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ViSNext‘22

Live Video Streaming through the ML Lens

Amr Rizk

PALUNO
The Ruhr Institute for Software Technology

Hello from Germany

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University of Duisburg-Essen (*1972, ~41.000 students)

PALUNO
The Ruhr Institute for Software Technology

paluno - The Ruhr Institute for Software Technology
~100 researchers
collaborations with leading industry partners

NOKIA BOSCH T BMW GROUP IBM
duisport SAP Infotainment

Prof. Amr Rizk, Head of the Networks and Communication Systems La
Research focus on

performance evaluation

programmable networks

immersive multimedia

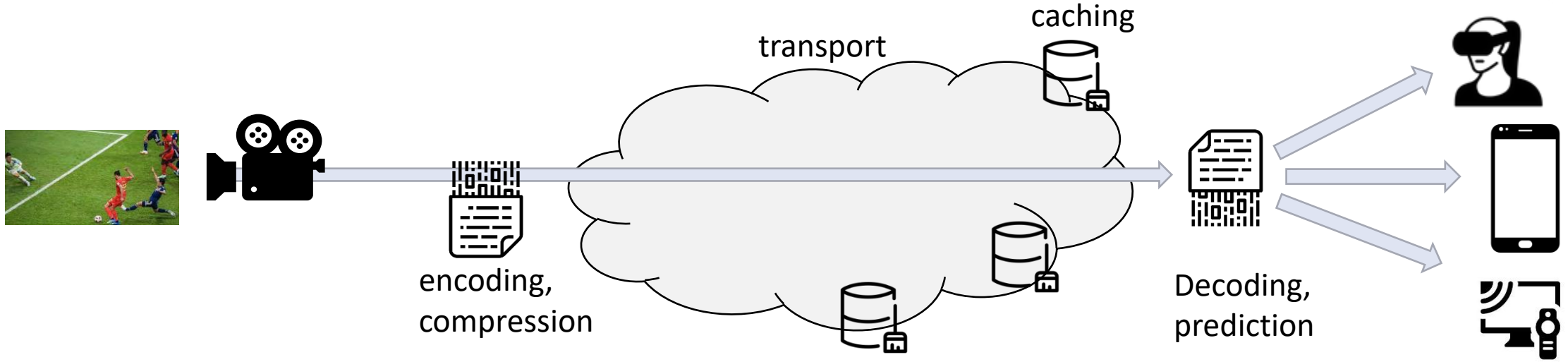
less controversy with point cloud streaming?

“Software is eating the World” – M. Andreessen (2011)

~~ML~~

Prediction	**Inpainting**	**Recognition**
classification	**Fusion**	**Obfuscation**
Estimation	**Embedding**	**Rate allocation**
Online decision making	**Coding**	**Scheduling**
Filtering & smoothing	**Compression**	**Transcoding**
	Object Tracking	**...**
	Super-resolution	
	Caching	
	Segmentation	

The Significance of ML in Video Streaming



decision making / reconfig	video quality selection, multipath scheduling, transcoding, …
prediction	available bitrate, head/user movement, cache hits, …
encoding	error concealment, Point cloud inpainting, …

Classical Problems of (Live) Video Streaming
1. Bandwidth Requirement

HD

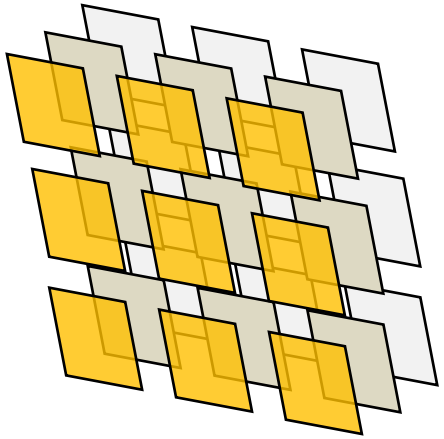
[X] Mbps

360°

[XY] Mbps

Point Cloud

[X] Gbps

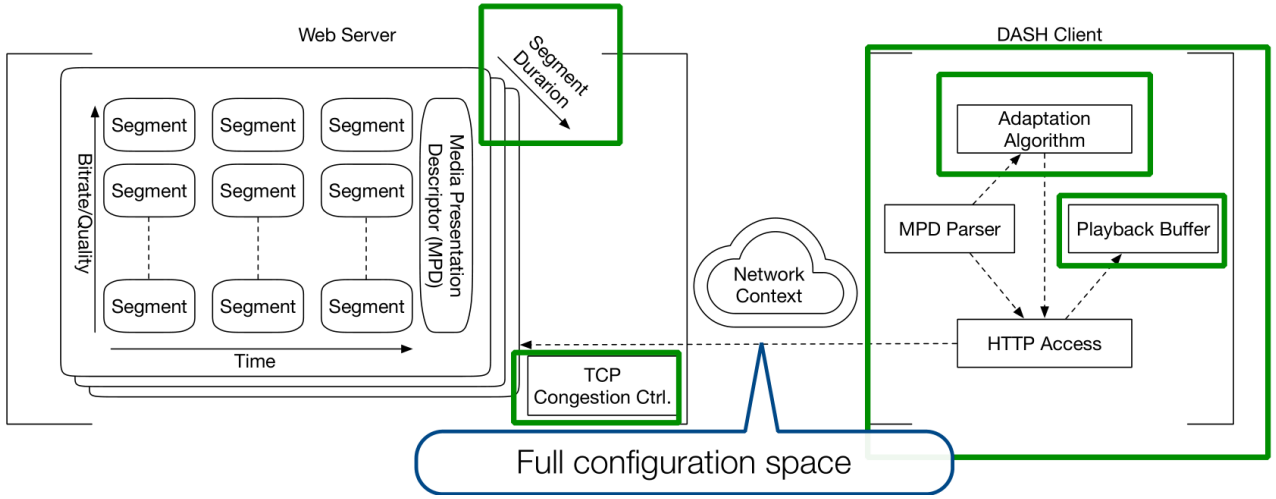


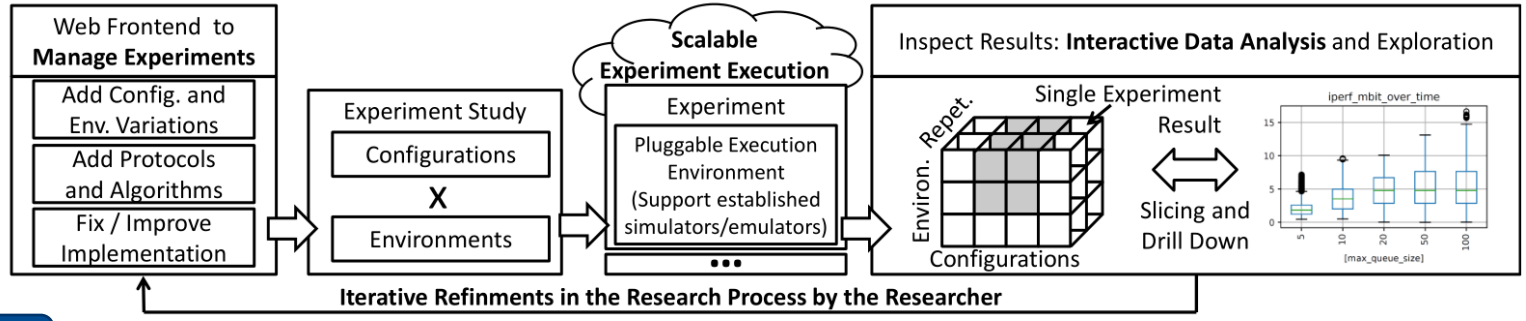
Light Field
Multi-view Video

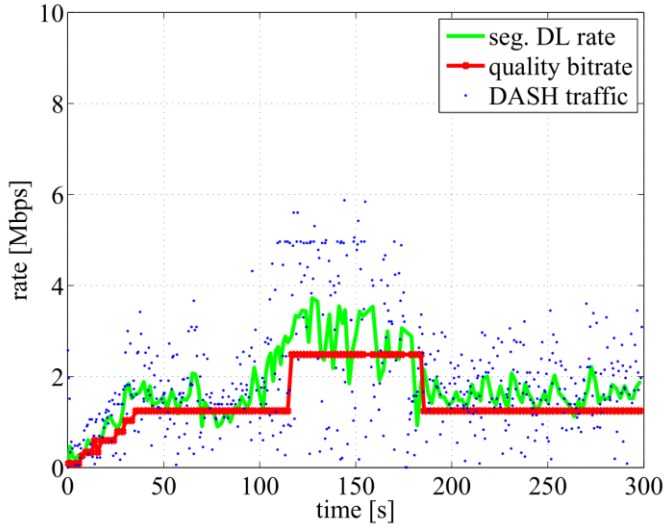
[XYZ] Gbps

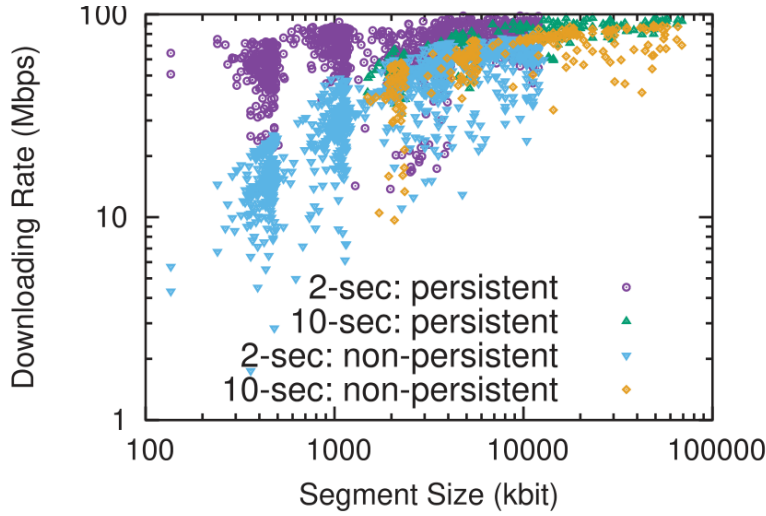
Bandwidth requirement

Classical Problems of (Live) Video Streaming
2. Bandwidth fluctuation



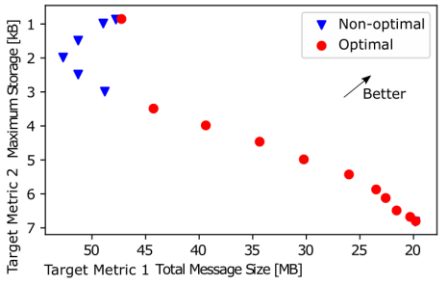






MACI

https://maci-research.net



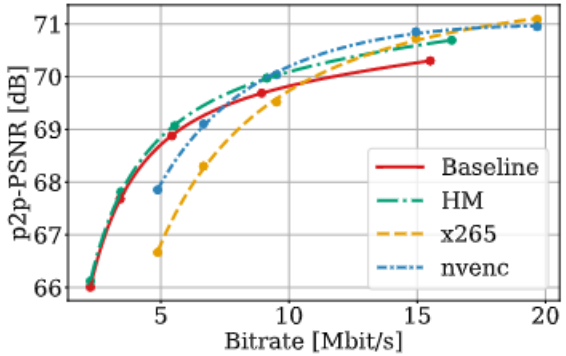
automatically generated pareto fronts

C. Wang, D. Bhat, A. Rizk, M. Zink: Design and Analysis of QoE-Aware Quality Adaptation for DASH: A Spectrum-Based Approach. ACM Trans. Multim. Comput. Commun. Appl. 13 (2017)

