New Software Solutions for Low-power Management of Green Smart Homes*

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Abstract: The research paper deals with new Green Smart Homes which offer original services such as the optimal power consumption, peak management, and home power selling while assuming an available home green energy. We propose a Master-Slave based architecture following the well-known industrial technology STM32F4. A microcontroller Slave Agent is proposed for each selected Home Device to control its local consumption, and a unique microcontroller Master Agent is proposed to control the whole architecture. The goal is to optimize the use of green energy, to minimize the consumption costs by exploiting the offers from providers and also the peak times. We model these services by using the model checker UPPAAL, and propose UML design diagrams for this architecture. A visual simulator of this STM32-based architecture is developed and applied to a case study proposed by Cynapsys.

1 INTRODUCTION

Home automation consists in the management of our equipments based on new technologies and also in the proper use of information. If it is properly used, the home automation can make real energy savings and be part of a sustainable development of the future electricity networks. Home automation presents itself as an alternative to reduce energy costs, increases intelligence at homes by the mean of sensors and actuators, as well as maintaining the power grid by the balance of supply and demand. To make life easier, Home Automation is an obvious choice, it allows to design a green grid, which is based on renewable energy and to encourage innovation through the latest discoveries in the field of high tech. In recent years, several studies about the automation were conducted; the most important proposes an approach that is based on the diversification and the decentralization of energy production sources and the development of a platform that enables the exchange and communication between different types of interconnected networks (Torbensen, 2008). Inspired by (Abras et al., 2008) home automation systems can be combined with Multi-Agent Systems for the home energy management and the adaptation of the consumption to the available green energy resources as well as the development of new algorithms for emergency and anticipation mechanisms. Among the used communication solutions at home automation systems, Internet, ZigBee or Bluetooth have been proposed to control households from an remote location by using visual interfaces and web applications. (A.Vichare and Verma, 2012)(Gill et al., 2009)(R.Piyare and M.Tazil, 2011). we are interested in this research in optimal home electricity management through the creation of new modern Home Automation Services. We propose an original reconfigurable home automation system Model which allows the dynamic change of the daily behavior at run time according to user requirements and energy constraints. The reconfigurable model of our approach consists of the execution and the control of three runtime services: a Power Consumption Management Service which is used to manage and control the power consumption of equipments at home. It adapts the energy demands to production

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systems through an action plan predefined by the user. The second service consists of the Management of the green low power distribution which is based on the decentralization of production through the use of renewable sources in low-voltage networks. This energy is stored in batteries and used according to a specific management and consumption policy. This service also allows the user to manage sales promotional offers, it may as well buy energy during discount periods, store it and use it when prices are inflated. Finally we propose the third peak management service which allows to manage high consumption periods by deactivating directly the equipments or delaying there execution. This service also allows to compensate the difference between the production and the consumption thanks to use of green energy that we assume stored in batteries. These original services meet exactly the different requirements of the modern and smart electricity grid. We propose a Multi-Agent based architecture to offer these services. It is composed of: (a) City Information Agents to gather the useful information for the distribution and the use of electrical energy, (b) City Master Agents that control Home Master Agents which supervise Home Slave Agents to be responsible for the operation of the electrical equipments at homes, and finally (c) Home Storage Agents to be deployed for the monitoring and the exploitation of renewable energy produced and stored in batteries at home. An original Master/Slave architecture is hierarchically proposed in the current paper to manage Information, Storage and the proper use of green electricity. This architecture is guided by a communication protocol that manages the exchanged messages between the different agents in order to perform the services discussed above. This optimal protocol allows the management of renewable energy, management of consumption peaks and management of electricity consumption. We also propose the formalization of these services and the design of the software with UML diagrams. We verify the whole architecture by proposing timed automata models, and apply UPPAAL for model checking(Alur and Dill, 1994),(Bengtsson et al., 1996). We aim to verify functional and temporal constraints since our system is strict and does not tolerate faults and mismanagement of used data and information. The study of our approach leads us to develop a simulation tool to be named X-SH which is an original product for the power management in smart homes. The paper's contribution is applied to a real case study provided by Cynapsys in order to discuss its advantages. The rest of this paper is organized as follows, the next section presents the state of the art of Smart Homes. Section 3 presents the Case Study of Cynapsys that will be assumed as a running example in this paper. Section 4 proposes the Multi-Agent Master/Slave architecture followed by a formalization of the problem and the proposed services, the UML design and the verification of timed automata models, The Simulation tool X-SH. Finally section 5 concludes this research works.

