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The ENCOURAGE ICT architecture for heterogeneous smart grids

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Abstract

The ENCOURAGE project aims at rationalizing energy usage in building by implementing a smart energy grid based on intelligent scheduling of energy consuming appliances, renewable energy production, and inter-building energy trading. This paper presents the reference architecture proposed in the context of the ENCOURAGE project, and relates it with the goals of its research efforts.

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***Abstract*—The ENCOURAGE project aims at rationalizing energy usage in building by implementing a smart energy grid based on intelligent scheduling of energy consuming appliances, renewable energy production, and inter-building energy trading. This paper presents the reference architecture proposed in the context of the ENCOURAGE project, and relates it with the goals of its research efforts.**

Keywords-component; energy trading; appliance scheduling; monitoring

I. INTRODUCTION

Our society relies on energy for most of its activities. The ever increasing needs for energy, resulting from the industrialization of developing countries and from the limited scalability of the traditional technologies for energy production, raises both problems and opportunities. The problems are related to the devastating effects of the greenhouse gases produced by the burning of oil and gas for energy production, and from the dependence of whole countries on companies providing gas and oil. The opportunities are mostly technological: novel markets have opened for both energy production via renewable sources, and for innovations that can rationalize energy usage. An enticing research effort can be the mixing of these two aspects, by leveraging on ICT technologies to rationalize energy production, acquisition, and consumption. The final goal would be the creation of a smart electrical grid that implements a good trade-off between flexible user configurability and efficient unattended execution.

One application domain bearing a strong influence on the energy budget regards the energy consumption in residential and non-residential buildings. In fact, recent works [1][2] highlighted that over 80% of EU energy demand is due to activities taking places into cities, and the residential sector is accountable for 28% of the total electricity needs in Europe.

The ENCOURAGE project [3] aims to develop embedded intelligence and integration technologies that will directly optimize energy use in buildings and enable active participation in the future smart grid environment. The goal of the project is to achieve 20% of energy savings through: improved interoperability between various types of energy generation, consumption and storage devices; inter-building energy exchange; and systematic performance monitoring.

This paper proposes an architecture for ENCOURAGE. Its goals are to fulfill the needs of current and future large-scale Smart Grid applications. In fact, one of the common points of Smart Grid systems is related to its size and complexity: a Smart Grid usually serves a large number of users by providing them the energy they consume, adjusting its operations in real-time based on the needs of the users. This characteristic and the fact that each actor responds to an independent entity, end up in organizing Smart Grids using component-based architectures.

ENCOURAGE encompasses several components, organized in a hierarchical manner. The first level of decomposition of the system is articulated into logical blocks, which are “Devices Management”, “Middleware”, “Supervisory Control” (SC), and “Energy Brokerage and Business Intelligence” (EBBI). The Devices Management logical block is the interface to the Home Area Networks of the buildings. The SC and the EBBI logical blocks provide intelligence to the smart grid, by computing the politics that improve the performance of the electrical grid. The Middleware logical block binds together the other components. Each logical block is composed by modules, which in some cases are divided into submodules. The decomposition of the architecture will be further developed in the next section.

The hierarchical decomposition of the system is also reflected in the logical aggregation of the intelligent buildings. The sensors and actuators that are deployed into the intelligent buildings build up a Home Area Network (HAN), and are accessed via embedded system called “Gateways”. The HAN Gateways are reachable by the internet, and can interact with the HAN devices via custom protocols. Each apartment, building, house can be inhabited by multiple HAN Gateways, and ENCOURAGE divides them into logical “Cells”, which control consumption and production equipment within a living/working environment – e.g. one house, one building. A Cell is indivisible from the point of view of the user that manages/owns/lives and works in it. A number of Cells are grouped into logical “MacroCells”, which are Cells that can exchange energy, thus with a joint EBBI and SC functionality. A MacroCell can be viewed as a group of cooperating users.

