Decentralised stable coalition formation among energy consumers in the smart grid (Demonstration)

Paper 5

ABSTRACT

The vision of the Smart Grid includes demand-side peak shaving strategies, such as real-time pricing or profile's based tariffs, to encourage consumption such that the peaks on demand are flattened. Up to date, most works along this line focused on optimising via scheduling of home appliances or micro-storage the individual user consumption. Alternatively, in this demonstration we propose to exploit the consumers social side by allowing them to self-organise into coalitions of energy users with complementary needs. To this ends, we present an agent-based Java simulation of a social network of energy consumers (based on the domestic electricity market and usage patterns of homes in the UK) that uses to converge to stable energy coalitions.

Categories and Subject Descriptors

I.2.11 [**Distributed Artificial Intelligence**]: Multiagent Systems

General Terms

Algorithms, Economics, Experimentation

Keywords

Decentralised Coalition formation, Stability, Smart grid, Energy

Online Material

`http://www.youtube.com/watch?v=FT25oETMkfw`

1. INTRODUCTION AND GOALS

Since energy cannot be stored efficiently on a large scale, the electricity grid must perfectly balance the demand of all customers at any instant with supply. In all current electricity grids this balance is achieved by varying the supply-side to continuously match demand. The amount of demand required on a continuous basis is usually carried by the baseload stations owing to low cost generation, efficiency and safety. However, these stations are slow to fire up and cool down, so they are not able to match the peakload periods that exceed this baseload that require, in contrast, the use of expensive, carbon-intensive, peaking plants generators. Although only running when there is high demand, these peaking plants generators are responsible of most part of consumers electricity bill.

Along this line, the vision of the Smart Grid includes demand-side peak-shaving strategies such as real-time pricing or profile's based tariffs to encourage consumption such that the peaks on demand are *flattened* [1]. A flattered demand results in a more efficient grid not only with lower carbon emissions but also with lower prices for consumers. Hence, some works [3, 4] focused on techniques that flatten individual consumer demand by automatically controlling home domestic or micro-storage devices. Unluckily, since each consumer independently optimizes its own consumption, the effectiveness of this approach has a clear limit on the consumer's restrictions and comfort (e.g. it will be unavoidable to get a consumption peak in the non-working hours of consumers).

Against this background, in this paper we show how the grid efficiency can be further improved from a social perspective. In particular, we explore the idea of allowing consumers to join into coalitions with other consumers with complementary energy needs. Then, a coalition of consumers can act in the market as a single virtual consumer with a flattened demand for which it gets much better prices. As part of the smart grid community, electricity consumers have already access to smart meters that allow them to monitor its (load) energy profile [1] in an hour-day basis. Moreover, given the huge recent success of social networks (e.g. at the time of writing Facebook has more than 500 millions users), consumers can use them as free interaction tools to self-organise into energy coalitions.

2. THE SOLUTION APPROACH

We model the decentralised energy coalition formation problem as a coalitional game [2]. Let $C = \{c_1, \ldots, c_n\}$ be a set of energy consumers and F the set of feasible coalitions among these consumers. Any feasible coalition $S \in F$ is defined as a subset of consumers $S \subseteq C$. Then, a game is completely defined by its characteristic function v which assigns a real value to every feasible coalition. In a game we aim to identify the coalition structure [2] that maximizes the efficiency of the system - i.e. the coalition structure with maximal value, $CS^* = \max_{\{CS\}} v(CS)$. Moreover, we needed to specify the following activities that take place in a coalitional game for this particular energy domain:

[1]The load energy profile is a graph of the variation in the electrical load versus time.

[2]A *coalition structure* is an exhaustive disjoint partition of the space of consumers into feasible coalitions.

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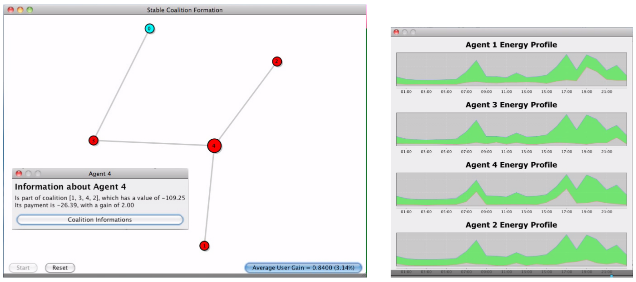

(a) (b)

Figure 1: Snapshots of a) the simulator main interface and b) the coalition energy profile inspector.

