AN EUP CLASSIFICATION FOR PARTIALLY DECENTRALIZED DOMESTIC ENERGY MANAGEMENT

Christoph Grimm, Professor, grimm@ict.tuwien.ac.at
Stefan Mahlknecht, Senior Engineer, mahlknecht@ict.tuwien.ac.at
Markus Damm, Research Assistant, damm@ict.tuwien.ac.at
Vienna University of Technology, Institute of Computer Technology, Vienna, Austria

ABSTRACT

The general problem addressed in this paper is optimal utilisation of renewable energy resources by managing the demand of appliances in private neighbourhoods and small offices/businesses. The core idea is to use wireless sensor/actor nodes to control electrical appliances in a way that local renewable energy resources like wind energy and photovoltaics are maximally exploited. Forecasts for the local renewable energy production are pre-processed by a central energy management unit which generates abstract cost functions. These cost functions might capture also other aspects like tariffs or load forecasts, and are then issued through the wireless network. The final decision making is then shifted to the sensor/actor nodes, and is based on these cost functions as well as the class of the appliance which is controlled. To this end, a classification of electrical appliances is presented which is suitable for the application scenario, and it is discussed how each class can be handled regarding energy management.

Keywords: demand side management, smart grids, classification, energy using products

1 INTRODUCTION

The goal of SmartCoDe (SmartCoDe, 2010) is to provide a wireless communication infrastructure for energy management (EM), or more precisely, demand side management (DSM) in the domestic sector. Wireless sensor/actor nodes are integrated into appliances to enable remote control by an Energy Management Unit (EMU). The nodes have to be cheap (<3€) and small in size (e.g. 1cm•2cm•2cm), in order to make the application attractive both economically and technically. SmartCoDe builds on the ZigBee wireless standard and employs highest-grade information security to ensure robustness against malicious attacks and intrusion.

The general concept of SmartCoDe considers a “local energy resource cluster” with:

- Local renewable energy resources like small-scale wind turbines and building-integrated photovoltaics. Via weather forecasts and other statistical means predictions of the renewable’s energy output are integrated into the energy management process.
- Local energy storage such as car batteries (plug-in hybrids, electric vehicles) which might also provide energy to the cluster if needed.
- Energy using Products (EuPs) such as HVAC, electric lighting, consumer electronics and white goods, whose power consumption is monitored periodically.

The EMU gathers the available data and controls the components of the cluster via the wireless nodes. Since the cluster can also sell energy to the grid, it is necessary to have predictable consumption/production behaviour. A common business model today for *large* consumers is that they pass their planned or expected load profiles to the grid operator, and are charged according to how far the profiles could be met. Therefore we assume that the local cluster has a certain target load profile to the grid. This load profile might be issued by the customer to the grid operator like described above, but could also be issued by the grid operator implicitly via time-dependent tariffs. It might even change over time due to dynamic tariffs and/or automated negotiations by both parties. Figure 1 shows an overview of the overall scenario.

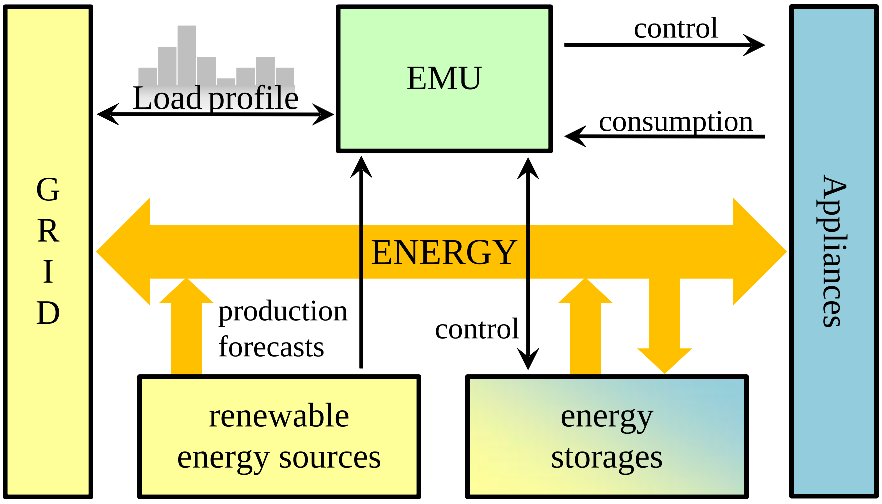

Figure 1 Conceptual Overview of a SmartCoDe cluster

An important aspect in designing such a system which is suitable for *general* cases is appropriate abstraction. For the problem at hand, we need a classification of EuPs in our target area (households, small businesses, i.e. not industrial) which covers all relevant cases such that each class can be treated the same way regarding DSM. Thereby we concentrate on *electrical* appliances.

