Consiglio Nazionale delle Ricerche
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Rapporto Tecnico N.:
RT-ICAR-PA-10-03

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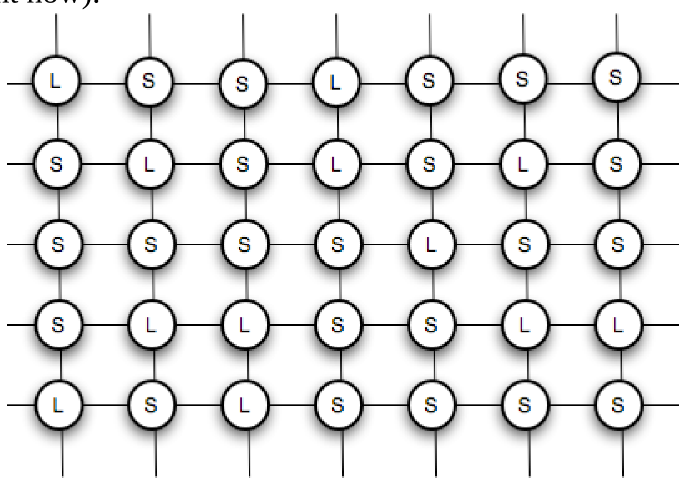
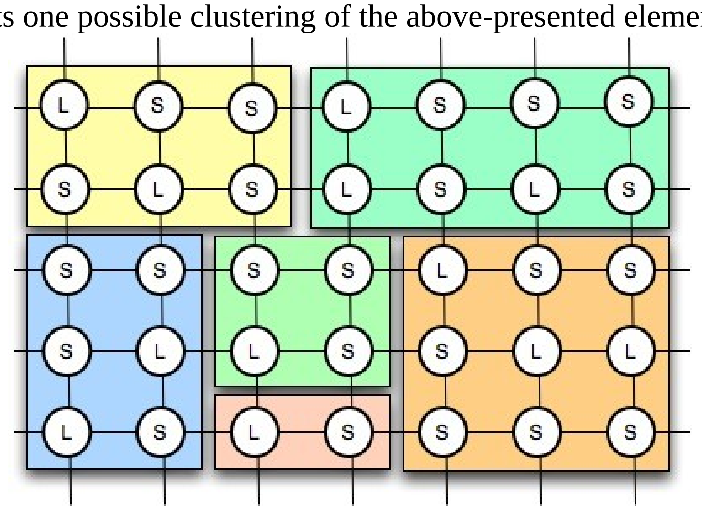
From Micro-Networks to Social Networks

We propose the adoption of a hierarchical decomposition of the problem. First of all we will represent the overall system (including all sources and loads composing a large network); then we will decompose it in a series of sub-systems (called micro-networks, also addressed as cells hence after). After that, we will study the details of these micro-networks (represented by agent societies in our approach) and, finally, we will have this cells interact in order to exchange their excess of power or require power from the others.

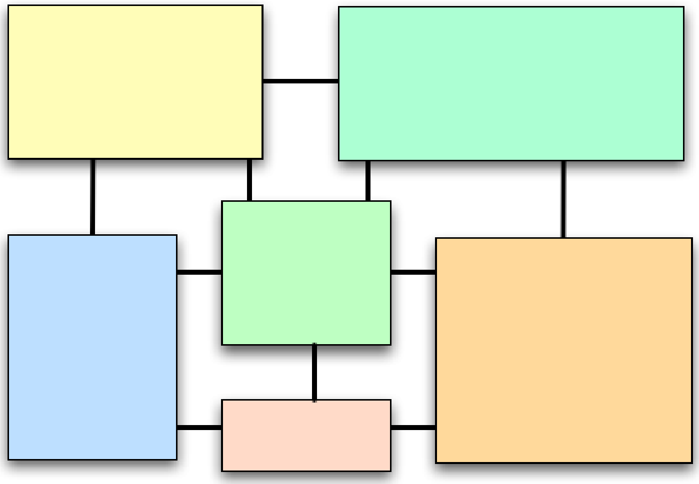
Suppose we have this system, it is composed of several sources and loads of different kinds (this difference is not relevant now).



