MATILDA

A HOLISTIC, INNOVATIVE FRAMEWORK FOR THE DESIGN, DEVELOPMENT AND ORCHESTRATION OF 5G-READY APPLICATIONS AND NETWORK SERVICES OVER SLICED PROGRAMMABLE INFRASTRUCTURE

5G PPP

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Mobile Edge Computing in the 5G Era – Bridging Applications and Networking Environments

Franco Davoli

DITEN-University of Genoa, Italy

CNIT – University of Genoa Research Unit and National Laboratory of Smart and Secure Networks (S2N)

with Raffaele Bolla, Roberto Bruschi and Jane Frances Pajo (on behalf of the MATILDA Consortium)

Outline

- Network softwarization
- 5G, virtualization and MEC
- From Cloud-native to 5G-ready applications
- Architectural solutions
- Multiple Orchestration levels
- Management & Control
- A glimpse to Energy Efficiency
- Conclusions

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)**

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)**

Cloud environment

- The VIM provides tenants with
  - inventories,
  - provisioning and de-provisioning operations,
  - management of virtual compute, storage and networking resources,
  - communication with the underlying physical resources (e.g., hypervisors, network switches, etc.)
- Given their complexity, a large part of these operations is often delegated and automated by a “**Service Orchestrator**”

Networking

- The definition of the ETSI NFV Working Group is perfectly compliant with the Orchestration/VIM layering infrastructure.
- Any actors (PaaS or SaaS providers) playing on top of the VIM layer shall have their own Orchestrator and, in case of PaaS providers, multiple Orchestrator modules might act in cascade.
- 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 technologies will significantly affect the cloud evolution.
  - Fog computing and **MEC** are two clear preliminary signs of this trend.

Ecosystem

- 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.
- During the latest few years, the NFV community selected OpenStack as the reference VIM for 5G/NFV environments.

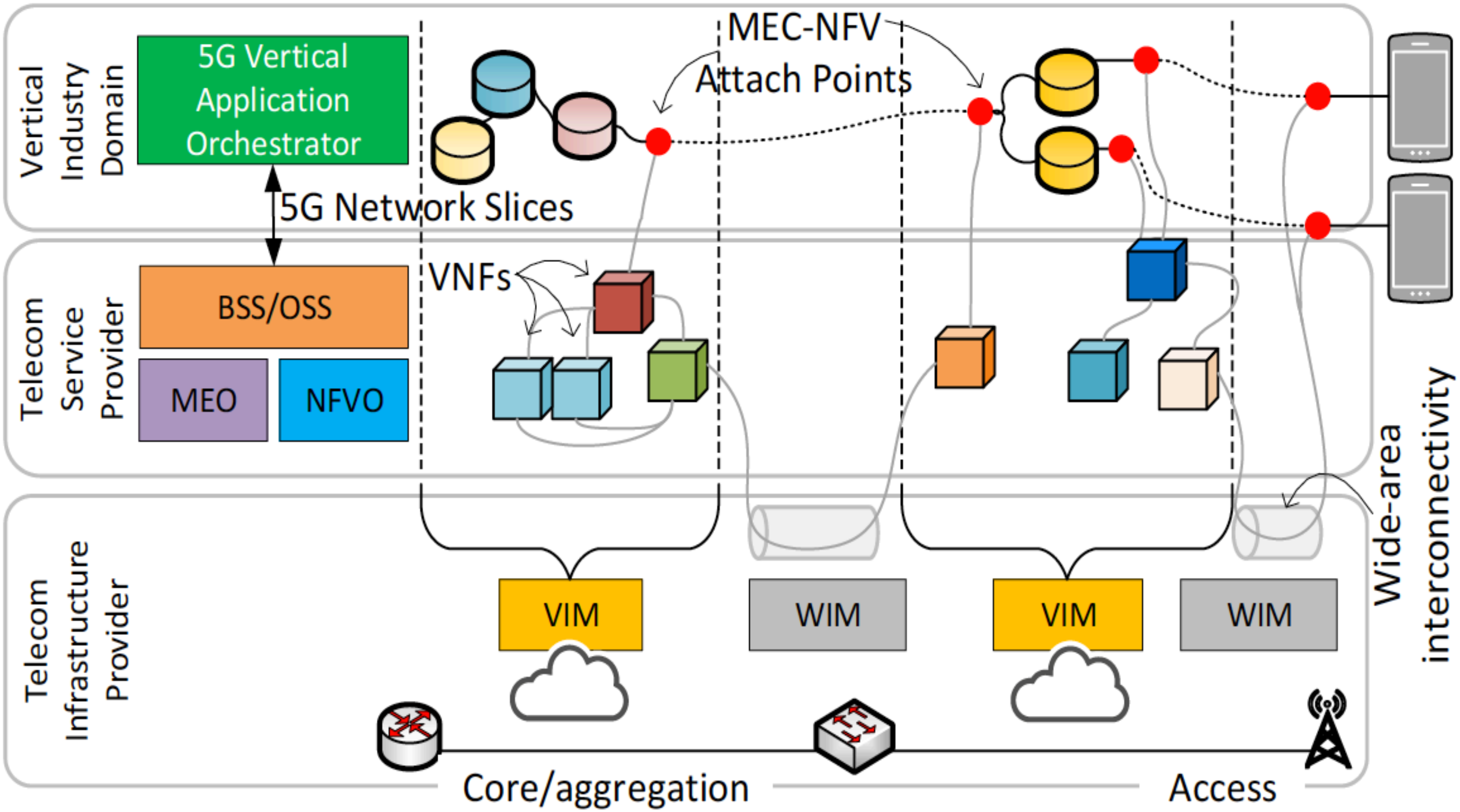
Ecosystem

- 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.
- **MATILDA** – *A Holistic, Innovative Framework for Design, Development and Orchestration of 5G-ready Applications and Network Services over Sliced Programmable Infrastructure* – an H2020 5G-PPP Innovation Action (IA) coordinated by CNIT and comprising 18 partners from 10 European countries, aims to fill this gap.

