Original Quality

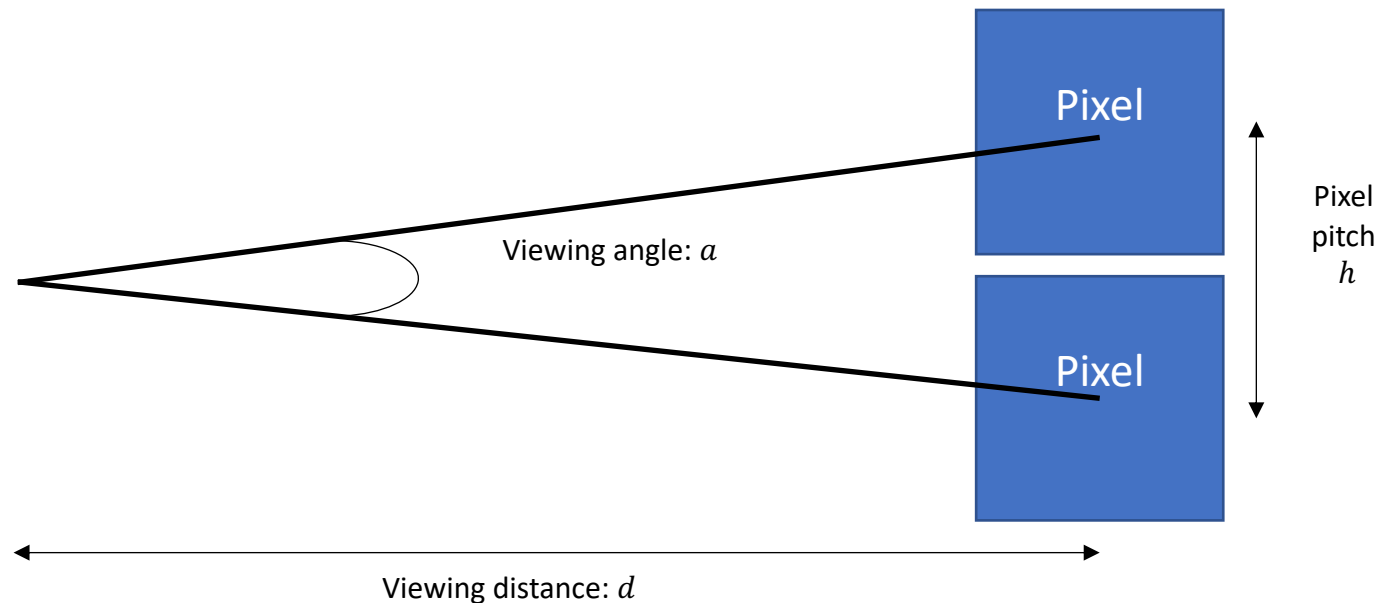


After ABS

Adaptive streaming can avoid stalling but damage the quality

# Large Video Volume

- Satisfying retina display on VR devices with 95° FoV
  - 5073×5707 resolution per eye
  - $a = 2 \tan^{-1} \left( \frac{h}{2d} \right)$

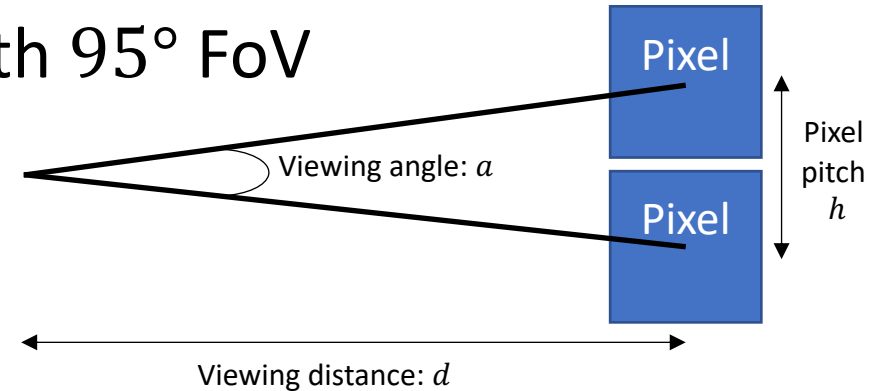


# Large Video Volume

- Satisfying retina display on VR devices with 95° FoV

- 5073×5707 resolution per eye

- $a = 2 \tan^{-1} \left( \frac{h}{2d} \right)$



- Bandwidth requirements under such resolution

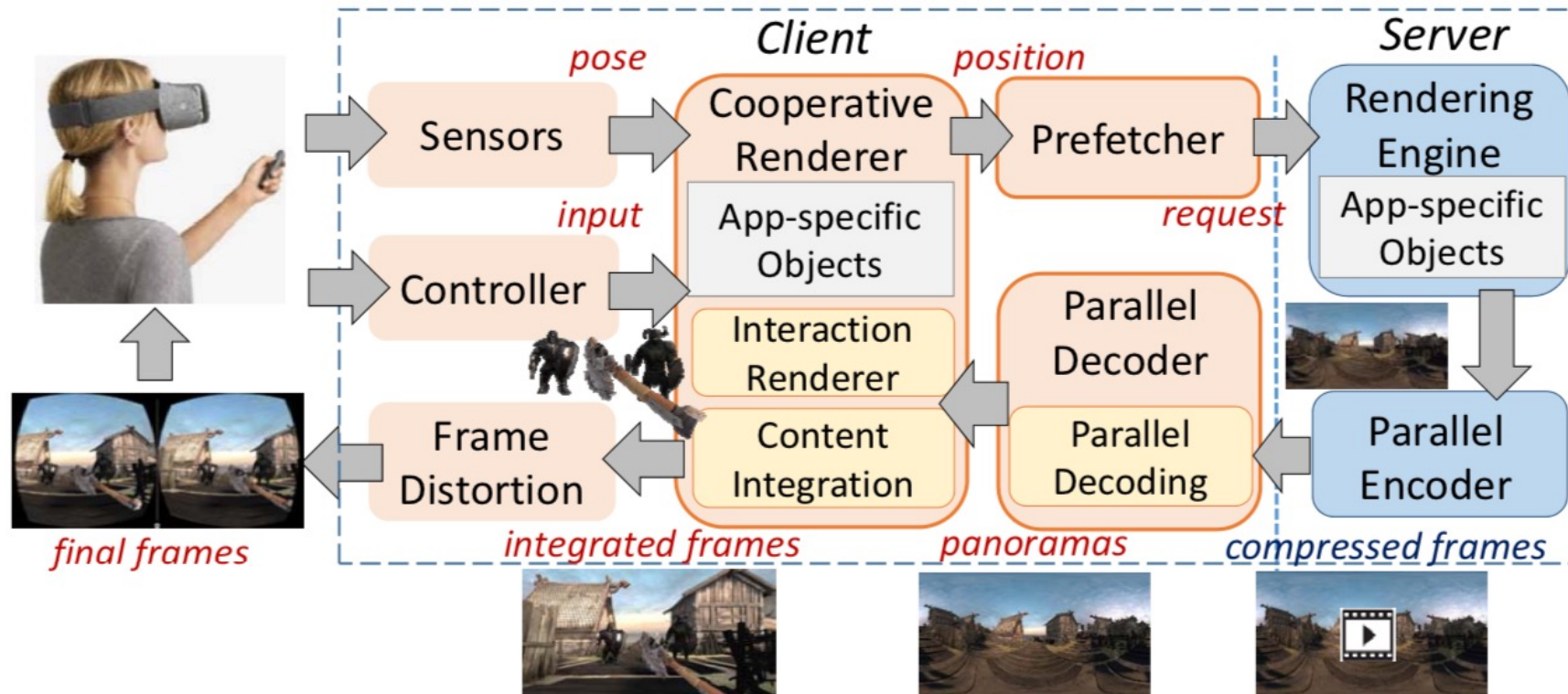
- 840 Mbps w/ 2D 60FPS

- 4.2 Gbps w/ 3D 120FPS

- 802.11ac: 1.3 Gbps in theory, 400 Mbps in practice

# Can we resort to existing technologies?

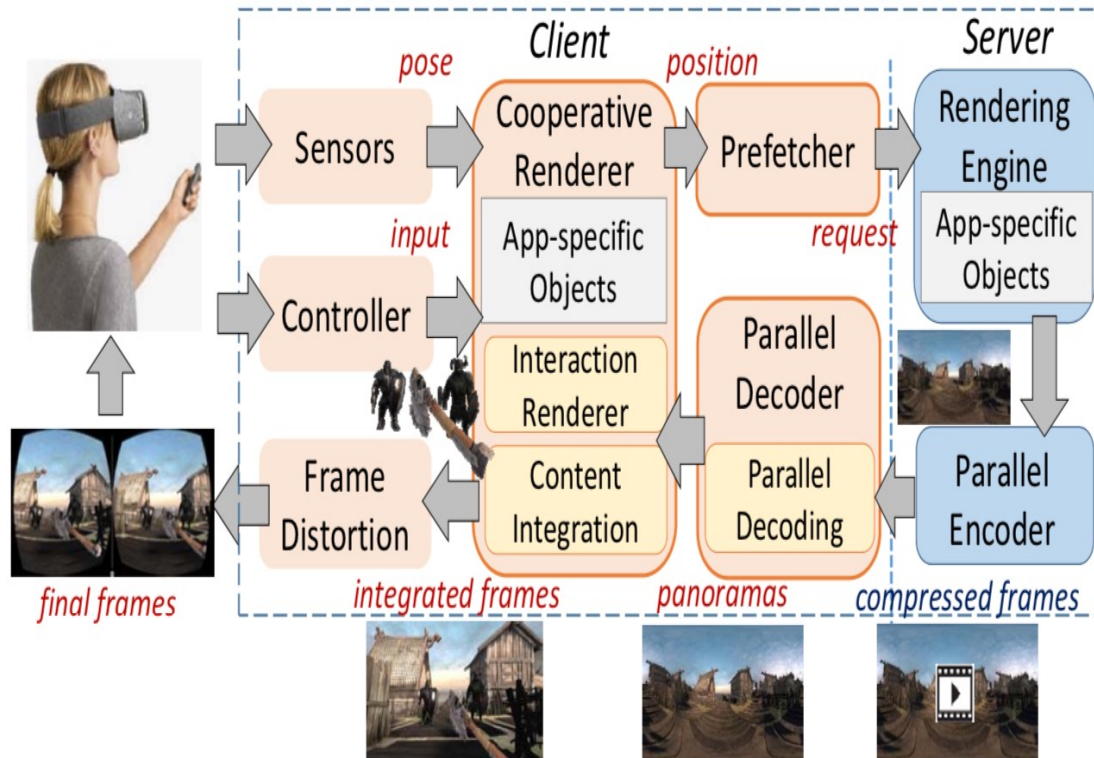
- Furion (MobiCom 2017):





