Project acronym: **DATAZERO**

Project full title: **DATAcenter with Zero Emission and Robust management using renewable energies**

D4.1: Model of the optimization problem of data centers. Cartography of the optimization tools

Version: 1.0

Date: 30/04/2017

Deliverable Number:	D4.1
Contractual Date of Delivery:	30/04/2017
Actual Date of Delivery:	
Title of Deliverable:	Definition of metrics and scenarios on which experiments will be based.
Dissemination Level:	Public
WP contributing to the Deliverable:	WP 4
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History			
Version	Date	Authors	Comments
0.1	17/10/2016	C. Varnier (ENSMM)	Version initiale
0.2	octobre 2016	P. Stolf, A. Sayah, P. Renaud-Goud, G. Da Costa	Description of some IT optimization problem
0.3		C Varnier, M Haddad, JM Nicod, L Philippe, V Sonigo, P Stolf, A Sayah, JM Pierson	Mathematical formulation of the optimization problem of scenario 2
0.4	06/03/2017	C Varnier, M Haddad, JM Nicod	Introduction, english translation
0.5	10/03/2017	P. Stolf, JM. Pierson	Added and updates of mathematical description for scenario 4 / IT part
0.6	14/03/2017	S. Caux	Added optimization problem formulation for power split
0.7	20/03/2017	C. Varnier	Document restructuration
0.8	27/04/2017	P. Stolf	Final reading and references
1.0	30/04/2017	J.M. Nicod, C. Varnier	Final version

Abstract
Responsible partner: FEMTO-ST **Participating partners**: UPS-IRIT, INPT-LAPLACE, EATON **Description**: This document presents all optimization problems that have to be considered in the DATAZERO project. Problems are: IT task scheduling, energy units commitment and sizing problems. For each one, a tentative macro-model is presented. An overview of optimization methods that are candidates for DATAZERO is also proposed.

Keywords
IT Scheduling problem, energy unit commitment, optimization model, optimization method

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Preamble

In the DATAZERO project several scientific communities (computer science, energy and automation) are working together. Due to this heterogeneity, scientific terms do not correspond exactly to the same meaning. Therefore, we propose here some common definitions that we use in the present document.

Optimization algorithm: algorithm that gives the best possible solution of a problem according to one or several criteria, e.g. minimize the energy waste when scheduling a set of tasks. An optimal algorithm has to be formally proven. On the other hand optimization techniques may also provide sub-optimal solutions: these solutions are guaranteed to be around the optimal solution in the case of approximation algorithms or are expected to provide empirically good results in the case of heuristics.

Scheduler: function that gives at least, for each task of a set of tasks, its start date and the allocated resource(s).

Control (static converter control): while the term control itself is very general, in the context of this project, it only refers to the control of the static power electronics converter attached to each energy unit. For example, the DC/DC converter attached to the battery receives as an input the current setpoint (i.e., how much current should flow in or out of the battery), and converts that into a PWM signal that will effect this command. The timescale of this scheme is in the millisecond range. It does not include optimal decision-making, although the parameters of the control can be optimized offline.

Dispatching (power split): this algorithm is in charge of defining, in real-time and at the second timescale, the current setpoint of each component in the power system. For example, assuming the datacenter load is 10 kW, it may decide to use 5 kW from the PV panels, 2 from the battery, and 3 from the fuel cell. It is usually not optimal, in that economic criteria are not considered. Its main goal is to ensure the electrical stability and security of the system. It is also essential in absorbing and mitigating the impact of forecasting errors. The algorithm itself does not use any prediction, and is thus purely reactive.

Energy unit commitment (scheduling): this algorithm is in charge of defining, periodically and at the day/week timescale, the power output of each component in the power system. Based on forecasts of the load, it defines how each component will be used over the selected horizon. The resulting schedule is especially useful for determining the best way to use storage units. It is usually the result of a rolling-horizon optimization, in that economic and technical criteria are considered. Its main goal is to ensure the electrical stability and security of the system.

Sizing (dimensioning): this algorithm is used to select the optimal characteristics of the components in the datacenter. For the power system, the outputs include the necessary power of each energy source and storage unit, as well as the storage capacity of storage units. For the IT part, the type and the number of servers and devices to use are elaborated. A necessary input is the forecasted IT workload to be served, while constraints can include spatial constraints, for example. The outputs can then be used to determine the adequate number of individual elements and their connection topology for a given product.

Energy source: a physical component that converts a primary energy source (e.g., solar radiation or wind) into electricity. Examples include PV panels and wind turbines.

Energy storage unit: a physical component that stores electric energy under a given form (electrochemical for batteries, chemical for hydrogen, mechanical for flywheels), and can be charged or discharged.

Energy units: energy sources and storage units

Introduction

Task description: "*the system modeling will provide a mathematical formulation of the multidimensional problem, deriving constraints on the placement of tasks on machines and constraints on electrical operation along time. The optimization objectives will be derived from the interesting metrics given from WP5 (T5.1). The modeling will concern the two problems described in the objective of this WP4: operating a given infrastructure with a given workload, and dimensioning an infrastructure for handling a given workload. A study will be conducted for analyzing the different optimization techniques and compare them for solving the problem, and a cartography produced.*
This cartography will include algorithms searching for exact solutions, in particular integer linear program (ILP) and mixed ILP. Even if the problems are NP-Complete, a modelization using such operational research approach can be useful. A resolution of the ILP for small problem instances using solvers helps comparing heuristics solutions to optimal ones on these instances. Moreover, a relaxation of the ILP is an option to find a first valid solution (a bound to the optimal) that has to be improve on the second step using for instance meta-heuristics methods (b-level resolution).
Besides, heuristics and metaheuristics will compose this cartography, in particular approaches based on genetic algorithms, fuzzy logic, simulated annealing. A specific interest is considered in this study for approaches capable of high dynamic behavior and robustness in case of uncertainty of the state of the system. For instance, the strong resilience of evolutionary algorithms when applied to real-world problems while still providing a sound theoretical background can be an advantage."

DATAZERO has to address several challenges described in the project proposal. In challenges 1 (make demand and envelope constraints coincide on electrical and IT planes), 2 (dimensioning the equipment), 4 (scheduling IT load and IT management) and 6 (optimization problem complexity) the optimization is a central problem.

Before studying optimization algorithms that will be helpful for the datacenter case, it seems to be interesting to develop more formally the optimization problems that should be solved to reach the main objective of the global DATAZERO project.

Optimization problems

DATAZERO embeds several optimization problems. Indeed, as shown in the figure 1 representing a schematic view of the DATAZERO middleware, the IT and Power decision modules are the main places where optimization is necessary. On the first hand, in IT decision module (ITDM), one has to deal with the allocation of the IT resources considering the available power while satisfying the required quality of service. On the other hand, in Power decision module (PDM), the required power should be produced using the available energy sources, while considering the forecasting demands.

