Fluid Network Planes

An Overview of Ongoing Network Softwarization Refactoring Trends

UNICAMP

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Agenda

Disclaimer

“Fluid Network Planes” was first presented as a Keynote of IEEE NetSoft'19, Paris, Jun .2019.

- A view on 10+ years of SDN
- Fluid Network Planes
  - The ‘Concept’
  - Instances

The ‘origins’ of the SDN term

MIT Technology Review

10 BREAKTHROUGH TECHNOLOGIES 2009

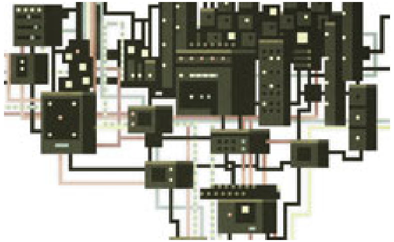
TR10: Software-Defined Networking

Nick McKeown believes that remotely controlling network hardware with software can bring the Internet up to speed.

4 comments

KATE GREENE

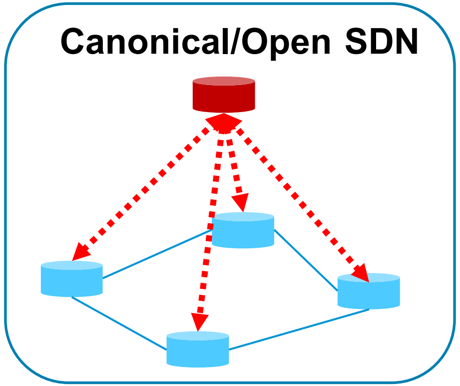
March/April 2009

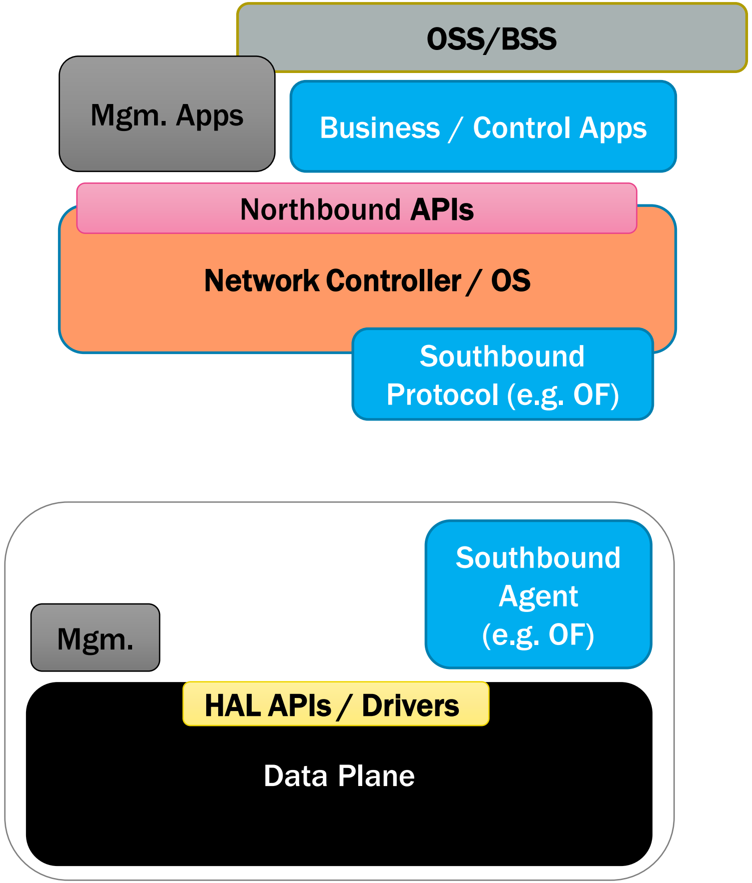


For years, computer scientists have dreamed up ways to improve networks' speed, reliability, energy efficiency, and security. But their schemes have generally remained lab projects, because it's been impossible to test them on a large enough scale to see if they'd work: the routers and switches at the core of the Internet are locked down, their software the intellectual property of companies such as Cisco and Hewlett-Packard.

SDN in 2009 - 2010

Control-plane component(s) Data-plane component(s)

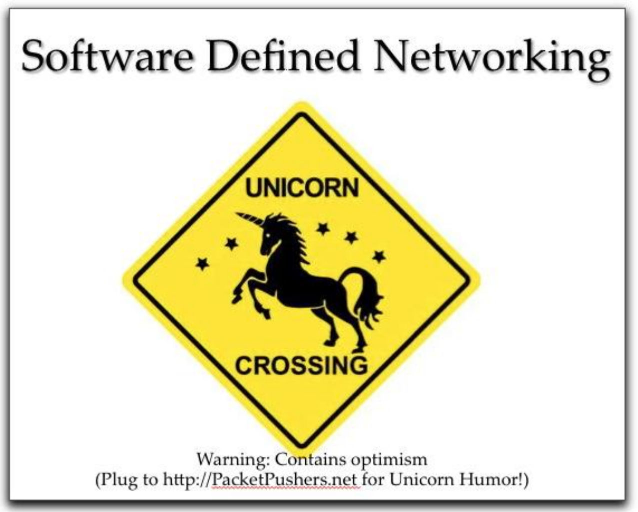




Source: C. Rothenberg (INTRIG/UNICAMP)

SDN in 2011 – 2012

SDN to the rescue!



So, what is **SDN**?

"OpenFlow is SDN, but SDN is not OpenFlow"

(does not say much about SDN) – Networking community

"Don't let humans do machines' work"

(probably right…) – Networking Professional

"Let's call SDN whatever we can ship today"

(aka 'SDN washing') – Vendor X

"SDN is the magic buzzword that will bring us VC funding"

(hmmm… N/A, N/C) – Startup Y

"SDN is the magic that will get my paper/grant accepted"

(maybe, but not at Tier-1 Conferences / Journals!) – Researcher Z

Headlines

"Google revamps networks with OpenFlow"
—ZDnet

"Prediction: OpenFlow Is Dead by 2014; SDN Reborn in Network Management"
—Mike Fratto, Network Computing

"Will OpenFlow commoditize networks? Impact Cisco margins?"
—Several media publications, Bloggers

".We share a more pragmatic view, noting Cisco (for example) is likely to view SDN as a TAM expansion opportunity…" *—Deutsche Bank Research note, Wired, April 2012*

"Hype around SDN/OpenFlow getting way out of Control. Where have I seen this before…" *—Ethereal mind, Blogger*

"SDN - Still Does Nothing"

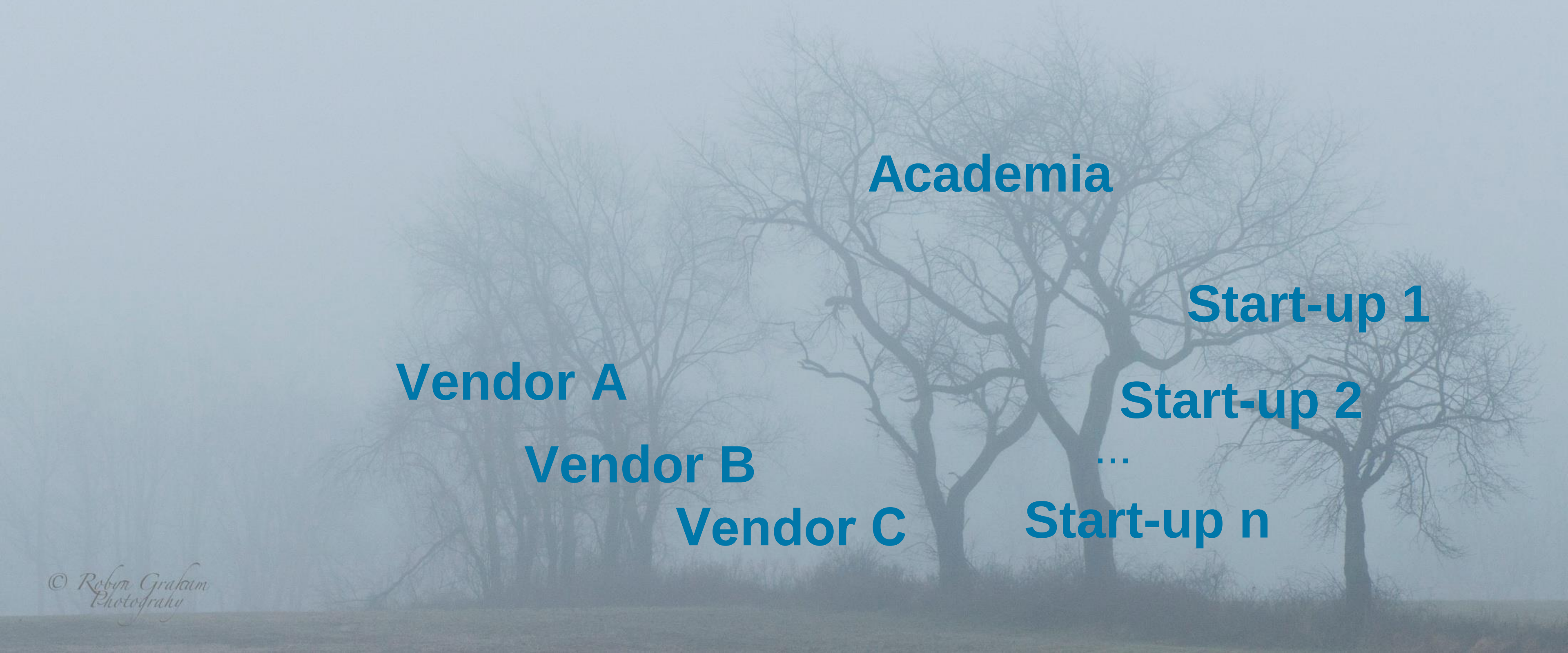
"SDN - Smells Dollars Now"

"SDN - Software Defined Not-working"

"SDN needs a bigger definition"
—Lippis report, 2012

Source: Adapted from A. Retana @ Lacnog'12

SDN in 2013 - 2015



Academia

Vendor A

Vendor B

Vendor C

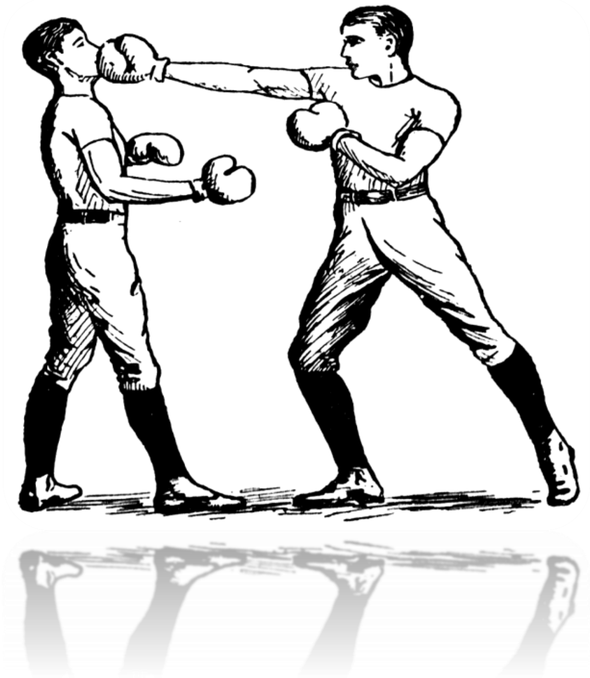
Start-up 1

Start-up 2

…

Start-up n

SDN in 2015 – 2020 → Network Softwarization (i.e. NFV + SDN + IBN + *xyz*)



Old / Existing

- CLIs & Manual labour
- Closed Source
- Vendor Lead
- Classic Network Appliances (HW)

New / Softwarized

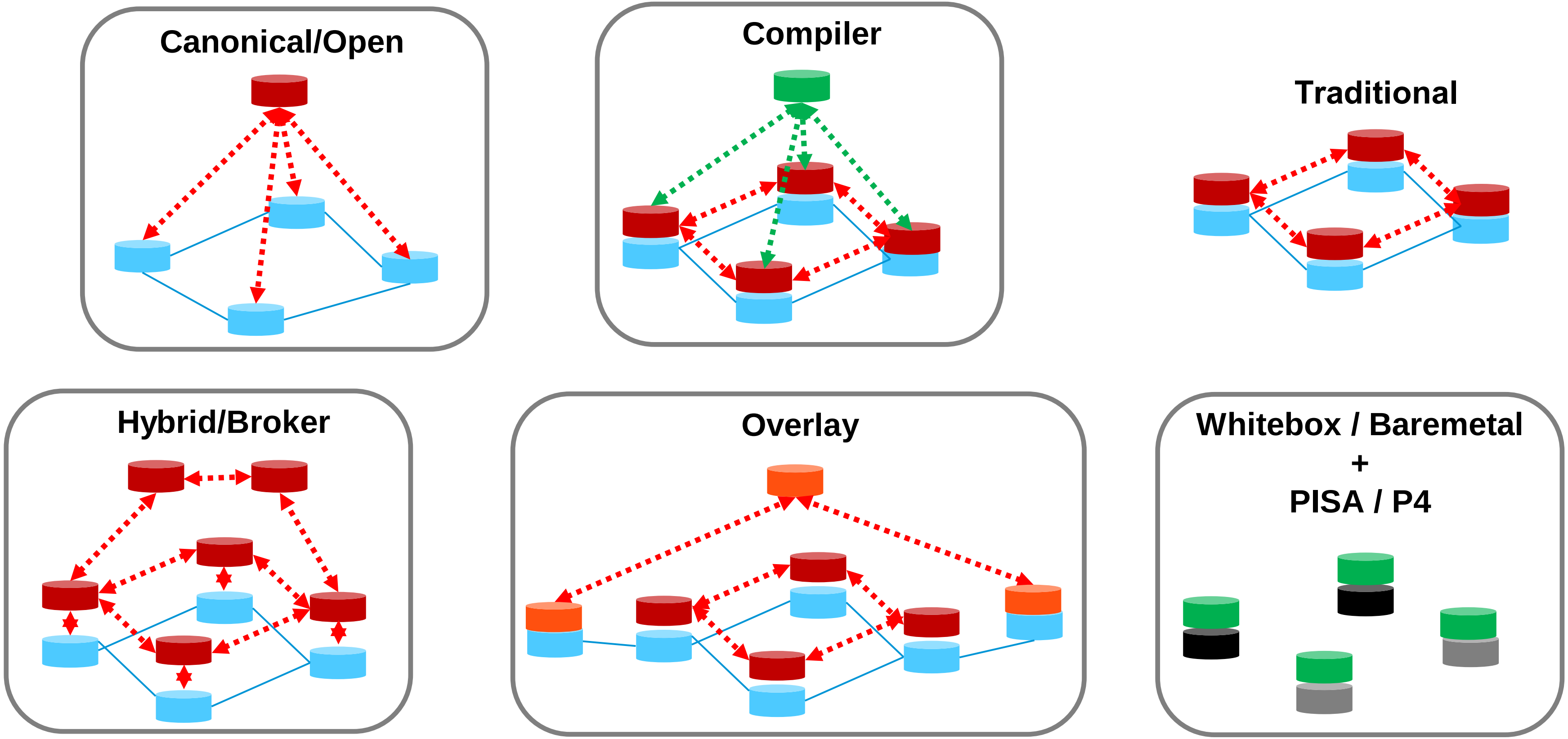
- APIs & Automation
- Open Source
- Customer Lead
- Virtual Network Functions (NFV/SW)

Source: Adapted from Kyle Mestery, Next Generation Network Developer Skills

Different Network Softwarization Models

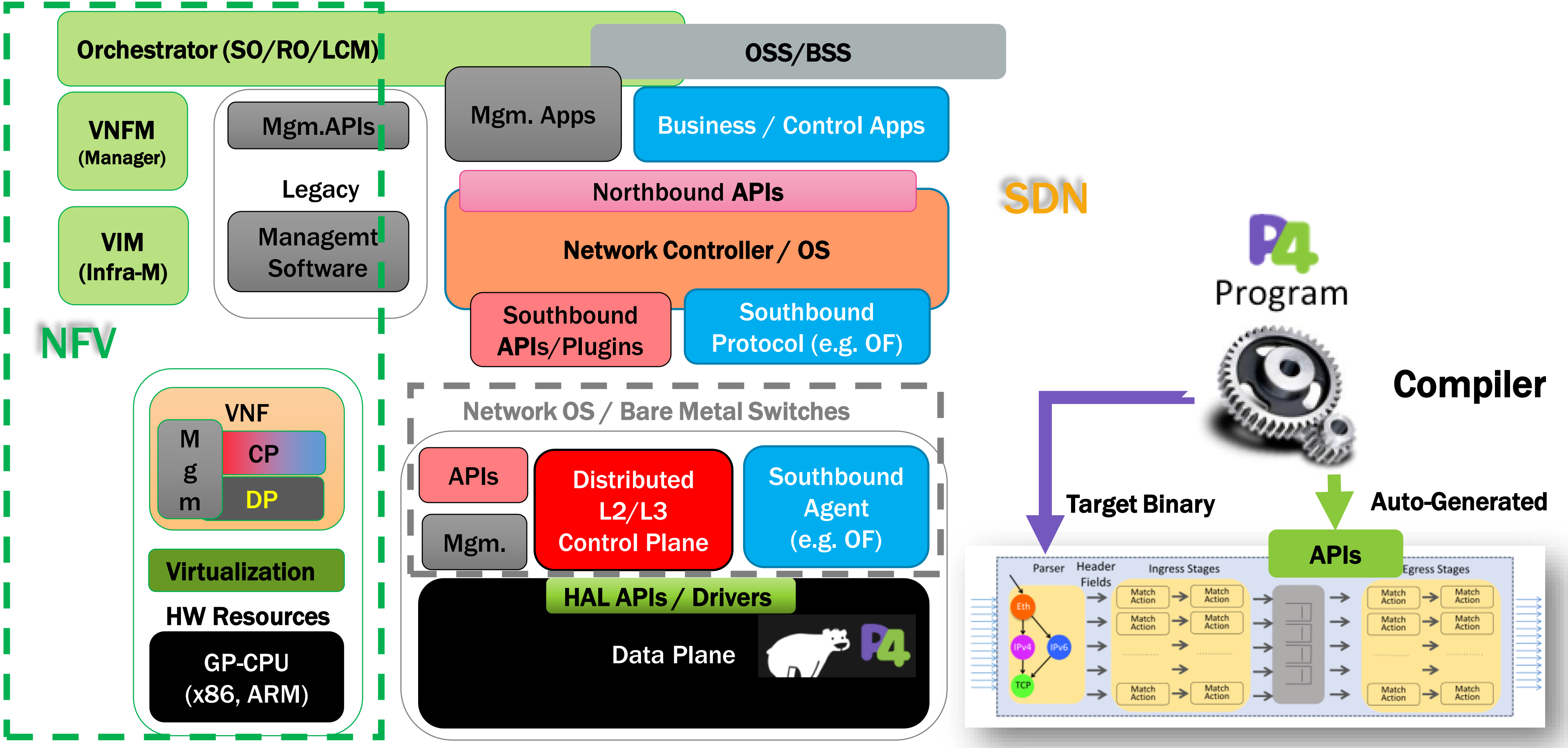
Control plane component(s)

Data plane component(s)



Source: C. Rothenberg (INTRIG/UNICAMP)

Models & Approaches to Program / Refactor the Netsoft Stack



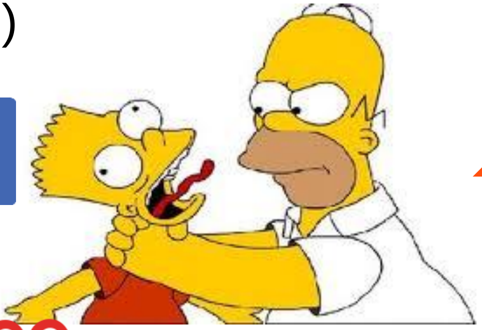
Source: C. Rothenberg (INTRIG/UNICAMP)

Network programmability? By whom?

Technical Expertise + Single Throat to Choke

Players with sufficient
SW Eng. + Network Eng.
& in-house Devops (NoOps?)