# Can we resort to existing technologies?

- Furion (MobiCom 2017):

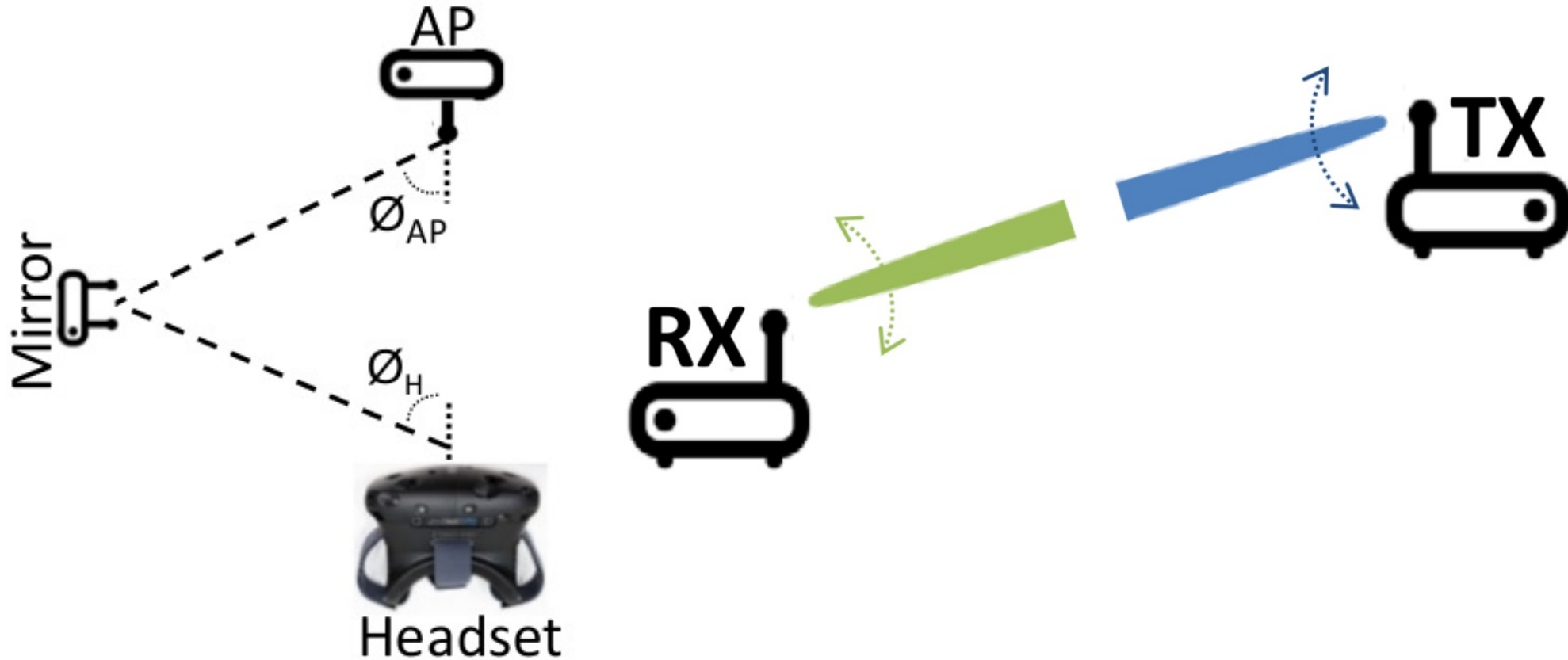


- Cloud offloading

- Can reduce computing loads on the VR sides
- But cannot relieve the loads of network communication

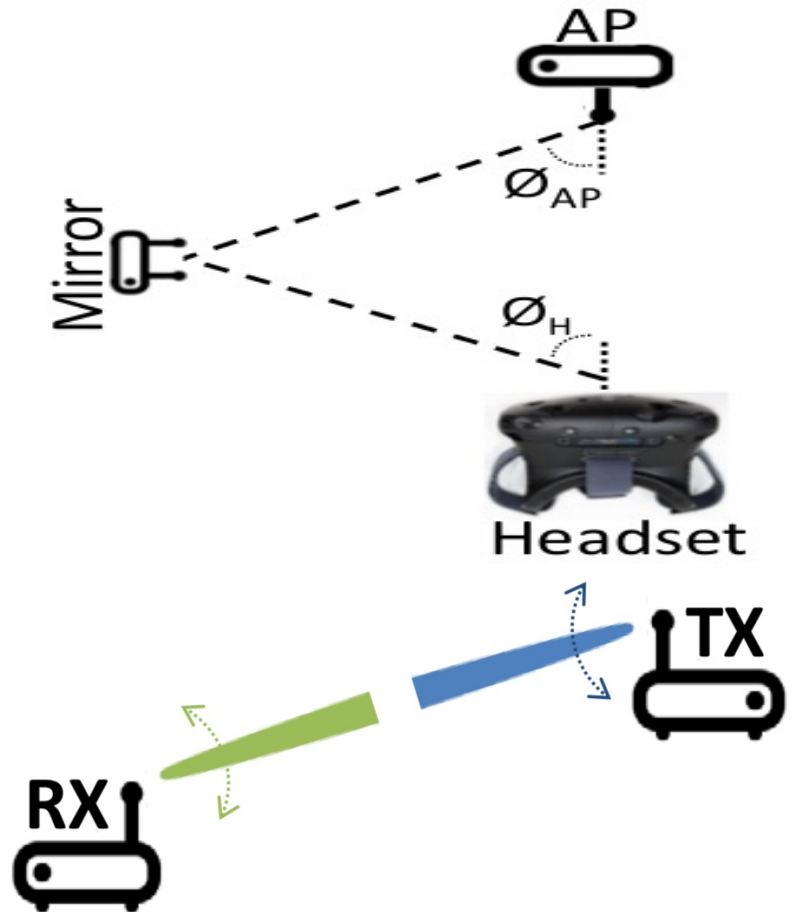
# Can we resort to existing technologies?

- MOVR (NSDI 2017):



# Can we resort to existing technologies?

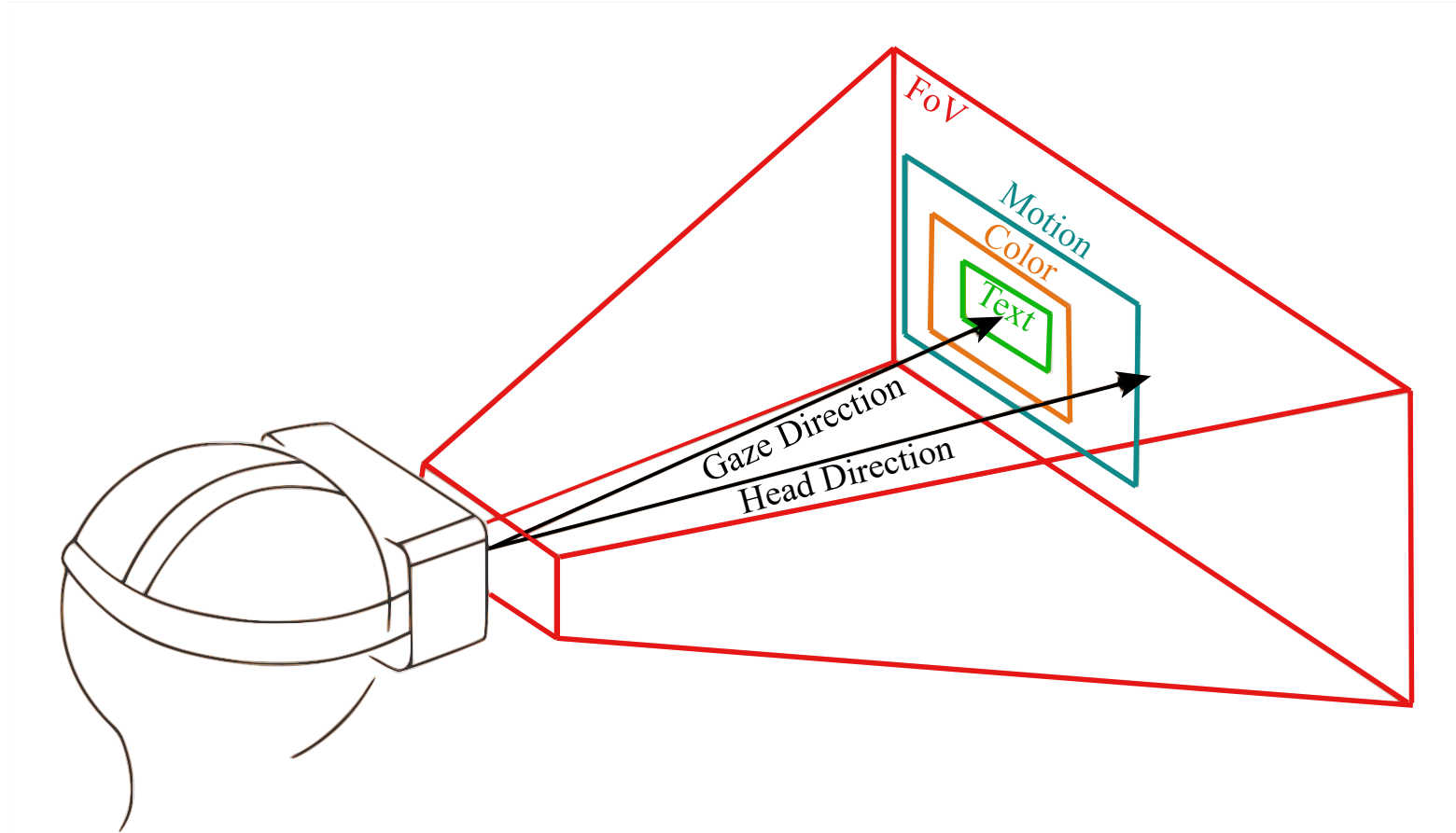
- MOVR (NSDI 2017):



