5G and Beyond: Perspectives on Fixed/Mobile/Cloud/Fog Integration, Network Management and Control, and Services' Deployment

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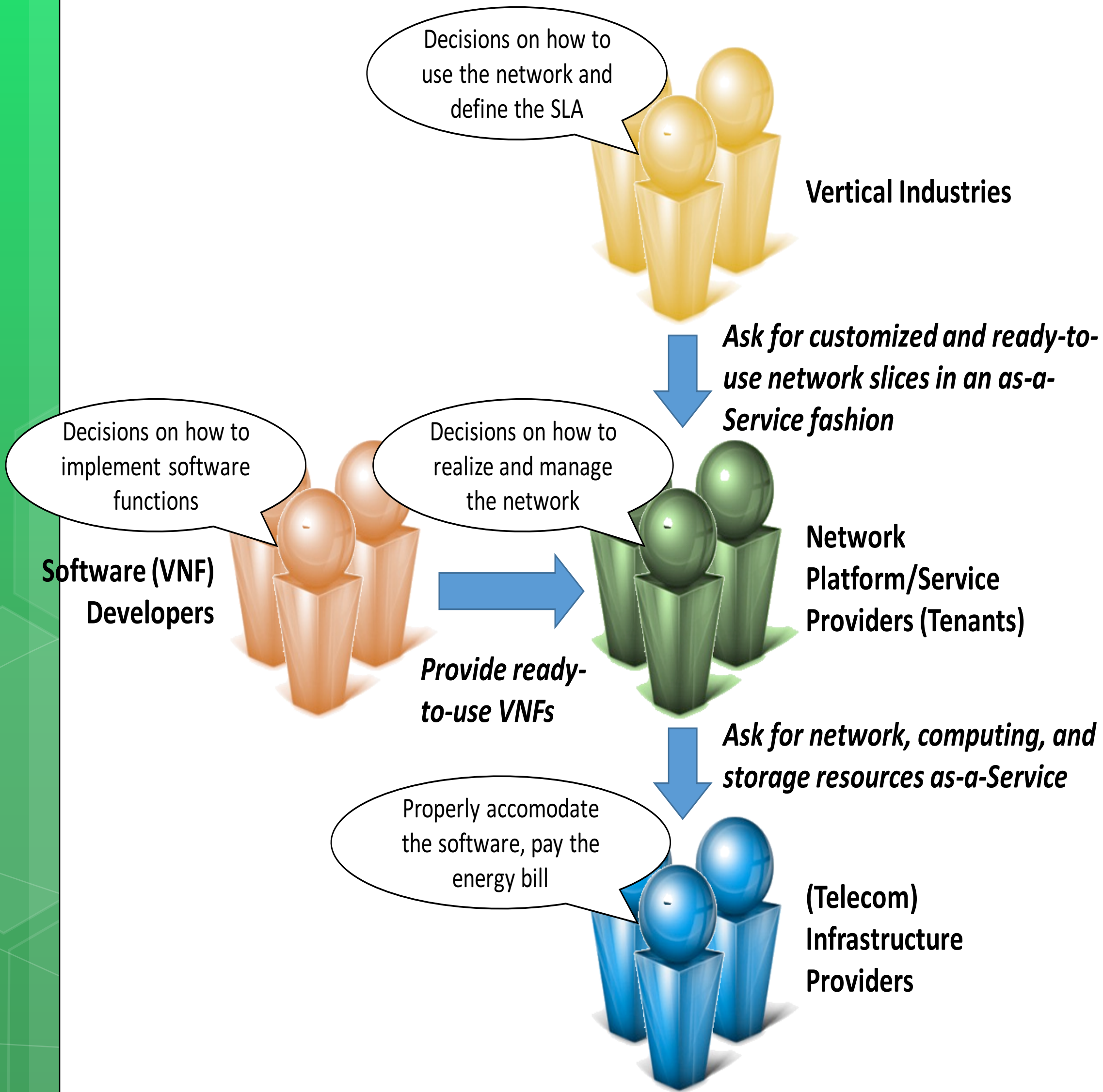
Trend Scenario



- **Network**:
  - More ***integrated*** (both in terms of fixed/mobile segments and networking/edge-/cloud-computing interaction), ***flexible*** and ***programmable***.

