Towards Emergent Energy Synchronization using Agents

Evangelos Pournaras
Systems Engineering Section
Faculty of Technology, Policy
and Management
Jaffalaan 5, 2628 BX
Delft, The Netherlands
e.pournaras@tudelft.nl

Martijn Warnier
Systems Engineering Section
Faculty of Technology, Policy
and Management
Jaffalaan 5, 2628 BX
Delft, The Netherlands
m.e.warnier@tudelft.nl

Frances M.T. Brazier
Systems Engineering Section
Faculty of Technology, Policy
and Management
Jaffalaan 5, 2628 BX
Delft, The Netherlands
f.m.brazier@tudelft.nl

ABSTRACT

Synchronization of energy consumption is a key determinant for the stabilization of smart energy grids. This paper proposes software agents that locally synchronize the energy usage of appliances to minimize the oscillations in global energy consumption. Agents can manage demand-side devices with periodic operation and synchronize their consumption locally resulting in an emerging global stability of energy consumption. The benefits and challenges of such an approach are discussed in this paper.

Categories and Subject Descriptors

I.2.8 [**Artificial Intelligence**]: Problem Solving, Control Methods, and Search—*Sceduling*

General Terms

Algorithms, Management

Keywords

multi-agent systems, emergent behavior, synchronization, distributed systems, energy management

1. INTRODUCTION

A high proportion of the society's energy consumption is a result of the *periodic* operations of end-user thermostatically controlled appliances, such as refrigerators, water heaters etc [4]. Demand-side management, such as load-shifting, can be applied by introducing agents based on *synchronization* principles and models for the control of energy usage.

Synchronization is a temporal cooperation scheme based on which software agents locally interact to achieve global goals [2]. Such synchronization principles are applicable in the smart power grids of the future as *periodicity* is a key property that mandates these systems.

Our earlier work [5] addresses the problem of self-management in distributed power systems. Demand-side management can be applied by controlling thermostatic devices. Their high energy consumption and simple periodical operation provide load-shifting potentials that can make power systems more robust during peak times and prevent blackouts. Furthermore, the management of these devices can complement well with load reserve and therefore supports the matchmaking between energy production and consumption [7].

This paper proposes the use of software agents for synchronizing the energy consumption of their thermostatically controlled appliances to provide emerging global stability in energy usage. The benefits and challenges of such an approach are discussed as part of our ongoing and future work.

Stabilization in energy consumption can emerge from applying synchronization models. The imitation of synchronization mechanisms observed in nature motivates their applicability in this application domain. Male fireflies use synchronization of their flashes for mating. Synchronization is achieved in a highly decentralized fashion without leaders or cues from the environment. Pacemaker cells in our hearts are based on similar decentralized synchronization principles to coordinate the firings that keep us alive.

Note that, in these examples, autonomous entities retain their own state and interact with their neighbors. Global synchrony emerges as a result of the interactions between them. Software agents, as such autonomous entities, are an ideal computing paradigm to (i) control and plan demand-side devices and (ii) facilitate synchronization principles and models.
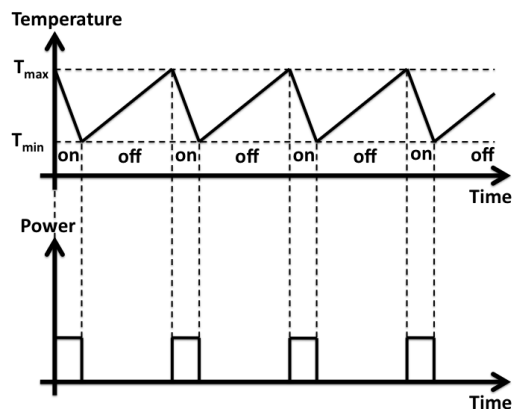
2. ENERGY SYNCHRONIZATION

This paper assumes that thermostatically controlled appliances can be controlled by software agents implemented as embedded controllers [3]. Synchronization is introduced as a synergy between cooperative agents willing to contribute in synchronization.

Agents control the current temperature and energy consumption states during the periodic operation of their thermostatic devices. These states are computed based on periodic utility functions as illustrated in Figure 1 for a cooling device. Note that, the graphs are simplified for illustration purposes. They depict a linear increase and decrease in temperature that approximates the behavior of the device in reality as illustrated in [1, 6].

During cooling (on-state), a device consumes energy and decreases its temperature. When a critical temperature value is reached, in this case T_{min}, the thermostat is turned off (off-state) and the temperature starts increasing again until the T_{max} value is reached. These temperature setpoints are the main constraints of synchronization illustrated in this paper.

The goal of the agents is to synchronize the devices in such a way that oscillations in the aggregated energy power consumed are minimum. For illustration purposes, the environment is assumed to be homogeneous: all agents are based on

Figure 1: The periodic temperature and energy variations over time for a cooling device.

the same utility functions. Demand-side management based on synchronization principles is applied as follows:

- Stabilization in the global consumption of thermostatic devices is achieved by desynchronization of the temperature and energy states of the devices. Agents are desynchronized by distributing their temperature states uniformly between T_{min} and T_{max}. This case applies when the aggregate energy consumption of non-thermostatic devices is stabilized, i.e., without considerable oscillations.
- Assume that a part of the global consumption exhibits a non-uniform distribution with peaks and valleys at various points of time. In this case, stabilization can be achieved by synchronizing the energy usage of thermostatic devices to an energy distribution that reverses the first one. As a result, the aggregate result of the two energy consumption patterns is an energy consumption pattern with minimum oscillations.

These synchronization approaches cover a wide range of applied demand side-management. Related work focuses on (i) either reactively minimizing individual peaks [6] on-demand, (ii) or simply desynchronizing temperature states [1]. In both cases, control occurs centrally.

Our vision goes one step beyond these centralized approaches. Distributed synchronization for emergent demand-side management can be achieved by modeling agents as pulse-coupled oscillators [8]. These models explain how and when oscillators synchronize their firings by advancing or delaying their phase. By performing local adjustments and adaptations in phase, global synchronization emerges inevitably under some conditions and assumptions [8].

Such an approach suggests that complex synchronization in thermostatic devices can be achieved by applying and getting more insights to theories and models of synchronization observed in nature and complex systems. Synchronization can be applied in other aspects of this problem as well. For example, energy synchronization to electricity prices can integrate emerging synergistic approaches to other market-driven approaches.

3. CHALLENGES

Although proposing synchronization models for demand-side management seems a promising approach, there are some crucial aspects to be considered. These models assume that agents (oscillators) are all coupled to each other. This implies that the network topology is a complete graph, which is against the decentralization principles of the future smart grids. Partial connectivity is most common for agents. Depending on the application, various topologies such as rings, trees and small worlds may be used to define the connectivity between agents. Exploiting the graph properties of such topologies can enrich the existing synchronization models to loosely coupled agents (oscillators).

Agents in this application domain are highly heterogeneous. Thermostatic devices have different technical features. Even in the case of exactly identical devices, the behavior of consumers affects the utility functions and therefore the synchronization. This can result to agents with no actual synergies, being unable to adapt the operation of their devices and synchronize. Nonetheless, modeling consumer behavior is crucial to further adapt the phase of the oscillators in the system. Finally, network delays and node failures can also influence synchronization.

4. CONCLUSIONS

This paper proposes the use of synchronized software agents for demand-side management. By (i) using agents to control thermostatic devices and (ii) modeling these agents as pulse-coupled oscillators, global energy stabilization can potentially emerge. This paper further sketches the challenges of applying synchronization models and principles in demand-side management. Certain restrictions and assumptions of the existing models are subject of investigation in line with our future research.

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