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Distributed Schemes, Innovative Solutions for Smart Grids: P2P, Multi-Agent Systems & Blockchain †

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Abstract: Clustering workshop of low TRL Smart Grids and Storage projects, focused on distributed schemes such as MAS, blockchain, P2P, among others. This workshop was organized by DRIvE project. The objective of the event was to establish common goals and methodologies among the participants, and to have a relevant discussion forum.

Keywords: distributed schemes; blockchain; peer-to-peer; multi-agent systems; smart grids; storage; demand response

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1. Introduction

"Distributed Schemes, Innovative solutions for Smart Grids: P2P, Multi-Agent Systems & Blockchain", was a workshop within the Conference Sustainable Places 2019 aimed at clustering EU funded projects working with three shared characteristics: (1) research area is smart grids and storage; (2) the technology readiness level (TRL) of the project foreground is low; (3) the projects are developing or using for their research distributed schemes. The objective of the workshop was to share the results of the projects and to identify synergies among the different researches.

This has been the first clustering workshop organized by DRIvE, and it is now foreseen to strengthen the communication and working forums among these projects.

2. Presentations

2.1. DRIvE: "Multi-Agent Technology for District's Demand Response"

The current smart grid paradigm for Demand Response provides for a centralised management of a limited number of individually-controllable assets through simple and reliable control strategies. This easy-win approach hides the real potential of DR and results in a very limited service offering, both for end users, eager to have an active role in the energy network, and grid operators, trying to keep up with the new challenges that the grid is posing in front of them. Against this background, DRIvE's vision is to realize a true decentralized "internet of energy" design in which a vast amount of distributed heterogeneous assets will participate to support a low-cost, maximal-green and collaborative energy network. DRIvE [1] aims to achieve this vision by means of a multi-agent aggregator platform that allows a decentralised negotiation between flexibility providers and grid stakeholders.

In more detail, this agent-based approach undertaken in DRIvE models the underlying energy grid as an energy (bipartite) collaborative network [2–4] composed of two types of agents: devices (representing any asset/actor that can adjust/change/defer its energy profile) and nets (virtual zones abstracting local flexibility markets in which energy and flexibility exchange is negotiated among devices and prices for these exchanges determined). In this way the optimization problem is decomposed into several and potentially simpler subproblems so that each agent defines its own constraints and goals in a decentralized way.

On the top of this energy network, agents execute a negotiation algorithm in which each subproblem is associated with an agent that solves it collaboratively with other agents. This negotiation algorithm is iterative, based on the Alternating Direction Method of Multipliers (ADMM) [5] and has four negotiation phases. First, each net associated with an actor interested on some DR action (AGR, BRP, DSO) recompute the incentives and send them to the potential participants of the corresponding local flexibility market (this message is aligned with the FlexRequest message from the USEF [6] framework). Upon receiving a request, each device agent updates its behaviour considering the received incentives. Finally, each device sends the new energy profiles associated with their updated behaviour to the local market (this message is equivalent to the FlexOffer message from the USEF framework). On convergence, this negotiation algorithm produces as output global agreed generation, distribution, storage, consumption and DR schedules for each different subsystem in the holonic structure defined by the energy network.

This agent-based approach has numerous advantages with respect to a typical centralised approaches, among the most important:

- Privacy: Prosumer private data (preferences, devices) stay in prosumer premises.
- Scalability: via a divide and conquer approach the original global optimization problem is decomposed into smaller subproblems which can be solved much easier an in parallel by different agents. This will allow true cost-effective mass-market (100's millions of heterogeneous assets) engagement and therefore support the real next generation smart grids.
- Autonomy: Each prosumer/asset schedules its own power profile based on its economical and comfort preferences.

In the DRIVE project, the multi-agent technology is tested, deployed and validated in a residential district composed of 39 houses situated in Woerden (Netherlands). Two services are tested in this demo site: the management of this local energy community (optimizing the energy exchange of the different members) and the congestion management (providing the DSO with the ability to buy prosumers' flexibility to deal with foreseen congestions). Initial preliminary results showed how this community optimization service increases self-consumption of locally produced energy and how it is able to deal with local congestions. They also show capacity of the battery to not only maximize self-consumption in this case but also to reduce peaks at the same time.

2.2. SHAR-Q: "Sharing Storage Capacity in Virtual Neighborhoods"

The large penetration of Renewable Energy Sources (RES) have arisen well-known challenges for a proper integration in the electric power system. The Electric Energy Storages (EES) are quickly emerging on the market, especially at lower voltages levels, providing a solution to those challenges, acquiring a clear and essential role in tomorrow power grids. SHAR-Q Project (Storage Capacity Sharing over Virtual Neighborhoods of Energy Ecosystems) [7] aims to design and create a decentralized collaboration framework where distributed energy ecosystems are connected into a Peer-to-Peer (P2P) interoperability network, in order to achieve the optimization of RES and EES, through sharing capacities among the participating actors.