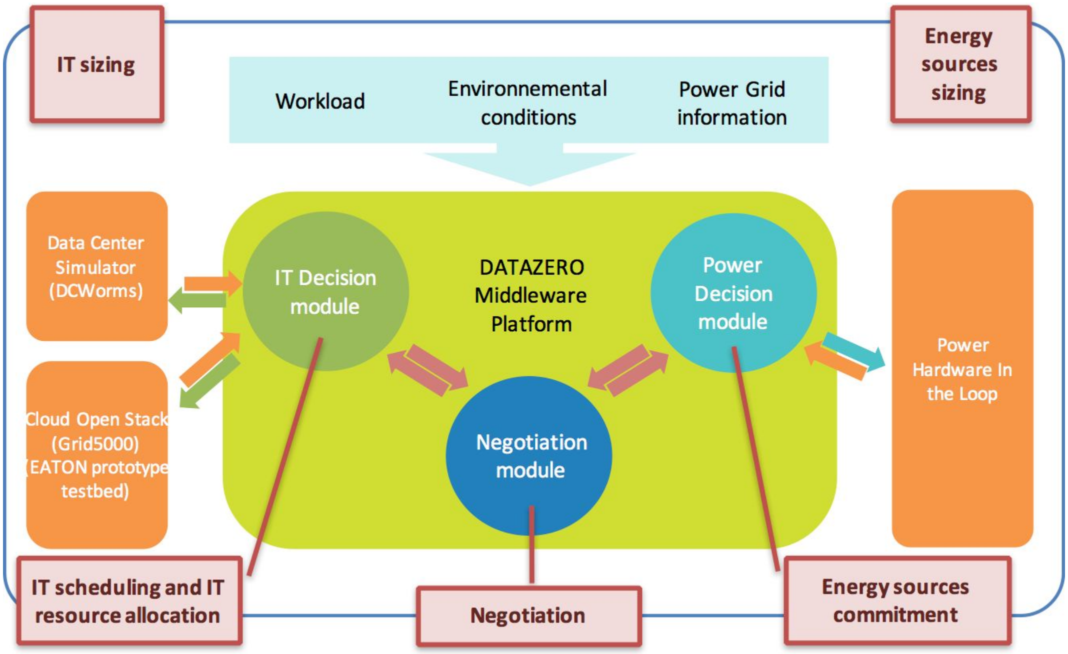


Figure 1: optimization problems in DATAZERO

Regarding both optimization problems that will take place in the ITDM and in the PDM, the timeline can play either a core role or a side role. In the *offline* problems, all data inputs are supposed to be known beforehand and the algorithm decides for a static energy commitment or for a static schedule at the current time (problem solved before the appliance and the solution is then 'played'). In the *online* problems, decisions are taken over time, relatively to events that occur sporadically. One only knows the past events, an 'instantaneous' decision is requested in a short time, e.g., migration of tasks when new unexpected tasks arrive, usage of stored energy since a cloud darkened the sky, etc.

Online problems are more dynamic ones. Several approaches are possible:

- A pure reactive approach that takes a decision at each new event (arrival of a task, passage of a cloud, etc.) and which, starting from the current situation, proposes a solution that can be optimal locally and in a very short time;
- A time window approach within which all is predicted/estimated and an optimization with optimal search (if possible) is made. The period is defined. It is a static problem by fragment. The size of the window and the resolution time available are the parameters of the problem, in particular for fixing the choice of the optimization method;
- Periodic semi-static approach with the search for a solution taking into account all that can be known at the moment of the decision, and then questioning this solution periodically according to the variations of the current situation.

DATAZERO addresses also, in its challenge 2, another kind of optimization problem, namely the infrastructure dimensioning. Both IT infrastructure and electrical infrastructure can be defined by solving an optimization problem.

Consequently, various decision problems have to be solved. In the following we propose to detail these problems. Each of them is described by several characteristics:

- Inputs: known data for solving the problem;
- Decision variables: levers of actions associated with a domain of possible values;
- Constraints: relations and restrictions that must be satisfied by the decision variables;
- Objective(s): mathematical function(s) to minimize or maximize.

In the DATAZERO project, several categories of problems have been already identified. They will be detailed in this document:

- Scheduling and resource allocation of IT tasks;
- Commitment and power dispatching for energy sources at the level of electricity production;
- IT resources and energy units (sources and storages) sizing.

Associated to this problem mapping, this document also presents an overview about optimization methods and their compatibility and consistency with DATAZERO optimization problems.

The following of the document is composed of two parts. The first one describes all optimization problems that have to be considered in the DATAZERO project. Problems are: IT task scheduling, energy units commitment and sizing problems. For each one, model of the data, decision variables and constraints are given. The second part proposes an overview of optimization methods that are candidates for DATAZERO. They are described with advantages and drawbacks regarding their applicability in DATAZERO.

A. Optimization problems in DATAZERO:

In the general framework of DATAZERO three decision modules have to cooperate, namely IT decision module (ITDM), power decision module (PDM) and negotiation module (NM). In classical datacenters, only the IT resource scheduling is addressed. Even if energy saving is one important concern, the main objective remains the quality of service. The energy sustainability in Cloud is allowed by an overprovisioning of the resources despite the energy consumption. Conversely, in DATAZERO, the energy is a crucial constraint since it is limited by the infrastructure of energy units and energy storage capacities. Consequently, IT resource scheduling is limited by the energy availability over the time. Thus, energy units have to be managed in order to satisfy the IT power load the best as possible. Moreover, power decisions should take into account both the IT load, Energy stored and weather forecasting as well as short term and long term.

In the following we propose to detail the underlying optimization problems to solve respectively on IT, energy and negotiation part. Besides, a discussion on sizing problems both on the IT and energy infrastructures is developed.

I. IT Scheduling

IT scheduling problems consist in allocating tasks on the IT resources under constraints depending on the IT platform current state and on forecasted energy availability. Several levers of decision are concerned as IT resource management (server switch on/off, process or virtual machine (VM) migration, frequency and voltage scaling, power capping,etc.).

1. Description of the problem:

The IT task scheduling is an optimization problem that can be dealt within 3 ways:

- Pure reactive approach: the algorithm reacts to an unexpected event and has to quickly adapt the current schedule to this new information.
- Time window approach: information within a time window about future IT load are known (either predicted or estimated) and the problem has to be solved for the current time window. At the end of the time window another problem will be solved for the next time window.
- Periodic semi-static approach: new information are stored and periodically a new schedule is performed based on current state and known information.

Depending on the way, the objective, constraints and inputs could be slightly different. In its general form the problem is expressed as follows:

Inputs (known data):

- Power profile on a given horizon;

- Known tasks: execution time, requested memory, due date, priority class, energy consumption profile, services and mixed batch. Informations for current tasks and an oracle for those who will arrive (perfect oracle);
- Current state of the system (tasks already scheduled and in progress, status of machines and virtual machines);
- IT Infrastructure (Machines types and numbers, Performance-Power ratio, associated characteristics, green levers for On / Off, DVFS, Migrations: associated energy and time costs).