- 60 Ghz

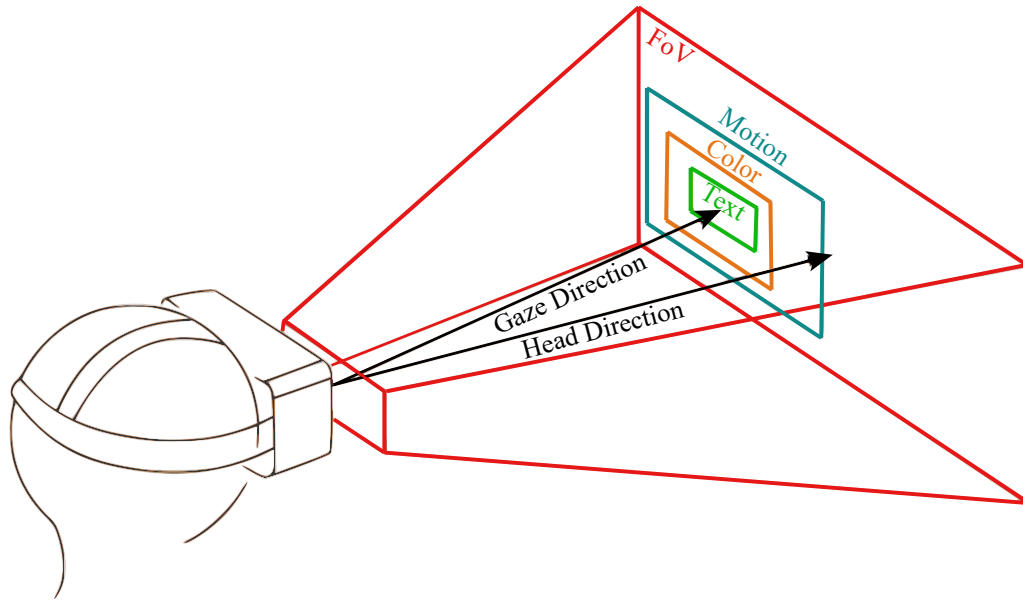
- Can relieve the loads of network communication
- But suffers when users move

# Our insight into this problem



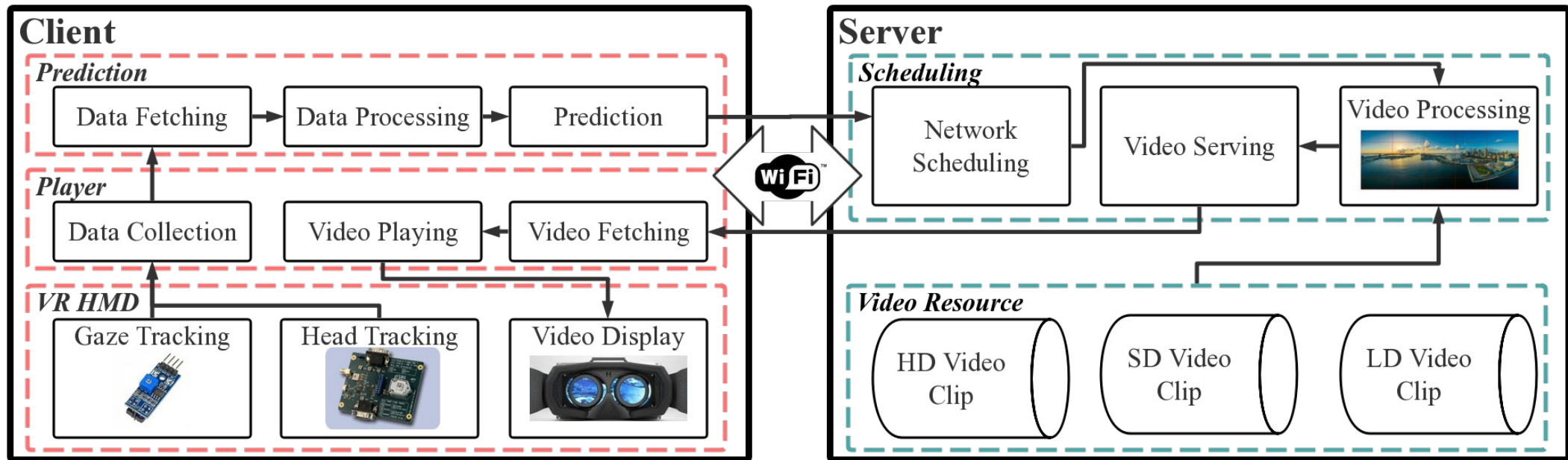
# Our insight into this problem

- The vision of humans is hierarchical



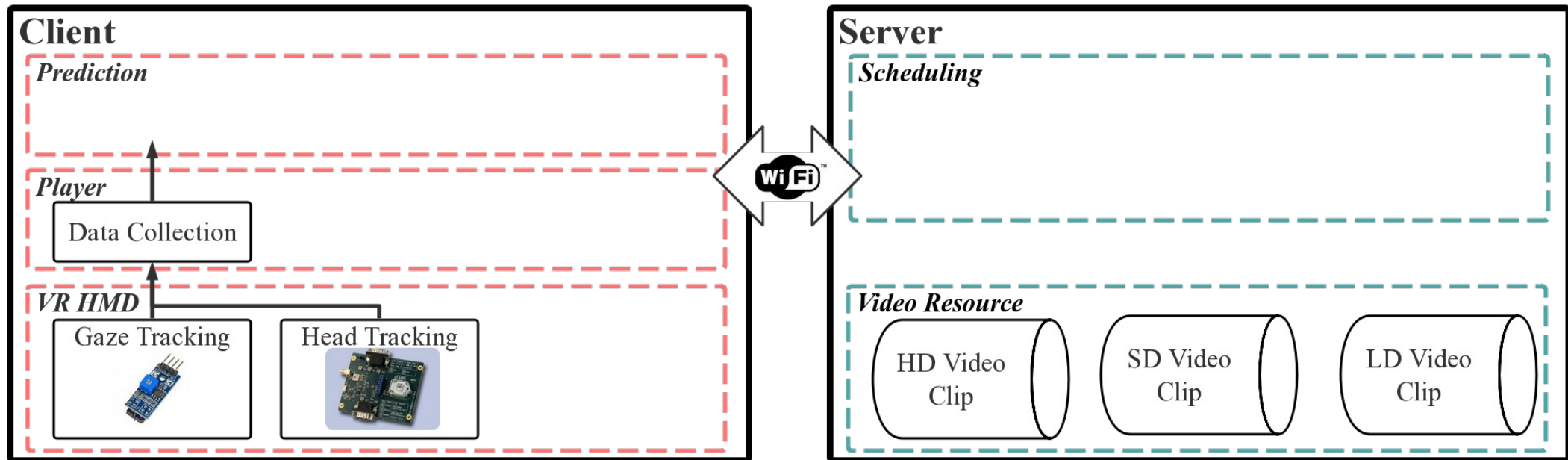
- Attention Area
  - Non-Attention
  - Out-of-Sight (OoS)
- } Field of View (FoV)

