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5G INDUCE

Open cooperative 5G experimentation platforms for the industrial sector NetApps

European Commission | Horizon 2020 European Union funding for Research & Innovation

5G PPP The 5G Infrastructure Public Private Partnership

S2N smart and secure networks

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Mobile Applications in 5G and Beyond – Orchestration, Performance Management and Energy Efficiency

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Outline

- Who we are
- Network softwarization
- 5G, virtualization and MEC
- From Cloud-native to 5G-ready applications
- Architectural solutions
- Multiple Orchestration levels
- Beyond 5G Management & Control
- Conclusions

Who we are and where we are

- **DITEN** is the **Department of Electrical, Electronic and Telecommunications Engineering, and Naval Architecture** of the **University of Genoa**
- **TNT Lab** is the **Laboratory of Telecommunication Networks and Telematics** of DITEN

CNIT – National Inter-University Consortium for Telecommunications

- Consortium of 37 Italian Universities
- Non-profit organization
- Founded in 1995
- Legal entity recognized by MUR (Italian Ministry of University)
- Mission: basic and applied research and advanced education in ICT
- 43 research units (37 universities+ 8 institutes of CNR)

- **6 National Laboratories** (Genova, Bologna, Pisa x2, L'Aquila, Napoli)
- **1300+ researchers; 100+ own employees**
- Funding from private companies and competitive programs only:
  - Europe H2020: 57 projects (23M€), **14 of them coordinated by CNIT (63M€)**, plus
    - Flagship Graphene, Flagship Quantum Information, Marie Curie ITN&IF
- **124 currently active projects, from:** Italy (Ministries, Italian Space Agency, Regions, local administrations), Europe, extra-EU (USA, China, South Korea, Taiwan, India, Israel), international institutions (EDA, ESA, ETSI, NATO), Private companies

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CNIT National Laboratory of Smart and Secure Networks (S2N), Genoa, Italy

Research Areas

Cybersecurity

- Protection of virtualized networking environments
- Multi-tier architecture
- Shared context security fabric
- Decoupled centralized business logic

5G and Beyond

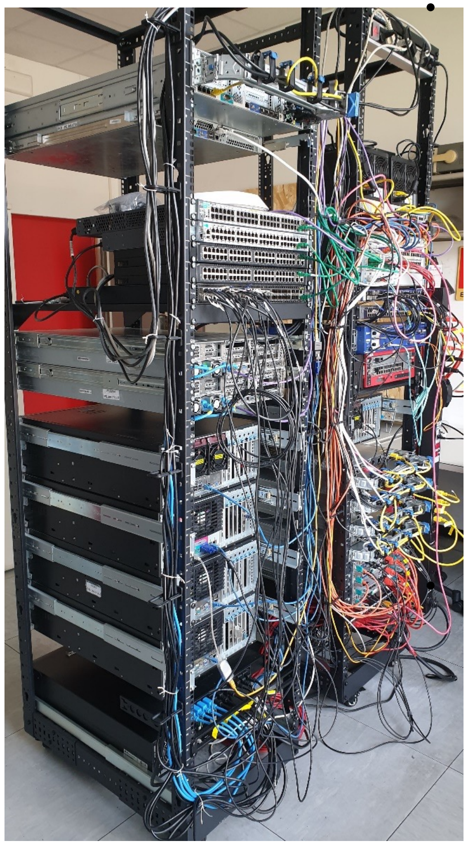
- Integration and convergence of mobile and fixed networking infrastructures
- From cloud-native to 5/6G-ready applications over dynamically configured and managed network slices.

Edge Computing

- Bringing cloud applications closer to users on the move by advanced SDN/NFV solutions within cloud-native technologies.

IoT

- Signal Processing solutions over IoT platforms
- Context-awareness applications in e-health, localization and UAV detection.



S2N Testbed

- **Infrastructure Level:**
  - 17 servers (700 cores, 2.5TB RAM, local & central SSDs/SAS storage >100TB),
  - 8 high-speed switches (918 ports from 1GbE to 40GbE),
  - 2x 5G NR gNBs, 3x LTE+ eNBs
  - Power monitors, hardware traffic generators, hardware firewalls, 12 UEs (drones, tablets, modems, etc.).
  - The test bed is flexibly managed through a Metal-as-a-Service approach (OpenStack instances as-a-Service)
  - Site-to-site and client-server VPNs
- **Platform Level:**
  - OSM
  - S2N OSS
  - 4/5G and networking VNFs
  - Vertical Application Orchestrator

S2N smart and secure networks

5G and network softwarization trends

- Modern cloud technologies and architectures are largely recognized as the foundations of the upcoming 5G ecosystem.
- They are expected to not only provide the needed means to allow the "softwarization" revolution in telecommunication infrastructures – mainly through the **Network Functions Virtualization (NFV)** framework – but also to act as key enablers for new (more pervasive and more network-integrated) computing paradigms like, for instance
  - **Mobile Edge Computing (MEC)**
  - **Fog Computing**

Cloud environment

- The cloud paradigms of
  - ***Infrastructure-as-a-Service (IaaS)***
  - ***Platform-as-a-Service (PaaS)***
  - ***Software-as-a-Service (SaaS)***

clearly define the type and the boundaries of offered service per actor.

- Actors offering IaaS services are providing their computing and/or networking infrastructures to third-party platform or software providers, usually referred to as *tenants*, through
  - **Virtual Infrastructure Managers (VIM)**
- Given the complexity of management and control operations performed by VIMs, a large part of them is often delegated to and automated by a "**Service Orchestrator**"

Networking

- The definition of the ETSI NFV Working Group is perfectly compliant with the Orchestration/VIM layering infrastructure.
- Although the NFV framework can be considered as an application of standard cloud computing technologies, it is a common opinion that the rising of 5G (and Beyond) will significantly affect the cloud evolution.
  - **Fog computing** and **MEC** are two clear preliminary signs of this trend.
- As the programmable resources will be an integral part of the 5G softwarized infrastructure, datacentres supporting 5G functions and vertical applications are supposed to be owned and maintained by **telecom infrastructure providers** (**telcos**), and to offer "private" (and in some case "hybrid") services.

