Wireless Virtual Reality

Facilitating Low Latency and Reliable VR over Heterogeneous Wireless Networks

UC San Diego JACOBS SCHOOL OF ENGINEERING

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MOTIVATION

Immersive Content

Resolution: 4K, 8K, 12K, 24K
Frame rate: 60fps, 90fps
HDR 360° panoramic video

VR Requirements

High Data rates: 1 Gbps
Low Latency: 50 ms
High Reliability: 99.9%

CHALLENGES

Current VR headsets are tethered to the computer or game system which limits user mobility and pose tripping hazard
Wireless 60 Ghz (WiGig) suffers from blockages and beam misalignments

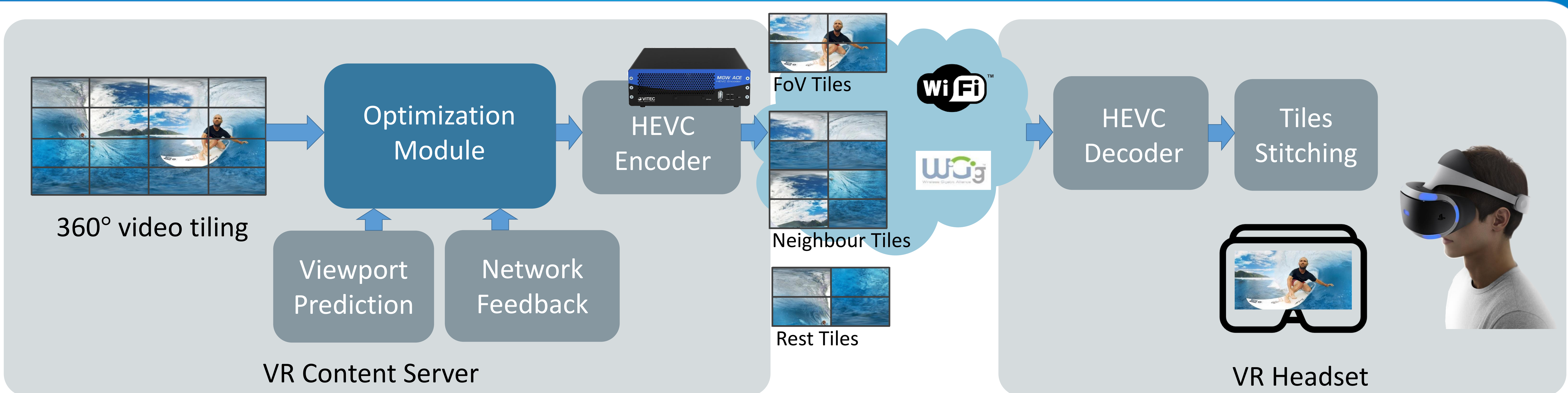
IDEAS

Use WiFi and WiGig interface for high reliability
WiFi: Reliable but low data rates
WiGig: High data rates but not reliable

Viewport aware tile-based streaming
Transmit tiles which are in viewport at high quality and other tiles at low quality

Optimization for better QoE and low latency
Choose a different quality for each tile
Choose one of WiFi or WiGig interface for each tile

DESIGN



ALGORITHM

Based on the current link conditions and user FoV prediction, the tiles are encoded with different qualities and transmitted over multiple interfaces. We design an optimization framework to maximize the QoE subject to stringent latency constraints.

$$\max_{Q_i, D_i} \; \sum_i w_i U(Q_i) + \frac{C}{Latency}$$

Subject to:

$$Latency = \max\left\{\frac{\sum_i (1-D_i) S_i(Q_i)}{R_{WiFi}} + L_{WiFi}, \frac{\sum_i (D_i) S_i(Q_i)}{R_{WiGig}} + L_{WiGig}\right\}$$