Architectural framework



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.

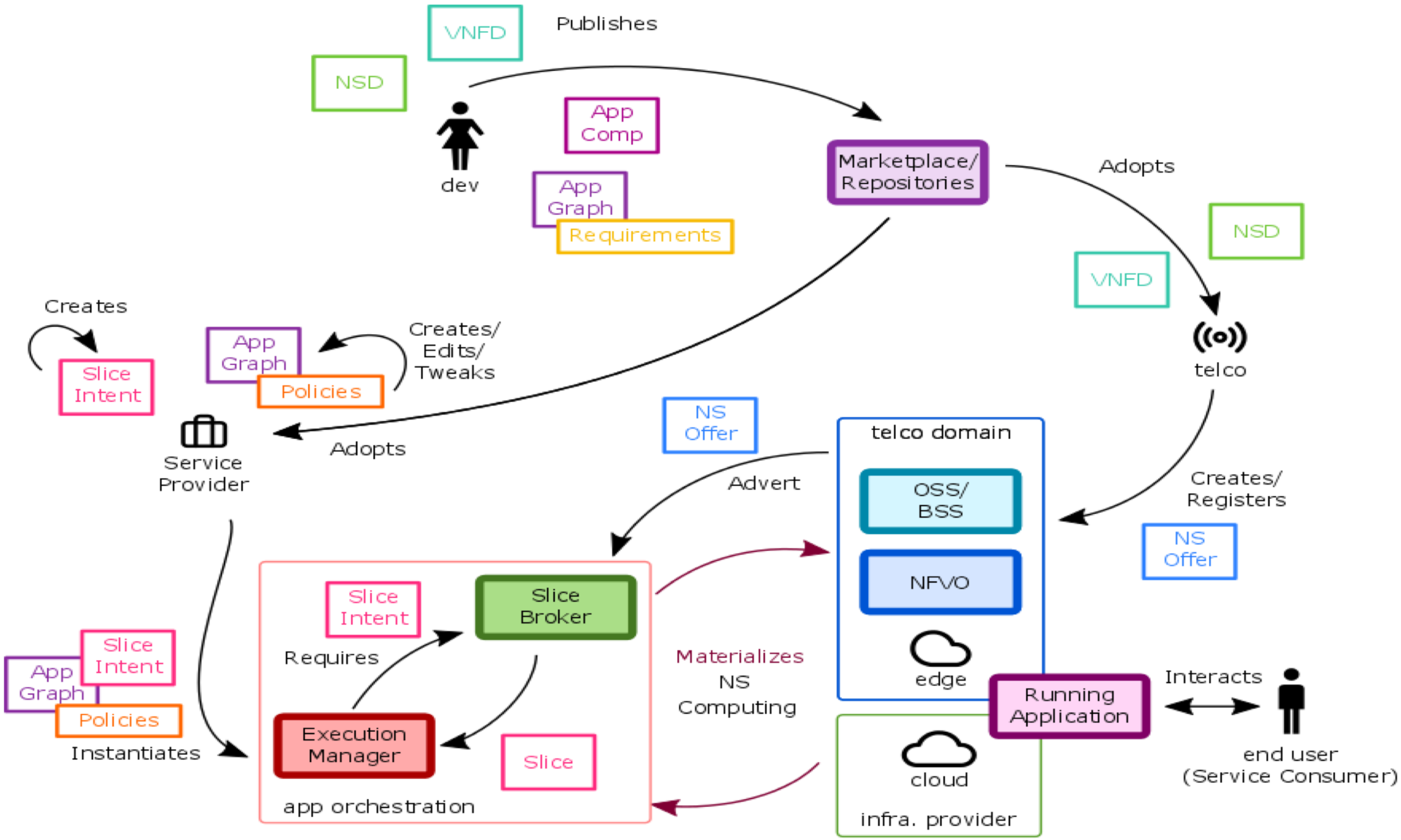
Orchestration Levels

- MATILDA introduces 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.

