Communication Network-Centric Smart Grid Services

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***Abstract*— Telecommunication networks and power grids are parallel hierarchical maintenance structures with system-wide reach. New ways of coupling the two network types open up the possibility of an optimized joint control of the 'energy' and 'transport' dimensions of the telecommunication network. Thus, the hitherto static and unidirectional powering of the telco network is replaced by feedback options and overall load variability with space and time. Given the fact that national carriers figure among the top energy consumers in national economies, this new flexibility can be assumed to be of a relevant scale, leading to optimized overall energy consumption. In the project DESI, funded by a German federal grant and conducted by a topically wide-ranging consortium, the different coupling mechanisms such as load-adaptive network operation mode or distributed energy storage capability are studied in detail along the entire information and communications technology (ICT) delivery chain. This contribution summarizes theoretical and practical project results and gives an overview on the final project goal: the development of an overarching control system for the ICT elements and the energy storage equipment as well as the deployment of a pilot implementation.**

Keywords—* *load-adaptive mode, energy storage, Smart Grid, telecommunication network, optical transport, multi-layer traffic engineering

I. Introduction

Telecommunication networks and power grids are designed to follow human activity patterns. As a consequence, the spatial hierarchical organization of both network structures mirrors the average population density distribution. The temporal network load follows diurnal, weekly and seasonal variations. In both dimensions (space and time), further fine-graining of the structure is possible – e.g. taking into account the business and residential contributions to the respective load. (See [1] for a comprehensive overview of traffic modeling.) In this paper, we investigate how the two parallel network structures are coupled. Historically, this coupling was established in a unidirectional way in the sense that the technical equipment of the telco network needed powering and was, thus, connected in a suitable way to the power grid. Nowadays, however, the telco network acquires the ability to act back onto the power grid: several different mechanisms lead to the electrical load of the communication network becoming variable in space and time. We will study these mechanisms with respect to their drivers, their leverage and their realization specifics. In the first section, we study – in principal considerations – the way the acting back of the telco network onto the power grid changes due to two sets of developments:

- technological advances in the telecommunication hardware and changes regarding network operations paradigms as well as
- systemic changes in the power grid organization.

We discuss the effects of the ensuing feedback loops from a systemic point of view. Here, the specifics of the network's hierarchical structure need to be taken into account. Following that, in section II, the coupling mechanisms realized in the DESI project are elaborated on in detail.

Specifically, these will be:

- Shaping the load homogeneously along the entire ICT production chain
- Shaping the load consistently over all network layers
- Shifting the load along the time axis by utilizing distributed storage functionality

In section III, we present the demonstrator as implemented in the DESI project including short sketches of the software

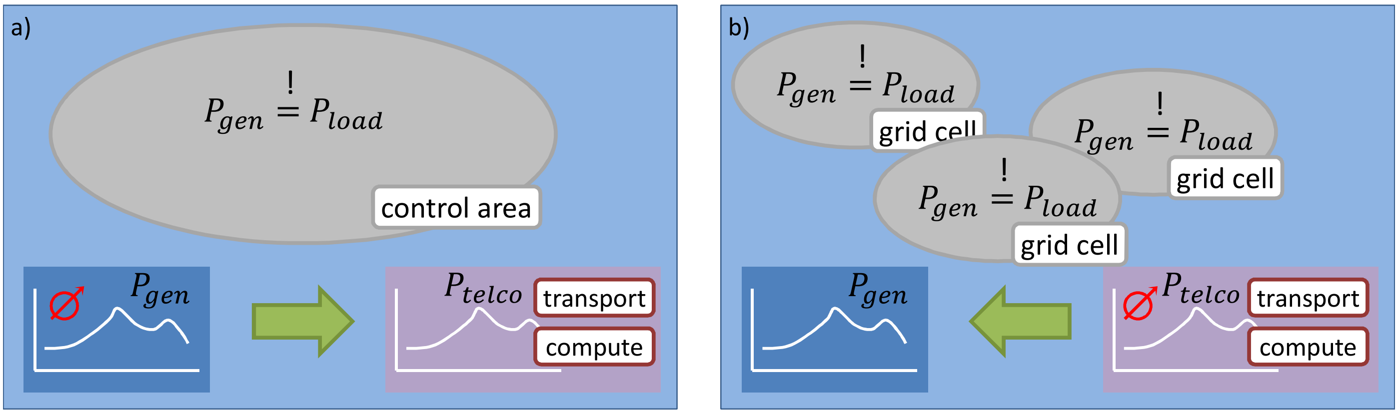

Fig. 1: Principal changes in the energy provisioning of the telco network; from traditional system (a) to the *Smart Energy* system (b).

architecture, the envisaged scenarios and characteristics of the involved hardware. In a summarizing outlook we put our work in perspective to the status quo and time lines.

