“Enabling Scalable and Sustainable Softwarized 5G Environments”

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With the emerging network *softwarization* solutions (specifically, Network Functions Virtualization (NFV), Software-Defined Networking (SDN), and the upcoming Cloud-Fog-Edge interplay), a unified, multi-domain and multi-tenant fifth generation (5G) telecommunications infrastructure is expected to emerge, on top of which highly flexible and programmable network services and applications can be deployed. However, despite the foreseeable gains in such softwarized environments, a number of open issues - both at the infrastructure and service levels - still need to be addressed to guarantee their smooth rollout. Focusing on the scalability and sustainability aspects of softwarized 5G networks, the thesis seeks to: *(i)* optimize the trade-off between power and performance in the underlying *commercial off-the-shelf (COTS)* hardware according to their corresponding workload dynamics; *(ii)* realize the connectivity among (possibly, geo-distributed) network service components, and effectively support its dynamic reconfiguration; and *(iii)* steer traffic flows according to the current (re)configuration of their corresponding services in a seamless fashion, with low computational and network overhead, as well as low technological requirements. The specific contributions are organized in the following three research axes, along the lines of the H2020 European Projects **INPUT** and **MATILDA**.

Infrastructure Modeling and Analytics: a complete analytical characterization of the $M^X/G/1/SET$ queueing model is presented, based on which a real-time analytics approach is proposed for *virtual network function (VNF)* workload profiling and estimation of network *key performance indicators (KPIs)* (specifically, power and latency) using - and adding value to - available hardware/software *performance monitor counters (PMCs)*. Experimental results show good estimation accuracies for both workload profiling and KPI estimation, with respect to the input traffic and actual measurements, respectively, demonstrating how the approach can be a powerful tool in augmenting the capabilities of *virtual infrastructure managers (VIMs)*.

Network Slicing and Mobility Management: a *Multi-Cluster Overlay (MCO)* mechanism is proposed to realize SDN-based geo-distributed *virtual tenant networks (VTNs)* and effectively support dense deployments of mobile *virtual objects (VOs)* at the Edge, as well as seamless user/services mobility through bulk inter-datacenter VO live migrations, while accounting for the finite-sized rule tables in SDN devices. Numerical results show that the MCO achieves up to over one order of magnitude smaller number of OpenFlow rules in the VTN implementation and rule updates during wide-area bulk migrations, demonstrating its high scalability with respect to state-of-the-art SDN mechanisms. Furthermore, in the context of the H2020 INPUT Project use case (i.e., *Personal Network-as-a-Service (PNaaS)*), experimental results demonstrate the MCO’s low computational complexity in terms of rule and rule update calculation times during service chain instantiation and wide-area bulk migrations, respectively.

Network/Services Management and Control: approaches for *(i)* dynamic VNF consolidation on energy-aware resources, *(ii)* user proximity- and inter-VO affinity-aware service migration, and *(iii)* team-theoretic decentralized load balancing among service instantiations are collectively proposed and evaluated as network/services management and control applications that would manifest the potentials of the main contributions of the thesis towards enabling scalable and sustainable softwarized 5G environments.

The complete version of the thesis is available by request from jane.pajo@tnt-lab.unige.it.