TECHNISCHE UNIVERSITÄT DRESDEN

CeTI Centre for Tactile Internet with Human-in-the-Loop

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Softwarized Networks for Resilient Cyber-Physical Systems

KuVS

Network Softwarization

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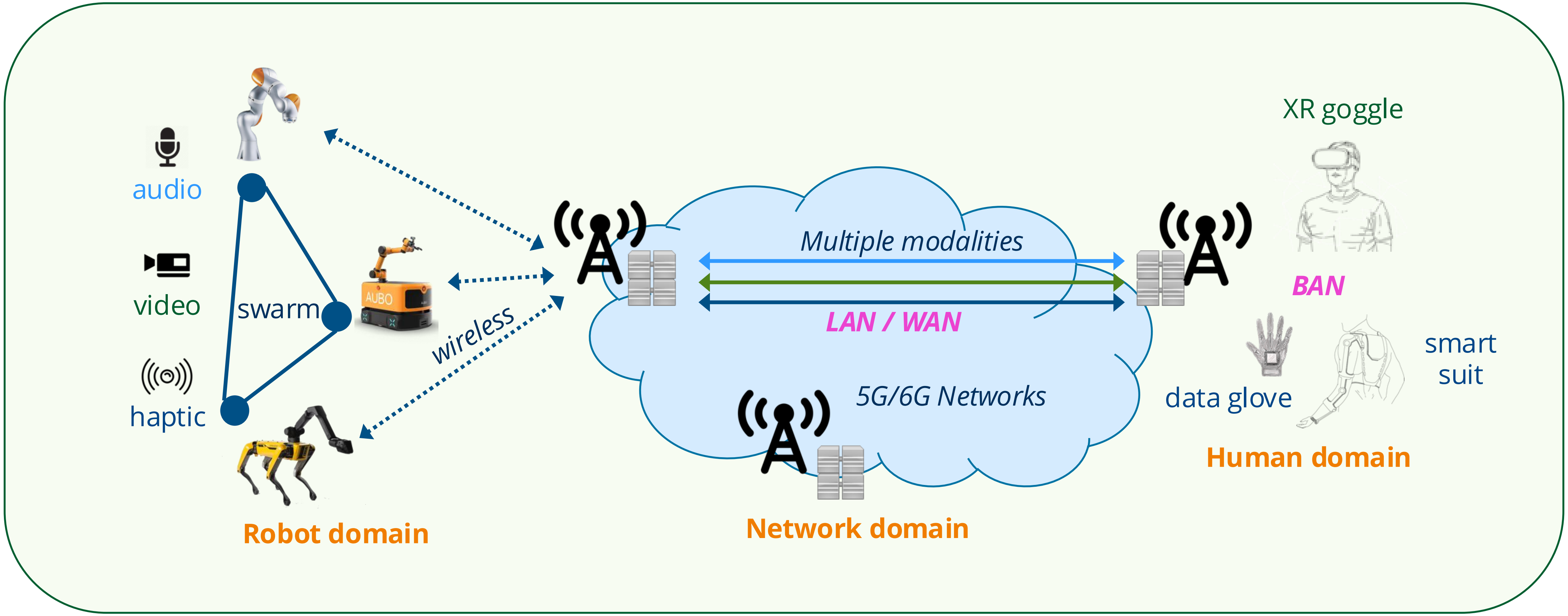
Landscape