II. FUNDAMENTAL CHANGES IN POWER SUPPLY AND CONSUMPTION

The role a substantial network-like energy consumer may play in the smart energy game change, or, *Energiewende* as it is termed in German, is illustrated in figure 1. Disregarding long-time, large-volume storage, the generation of electricity has to be balanced at any given point in time with the demand. The spatial reference frame is – traditionally – given by rather large control regions which allow for some internal arbitrage. It can be seen from Fig. 1 that, in the traditional system (left graphics), the only steering option resides with the generation.

In the new organization paradigm of a Smart Energy provisioning system, the necessary fit of generation with consumption has now to be reached by adjusting the load. This crucial change results from the reliance on renewable energy sources (solar and wind) the availability of which is inherently volatile. (Of course, for possibly sustained intermediate stages, control power plants running on natural gas will be part of the system, allowing for shaping the generation characteristics to a large extent. Also, heavy overprovisioning allows for generation control by just shutting down unnecessary facilities – such a regime would, however, demand very unhealthy capital expenditure volumes.) Furthermore, the reference area for balancing will shrink down in size from today's control regions leading to a more local organization of energy balances. This tendency favors telco network-borne grid services as it is omnipresent due to its coverage property: wherever a grid cell is established there will be relevant telco network infrastructure.

Let us now discuss the technological evolution underlying the right-hand side scheme (Fig. 1b) from the telecommunication network's point of view. First, technological advances in the network equipment make it possible, for the first time, to tune the power load of the network to the bandwidth demand – a regime usually called load-adaptive mode. Whereas the load-adaptive mode of the transport faculty of the network will shape the consumption characteristic to the actual traffic demand in the ICT domain and does, therefore, not provide novel degrees of freedom for the energy provisioning system, it has been shown elsewhere, that compute facilities may migrate through the network following, for instance, energy price incentives [2], establishing thus a spatial variability of consumption. Second, the storage capacity installed in the battery banks of the power backup systems at a large number of network sites and data centers may be managed to yield a temporal variability of the load. Also, following the decentralized character of the energy provisioning system, the scale of management is reduced to "grid cells" (see Fig. 1b) where generation, demand and storage are tuned for optimal interplay. The telco network's technology sites may be viewed as quasi natural nuclei of grid cells. Considering that national carriers range among the top energy consumers in developed economies, it may be stated as a result, that the telco network turns into a spatio-temporal, system-wide control capacity for the power grid.

III. THE THREE DESI DOMAINS – AN END-TO-END VIEW

In the following, potential and constraints of load-adaptive mode in the DESI domains fixed customer networks, fixed broadband networks, and energy storage equipment are explored in detail. To some degree, the findings can be applied to other important network domains like mobile access networks and data centers as well; however, these are out of scope of this project.

A. Local customer networks: Organizing the traffic load

Transforming telecommunication networks towards load-adaptive operation starts with the first link in the chain: the traffic sources in customer networks. In the DESI project, we employ and enhance an energy management solution that controls local IT-loads within an enterprise including the office and datacenter environment. This system provides monitoring, control and analytics for any network attached loads. As an example, it monitors the energy demand of a PC workplace. Based on this data the solution is able to determine optimization potential by autonomously identifying systems that are powered on during out-of-business hours and can take direct action to put it into standby if desired.

While this mechanism can run in an autonomous fashion to a certain degree it is also possible to interface the control mechanism with external systems such as the DESI energy controller (see section IV). This allows a direct control of endpoint-loads, enabling the control plane to reduce energy consumption as well as lowering the network load towards the provider network.

In principle the same mechanism can be used as a grid-service, for example to enable automated demand response for load-shedding in case of pending brown-outs or similar.

B. IP/optical broadband networks: Power optimization through dynamic traffic engineering

In addition to technological improvements that keep lowering the – generally fixed – energy consumption of telecommunication networks, there is a huge potential for additional energy savings: Load-adaptive network operations, in which transport capacities are adapted to match actual demand of the customer networks.

Fixed access networks based on Digital Subscriber Line (DSL), Ethernet, or Passive Optical Network (PON) technologies already offer power management features, e.g. DSL L2/L3 [3] or Ethernet LPI [4], that can be used to decrease energy consumption in periods of low traffic. However, in the heterogeneous, multi-layered environment of aggregation and core networks things are more complex and still lack standardization. On the other hand, the meshed architecture of the inner part of the network opens up new possibilities of energy savings by partially shutting down network elements.