AT&T Microsoft NTT Goglee



- Intent-based (languages + APIs)
- Design + Run-time (NS)DKs
- ML/AI assistance
- Automation of Test + Benchmarking (pre-deployment + + day0 & day-2 ops)

The **long tail** of players
(e.g. smaller SPs, ISPs, enterprises, campus, governments, etc.)

The **Fluid Networking** landscape

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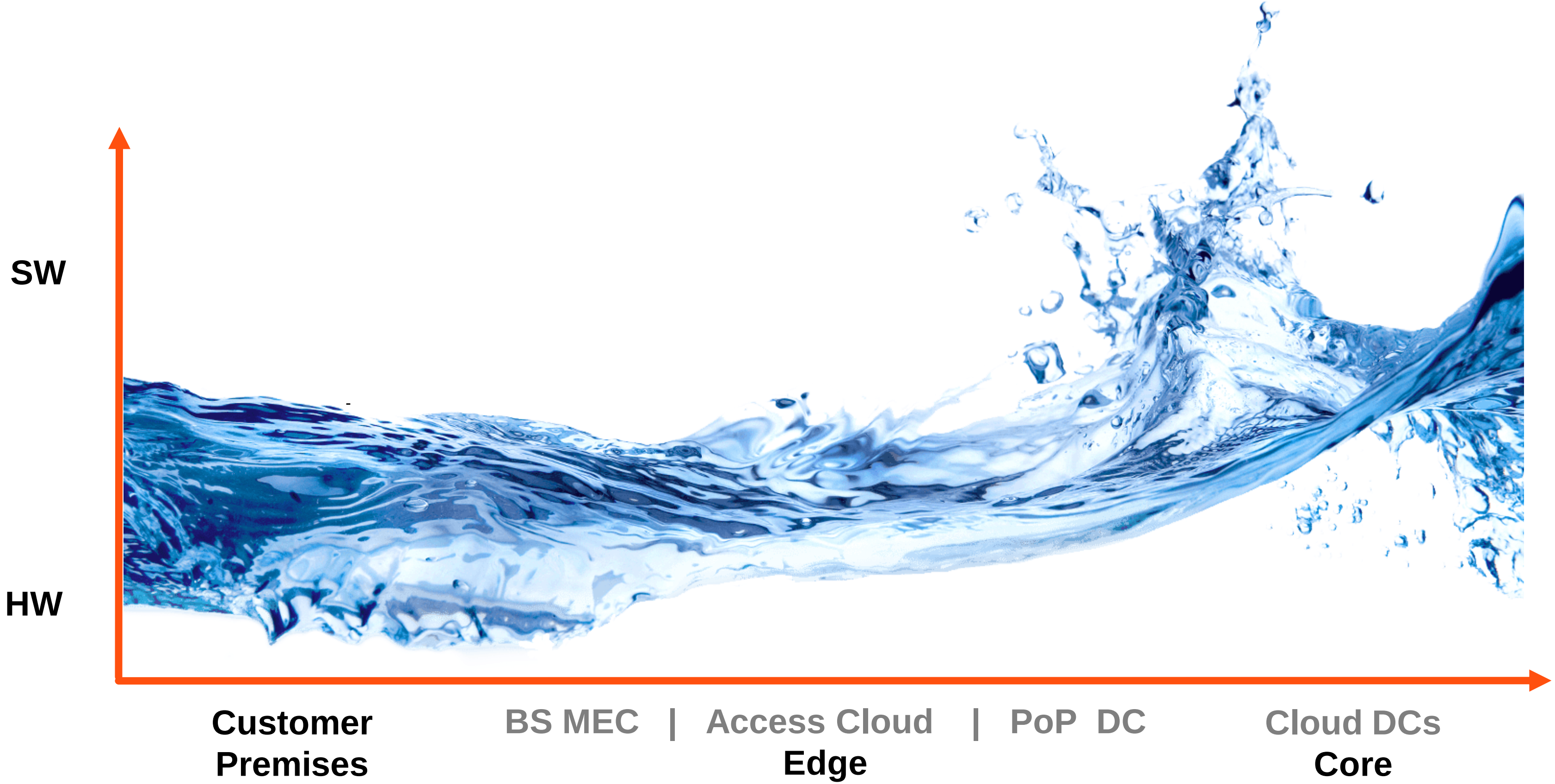
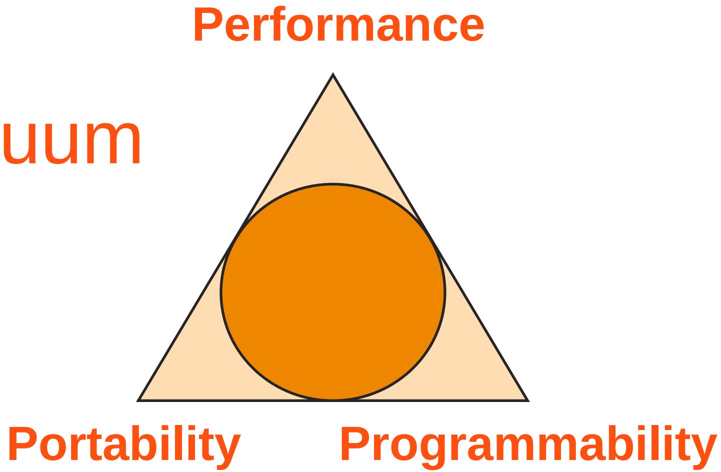
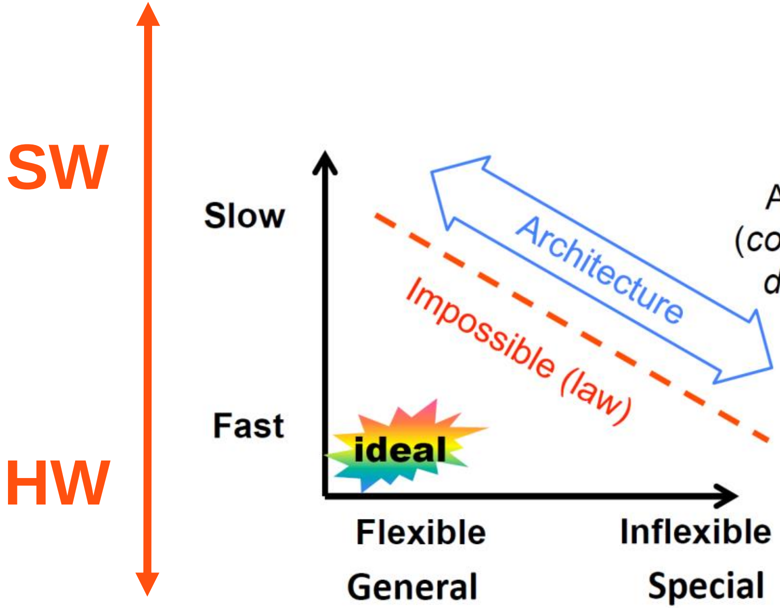


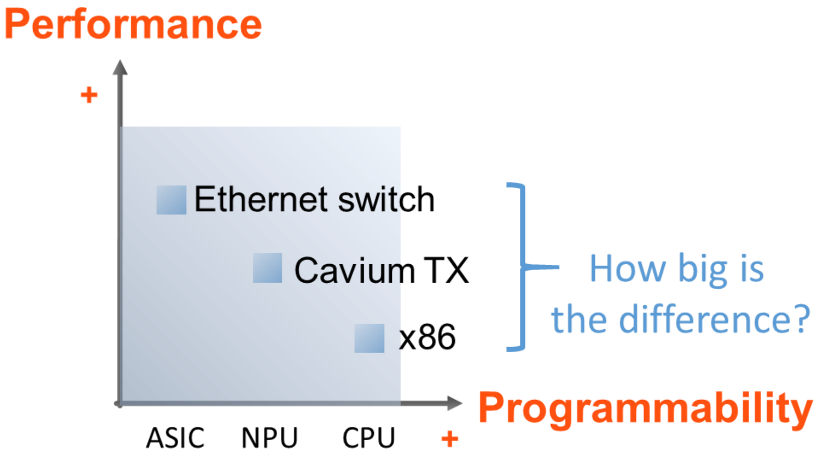
Fluid Networking: HW-SW Continuum



Source: C. Rothenberg. P3 Trade-offs. 2017



Source: D. Meyer (Courtesy by J. Doyle)



Source: G. Pongracz. "Cheap silicon". HotSDN13

Fluid Networking: HW-SW Continuum

TABLE II
TECHNICAL CONCEPTS AND THEIR SUPPORT OF FLEXIBILITY IN NETWORKS. (✓: MAIN TARGET)

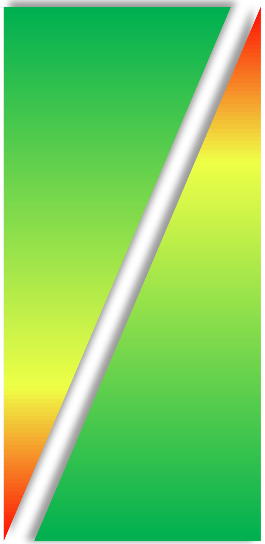
Category	**Aspect** (see Sec. III-B)	**SDN**	**NFV**	**NV**
Adapt configuration	Flow Configuration: flow steering	✓	-	-
	Function Configuration: function programming	-	✓	-
	Parameter Configuration: change function parameters	-	✓	✓
Locate functions	Function Placement: distribution, placement, chaining	-	✓	✓
Scale	Resource and Function Scaling: processing and storage capacity, number of functions	✓	✓	✓
	Topology Adaptation: (virtual) network adaptation	-	-	✓

Flexibility*
(programmability + portability)

SW

- **Containers**
- **User space**
- **Kernel space**
- **Drivers, I/O SDKs**
- **General-purpose CPU**
- **HW-accelerated features****
- **FPGA**
- **GPU, TPU,**
- **Programmable NIC, ASIC**
- **Domain Specific Architectures (DSAS) e.g., P4 + PISA**

HW



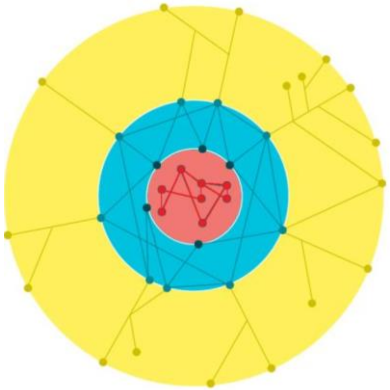
Performance***

* M. He et al. **Flexibility in Softwarized Networks: Classifications and Research Challenges**. IEEE Survey & Tutorials, 2019

** Linguaglossa et al. **Survey of Performance Acceleration Techniques for Network Function Virtualization.** Proc. of IEEE, 2019

*** G. Bianchi. **Back to the Future: Hardware-specialized Cloud Networking.** 2019

Fluid Networking: Quest for Latency / Fog & Cloud Continuum



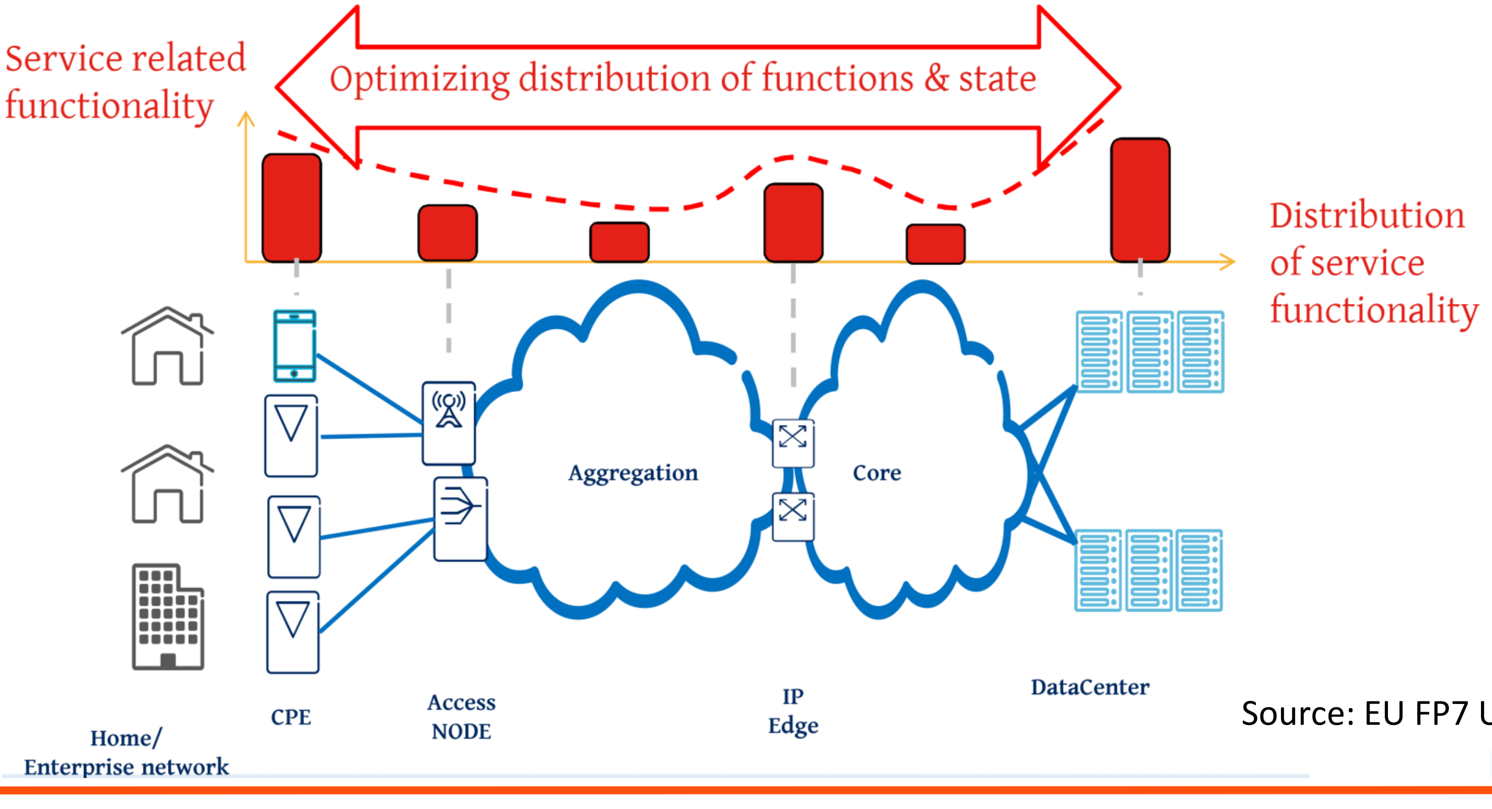
- 15 Data centers
- 100 Points of Presence (PoPs)
- 1000+ Edge nodes

