

TOWARDS TRULY IMMERSIVE HOLOGRAPHIC-TYPE COMMUNICATION

[Filip De Turck](#)

WELCOME FROM BELGIUM



Comprehensive university
Founded in 1817
43,281 students



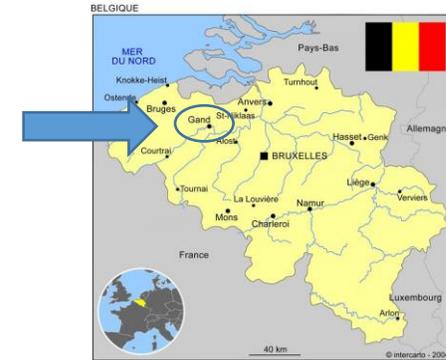
R&D, nano electronics and digital technologies
Founded in 1984
4,000 researchers



Internet Technology and Data Science Lab
300 internet experts and data scientists
500+ collaborations with innovative industry partners



<https://idlab.technology/>



PROF. FILIP DE TURCK

- Professor at Ghent University-imec, Belgium
- Expertise in softwarized network management, networking and service delivery, many research projects in collaboration with industry
- Editor-in-Chief of IEEE Transactions on Network and Service Management (TNSM)
- Past Chair of IEEE Technical Committee on Network Operations and Management (CNOM)



IEEE ComSoc Technical
Committee (TC) on
Network Operations and
Management
(IEEE CNOM TC)



ComSoc Technical Committees

Big Data

Cognitive Networks

Communication Theory

Communications & Information Security

Communications Quality and Reliability

Communications Software

Communications Switching & Routing

Communications Systems Integration & Modeling

Computer Communications

Data Storage

e-Health

Green Communications & Computing

Information Infrastructure & Networking

Internet

Internet of Things, Ad Hoc & Sensor Networks

Molecular, Biological and Multi-Scale Communications

Multimedia Communications

Network Operations & Management

Optical Networking

Power Line Communications

Radio Communications

Satellite & Space Communications

Signal Processing and Computing for Communications

Smart Grid Communications

Social Networks

Tactile Internet

Transmission, Access, & Optical Systems

Wireless Communications

Network Resource Management

- Is of prime importance for telecommunication network operators, equipment manufacturers and data center providers as it allows to
 - make efficient use of the available resources,
 - offer service guarantees,
 - and make sure that services can be delivered with high quality of experience to end users.
- Given the strong competition in the telecommunication domain and the increasing expectations of end-users, network operators and providers need reliable network resource management algorithms and methodologies.
- Ad hoc solutions often result in low resource utilization and high overhead, given the dynamic nature of resource availability and inherent complexity of resource allocation algorithms.

Softwarized Networks



Softwarized networks bring virtualization concepts to the network



Have proven to be particularly important for the industry, including telecommunication operators, cloud infrastructure and service providers.



Paper on efficient placement of virtualized network functions received 495 citations to date.

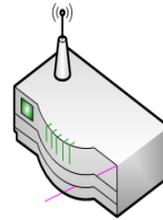
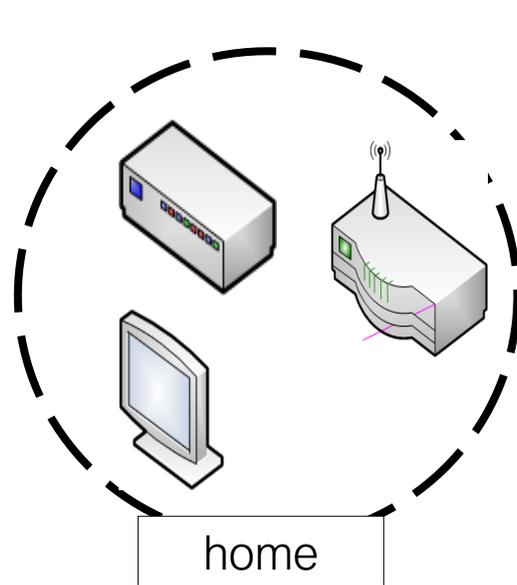


Contributions to:

- the development of learning algorithms for dynamic resource management in softwarized networks, and
- resource management for survivable optical networks

What is network
function
virtualisation?

use case: residential equipment



Home gateway (HGW):

- DHCP server
- NAT router
- Firewall
- QoE monitoring

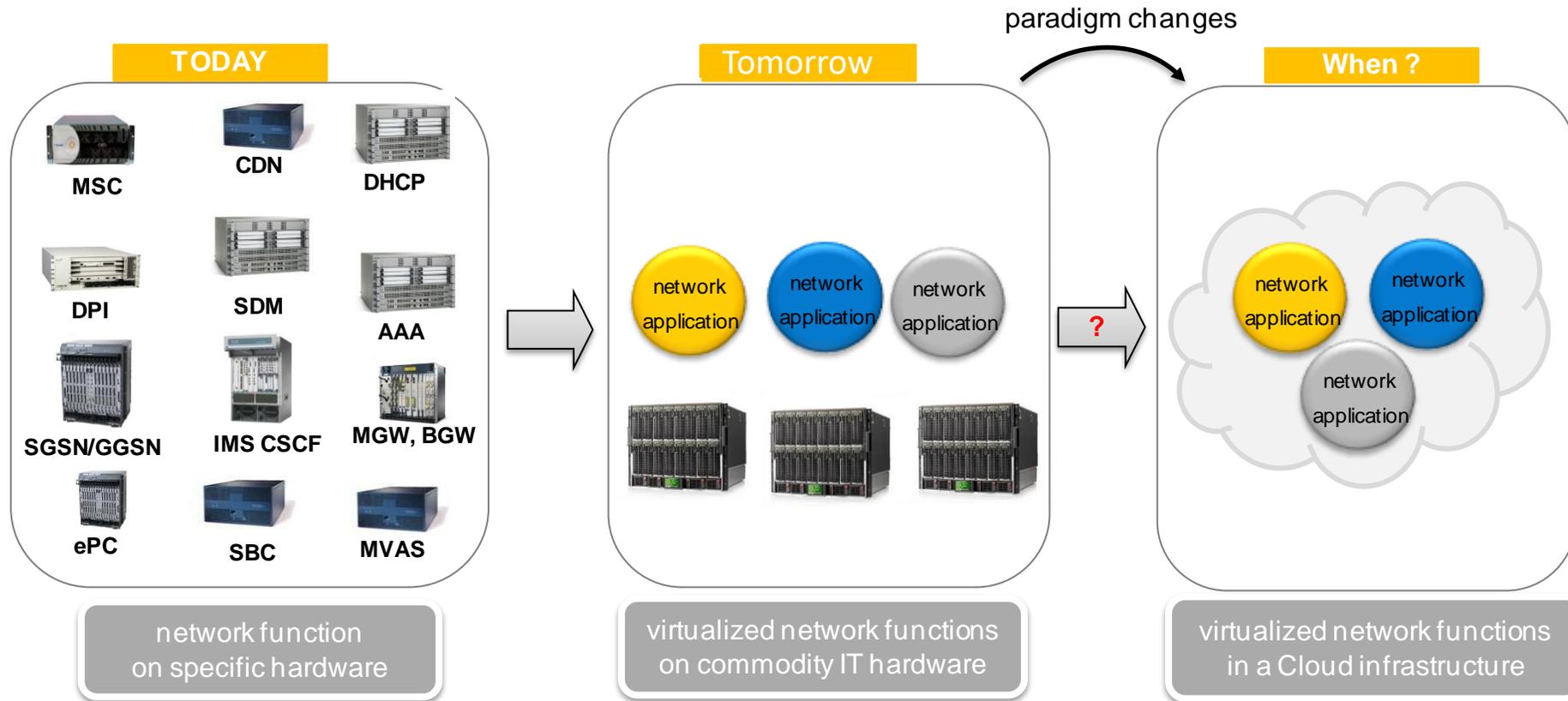


Set top box (STB):

- Decoder
- Storage
- Middleware
- Streaming client

= network functions

Network Function Virtualization



Advantages

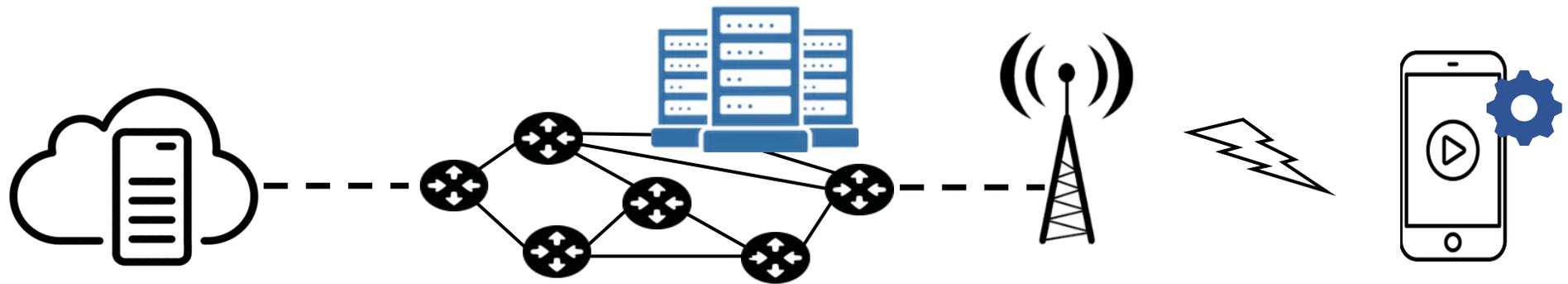
for Network Operator:

- Replace dedicated hardware with generic hardware and software-based functions
- Maximize resource utilization and optimize energy usage
- Faster and easier deployment, configuration, and updating of network functions
- Support for the Network-as-a-Service business model

for Service Provider:

- Dynamically scale network, computing and storage resources based on service requirements
- Reduced time to market for services