Our analysis of various network elements shows that power management can be performed on different levels [5]: While power saving features on subsystem level, e.g. in control processors, are generally performed autonomously (opportunistic sleeping), measures on system/network level, in particular when more than two network elements are affected, require network-wide coordination and management. The energy-aware path selection techniques implemented in the DESI energy controller preserve minimum connectivity while putting unused network resources to sleep or powering them down entirely. In our work we are considering the deactivation of IP router ports that are unused due to routing decisions solely on IP level as well as those that become obsolete when actively bypassing intermediate IP nodes on the optical layer.

We found the power reduction potential of these system/network-wide techniques to be of several orders of magnitude larger than those on subsystem level. For a more detailed analysis a generic network element model was developed that can be individually parameterized for access, aggregation and core network nodes [6]: Such a modular network element consists of a basic node (which includes common equipment like power supply, internal cooling, or switch matrix), line cards (LC), port-groups (PG) and individual ports (P), see Fig. 2b. We validated this model and its theoretically derived power characteristic on a state-of-the-art telecommunication network element. To this end, we chose a 4 Tb/s system that combines features of a packet router and an optical transport node and thus yields power values that are applicable to various types of equipment. Amongst others, for the case of transporting 80× 10 Gb/s Ethernet signals over 40 Gb/s OTU3 wavelength-division multiplexing (WDM) light paths, the power consumption in relation to activated capacity was measured.

Configuring all available power reduction capabilities (port / port-group power save, adaptive fan control etc.), a remarkably load-proportional curve was obtained (Fig. 2a). This result confirms the energy saving potential of load-adaptive networking even with current equipment, which is expected to be in the field for more than ten years to come. Still, much work remains to be done, in particular, reducing the idle power consumption of a basic node.

As in this setup power saving opportunities are dependent on the state of the 10 Gb/s Ethernet client signals, a multi-layer control spanning client (IP) and transport (OTN/WDM) parts of the network is required. In the DESI project, this intelligence will reside in the DESI energy controller (section IV).

C. *Distributed energy storage: Taking advantage of volatile energy demands and generation*

In the preceding paragraphs, we have shown how new technology enables the electrical network load generated by its “transport” and “compute” functionality becomes a variable entity. Coming back to the principal argument of this paper, the infrastructural coupling of telco network and power grid, we may identify a further important mechanism. This is given by the telco networks power backup systems which include necessarily storage capacity, usually realized in electrochemical media. In Germany, this capacity sums up to roughly one gigawatt hour. In the DESI project, the top-level controller of the uninterruptible power supply (UPS) systems is connected to a backend where a battery scheduling algorithm resides. This algorithm computes, on the basis of stock exchange prices, load prognoses and battery status data an optimal charge/discharge schedule for the battery for the next 24 hours. Combing the actual network load and the battery’s storage capacity results in a powerful load-shifting potential stretching over the entire reach of the telco network.

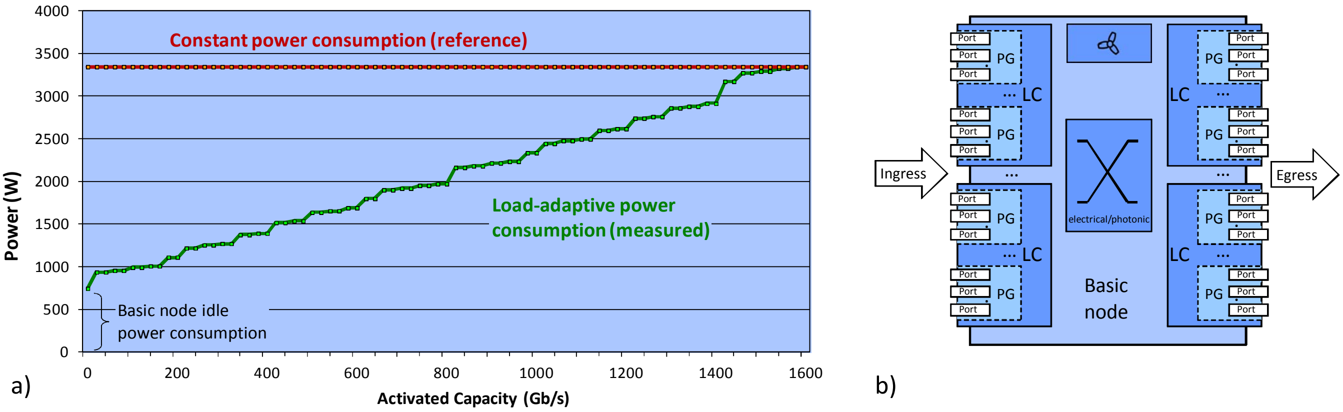

Fig. 2: Measured power consumption characteristic as a function of the activated capacity (a) for a system that can be described by a generic network element model (b).

