2016 Intl IEEE Conferences on Ubiquitous Intelligence & Computing, Advanced and Trusted Computing, Scalable Computing and Communications, Cloud and Big Data Computing, Internet of People, and Smart World Congress

Bridging the Gap between Real and Simulated Environments: a Hybrid Agent-Based Smart Home Simulator Architecture for Complex Systems

Oihane Kamara-Esteban*, Gorka Sorrosal*, Ander Pijoan*, Tony Castillo-Calzadilla*†, Xabier Iriarte-Lopez*
Ana M. Macarulla-Arenaza*, Cristina Martin*, Ainhoa Alonso-Vicario*, Cruz E. Borges*
*DeustoTech Energy - Fundación Deusto, Avda. de las Universidades 24, 48007, Bilbao, Spain
†University of Oriente, N. de Anzoátegui, Technological Institute, Via Alterna, Barcelona, Venezuela

{oihane.esteban, gsorrosal, ander.pijoan, ana.macarulla, cristina.andonegui, ainhoa.alonso, cruz.borges}@deusto.es
{tony.castillo, xabier.iriarte.lopez}@opendeusto.es

***Abstract*—Deployment and maintenance of Smart Homes and Smart Grids in real environments is an expensive and lengthy process. In this paradigm, simulations play an important role by providing means of emulating the behaviour of the aforementioned systems. However, these simulations may suffer from lack of accuracy due to the inability to properly reproduce the operation of complex technologies such as solar panels, Heating, Ventilating and Air Conditioning systems (HVAC), sewerage networks or water provisioning. Within this context, this paper presents a Smart-Home Simulation architecture that is able to carry out more representational simulations by merging agent-based simulation of human behaviour with real-world modelling capabilities such as those provided by the Simulink software. Based on the simulation of human behaviour, water and electricity consumption profiles are generated and sent to Simulink models using the TCP/IP communication protocol. The obtained results show that a synchronized connection of both platforms is feasible, enabling a more accurate representation of the systems involved.**

I. Introduction

The fast pace at which technology advances has endowed everyday objects with new characteristics that broaden their purpose. This purpose goes far beyond than that of simple inanimate entities which respond to stimuli. These objects are now able to “sense”, “think” and “act” together as a greater intelligent “being”. Smart Homes are a clear example of this paradigm. Being monitored by ambient intelligence, Smart Homes offer a better quality of life by introducing assistive services and a centralized control of automated appliances [1]. User comfort, safety, security, and even energy conservation are optimized through the use of context-aware services which are able to sense the physical environment and adapt their behaviour accordingly [2].

Smart Home technologies have achieved significant improvements in health care efforts, such as assessing the wellness condition of the residents [3], generating alarms if any abnormal vital sign is detected, or even monitoring physiological data and recognizing sleep stages [4]. Of all the focus groups, elderly people are highly benefited from the inclusion of home automation in everyday living since this kind of deployment is able to recognize falls, immobility and reaction incapacity among patients with either physiological or psychological problems [5].

Another clear advantage of home automation is its unprecedented potential for saving energy, and consequently, saving costs. For example, the cost related to electric bills can be minimized when lights are automatically turned off in empty rooms, which in turn can be cooled or heated based on their level of occupancy [6][7]. At the most basic level, home automation allows to schedule the programmability of the devices so that the energy usage corresponds to the occupants daily schedule. However, the introduction of more flexible automation systems may allow to further customize this scheduling to fit and predict the users needs, extending its applicability to other areas such as water provisioning, waste management and heating control systems.

All in all, Smart Home technologies are based on what is known as the Internet of Things (IoT). IoT refers to a group of interconnected objects identifiable through a digital network that can sense and be controlled remotely, resulting in improved efficiency, accuracy, and economic benefits for the final user [8]. The versatility of IoT ranges from Home Automation on a simple, isolated level, to its use in Smart Grids for the adequate management and balancing of resources for several buildings connected to a common grid.

The design of a system that can integrate such a large range of applications and technologies while meeting and balancing all the necessary requirements is a complex task. The technological, social and economic impacts of its introduction need to be carefully analyzed as well as the added value and benefits it may provide. Within this context, simulations play an important role by providing a testing environment in which to model each subject separately, customizing both their individual operation and interactions with each other in order to evaluate the trade-off among the different components in a prior phase to that of a real scale implementation. Though the advantages

978-1-5090-2771-2/16 $31.00 © 2016 IEEE

DOI 10.1109/UIC-ATC-ScalCom-CBDCom-IoP-SmartWorld.2016.116

and benefits of simulation environments are quite clear, there is still a high level of uncertainty. Due to the difficulty to model some real world processes, simulation engines tend to make artificial assumptions that may not closely resemble how a certain subject operates, whether it is a solar panel, Heating, Ventilating and Air Conditioning systems (HVAC), a water pump, a sewage network, etc.

A. IoT in Home Automation

IoT is able to bring together both the physical and the information world through the use of sensors, which monitor the environment, collect data and generate responses according to its dynamics. Within IoT, the concept of context awareness plays an important role. Context awareness is the concept of leveraging information about the end user in order to improve the quality of the interaction [9]. Having information about the situation under which they operate, devices can react accordingly and are even able to make assumptions and predictions about the needs of the user.

