SMITh

Smart **M**etering with **I**nternet of **Th**ings

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Project description

SMITh (Smart Metering with Internet of Things) is a one year project launched in 2016 within the XII cycle of Alta Scuola Politecnica. The project has involved academic institutions (Politecnico di Milano and Politecnico di Torino) as well as two industry partners, Edison and Reti. The project goal was to develop a feasibility study of an IoT (Internet of Things) system for applications in the field of Demand Response (DR) and energy management.
The SMITh project received the contribution of a team of students, academics, and professionals coming from the fields of electrical and energy engineering, computer science, and service design. A comprehensive solution was developed addressing the technical specifications, the market integration, and the user experience domains.
The main goal of the SMITh project is to develop an ecosystem based on IoT which coordinates sensors and actuators to optimize the energy consumption of a typical household providing DR services in synergy with the energy utility. The specific objectives of the project were the following:

- Create a cloud system where all components are interconnected and can interact without leveraging a central logic controller
- Modularize power bills so that energy companies and users could agree on custom fees
- Automatically schedule consumptions to minimize electricity bills, also taking advantage of some services that loads can provide to the distribution grid.

In particular, the goals can be grouped in three main disciplinary areas:

1. IoT and system architecture
2. Energy services and market
3. Service design and User Interface (UI)

This project can be described as a technology push project, where the suitability of a new emerging technology in the IoT sector is tested to respond to a demand arising from the energy sector (need of active demand to provide system flexibility).

Tasks and skills

Davide Comuzzi: Davide is a service system designer and his main task was the user requirements analysis done through interviews and workshops. He also carried out the study on state-of-the-art trends in user experience connected to IoT and energy management.
Simone Prato: as Energy engineer, Simone contributions were: analysis of demand response potential and barriers to adoption in the energy market, definition of energy pricing mechanisms and modeling of agents in the algorithm. Description of simulation scenarios, simulation running and data analysis to evaluate the algorithms performance and potential.
Francesco Sala: Electrical engineer specialized in energy systems, Francesco worked at the analysis of demand response and pricing mechanisms. He also developed the

mathematical models of the battery and PV systems within the algorithm. As team controller, Francesco supervised the whole team activities and the project budget.

Andrea Semprebon: Computer Science engineer, Andrea took care of the following tasks: analysis of technological feasibility, definition of appliances' mathematical model, development of custom algorithm for distributed optimization, development of backend and web interface for data visualization.

Andrea Taverna: as service designer, Andrea worked at the development of the user interface and at the realization of a model prototype. He also contributed to the user requirements analysis and took care of the graphical design of the presentation video.

Abstract

The ongoing transformation of energy systems towards a decentralized production model requires a new centrality and active involvement of energy consumers (or prosumers) in electricity markets. The consumption behaviors should be adapted to market conditions providing savings to the customers and benefits to the energy system as a whole. Customer empowerment requires the adoption of innovative technologies, such as sensors, controllers, and communication systems on a vast scale and with high levels of reliability.

SMITh project provides a totally innovative solution in this field exploring the opportunities offered by IoT and decentralized multiagent optimization.

Understanding the problem

In the future, an ever increasing amount of electricity will be produced from Variable Renewable Energy Sources (VRES). This trend, supported by climate and environmental policies, is poised to deeply change the way power systems are operated towards a Smart Grid paradigm. In particular, an increasing need of flexibility is evident to cope with the variability of energy sources like sun and wind. If decreased flexibility is made available on the supply side, due to the dismissing of traditional generating plants, the demand side must be involved in providing flexibility. Demand Response (DR), i.e., the adjustment of consumption behaviors based on external signals such as energy prices, is seen as a fundamental resource of flexibility in future power systems. The challenge to exploit this opportunity arises from three different levels:

- Technology innovation is required in the house environment to create a smart home where energy consumption can be monitored and optimized thanks to sensors, intelligent controllers, and communication systems.
- Market and regulatory reforms are needed in order to allow such systems to be commercialized integrating DR services in the existing electricity market architecture.
- User experience (UX) requirements should be satisfied, preserving privacy and comfort, and allowing the user to interact with the system in an intuitive and flexible way with a clear perception of benefits.

