10th International Workshop on Intelligent Solutions in Embedded Systems, 2012

Design Guidelines for Smart Appliances

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***Abstract*—Embedded intelligence can help controlling and reducing the energy consumption of appliances to a significant amount. Such a smart appliance will consist of a communication interface, a local processing and decision unit and the appliance's actual function. Sophisticated functions for such a device will involve a notion of real-time with a respective time format, a generic database that contains energy usage logs, error messages, warnings and real-time measurements for power usage, and an embedded self-description that allows to integrate the device into a system with minimum manual configuration. While there exists concepts for smart plugs and smart outlets that can be applied to "smarten" an existing device, in general we need to assume that the variety of appliances and technologies will require the support for various architectures including software solutions that integrate into the functions of an appliance with existing computing power, e.g. a DVD player or a state-of-the-art television set. Thus there is a need for architectural services with flexibility for different hosting systems while keeping the interoperability with respect to a smart home control system.**

Keywords: smart grid, smart home, smart transducer, smart plug, appliance, plug-and-play

I. INTRODUCTION

The smart grid, as the next generation power grid will embed digital services to gather, distribute and coordinate the behavior of suppliers and consumers in order to improve the efficiency, importance, reliability, economics, and sustainability of electricity services [1]. Household appliances such as heating, ventilation, air conditioning, refrigerators, stove, hotplates, etc. account for a major part of the residential electricity consumption. In order to support the smart grid, these appliances have to be integrated with the ability to monitor their energy usage and, possibly, to remotely control their electricity usage. Existing concepts such as smart plugs or smart meters provide some of this basic features but fail to integrate tightly with the functions and sensors of the appliance. It is the purpose of this paper to review possible architectural components for such a tightly integrated smart appliance [2] such as hardware issues, software, and communication services. Based on this survey, we will sketch design guidelines for such a smart appliance. While there is great flexibility in the hardware used for providing computational ability by the device, we promote a set of architectural services in order to make an appliance grid-aware and to provide interoperability with respect to the smart home control system.

II. HARDWARE

To offer a design guideline for smart appliances it is important to define the used hardware. This includes a lot of parts and is depending on the employed application. In general, we assume that the smart appliance should have a metrology unit, in which the current, voltage, power and other electrical values are measured and computed. Another important part of the design is the computing unit of smart appliances, e. g., a digital signal processor (DSP), a field programmable gate array (FPGA), a microcontroller unit (MCU) or an advanced RISC machine (ARM) processor. The essential hardware parts of the smart appliance can be divided into *passive* and *active* units. The passive units provide the possibility to measure the power consumption and to record these data. Active units are responsible for interaction with the environment. This can be switching the device on/off or the interactions between the device with human users.

In the following section the parts *requirements*, *computing unit*, *passive unit* and *active unit* of the design are discussed in more detail and several examples are introduced. Finally a characteristic table of all shown hardware concepts is presented.

A. Requirements

The smart appliance control hardware has several hardware requirements. One of these requirements and constraints is the **cost-efficiency** of the device. Cost depends on the basic system price (hardware, software development costs and licenses) and on the costs to operate the smart appliance control system, for example in terms of its own (stand-by) power consumption. For example, if we assume that we want to equip every appliance at home with a meter and a communication unit, it is not appropriate to use expensive DSPs for controlling and metering tasks. A further constraint is the **size** and the **form factor**. The size depends on the choice of the device position and the requirements of the desired application. Questions arising from that are: Which have to be clarified in advanced. Should the device use some "sleep" mode or being switched on/off periodically? Should it be supplied directly from the grid or by some separate power source like a battery? Can the control system be fed by an energy harvesting systems [3], [4]? A further important constraint on the hardware is the ability to perform measurements and actions with respect to real time. How often should the power consumption of the appliance be measured? Is it necessary to establish a connection link between devices during the whole operation time or only for predefined points in time?

B. Computing Unit

For the central computing unit it is possible to distinguish between *MCU*, *DSP*, *FPGA* and *ARM*.

1) Microcontroller: In general, a microcontroller is a chip used to compute some simple tasks and to control electronic devices. It features for example a central processing unit, which differs in bit-size from 8 to 64 bits. An MCU allows to control inputs and outputs, to create timers and to store data in RAM, ROM, EEPROM or Flash. Through this ability to control, to modify and to compute data an MCU is attractive for smart appliance applications, because of its cost and powerefficiency.