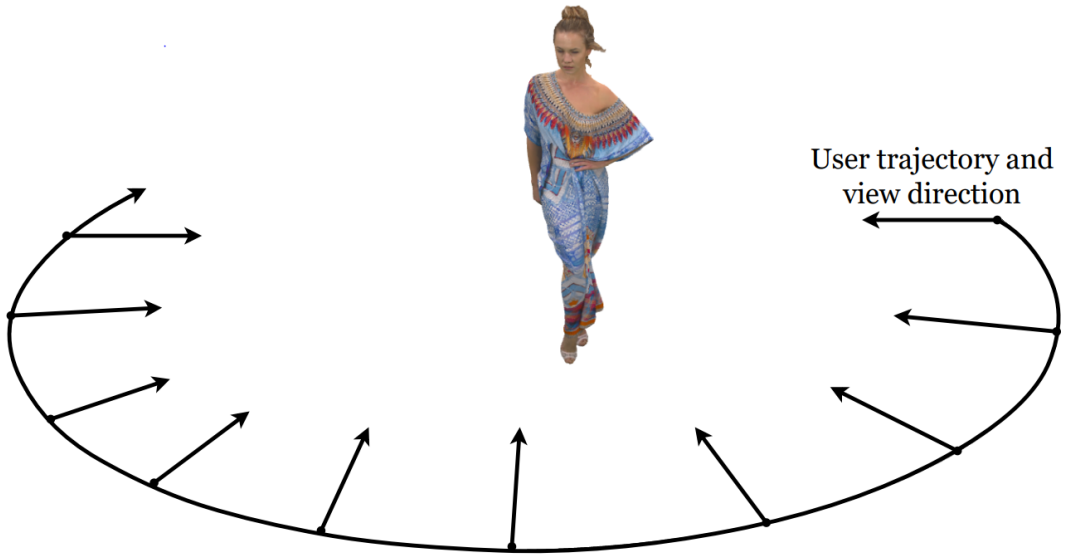
A. Frömmgen, D. Stohr, B. Koldehofe, A. Rizk: Don't repeat yourself: seamless execution and analysis of extensive network experiments. ACM CoNEXT 2018

Classical Problems of (Live) Video Streaming
3. Utility

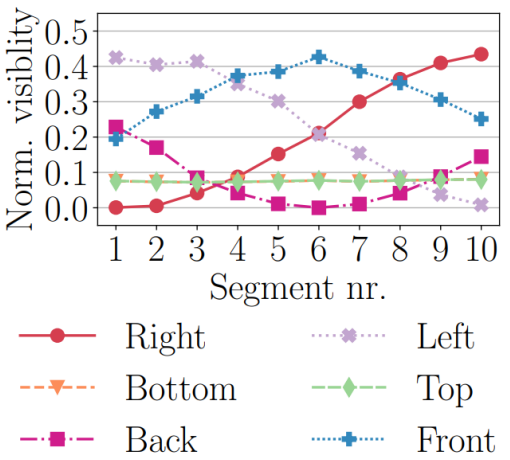
- Objective vs. Subjective Studies
  - QoS/QoE
  - MOS
  - (PSNR), VMAF
  - P2P PSNR, Y-PSNR, PCQM, logP2D-JGY
- Rate-Distortion comparison (e.g. Bjøntegaard Model)

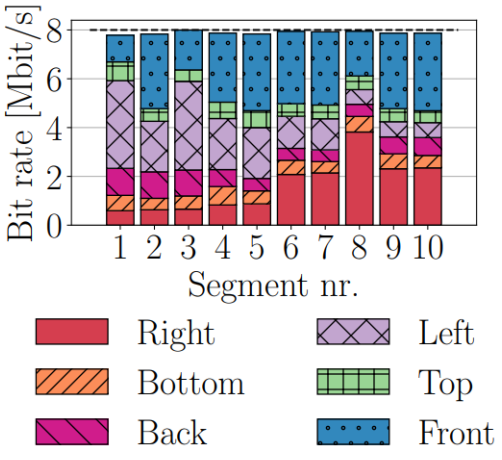


More Problems of (Live) Video Streaming
4. User Interaction



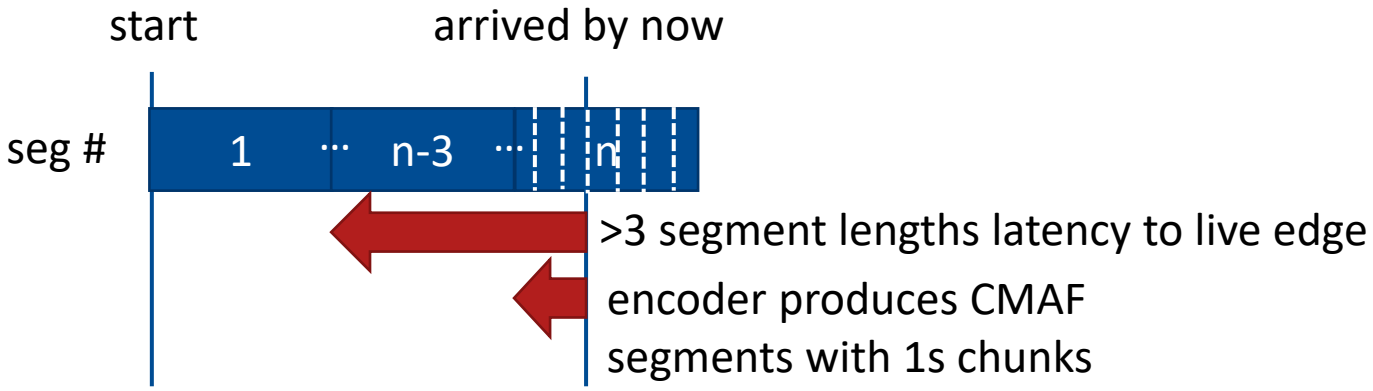
Interaction with a Point Cloud object

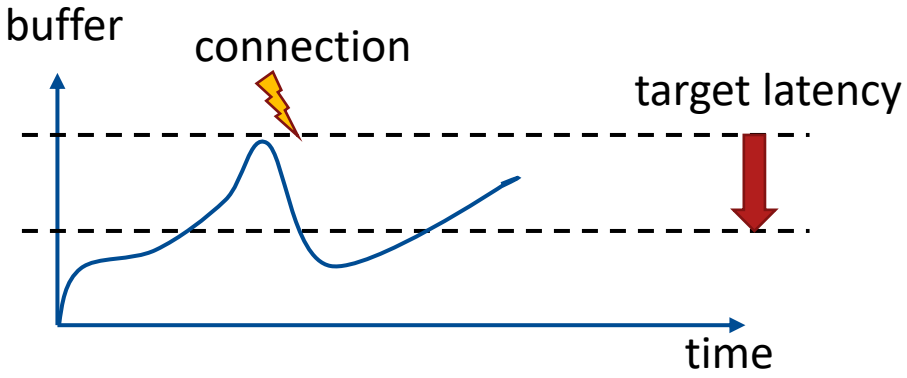




More Problems of Live Video Streaming
5. The latency-buffering dilemma

CMAF Chunks

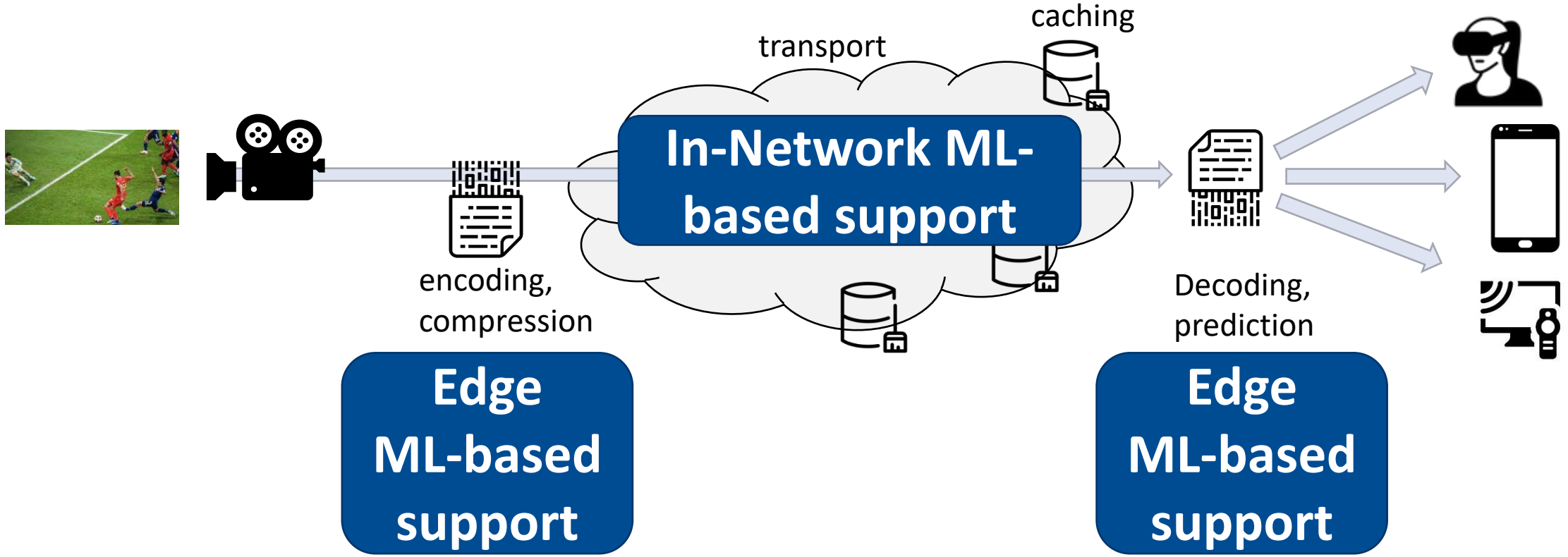




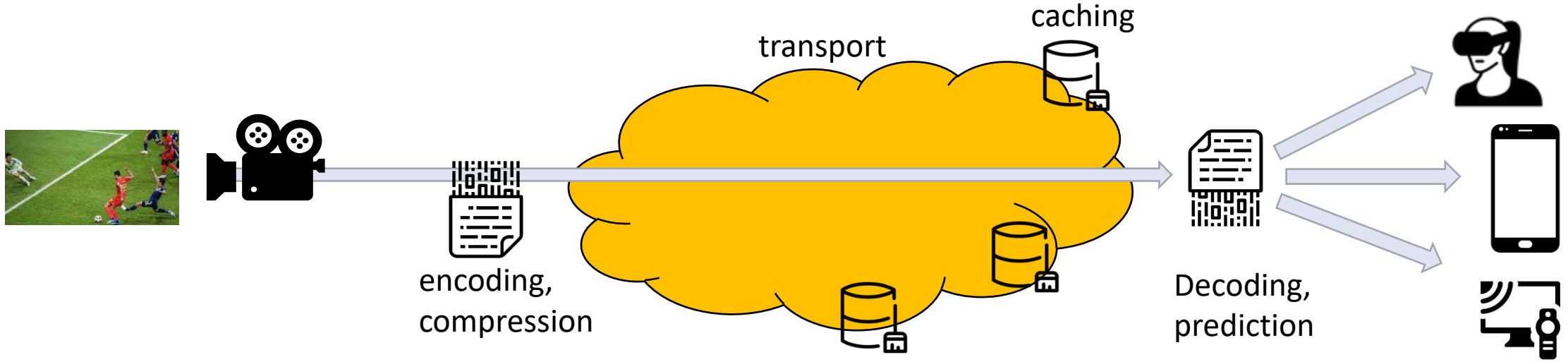
needs fast + accurate prediction

inspired by D. Silhavy

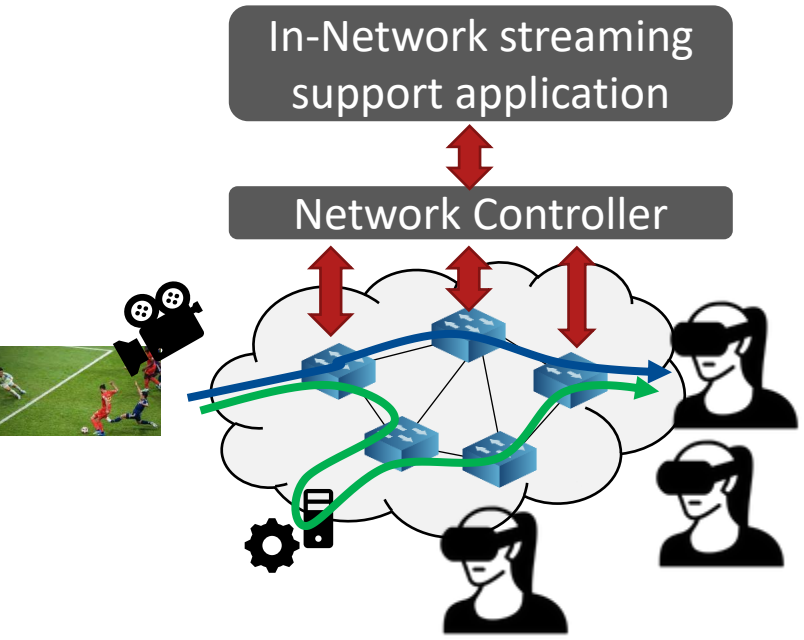
(Live) Streaming through the ML lens
Where? And What?