There is a wide range of Home Automation Systems available, which consist on a suite of products designed to work together through Wi-Fi or power line communications such as thermostats, security systems, blinds, lighting and door locks. Popular home automation protocols include X10, Z-Wave, Insteon, Wi-Fi, Bluetooth and Zigbee [10]. These devices monitor, gather and send data about the environment to a cloud-based service that takes decisions according to manually programmed rules or inferences through the analysis of the occupants' behavioural patterns.

This whole collection of captured data gives rise to new Smart Digital Services that go beyond the services that an isolated embedded system can provide. In this new paradigm, Smart Homes can control basic environmental parameters such as light, temperature, and heating according to the choices and habits of the occupant [11]. Researchers can also add extended operations such as selection of TV programs, display of cooking recipes or even forgotten property-check services [12]. Other popular services include remote monitoring of domestic appliances [13] and load balancing for energy conservation [14].

B. IoT in Smart Grids

On a broader scale, IoT can be applied to transportation networks or Smart Grids, enabling a whole new myriad of services including, among others, energy load balancing, intelligent water provisioning, maintenance of sewerage networks, avoidance of traffic congestions, and waste management. Focusing on energy provisioning, Smart Grids are expected to spread the intelligence of the energy distribution system from a centralized core to many peripheral nodes in order to facilitate an accurate monitoring of energy losses, precise control of the whole energy distribution network, load balancing and better blackout management. Both the abstract concept and the final purposes of these intelligent nodes are clearly comparable to those of the IoT. In this area, community energy solutions such as targeted energy efficiency, district energy, microgrids, local energy generation, and energy storage represent an important opportunity to fundamentally change the way the energy system operates. The quest for sustainable energy models is the main factor driving research on Smart Grid technology. Smart Grids represent the bridging paradigm to enable highly efficient energy production, transport, and consumption along the whole chain, from the source to the user.

However, the testing of IoT solutions within the scope of Smart Grids is quite a challenge due to the expensive nature concerning the construction of pilot sites or the developing of scale models. In addition, Smart Grid simulation platforms are scarce. Works like [15], [16] and [17] focus on the simulation of the usage of household appliances relying primarily on the load balancing of energy consumption for a certain grid layout under controlled conditions. As mentioned before, one of the issues with simulations is the inability or difficulty to replicate the exact operation of some of the components because the modelling language or software may have limitations in terms of capabilities to model the physical, communication or even control logic aspects.

II. Related Work

Smart Homes and Smart Grids can be analysed from two different points of view depending on the nature of the context on which they are built:

A. Real environments

The deployment of Smart Homes in real environments involves the physical and technological equipment of a building for precise monitorization. This process relates to the analysis, acquisition, and installation of a set of devices for Home Automation, whether they are already on the market or they respond to a particular implementation for research purposes. In this case, there are several important issues that must be taken into account, such as the lengthy process of configuration and maintenance of the devices as well as the amount of time needed to acquire a sufficient amount of data for the analysis.

The MavHome project [18] is a clear example of Smart Home implementation in real environments, aimed at creating a sandbox that perceives the state of the home through sensors and acts upon it through device controllers. Its architecture is divided into four layers: a) physical (60 X10 hardware devices plugged into the home electric wiring system), b) communication (exchange of information among devices) c) information (generation of knowledge for decision making) d) decision (execution of actions based on the information supplied). Decision making is based on a finite-order Markov model which predicts inhabitant future actions in order to automate and improve repetitive activities to meet the house goals in terms of comfort and costs. Other projects like GatorTech [19] are heavily focused on elder care and proactive health. In this case, the authors propose a middleware architecture that comprises separate physical, sensor-platform, service, knowledge, context-management, and application layers. The central system collects the data provided by the sensors and gives indications to whether there is any anomaly in the residents behaviour or vital signs.

In the case of Smart Grids, the deployment comprises the leverage of several Smart Homes connected to a common grid. Data from several sources is aggregated and analysed from a centralized point of view with the purpose of balancing resources in several areas, such as energy load, water usage and waste management.

Projects like Nemo&Coded (NEtworked MOnitoring & COntrol, Diagnostic for Electrical Distribution) [20] focus on the modeling, design, implementation and operation of networked hardware/software smart devices for the low voltage electrical distribution domain by building dynamic energy efficiency services [21]. The infrastructure consists of an acquisition platform for collecting energy data in real time by guaranteeing the interoperability of their hardware/software devices, independently of their equipment or communication technologies. The main novelty lies on the use of intelligent and autonomous distributed nodes to process semantic information known as PGDINs [22], which integrate several of the large number of existing standards in the electricity sector, enabling the process of events and data in an autonomous way.

The smart grid experimental system by the Fukushima National College of Technology [25] is an interesting example of real scale deployment for teaching purposes. The system consists of a gas engine cogeneration system, a wind power system, a solar power system, a battery system and an uninterruptible power supply system, by which important loads are supplied power during the grid power failures. A SCADA system monitors the electricity demand and balances resources according to the users needs and the optimum operation of the whole system.