Source: Google Cloud Infrastructure

Customer Premises | BS MEC | Access Cloud | PoP DC | Cloud DCs

Edge | **Core**

Fluid Networking: Optimizing the E2E Compute Pool

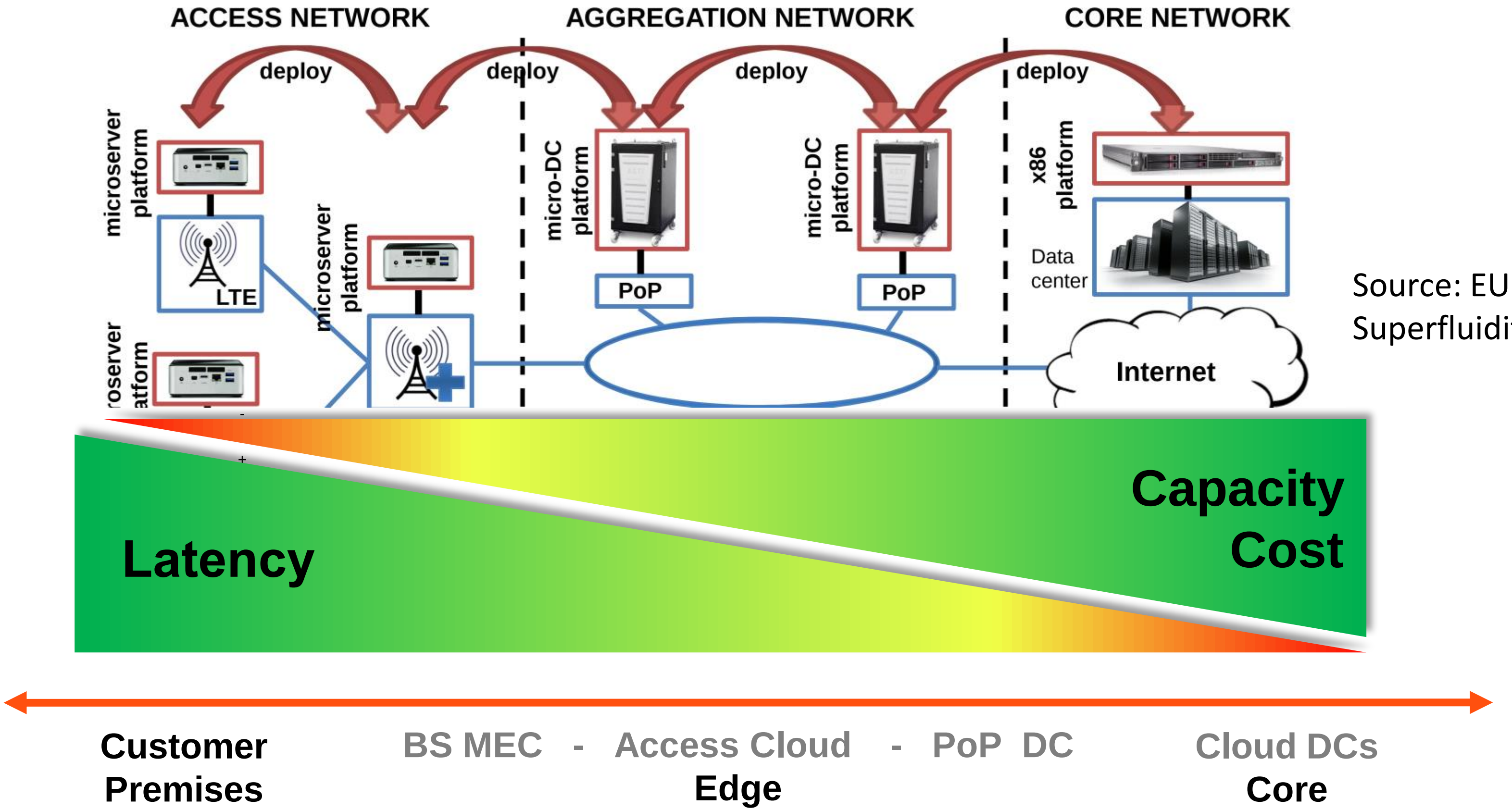


Source: EU FP7 UNIFY

Customer Premises BS MEC | Access Cloud | PoP DC Cloud DCs

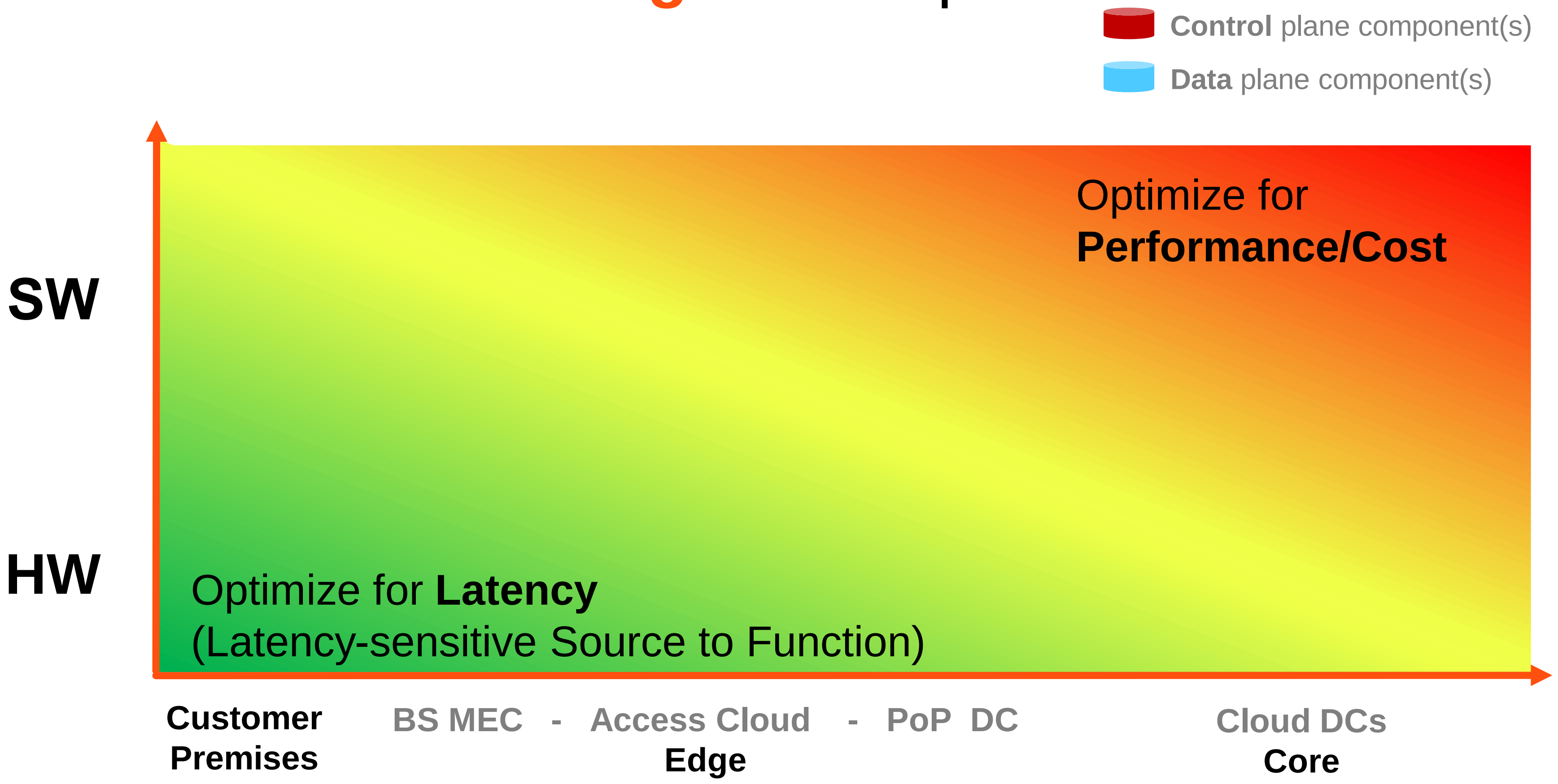
Edge **Core**

Fluid Networking: Decoupling functionality / location

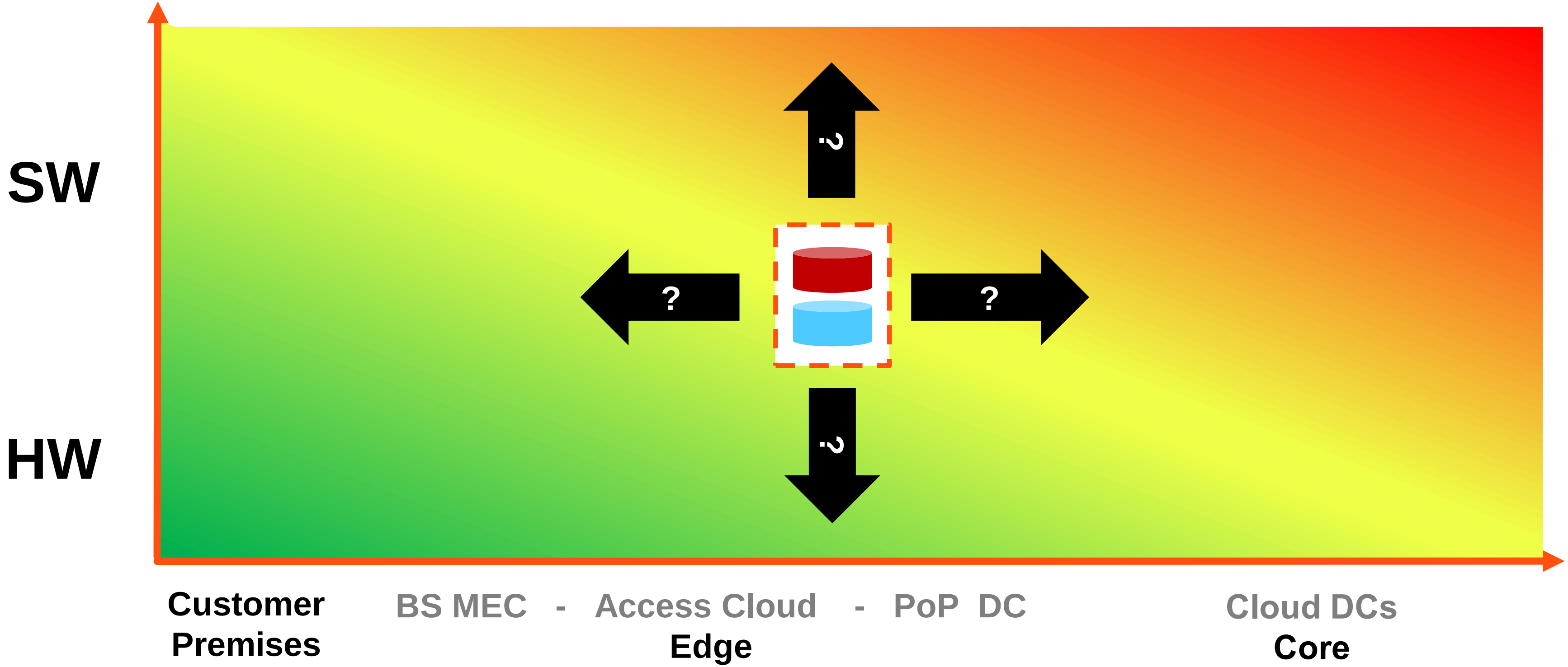


Source: EU Superfluidity

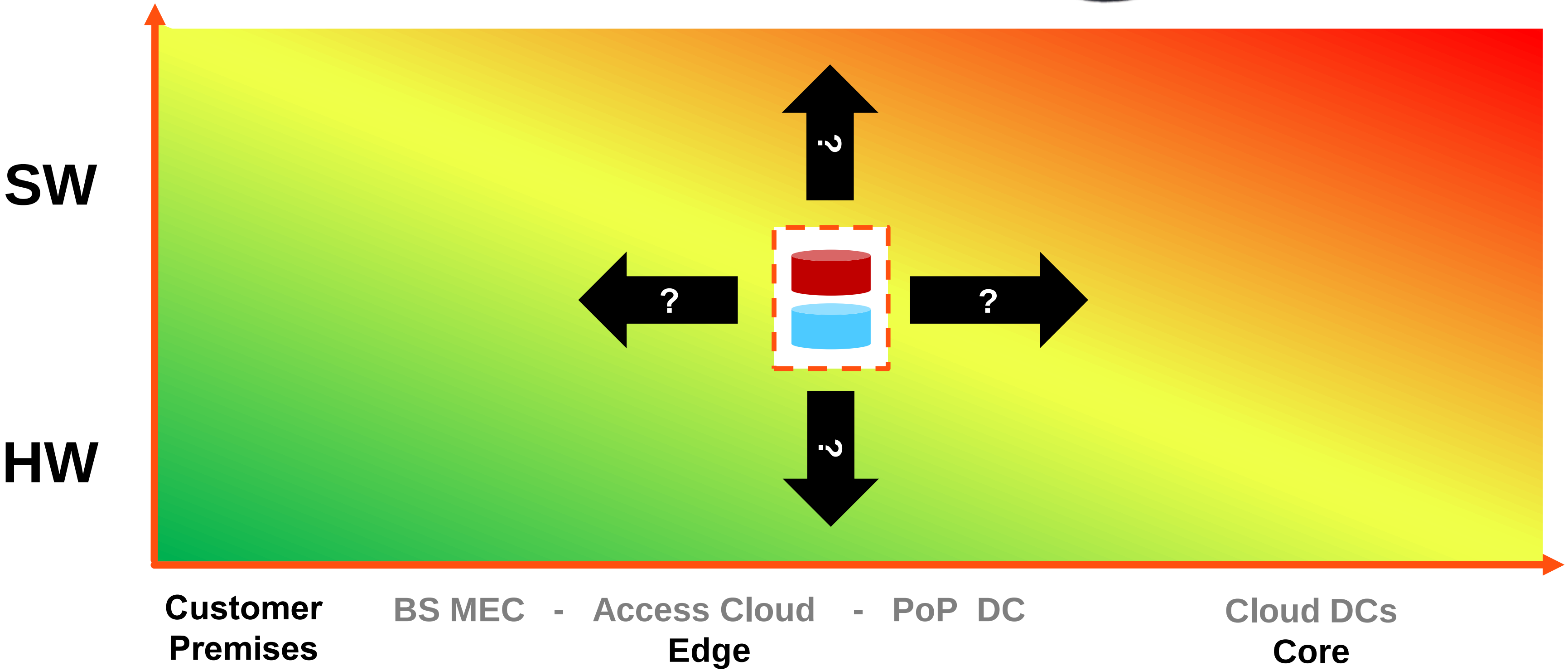
The Fluid Networking landscape



The Fluid Networking landscape



The **Fluid Networking** landscape



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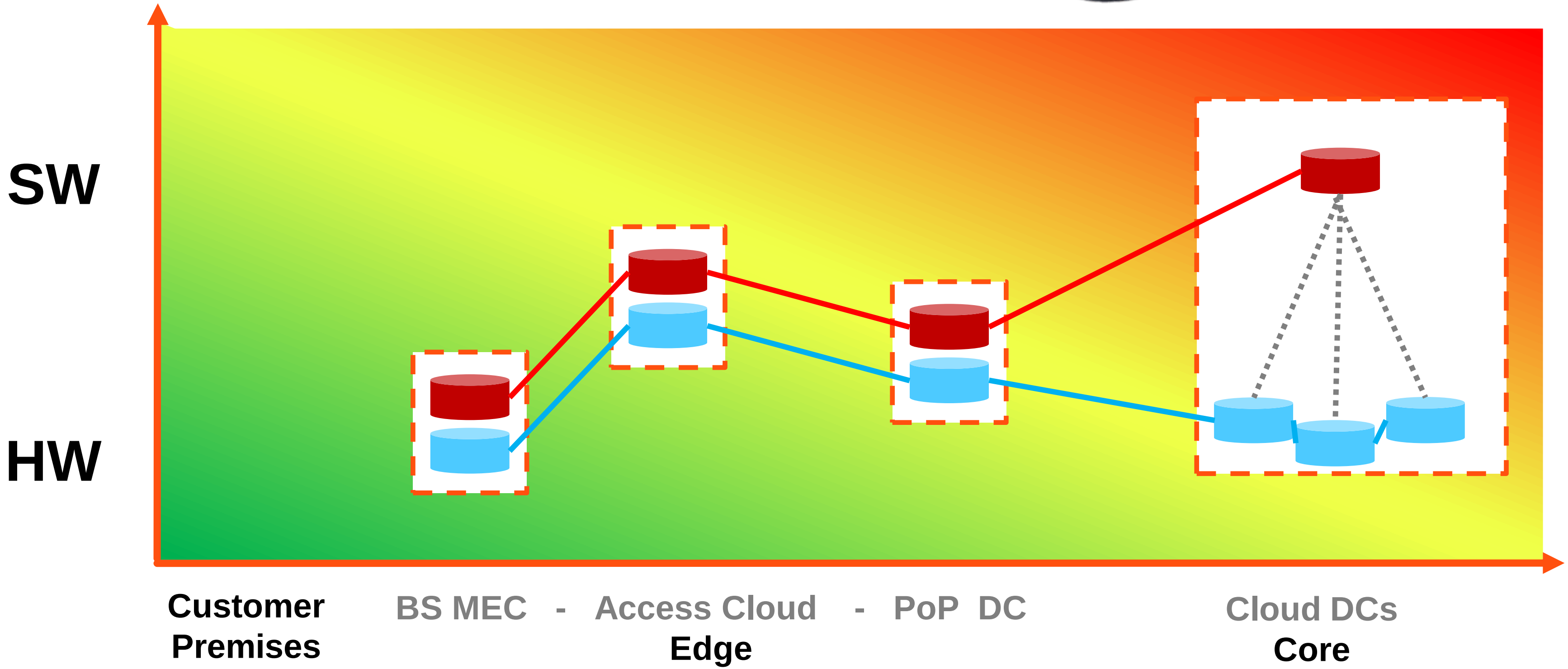

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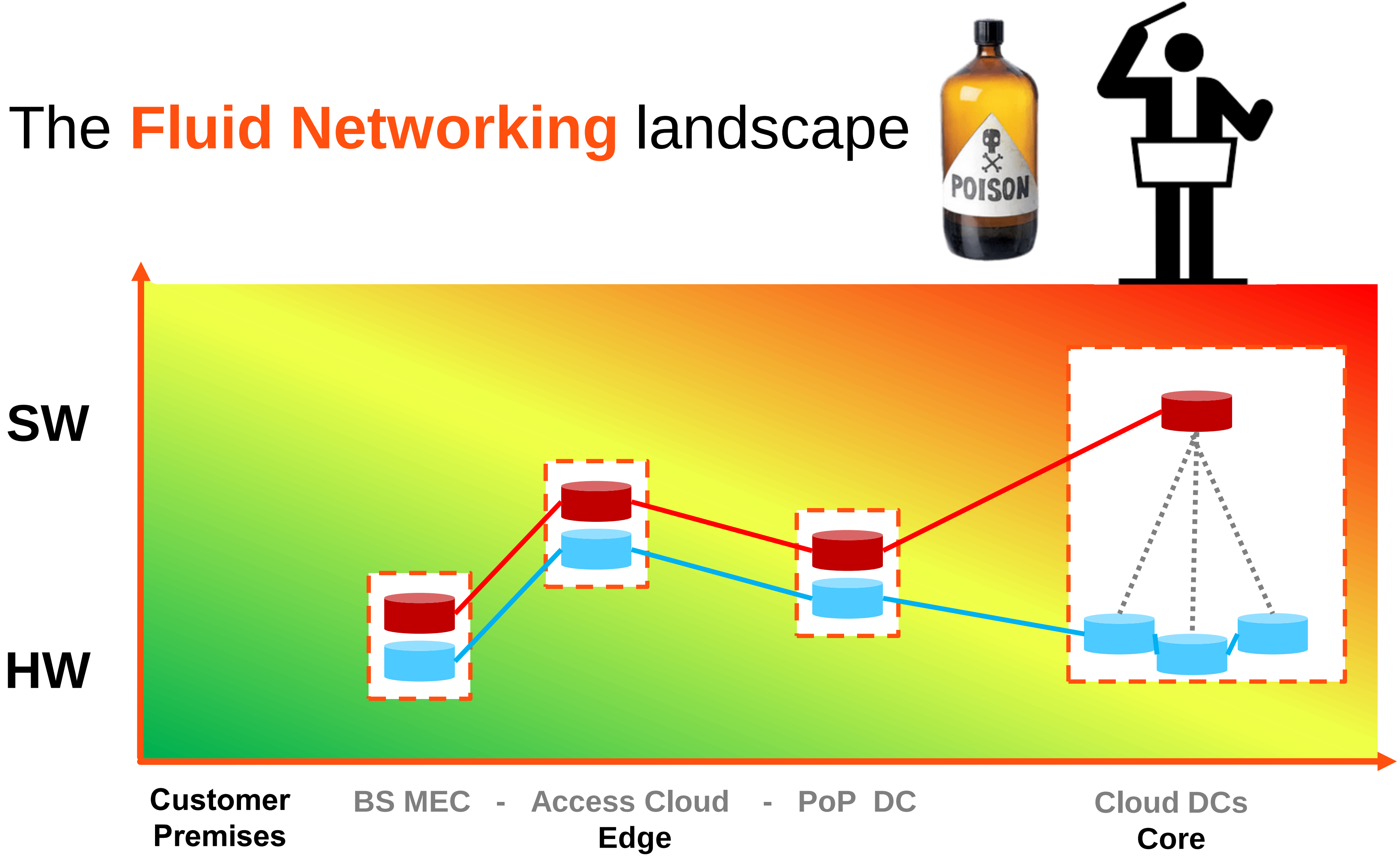