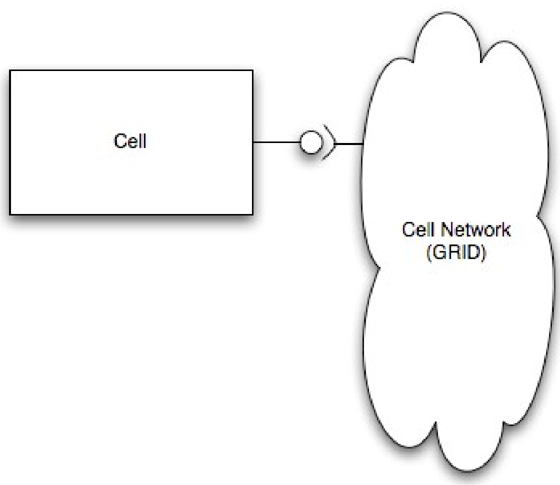
In our approach, we divide that system in subsystems (micro-networks or cells), each one containing an arbitrary number of power sources and loads.
Figure below represents one possible clustering of the above-presented elements in cells.



For the purpose of our work, we simplify the relationships among neighbour cells as we represented in the figure below. In this figure we can see each cell as a partially autonomous micro-network that has only one link with each other cell of the neighbourhood.



By moving the viewpoint from the overall picture to the situation of one single micro-network, we can represent that as in next figure. This corresponds to study a system composed of one cell and a grid. The grid represents the sum of the interactions that each cell has with all the others. The grid is (by now) supposed to be capable of providing or receiving energy to/from the cell according to its needs without limits in the amount of this energy.



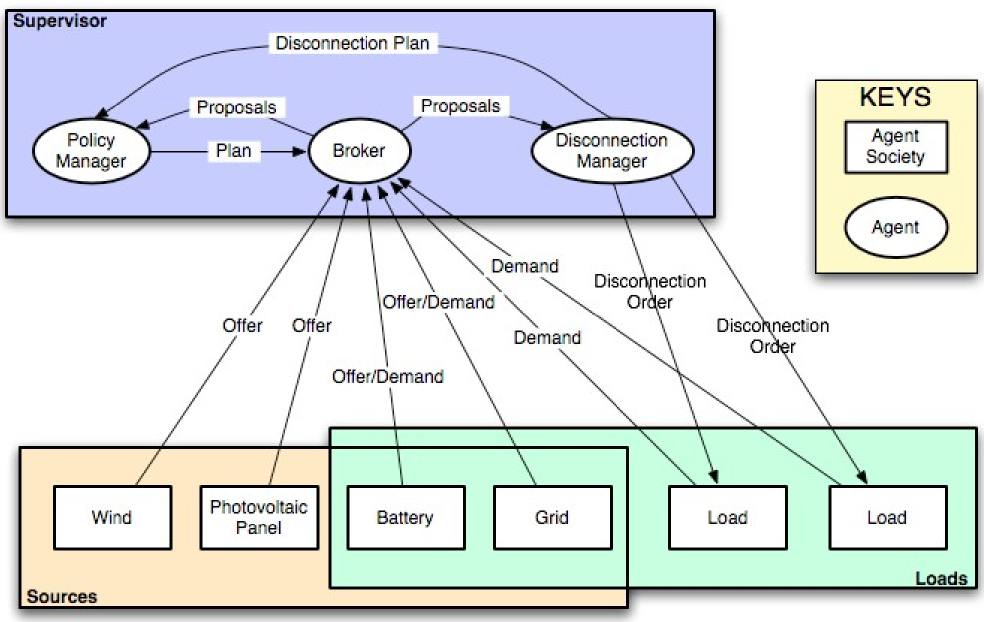
In the following, we suppose the cell is composed of:

- One Wind plant
- One Photovoltaic panel
- One Storage plant (labelled battery)
- One Grid (as already said, it represents all the interactions of the cell with neighbour cells).
- Two Loads (each one, for instance, representing a different load type like residential or industrial or using a different approach, each one can model a geographical area).

It is worth noting that in our approach we do consider different geographic positions of the involved cell elements. As a consequence if two wind plants are part of the cell, they are likely different and, also, we expect to have at the same time a different production of energy from them because of different weather conditions.