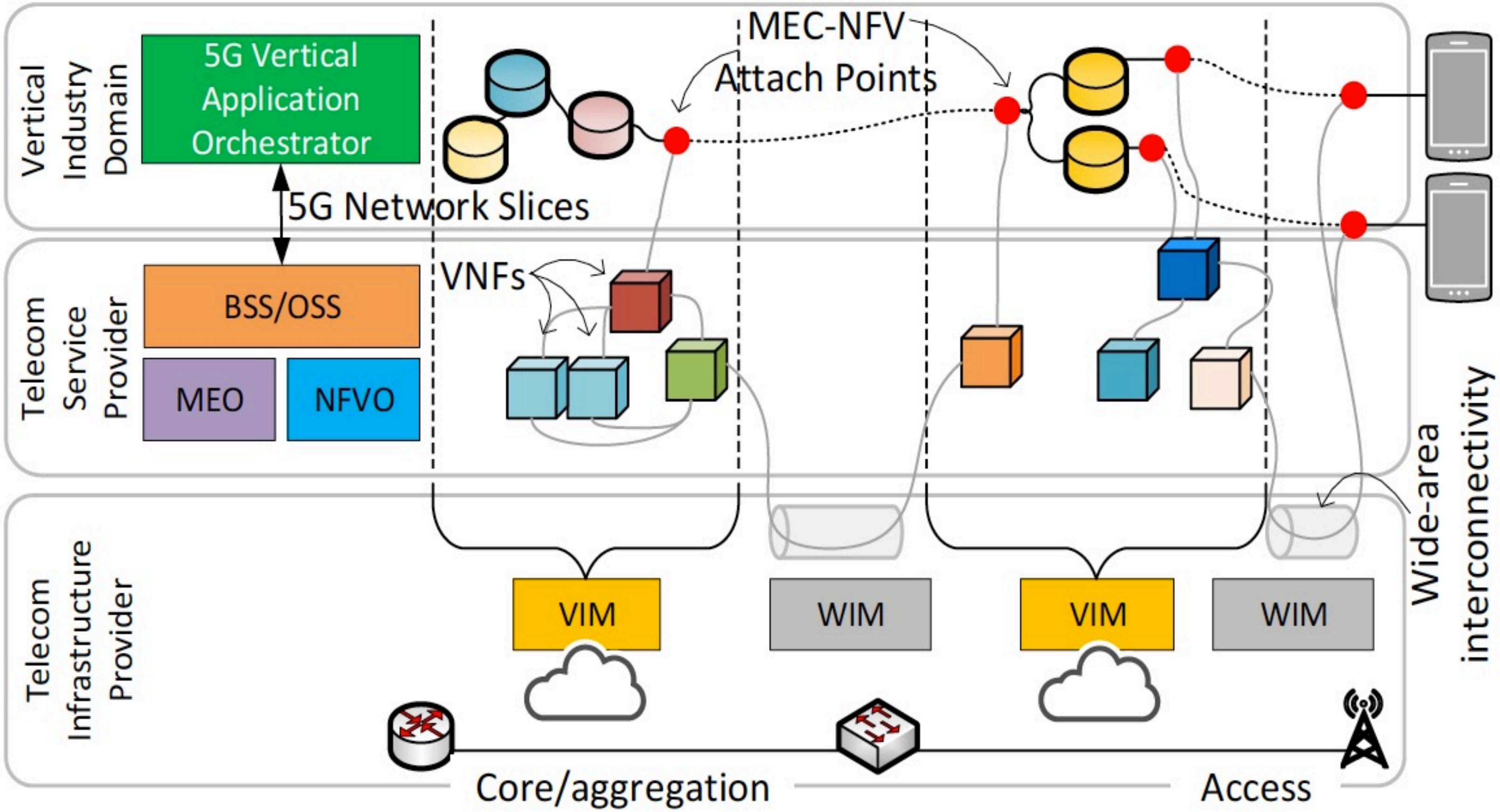
Ecosystem

- In this complex integrated scenario, it has become of paramount importance to clearly **separate orchestration concerns** between the **application world**, which is closer to the cloud-native approach, and the **telco NFV platforms**.
- The latter, though stemming from a similar paradigm, are oriented to providing **Network Services (NSs)** to the **vertical applications**, in order to offer flexible and dynamic resource allocation that should be tailored to the applications' needs.
- At the same time, they should allow **Network Service Providers (NSPs)** and **Infrastructure Providers (InPs)** to play their respective roles in full autonomy to compete in the telco marketplace to offer the best possible services and to try to maximize their revenue by efficient use of resources.
- In this framework, the concept of **network slicing** has emerged as a powerful architectural tool.

From Cloud-native to 5G-ready applications

- It is then necessary to **fill the integration gap** between the digital systems that enable **enhanced cloud-native services** and the **network layer**, by providing the tools to foster and speed up the extension/evolution of the cloud paradigm into the 5G ecosystem, intrinsically bridging the vertical application domain and the NS domain.
- As a step in this direction, **MATILDA** – *A Holistic, Innovative Framework for Design, Development and Orchestration of 5G-ready Applications and Network Services over Sliced Programmable Infrastructure* – (2017-2020), an H2020 5G-PPP Innovation Action (IA) coordinated by CNIT-S2N and comprising 18 partners from 10 European countries, aimed to fill this gap.
- MATILDA introduced a set of novel concepts including the **design and development of 5G-ready applications** -based on cloud-native / microservice development principles- the **separation of concerns among the orchestration** of the developed applications and the required NSs that support them, as well as the **specification and management of network slices that are application-aware** and can lead to optimal application execution.

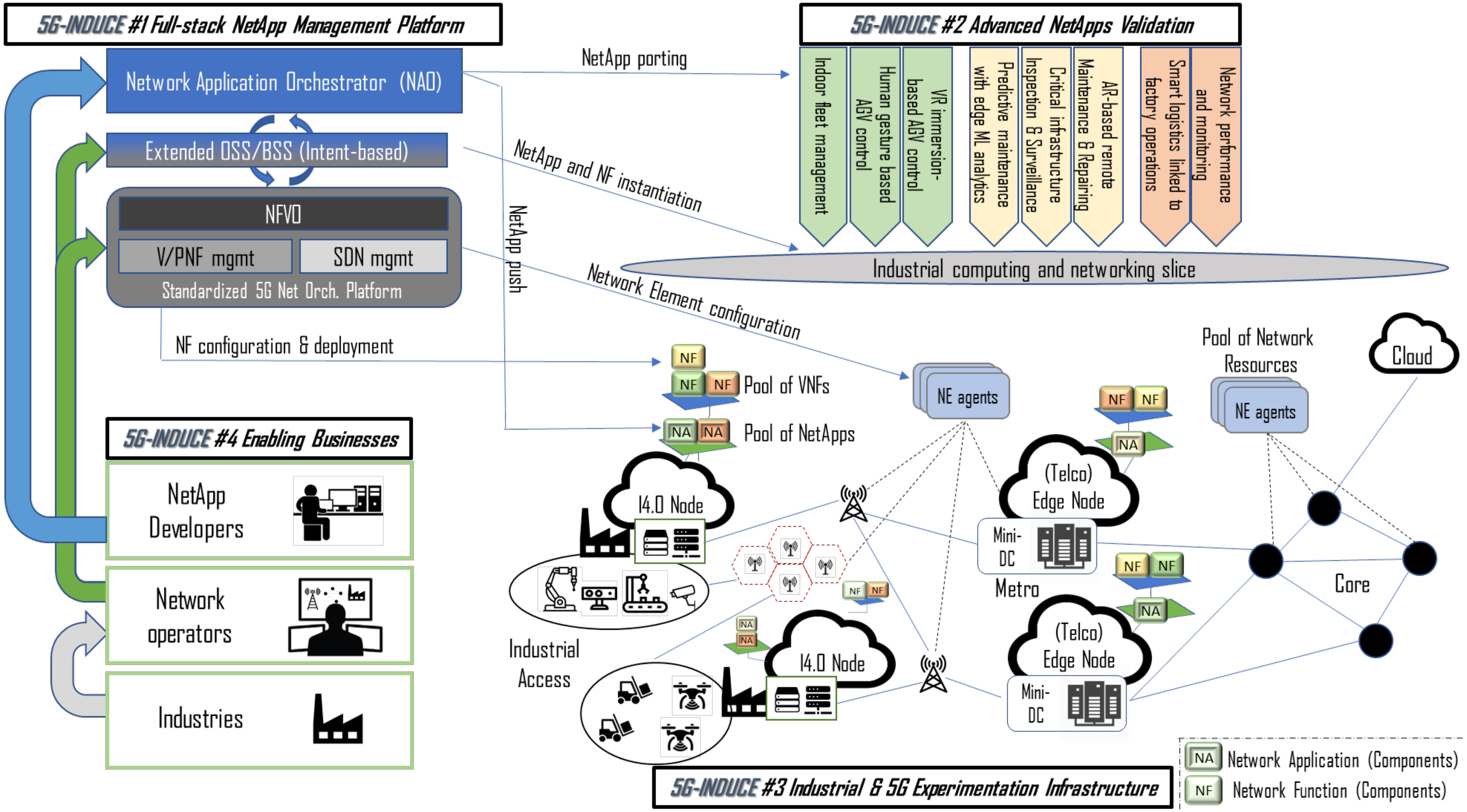
MATILDA Architectural framework



Source: R. Bruschi, R. Bolla, F. Davoli, A. Zafeiropoulos, P. Gouvas, "Mobile Edge Vertical Computing over 5G Network Sliced Infrastructures: An Insight into Integration Approaches," *IEEE Commun. Mag.*, vol. 57, no. 7, pp. 78-84, July 2019.