Decision Variables (instantiated variables to solve the problem)

- Which task will be executed, when and where ($e_{i,j,t}$) and which level of quality (degraded or non degraded mode)
- State of machines: On / Off, frequency, migration.

Constraints to satisfy

- Power consumption should be lower or equal to the power profile given in input;
- Respect of resources availability (cpu, memory, machines ...)

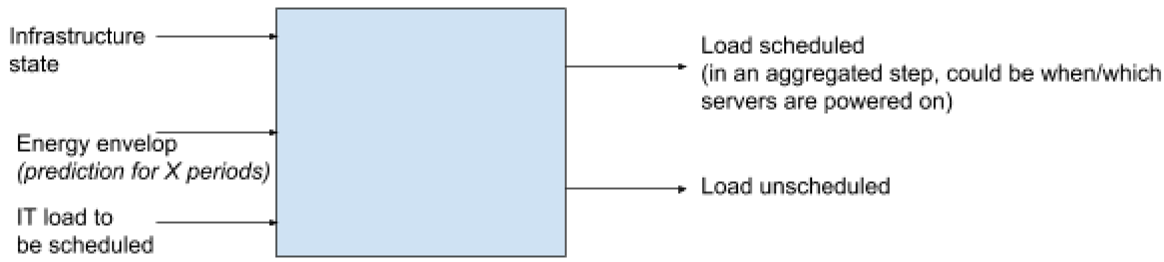
Optimization objective(s)

- Primary objective: maximization of the quality of service (QoS) (minimization of the number of exceeding due date and/or yield[1] of the services);
- Secondary objective: minimization of expected energy consumption.

Type of solutions

- Only one solution for the final decision;
- A set of solutions (during negotiation, for example).

2. Mathematical modeling



IT scheduling receives as inputs the current state of the infrastructure (number of servers available, their characteristics…), the energy envelop available for a time period and the IT load to be scheduled. The output of the problem is the scheduling of the IT load and maybe a part of it which can't be executed with power budget given. IT load can be seen as an aggregation of a set of precise jobs to be scheduled. The figure below presents the problem when all precise information of the load is known (set of jobs).

[1] yield: satisfaction of service which mesure the satisfaction resource threshold

Starting of the modelization:
Jobs:

- job J_j = Phase Finished Set : $J_{j,p} = [t_{j,p},\ cpu_{j,p},\ mem_{j,p},\ ...]$
    - $t_{j,p}$: Duration of the phase p for job j for a reference machine ($v = 1$)
    - $mem_{j,p}$: Amount of memory used during the phase p for job j
    - $cpu_{j,p}$: Percentage of CPU (Processing Element) occupancy
- jobs of service type:
    - number of phases could be infinite
- jobs of batch type:
    - r_i : release date (arrival date)
    - d_i : due date (final date to later)
- QoS :
    - for HPC jobs, defined by the delay between the due date and the end of execution time
    - for service defined:

$$QoS = \frac{\%cpuRequired}{\%cpuObtained}$$

Machines:

- machine H_i :
    - Set of frequencies : $\{f_{i,l}\}$
    - $Pmin_i$: Idle machine power i
    - α_i : Coefficient dependent on the machine
    - $Pmax_{i,l} = g(Pmin_i, f_{i,l}, \alpha_i)$: Power with cpu 100% at frequency $f_{i,l}$
    - Mem_i : Amount of available memory
    - C_i : Number of cores
    - $\phi_{i,p} = f(mem_{i,p},\ UsedCPU_{i,p},\ ...)$: Power required for the execution of the phase p of job i

Energy profile:

- Set of intervals $[t_1,\ t_2]$ with a constant power value.
- Time interval

For long period, the notion of job could be replaced by notion of load.

II. Energy source management

The power decision module is responsible for the delivery of power regarding the IT requirements. In this module, several decision levels have to be designed:

- **control level** (in reaction to rapid variation): this level is responsible for furnishing the good level of power at each instant by controlling the inverters. A control unit has to be able to react in real time to very short events due to unexpected load variation and/or weather uncertainties. It could be managed by robust inverter controls, or if requested an instantaneous decision should be implemented (such as fuzzy decision for example). There is no optimization at this level.
- **dispatching level** (from second to few minutes/hours): the decisions should guarantee that considering a known load required, the energy units are running such that they provide the expected power level. At this level, the optimization process makes use of the energy units that are already started and combines it with short term storages to ensure the energy consumption of the datacenter.
- **unit commitment level** (from hour to few days): this decision level is responsible for defining the best way to achieve the forecasted power demand or to store energy. Considering the weather forecasting for the next period, it optimizes the use of the different units. Their action levers are the unit commitments associated to its running mode, unit stops and energy storage management. It should also take into account the aging of the different unit for making its decision.
- **storage management level** (for several month): this level is responsible of the sustainability of the energy consumption during all the year. At this level, the objective is to ensure that the storage management is in adequation with the IT power demand at a long term. The solution proposed by the optimization should be considered as a constraint or preference for the lower levels.