This configuration is sufficiently simple to be discussed in this paper; it allows the realization of a realistic model and at the meanwhile the number of elements remains limited to an easily observable set.

From the software architecture point of view, each cell can be regarded as composed of a society of agents. This society is in turn composed of local sub-societies (each sub-society can be a society of agents itself), each one modelling one of the main elements of the cell with the adjunction of a Supervising society.
The Supervising society is responsible for ensuring a strategic supervision of the energy flow in the cell. It can include an expert system in order to minimize the cost, forecast future needs, optimise the response to high-demand situations as well as to face critical situations demanding exceptional decisions like loads disconnection or sudden sources failures.
The local management of power flow inside each cell element (source/load) is left to single societies responsible for the cell element itself. These societies are self-interested (this means they aim to pursue some private objectives) but also collaborative (this means they will accept requests coming from the remaining part of the cell if not in contrast with their own goals).



In the above reported figure we can see three main agent societies:
Loads: it includes external loads (residential, industrial, …), Grid, Battery. The latter two belong to this society when they ask for power.
Sources: it includes all sources (Wind panels, Photovoltaic panels, battery, grid). Grid and Battery belong to this society when they produce power.
Supervisor: It is the society where demands and offers of power are satisfied by adopting a general strategy based on physical, ecological, economical constraints and the demand forecast.

Details of each element will be deepened in the following.

Supervisor Society

This society is composed of three agents: Broker, Policy Manager, and Disconnection Manager.

- **Broker**: It is an agent responsible for the brokerage between energy consumers and suppliers. It receives power offers and demands by all the elements of the cell and it is responsible for immediately verifying the possibility of satisfying the demand of power.
  This corresponds to verifying the following equation:

  (ALL POWER OFFERS)>=(ALL POWER DEMANDS)

  The Supervisor Society has to provide an immediate response if this equation is not positively satisfied (this is a responsibility of the Disconnection Manager agent). Conversely, if the equation is satisfied, the Policy Manager agent is notified of the power demands and offers and it prepares a plan according to its solution strategy. The Broker is responsible for verifying the equation and immediately notify the Policy Manager or the Disconnection Manager according to the result.

- **Policy Manager**: it is an 'intelligent agent', that can include an expert system. This agent decides: (i) how much power should be provided by each source; (ii) if a battery should recharge (by buying energy) or discharge (by providing energy); (iii) if the grid is going to sell or buy energy to/from the cell. In the actual implementation of the decision process, the agent includes a rule system that o ptimises energy flow in terms of cost. The lowest cost energy produced by sources is used to feed loads. When a surplus of energy is available (more energy produced than required by loads in the cell), this energy is sold to the grid (usually at a very low price). When the energy produced in the cell is not sufficient for feeding loads, then energy is bought from the grid (usually at an high price). The difference between the prices of energy bought and sold from the grid is one of the parameters considered by the Policy Manager. It tries to store the energy in the cell (using batteries) instead of selling it to the grid when possible. Besides, the Policy Manager tries to use energy from batteries when possible instead of buying it from the grid (in the hypothesis that batteries have been recharged by using low-cost renewable energy). There is one significant exception to this general behaviour: the necessity of recharging batteries in time to face forecast peeks of the demand motivates the batteries themselves to not offer energy in some hours while requiring to buy it. The Policy Manager will enable the necessary battery recharging by assigning to them the required energy alto to the maximum cost (from the grid) when necessary.
- **Disconnection Manager**. It is responsible for applying the established disconnection plan of loads or adapting it as a consequence of unforeseen events. In this way the cell protects itself from overloading or damages occurring in some crucial source. It is worth to note that the proposed architecture, spontaneously responds to blackouts propagations since it gives priority to the independence of the cell and it asks for power or provides power to the remaining part of the network (the grid) only if necessary/available.

