Towards Service Orchestration Between Smart Grids and Telecom Networks

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Abstract. In the last years, the research efforts in smart grids (SG) and telecommunication networks (TN) have been considerable but never converged to a common view and, due to the lack of strong interactions between the two worlds, only limited benefits have been achieved. We envision in this paper that future TN (as well as any other ICT application) will interact with the SG, enabling (1) the TN to know the energy source and cost that is currently powering its equipment, (2) to turn the TN into an active client which can request to the SG the quantity and quality (e.g. green) of energy that it needs, and (3) a service orchestration between SG supply system and TN operations. As a consequence, the enabled interoperability between TN and SG would allow TN to take energy-aware management decisions in function of energy-related information provided by the SG. For example, TN can route packets with the objective of optimizing green criteria, while SG can route the energy towards the TN clients with the objective of not wasting surpluses of green energy. These new energy and data routing capabilities can be exploited not only by SG operators and telecom carriers but also by any energy consumer/producer within the ICT world. This may include industry and institutional ICT premises, datacenters, home automation, wireless and mobile cellular networks, which will be able to implement their own energy-aware management and operations (M&O) by considering the quantity, quality and cost of the energy currently provided by the smart grid.

Keywords: Telecommunications networks · Smart grids · Service orchestration · Energy efficiency

1 Introduction

In the last years, larger and larger demands in terms of both network connectivity and energy provisioning have being fostered by the astonishing development of the Information and Communication Technologies (ICT). The ever-increasing data volumes to be processed, stored and accessed every day within the modern Internet-based

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infrastructures, empowered by ultra-high speed communication networks, result in the ICT energy demand to grow at faster and faster rates. For this reason, energy-oriented networking practices are being investigated in order to lower the ecological footprint of modern communication infrastructures.

However, since the electrical energy needed to power ICT devices is not directly present in nature, it has to be derived from primary energy sources, i.e. from sources directly available in nature, such as oil, sun, nuclear, etc. Some of them are renewable, since they come from natural *flows* (like sunlight, wind and tide), regenerating on a relatively small time scale, while others are not-renewable, since they come from specific natural *storages* (like fossil fuels or nuclear), which take eras to form [1]. The scarcity of the traditional fossil energy sources with the consequent rising energy costs have become one of the major challenges for the Information and Communications Society (ICS). Therefore, as part of the anthropological ecological footprint, the energy consumption and the indirect GreenHouse Gases (GHG) emissions are now considered as new constraints for ICT. Nevertheless, the ICT sector has the ability to reduce its ecological footprint (and hence its energy consumption and GHG emissions) through the use of innovative technological solutions [2].

For these reasons, new energy management and distribution paradigms are emerging, based on the concept of Smart Grid (SG), introducing full control, as well as adaptability and dynamism on the exploitation of energy sources, in order to make the most from the available options and drive the change toward a more sustainable society.

The purpose of this work in progress article is to analyse the possibilities offered by the SGs and, in particular, Microgrids and their interoperability with the Telecommunication Networks (TNs). This work aims at illustrating (1) the energy-follows-data and (2) the data-follow-the-energy techniques, and (3) setting the bases for future research that may unify the energy-follows-the-data and data-follow-the-energy into a common *energy-oriented SG&TN paradigm* with the potential to become a new reference architecture for SGs deployments supporting the ICT world.

2 Technological Background

2.1 Smart Grids

A SG [3] is an electrical grid that uses ICT to gather and act on information related to the generation, transmission, distribution and consumption of energy in an automated fashion in order to improve the efficiency, reliability, economics and sustainability of the whole energy process. Classic grids were designed for one-way flows of electricity, whereas a SG is able to handle in a better way bi-directional energy and information flows between the consumer (industrial and/or private users) and the grid, allowing for distributed power generation from photovoltaic panels on building roofs, fuel cells, charging to/from the batteries of electric cars, wind turbines, pumped hydroelectric plants, and other sources. It is therefore emerging as promising solution both to achieve drastic reductions in GHG emissions and to cope with the growing power requirements.

