MIRACLE

Micro-Request-Based Aggregation, Forecasting and Scheduling of Energy Demand, Supply and Distribution

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D7.4 Yearly public report for the 1st year

Work package – 7

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Author(s)	Henrike Berthold, SAP AG; Matthias Böhm, TU Dresden; Christos Nychtis, CRES; Ralf Rantzau, Aalborg Universitet; Jack Verhoosel, Mente Konsman, TNO; Zoran Marinsek, INEA; Bogdan Filipic, Jozef Stefan Institute
Reviewer(s)	No reviewer

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1 Summary

The energy sector is in transition. Firstly, the liberalisation process forces companies to restructure their value chain in order to increase their market efficiency. Secondly, in order to reduce carbon emissions, the use of renewable energy sources is enforced by national and international regulations. Thirdly, smart metering is being widely adopted and with it consumers will be involved actively. The main goal of the project is to develop an ICT system that fits the future liberalised energy sector and enables the integration of a higher rate of distributed and renewable energy sources into the electricity grid. We will explore an approach for demand (and supply) side management in which electricity consumers and producers issue flex-offers indicating flexibilities in time and amount of the electricity. These flex-offers will be processed by our system in order to balance electricity supply and demand in near real-time and thus allow to use not-schedulable renewable energy sources much better.

Since the beginning of the project in January 2010, we have analysed the state of the art in the European energy market regarding players, their roles and processes they are involved in and in the three core functionalities: 1) data collection, aggregation, analysis, 2) forecasting, and 3) scheduling and negotiation. We have also analysed related projects and developed a standardization roadmap. Based on that we have designed the processes for the integration of the flex-offer technology into balance groups and market balance areas; we have drafted the data model; we derived requirements and constraints to the approaches for core functionalities; and we have developed approaches to the technical functionalities which fulfil the requirements.

On the web-site www.miracle-project.eu you can find more information about the MIRACLE project including publicly available publications and deliverables.

2 Project objectives for 2010

The objectives of the project in 2010 have been to research and document the state-of-the-art in all related areas, to identify roles and design the processes for the proposed flex-offer management on different levels of the energy system namely balance groups and market balance areas, and to develop first approaches to the core functionalities i.e. data collection, aggregation, and analysis, forecasting and scheduling/negotiation.

3 Work progress and achievements in 2010

3.1 Architecture and process model (WP1)

3.1.1 Objectives of the work package

The objectives of this work package are to specify role and process model of actors in the Electricity Market system and to prepare the draft for the overall architecture of the Miracle Energy data management system.

3.1.2 Results of the work package

In this work package, we have described the goals of our envisaged Energy data management system (EDMS) and the observations and assumptions we have made and we will build upon. A major prerequisite to design the EDMS in a way that it will be applicable to the future liberalised energy sector is to understand the current situation of the energy sector in different European countries and foresee its future structure. We therefore have described the current national electricity markets for some European countries in detail and have compared the activities of the national players to the roles defined in the ETSO harmonized model. Based on that, we have designed the EDMS and the processes in which it is used. We have described the use cases on two hierarchical levels of the energy system, on balance group level and in market balance areas in terms of roles involved and processes executed on these levels. Finally, we have described functional, non-functional, and market-system-based requirements for the EDMS and we have designed its conceptual architecture.

3.1.2.1 Description of the Miracle system and processes

In describing the framework for Miracle project, the point of view relevant to the task of managing and controlling the electricity market system is used which provides the following main constituents:

- the structure of system itself and its environment,
- the roles of the entities that constitute the system, and
- the processes that occur in these roles

The description of the constituents uses:

- conventions, terms and categories, used in the Harmonized Electricity Market Role model
- terms and categories, required by the Miracle technology; this only if they are not in contradiction with the previous requirement.

Based on observation of the Harmonized Electricity Market Role model and related documents, the basic assumptions we have made are that the electrical energy market system can be decomposed into smaller nested primary subsystems, where each has essentially the same functions as “parental system”. The following subsystems are exposed in detailed description

- balance group system,
- market balance area system.