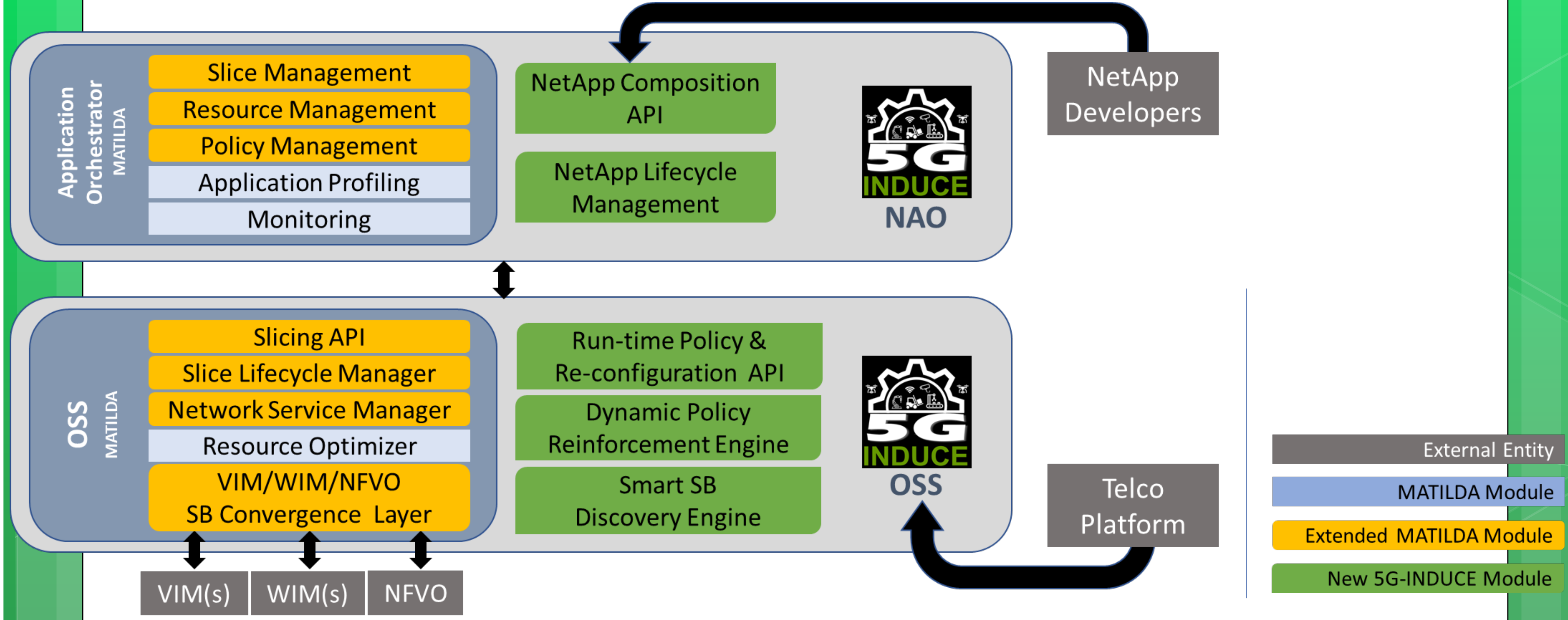
Example deployment of a vApp into a 5G infrastructure, main involved stakeholders and related architectural key building blocks. Also shown is the deployment of vApp components and VNFs into multiple VIMs, and their attachment to realize the interconnectivity among VIMs and towards UEs in the mobile network.

Further integration of NetApps – The 5G-INDUCE approach



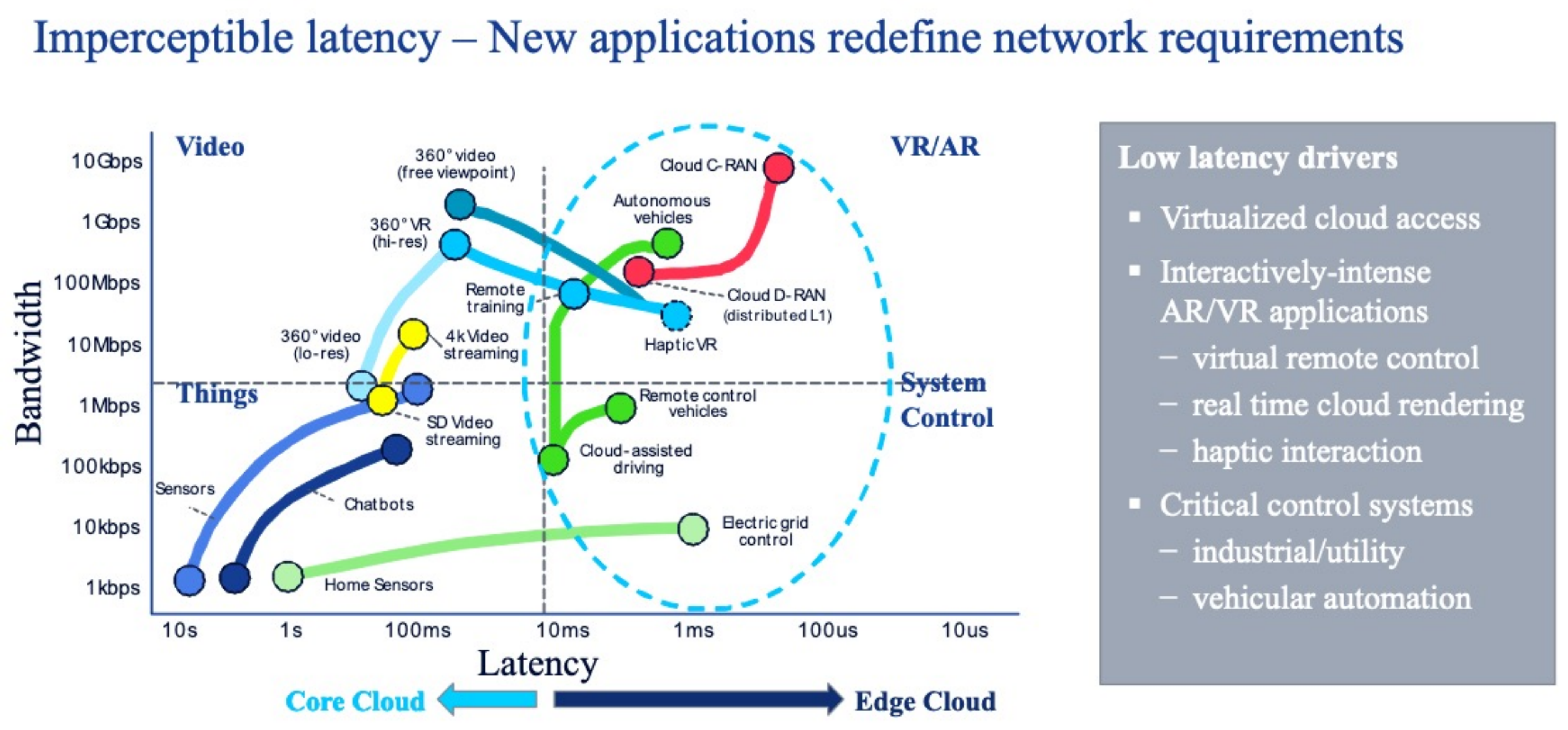
5G-INDUCE (2020-2023, 21 partners, CNIT-S2N coordination) targets the development of an open, ETSI NFV compatible, 5G orchestration platform for the deployment of advanced 5G NetApps for Industry 4.0 verticals.