# Solution: FoVR

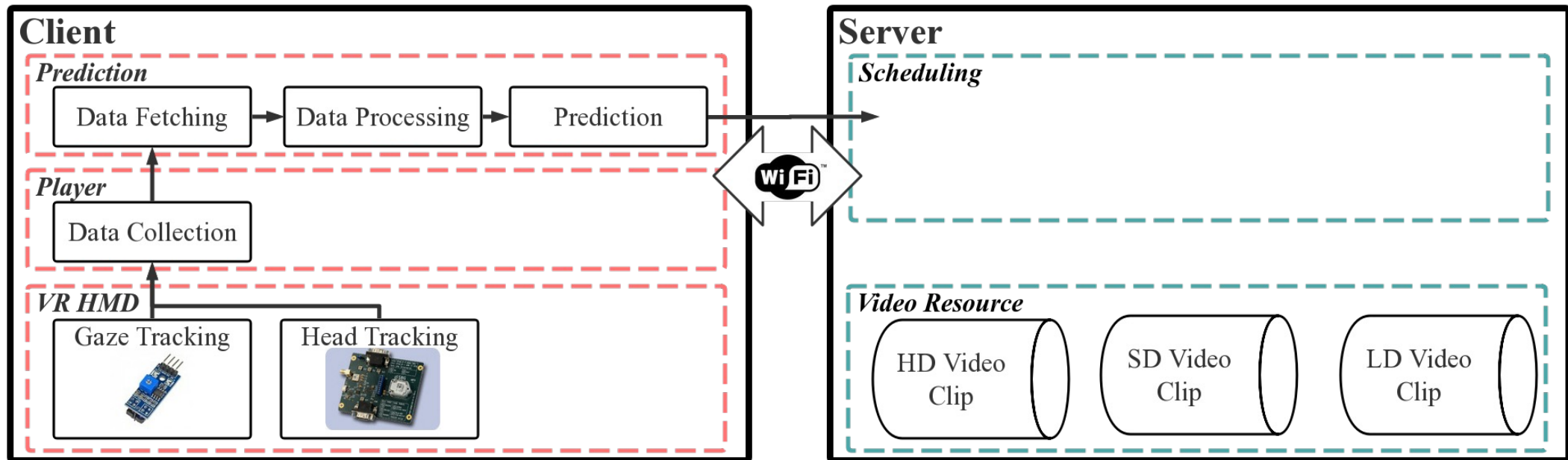


Attention-based VR Streaming through Bandwidth-limited Wireless Networks

# Solution: FoVR

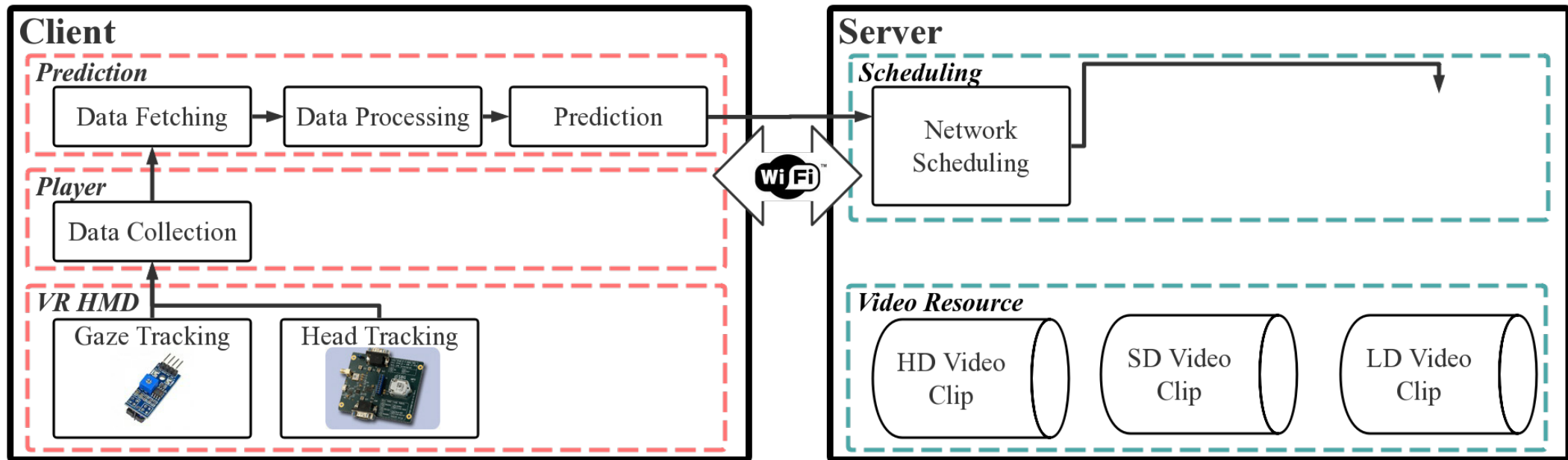


# Solution: FoVR

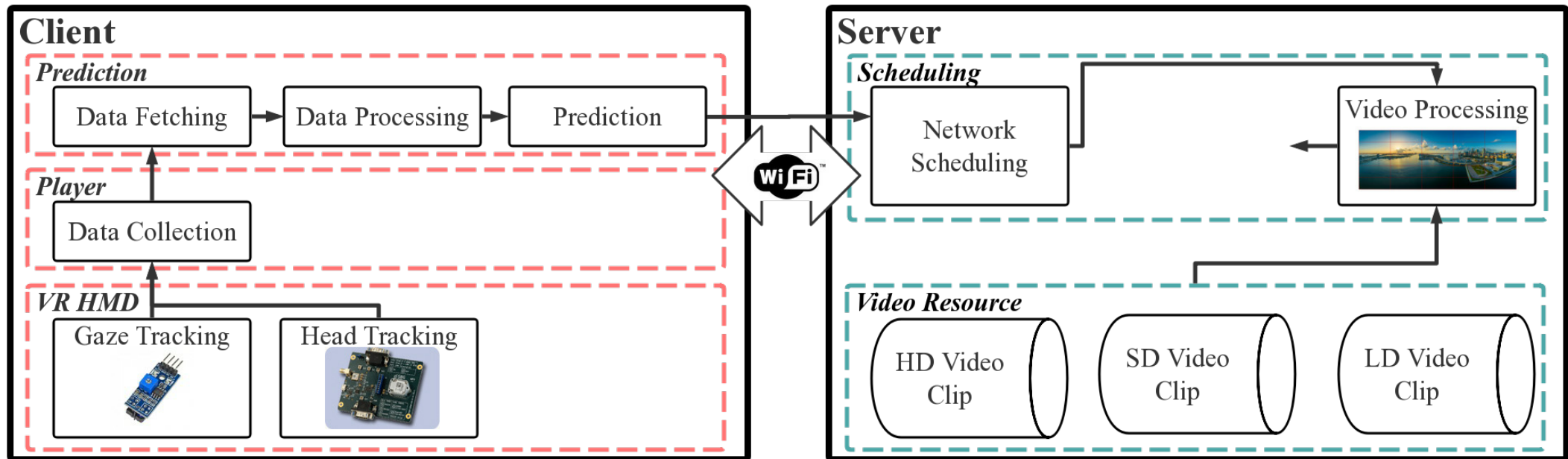




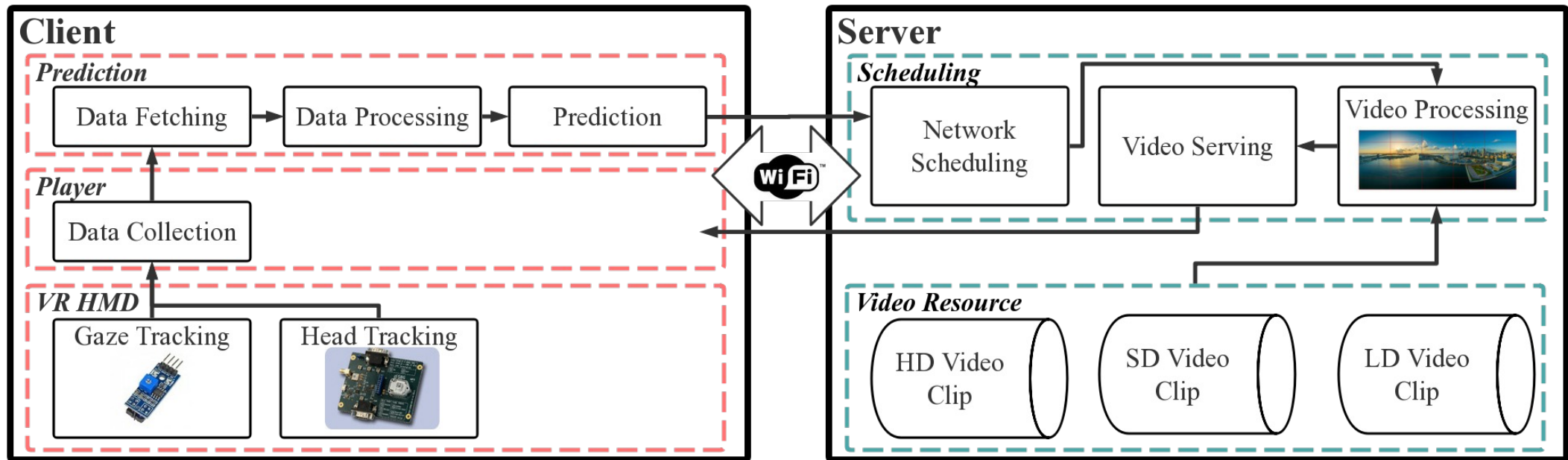
# Solution: FoVR



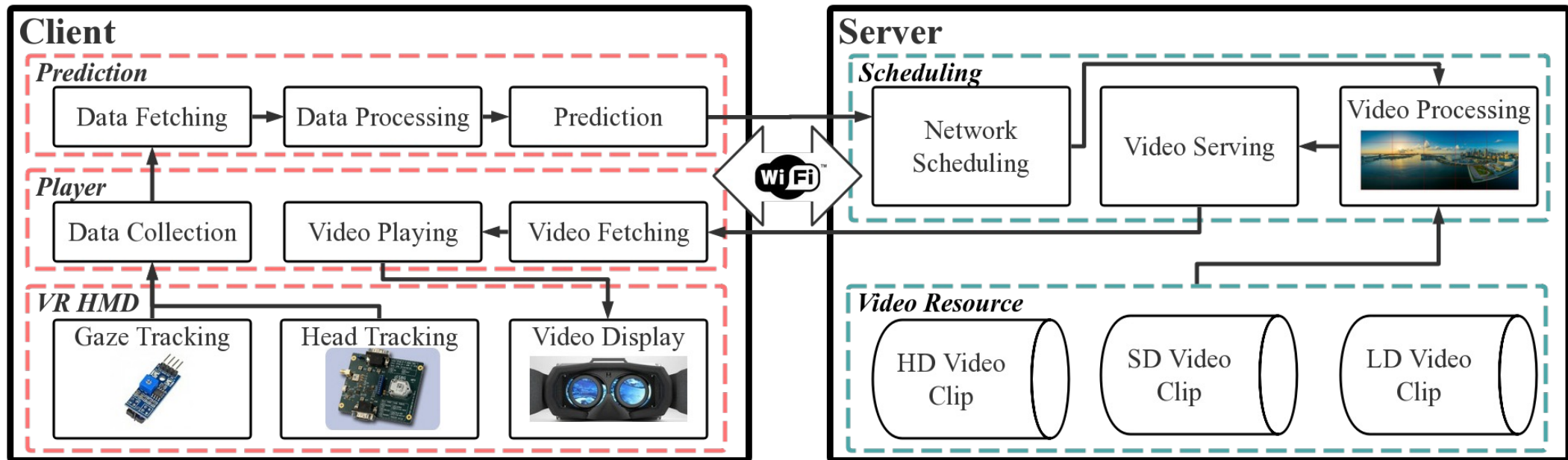
