Agent-based Mediated Control in Smart Grids

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***Abstract*—The emerging smart grid is a complex system of systems that will heavily depend on information and communication technologies for monitoring and control. As it aims at integrating multiple stakeholders including the end-users, there is evident the need for automating these mass interactions. Agents pose an interesting approach that could empower several aspects of the evolving infrastructure. Applications areas include modelling and simulation, end-user mediation, asset management etc. Especially in dealing with non-deterministic behaviour and empowering automation and negotiation will be valuable in strengthening the cooperation and service-driven interaction of smart grid stakeholders.**

I. Motivation

Changing the practices of the last 100 years, we are moving towards a sophisticated electricity grid and an Information Technology empowered [1] cooperative infrastructure. It has been shown that value is created when interactions among people, businesses and generally entities exist. For these interactions to happen, networks are formed that operate with their own rules over an infrastructure. The electricity grid is such an infrastructure connecting however entities with very limited interactions among them up to now; this will radically change in the emerging smart grid.

The smart grid is an emerging concept targeting to provide the next-generation electricity network that will boast advanced configurability, reactiveness, and self-manageability. It is a complex infrastructure depicting system of system characteristics [2] such as interdisciplinary nature, operational and managerial independence of its elements, geographical distribution, high heterogeneity of the networked systems as well as emergent behaviour and evolutionary development. It is expected to be the key part in a global ecosystem of interacting entities, whose cooperation [3] will give birth to innovative cross-industry services. One of the key driving forces behind these efforts is energy efficiency and better management of the available resources (locally and globally). In order to achieve this, fine-grained monitoring and management is needed.

Monitoring and Control will be of key importance, and over a highly heterogeneous and complex system is going to be very challenging. Although both of them are heavily investigated for years, most of the approaches consider tightly controlled environments. However in the new emerging decentralized infrastructure achieving real-time monitoring and enforcing the necessary control is still an active area of research.

II. Agents in the Smart Grid

The agent technology has been around with us for quite some years. Their characteristics such as autonomy, reactivity, social ability and persistence make them a promising approach also for the smart grid era. The application domains vary and can be used for aspects such as modelling and simulation, glueing heterogeneous systems, acting as proxies for the users, taking automated decisions based on the available context and internal goals, negotiation, infrastructure management etc. Hence today we can witness several agent-like approaches; for instance we have monitoring & surveillance agents, shopping and price-checking bots, personal agents, web crawlers. However specific approaches also target the smart grid; several efforts exist today where agents take the role of either collecting data and deciding based on intelligent strategies or negotiations e.g. the PowerMatcher [4], MAGIC [5], D'ACCORD [6], as well as BEMI [7]. The integration of cyber-physical systems with the smart grid generally is an emerging area of research with plenty of challenges to master [8].

As an example a key idea of the smart grid is that demand side management can be achieved by having prosumers (producers and consumers) reacting to price signals of the utilities. Existing efforts in several ongoing projects have demonstrated that unless this is automated at user side, little or no success is to be expected. Hence agents are expected to act as proxies of users and act according to their wishes.

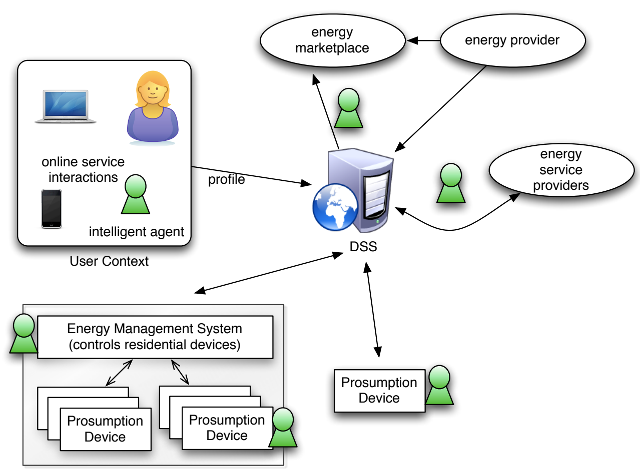

Fig. 1. Indicative interactions based on Prosumer proxy agents

As depicted in Fig. 1 it is not realistic to expect that the users will be themselves active the whole time e.g. responding to price signals send from their energy provider by adjusting their behaviour. A more realistic approach is that they will maintain a profile which expresses their behavioural habits, needs, and captures also the flexibility potential of altering their energy behaviour. This profile will be communicated online to a decision support system. The creation of the profile may be explicitly done by the user or indirectly deducted by