The current trend for smart grids is to drive their development by the principles of interoperability, scalability, and creation of new market opportunities. The interoperability between the modules and with external entities/applications is entrusted to the abstraction created by mediating any interaction via interfaces. Moreover, ENCOURAGE's interfaces leverage on existing standards to ease their implementation. Scalability is provided by mediating communications via a Middleware layer, and supporting the logical blocks with a cloud-based infrastructure. Additionally, the middleware uses a publish/subscribe layer to allow for transparent implementation of distributed applications. Novel market opportunities can be created by the approach of ENCOURAGE since its services can be provided by any entity capable of offering the services envisaged by the SC and EBBI logical blocks. Multiple different gateways can be located in each home or building (e.g. one controlling energy production, one controlling home automation devices, and one controlling the energy production), which can then be logically aggregated in a single a Cell and exposed to the control applications.

This document defines the overall architecture of the ENCOURAGE platform, presenting the structure and functionalities of its components. Furthermore, it defines the main interface standards to be used for interoperability, together with the interconnection of the platform with the external environment. Finally, the document provides the mapping of the requirements of the system on the components that implement the underlying functionality.

II. RELATED ARCHITECTURES

In the last few years, a number of European initiatives have addressed the problem of defining an architecture for smart grids. The most prominent results that have enriched the state of the art are related to the European projects eDiana, ENERsip, and ADDRESS.

The main goal of the eDIANA (Embedded Systems for Energy Efficient Buildings) project [4] is to enable sustainable urban life through rationalization in the use of resources while increasing comfort in urban environments by means of embedded intelligence and integration technologies. The eDIANA approach is to prioritize energy consuming appliances to rationalize energy usage at given time and date, while adding more flexibility in the provision of resources and better situation awareness for the citizen and for service and infrastructure owners. At architectural level, eDiana introduced the concept of Cells and MacroCells, which ENCOURAGE adopt.

Like ENCOURAGE, the eDIANA Platform describes a number of logical devices and functions that can be physically implemented in a variety of forms. Nevertheless, contrary to eDIANA, ENCOURAGE only specifies the interfaces provided by the building gateways and the functions of the devices themselves, and leaves the implementations completely out of scope.

Building on the eDiana experience, ENCOURAGE allows multiple hooks to be provided for a single Cell or

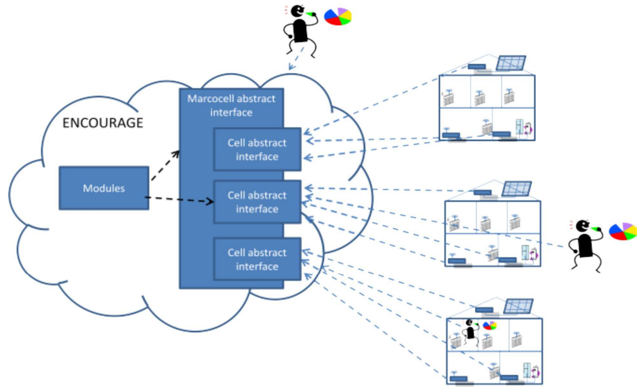

Figure 1 Example of Cells and MacroCells

MacroCell, being the ENCOURAGE platform capable of abstracting a single domain from the multiple hooks. Also, ENCOURAGE supports systems where Cells individually have a connection to the grid, thus holding a contract, whilst, if also arranged in a MacroCell, try to optimize in conjunction the local efficiency of energy.

The ENERsip (ENERgy Saving Information Platform for generation and consumption networks) project [5] goal is to optimize energy demand, by coordinating consumption and generation. ENERsip provides an integrated architecture for near real-time generation and consumption matching in residential and commercial buildings and neighbourhoods. This platform provides functionalities such as monitoring usage patterns, controlling energy generation, providing recommendations to users on how to optimize usage. It also integrates at neighbourhood level demand and generation, and provides mechanisms to integrate with other energy grids.

As ENERsip, ENCOURAGE addresses the same domains, although ENCOURAGE assumes the in-building domain to be abstracted through the gateways (end points in ENERsip terminology). Furthermore, ENCOURAGE addresses the simultaneous integration of Buildings in a higher-level domain of energy generation and consumption, but still allowing the local control and interaction. ENCOURAGE also specifies an M2M infrastructure, which allows to interoperate several different gateways, in multiple domains.

The ADDRESS (Active Distribution network with full integration of Demand and distributed energy RESourceS) project [6] main focus is on solutions to enable active demand exploitation.