Exploring the opportunities

The DR pilot projects which are currently underway usually exploit a centralized intelligence. A typical example is represented by the Address project, led by Enel, EDF, and Iberdrola, where a central unit, called "energy box" performs the whole optimization and then sends commands to each appliance. This dominant trend emerged from a wide state-of-the-art analysis and is mainly due to the fact that distributed intelligence is still not reliable enough and too complex (mainly due to the need of coordinating many agents).

However, a distributed solution offers the advantages of being more resilient to single failures and avoiding the need to share all the information about each device functioning (e.g., proprietary data on consumption cycles) enhancing also the user privacy.

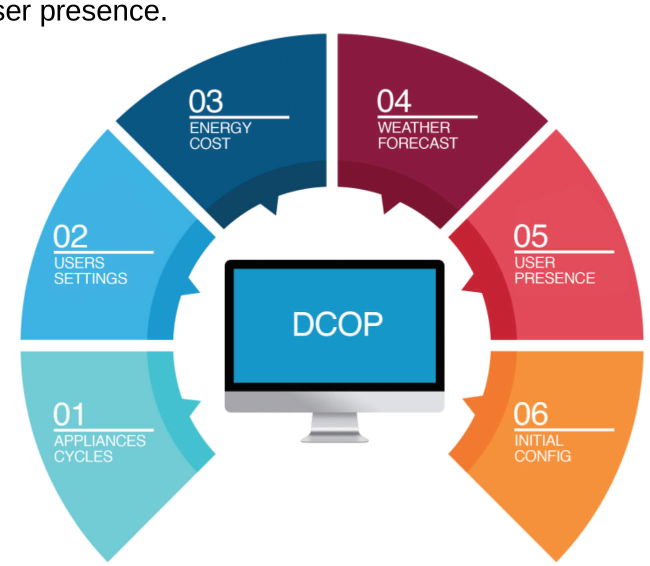
The decision, in agreement with the industrial partners Reti and Edison, was to try to develop a feasible system based on intelligent agents and distributed optimization, which could compete with current more mature centralized solutions.

From an energy market perspective, several mechanisms could be considered, mainly belonging to explicit and implicit DR categories. In explicit DR, loads participate directly in the electricity market via aggregation, offering bids to change their consumption and receiving direct payments.

In implicit DR, consumption behavior is adjusted on the basis of a price or volume signal coming from the market (e.g., a dynamic price). In our analysis we chose to investigate implicit mechanisms and in particular to compare real-time prices (defined each 15minutes) with the current Time-of-Use (ToU) tariff system, which involves only a price differentiation between peak and off-peak periods.

Generating a solution

The solution developed is based on the concept of a distributed optimization system that is able to optimally schedule the consumption of several electrical appliances for the next 24 hours. The selected representative appliances were the dishwasher, the washing machine, and the boiler, since they belong to the class of thermal or shiftable loads, which offer the biggest potential in terms of DR services. Also a solar photovoltaic (PV) system and a battery were included to account for a future prosumer scenario. The input parameters of the system are the appliances cycles, the preferences set by the user (e.g., finish before or start after time *t*), the energy cost in each time step, weather forecast to calculate PV production, the initial configuration of the system (e.g., battery state of charge), and the user presence.