SGs promise to change the traditional energy production/consumption paradigm in which one large energy plant provides the whole region with energy, towards a configuration in which many (small, renewable and differentiated) energy plants interchange the energy with the power distribution grid. Such *microgrids* produce their own energy and release the excesses of (green) energy to the SG, which redistributes it together with the energy produced by the legacy power plants to the sites where the energy is needed or the renewable energy is currently not available.

Such a solution facilitates the integration of increasing percentages of unmanaged energy as wind and solar and the support of the energy storage capacity, supporting massive connection of electric or hybrid vehicles, both for charging and for dumping energy into the grid, as well as other potential energy accumulators such as pumped hydroelectric plants.

SGs open a new scenario in which the energy production and consumption can be closely matched avoiding peak power productions, and in which the energy quantity, quality and cost vary in function of the power plant producing it.

2.2 Microgrids

A Virtual Power Plant (VPP) [4] is a wide area cluster of distributed energy generators that are collectively run as a unique entity and controlled by a central system. A VPP enables to control several sources of energy as a single virtual entity, exploiting their own peculiar characteristic in order to deliver peak loads or load-aware power generation at short notice. In this architecture, however, the energy streams produced by the different sites are mixed all together and it is not possible to know if the energy being distributed is green or not; only the percentage of the green energy is known.

The evolution of the current electricity grids into SGs inevitably involves the introduction of new intelligent devices with local decision-making and communication capabilities. As a result, it is necessary to introduce a new generation of Intelligent Electronic Devices (IEDs) at all the grid levels with different roles within the SG, such as smart metering, protection, power switching, Remote Terminal Unit functions (RTUs), Phasor Measurement Units (PMUs), etc. The main characteristic of a SG is that it allows the distribution of electricity from suppliers to consumers and vice versa by using digital technology in order to save energy, reduce costs and increase reliability. To achieve this goal an optimum distribution of energy is required, involving the need of energy storage capabilities (something really complex and expensive) when there is a surplus or restructuring the current system in order to flexibly accommodate the demand by exploiting new SG technologies. In that sense, the deployment of small and distributed generation islands, called microgrids [5], could facilitate the development of more flexible SGs. A microgrid is a small cluster of loads and generators acting as a single system to provide electrical or thermal energy (Fig. 1). Under normal circumstances, the excess/lack of electric power will be exported/imported into/from the macrogrid (i.e. the traditional larger, centralized grid). Microgrids can be disconnected from the macrogrid [6], communicate with each other and interchange energy among them when needed. The creation of microgrids

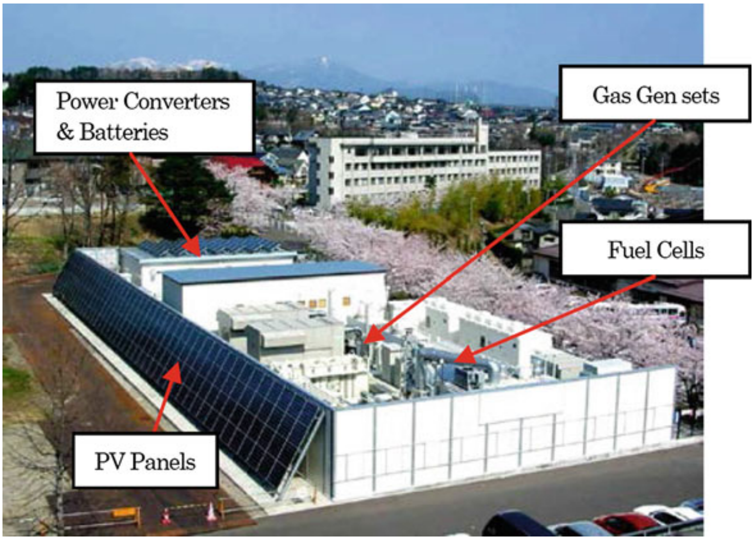

Fig. 1. Picture of the Sendai Microgrid, located on the campus of Tohoku Fukushi University in Sendai City, Tohoku district, Japan [6].

will limit the current dependency from the central power plant, increasing the reliability of the grid.

The evolution of SGs towards a fully flexible, efficient and reliable system able to interoperate with TN is expected to come through the interconnection of microgrids.