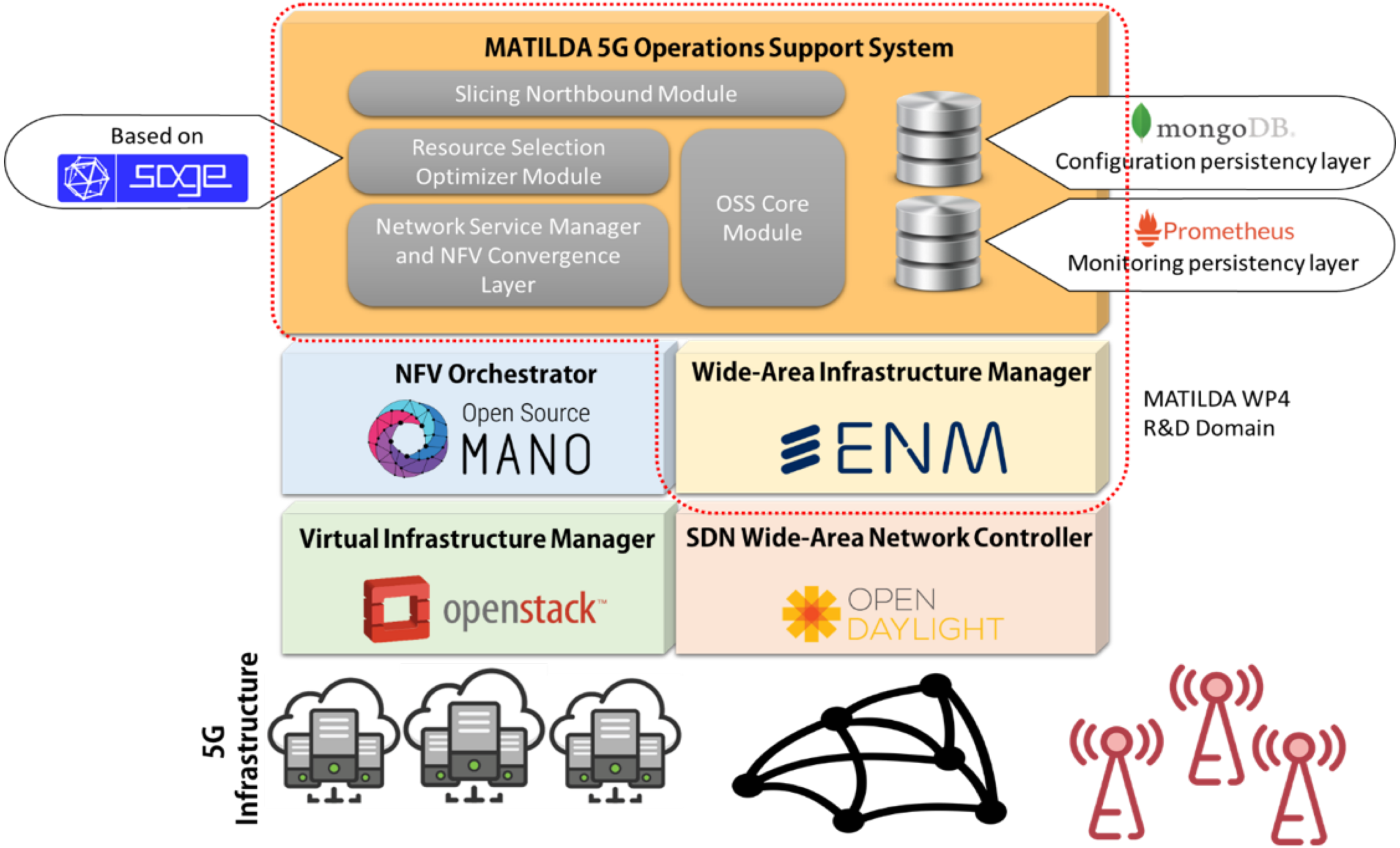
Vertical Application Orchestrator

- A set of **intelligent vertical application orchestration mechanisms** realizes the proper placement and orchestration of 5G-ready applications over the created application-aware network slices. The **Vertical Applications Orchestrator (VAO)** provides
  - a **deployment and execution manager** that supports the production of optimal deployment plans, as well as the management of the overall execution of the application
  - a set of **data monitoring mechanisms** which collect feeds from network and application-level metrics
  - a **data fusion, real-time profiling and analytics toolkit**, which produces advanced insights through machine learning mechanisms and provides real-time profiling of the deployed components, application graphs and VNFs
  - **service discovery mechanisms** for supporting registration and consumption of application-oriented services following a service mesh approach
  - a **context awareness engine** providing inference over the acquired data and support of runtime policies' enforcement
  - mechanisms supporting **interaction among the VAO and the 5G programmable infrastructure management** tools.

Applications lifecycle, stakeholders and metamodels



MATILDA 5G Telecom and Infrastructure Platforms



MATILDA 5G Telecom and Infrastructure Platforms

- Five **architectural building blocks**
  - **Operations Support System** (OSS)
    - receives the **slice intents** from the VAO
    - coordinates the work of all the other building blocks in the Telecom layer platform to set up and to properly configure base 4/5G network services, network slices, and edge computing resources
    - acts as the main configuration/interfacing point for Telecom Platform Providers
  - **NFV Orchestrator** (NFVO) – [Open Source MANO]
    - manages the lifecycle of the network services composing the base 4/5G services, and of the ones provided to slices in a shared or isolated fashion
    - is in charge of Day-2 operations for Physical Network Functions – PNFs (e.g., g/eNodeBs)