2 BACKGROUND

We present in this section an overview on Home Automation Systems, System Reconfiguration and Master/Slave Agent based architecture.

2.1 Home Automation Systems

Nowadays, the research works in the field of home automation systems have a unique direction to look for luxury, comfort and the mixture between daily tasks and new technologies. The authors in (AlShu'eili et al., 2011) propose a new approach for voice recognition based wireless home automation system to control all lights and electrical appliances at home or offices by using voice commands, they propose a verification test based on the voice recognition. However, this approach is weak against identity theft and imitating the voice of the house's owner, so anyone can take control of the home. According to (Nunes, 2010), an architecture for a home automation system is given, which has a distributed nature, very modular and can easily be expanded in size and functionality. The authors present two types of constitutive modules interconnected through a network. The proposed approach consists of Supervision Module (SM) and a Control Module (CM) to be interconnected by a Communication Network, a simple system with an Action/Reaction mechanism. In (Debono and Abela, 2012), the authors present an implementation of a home automation system through a central FPGA controller as a simple solution whereby the user control devices by employing a central field programmable gate array (FPGA) controller to which the device and sensor are interfaced. The control is established by using a communication with the FPGA from a mobile phone through its interface. A design of a networked monitoring System for home automation is presented in (Song et al., 2007). The system consists of a base station, a home server, wireless sensor nodes and smart user terminals such as PC and PDA. A ZigBee-Based Home Automation System is developed in (Gill et al., 2009). the authors present a flexible and low cost home automation infrastructure. The home's low data rate, control and monitoring needs are catered by using ZigBee. the authors in (Ha, 2009), try to present a dynamic integration of ZigBee home networks into home gateway by using OSGi service registry. The proposed architecture is divided into two layers of ZigBee home networks; physical and logical interface. A realization of home remote control network based on ZigBee is described in(Shunyang et al., 2007); the authors present the ZigBee as an emerging wireless communication technology with low cost and low power characteristics.

2.2 Reconfigurable Embedded Systems

We assume that an embedded system is reconfigurable if it changes its software or hardware behavior at run-time according to user requirements. The software reconfiguration is any operation allowing the addition, removal or update of software tasks that implement the system to encode corresponding functions. The software reconfiguration is assumed to be any operation allowing the addition, removal or update of hardware components according to user requirements. An addition or removal can be of memory, of data-event inputs-outputs, or of a new network for communication. The update of hardware components can be the modification of the processor speed. We are interested in this paper in software reconfigurations. We distinguish two reconfiguration policies: static and dynamic reconfigurations (Wang et al., 2010). Static reconfigurations are applied off-line to implement changes before the cold start of the system (Angelov et al., 2005), whereas dynamic reconfigurations are dynamically applied at run-time.(Seokcheon, 2010)(Hu et al., 2011) Two cases exist in the latter: manual reconfigurations applied by users(Rooker et al., 2007) and automatic reconfigurations to be applied by intelligent agents (Seokcheon, 2010)(Khalgui et al., 2011).

2.3 Master/Slave Multi-agent Architecture

According to the authors in (Megherbi and Madera, 2010), the Master-Slave architecture is described as the most popular and widely used architecture in the distributed systems. Master software nodes assign each slave node for a specific amount of work, and once the slave has completed its task, it reports the results back to the master. In (Nwana et al., 1996), the authors propose a coordination model in software agent systems, based on Master-Slave architecture, the master agent plans and distributes fragments of the plan to the slaves. The slaves may or may not communicate among themselves, but must ultimately report their results to the master agent.

2.4 Contribution: New Services for Smart Homes

According to the study of these research works proposed in Smart Grids, Home Automation Systems, Multi Agent Systems, and Reconfigurable Embedded Systems, we find that the researches carried out: do not respond exactly to the requirements of the modern world, do not consider the exponential growth of the energy consumption, and do not follow the new technical and technological progress. These works are simple, wobbly, and too generalizing. Indeed they lacked precision and intelligence. We propose in the current paper a new Master/Slave Multi-Agent architecture in order to: (a) decentralize the control, (b) guarantee the determinism, (c)and reduce the number of messages circulating in the network. This original architecture allows: (a) the management of the energy consumption, (b) the management of peak period, (c) the use of renewable green energy to be stored in batteries, (d) and the management of the promotional offers from providers when the prices are down.