B. Simulation environments

The high economic investment and time restrictions related to the deployment of Smart Homes and Smart Grids in real or scaled environments highlights the advantages of simulation models. In order to support the implementation in the real Smart Home, it is necessary to demonstrate that things can be achieved in a simulator which deals with virtual appliances and devices that model a real Smart Home environment.

The Interactive Smart Home Simulator (ISS) [23] proposes a context aware simulation system comprised of several electronic devices distributed on an apartment. The simulator is comprised of a context retriever which requests and receives sensor information from the home appliances. A centralized server is the central control in charge of taking decisions according to changes in the environment and the behaviour of the house occupants. This simulator demonstrates the exchange and update of information as perceived by the Smart Home on changes in the environment

The Intelligent Project Home (IHome) [24] uses multi-agent system technology to the problem of managing an intelligent Smart Home environment. The simulation is populated with distributed intelligent home-control agents that control appliances and negotiate over shared resources with the objective to automate the tasks made by humans. Each household appliance is represented by an agent and the model coordinates over electricity, hot water, noise or sound levels, and room temperature in each of the modeled rooms. The agents make decisions about the activity that the occupant does depending on the availability of the resources, whether there is not hot water, the temperature outside, etc.

Within Smart Grids, projects like MASGrip [16] propose a multi-agent system that models the internal operation of smart grids. This system considers all the typically involved players, each player being represented by one agent with the capability of representing the actual corresponding player and to simulate its actions. The agents involve not only the devices within the Smart Homes, but also an agent that simulates negotiations within the Electricity Market (MASCEM). In order to efficiently analyze the quality of the simulated smart grid management, it is essential to provide the means for the MASGriP system to be able to perform the required negotiations in the electricity market, information not always available.

Karnouskos et al. [25] propose an agent simulation system that simulates discrete heterogeneous devices that consume and/or produce energy, that are able to act autonomously and collaborate. The bottom layer is the simulator layer and contains all the agents which represent energy generating and/or consuming devices. The agents utilize the full communication capabilities offered by the agent platform and execute in order to offer the desired functionality. The simulator focuses heavily on maximizing user comfort.

All in all, Smart Homes and Smart Grids constitute an interdisciplinary domain considering the variety of technologies that come together to reach a common objective. Within this context, the main objective of this paper is to design and test a simulation platform that is able to replicate the behaviour of the residents of a small neighbourhood on their own houses. Each house is equipped with several smart appliances simulating energy, water, and gas consumption, and resource providers such as a solar panel, a hybrid heating system, and a water deposit. The platform will evaluate the feasibility of integrating these two modelling approaches in order to bridge the gap between the configuration of a a simulated and a real Smart Home. This simulation platform will improve the state of the art in two aspects: on the one hand, it will serve as a Computer Aided Design solution for Smart Homes or Smart Grids, while on the other hand, it can be used as a benchmark system for the testing of new control algorithms for the Smart Home or Smart Grids services (from energy boxes to traffic light control and virtual power plants).

III. Components

For the purpose of this case study, we selected a small urbanization composed of 12 single residential homes with a similar inner layout consisting of a kitchen, a bedroom, a bathroom and a living room. Each house is configured in the same way and is equipped with the following technologies:

- **Sensorized household objects**: Every single appliance in the house is monitorized through consumption sensors depending on the types of resources it needs to operate: energy, water or gas. For example, the sensor associated to a single light switch monitors the energy consumption, while the sensor associated with he washing machine monitors energy, gas, and water consumption. The distribution and type of resource needed by each sensor is shown in Table I.

- **Solar panel**: The house is equipped with a solar panel that converts the energy of light directly into electricity through the photovoltaic effect. The electricity produced can then be fed into the house main electricity supply or stored in a battery for further use.
- **HVAC system**: Heating and air conditioning is provided by a system composed of two gas boilers (350 kW). The HVAC system is equipped with an independent PID control system that continuously maintains the temperature of the water deposit.
- **Water deposit**: A single deposit feeds water to the house. The deposit is equipped with a pump that keeps the amount of water at a certain setpoint.

TABLE I: Distribution of sensors in the Smart Home

Place	Sensors	Energy	Gas	Water
Bathroom	1 toilet			X
	1 shower faucet		X	X
	1 sink faucet		X	X
	1 lightswitch			
	1 door			
Bedroom	1 closet			
	1 cabinet			
	1 door			
	1 lightswitch	X		
Hall	1 door			
	1 lightswitch	X		
Kitchen	3 cabinets			
	3 drawers			
	1 washing machine	X	X	X
	1 burner		X	
	1 dishwasher	X	X	X
	1 sink faucet		X	X
	1 oven	X		
	1 microwave	X		
	1 freezer	X		
	1 door			
	1 lightswitch	X		
Living room	1 TV	X		
	1 radio	X		
	1 lamp	X		