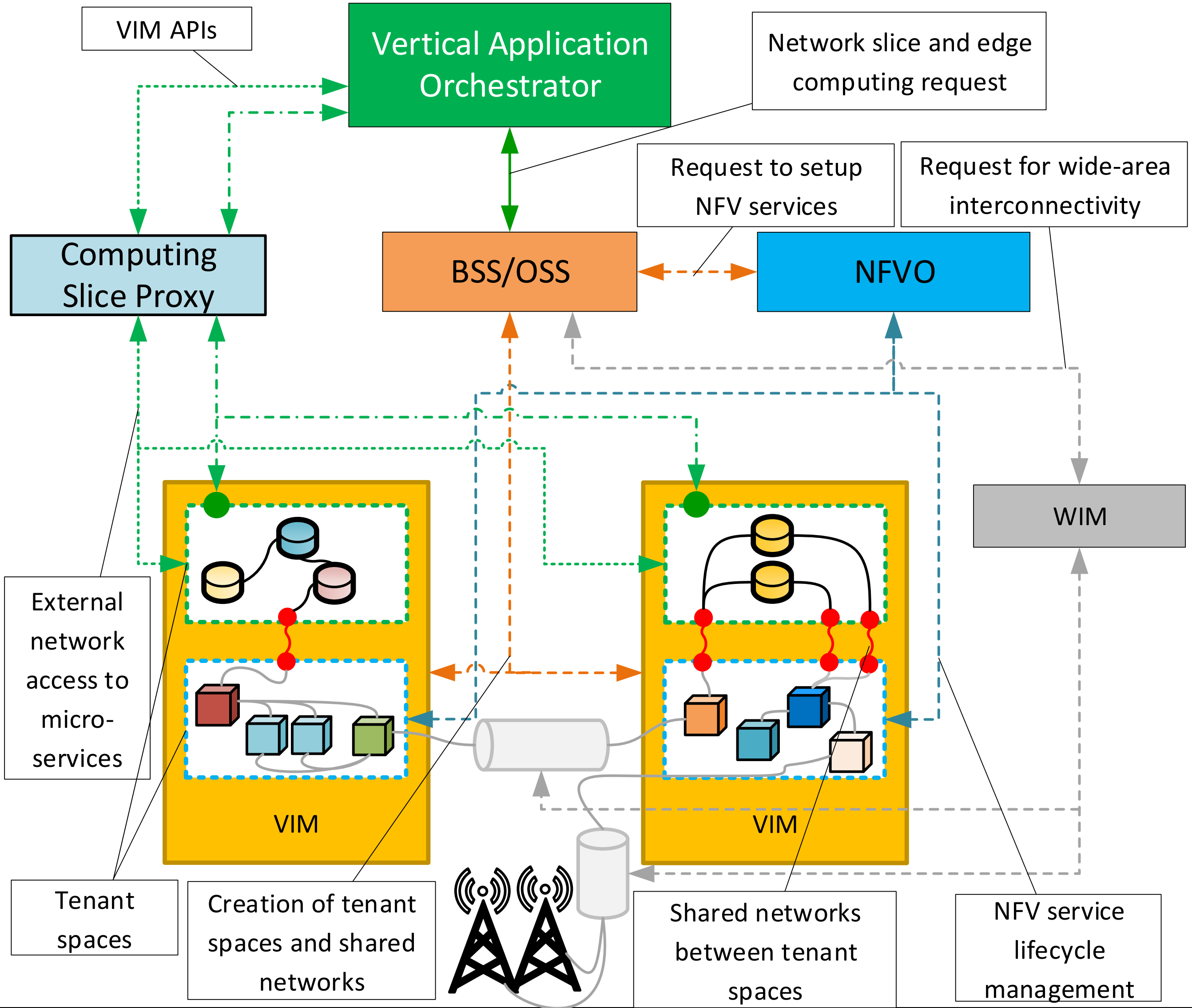
MATILDA 5G Telecom and Infrastructure Platforms

- **Wide-area Infrastructure Manager** (WIM)
  - manages and monitors the wide-area communication resources
  - creates network overlays to be used in a shared or isolated fashion by vertical applications telecommunication services
  - provides information on which resources (e.g., VIMs, PNFs, etc.) can be selected in the distributed 5G infrastructure to create slices/services in order to satisfy vertical application performance requirements (e.g., end-to-end latency, bandwidth, etc.)
  - connects on the SouthBound to networking devices either in a direct fashion or through SDN controllers.

MATILDA 5G Telecom and Infrastructure Platforms

- **Virtual Infrastructure Manager** (VIM – one instance per each distributed computing facility)
  - abstracts and exposes computing, storage, and networking capabilities of datacenters within the 5G infrastructures
  - isolates the various tenant domains (i.e., NFV domains and Vertical Applications' ones)
  - creates shared resources to properly "attach" these domains
- **Wide-Area SDN Controller** (WSC) [OpenDylight]
  - interconnects the control agents of the SDN devices in the wide-area network for monitoring and configuration purposes
  - exposes a NorthBound interface mainly towards the WIM and Telecom layer monitoring frameworks

VIM-level integration of vApps



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.

