CELTIC-PLUS/EUREKA
Smart Connected World

Project-ID: C2012/1-1 ACEMIND

Deliverable D3.2

GreenHome

Part: General presentation

Contractual Date of Delivery:	*30/09/2014*
Actual Date of Delivery:	*30/09/2014*
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Work package:	**WP3**
Security:	**PU**
Nature:	Report
Version:	**1.0**
Total number of pages:	36

Abstract

In this document, we describe the state of the art concerning the home electricity use in the more general context of the electricity grids. The evolution towards the so called smart home grids is described as well as the current approaches to automatically shape the home demand.

Then, in this context, we propose an innovative home solution to even out electrical power consumption peaks. The proposal consists of a specification and definition about system architecture and a control algorithm in order to efficiently manage electrical loads (white and brown appliances) and sources. The starting point is that consumers will require networks to be simple to install, with home automation integration but without the need of any new wiring and with actual energy efficiency improvement results.

For this goal, we introduce a new algorithm to flatten the potential Electric Peak inside the Home Network. We present the principles of our proposal; define the architecture as well as the protocol used between each component.

Keyword list

Heterogeneous mesh home networks, energy-efficient networks, peak shaping algorithm and protocol, Home energy optimization, convergence layer, quality of service.

Executive Summary

Electrical networks are at a turning point. Historically, the distribution part of the grid was centralized, synchronous and exclusively radial. This distribution part was then connected to the central high-voltage transmission grid to end-users through medium and low-voltage feeds. However, new constraints such as energy transition and in particular renewable energy require changes to this architecture.

This deliverable deals with these aspects. In the first part, the current evolution of the electrical networks from a centralized distribution network to microgrids and smart home grids is described. Then, we describe in more details the concept of home load management and in particular the current research approaches. We describe our new approach which aim to extend further the scope of the considered equipment and to avoid the use of any consumption threshold and to avoid fixing the time slot for all household equipment as this could result on quick and frequent transitions from the ON state to the standby state. In such a way, equipment would likely be damaged or could have an altered functioning.

Our proposal provides a simple and effective solution for resource management and optimized electrical power of a household in order to flatten the potential Electric Peak. First, the deliverable describes how the different devices and resources could be classified. Then, by taking advantage of historical data, meteorological data, and regular updating of Consumers C and Resources R of a house, we describe how we could provide an adapted planning to limit the operator use of energy and especially to avoid high load demands during electrical peak periods while assuring use simplicity and transparency for customers.

Finally, the deliverable focuses on the technical specifications of our approach (software architecture, protocol used between each component) and provides a quick description of the demonstrator v1.

Impact on the other Work-packages

The architecture and the components described in this document (Dashboard, GreenHome coordinator, appliances) will be implemented in the Acemind GreenHome demonstrator. Therefore, there is an impact of this deliverable on WP4 which defines Acemind demonstrators.

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Document History

First name	Last name	Version	Comments

List of Acronyms

Acronym	Meaning
<ACEMIND>	<Advanced Convergent and Easily Manageable Innovative Networks Design>
<GENA>	<General Event Notification Architecture>
<mDNS>	<Multicast DNS>
<REST>	<REpresentational State Transfer>
<SOAP>	<Simple Object Access Protocol>
<SSDP>	<Simple Service Discovery Protocol>
<UPnP>	<Universal Plug and Play>

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1 Introduction

Our demonstrator proposes a simple and effective solution for optimized management of electrical power sources and loads of a household, in order to flatten the peak electricity demand. The first step is a judicious classification of equipment consumption and renewable production equipment. Then, from historical data, weather data and regular updating from consumers and resources devices of a home, our system provides an adapted planning in order to limit the use of the power consumption from an operator and especially to avoid the peak electricity demand without constraint to the user or customer.

2 Context and State of the art

2.1 Home electricity use in the overall evolution of electricity grids

The evolution of electrical networks follows a route resulting from the interaction of three distinct driving forces and their respective constraints [PRI 12]**Erreur ! Source du renvoi introuvable.** :

- the energy transition, mostly the need to substitute fossil fuels by renewable energy, but also to use fossil fuels resources less wastefully, as long they remain used ;
- the autonomous evolution of a large technological system that tends to lead "naturally" to the most efficient solution that satisfies best the constraints imposed on the system, including the preceding one ;
- the weight of incumbent actors that may pull in the opposite direction from the former evolutions, towards extending the use of existing power generation plants and maintaining the associated centralized architecture and centralized control of the grid.

The following subsections describe these evolutions.

2.1.1 Centralized generation and radial distribution

The architecture of existing grids is centralized, synchronous and exclusively radial for the distribution part of the grid, which connects the central high-voltage transmission grid to end-users through medium and low-voltage feeds. The core high-voltage transmission part has, by contrast, a mesh architecture.

In the current model of the pre-smart grid which is "sources follow loads", balancing aggregated loads and sources is handled by the operators who are in charge of the central transmission systems, which is closely monitored for this by distributed sensors detecting frequency and voltage fluctuations. The obvious advantage of handling load-source balancing at this scale is that random fluctuations of individual loads even out at the scale of the overall network. The aggregate demand, as pooled and centralized through the transmission system, does of course still vary, but in a smoother and more predictable way, through well-characterized daily, weekly and seasonal peaks and troughs of demand, except if some self-reinforcing event leads them to diverge.

Adapting generation to demand is done mostly by keeping "spinning reserves" of power that can be injected almost instantly and other power plants that are kept in standby but can be turned on on short notice.

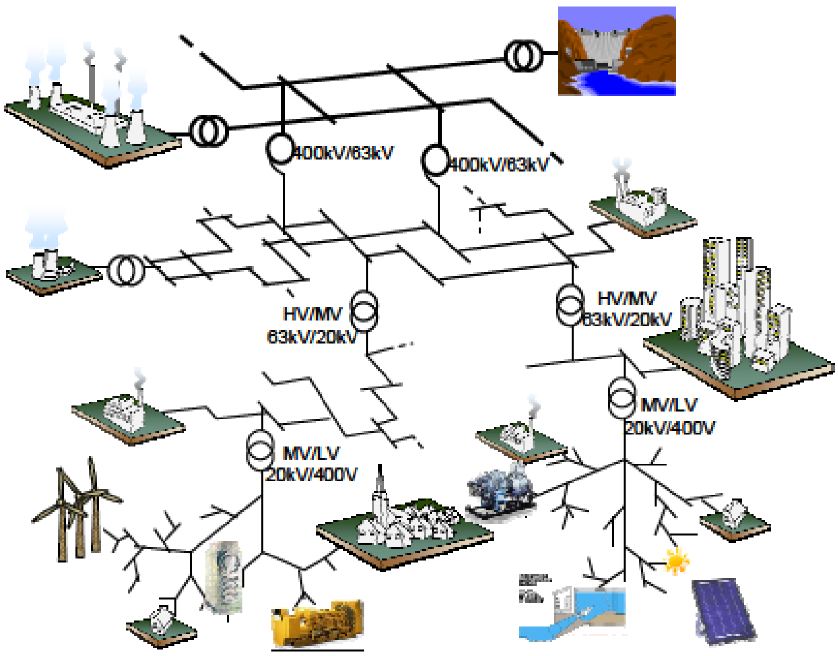


Figure 1: Architecture of the (pre-smart) grid[1]

[1] from *Smart Grids,* Hadjsaïd & Sabonnadière

2.1.2 Distributed generation and the evolution of distribution systems

The existing architecture separating a mesh core network from a radial distribution network is adapted to generation resources that are themselves also centralized and get connected directly to the high-voltage transmission grid. The current problem facing distribution grids is that decentralized generation resources, mostly renewables (Wind turbines PV panels) but also small-scale co-generation units, get attached directly to the low or medium voltage distribution grid that is not designed to handle the bi-directionality of the energy flow to such an extent, when generation resources become pervasive throughout the network[2] . Distribution systems are thus facing a double threat from the variability and the pervasiveness of renewable resources which can lead to their tension fluctuating wildly and uncontrollably, to the point where the distribution network would become uncontrollable. Most distribution networks, by contrast to transmission networks *are not supervised* and instabilities that occur in a branch of the networks may amplify and propagate before they get detected.

2.1.3 Load management for smart distribution systems

Balancing sources and loads is a completely different problem when it gets handled at the scale of the distribution network, first because random variations do not even out as they do on a larger scale, and also because the “sources follow loads” model cannot apply at this scale where reserves of sources are not necessary available or cost-effective. One of the solutions is to be able to (at least partially) control loads so that the balancing act may partially integrate a “loads adapt to available sources” dimension.

Ultimately, load management assumes a fully smart grid with bidirectional communication, making it possible not only to monitor loads on a fine-grain basis, but also (ideally) to control them with the same granularity. This could be done while keeping a centralized model, only imposing centralized control from the grid to the loads that hitherto could assume that power would always be available when they needed it. It is realistic to assume that few distribution operators are ready to assume this responsibility, which would pose obvious problems of customer relationship and would likely lead to an explosion of complexity in the management of these loads. It is therefore reasonable to apply a subsidiarity principle where management of individual loads would be delegated to a local scale where knowledge about their actual use can best be brought to bear, while upholding the rights of all stakeholders.

2.1.4 Towards microgrids and decentralized distribution

Moving away from the centralized view of traditional distribution networks, the grid can thus evolve so as to integrate partially autonomous subnetworks on several possibly nested scales, like buildings, districts or cities. Partial or total control autonomy for such microgrids may already exist for some non-residential buildings such as industrial compounds or military installations that use their own generation resources for obvious security or reliability reasons, and to a lesser extents for city districts. Total control is already extant for electrical grids such as those of islands, or in developing countries where the electrical grid is not fully connected. The phrase “microgrid” implying at least partial control autonomy and minimum local balancing between loads, sources and storage is especially used for districts, and it has already been widely studied, even if mostly deployed in pilot projects so far.

The decentralization of control afforded by these different solutions will probably spread only very gradually, in a way similar to how it took place for telecommunication networks. The decentralization process would thus operate itself in a decentralized way, starting from small peripheral subnetworks for which safety issues are not currently perceived as too critical, and migrating from there to the core.

Control models could themselves evolve from partial centralization, with a single controller managing each of these intermediary levels, towards more radical solutions using multi-agent systems, where each entity connected to the network is represented by a software agent acting as a peer in the global optimization process by exchanging its own constraints with other agents, all arriving at a solution satisfying (generally sub-optimally) all of the constraints without any central controller. These solutions, which have been widely studied in research projects (e.g. [DIM 04]), are the ultimate in decentralized control. In an even more long term and radical vision [HOM 07], the exchanges between agents would not be limited to mutual optimization constraints, but would serve as support for auctions for quotas of electrical energy that would be bought or sold by software agents acting on behalf of loads or sources, respectively. The granularity of these auctions might be temporally as fine as the fluctuation of conditions on both sides would warrant, with a limit possibly placed by the reluctance of human agents to relinquish such total control of their energy budget to software agents, rather than to a utility...