Choosing an MCU depends on the used and desired application. It is most suitable if basic cost and size are more important than computing performance.

2) Digital Signal Processor: A DSP has the same abilities as an MCU but is optimized for computationally intensive tasks such as FFT or DFT or digital filters. For smart appliances, DSP are the best choice if complex and math-intensive tasks need to be computed locally. A possible application of a DSP would be non-intrusive load monitoring, where the power consumption of the entire household is monitored by one meter and appliances are detected by their respective power consumption profile the respective appliances are detected [5], [6].

3) Field Programmable Gate Array: An FPGA is a device, which can be programmed at logic circuit level. The main advantage of an FPGA is that additions and multiplications can be computed in parallel. Computations which can be parallelized can thus be executed faster with an FPGA than with a DSP or an MCU. FPGAs have not been frequently used in more efficient smart appliances because FPGA are expensive and programming them is complicated and time consuming.

4) Advanced RISC Machine: The ARM processor are an widespread technology commonly used in the smart phone segment and for the entertainment devices. ARM processors are optimized for execution time and power consumption. Therefore, this processor family will play a major role in the context of smart appliances. For example, an ARM-based device could handle power profiles or the optimization of household power consumption.

C. Passive Units

Every smart appliance provides one or several passive features for measuring, data storage and communication. Accordingly, this section includes the parts *data storage*, *metrology unit* and *communication interface*.

1) Data Storage: The simplest way to locally store data in a smart appliance is to use the EEPROM or the flash memory of an MCU. These storage opportunities are called the embedded storage and offer a relatively small storage capacity. To store measurements in the long term dedicated storage devices are beneficial. In this context, imaginable solutions are external USB sticks or SD cards. For large amounts of data, an external storage device could be connected via eSata or USB. Another possibility is a network solution with a central storage server.

2) Metrology Unit: To save power it is necessary to measure the consumed power. The power consumption can be calculated based on voltage and current measurements. Calculation can be done either in hardware or software. Hardware power evaluation employs metering ICs. Currently, there are several metering ICs on the market, which mainly differ by their output interface. Some produce a frequency proportional to the power and others produce real valued outputs for active, reactive and apparent power [7]. In contrast, with software power evaluation the power is directly calculated in a processing unit. With this technique it has to be considered, that the MCU or DSP is constantly busy, which will add to the power consumption of the smart appliance itself.

In the following, solutions for particular voltage and power measurements are discussed. The voltage measurement can easily be done with the help of an analog-to-digital converter and one resistor [8]. But there are several possibilities to measure the current. The most simple one is the usage of a shunt resistor [9]. This technique uses a resistor in range of $m\Omega$ to $\mu\Omega$ in series to the smart appliance. Measuring the voltage drop across the resistor, the current value can be calculated. This technique is quite cost-effective and of small form factor, but has some disadvantages, for example that the resistance is affected by the actual temperature and that the actual power depends also on the voltage. For exact measurements, this cross correlation with the resistor's temperature has to be considered during the measurement result calculation [9]. Another disadvantage is that the voltage drop of the shunt resistor can damage the measuring system, if the load consumes a lot of power [9].

A further possible current measurement technique is the usage of a current transformer. The current transformer is built up of two coils with opposite polarity. The main principle of the current transformer is to transform the current from the primary coil to the secondary coil with the help of magnetic induction [9]. Next, the current transformer transfers the current to a voltage with the help of a resistor. In general, a current transformer has the advantage that the high voltage part is decoupled from the low voltage part. But the coils of the current transformers are relatively large and therefore not suitable for many applications in the smart appliance area.

Another technique for current measurement is the Hall effect sensor. This type of sensor uses the Hall effect to measure the current and also implements an isolation between high and low voltage part. One advantage of the Hall effect sensor is that the sensor is very precise and it is possible to build it up with ICs. Accordingly, the size of the Hall effect sensor is suitable for smart appliance designs.

3) Communication Interface: A further important task of a smart appliance is the transmission of data. For that we refer to Section III.

