Smart Home Information Management System for Energy-Efficient Networks

Published Version:
PERUZZINI, M., Germani M, Papetti A, Capitanelli A. (2013). Smart Home Information Management System for Energy-Efficient Networks. Springer [10.1007/978-3-642-40543-3_42].

Availability:
This version is available at: https://hdl.handle.net/11585/957942 since: 2024-02-14

Published:
DOI: http://doi.org/10.1007/978-3-642-40543-3_42

Smart home information management tool for energy-efficient networks

Abstract. Energy efficiency of modern systems imposes the intelligent management of a huge quantity of data and the collaboration between multiple stakeholders. Indeed, thanks to recent developments in ICT (Information and Communication Technologies) and IoT (Internet of Things), it is possible to achieve higher performances and offer new energy-control services. However, data must be not only retrieved but also translated into significant information and related to interoperable tasks. This paper focuses on smart home energy control and defines a methodology to improve smart home information management in order to create an extended energy-efficient network comprehending the distributed manufacturing enterprise as well as the energy utility and the consumers. The case study focuses on a sub-set of interoperable smart devices and shows how to apply the proposed information management model to make an extended virtual enterprise provide energy-control services.

Keywords: Energy-efficient networks, Interoperable smart home system, Internet of Things (IoT), Virtual Enterprise (VE), Energy-control services

1 Introduction

The growing attention to sustainability and the capabilities of recent technologies suggest creating intelligent networks to realize a more efficient use of the energy resources. Such an idea is particularly interesting if applied to smart homes for two main reasons: the high environmental impact of the residential sector, which is responsible for about 20% of total consumption, and the direct influence on the users' everyday life and behaviors with the final aim to educate people to realize energy efficiency. Data aggregation and sharing within the networks can be guaranteed by modern Internet of Things (IoT) approaches and supported by available Information and Communication Technologies (ICT) tools. Also networks are evolving from the traditional concept of distributed enterprise as an aggregation of manufacturing companies and their supply-chains [1] to a new concept of Virtual Enterprise (VE) based on open service ecosystems [2]: a distributed virtual network made up of devices, manufacturers, service companies, public entities, until customers and their homes, working as a Living Lab [3]. The high-level objective is creating a continuous flow of information within the VE that can be used to support real-time decisions, optimize the use of resources and increase safety and quality of life.

In this context, good information management is fundamental to achieve the expected goals. Indeed, the rising intelligence of smart devices makes a large amount of data available, but their complexity hinders classification, transmission and interpretation of essential data. Both aspects may drastically reduce the potential benefits and limit the diffusion of smart home energy management [4]. As a consequence, devices' interoperability in smart home is still an open issue [5].

The research idea starts from an evidence: every day people get in touch with a lot of home appliances but often their use is not appropriate and their care is neglected. In this context, the paper proposes a structured methodology to properly classify significant information and intelligently manage the smart device information network according to the devices' interoperability potentials and the users' needs. The main scope is to make home devices really interoperable and provide energy-efficient services for final users, to make them aware of energy consumption or properly care about devices' maintenance. It considers the most popular home devices and all the generated information, which could be implemented by a knowledge-based tool.

The case study demonstrates how to use the proposed methodology in practice. In particular, it is adopted to investigate and manage a real smart home scenario comprehending a set of devices and an industrial network to create energy-control services. Finally, few examples of such services are described.