→ **Dynamic resource allocation** – essential aspects:

  - New network management & control paradigms
  - Energy-efficiency among major KPIs, along with performance (energy-performance tradeoff)
  - Autonomic service deployment capabilities and generation of ensuing network slices and network functions chains

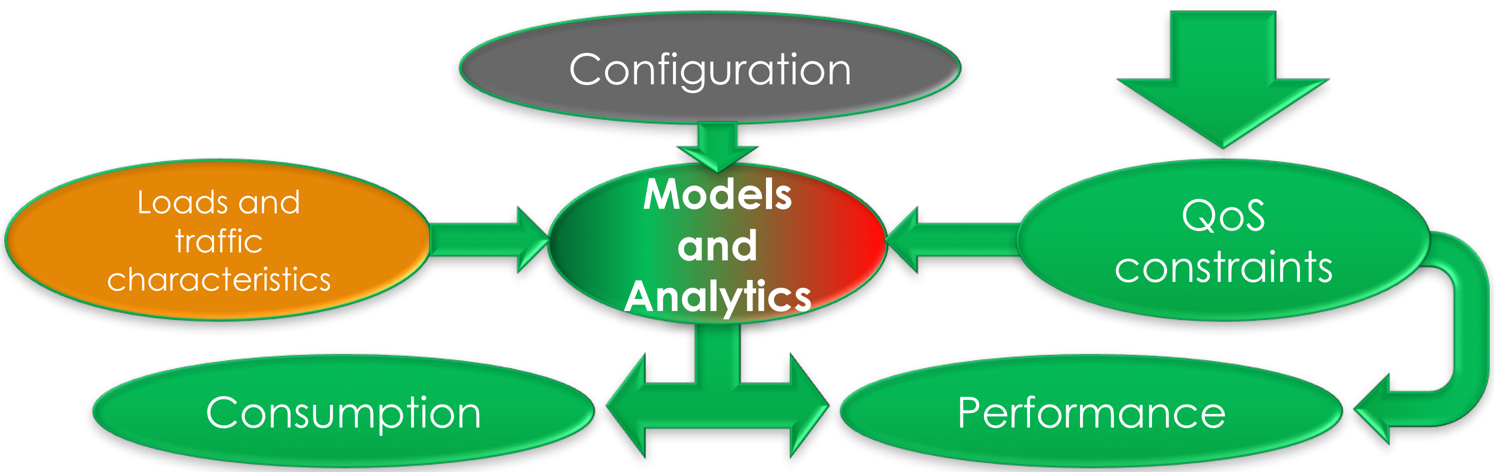
Integrated management and control for *Dynamic* Traffic Engineering

- With SDN and NFV, the premises are there for a – **technically and operationally** – easier way to more sophisticated
  - Control
    - Quasi-centralized / hierarchical (LCPs, NCPs)
    - Completely distributed (game theory, team theory)
  - Management

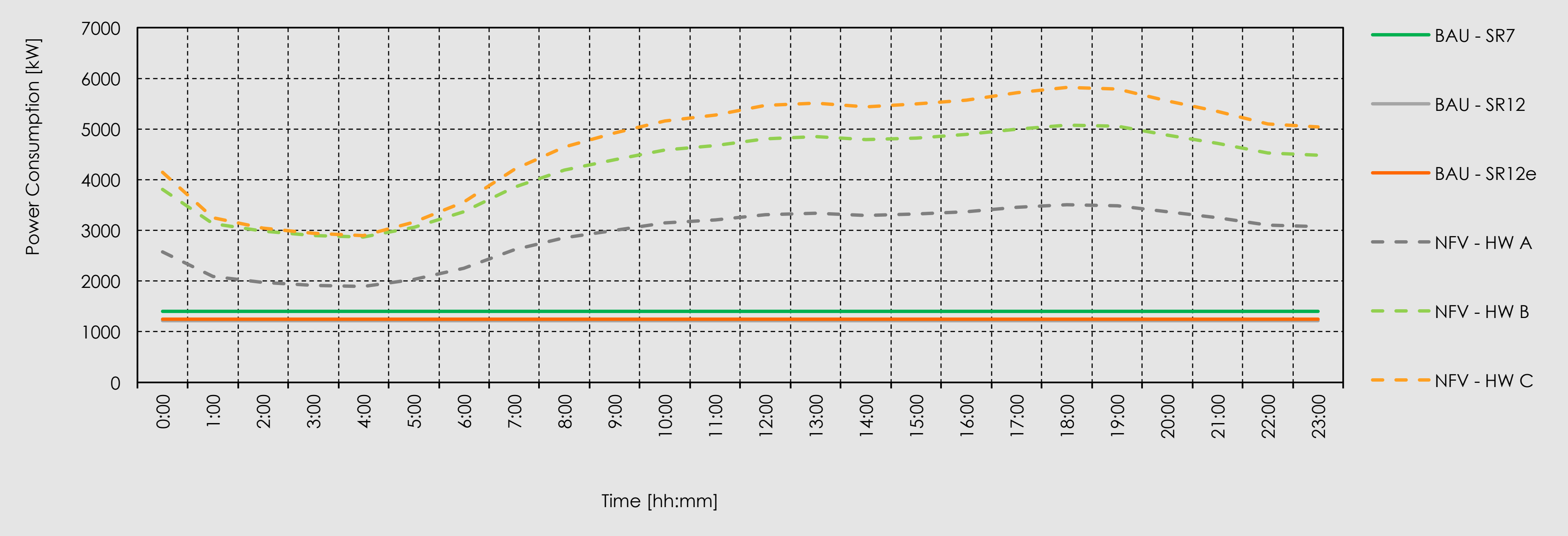
  Tighter integration with control strategies, closer operational tools, perhaps only difference in time scales (NCPs)