D. Active Unit

A smart appliance is a device, which not only collects, computes and communicates data, but the smart appliance it also interacts with the environment of the device. Therefore, it makes sense to distinguish between the cases *device interaction* and *human interaction*.

1) Device Interaction: The meaning of device interaction is how the device interacts with its environment. This can be for example the possibility to switch devices on and off. To accomplish this it is necessary to equip the smart appliance with an electronic switch. A possible device for this task is for example an electro-mechanical relay. Such a relay can switch some load on and off depending on a certain control signal, which could easily be produced by an MCU or a DSP. But electro-mechanical relays have some disadvantages. The main disadvantages are the size of the device (too big), the low switching speed and the limited switching lifetime [7]. To overcome these disadvantages of electro-magnetic relays, it is possible to use so called solid-state relays. These devices have high switching speeds, are relatively small and are not limited on the switching lifetime. The possibility to reliably switch a device off and on, can also be a big safety feature, which protects the device itself and as well as also persons interacting with the device.

A further possible environment interaction of the smart appliance could be the ability to dim an appropriate device. This means to control for example the intensity of a light according to a control signal or by human interaction. A thyristor circuit is usually needed to control the device.

Moreover, many home appliances consume considerable power in the stand-by mode. A smart appliance should thus be able to significantly reduce energy consumption when the device is not in use.

2) Human Interaction: The interaction ability of the device with a human user is a further important requirement. To establish a connection between device and user several ideas are imaginable. One and the most apparent solution is to use some visualization effect. This can vary from a small LCD display up to a touch-screen display. The choice of the used display depends on the desired application. Another interesting idea is suggested by the company Digitalstrom[1]. They use colored casings to encode the devices application type (e. g., blue casing for light, red for alarm systems, ...).

E. Summary of Hardware Concepts

In Table I we illustrate and summarize the most important hardware concepts. For that we present the costs of the different technologies with an example and their general characteristics. Costs are based on single units and listed for comparison only.

III. COMMUNICATION INTERFACES

One major idea of the smart grid concept is to provide a two-way communication between the entities of the smart grid system. Therefore, many different smart communication techniques exist which are suitable for smart appliances.

A. Requirements

1) Reliability: A reliable communication system should provide a complete, trustable and correct communication process.

2) Security: A further important attribute is to guarantee that the transmitted and received data is not manipulated or modified.

Technology	**Costs in €**	**Example**	**Characteristics**
MCU	0.5-20	TI MSP430[1]	control & maintenance & simple operation tasks
DSP	5-200	TI DaVinci[1]	complex math-intensive operation tasks
FPGA	> 50	Xilinx Spartan6[2]	not used yet, because of costs & programability
ARM	1-50	TI Sitara[1]	low power embedded processor for complex operation task
SD-Card	5-100	-	longterm data storage
External HDD	50-1000	-	longterm data storage
Metrology IC	ca. 1	Analog Devices ADE7753[3]	direct computation of the power
Shunt Resistor	0.01-5	-	power evaluation in software & temperature dependent & current measurement
Hall Effect Sensor	ca. 2	Alegro ACS712[4]	precise power evaluation & current measurement
Solid-State Relay	ca. 5	Sharp S216SE1[5]	direct computation of the power & switching ability

TABLE I
CHARACTERISTIC TABLE OF DIFFERENT HARDWARE CONCEPTS

[1] Texas Instruments: http://www.ti.com/
[2] Xilinx: http://www.xilinx.com/
[3] Analog Devices: http://www.analog.com/
[4] Alegro MicroSystems: http://www.allegromicro.com/
[5] Sharp Microelectronics: http://www.sharpsme.com/

3) Privacy: The communicated information should be available for persons who are authorized to see, use and change it. It should not be possible to eavesdrop or to modify the data. One possible solution for that is to use an **authentication** and **ciphering** technique.

4) Availability: The communication system should allow to react on events in the grid. Another aspect is **quality of service** (QoS) [10].

B. Wireless Communication Techniques

If we equip the smart appliance with a wireless communication technology several advantages arise, for example the support of user and device mobility and no cable installation. But the wireless communication also entails disadvantages such as the loss of the physical barrier. It becomes easier to eavesdrop or even manipulate and spoof transmitted data. Beyond that, also the fact that many devices and technologies share the same wireless channel generate negative effects. Many interferences are produced which reduce the communication quality. In the following the technologies *wireless LAN*, *Cellular Communication*, *WiMAX* and *ZigBee* are presented.