2.1.5 Towards smart home grids

[2] Traditional grids do allow for generation resources to connect to the low-voltage grid, but these remained few and far between, insignificant in aggregate power compared to the bulk generation units

Moving down from district, compound or building-scale microgrids, the home environment can itself be addressed as an autonomous microgrid. It is the best test bed for assessing new possibilities for distributed management of electricity because it is where Internet-centric state of the art ICT using open and standard solutions is already the most widely deployed, compared to say, industrial compounds that may still use closed and proprietary solutions.

Home Area Networks have gone through an initial development focusing on traditional computing (PC, gateways, routers, Network Attached Storage, etc.), and have expanded to integrate state of the art consumer electronics and multimedia equipment (audio /video media players, digital photo frames, etc.).

The next stage is the integration of home automation and household appliances into these networks. Closed and proprietary solutions for home automation have already been proposed for some years and to this day have consistently failed to find a significant market. The players in the domain entertain the hope that energy management in the home could be for home automation the equivalent of the “killer application” that the web was to the internet, bringing value immediately recognized by the users in a context of more expensive energy and stronger environmental constraints. This will involve a gradual integration into the home network, not only of home automation and white and brown goods, but of all equipment which has an impact, even indirectly, on the consumption, generation and storage of electricity, thus achieving the “Smart Home Grid” by coupling ICT Home Area Networks with the local electrical network of the home. This first stage of integration of “non-ICT” yet connected equipment on the Home Area Network requires extending it beyond the core networking technologies (WiFi and Ethernet) which presently support it. These extensions can use specific wired solutions such as power line communication, specific standards of radio communication such as Zigbee which are adapted for the interconnection of resource-constrained devices with a low bitrate. These so-called “capillary” networks are themselves interfaced to the local area network through a specific secondary gateway. The newer hyped-up generation of non-ICT connected devices may use Bluetooth or even WiFi to connect by way of a smartphone or tablet, possibly bypassing the home network gateway to feed information directly into a proprietary cloud from where it would have to be repatriated back into the home network.

A more ambitious solution aims to integrate into this Smart Home Grid all legacy home equipment that has an energy impact, not only those endowed with a data network connection. For this, a solution which has by now become commonplace is to insert a so-called “smart” receptacle-plug between the device’s own mains power plug (supposing it has one accessible) and the wall socket. This smart plug is equipped with a current sensor and an actuator (a switch and possibly a dimmer). The minimal possibility thus provided to supervise and control this device can suffice to represent it as an informational entity on the home area network, in the same way as a directly connected network peer. Figure below illustrates what may be the perimeter of a classical local home network extended to a « Smart Home Grid ».

Figure 2: Perimeter of a home area network extended to a « Smart Home Grid »

Extending this idea leads to indirectly supervising and controlling all types of home equipment by exploiting all sensors and actuators available in the house, supposed to be connected to the home area network. Smart plugs are but one among many such sensors and actuators that can serve as intermediaries for indirectly connecting all electrical equipment of the home, but can also, in an even wider perspective, be used to supervise purely passive entities such as rooms, walls or windows. An infrared camera could thus be used to monitor the thermal state of a room, but also as a complementary sensor for all devices radiating heat in a room. Without delving into the technicalities of the association of these sensors to devices [HU 11], suffice it to say that they can be used as connectivity intermediaries very much like regular network interfaces.

Within a house, building and more generally a closed indoor environment, the possibility of sharing all available sensors and actuators available in these environments turns them into genuine smart spaces and establishes a very strong link, at several additional levels, between energy management and the general research agenda of ambient intelligence [PRI 08]. The use of sensor data in such a smart space can be either direct as previously explained for equipment supervision, but also, and mostly, indirect, as context for inferring high level information on this space in general, (e.g. on the presence or activity of the occupants of this space), information which is particularly relevant for energy management

The « Smart Home Grid » understood as above provides considerably richer and more fine-grain information than the smart meter, and also makes it possible to control individual home devices, which used to be possible (using dedicated powerline communication interfaces) only for the biggest loads in the home. But its main potential use goes far beyond such demand management.

2.1.6 Beyond load management : towards comprehensive home energy management

As indicated before and represented in figure 1, the perimeter of the Smart Home Grid may be extended not only to regular household appliances viewed as electrical loads ("white" and "brown" goods), but also to energy generation and storage equipment available within a house, if applicable. Exploiting the availability of general information on the house as a smart space (typically the presence or activities of the occupants of the house at different levels of granularity), the integrated and comprehensive management of all energy equipment in the house makes for a level of local optimization which goes much beyond global optimization under grid-originating constraints, which translates locally into power-based control criteria such as load shedding for peak consumption shaving. By contrast to this power-centric global optimization, local optimization will mostly be energy-centric.

2.1.6.1 Energy-efficiency-oriented optimization

This optimization may first correspond to an exploitation of unexploited energy efficiency "resources" existing within a house, understanding efficiency in a strict sense as the ratio between the output *service* and the input energy [LOV 04] [GER 10]. These intrinsic efficiency gains are independent from whether the home uses grid power or its own energy resources. They may typically result from turning off or adjusting the heating, lighting or the stand-by state of domestic appliances by taking into account the presence or activity of the occupants of the house. They do not replace conventional efficiency measures (such as weatherizing or insulating the house) but complement them by requiring much less upfront investment, especially if the corresponding infrastructure is shared as we have suggested here. Low-hanging efficiency fruits may be reaped in this way that ideally would have no effect at all on the experience of the home user, being totally transparent to him.

In a coarse grain fashion, this may amount to turning off space or water heating when the home is empty, turning it on just before users return so that the target temperature is reached right on time. For most homes that may be empty approximately one third of the time, a huge efficiency gain of around 30% can be reaped this way, ideally without any impact on the comfort of home users (this depending on the heating technology that is used).

This same idea of presence adaptation could also apply on a finer grain at the level of individual rooms of the home, or even zones of a room, with diminishing returns obviously due to the inertia of the heating process and the need for finer grain instrumentation. In the (theoretical) limit, *an ultra-efficient home would heat only the home users individually by radiative heating using directive radiators in the far infrared range*. This is intrinsically much more efficient than heating the entire volume of air inside the home by convection, as is usually done. For optimal comfort, such a solution would require tracking the users through the home just as follow-me scenarios have proposed to do it for ambient audio or video communication. It would also be possible to adapt to the activity of users, not only to their position, heating less a user who is engaged in a physical activity such as cooking, heating more a user who is reading or working at his desk, but heating less a sleeping user! It can even be argued that this user-targeted heating could ideally provide higher comfort than traditional heating of the air because it avoids drafts of cold air that may exist in a poorly insulated home (actually in all homes except passive ones!) and it also avoids moving around dust and particulate matter as convection heating inevitably does. *This is a very interesting case of the theoretical limit of substituting information (the knowledge of home users position and activity) for energy for intrinsic efficiency gains*! For new construction, building a passive home would obviously be a more direct route to efficiency, yet a solution approaching this is still better when an existing building cannot be insulated efficiently enough. The same idea of targeting and tracking users could apply to lighting, with much more reduced gains in overall energy use when taking in to account the (already very high) efficiency of state of the art LED lighting. Automatically optimizing the lighting to take into account activity does still provide comfort gains (e.g. using that may warrant it even if the efficiency gains are limited.

2.1.6.2 Local balancing of sources and loads with storage optimization

In the longer term, expecting the generalization of distributed generation in homes and a general evolution of the grid towards decentralization and asynchronous decoupling, local optimization will primarily address, jointly with intrinsic efficiency as put forward before, the use of loads in relation to the availability of power from local sources (typically from renewable energy) or energy stored locally, the use of grid sources, if used at all, being viewed as a secondary or last resort possibility; when these local resources aren't available, weighing both alternatives according to the price or carbon footprint of remote energy.
In this perspective, energy management relies on optimizing an energy budget on different time scales, taking into account previsions of both consumption and generation together with the state of storage reserves on these scales. On a daily basis, which is the most basic time scale on which to perform this optimization, a typical consumption prevision for e.g. a week day, would be compared against a prevision of wind or solar generation taking into account weather forecast and the state of reserves. If generation+ available reserves could not match the consumption prediction, the energy management system could decide to postpone some deferrable uses of electricity until the next day, taking into account an order of priority among these together with knowledge about the activities of users. This load shifting is completely different from power-directed load shedding in classical distribution systems, which is aimed at shaving aggregated peaks that would require the onlining of costly generation reserves on the grid. Here the power criterion is irrelevant as long as local peaks of instantaneous *power* demand can be met by local storage and generation, what matters is staying within a pre-estimated *energy* budget on a given time scale. The contrast between these two types of criteria is illustrated in Figure 3.

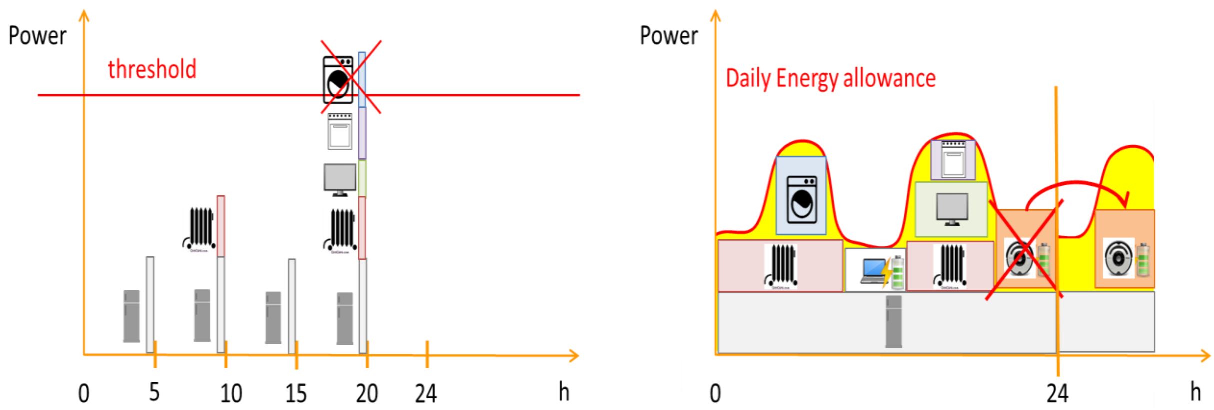


Figure 3: Power vs energy-based optimization

2.1.6.3 Three-pronged comprehensive home energy management :

A truly comprehensive home energy management would have to combine the three types of criteria described before

- power-based instantaneous optimization (grid-directed demand management)
- optimization targeting intrinsic efficiency gains
- optimization based on the prioritized use of a local energy budget, stored and generated locally

Obviously these three optimization criteria are not independent and would have to be weighed against each other in a comprehensive system: intrinsic efficiency could be a meta criterion, implying also that local energy use is always preferable to the use of grid power when possible, because it is intrinsically more efficient at the global level (it avoids the transmission losses inherent in using remote power through the grid).