Local Control Policies

Network Control Policies



Why energy concerns?



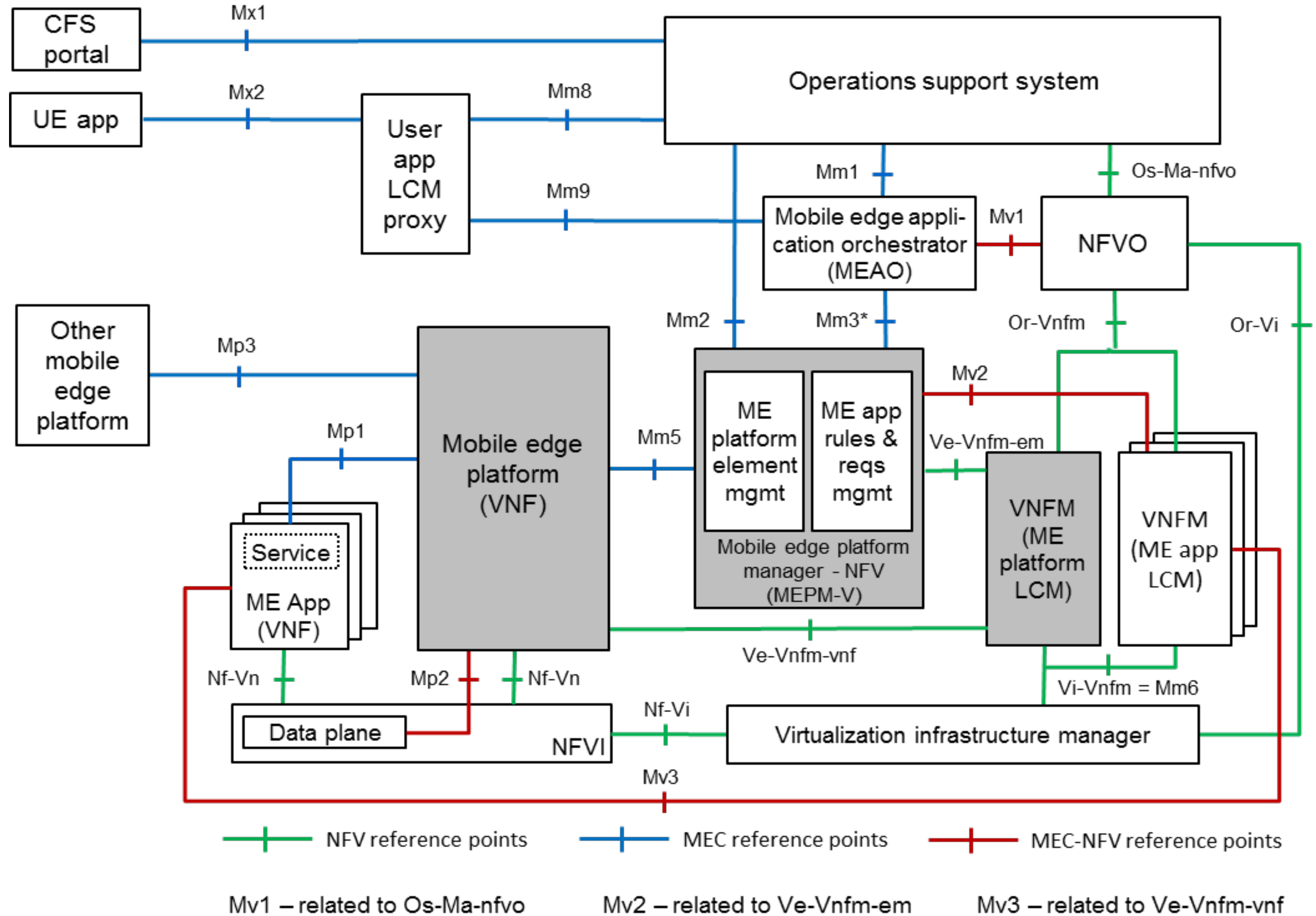
- Estimate of the average power requirement during a day for the minimum number of LTE S-GWs based on NFV or BAU technologies, which are needed to serve Western Europe traffic during a day.
  - BAU LTE S-GW estimate based on the datasheet values of the latest-generation legacy hardware-based Nokia products (SR7, SR12, and SR12e).
  - NFV estimate based on the Nokia Virtual Router performance reported by the manufacturer, and running on three different classes of x86-based state-of-the-art servers, namely cores' #- (HW A), power- (HW B), and frequency-optimized (HW C).