$$Latency \leq 50ms$$

Utility function to minimize QoE

$$U(Q_i) = A \log B \frac{S_i(Q_i)}{\max_i S_i(Q_i)}$$

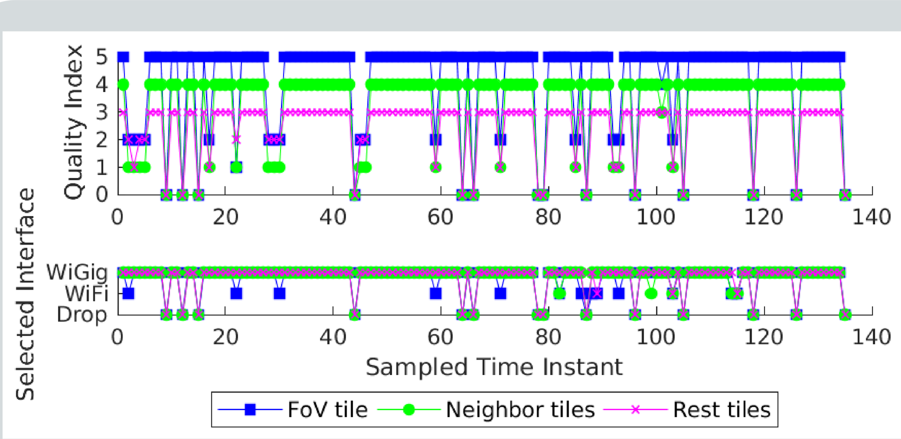
$S_i(Q_i)$ = Size (Bytes) of tile i corresponding to the quality Q_i,
$Q_i \in \{1, \dots, 5\}$ Quality values for each tile i

$$D_i = \begin{cases} 1 & WiGig\ link\ is\ selected \\ 0 & WiFi\ link\ is\ Selected \end{cases}$$

$R_{WiFi}, R_{WiGig}, L_{WiFi}, L_{WiGig}$ = Rate and Latency of the WiFi and WiGig links.

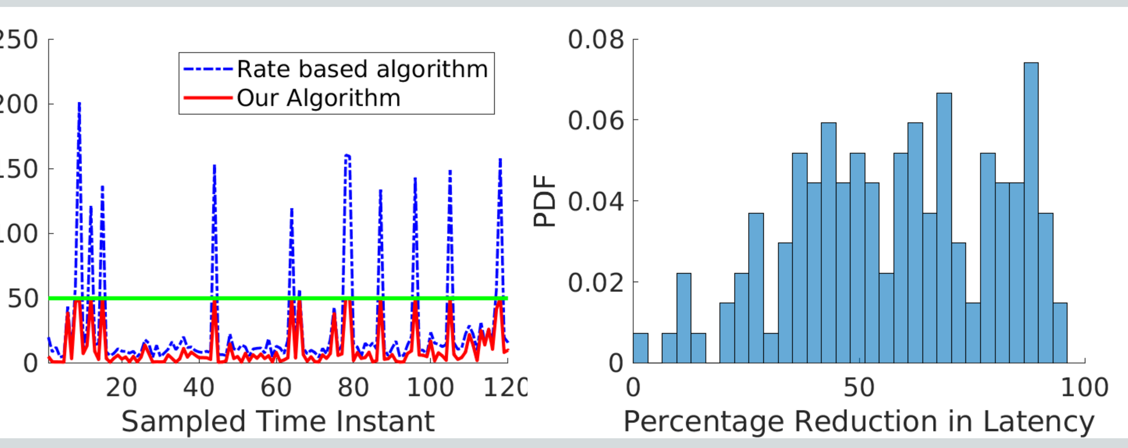
RESULTS

Setup: We use wilocity wil6200 802.11ad wireless network adaptor and Quantenna board for measurements, FFmpeg tools for tiling the VR video, and x265 libraries for HEVC encoding and decoding.



FoV tile is transmitted with the highest quality.
Mostly WiGig interface is selected.
Frames are dropped when neither WiFi nor WiGig can meet the latency requirements.

Our algorithm provides a significant reduction in latency as compared to rate based approach [4]



SUMMARY

Untethered, low latency and reliable VR video streaming is possible through a viewport-aware tile-based system that utilizes both WiFi and WiGig interfaces.
For real-time VR, delivering a frame after a deadline has no value.

FUTURE WORK

Accurate viewport prediction and region based video coding are active research areas. Channel codes such as rateless codes can be used to ensure a graceful degradation of video quality with wireless link conditions.

RELATED WORK

MoVR [1] designs a custom reflector to provide reliable VR over mmWave link. The authors of [2] designs a rate based approach to maximize QoE over heterogeneous interfaces but they do not focus on latency. Furion [3] provides a cooperative renderer architecture which is orthogonal to our work.

[1] Abari, Omid, Dinesh Bharadia, Austin Duffield, and Dina Katabi. "Enabling High-Quality Untethered Virtual Reality." In *NSDI*.
[2] Huang, Wei, et al. "QoE-Oriented Resource Allocation for 360-degree Video Transmission over Heterogeneous Networks." arXiv preprint arXiv:1803.07789 (2018).
[3] Zeqi Lai, Y Charlie Hu, Yong Cui, Linhui Sun, and Ningwei Dai. 2017. Furion: Engineering High-Quality Immersive Virtual Reality on Today's Mobile Devices. In MobiCom, ACM.