Cyber-Physical Systems with Human-in-the-Loop



Latency challenge

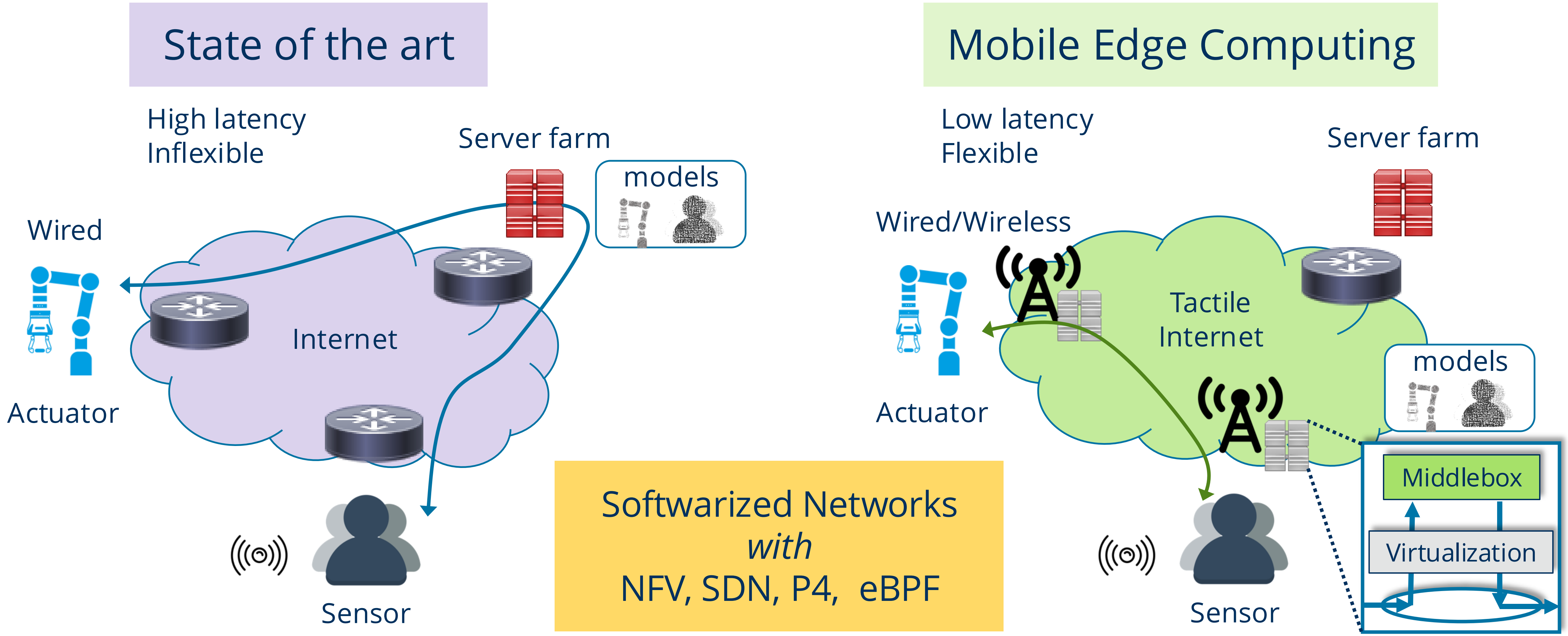
Humans are affected by latency

Latency challenge

Machines are affected by latency

Simulated network latency

Reduce Latency
Mobile Edge Computing



Research Highlights

Computing Latency	**CALVIN**	Xiang et al. **Reducing latency in virtual machines: Enabling Tactile Internet for human–machine co-working**. IEEE Journal on Selected Areas in Communications, vol. 37, no. 5, pp. 1098–1116, May 2019.
Audio Processing	**FastICA**	Wu et al. **Accelerating industrial iot acoustic data separation with in-network computing**. IEEE Internet of Things Journal, vol. 10, no. 5, pp. 3901-3916, May 2022.
Resilience	**StateOS**	Doan et al. **StateOS: Enabling Versatile Network Function Virtualization in Edge Clouds**. IEEE Network Operations and Management Symposium, May 2024.

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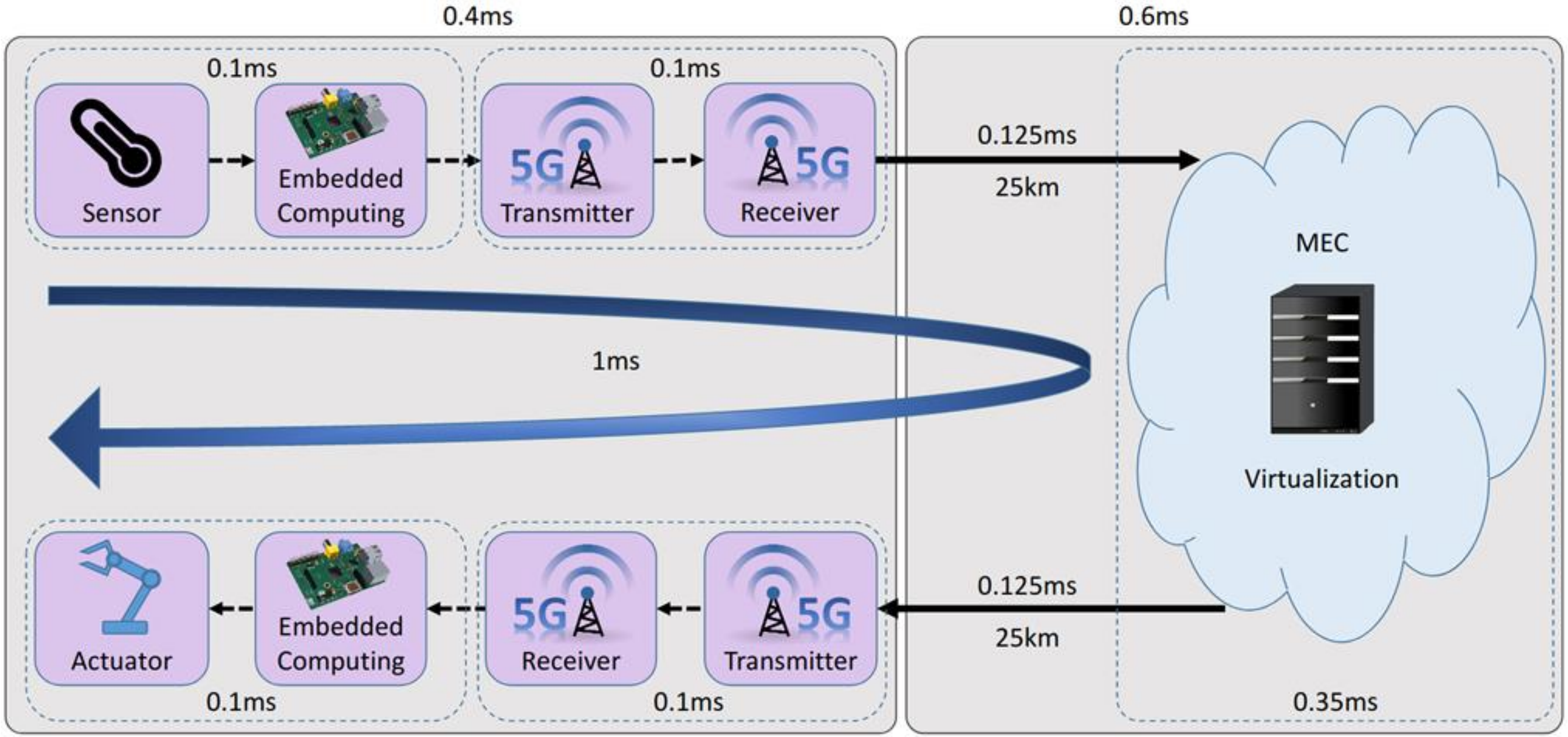
CALVIN
Reducing Latency in Virtual Machines: Enabling Tactile Internet for Human-Machine Co-Working

(link to paper: https://ieeexplore.ieee.org/abstract/document/8672612)

Question:
How ready are current networks for tactile applications?