ADDRESS has a dimension not present in ENCOURAGE, as it deals also with the operation of the distribution network which takes into account active demand services, and with the interaction with an aggregator who interfaces residential and small commercial users with the energy market [7]. The focus is more on the market operators side, who interacts in a peer to peer relationship with the user, whilst ENCOURAGE intends to allow local optimization of resources, through local energy trading, before interacting at a higher-level with the market and the Distribution System Operators (DSOs).

III. ARCHITECTURE OVERVIEW

Existing home automation and smart building infrastructures are usually constituted by separate automation systems (HVAC system, building/home automation, water/gas/energy metering), each reachable via a different HAN Gateway. Each of these systems usually has its own user interface and gateway. In the case of the ENCOURAGE system, all gateways (and HAN devices) pertaining to the same user are grouped into a Cell. The entry point to the Cell is the Cell Abstract Interface, which behaves as a logical aggregator, central to the ENCOURAGE architecture, and is responsible for allowing multiple gateways per Cell (thus leveraging legacy systems), and allowing other components to interact with a Cell as a single entity. Cooperating users are group into MacroCells. An example of the Cell/MacroCell aggregation is depicted in Figure 1, where a group of houses is logically joined together via the middleware layer. This aggregation allows for the execution of specific control policies, which allow these houses to cooperate on energy production and storage.

The success of ENCOURAGE in real deployments depends on a few factors that characterize the proposed architecture. These key factors are **Interoperability with present and future systems**, ensured by using international standards in the internals of the system and by interacting with existing custom technologies via Middleware Plugins (described later on in this section), **Scalability and QoS**, which rely on the usage of a cloud infrastructure that can grow elastically and assign QoS capabilities to connections as needs arise, and **Security**, ensured by a highly tested infrastructure based on VPN connecting HAN GW to the Middleware and the latter to the higher layer modules that take decisions to enhance the efficiency of energy usage.

ENCOURAGE encompasses several components that work together to create the necessary synergies for a functional and effective platform to empower smart grid applications. To reach this goal, the project designed an architecture that is depicted in Figure 2 and whose Logical Blocks are:

Device Management: it provides access to, and control of, devices – i.e. access and integration mechanisms for the various heterogeneous devices that either reside inside the building (HVAC equipment, sensors, actuators, meters / sub-meters, etc.) or located in the exterior spaces like the local generation and storage equipment;

Supervisory Control (SC): it implements strategies to orchestrate the operations of different subsystems in a Cell, like Heating, Ventilating, and Air Conditioning (HVAC) systems, lighting, renewable energy generation, thermal storage, taking into account that each subsystem potentially comprises a large number of embedded devices. The SC will schedule energy-consuming appliances in a Cell, taking into account the energy produced locally by the user. The SC will be focused either on supply side (local generation control), demand side (load management), or combination of both (energy management);

Energy Brokerage and Business Intelligence (EBBI): it supports inter-building energy exchange in the MacroCell, and decides when to "produce, store, buy, sell, use" energy. This brokerage agent communicates directly with other buildings and local producers to negotiate possible use of the electricity produced locally in their premises. The component develops adequate strategies involving short and long term decision, taking into account the historical consumption data and production forecast;

Middleware: represents an event processing system that takes the data from the building network and processes it as a stream of events. The middleware can be seen as being composed of multiple event processing agents that exchange information between event producers, event consumers, and other agents. This approach will not only handle simple events but it will also allow for inference of complex events by combining simple ones. The Middleware will be able to host various applications, such as the device diagnostics.

In terms of these higher-level logical blocks, Devices Management is identified with the execution elements, the Middleware is the communication layer, and SC and EBBI are the decision elements. Figure 2 provides insights on the deployment view of the architecture. The