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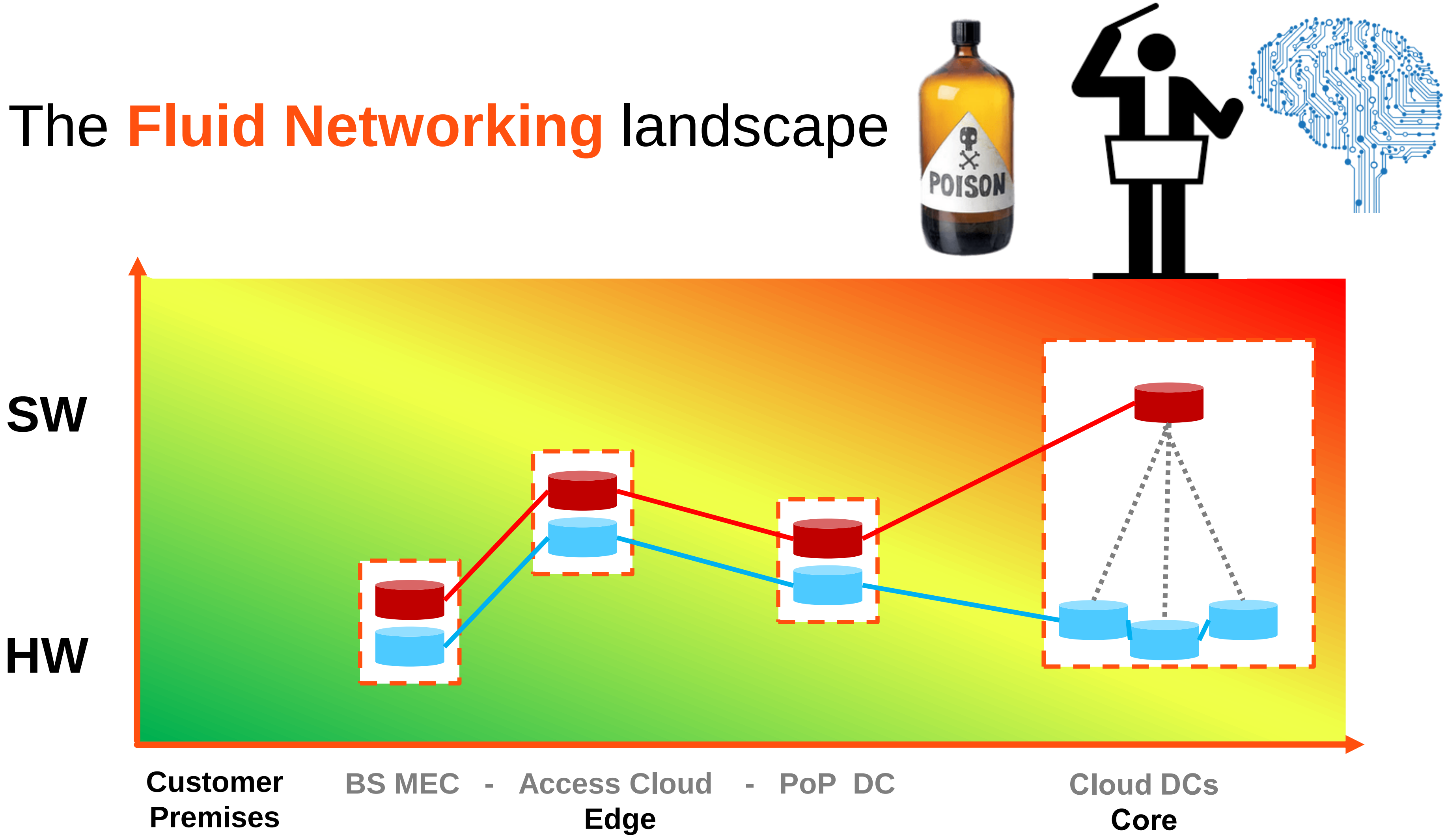
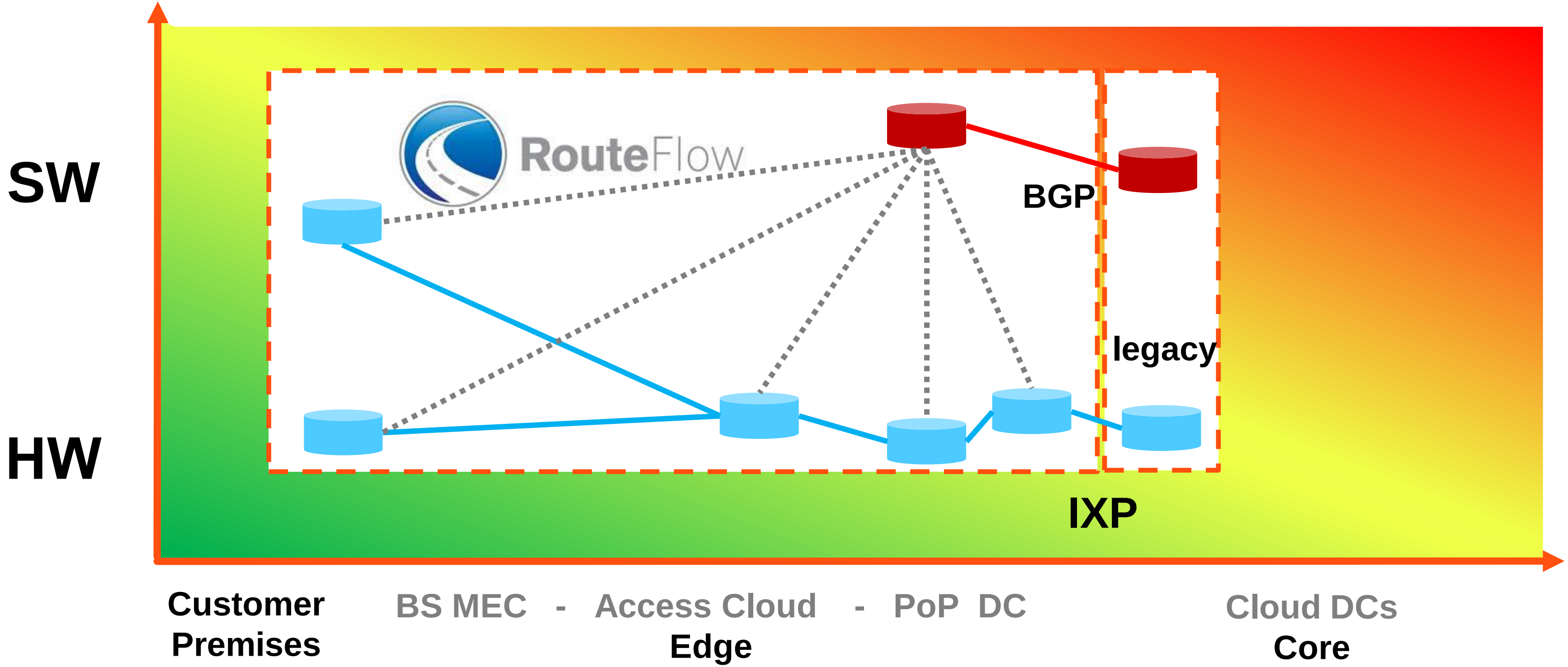
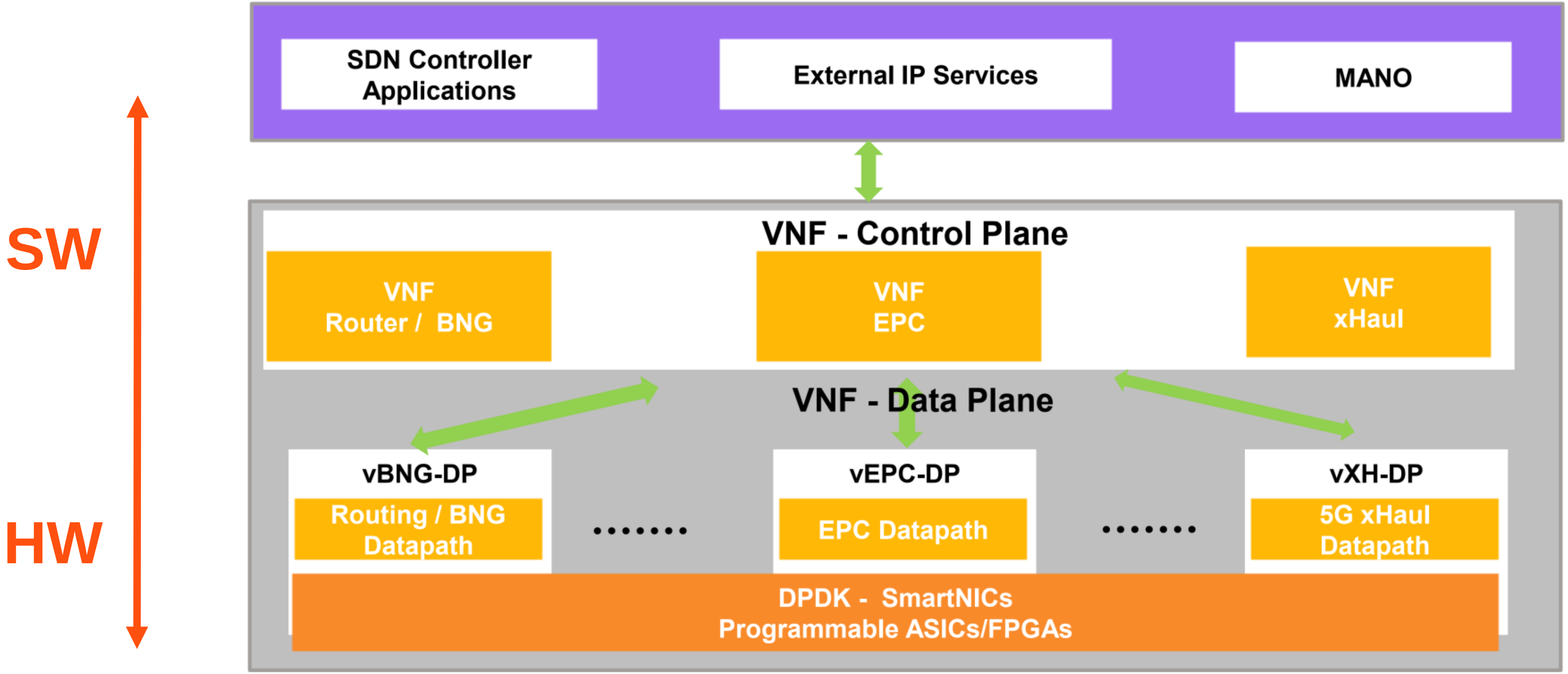


Instances of
Fluid Network Planes

RouteFlow (2010 -)

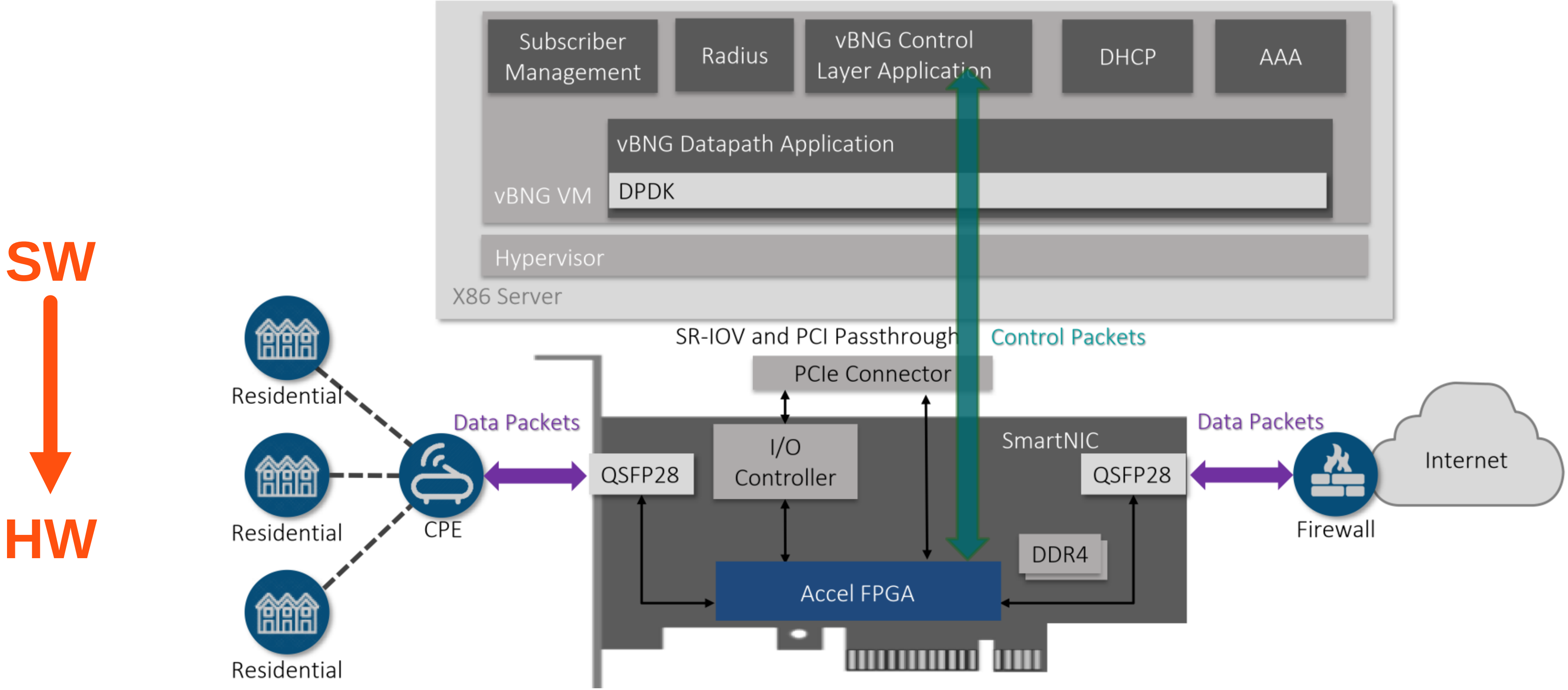


NFV layers of SW, Virtualization and HW platforms



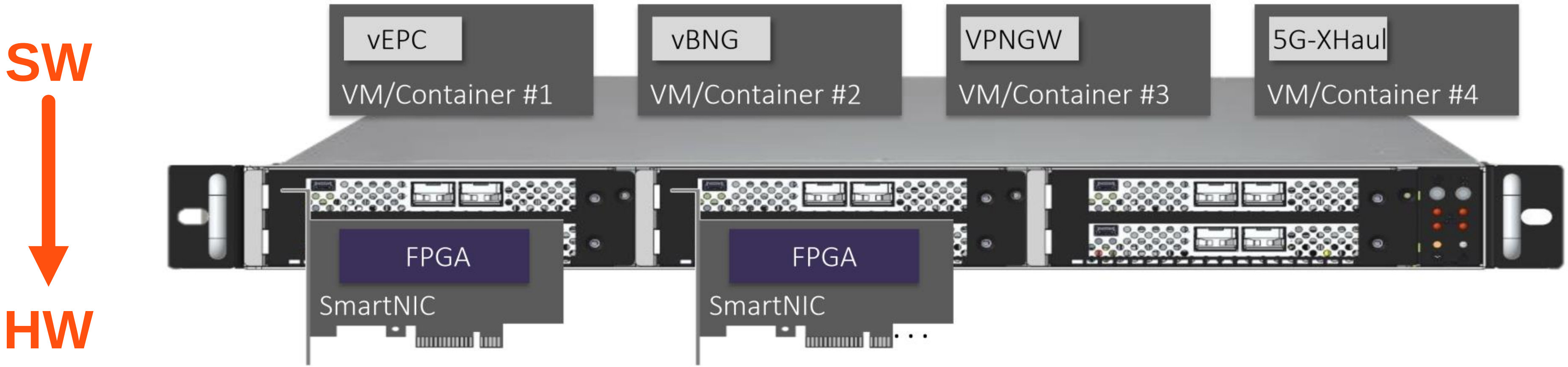
Source: https://www.dpdk.org/wp-content/uploads/sites/35/2018/12/Kalimani-and-Barak-Accelerating-NFV-with-DPDK-and-SmartNICs.pdf

VNF offloading to Hardware



Source: https://www.dpdk.org/wp-content/uploads/sites/35/2018/12/Kalimani-and-Barak-Accelerating-NFV-with-DPDK-and-SmartNICs.pdf

VNF offloading to Hardware

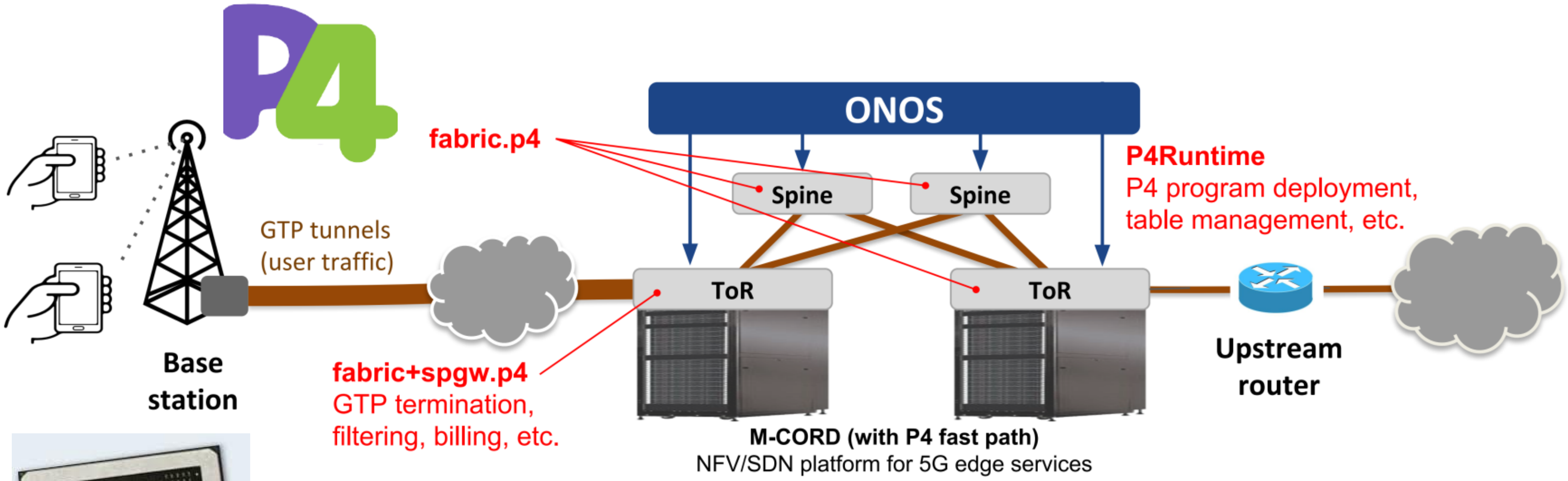


Source: https://www.dpdk.org/wp-content/uploads/sites/35/2018/12/Kalimani-and-Barak-Accelerating-NFV-with-DPDK-and-SmartNICs.pdf

VNF offloading on multi-vendor P4 fabric controlled by ONOS via P4Runtime

SW

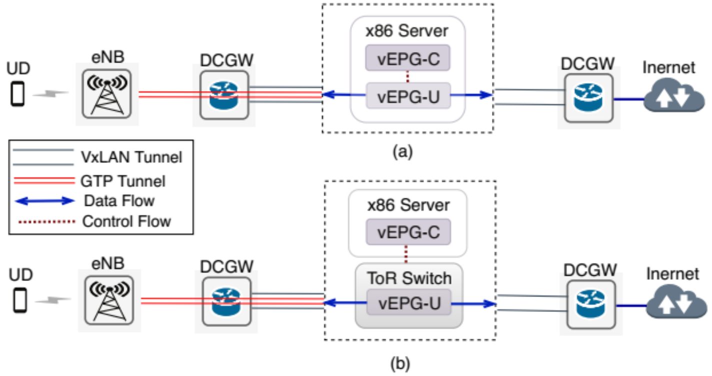
HW

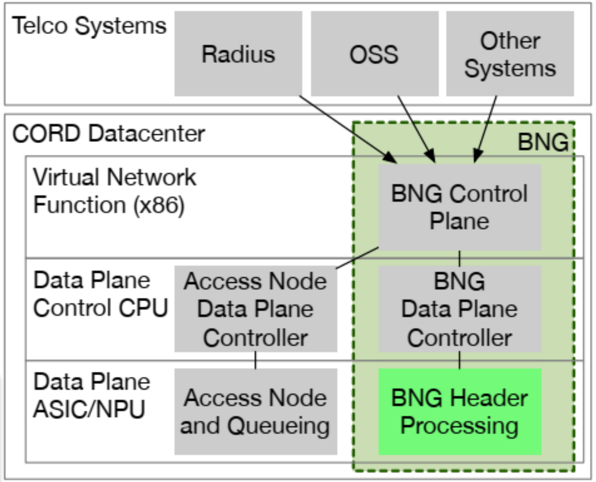


Source:
https://p4.org/assets/P4WS_2018/7_Carmelo_Cascone_VNF.pdf

Related work at TUD and UNICAMP

Ralf Kundel, Leonard Nobach, Jeremias Blendin, Hans-Joerg Kolbe, Georg Schyguda, Vladimir Gurevich, Boris Koldehofe, Ralf Steinmetz. **P4-BNG: Central Office Network Functions on Programmable Packet Pipelines.** CNSM'19





. 3: CORD-Service Edge component overview.