IV. THE DESI DEMONSTRATOR

In this section we discuss the exemplary demonstrator set-up of the DESI project.

A. *Architecture*

In Fig. 3 the system architecture of the DESI demonstrator is shown.

The main component is the controller which plays three roles: One is controlling the network part and managing the routing decisions for both the Generalized Multi-Protocol Label Switching (GMPLS) control plane (CP) and the OpenFlow control plane. The second part is controlling the energy part along the lines described in the above paragraph: the battery schedule as calculated in a suitable backend function is enforced via a telematics link onto the local UPS controllers. It must be noted, though, that there is a logical nexus between battery schedule and dynamical traffic engineering: Lower power states in the network equipment demand lower back-up capacities, setting free further manageable storage capacity. The third part is triggering the edge and helping to optimize requests to the core network. The trigger signal is used by the energy management software to prevent e.g. backups at times, where the core network capacity is reduced.

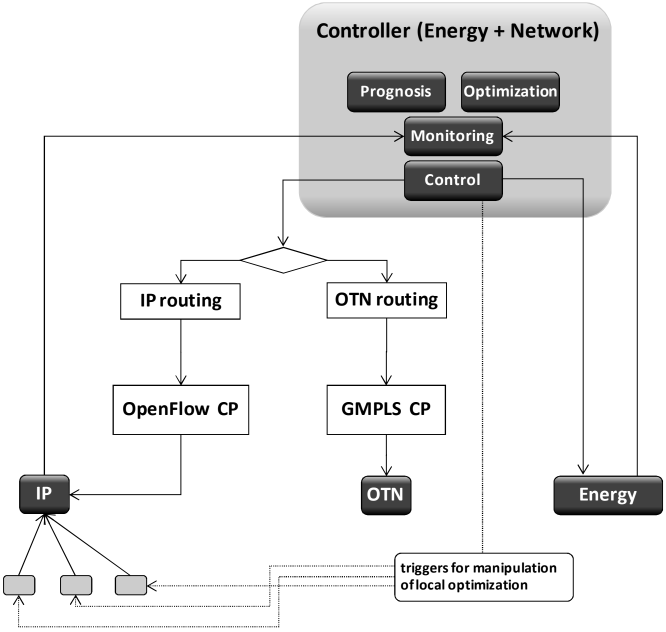

Fig. 3: Control architecture of the DESI solution: consistent treatment of telco network and energy degrees of freedom.

The controller is implemented on an Intel x86 Linux platform. For the optimization of the energy part a Mixed Integer Programming (MIP) approach is used. For the network part the controller analyzes the traffic flows and recognizes traffic patterns. These traffic patterns are the basis for making the switching decisions between different scenarios, which will lead to the reduction of energy consumption in the network.

The demonstrator shows for the first time a classical Software Defined Networking (SDN) approach in combination with optimization and control of parts of the energy domain. In the following, the individual mechanisms of energy adaptability realized in the DESI demonstrator are introduced. Triggered by detected traffic patterns, these mechanisms may be combined to show live-like load-adaptive mode as motivated above in the demonstrator network.

B. Demonstrator mechanisms

In DESI, four individual mechanisms have been identified to reduce the energy consumption in the core data transport network. Mechanisms I-III are depending on the current load situation in the network and consider only the core network elements, i.e. Layer 3 switches and optical transport network equipment. Contrary to these load driven improvements to reduce the energy wastage, mechanism IV involves the customer to schedule his traffic demands depending on the availability of free resources to transport his data. All adaptability options are managed by the energy controller that oversees the whole network load of the operator and interfaces the customer for high load demands. Moreover, the energy controller generates load signals and prognosis data for the energy storage part of the setup, which will lead to additional savings. While the demand side management use-case of the fourth mechanism goes beyond the scope of this paper, the first three are illustrated in Fig. 4 and described in more detail in the following:

I) Shutdown of unused IP interfaces

Depending on the load of the network traffic not all IP interfaces are necessary to switch all packets without compromising the stability of the network. Hence the energy controller can exploit this power-saving potential by turning off ports of link aggregated groups or even aggregate traffic on fewer links.