Adaptive Service Delivery



VOLUMETRIC MEDIA

FROM 2D TO IMMERSIVE VIDEO

2D
Video



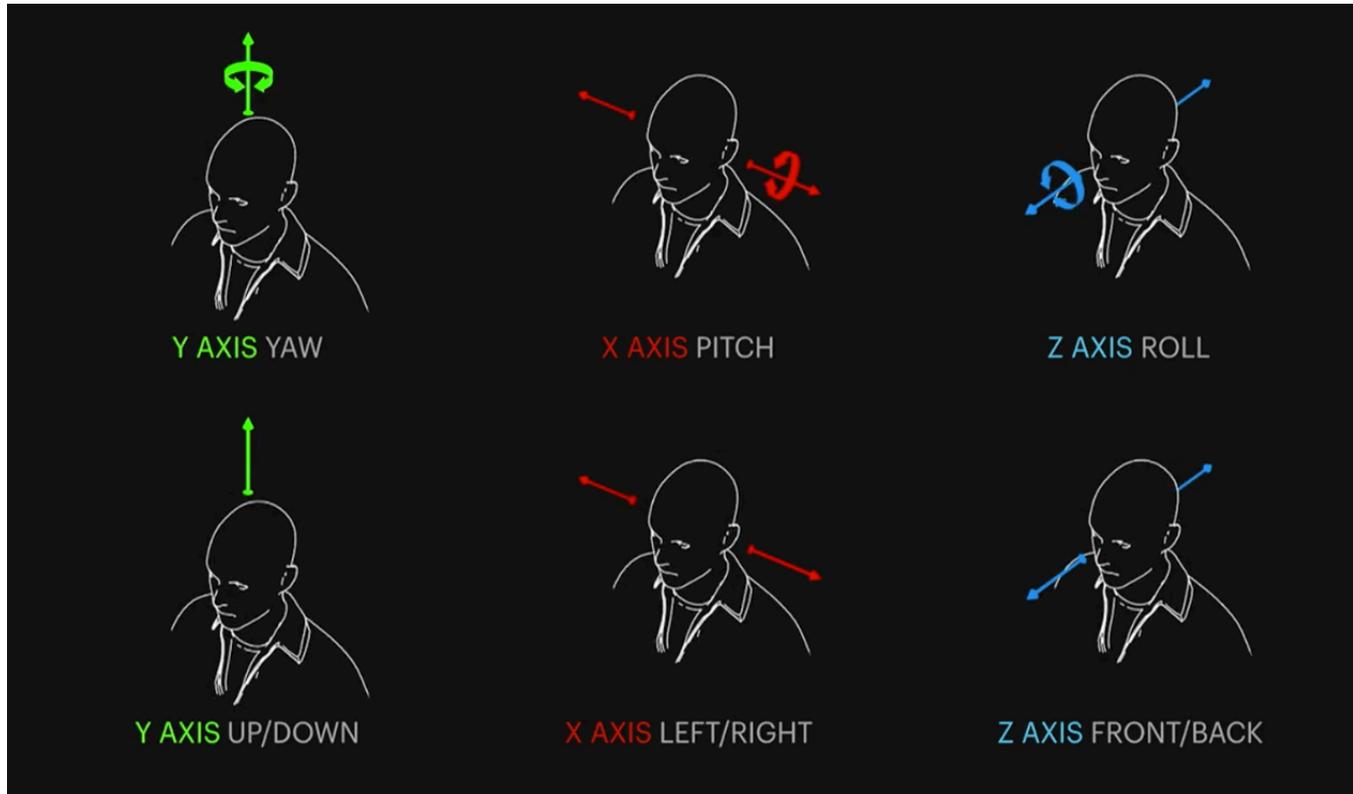
Volumetric
Media



360 Degree
Video



WHAT DOES VOLUMETRIC MEDIA PROVIDE?



Adds parallax → multiple views
Six Degrees of Freedom

USE CASES



Holographic Collaboration & Conferencing [1]



Tele-Surgery & Remote Patient Monitoring [2]



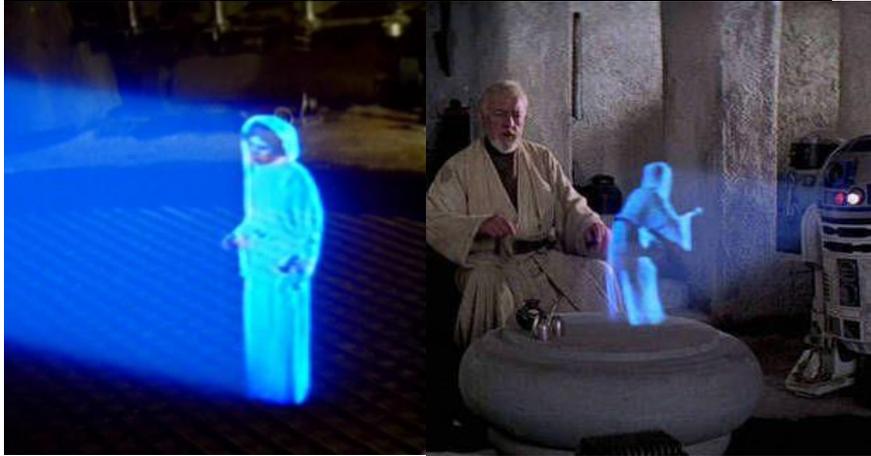
Remote Industrial Monitoring & Management [3]

[1] S. Gunkel, H. M. Stokking, M. J. Prins, N. van der Stap, F. B. ter Haar, and O. A. Niamut, Virtual reality conferencing: multi-user immersive VR experiences on the web. In Proceedings of the 9th ACM Multimedia Systems Conference (MMSys '18). Association for Computing Machinery, New York, NY, USA, 498–501.

[2] J. Heyse, M. Torres Vega, T. De Jonge, F. De Backere, and F. De Turck, A Personalised Emotion-Based Model for Relaxation in Virtual Reality. *Appl. Sci.* **2020**, *10*, 6124.

[3] M. Torres Vega, et al., Immersive Interconnected Virtual and Augmented Reality: A 5G and IoT Perspective. *J Netw Syst Manage* **28**, 796–826 (2020).

Holograms are not science-fiction anymore



Star Wars: Episode IV – A New Hope (1977)

- Local application
- Bandwidth requirements (Gb/s) too high for remote access
→ Compression
- Need for objective, real-time QoE monitoring

newsround

A German circus uses holograms instead of animals and it looks amazing!

© 6 Jun 2019 Last updated at 19:50

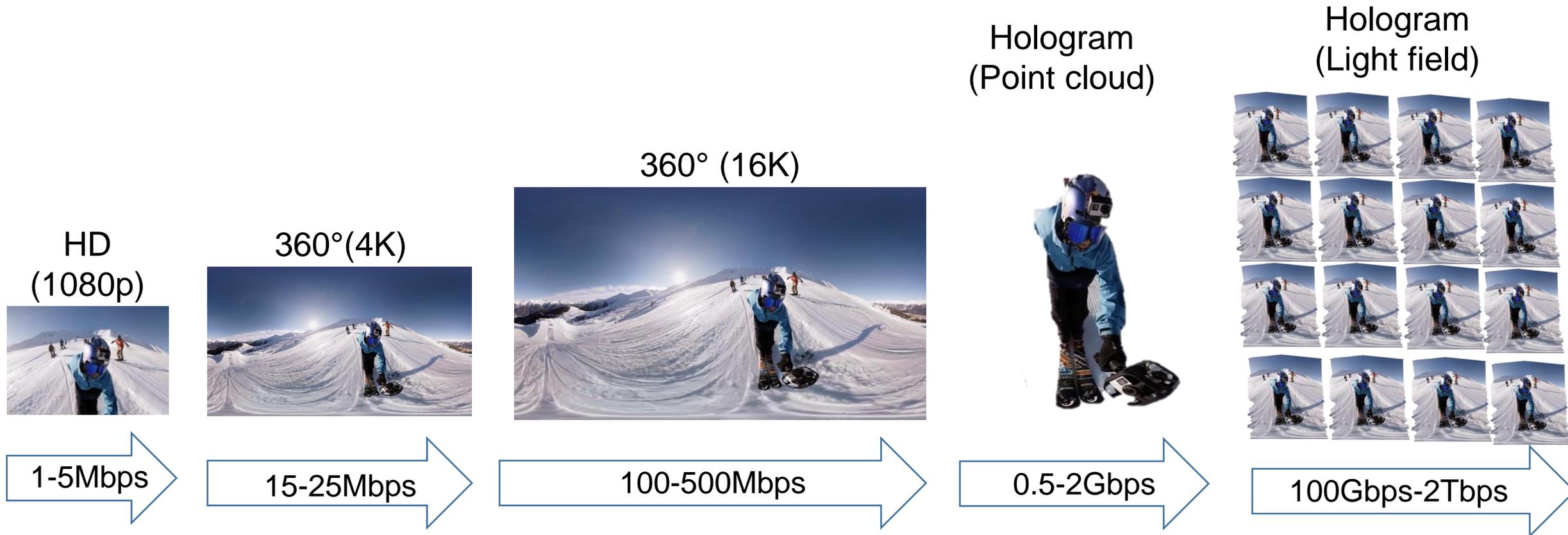


@CIRCUSTHEATERRONCALLI

A German circus has become the first in the world to use holograms instead of real animals in its acts.

<https://www.bbc.co.uk/newsround/48543263>

ULTRA-HIGH BANDWIDTH REQUIREMENT [1]



[1] A. Clemm, M. Torres Vega, H. K. Ravuri, T. Wauters and F. De Turck, "Towards Truly Immersive Holographic-Type Communication: Challenges and Solutions," in *IEEE Communications Magazine*, vol. 58, no. 1, pp. 93-99, January 2020.

CAN CURRENT TRANSPORT AND
APPLICATION INFRASTRUCTURES DEAL
WITH VOLUMETRIC MEDIA DELIVERY?