Another more user-directed set of criteria could apply across the three types of optimization, by categorizing the energy services that are expected from different appliances and loads, in the following categories ranked by descending order of priority

- safety
- security
- work support
- comfort
- entertainment

In either of the three types of optimizations, services in the safety category could never be the target of load shedding or shifting, whereas other services could be modulated according to their respective priorities by taking into account local context information.

This joint objective of intrinsic efficiency and optimization taking into account the availability of local renewable energy as well as intrinsic efficiency and grid power had been addressed early on by the ReActivHome[3] project [PRI 11], through a comprehensive home energy system along the lines outlined before.

Figure 2 illustrates in a very simplified view of the alternative between global optimization, typically limited to demand management, and local optimization exploiting a full-fledged Smart Home Grid. In the first case, the biggest loads in a home can be controlled directly by the distribution operator in order to be for demand shaping by load shedding[4]. This does in fact amount, as put forward in section 2.1.3, to extending the distribution grid (or at least its centralized "top-down "management) inside the home, to this piece of equipment. In the second case, we have by contrast an autonomous level of control for the home and a clear separation between the distribution grid and the Smart Home Grid, with an interface which can be used to exchange aggregate information required for interoperability between the Smart Home Grid and the global grid, yet hiding from the grid information that is purely local to the house and leaving at this level the choice of how to pass on the constraints arriving from the upper level. This last point is consistent with the principle of subsidiarity and "separation of concerns", universally adopted in the design of large-scale information systems, as it is essential to the scalability and robustness of these systems.

[3] https://reactivhome.rd.francetelecom.com

[4] Millions of domestic water heaters in France were thus, well before SmartGrids became a buzzword, remotely controlled by the operator, using analog powerline communication technology.

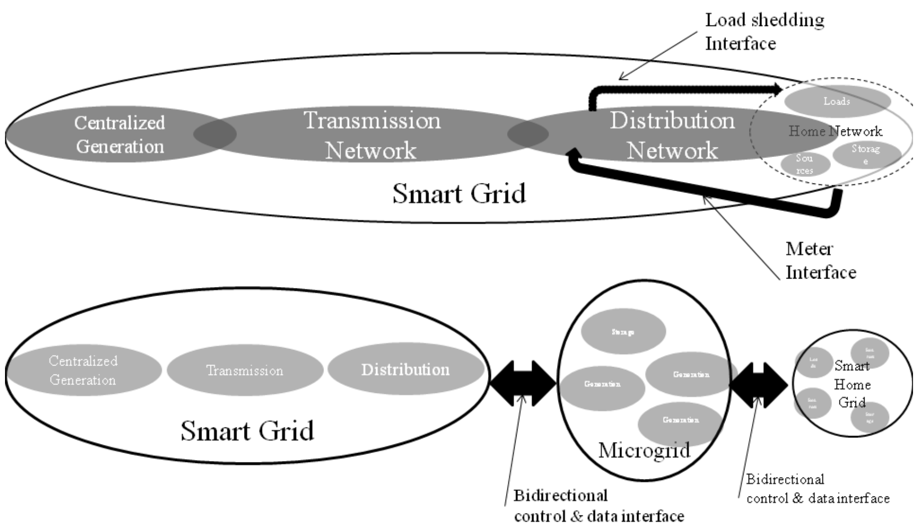


Figure 4: Separation of concerns & control autonomy for "Smart Home Grid"

In this way, the local home energy management system brings to bear all the local information it has to adapt to these constraints in a way that is best for the home user: thus, if a request for load shedding is transmitted from the grid down to the interface of the home energy management system, it can be applied to the device for which this has the least impact according to the present local context (activities taking place inside the home *together with* state of local energy reserves that can be brought to bear), and its application adjusted accordingly, whereas a centralized system would directly shed the equipment that it controls with a systematic and context-blind policy.

2.2 Home electricity usage trends

According to the International Energy Agency figures, worldwide electrical power consumption could more than double from 2012 to 2030 since the world's population continues to grow. Moreover, household electricity consumption has been increasing steadily over the last decades (Figure 5 and Figure 6).

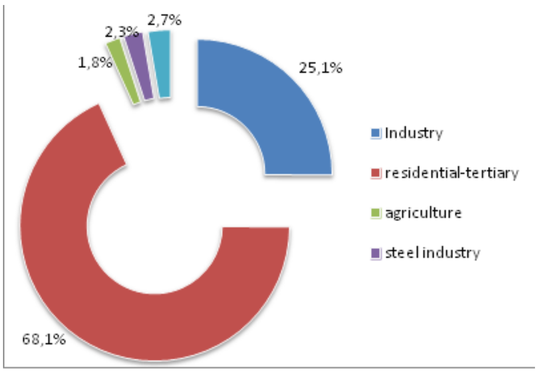


Figure 5***:*** **Distribution of electricity consumption in France 2010 (by sector)**[5]

5 Bilan énergétique de la France pour 2010,» Commissariat général au développement durable, 2010

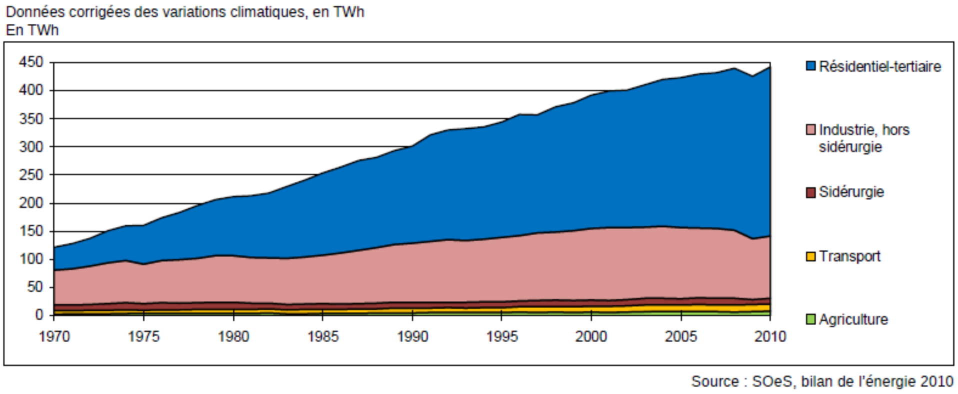


Figure 6: Electricity consumption evolution by sector (France) [6]

Finally, not only is aggregate electrical power consumption increasing, but records in consumption peaks are increasing faster (Figure 7). This is partly due to the massive use of direct electrical space heating in France, fostered by the national electricity operator as an a posteriori justification for massive investment in nuclear power generation, whereas it has been banned altogether in other countries (e.g. Sweden, Denmark).

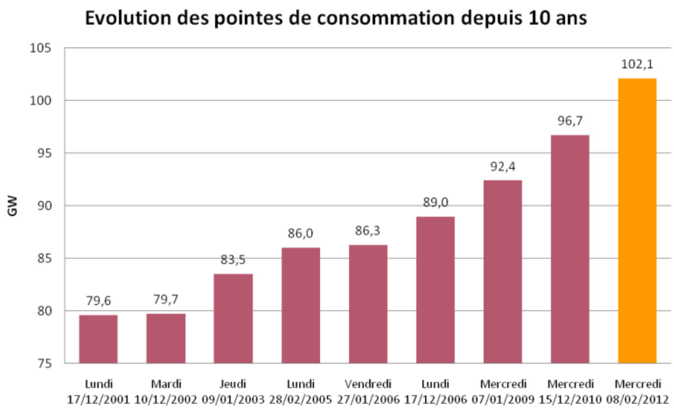


Figure 7: Annual peak consumption records (France from 2001 to 2012) [BAR 12]

These consumption peaks disproportionately affect the investment and operating costs of the grid, including transmission (line loss), generation (with the need to keep non-spinning supplemental and replacement reserves (in standby operation at so-called "peaker plants") and fuel costs which directly influences the pricing models. Therefore, faced with the challenging requirements of energy transition away from fossil fuels, it becomes urgent to optimize and rationalize the daily use of energy by evening out the power peaks and limiting their emergence frequency.

2.3 Non-technical solutions and incentives for demand shaping

Several solutions have been implemented in the last few years. Among them we can mention:

ECOWATT (France)

This approach aims to raise public awareness about energy demand. The purpose is to encourage customers to make further effort towards less energy consumption. This approach is based on a communication campaign that invites Bretons to register on the site (www.ecowatt-bretagne.fr) which triggers alerts incentivizing the population to adopt eco-citizens gestures. Thus, the followers can reduce their consumption during demand peaks during winter especially after 6 pm.

The EDF pricing peak hours – off-peak hours (Blue Edf Tempo tariff) (France)

[6] Bilan énergétique de la France pour 2010,» Commissariat général au développement durable, 2010

In the traditional forms of pricing, the price per kWh is similar throughout the year, with a 2-tiered pricing being usually offered depending on the hour of the day and possibly the day of the week (week-ends and nights being off peak). With the Tempo tariff, there are 3 different prices depending on the "color of the day". This is again due to the weight of electric space heating in the aggregate consumption, peak corresponding to the coldest winter days

-There are 300 blue days where the price per kWh is much lower than other tariffs.

-Then 43 white days when the price of kWh is equivalent to that of the conventional tariff.

-And finally 22 red days, when the price of kWh is much more expensive.

EDF determines white and red days, depending on their consumption forecast to discourage customers of consuming too much during these days.

Ontario Electricity Board approach (USA)

In order to flatten consumption peaks, OEB has split electricity tariffs into three categories: during peak, mid-peak and off-peak periods. Such model provides customers and economic and incentive pricing to limit power consumption during critical periods.

12004 SEAS - Smart Energy Aware Systems (France)

SEAS[7] is an Itea project. It aims to increase energy efficiency and sustainability via smart energy awareness systems in building and micro-grid environments.[9]

2.4 Approaches to automatic shaping of home demand

Regarding the academic and research side, there exists several home-related solutions which focus on flattening power consumption peaks, for instance authors in [VED 12] have designed a Least Slack First scheduling algorithm for household loads, inspired by the well-known Earliest Deadline First algorithm. The proposed solution consists of deciding which equipment to feed after each timeslot T.

In the industrial field, in order to flatten the power consumption peaks, authors in [TIN 11] used the same scheduling principal while modelling the power supply system as a real-time computer system. Thus activation/deactivation of the household equipment's are managed periodically based on timeslots.

None of earlier mentioned solutions provides an optimized solution to consume energy efficiently while exploiting the eventual renewable resources within home. Indeed, EcoWatt and ERDF and OEB solutions require customers to be attentive to their household equipment consumption, or to implement tools that limit the power consumption which can cause discomfort in everyday life. Moreover, regarding solution [VED 12], household equipment's are not wholly considered.