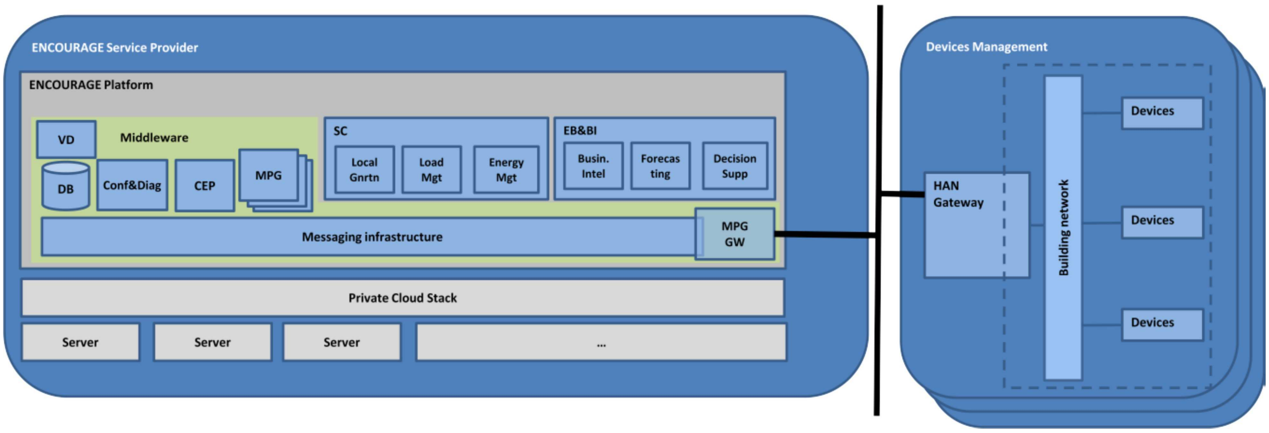

Figure 2 ENCOURAGE Architecture

ENCOURAGE Platform is composed by all the software components that are deployed over a Private Cloud Stack, and together with the cloud and with the physical servers providing computational power, it presents itself to the users as the ENCOURAGE Service Provider. Furthermore, the Private Cloud is intended to be extendable to make use of External Cloud Providers for scalability.

Beside the components in the ENCOURAGE Platform, ENCOURAGE encompasses also a set of interfaces to interact with sensors and actuators in the Home Area Network (HAN). These HAN devices are managed by HAN Gateways (HAN GWs) of different vendors. The communication between the HAN GWs and the ENCOURAGE Platform are mediated by ENCOURAGE Middleware Plugins (MPGs), and can be transported using different protocols. If they want to access the existing MPG, HAN GW manufacturers can add a module to their gateway that translates the home/building automation protocols of the HAN devices into the EACS (Energy Automation and Control System) protocol, originally developed in the Homeport project [8] and now adopted as a building block of ENCOURAGE. An alternative for the manufacturers is to implement a MPG for their custom protocol. In both cases, the MPG is in charge of translating the RESTful [9] communication from the HAN GWs into the native Publish/Subscribe protocol of the Middleware.

Next sections are devoted to illustrate the logical blocks of ENCOURAGE.

IV. Devices Management

This section discusses the ENCOURAGE architecture devoted to the management of the devices located on the HAN side. In particular, this section discusses the bus end-points that connect the HAN Gateways to the Messaging Infrastructure, the architectural functionalities that must be present on the HAN Gateway, the data storage subsystem that is deployed on the ENCOURAGE Service Provider to support device management. Apart to the module for "communication with HAN devices", this logical block contains the module "GW configuration services" that is used to configure HAN GWs and HAN devices, and the module for "virtual metering".

A. *Communication with HAN devices*

In order to shield the ENCOURAGE architecture from specific and custom/proprietary implementations in the HANs, and also to support the easy adaptation of existent solutions, ENCOURAGE only specifies the interface between the HAN gateway and the Middleware, and gives no suggestions on how the HAN is implemented. The module "communication with HAN devices" is used to provide support to gateways produced and deployed by a potentially large number of providers. It is composed by two different submodules, "HAN GW adapter" in the HAN gateway, and the "Middleware Plugin". Existing systems can interoperate with ENCOURAGE, by simply inserting a "HAN GW adapter" into their HAN GW, to be able to interface to the "Middleware Plugin", which is the entry point to the Middleware (Figure 2). Alternatively, manufacturers can implement a "Middleware Plugin" for the protocol already used in the HAN GW.

Regarding the message transport paradigm between the gateways and the ENCOURAGE Service Provider, standard protocols go in two different directions, by mediating communication via Request/Response or Publish/Subscribe paradigms, hence ENCOURAGE provides two different ways of interacting, one for each communication paradigm. The connection of the ENCOURAGE Service Provider to the HAN Gateways happens in a RESTful manner. The adapter on the Middleware side (the Plugin) is part of the Messaging Infrastructure, and it communicates via Publish/Subscribe and Request/Response with the rest of the ENCOURAGE system.