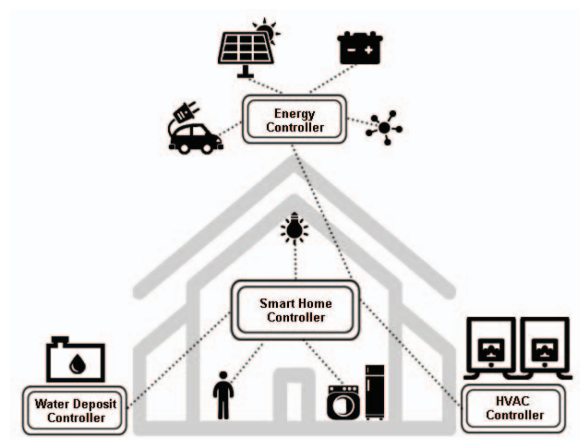
The objective of the simulator is to be able to not only replicate the behaviour of the Smart Homes in terms of activity recognition and automation, but to go further and provide an intelligent system that based on the resources available, whether it is an HVAC, a water deposit or a solar panel, is able to manage itself according to the occupants behaviour. We intend to show that the use of real simulation models concerning these elements will help improve the accuracy of the simulation

IV. Ideal Smart Home Architecture

Every Smart Home project focuses on the creation of an environment that behaves as an intelligent agent which perceives the state of the home through sensors and acts upon the environment through actuators with the objective of maximizing the comfort and productivity of its occupants. In order to achieve these goals, the house must predict, reason and adapt to its inhabitants. We propose to go a step further and build a system that integrates all complex systems within a home, such as HVAC, energy and water provisioning, etc, and actuates upon them so as to reach an optimum level of efficiency and comfort. This proof of concept can then be later extrapolated to the balancing and leverage of resources within Smart Grids.

The architecture envisioned according to the Components described in Section III is detailed in Figure 1.

Fig. 1: Ideal Smart Home Architecture



- **Energy Controller**: This controller is in charge of attending the energy demand within a Smart Home considering all the energy sources connected to it. In our case, we consider four energy sources: the actual electric distribution network, the existence of solar panels, solar batteries and the introduction of the electric car. When energy is demanded the controller leverages the petition, and determines the source of the electricity based on issues such as the load, the hourly energy price, and the saturation of the distribution network. If needed, the controller may also feed the distribution network directly.
- **HVAC Controller**: This controller governs the behaviour of an hybrid boiler system so as to meet the demands in terms of heating and hot water while maintaining a constant temperature. The purpose of the controller is to optimize the system performance while meeting the objectives of energy efficiency,
- **Water Controller**: This controller act upon a deposit that feeds water to the house. In case the water reaches a certain threshold, the controller may activate a pump to maintain the level at a certain setpoint.
- **Smart Home Controller**: This controller is the central axis of the system. It collects data from the sensors attached to the appliances and distributes the information to the other controllers in the house. The system also comprises a module for activity recognition and forecast-

ing as well as an optimization algorithm that analyses the occupants behaviour so as to leverage the resources and meet the comfort and efficiency objectives.

V. Smart Home Simulator Architecture

The central point of our Smart Home Simulator is the Agent Environment. Within MAS technologies, the Agent Environment concept has been recognised as an independent and living first-class entity called to play a relevant role in modelling dynamic real world problems. Real world scenarios are inherently dynamic, they change beyond the agent's control. This dynamism must then be modelled explicitly aside by implementing processes that can change the state of the Agent Environment.

From a functionality point of view, an Agent Environment comprises several mechanisms to address different levels of support that should be available in every agent system, such as, an interaction mediation that enables agents to interact and communicate, a centralised synchronisation protocol that supports the simultaneity of actions for system consistency, an overlay network that represents relationships between agents and notification of contextual events for the production, and delivery of event notifications to create dynamic agent contexts.

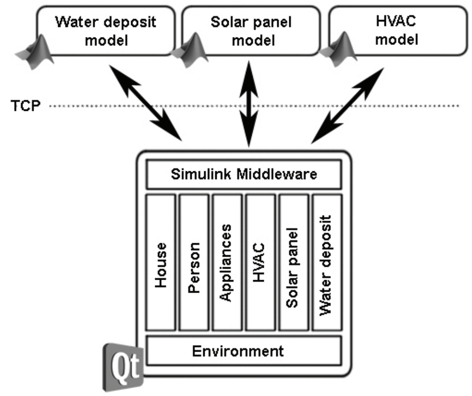
Following this roadmap and from the standpoint of human behaviour modelling, our Agent Environment consists of both a physical and a social environment, which come together to form the Intelligent Environment where both objects and people are situated. On the one hand, the physical environment ensures none of the spatial constraints are violated and, on the other hand, the social environment is responsible for managing communications, roles and knowledge by giving agents a social and communicative .

We define an intelligent environment as one that is able to acquire and apply knowledge about its inhabitants and their surroundings in order to adapt to the inhabitants and meet the goals of comfort and efficiency. These capabilities rely upon effective prediction, decision making, mobile computing, and databases. With these capabilities, the home can control many aspects of the environment such as climate, water, lighting, maintenance, and entertainment. Intelligent automation of these activities can reduce the amount of interaction required by inhabitants, reduce energy consumption and other potential wastages, and provide a mechanism for ensuring the health and safety of the environment occupants. Figure 2 shows the communication between the simulator and the Simulink models.