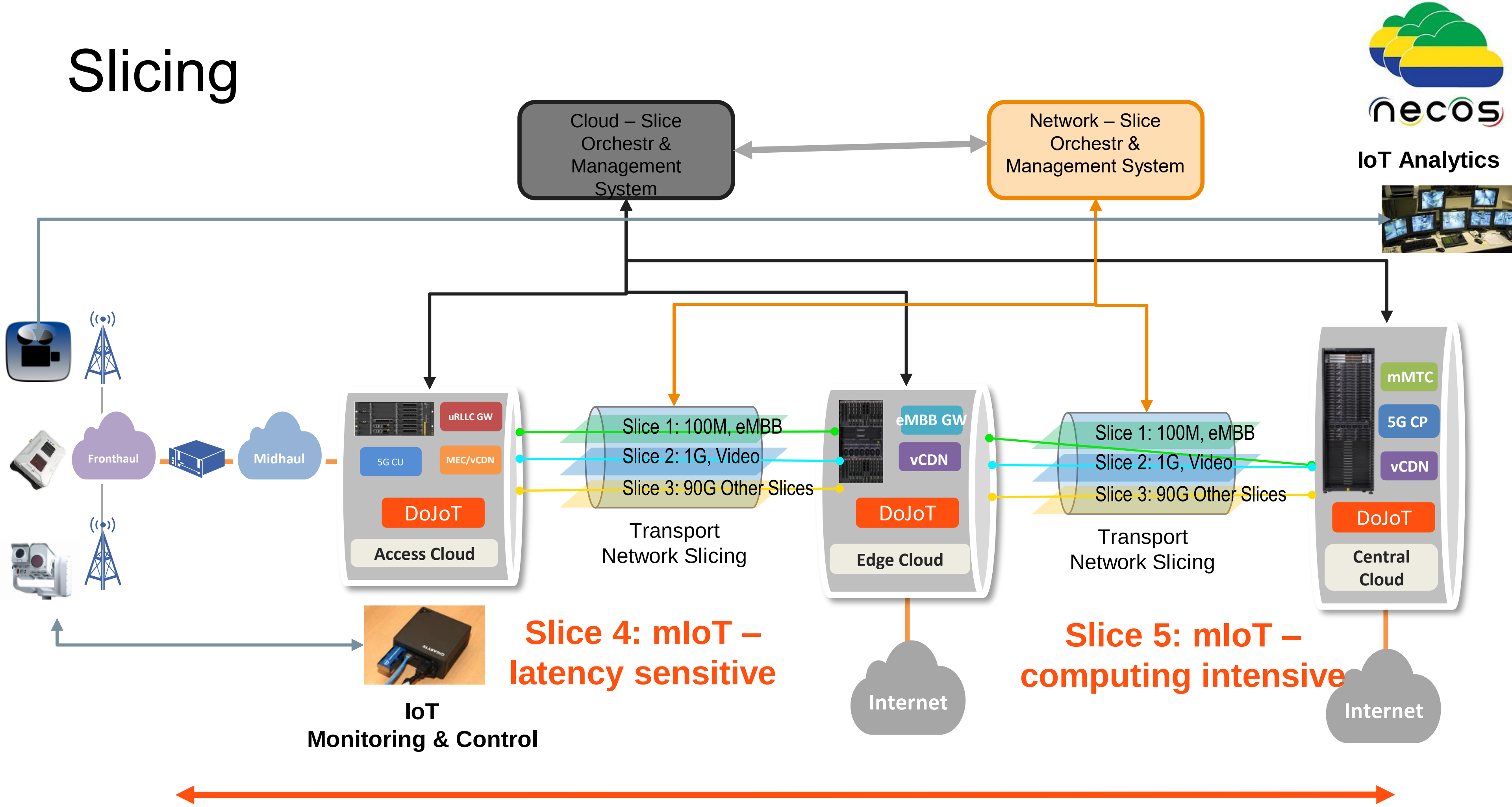
SW

HW

Suneet Kumar Singh, Christian Esteve Rothenberg, Gyanesh Patra, Gergely Pongrácz**. Offloading Virtual Evolved Packet Gateway User Plane Functions to a Programmable ASIC**. In 1st ACM CoNEXT Workshop on Emerging in-Network Computing Paradigms (ENCP'19)

Pattam Gyanesh Patra, Fabricio Rodriguez, Juan Sebastian Mejia, Daniel Lazkani Feferman, Levente Csikor, Christian Esteve Rothenberg, Gergely Pongrácz. **Towards a Sweet Spot of Dataplane Programmability, Portability and Performance: On the Scalability of Multi-Architecture P4 Pipelines**. In IEEE JSAC, 2018

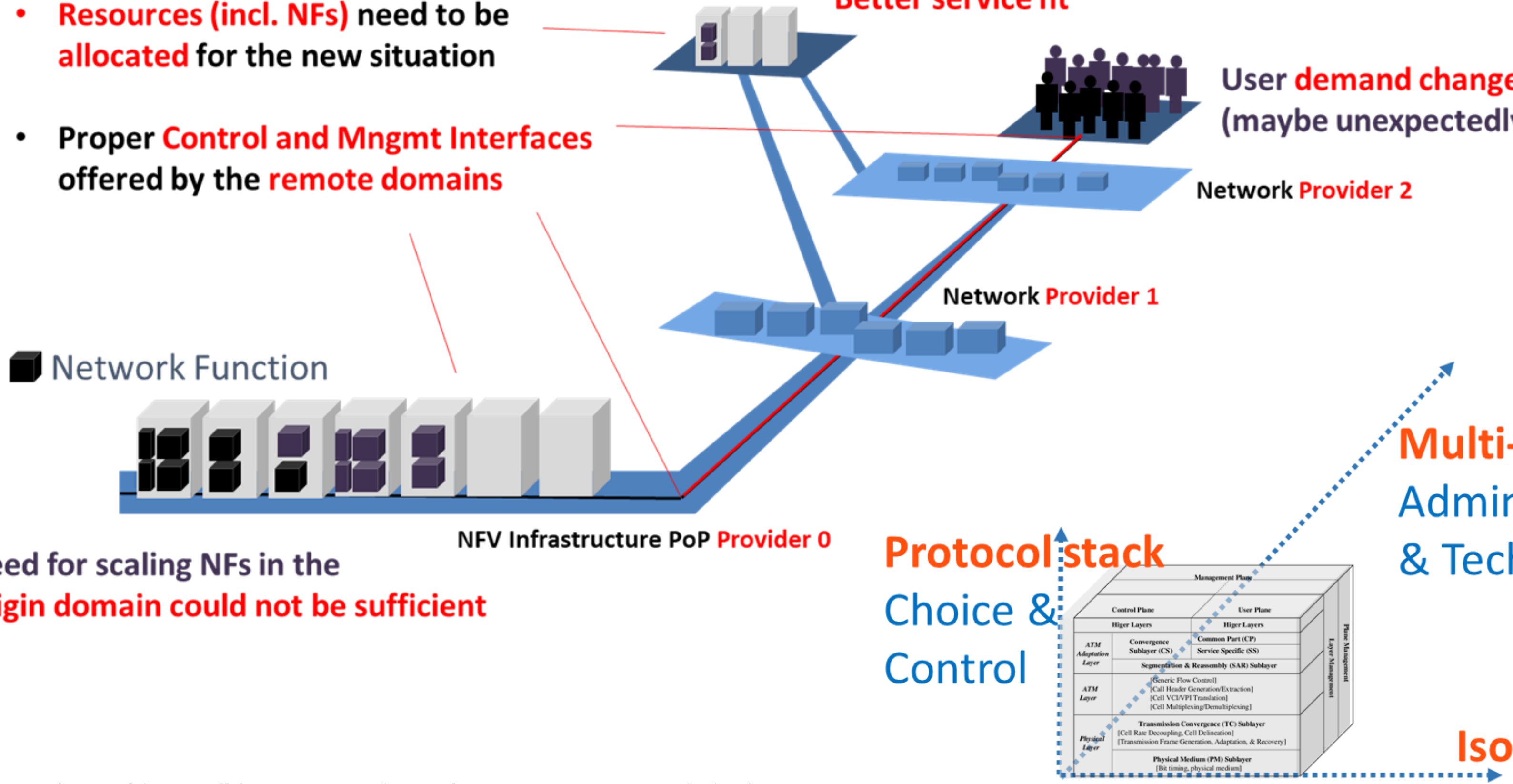
Slicing



Source: http://www.h2020-necos.eu/

Slicing

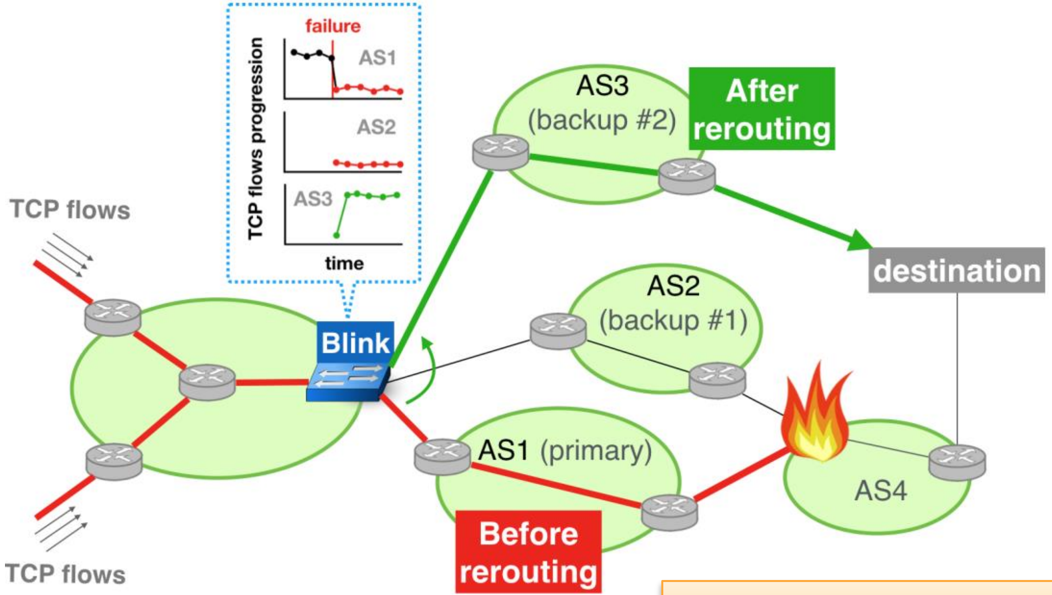
- **Resources (incl. NFs) need to be allocated for the new situation**
- **Proper Control and Mngmt Interfaces offered by the remote domains**



Need for scaling NFs in the origin domain could not be sufficient

Source: Adapted from slide courtesy by Luis M. Contreras, Telefonica.
http://www.h2020-necos.eu/

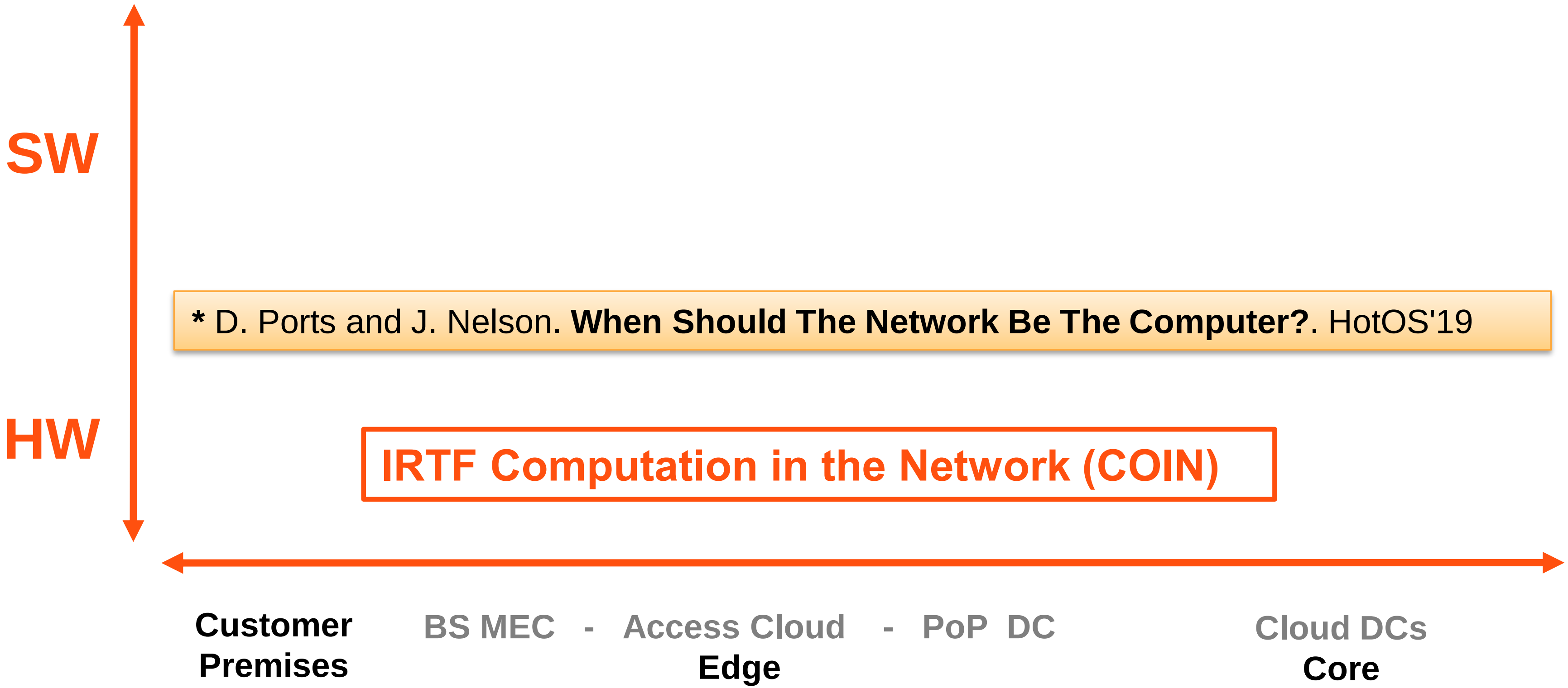
Control Plane functions (BGP) offloading to HW

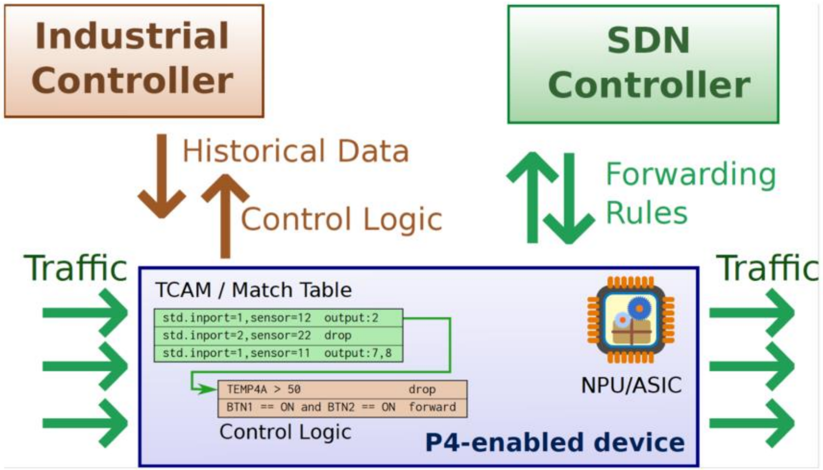


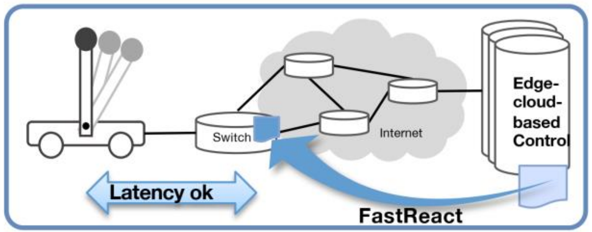
E. Costa Molero et al. **Hardware-Accelerated Network Control Planes**. HotNets'18

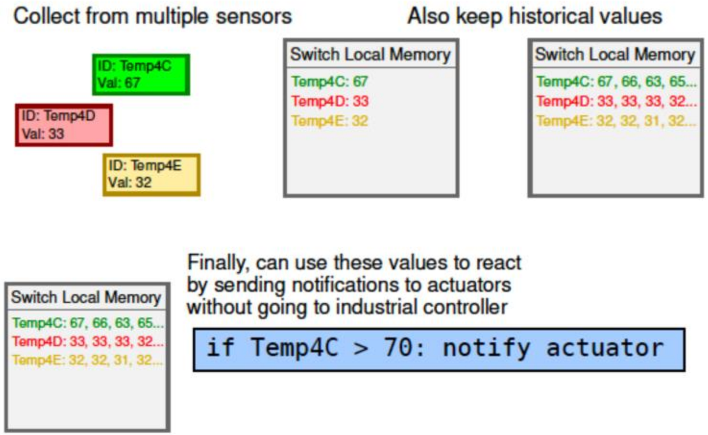
T. Holterbach et al. **Blink: Fast Connectivity Recovery Entirely in the Data Plane**. NSDI'19

Computation in the Network

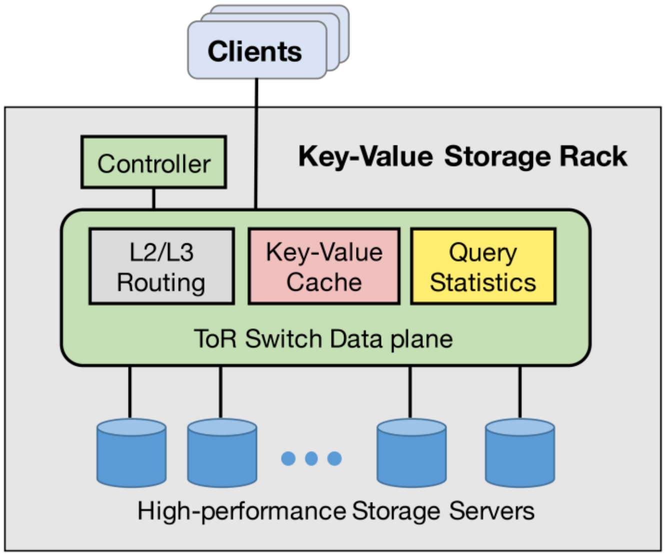




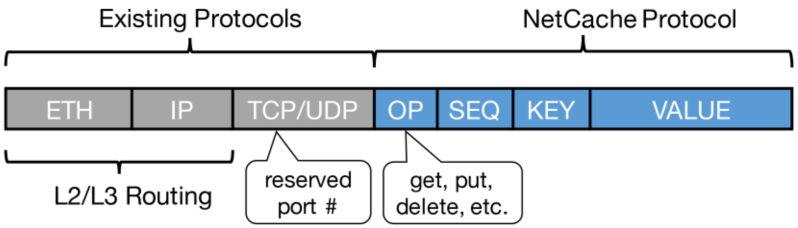




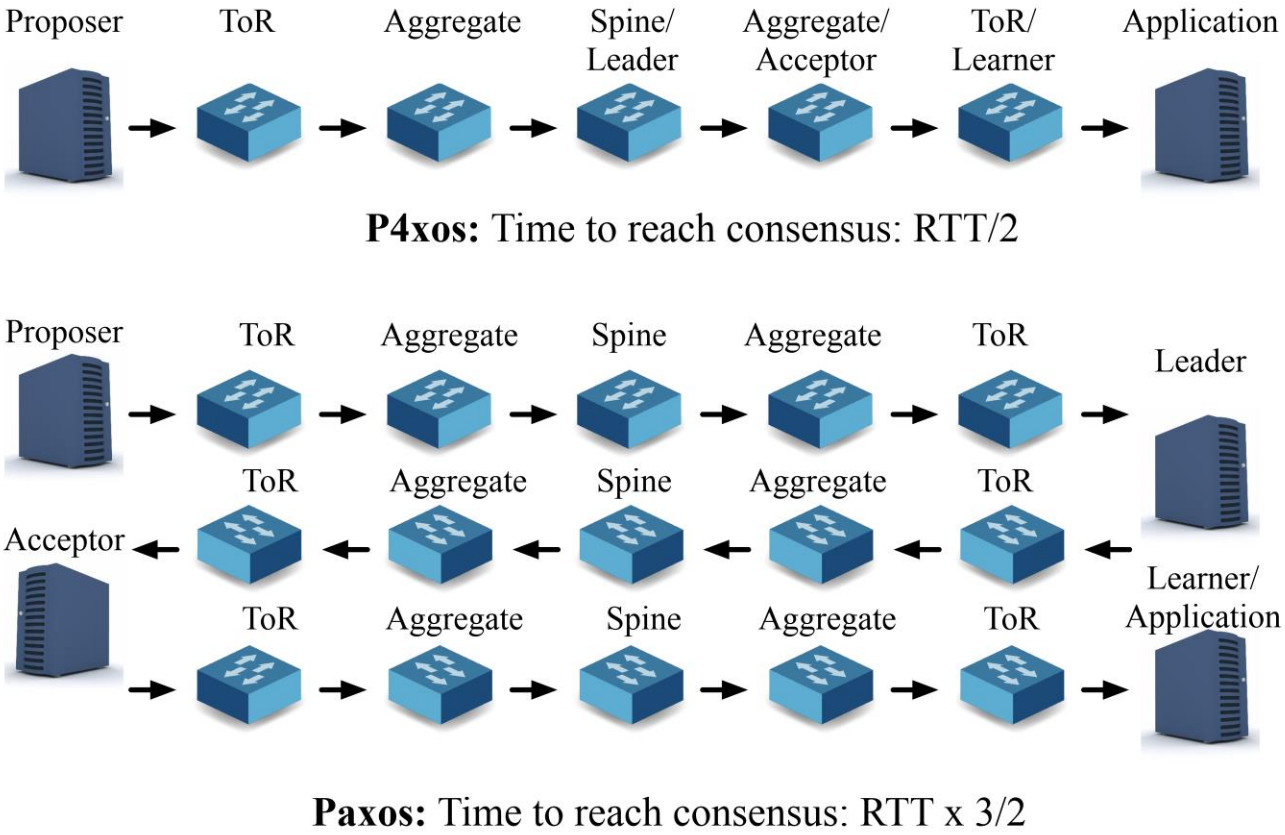
J. Vestin et al. **In-Network Control and Caching for Industrial Control Networks using Programmable Data Planes**. 2018



(a) NetCache architecture.