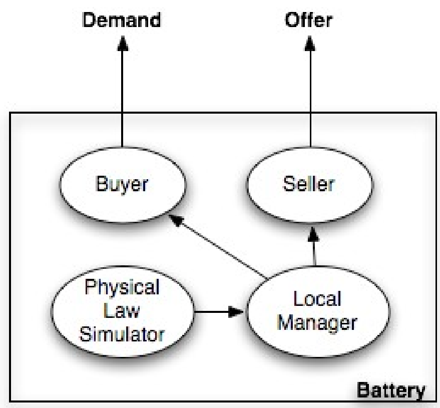
Sources society

Sources Society is composed by all cell elements that can generate power. Each of these elements is a society of agents too. Since some elements can sometime generate and other times consume power, these elements are both members of the Sources and Loads societies. When an elements provides power it plays the role of *Producer* in the Source society. When an element buys power, plays the role of *Consumer* in the Loads society.
Typical members of a Sources society belong to renewable sources, batteries (while

providing power), and the grid.
The most complex (and complete in structure) element of this society is the Battery society. For this reason it will be described at first and then the others will be discussed by reporting the differences they have from the battery.

Battery Society

The Battery society is composed of the following agents (see figure):



- **Buyer**: it is responsible for contracting the buy of energy for charging the battery. It dialogues with the Broker agent (Supervising society). When buying power, the Battery plays the role of *Consumer* in the Loads society. The energy is bought at a price that depends on the seller source (this is communicated to the Buyer agent by the Broker agent). The Buyer agent sends a Demand message to the Broker in order to notify it of its will to buy power (it also specifies the amount of power it needs) and it receives the specification of the assigned power (equal or less to the required one) and the corresponding price. We suppose that the implementation of the agent will use a contract-net protocol for interacting with the Broker agent (that starts the call for proposal phase by asking to all sources and loads of manifesting their will). It is worth noting that it is a responsibility of the Broker agent communicating the lowest cost seller to the Buyer according to the plan conceived by the Policy Manager agent.
- **Seller:** it is responsible for selling the produced energy. In this case the Battery is playing the role of Producer. It dialogues with the Broker agent in order to sell its energy. We adopted the hypothesis that renewable source energy can always be sold (at least to the grid) and that a renewable source has to never limit its production in order to obey to external constraints. There are two kinds of price policies in our system: fixed (photovoltaic and wind panels), variable (price according to several different parameters, for batteries, grid). The price is calculated by the Local Manager as the average sum of the buying cost of the sold energy.
- **Physical Law Simulator**: it is responsible of simulating the battery physical model. It updates parameters related to the battery lifecycles and calculates the available power according to the below reported formulas.
Physical state of the battery is characterized by the following parameters:
  - EN: Nominal Energy of the battery (usually expressed in kWh)
  - Life-cycle: a cycle of charge and discharge of the battery down to the 10% of its nominal energy. The producer of each battery declares the maximum number of life-cycles for it. After that number, performance of the battery becomes worse. If discharge goes below 10%, the number of residual cycles

and the life of the battery are affected.

- Number of Equivalent Life-cycles: if the battery performs a minimum charge-discharges cycle from 90% to 10% of its nominal energy, we consider that as an equivalent life-cycle. The number of equivalent life-cycles just count the performed cycles.
- nlc: Nominal Life-cycles. This parameter is declared by the battery producer and represents the battery length of life.
- Daily discharge %: the minimum level of battery charge during a day

Physical simulation of the battery includes the possibility of setting up (by using a graphical interface) the following parameters:

- nlc
- life-cycles already performed by the battery at simulation start-up (for studying the degradation of batteries behaviours with usage and its effect on the system)
- EN
- Charge level (%)

Battery efficiency η is calculated according to the following formulas:

IF [illegible] **THEN**

[illegible]

ELSE

IF [illegible] **THEN**

[illegible]

ELSE

[illegible]

Where E= energy exchanged during the time-slot.

Constraints on battery behaviour

- In order to avoid stressing the battery and reducing its life, we also suppose to let it supply only up to 10% of its maximum energy per hour.
- The battery cannot discharge to less than the 10% of its EN.

- **Local Manager**: It is responsible for the local policy to be adopted. The local policy is aimed at ensuring the best performance of the battery (egoistic behaviour) and at the meanwhile collaborating with the whole cell by ensuring a proper recharge before facing a forecast high demand of power from loads. It asks to Seller or Buyer to start the selling/buying activity when necessary.

