REQUIREMENTS AND PROSPECTS FOR CONSUMERS OF ELECTRICAL ENERGY REGARDING DEMAND SIDE MANAGEMENT

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1. Introduction

Demand Side Management (DSM) and energy management in general usually tries to take influence onto the energy consumption of a number of energy consumers. Typically, these consumers (devices, machines, buildings, etc.) are interconnected with some network and equipped with the respective hardware to influence their consumption behavior. Depending on the details of the energy tariff and contract, the consumption of these DSM-members is then smoothened or forced into some certain schedule. Modern building automation interconnects virtually all electric devices like the heating system, air conditioning, lighting, ventilation and so forth so that modern buildings offer a number of networked devices that can take part in a DSM system. But still there is the need to connect previously non-networked appliances to such a DSM system. These consumers have to fulfill a number of attributes in order to take part in this „DSM-ification". This paper describes the different aspects of this problem and provides the corresponding solutions.

One crucial point in the architecture of the DSM system is, whether it is centralized or decentralized. This touches the algorithm design as well as the location of "knowledge" about the problem. See [1] for a discussion on distributed and non-distributed algorithms. In this work, however, this question is of no relevance. We suppose some algorithm that can optimize a number of consumers that provide a set of information, not depending if it is centralized or distributed.

The starting point of this discussion is a number of electrical consumers that are supposed to be equipped with the necessary computing power and networking capabilities in order to supply some algorithm with information and to receive resulting commands that influence their (future) behavior. After discussing the different ways of DSM-ification some practical examples are given. The paper ends with a conclusion and an outlook on future research.

2. Problem and related work

The DSM problem is, seen in an abstract manner, an optimization and scheduling problem. Some resource is to be organized and distributed among some consuming entities, in order to meet some requirements, depending on the goal of the DSM problem. These entities usually have a task to fulfill or some program to execute where they consume the resource. Taking influence onto the consumption schedule of the individual entities also affects the execution of their tasks, which might not be wanted. The goal is to find a global schedule that satisfies all local objectives (programs, deadline for tasks) and the global one (overall power-consumption chart).

Related work to this subject can be found in factory automation where machines and other resources must be planned and scheduled or in distributed computation, where resources like CPU time must be distributed efficiently among a number of processes.

These problems, and optimization problems in general, are tending to be very complex [2]. As a result, the solution of such problems is not easy to find. Modeling the problem to a search space can result in an infinitely or very large space that can never be searched completely. Therefore the right quantification and discretization must be applied to solve these problems afterward with appropriate algorithms [3].

What the algorithm needs is information about the predetermined future behavior and the possible and estimated future behavior of the consumers. Additionally, each consumer might have alternatives for its energy-consumption plan. This is, it might be able to postpone or anticipate its consumption partially or totally. The algorithm is then in charge of choosing the right alternatives so that the overall consumption satisfies the given global goal. The question is where and how this information is stored.

One way would be to model all energy-consuming entities into a mathematical model and store this model in a database-like storage system. This is virtually impossible because of the complexity of the system. Additionally the behavior of certain devices is almost unpredictable, just think of the heating system of a building being influenced by persons, the weather and other stochastic events. This “central knowledge” has the advantage of an overview over the global problem. The disadvantages are its bad scalability and its complexity. Therefore we prefer distributed and on-demand knowledge.

The devices themselves should store and maintain their model which might be ranging from lights to air-conditioning systems very simple or pretty large. The stochastic aspects of the system must be estimated and learned. Sensors for the weather and persons, calendars for repeating events, and other sensorial enhancements increase the “consciousness” of the system. A device might be able to estimate its usage hours in advance, just by realizing the facts that it is Monday, it is raining, and a certain person is present because the system has limited learning and abstraction capabilities.

Furthermore, devices with some autonomy (like washing machines, the heating system, etc.) might also have a choice when and how to consume energy. If some local task is supposed to be finished by some certain deadline, the device might have some freedom for its local schedule. These degrees of freedom can be announced to the optimizing algorithm who is in charge to find a global constellation that performs best.

How ever these estimations and predictions are done and how ever accurate they are, we isolate one input and one output that are usually missing on electrical devices:

- input: a way to tell the device orders for their behavior (taking influence)
- output: a way to find out what the device will and can do next

The output might be a table of predictions and future possibilities, or the capability of negotiation. In both cases the input and the output are tightly related. We do not settle on one method like negotiations, search rooms, etc. but rather focus on the common problems of these methods, namely:

- what can consumers offer, and
- how can consumers be integrated into a DSM system.

Sections 3 and 4 give a taxonomy of DSM-devices and discuss how conventional and existing energy-consuming devices can be extended to offer the above interfaces.