DYNAMIC POINT-CLOUD SCENES REQUIRE A SIGNIFICANT AMOUNT OF DATA



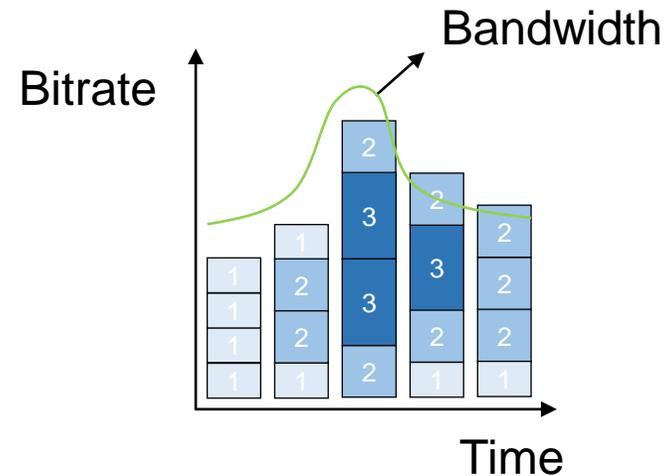
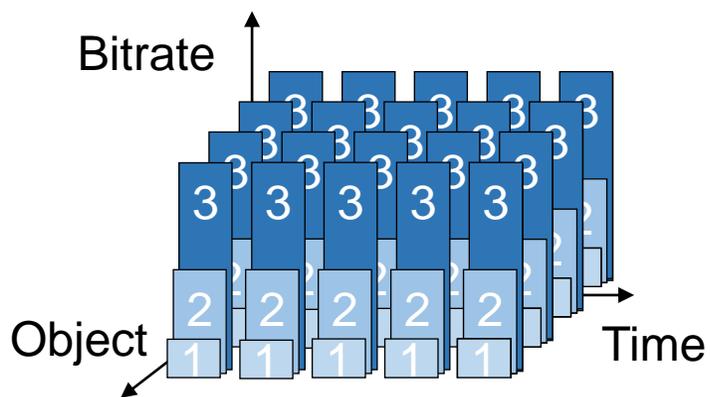
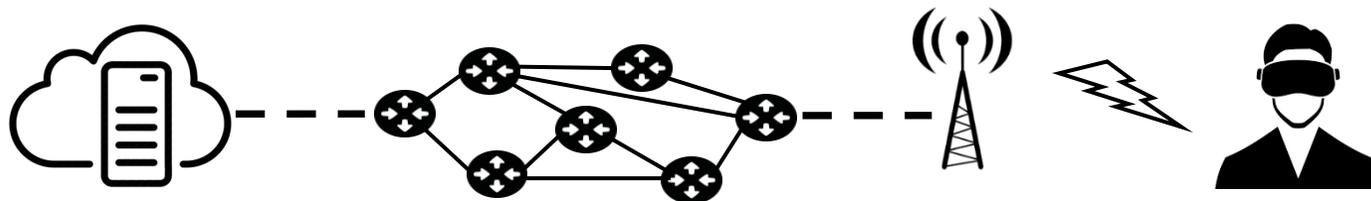
4.1 Gb/s



5.6 Gb/s

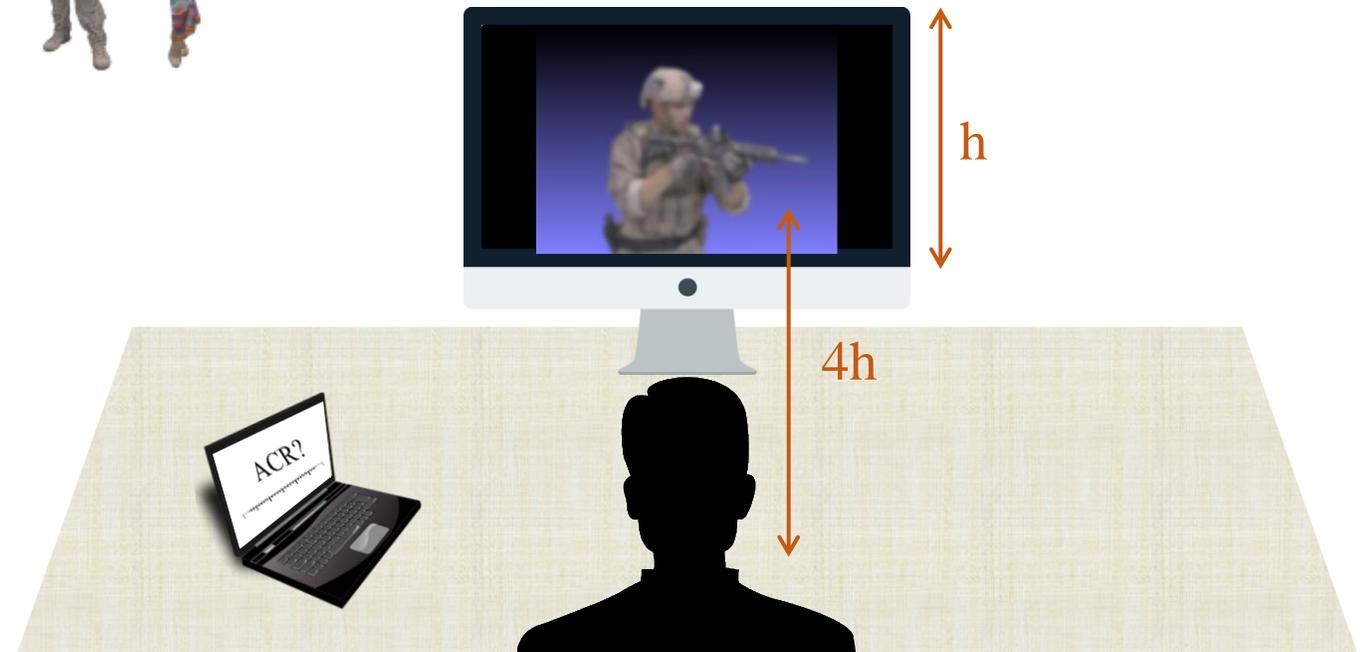
Streaming a scene with 4 similar objects would require 19.2 Gb/s!

WE CAN STREAM IT USING ADAPTIVE STREAMING



WE CAN EVALUATE THE QUALITY BY MEANS OF SUBJECTIVE STUDIES...

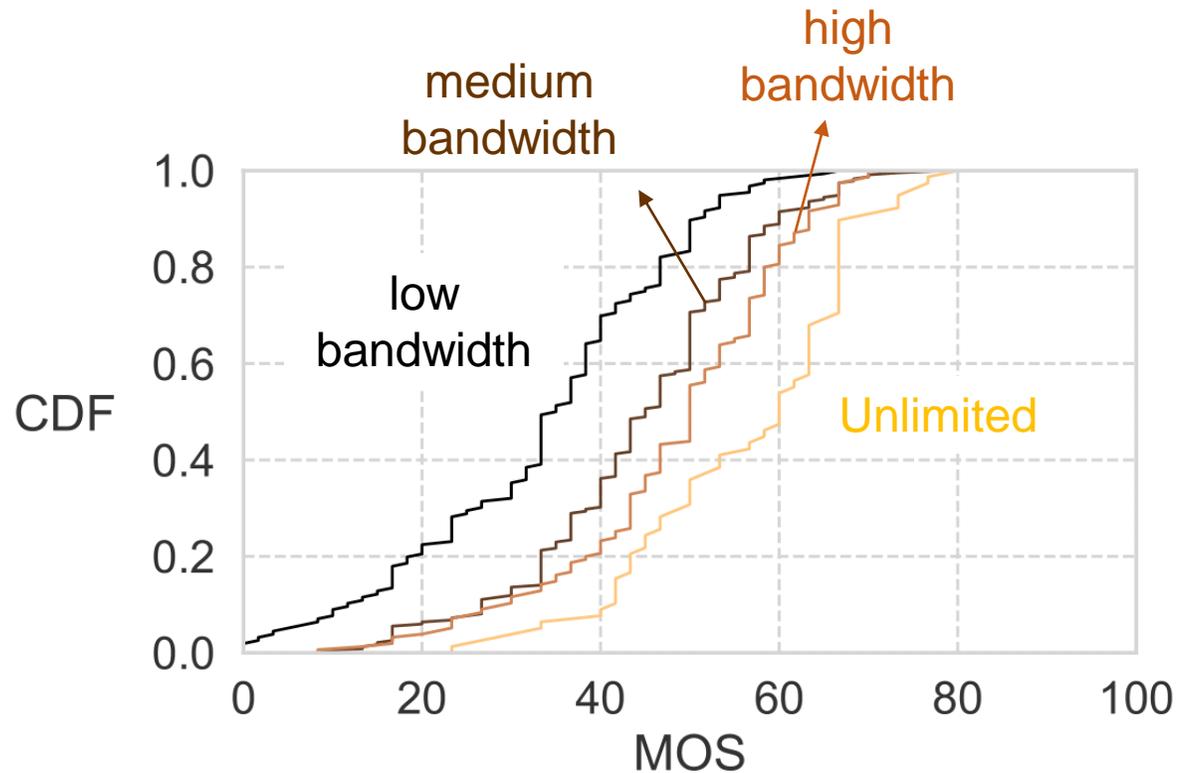
- Four Point Clouds
(Raw data rate 19Gb/s)
- Three different video sequences
- 8 configurations/video
(bandwidth, allocation, prediction)



Single Stimulus (30 subjects)

EVALUATION OF SUBJECTIVE QOE

OUR OBSERVATIONS [1]



- Subjects can distinguish between different bitrates
- However, the difference in QoE is not significant
- People do not perceive delivered data as good quality: MOS < 80% (4) in all cases and close to 60% in average

[1] J. van der Hooft, M. Torres Vega, C. Timmerer, A. C. Begen, F. De Turck and R. Schatz, "Objective and Subjective QoE Evaluation for Adaptive Point Cloud Streaming," 2020 Twelfth International Conference on Quality of Multimedia Experience (QoMEX), 2020.

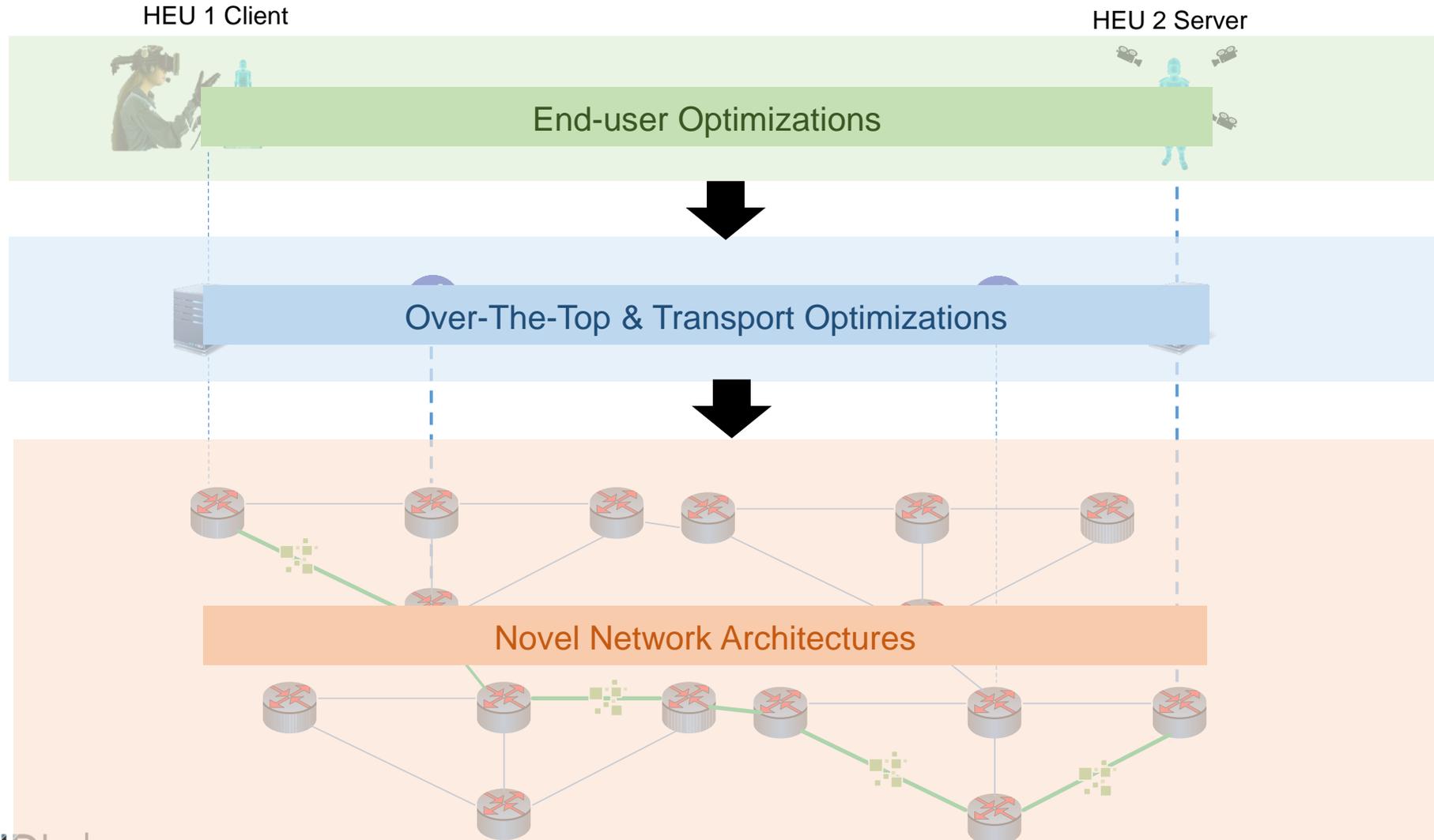
WHAT DOES IT MEAN TO THE NETWORK?