Regarding the encoding of the messages between the Plugin and the rest of the ENCOURAGE applications, the commitment to adhere to international standards led ENCOURAGE to adopt a protocol based on IEC61968 standard family. The messages adhere to the IEC standards and are then encoded into (compressed) XML stanzas, hence providing a trade-off between the interoperability of the system, and its efficiency.

B. *GW configuration services*

The module "GW configuration services" copes with the configuration of HAN devices, and the HAN GW. A database with configuration data is deployed on the ENCOURAGE Service Provider, to provide both fast access to the configuration, and redundancy and security features needed to ensure a reliable configuration of the devices.

The HAN Gateways can support a vast set of functionalities that range from providing consumption data for driving the generation and storage of energy in the HAN, to providing information on metering of individual sockets (even when not co-located with the meter). Depending on the architecture of the HAN Gateway, it can support different levels of intelligence and programmability, featuring computational power and data storage capabilities. The configuration database contains a set of HAN Gateway profiles, to be used to create ontology, and a standardized view, on the HAN Gateway functionalities, to ease their configuration.

C. *Virtual metering*

The "virtual metering" module provides non-intrusive load metering of HAN devices by using signal processing techniques. ENCOURAGE performs pattern matching between the measured power consumption, and a number of profiles corresponding to known consumption patterns. This operation needs a computational power that would be a too large burden for the HAN Gateway, and the comparison with a potentially large quantity of data (the consumption profiles), hence the techniques is based on transporting the data series related to the power consumption in the HAN to the ENCOURAGE Service Provider, and on the pattern matching performed there.

V. MIDDLEWARE

The Middleware is constituted by the modules "Messaging Infrastructure", "Virtual Devices", "Database", "Complex Event Processor", and "Configuration and Diagnostics" modules. The Middleware can also contain several "Middleware Plugin" submodules described in the section on "Devices Management". In the context of the Middleware, we will also provide details on the cloud infrastructure that supports the ENCOURAGE Service Provider.

The Messaging Infrastructure links the different ENCOURAGE components together, enabling the exchange of messages using different communication paradigms (e.g. request/response and publish/subscribe) and it provides the interconnection with the plugins that connects with entities external to the ENCOURAGE Service Provider.

Every time that an application wants to interact with a device, to read its status or to command it to actuate on the physical world, it interacts with an agent contained in the Virtual Device module. The Service Provider will then dispatch messages to the database to retrieve data that were already collected, or to the correct HAN GW to reach a HAN device.

The Database module (DB) contains the current status of the virtual representations of sensors and actuators of the system, and it also stores historical data of interest. The DB module works in close cooperation with the Virtual Device (VD) module that takes care of making available a representation of each device, Cell and MacroCell for the ENCOURAGE applications.

The Complex Event Processor (CEP) is a processing element that processes events in real-time and correlates them to compute "complex events" related to multiple data readings. These events can include actuation (e.g. switch off house lights).

The Configuration and Diagnostics module is responsible for the interaction with the configuration system used inside ENCOURAGE Cells.

A. Messaging Infrastructure

The Messaging Infrastructure module links all ENCOURAGE components, connecting the decision elements, part of EBBI and SC logical blocks, and the execution elements in the HAN, and with the other modules of the Middleware layer. The execution elements (mechanisms) collect data from the surrounding environment, and act on the environment to implement changes. The decision elements (politics) contain logic to perform computations based on the information received by the execution elements. After getting data from execution elements, and processing the data, the decision elements send commands back to the execution elements, to implement energy-efficient and business-efficient changes.

The Messaging Infrastructure reduces the complexity of inter-application communications since it works as a message bus, thus applications use only one communication protocol and are only required to maintain one connection with the message bus, instead of a connection per each application it is interacting with.

The Communication Infrastructure is capable of supporting both publish/subscribe and request/response communication paradigms. The request/response paradigm involves a client contacting a server to issue a request, and a server processing the request and sending back a response to the client. In a publish/subscribe system, publishers state the availability of information by defining an event on the Messaging Infrastructure, and afterwards they start sending event-related messages to the Messaging Infrastructure. When a receiver wishes to receive data related to an event, it subscribes to that event, with the effect of the Messaging Infrastructure relaying related notifications. This way publisher and subscriber do not need to know each other, decoupling both applications. This module also allows increasing the scalability of the overall system since it allows for parallel operation, message caching and improved message routing.