3. DSM-able energy consumers

There is usually just a small number of really “important” energy consuming appliances which have a consumption high enough to be controlled, like water heating [4]. Large office buildings or something similar, however, might have thousands of independent small consumers like the lighting system or sun blinds. Massive networking and building automation enables them to take part in the DSM system. Thus, we classify energy consumers into those that can influence their behavior and those who can not:

- Active: These devices are the real DSM-able parts in the system. They issue a prognosis about their future consumption and their future alternative behavior. The are able to chose one of these alternatives to change the overall consumption.

- Informative: They only issue a consumption prognosis and lack of the possibility of actively changing and controlling their consumption. They can and must take part in a DSM environment, but only active devices can actively contribute to the DSM goal.
- Non-Informative: The consumption of devices that are not part of the DSM system (no communication-network connection, etc.) can only be measured at a (central) energy meter.

Even non-informative devices must be part of the model and the calculations because they also contribute to the overall energy consumption. We propose two solutions: letting them being represented (individually or in common) by a virtual device or plugging them into a socket that would manage their power supply. Section 4 discusses both possibilities.

Both types of DSM-able consumers, active and informative, may be sorted out regarding the kind of prognosis they issue. Moreover, some devices do precise predictions, while others can only estimate how likely is that such consumption will happen. Such further classification is the following:

- Consumers that issue an exact prognosis: The device knows accurately the amount of energy to be consumed and the certain point of time when it is going to be needed.
- Consumers that issue a probable prognosis: The device issues a prognosis, where all the energy-consumption predictions are completed with a probability estimation. More accurately, the consumer does not predict how much energy is going to be needed at what time, but how likely is that a certain amount of energy will be needed at what time. The difference between active and informative devices stems from the amount of data provided. Whereas active consumers provide the different possibilities that they have, informative ones only know the probability and the amount of energy.

The prognosis is obtained from diverse sources: statistics, learning, Gauss-bell for light switches, etc. Thus, the more complex and intelligent the device is, the more accurate the prognosis. For instance, a heating system that uses statistics to issue a daily energy-consumption prognosis should consider differences between day and night, seasons, weekend or holidays and work-days, etc. On the other hand, there are also different kind of prognosis, depending on the period to be covered [5]: long-term and short-term. The behavior of a DSM-environment may vary regarding what type of prognosis do their devices issue.

Table 1 gives the classification of devices that may be included in a DSM environment.

Type	Description
Active	Take part in the DSM-process and may regulate their own consumption.
Accurate Prognosis	Probability = 1: Example: Task1: 0,3 Kw/h at 15.00 (variation ± 2 min), 30 sec. long Task2: 0,1 Kw/h at 15.01 (alternatives at 15.02, 15.06), 16 sec. long
Probable Prognosis	Probability < 1 Example: Task3: 0,05 Kw/h at 15.00 (variation ± 10 sec.), with 89% probability, 1 min. long Task4: 0,15 Kw/h at 16.00 (variation ± 10 min.), with 30% probability, 12 min. long

Informative	Issue a prognosis but cannot regulate their own consumption.
Accurate Prognosis	Probability = 1 Example: Task5: 0,35 Kw/h at 15.03, 16 min. long Task6: 0,13 Kw/h at 15.19, 48 sec. long
Probable Prognosis	Probability < 1 Example: Task7: 0,1 Kw/h at 15.20 with 30% probability, 1 min. long Task8: 0,8 Kw/h at 15.21 with 30% probability, 3 min. long

Table 1: Classification of devices involved in a DSM environment

4. DSM-ification of energy consumers

As explained in the previous section, devices included in a DSM environment must be able to issue a prognosis, to control somehow their energy consumption or both simultaneously. In case they don't implement such features, there is still a way to let them participate in a DSM environment: the DSM-ification. When a energy consumer gets DSM-ificated it becomes ready to be included into a DSM system, either as active or as informative member.

Principally, there are three solutions that allow the DSM-ification of an energy consumer:

- Replacement of the original controller: Involves the substitution of the original hardware controller of the device by a new and DSM-able one. It may be an expensive solution, since the new controller must gather old and DSM-related functionality. Therefore, this modality of DSM-ification is only feasible if the vendor participates in the development of the new controller. Depending on this controller, the consumer will become active or informative. In case it only issues the prognosis but cannot control the behavior of the device, it will be an informative one. If the new controller both manages the behavior of the device and issues a prognosis, it will be an active DSM device. Finally, the replacement is not always possible, since there are some devices that do not allow it due to hardware reasons or just because the intern logic of the devices makes it impossible.
- Establishing a tight support: This modality consist of installing embedded sensors that deduce the state of the device. If the device is a simple one, with well-known states, (as, for instance, a washing-machine, where it is possible to know the amount of energy needed in every state), it could be possible to devise a system that enables the device to be DSM-able. Thus, the sensors would detect the status and then, they could issue a prognosis. If the sensors inform to a local controller that manages some actuators, they could even influence the behavior of the device. For instance, some states of a washing machine could be rescheduled or delayed, if needed. Establishing a tight support is cheaper than replacing the controller, but the quality of the DSM behavior will be lower.
- Establishing a loose support: This solution aims to directly control the power cord of the device. A controller that participates in the DSM system manages the power that the consumer receives. This modality works with a very small range of simple devices that may be switched off an on without any damage or alteration in their status.