3 CASE STUDY: CYNAPSYS HOME AUTOMATION SYSTEM

We present in this section the Cynapsys Smart Home (to be denoted by CSH) which was maintained as the reference case study of our company in the current project. We assume a house to be composed of six rooms and a garden. Each home area is supposed to be controlled by a STM32 F4-based electronic equipment for the optimal daily energy consumption (STMicroelectronics, 2013). CSH ensures serenity and control of ambient lights, appliances and access. The Proposed CSH provides automated blind controls to open or close, and to be based on times or light and heat levels. An integrated cooling and heating system to optimize the energy use through pre-determined scheduling or temperature controls, as well as the management of the smart meter to control electricity consumption in real-time and the promotional offer of the energy providers. We propose a control irrigation system and pool pump operation management and finally the integration of new green renewable energy production sources to be composed mainly by wind and solar panels that we store in home batteries. The CSH shows many interests: (a) the billing service, (b) the conservation of energy, (c) the peak management, (d) and the use of renewable energy. Figure 1, provides a description of CSH that we assume as a running example in this paper.

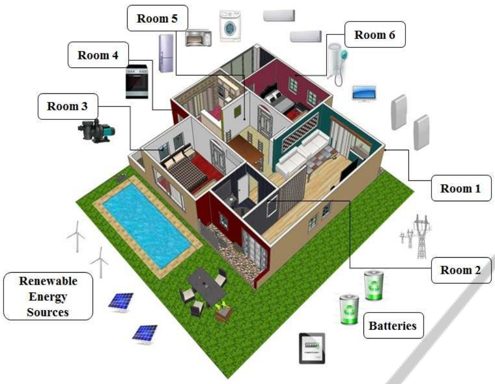

Figure 1: CSH case study.

We propose the characteristic of the CSH equipments in the table below with real values about the energy consumption, the frequency of use and the priority of each device.

Table 1: Electrical Equipment Characteristics.

Equipment	P	UF	CA	Pr
Combined Fridge	100 W	Continuously	875	2
Air Conditioning	150 W	5 H/day	450	2
Washing machine	940 W/C	3 cycles/week	135	1
Microwave	500 W	1.5 H/Week	36	1
Boiler	2000 W	80L/day	400	1
Heating	60 W	Continuously	345	2
Pool Pump	1500 W	5H/day	750	1

Where:
P: is the equipment power (watt)
UF: is the equipment usage frequency
CA: is the equipment Calculated amount (KWH)
Pr: is the equipment Priority.
The data presented above will be used in the implementation of our proposed new services such as the management of peak demand or help the user to rationalize its energy consumption and pay less. In this section, we propose a novel idea which is based on the classification of household tasks into two broad categories, the first category contains the permanent tasks, *i.e* the daily tasks that have the highest priority such as: radiators and heater. The second category contains temporary tasks that can be delayed, such as television, washing machine, dishwasher and iron. We will assume that we have three tariff zones in a day as described in Table II: (a) from midnight to 8am, (b) from 8am to 16pm is a middle zone and (c) from 16 pm until midnight. The first zone is used for the normal consumption and we attribute coefficient 2 to this period. The second one is characterised by a consumption peak and has the high coefficient equal to 4. The last one is a medium zone with consumption coefficient equal to 3.

Table 2: Pricing zones.

	Normal Zone	Peak Zone	Medium Zone
Time Slot Time Slot	00.01 to 8am	8.01am to 16pm	16.01pm to 00.00
Coefficient	2	4	3
Price Mill/KWH	130	260	195

In the following, we will present the advantages of using three tariff zones for both continuous and partial time tasks.