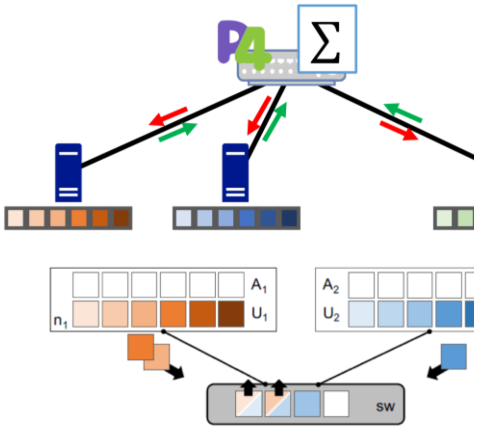


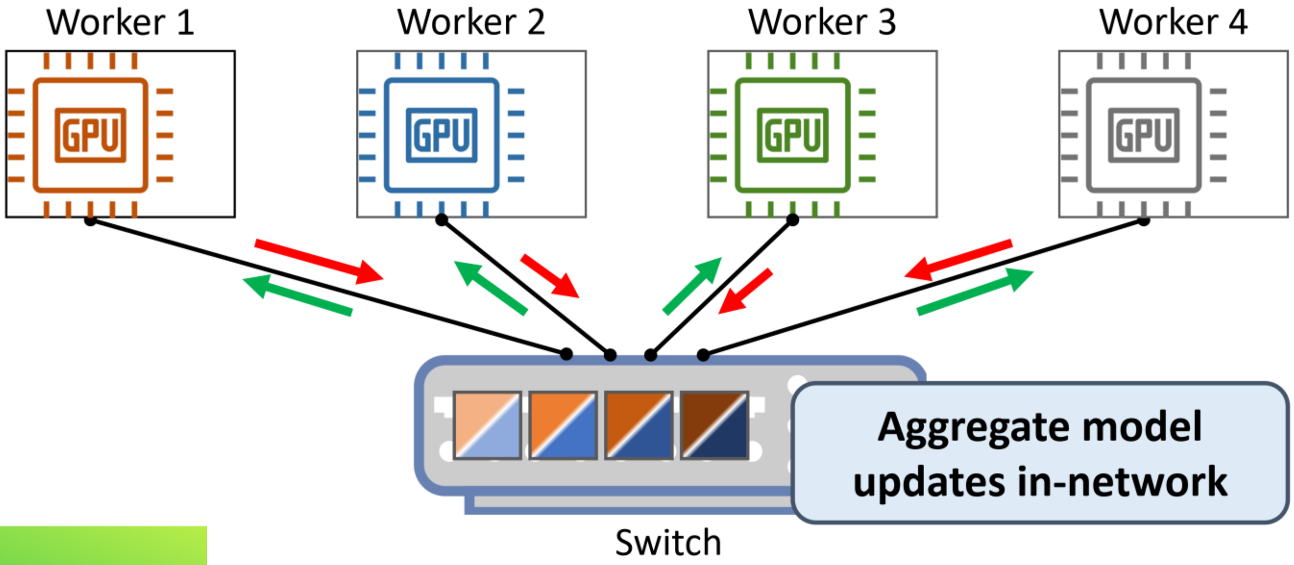
X. Jin et al. **Netcache: Balancing key-value stores with fast in-network caching**. SOSP'17

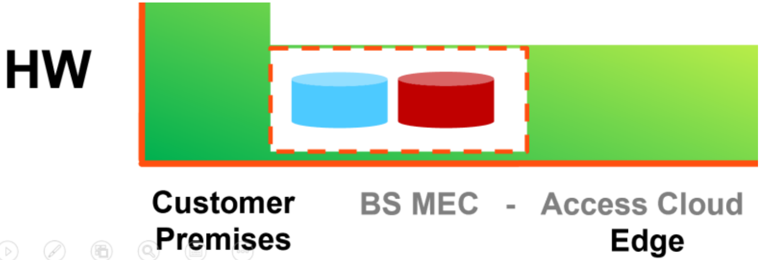


H. Tu Dang et al. **P4xos: Consensus as a Network Service**. 2018

SwitchML: the network is the ML accelerator







A. Sapio et al. **Scaling Distributed Machine Learning with In-Network Aggregation**. 2019

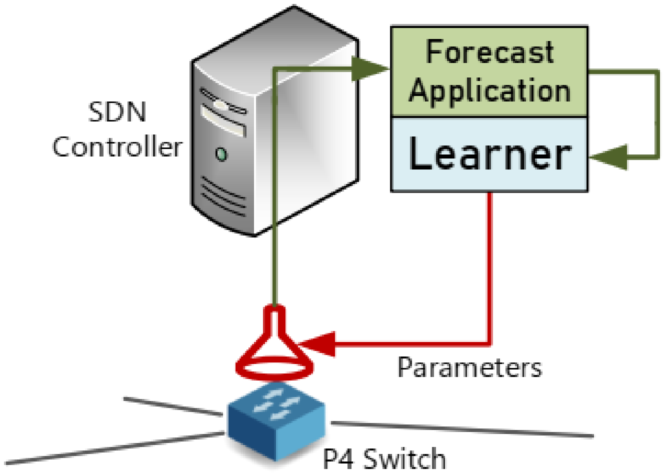


Fig. 1: Architecture of the preprocessing: A linear regression learns its parameters from historic values of a forecast and pushes them to the data-plane elements where they are used to estimate the importance of measurements and filter irrelevant measurements.

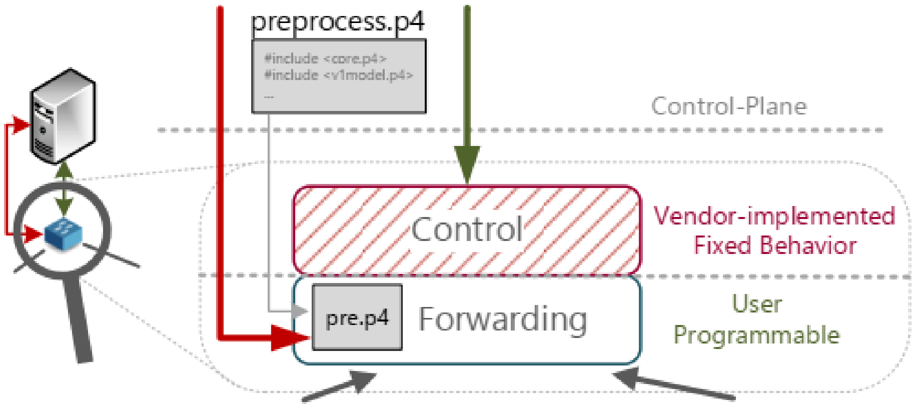


Fig. 3: Abstract switch architecture divided in control and forwarding layer. The control layer serves as interface to the control-plane and maintains that communication. The forwarding layer behaves according to the installed P4 program whenever packets arrive.

Rhaban Hark, Divyashri Bhat, Michael Zink, Ralf Steinmetz, Amr Rizk. **Preprocessing Monitoring Information on the SDN Data-Plane using P4**. In Proceedings of the IEEE NFV-SDN 2019

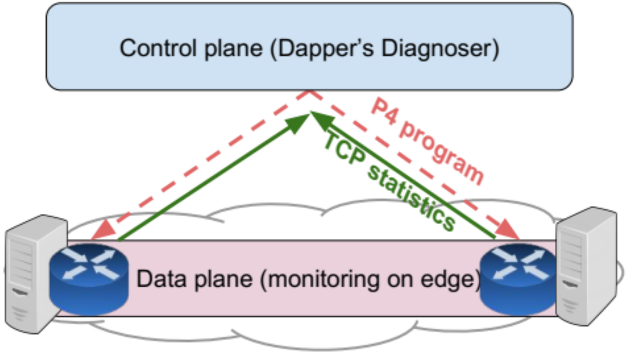
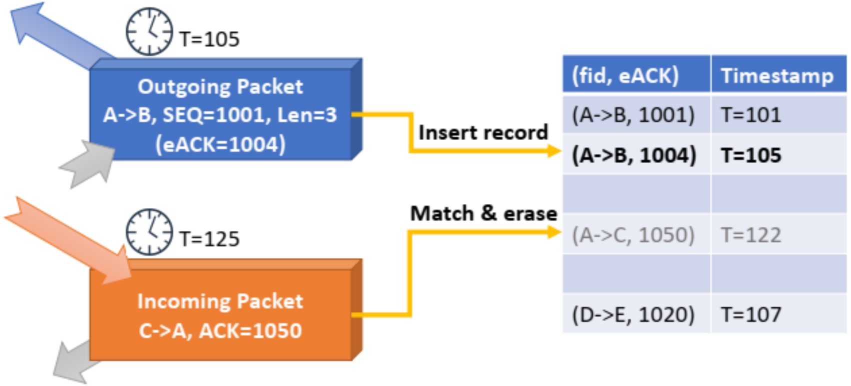


Figure 2: Dapper's architecture : (1) data plane monitoring on edge, (2) control plane diagnosis techniques

Mojgan Ghasemi, Theophilus Benson, and Jennifer Rexford.
Dapper: Data Plane Performance Diagnosis of TCP.
In Proceedings of the Symposium on SDN Research (SOSR '17)



Xiaoqi Chen, Hyojoon Kim, Javed M. Aman, Willie Chang, Mack Lee, and Jennifer Rexford. **Measuring TCP Round-Trip Time in the Data Plane**. In Workshop on Secure Programmable Network Infrastructure (SPIN '20)
P4 Tofino implementation of TCP RTT Measurement:
https://github.com/Princeton-Cabernet/p4-projects/tree/master/RTT-tofino

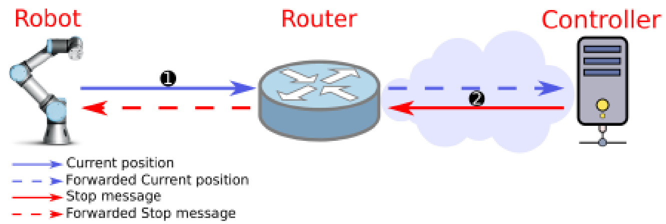


Fig. 4: Traditional scenario without in-network control.

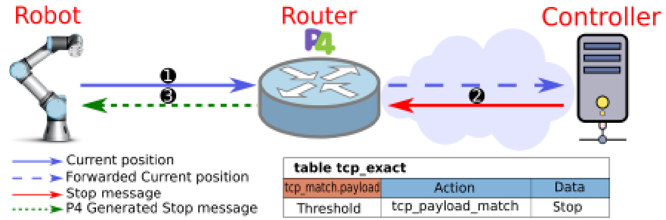


Fig. 5: In-network P4-based implementation.

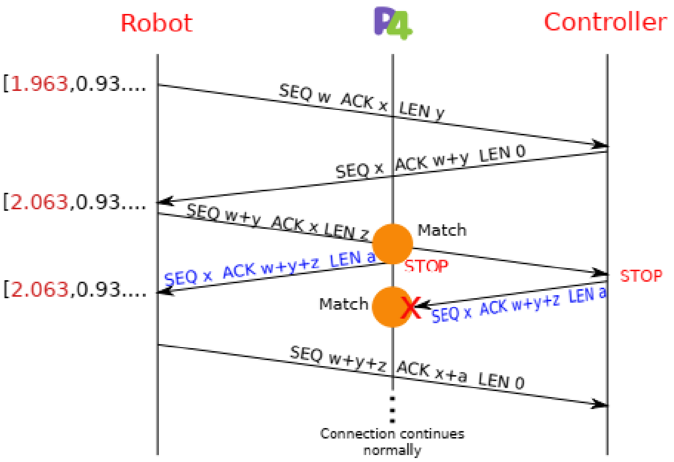
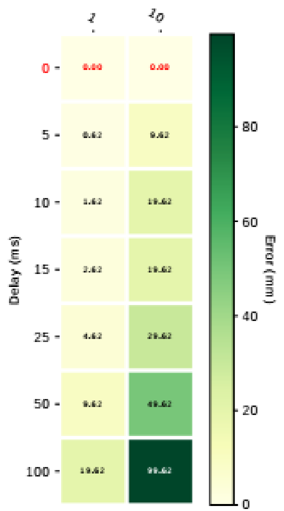


Fig. 6: TCP session approach.



(b) Steps of 1 - 10 mm

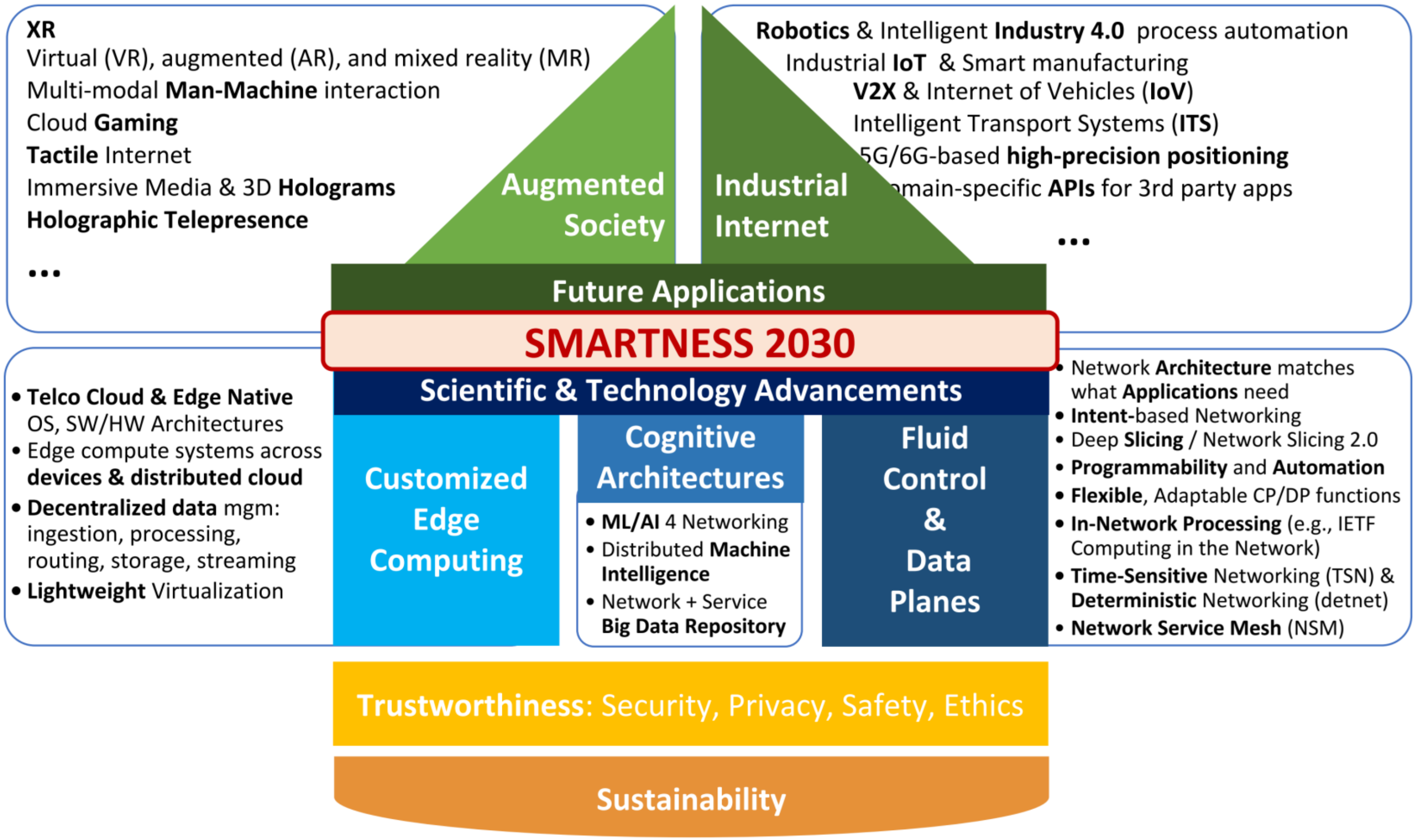
Fig. 8: Stop position error without in-network actions. Acceleration of $(30°/s^2)$.

Fabricio Rodriguez, Levente Csikor, Carlos Recalde, Christian Esteve Rothenberg, Gergely Pongrácz**. Towards Low Latency Industrial Robot Control in Programmable Data Planes.** In IEEE NetSoft 2020, Ghent, Belgium, June 2020.

Conclusions

- *Fluid Networks* are here to stay
- Just a *term* to refer to the confluence of technological advances that are re-shaping networks (functions and architectures)
  - High-performance SW I/O and Virtualization Stacks
  - True Programmable Networking HW (NICs and ASICs)
  - Vast amount of Computing, from the Edge to the Core
  - Many instances in the literature and many opportunities ahead

SMARTNESS (Smart Networks and Services for 2030)



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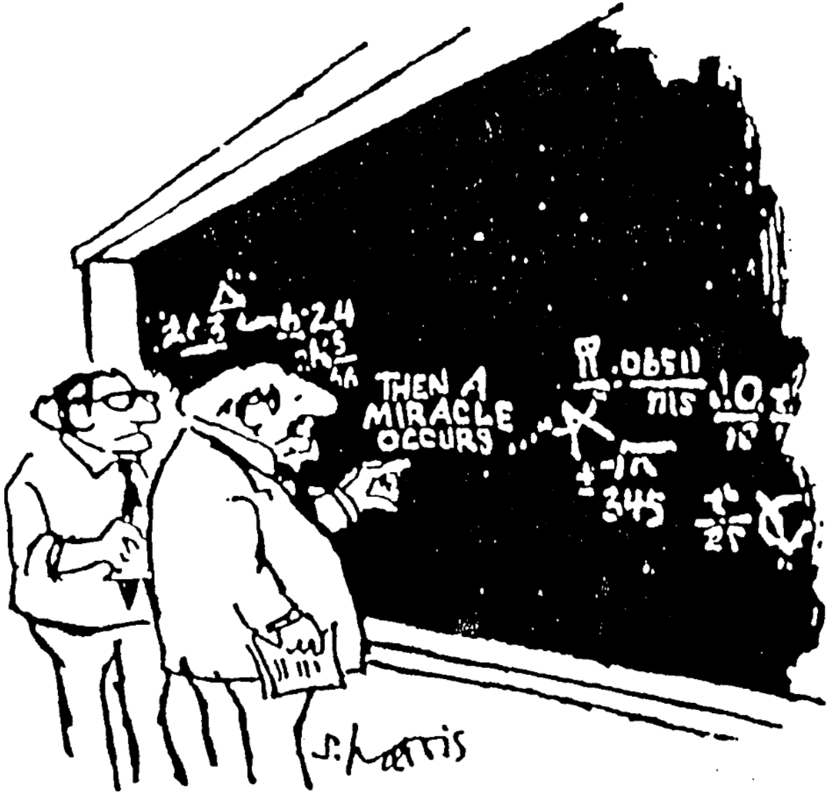
Credits

- http://www2.technologyreview.com/article/412194/tr10-software-defined-networking/
- Fluid 1 image source: https://www.trzcacak.rs/detail/199233/
- Fluid 2 image source: http://www.pngall.com/water-png/download/1933
- Intelligent Brain image source: https://ui-ex.com/explore/transparent-brain-artificial-intelligence/
- Orchestrator image source: https://apievangelist.com/2015/02/06/when-you-are-ready-for-nuanced-discussion-about-who-has-access-to-your-api-i-am-here/
- Poison image source: https://www.stickpng.com/cat/miscellaneous/poison?page=1

Danke!

Questions?



