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# Smart devices for demand side power consumption management

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**Abstract**

Demand side power consumption management will become increasingly important in the near future, as power networks move from a "consumption-oriented generation" to a "generation-oriented consumption" paradigm. This requires decision making capabilities at the demand side for deciding how much power will be consumed, when energy prices fluctuate or demand responses are requested. The goal of this research is to develop a generic system which enables individual devices to autonomously determine their power consumption. The proposed system for smart devices is based on the concept of intelligent products, in which decision making agents provide intelligence to individual devices, turning them into smart devices capable of managing their power consumption. The evaluation demonstrates the feasibility and usefulness of the proposed system.



*Keywords:* Smart Grids; Demand management; Intelligent products

## 1. Introduction

Currently, energy management is typically based on the assumption that power demand cannot be controlled. Hence, energy providers always need to have sufficient power generation capacity to satisfy peak demand, and they continuously need to generate the amount of power required by the present consumption to

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ensure the stable operation of power systems. Such “consumption-oriented generation” will become increasingly difficult in the future, as energy generation will be more heavily based on volatile sources of energy such as sunshine and wind. With the recent development of Smart Grids, it is however envisaged that power systems will move from this “consumption-oriented generation” paradigm towards a “generation-oriented consumption” paradigm [1].

The basic idea behind “generation-oriented consumption” is that power demand can be influenced in order to make it match the present power generation. Two approaches to enable such demand management are often proposed: demand response and dynamic pricing. Demand response is mainly focused on reducing peak consumption, while dynamic pricing is focused on continuously balancing power demand with the present power supply. Both approaches require some form of intelligence or decision making capabilities at the demand side for deciding how much power will be consumed. Although numerous papers address a wide variety of topics relevant for the development of Smart Grids, few papers tackle the issue of how decisions on power consumption can be made at the demand side, when energy prices fluctuate or demand responses are requested. This paper tries to provide an early contribution in addressing this gap in literature.

The goal of the research as described in this paper is to develop a generic system which enables individual devices to autonomously determine their power consumption, given the current circumstances and the owner’s preferences. A design science approach [11,19] has been adopted for the development and evaluation of this system. The proposed system is based on the concept of intelligent products [18]. Intelligent products can represent individual devices such as home appliances and electric vehicles, and are capable of autonomously performing some of the repetitive tasks required for determining their power consumption. Such tasks include collecting and analyzing all relevant information, as well as determining the necessity for the device to consume power. In this way, the proposed system enables enhanced balancing of power demand and generation by making decisions on the level of individual devices.

## 2. Related work

Smart Grids is currently a very active field of research. The European Union, United States, China as well as Taiwan have proposed architectures for Smart Grids based on smart meters, and are working on several small-scale pilots [13]. A variety of topics relevant for the development of Smart Grids have been discussed in literature (see e.g. [2,4,6,7,9]). Among those, Advanced Metering Infrastructure (AMI) is considered to be the most important enabler for the development of Smart Grids, as it is responsible for measuring, collecting, storing, and analyzing energy consumption data in an automated way [10,14].

The Advanced Metering Infrastructure of Smart Grids enables a two-way flow of information between the power consumers and providers. With the installation of smart meters, providers are able to change the energy price in order to reduce consumption during peak hours [8]. However, how appliances can be controlled to actually reduce their power consumption has not yet been thoroughly studied. Some studies proposed a centralized approach, in which a smart device controller is placed within a Home Area Network, which controls all the appliances in that building or house (see e.g. [3,15]). However, a centralized device controller may not be aware of appliance-specific properties, which can result in undesirable decisions on power consumption. Hence, a novel distributed approach based on the concept of intelligent products is proposed in this paper.

The concept of intelligent products comprises two main sources of knowledge. The first source is formed by state of the art theories and frameworks in the field of intelligent products (see e.g. [12,16,20]). The recent research trends, emerging architectural designs, and novel application domains in this field are surveyed in [18], leading to the formulation of a classification model which has been used as a research framework. The second source of knowledge is based on application oriented experience, which was gained during the iterative development of an intelligent products architecture and the evaluation of that architecture by means of validating various prototypes [17].