1) Wireless LAN: Wireless LAN technology is a very common and well-known technology. In terms of smart appliance design and application the wireless LAN technology plays a supporting role for protection and monitoring up to now [11]. A factor and advantage of wireless LAN are the high data rate and coverage to be achieved. In contrast, the fact that more than one technology like ZigBee, Bluetooth etc. are sharing the same frequency band is adversely and thus, leads to interferences and quality loss.

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[1] Digitalstrom: http://www.digitalstrom.org/

2) Cellular Communication Technique: Further possible communication technologies are cellular communication techniques like GSM, GPRS, UMTS, and LTE. A big advantage using a cellular technique does not require building up a new network [12]. Hence, cellular techniques are widespread, cost efficient and very secure. Cellular communication techniques can be used as a Supervisory Control and Data Acquisition (SCADA) system or a mobile phone as monitoring and metering device. A programmed app enables the user to control or to monitor the usage of smart appliances. One example of an monitoring application using GPRS is presented in [13].

3) WiMAX: Because of the high transmission range and high data rate the Worldwide inter-operability for Microwave Access (WiMAX) provides a good solution for Automatic Meter Reading (AMR) for smart appliance applications. Furthermore, also information on real-time pricing of the consumers power consumption can be collected with the help of WiMAX. In [14], for example, it is shown that it is beneficial to shift loads to off-peak times. WiMAX has problems to establish a correct data communication at frequencies above 10 GHz, because of the communication quality loss due to occurrence of obstacles. Thus, lower frequency ranges should be used. The licensed frequency bands for WiMAX are 2.5 GHz, 3.5 GHz and 5.8 GHz.

4) ZigBee: One important communication standard for smart appliances is ZigBee [15] based on the IEEE 802.15.4 standard. The U.S. National Institute for Standards and Technology defines ZigBee and the ZigBee Smart Energy Profile (SEP) as the most suitable communication standard for smart grid technologies [15]. In the area of smart grid ZigBee can easily be used for load control, for real-time pricing, energy monitoring, for remote control, for remote meter reading [16] for Advanced Metering Infrastructures (AMI) and for Home Automation Networks (HAN) [12]. But ZigBee also has some disadvantages, which are low processing abilities, small memory size and also the used frequency bands. The shared license-free industrial, scientific and medical (ISM) frequency band is used by many other communication techniques like IEEE 802.11, WiFi and Bluetooth leading to potential interferences.

C. Wired Communication Techniques

Beside the wireless communication technologies it is also possible to use wired communication technologies for smart appliances. The most important agent in this area is the Power Line Communication (PLC).

1) Power Line Communication: PLC has the big advantage that it can use existing power lines for communication and is also suitable for urban areas [12]. But it has a broadcasting data transmission behavior which makes security and privacy aspects difficult. Due to the nature of the power grid also other problems arise and reduce the quality of the communication. One of these problems is for example that the power grid is afflicted with a noisy environment and that the communication quality is also affected by the used network topology, used devices and also the distance between the devices [12], [17].

2) Fieldbus and Home Automation Bus Systems: Fieldbus systems such as CAN [18], Flexray [19], or real-time smart transducer networks [20] provide a fast and highly reliable networking for smart devices, however with considerable cost for wiring and devices. Therefore, they are not an option for smart home automation, but may be applied in industrial environments. In the field of home automation, there are several domestic network technologies which might be attractive since they offer established control and communication function for smart devices [21], [22].

Technology	**Data Rate**	**Range**	**Frequency Band**	**SG App**
WLAN	54Mbps	100m	2.4, 5.8GHz	protecting & monitoring
GSM/ GPRS	240kbps	10km	894/1900 GHz	SCADA & monitoring & AMR
UMTS	2,3Mbps	10km	1.92-198GHz 2.11-2.17GHz	SCADA & monitoring & AMR
WiMAX	70Mbps	50km	2.5GHz, 3.5GHz, 5.8GHz	AMR
ZigBee	250kbps	50m	2.4 GHZ	HAN, AMI
PLC	3Mbps	3km	30MHz	AMI

TABLE II
COMPARISON TABLE OF DIFFERENT COMMUNICATION TECHNOLOGIES

D. Comparison between Communication Interfaces

In Table II a comparison of the different communication techniques are presented. This includes the maximum data rate, the maximum transmission range, the used frequency bands and the prospective smart grid application for every technology [23].