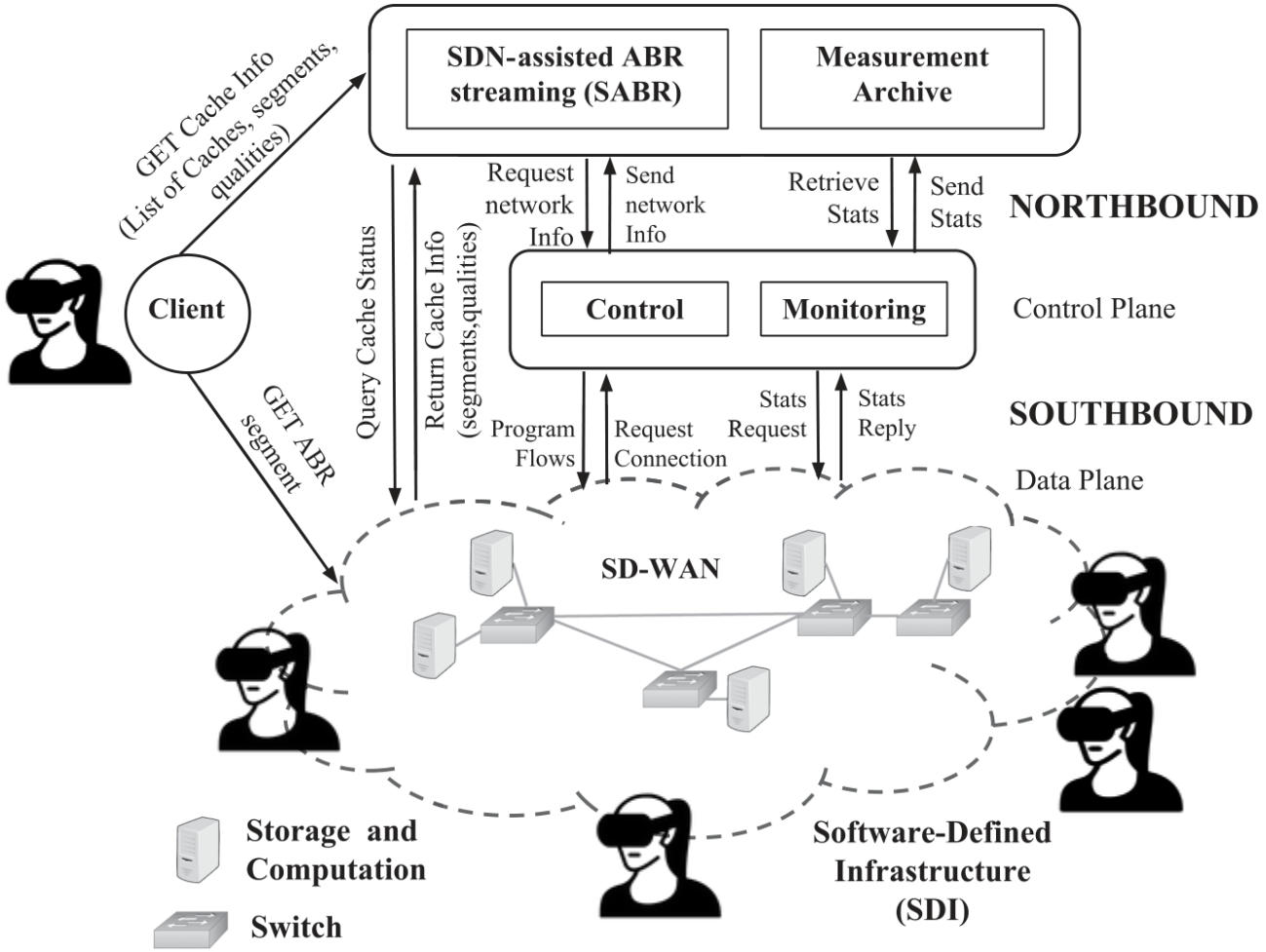
(Live) Streaming through the ML lens
In-Network streaming support



(Live) Streaming through the ML lens
In-Network streaming support

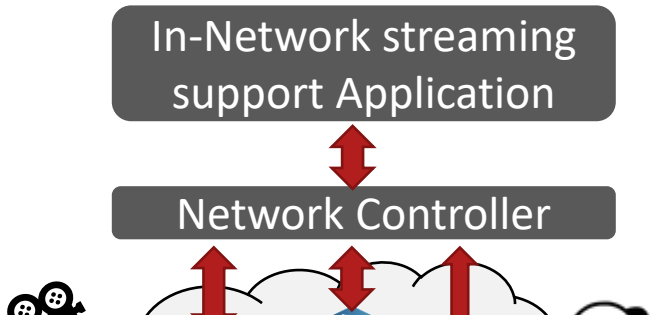


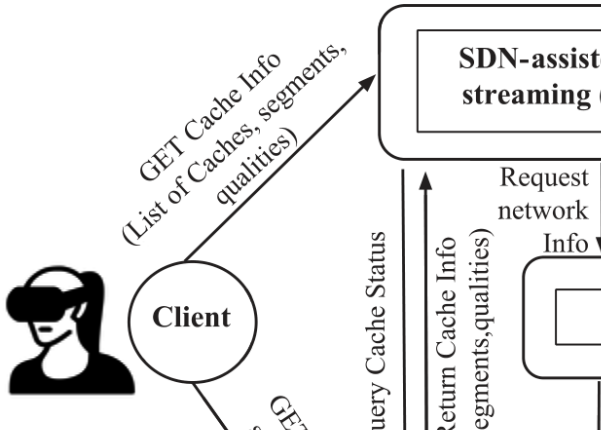
1. control streaming traffic
2. control in-network applications (VNFs)

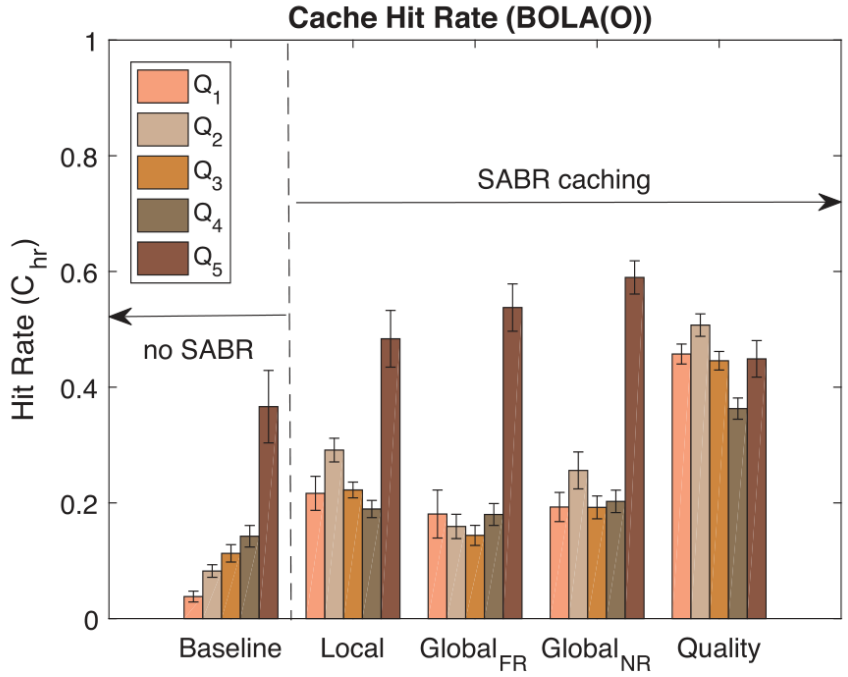


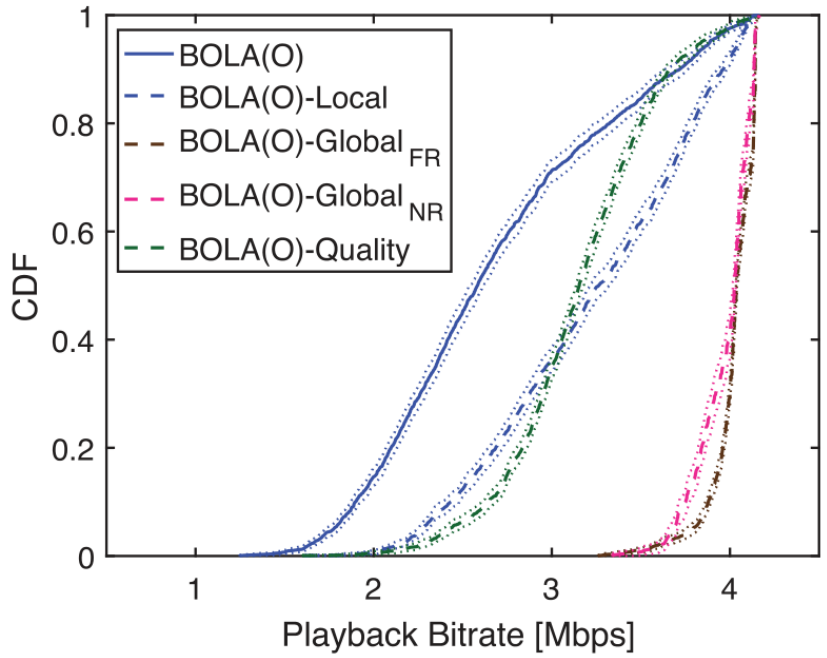
D. Bhat, A. Rizk, M. Zink, R. Steinmetz: SABR: Network-Assisted Content Distribution for QoE-Driven ABR Video Streaming. ACM Trans. Multim. Comput. Commun. Appl. 14(2s): 32:1-32:25 (2018)

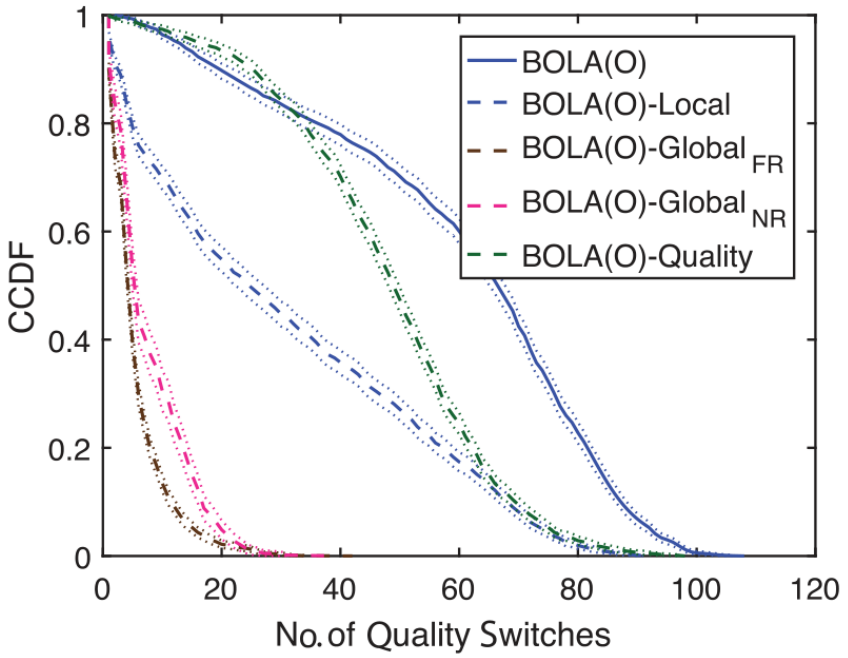
(Live) Streaming through the ML lens
In-Network streaming support