The complete system consists of the active components called roles, which carry out the processes and which constitute subsystems called domains, and of accompanying boundary conditions. The roles interact through messages. The key concept for the definition of processes, roles and subsystems with accompanying boundary conditions (which are imposed by the processes carried out by the roles in the surrounding joint and supportive subsystems), was definition and analyses of the use cases.

3.1.2.2 Use case analysis

As already mentioned in the previous Section, to define and analyze the processes in primary subsystems the Use Case analysis has been used.
The use cases described and analyzed in this document were chosen and formed in the way to follow the Miracle project goals. The use case scenarios, its boundary conditions and roles involved were determined in the way to expose the main characteristic of Miracle project – energy scheduling and delivery on the basis of the prosumers flex-offers.
The following use cases have been defined to analyze and define the primary processes of the two complete primary subsystems of the electricity market:

- Balance Group Use Case, structured into 3 scenarios (sub cases)
- Market Area Use case, structured into 3 scenarios (sub cases)

In selecting these use cases, two main criteria were adhered to:

- The use cases should together describe complete area of the electricity market where the Miracle solution can be used
- The use cases within each subsystem (Balance Group, Market Balance Area) are selected in a way to establish clear understanding of interdependencies and causality, i.e. to act as a yardstick for establishing the requirements for development. The complete use case for BG is use case 3, the complete use case for MBA is use case 2, while the MBA use case 3 provides the necessary inputs and descriptions to introduce the Miracle technology into the inter-MBA energy trading.

It is important to note also that by respecting the first criterion the two groups of use cases cover the trial cases planned for Miracle:

- BG Use case covers: household community, and sufficiently the LDE trial
- MBA use case covers sufficiently the TSO trial

The process descriptions and analyses in the use cases showed that processes like “aggregation”, “scheduling” and “price setting” are closely coupled and cannot be described independently on either Balance group or Market balance area levels. The “capping” process was named “matching” and it suggests that an iterative procedure is needed to reach the optimization criteria. The “contracting” process is confirming the matching result and fixing the flexibilities.
The analyses of the flex-offer content suggested to enhance it with additional parameters “acceptance” and “assignment”, which are necessary for the prosumer to control the load or the production unit. These parameters have also important influence on the matching algorithm process. In the present electricity market system, the Market operator defines the “trading period” (day-ahead, hour-ahead…) and the users (suppliers) need to adapt the timing of their offers to it. On the other hand, on the level of the BRP the assignment and acceptance of the flex-offers define the trading period.

The usage of the Miracle technology on the level of the Market Operator transfers the flexibilities to the higher level for external trading. The present electricity market system rules obligates the fixed energy flow at contracting point, therefore it is suggested that Market Operator is assigned to a new task of the scheduling the flexibilities before they are finally fixed at the point of contracting. In order to carry this active function out properly, the Market Operator will need to have some optimization criteria, which are necessary for the matching process.

3.1.2.3 Conceptual architecture

The EDMS is organized in a multi-level hierarchy of nodes as shown in Figure 1. A node is called a Node of the Energy data management system (NEDMS).