IV. SOFTWARE ARCHITECTURE

A decade ago, software for embedded devices was developed as a monolithic piece of code which was tailored to a particular hardware platform. In the case of smart appliances we face the following problems:

- The underlying processing hardware might be different depending on the device. For appliances which already feature a processing device, an integration of the smart grid software services with the embedded device might be attractive as long as the extra software complexity can be handled.
- The implemented software features and services might depend on the appliance. Thus, apart from basic services such as communication, metering, or timestamping, device-specific functions can be found. Even for identical computing hardware, the actual software parts might differ.
- Software is not "burned" into the device but, at least potentially, subject to change. Therefore, a convenient and safe mechanism for software updates is required.
- The embedded appliance software might consist of several modules from different vendors. This requires also some safety features in order to avoid a takeover by a single malicious "add-on" module.

All these issues increase the complexity of a smart appliance network for the smart grid. In order to handle this complexity, the (human) system administrator needs to be supported by

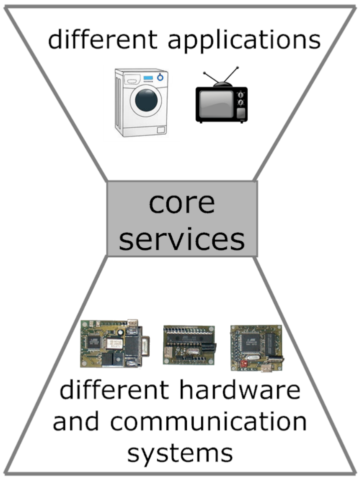

Fig. 1. Waistline architecture model for smart appliances

(semi-)automated configuration tasks. Therefore, each appliance needs to be able to describe its features in a machine-readable format, which can be interpreted by a configuration tool.

A. Waistline Architecture Model

A possible approach to cope with the system complexity would be the introduction of a **waistline** architecture [24, chapter 7.2.1] as depicted in Figure 1.

A waistline architecture is characterized by a minimum set of core services which provide the connection between a wide variety of basic hardware and communication services and different application types.

Possible core services would be:

- **Time service:** To relate events and measurements to each other and to plan coordinated actions across different devices we propose each smart appliance to provide a real-time clock as a time service. The provided time should be of reasonable granularity to support control loops with a period of around 1ms while having an epoch equal to at least the lifetime of the device. It would take only a 42 bit clock to cover 100 years with a granularity of 1 ms. Every embedded device described in section II provides an internal clock. Typically, this internal clock is based on a 16 or 32bit timer, some devices also offer a real-time clock with a longer horizon. Even for the "short" timers it is possible to extend the epoch with minimum software effort. A 16 bit timer extended by a 32 bit overflow counter would be already sufficient to cover the above example of 100 years. As proposed in [25], such a time service should reflect a global time, i. e., the clock states should be synchronized among the devices. Therefore, the time service should also include a clock synchronization service. The timer should be provided in a standardized way to all applications. In order to optimally match the limited hardware capabilities of the appliances, precision, granularity, and the horizon of the time representation may vary between different appliances.
- **Measurement service:** The measurement service should be a comprehensive data structure where all the available observations are provided. Observation means the combination of measurement value, measurement instant (related to the time service described before), and measurement description. The description can be a short name giving information about what value has been measured here. An example could be measurement of the appliance's power consumption. Additional information includes information about the measurement frequency, the next measurement update or possible error conditions. Some values may be also derived from other measurements by sensor fusion [26].
- **Storage service:** The storage service should make the particular hardware aspects of data storage and retrieval transparent and basically provide a database where an application can save its state. By defining an explicit storage service it will be also possible to back up the software state of an appliance or to migrate the current state to a new appliance.
- **Communication service:** The communication service should encapsulate the particular hardware implementation of the communication. However for some applications aspects such as available bandwidth, delay and connectivity should be accessible. The communication service should also provide different channels for real-time and non-real-time communication in order to support distributed control loops.
- **Device description:** The last core service should provide an electronic datasheet of the device's function including a list of installed software modules including their current version number and basic features. The device description is a basic requirement for enabling a plug-and-play-like configuration service [27]. Some appliances might be so sophisticated to allow software updates and even installations of new "apps" (*have you already downloaded the new Cappuccino App for the coffee maker?*) to enhance their features.