This document is structured as follows: In Section 2, we present our proposal for such an EuP-classification, where we go into detail on the consequences regarding DSM for each class in Subsection 2.1. In Section 3 we sketch the overall EM-approach for SmartCoDe, before concluding in Section 4.

2 AN EUP CLASSIFICATION WITH RESPECT TO ENERGY MANAGEMENT

Figure 2 shows an overview of our proposal for the classification of Energy Using Products (EuP), and Table 1 on the following page goes more into detail. The first three columns of Table 1 contain the class name, the source of the class name, and a brief description of the class. The "Parameters" column contains three sub-columns:

- Configuration: These parameters are updated rarely by the user through the EMU, or by the EMU itself according to a schedule or a policy defined by the user.
- Sensor input: These parameters are provided either by the EuP itself or by the SmartCoDe node’s sensor interface.
- Online user input: These parameters are updated frequently by the user directly at the device (possibly through the SmartCoDe node).

Note that only those parameters are listed which are specific to the particular class. There are additional generic parameters which are relevant for every class, like the power consumption of an EuP.

The column labelled "Action" gives an outline on how this EuP class could be handled by SmartCoDe depending on the parameters. The actions are described in a way that leaves open which part of the action is handled by the EMU and which part is handled by the SmartCoDe node. For example, the action described for the class VARSVC (which effectively constitutes a control loop) could be handled by the SmartCoDe node itself. It also leaves open the question of how far SmartCoDe parameters are used for the handling of the specific device. The last column gives some examples of EuPs falling into the respective class.

2.1 Relevance regarding Demand Side Management

In this section we discuss what leverage each of the classes provides regarding DSM. From a practical point of view, the two most interesting classes regarding demand side management are VSTSVC and SKDSVC.

Figure 2 EuP classification: Overview

2.1.1 VSTSVC

The advantages and properties of virtual storages like freezers or heaters are well known, see for example (Kupzog & Roesener, 2007) or (Malik & Cory, 1997). The core idea is to cool down (resp. heat up) in favorable times (e.g. when wind energy is abundand or grid energy is cheap), such that the apliance can be turned off in unfavorable times. This is possible since the (virtually always thermal) services provided by VSTSVC EuPs is inert enough. However, the time frames involved can reach from several minutes (fridge) to even a day for large building air-conditioning. Forecasts on the energy conditions are not essential for DSM of VSTSVC EuPs. They can react instantaneously to changing conditions, unless they are at the “opposite end” of their boundary conditions, e.g. fully cooled down to their lower threshold already when the solar panel output increases. If energy forecasts are taken into account, such circumstances can be avoided. However, a temperature forecasts must be used also in order to make control plans.

2.1.2 SKDSVC

The idea of using EuPs with a schedulable service (like washing machines or dishwashers) for DSM is simple: In addition to a program, the user inputs a latest stop time until the service has to be finished. Then the program is started within this time frame such that the runtime lies within favourable energy conditions. This can be done effectively only if a forecast on the energy conditions is available. Also, having a typical load profile available for the specific program is helpful for planning, since SKDSVC EuPs will seldom draw a constant load when they run. A washing machine, for example, has typically a load peak at the program start, when water is heated up, and at the end of the program during centrifuging.

In principle, it would even be possible to interrupt a specific program. However, this might result in a quality loss in the respective process (e.g. washing clothes). Measurements like these have to be developed closely with the process experts, i.e. the white goods manufacturers. At the moment, we only consider to run a specific program completely once it’s started without any interruption.