2 Information management for smart home interoperability

The smart home is a special place where all the sub-systems are interconnected allowing the users to save energy, to reduce operating costs and to improve safety, comfort and multimedia services [6]. In recent years the attention is mainly focused on technological integration based on device connectivity and home area network (HAN) [7]. A considerable amount of new solutions for smart home automation have been recently developed, but each of them generally has a different communication protocol and requires a specific architecture. There are open or proprietary systems: the former has public operating specifications and proposes a standard communication protocol that can be used by companies to develop compatible devices (e.g. Konnex, Lonworks, Zigbee); the latter are produced by a single company (or industrial consortium) for specific home automation systems and the technical information are usually reserved (e.g. SCS by Bticino and Legrand, Vimar By-Me, C-BUS of Schneider Electric). In both cases, the definition of standards and common rules almost within a certain virtual enterprise are fundamental to make devices interoperable and integrate products from different manufacturers [8]. However the issue of interoperability is particular challenging due to the huge amount of data to manage and the level of complexity of the devices' integration. Although the idea of smart appliances connected within a home network is not new, smart home management has still some open issues. In this context, the European Committee of Domestic Equipment Manufacturers (CECED) established a preliminary application profile for smart home by promoting the CENELEC standard (EN 50523-1, EN 50523-2). Although data are collected and transmitted, they are rarely converted into significant information and used for real time feedback. Recently several system architectures for interoperability and energy management purposes have been proposed [9], and several projects have been developed in different countries such as Smart Energy 2.0 [10], Energy@home [11], E-Energy [12], ADDRESS [13], REserviceS [14]. However, they deepen specific issues like monitoring, analyzing and estimating energy consumption [15], or investigate particular device applications (e.g. energy management by smart grids) but none of them defines an overall and unique standard data management tool for high-level purposes. Some recent projects are focusing on data elaboration and data mining to realize services for different purposes, such as supporting manufacturing enterprises cooperation like MSEE [16], creating person-centric immersive environments like SM4All [17], or proving support to elderly people disabilities like HOPE [18]. However none of them cares about devices' interoperability and defines standard rules for information exchange between devices, users and utilities. In addition to energy information management, many other services could be integrated thanks to the existing technological infrastructures. However, there is a lack of an overall vision and a strategic roadmap for future developments. Although some companies recently faced the devices' remote control on white goods [19], remote control services (e.g. remote start-finish, remote maintenance, etc.) cannot be successfully implemented due to devices' regulation constraints, safety regulations and lack of interoperable system architecture. Indeed, remote maintenance concepts should be independent from the architecture capabilities as well as the devices' specific HW and SW characteristics [20].

3 The methodology for network energy management

The research overcomes the limits of the actual system by providing a method for the classification of the information involved in smart home energy management and the definition of an intelligence-based management model to handle energy-efficiency. The approach can be synthetized in four steps:

1. Classification of smart home devices into homogenous classes (Tab.1): it considers the most popular devices in smart homes and catalogues them for typology, input and output data, and interaction modalities;
2. Identification of a set of information categories for the smart home (Tab.2): it considers all the information necessary to include energy-control services and encourage their continuous improvement;
3. Definition of a general information management model (Fig.1): it correlates the information categories, the device functionalities, the network actors and the input/output data flow to provide a general model for smart home interoperability;
4. Definition of rules to support services into the network: it provides a set of algorithms to realize energy-control services with reference to the network actors (i.e. customers, energy utility, company technical staff, etc.) and allows detailing the actions in the information management model (Fig.1).

Such a model can be implemented by a proper system architecture, exploting existing technologies, such as power line standards (e.g. X10, HomePlug), wired communication standards (e.g. Ethernet, USB, HomePNA), and wireless communication standards (e.g. ZigBee, Wi-Fi, Bluetooth). All data will be collected and concentrated into a local gateway that serves as a bridge between the home network and the Internet [23].

Table 1. Information model device classes

Device class	Description
Household Appliances (HA)	It includes different classes such as cooling (refrigerator and freezer), cooking (oven, hob, and hood) and laundry (washer, dryer, and dishwasher), that are usually enhanced by a microcontroller to manage automatic operation mode and remote control mode [9], and a communication node to make the devices connected (e.g. Ultra-Low cost Power-line (ULP) [21])
Meters (M)	It includes electricity, gas and water meters, whose data are communicated through the home network and/or the smart grid in real time and can be remotely controlled. It can include also control and safety systems (e.g. electrical safety, gas leaks, water leaks)
Environmental Control (EC)	It comprehends common classes of components such as lighting, doors, windows, alarm system and sensors, window curtains and shutters, which can be grouped because they can be controlled by similar functions (e.g. turn on/off, intensity regulation, opening/closing control, opening regulation)
DHW and HVAC (HW)	It includes Domestic Hot Water devices (DHW), Heating, Ventilation and Air Conditioning devices (HVAC), and all the devices and sensors related to their functioning, even when located in different areas or on other devices (e.g., sensors of indoor/outdoor temperature, humidity sensors, etc.)
Consumer Electronics (CE)	It includes a wide range of devices from entertainment systems (e.g. TV, game console, audio equipment and players) to small household appliances (e.g. coffee makers, electronic cutters or graters, toasters), characterized by constant and low energy consumption and off/on switching