5G-INDUCE NAO & OSS in support of NetApp developers



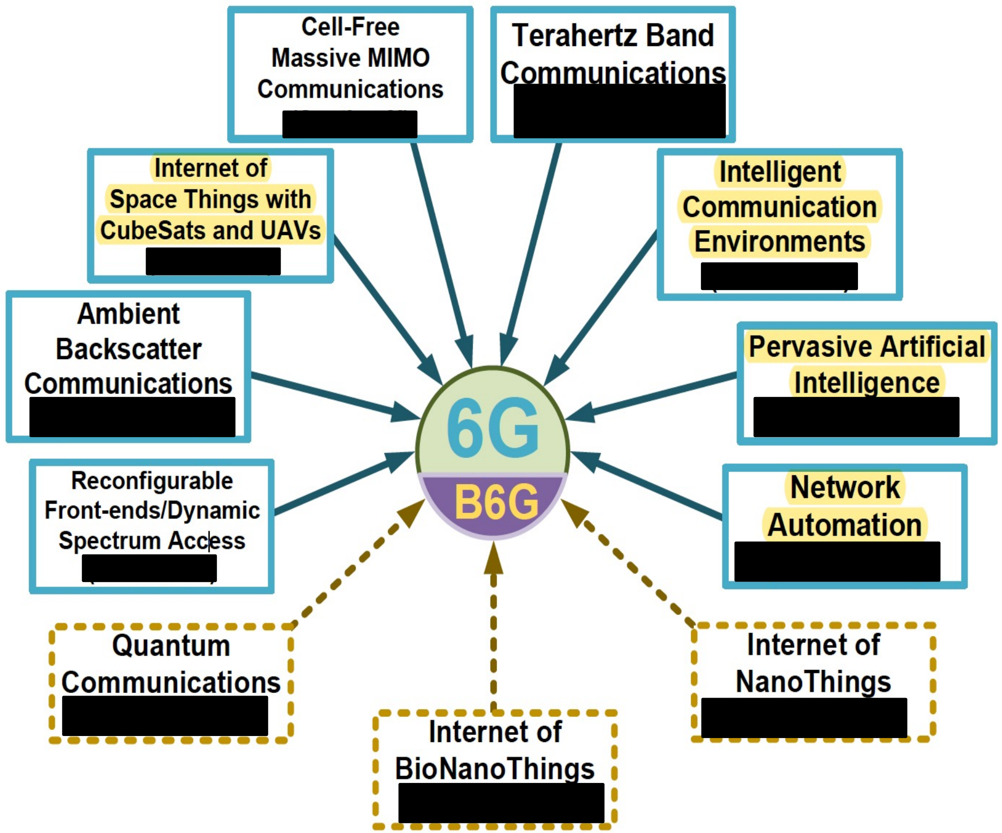
- NAO: Providing NetApp developers with the capability to define and modify the application requirements
- OSS: Exposing the network capabilities to the end users on the application level without revealing any infrastructure-related information
- Platform to be integrated over three 5G Experimentation Facilities in Spain, Greece, and Italy, while including links toward actual industrial sectors, to showcase NetApps in a real 5G environment

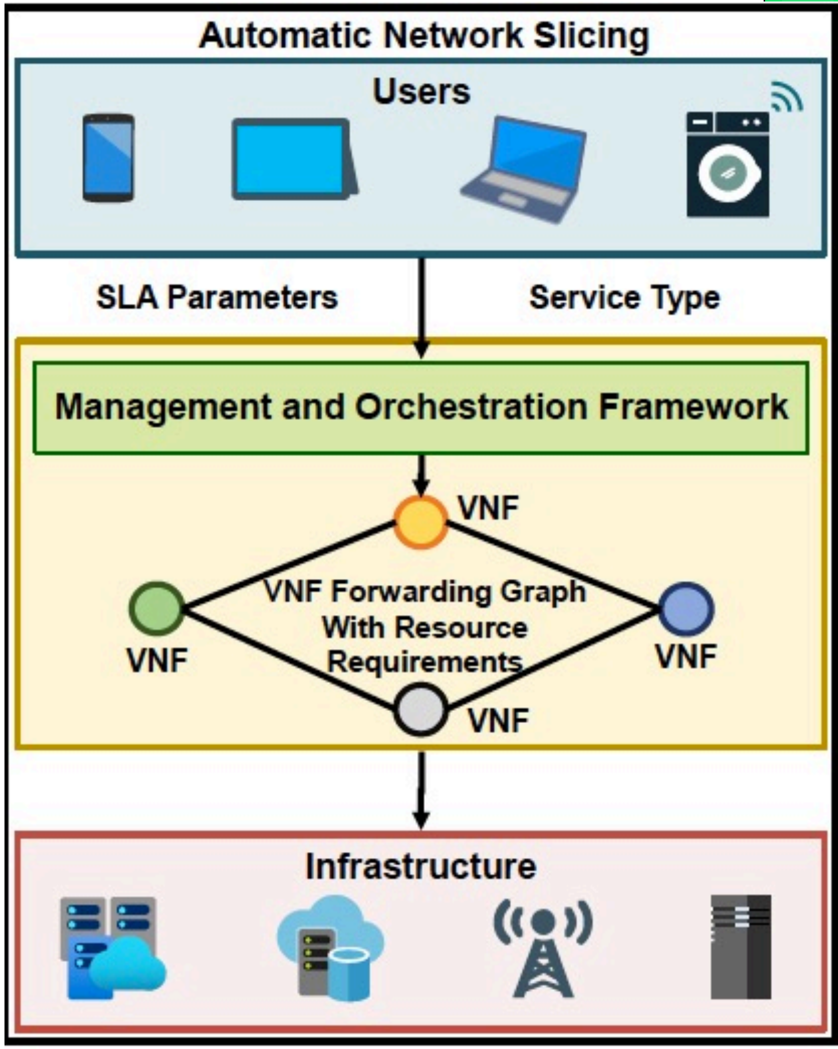
And Beyond 5G?



Source: W. Mohr, "Future Network Architecture Vision," presentation at the *Vision for Future Communication Summit*, Lisbon, Portugal, Oct. 2017; http://futurecomresearch.eu/previous/2017/site_pres/1M2/Werner_Mohr.pdf