Low-latency vNF
Delay budget



Delay budget for vNF: ***0.35 ms***

Low-latency vNF
Sources of latency

Open research question

(1) Packet processing in side VM

(2) Packet transfer between VM and VM bridge

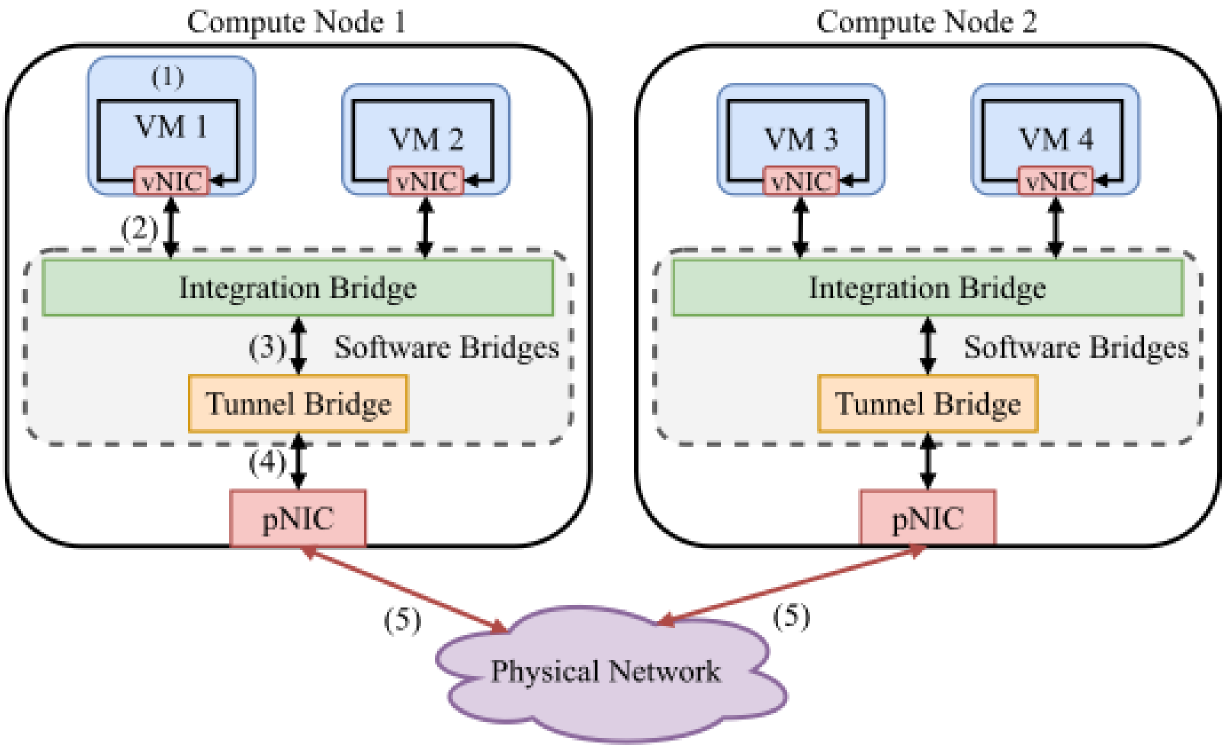
(3 & 4) Relating to tunnel bridges

SoA:
Openstack's OVS-DPDK

(5) Between physical NICs

Hardware dependent:
COST

openstack™

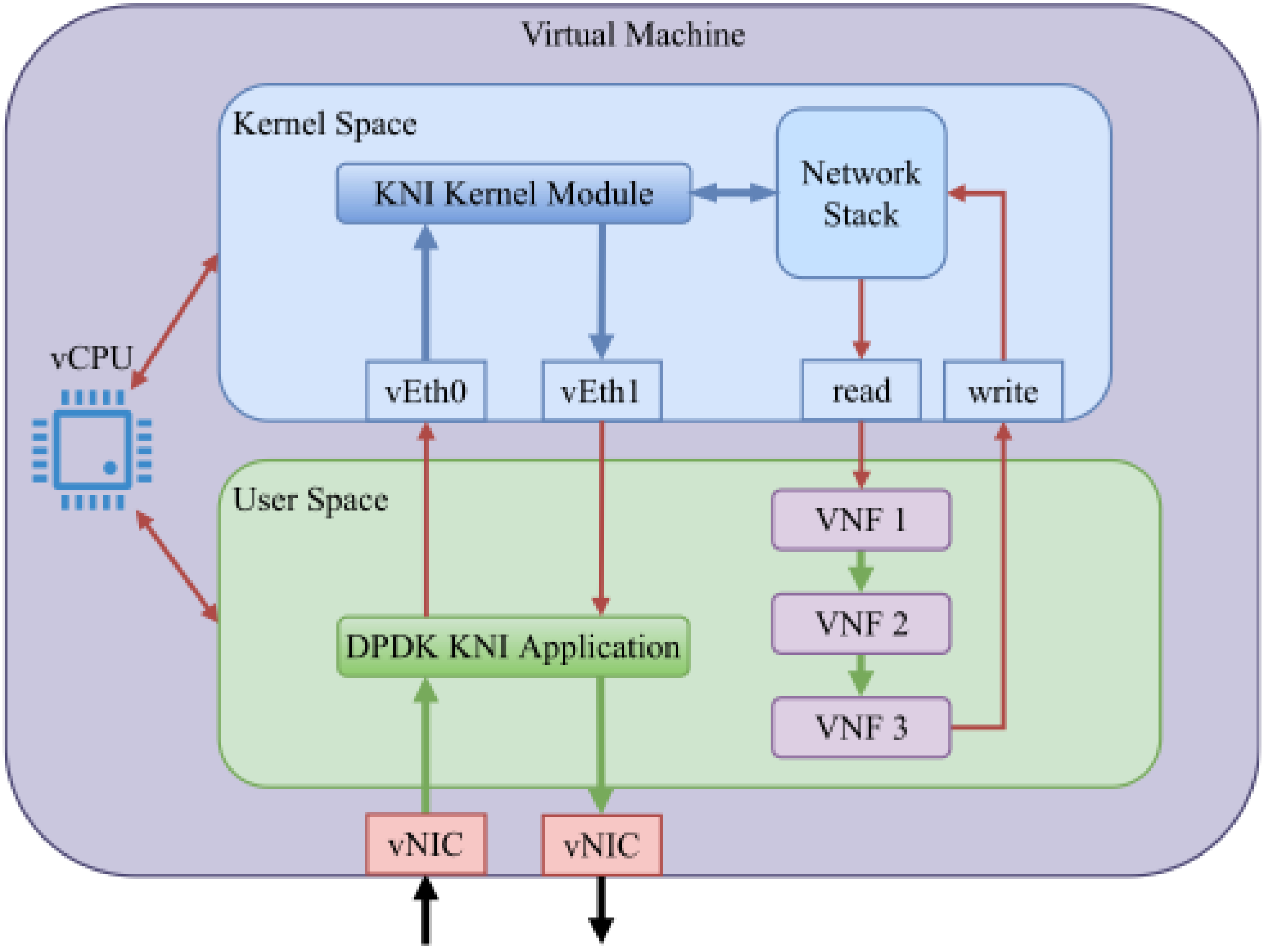


Low-latency vNF

Centralized scheme

Issue 1:

CPU overhead, due to context switching

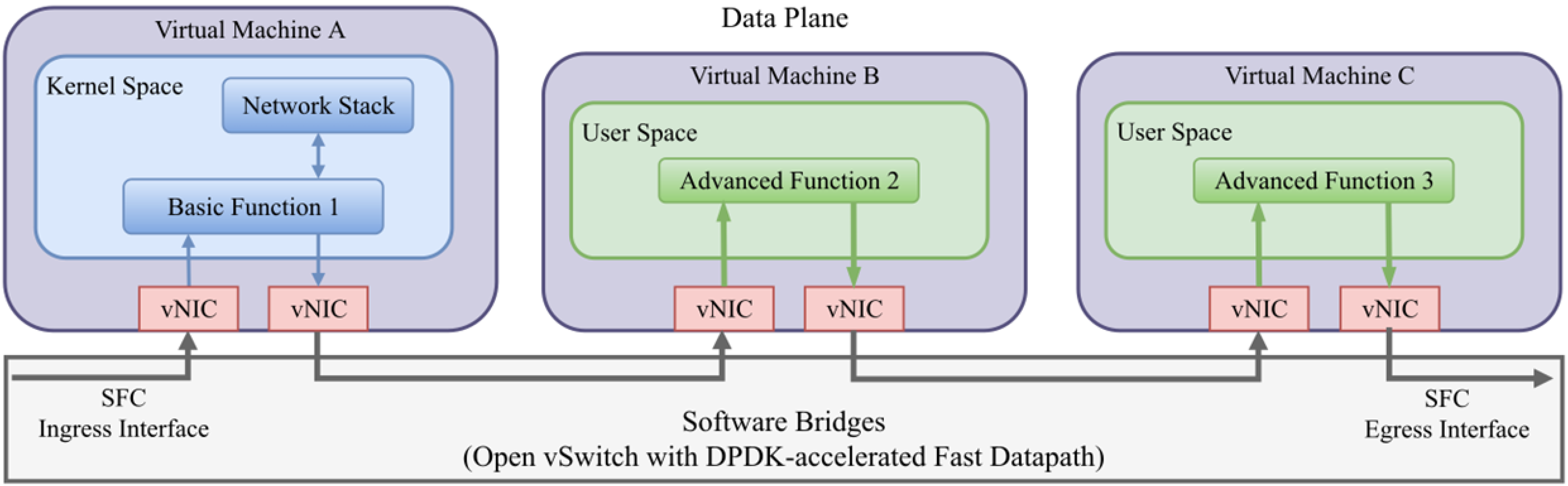


Issue 2:

Data read/write between kernel and user spaces

Low-latency vNF

CALVIN: Illustration of strategies

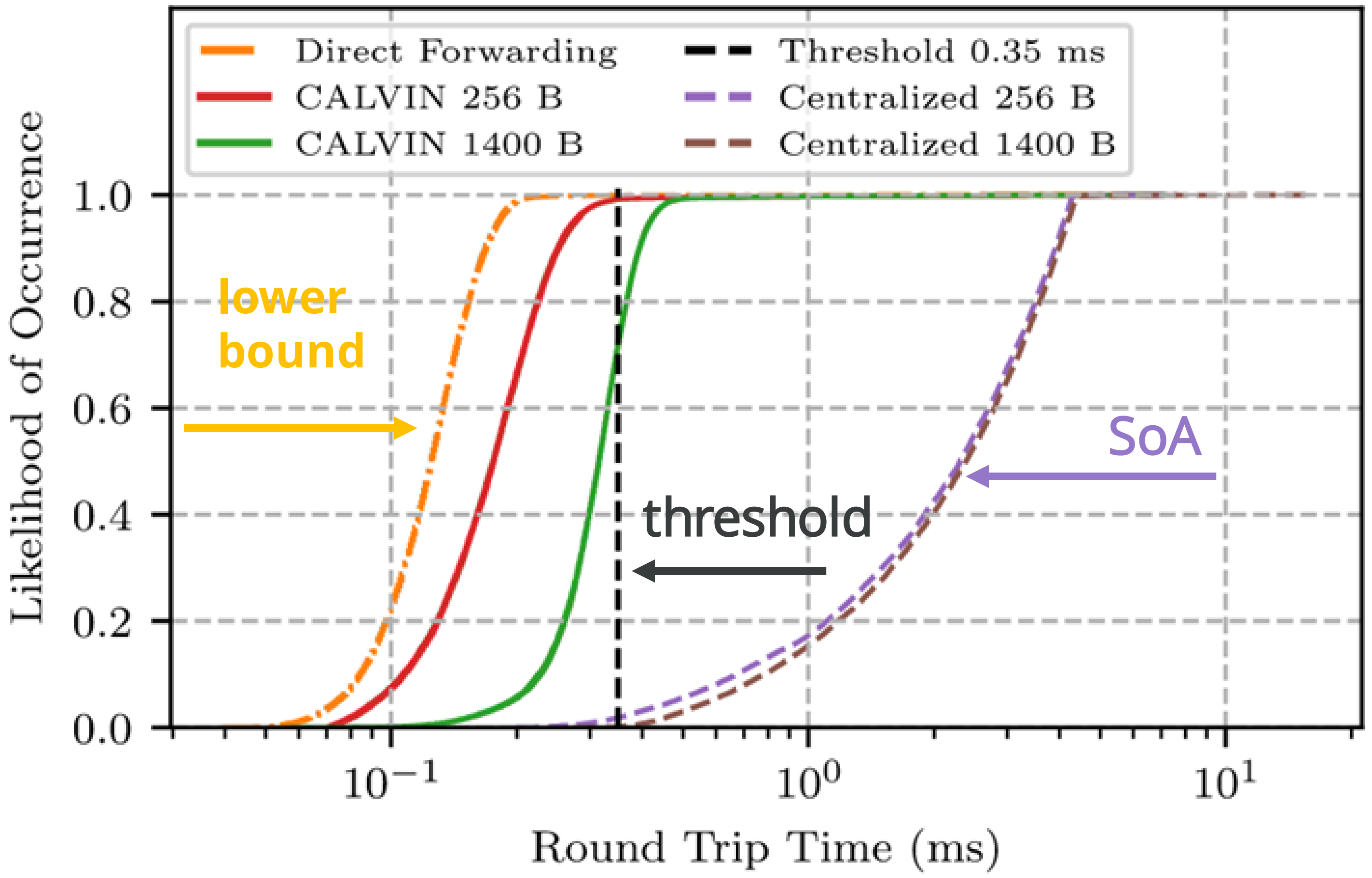


Low-latency vNF

CALVIN: Results

Fast:
Possible to reach 1 ms latency for *certain* tactile applications

Light:
Tradeoff in *significantly* lower bandwidth



Softwarized Networks (SN) for Audio Processing

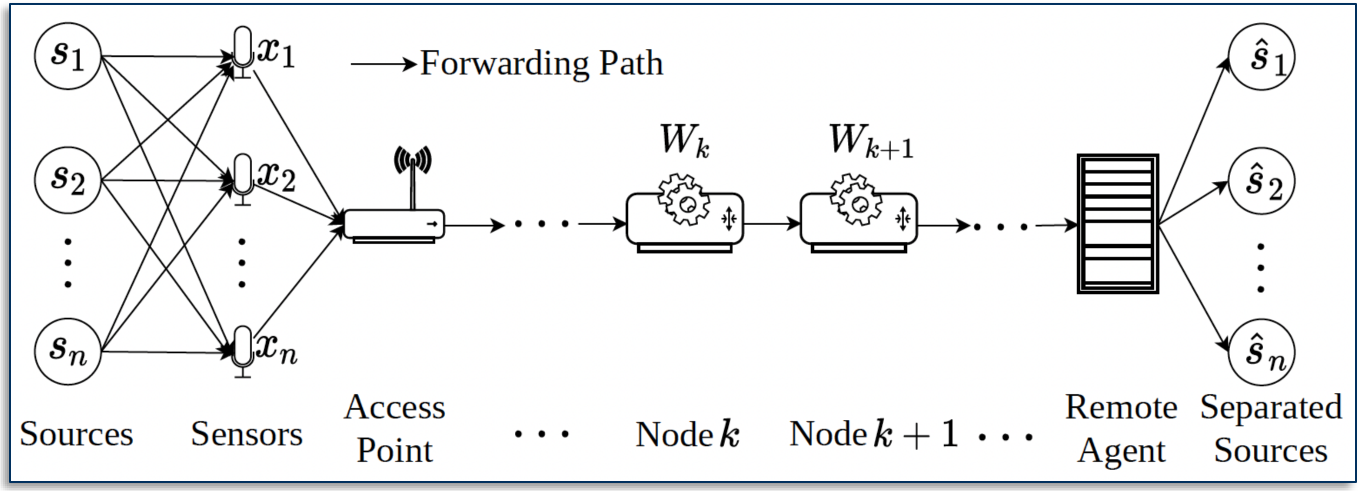
(link to paper: https://ieeexplore.ieee.org/abstract/document/9779873)

Questions:

1) Is SN useful for multi-node scenarios?
2) Is SN helpful for high-bandwidth applications?

Acoustic Data *(Blind Source)* Separation

Problem formulation



s_i	Source data of the i^{th} machine.
x_i	Noised data of the i^{th} sensor.
X	Noised data matrix received by AP.
m	Total time span.
n	Total number of IoT sensors.
W	Solution matrix estimating S with X.
W_k	Temporal solution matrix on the k^{th} node.
$\hat{s}_i$	The i^{th} estimated source signal.
$\hat{S}$	Estimated source data matrix.

$$X = A \times S$$

S is unknown → receiver blinds to source signal

$$\hat{S} \leftarrow W \times X = A^{-1} \times X$$

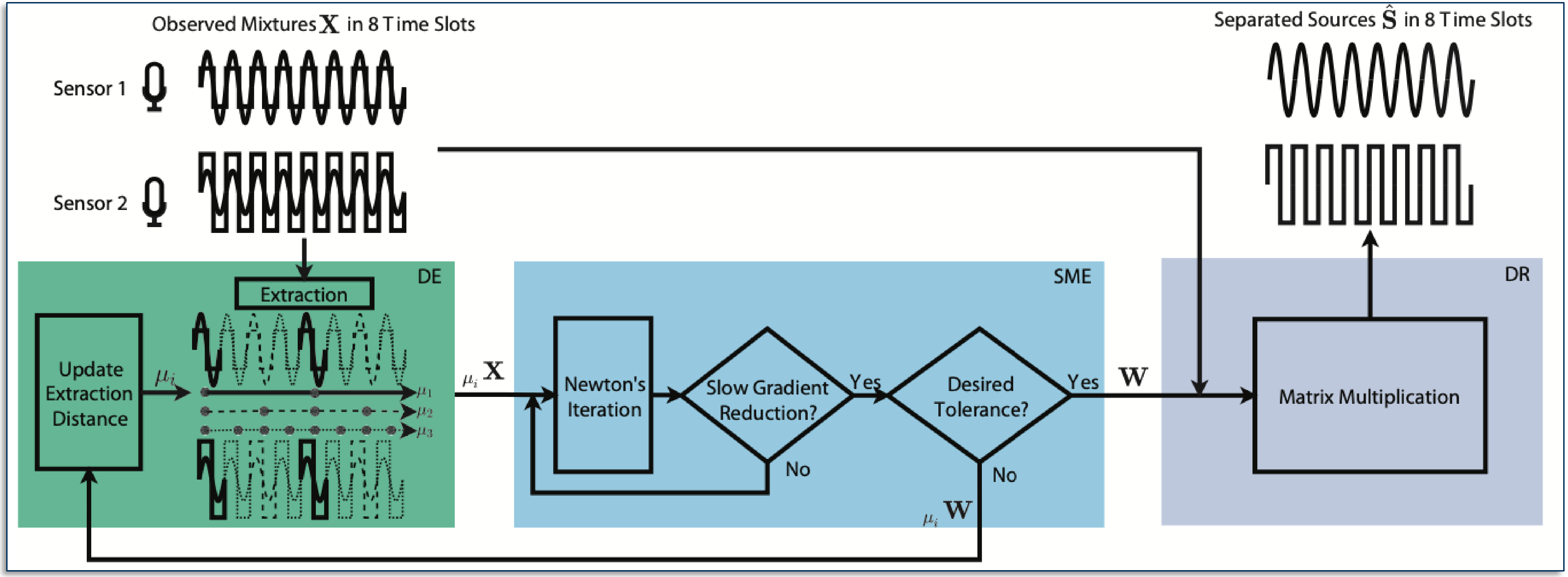
Blind Source Separation → ***Goal:*** estimate W