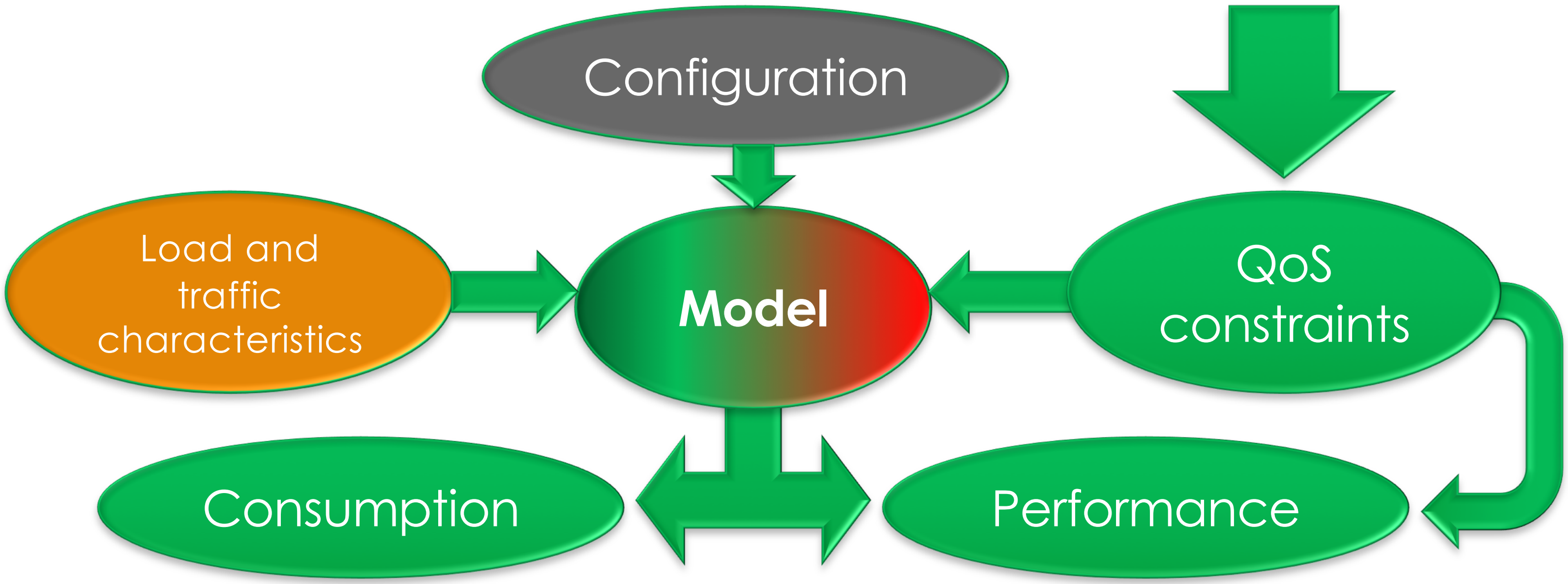
Analytical models for control

- 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.

Models for control

- If we change the consumption we change also the performance

We need <u>to model a device in terms of consumption and performance versus loads and configurations</u>