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an intelligent agent via his everyday behaviour or future plans (e.g. business calendar). The DSS is expected to assist users to take automated decisions that can then be enforced on their infrastructure i.e. their prosumer devices such as household appliances, electric car, business environment etc.

Today we have energy management systems (EMS) that play the role of the mediator and control energy devices. They could in cooperation with a DSS seamlessly adjust the tasks and functionalities of the infrastructure so that (i) user's wishes are always respected and (ii) goals are optimized. In the future we might have this functionality directly embedded on smart devices that may even push further the aspects of infrastructure customizability and control. As a difference today's EMS at least in residential areas offer only ON/OFF functionality for the controlled devices (e.g. [4], [5], [7]): however an open smart device may expose its operating states as services [9] that could be further negotiated/controlled by agents and not be treated as black-boxes. So today's futuristic scenarios where devices re-plan the actions expected from them based on user's constraints and external interactions may be realised. As an example of such a goal one can consider an electric car that should be charged with the cheapest electricity but be ready by 07:00 in the morning for its owner to drive to work. An intelligent agent would monitor electricity prices, would know based on historic values and prediction when to bid in the energy marketplace and would bid the appropriate amount of energy to charge the electric car so that all tasks in user's calendar can be achieved (which may mean that the car must not be fully charged but make sure that all planned trips before the next charging capability can be realized).

As we see the emerging smart grid will heavily depend on the interaction of the prosumers themselves, of the prosumers and online energy services as well between the prosumers and their devices. The agents could play a key role by automating those interactions and hide the complexity of decision making.

Another interesting area is that of asset management. As pointed out the smart grid heavily depends on cyber-physical systems [8] and agents could ease their management. Many of the elements of the smart grid infrastructure are expected to be mobile while the heterogeneity will further increase. Maintaining all systems will be a nightmare, especially if one considers the issues such as policy enforcing and federation. However again agents could play a significant role here by proactively roam the network, identify problem areas and proactively fix them. Typical example could be the upgrading of service software on the nodes that are in the infrastructure. This would imply that the agents that roam the network identify and on the fly issue upgrades to the devices entering a provider's infrastructure making sure that they evolve as part of a larger ecosystem. An electric car charging at a charging station may also receive updates to the services it has and/or enable agents to run diagnostics and proactively identify problem areas. Needless to say that several challenges concerning security, trust and privacy will need to be tackled before such approaches can be realised.

Apart from integrating with the real-world, multi-agent systems offer great simulation capabilities for dynamic systems. Since the emerging smart grid is a dynamic and complex ecosystem based on cooperation and negotiation, the agents may assume the roles of the smart grid stakeholder systems interacting [10]. Such simulations e.g. of a smart grid city are still today in embryonic state. Of course smaller parts simulating a specific scenario or a market exist, however we need modelling capabilities and simulators that can capture the massive number of aspects involved in a smart grid ecosystem and simulate large scale infrastructures at city/region and beyond levels. Especially for business opportunities to be identified and tested, such tools would be a must.

III. Conclusion

Today we see again rising interest for the agents who seek a role in the smart grid. A similar trend was witnessed over a decade ago in the telecommunication domain as well as the industrial manufacturing. It seems however that in the smart grid era the agents could play a key role in several of its aspects, from modelling and simulating its part, maintaining and managing it, up to seamless interfacing between the users and the infrastructure. To what extend these will become a reality relies not only on the technical advances but also on the services that they will offer to the stakeholders. Due to the cyber-physical nature of the smart grid, issues such as security, trust and privacy should be considered to any agent-based approach.

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