Challenge 1 (Computing):
Transform a centralized algorithm into a decentralized one

Challenge 2 (Networking):
Coordinate Forwarding and Computing functions

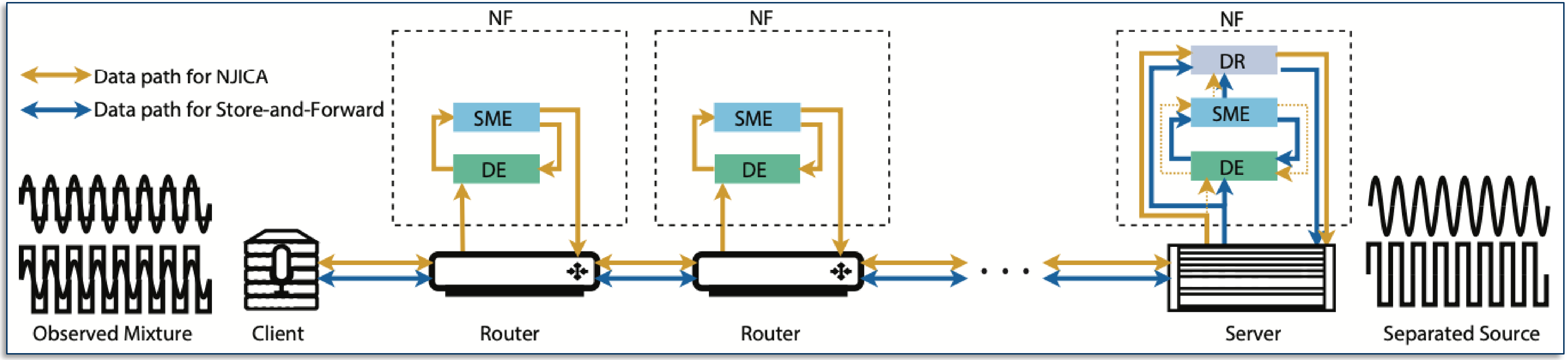
ICA - Independent Component Analysis

Centralized algorithm (cICA)



ICA - Independent Component Analysis

Distributed algorithm



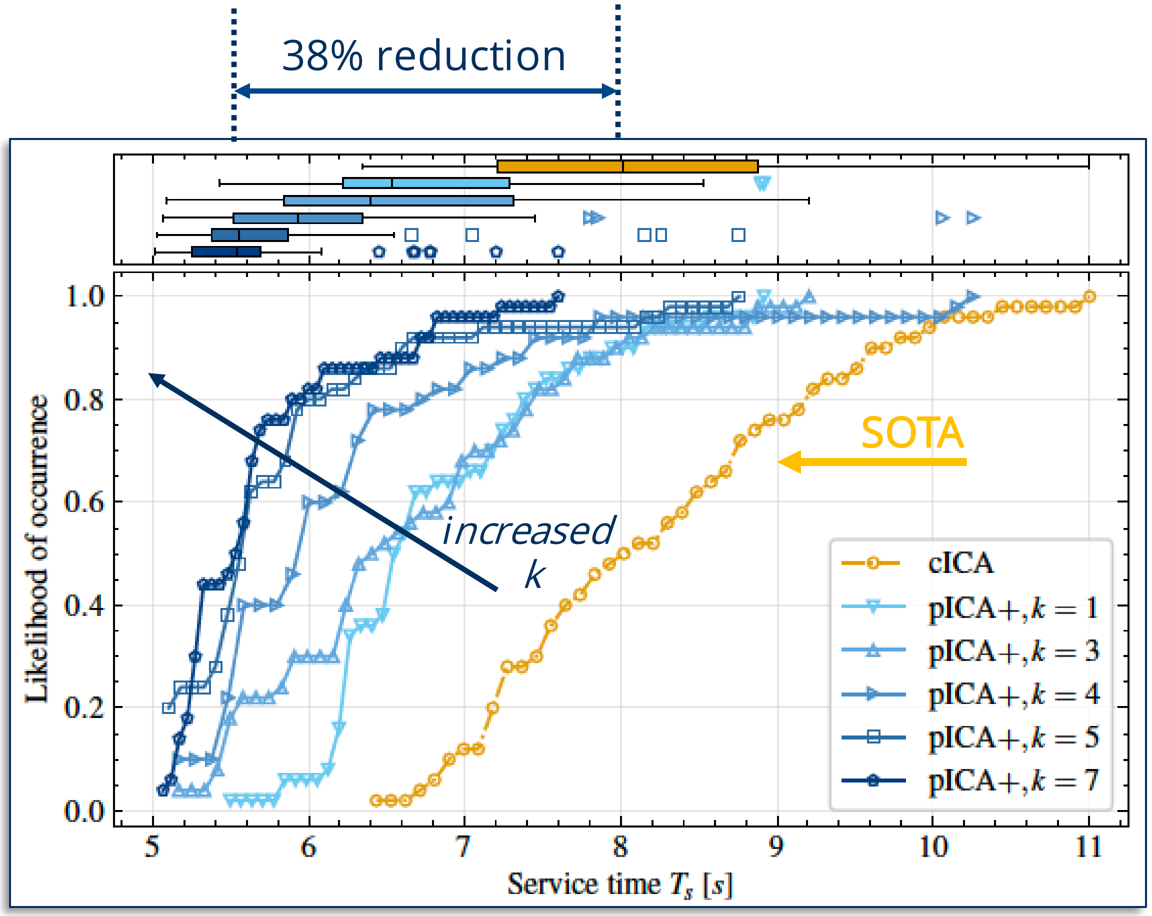
Greedy Strategy:

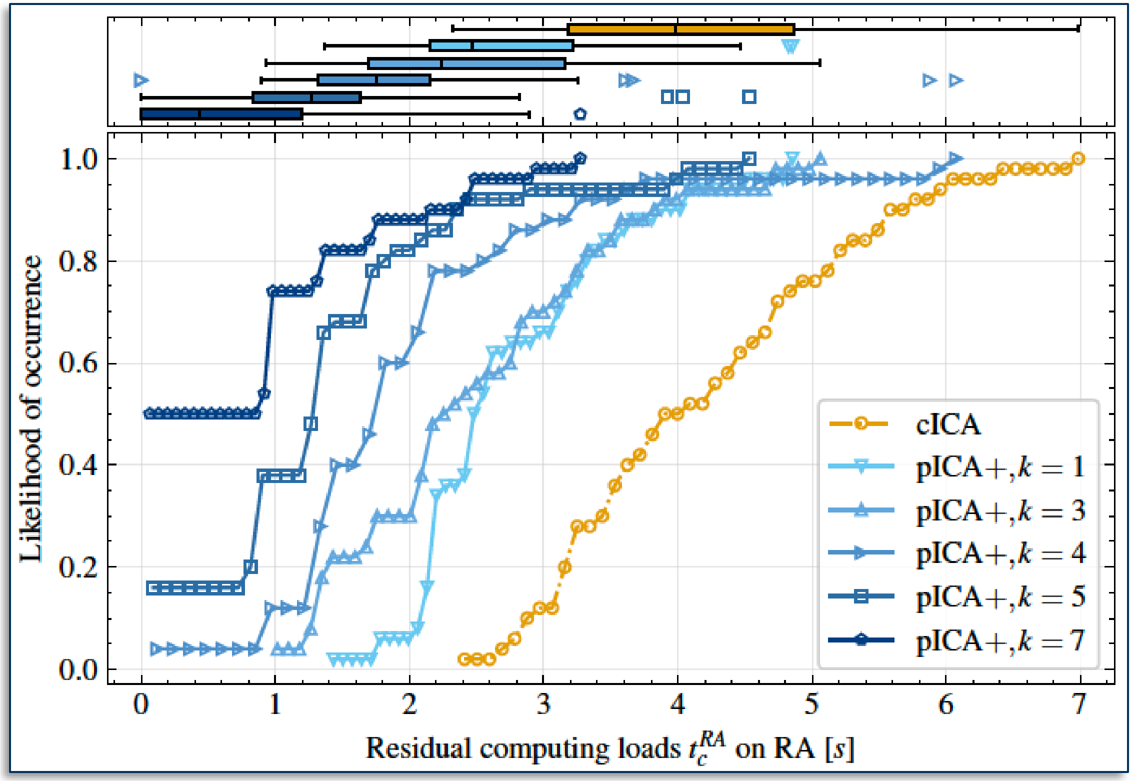
- Keeps running estimation (SME) until improvement from gradient-descent iterations gets slow down

Progressive Strategy:

- Increases cached data on every node progressively along the forwarding path

Acoustic Data Separation
pICA -Results



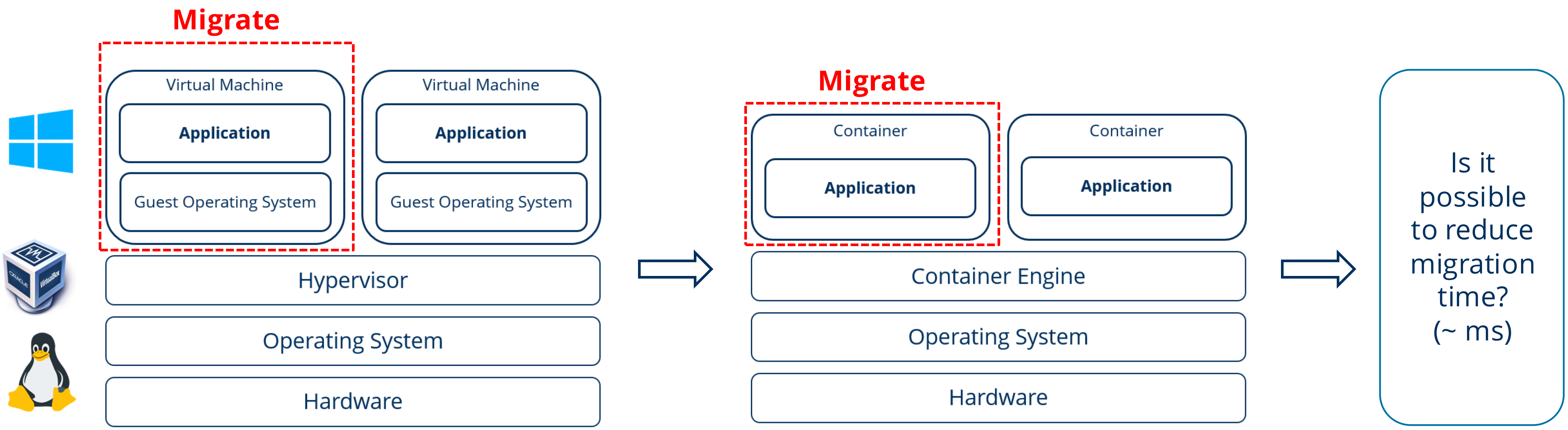


StateOS
Enabling Versatile Network Function Virtualization in Edge Clouds

(link to paper: https://ieeexplore.ieee.org/abstract/document/10575285)

Questions:
How to improve the resilience of virtualized apps?

Resilience in MEC
Virtualization technologies



Migrate virtual machine
tens of seconds [1]

Migrate Docker container
few seconds [1]

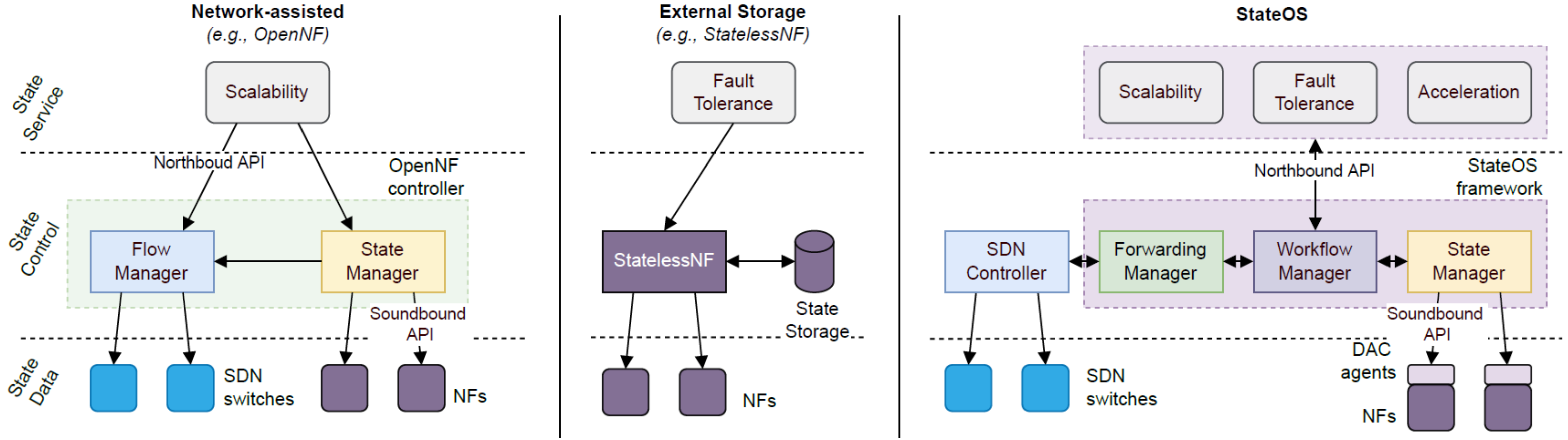
[1] Source: https://www.bell-labs.com/institute/publications/itd-19-59189l/#gref