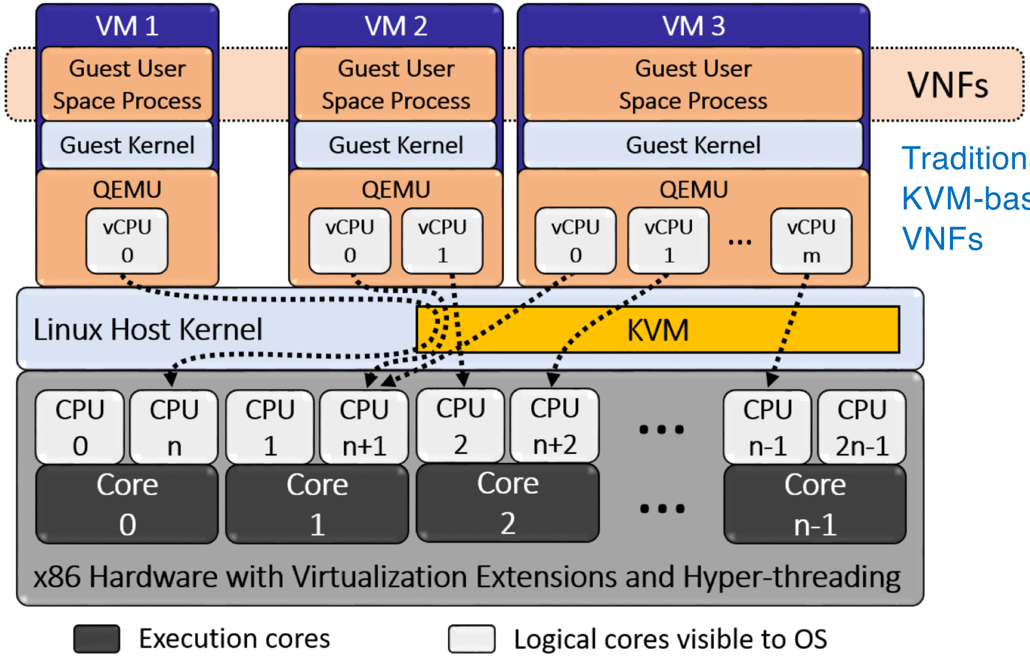


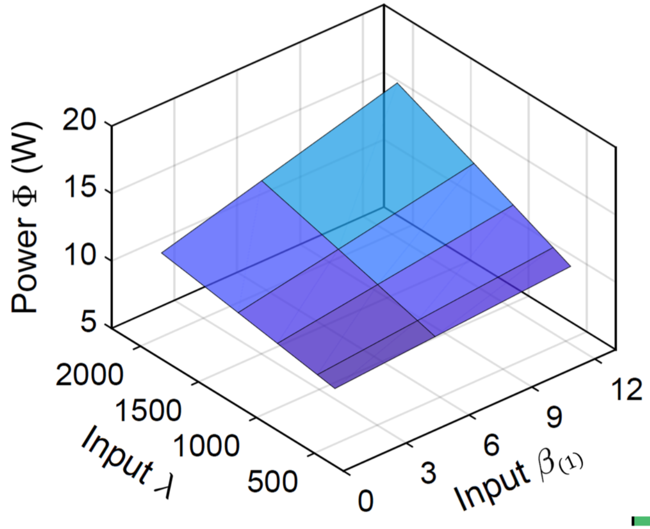
Queueing models for performance analysis and control

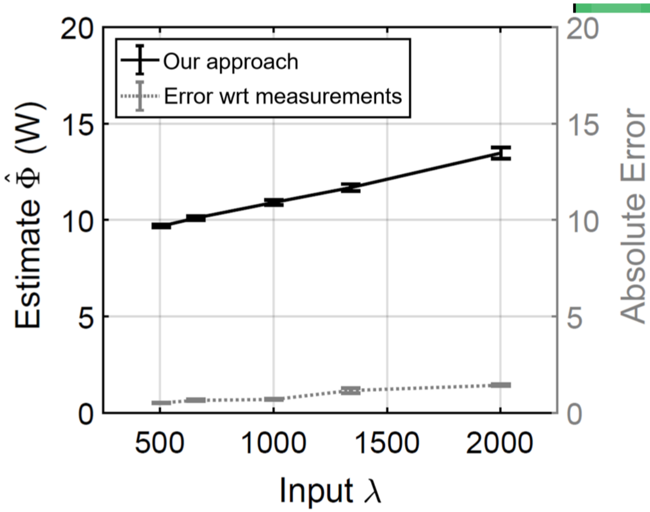
- Models based on classical queuing theory (e.g., the **$M^X/G/1/SET$**[1,2,3]) lend themselves to performance analysis or parametric optimization for adaptive control and management policies over longer (with respect to queueing dynamics) time scales.
- Game/Team Theory optimization and/or Hierarchical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

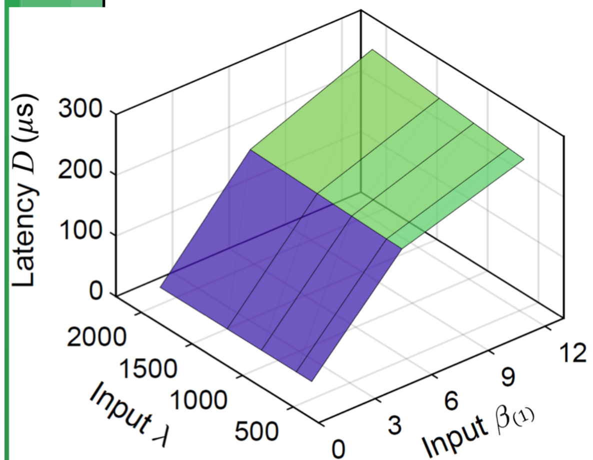
1. R. Bolla, R. Bruschi, A. Carrega, F. Davoli, "Green Networking with Packet Processing Engines: Modeling and Optimization," *IEEE/ACM Trans. Netw.*, vol. 22, no. 1, pp. 110-123, Feb. 2014
2. R. Bolla, R. Bruschi, A. Carrega, F. Davoli, J. F. Pajo, "Corrections to: "Green Networking with Packet Processing 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," submitted to *IEEE Trans. Green Commun. & Netw.*, 2019 (under revision).
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.

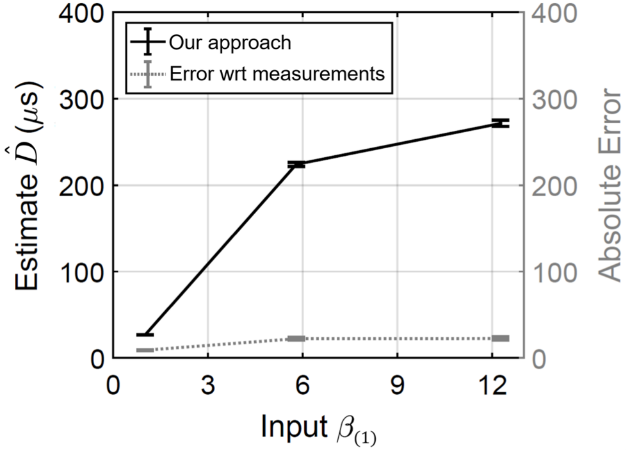
Queueing models
for performance analysis and control