A. Qt implementation

In search of a highly abstract and scalable solution that suited this new approach, the energy box has been developed from scratch using the C++ programming language. It is built upon Qt Framework, a widely used cross-platform framework for developing native C++ applications along with interesting extensions, such as signals and slots for enabling remote event invocation, a meta-object compiler, and the ability to detach pieces of code and move them to separate threads.

Fig. 2: Smart Home Simulator Architecture



The use of Qt has allowed us to create a complete independent and robust simulation engine based on our understanding of what an Agent Environment should be. All the Qt features make it possible to model more accurate agents and passive entities by using an event-driven paradigm. The execution flow of an agent will be heavily influenced by events such as messages from other agents/entities, sensor outputs, or even its own actions, just like in real life, where humans are constantly bombed by stimuli.

Parallelisation and queueing management is controlled by splitting the workload into individual threads/event queues and by moving agents from one to the other by working out the most efficient execution flow. The QMutex class of Qt Framework complements parallelisation by providing access serialisation to critical resources and attributes between threads. Sensor messaging is built upon the system of Qts signals and slots: one of its central features and, probably, the characteristic that differs the most from the functionalities provided by other frameworks. Signals and slots follow a publish/subscribe mechanism where objects emit notifications that are listened by other objects in the environment. A class that emits a signal neither knows nor cares which slots receive it and may send additional arguments of any type. It is up to the other agents to create a slot for the signals they want to listen to if they want to know when they have been triggered. This model behaviour is based on MASSHA [26], an agent-based simulator for human activities in intelligent environments that, in contrast with previous approaches, is based on environmental multi-agent theories to model and simulate intelligent environments, inhabitants and their interactions.

Each household appliance is modelled as a passive agent, i.e. an agent that responds to stimuli but does not interact with others on its own. When an agent executes an action that uses any of these appliances through their get and set methods, the passive agents react by activating/deactivating themselves and emitting signals of consumption to Simulink through the TCP/IP protocol.

B. Simulink implementation

Simulink is a block diagram environment specifically designed for the implementation of model based simulations.

This visual programming environment is integrated in the programming environment of MATLAB. Simulink provides libraries with pre-designed and configurable models of mechanical, electronic and physical elements. Therefore, it provides an ideal environment to develop real simulation models of complex systems such as HVAC systems and solar panels, as well as more common systems like water deposits. The following models simulate the behaviour of those services within the Smart Home simulator architecture.

The water deposits are simple models that simulate how water is consumed according to the Smart Home demand and how the water deposit is filled trough a water pump. Figure 3 shows the block diagram implemented in Simulink to simulate the behaviour of the common water deposit for different water consumption profiles.

Fig. 3: Diagram of the implemented model for the water deposit management system

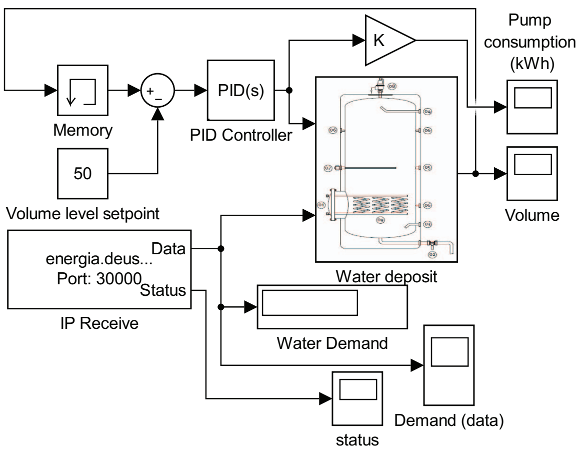


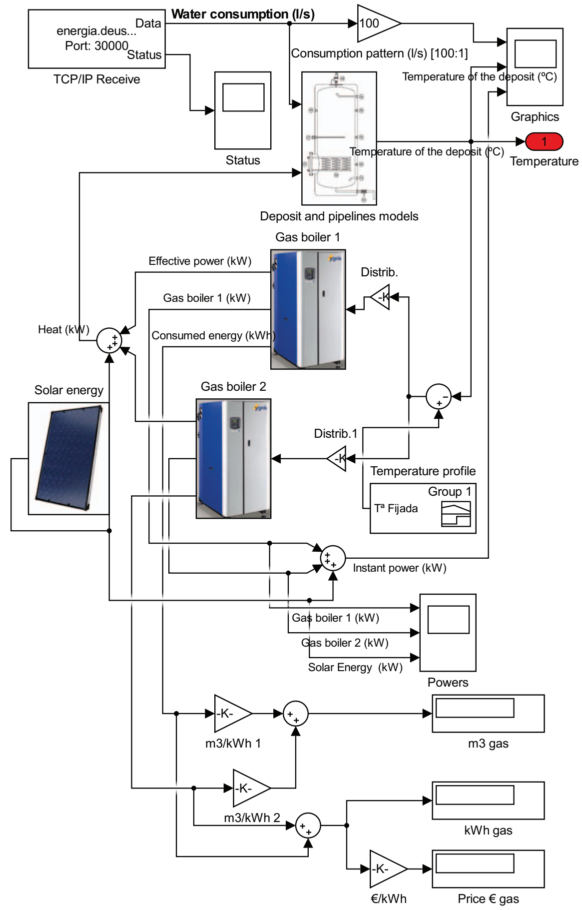
Figure 4 shows the simulated HVAC system, which consists on two gas boilers connected in parallel. Each boiler is defined by its efficiency curve and maximum power (350 kW). The incoming demand is distributed between both boilers, being one of them the main boiler. The following commercial heating systems have been studied in order to build a more realistic simulation model:

- **Biomass boilers:** Pellematic (10-56 kW), Viessman pyrotic (390-1250 kW)
- **Gas boilers:** Ygnis Varmax (127-477 kW), Beretta Power Plus (50-100 kW), Viessman Vitodens (1.9-35 kW)
- **Gasoil:** Junkers Suprapur-O (22-35 kW)
- **Heat pumps:** Carrier 30RQS (39-160 kW)

The last modelled installations were been the solar panels. The objective is to study their effect on the performance of the global system, specifically with the introduction of the electric car. The generated energy is simulated with solar irradiance data and is stored in a sizeable battery module depending on the consumption profiles.

Each simulated installation is controlled by PID controllers in order to maintain the established setpoints. These controllers have been configured to correct the possible deviations in the

Fig. 4: Diagram of the implemented model for the HVAC system.



minimum response times and without excessive overshoots. The objective is to maintain the established deposit level and hot water temperature level.

The Simulink models are executed independently. They receive the real time simulated demand data regarding electricity, and hot or cold water from the Smart Home simulator. Then, the Simulink models execute the simulation for the modelled water pump, boiler system, and solar panel, for the specific demand at each point in time. Once the simulation finishes, Simulink sends the result of the simulation back to the Smart Home simulator. The data transmission between both modelling platforms is achieved through the use of the TCP/IP communication protocol. The main problem relies in the synchronization of all the simulations in order to maintain the same simulation time over all the systems. Each simulation can be run in a different device and each model has a different computational cost, which causes de-synchronization between the models.

VI. Results

The results obtained by using the proposed simulation architecture are quite promising. The agent-based Smart Home Simulator is capable of reproducing a person's behaviour for different simulation times and during different activity peaks of the day. This module generates the consumption profiles according to the human activities simulation and sends the information to the parallel executed Simulink modules which are able to simulated common services of the building. Figure 5 shows an example of consumption simulation.

Fig. 5: Simulation of consumption within the Smart Homes.

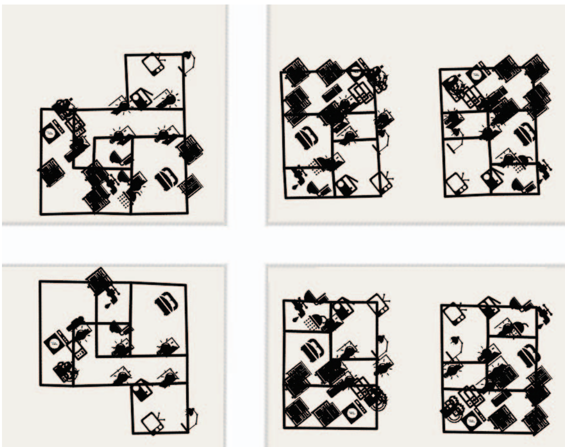
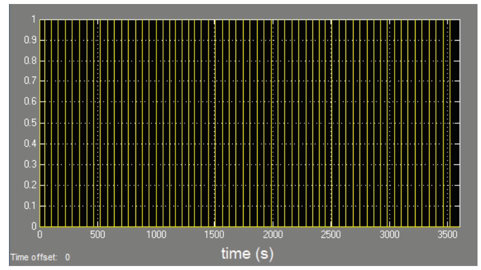


Figure 6 shows the frequency at which the consumption data is received by Simulink models. As can be seen, the data reception is very stable and regular. The transmission has been set to be received every 60 seconds of the simulation time. However, each model runs at a different simulation speed due to their computational cost. A simulation of the consumptions generated for 1 h, takes 184.5 s for the water deposit model and approximately 2070 s to simulate the HVAC system. Therefore, the data transmission must be synchronized between the different simulation modules to maintain the same time line between all of them.

Currently, the data transmission is synchronized based on the estimated computational cost for each Simulink model. However, in order to maintain the same simulation time across the models, in future works, the complete simulation will be carried out by time segments. Each model will simulate the response to the generated demand for a limited time segment and waits until all the simulations have finished. During these simulation pauses, the Simulink models send back their results to the Smart Home simulator. Finally, once all the simulation of services have finished, the Smart Home simulator sends a new batch of consumption data for the next time segment. Thereby, the simulation time will be maintained across all the models with acceptable deviations, despite being executed in different platforms. An specific Simulink block will be developed to manage the TCP/IP data transmission and to synchronize the simulation of each model.