- For a continuous task, for example refrigerator:
  - With a unique tariff (peak zone): The annual consumption in Tunisian Dinar is equal to:

$$875 * 0.260 = 227.5\ TND/Year. \quad (1)$$

  - With three tariff zones: The annual consumption in Tunisian Dinar is equal to:

$$(875 * (0.130 + 0.260 + 0.195) \div 3) = 170.6\ TND/Year. \quad (2)$$

- For a partial time task, for example the pool pump:
  - With a unique tariff (peak zone): The annual consumption in Tunisian Dinar is equal to:

$$(750 * 0.260) = 195\ TND/Year. \quad (3)$$

  - With Normal tariff zone: The annual consumption in Tunisian Dinar is equal to:

$$(750 * 0.130) = 97.5\ TND/Year. \quad (4)$$

In the first case, we notice a gain in the bill equal to $(227.5 - 170.6)$ TND. In the second one, the user choices the cheapest pricing zone and can earn the half of the price $(195 - 97.5)\ TND$.

To test the peak management service, the electricity daily consumption estimation during a summer day is as follows (using Table I):

$$(2.4 + 0.75 + 0.45 + 0.11 + 1.09 + 7.5) = 12.3\ KWH/Day. \quad (5)$$

The available energy during peak consumption period is equal to 2 KWH/Day. So in this case, the requested value is equal to 10.3 $KWH(12.3 - 2)$. We propose to deactivate the less priority equipments during peak periods. So we will only keep the refrigerator and air conditioning and the daily consumption will be equal to:

$$(2.4 + 0.75) = 3.15 KWH/Day. \quad (6)$$

Compared to the provided value, we still need 1.2 KWH to meet the daily electricity lack. We assume that we have domestic batteries to store energy produced by renewable sources. The used batteries are divided into two parts. The first part uses 70% of the available capacity for optimizing the production. The second part uses 30% to solve the peak consumption problems. For example, if the battery available amount of energy is equal to $4KWH$, we have to use only 30% of this amount, which is equal to $1.2KWH$

After using our idea, we we

re able to avoid a peak consumption by delaying the execution of some lower priority equipment and compensate the remaining value through the use of renewable energy available in the battery.

4 MULTI-AGENT BASED SOLUTION

In this section, we propose a Multi-Agent based Architecture, for our CSH to control and manage the domestic energy consumption. Our architecture consists of a one Home Master Agent controlling a number of Slave Agents corresponding to their equipments. We have also Storage Agents functioning together with the Green Agents for the production and the storage of the green renewable energy.

Figure 2: Multi-agent based architecture.

4.1 Agents Description

In this section we will introduce the various agents used in our approach. We have four kinds of agents:

1. ***Home Master Agent.*** It controls and optimizes energy consumption and encourages the use of the green renewable sources. It coordinates between all the Slave Agents controlling their corresponding equipments.
2. ***Home Slave Agent.*** They control the electrical equipments by stopping and resuming their functioning through a mechanism of Sensors/Effectors,
3. ***Green Agent.*** They control the production of the renewable energy sources,
4. ***Storage Agent.*** They control storing in batteries the energy produced by green renewable sources, to be used in the case of peak consumption.

4.2 Agents and Services Formalization

In this section we propose a formalization of the agents and the original services used in the contribution.

4.2.1 Formalization of Agents

Let

- $Sys_{CSH} = \{MA, \xi_{SA}, \xi_{GA}, \xi_{STA}\}$ be the Cynapsys Smart Home Multi-Agent based System composed of a Master Agent MA, N Slave Agents SA, M Green Agents GA and finally K Storage Agents. Let:
- $\xi_{SA} = \{SA_1, ..., SA_N\}$ be the set of Slave Agents for the control of rooms,
- $\xi_{GA} = \{GA_1, ..., GA_M\}$ be the set of Green Agents,
- $\xi_{STA} = \{STA_1, ..., STA_K\}$ be the set of Storage Agents,
- $Sys_e = \{e_1, e_2, ..., e_n\}$ be the set of electrical equipments.

4.2.2 Agent's Parameters

Let $MA = \{ID, EC, ASL, NLV\}$ be the Master Agent list of parameters, where:

- ***ID***: the Identifier of the agent composed of a String,
- ***EC***: the daily estimated energy consumption,
- ***ASL***: the Available Stored Load energy,
- ***NLV***: the Needed Load Value used in the case of peak consumption and daily production management.

Let $e_i \in Sys_e$ where e_i has:

- ***ID***: be the Identifier of the electrical equipment,
- $EC(e_i)$: be the daily estimated consumption of the electrical equipment,

Let $sa_i \in \xi_{SA}$ where sa_i has an ID, an NLV, and and a set of equipment Sys_e to control.