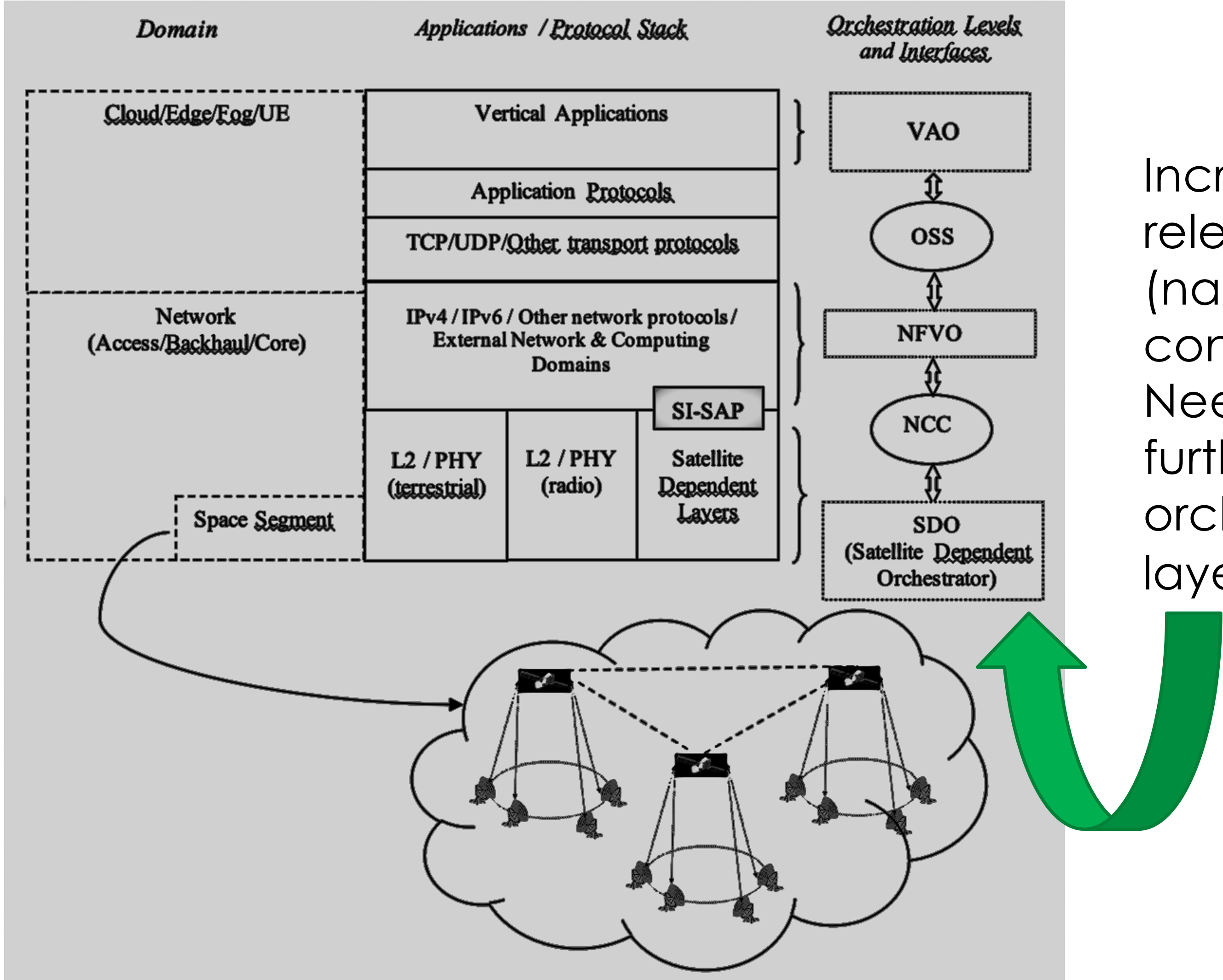
And Beyond 5G?





Source: I. F. Akyildiz, A. Kak, S. Nie, "6G and Beyond: The Future of Wireless Communications Systems," *IEEE Access*, vol. 8, pp. 133995-134030, July 2020.

And Beyond 5G?



Increased relevance of (nano)-satellite constellations – Need of a further orchestration layer?

Source: F. Davoli, M. Marchese, "Resource allocation in satellite networks – From physical to virtualized network functions", in P Nicopolitidis, S. Misra, L. T. Yang, *Advances in Computing, Informatics, Networking and Cybersecurity: A Book Honoring Professor Mohammad S. Obaidat's Significant Scientific Contributions*, Springer Nature, Cham, Switzerland, 2022.

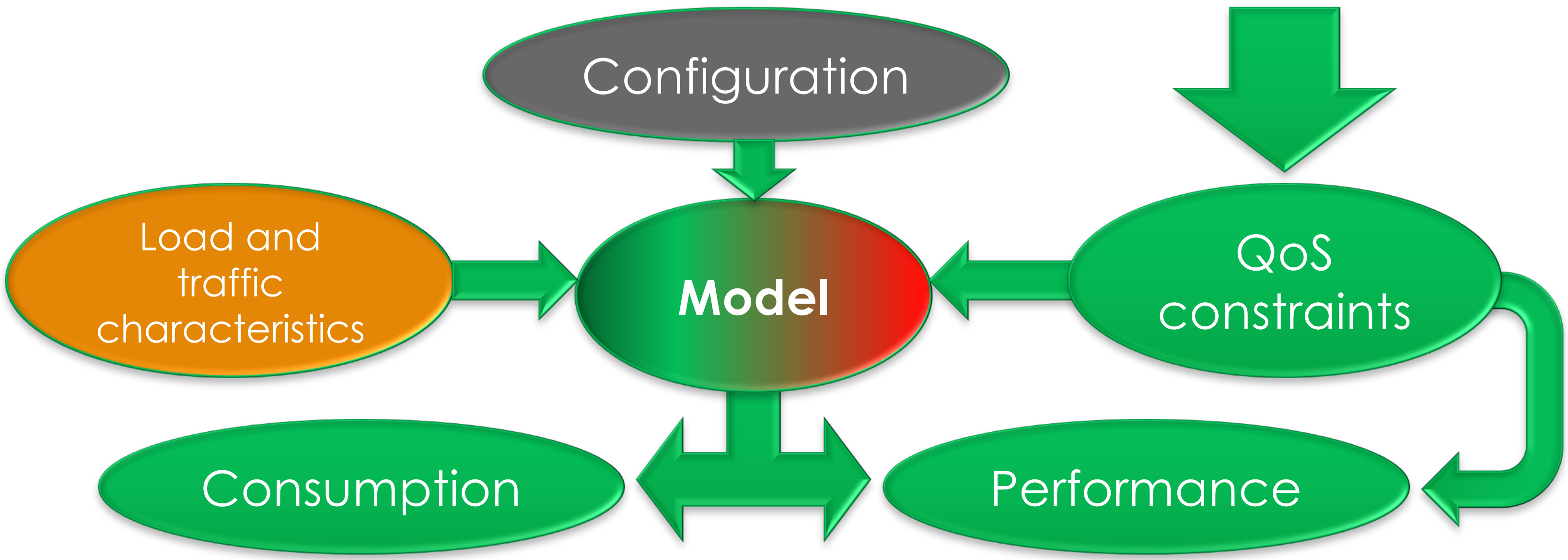
Analytical models for control

- In this scenario, **network management and control strategies** are essential to
  - orchestrate all needed functionalities
  - supervise and optimize the allocation of resources
  - ensure that KPIs (including **energy-efficiency**)are met for network slices under
    - the dynamic evolution of user-generated traffic
    - multiple tenants, service and infrastructure providers.
- Indeed, though a general reduction in OpEx is expected (besides the reduction in CapEx entailed by the use of general-purpose hardware) from the upcoming revolution in networking paradigms brought forth by SDN and NFV, this reduction will not come without the adoption of specific management and control solutions.
- Further, another relevant emerging aspect is the need for **faster response to control actions – even down to the sub-millisecond scale**, e.g. in Industry 4.0 applications.

Models for control

- There is typically a tradeoff between power consumption and the performance KPIs.

Unless applying AI/ML techniques specifically meant to bypass the issue of modeling, we need to model a VNF in terms of consumption and performance versus load and configuration