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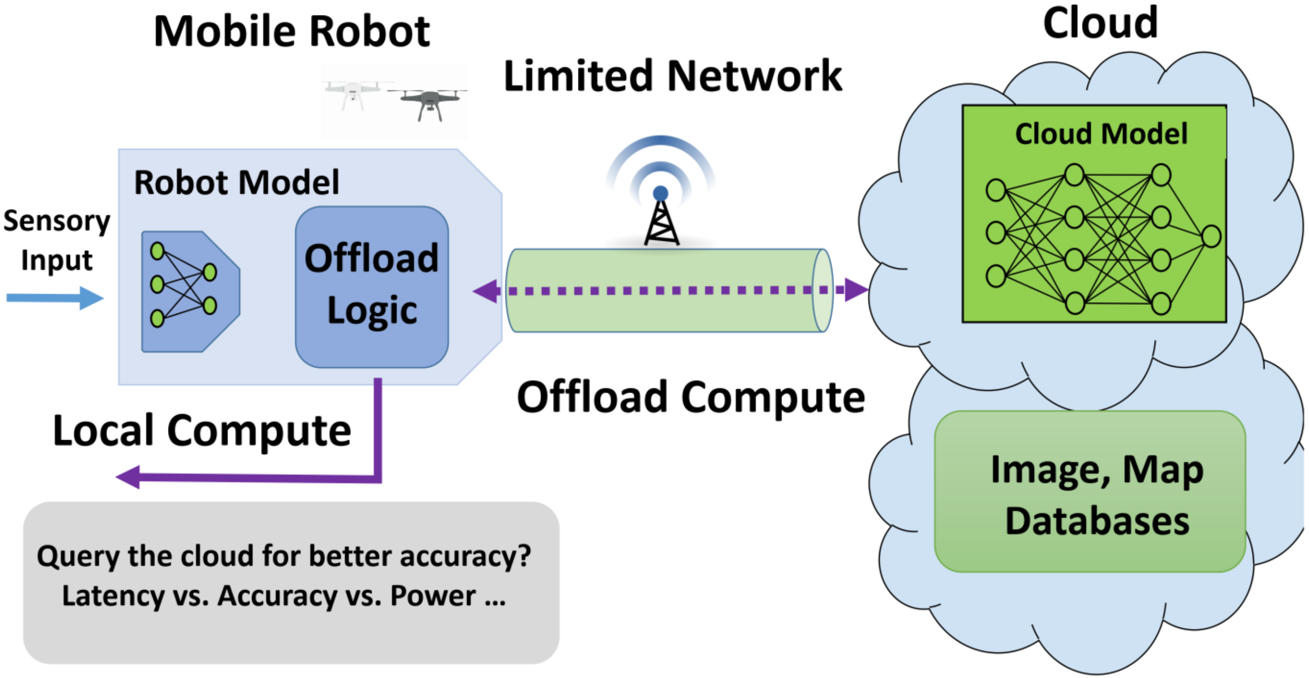

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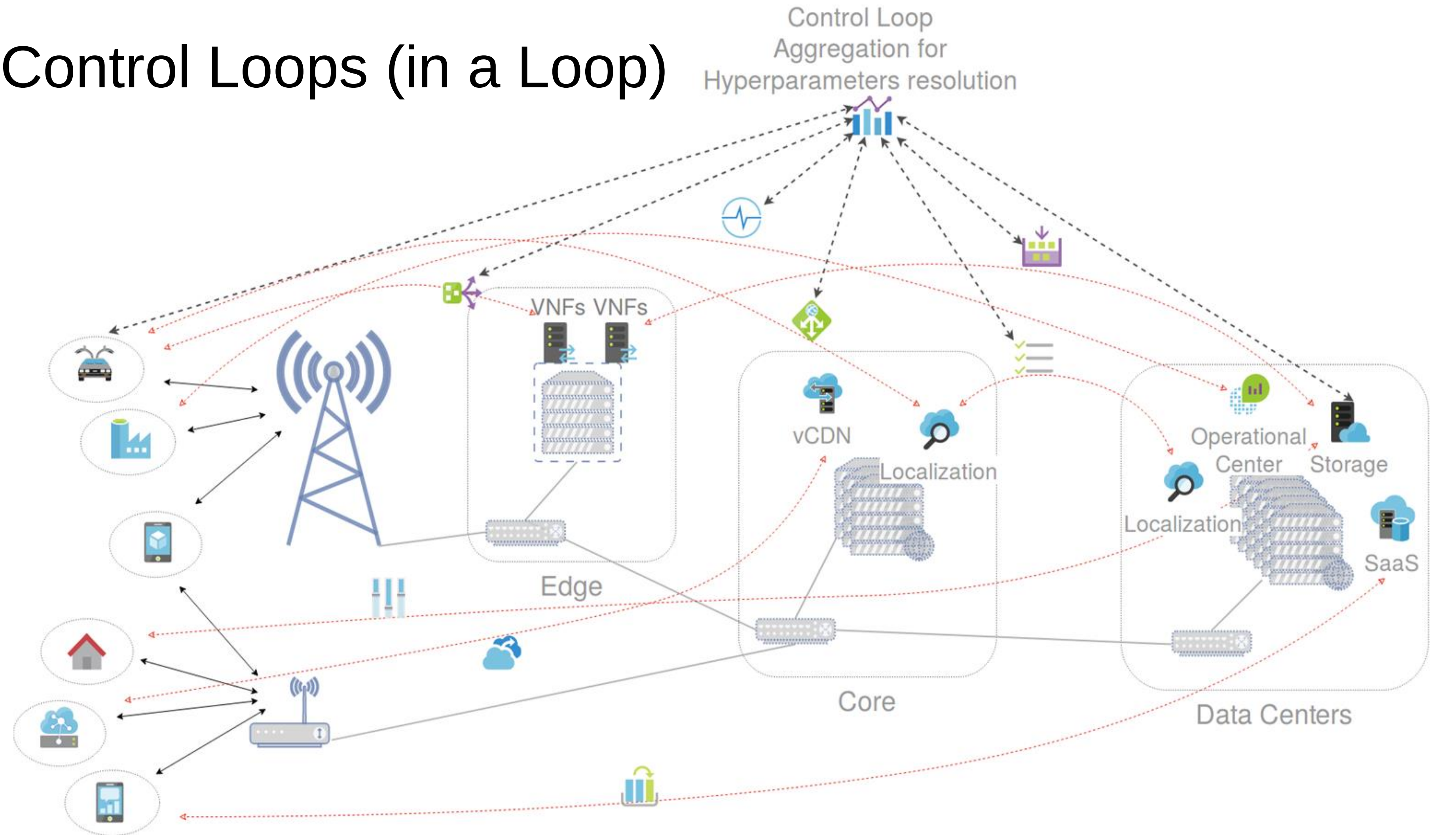
Control Loops (in a Loop)



Flexibility

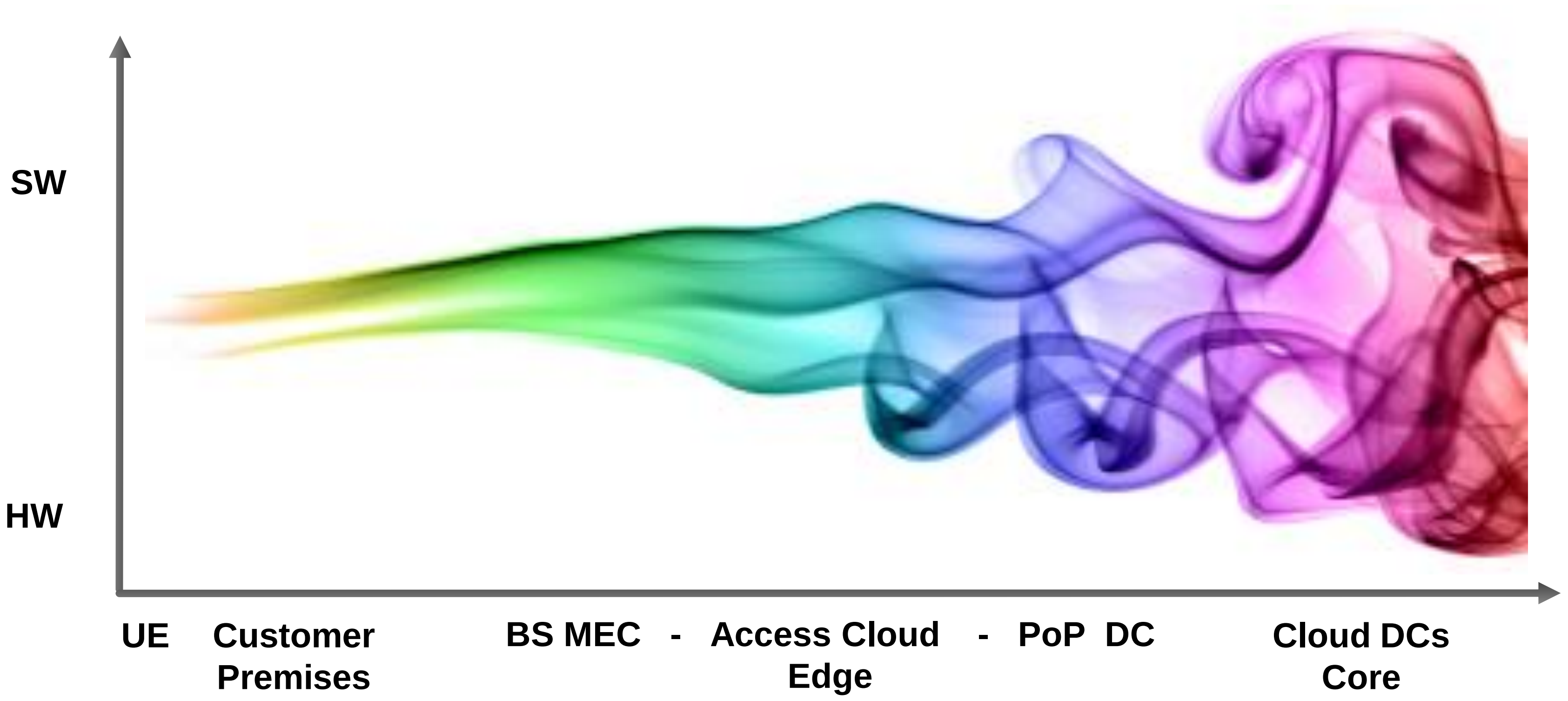
- M. He et al. “Flexibility in Softwarized Networks: Classifications and Research Challenges”

TABLE II

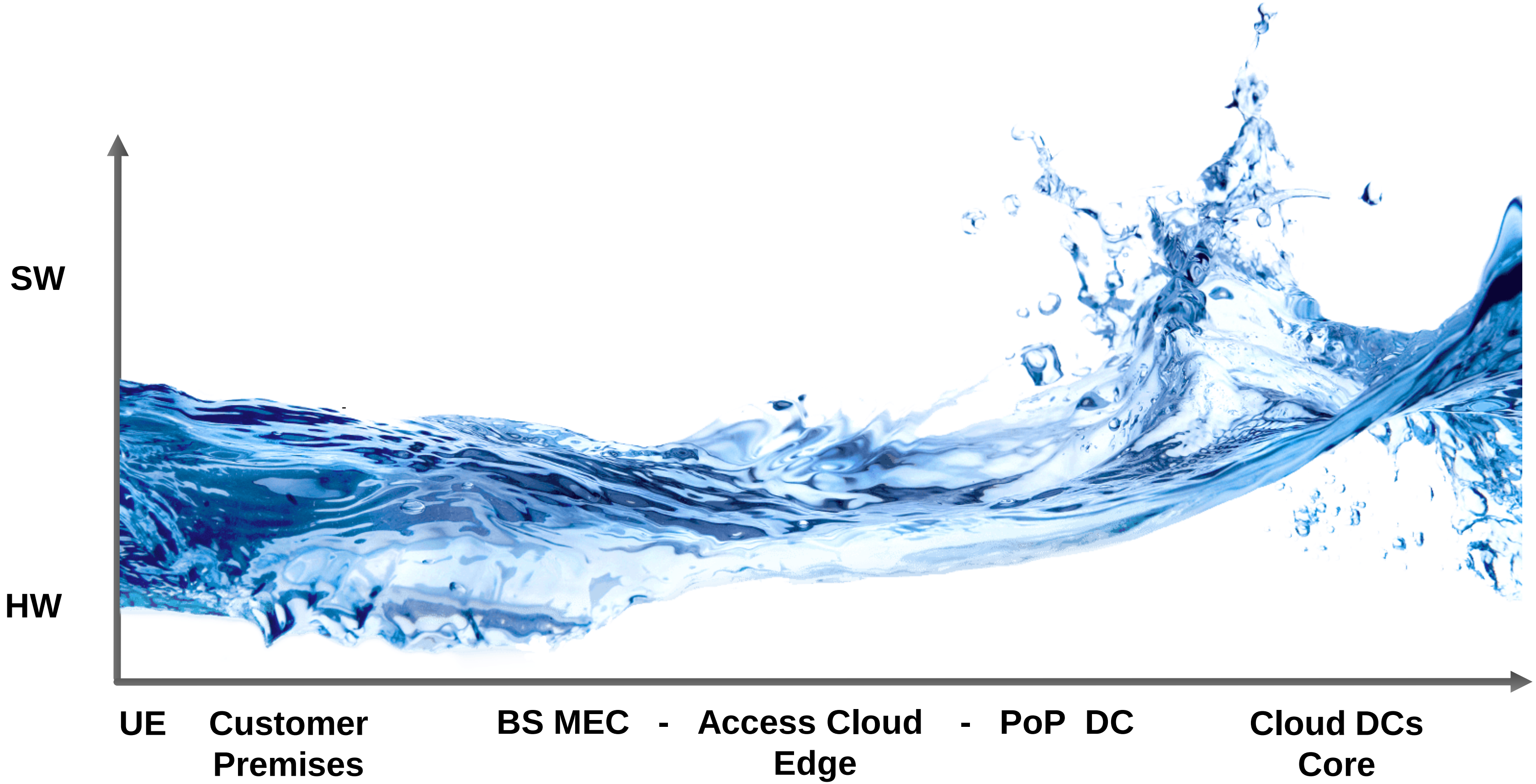
TECHNICAL CONCEPTS AND THEIR SUPPORT OF FLEXIBILITY IN NETWORKS. (✓: MAIN TARGET)

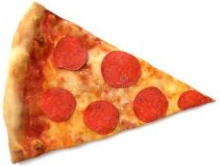
Category	**Aspect** (see Sec. III-B)	**SDN**	**NFV**	**NV**
Adapt configuration	Flow Configuration: flow steering	✓	-	-
	Function Configuration: function programming	-	✓	-
	Parameter Configuration: change function parameters	-	✓	✓
Locate functions	Function Placement: distribution, placement, chaining	-	✓	✓
Scale	Resource and Function Scaling: processing and storage capacity, number of functions	✓	✓	✓
	Topology Adaptation: (virtual) network adaptation	-	-	✓

The Fluid Networking landscape

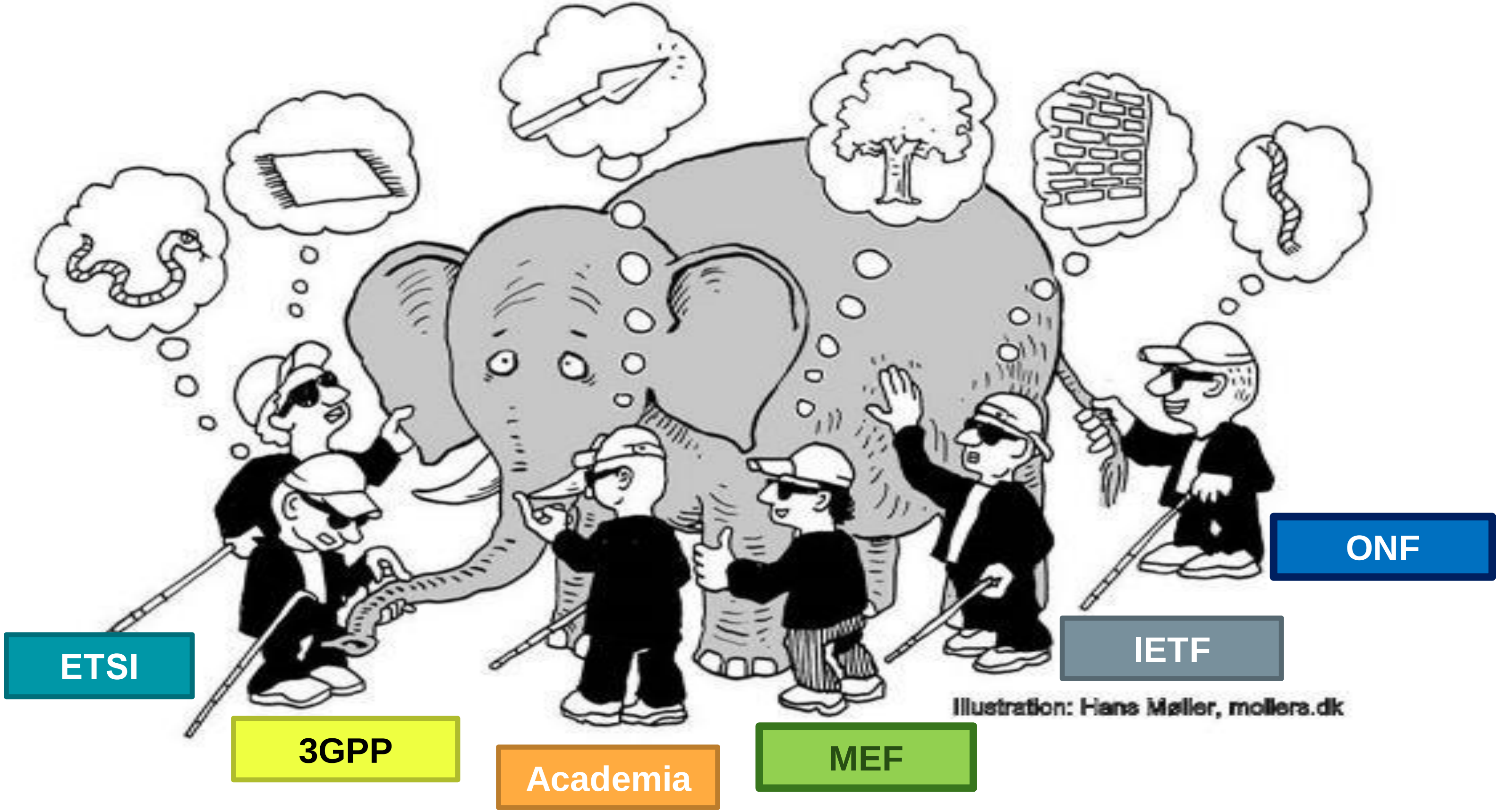


The Fluid Networking landscape

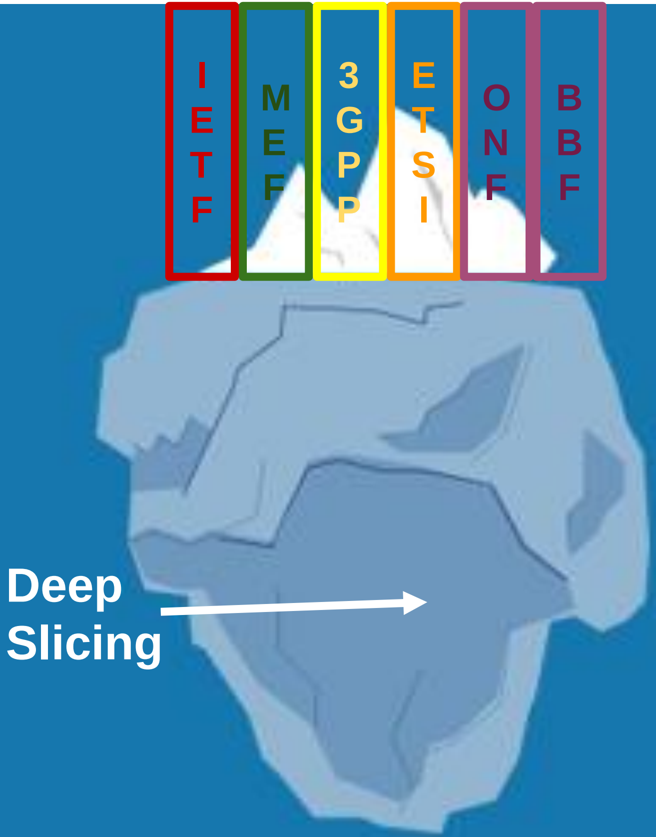




What is a Slice?