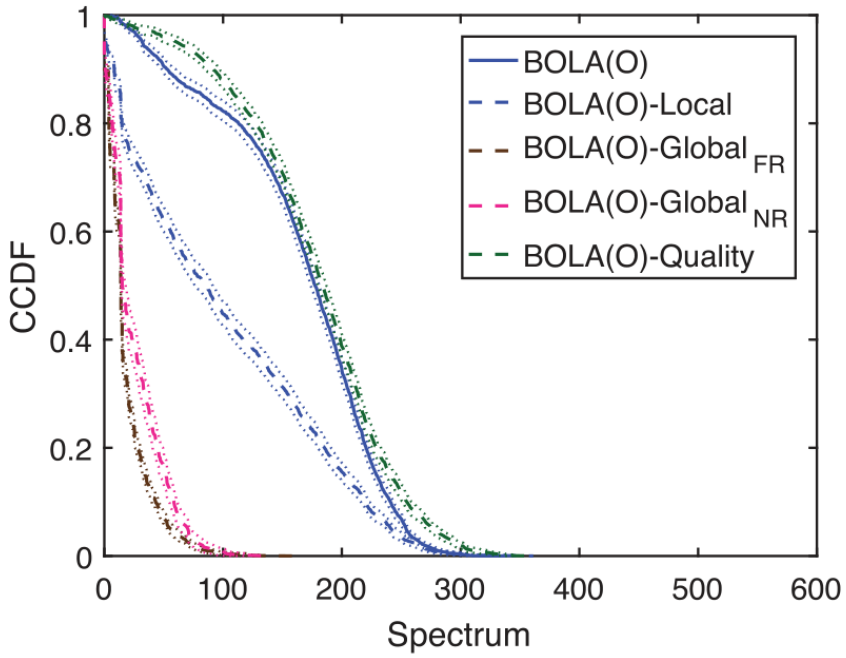




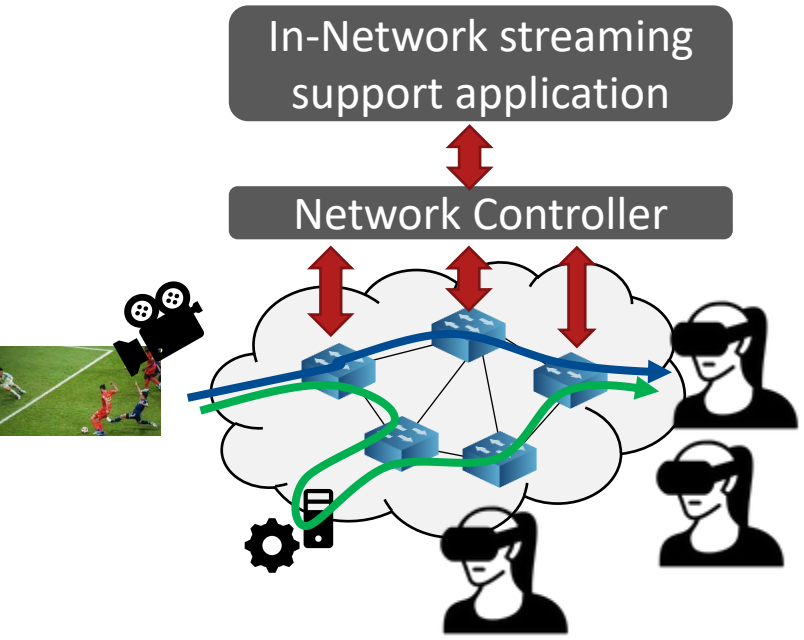


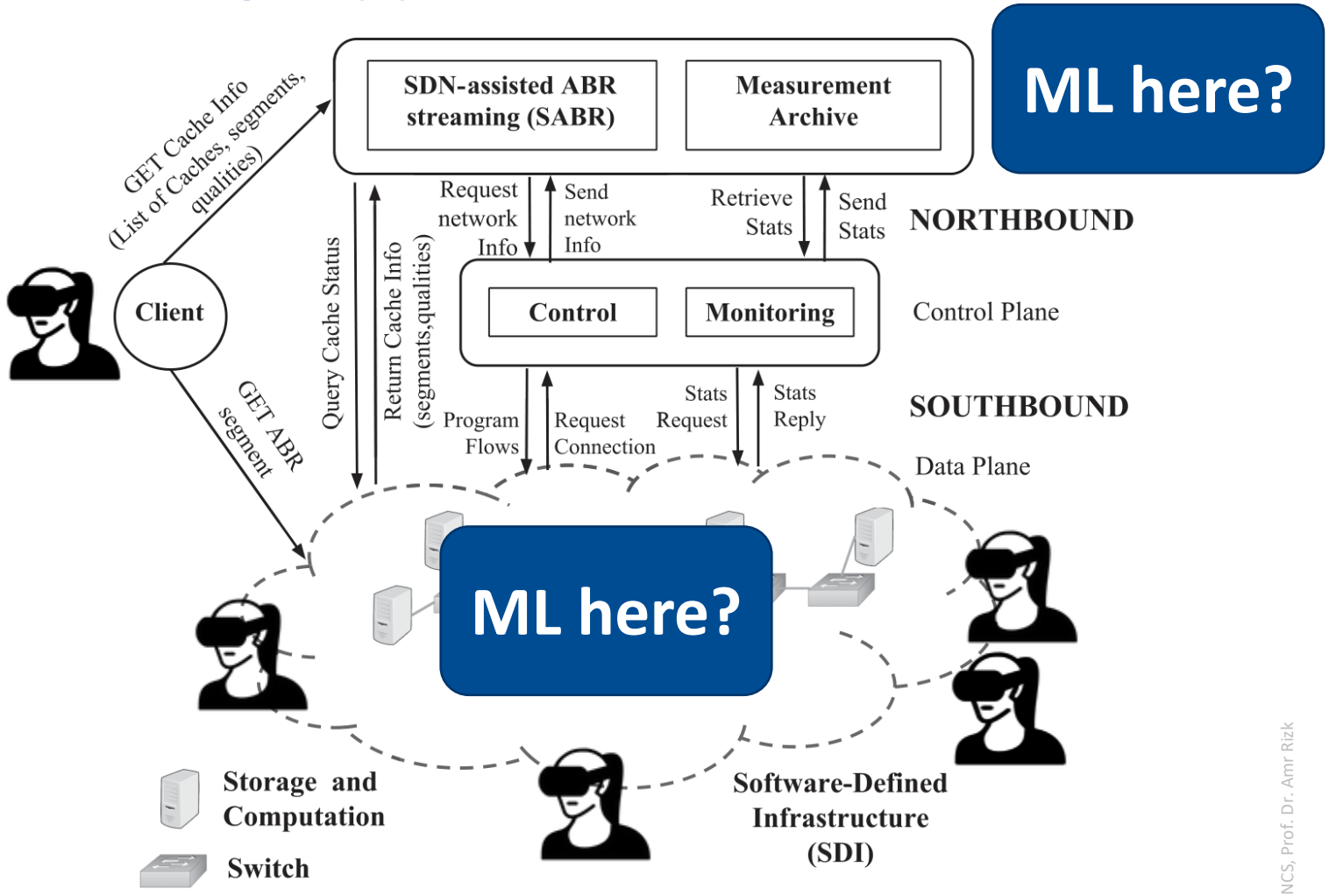






(Live) Streaming through the ML lens
ML-based In-Network streaming support





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(Live) Streaming through the ML lens
ML-based In-Network streaming support

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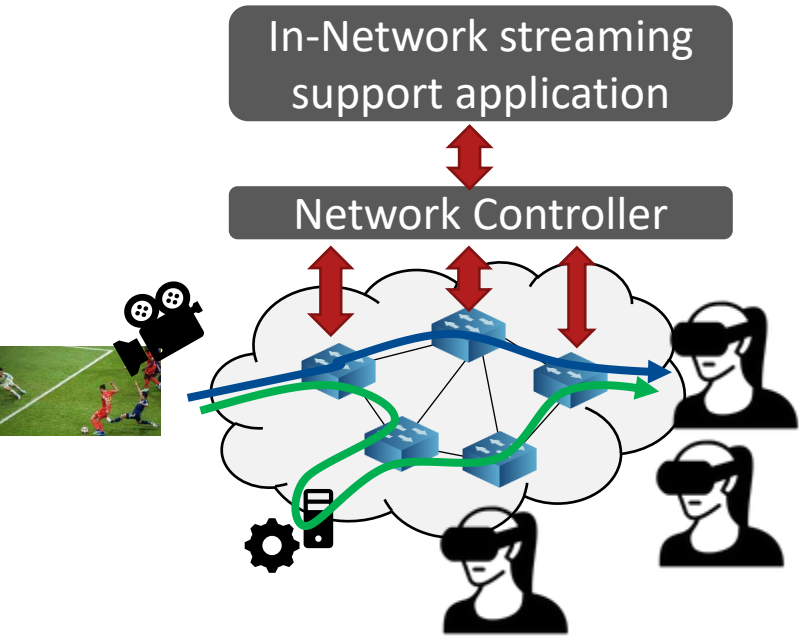
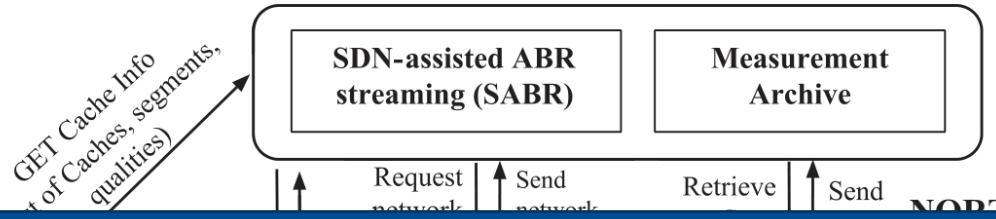
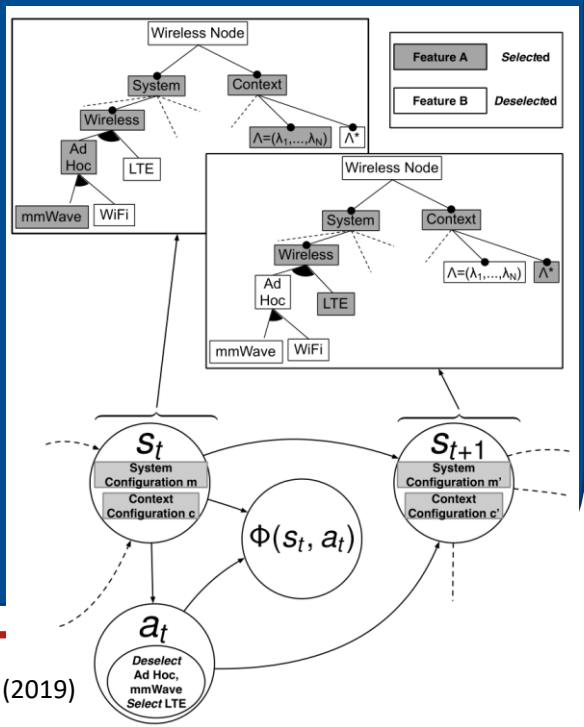