# Solution: FoVR



# Solution: FoVR

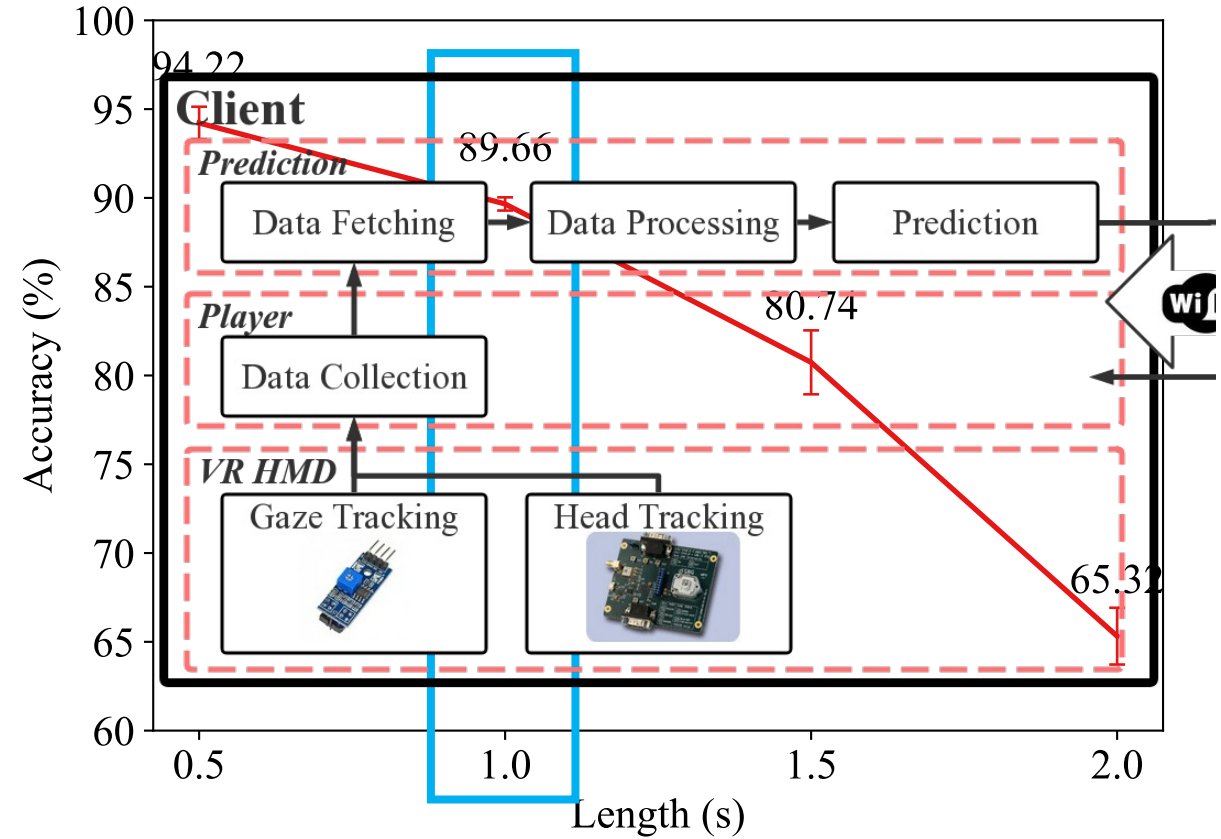


# Solution: FoVR

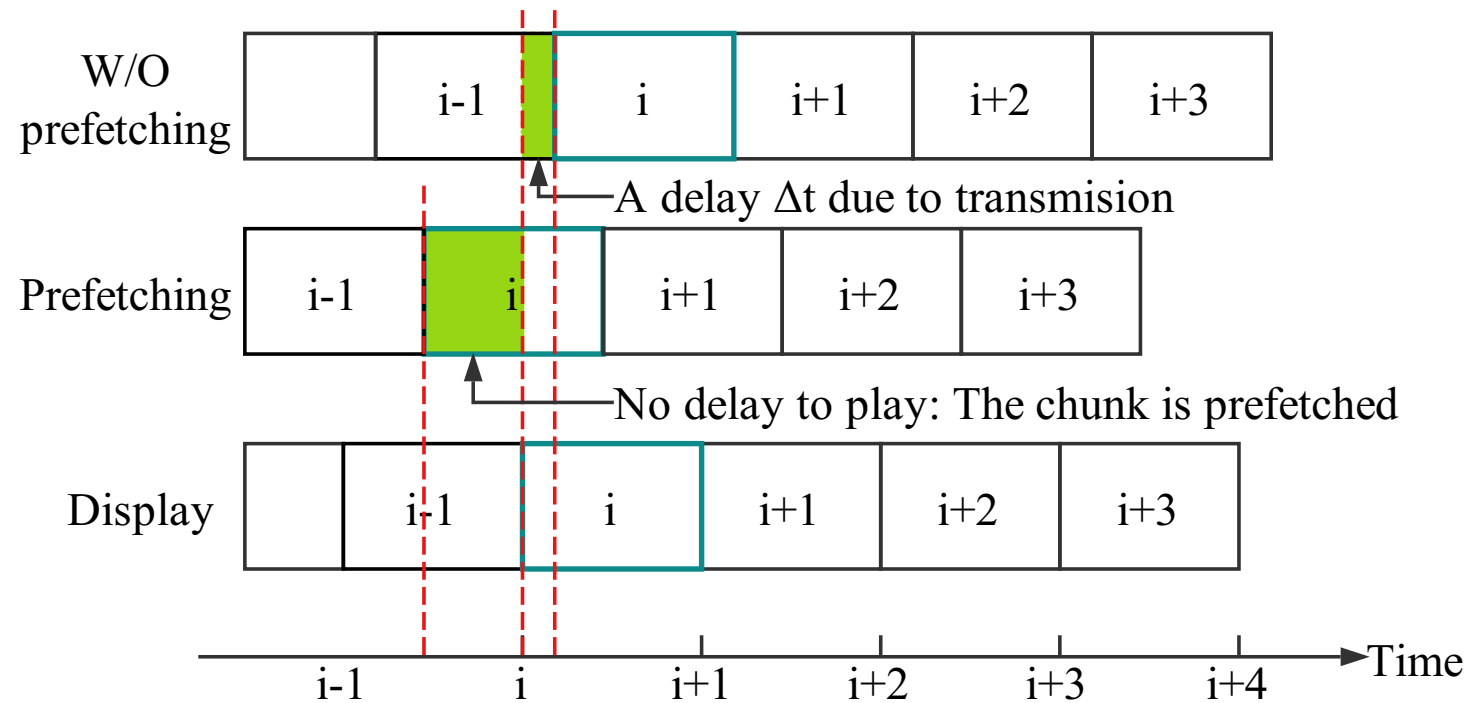


# Prediction

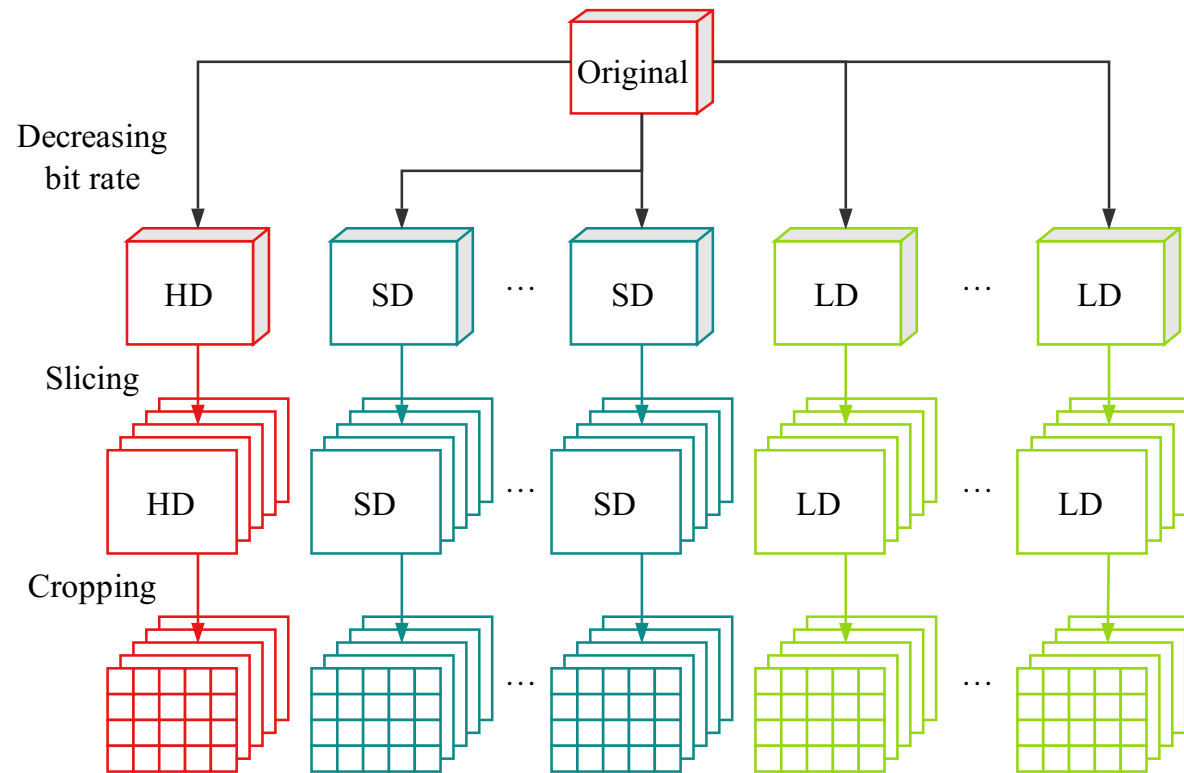
- Prediction
  - Model: Support Vector Regression
    - w/ RBF (Radial Basis Function) kernel
  - Time Window: 1s
  - Prediction Tolerance: 5°