- End-user based or over the top optimizations are not sufficient to satisfy the user (MOS < 60%)
- These techniques do not cater to the latency requirement
- Network layer needs to complement the application layer approaches
- Cross-layer based end-to-end architecture for volumetric media delivery

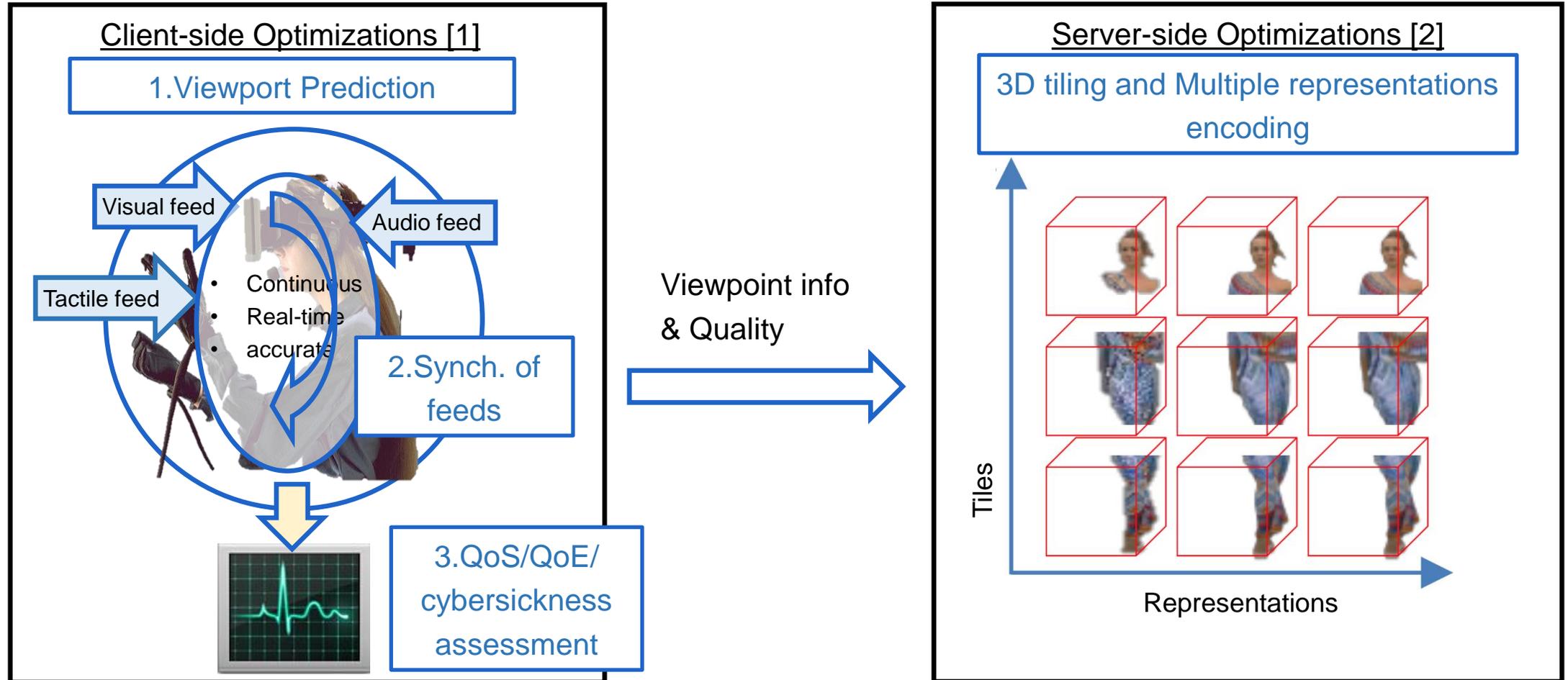


HOW TO ACHIEVE TRULY IMMERSIVE
VOLUMETRIC DELIVERY?
A CROSS-LAYER APPROACH

TRULY IMMERSIVE HTC: A CROSS-LAYER APPROACH



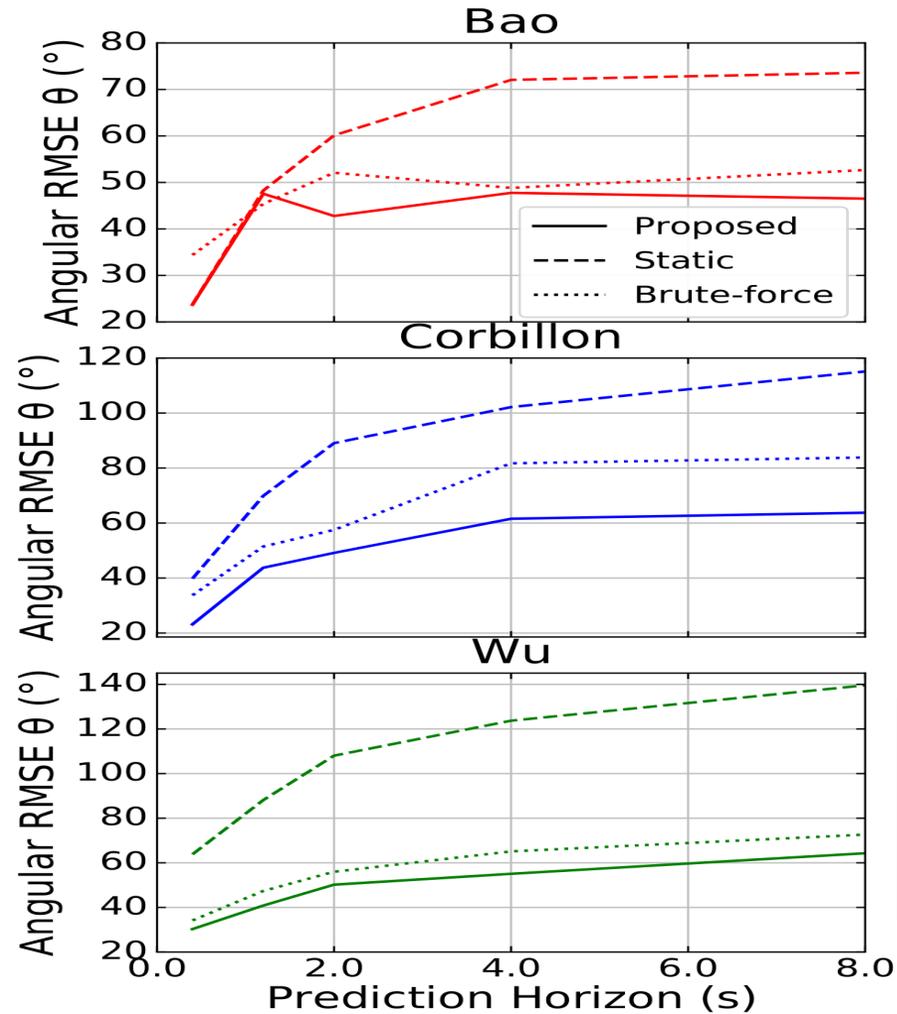
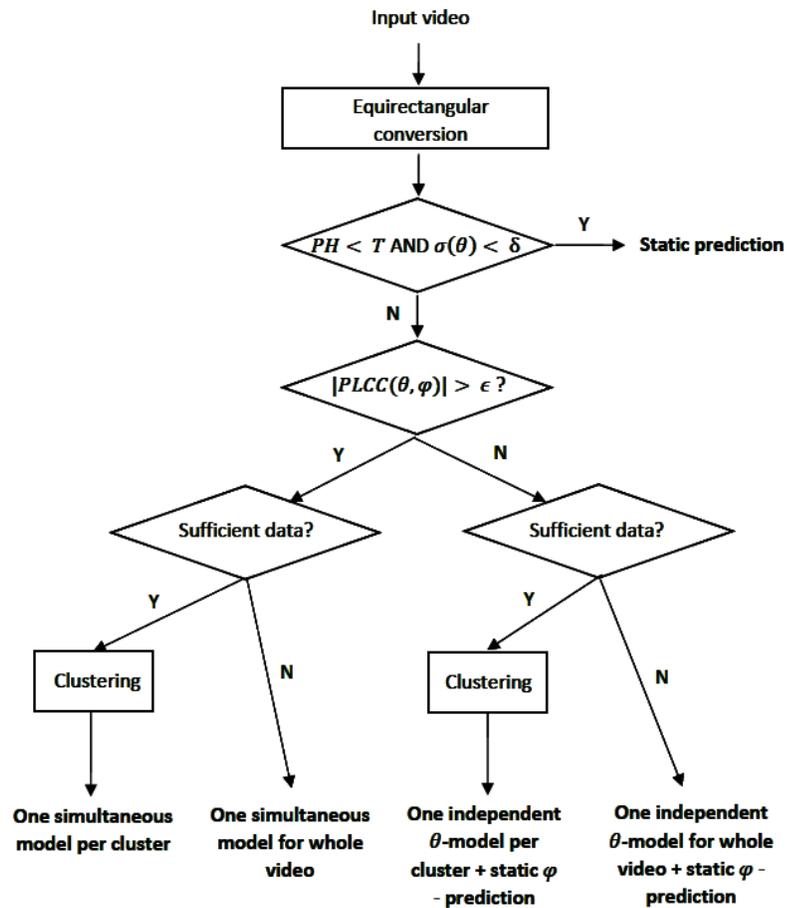
END-USER OPTIMIZATIONS