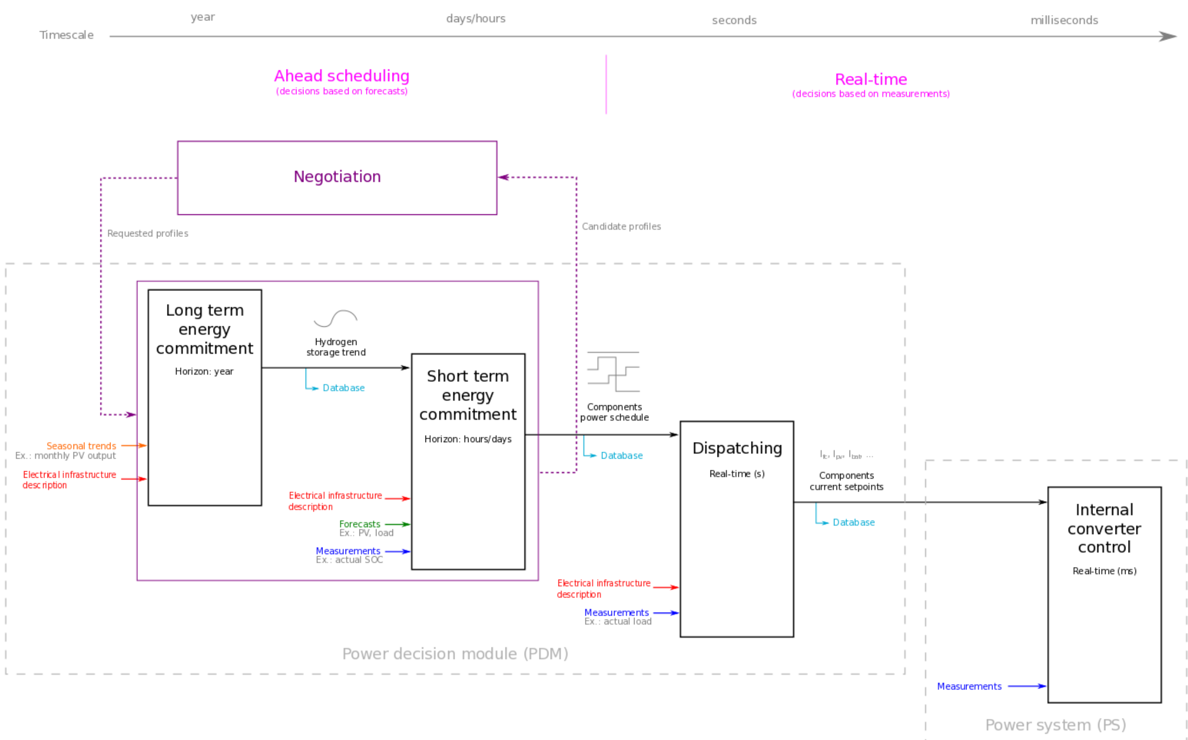


Figure 2 : different optimization levels of the power decision module

The power decision module has to manage several levels of decision (see figure 2). The optimization underlying problems are interleaved. Indeed, the solutions proposed at a given level becomes either constraints or preferences for the immediate lower level.

Finally, in PDM, three optimization problems are encountered. The next section describes these problems namely dispatching, unit commitment and storage management problems.

1. Description of the power decision problem

Inputs (known data):

- Renewable energy profile (wind prediction by period, solar radiation by period)
- State of charge for short and long term storage (battery, supercapacitor, hydrogen)
- Power Demand profile (by period T)
- Min-max power per energy source
- Min-Max energy per storage unit
- Energy units infrastructure (type of source, number of sources, performance characteristics or power model produced)

Decision variables:

- Power level by source category and period (positive or negative when deciding to recharge a storage element)

Constraint to satisfy:

- Constraint of stock limitations (battery and hydrogen) and constraints of power per source (Min and/or Max). A limitation of the variation of current over a given duration must be taken into account, in particular on the fuel cell.
- Satisfaction of demand (power required per period)
- Minimum threshold for use of an electrolyser
- Minimum threshold for use of a fuel cell
- Minimum threshold for use of a battery
- Respect of the min/max power level of energy sources
- Respect of the min/max level for storage units
- Initial and/or final state of charge (SoC) of storage units

Optimization objective (s)

- Minimization of cost (capex, opex, etc.)

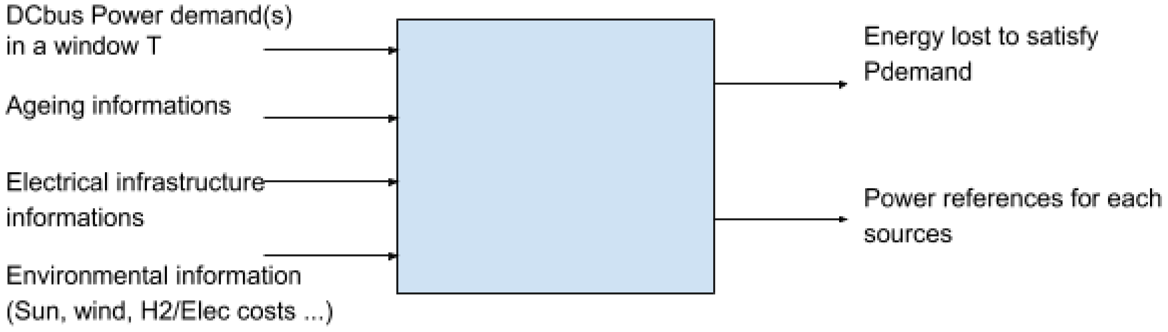
Preferred use:

- Limited start and stop times for a battery (limit ageing).
- Minimize the large current variations for a battery (limit ageing).

Comment: the purchase or resale of electricity is not considered because it is not relevant to the project. The goal is to do without it. This information may however be relevant information to be visualized but does not intervene in the optimization problems.

2. Mathematical modeling

a. Dispatching problem



DCbus Power demand :

- $Pdem_k$: power required for interval $k \; with \; k \; in \; [(k-1).dt, k.dt]$ and $k = 0...T$
  (T from few second to minutes)

Ageing per source

- set of parameters evolving with time: threshold/law variations

Sizing-Fixed per source:

- Photovoltaic panels: A (area in m²);
- Hydrogen stock: Vh (volume in m^3);
- Capacity(A.h);
- Max Power (W).

Meteorology forecasting (depending on fixed information such as geographical position, date, season, etc.):

- Solar radiation
- Wind forecasting

Energy lost:

- l_i : amount of energy lost by each sources (due to the efficiency of the source);

All power references:

- $P_{i,k}$: Power delivered by source i during interval k with $k \; in \; [(k-1).dt, k.dt]$ and $k = 0...T$.

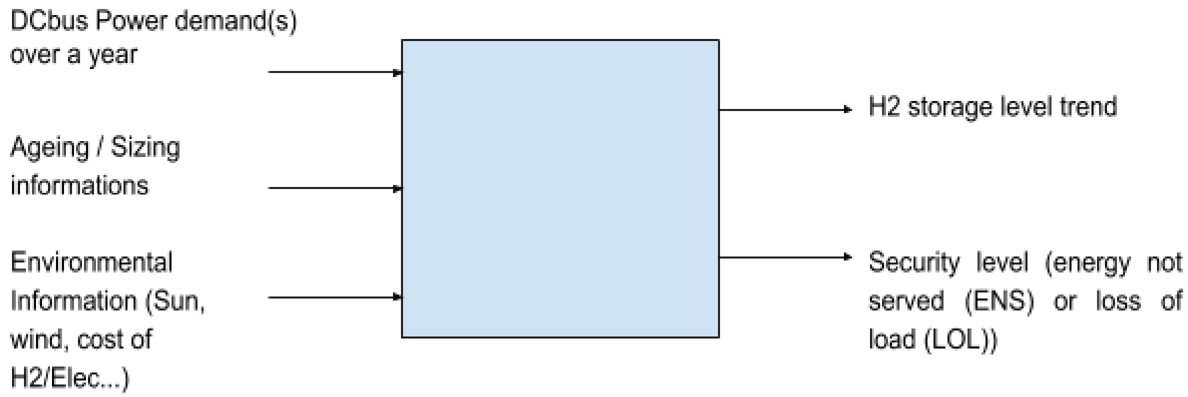
On a given prediction time duration T, called the validity period (**to be verified** if all is known in T or if news can refresh information 'dynamically' constituting a slipping window), the optimization problem deals here with a time-series constituting an optimal power splitting between all available sources. Considering the only one consuming is fuel cell system (hydrogen consumption), the optimisation has to minimize this consumption 'playing' with storage elements and the other power sources closely linked to weather prediction (wind turbine, solar panel) to satisfy each time in the window T the total power demand (DCbus Power).
That includes energy and power sources behaviour characteristics which are computed (source profiling WP2.3) both described in voltage/current and power/efficiency profiling.