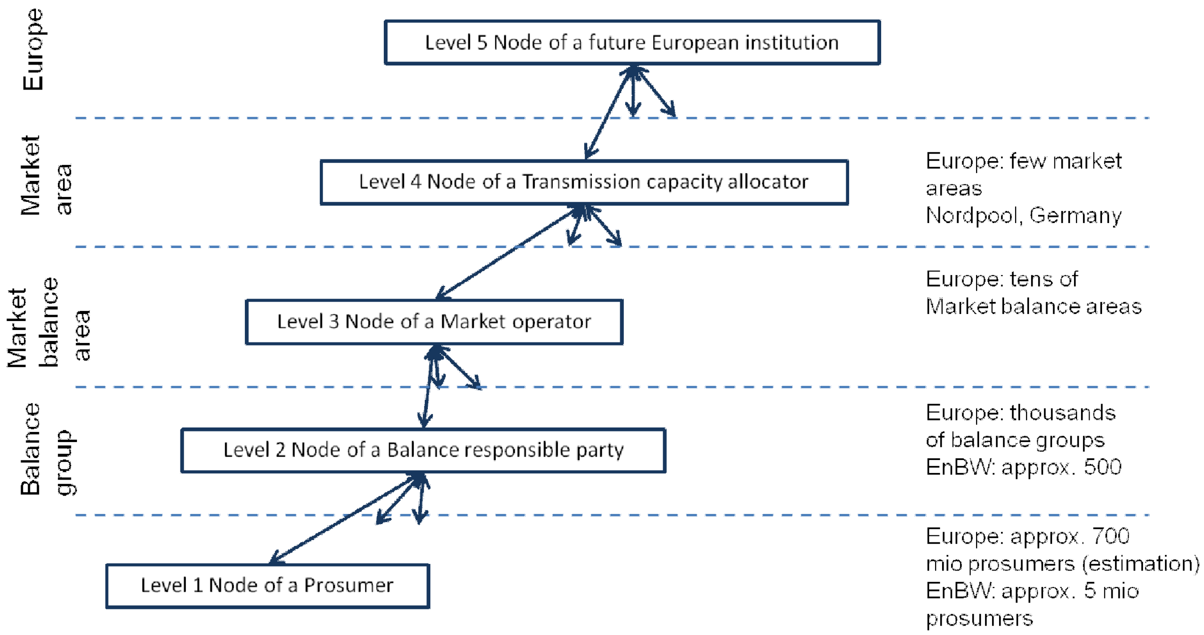

Figure 1: Hierarchical architecture of the EDMS

Each node has the same conceptual architecture (see Figure 2). It has the following components:

- Control component,
  The control component orchestrates the functionalities of the other components to provide the functionality which is specific for a type of actor i.e. Prosumer, BRP or Market operator. It is responsible for the communication with the nodes of other actors.
- Forecasting component
  The forecasting component predicts non-schedulable demand and supply. It selects and applies forecasting models automatically.
- Aggregation component,
  The aggregation component aggregates flex-offers to aggregated flex-offers and disaggregates them. The goal of the aggregation is to reduce the number of flex-offers for further processing. An aggregated flex-offer should keep as much flexibility provided by the lower level flex-offers as possible.

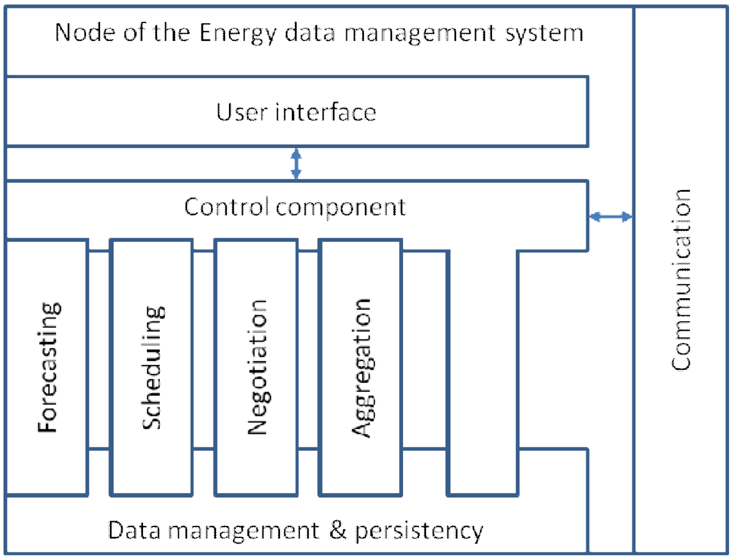

Figure 2: Architecture of a Node of the Energy data management system

- Scheduling component,
  The scheduling component schedules energy supply and demand. The goal of scheduling is to enable the use of more renewable energy. Scheduling is used by the participants to balance demand and supply (BRP), to minimize the cost of electricity which must be bought (BRP) or to maximize the profit of electricity which can be sold (BRP).
- Negotiation component,
  The negotiation component controls the communication protocol which turns flex-offers into accepted flex-offers. Within the negotiation procedure, the price is set.
- Data management and persistency component,
  This component manages all data of the node. It processes data-intensive operations efficiently. The data management system stores incoming and outgoing flex-offers, assignments, forecast models and the history of electricity measurements.
- Communication component, and
  The communication component processes incoming and outgoing discrete messages (such as flex-offers) and continuous data streams (such as measurements).
- User interface.
  The user interface (UI) are tailored to the actor. For the prototype, we plan to implement UIs for selected scenarios.