[1] S. Van Damme, M. Torres Vega and F. De Turck, "Human-centric Quality Management of Immersive Multimedia Applications," *2020 6th IEEE Conference on Network Softwarization (NetSoft)*, 2020, pp. 57-64

[2] J. Park, P. A. Chou, and J.-N. Hwang, "Rate-Utility Optimized Streaming of Volumetric Media for Augmented Reality," *IEEE JETCAS*, vol. 9, 2018, pp. 149-62

PREDICTING USER LOCATION WITH ML [1]



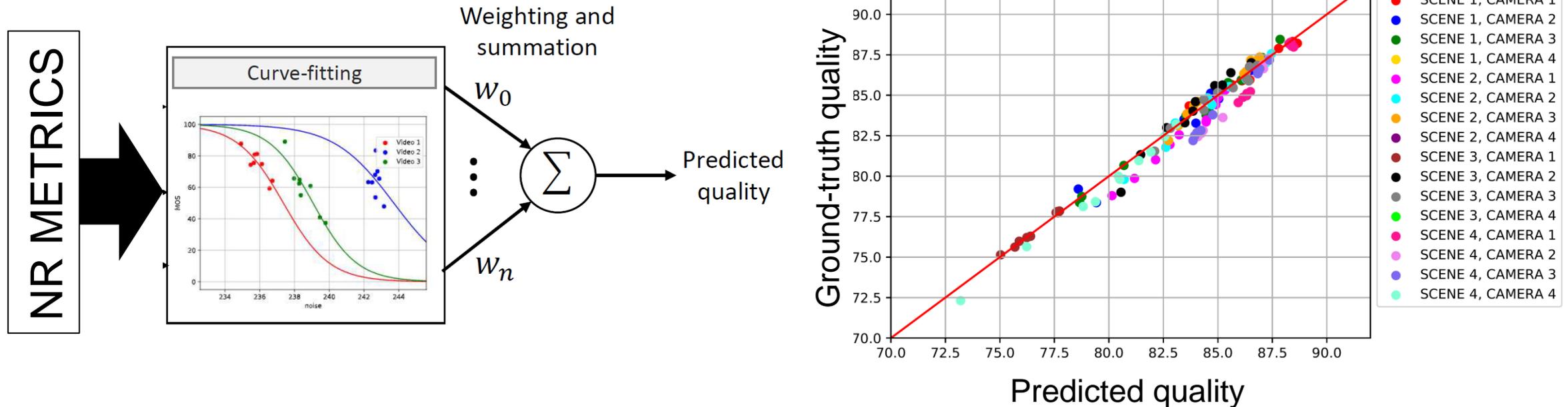
Preprocessing of historic data allows for better predictions

Better prediction results than just ML or static

Prediction error limited for long prediction horizon

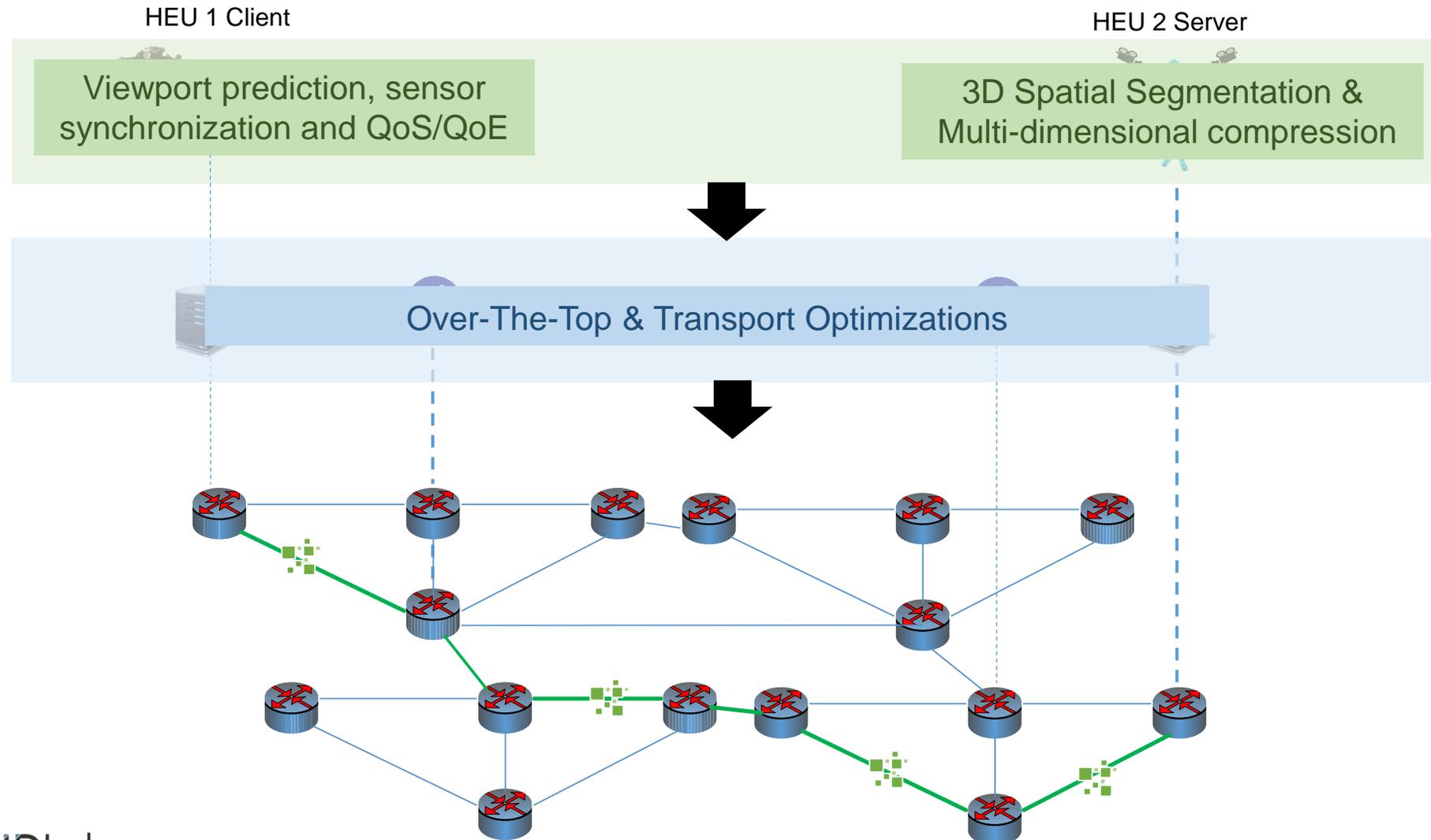
[1] S. Van Damme, M. Torres Vega and F. De Turck, "Machine Learning based Content-Agnostic Viewport Prediction for 360-Degree Video" July 2021 ACM Transactions on Multimedia Computing, Communications and Applications DOI: 10.1145/3474833

PREDICTIVE MODELLING OF IMMERSIVE QOE [1]



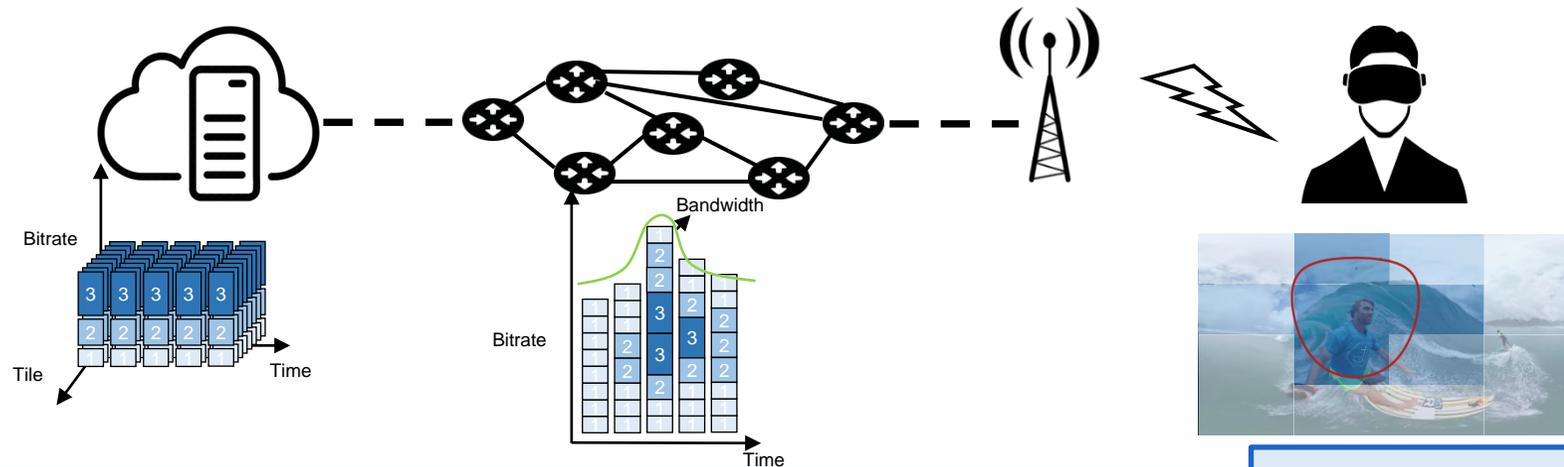
A linear sigmoid combination of no reference metrics achieves 99% accuracy in a large point cloud dataset

A CROSS-LAYER APPROACH: TRANSPORT



CURRENT VIDEO TRANSMISSION: QUALITY VS DELAY

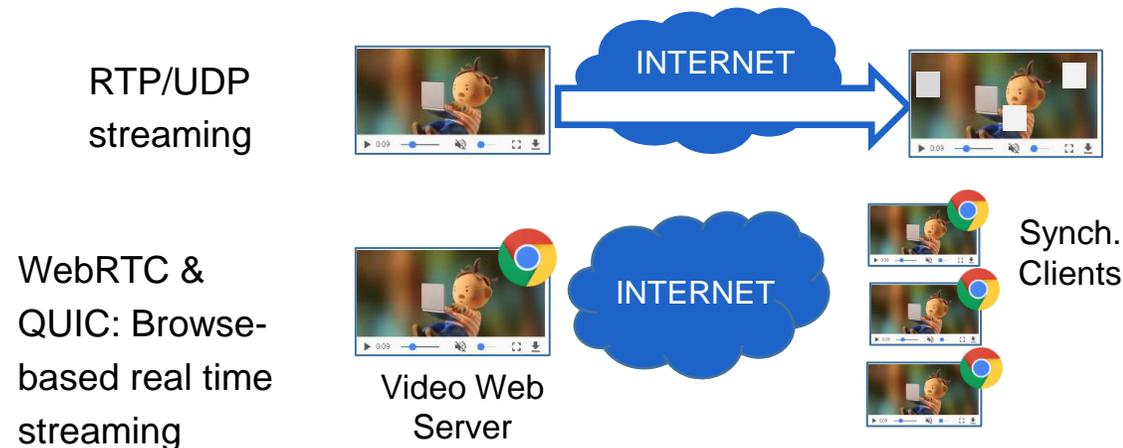
HTTP ADAPTIVE STREAMING: QUALITY OPTIMIZATION



- ☺ Quality and Bandwidth optimization
- ☹ Segmentation: no life
- ☹ Processing, buffering and protocol overhead: no real-time

Is it possible to get the best of both worlds?