Our new approach aims to extend further the scope of the considered equipment and to avoid the use of any consumption threshold. Regarding solution [4], fixing the time slot for all household equipment could result on quick and frequent transitions from the ON state to the standby state. In such a way, equipment would likely be damaged or could have an altered functioning.

[7] https://itea3.org/project/seas.html

3 GreenHome operating principle

Our proposal provides a simple and effective solution for resource management and optimized electrical power of a household in order to flatten the potential Electric Peak. The first step is a judicious classification of the consumption of electrical equipment, renewable and nonrenewable resources. Then, by taking advantage of historical data, meteorological data, and regular updating of Consumers C and Resources R of a house, our proposal provides an adapted planning to limit the operator use of energy and especially to avoid high load demands during electrical peak periods while assuring use simplicity and transparency for customers.

Thus, the proposed solution aims to sleek home's power consumption and reduce consumption peak by up to 70% (Figure 8). On a wider scale of houses, the gain could be transposed up to 20%. This percentage can be further improved with an optimized management of renewable energy sources (Figure 9).

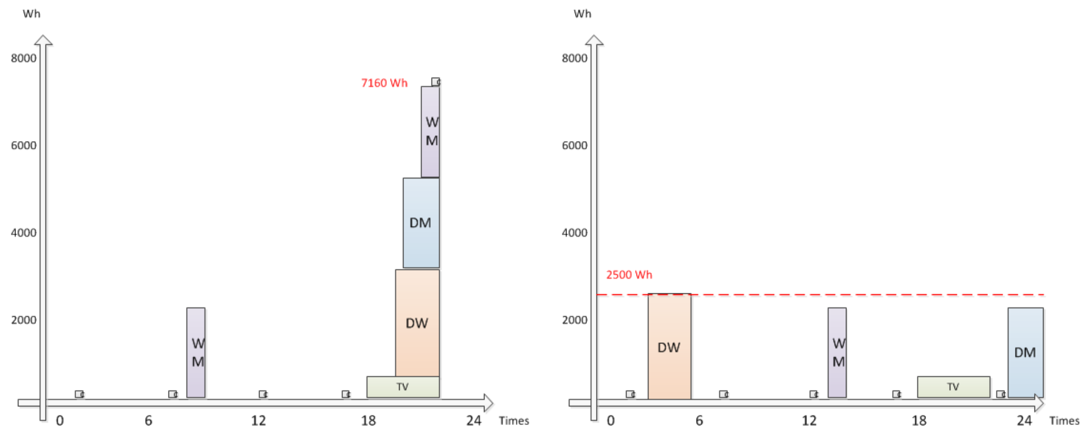


Figure 8*:* Non optimized consumption repartition example (left) and optimized example (right) **(WM: Washing Machine, DW: Dish Washer, DM: Dryer Machine, TV: Television, F: Fridge)**

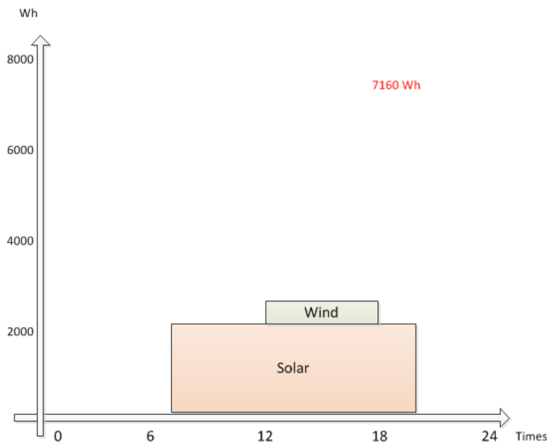


Figure 9: Renewable resource example

3.1 Data sources

3.1.1 Consumption Data

The first data source is information concerning electrical devices that consume energy. Such information is to be recorded by the client or obtained from the device via wired data transmission (power line, Ethernet ...) or wireless data transmission (WiFi, ZigBee ...) or simply obtained from the Internet using equipment brand/model or the reference.

This information could be separated into 2 categories (non-exhaustive list):

- Device information (static):

- Device ID (MAC / Serial / Manufacturer assigned ID)
- Device Manufacturer (or Brand)
- Device Model (Model number)
- Software version (Need to be updated only when a firmware update occurs)
- Device Name (My Washer, etc …)
- Device Type (Washer, Dish Washer, etc…)
- Device Category (Ca, Cb, Cc as mentioned below)

- Program information (varies):
    - Electrical Signature (Cycle duration-power sequences) (i.e {[duration1, duration2,…], [power1,power2,…], [maxpower1, maxpower2,…]})
    - Current cycle number
    - Current cycle remaining time
    - Instantaneous power consumption in W
    - Current cycle interruption mode (1: active, 0:passive)
    - Maximum delay for the interruption (for example 20 minutes, this will depend on appliances and program, for demonstration purpose, the maximum delay could be set to 60 minutes)
    - Device State (working, on, paused, off/stand-by)

Electrical signature array will be updated during runtime. The frequency of the updates will be once per second at most and probably once per 5 minutes.

From such information, it’s possible to classify household equipment into three categories of electrical consumers C:

- Ca : Device whose use is always immediate (Available)
- Cb: Device that works with cycle or even with sub-cycle, and that’s often controllable, nevertheless emergency degree of use is either selected or postponed (Revalidate)
- Cc: Device that works with charging and release time, is rarely controlled by user and whose use’s emergency degree is either selected or anticipated/postponed (Transparent)

Such classification system allows us to set initial «priority» regarding electrical consumers: Ca>Cb>Cc

Indeed:

- Customers comfort is a matter of high priority. (TV, kitchen, lighting…)
- Management of low priority equipment has to be transparent for customers.

Appliance	Type: A: Available B: Re-push C: Transparent	Average Usage (Hours/Day)	Consumption (KWh/Day)	Consumption Cumulated (KWh/Day)	% / Total
Refrigerator	C	16	1,014	1.014	36%
Dryer	B	0,79	0,63	1,644	59%
Dish Washer	B	3,02	0,53	2.174	78%
Washing Machine	B	1,53	0,41	2.584	92%
Oven	A	0,3	0,216	2.8	100%
Total			2,844		

Table 1: Devices classification example (3 categories)

This table can also highlight a fundamental characteristic of household electrical equipment; they are generally in accordance with the Pareto concept; that is to say that 20% (Figure 10) of electrical equipment household uses almost 80% of the power consumption. Advantageously, these facilities come mainly in categories b and c.

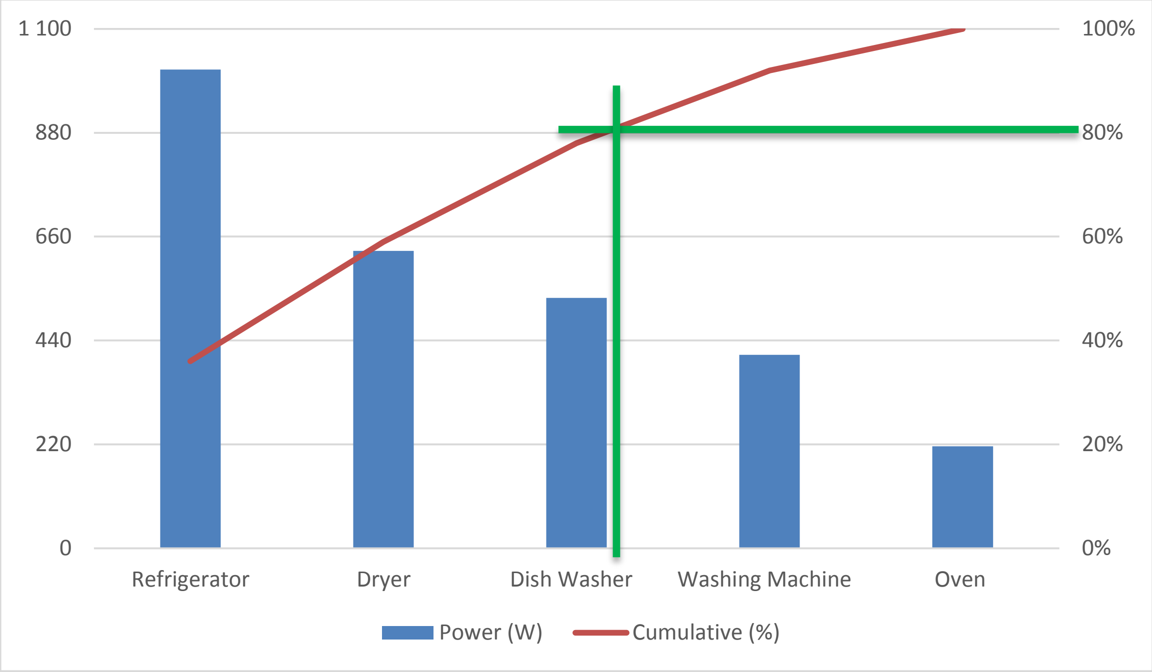


Figure 10: Household electrical equipment example (Pareto Diagram – Green lines)

Ca equipment will not be managed because the customer usually wants to use it immediately except for charging small electrical appliance.

Cb equipment is equipment with different cycles and sub-cycles. They are often controlled by the user, but the use can be deferred. If the client wishes to make immediate use, in this case it must revalidate the application by pressing a second time on the power button for example “Re-Push”. These devices generally have cycles and sub-cycles with pauses. It is therefore possible to eventually share the consumption cycle stages as shown for example in Figure 11 which shows the Electrical Signature of the “Eco 50” program with full load for a Dish Washer. However, there is maximum delay for the interruption of each cycle to maintain the quality and functions of the device.