The ENCOURAGE Messaging Infrastructure can also be configured to filter events. In such cases, the event subscriber can configure the module in order to be only notified if a given rule is met. This functionality can be supported by the Messaging Infrastructure or by implementing it indirectly by configuring the Complex Event Processor module.

The Messaging Infrastructure is agnostic to the content of messages. Consequently, it is the responsibility of the applications to interpret the content of messages. Anyway, the messages have to adhere to the Common Information Model (CIM) standard family IEC 61968, which defines the format of data for information/commands exchange in an electrical system. Of particular interest is the IEC 61968-9 [10] standard which is a specialization of the CIM model for meter reading and control. The data encoding formats defined by IEC 61968-9 are structured upon complex and large XML messages. The coding and decoding operation of XML messages have high processing requirements and a large bandwidth is required for its transmission. Solutions, to the problem relay on using binary XML formats (e.g. EXI), which are able to compress the XML payload and at the same time have more reduced processing requirements.

B. Virtual Devices

The content of messages exchanged through the Messaging Infrastructure (MI) is not parsed or by any means interpreted by it. Therefore, the messages are only parsed by the applications when received. Anyway, the Middleware provides virtual device representations that can be targeted by messages. The virtual representations allow the devices to expose their internal status and to send data and receive commands.

The Virtual Devices (VD) module provides the abstract representation of Cells and MacroCells, allowing applications to abstract from the identity and structure of the device's HAN Gateway and the eventual multiple gateways per building.

C. Database

The Database module is used to store ENCOURAGE system information, such as historical data for devices. Another responsibility of the Database is to store the current status of devices, hence supporting the VD module. This data can be used by both the SC module, and to predict energy consumption and production.

Different kinds of data may be stored in the database, which potentially aggregates different physical databases, and each kind of data will have its own database connector, responsible for serving that information set. Data regarding user profiles and login credentials, configuration of the modules, and runtime data to pilot the decision making of EBBI and SC logical blocks may be stored and manipulated within the system.

D. Complex Event Processor

The Complex Event Processor (CEP) is an engine that is capable of detecting real-time, asynchronous, independent incoming events of different types, and correlating them into outgoing events, called "complex events". The key difference with other concepts such as Business Rules and Event Stream Processing is that the incoming events can be asynchronous and of different types. Another difference is that the CEP has temporal awareness.

The CEP Engine reads events from and writes Complex Events to a Data Source, processing them based on a complex event specification provided in the proprietary Dolce language. Data Source can be Internet sockets, the file system, databases and RESTful interfaces. The Format Adapter adapts the incoming event to the internal CEP format and converts Complex Events from the internal format to a desired output format.

As an example assume two events: i) Sensor 1 detects a raise in temperature in Room 1; ii) Sensor 2 detects smoke in Room 2. If we are trying to determine if there is a fire, two isolated events are not enough since they could have occurred separated by 1 hour. The CEP allows to setup a rule to filter these events when they occurred within 5 minutes, and to cross-check against more correlated events, like iii) Sensor 3 detects smoke in Room 1; iv) Sensor 4 detects a raise in temperature in Room 2.

The CEP can be configured by any ENCOURAGE application at runtime, in order to adapt to the scenario at hand. The CEP is able to rapidly detect and react to multiple events and, after detection, it creates one or more new events that can be delivered to the applications that configured the complex event, or even control in-house devices through the respective VD.

The CEP can be executed in a massive parallel and distributed environments, since, for example, it might be configured to react to events in 1000 houses to switch off the heating if the energy prices are too high, with a different price threshold in each Cell.

E. Configuration and Diagnostics

The Middleware contains a Configuration and Diagnostic module, composed by the "Configuration" submodule, and the "Diagnostic" submodule. The Configuration submodule is responsible for the configuration of the overall ENCOURAGE platform, including the middleware itself, the HAN gateways, the devices in the HANs, and the Middleware Plugins. This submodule also interacts with the DB module to store configuration data. The Diagnostic submodule allows to monitor the status of the different components of the ENCOURAGE platform.