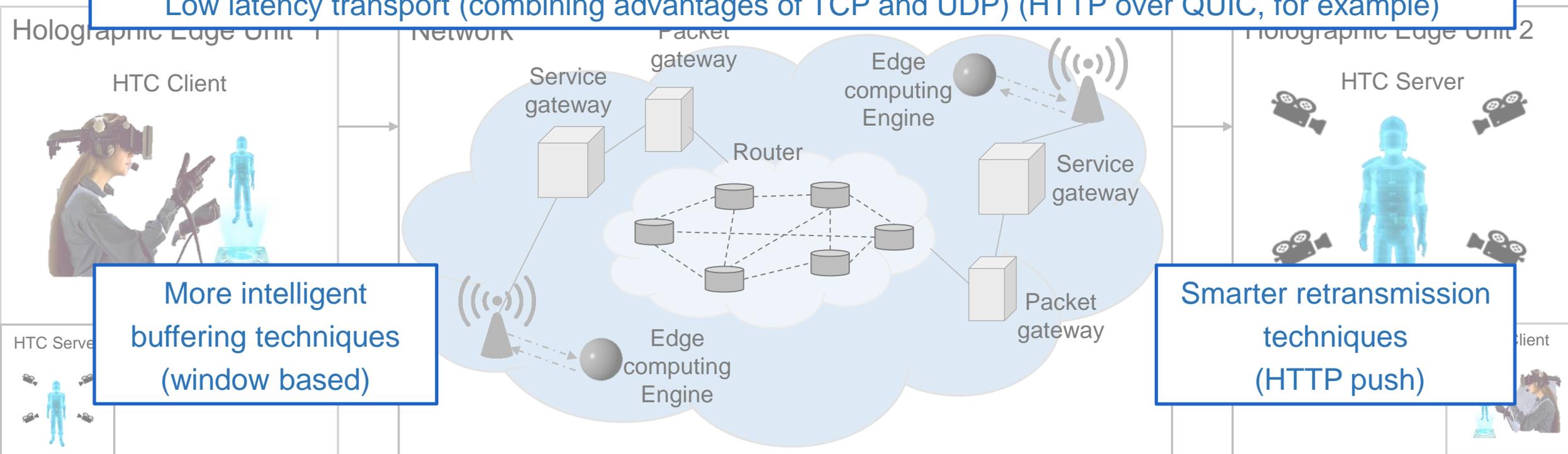
RTP/UDP STREAMING: LATENCY OPTIMIZATION



- ☺ Latency optimization
- ☹ Very limited quality control -> problem for HTC
- ☹ Very low resilience (packet loss prone)

OVER THE TOP & TRANSPORT OPTIMIZATIONS

Low latency transport (combining advantages of TCP and UDP) (HTTP over QUIC, for example)

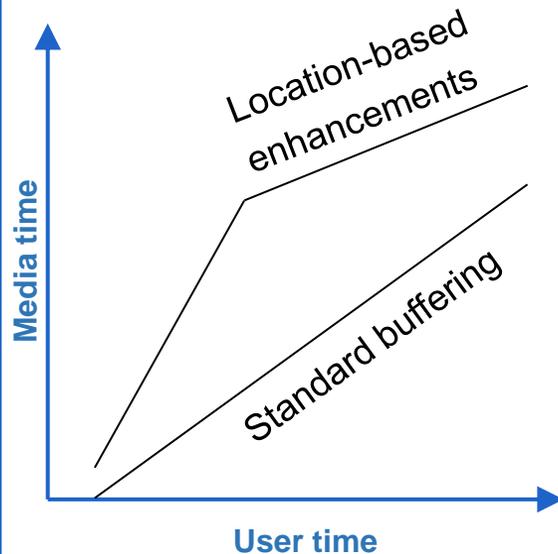


More intelligent buffering techniques (window based)

Smarter retransmission techniques (HTTP push)

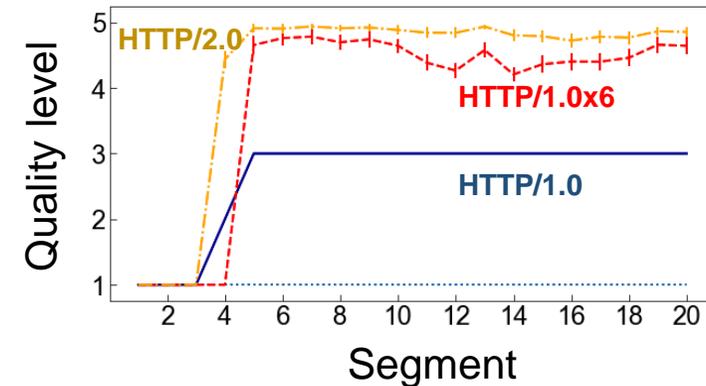
TRANSPORT AND OTT OPTIMIZATIONS

More intelligent buffering techniques: Window-based buffering [1]



- Buffer= interval or window
- Allows to access not only the end of the buffer.
- Able to respond with low latency to unexpected user interactions.

Smarter retransmission techniques: HTTP2 push for 360-degree video [2]

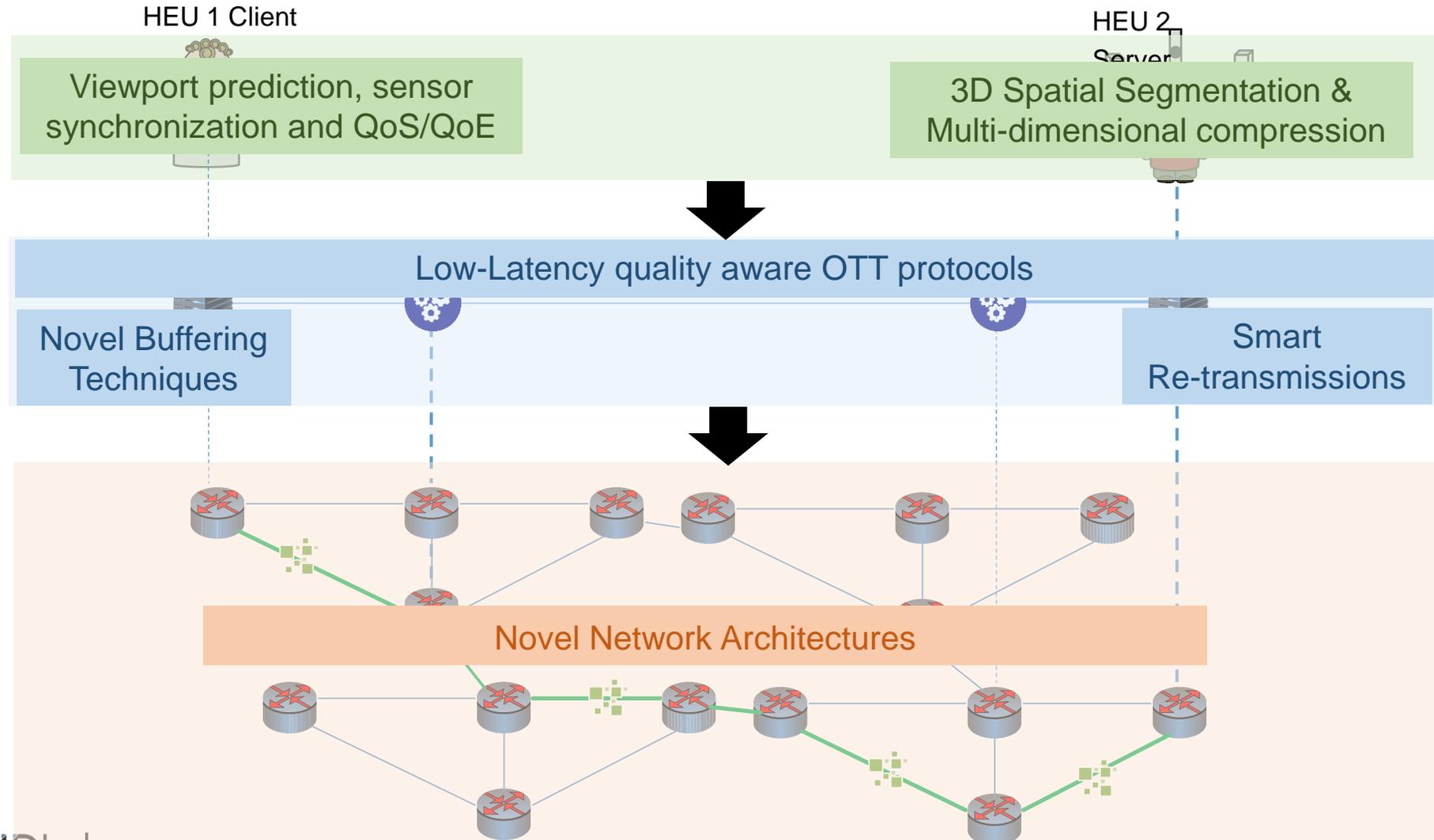


- Thanks to push, HTTP2 (yellow) can acknowledge multiple packets simultaneously
- It allows for highest and more stable quality delivery