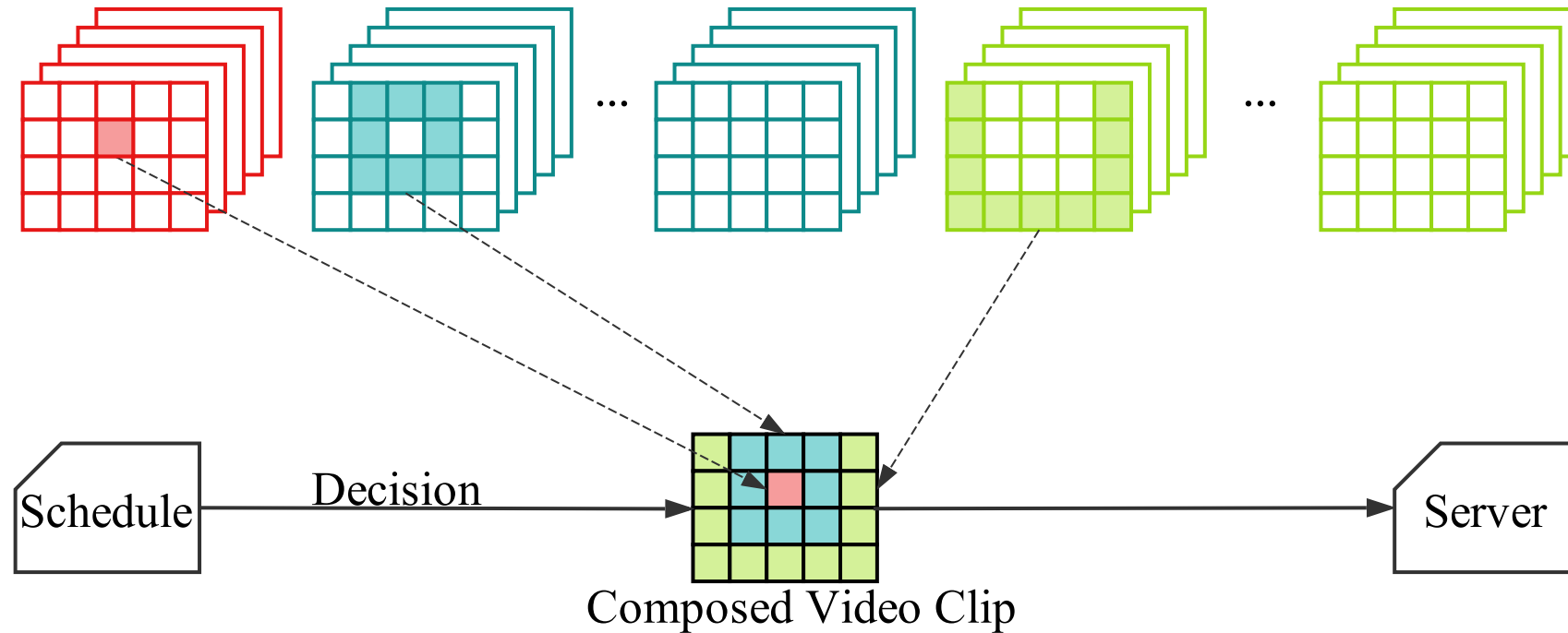
# Prefetching



# Video Composition – Offline Processing



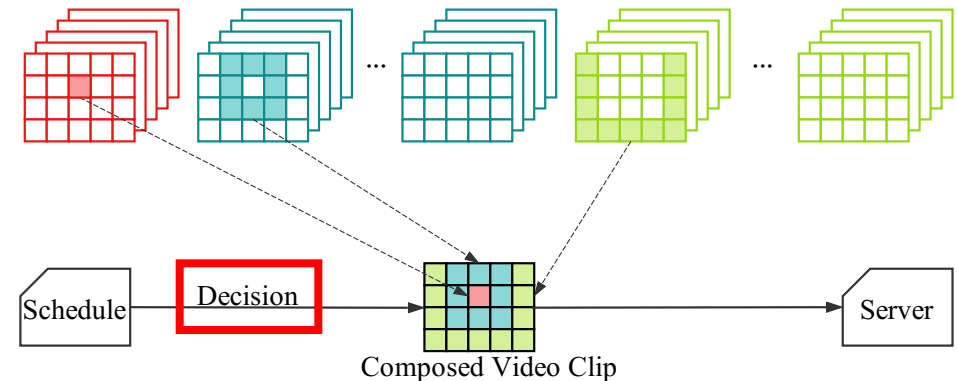
# Video Composition – Online Processing





# Scheduling – Decision

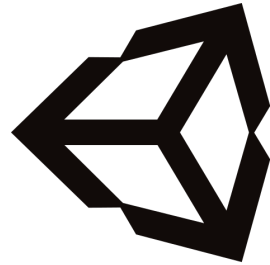
- Goal: Maximize the Quality of Experience (QoE)
  - Bitrate-based Video Quality Assessment (BVQA)
    - Calculated for each tile based on their bitrate
  - QoE Metric:
    - $QoE = \sum_{i,j}^{i=N_x, j=N_y} BVQA_{ij} \times Weight_{ij}$
  - Knapsack Problem
    - Greedy Algorithm