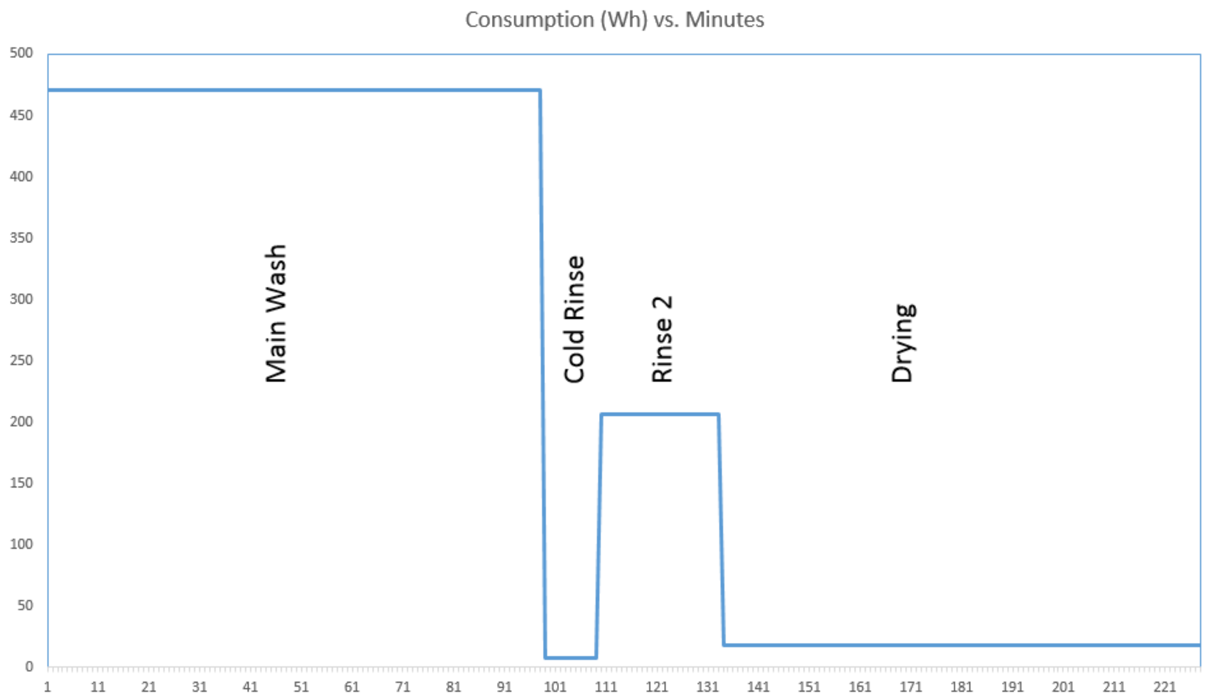


Figure 11: Dish Washer Cycle example

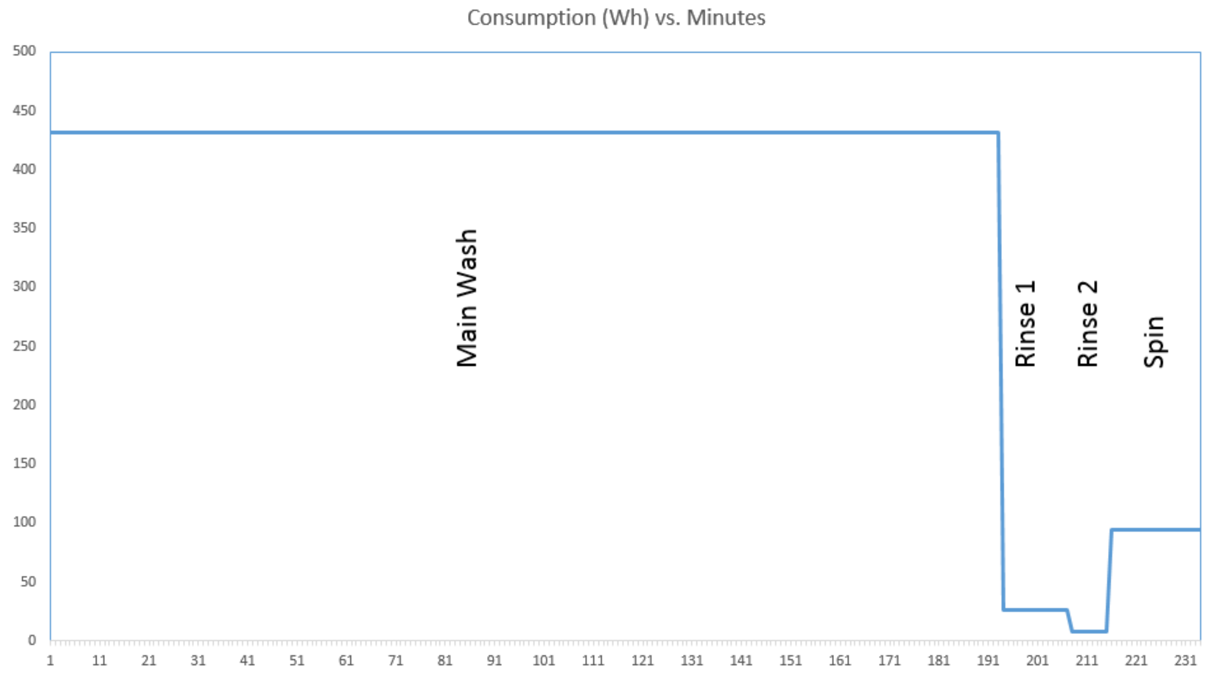


Figure 12: Washing Machine Cycle example

Cc equipment is generally not affected directly by the user control. They have most often cyclic and continuous operation following their respective instructions. They have in this case a cycle distribution characterized by a charging time to achieve the minimum or maximum point and a release time to return to the level of the minimum or maximum set point, as shown for example in Figure 13 and Figure 14. Energy consumption statistics in these two graphs are identical and belong to total energy consumption of both cabins (cooler & freezer).

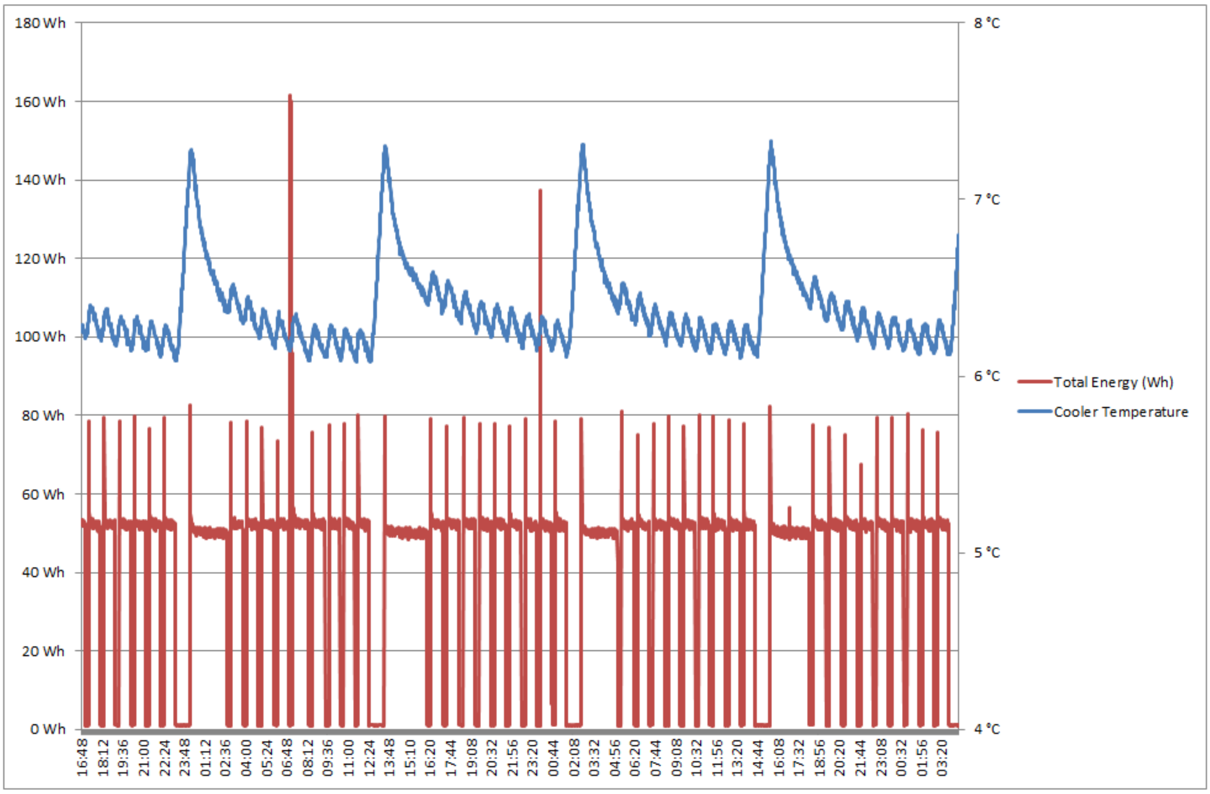


Figure 13: Total Energy vs. Temperature for Fridge

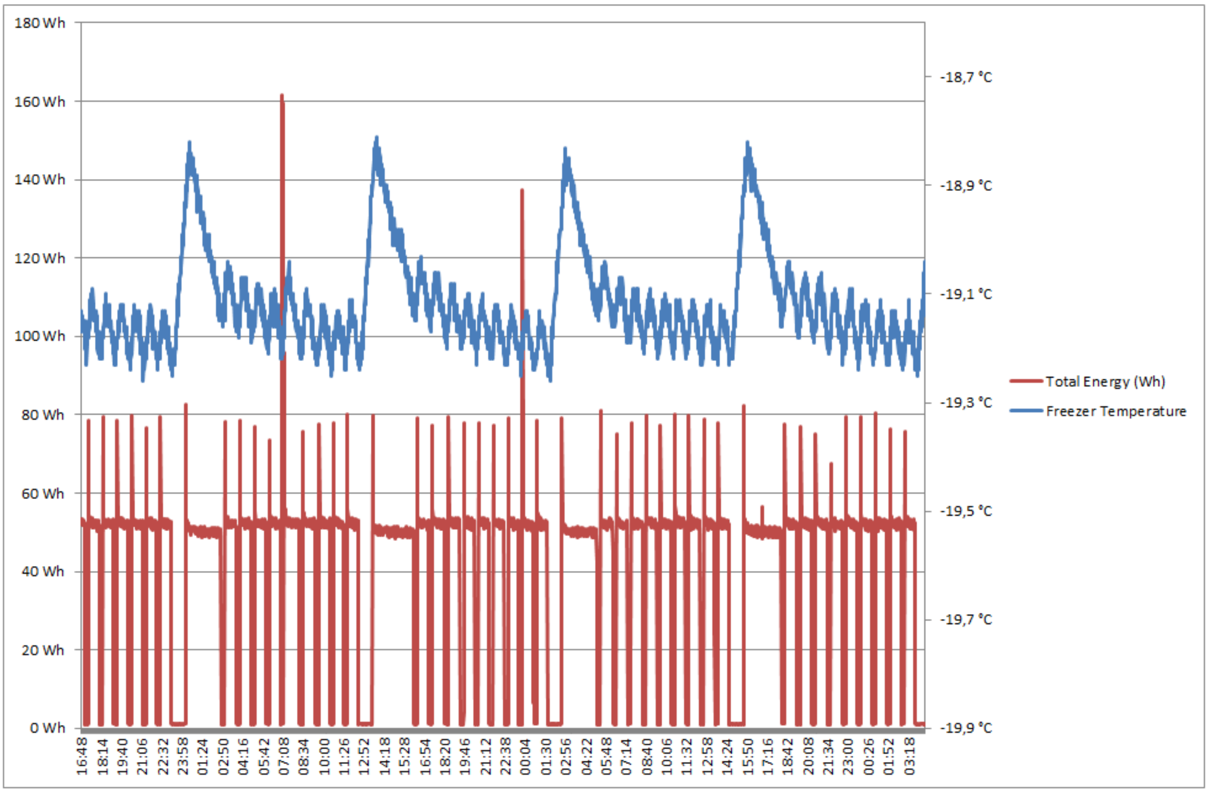


Figure 14: Total Energy vs. Temperature for Freezer

3.1.2 Renewable Data

The second data source is the characteristics of energy resources available at home.

