Energy Management in Virtualized Networks

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Summary

Efficient energy management is a key necessity for the future generation networks. In line with this, the 5G-Infrastructure Public-Private Partnership (PPP) has set the following requirements as Key Performance Indicators (KPIs) for energy management: (i) energy efficiency improvement by at least a factor of 3 and (ii) reduction of energy cost per bit by a factor of 10. Virtualization plays a key role in energy management, wherein efficient utilization of storage and computation resources and network infrastructure is made possible. In this thesis, we address the issue of improving energy efficiency by formulating optimal routing strategies in SDN based 5G backhaul networks. Moreover, we investigate different virtualization technologies in order to establish how well they perform in terms of different performance measures: resource usage and energy consumption. In addition, we analyze IoT traffic, which is characterized by long inactivity times and then quasi-synchronous transmissions, to model the Evolved Packet Core (EPC) and to effectively scale the EPC components to real-time resource requirements of the peculiar IoT traffic.

First, we consider optimization of energy expenditure in the backhaul network, one of the main areas where efficient resource usage in 5G wireless networks can contribute to a tremendous amount of energy saving. We contribute to this aspect by developing an Energy Management and Monitoring Application (EMMA) that runs on top of a Software Defined Network (SDN) controller. This application is able to control the state of links and routing nodes according to the traffic load, resulting in the activation of minimal number of links and nodes. EMMA tries to route incoming traffic requests through already active links. It activates new links and/or nodes, whenever the already available links and nodes can no longer meet the QoS requirements for all flows. On the contrary, EMMA turns off links and nodes whenever they become underutilized. Before turning off links and nodes, the application reroutes the flows passing through these links and nodes to a path that can support them. We compare our energy efficient routing strategy, EMMA, against the optimal routing strategy and No-Power Saving Strategy to have insight

into the amount of energy saved with EMMA in place as a routing application.

Next, we study the performance of virtualization environments where Virtual Network Functions (VNFs) are deployed, in the context of Multi-access Edge Computing (MEC). To this end, we carry out a wide range of experiments on two representative virtualization technologies: light-weight containerization technology and traditional virtualization technology. We profile and study the resource usage and energy consumption, in this virtualization environments, of different applications with unique requirements for system resources. For our experiments, we chose VirtualBox and Docker from traditional virtualization technology and light-weight containerization technology, respectively. We study the performance of a number of virtualized synthetic and real-world applications in both of the above mentioned virtualization environments.

Finally, we consider Massive-Internet-of-Things (MIoT), one of the main cases in which 5G is used, to characterize the Cellular MME by analyzing its delay and control traffic overhead in serving requests from Massive IoT devices. We study the traffic arrival analytically and Evolved Packet Core (EPC) components through the profiling of real-world EPC implementation from OpenAirInterface, which reveal Mobility Management Entity (MME) is the bottleneck among the EPC components. Then, we use the results of the analytical and practical studies to model the MME as M/D/1-PS queue. We use the MME model to obtain a closed form expression of the delay at which bearer requests are served. In order to verify the analytical results, we perform several simulations on the 3GPP IoT traffic model and on real traffic traces. Finally, we exploit our model for proper scaling of the assigned EPC system resources to match the traffic requirements.