# Implement

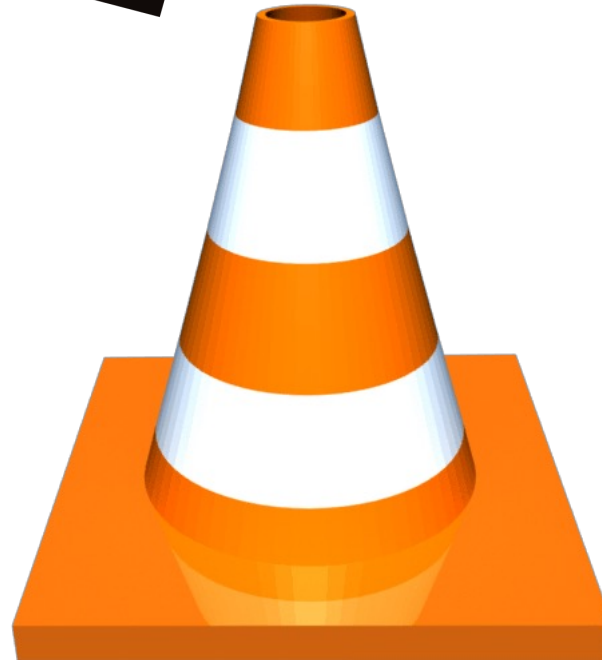


VR HMD

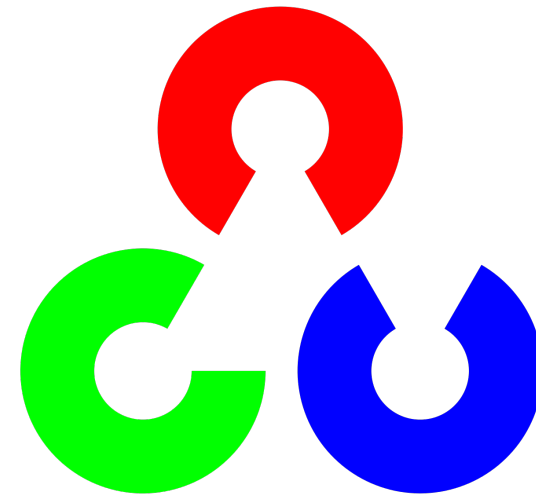


**unity**

**RTMP**



Client

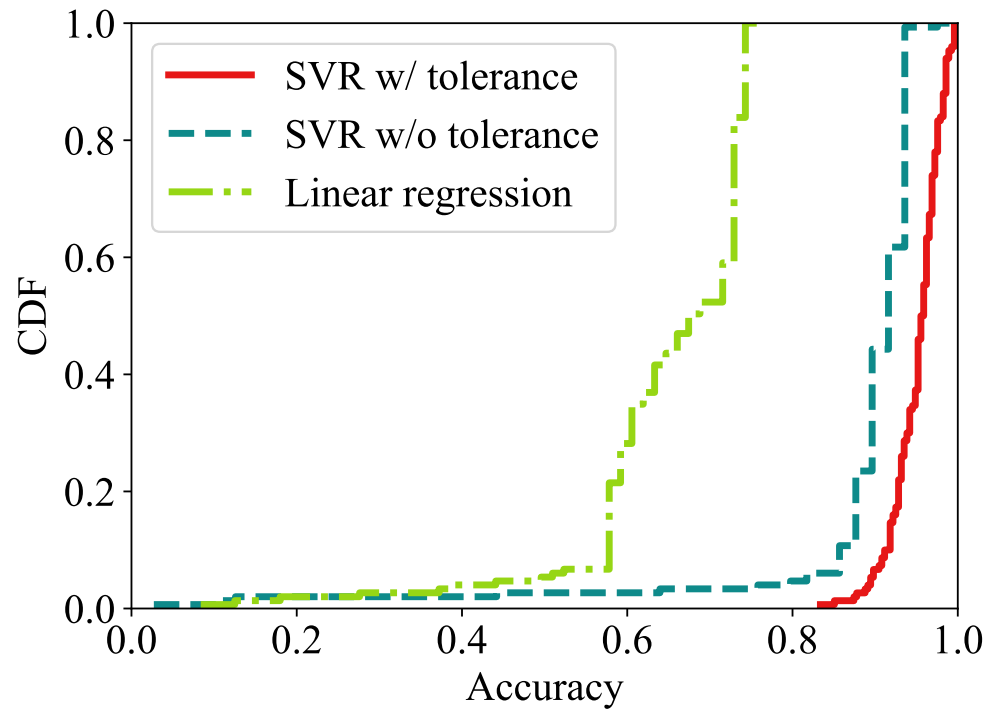


**OpenCV**

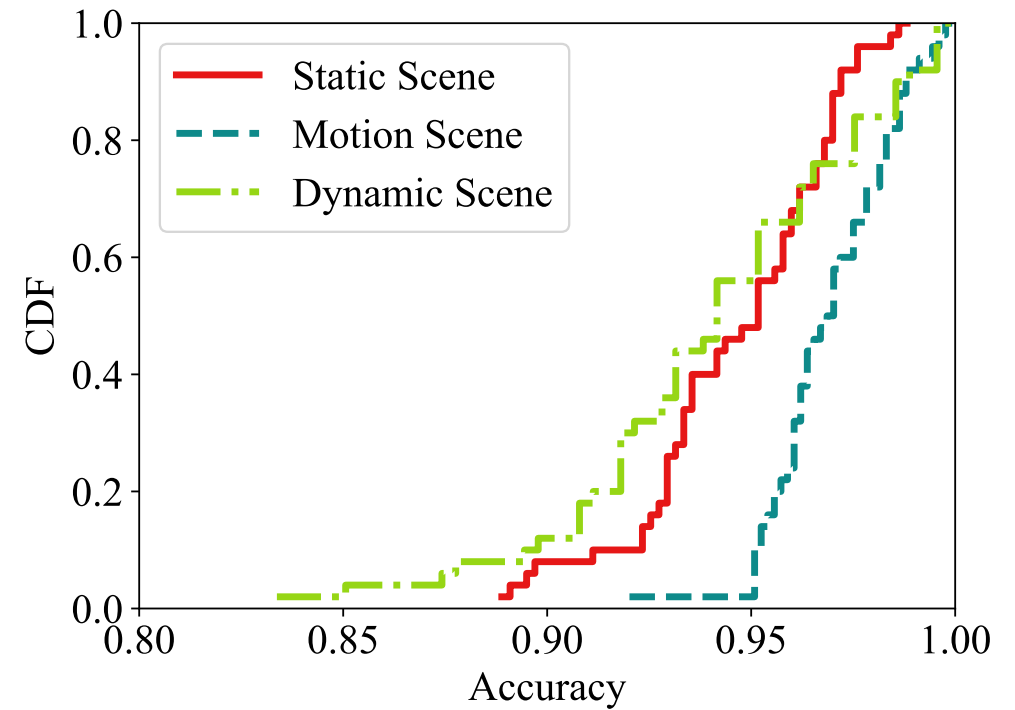
Server

# Evaluation – Prediction

- Prediction Accuracy



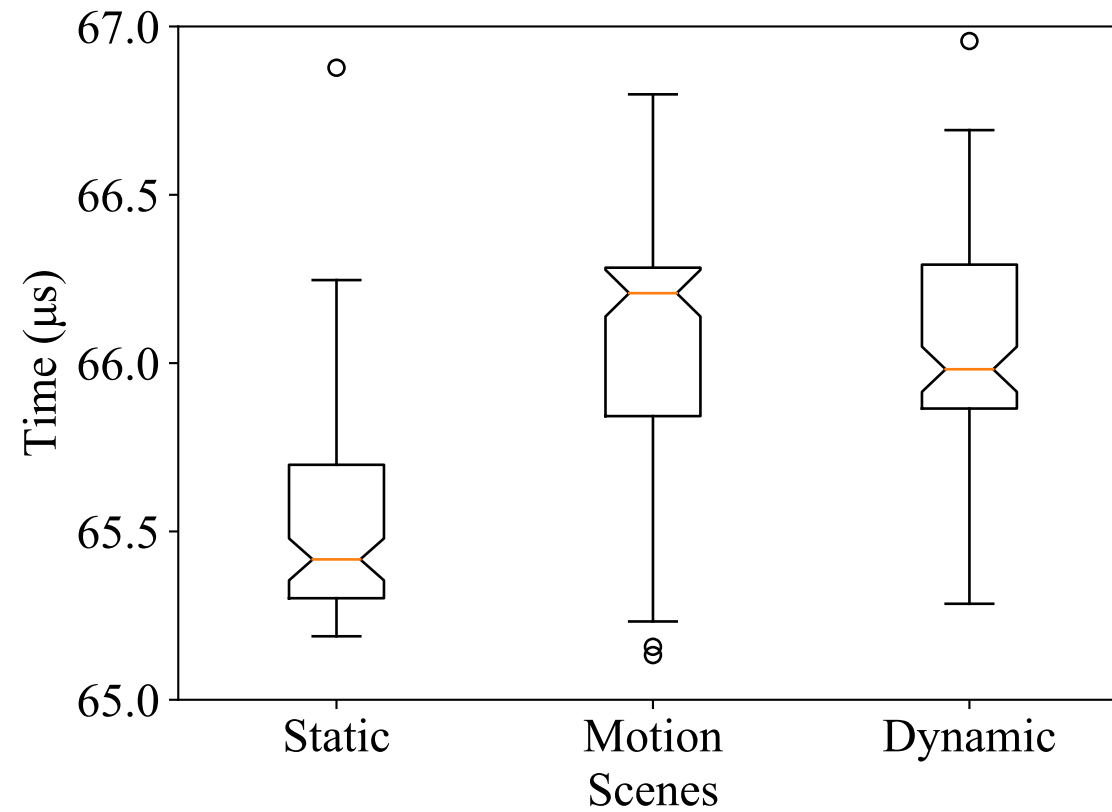
Different Methods



Different Scenes

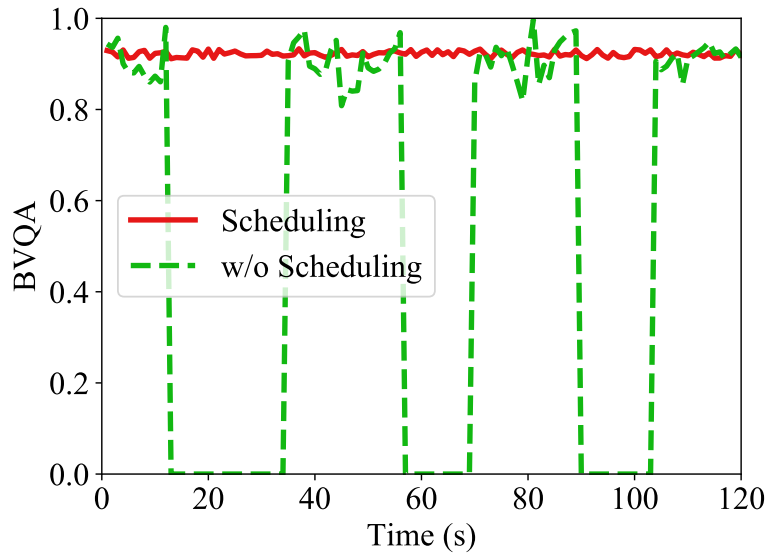
# Evaluation – Prediction

- Prediction Delay

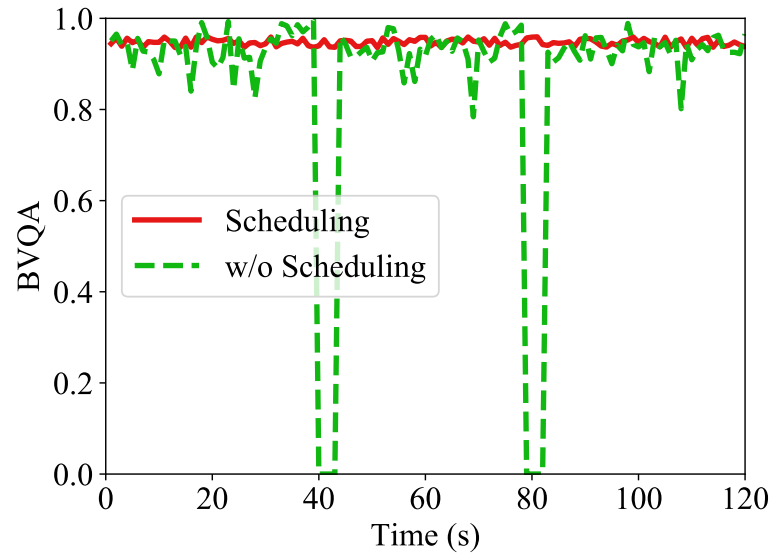


# Evaluation – Scheduling

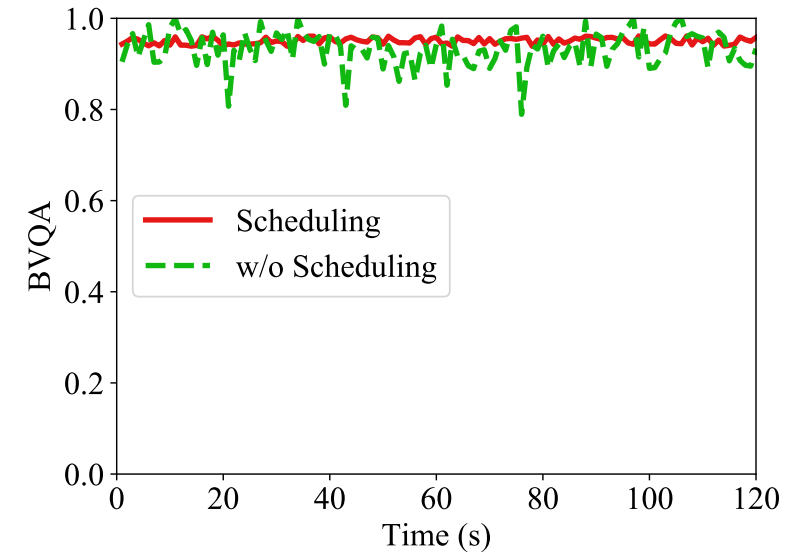
- Scheduling under different bandwidth



10Mbps



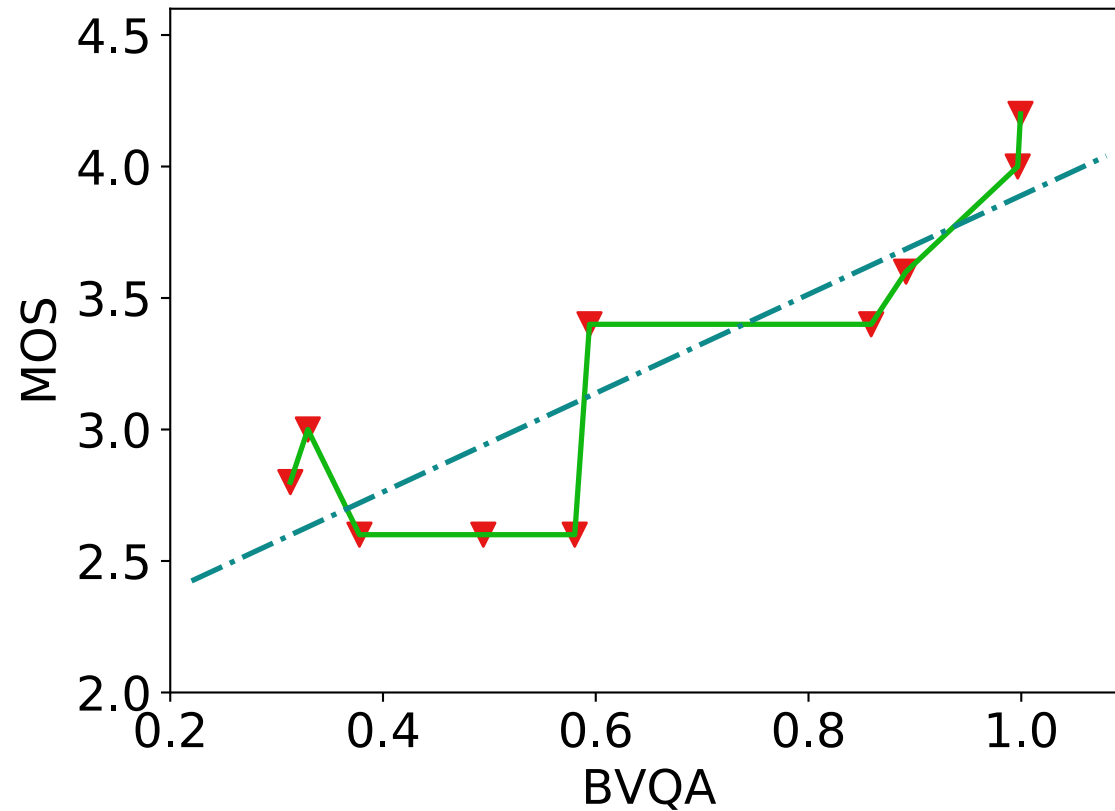
50Mbps



100Mbps

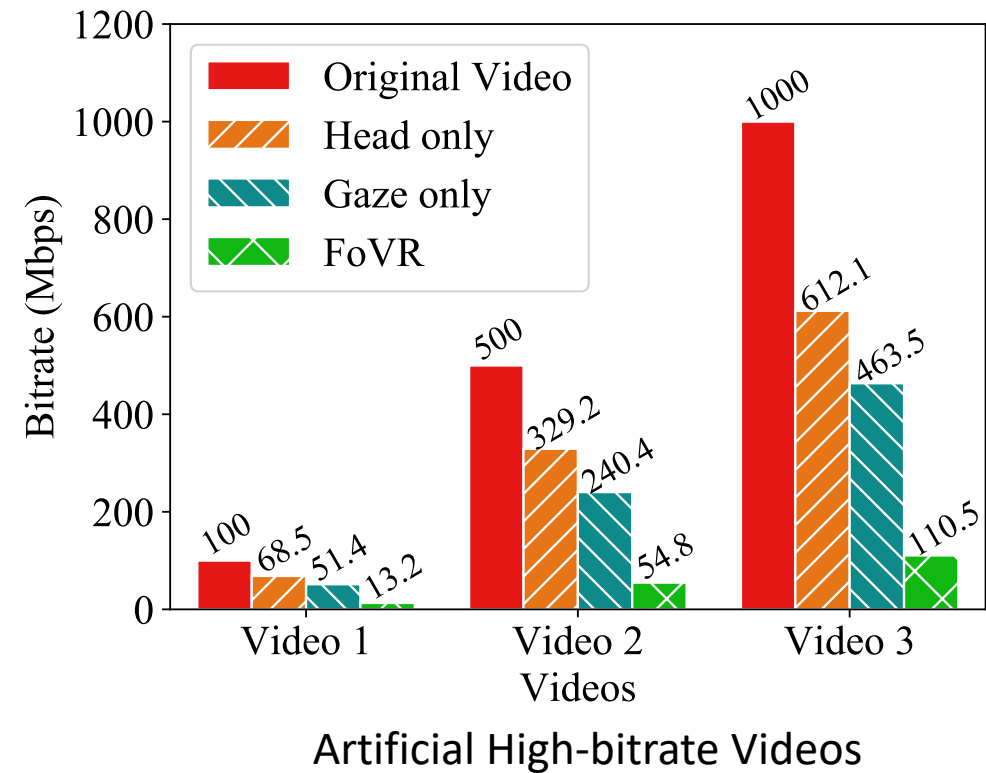
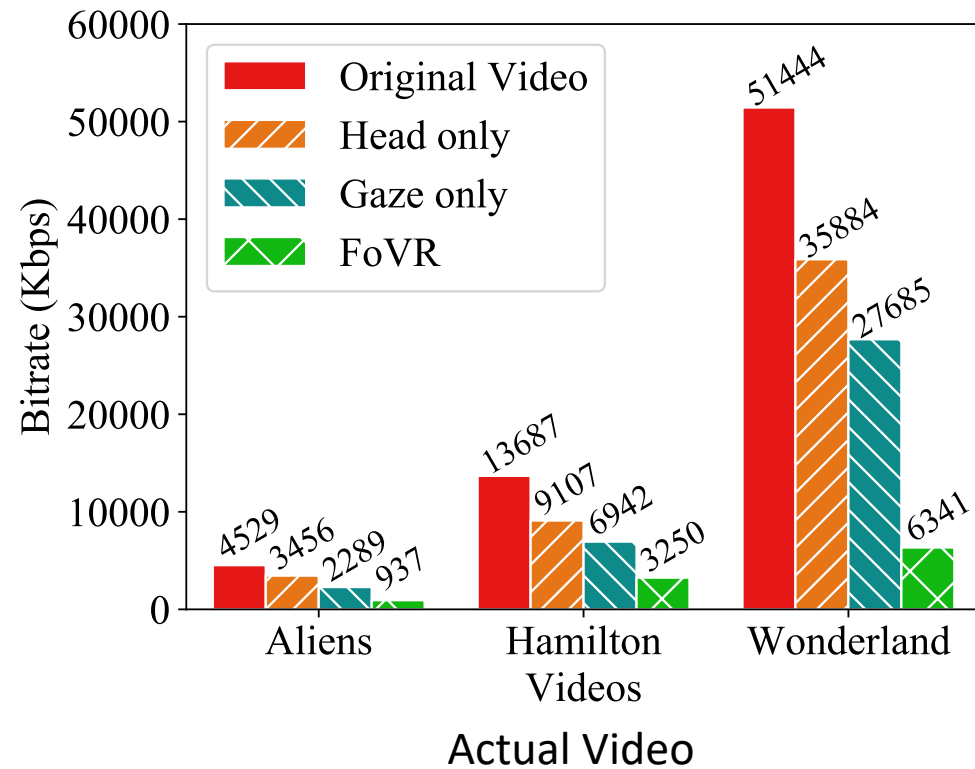