- ***ID***: be the Identifier of the Slave Agent,

- $NLV(e_i)$: be the Slave Agent Needed Load Value corresponding to the equipment e_i.

  Let $ga_i \in \xi_{GA}$ where ga_i has an ID and a DPV

- ***ID***: the Identifier of the Green Agent,
- ***DPV***: the Daily Production Value.

Let $sta_i \in \xi_{STA}$ where sta_i has an ID and a STV

- ***ID***: the Identifier of the Storage Agent,
- ***STV***: the Stored Value.

4.2.3 Formalization of Services

The intelligence in power systems spreads starting houses, through intelligent cities to arrive at a smart grid.

Let:

- P_e be the equipment power amount,
- P_G be the general available energy.

Our system should always satisfy the following equation:

$$\sum_{i=1}^{n} ECe_i < P_G \tag{7}$$

let:

- Pr_t be the total price of the energy consumption,
- Pr_i be the price at the instant i,
- C_i be the consumption at the moment i,
- Pu_i be the unit price of the KWH at the moment i,
- $Pr_i = C_i * Pu_i$,
- Tr_c be the Consumption Threshold.

Our approach must satisfy the system represented by the equation below, which consist of using the three tariff zones, $i \in [0,1,2]$ where zero corresponds to the first tariff zone, one for the second one and two for the third one:

$$Pr_t = \sum_{i=0}^{2} Pr_i \tag{8}$$

The problem is to find the right formulas of energy consumption during the appropriate periods to minimize the total cost.

The equation is therefore to establish an optimization relationship having the form:

- $MinPr_t$,
- $Pr_t < Tr_c$.

Let:

- EC be the estimated daily consumption of a house,
- ECe_i be the estimated consumption of a single device e_i per day.

The estimated daily consumption is given by the following equation:

$$EC = ECe_1 + ECe_2 + ... + ECe_n = \sum_{i=1}^{n} ECe_i \tag{9}$$

Let:

- Pv be the Peak Value provided by the energy producers,
- STV be the available capacity in the battery.

In the case of a peak detected by the energy producer, the power source become the battery in case of presence of sufficient load. In our approach, we have 30 % of the capacity of our battery remains untouchable, this part is dedicated to solving the problem of peak consumption as described in the equation below:

- $Pv = 0.3 * STV_i$,
- STV_i be the stored value of the Storage Agent i.

4.3 Service Protocols

In this section, we propose a Service Protocol to coordinate all used agents in the implementation of the different proposed services.

Algorithm 1: Green Energy and Storage Device Management.

foreach $ga_i \in \xi_{GA}$ **do**
  $STV_i = \sum_{i=1}^{n} DPV_i$
end
// The Sum of the Daily produced Value provided from different green renewable sources represents the Stored Value used in the Peak Management Service.
foreach $sta_i \in \xi_{STA}$ **do**
  $STV = \sum_{i=1}^{n} STV_i$
end
if $Date == Date\_Peak$ **then**
  $Pv = STV * 30 \div 100$;
  //The Peak Value represents 30% of the available capacity on the Battery
end

The next algorithm deals with the management of the interaction and the communication between the used agents used in order to handles the power consumption optimization.

4.4 Timed Automata Models

In this paper, we propose a global approach for the design of adaptive reactive systems, i.e. systems that dynamically adapt their architecture depending on the

Algorithm 2: Home Master Agent and Home Slave Agents Energy Management.

Init
$Date <> Date\_Peak$
$State = Enabled$
while $Date = Date\_Peak$ **do**
  foreach $sa_i \in \xi_{SA}$ **do**
    if $Priority == 1$ **then**
      $State == Disabled$
    end
    if $NLV <= Pv$ **then**
      MA Sends a $giveSolution(MA, STA)$
    else
      foreach $sa_i \in \xi_{SA}$ **do**
        $State = Disabled$
      end
    end
    if $Event == PromotionalOffer$ **then**
      MA Sends $Store(MA, STA)$
    else
      foreach $sa_i \in \xi_{SA}$ **do**
        if $(Priority == 1)$ And $(Zone <> NormalZone)$ **then**
          $State = Disabled$
        end
      end
      if $Pr_t >= Tr_c$ **then**
        foreach $sa_i \in \xi_{SA}$ **do**
          $State = Disabled$
        end
      end
      $State = Enabled;$
    end
  end
end