ML here

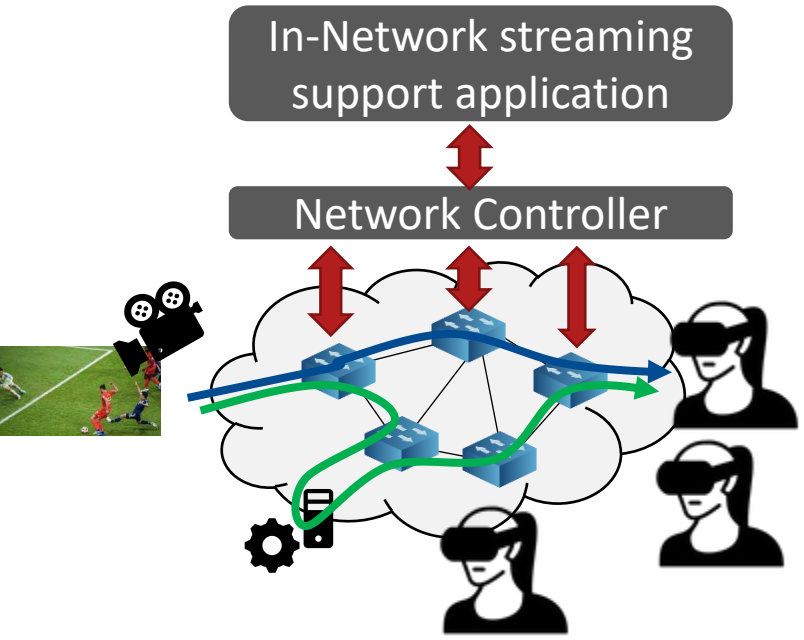
Time scale (coarse):
- **predict available bandwidth (e2e) [Bhat'18]**
- **predict coding times [Amirpour'22]**
- **QoE regression**
- **network reconfiguration (Transitions as a RL problem) [Alt'19]**
  - **routing, multicast, multipath**
  - **AQM, scheduling**

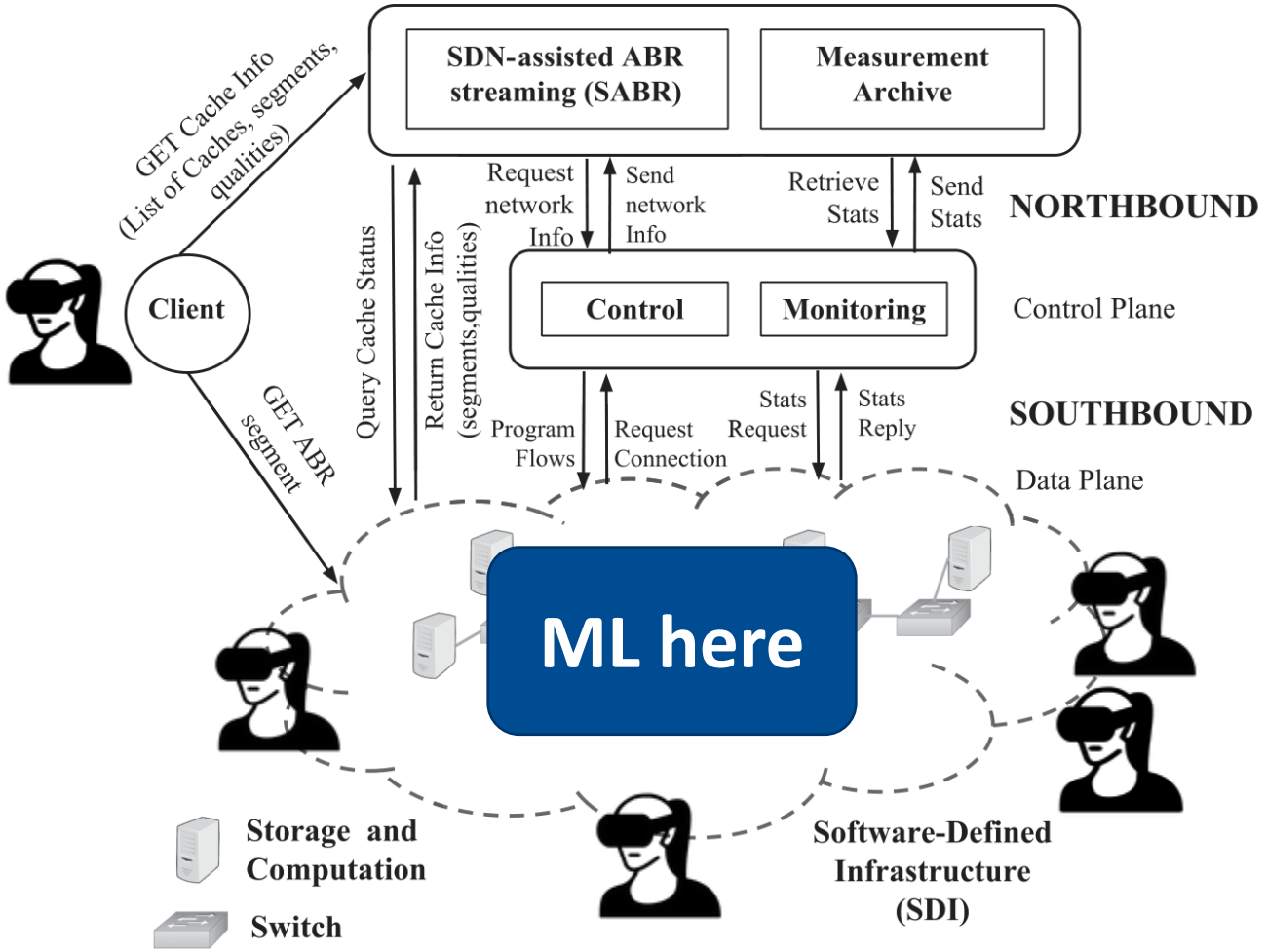


1. control streaming traffic
2. control in-network applications (VNFs)

B. Alt et al, Transitions: A Protocol-Independent View of the Future Internet. Proc. IEEE 107(4): 835-846 (2019)

(Live) Streaming through the ML lens
ML-based In-Network streaming support





1. control streaming traffic
2. control in-network applications (VNFs)

(Live) Streaming through the ML lens
ML-based In-Network streaming support

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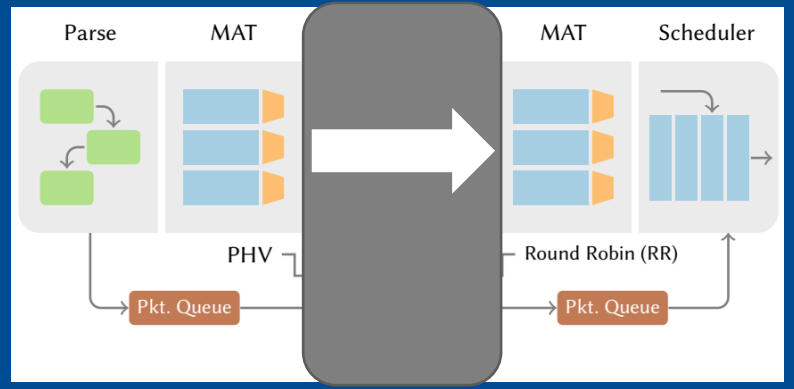
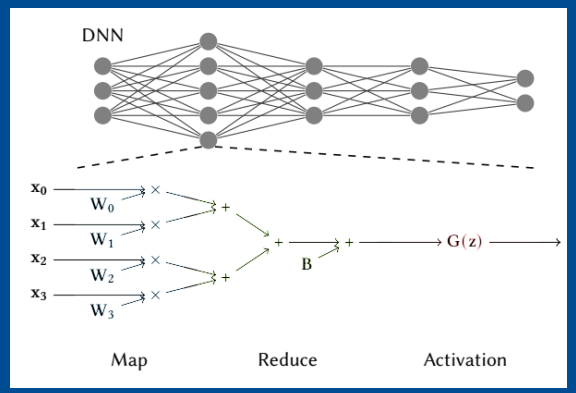
Time scale (very fine):
per packet on the network switch
- **classification**
- **which inference tasks work well on NALU?**
- **for autoencoding -> limitation of hardware?**





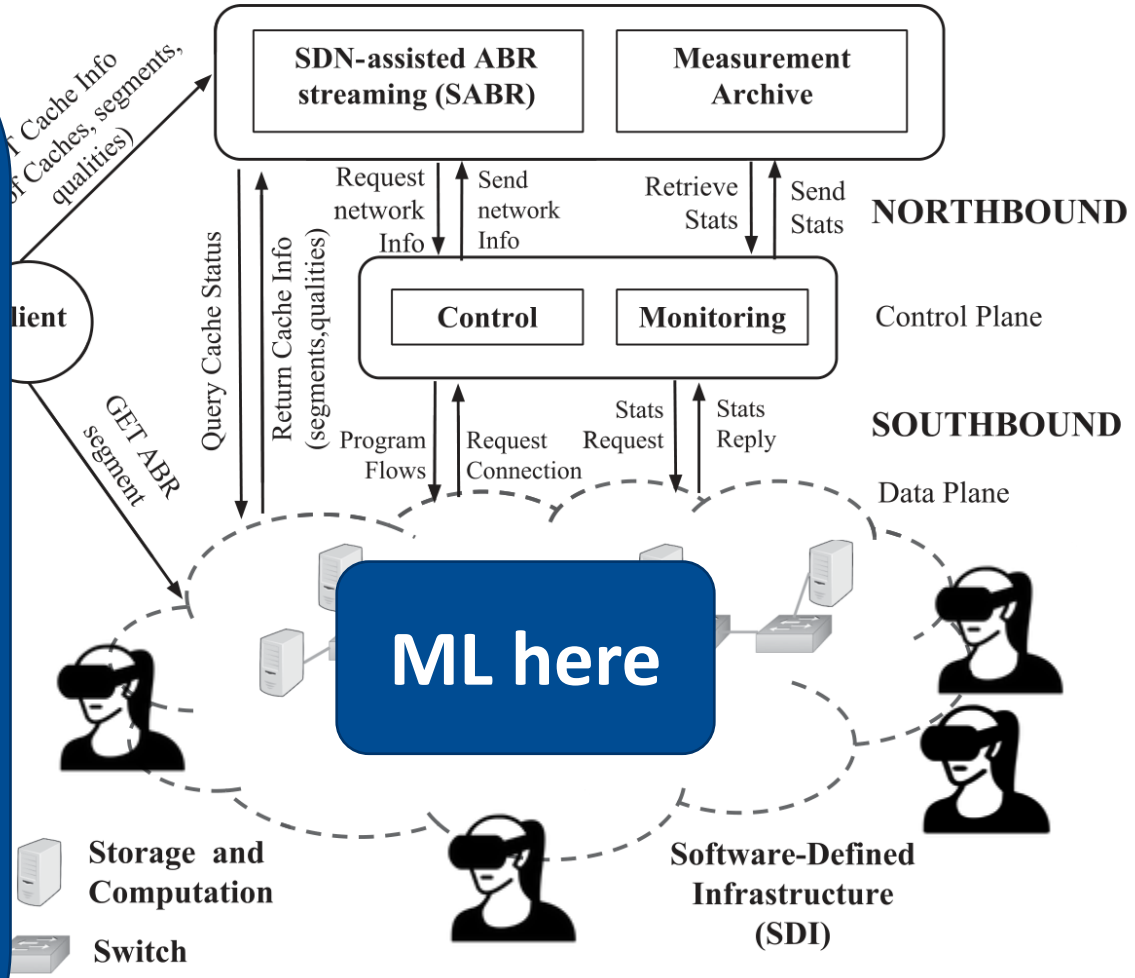
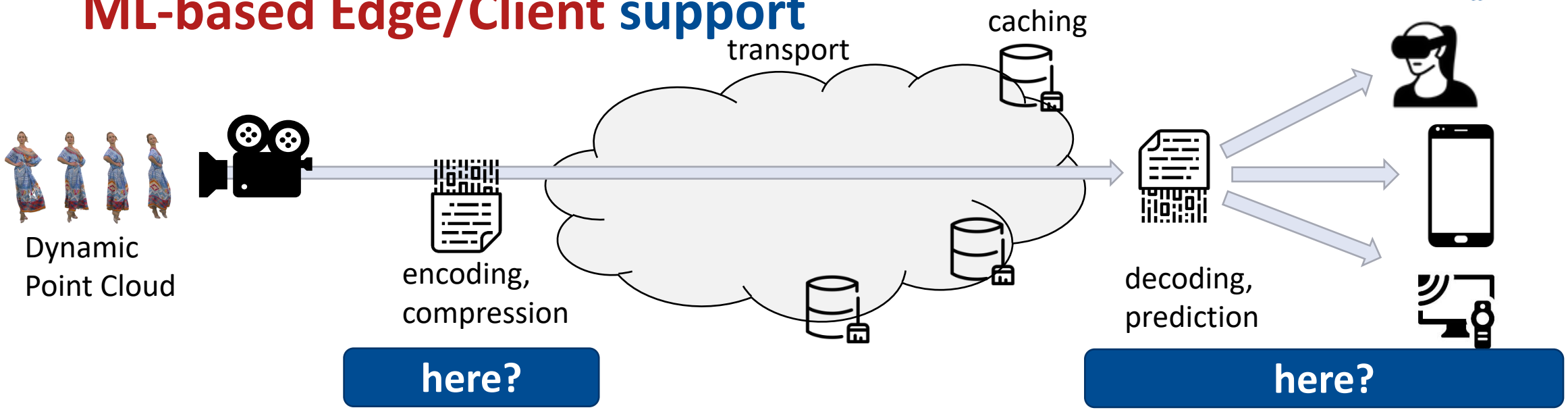
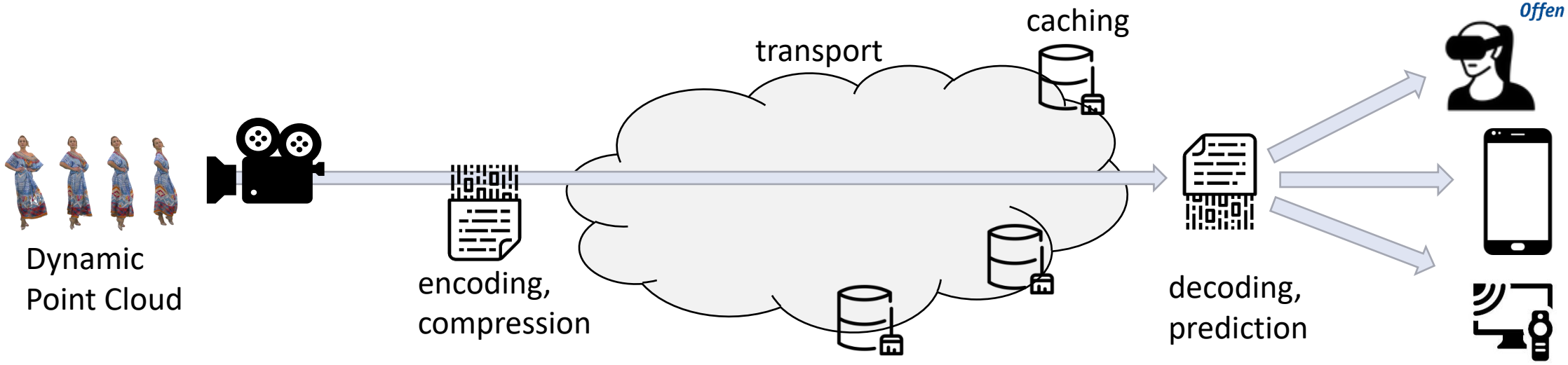