Table 2 that summarizes the different ways of DSM-ification, the benefits they may bring and their problems.

Solution	Consists of	Advantages	Disadvantages
Replacement of the controller	Substitution of the original controller by a DSM-able new one.	The device becomes DSM active	•Not always possible •Might be expensive •Only feasible with the help of the vendor
Tight support	Embedded sensors deduce the aim of the consumer and local controllers manage it	•Cheap solution, compared to the previous one •Easy to develop in well-known-state devices	•Too complicated for devices with too many or dynamical states. •Quality of DSM behavior lower than in previous solution.
Loose support	Management of the power cord.	•Cheap solution •Easily installable	•Sometimes has no meaning •Sometimes even not informative •Not always applicable

Table 2: Summary of the different ways of DSM-ification

As already introduced, some consumers cannot be DSM-ificated by the aforementioned processes. They must be included in the DSM-calculations, however, so we address the following solutions:

- DSM-proxy: it consist on a socket, where the non-DSM devices would be plugged in, and that could be switched on or off, when needed. It is a coarse DSM-ification with loose support, that maintains all its disadvantages.
- Virtual device (VD): A non-DSM consumer (not connected to the DSM communication network), or a group of them, are represented in the DSM process by a so-called virtual device. VDs are software programs (software agents) running on a controller or computer included in the DSM environment that detect when a certain device is switched on or off with the help of a sensor. If the device is in use (consuming energy) the VD takes part in the DSM negotiation and announces the current consumption of its device. It may issue even a prognosis, in case it is able to learn or uses some statistics (just as informative consumers do). The VD might be attached to the global energy meter and deduces the usage of the individual appliances via some mathematical analysis and a build-in model [6]. In conclusion, VD can be seen as the software version of a DSM-proxy, with the advantage that powerful VDs (these able to use statistics or to learn) may achieve to convert their non-DSM-able consumers into informative ones and thus, suitable for a DSM process.

Finally, let us have a look at simple example to better illustrate how a DSM-environment works. The DSM-system comprises four different energy consumers: a refrigerator, one vitro-ceramic cooker, a lighting system and a heating system. Figure 1 illustrates their features while Table 3 shows the situation at a certain point of time *t*.

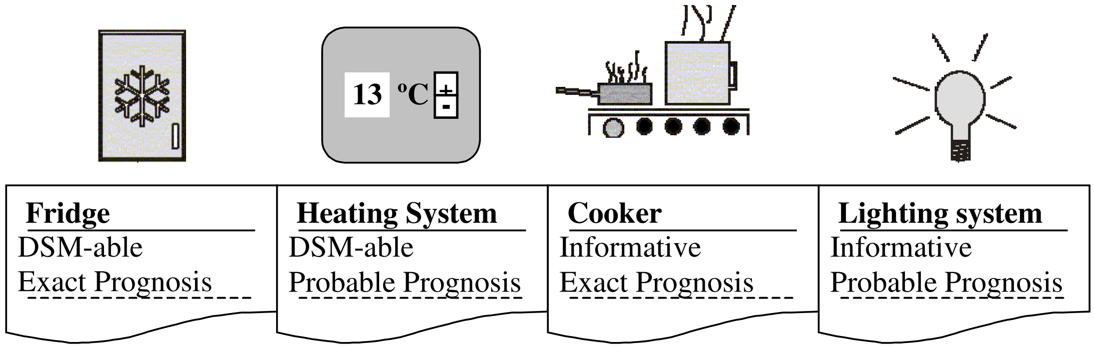

Figure 1: DSM environment with four different kind of consumers

Consumer	Time	kW	Probability	Duration
Fridge	t	0,2	100%	18 minutes
Heating System	t	3	45%	34 minutes
Cooker	t	2	100%	6 minutes
Lighting System	t	0,8	84%	50 minutes

Table 3: Situation of the devices at time = *t*

There are two additional elements that allow to include non-DSM-able devices in the DSM process: VDs and DSM-proxies. A number of electrical and portable heating-devices are *plugged into* a DSM-proxy and a TV virtual device (TV-VD) controls the television set. The TV-VD is a complex software agent that, after a learning process, knows that at time *t* it is very likely that the TV will stay switched on at least 30 further minutes.