context. We use the timed automata formalism for the design of the agent's behavior to check and verify functional and temporal properties of our inter-agent communication protocol. This allows their evaluation regarding logical correctness and timeliness, thanks to model-checking and simulation techniques. According to (Palshikar, 2004), model checking is the most successful approach that's emerged for verifying requirements. The idea is that by ensuring that the model satisfies enough system properties, we increase our confidence in the correctness. As follows we present a Timed Automata Model for the example of agents that we propose in our approach. We model the Home Master Agent with its two main important services: Distribution and Peak Management which has been described above. The Home Master Agent is responsible of the whole house control by supervising a set of Home Slave Agents which in their turns are responsible of the home's electrical equipments. Figure 3 shows the timed automata model of the Home Master Agent.

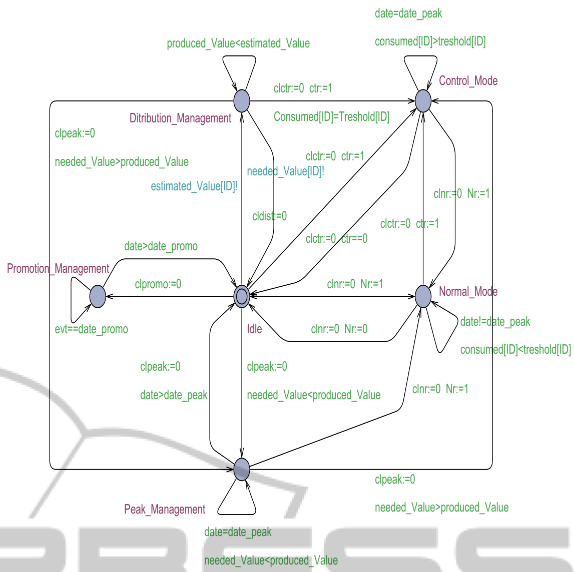

Figure 3: Home Master Agent Timed Automata.

This automata consists of different states related to the different operations of the Home Master Agent. The default mode is the normal mode, however, the transition to the control mode is activated by: (a) the arrival of preemptive events, (b) functional constraints related to exceeding consumption threshold, (c)the arrival of a peak load, (d)time constraints related to power management across shutdown, (e) and activation of equipments to consume intelligently and during specific periods. Figure 4, shows the transaction of distribution management, which is an important service in our theoretical approach. The decentralization of the distribution in this work is a major asset for ensuring optimization, maintaining the network and the integration of renewable sources for the energy generation. The reactive system upon detection of failure or the arrival of a new promotional offer from the provider. In this case, we verify the amount of renewable energy to be available in the battery. Following the application of the formulas given above, our system decides if the new source of energy an be used or not. Our reactive system will be efficient in this case while respecting imposed time and ecological constraints.

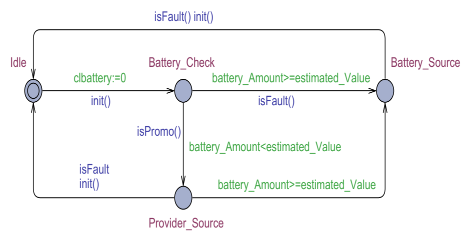

Figure 4: Distribution Management Service Timed Automata.

The proposed approach allows the management of peaks by using useful information to be sent from the provider. Figure 5 describes the mechanism of energy management during peak periods. Our goals: (a) the minimisation of the energy consumption during these periods, (b) take into account environmental impacts and cost of energy productions, (c) optimisation of the overall energy generation plan by anticipating consumer demands while ensuring comfort, (d) taking into account resources and environmental constraints, (e) and better control of consumption and local distribution. The management of high consumption periods is based on the use of compensation for energy requests through house storage devices to be connected essentially to green production sources. The system is converted to a control mode after the arrival of a peak load event. The source of production becomes a local battery after the checking of its capacity. This is done with a specific management policy with efficient calculation methods to guarantee green and low cost energy for users.

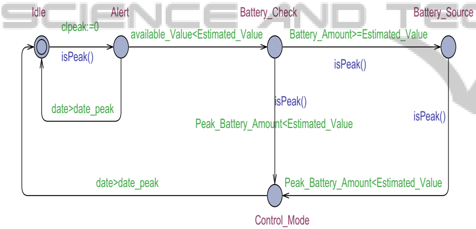

Figure 5: Peak Management Service Timed Automata.