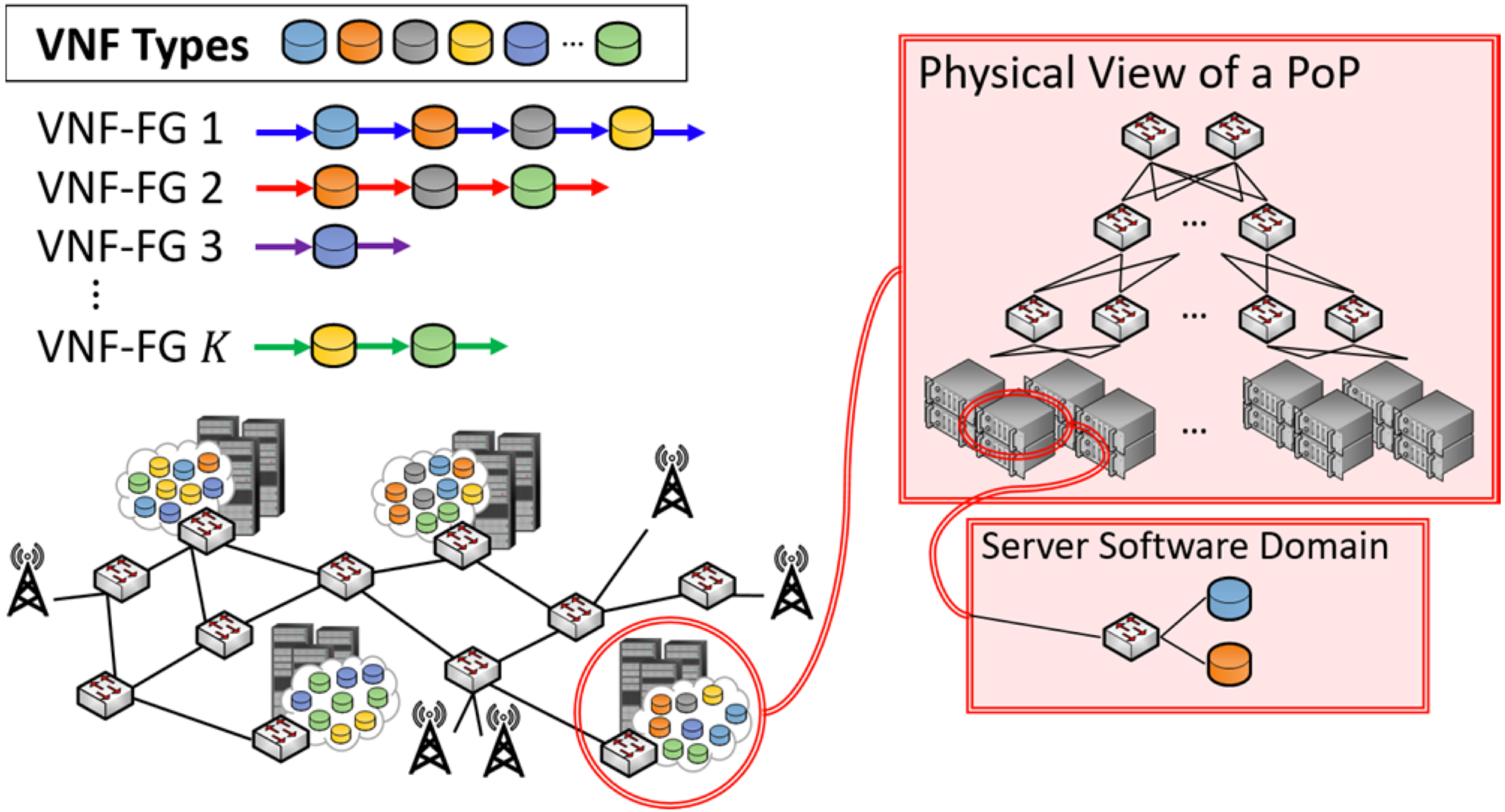






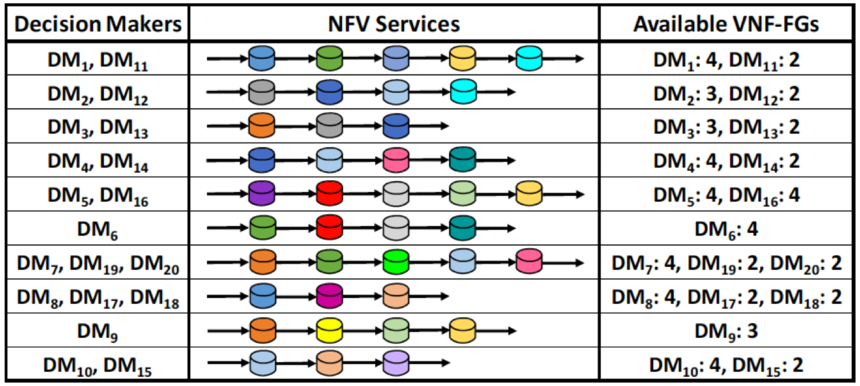


Queueing models for performance analysis and control



Distributed VNF Chains Scenario

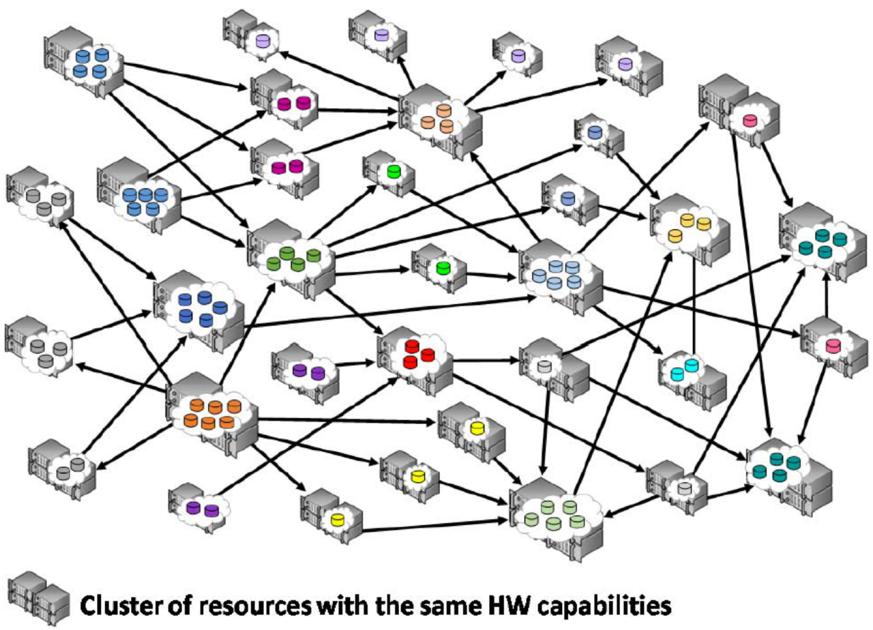
Queueing models
for performance analysis and control



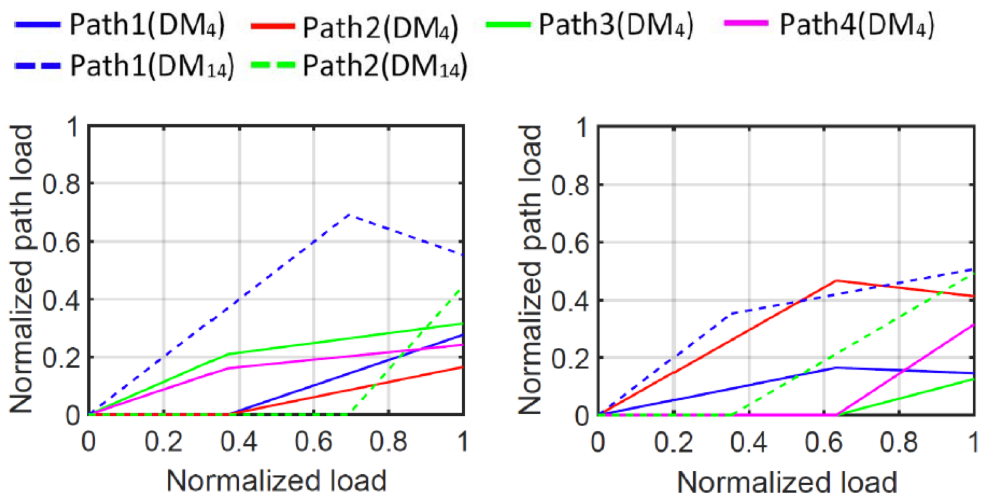
Decision Makers	NFV Services	Available VNF-FGs
DM_1, DM_{11}		DM_1: 4, DM_{11}: 2
DM_2, DM_{12}		DM_2: 3, DM_{12}: 2
DM_3, DM_{13}		DM_3: 3, DM_{13}: 2
DM_4, DM_{14}		DM_4: 4, DM_{14}: 2
DM_5, DM_{16}		DM_5: 4, DM_{16}: 4
DM_6		DM_6: 4