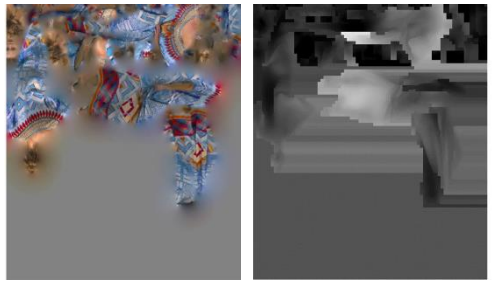
Fig. source: T. Swamy et al., Taurus: A Data Plane Architecture for Per-Packet ML, *ML4Net'20 / SIGCOMM'22*

(Live) Streaming through the ML lens
ML-based Edge/Client support



Point Cloud Streaming (VPCC)



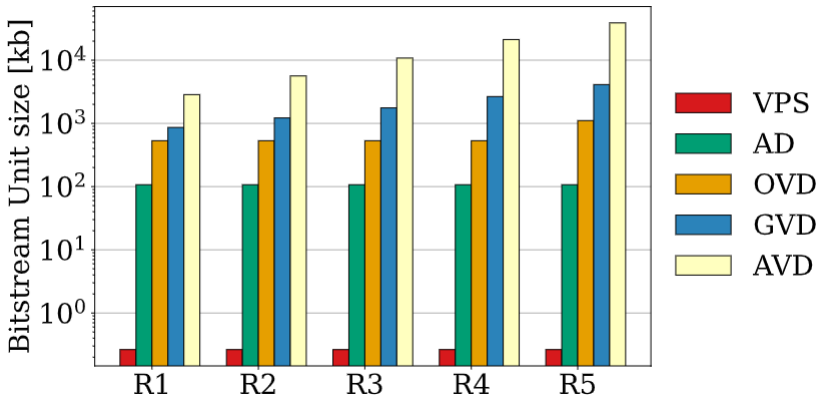


Bitstreams:
Attribute (left) and
Geometry (right)

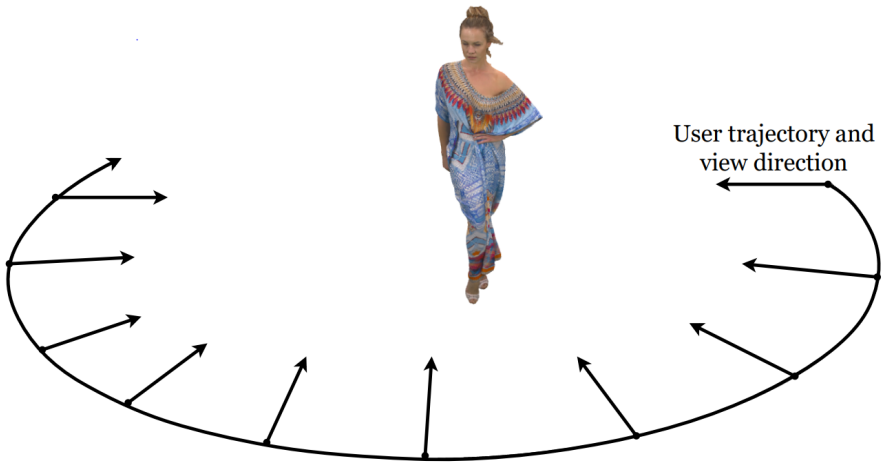
2D projections are **packed into image frames** and **compressed with legacy video codecs.**

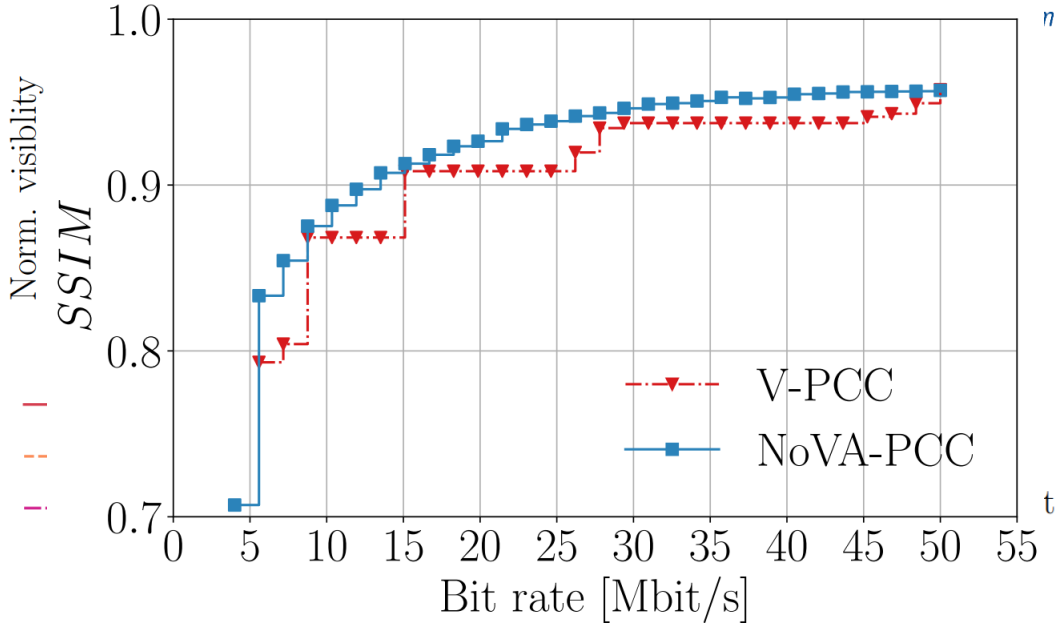
The bitstream of V-PCC consists of:

- Geometry bitstream
- Attribute bitstream
- Occupancy map
- Auxilary information



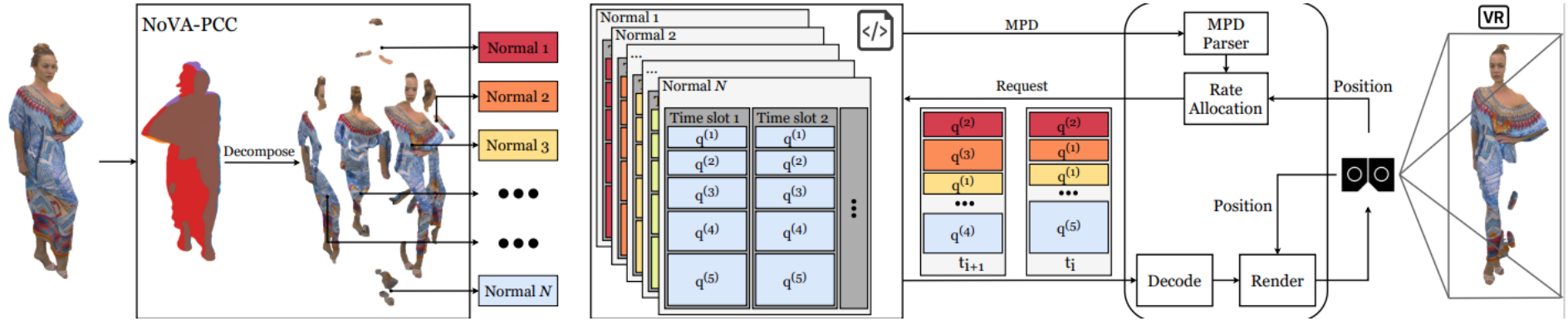
Challenge 1: User interaction with PC objects





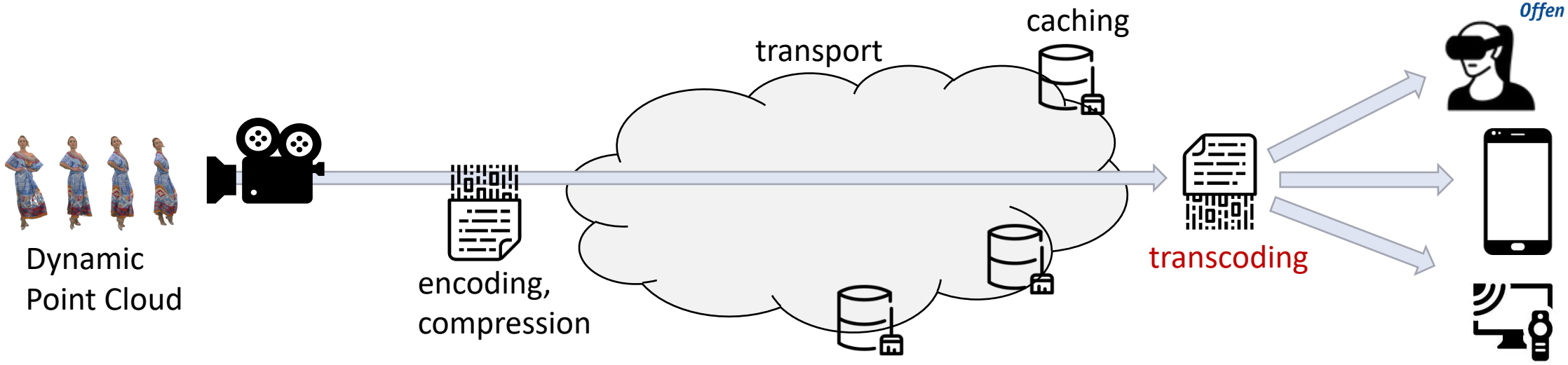
Approach: Point Cloud decomposition

- Cube-based approach [Li et al., 2020; Liu et al.,2020]
- View-based approach [Subramanyam et al.,‘20, Zhu et al.‘20, M. Rudolph‘22]