Table 1 EuP classification: detailed description

Class	Abbrev. from	Description	Parameters			Action	Examples
			Configuration	Sensor input	Online user input		
SKDSVC	schedulable service	The EuP provides a service which runs for a certain time and can be scheduled within a certain time span.	runtimes & power profiles of the different programmes	none	earliest start time, latest stop time	On input of earliest start time and latest stop time, SmartCoDe has to find a start time within the given bounds which minimizes costs.	washing machine, dryer, dishwasher, baking machine
VSTSVC	virtually storable service	The EuP provides a inert service which can serve as a virtual storage	interval defining upper & lower tolerance bounds	value describing the current state of the service, mostly temperature	current user demand	SmartCoDe has to keep the state of the service within the threshold values such that costs are minimized, exploiting the virtual storage property.	Fridge, Freezer, HVAC, Water-boiler
VARSVC	variable service	The EuP provides a service which might vary due to user interaction and/or daytime	interval defining upper & lower tolerance bounds	value describing the current state of the service, e.g. illuminance	current user demand	SmartCoDe has to keep the state of the service within the threshold values (determined by the current user demand and the tolerance bounds) such that costs are minimized.	lighting controlled by illuminance level (e.g. in garden, at entrance), dimmable lighting, blinds
ETOSVC	event-timeout controlled service	device is switched on and kept on by sensor events, and switched off in absence of sensor event	absence time span for switching off	event, e.g. presence detection	none (indirectly through sensor input)	SmartCoDe switches device on if event is detected, and switches it off after the time span set if the event did not occur again.	lighting controlled by presence detector (e.g. on corridor)
COMCON	complete control	charging and using up power decoupled; latter only restricted w.r.t. time slots & minimal service	minimal runtime per time span, time slots	current charge status	none	SmartCoDe charges the device and runs the device within the given time slots such that costs are minimized.	robot vacuum, robot lawn-mower
CHACON	charge control	charging and using up power decoupled; latter is mostly (or solely) user-dependent	charging policy	current charge status, device presence	device removal	SmartCoDe charges the device according to the charging policy such that costs are minimized.	battery & cellphone chargers, hand-held vacuum, emergency backup storages
CUSCON	custom control	device does not fit into other classes, therefore custom control by user and/or EMU	none	none	user demand / EMU demand	SmartCoDe does not control the device except through direct user-input or EMU control	HiFi, PC, Oven

2.1.3 CHACON and COMCON

Regarding DSM, battery chargers are somewhat in between VSTSVC and SKDSVC. On one hand, they can be regarded as providing a service (the charge status), which only deteriorates marginally when the charging is stopped; this resembles VSTSVC. On the other hand, the ultimate goal is a full charging, possibly until a certain deadline. This aspect is more like SKDSVC, especially when keeping in mind that the charging process might even exhibit a specific load profile; see e.g. (Dung & Yen, 2010).

Depending on the rechargeable battery technology it might not be advisable to interrupt the charging process once it has started (battery lifetime issues), i.e. the safest strategy is to plan charging in one go according to an energy forecast, taking specific charging profiles into account. Therefore, CHACON EuPs can indeed be treated like SKDSVC. However, with a more detailed knowledge on the battery's characteristics, more elaborate schemes can be developed.

An interesting variation of CHACON is the COMCON class, which encompasses robotic services where the EMU can have complete control on when to charge and also when to use up the stored energy. A good example here is a robot-lawnmower which could be controlled such that it mows the lawn of an estate completely on average every two weeks, scheduling the charging and mowing according to energy availability and cost. We won't work out details on DSM of such robotic services in the project, since they are still very exotic, and there are also many ways to trigger the operation (e.g. sensors, minimal duty cycles or user demand) depending on the precise application. But it is obvious that this class could provide an excellent leverage regarding DSM.

2.1.4 VARSVC and ETOSVC

We collect these two classes together here since they mostly cover lighting applications, although fans fall also into the VARSVC class (the cooling effect is not inert), and e.g. a public message screen controlled by a presence detector would be part of the ETOSVC class. For our typical application scenario, a household or office in the European Union which is connected to the public grid, VARSVC provides virtually no leverage regarding DSM. While it would be possible in general to dim lights according to the current energy conditions, it is unlikely that the typical user in this scenario would tolerate that. However, this may be different in islanded scenarios (i.e. with no grid connection), where such unpleasantness might be tolerable to ensure more vital operations like fridges.

The DSM possibilities of the ETOSVC class are minimal regardless of the scenario. The only possibility would be to manipulate the timeout-thresholds according to the energy conditions.

Therefore, we foresee no cost-function dependent EM for VARSVC and ETOSVC in SmartCoDe. However, the basic approach in these classes, e.g. diming lights in order to exploit natural light and using presence detection is energy-saving per se. Also, the two approaches could be combined.