2.3 Telecom Networks

The modern Internet is connected through ultra-high speed networking infrastructures, which gobble up huge and ever increasing amounts of electricity. Furthermore, with the higher and higher demand for bandwidth, connection quality and end-to-end interactivity, network infrastructures are requiring more and more sophisticated and power-hungry devices, such as signal regenerators, amplifiers, switches, and routers. These components tend to increase the energy needs of global communication facilities. Hence, it can be easily foreseen that in the next years the Internet will be no longer constrained by its transport capacity, but rather by its energy consumption costs and environmental effects. Network equipment is foreseen to play a fundamental role in reducing GHGs emissions as it allows premises, data centres, storage and computational power to be interconnected and possibly dislocated near renewable energy plants and accessed virtually from any part of the world through high-speed connectivity. At the state of the art, miniaturization and ICT growing dynamics (i.e. Moore's and Gilder's laws) have not had the expected counterpart in power consumption reduction in the networking scenario. Miniaturization has reduced unit-power consumption but has allowed more logic ports to be put into the same space, thus increasing performances and, concomitantly, power utilization. Thus, despite architectural and semiconductor technology improvements, power consumption of network devices is still growing almost linearly with bit-rate and traffic volume. As a consequence, the total power required per a network device is exploding. It is hence necessary to adopt a systemic approach that comprises both state-of-the-art technologies improving energy-efficiency and new strategies allowing for energy-aware operation and management, acting in a cooperative fashion to achieve energy-oriented ICT [7].

3 Envisioned Scenarios

In the latest years, the efforts in the areas of SGs and energy-oriented TNs have been considerable but usually separate. At the state-of-the-art, the SG and its clients do not communicate each other (except for remote metering of consumption), and their interaction is just limited to the “blind” provisioning of raw energy from the grid to the equipment. The traditional electricity grid acts as a passive supplier, transmitting (long reach and high voltages) and distributing (short reach, middle and low voltages) the electric energy without any knowledge on the actual current energy demand of the clients. On the other side, TNs act just as passive clients of the SGs, receiving the energy without any knowledge about where it comes from, what is its environmental impact on the biosphere and actual final cost. Anyway, such information is essential to manage and operate ICT and SGs in order to exploit the renewable energy sources and lower their overall ecological footprint [8, 9]. In current SGs, the information is mainly related to the transmission and distribution infrastructure and little or no information on the electricity usage comes from the customers. Furthermore, the information provided by the grid is not used at all by the customers, who could take great advantage from the awareness of the current quantity, quality, and cost of the energy.

The enabling solution for an energy-oriented SG&TN system is to create a *bi-directional communications Interface between the SG infrastructure and the TN Control Planes* (ICP) in order to allow their interaction and the consequent optimization of the ecological footprint. The ICP will not only permit the users to adapt their behaviour, in terms of energy consumption according to the information received from the grid, but will allow them to request specific energy demands based on their scheduled activities, thus enabling bilateral dynamic interactions between the clients and energy providers. Two bidirectional flows are in fact present: the *energy flow* between the SG and the clients’ premises, and the *information flow* between the SG and the clients’ premises and among the different components of the SG infrastructure itself (from the energy plants to the transmission and distribution network). Smart meters at the clients’ houses and PMUs in SG network provide such information which is then processed in SG control centres to manage and route the energy production and distribution in a similar way network and link state information is processed by the TNs control plane to route connection requests.

Basically, SGs will actually transform the traditional centralised electric grid in a distributed system, in which any agent that is connected to the network may provide-and-consume energy and information flows, becoming at the same time a producer and a consumer (*prosumer*). The ICP-enabled SG&TN model will add the ability to consumer to become *proactive*, allowing them to request specific energy demands to the SG. Such a distributed network will dramatically decrease the losses resulting from the long distance energy transport (data will be sent farther, not energy), and enable the easy interaction between proactive prosumers and the grid.

In such an environment, the control planes in both TN and SG manage the allocation of switching and transmission resources, both in terms of data and energy, through a proper signalling protocol. The idea is that such a communication model can be utilised by the client to: (1) know the energy source that is currently powering its equipment (e.g. green or dirty, renewable or fossil, battery or online) and (2) request a quantity and quality of energy (e.g. 10 kW of power coming from green energy source for a low priority task), so that to implement real, up-to-date, and active/pro-active energy-awareness. The key to exploit different variable energy sources is the adaptation of demand management concept where demands can be supplied *on the fly*. The ICP interface enables such dynamic adaption and unveils totally new potentials for the energy management problem, which were not possible before. In the following, we identify three scenarios that eventually, by assuming the possibility of such an interface, provide an *energy-oriented SG&TN system*.