A minimum version of the described core services can be realized even for small microcontroller systems. The implementation should also be kept lean in order to reduce the cost of adapting the core service software to new appliances. Another challenge lies in designing the services in a way to cover the features of every possible appliance.

V. APPLIANCE DEMAND RATING

We distinguish between the following four appliances families:

- Domestic Appliances
- Entertainment Appliances
- Infrastructure Appliances

In Figure 2 the four appliance families are illustrated with their common devices. The domestic appliances contain for example a refrigerator, washing machine, stove and etc. Some of the appliances of this family have high power demand of all devices. In contrast, the families entertainment and infrastructure consumes less power and accordingly influence the total power consumption to a lesser extent. Although, devices belonging to the permanent family, can be distinguished

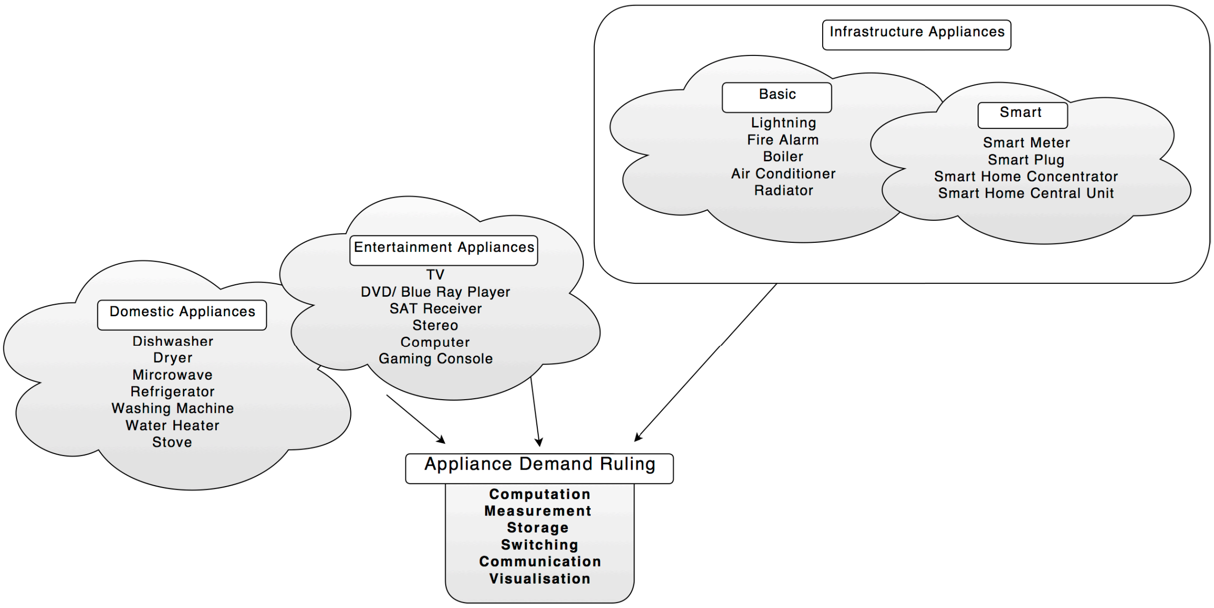

Fig. 2. List of appliance differentiation and possible appliance demand rules

between basic and smart. Basic devices are for example the lightning or the fire alarm. Smart infrastructure devices are a new introduced appliance family, which are responsible an the one hand for measure power consumption and communicate with the smart grid and on the other hand to make decisions how to optimize the current power consumption to reduce power requirements and also environmental pollution by unnecessary power wasting.

The hardware and software concepts introduced before can be applied to the four appliance families dependent on their tasks and characteristics. We defined the following ruling facilities to find out which task and characteristic every special appliance family should have:

Computation (Comp): Does the task of the appliance need high computation abilities?
Measurment (MS): What characteristics should be measured and how with which precision?
Data Storage (ST): Should the appliance provide a storage ability?
Switching (SW): Should it be possible to switch the appliance on/off remotely? Is zero watt a requirement?
Communication (Comm): What are the communication requirements of the appliance?
Visualisation (VIS): Should the device be able to visualize predefined and computed data (e.g. power consumption, on/off time, etc.)?