Table 2. Information categories

Information cat.	Description
Continuous Monitoring (CM)	It includes all the information that is continuously monitored when the devices are turned on, which mainly consists of resources consumption data (e.g. energy, water, etc.). Such data can be used to provide a direct feedback to final users to encourage a more efficient use of energy as demonstrated by recent studies [22]
User Interaction (UI)	It refers to all the information regarding the user-product interaction and characterizing the users behaviors (e.g. selected options, duration of use, time of use, frequency, etc.). Such data are used for statistic analysis and user behaviors investigation
Control Parameters (CP)	It considers the functional parameters of the home devices, which continuously analyzed and compare with a set of target parameters. Such data are used to predict problems, detect dangerous conditions, and supervise device functionality and user security
State Parameters (SP)	It refers to all information regarding the status of home devices, which is used to monitor a particular scenario or to carry out device remote control
External data (EXT)	It refers to data generated by external entities (e.g. building typology, occupants' characteristics, economic indicators, fees of utilities, climatic conditions) and device reference information (e.g. datasheets, standard consumptions, etc.), contributing to define the analyzed scenario
Derived data (DER)	It refers to data derived from post-processing elaboration and statistics analysis, which can be used for realizing specific service functionalities (e.g. average time of use, average expenditure over the time, use frequency of a particular function)

The definition of a general model is the key point to realize services able to exploit device interoperability. It also represents the first step toward the design of a proper smart management tool able to intelligently use the information generated by home devices for energy efficiency in smart homes.

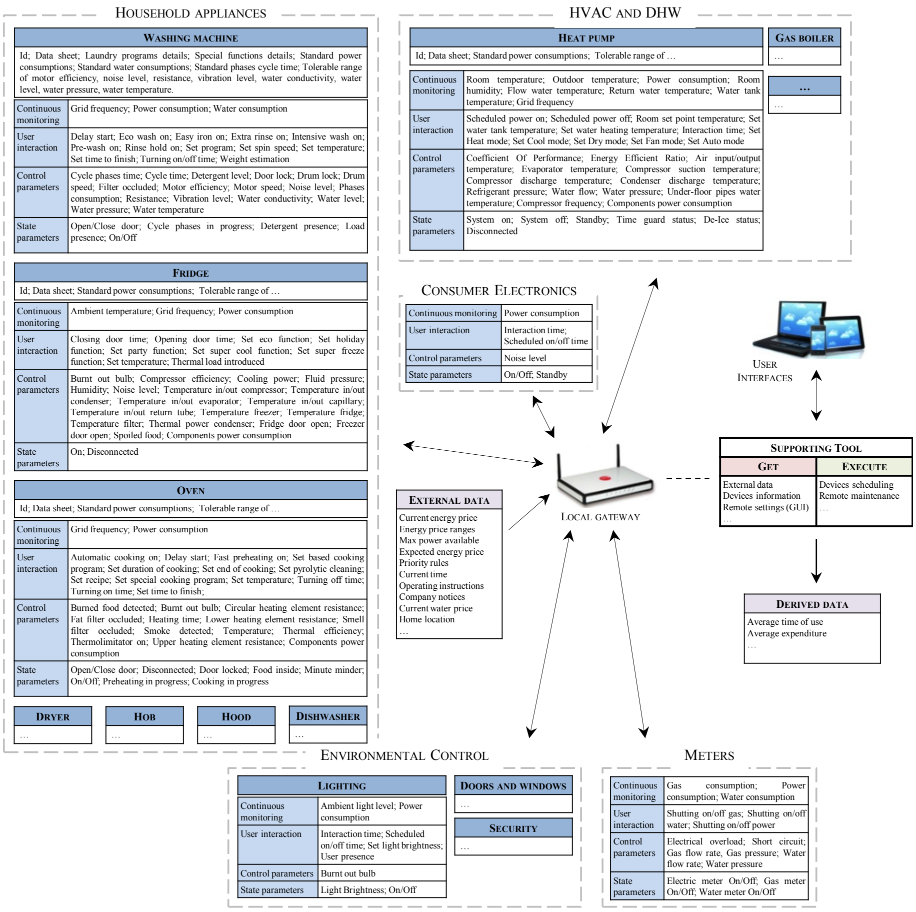

Fig. 1. Information management model for smart home interoperability

4 The case study

The proposed methodology is adopted to manage an interoperable network where all devices cooperate to optimize energy saving. It considers a set of appliances representing the most energy consuming and most popular devices in dwellings: heat pump (HP) for HW class; washing machine, oven, and fridge for HA class; lighting (L) for EC class; and a set of generic items for CE and M classes. In particular, CE items can be easily generalized by considering a sub-set of information provided by a generic smart plug (e.g. energy consumption, interaction time and device status). Similarly, M items can be represented by consumption and control parameters (e.g. short circuit, gas leaks, water leaks). The interaction between the devices and the management tool is ensured by dedicated applications. The case study proposes a hypothetical system architecture, made up of a set of smart devices and smart plugs, a

Zigbee communication node, a local gateway to collect all data and make them available to a central management system (i.e. Energy Manager), and a set of user interfaces (i.e. web or mobile apps). The Energy Manager can apply specific algorithms to properly manage data and provide intelligent-based commands. Data can be accessed for different purposes by dedicated interfaces (e.g. user, company staff, utility staff). The ecosystem involves several actors: appliances producers (Marketing Dept., R&D and Technical Service), a home automation supplier, an Energy Utility, a technical assistance company, and the Consumers. Two services are described as an example of the system functionalities and potentialities.