State Management

StateOS – Beyond State of The Art

Observations:

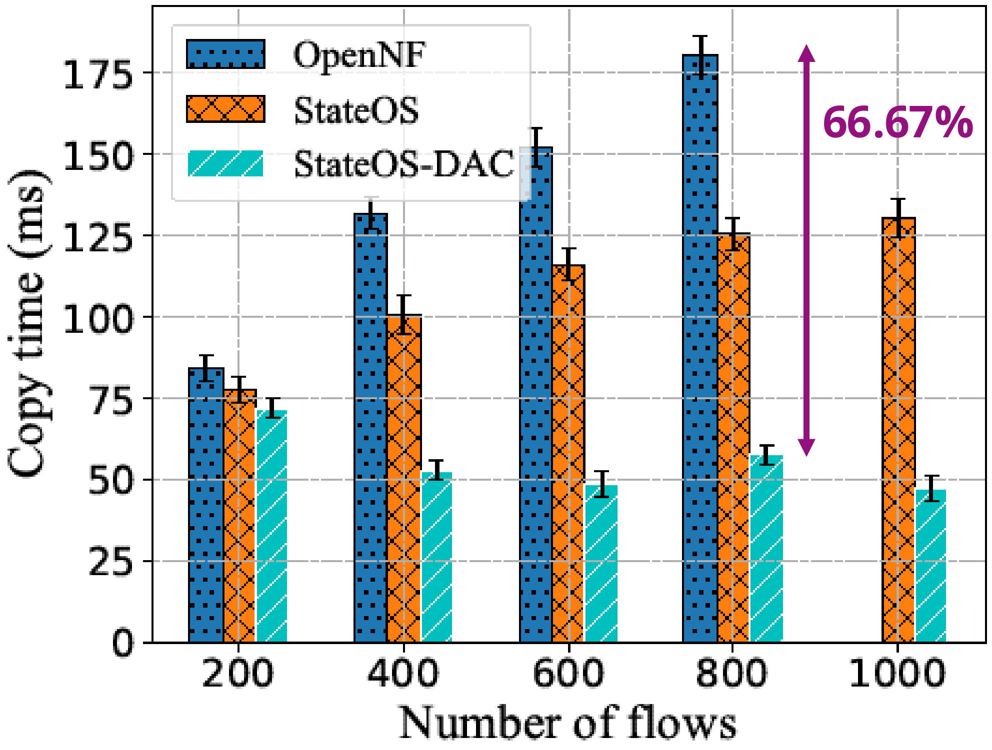
- Slow-changing states
- Fast-changing states

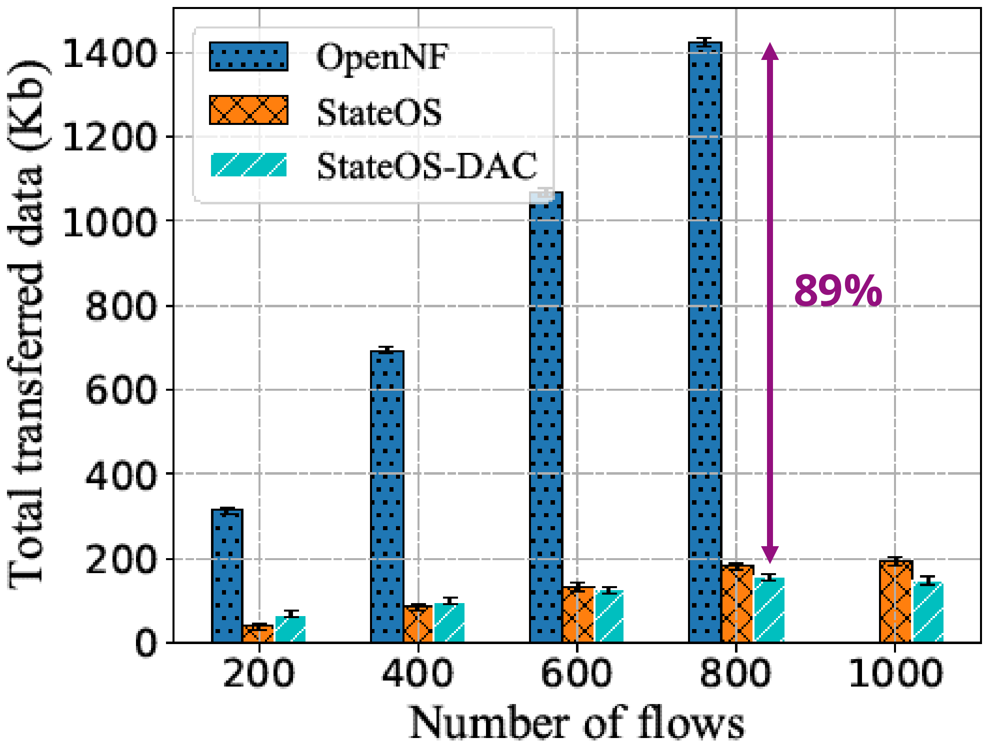


State-Of-The-Art

Performance Evaluation

Fault Tolerance





StateOS-DAC significantly outperforms OpenNF for PRADS in terms of move time and the total data for state transfer

Summary of Research Highlights

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