2.1.5 CUSCON

This collects all these EuPs which won't allow for automated DSM activities, mostly because of high user interaction. While we don't foresee cost-function based EM, we still allow for the EMU to switch CUSCON EuPs directly. That way, the user can still define custom EM schemes, or even use the SmartCoDe infrastructure for safety purposes, e.g. switching off an oven when no one is present in an apartment.

2.2 Technical and legal limitations of EuPs

For some EuPs, there might be limitations regarding how often they can be switched on and off:

- Fridges can break (compressor failure) due to too high switching rates.
- Certain lamp types (e.g. high pressure lamps) have time limits for switching them on again after the last switch off.

For other types of EuPs, certain requirements regarding the duty cycle might need to be met:

- Boilers might be obliged to heat up water to certain temperatures in certain limits for hygienic reasons (e.g. 70° C once a week to avoid Legionellae contamination, see (Deutscher Verein des Gas- und Wasserfaches e.V., 2004)).
- Water pumps might need certain minimal operation (e.g. once a week for one minute) to avoid jamming even if the water they pump is not needed.

These limitations have to be considered when necessary, but will not be explored further here. In general, they will result in extra boundary conditions to be incorporated into the energy management process.

3 A PARTIALLY DECENTRALISED DSM APPROACH

From the previous section it becomes apparent that the EMU has to have a somewhat detailed knowledge of the EuPs it controls, depending on the EuP class and the application scenario considered:

- load profiles of different programs
- temperature characteristics
- battery charging policies and load profiles
- minimal/maximal duty cycles

That is, the EMU basically has to maintain a “virtual copy” of the SmartCoDe cluster with respect to the relevant parameters. This, in turn, would result in a significant overhead every time an EuP is removed, replaced or added to the cluster.

Therefore we propose a partially decentralised approach where the EMU issues abstract cost functions on which the SmartCoDe nodes act autonomously. That way the EMU does not need to care about the class specific conditions and DSM strategies, since these are handled by the wireless node software locally at the EuP.

The idea of the cost function is that it provides abstract energy costs for a certain future time period, taking into account tariff, forecasts of local energy production and even power consumption forecasts based on usage statistics. For example, the abstract energy cost for a certain time span might be minimal even if the grid tariff during that time is at a maximum because the local power production is so high (e.g. a sunny & windy day) that it covers the lot of the possible local power consumption.

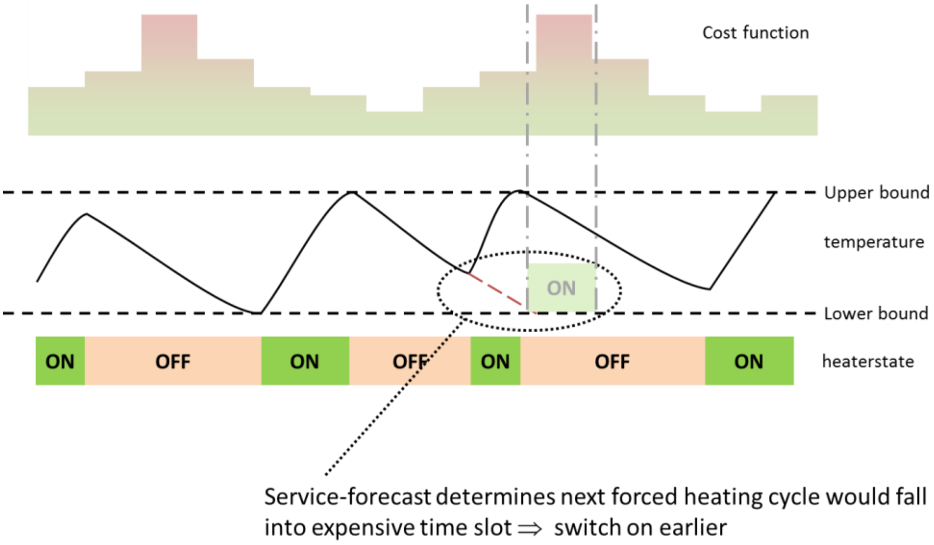

Figure 3 Bang-Bang control of a heater taking cost function into account

The SmartCoDe nodes now take this abstract energy cost figures into account regarding their local control decisions. Figure 3 shows how this would work with a heater as a representative of the VSTSVC (virtual storages) class. Basically, the algorithm is a simple bang-bang control, but the heater is switched on resp. off earlier if the cost function suggests this. It tries to avoid heater activation in costly times, and tries to turn it on in cheap times. To this end, it makes use of an internal forecast for the temperature it controls.