At each time slot, this agent will compute both a maximum exchangeable (MEE) and a suggested exchangeable (SEE) amount of energy. SEE is normally the 10% of battery capacity per hour (eventually proportionally less if the time slot is shorter than 1 hour).

This agent calculates the price used for selling power. This is the result of a weighted average of the buying cost of the stored energy. It also considers the losses caused by the battery efficiency. The formulas used for calculating the price are:

Daily work cost = ((total cost of battery)/(number of equivalent life-cycles))+(daily cost of energy lost in losses)

We assume that :

Total cost of battery = 150€/kWh

Number of equivalent life-cycles = $nlc - \frac{\frac{nlc}{2}}{60}(daily\_discharge\% - 10)$

Wind Plant Society

The configuration of this society is very similar to the one represented for the battery but the Buyer agent is not present. Moreover the Physical Law Simulator agent observes the laws of a wind panel.

Local Manager agent. The behaviour is quite simple since it always propose to sell all the produced power.

Physical Law Simulator (PLS) agent. It calculates the produced energy on the basis of wind speed. In the implementation, we suppose that the plant has a nominal power of 10kW. The adopted formula is: P[Watt] = αV^3 with α=80 for a 10kW nominal power source plant. The selling price for energy is: 0,07 €/kWh.

Photovoltaic Panels Society

The structure is very similar to that of wind plants. There is no buyer agent since this source has no load capability (no storage device in it).

Physical Law Simulator (PLS) agent. It calculates the produced energy on the basis of sun radiation with a linear law. For a plant with a nominal power of 10kW, the formula is:

$P = \beta \bullet G$

where G is sun radiation and β=10,5 for a 10kW nominal power source plant.

Grid Society

The buyer and seller agents compose it. They always ask to sell and buy an almost infinite amount of power (several magnitude orders greater than power managed within the cell) at a fixed, time-depending price.

Loads society

Loads society is composed of cell elements that consume power. They can be actual loads as well as rechargeable elements.

Load Society

Each load is composed of only two agents: the buyer agent and the physical law simulator agent. This latter is in this specific implementation responsible for randomly selecting the data set belonging to one day from the historical repository and adopt that for simulating the behaviour of the load in the current date.

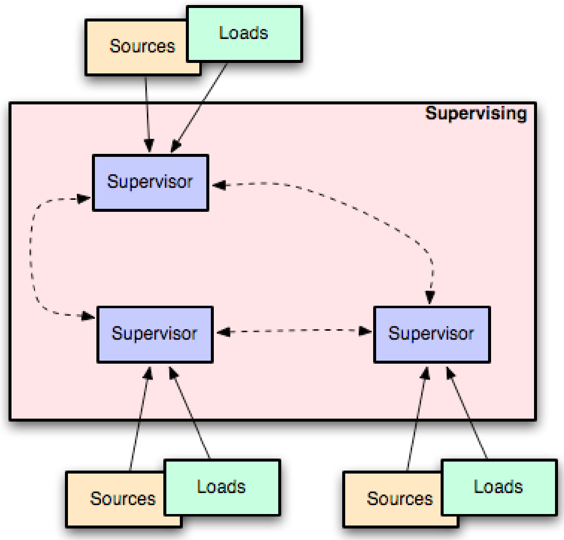
Extension of the proposed approach

Each Supervisor society is in contact with similar societies of neighbour cells and cooperation can happen among them.

This cooperation is a peer-to-peer activity that does not have a centralized decision locus since this would introduce a bottleneck in case of huge systems thus limiting the scalability of the approach.

As a consequence of this cooperation, one cell can warn the others that a high demand of power is forecast for the next few hours and them will prepare themselves to support this demand by adopting proper storage policies.

Figure below depicts the cooperation scenario among three neighbour cells.