II) Shutdown of unused OTN interfaces

As a natural consequence of I) optical client interfaces (“grey” ports) can be shut down as soon as the corresponding ports on the IP router have been deactivated. Exploiting the flexibility of the optical layer (electrical ODUk switching, photonic OCh switching), traffic can be re-groomed so that all IP traffic may be removed from an optical link and thus its “colored” ports can be shut down. Leveraging its optimization component, the energy controller is furthermore feasible to re-route the data in an energy efficient way to its destination. This might lead to a slightly longer distance of transport by gaining the ability to shutdown additional optical links.

III) IP router bypass

Further optimization can be achieved if IP router transit traffic is dynamically handled at the more energy efficient optical domain (“IP offloading” [7][8]). Again, this requires a certain degree of switching flexibility in the OTN layer. In turn, interfaces between the IP router and the optical transport node can be shut down like in scenarios I) and II).

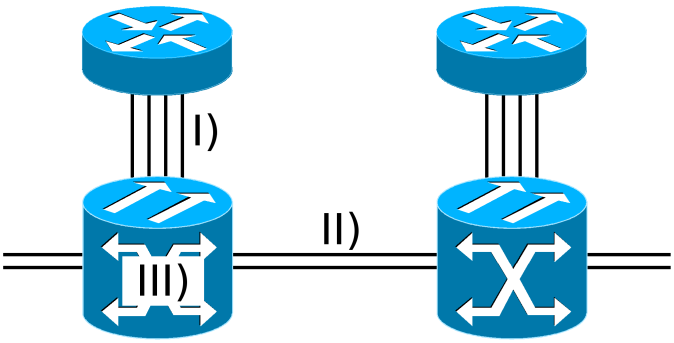

Fig. 4: Schematic illustration of the scenarios as realized in the DESI demonstrator (for explanation see text).

C. Quantitative results

Energy savings from scenario mechanisms I-III are strongly dependent on the actual network architecture. Therefore we chose a generic yet realistic network setup for the demonstrator, which employs, inter alia, high- and low-bitrate IP interfaces, legacy SDH traffic flows that cannot be changed, OTN switching at certain locations, and – for the energy part – conventional lead acid batteries that are actually deployed in central offices.

First numerical results for the used OTN network elements indicate energy savings of 20% - 30% between low- and high-traffic configurations. Similar numbers are obtained for the corresponding IP routers which follow the same node architecture, see Fig. 2b. These results are in line with other studies on reduction of network energy consumption that build on similar methods [9]. In the energy domain, the principal effect is to make the combined entity telco equipment plus UPS system responsive to external signals, e.g. price signals. With the implemented purchase-optimizing battery schedule, the demonstrator clearly shows the avoided purchases during high-price periods to be in the bracket [1.2, 2.8] € per hour, whereas the recharging costs in low-price times are in the range [0.4, 1.6] € per hour (values from July 2013). In the future, further schedule drivers will be studied such as offers in the control energy market.

As a general remark it should be stated that the demonstrator rationale is not primarily to obtain numerical values for a well-defined experimental set-up, but rather, for the first time to study systemic effects of a cross-domain energy efficiency management. The authors will report on these after the extended experiments envisaged for the demonstrator phase of the project.

V. Summary and Outlook

We have started the presented work from the observation that a number of common "natural" characteristics of the telco network and the power grid provide powerful coupling options which may be exploited in the *Energiewende* system's change. We have shown how the load-adaptive mode of network operation may be combined with management of the network's intrinsic energy storage capacity under the logic of a joint control framework. The demonstrator realized within the publically funded DESI[1] project presents for the first time an architecture and a concurrent overarching algorithmic solution for energy efficiency management of a telco system coupled in two dimensions:

- First, coherent energy management behavior along the ICT delivery chain is ensured (see II.A); local customer networks and core network contribute to a joint energy consumption minimum.
- Second, energy consumption reductions in the telco WAN domain affect the UPS requirements at network sites. The resulting variations in the electrical storage capacity lead to alterations in the calculated battery schedules.

In contrast to an extended body of work concerned with simulation, the demonstrator will enable the project consortium to carry out hardware experiments on real-life network equipment, battery technology and trigger data.

The paradigm shown here may, in future, be expanded to incorporate further parts of the telco network. Obviously, the inclusion of mobile access networks will pose no major problem since the system's analysis is upheld. A little more complex is the inclusion of data centers which are becoming ever stronger sources and sinks of data traffic. Their placement, operation and – possibly – load balancing may result in alterations to the solution presented here. The principles of telco and power grid domain coupling as presented for the first time in this contribution remain, however, completely intact.

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