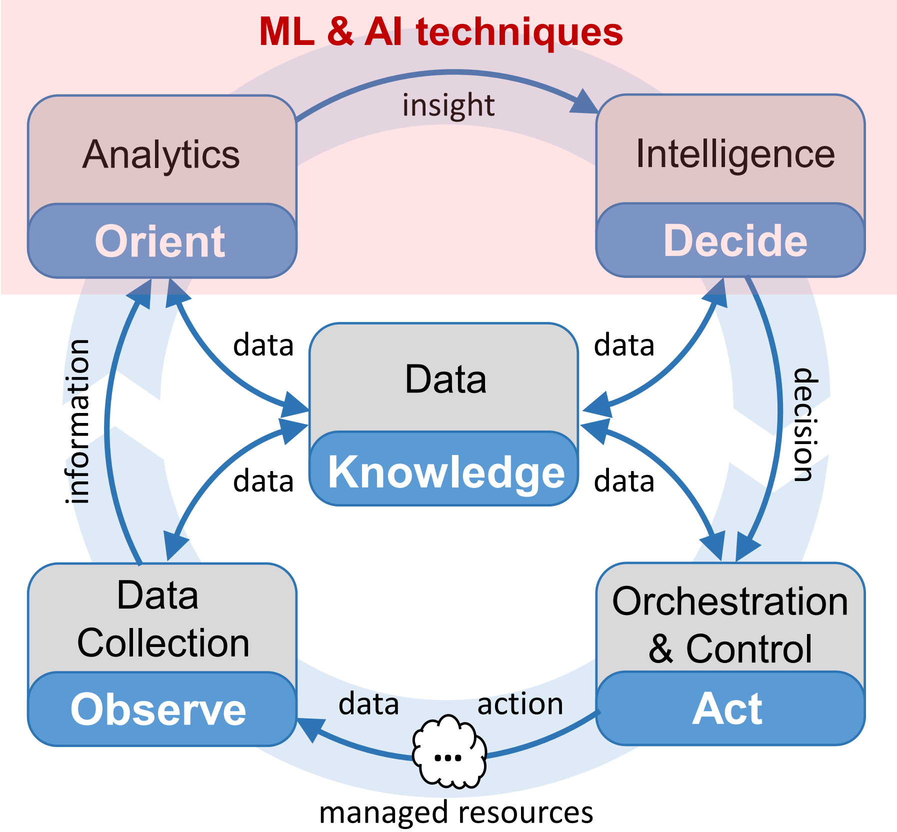
Modeling does not prevent the application of AI/ML to the synthesis of complex control strategies!

Models for performance analysis and control

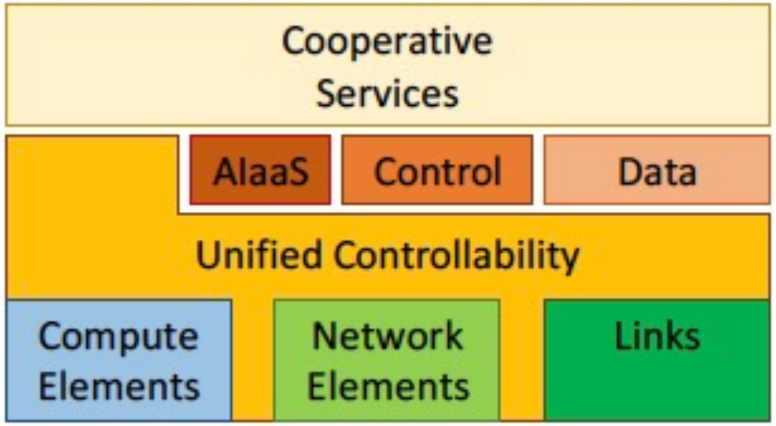
- Models based on classical queuing theory (e.g., the **M^X/G/1/SET**[1,2,3]) lend themselves to performance analysis or parametric optimization for adaptive control and management policies over longer (with respect to queueing dynamics) time scales.
- Game/Team Theory optimization and/or Hierarchical Control may apply in many distributed information contexts with decentralized information[4].
- Dynamic pre-configured techniques (e.g., switching control) may be needed for very fast adaptation to changes.

1. R. Bolla, R. Bruschi, A. Carrega, F. Davoli, "Green Networking with Packet Processing Engines: Modeling and Optimization," *IEEE/ACM Transactions on Networking*, vol. 22, no. 1, pp. 110-123, Feb. 2014
2. R. Bolla, R. Bruschi, A. Carrega, F. Davoli, J. F. Pajo, "Corrections to: 'Green Networking with Packet Processing Engines: Modeling and Optimization'," *IEEE/ACM Trans. Netw.*; published online 10 Oct. 2017, DOI: 10.1109/TNET.2017.2761892.
3. R. Bolla, R. Bruschi, F. Davoli, J. F. Pajo, "A model-based approach towards real-time analytics in NFV infrastructures", *IEEE Transactions on Green Communications and Networking*, vol. 4, no. 2, pp. 529-541, June 2020.
4. M. Aicardi, R. Bruschi, F. Davoli, P. Lago, J. F. Pajo, "Decentralized Scalable Dynamic Load Balancing among Virtual Network Slice Instantiations", *Proc. 2018 IEEE Global Communications Conference Workshops: International Workshop on Advanced Control Planes for Software Networks*, Abu Dhabi, UAE, Dec. 2018.

AI/ML for performance analysis and control



Source: "Zero-touch Network and Service Management (ZSM); Reference Architecture," ETSI GS ZSM 002 V1.1.1, Aug. 2019. https://www.etsi.org/deliver/etsi_gs/ZSM/001_099/002/01.01.01_60/gs_ZSM002v010101p.pdf