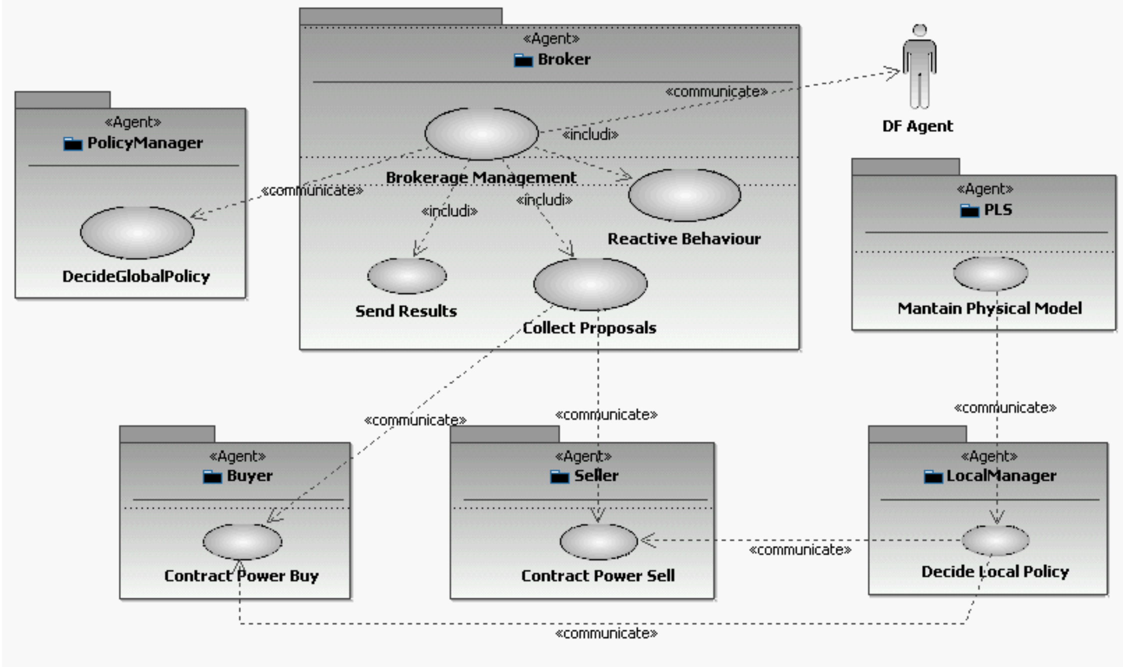


Some Design Details

The design has been performed by adopting the PASSI2 methodology (an extension of classical PASSI).