This interoperability network aims to connect the RES and EES assets capacities of the neighbourhood at local or even regional level into a collaboration framework. Both generation and storage capacities shared within the virtual community could mitigate the consumption/production peaks among the participating actors. In contrast with the existing solutions that are mostly centralized, the SHAR-Q concept is fully decentralized where each end-user has under control his/her involvement in the collaborative processes. In this case the prosumers do have the possibility to monitor their behavior and to manage their participation and contribution to the collaborative energy ecosystems on their own, in a way that resembles the social web portals.

The solution has been designed and implemented following an IoT approach: it is based on an open interoperable gateway with the corresponding open API that connects the smart energy resources operated by different actors into the collaboration framework. On the top of the collaboration framework, a set of added value services have been developed and deployed for the monitoring and control of the assets. In particular a multi-objective optimization technique has been adopted for the optimal control of the EES in presence of RES.

The Shar-Q solution is under testing and validation phase in three different pilot sites, where the communication and operation capabilities will be proven together with the performance of the optimization services.

2.3. DELTA: "Permissioned Blockchains and Virtual Nodes for Reinforcing Trust between Aggregators and Prosumers in DR Programs"

The energy sector is rapidly transforming due to the advancement and penetration of distributed energy resources (DERs) and renewable energy sources (RES), in order to reduce greenhouse gas emissions and energy waste. On the one hand, the EU has set ambitious targets that aim to reduce emissions by 40% by 2030 and to increase the share of renewable to 20% by 2020. To address grid fluctuations brought on by renewables, maintain a secure supply of energy and also improve market competition, Demand Response (DR) has been globally identified as the key enabler. However, on the other hand, the massive deployment of a wide variety of IoT devices, smart meters and other Smart Grid technologies, introduce additional challenges for DR schemes, as the scale and complexity of Smart Grids grows disproportionately. Clearly, these developments dictate the need to shift to decentralized, or even local, management and control schemes to harness the potential of these technologies, especially in the low and medium voltage network, since they currently remain untapped. In addition, there is an inherent need to guarantee interoperability due to the vast number of, e.g., hardware and software stakeholders. Nevertheless, even if we manage to achieve all the aforementioned technological and regulatory feats, we still need means that promote trust and incentivize the participation of end customers and key stakeholders in large scale DR schemes.

In DELTA EU funded project [8], we present the design of an energy system that advances the state-of-the-art, addresses all of the aforementioned issues and facilitates large scale DR schemes. Our main innovation revolves around the introduction of a Virtual Node (VN) layer between end customers and energy aggregators that extends the notion of Virtual Power Plants (VPPs) and diminishes the complexity of aggregators. This new layer is equipped with a multi-agent, intelligent decision support system that clusters customers based on a variety of flexibility provisioning characteristics. VNs employ load forecasting, optimal dispatch tools, as well as, novel matchmaking algorithms to provide for increased autonomy, self-balancing and grid stability maintenance. Our solution employs fog-enabled intelligent devices (FEIDs) at the customer's level that, coupled with smart meters, and lightweight forecasting tools, transmit real time energy-related data to the VNs. FEIDs can issue control actions to the site's assets either directly, or indirectly via a BMS/EMS, based on DR signals. To provide for interoperability, our system employs OpenADR 2.0b, the latest and most established standard for DR programs. Our system complements OpenADR by employing a decentralized, blockchain-based smart contract platform that, via its auditability, immutability, security and privacy features promotes trust and incentivizes participation of key stakeholders in large scale DR schemes as it can provide monitoring and financial settlement of energy-related transactions, as well as, a concrete overview of the energy supply chain.

2.4. FHP: "The FHP Dynamic Coalition Manager Concept: A Distributed Optimization Scheme for Optimal Flex Activation Decision"

The goal of the Flexible Heat and Power (FHP) project [9] is to mitigate the curtailment of Renewable Energy Sources (RES) by using power-to-heat resources such as heat pumps. These heat pumps can use the thermal inertia of a building and/or the flexibility of a large thermal seasonal storage to shift their power demand based on the renewable energy production. The available electric flexibility is used to absorb the excess of renewable generation and to avoid RES curtailment. Together with this, grid constraints are taken into account to avoid local power congestion and to maintain voltage stability in the grid.

To achieve this goal a multi-agent framework is implemented which is able to collect the electric flexibility of the distributed energy resources (DERs), generate optimal power demand profiles for these DERs and activate these profiles. In FHP this framework is called the Dynamic Coalition Manager (DCM) because it manages a dynamic cluster of DERs, e.g. at all times a DER is able to decide if it wants to offer flexibility to an available DCM and how much flexibility it wants to offer, this ensures that the DER is always in control of its own flexibility.

The DCM consists of three different types of agents: a collector, a planner and a dispatcher. First the collector will collect the forecasted baseline consumption together with the forecasted flexibility of all the participating DERs in its cluster. Based upon this forecast and the cluster objective, the planner will calculate an aggregated optimal power demand profile which is used by the dispatcher to disaggregate this optimal plan over the individual DERs. The disaggregation is achieved by applying the Alternating Direction Method of Multipliers (ADMM) [5] which is a robust version of the dual decomposition algorithm.

The FHP solution is currently deployed in two field trials, one in which six buildings are controlled in the city of Karhlshamn (Sweden) and another one in which a large thermal seasonal storage (Ecovat) is controlled in Uden (The Netherlands).

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