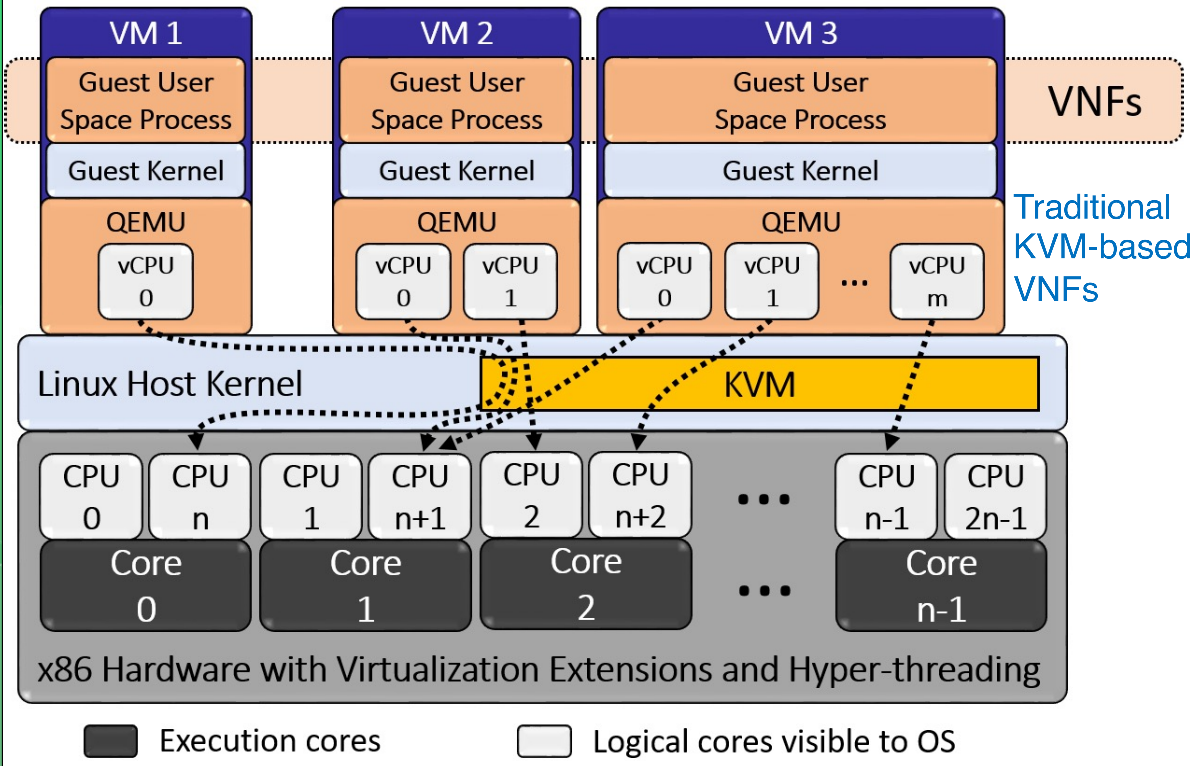


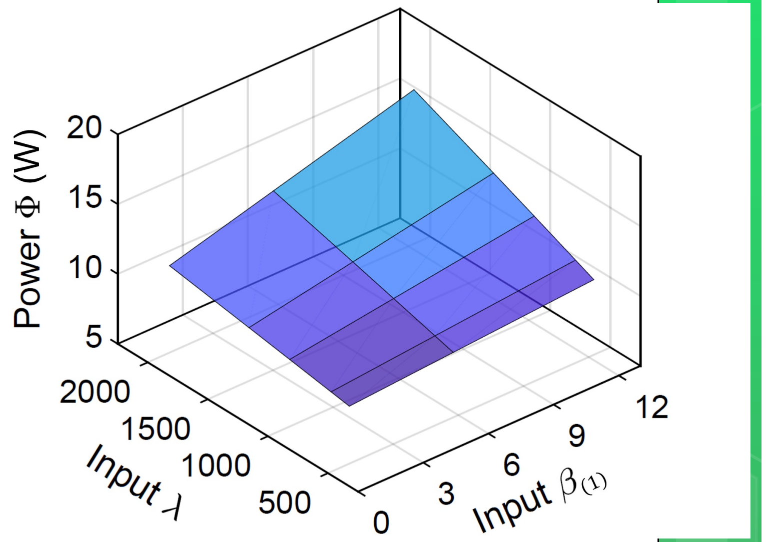
European Technology Platform NetWorld2020 (now NetWorldEurope), *Strategic Research and Innovation Agenda 2021-27*, "Smart Networks in the context of NGI", Sept. 2020.

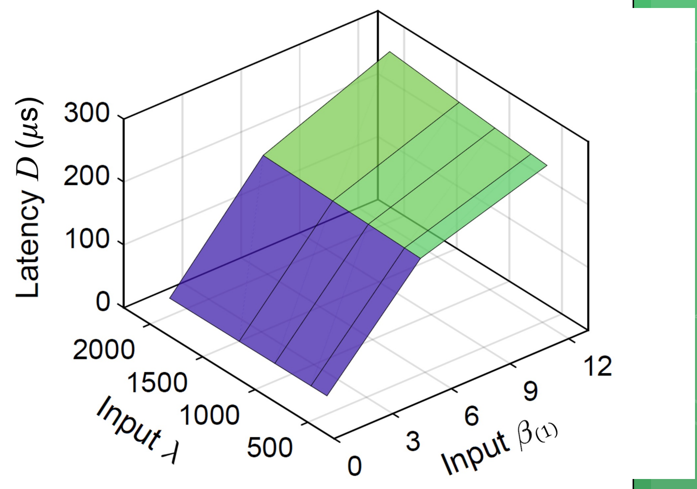
In control systems **Fixed Structure Parametrized Functions** (FSPF – e.g., Neural Networks) are a powerful tool to approximate optimal control techniques in Infinite Dimensional Optimization (IDO), i.e. *functional*, problems.

See: R. Zoppoli, M. Sanguineti, G. Gnecco, T. Parisini, *Neural Approximations for Optimal Control and Decision*. Springer Nature, Cham, Switzerland, 2019.

Application of queueing models







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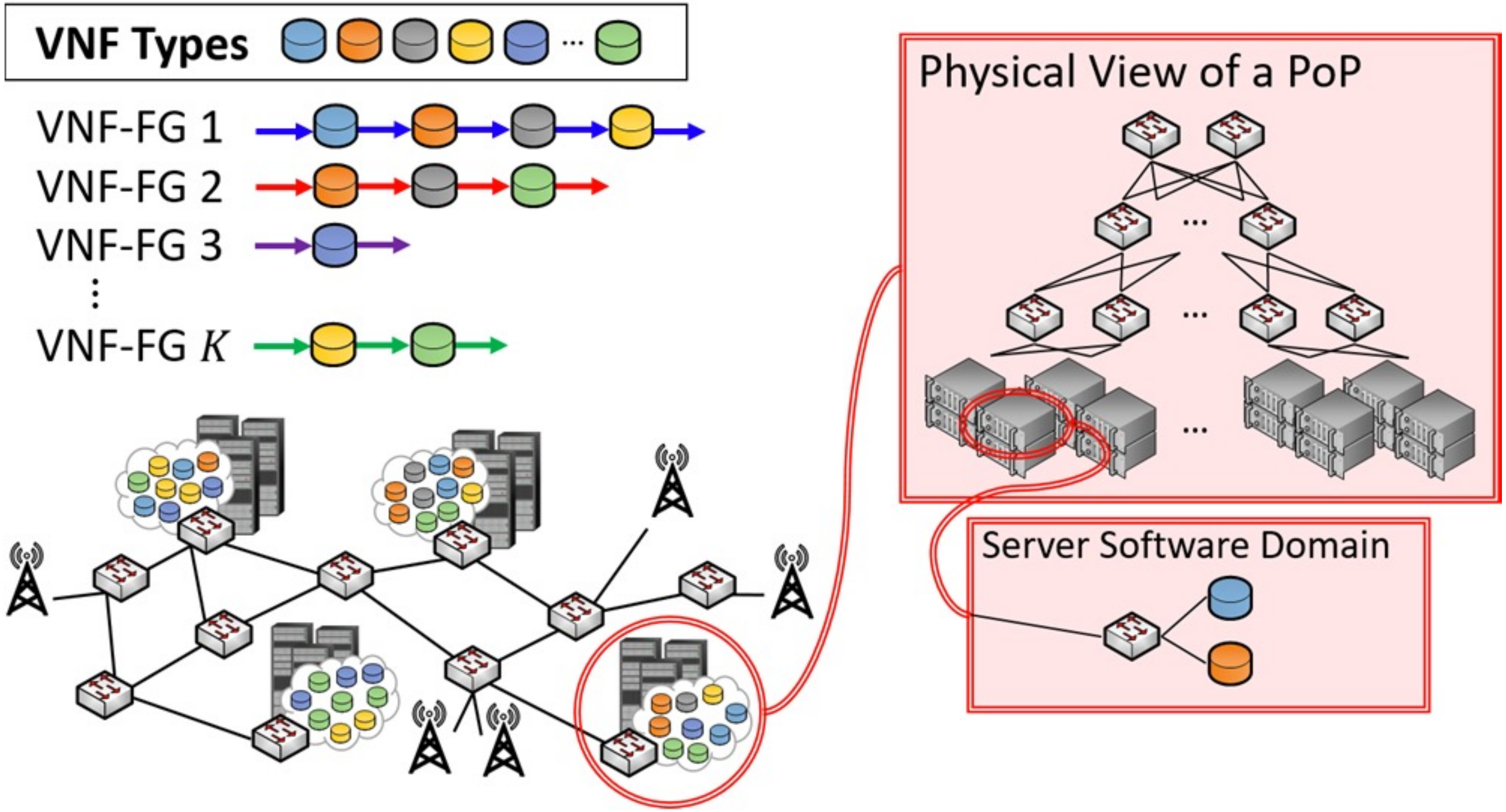


Delay-power consumption tradeoff in a Distributed VNF Chains Scenario – A Team Theory approach