## 3. System design

The proposed system design as presented in this section is based on the concept of intelligent products. An intelligent product is defined as a physical product combined with an information-based representation of the product stored in a database and intelligence provided by a decision making agent [16]. The connection between the physical product and the information-based representation can for example be made by using sensors. In this way, the decision making agent can continuously determine the condition of the physical product, by reading the sensor values, and make decisions based on that determined condition.

In the proposed system design, the concept of intelligent products is applied for electric devices, in order to turn them into so-called smart devices. For every device, a decision making agent is availablein the system, which can make decisions on the present power consumption of the device it represents. The behavior performed by the agents to achieve this is introduced next, according to the three levels of intelligence for intelligent products as prescribed by Meyer et al. [18]: information handling, problem detection, and decision making.

### *3.1. Information handling*

On the level of information handling, an agent representing an electric device has to collect the available relevant information from two main sources: the device it represents and the power network the device is connected to. All relevant information about the device it represents has to be collected, as this information is necessary for deciding how much power will be consumed. For example, an agent representing a refrigerator has to know the current temperature inside the compartment in order to determine whether additional cooling is required. Relevant information about the power network also has to be collected by the agent in order to make an adequate decision on the power consumption of the device it represents. Such information includes the present energy price and whether demand response is requested. For example, if the temperature in the refrigerator is relatively low, but the energy price is relatively high, the agent can decide to postpone cooling for a small period of time, hoping for a lower price in the next half an hour. However, if the temperature is relatively high, postponing might not be an option.

### *3.2. Problem detection*

Every agent has to determine whether the device it represents is in a problematic state or not. In this context, a problematic state refers to the situation where power consumption is crucial for the device, irrespectively of the energy price or requested demand response. Whether a device is in a problematic state is typically based on device-specific thresholds or owner-specific deadlines. An example of a device-specific threshold is a refrigerator whose interior temperature should not exceed 7 degrees Celsius. When the agent representing this refrigerator detects a temperature above this threshold, it will update the status of the refrigerator to problematic, and will thereby allow the refrigerator to consume power irrespectively of the present cost or requested demand response. An example of an owner-specific deadline is an electric vehicle which has to be fully charged before 8AM. When the agent representing this electric vehicle detects that there is no time available anymore to postpone charging, it will update the status of the electric vehicle to problematic, allowing it to consume all power necessary to still be able to make the deadline.

### *3.3. Decision making*

When a device is not in a problematic state, the agent representing it has to decide whether power consumption is desirable based on information available about the device and information about the power supply. For this purpose, every agent applies a utility function for determining whether consuming power will result in a positive utility. This utility function is based on device-specific thresholds, owner-specific deadlines, and the present energy price. In this way, the agent is able to find a balance between the thresholds and deadlines on one hand and the present energy price on the other hand. For example, an agent is more likely to accept a higher energy price, when there is little time available to complete a task (e.g. clothes in the dryer have to be dry before 10PM) or when it becomes closer to device-specific thresholds (e.g. the temperature of the refrigerator is reaching 7 degrees Celsius). However, when there is more time available to complete a task, the agent will try to minimize the energy costs by performing this task when the energy price is relatively low.

## 4. Evaluation

The system design as presented above is evaluated by means of descriptive scenarios [11], in order to demonstrate its feasibility and usefulness. Two envisaged scenarios in which the proposed system for smart devices is likely to be beneficial are described in greater detail next.

### *4.1. Appliances in a Home Area Network*

Within a Home Area Network, many different appliances are typically connected to the power network. Such appliances include refrigerators, freezers, heaters, PCs, dish washers, clothes washers, clothes dryers, electric vehicles, etc. Every kind of appliance has its specific power consumption properties and requirements. For example, a refrigerator has little flexibility on when to consume power, as it always has to keep the temperature of its compartment between certain thresholds.  On the other hand, a clothes dryer can have more flexibility, as it is often not an issue if the clothes are dried one hour earlier or later. As another example, a PC has to consume power when somebody wants to use it, while an electric vehicle requires charged batteries when somebody wants to use it. Hence, in the latter case, power consumption has to take place at any arbitrary moment before usage, as long as the batteries are charged in time.