3.1.3 Summary of the progress

The role and process model for the two use cases balance group and market balance area is mature. The conceptual architecture is agreed upon. With the description of the role and process model, the use cases and the conceptual architecture of the EDMS, work package 1 provides the base for all technical work packages. The detailed architecture will be designed in the next 6 months based BG and MBA processes. Final adjustments to the role and process model might be done in the next 6 months, too. Both will be documented in the deliverable D1.3 Conceptual draft of the flex-offer management architecture and its design.

3.2 Data specification (WP2)

3.2.1 Objectives of the work package

This work package aims to develop a data model that describes how energy supply and/or demand can be shifted in order to compensate for the unpredictable nature of renewable energy sources. Building on the data model messages will be specified that allow the different players in the energy field to exchange information on shiftable energy loads.

The aim of the data model that is being developed as part of the MIRACLE project is twofold. First it serves as a means of alignment between the various work packages ensuring proper co-operation of all the components involved in the MIRACLE Electricity Data Management Systems (EDMS). The concepts developed this work package will be directly used by work packages 3 (aggregation) and 5 (scheduling).

Second there is the standardization aim; the data model (and the messages that are derived from it) is input for an active standardization process which is the subject of work package 7 (Standardization).

3.2.2 Results of the work package

The main results of this work package during this first year of the project were deliverables D2.1 and D2.2. D2.1 is a deliverable that describes the State-of-the-art on data modelling, D2.2 describes the data model itself and the resulting messages.

3.2.2.1 State of the art analysis

The state of the art analysis focuses mainly on two subjects; data modelling approaches and existing data models.

Three modelling approaches are described; Unified Modeling Language (UML), UN/CEFACT's Modeling Methodology (UMM) and Object Role Modeling (ORM).

For the existing models, two international standard organizations are relevant; ebiX and IEC.

ebiX has developed models for Customer Switching Process and for the Exchange of Metered Data. These models describe the business processes and the corresponding message definitions and do so by using the aforementioned UN/CEFACT's Modeling Methodology.

The Common Information Model (CIM) is a data model by the IEC that aims to describe all major objects that an electric utility enterprise is typically involved with.

The following conclusions are drawn:

- UMM is the methodology of choice for the development of the WP2 deliverables. It is an international standard that describes different viewpoints that help guide the process of modeling. The artifacts that are part of these viewpoints are UML based. UMM has also been adopted by ebiX which serves as a good example of the application of UMM for the energy area.
- The main subject of the Miracle project; shiftable consumption and/or production is not being covered by the existing models in the energy area. Therefore specific models will have to be developed in Miracle that are able to cope with these concepts.
- Part of the Common Information Model by the IEC provides a solid basis for the Miracle data model. Basic energy concepts that already have been modeled can be reused.

3.2.2.2 Data model, specification of request and negotiation messages and contracts

This deliverable D2.2 is an initial version of the data model; a final version of the data model and the specification of messages will be available in M18 of the MIRACLE project. This aligns the timelines of this work package with other work packages depending on the data model. Also it allows feedback from these work packages to be processed, thereby strengthening the final version of the model.
The focus of this initial version is on the `FlexEnergy` concept which is a central concept for the MIRACLE project. With this concept flexibility in both the production and consumption of electricity can be expressed. The model presented in this deliverable is the result of various discussions within the project. The `FlexEnergy` concept will be directly used by the work packages 3 (aggregation) and 5 (scheduling) and it is also the focal point of the standardization activities. Figure 3 shows part of the FlexEnergy concept as it can be found in the data model.