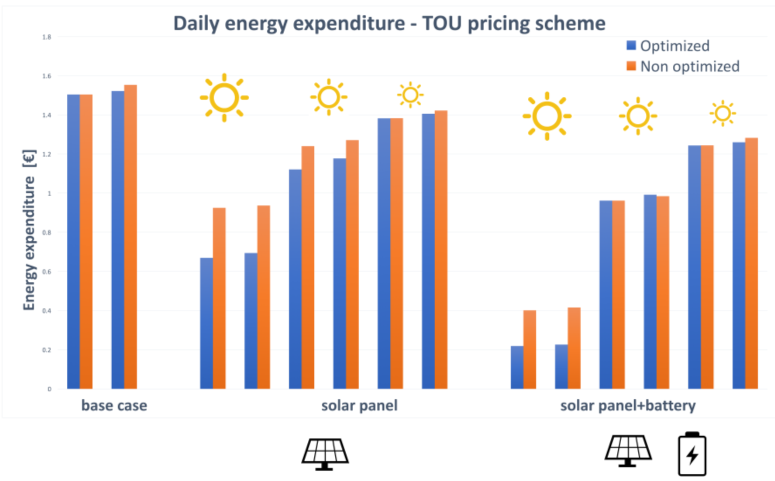


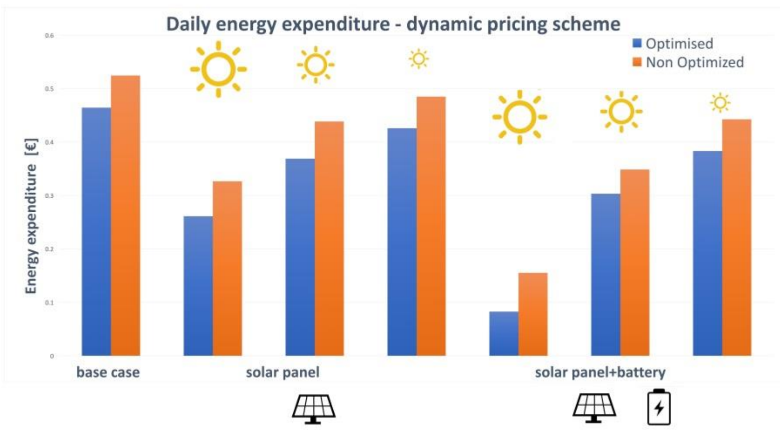
The output of the system is an optimized consumption schedule for each appliance which minimizes the electricity bill costs.

A complicate part was the development of the optimization algorithm. The corresponding mathematical problem belongs to the class of Distributed Constraint Optimization Problems (DCOP) since we do not have a central optimizer, but all the appliances act as intelligent agents that run the optimization in a coordinated way exchanging messages. Existing algorithms able to solve this type of problems were first considered. But we discovered that they are able to handle few agents and a limited number of time steps due to the exponential increase of messages exchanged.

Therefore, a new innovative algorithm was specifically developed for this project using a modified version of DPOP (Dynamic Programming Optimization Problem), able to perform much more efficiently and minimize the data exchanged. The algorithm was programmed in Python.

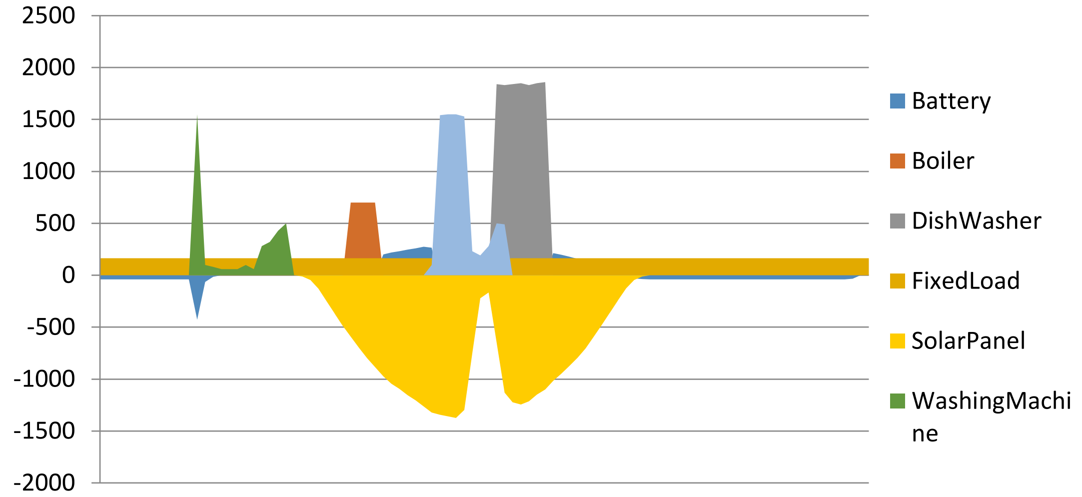
Once tested the proper functioning of the algorithm, realistic scenarios were developed to see the results deriving from its application to a real house. Appliances cycles were modeled using data coming from Edison Smart Home. Also real solar data and energy prices from the Italian energy market regulator (GME) were used.
Simulations considering several scenarios (presence or absence of PV system and battery, different solar radiation levels, different energy tariffs, etc.), with and without the use of SMITh system, were carried out. Simulations gave very positive results, with an average **saving on the energy bill** equal to **12% in case of ToU** tariffs and **19% in case of real-time prices**. Savings **on a single day** reached **up to 46%** depending on solar radiation levels and user preferences.