# Evaluation – Subjective

- Mean Opinion Score



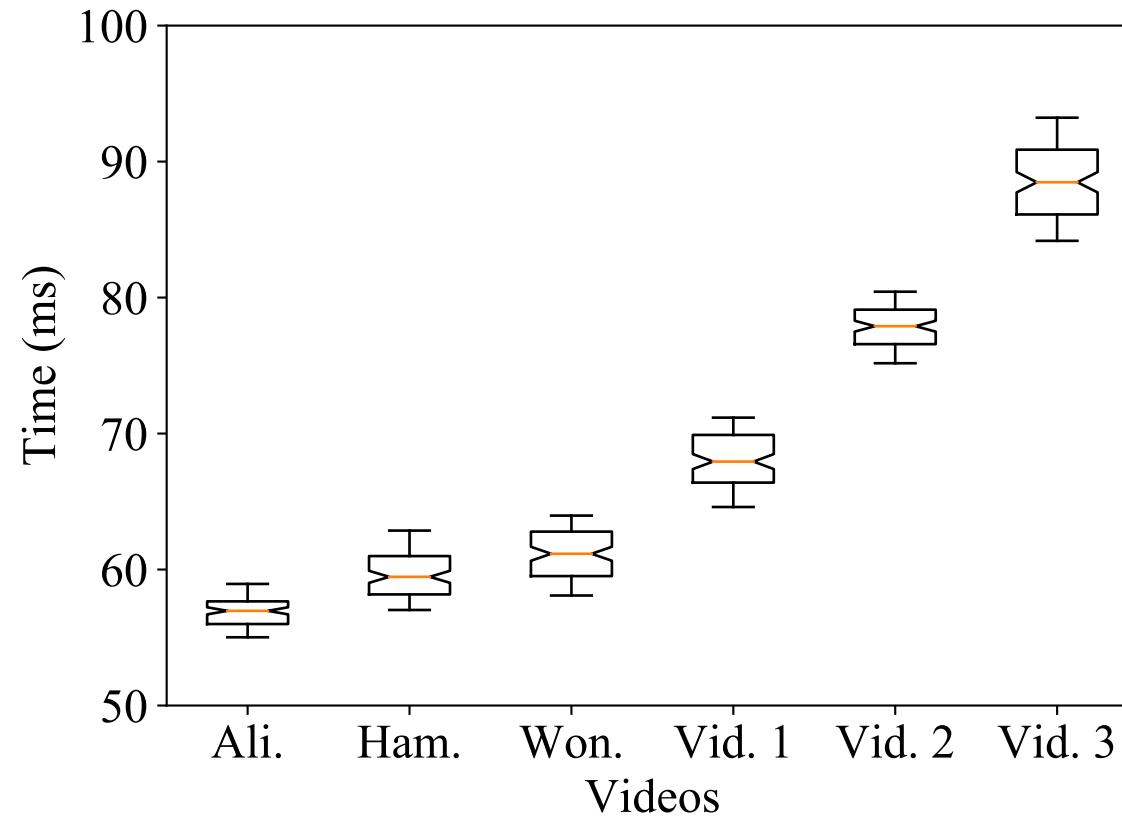
# Evaluation – Overall Compression

- Compression Ratio



# Evaluation – Overall Compress

- Compress Ratio





# Contribution

- We propose FoVR, a hierarchical structure of 360° video streaming on mobile VR HMD. The design of FoVR exploits the humans' hierarchical vision and composes mixed-quality VR clips, with a promise of saving bandwidth while maintaining a high QoE.
- We implement FoVR on commercial VR HMD and conventional Wi-Fi networks. We extensively evaluate FoVR in many scenarios. The evaluation results demonstrate that FoVR reduces the bandwidth cost by 88.9% and 76.2% in average, respectively compared to the original 360° video streaming and the state-of-the-art approach.

Thanks For listening

Q & A