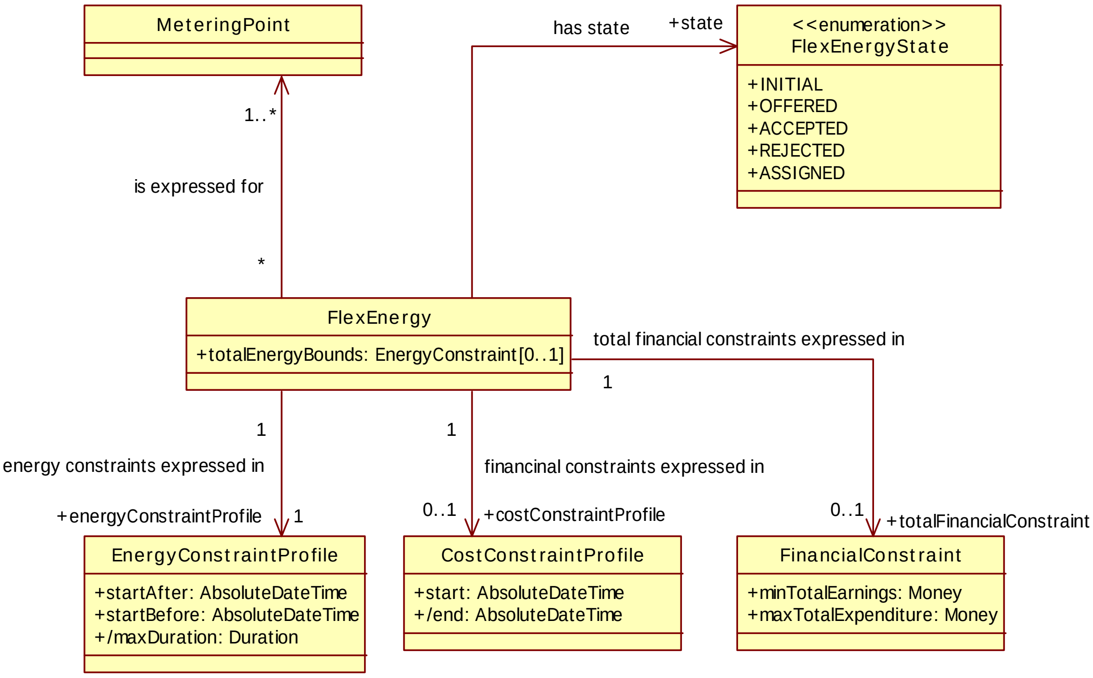

Figure 3: Data model fragment showing the FlexEnergy concept

FlexEnergy can be offered to other players in the energy field. They can use FlexEnergy to compensate or balance unpredictable Renewable Energy Sources. Figure 4 depicts the FlexOffer (short for FlexEnergy Offer) business process.

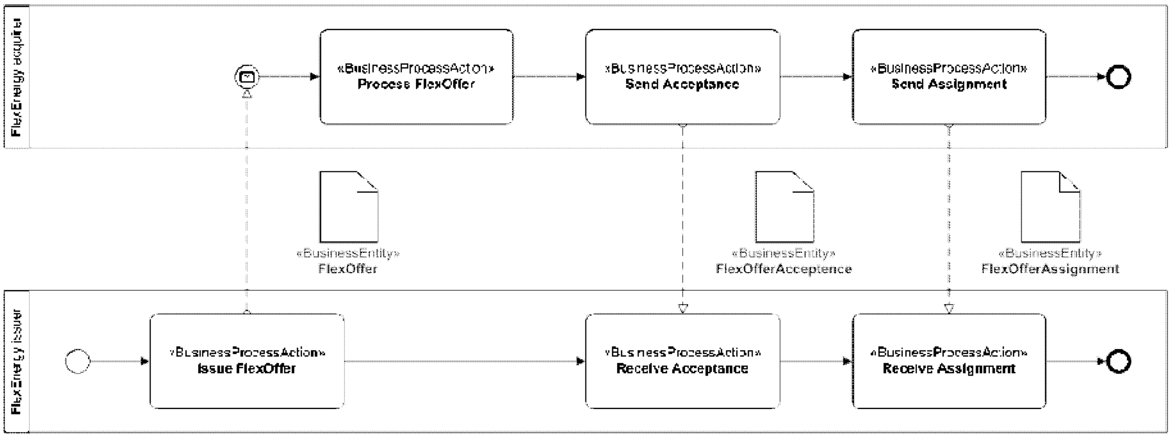

Figure 4: FlexOffer Business Process

The Business Entities (messages) that are exchanged between the two parties (FlexOffer, FlexOfferAcceptance and FlexOfferAssignment) are also described in this deliverable.