4.5 Implementation

4.5.1 UML Modeling

We propose a UML model to implement the software version of our home system. Figure 6, shows the class diagram "Home Automation System" (abbreviated by HAS) that represents the whole Multi-Agent architecture. This class manages all interactions in the system. It is related to the provider interface class which allows interaction with energy producers, and the user interface class which allows manual accesses of users into the system. An Agent class is proposed to represent both Home Slave Agents and Home Master Agent through an inheritance relationship. Figure 6 shows the whole class diagram.

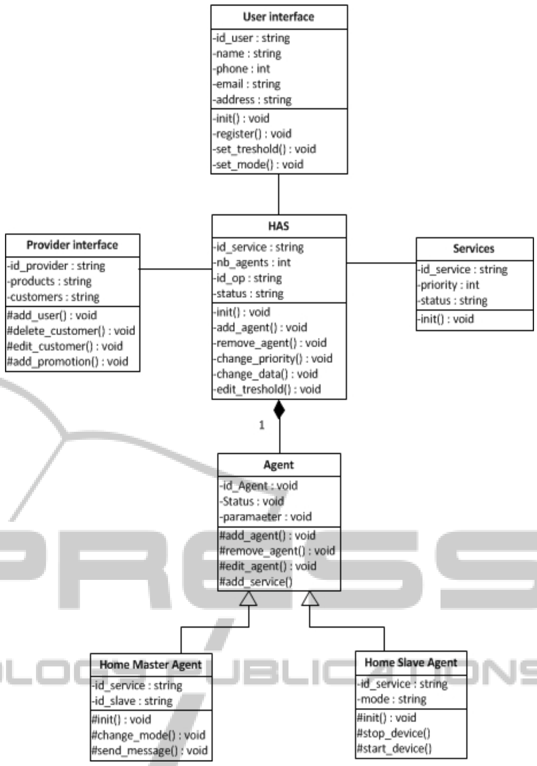

Figure 6: Home Automation System class Diagram.

4.5.2 X-SH Simulation Tool

The simulation is mandatory for the development and deployment of our system model. This model represents the main characteristics of the selected physical, abstract system or process. Simulation is used in many contexts, such as simulation of technology for performance optimization, safety engineering, testing, training and education. In this section, we present a tool to be called X-SH that we developed at Cynapsys for the electrical energy management. This tool simulates the services that we describe above by using real-time data collection.It reacts to various changes of the electrical network. This tool can be used by both users and producers for the estimation of the daily energy consumption in order to optimize the use of green sources, manage peak periods, manage offers from producers. After the authentication interface to be used for a required security, the main interface appears to include the various offered services that we describe above: (a) Equipments Management service, (b) Consumption Management service, (c) Consumption Threshold service, (d) and Sale Management service (Figure 7).

Figure 7: Main Interface Energy Management Tool.

In Figure 8, we show the equipments management interface. The households are controlled by the Home Slave Agents. The X-SH Simulation tool allows the addition of new equipments, removing or changing priorities according to periods of use and operation modes.

Figure 8: Equipment Management Interface.

Figure 9, shows the consumption management service which is provided by our simulation tool X-SH. The interface informs the users about the values of the estimated consumption for a period and the actual daily consumption.

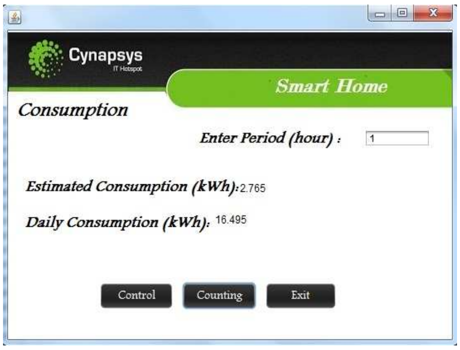

Figure 9: Consumption Management Interface.

In Figure 10, we show the consumption Threshold management Interface. This service allows to avoid the energy waste or loss as fixed by users. In the case of exceeding Threshold, we are directly informed about the passage of the home to the control consumption mode.