This demand ruling is also illustrated in Figure 2. To make and suggest a guide for smart grid appliance we propose in Table III, which appliance family should be attached with which hardware concept. To summarize the demand rating in Table III we can say that the domestic family typically has a MCU, a task-dependent accurate measurement unit (hall effect sensor, metrology IC), a embedded storage unit (power consumption recording, because of biggest power consumption influence), a switching ability (for standby killing and power consumption optimizing), a visualization unit (size and functionality dependent on the application) and possibly ZigBee or PLC as communication technology (dependent on the application preferred technology). An appliance of the entertainment appliance might have a MC, DSP or ARM (dependent on the computation effort of the application), a task dependent accurate measurement unit (hall effect sensor, metrology IC), a dedicated storage unit, a switching ability (for standby killing), a visualization ability (size and functionality dependent on the application) and a ZigBee or PLC communication unit (dependent on the application preferred technology). In our association the low cost appliance family are the basic devices of the infrastructure appliance family. This devices need a MCU, a shunt resistor for power measurements (because of relative small and permanent power consumption), a embedded storage unit, no switching ability, no visualization ability and ZigBee and PLC with the aim of low power and demand communication. Finally we consider the smart devices of the infrastructure family. Devices in this family are very dependent on the desired application. So for the demand ratings computation, measurement, storage, visualization all preferable hardware concepts are imaginable. Beyond, if we consider the switching ability it is suggested that smart infrastructure devices should not be turn off, because the are responsible for the recording and optimization of the power consumption. Finally, if we consider the communication ability of the smart infrastructure devices, we can see in Table III that nearly all presented communication technologies are imaginable. Dependent on the application either short distance communication technologies like ZigBee and PLC can be used (e.g. smart plug, smart meter communication to an central data concentrator and computation unit) or long distance communication technologies like cellular communication techniques (GSM, GPRS, UMTS) and WIMAX (e.g. for remote smart meter reading of the total household power consumption by

Demand	Household	Entertainment	Permanent	Smart Grid
Comp	MCU	MCU,DSP,ARM	MCU	MCU, DSP, ARM
MS	HES^1, MIC^2	HES^1 MIC^2	SR^3	HES^1, MIC^2 , SR^3
ST	ES^4	DS^5	ES^5	DS^4, ES^5
SW	✓	✓	-	-
Vis	LCD	LCD	-	-
Comm	ZigBee, PLC	ZibBee, PLC	ZigBee, PLC	CC^6 WiMax, PLC, ZigBee

TABLE III
DEMAND RATING FOR APPLIANCE FAMILIES HOUSEHOLD, ENTERTAINMENT AND PERMANENT

[1] HES...Hall effect sensor
[2] MIC...Metrology IC
[3] SC...Shunt Resistor
[4] DS...Dedicated Storage (SD card, HDD, Database)
[5] ES...Embedded Storage (EEPROM, Flash)
[6] CC...Cellular Communication Technique (GSM, GPRS, UMTS)

the electricity provider).

VI. OUTLOOK AND CONCLUSION

To define a generic design for a smart appliance is extremely difficult due to the many different vendors and device functions. This can also be seen by the features of existing solutions, which cover several aspects but still leave potential for improvement.

In this paper, we have first clarified the major requirements from a hardware and software perspective, followed by a an analysis of potential communication techniques, each with their specific advantages and disadvantages.

The great variety of design choices and non-existence of a monopole player in the appliance market will make it unlikely that a single system will prevail. The expected market will thus bring a zoo of partially interoperable, but quite different solutions, comparable to the Linux-based software world or the hardware base for Android smartphone devices. A (yet to be defined) waistline software architecture might however help in coping with these issues.

VII. ACKNOWLEDGMENTS

This work was supported by Lakeside Labs GmbH, Klagenfurt, Austria and funding from the European Regional Development Fund and the Carinthian Economic Promotion Fund (KWF) under grant KWF-20214|22935|24445. We would like to thank Kornelia Lienbacher for proofreading the paper.

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