3.1 Energy-Follows-the-Data

In the energy-follows-the-data approach, a microgrid A that has a surplus of green energy (meaning that the energy demand in its influencing area is lower than its current energy production), can be connected to an adjacent microgrid B which has a higher energy demand, so that the green energy surplus can flow from microgrid A to B and no energy has to be drawn from the macrogrid, or the current dirty energy production of microgrid B can be decreased, thus lowering its carbon footprint (Fig. 2).

This can be accomplished if the SG architecture is based on an interconnection of microgrids using energy routers [10]. These energy routers allow connecting different microgrids following circuit-switching techniques [11]. However, when changing the route of a data communication path, data are not lost, but changing the route of

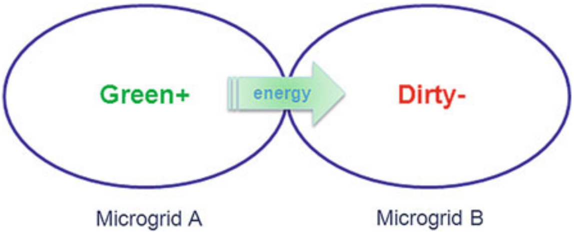

Fig. 2. The energy-follows-the-data approach: the green energy surplus of microgrid A can satisfy the power demand of microgrid B, not increasing or even lowering its (dirty) energy production.

energy, part of the energy can be lost on the way due to electric impedance and dissipation; therefore, in the energy-follows-the-data, adjacency concept and proximity of microgrids should be taken into consideration. Good results in this scenario are quite straightforward, but accurate simulation is needed to exactly quantify the achievable savings in terms of energy (resources), GHGs and money.

The energy-follows-the-data is a technique that entirely resides in the SG control plane, and no interaction is still needed with the TN control plane. In this sense, the more generic term of e*nergy-follows-the-demand* can be used.

3.2 Data-Follow-the-Energy

In the data-follow-the-energy approach (such as follow-the-sun, follow-the-wind, follow-the-tide, etc. [12]), TNs can send their data, among multiple functional-equivalent sites, to the ones that are currently powered by green energy sources. This implies a certain degree of energy-awareness of the TN control plane, since it needs to know which site is currently powered by green energy. This can be done in several ways: manually, agnostically (e.g., "blindly" following the sun according to statistical or forecasting knowledge) or automatically (e.g., employing appropriate OSPF-TE extensions to carry up-to-date energy-related information [13]).

In the data-follow-the-energy approach, the preferred sites to which data are retrieved/stored/transmitted are the ones currently powered by green (or renewable, or less costly – depending on the energy optimisation objective) energy sources (e.g. solar panels during the daytime). In this approach, the facilities, which are already powered by green energy sources, will be utilised, and no action is required in the SG control plane; this technique resides in the TN control plane.

In the example shown in Fig. 3a, the energy-aware TN control plane would choose the path passing through microgrid A to route the connection among the extreme routers; similarly in Fig. 3b, among two datacentres belonging to the same content distribution network (CDN), the one powered by green energy would be preferred.

Many techniques employing the data-follow-the-energy technique have already been employed, demonstrating the effectiveness of such an approach [8, 9, 14–16].

As shown in the example, since not only the TNs, but also other smart ICT premised can operate in such a way to selectively increase their energy demand, the more generic term of *demand-follows-the-energy* can be used.

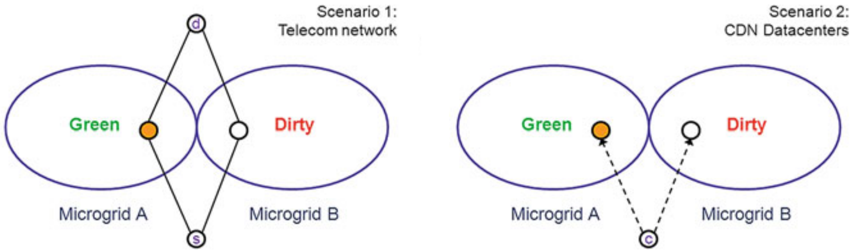

Fig. 3. The data-follow-the-energy approach in a) telecom network and b) CDN datacenters scenarios.