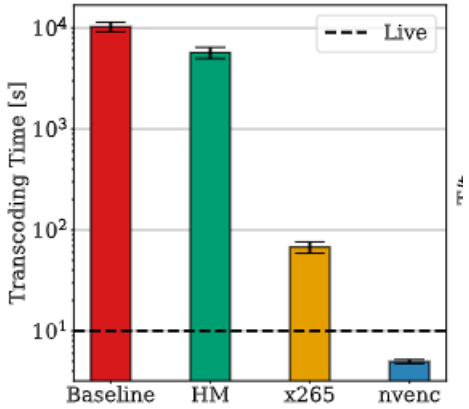


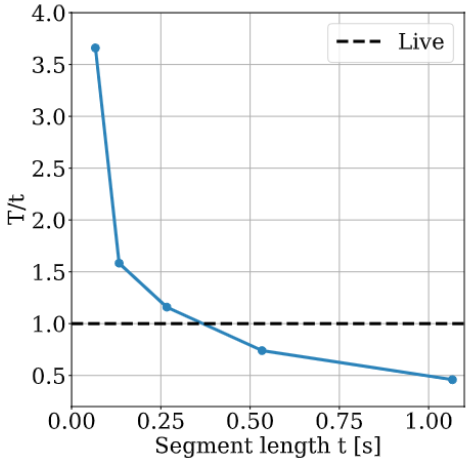
M. Rudolph and A. Rizk, 2022, View-Adaptive Streaming of Point Cloud Scenes through combined Decomposition and Video-based Coding, Workshop on Advances in Point Cloud Compression, Processing and Analysis (APCCPA)

Challenge 2: Transcoding PC objects



Live Transcoding and Point Cloud reconstruction based on encoded video streams



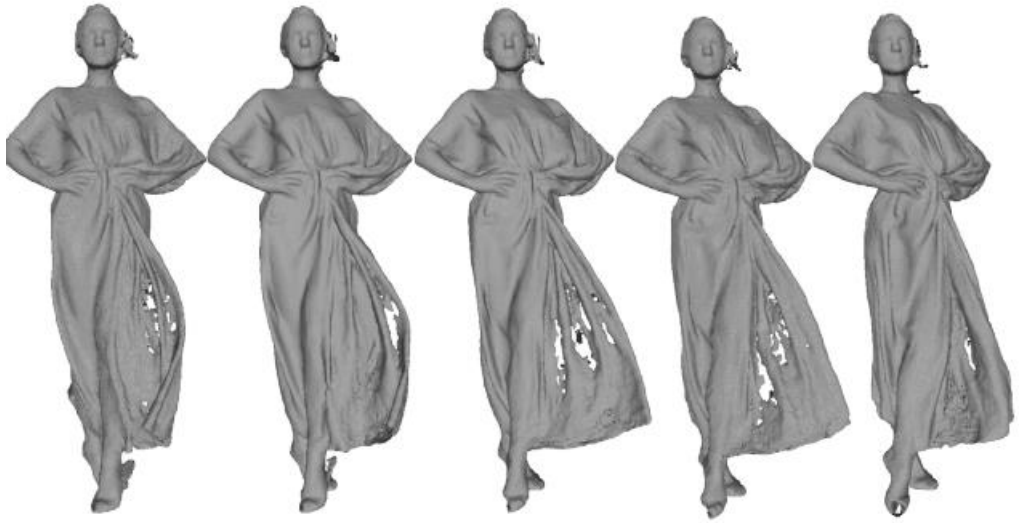


M. Rudolph and A. Rizk, On Live Transcoding of Video-based Coded Point Cloud Streams, *under submission*

Challenge 3: Error concealment

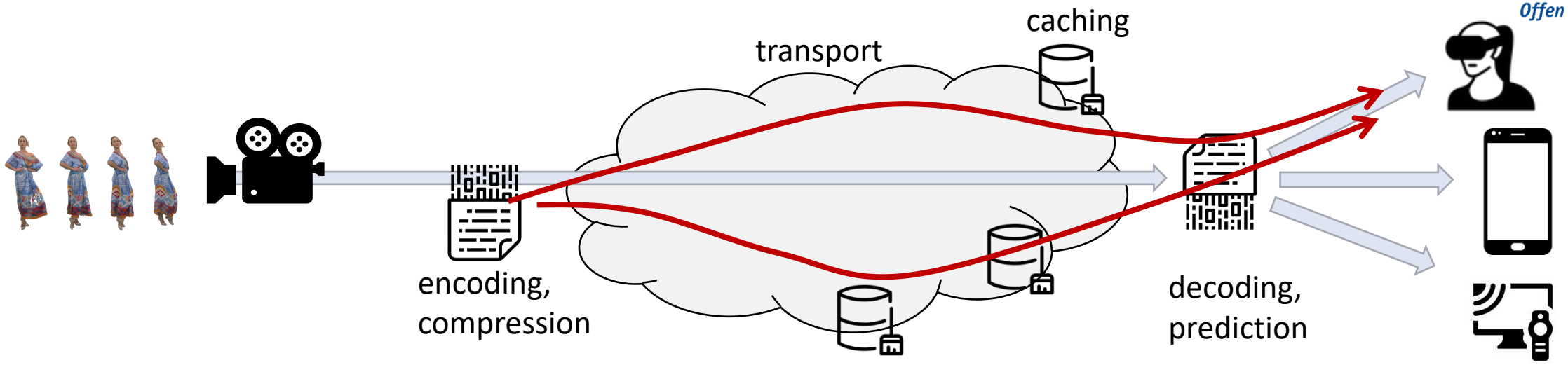
ML for error concealment at encoding time (Inpainting)

- split PC into cubes
- interpolate using intra and inter-source cube
- rationale:
  - similarity within vicinty in frame
  - consistency across frames



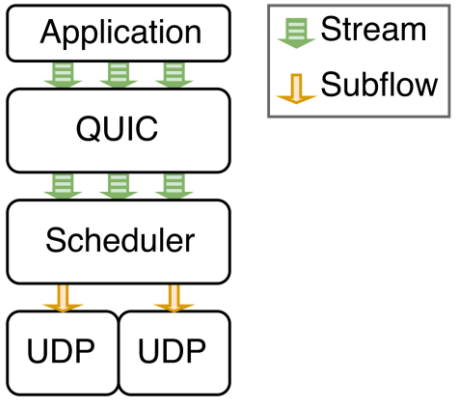
Source: Fu et al. 3D Dynamic Point Cloud Inpainting via Temporal Consistency on Graphs, ICME'20

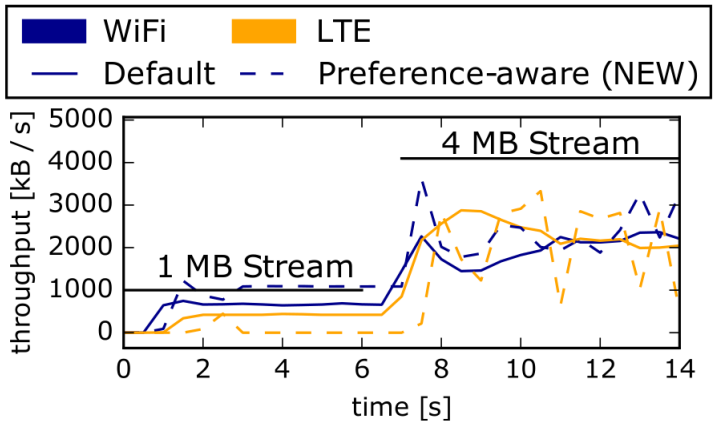
Challenge 4a: Edge-side Multipathing (server push)



Application-aware Multipath scheduling, i.e., treat different subflows *differently*

- mapping of application data to subflows
- mapping of subflows to paths
- set subflow config …

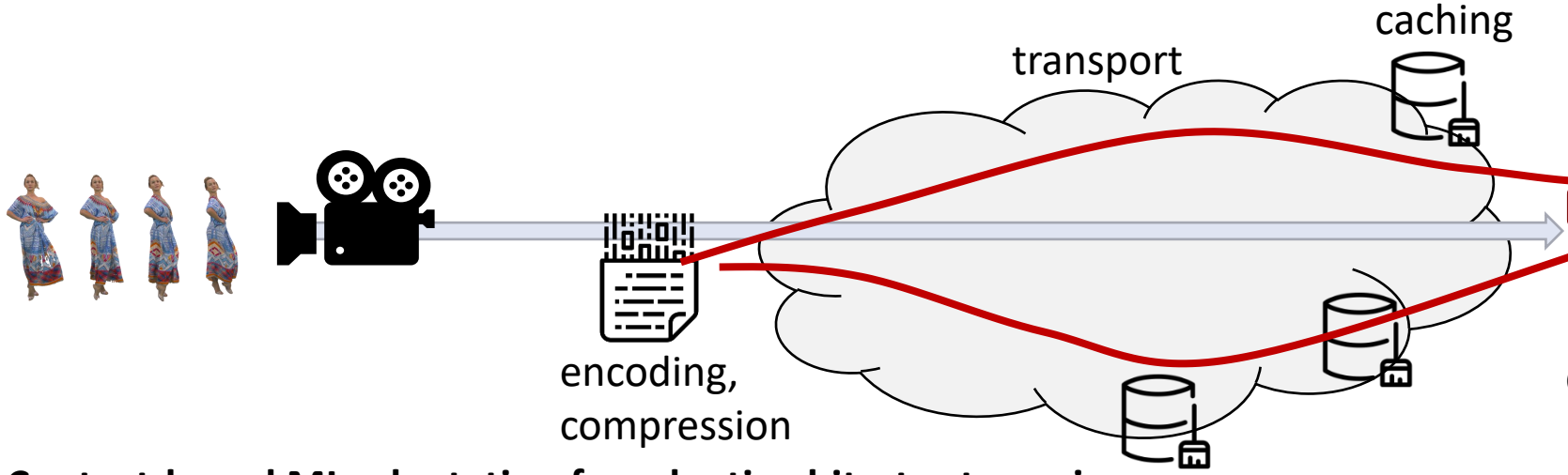




only *switch-on* additional path when the stream quality rises

T. Viernickel, A. Frömmgen, A. Rizk, B. Koldehofe, R. Steinmetz: Multipath QUIC: A Deployable Multipath Transport Protocol, ICC'18
A Frömmgen, A. Rizk, T. Erbshäußer, M. Weller, B. Koldehofe, A. Buchmann, R. Steinmetz: A Programming Model for Application-defined Multipath TCP Scheduling, ACM Middleware'17

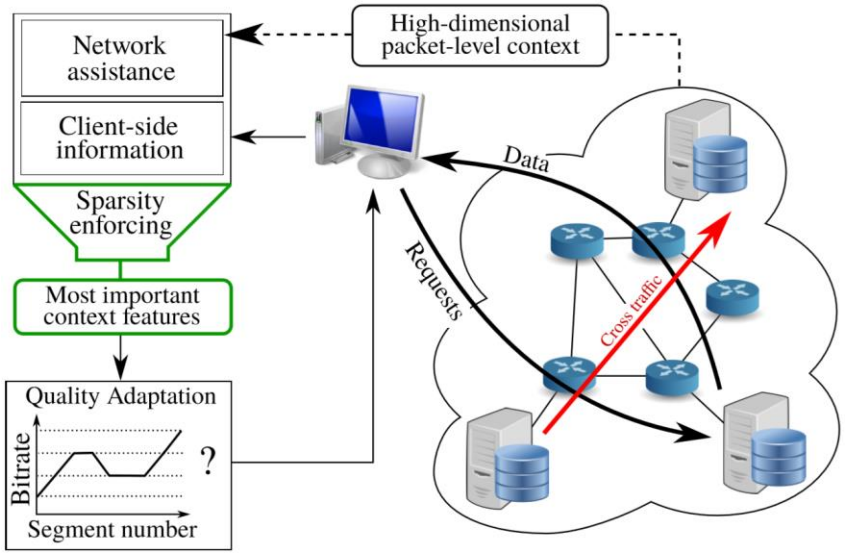
Challenge 4b: Edge-side Multipathing (client pull)