3.2.3 Summary of the progress

The most important achievement for WP2 this year is that the FlexEnergy, FlexOffer and related concepts have been agreed upon by the project. This serves as an important basis for other work packages (mainly aggregation and scheduling) to continue their work.

The final version of the data model and message specification (to be delivered in M16) will have a broader focus than this one. It will describe all major data concepts that are used by each EDMS component. Not only will it feature an extended data model but there will also be more emphasis on the actual messages that are exchanged between the various players of the energy market. The processes described in D1.2 serve as important input for this part of the deliverable.

3.3 Data collection and analysis (WP3)

3.3.1 Objectives of the work package

The objectives of this work package are to

1) Model, design, develop and test an efficient and scalable data warehouse solution that enables the collection and subsequent analysis of data gathered within the context of MIRACLE
2) Develop and test data warehouse technology that allows the tight and effcient integration and analysis of forecasting data with other types of data.

3.3.2 Results of the work package

We have made an in-depth analysis of the state-of-the-art in data collection and and data integration, in data analysis and query processing, as well ad in query optimization. This analysis serves allows us to understand the options for the design and architecture of the EDMS.Furthermore, we have studied and proposed techniques for aggregation of flex-offers and provided a specification.

3.3.2.1 State-of-the-art in data collection and analysis

The main challenges of the future electricity network are the active customer involvement and the better integration of renewable energy sources. The MIRACLE project has an objective to achieve both. Its approach is based on the real-time (or almost real-time) operation of the computer infrastructure that processes large number of micro-requests and performs scheduling and forecasting in real-time.

In the study, we presented the requirements for the MIRACLE infrastructure, and reviewed the available solutions in order to meet those requirements. We presented research results of horizontal and vertical data integration and proposed to make further investigation of materialized integrated systems and real-time data streaming systems. Although they both are relevant in the context of MIRACLE requirements, none of them can be taken as out of the box solution. We analyzed various aspects of the state-of-the-art data exchange and web scale data management systems, and suggested to use a new tailor-made electricity data analysis and collection system. Furthermore, relevant research results on query optimization and distribution techniques were described in the context of the MIRACLE scenario in order to minimize the amount of transferred data and ensure scalability of the system. However, we cannot use any of them in MIRACLE directly, thus additional research must be conducted in this field. The types of uncertainties and inconsistencies in the data were identified and methods handling them were reviewed. We also described existing systems in the energy domain and showed their relevance for the MIRACLE project.

The data collection requirements can be satisfied while taking advantage of materialized integrated systems and real-time data streaming management systems. System scalability can be achieved using the same materialized integrated system which is inherently distributed and forms a multi-tier data warehouse infrastructure. Some techniques from the area of early aggregation in sensor networks can be applied in order to reduce the amount of transferred data, thus reaching a real-time performance of the system.

We identified further research activities based on the current state-of-the-art in data collection and analysis in order to design the future electricity network, since there were no such large scale, highly reliable, precise systems built before.

3.3.2.2 Initial Specification of Data Collection and Analysis System

First, we analyzed the data collection and management system, a sub-system of the local energy data management system (LEDMS). The analysis resulted in a set of functional and non-functional requirements for the system. Based on the analysis, we described the design and architecture of the system and discussed the tasks of its sub-components.

Second, we presented several aggregation algorithms and discussed the benefits and characteristics.

Third, we proposed the functionality that will be implemented in the Version 1 (the first iteration, initial prototype) and the Version 2 (the second iteration, final integrated specification and prototype) of the system.

With respect to the algorithms for flex-offer aggregation (and disaggregation), we evaluated four aggregation algorithms and discussed their advantages and disadvantages. It turns out that static aggregation algorithms are relatively fast, but cannot provide a good compression, and dynamic aggregation is very flexible, but computationally expensive.