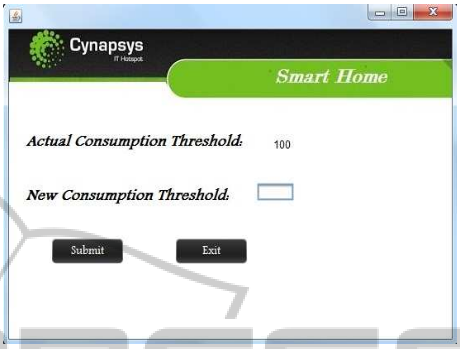

Figure 10: Set Threshold Consumption Interface.

The last service proposed by our consumption management tool X-SH consists of the management of the provider promotional offers (Figure 11). In the case of lower prices, the user can change its production source from the battery to the provider. We consume less in this case and can help to preserve energy that we store in the batteries for future uses, management electric failures, and management of peak periods.

Figure 11: Sale Management Service Interface.

4.5.3 Contribution Analysis

The testing of our simulation tool at Cynapsys helped us to better assess the gain of the proposed approach. Thanks to this contribution, the management of the power consumption shows a remarkable gain that costs 50 TND = 227 TND - 170 TND before the application of our approach and after (1 Euro = 2.2 TND in January 2014). This gain is very important for any Tunisian family in the medium society class. (Figure 12).

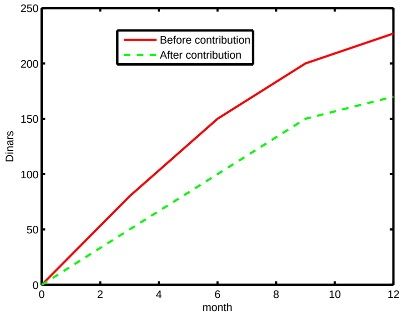

Figure 12: Comparison between the energy consumption before (Red) and after (Green) the contribution.

We propose also in Figure 13, the test of the thresholds consumption service that we did at Cynapsys. We note that during the same period, the user can consume energy intelligently by considering the priority of each equipment and the production of renewable energy from batteries. The consumption should not exceed the fixed amount.

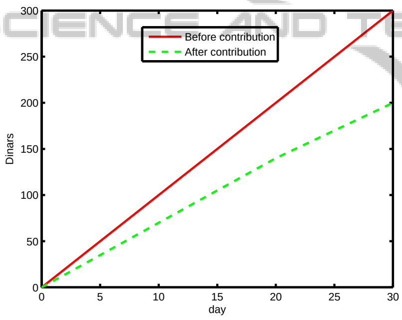

Figure 13: Comparison between the energy consumption without threshold (Red) and with threshold (Green).

Finally we propose in Figure 14 a histogram showing the use of renewable energy in our approach. We choose a summer day, which is characterized by a high consumption of electricity and an alert of peak from the provider. We applied an optimal management of the energy with the participation of the renewable sources that costs 38.09%.

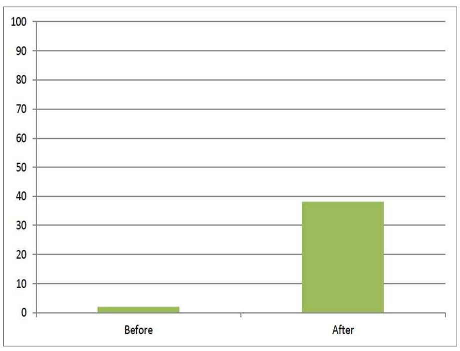

Figure 14: Green renewable energy participation.

5 CONCLUSIONS

This paper deals with a new Multi-Agent architecture for Smart Homes, which propose, new services for users such as: (a) Peak Management, (b) Promotion Offers Management, (c) Consumption Management. We offer a Home Master Agent that controls the whole architecture, interacts with the energy provider, coordinates with home users in order to optimise the green energy that we assume available at home. A Home Slave Agent is proposed for the local control of each equipment. We propose a communication protocol between these agents to support all the services that we propose above. Since the architecture that we propose is real-time and based on concurrent operations, we propose timed-automata models for these agents and verify their correctness by using UPPAAL. We developed a simulator X-SH which can be used by both home users and providers in order to estimate and manage the daily consumptions. This tool was tested at Cynapsys and some experimental results are exposed in this paper. In our future work, Cynapsys plans the real commercialisation of this product. We are planning in this case to finish the complete deployment of this simulator as well as Agents on microcontrollers following STM32F4 technology. The real commercialisation and distribution is planned for the end of 2014.

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