- Brand,
- Model,
- Immediate resource Wh,
- Discharging time Wh,
- Meteorological data.

Such information about electrical resources could be stored by the user or just collected directly from the device or even obtained from Internet using equipment brand or reference.

We can also classify energy resources into three categories:

- Ra: Renewable resources depending on meteorological conditions (solar, wind…)
- Rb: Renewable resources depending on reserves amount (batteries)
- Rc: Unlimited resources from energy supply operator.

Such classification system allows us to set a second « priority » regarding electrical resources: Ra>Rb>Rc

Indeed:

- Customers comfort is a matter of high priority
- Electricity can hardly be stored (transmission losses, electrical/chemical conversion losses).

The third source of data is the history of electrical consumption. The same approach can be achieved for renewable resources with for instance daily, weekly, monthly or annual data.

4 Management example

Using a specific management algorithm, which can be integrated either on a laptop, plug or a Box, the last mentioned classifications allow a differentiated treatment for each electrical device. Our proposal consists of system architecture and a control algorithm in order to efficiently manage electrical consumers and resources including renewable and stored energy. Since our solution is mainly software, its cost is very low and its implementation would be easy.

More concretely, we propose a control algorithm and management example based on the following example (Figure 15 and Figure 16), the management of three resources (the fourth being the electricity supplier, e.g. ERDF in France) and three different consumers on an hourly range of 18 to 22 hours. Resources and consumers are:

- Ra: Renewable Resources Solar running 18 to 20 hours in this example and providing power 1000W
- Ra: Renewable Resources Wind 18 to 22 hours in this example and providing a power of 500 W.
- Rb: Battery with a reserve of 500 W during 2 hours.
- ERDF : not limited in time and resources from the electric supplier
- Ca: Available. Device whose use is always immediate, LCD TV in this example with a 140 W current consumption
- Cb: Re-Push. Device with cycle and sub-cycle, a washing machine in this example with a 2000 W maximum instantaneous power consumption during four cycles and maximum delay of 20 minutes for the interruption of each cycle.
- Cc: Transparent. Device with charging and discharging time, rarely controlled by the user, in this example a freezer for instant with 220 W consumption and a 60 minutes discharging time.

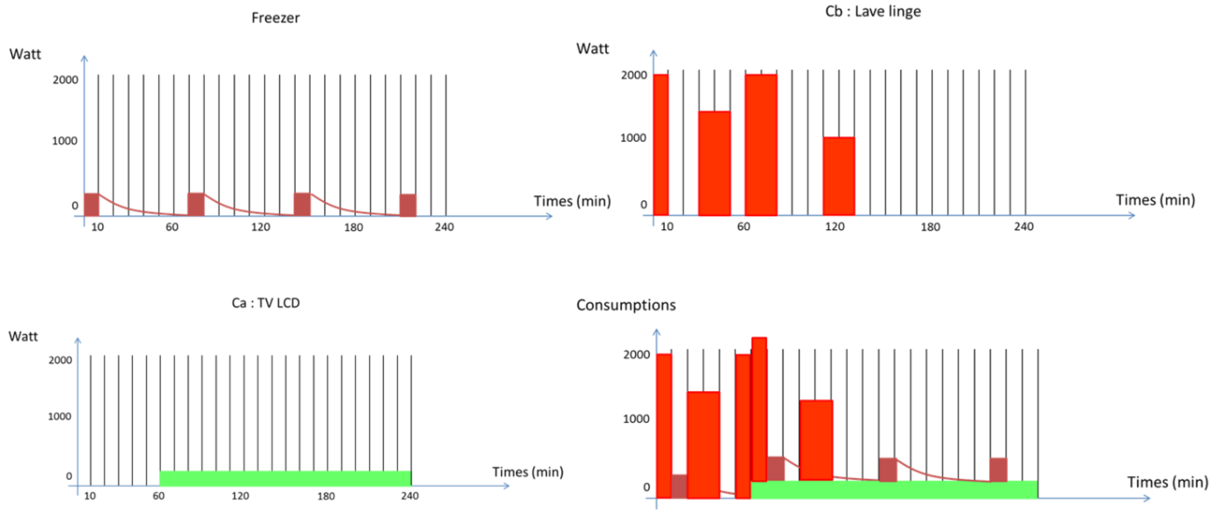


Figure 15: Consumption devices cycle example and total value (bottom right)

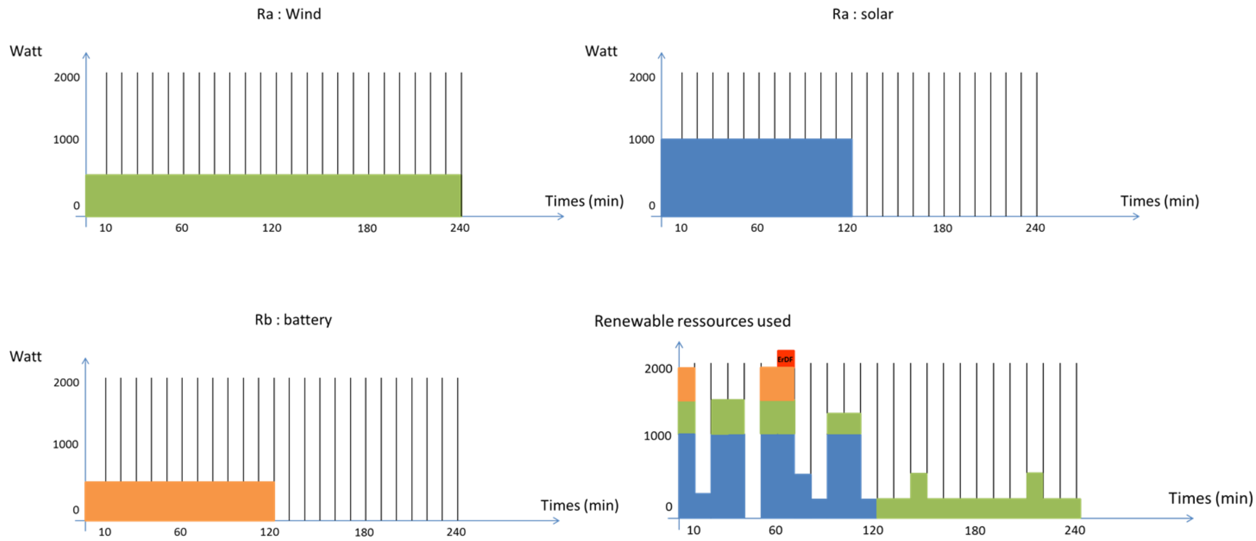


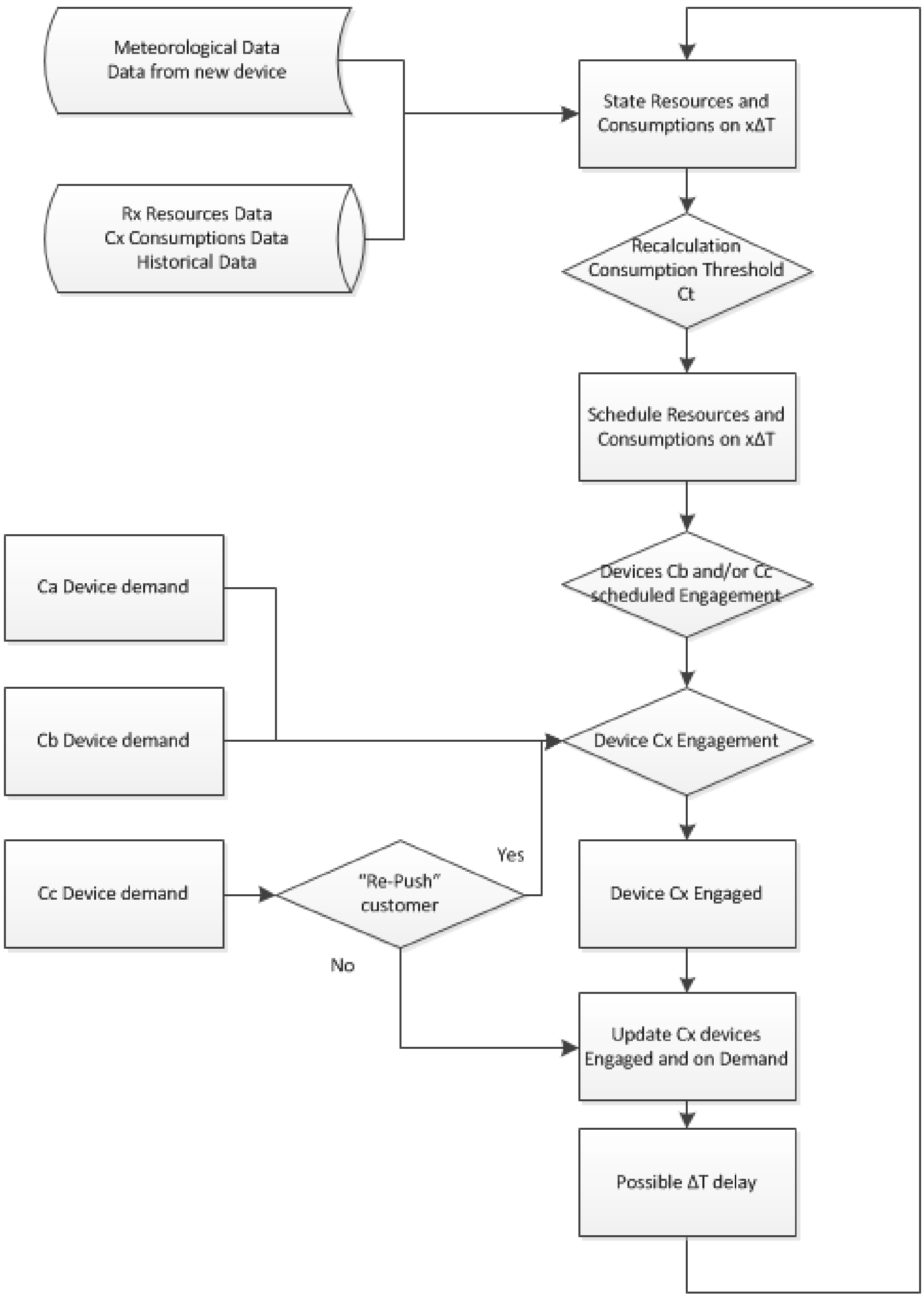
Figure 16: Renewable resources cycle example and total value (bottom right)

In this example, the resource requirement from an electric supplier could be limited to 140 W during 10 minutes.