Depending on sizing, power sources and storage elements are limited to max Power and/or min/max Energy to respect.
For window actualisation purposes an initial state of charge as to be fixed, and a target fixing the final state of charge too.

b. Unit commitment problem

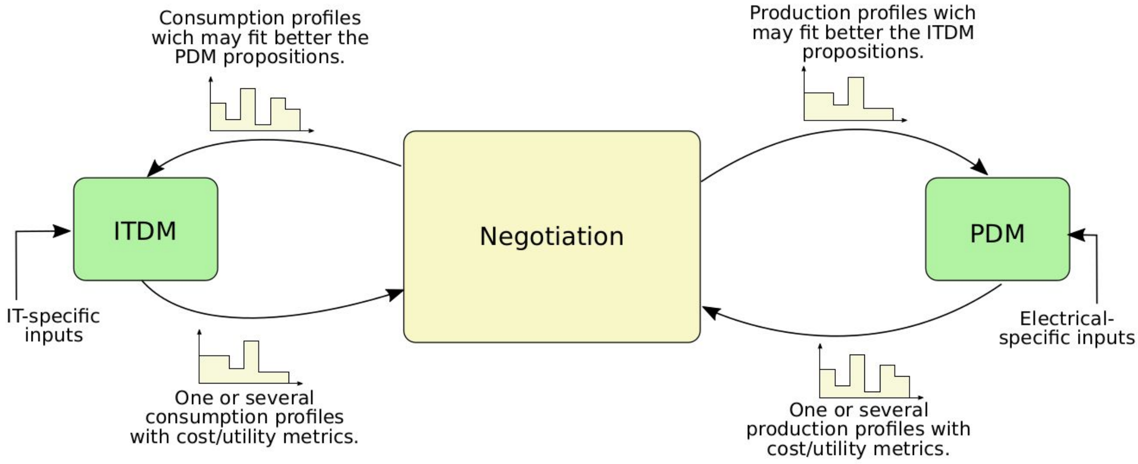
The unit commitment optimization is more or less the same problem statement as the dispatching problem. One can then used the same model. The main difference is the time horizon T (from hour to many days) and the sampling size dt. They are much more larger in this problem than in dispatching one and lead to consider aggregated data. Others important information are the weather prediction and the ageing parameters that should be consider at this level of optimization.

c. Storage management problem



Here the objective is to provide a trend for hydrogen storage and PV generation over the course of several weeks (until one year), that can be used for. Its focus is thus on the seasonal trends in the system. As it is impossible to obtain renewable generation forecasts over such long periods, historical data (solar radiation, wind speed) is used to run the optimization. It is expected that the same seasonal patterns are observed each year. Decisions focus on the daily or weekly energy flows instead of power flows. For example, an estimate of the daily PV generation can be obtained, and used for obtaining a preliminary daily trend of components use. Similarly, the trend in hydrogen storage use can also be scheduled this way. The outputs of this optimization are used as starting points for previous described optimization problem (e.g., to have an hydrogen storage level target at the end of the horizon).
Due to the sampling granularity, components with short time constants, such as batteries, are not considered. On the contrary, the ageing of the components becomes more significant than in other cases, and must be considered.
Another output is the security level of the system, which can be measured as the energy not served (ENS) or the loss of load. In other words, it corresponds to the demand that cannot be met by the system, as no feasible solution exists. The highest level of security is reached when not shed load is expected.

III. Negotiation IT/Elec



The goal of the optimization problem is here to find an agreement between IT power consumption and the electrical production. The negotiation module will guide the Decision Modules optimization in order to converge to power profiles feasible by IT and Electrical part. As IT Decision Module would like to execute jobs when it is better for QoS constraints, even if it makes its optimization with energy consumption minimization, it is important to confront it with the renewables sources availability. So, the negotiation will provide a good compromise.

The negotiation does not aim to make a global optimization, so it should find a good trade-off with as few specific information as possible. It does not aim to model the IT or Elec infrastructures and constraints. The information required should be “cost” or “profit” metrics (possibly aggregated). Multiple negotiation “rounds” will be possible ; at each round a set of “hint profiles” may be sent to the IT and Power DMs for the next round. The profiles are advices or requirements from each part and will be refined at each round in order to find a global compromise.

The profiles description (message format) will be given in deliverable D3.1.

The negotiation begins at the initiative of either ITDM (new tasks submitted...), PDM (changes in the production forecast, failing element...) or negotiation module itself (to guarantee continuity in case of long time spent without negotiation). The negotiation make use of the following information:

- Power profiles required for IT (min / max depending on the profiles) for different time windows and associated vector of preference indicators (IT cost, reliability, etc...).
- Power profiles proposed by electric part and associated vector of preference indicators (cost in euros, energy loss, state of storage, etc…)

There could be different profiles for the same time window or a set of profiles for different time windows (based on some forecasting and confidence).

The negotiation process will be studied in task 4.3 and the deliverable D4.3 will detail the algorithm used.

IV. Infrastructure Sizing

Datacenters have to deploy services and computation abilities. In order to furnish a given quality of service, a power level has to be delivered on time considering at least one year period. The ambition of DATAZERO is to size a datacenter that is able to absorb all the demand profiles depending on seasonality fluctuation. This task does neither consider the mean nor the instantaneous power demand. Then, the infrastructure sizing problem is an optimization problem whose goal is to find the right electrical architecture combined with the right IT infrastructure that give an answer to this challenge.

Remark: the electrical sizing and IT sizing problems are interconnected. They need the result of the other problem as an input. For instance, here in electrical sizing, it is supposed that the IT load (annual usage of the datacenter) is known, but this IT load could not be transformed in a required power since it would be necessary to schedule the load. It will lead to maximize the power level required, which is contradictory with the aim of DATAZERO project (the electrical sizing would be too large and too expensive). Consequently, the two problems may probably be linked and an iterative approach has to be identified in order to avoid this issue. The proposed method would converge to a tradeoff between IT annual power demand and electrical size.

1. Problem description

Inputs (known data):

- IT workload for a year
- Solar radiation profile according to geographical position
- Wind profile according to geographical position and height
- Location of the data center
- Available space (roof area, field space, number of floors, servers location, etc.)
- Available energy units:
    - Primary sources:
        - Photovoltaics (type (fixed/mobile, technology), size, efficiency, installation and operating costs (CAPEX/OPEX), power production according to sun radiation, orientation and inclination)
        - Wind turbines (type, height, diameter, power production profile as a function of wind)
    - Secondary sources and storages:
        - For seasonal balance:
            - Fuel cells (type, power min, power max, efficiency, installation and operating costs, etc.)
            - Hydrogen devices (electrolyzer efficiency, tank volume, costs, etc.)