Source: R. Bolla, R. Bruschi, F. Davoli, C. Lombardo, J. F. Pajo, O. R. Sanchez, "The dark side of network functions virtualization: A perspective on the technological sustainability", *Proc. IEEE Intern. Conf. Commun. (ICC 2017)*, Paris, France, May 2017.

Models for performance analysis and control

- Models based on classical queuing theory (integrated with energy-related characteristics – e.g., setup times) lend themselves to performance analysis or parametric optimization for adaptive control and management policies over longer (with respect to queueing dynamics) time scales.
- Fluid models suitable for real-time control can stem from them, or even from simpler, measurement-based, stochastic continuous fluid approximations.
- Lyapunov optimization (e.g., the book of M.J. Neely) also presents some interesting features.
- Energy spent in both strategy computation and control actuation should be a concern.

MEC & NFV



Source: Draft ETSI GR MEC 017 V0.6.1 (2017-10) - Mobile Edge Computing (MEC); Deployment of Mobile Edge Computing in an NFV environment

Modeling & control challenges with NFV

- The introduction of NFV changes the perspective quite a bit with respect to "legacy" networking equipment:
  - The hardware (HW) that consumes energy belongs to the **Infrastructure Provider**, which in general may not coincide with the **Network Service Providers** (in a **multi-tenant** environment);
  - The HW is shared by multiple **Virtual Machines** (VMs) or by **Network Slices**, through a virtualization environment;
  - Queueing models can be identified and used to assess the performance of VMs as function of the virtual resources assigned to them (as well as to control their assignment), but the relation between the performance of the VMs and their energy consumption is not straightforward.

Conveying energy awareness to the Management Plane: the role of abstractions

- Standardization achieved on non-virtualized routers/switches with the **Green Abstraction Layer (GAL) – ETSI Std ES 203 237** providing an abstract interface to exchange energy-related capabilities/parameters.
- Possible lines of action for a GALv2
  - Queueing models for aggregated traffic only (per server/core);
  - Simpler aggregated models for HW energy consumption (e.g., Generalized Amdhal's Law), more detailed queueing models for execution machines;
  - **Use of "virtualized" Energy Aware States as backpressure from the Infrastructure Provider to create incentives toward tenants to become energy-aware.**

Back to model parameters and analytics

- Traffic parameters not straightforwardly directly measurable
- Indirect measurements as a role for data analytics
  - Use of available hardware/software performance monitor counters (PMCs) on hosting servers;
  - Model-based analytics for profiling VNF workloads, to derive traffic statistics by exploiting their relation with measurable KPIs;
  - Application in anomaly detection, usage-based pricing, VM sharing, dynamic core assignment, kernel-bypass VNF implementations.