The format of the cost function is straightforward: It has a starting time, followed by several pairs of a time period and the value the function has during that period. That is, we describe the cost function as a step function. This is basically a generalization of the load control event in ZigBee Smart Energy (ZigBee Alliance, 2008); the abstract energy costs there are expressed as criticality level.

Figure 4 shows how the cost function approach fits in the global DSM strategy of SmartCoDe. To manage load balancing, we have to use *several* cost functions. That is, each cost function "controls" a certain subgroup of the EuPs. $E_1,\ldots,E_n$. This avoids the severe imbalances that might be caused if a large number of EuPs obey to a single cost function. The EuP grouping (with possible dynamic re-grouping) has to be done by the EMU.

Since we want the EMU to need as little knowledge as possible about the specific EuPs, it also does not know how an EuP reacts on a cost function. In the case of VSTSVC, for example, this would involve knowing the current temperature managed by the EuP. Therefore, we foresee the EuPs to report an estimate of the future power consumption. The idea is as follows: when the wireless nodes get their cost function, they make a control plan for their EuP for a certain time interval. Out of this control plan, they can then compute the expected power consumption, and pass this information on to the EMU, possibly together with a record of the past power consumption. This could be realised as a simple load-profile, again expressed as a step-function. The EMU can now take these power estimates into account when computing the next round of cost functions.

The exact format of tariff t and the forecasts $f_1,\ldots,f_r$ (for the renewables power output) are of no concern here. Indeed, an advantage of the cost function approach is that it is independent of tariff models, forecast formats and even optimisation targets. Any changes there only have to be implemented in the EMU, the cost function format and the node algorithms can stay the same.

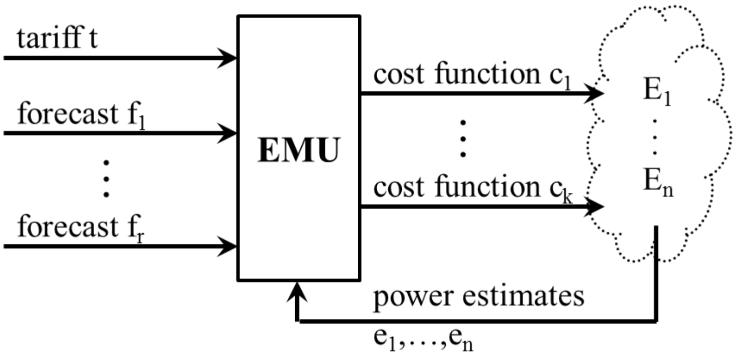

Figure 4 SmartCoDe Demand Side Management: The global view

Another important advantage of this partially decentralized EM approach is that the control decisions for the respective appliances can be prepared by those with the most competence for that task: the manufacturers. While they have to adapt to the communication infrastructure (e.g. ZigBee wireless communication and the interfaces), the implementation of the control algorithm lies completely within their hands; they just have to take one more parameter into account: the cost function. Therefore, the needs of the particular EuP (like those listed in Section 2.2) and the service/process they provide can be addressed better than by a 3rd party EMU. In fact, from discussions with white good manufacturers it became apparent that they reject the notion of outside 3rd party control of their products, such that our approach should be largely acceptable for the industry.

4 CONCLUSION AND FUTURE WORK

In this paper we presented the classification of Energy using Products (EuPs) used in the SmartCoDe project. The classification is specific to our application scenario in the domestic / small business area with renewable energy resources nearby but a usual public grid connection also available. We outlined the options for demand side management (DSM) for each class, and sketched a partially decentralised energy management (EM) approach where part of the control decision remains with the wireless sensor/actor nodes within the EuPs. This also leaves the EuP-specific parts of the control in the responsibility of the manufacturer.

Future work will include working out the details of the partially decentralised EM concept. This includes handling the big control loop in Figure 4 with an appropriate controller in the EMU, which raises several questions and issues, for example:

- What are good time frames for cost functions updates?
- In how far has the class of an EuP to be considered by the EMU-controller?
- How can stability issues be avoided?
- How can we ensure robustness against bad/imprecise forecasts regarding energy production (renewables) and energy consumption (EuPs)?
- How can we communicate power consumption flexibility from EuP to EMU?

To evaluate our approach and tackle these questions, we use a SystemC-based simulation environment which is also used for virtual prototyping and software development, and a real-life demonstrator will also be built.

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