All the architecture has been tested for different simulation times. Figures 7 and 8, show the simulation of the HVAC system for 1 hour of consumption data. In Figure 7, the yellow line shows the consumption profile received from the Smart Home Agent, the red one is the total instant power

Fig. 6: Frequency of data reception



needed by the installed heating system and the blue line is the temperature of the water deposit which is set to maintain a constant temperature of 75 °C during the day.

Figure 8, shows the power consumption of the HVAC system disaggregated for the two installed boilers. As previously stated, the heat power demand is divided between the boilers. Currently the distribution between both is fixed, but in a future version of the model the demand will be intelligently distributed based on the efficiency, used fuel and responsiveness of each boiler.

Fig. 7: HVAC system simulation: Temperature of the deposit and the instant accumulated power.

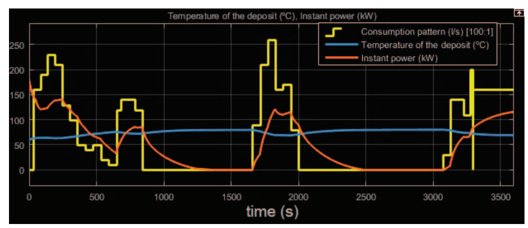
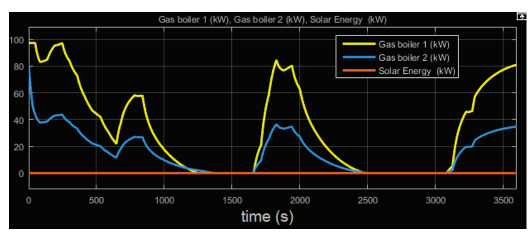


Fig. 8: Gas boiler power profile for a 1 hour simulated consumption profile.



VII. Conclusion and Future Work

The main contribution of the research presented in this paper is the feasibility to integrate an agent-based Smart Home simulator with the modelling capabilities offered by platforms like Matlab/Simulink, which are specifically designed to solve engineering and scientific problems. The advantages of this kind of approach relies in the ability to accurately model dynamic complex systems such as HVAC, solar panels or microgrids, bridging the gap between simulation and real implementation along with the benefits in terms of cost, maintenance and deployment. In this sense, the future developments considered as a follow up of the work presented in this paper are detailed next:

- **Improve the HVAC model and solar panel models.** The objective is to enlarge the energy agent controller so as to accurately design the way the system works, even introducing the electric vehicle. Once available the extended models, the simulations of the global system will support the decision making when dimensioning new buildings or to improve the efficiency of the existing installations.
- **Improve the synchronization between the simulated services.** An specific Simulink block will be developed to manage the TCP/IP data transmission and to synchronize the simulation of each model in order to maintain the same simulation time across all the models and platforms.
- **Build a microgrid with several sources of generation.** The next step in the simulation will focus on integrating the Smart Home within a Smart Grid comprised of several sources of generation and services such as waste collection and management, sewerage networks, etc
- **Integrate FIWARE as communication protocol.** The most pressing problem in Smart Homes deployment is the lack of compatibility between different protocols from different vendors and the scarce amount of ICT platform standards. Most appliances only support a specific protocol, which specific protocol, which is a problem when using different vendor products without changing existing devices and protocols. We plan to integrate and test FIWARE standard to create a common data model for the different devices operating all over the simulation.

ACKNOWLEDGMENT

This work was carried out with the financial support of a) GREEN_TRAVELLING (Era NET Transport 6/12/IN/2014/195 label) partially founded by *Diputación Foral de Bizkaia* through the *Plan de Promoción de la Innovación* (6/12/IN/2014/-195) and by the Basque Government through the GAITEK program (IG-2014/0000133) b) Industrial Ph.D. grant given by the University of Deusto (2015- 2018), c) Ph.D. grant PRE_2015_2_0003 given by the Basque Government, and d) the Erasmus Mundus SUD-UE 1301256 given by European Commission.

REFERENCES

[1] M. R. Alam, M. B. I. Reaz, and M. A. M. Ali, "A review of smart homespast, present, and future," *Systems, Man, and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, vol. 42, no. 6, pp. 1190–1203, 2012.

[2] R. J. Robles and T.-h. Kim, "Review: context aware tools for smart home development," *International Journal of Smart Home*, vol. 4, no. 1, 2010.

[3] G. Virone, N. Noury, and J. Demongeot, "A system for automatic measurement of circadian activity deviations in telemedicine," *Biomedical Engineering, IEEE Transactions on*, vol. 49, no. 12, pp. 1463–1469, 2002.

[4] H. Andoh, K. Watanabe, T. Nakamura, and I. Takasu, "Network health monitoring system in the sleep," in *SICE annual conference*, 2004, pp. 1421–1424.

[5] S. Helal, B. Winkler, C. Lee, Y. Kaddoura, L. Ran, C. Giraldo, S. Kuchibhotla, and W. Mann, "Enabling location-aware pervasive computing applications for the elderly," in *Pervasive Computing and Communications, 2003.(PerCom 2003). Proceedings of the First IEEE International Conference on*. IEEE, 2003, pp. 531–536.

[6] D. Casado-Mansilla, J. López-de Armentia, and D. López-de Ipina, "Will eco-aware objects help to save the world?" in *Ubiquitous Computing and Ambient Intelligence*. Springer, 2012, pp. 17–24.