At system start-up the Configuration submodule is responsible for the initialization of all ENCOURAGE modules as well as to setup parameters on the HAN Gateways.

F. Cloud Infrastructure

The cloud infrastructure of the ENCOURAGE Service Provider provides a flexible and extensible platform for the deployment of ENCOURAGE services and applications. This infrastructure is built on top of an existing open source Cloud infrastructure (OpenNebula) [11], and the infrastructure addresses technical integration and interoperability with different cloud systems through the use of Open Cloud Computing Interface and Open Virtualization Format standards.

The software needed to manage the cloud infrastructure can be split in 2 layers: the Service Management Layer and the Cloud Infrastructure Management Layer. The Service Management Layer includes all the software that manages the service lifecycle. It is in charge of deploying, undeploying and optimizing a service at runtime. The Cloud Infrastructure Management Layer is closer to the hardware and it is in charge of monitoring the physical infrastructure and VMs, to provision VMs when needed.

VI. SUPERVISORY CONTROL

The SC logical block is built upon three components called "Local Generation Control", "Energy Management" and "Load Management". The Local Generation Control module takes care of energy production by renewable located in its Cells. The Energy Management module is responsible, in cooperation with the EBBI logical block, for the execution of the energy brokerage plan. The Load Management module supports demand side management by controlling individual energy consuming devices/loads in real time. As such, the Local Generation Control and Load Management are placed at the Cell level, while the Energy Management is placed at the MacroCell level.

A way to optimize energy usage is to minimize the mismatch between the locally produced energy and the locally consumed energy e.g. by controlling the heating in the houses through controlling heat pumps and/or setting the set points for room temperature in each house.

A significant portion of the optimized variables will be indicators whether a specific piece of equipment should be running or not ("on/off"), such as the heat pumps mentioned before, whereas the other variables will allow adjustment of set points, typically for heating and air conditioning (temperature), ventilation (fan speed) and lighting systems (illumination level). The high level decision on the set points are taken in the SC, provided to the HAN GWs, and thereafter the GWs will take care of matching sensor readings with the set points to switch on/off the appliances, without relying on the ENCOURAGE Service Provider for micro-management of the actuators.

The next sections discuss the different modules that constitute the Supervisory Control block as well as the requirements and interaction with the Middleware block.

A. Local Generation Control

The Local Generation Control module manages the control of local energy generation sources (with a special emphasis on renewable sources) and local devices for energy storage.

The control of local energy generation encompasses algorithms that will reflect the expected operation – i.e. if the generation source can be shared by multiple consumers, or if it has just one owner who will determine the preferred mode of operation. Among the controlled local storage devices, there can be batteries, hydrogen based storage, and electric cars.

B. Load Management

The Load Management module is responsible for controlling the individual loads in such a way that the user comfort is not affected, and if possible even increased. Besides that, this module shall allow the Energy Management module to optimize the power consumption with respect to minimizing the power used and maximizing the consumption flexibility. The load control strategies assume the classification of the type of load (as critical, curtailable or reschedulable) and the execution of adequate control rules for each kind of load. Some of the rules can be implemented in the module itself, but other rules leverage the capabilities of the Complex Event Processing module.

C. Energy Management

The Energy Management module is responsible for the actual energy optimization in order to locally use, to the extent possible, energy produced locally. This module makes use of the functionalities provided by the Local Generation Control and the Load Management modules. It coordinates and dispatches the multiple generation, consumption, and storage devices connected to the local microgrid or to the building network.

This module can be hosted in a centralized supervisory controller, or it can run on a HAN Gateway. In fact, the Supervisory Control logical block and the Middleware are designed as distributed systems, hence the modules can be deployed on the same server, or hosted on different servers on the same platform or even on a Wide Area Network or partially in the HANs of the users. The communication between this Supervisory Control module and the Middleware is based on the soft real-time communication mechanisms of the Messaging Infrastructure module, meaning that the communication between the Middleware and the Supervisory Control should provide communication characterized by Quality of Service (QoS) with the granularity of one minute. If the system is not able to fulfill this QoS, then a notification is given to the user.