Algorithm	Bitrate [Mbps]	Quality switches [#]	Switch magnitude [Mbps]	Average parameter update time [ms]
CBA-OS-SVI	**3.10**	**6**	**0.57**	15
CBA-VB	2.58	**6**	0.65	325
LinUCB	2.24	14	1.07	**6**
BOLA	2.63	36	1.19	
PANDA	2.51	16	1.00	

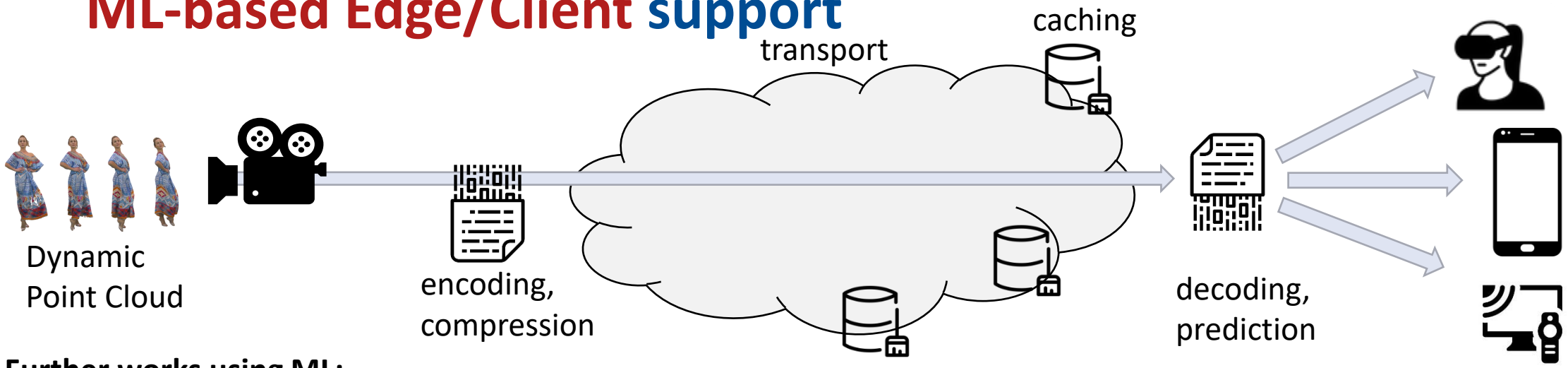
Context-based ML adaptation for adaptive bitrate streaming

- (If additional (however noisy) meta-data are available then better decisions)
- Contextual Multi-armed bandits: each action, at each time step, has some multi-dimenstional context information (latency per chunk,…) available
- Higher-dimensional, noisier context means longer learning times
- Approach: Enforce sparsity to shrink the context keeping most important information
- only 1 segment length (2s) between decisions -> speed up inference time by using less samples to update the model



B. Alt, T. Ballard, R. Steinmetz, H. Koeppl, A. Rizk: CBA: Contextual Quality Adaptation for Adaptive Bitrate Video Streaming. IEEE INFOCOM'19

(Live) Streaming through the ML lens
ML-based Edge/Client support



Further works using ML:

- to predict the user view-port movement
- to reconfigure the ABR streaming algorithm
- to learn application specific congestion control
- to optimize content caching at the edge

and many more…

my personal take on …

Open Challenges

$$QoR = \frac{A}{A^*}$$

e.g. accuracy

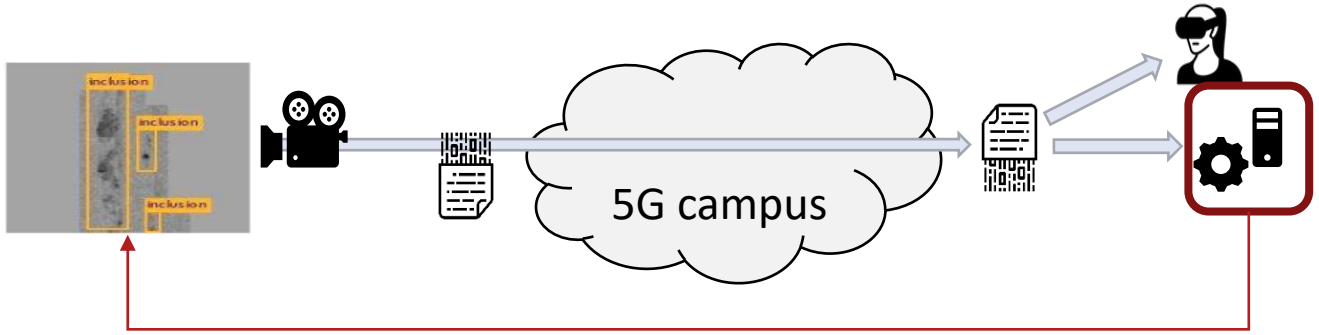
e.g. highest accuracy possible

UNIVERSITÄT DUISBURG ESSEN

Offen im Denken

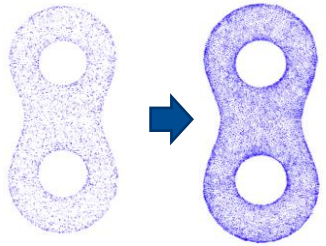
From QoE to Quality-of-Result (QoR)

- complete the feedback loop

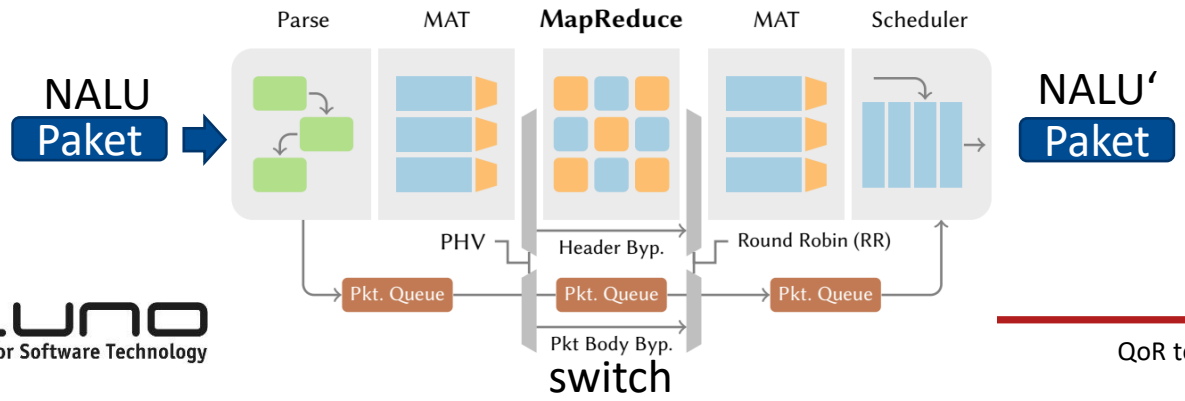


Live Dynamic Point Cloud Encoding with VPCC

- **Dynamic** Point Cloud Super-resolution?



Data-plane video streaming applications



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QoR term attributed to Li et al.: *MobiQoR, source super resolution Wu et al.‘19*

Thanks to wonderful collaborations/students

- Michael Rudolph
- Denny Stohr
- Alexander Frömmgen
- Cong Wang
- Divya Bhat
- Trevor Ballard
- Ralf Steinmetz
- Michael Zink

QoR term attributed to Li et al.: *MobiQoR*

Shameless Plug

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Volume 198

In progress

15 January 2023

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The International Journal for the Computer and Telecommunications Industry

Computer and **Communications networks** are key infrastructures of the information society with high socio-economic value as they contribute to the correct operations of many critical services (from healthcare to finance and transportation). **Internet** is the core of today's **computer-communication ...**

View full aims & scope

Aims & Scope

- Emerging technologies for next generation network
- LAN/WAN/MAN
- Future Internet architecture, protocols and services
- Content- and service-centric architecture
- Mobile and ubiquitous networks
- Self organizing/autonomic networking
- Green networking
- Internet content search
- QoS and multimedia networking
- Opportunistic networking
- On-line social networks
- Internet of things
- Public safety communication networks
- Network applications (web, multimedia streaming, VoIP, gaming, et
- Trust, security and privacy in computer and communication networ
- Modeling, measurement and simulation
- Complex network models
- Internet socio-economic models
- Experimental test-beds and research platforms
- Algorithmic aspects of communication networks
- Network scaling and limits

my personal take on …

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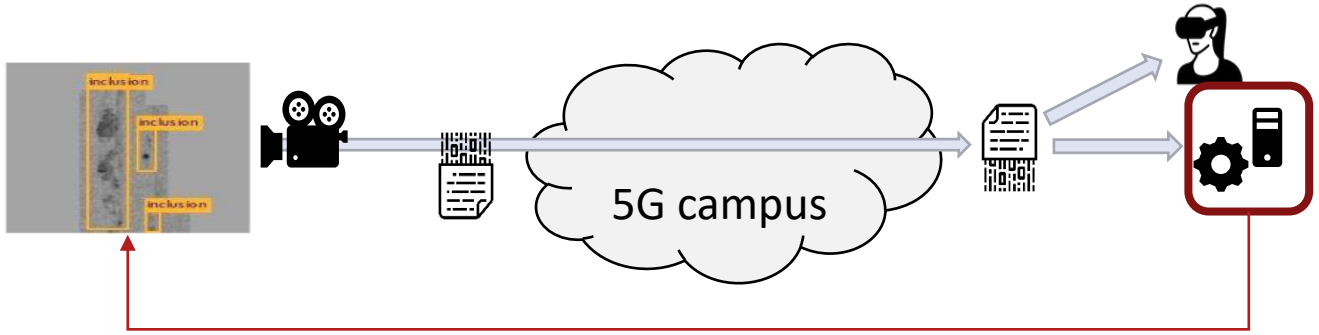

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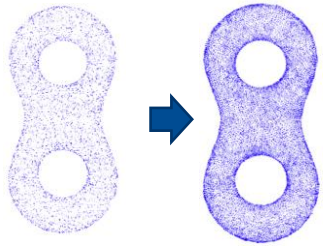

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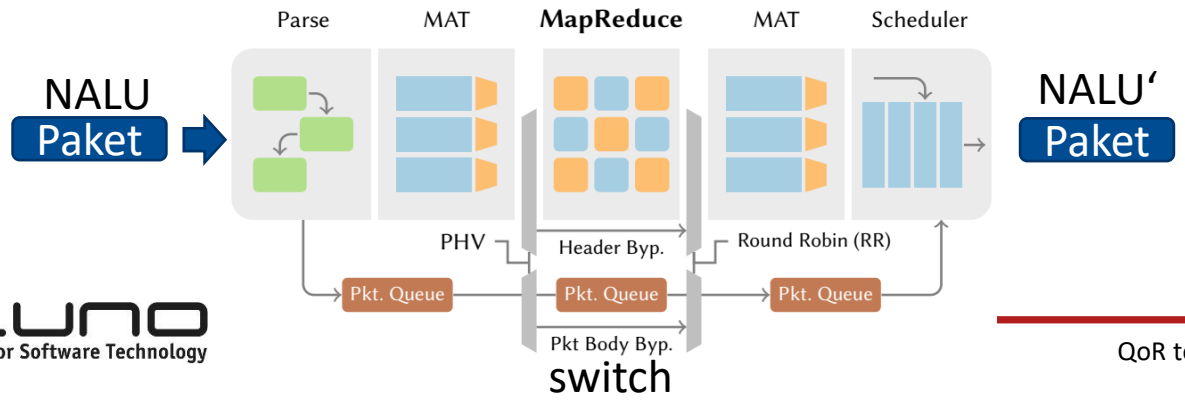

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