Static aggregation algorithms highly depend on aggregation settings, e.g., for shaping electricity profile, grouping micro-flex offers. As a consequence, if the same settings are applied for aggregation of multiple macro flex-offers, the aggregation component will produce quite similar macro flex-offers, e.g., all having flat profiles.

For scheduling function it might be advantageous to have more distinct macro flex-offers, since it would be able to rapidly adapt to new market conditions by shifting only few exceptional macro flex-offers. Thus, multi-result static aggregation was introduced. It allows choosing the other profile of macro-flex offer and provides some variety of profiles for the scheduling algorithm. On the other hand, multi-result aggregation algorithm provides even smaller compression rate since it is based on static aggregation approach (which is not very compressive) and produces multiple results. The dynamic aggregation algorithm can offer a good compression rate (any number of micro flex-offers can be combined into one macro flex-offer), but the associated flex-offer method is computational demanding and quite slow. The proposed hybrid aggregation approach is intended to combine static and dynamic algorithms and explore their advantages. The static approach is very fast, and dynamic one is very flexible. As a result, the hybrid aggregation algorithm is leveraging between fast and flexible properties, i.e., if one produces only few meso flex-offers after static aggregation step, then dynamic aggregation will be very fast but not flexible, and oppositely, if one has lots of meso flex-offers after the first step, then dynamic aggregation can offer lots of flexibilities, but relatively slow FOM method.

These properties of hybrid aggregation must be controlled through aggregation settings.

For the Version 1 of MIRACLE prototype, we decided to implement the static lossy aggregation approach since it offers fast computation and an acceptable compression rate. Although it discards some time flexibilities, aggregation settings can be used to work around this problem. Aggregation settings for grouping can be adjusted such that grouping of micro flex-offers is based on their time flexibility properties. For Version 2 of the prototype, we will use a hybrid aggregation algorithm since it offers a lot of possibilities named previously.

3.3.3 Summary of the progress

All goals of this work package have been achieved.

3.4 Forecasting (WP4)

For real-time scheduling of energy demand and supply flex-offers within MIRACLE, accurate and efficient forecasting of energy demand and supply is a fundamental precondition in order to take into account the future behaviour of energy demand as well as energy supply of renewable energy sources (RES). In this section, we briefly describe the main objectives of forecasting within the MIRACLE project as well as the work package progress in terms of concrete results, we have achieved so far.

3.4.1 Objectives of the work package

The general objective of this work package is the development of a general forecasting approach for energy consumption and production, which is tailor-made for the specific requirements of real-time scheduling in terms of necessary functionality and the intended system architecture of the MIRACLE project. In detail, this includes the following more concrete objectives:

- Review and adaptation of state-of-the-art forecast approaches for their application within the MIRACLE project,
- General MIRACLE forecasting approach with regard to the roles and processes of scheduling energy demand and supply in a distributed system architecture,
- Accurate forecast model types, tailor-made for forecasting energy demand and supply as well as flex-offer forecasting,
- Efficient forecast model maintenance strategies,
- System architecture integration (in particular with regard to scheduling and aggregation), and

- Integration of external information such as weather and sensor information for higher accuracy of forecasting.

3.4.2 Results of the work package

Based on the review and adaptation of state-of-the-art forecast approaches, we developed the general MIRACLE forecasting approach as well as we specified tailor-made forecast model types and model maintenance strategies. These results have been described in very detail within the deliverables D4.1, D4.2, and D4.3. Hence, in the following, we describe only briefly these conceptual results and the main conclusions of our extensive experimental evaluation, which implies the directions of important future work within this work package.

The general MIRACLE forecasting approach comprises forecast models for energy demand and supply, the system architecture integration and concepts for the continuous model adaptation in the presence of evolving time series. Essentially, we follow the traditional approach of model-based forecasting that relies on the steps model identification (select the forecast model), model estimation (determine the model parameters), and forecasting (use the trained model for short-term and long-term predictions), model evaluation (evaluate the error of the forecast model), and model adaptation (decrease the error by adjusting the forecast model). This enables reliable and efficient forecasting for the process of balancing energy demand and supply by scheduling energy flex-offers.