DM_7, DM_{19}, DM_{20}		DM_7: 4, DM_{19}: 2, DM_{20}: 2
DM_8, DM_{17},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

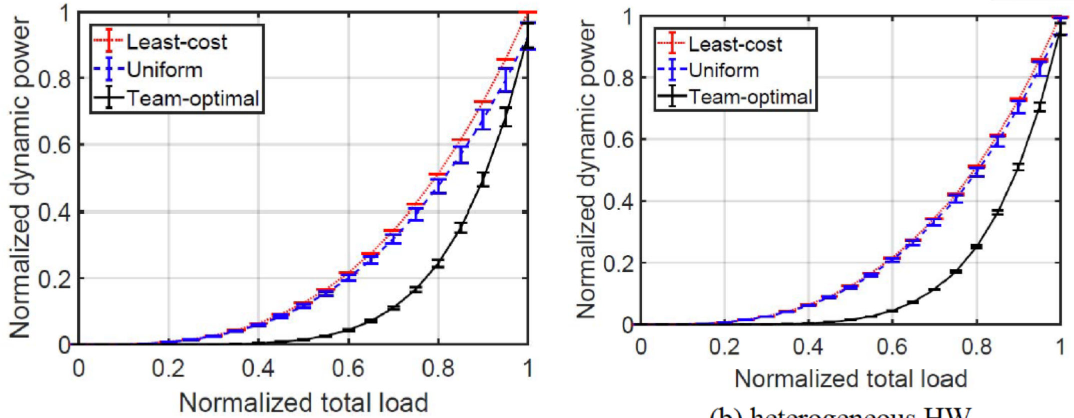


(b) NFV network



(a) homogeneous HW

(b) heterogeneous HW



(a) homogeneous HW

(b) heterogeneous HW

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.
- The separation between VAO, MEO (Mobile Edge Orchestrator) and NFVO 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 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**
- 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.