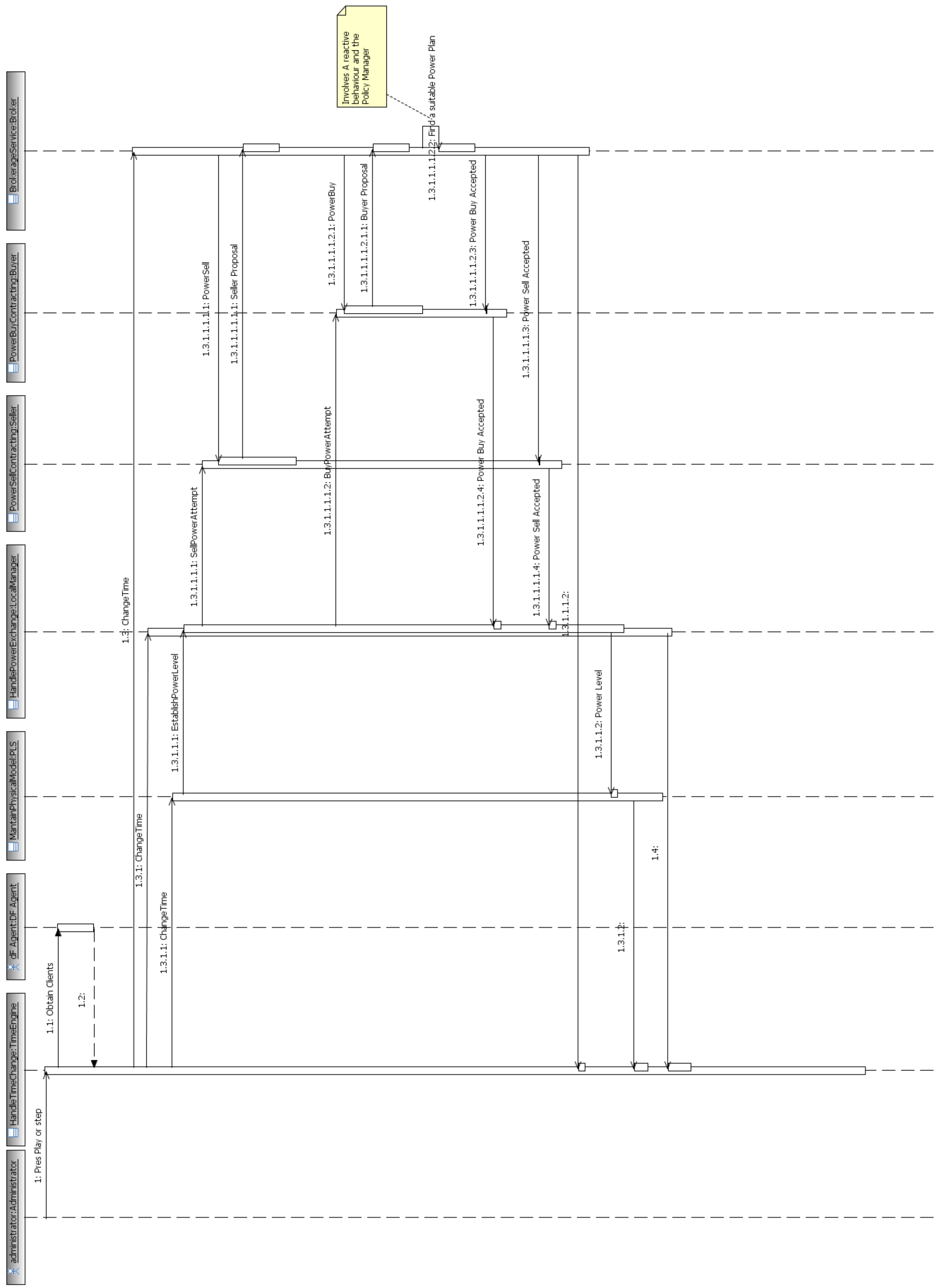
Below the PASSI Agent Identification diagram is reported. It is used to identify the set of agents that will be used to solve the problem and their responsibilities in terms of requirements to be accomplished. In the diagram, that is an adapted UML Use-case diagram, agents are represented by packages, while ovals represent requirements (use cases) and relationships between use cases belonging to different agents are represented by communication relationships.

This diagram represents from a requirements point of view the situation already described before.



In the next diagram (a sequence diagram designed as a part of the PASSI Role Identification phase) we report messages exchanged by agent roles in a typical usage scenario of the proposed simulation tool.

In this scenario agent roles contract the amount of energy to be sold/bought by each single cell.



administrator:Administrator
HandleTimeChange:TimeEngine
dF Agent:DF Agent
MantainPhysicalModel:PLS
HandlePowerExchange:LocalManager
PowerSellContracting:Seller
PowerBuyContracting:Buyer
BrokerageService:Broker
Involves A reactive behaviour and the Policy Manager
1: Pres Play or step
1.1: Obtain Clients
1.2:
1.3: ChangeTime
1.3.1: ChangeTime
1.3.1.1: ChangeTime
1.3.1.1.1: EstablishPowerLevel
1.3.1.1.1.1: SellPowerAttempt
1.3.1.1.1.1.1: PowerSell
1.3.1.1.1.1.1.1: Seller Proposal
1.3.1.1.1.1.2: BuyPowerAttempt
1.3.1.1.1.1.2.1: PowerBuy
1.3.1.1.1.1.2.1.1: Buyer Proposal
1.3.1.1.1.1.2.2: Find a suitable Power Plan
1.3.1.1.1.1.2.3: Power Buy Accepted
1.3.1.1.1.1.2.4: Power Buy Accepted
1.3.1.1.1.1.3: Power Sell Accepted
1.3.1.1.1.1.4: Power Sell Accepted
1.3.1.1.1.2:
1.3.1.1.2: Power Level
1.3.1.2:
1.4:

Acknowledgements

I would like to thank M. Cirrincione (UTBM), S. Gaglio (University of Palermo), M. Pucci (ISSIA-CNR) and G. Vitale (ISSIA-CNR) for their fundamental contributions in the definition of this approach.
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