Service no.1: Smart device scheduling

The main objective is offering to the final users an intelligent regulation of the devices' functioning in order to save energy and reduce the home consumption. It indirectly allows also reducing the operational cost for users and improving their quality of life. The network brain is the Energy Manager, a knowledge-based tool able to run specific algorithms for efficient device scheduling according to external parameters and user preferences. Figure 2 presents the so-called "*Out of home*" scenario: when the user goes out, the "*I'm going out"* mode is running and the "*I'm out*" mode is activated to monitor the home devices according to the pre-defined preferences; when the user comes back, the *"I'm coming back"* mode uses internal and external data to enable the desired functions (e.g. turning on and preheating the oven according to the effective user's coming). According to the information received and read (*GET*), the system defines a set of actions (*EXECUTE*) to achieve the expected results. Flow box provides the actions path. Such a service offers standard actions (e.g. switching off lighting and alarm system), energy overload management (e.g. devices functioning is scheduled according to the energy cost and user preference in terms of priority, start or finish time), upgrading according to real time user notifications (e.g. change of the expected finish time for the washing machine), grid balancing (e.g. windows opening regulation according to the weather).

I'M GOING OUT

FLOW	GET	EXECUTE
GUI → HA → … → SP →	Return at home time; Set time to finish; Anticipate start; Scheduled start; Close all windows on All parameters	Control if the state parameters are comply with the conditions to enable the remote control else notice the user. Close windows if the related function is on.
EC → L → SP → CE → SP → HW → HP → CM →	On/Off On/Off Rooms and outdoor T	Activate alarm system; Switch off lighting; Set Heating ECO mode.
HA → … → M → CM → HA → … → UI → EXT →	Standard power consumptions Power consumption Scheduled turning on; Scheduled cycle duration; Scheduled cycle/phases consumptions Current energy price; Energy price ranges; Max power available; Expected energy price; Priority rules; Current time	Schedule the devices start that minimizes the energy expenditure for the user according to the priority rules, max power available and the user needs.

→

I'M OUT

FLOW	GET	EXECUTE
GUI → EXT → HW → HP → CM	Automatic regulation on; Max open time Weather; Wind Outdoor T	Regulate the windows opening/closing according to user settings and external conditions.
GUI →	User update about Return at home time and others settings	Upgrade the scheduling according to the new settings.
	-	Turn on the specific device at the scheduled time.
M → CM →	Grid frequency	Cycle management by means DDC technology.

↓

I'M COMING BACK

FLOW	GET	EXECUTE
HW → HP → CM →	Rooms and outdoor T	Turn on the devices that have an anticipate start in respect to the Return at home time. Disable the heating ECO mode.
		Switch on "welcome" lighting.

←

I'M HERE

FLOW	GET	EXECUTE
GUI →	Welcome on	Deactivate alarm system.

Fig. 2. Tool rationale of the "Out of home" scenario

Service no. 2: Recommendations for optimal use and product care
It aims to assure correct product maintenance and support the consumers in taking care about their devices by remote assistance and personalized recommendations. It finally allows optimizing the devices' consumption and cost, and keeping the home safe. Such a service basically exploits CP data collected from the devices to automatically detect malfunctioning and run preventive or predictive actions. For instance, during washing machine operation "cycle phases time" and "consumptions" data are continuously sent to the technical assistance company or to the manufacturer to be analyzed. Post-processing allows detecting whether the monitored parameters (e.g. motor speed, resistance) move away the standard or exceed the expected thresholds. Furthermore, analyzing the correlation between CP, SP, CM and UI data allows capturing also hidden malfunctioning (e.g. if the temperature in the oven is different from the set temperature, the system controls the program set and the resistance value and finally provides an alert). The user is noticed by messages about devices' troubles, repairing actions or scheduled interventions).

Both services exploit the network interoperability to overcome the main limits of the existing systems, which usually provide just energy consumption visualization and regulation. The proposed scenario offers advantages to all the ecosystem actors.