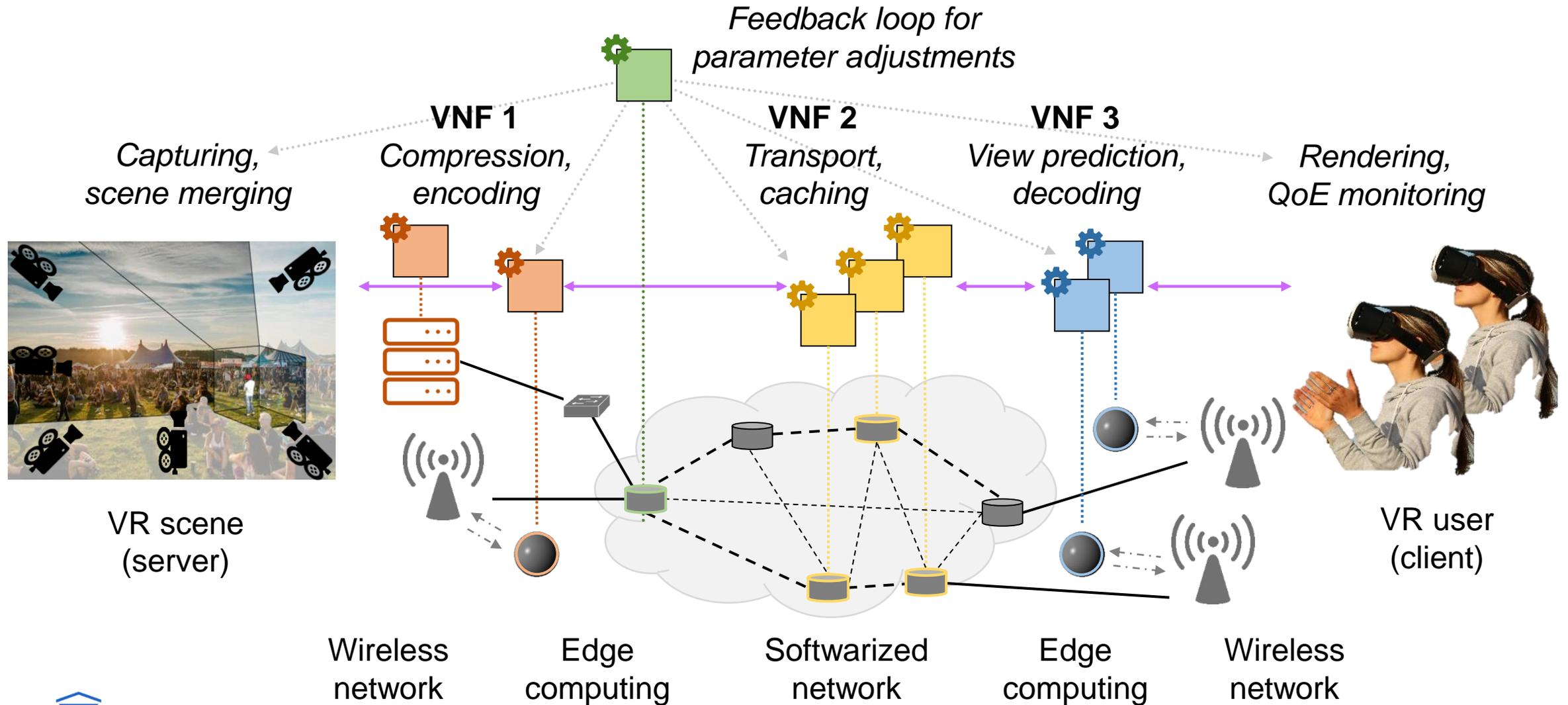
[1] J. Park, P. A. Chou, and J.-N. Hwang, "Rate-Utility Optimized Streaming of Volumetric Media for Augmented Reality," IEEE JETCAS, vol. 9, 2018, pp. 149–62

[2] J. van der Hooft, M. Torres Vega, S. Petrangeli, T. Wauters, and F. De Turck, "Tile-based Adaptive Streaming for Virtual Reality Video", ACM Trans. Multimedia Comput. Commun. Appl. 15, 4, Article 110 (January 2020), 24 pages.

TRULY IMMERSIVE HTC: A CROSS-LAYER APPROACH



SERVICE FUNCTION CHAIN OPTIMIZATIONS

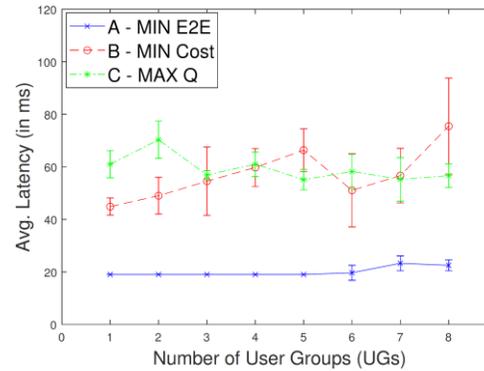


EFFECTS OF SFC ON E2E LATENCY [1]



Live without View Prediction

Capturing, encoding, merging,
transport, rendering

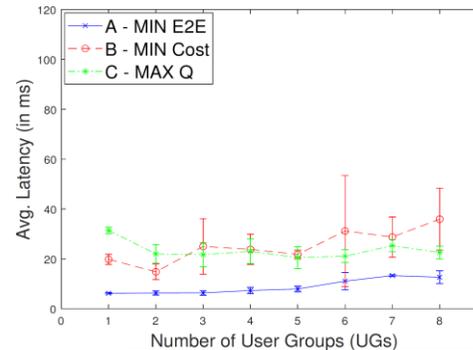


Even optimizing latency (blue line), users experience an average latency of 19 ms even for a small number of user groups.



Live with View Prediction

Capturing, encoding, merging,
transport, view prediction, rendering

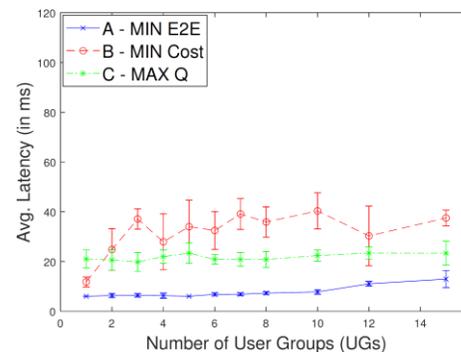


The addition of view prediction to the live scenario helps to reduce the user-perceived latency (blue line), but it brings additional costs (red line).



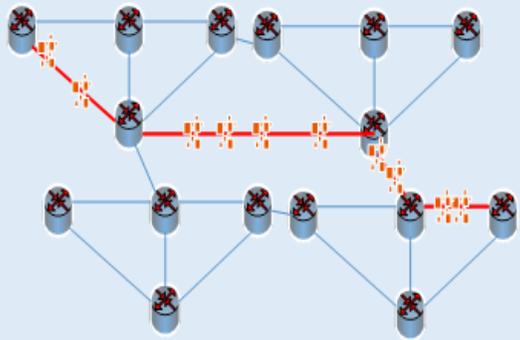
On-demand

Transport, view prediction,
rendering

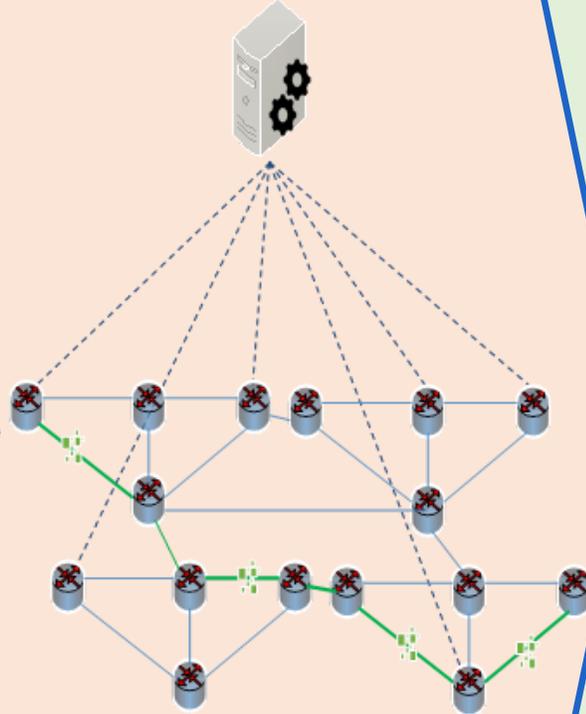


The on-demand scenario shows that deployment costs are considerably reduced, while keeping the E2E latency very low (3-4 ms), but it is not suited for live scenarios.

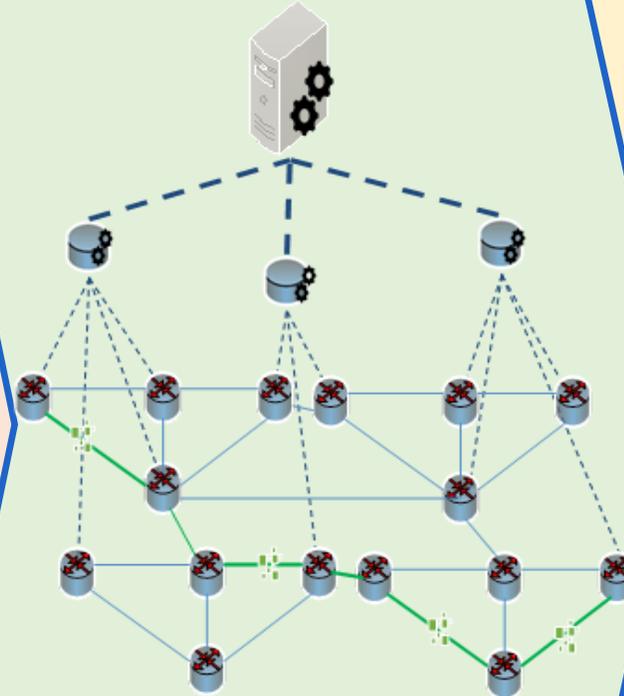
TOWARDS FULLY DECENTRALIZED NETWORKS...