        - Daily Balance:
            - Batteries (efficiency, energy capacity, Pmax)
            - Supercapacitors (efficiency, energy capacity, Pmax)
- Available servers
    - Characteristics: power, MIPS, cores, RAM, DVFS
- Other IT devices:
    - Available UPS
    - Available Racks (size, etc.)
- IT policy (only renewable, money, % of renewable aimed)
- Cooling profile: model that allow to define the energy consumption of cooling depending on the season

Constraints

- Space constraints (maximum area, security norms for fuel cells)
- Satisfaction of annual energy demand (per hour or day)
- Respect the percentage of renewable energy used (IT policy)

Decision Variables

- number of energy units of each type
- number of servers of each element of the catalog

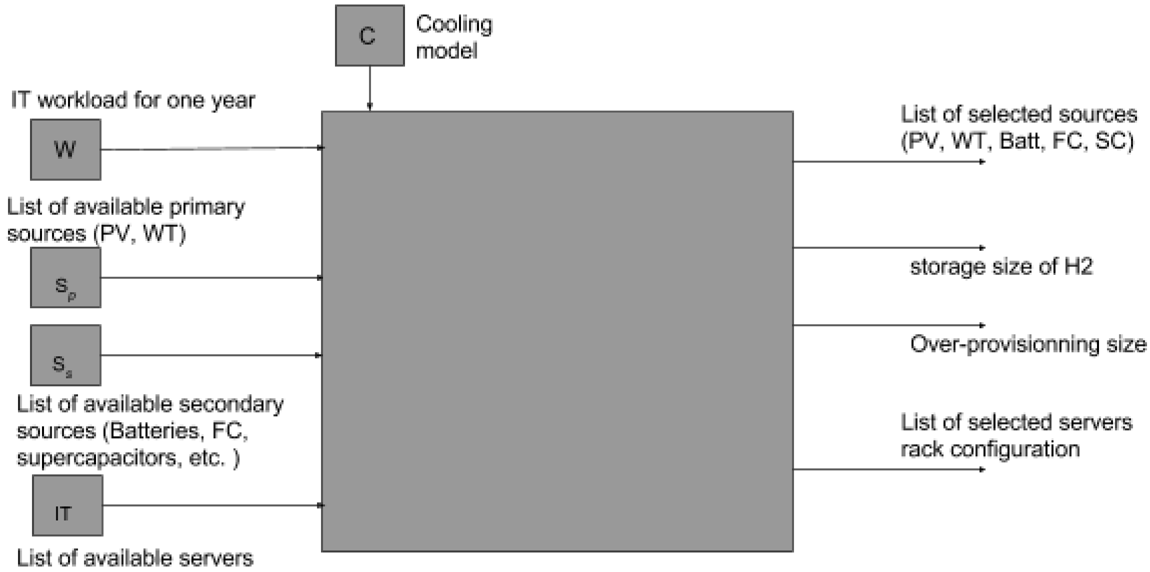
Objective

- Minimize CAPEX and OPEX
- Minimize the service level agreement (SLA) violation cost

2. Mathematical modeling

Primary sources: $S_p = [WT, PV]$

- PV : Photovoltaics = $[X, Pmax, T, \eta]$
    - X : Geographic position
    - $Pmax$: Maximal power of the photovoltaics
    - T : Type of the photovoltaic
    - η : Efficiency
- WT : Wind Turbine = $[X, H, Pmax]$
    - X : Geographic position
    - H : Height of the WT
    - $Pmax$: Maximal power of the WT



S_s = Secondary sources: [FC+H2, Batt+Supercap]

- FC_i+H2: Fuel Cell and Hydrogen system = $[Pmin_i\,,\ Pmax_i\,,\ \eta_i^{fc}\ ,\ \eta_k^{h2}\,,\ V]$
    - $Pmin_i$: Minimal Power of the FC of type i
    - $Pmax_i$: Maximal Power of the FC of type i
    - η_i^{fc} : Performance or efficiency of the FC of type i
    - η_k^{h2} : Performance or efficiency of the Electrolyzer of type k
    - V : Volume of the tank of Hydrogen

W = IT Workload of the Data center

B. Overview of the optimization methods

A lot of optimization methods are described in the literature. In the following we propose to present an overview of those which could be used in DATAZERO project. Methods are not detailed here, one can referred to the bibliographical references.
Optimization methods are categorized in two main sets. The first one contains “exact methods”. These are the one which can provide an optimal solution to minimization or maximization problems. The second one called “approached methods” lists algorithms that are able to approximate the best solution of an optimization problem. They do not guaranty that optimal solution is carried out.
In the following for each optimization approach the advantages and drawbacks are brought out. For exploring more deeply the matter, a list of references is proposed at the end of the document.

I. Exact methods

- Greedy Algorithms
    - Advantages: Provides optimal solutions under certain conditions
    - Disadvantages: Only for problems with strong assumptions
    - Applicability in DATAZERO:
        - Interesting to map the difficulty (complexity) of problems (IT and GE)
        - Not adapted for dynamic problems

- Constraint programming
    - Advantages: Expressiveness of the mathematical model of the problem, possibility of solving a constraint satisfaction problem (CSP) for existence of solution
    - Disadvantages: Computation time (close to linear programming)
    - Applicability in DATAZERO:
        - Interesting to know if a problem has a solution

- Branch and bound
    - Advantages: Quickly reaches a first acceptable solution. No mathematical modeling required.
    - Disadvantages: Necessity to define an efficient terminal. Problem must be decomposable into subproblems
    - Applicability in DATAZERO: All static problems

- Linear programming (integer, mixed)
    - Advantages: formal modeling of a problem, characterization of a solution, comparison with approximate methods on small problems (or nonrealistic optimals)

    - Disadvantages: slow resolution on large problems. Difficulty in writing the equations and choosing the right variables of the model, especially to go faster.
    - Applicability to DATAZERO:
        - Difficult on IT issues (time aspect and number of tasks and resources)
        - Possible on GE problems (size seems more affordable)

- Dynamic programming
    - Advantages: Can allow polynomial or pseudo-polynomial resolution
    - Disadvantages: Difficulty expressing the problem in a recursive form. Based on the existence of optimal subproblems
    - Applicability to DATAZERO:
        - Sizing issues

II. Approached methods

- Meta-heuristics (such as Genetic algorithms - GA, Colonies of ants, Particle Swarm Optimization, simulated annealing)
    - Advantages: Allows to produce a large number of adapted solutions quickly. It also makes it possible to approach a local minimum starting from an existing solution. The cost of implementation is low. it is robust (the solution does not change completely) when we start from a solution to find others with slightly different conditions.
    - Disadvantages: The problem of GA type methods is slowness on a large scale (compared to wolverine). Difficulty in mixing the problem with metaheuristics. Difficulties in setting parameters (eg mutation rate, population size, evaporation rate, ...).
    - Applicability to DATAZERO:
        - Adapted to IT and energy optimization problems (excluding reactive problem with very low latency)

- Heuristic greedy
    - Advantages: Locally optimal decisions. Easy implementation.
    - Disadvantages: The combinations of choices locally optimal do not always lead to an overall optimum. Not always possible to limit the distance to the optimal.
    - Applicability in DATAZERO:
        - Applicable to all problems

- Methods based on fuzzy logic
    - Advantages: once the belonging functions and the rules have been set, real-time operation, high robustness of the approach, possibility of varying the settings according to the aging of the components

Logic of type 2: possibility to integrate knowledge of a large number of experts = merging expertise

- Disadvantages: large number of parameters of adjustment.