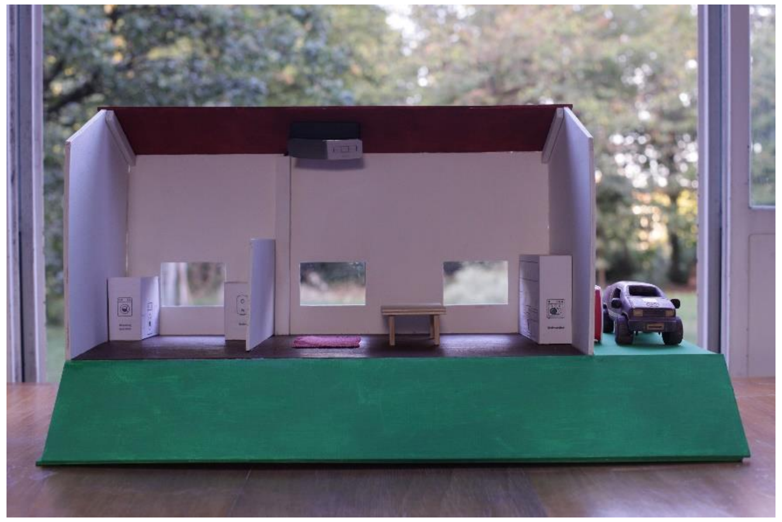


Savings emerged to be higher in case a more dynamic pricing scheme is in place, as it will be probably the case in the near future but today happens only in few countries (e.g., Norway).
Benefits are also higher in presence of PV system and battery since the optimization helps to shift the consumption towards periods of higher solar production avoiding withdrawing energy from the grid.

Additionally a prototype using Raspberry Pi microcontrollers was realized to test if the algorithm can effectively run in a distributed way. Communication was realized using Wi-Fi protocol, even though other protocols can be used (e.g., such as ZigBee). The test gave positive results validating the possibility to concretely deploy the system conceived. One obstacle to full commercialization still lies in the fact that the controller should be incorporated in the appliances by the manufacturer.



Finally, the interface of a web app was developed even though still not complete. The interface was designed taking into account requirements coming from the user experience domain such as the visualization and interaction needs of the user, the priority to clearly show the economic and environmental benefits obtained using the system and the lowest degree of intrusiveness possible.



The positive results obtained will be the basis for continued development of the system, hopefully in cooperation with the actual project partners and other interested parties. Attention will be focused on the following activities:

- Increase the number of appliances controlled including heating/cooling systems and electric vehicles.
- Improve the model accuracy of agents: e.g., battery model, use of stochastic solar production forecasts, etc.
- Consider more complex pricing schemes: e.g., *scambio sul posto* for solar PV production.
- Consider a possible interface mechanism with aggregator to offer ancillary services, like participation in explicit DR mechanisms.
- Implementation of a field prototype with real appliances at Edison Smart Home R&D Lab.
- Finalization of the graphical user interface.