VII. Business Intelligence & Energy Brokerage

The EBBI logical block manages the participation of a Cell/MacroCell on energy brokerage, and on long term retrofits, equipment replacements and other capital investment actions. These functions are supported by the "Forecasting", "Decision Support" and "Business Intelligence" modules. The Forecasting module (FC) is in charge of predicting the quantity of energy that will be used and produced in a certain time frame based on historical data and real-time data (such as weather forecasts). The Decision Support for Energy Brokerage (EB) module is capable of taking informed decisions on exchanging energy between buildings that have overproduction and ones that have underproduction. The Business Intelligence module (BI) is in charge of delivering reports, KPIs and non-real time alerts to enable the analysis of the whole ENCOURAGE platform's operation.

This logical block depends on the Middleware plugins, which are responsible for the communication with external entities to obtain data relevant for the energy brokerage process or the energy forecasting, e.g. the utilities, the energy marketplaces, and the weather forecast service providers.

A. Forecasting

The Forecasting module (FC) produces forecast files for energy production and consumption, with forecast intervals of 15 minutes over a forecast period of 24 hours. The module consists of two submodules, Generation Forecasting (GFC) and Consumption Forecasting (CFC). The forecast information can be used by the Energy Brokerage module and the SC logical blocks, with possibly the CEP handling the data processing.

The GFC delivers a forecast of energy, using:

- Historical energy generation information, obtained from the Middleware Database;
- Meteorological data, obtained from a Middleware Plug-in towards the forecasting service provider;
- Master information with data about generation plants, like location, technology and power.

A generation forecast can be provided for each production facility of the Cell/MacroCell. For example, in the ENCOURAGE demonstrator in Jadevej [12], which consists of 8 houses with one solar panel each, a forecast for each of the panels (and/or a forecast for the whole 8 panels) can be provided.

The CFC delivers a prediction of the energy that will be consumed for the next 24h with 15 min precision, using:

- Meteorological data, obtained from a Middleware Plug-in towards the forecasting service provider;

- Historical disaggregated quarter-hour consumption;
- Master information with data about consumption points such as user profile, installed consumption power (disaggregated or not, washing machines, fridges…), and contracted power.

It is also possible to receive generation information from an external provider instead of providing ENCOURAGE-specific algorithms.

B. Decision Support for Energy Brokerage

The Decision Support for Energy Brokerage module (EB) is connected to the Forecasting module through the Messaging Infrastructure module; it receives as input data the generation forecast files generated in the Forecasting module, as well as utilities offers and market prices, through the adequate Middleware Plug-ins, which connect to utilities and market. EB module receives also the real-time consumption data and the storage state levels from the VD module. Additionally, the module needs information about current and future generation capacity, current status of the local electricity market and offers or requests coming from other buildings.

With all this information, this module will present to the user the strategies to be adopted: buy (from its neighbour, from the market), sell, store, activate consumption, stop consumption, etc. The strategy will be accepted by the user and provided to the SC, which will implement the necessary actions to abide to the strategy.

C. Business Intelligence

This module uses a dedicated database (data warehouse) that contains aggregated data useful for Business Intelligence (BI) analysis. A Middleware Plug-in will therefore store and retrieve the data of interest on the DB.

The module uses data on historical consumption, consumption breakdown, real-time consumption, historical production, current production, utilities/market prices, generation and consumption forecasting, and data from Supervisory Control. The BI module generates reports, KPIs and alerts addressed to the user or the energy manager of the Cells/MacroCells. These outputs will help the energy manager/user to analyse the energy behavior of each device, Cell and MacroCell and determine:

- if the energy behavior stays between established limits;
- if the decision support for energy brokerage is working properly;
- what are the main tendencies of consumption, production, processing events, etc.

There will be economic reports, Supervisory Control actions and alarm reports, energy efficiency objectives performance and consumption reports. All analyses will be performed at non-real time level (short, mid or long term analyses).

VIII. CONCLUSIONS

The paper presented the reference architecture of the ENCOURAGE research project, which aims at developing a smart grid that rationalizes the use of energy in residential and non-residential environments. The work described the differences between the delineated approach and different research projects that are currently active in Europe, thus providing both background to ENCOURAGE, and proving its benefits in pushing forward the state-of-the-art.

Ongoing work aims now at implementing the proposed system, and at measuring the impact of the proposed mechanisms for energy saving.

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