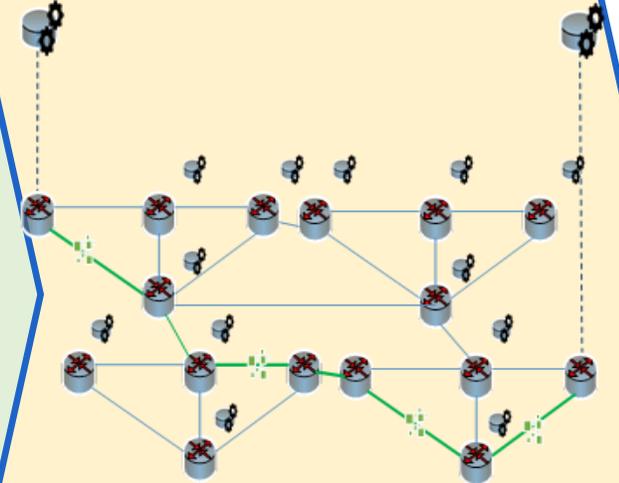
Current network infrastructure



Software Defined networks

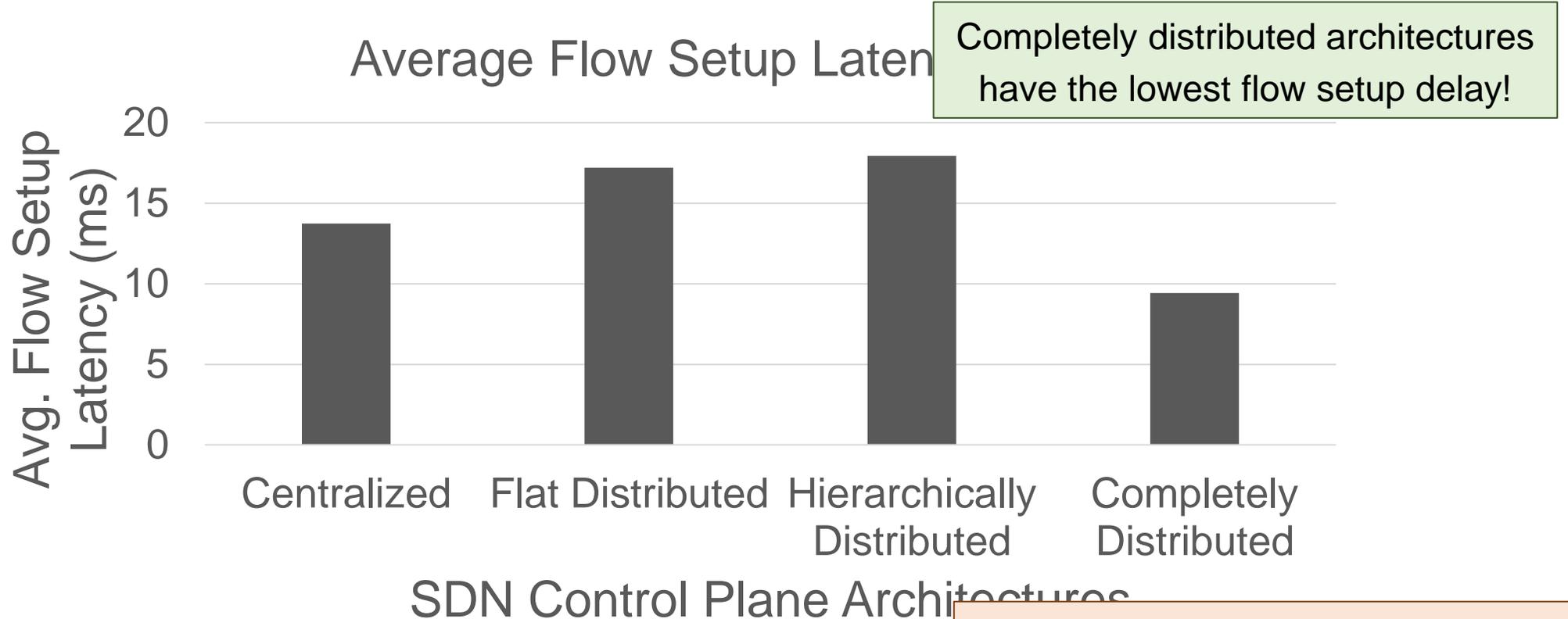


Hierarchically decentralized SDN



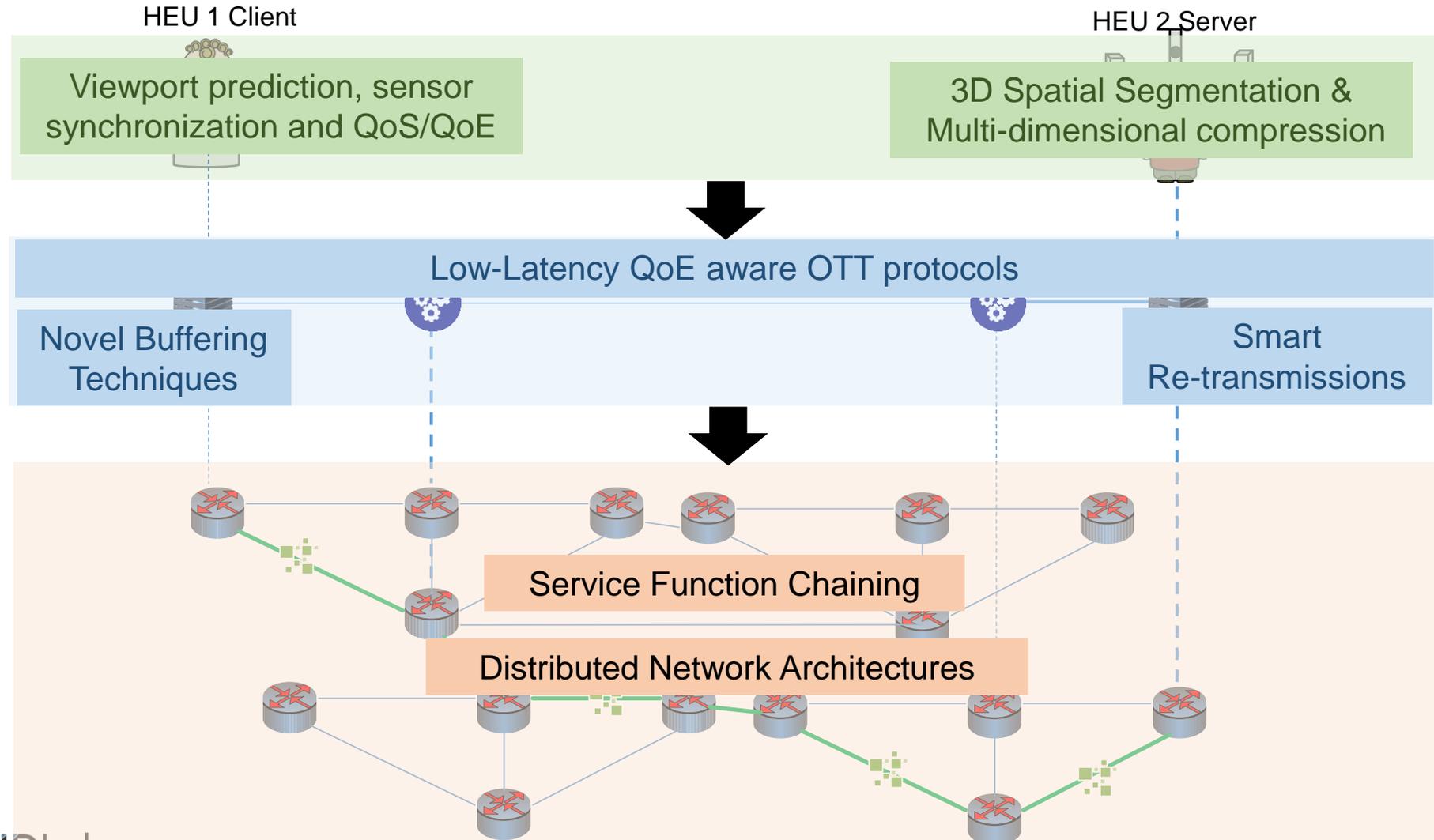
SDN with logically (& completely) decentralized controller

FLOW SET-UP LATENCY ANALYSIS FOR DIFFERENT SDN ARCHITECTURES [1]



[1] H. K. Ravuri, M. Torres Vega, J. van der Hooft, T. Wauters, B. Da and F. De Turck, "On SDN Architectures," 2020 11th International Conference on Network of the Future (NoF), 2020, pp. 23-27

TRULY IMMERSIVE HTC: A CROSS-LAYER APPROACH



CONCLUSIONS AND CHALLENGES

OPEN CHALLENGES AND TOPICS

Application optimizations (to increase QoE) (end-user and server side)

- Encoding strategies: Tiling, point clouds, light fields
- QoE modeling, haptics
- View prediction and content prefetch
- Adaptive Bit Rate (ABR) selection focused on what the user is looking at

Network optimizations (to increase QoE by adapting quality / reducing latency)

- Protocols (DASH, WebRTC, QUIC) to be able to leverage the quality vs latency tradeoff.
- Softwarized networks to reduce latency: SDN/NFV, distributed flow setup
- Computational offloading to reduce latency and increase quality (Cloud/edge/fog, Mobile Edge Computing (MEC), Service Function Chaining (SFC))
- Transport enablers: Segment routing, packet scheduling / caching / prioritization / retransmission / dropping

IEEE TRANSACTIONS ON NETWORK AND SERVICE MANAGEMENT

IEEE Transactions on
Network and
Service Management
(TNSM)

- Submission format: 12 pages + extra pages
- Regular call + special issues + extended versions of best papers selected from conferences
- Current issue: Volume 18, Issue 4
- JCR Impact factor: 4.195
- H-index: 51 (as of 11/21)

Searchable index

Search entry

Use quotation marks (" ") for exact matches

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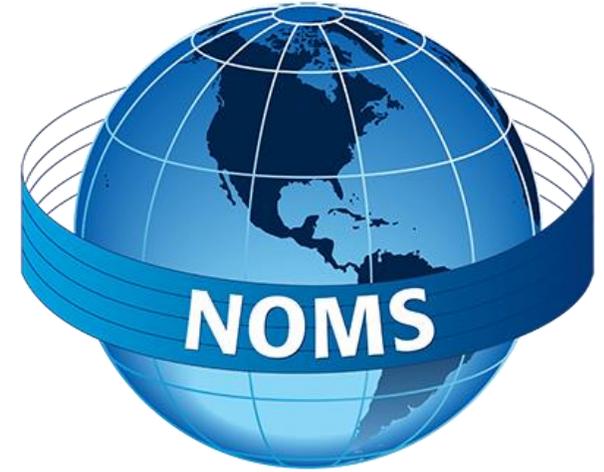
Author	Title	Year ↓	Issue	Keywords
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Vignesh Sridharan and Mohan Gurusamy	Game-Theoretic Framework for Malicious Controller Detection in Software Defined Networks	2021	Early Access	Control systems Switches Security
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Matching entries: 1116 1 - 1116 of 1116



TNSM Overview – Analytics
<http://www.tnsm-overview.org>

Conferences on Network and Service Management



Thanks to the team

- Maria Torres Vega
- Tim Wauters
- José Santos
- Hemanth Kumar Ravuri
- Sam Van Damme
- Jeroen van der Hoof



“No, you can’t wipe `em off. They’re holograms.” - Tobias Becket to Chewbacca in Solo (2018)
“Holograms are the next video” – Philip A. Chou

Thank you for your attention!
Any questions or comments?