Turning home appliances into smart devices is beneficial for demand side power consumption management due to several reasons. Firstly, the number of appliances which need explicit control from humans for demand management can be reduced, as the appliances can autonomously make decisions on their power consumption. This is especially beneficial when the number of appliances is high. Secondly, as every appliance has its specific power consumption properties and requirements, a smart device is more capable of managing its power consumption than a centralized entity within the Home Area Network. This is due to the fact that such a centralized entity may not be aware of appliance-specific properties, which in turn can results in undesirable decisions on power consumption. Finally, by applying intelligent agents for turning home appliances into smart devices, one can take advantage of the methodologies and solutions provided by the multi-agent paradigm [5].

By applying the system design based on the concept of intelligent products, as presented in the previous section, the home appliances can be turned into smart devices. In this way, each appliance can autonomously make decisions on its present power consumption. When an agent representing an appliance receives a request for demand response, it can apply its problem detection behavior to determine whether the appliance is in a problematic state. If the appliance is not in a problematic state, it can be temporarily turned off. When the state of the appliance becomes problematic, or when a demand response is no longer needed, the appliance can resume normal operation. Next to that, the agent can apply its decision making behavior for dealing with dynamic energy prices. In this way, every agent representing an appliance can determine whether power consumption is still desirable when the energy price changes.

### *4.2. Electric Vehicles in a parking lot*

In future parking lots, electric vehicles can be charged while being parked. The power available for charging cars however is always limited due to the ampacity of power lines and the capacities of transformers in place. Therefore, only a small part of the parked electric vehicles can be charged simultaneously, although most vehicles typically require charging. Moreover, the power requirements can be different for every vehicle. Some vehicles will only be parked for a short period of time, while others are parked overnight or even for several days. In the first case, there is little flexibility on when to charge the vehicle, while in the latter case, the flexibility on when to charge the vehicle is far greater. Moreover, some vehicles only require a small driving distance after parking, while others need to drive further and thus require a fully charged battery. Because of the limited power capacity availability and the differences between vehicles, the development of a smart solution is required.

Turning these electric vehicles into smart devices is beneficial for demand side power consumption management, for similar reasons as is the case with home appliances. Moreover, this approach can be applied to ensure that the total power consumption will not exceed the capacity of the power lines and the transformers in place at the parking lot. In order to achieve this, a parking lot only has to dynamically adjust the energy price for charging cars based on the present demand. The agents representing the electric vehicles will apply their decision making behavior for dealing with these dynamic energy prices. Hence, an agent representing an electric vehicle will more likely accept a higher energy price, when there is less time available to sufficiently charge the battery. Moreover, the price an agent is willing to accept will also based on how much charging is still required. How long the vehicle will be parked and how much charging is required are based on the owner’s schedule and preferences, and the agent is either informed about these, or the agent can estimate these from previous visits to this specific parking lot. In this way, the presented approach will result in a balanced power supply and demand, without overloading the power lines and the transformers in place.

## 5. Conclusions and future work

Demand side power consumption management will become increasingly important in the near future, as power networks move from a “consumption-oriented generation” to a “generation-oriented consumption” paradigm. This requires decision making capabilities at the demand side for deciding how much power will be consumed, when energy prices fluctuate or demand responses are requested.

In this paper, a generic system has been presented, which enables individual devices to autonomously determine their power consumption. The proposed system for smart devices is based on the concept of intelligent products. These smart devices are capable of managing their own power consumption. The two descriptive scenarios, home appliances in a home area network and electric vehicles in a parking lot, have demonstrated the feasibility and usefulness of the proposed system.

To further confirm the feasibility and usefulness of the system, as well as to gain additional insights on the effectiveness and robustness of the system, a prototype of the proposed system is currently being realized. In future work, this prototype will be used for controlled experiments and simulation studies. Moreover, future work will be focused on developing more advanced decision making behavior for the agents representing electric devices, for example by enabling them to negotiate with each other about their power consumption.

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