References

Greedy Algorithms

Abdallah Ben Othman, Jean-Marc Nicod, Laurent Philippe, Veronika Rehn-Sonigo, *Optimal energy consumption and throughput for workflow applications on distributed architectures*, Sustainable Computing: Informatics and Systems, volume 4, issue 1, pages 44-51, March 2014, ISSN 2210-5379,
https://doi.org/10.1016/j.suscom.2014.01.001

Constraint programming

Vipin Kumar. *Algorithms for Constraint-Satisfaction Problems: A Survey*. AI MAGAZINE volume 13, issue 1, pages 32-44, 1992.
https://www.aaai.org/ojs/index.php/aimagazine/article/view/976/894

Branch and bound

E. L. Lawler, D. E. Wood, *Branch-and-Bound Methods: A Survey*. Operations Research, volume 14, issue 4, pages 699-719, August 1966.
http://dx.doi.org/10.1287/opre.14.4.699

Aiying Rong, Risto Lahdelma, *An efficient envelope-based Branch and Bound algorithm for non-convex combined heat and power production planning*, European Journal of Operational Research, volume 183, issue 1, pages 412-431, November 2007, ISSN 0377-2217,
https://doi.org/10.1016/j.ejor.2006.09.072

Linear programming (integer, mixed)

Nathalie Herr, Jean-Marc Nicod, Christophe Varnier, Louise Jardin, Antonella Sorrentino, Daniel Hissel, Marie-Cécile Péra, *Decision process to manage useful life of multi-stacks fuel cell systems under service constraint*, Renewable Energy, volume 105, Pages 590-600, May 2017, ISSN 0960-1481,
https://doi.org/10.1016/j.renene.2017.01.001

Stéphane Chrétien, Jean-Marc Nicod, Laurent Philippe, Veronika Rehn-Sonigo, and Lamiel Toch. 2015. *Using a sparse promoting method in linear programming approximations to schedule parallel jobs*. Concurrency and Computation : Practice and Experience, volume 27, issue 14, pages 3561-3586. September 2015.
http://dx.doi.org/10.1002/cpe.3350

Tom Guerout, Yacine Gaoua, Christian Artigues, Georges Da Costa, P. Lopez, Thierry Monteil. *Mixed integer linear programming for quality of service optimization in Clouds.* In : Future Generation Computer Systems, Elsevier, volume 71, pages 1-17, june 2017.
http://dx.doi.org/10.1016/j.future.2016.12.034

Damien Borgetto, Henri Casanova, Georges Da Costa, Jean-Marc Pierson. *Energy-Aware Service Allocation. In Future Generation Computer Systems*, Elsevier, volume 28, issue 5, pages 769-779, *may* 2012.
http://dx.doi.org/10.1016/j.future.2011.04.018

Remi Sharrock, Thierry Monteil, Patricia Stolf, Olivier Brun. *Autonomic computing to manage green Core networks with Quality of Service.* regular paper In : Energy Efficiency in Large Scale Distributed Systems Conference (EE-LSDS 2013), Vienna, 22-24 april, Springer, pages 248-263, 2013.
http://dx.doi.org/10.1007/978-3-642-40517-4_20

Bei Li, Robin Roche, Abdellatif Miraoui, *Microgrid sizing with combined evolutionary algorithm and MILP unit commitment*, Applied Energy, volume 188, pages 547-562, Feb 2017, ISSN 0306-2619
http://doi.org/10.1016/j.apenergy.2016.12.038

Dynamic programming

F. Hanna, L. Marchal, J. M. Nicod, L. Philippe, V. Rehn-Sonigo and H. Sabbah, *Minimizing Rental Cost for Multiple Recipe Applications in the Cloud*, IEEE International Parallel and Distributed Processing Symposium Workshops (IPDPSW), Chicago, pages 28-37, 2016.
https://doi.org/10.1109/IPDPSW.2016.71

Jean-Marc Nicod, Léo Obrecht, Christophe Varnier, *Task Scheduling to Extend Platform Useful Life using Prognostics*, IFAC Proceedings Volumes, volume 46, issue 9, pages 134-139, 2013, ISSN 1474-6670.
http://dx.doi.org/10.3182/20130619-3-RU-3018.00522.

Mouloud Guemri, Ahmed Neffeti, Stephane Caux, Sandra Ulrich NGueveu, *Management of distributed power in hybrid vehicles*. Optimization and Engineering – Springer OPTE (2014), volume 15, pages 993–1012, october, 2014.
http://dx.doi.org/10.1007/s11081-013-9235-5

A. Ravey, R. Roche, B. Blunier and A. Miraoui, *Combined optimal sizing and energy management of hybrid electric vehicles*, 2012 IEEE Transportation Electrification Conference and Expo (ITEC), Dearborn, MI, pages 1-6, 2012.
http://dx.doi.org/10.1109/ITEC.2012.6243420

Anne Benoit, Paul Renaud-Goud, Yves Robert, Rami Melhem, *Energy-aware Mappings of Series-Parallel Workflows onto Chip Multiprocessors*, In Parallel Processing (ICPP), 2011 International Conference on, Taipei City, Taiwan, pages 472-481, october 2011.
https://doi.org/10.1109/ICPP.2011.61

Anne Benoit, Paul Renaud-Goud, Yves Robert, *Performance and Energy optimization of concurrent pipelined applications*, In IEEE International Parallel & Distributed Processing Symposium IPDPS 2010, 19-23 April in Atlanta, USA, pages 1-12, 2010.
https://doi.org/10.1109/IPDPS.2010.5470483

Meta-heuristics

El-Ghazali Talbi, 2009. Metaheuristics: *From Design to Implementation*. Wiley Publishing, 624 pages, july 2009. ISBN: 978-0-470-27858-1
http://eu.wiley.com/WileyCDA/WileyTitle/productCd-0470278587.html

Ilhem Boussaïd, Julien Lepagnot, Patrick Siarry, *A survey on optimization metaheuristics*, Information Sciences, volume 237, New York, NY, USA, July, pages 82-117, ISSN 0020-0255, 2013.
http://dx.doi.org/10.1016/j.ins.2013.02.041

Bianchi, L., Dorigo, M., Gambardella, L.M., Gutjahr, W.J., *A survey on metaheuristics for stochastic combinatorial optimization.* Natural Computing, volume 8, issue 2, pages 239-287, 2009.
http://dx.doi.org/10.1007/s11047-008-9098-4