Towards **Deep Slices**



Fragmented Standardization

Business & Technological challenges
From infrastructure sharing to any-layer any-resource sharing (from PHY to APP)

Deep
End-to-End, Multi-Domain (tech + admin)
Tenant Choice & Control
Isolation
Scalable

any resource, any function anywhere

Deep Slicing: Challenges up front

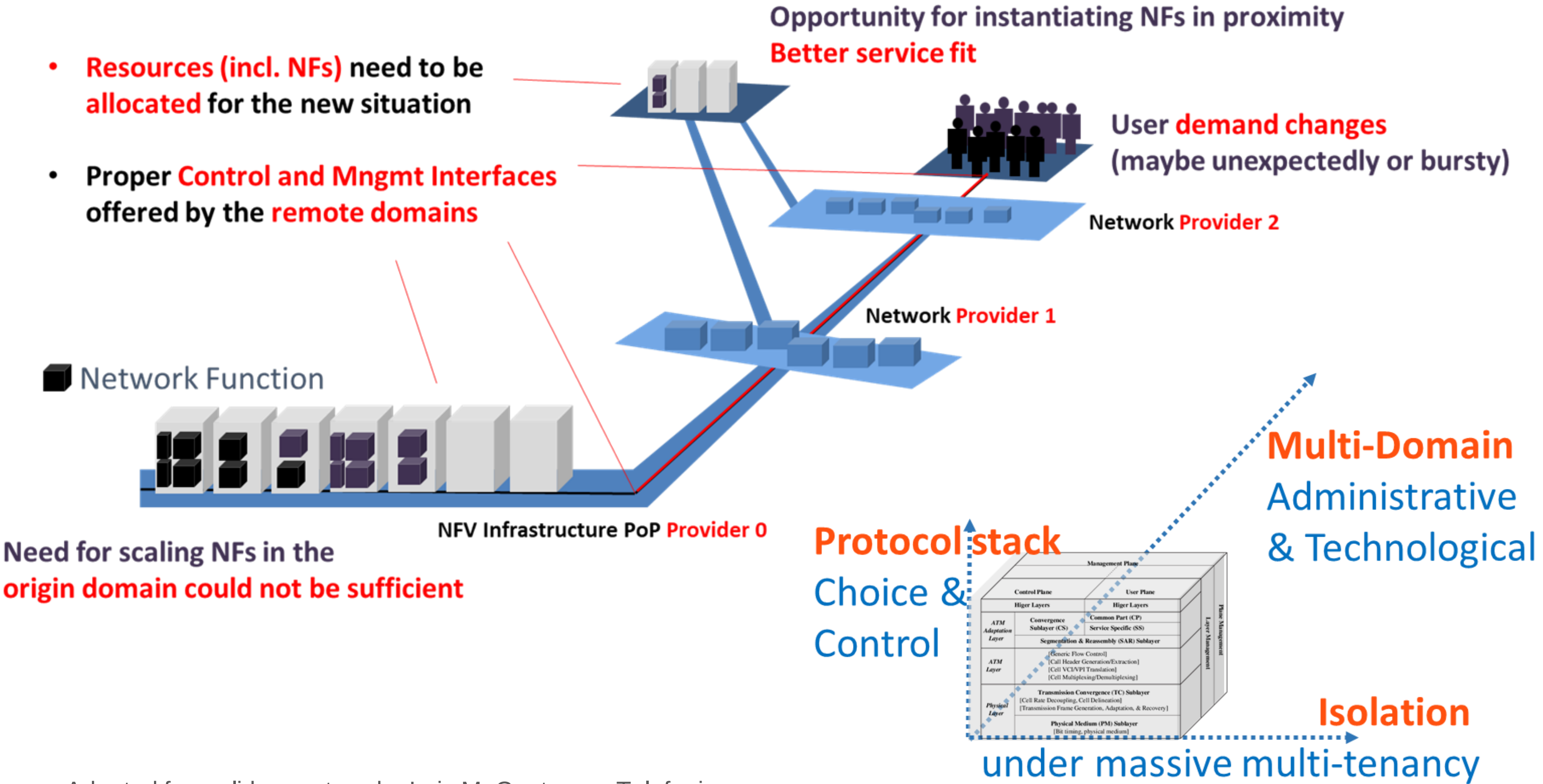
Standardization gap goes hand by hand with a series of **key challenges from provider's perspective** on (i) scalability, (ii) arbitration, (iii) slice planning and dimensioning, and (iv) multi-domain (cf. [FG-NET-Contribution]). Both business and technical implications can be deemed necessary for such multi-operator slice provisioning context.

From the **business** side, some key implications include: (i) coordination models, (ii) inter-provider SLAs, (iii) pricing schemes, (iv) service specification, and (v) customer facing advertisement.

From a **technical** perspective we highlight (i) slice decomposition, (ii) discovery of domains, (iii) common abstraction models, (iv) standard interfaces/protocols, APIs.

Source & further reading: Doc.6 ITU-T FG 2030 contribution: Network 2030 Challenges and Opportunities in Network Slicing
https://extranet.itu.int/sites/itu-t/focusgroups/net-2030/_layouts/15/WopiFrame.aspx?sourcedoc=%7bC4E9266E-1058-4035-AA25-451ABCB5C07B%7d&file=NET2030-I-006.docx&action=default

- Resources (incl. NFs) need to be allocated for the new situation
- Proper Control and Mngmt Interfaces offered by the remote domains



Source: Adapted from slide courtesy by Luis M. Contreras, Telefonica

Acknowledgments

Work by Christian Rothenberg was supported by the Innovation Center, Ericsson Telecomunicações S.A., Brazil under grant agreement UNI.64.

Ack. Mateus Santos and Pedro Gomes for input insights

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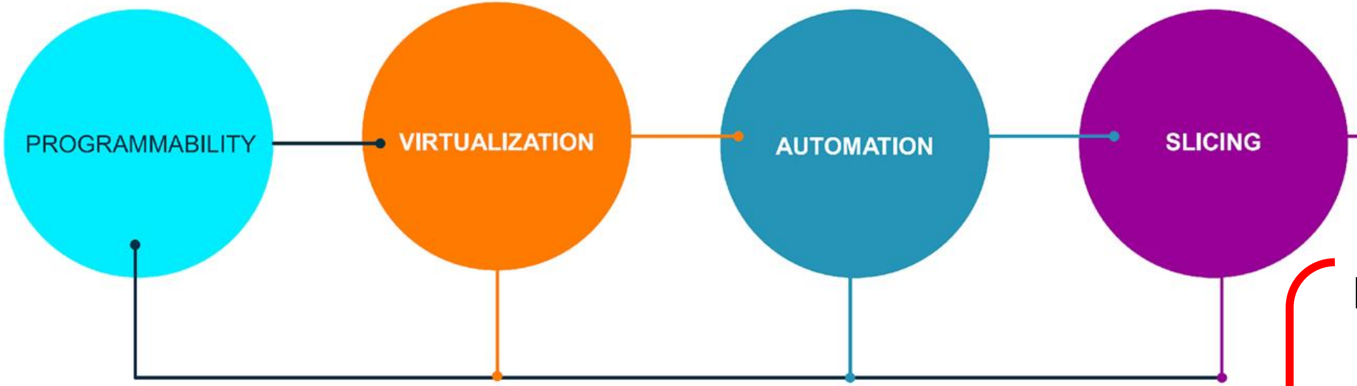
Luis M. Contreras and Alex Galis, co-authors of ITU-T FG 2030 input Doc.6: Network 2030 Challenges and Opportunities in Network Slicing.

Raphael Rosa (PhD candidate at UNICAMP), for his contributions to the vision around Unfolding Slices, Control Loops (in a Loop), Disaggregated Metrics/Prices, and Smart Peering

Slicing Journey: from 5G towads 2030



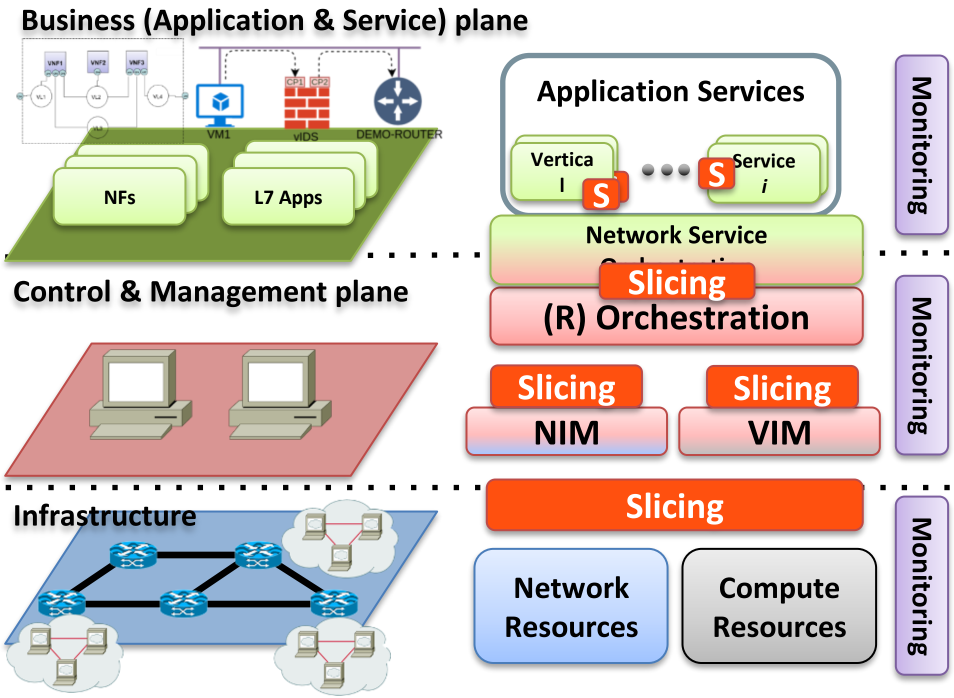
5G → **2030**

Executive Summary

- **From siloed slices to generalized network cloud slicing**
- **Deep, massive resource sharing & multi-tenancy**
- **New Tenant-Provider relationships and power of choices**

Source. Adapted from slide courtesy by Luis M. Contreras, Telefonica

Different Slicing Models & Approaches



Mode 3: Service-based
[Service Slice aaS]

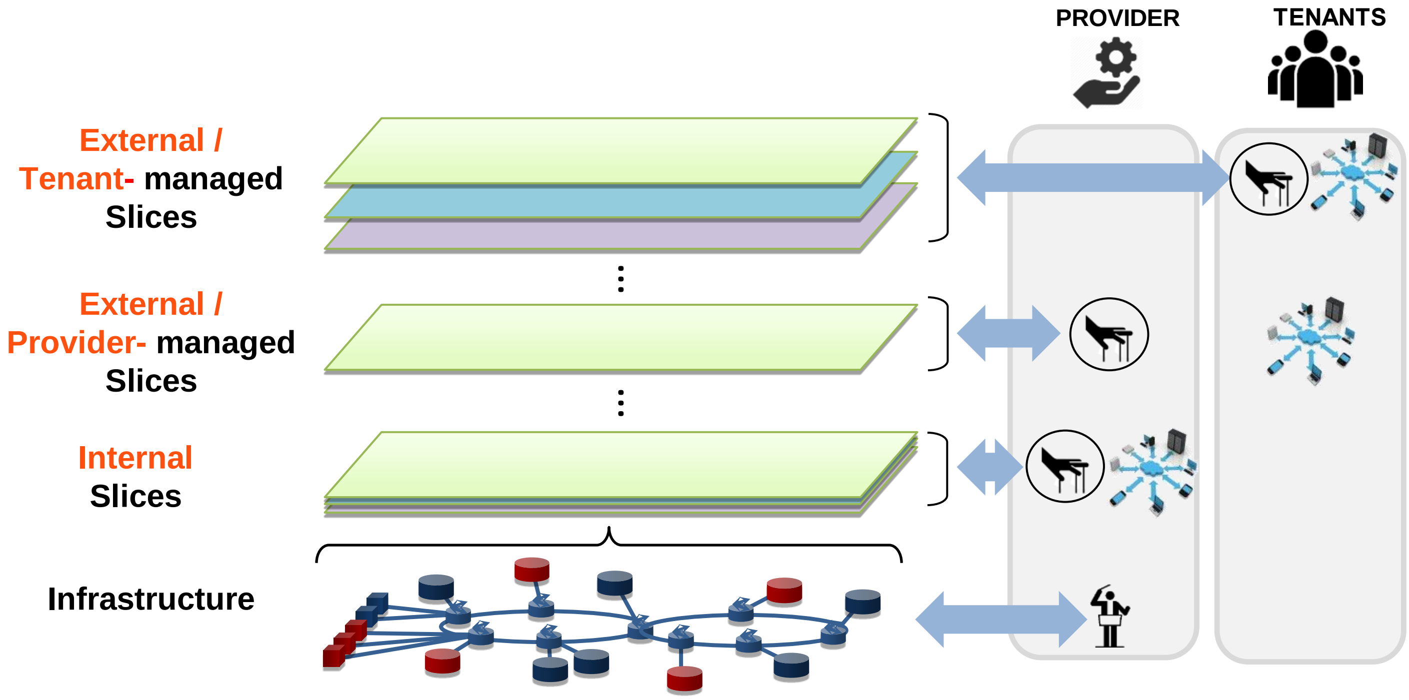
Mode 2: MANO-based
[NFV aaS]

Mode 1: VIM-dependent
[Platform Slice aaS]

Mode 0: VIM-independent
[Infra Slice aaS]
[Bare-metal Slice]

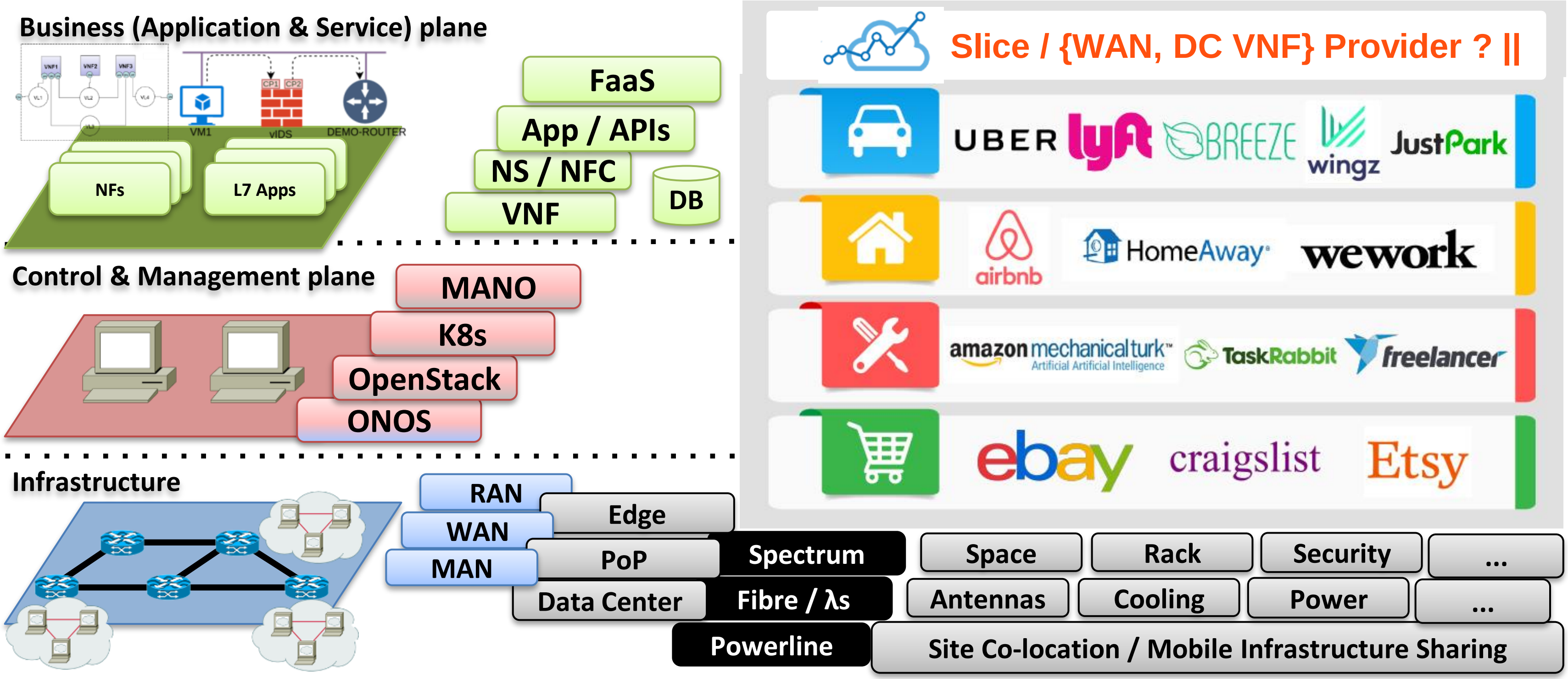
Source: The NECOS project, Novel Enablers for Cloud Slicing. http://www.h2020-necos.eu/

Types of Slices and Control Responsibilities



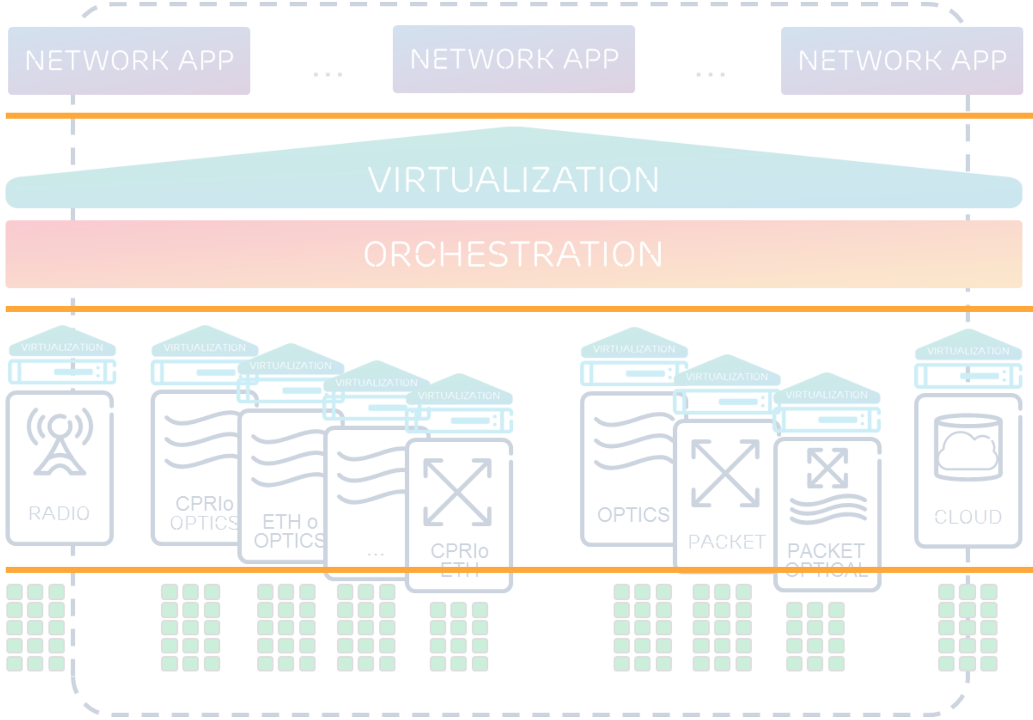
Source: A Network Service Provider Perspective on Network Slicing. Luis M. Contreras and Diego R. López. IEEE Softwarization, January 2018

Slicing under massive any resource multi-tenancy (gone wild) … or when sharing economy meets cloud network slicing



Source: http://www.h2020-necos.eu/ Source (image "sharing economy"): https://www.kreezalid.com/blog/78403-what-is-sharing-economy

Expose just enough information to make optimal resource orchestration.



Orchestration Layer: ~1

Domain Controllers: 10s

Network nodes: 1000s

Provide service

Simplified view
Relevant data

Detailed control
Technology dependent

Source: Netsoft 2017 Tutorial: End-to-End Programmability and Orchestration in 5G Networks.