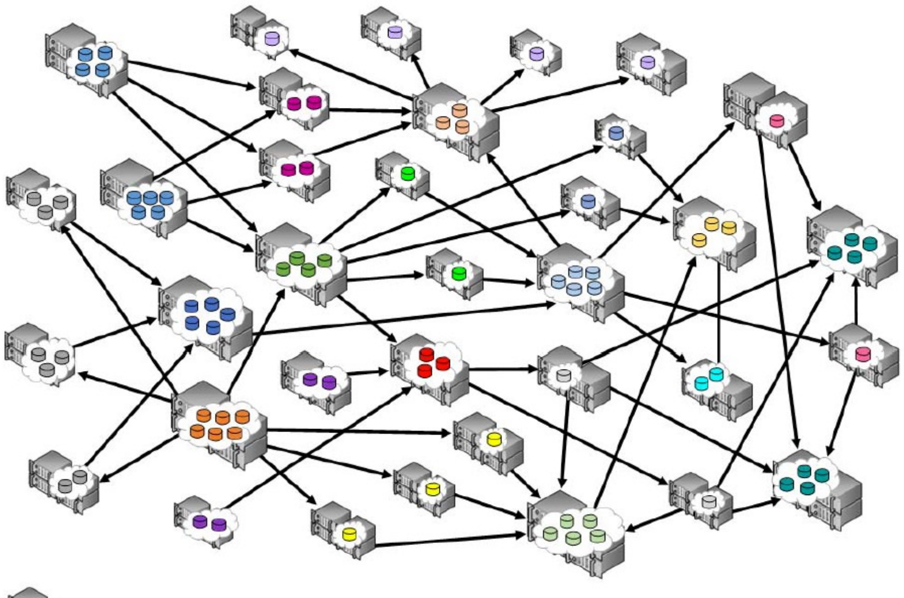
Source: M. Aicardi, R. Bruschi, F. Davoli, P. Lago, J. F. Pajo, "Decentralized Scalable Dynamic Load Balancing among Virtual Network Slice Instantiations", *Proc. 2018 IEEE Global Communications Conference Workshops: International Workshop on Advanced Control Planes for Software Networks*, Abu Dhabi, UAE, Dec. 2018.

Application of queueing models

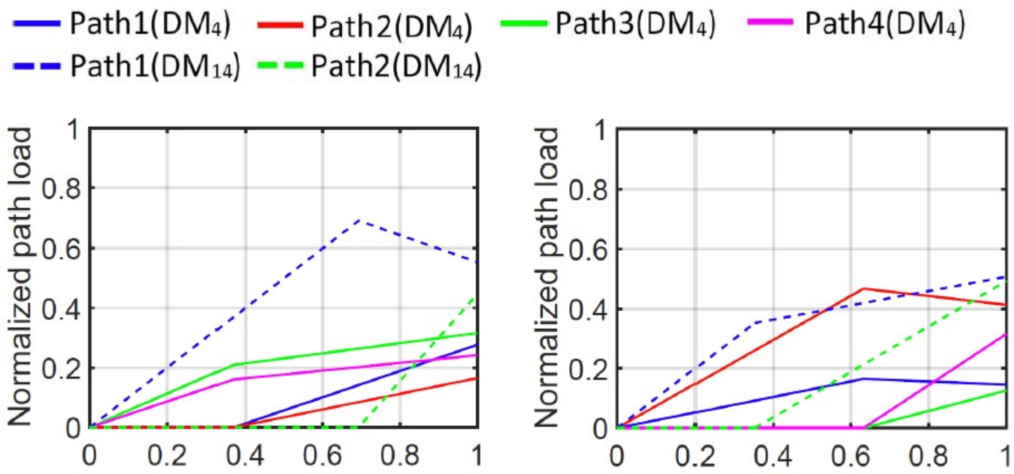
Decision Makers	NFV Services	Available VNF-FGs
DM_1, DM_{11}		DM_1: 4, DM_{11}: 2
DM_2, DM_{12}		DM_2: 3, DM_{12}: 2
DM_3, DM_{13}		DM_3: 3, DM_{13}: 2
DM_4, DM_{14}		DM_4: 4, DM_{14}: 2
DM_5, DM_{16}		DM_5: 4, DM_{16}: 4
DM_6		DM_6: 4
DM_7, DM_{19}, DM_{20}		DM_7: 4, DM_{19}: 2, DM_{20}: 2
DM_8, DM_{17}, DM_{18}		DM_8: 4, DM_{17}: 2, DM_{18}: 2
DM_9		DM_9: 3
DM_{10}, DM_{15}		DM_{10}: 4, DM_{15}: 2

(a) NFV service specifications

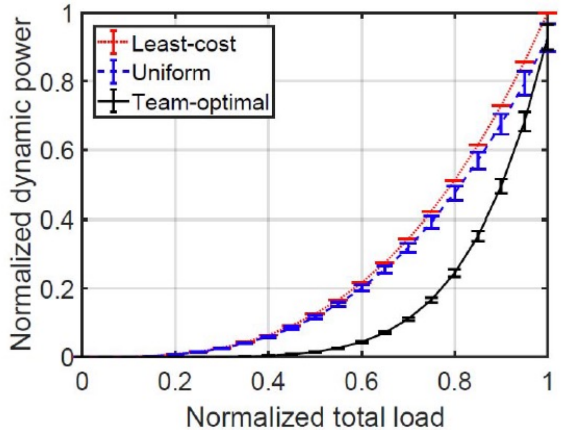
VNF Types	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t
# of Instances	9	6	8	5	4	4	3	4	2	3	5	3	2	2	5	2	3	2	4	8



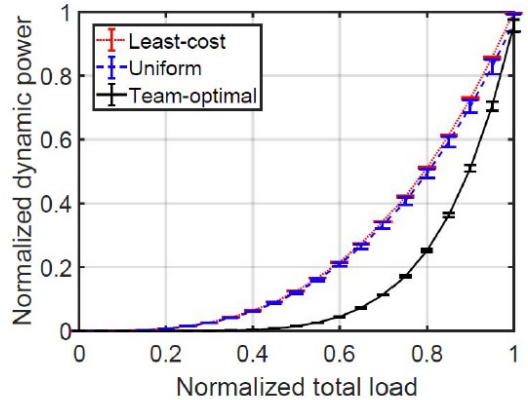
(b) NFV network



(a) homogeneous HW (b) heterogeneous HW



(a) homogeneous HW



(b) heterogeneous HW

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- Paper submission: 13 December 2021
- Paper acceptance notification: 14 February 2022
- Camera-ready paper submission: 14 March 2022

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Special issue on

Integrated and autonomous network management and control for 6G time-critical applications

Call for papers

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Suggested topics (but not limited to):

New architectures for network management and control

- Convergence toward integration of management and control
- Advanced management and control architectural paradigms capable of facing the challenges of reduced response times
- Distributed and hierarchical integrated management and control paradigms
- 6G network scenarios for integrated and autonomous network management and control
- Network control and management loops interaction vs. integration

Network reliability, fast scalability, reconfigurability and energy efficiency for time-critical applications

- Advanced model-based and AI/ML-based control techniques
- ML algorithms for fast dynamic resource allocation
- Fast scalability of network slices
- Control/management paradigms with energy-performance trade-off
- Feasibility and challenges for sub-millisecond network control and management
- Management and control techniques for reliable and highly available services
- 6G time-critical applications and verticals

Use cases and enabling technologies

- Use cases and requirements for real time and near-real time network control and management
- Case studies and use cases in Industrial IoT applications with tight response times
- Enabling technologies for operational tasks (monitoring, measurement acquisition, policy adaptation, actuation)
- Strategies for the allocation of computational tasks among micro-datacenters in the edge and datacenters in the cloud

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Conclusions

- We have briefly examined the ongoing development of architectural and functional solutions for orchestration and management in the cloud and in virtualized telco platforms, along with their perspectives in the framework of 5G and beyond.
- The **separation between Orchestrators at various architectural levels** has been highlighted, along with their interaction through the concept of slice intent and the OSS.
- Within the challenges posed by the Future Internet in general, and particularly by the strong wireless/wired integration of the 5G/6G environment, four broad topics, among others, can be seen as interacting and mutually influencing:
  - **flexibility, programmability and virtualization** of network functions and services
  - **performance requirements** (in terms of users' Quality of Experience – QoE – and its mapping onto Quality of Service – QoS – in the network),
  - **energy efficiency**
  - **network management and control, especially at very short time scales**
- Sophisticated control/management techniques can be realistically deployed – *both* at the network edge and inside the network – to dynamically shape the allocation of resources and relocate applications and network functionalities, trading off QoS/QoE and energy at multiple granularity levels.