5 Control algorithm proposal

The classification system allows us to define a first "Priority" for electrical consumers: Ca> Cb> Cc and a second "Priority Order" for electrical resources: Ra> Rb> Rc. This classification could be additionally completed by a history of consumption and weather data for projection capabilities and thus provide advance starting for equipment Cb or Cc.

Example of distribution algorithm and resource consumption



The consumption threshold corresponds to the remaining margin available if an additional consumer is engaged in a cycle. For instance, the threshold may be 50 % when customer is at home or there is no activity and 80% when there is nobody at home. Advantageously, this threshold is recalculated based on the state of resources and consumption at time T and historical data including habits or behaviours of users.

Ca consumer demand is still treated without delay.
Cc consumer demand to be treated as a Ca consumer due to the critical point of discharging time period or a new set point change as a result of user requests.

ΔT is the smallest cycle or sub-cycle of a consumer Cb or smaller time charge Cc consumer.

Thus, each new cycle time (or time slot or ΔT), it is possible to propose the algorithm for the management and distribution and consumption planning and resources.

6 Technical specifications

6.1 Architecture

The different components of the architecture are described in Figure 17:

- Appliances: Dish Washer, Washing Machine …
- GreenHome Coordinator: it will communicate with Appliances using mDNS/REST. GreenHome Coordinator will also centralize the information from all Appliances and communicate with the Acemind Dashboard,
- Notifications will be sent using alive TCP connections,
- Acemind Dashboard: User will be able to view some particular data related to home appliances.

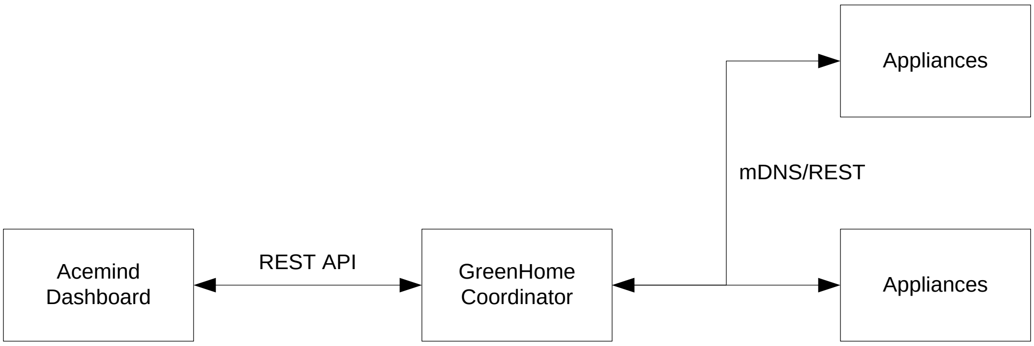


Figure 17: GreenHome components

6.2 Software architecture proposal

The proposal is to use mDNS for the discovery and a REST API for the description, control and live TCP connections for eventing steps (Figure 18).

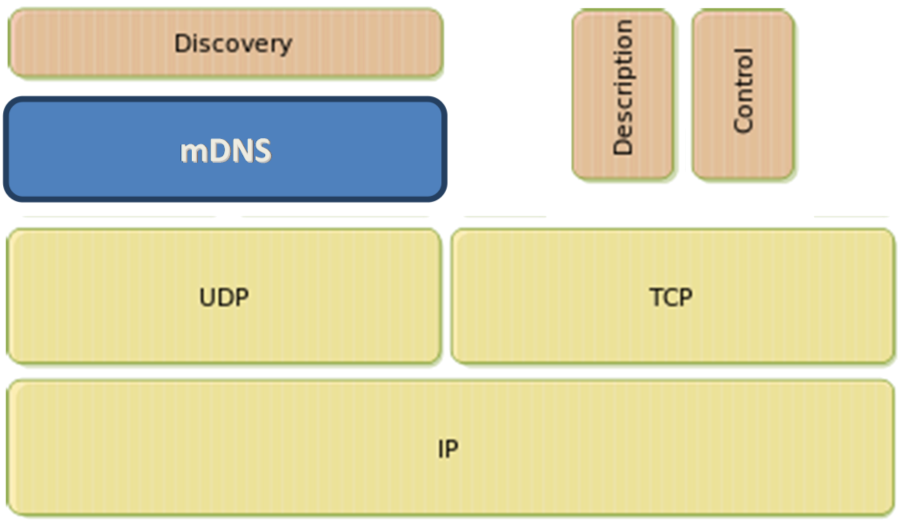


Figure 18: mDNS/REST protocol stack

Other protocols are also possible such as UPnP[8], AllSeen[9], QeO[10] and CoAP[11].

[8] http://upnp.org/specs/arch/UPnP-arch-DeviceArchitecture-v1.0.pdf
[9] https://www.allseenalliance.org

6.2.1 Appliance Discovery through mDNS

mDNS is a zeroconf service used for domain discovery. In local networks or networks that lack a DNS server installed, mDNS helps nodes to discover addresses of other nodes. When an mDNS service runs on a node, a UDP socket listens to the port number 5353 on multicast IP address 224.0.0.251 using joinGroup methods. For discovery, the explorer node broadcasts a message to port number 5353 over local network using multicast IP address 224.0.0.251. Nodes that run mDNS services reply back with a message which embodies service information like IP, port, service name, etc.

The mDNS service name published by the appliance is _appliance._tcp._local. The port number used to send command and receive notification is not provided by mDNS.

The mDNS Ethernet frame is a multicast UDP packet to:

- MAC address 01:00:5E:00:00:FB (for IPv4) or 33:33:00:00:00:FB (for IPv6)
- IPv4 address 224.0.0.251 or IPv6 address FF02::FB
- UDP port 5353

Its payload is based on the DNS packet format. It consists of two parts—the header and the data.

offset (bytes)	0	1
0	ID = 0x0000	
2	Flags	
4	QDCOUNT	
6	ANCOUNT	
8	NSCOUNT	
10	ARCOUNT	
12	Data	

mDNS broadcast packets will have definitions in the name field as follows:

<devicetype>?<devName>?<IPb3>?<IPb2>?<IPb1>?<IPb0>
For a washer, if custom name and IP address are "MyWasher" and 172.168.0.103 respectively, the service name will be as follows:

Washer?MyWasher?172?168?0?103

Other important broadcast attributes:
mDNS service port number: 1905
mDNS service type: _appliance._tcp._local
mDNS service TTL: 300

6.2.2 Static Data

To retrieve the static consumption data described in section 3.1.1, the coordinator will connect to a predefined port through a REST API.

Coordinator needs to know device information like device type, device name or device id in order to apply convenient actions. Static data is device information that does not change for a long period of time.

Requesting Device Info:

Request: port=1906&type=acmd&req=sInfo

Reply: {

[10] http://www.i-speak-geo.com
[11] http://tools.ietf.org/search/draft-ietf-core-coap-18

"Id"": "f023e2133243",
"Brand": 0,
"Model": "3243",
"SoftwareVersion": "v1.0",
"DeviceName": "MyWasher",
"DeviceCategory": 1,
"DeviceType": 1
}

Parameter Name	Type	Description
Id	string[12]	Unique id for the appliance
Brand	ui8	ID of the manufacturer
Model	string[64]	Model of the appliance
SoftwareVersion	string[32]	Software version of the appliance
DeviceName	string[64]	Friendly name given by the user to its appliance
DeviceCategory	ui8	Category of the device: 1 for Ca, 2 for Cb, 3 for Cc. If the user switch off or on the power management of its device, the deviceTypeCategory will be updated to reflect this change.
ApplianceType	ui8	Type of the appliance: 1 for Dish Washer, 2 for Washing Machine …

Appliance	mDNS name	Device Type
Washing Machine	Washer	1
Refrigerator	Refrigerator	2
Dishwasher	Dishwasher	3
Oven	Oven	4
Dryer	Dryer	5
Freezer	-	-
Air Conditioner	-	-
…		

Brand	Brand ID
Grundig	0
Arçelik	1
Beko	2
Samsung	
Bosch	
Miele	
Siemens	
Philips	
…	

6.2.3 Dynamic Consumption Data

Coordinator needs to be aware of state of appliances. For this purpose, a data packet for state transfer should be defined. For this purpose, a command for program info will be defined.

Requesting Program Info:

Request: port=1906&type=acmd&req=dInfo

Reply: {

```
    "ElectricalSign":{
        "Duration": [99,12,25,94],
        "Power": [472,12,202,22],
        "MaxPower": [552,13,242,25]
        },
    "Cycle": 1,
    "CurrentCycleRemTime": 91,
    "InstantaneousPower": 403,
    "Interrupt": 1,
    "MaxDelay": 23,
    "State": 3
    }
```

Parameter Name	Type	Description
Duration	Array of ui16	Duration in minutes of each cycle
Power	Array of ui16	Average energy consumption in Wh of each cycle
MaxPower	Array of ui16	Maximum power consumption in W of each cycle (peak value of each cycle)
Cycle	ui4	Current cycle number
CurrentCycleRemTime	ui16	Current cycle remaining time in minutes
InstantPower	ui16	Instantaneous power consumption in W
Interrupt	ui4	Indicates if the current cycle can be interrupted, this information is provided only for the current cycle and not for the other ones
MaxDelay	ui16	Maximum interruption delay in minutes of the current cycle, this information is provided only for the current cycle and not for the other ones. It can be dynamically set by appliance during run time.
State	ui4	State of the appliance: 0 for off/standby, 1 for on, 2 for -work, 3 for pause

6.2.4 Interruption command

When the coordinator wants to interfere with appliance work sequence, it needs to send an interruption message. Coordinator will send another message at the end of interruption so that appliance can resume work sequence.

An Example can be as follows:

To interrupt work sequence,

Request: port=1906&type=acmd&req=pause **Reply:** `{"state":3}`

`At the end of interruption,`

Request: port=1906&type=acmd&req=play

Reply: `{"state":2}`

Parameter Name	Type	Description

type	string[4]	request type, in the example it's Acemind (acmd)
req	string	Command to send (play, pause)

State	Enumeration
Off/Standby	0
On	1
Working	2
Paused	3

6.2.5 Notification command

To notify the coordinator that the user pushed the start or pause button of the appliance, a notification mechanism is needed. Indeed, if the coordinator decides to interrupt the appliance, the user must be warned immediately to be able to push the button again.

When a meaningful change occurs on appliances, coordinator should be notified. Coordinator will then launch related routines. The proposed solution is keeping an alive TCP connection between coordinator and each appliance. Coordinator will be running related routines when it detects a meaningful change on one of the appliances.