Genetic algorithms

Jia Yu and Rajkumar Buyya. 2006. *Scheduling scientific workflow applications with deadline and budget constraints using genetic algorithms*. Sci. Program. volume 14, issues 3 & 4, pages 217-230, december 2006.
http://dl.acm.org/citation.cfm?id=1376960.1376967

J. Kolodziej, S. U. Khan and F. Xhafa. *Genetic Algorithms for Energy-Aware Scheduling in Computational Grids.* In International Conference on P2P, Parallel, Grid Cloud and Internet Computing (3PGCIC). 26-28 oct, Barcelona, Spain, 2011.
http://ieeexplore.ieee.org/document/6103133/?tp=&arnumber=6103133

Tom Guérout, Samir Medjiah, Georges Da Costa, Thierry Monteil, *Quality of service modeling for green scheduling in Clouds*, Sustainable Computing: Informatics and Systems, volume 4, issue 4, pages 225-240, ISSN 2210-5379, December 2014.
https://doi.org/10.1016/j.suscom.2014.08.006.

Patricia Stolf, Damien Borgetto, Mael Aubert. *Host management policy for energy efficient dynamic allocation (regular paper).* In International Workshop on Resilience and/or

Energy-aware techniques for High-Performance Computing (RE-HPC), Hangzhou, China, 07/11/2016-09/11/2016, IEEE, (inline), april 2017.
http://doi.org/10.1109/IGCC.2016.7892622

T. M. Hansen, R. Roche, S. Suryanarayanan, A. A. Maciejewski and H. J. Siegel, *Heuristic Optimization for an Aggregator-Based Resource Allocation in the Smart Grid*, in *IEEE Transactions on Smart Grid*, volume 6, issue 4, pages 1785-1794, July 2015.
http://doi.org/10.1109/TSG.2015.2399359

Particle swarm optimization

S. Caux, D Wanderley, M Fadel, D. Hissel, *On-line Energy Management for HEV based on Particle Swarm Optimization*. EPJ-AP: European Physical Journal – Applied Physics, volume 54, issue 2, 8 pages, May 2011.
https://doi.org/10.1051/epjap/2010100248

M. R. AlRashidi and M. E. El-Hawary, *A Survey of Particle Swarm Optimization Applications in Electric Power Systems*. in IEEE Transactions on Evolutionary Computation, volume 13, issue 4, pages 913-918, Aug. 2009.
https://doi.org/10.1109/TEVC.2006.880326

Ant colony optimization

M. Dorigo, M. Birattari and T. Stutzle, *Ant colony optimization*, in IEEE Computational Intelligence Magazine, volume 1, issue 4, pages 28-39, Nov. 2006.
https://dio.org/10.1109/MCI.2006.329691

Heuristic greedy

Anne Benoit, Mathias Coqblin, Jean-Marc Nicod and Veronika Sonigo, *Optimizing memory allocation for multistage scheduling including setup times,* Journal of Scheduling, volume 19, issue 6, pages 641 - 658, dec 2016.
https://doi.org/10.1007/s10951-015-0437-x

Anne Benoit, Alexandru Dobrila, Jean-Marc Nicod, and Laurent Philippe. *Mapping workflow applications with types on heterogeneous specialized platforms*. Parallel Computing, volume 37, issue 8, pages 410-427, August 2011.
http://dx.doi.org/10.1016/j.parco.2010.12.001

Hongyang Sun, Patricia Stolf, Jean-Marc Pierson. *Spatio-temporal thermal-aware scheduling for homogeneous high-performance computing datacenters. In Future Generation Computer Systems*, Elsevier, volume 71, pages 157-170, f*ebruary* 2017.
http://doi.org/10.1016/j.future.2017.02.005

Damien Borgetto, Patricia Stolf. *An Energy Efficient Approach to Virtual Machines Management in Cloud Computing.* regular paper. In International Conference on Cloud Networking, Luxembourg, 08/10/2014-10/10/2014, IEEE, pages 229-235, 2014.
http://dx.doi.org/10.1109/CloudNet.2014.6968997

Damien Borgetto, Rodrigue Chakode, Benjamin Depardon, Cédric Eichler, Jean-Marie Garcia, Hassen Hbaieb, Thierry Monteil, Elie Pelorce, Anouar Rachdi, A Al Sheikh, Patricia Stolf. *Hybrid approach for energy aware management of multi-cloud architecture integrating user machines.* Journal of Grid Computing, Springer-Verlag, Special issue : Green Cloud Computing, (inline), december 2015,
http://link.springer.com/article/10.1007/s10723-015-9342-y

Sandra Ulrich Ngueveu, Stéphane Caux, Frédéric Messine, Mouloud Guemri. *Heuristics and lower bounds for minimizing fuel consumption in hybrid-electrical vehicles.* 4OR Journal, pages 1-24, 2017.
http://dx.doi.org/10.1007/s10288-017-0343-5

Methods based on fuzzy logic

Hongyang Sun, Patricia Stolf, Jean-Marc Pierson, Georges Da Costa. *Energy-efficient and thermal-aware resource management for heterogeneous datacenters.* In : Sustainable Computing: Informatics and Systems, Elsevier, Special Issue on Energy Aware Resource Management and Scheduling (EARMS), volume 4, issue 4, pages 292-306, august 2014.
http://dx.doi.org/10.1016/j.suscom.2014.08.005

Hongyang Sun, Patricia Stolf, Jean-Marc Pierson, Georges Da Costa. *Multi-Objective Scheduling for Heterogeneous Server Systems with Machine Placement.* regular paper. In IEEE International Symposium on Cluster Computing and the Grid (CCGrid 2014), Chicago, May 26-29, IEEE Computer Society, 2014.
https://doi.org/10.1109/CCGrid.2014.53

Ahmed Neffati, Mouloud Guemri, Stéphane Caux, Maurice Fadel, *Energy management strategies for multi source systems*, Electric Power Systems Research, volume 102, pages 42-49, September 2013, ISSN 0378-7796,
https://doi.org/10.1016/j.epsr.2013.03.008.

S. Caux, W. Hankache, , M. Fadel, D. Hissel. *On-line Fuzzy Energy Management for Hybrid Fuel Cell Systems.* In IJHE – Int. Journal Hydrogen Energy. vol 35, issue 5, pages 2134-2143, march 2010.
https://doi.org/10.1016/j.ijhydene.2009.11.108

Robin Roche, Lhassane Idoumghar, Benjamin Blunier, Abdellatif Miraoui, *Imperialist Competitive Algorithm for Dynamic Optimization of Economic Dispatch in Power Systems*,

International Conference on Artificial Evolution (Evolution Artificielle) EA 2011: Artificial Evolution, pages 217-228, 2011.
https://doi.org/10.1007/978-3-642-35533-2_19