[7] V. L. Erickson and A. E. Cerpa, "Occupancy based demand response HVAC control strategy," in *Proceedings of the 2nd ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Building*. ACM, 2010, pp. 7–12.

[8] F. Xia, L. T. Yang, L. Wang, and A. Vinel, "Internet of things," *International Journal of Communication Systems*, vol. 25, no. 9, p. 1101, 2012.

[9] C. Perera, A. Zaslavsky, P. Christen, and D. Georgakopoulos, "Context aware computing for the internet of things: A survey," *Communications Surveys & Tutorials, IEEE*, vol. 16, no. 1, pp. 414–454, 2014.

[10] C. Gomez and J. Paradells, "Wireless home automation networks: A survey of architectures and technologies," *IEEE Communications Magazine*, vol. 48, no. 6, pp. 92–101, 2010.

[11] S. K. Das, D. J. Cook, A. Battacharya, E. O. Heierman, and T.-Y. Lin, "The role of prediction algorithms in the MavHome smart home architecture," *Wireless Communications, IEEE*, vol. 9, no. 6, pp. 77–84, 2002.

[12] T. Yamazaki, "Beyond the smart home," in *Hybrid Information Technology, 2006. ICHIT'06. International Conference on*, vol. 2. IEEE, 2006, pp. 350–355.

[13] M. S. H. Khiyal, A. Khan, and E. Shehzadi, "SMS based wireless home appliance control system (HACS) for automating appliances and security," *Issues in Informing Science and Information Technology*, vol. 6, pp. 887–894, 2009.

[14] A. Zoha, A. Gluhak, M. A. Imran, and S. Rajasegarar, "Non-intrusive load monitoring approaches for disaggregated energy sensing: A survey," *Sensors*, vol. 12, no. 12, pp. 16 838–16 866, 2012.

[15] S. Karnouskos and T. N. d. Holanda, "Simulation of a smart grid city with software agents," in *Computer Modeling and Simulation, 2009. EMS '09. Third UKSim European Symposium on*, Nov 2009, pp. 424–429.

[16] P. Oliveira, T. Pinto, H. Morais, and Z. Vale, "Masgrip: A multi-agent smart grid simulation platform," in *Power and Energy Society General Meeting, 2012 IEEE*, July 2012, pp. 1–8.

[17] M. Pipattanasomporn, H. Feroze, and S. Rahman, "Multi-agent systems in a distributed smart grid: Design and implementation," in *Power Systems Conference and Exposition, 2009. PSCE '09. IEEE/PES*, March 2009, pp. 1–8.

[18] D. J. Cook, M. Youngblood, E. O. Heierman III, K. Gopalratnam, S. Rao, A. Litvin, and F. Khawaja, "MavHome: an agent-based smart home," in *null*. IEEE, 2003, p. 521.

[19] S. Helal, W. Mann, H. El-Zabadani, J. King, Y. Kaddoura, and E. Jansen, "The Gator Tech Smart House: a programmable pervasive space," *Computer*, vol. 38, no. 3, pp. 50–60, March 2005.

[20] Y. K. Penya, J. C. Nieves, A. Espinoza, C. E. Borges, A. Peña, and M. Ortega, "Distributed semantic architecture for smart grids," *Energies*, vol. 5, no. 11, pp. 4824–4843, 2012.

[21] Y. K. Penya, C. E. Borges, A. Pea, and O. K. Esteban, "Service-orientation vs. real-time: Integrating smart-homes into the smart-grid," in *Industrial Electronics Society, IECON 2013 - 39th Annual Conference of the IEEE*, Nov 2013, pp. 5755–5760.

[22] A. Espinoza, Y. Penya, J. C. Nieves, M. Ortega, A. Pea, and D. Rodrguez, "Supporting business workflows in smart grids: An intelligent nodes-based approach," *IEEE Transactions on Industrial Informatics*, vol. 9, no. 3, pp. 1384–1397, Aug 2013.

[23] T. Van Nguyen, J. G. Kim, and D. Choi, "ISS: the interactive smart home simulator," in *Advanced Communication Technology, 2009. ICACT 2009. 11th International Conference on*, vol. 3. IEEE, 2009, pp. 1828–1833.

[24] V. Lesser, M. Atighetchi, B. Benyo, B. Horling, A. Raja, R. Vincent, T. Wagner, P. Xuan, and S. X. Zhang, "The UMASS intelligent home project," in *Proceedings of the third annual conference on Autonomous Agents*. ACM, 1999, pp. 291–298.

[25] S. Karnouskos and T. N. De Holanda, "Simulation of a smart grid city with software agents," in *Computer Modeling and Simulation, 2009. EMS'09. Third UKSim European Symposium on*. IEEE, 2009, pp. 424–429.

[26] O. Kamara-Esteban, G.Azkune, A. Pijoan, C. E. Borges, and D. L. de Ipiña, "MASSHA: An agent-based approach for human activity simulation in intelligent environments. in review process," *IEEE Transactions on Human Machine Systems.*, 2015.