Coordinator should firstly introduce itself to appliances by requesting a port number, which will be later also used as an id for the coordinator. To acquire a port number, coordinator will follow command set below:

Request: port=acemind
Response: {"port":1906}
In this example provided port number is 1906. Coordinator should open a TCP connection to this port number.
After connection is established, appliance will send the initial notification through new connection as below:
Message: {"newport": "Connection accepted."}

In case of a notification, the message will be the same as program info command:

Message: {

```
        "ElectricalSign":{
                "Duration": [99,12,25,94],
                "Power": [472,12,202,22],
                "MaxPower": [552,13,242,25]
                },
        "Cycle": 1,
        "CurrentCycleRemTime": 91,
        "InstantaneousPower": 403,
        "Interrupt": 1,
        "MaxDelay": 23,
        "State": 3
        }
```

6.2.6 Algorithm implementation

Firstly, the coordinator will retrieve the available Acemind appliances through mDNS request.

At this moment, the coordinator will also retrieve the static Data.

Then, when the user pushes the start button, the coordinator will be notified that the user wants to start its appliance.

If this is the first appliance, the coordinator will not be doing anything and the appliance will start normally. The coordinator will be notified frequently by the appliance off the power consumption and status (cycle's power consumption, remaining time, etc ...).

When the user pushes the start button of the second appliance, the coordinator will be notified. The coordinator will decide if it is needed to interrupt one of the appliances depending on total power consumption and power consumption threshold, cycle’s power consumption, etc ...

The different steps of this algorithm are described in Figure 19 and Figure 20.

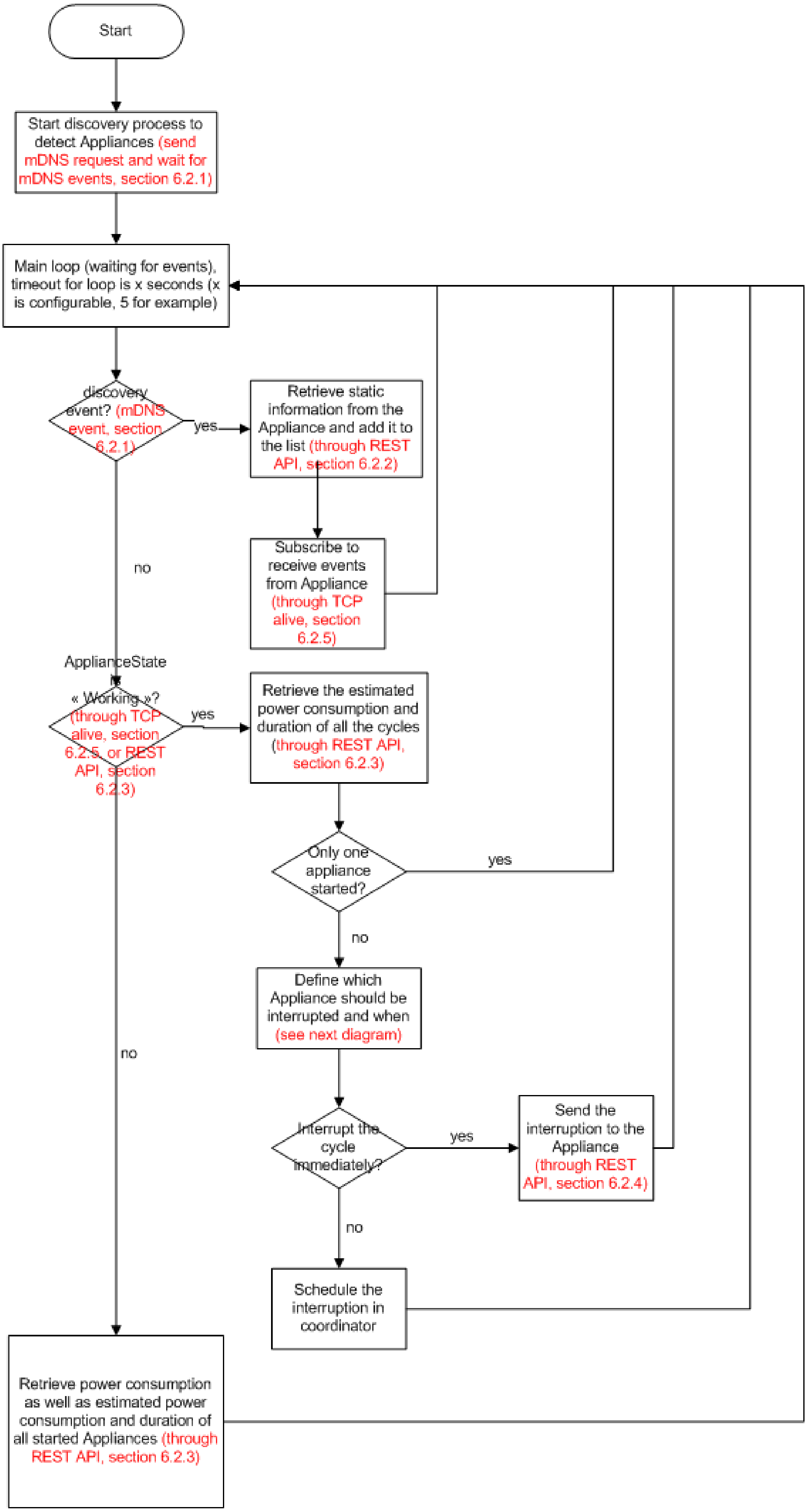


Figure 19: Algorithm implementation

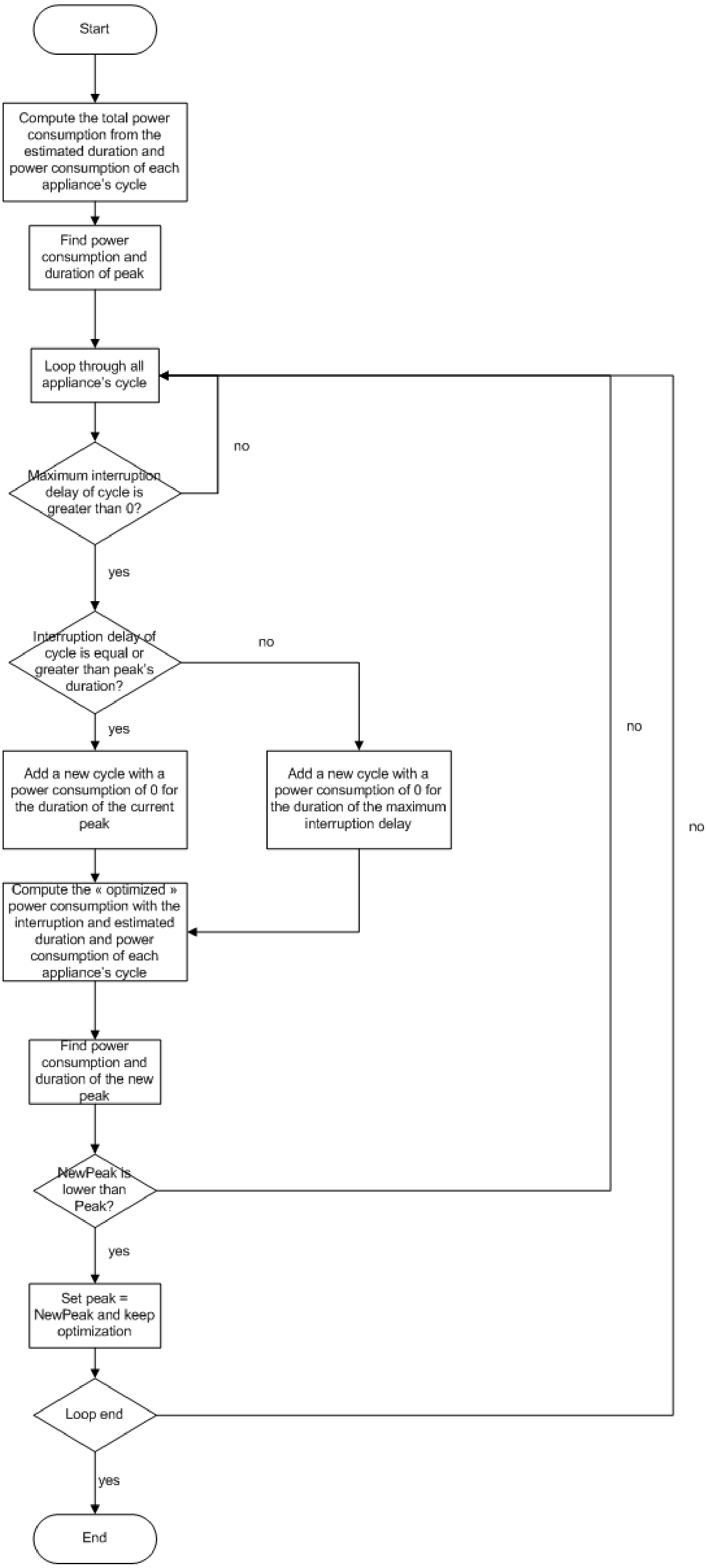


Figure 20: Algorithm implementation (part 2)

7 Demonstrator implementation

Two types of electrical consumers will be available: the Washing machine and the Dishwasher. Both devices are classified in Cb category.

The communication between the coordinator and the electrical consumers will be over Wi-Fi 2.4 GHz.

The demonstrator will not implement the management of the renewable resources.

The washing machine and dishwasher will be implemented by Arçelik and the coordinator will be implemented by Orange on a Linux machine in C, it could be provided to Arçelik inside a Virtual Machine. In a second step, Orange plan to put this implementation on a home gateway. The home gateway already embeds mDNS as well as a REST Web Server which could publish the information received from the appliances (such as power consumption, description ...) to the Acemind Dashboard on the LAN or WAN access.

8 Performance evaluation

8.1 Scenario 1: Consumption energy

In scenario 1, the Washer will be started manually by the user.

Then after sometime (for example 5 minutes), the user will try to start its Dishwasher. At this moment, the coordinator will try to find an optimisation to reduce the peak power consumption. The best optimisation will be used and so the Dishwasher will be interrupted during one of its cycle.

At any moment, the Acemind Dashboard will display information to the user (status of its devices, remaining duration time).

8.2 Scenario 2: Renewable energy

The demonstrator will not implement the management of the renewable resources.

9 Conclusion

In this deliverable, we presented the main parts of the GreenHome principle. In particular, this deliverable described in details why smart home grids are emerging and what the limitations of the current approaches were. Then, the deliverable describes the GreenHome proposal: the theoretical principle as well as the technical implementation.

In the next steps, we have to implement the first v1 of the demonstrator with two appliances: Washer and Dish Washer. And then, we could enhance this demonstrator by displaying the information retrieved by the GreenHome coordinator to the user through the Acemind Dashboard. A second option would be to add more devices to GreenHome demonstrator such as radiator or more resources such as batteries.

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