3.3 Service Orchestration in SG&TN System

The SG&TN service orchestration, which we propose here for the first time, consists in combining the data-follows-the-energy and energy-follows-the-data approaches. Such a system results in a multi-level network in which the distribution of energy (the *offer*) can be jointly optimised with its utilization (the *demand*) in ICT elements. Among different functionally equivalent possibilities, the TN can select a network element in a microgrid (data routing in the TN) which the SG can simultaneously power with green energy (energy routing in SG between microgrids). Figure 4 illustrates this case.

Initially, none of the two microgrid in which the TN has a router is powered by green energy. However, microgrid B is adjacent to microgrid A, which is supposed to have a green energy surplus. In such a case, the TN and the SG can act in concert through the ICP interface: the TN control plane will ask to the SG control plane green energy provisioning for its router in microgrid B, thus selecting microgrid B instead of microgrid C according to a data-follow-the-energy approach, and simultaneously, the SG control plane will provision the green energy from microgrid A to microgrid B, according to an energy-follows-the-data approach.

Note that such an optimization is possible only if the SG&TN systems operate in an orchestrated fashion.

In general, an ICT client can request an energy provisioning to the SG, specifying both the quantity and quality of the requested energy. The SG will thus fulfil or reject the request according to profitability/availability criteria. If the SG decides to accept the request, an appropriate energy path has to be established between one of the energy sources available and the site where the energy is needed. Depending on the outcome of the request, the ICT can then select the microgrid or not.

Note that, in general, the data represent the *demand* and the energy represents the *offer*, therefore configuring a smart SG&TN demand/offer matching scenario.

To make the approach viable, the following elements have to be provided:

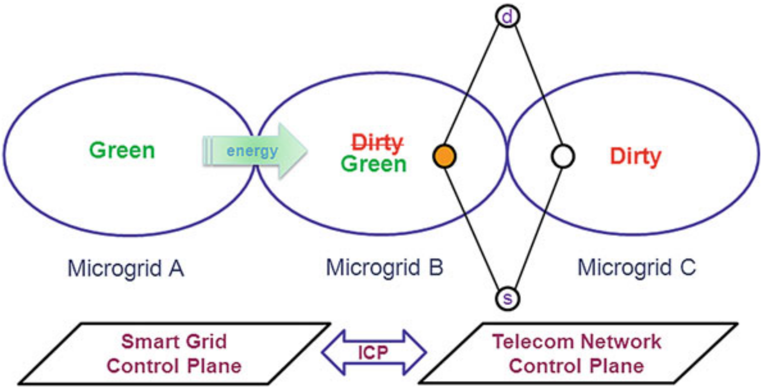

Fig. 4. Service Orchestration between SG&TN; the TN control plane selects the router in microgrid B which the SG control plane simultaneously powers with green energy of microgrid A.

(a) The ability to control the transfer of green energy between microgrids;
(b) Since the energy dissipation losses are high, the distance between microgrids must be considered as a constraint in the decision-making process;
(c) The existence of an interface between TNs and SGs and the relative policy agreements between all involved TN and SG operators;
(d) Security mechanisms and privacy issues should be addressed.

4 Conclusions

In this paper, we envision that the main progress beyond the state of the art will be the unification of the smart grid (SG) and telecom network (TN) infrastructures to exploit the potentials of the orchestrated approach. In this scenario, SG will provide the TNs with the information about the current use of the energy sources and TN will act as a proactive client of the SG, which will provide the energy when and where it is needed, and with the required output power. The interoperability between SG and TN control planes will optimize the SG&TN performance and minimize the energy requirements, GHG emissions, and energy costs. Innovative energy-aware algorithms and protocols can make possible the interaction between SG and TN via the ICP interface in a holistic systemic approach enabling previously unachievable reductions in the energy consumption of network and cloud infrastructures, towards sustainable society growth and prosperity.

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