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

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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

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?

• MOVRE (NSDI 2017):

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

  - Mirror
  - $\phi_{AP}$
  - $\phi_H$
  - Headset

• 60 Ghz
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
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Prediction

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

W/O prefetching

Prefetching

Display

A delay $\Delta t$ due to transmission

No delay to play: The chunk is prefetched
Video Composition – Offline Processing

[Diagram showing the process of video composition through offline processing, including stages of decreasing bit rate, slicing, and cropping.]
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

![Diagram of scheduling and decision process]

Schedule → Decision → Composed Video Clip → Server
Implement VR HMD

Client

Server

VR HMD

unity

RTMP

OpenCV
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

| Actual Video     | Bitrate (Kbps) | Artificial High-bitrate Videos | Bitrate (Mbps) |
|------------------|----------------|--------------------------------|----------------|
| Aliens           | 4529 3456 2289| Video 1                        | 100            |
|                  | 937            |                                | 68.5           |
|                  | 13687          | Video 2                        | 500            |
|                  | 6942           | Videos                        | 51.4           |
|                  | 3250           |                                | 13.2           |
|                  |                |                                |                |
| Wonderlon        | 51444          | Video 3                        | 1000           |
|                  | 35884          |                                | 463.5          |
|                  | 27685          |                                | 110.5          |
|                  | 6341           |                                |                |

- Original Video
- Head only
- Gaze only
- FoVR
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