Coalitional Value Calculation. The value of a coalition S, $v(S)$, is the total payment that the set of consumers need to carry out to cover the demand of their joint energy profile[3]. Analogously to the operation of the current grid, we consider that consumers buy directly their electricity in two different markets: the forward market and the day-ahead market. In the forward market, consumers in a coalition S buy in advance the fix continuous amount of energy of their joint energy profile, $base(S)$, for a better price. The amount of energy that exceeds this baseload, $peak(S)$, is bought in the day-ahead market.

$$v(S) = -base(S) \cdot p_F - peak(S) \cdot p_{DA} \qquad (1)$$

where p_F and p_{DA} are the unit energy price in the forward and the day-ahead market respectively.

Since $p_F < p_{DA}$, the flattered the energy profile, the most a coalition of consumers can buy in the forward market and the lower the payment of the coalition.

Network-based coalitions. Social networks not only provide a way of interaction among energy consumers but also restrict coalition membership by reflecting realistic barriers to the formation of certain coalitions. In particular, consumers may not want to join coalitions with unknown consumers for which they do not have any source of trust regarding their reported profiles or their capacity to meet their payment obligations. In contrast, if the social network is used to restrict coalition membership customers join coalitions of *friends of friends*, being always somebody responsible in the coalition for the introduction of a new member.

Payoff Distribution. Consumers in a coalition are permitted to freely distribute the coalitional value among themselves. Thus, in addition to the set of optimal coalitions, CS^*, the outcome of the game also needs to specify a payoff vector $\rho = \{\rho_1, \ldots, \rho_n\}$ that divides the value of optimal coalitions among consumers ($\sum_{c_i \in C} \rho_i = v(CS^*)$). However, since consumers are selfish agents, the value of a coalition should be distributed among its members in such a way that coalition members have no incentive to break away from the identified efficient coalition. When this happens, we say that payments are stable[4]. To be stable, these set of payoffs needs to make sure that there is no other outcome that can make a set of consumers better-off ($\forall_{S \in F} : \sum_{c_i \in S} \rho_i \geq v(S)$).

[3]The joint energy profile is computed as the addition of individual energy profiles.

[4]We focus on the core as main stability solution concept.

3. THE PLATFORM

As a response to these challenges we developed a platform that allows energy consumers to organise into stable energy profile coalitions. The interface is shown in Figure 1. The demonstration starts by asking the user the number of energy consumers for the simulation. Moreover, the user can choose between creating the social network randomly, or, alternatively, create a user defined social network from scratch. In both cases, the platform generates a set of nodes (see Figure 1(a)), one per energy consumer, and allows the user to modify the network by adding/removing links in an easy way. Each node has an energy profile loaded from real data characterizing the domestic electricity market and usage patterns of homes in the United Kingdom.

Once the coalition formation scenario is set, the simulation starts a message-passing algorithm that organises energy consumers into stable optimal coalitions. Upon convergence, energy consumers in the same coalition are coloured with the same colour. For example, observe that in Figure 1(a), consumers 1, 2, 3, and 4, all coloured in red, form an energy coalition whereas consumer 0 is on its own. On the right lower corner, the application also shows the average consumer gain of consumers – that is the gain that represent the consumer assigned payoff with respect to the value of its individual energy profile.

By clicking on a node, the GUI displays statistical data related to the specific energy consumer such as its coalition, the coalition's value and the individual payment that the consumer contributes to the coalition. Consumers payments are set in such a way that consumers do not have any incentive to deviate. Finally, the platform also allows to visualize the energetic profiles of coalition members (see Figure 1(b)). Each chart plots a consumer energy profile, delimited by a red line, and the joint coalition energy profile, delimited by a blue line. The difference between the joint and the individual profile is filled in green. The GUI offers the user with an effective way of restarting simulations after reconfiguring the network topology, testing how the existence or the nonexistence of a particular link affects the emerging coalitions and consumers gain.

As a simulator, this platform provides to the users with a proof of concept of what we can do already today as energy consumers in order to get cheaper and greener energy. Furthermore, it presents the decentralised coalition formation problem among energy users to the community as an exciting real-world domain for the applicability of multi-agent technology.

4. REFERENCES

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