5 Conclusions

The paper proposes a methodology to improve smart home information management by promoting device interoperability and network collaboration for energy efficiency. It allows classifying smart device data and adopting an information management model to propose energy-control services. The research aims to overcome the main issues of existing smart homes by mapping the devices' functions and data, correlating the devices' functions with the smart home actions, and defining what information to send/receive to achieve a more aware and controlled energy consumption. The use case demonstrates how the methodology can supports energy saving in smart home by presenting two energy-efficient services. The proposed scenario offers multiple advantages: the customers have a continuous feedback on their product functioning, save energy and cost, and benefit from the reduction of failure rates and downtime; the appliances producers monitor their product by receiving useful information and can provide efficient and immediate assistance (Technical service Dept.), can highlight the most critical aspects to define design improvements (R&D Dept.), and can identify the users' behaviors to conceive new marketing proposal (Marketing Dept.); technical assistance companies and home automation suppliers can cooperate with the manufacturer to offer additional or customized maintenance services; utilities can create customized services and collaborate with the other ecosystem actors to create new business opportunities.

References

1. Byrne, J.A., Brandt, R., Port, O.: The virtual corporation. The company of the future will be ultimate in adaptability. Business Week, vol. 36, pp. 36–40 (1993)
2. Chesbrough, H.: Open Innovation. Harvard Business School Press, Boston (2003)
3. Wellsandt, S., Kalverkamp, M., Eschenbacher, J., Thoben, K.D.: Living Lab approach to create an Internet of Things service. In: Proc. 18th Int. Conf, Engineering, Technology and Innovation ICE, pp.1-9, IEEE press (2012)
4. Kim, S.L. Hwang, J.: Real-time Energy Monitoring and Controlling System based on ZigBee Sensor Networks. In: Proc. Computer Science, vol. 5, pp. 794-797 (2011)
5. Chen, C.Y., Tsou, Y.P., Liao, S.C., Lin, C.T.: Implementing the Design of Smart Home and Achieving Energy Conservation. In: 7th IEEE International Conference on Industrial Informatics (INDIN 2009), pp. 273-276 (2009)
6. Wong, J.K.W., Li, H., Wang, S.W.: Intelligent building research: a review. In: Automation in Construction, vol. 14, pp. 143-159 (2005).
7. Perumal, T., Ramli, A.R., Leong, C.Y., Samsudin, K., Mansor, S.: Interoperability Among Heterogeneous Systems in Smart Home Environment. In: Atlantis Ambient and Pervasive Intelligence, vol. 2, pp. 141-157 (2010)
8. Kailas, A., Cecchi, V., Mukherjee, A.: A Survey of Communications and Networking Technologies for Energy Management in Buildings and Home Automation. In: Hindawi Publishing Corporation Journal of Computer Networks and Communications, Article ID 932181 (2012).
9. Alam, M.R., Reaz, M.B.I., Ali , M.A.M.: A Review of Smart Homes-Past, Present, and Future. In: IEEE Transactions on Systems, Man, and Cybernetics-Part C: Applications and Reviews, vol. 42, pp. 1190-1203 (2012)
10. http://www.zigbee.org/SmartEnergy
11. http://www.energy-home.it
12. http://www.e-energy.de
13. http://www.addressfp7.org
14. http://www.reservices-project.eu
15. Shin, J., Hwang, J.: Intelligent energy information service based on a multi-home environment. In: Proc. Computer Science, vol. 10, pp. 197-204 (2012)
16. http://www.msee-ip.eu
17. http://www.sm4all-project.eu
18. http://www.hope-project.eu
19. Bansal, P., Vineyard, E., Abdelaziz, O.: Advances in household appliances - A review. In: Applied Thermal Engineering, vol. 31, pp. 3748-3760 (2011)
20. Mullera, A., Marquezb, A.C., Iung, B.: On the concept of e-maintenance: Review and current research. In: Reliability Engineering and System Safety, vol. 93, pp. 1165-1187 (2008)
21. Ricci, A., Aisa, V., Cascio, V., Matrella, G., Ciampolini, P.: Connecting electrical appliances to a Home Network using low-cost Power-Line Communication. In: Proc. International Symposium on Power Line Communications and Its Applications, pp. 300-304 (2005)
22. Bonino, D., Corno, F., De Russis, L.: Home energy consumption feedback: A user survey. In: Energy and Buildings, vol. 47, pp. 383-393 (2012).
23. Cheng, S.T., Wang, C.H., Horng, G.J.: OSGi-based smart home architecture for heterogeneous network. In: Expert Systems with Applications, vol. 39, pp. 12418-12429 (2012)