In case that these devices are working, their DSM-relevant data at time *t* will be as depicted in Table 4.

Consumer	Time	kW	Probability	Duration
TV-VD	t	0,1	90%	30 min.
DSM-proxy	t	2	100%	1 sec.

Table 4: DSM-relevant data of the TV virtual device and the DSM-proxy

According to this data, all of them will need some energy at *t* (at least probably). The cooker and the lighting system do participate in the DSM process, since they provide information about the energy, they are going to consume. So do the portable heating-devices and the TV, but through their respective means: software (a virtual device) and hardware (a DSM-proxy). Prognosis and information about the energy consumption are, however, not enough to achieve a DSM regulation. After applying a DSM algorithm, *only* the fridge and the heating system will modify their behavior and this modification is the fact that makes the DSM system feasible. In a critical time or rush hour, even the portable heating devices could be switched off for a while.

5. Examples

The Institute of Computer Technology does practical research in DSM in a number of industrial and academic projects. The main focus lies on the networking technology, which is the reason why sometimes different types of networks are used and tested for their usability.

One case study of equipping a given consumer device with a network node for DSM is called “The Smart Fridge” [7]. A number of different network types were applied to a standard refrigerator: LonWorks [8], The European Installation Bus EIB [9] and an embedded controller with an Ethernet interface. The original control PCB (printed circuit board) of the refrigerator was replaced by a new one. It contained the control application for the refrigerator as well as the network node with the network protocol and the appropriate profiles. In the case of LonWorks LonMark profiles [10] were used to represent the services and functionalities of the device in the network. Additionally, the refrigerator was equipped with a number of new and additional sensors like power consumption measurement and humidity measurement. The method of DSM-ification was the most intrusive one: replacement of the controller that opened the door for adding various features and sensors.

A larger project called “smart kitchen” interconnects a number of different parts of a kitchen (light, oven, sunblinds, etc.) via a similar network and is therefore a useful lab to test new ways of DSM and DSM-ification [11]. It uses standard home- and building automation appliances, interconnected via a LonWorks network.

A project of larger scale is currently started in the field of global energy management, where whole buildings are interconnected and supposed to do DSM in order to reduce energy costs. The principles of the algorithms and information flow are the similar to those in local DSM networks. The main difference to local DSM networks is that the nodes are normally off-line since they are very likely interconnected via some telephone- oder GSM-network which results in costs for time, bandwidth or amount of transmitted data. Therefore communication must be minimized and also the network management of such a system has very special requirements (ad-hoc networking, plug-and-work, etc.). The DSM-ification happens in two layers. Each site that is included into the global DSM network has a local DSM system as well. The first application of this system will be three sites of the School for Applied Sciences in Hamburg, Germany.

6. Conclusion and further research

Integrating a domestic or industrial energy consumer into a DSM network may result in a fundamental change of this consumer and might interfere with the consumer processes depending on the chosen method. One step towards a working solution is to involve the producers of consumer electronics, machines and other energy consuming devices into this development process. Modern appliances should be equipped with some kind of interface, a network interface or just an ordinary communication interface, that offers information and control capabilities. The way to such “extendable” devices can only be via standardization of hard- and software interfaces, protocols and applications. Further research must therefore be done on standard proposals and abstract protocols and profiles for DSM-able energy consumers. Thus, in this paper, we have dealt with the first step toward this standardization efforts: the classification of energy consumers regarding DSM and how to DSM-ificate non-DSM-able devices.

Moreover, pendent topics are the development of effective and realistic optimization algorithms that are applied to real-live scenarios, and there is still an open question to answer, whether is it worthy to DSM-ificate all home appliances in a domestic dwelling. The topic that rises here is a hierarchy of DSM-clusters that group flats, building and maybe whole districts. The underlying network technology of such a “global” energy-management system is entirely different from the building-automation networks that were supposed in this article. Additionally, the larger the DSM community gets, the more interesting are the possibilities of DSM for the energy distribution, energy-transfers and energy-supply contracts. Finally, another upcoming subject is the development of learning consumers that can issue a usable prognosis.

The given taxonomy of devices and “DSM-ification” is the basis for this further work. Future projects and articles will investigate the economical and technological feasibility of the various concepts in the domains of building- and industrial automation.

Abbreviations

DSM Demand Side Management
CPU Central Processing Unit
VD Virtual Device
PCB Printed Circuit Board
EIB European Installation Bus
GSM Global System for Mobile Communications

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