3.4.2.1 Forecast Model Types

Several approaches of energy demand forecasting exist, whereas only few approaches for supply forecasting could be found in the literature because supply forecasting is a new requirement imposed by the rapidly increasing amount of renewable energy sources. From a mathematical perspective, existing techniques of forecast models can be classified into autoregressive models (e.g., ARIMA), exponential smoothing (simple, trend, trend and season), and machine learning approaches. Furthermore, there is a separation into single-equation models (a single model describes the whole time series), and multi-equation models (logical time series decomposition and individual models for each decomposed time series, e.g., specific hour models).

In order to enable reliable forecasting of energy demand and supply on different levels of the system hierarchy within the MIRACLE project, which imply fully different requirements on the used forecast models, we decided to use two complementary models of different categories of these two classification schemes.

As our base forecast model types, we use (1) the EGRV-Model (Engle, Granger, Ramanathan, and Vahid-Arraghi) and the (2) HWT-Model (Triple Seasonal HWT Exponential Smoothing). First, the EGRV-Model (multi-equation, autoregressive) is known to produce high accuracy forecasts on time series with systematic patterns such as aggregated energy demand with its typical daily, weekly, and annual behaviour but also for aggregated energy supply. Second, the HWT-Model (exponential smoothing, single-equation) is used as a robust fall-back strategy for time series with strong variations such as RES energy supply on producer-level but partly also for energy demand on consumer level. Both models are specifically designed for energy data. Furthermore, we extended these models by concepts for long forecast horizons, the integration of calendar information, weather information, and context knowledge, error corrections as well as we introduced how to use these models for forecasting of MIRACLE flex-offers. Finally, our experimental evaluation has shown that all use cases of forecasting in MIRACLE could be realized appropriately by these two models. However,

on the level of individual producers (especially, RES supply) or consumers, there is still potential for further enhancements with regard to the forecast accuracy.
As our error metric, we primarily use a modified version of the SMAPE (Symmetric Mean Absolute Percentage Error) in order to allow for interpretable results in the sense of a percentage between real measurements and forecast values, where this accuracy is bounded by the interval [0,1]. The error metric has high importance because the parameter estimation (model training), the model evaluation, and the interpretation of results depend on it.

3.4.2.2 Forecast Model Maintenance

With regard to real-time scheduling, we want to reuse trained forecast models. For this purpose, and with regard to the evolving time series of energy consumption and production, incremental maintenance of forecast models is required. This prevents full re-computation of forecast models (which is a problem with high computational complexity) for all new measurements and thus, ensures efficient forecasting.
The training of forecast models is, essentially, the search for the best combination of the d parameter values of a forecast model with regard to minimizing the resulting error between forecast values and real values (training data). This results in a d-dimensional search space and thus in an exponential problem with regard to the number of model parameters. For this step of parameter estimation, existing work is mainly classified into local and global search procedures, where local optimization might have the problem of starvation in local suboptima but it can be solved more efficiently than global optimization. Similar to the use of two complementary forecast models, we use also two local and two global optimization algorithms. We have chosen parameter estimators, which all do not require a derivable function, in order to support arbitrary error metrics and forecast models. While Nelder-Mead (e.g., also used in R) and Hooke-Jeeves are commonly used local optimization algorithm, we additionally use global optimization procedures with the aim of preventing starvation in local optima. For this purpose, we use our tailor-made extended grid search framework and the known simulated annealing algorithm as a fall-back strategy. In addition, we support different model evaluation strategies (on-update, on-time, on-threshold, on-demand) in order to determine when to trigger model adaptation. As the default, we use a combination of on-time and on-threshold in order to reduce the risk of wrong parameterization of the individual evaluation techniques. Once, model evaluation was triggered, forecast model adaptation techniques are used in order to take into account context knowledge of former parameters for efficient parameter re-estimation. With regard to preliminary experimental results concerning accuracy and efficiency, we use old parameter values in combination with our extended grid search as our default method. However, especially, with regard to parameter-estimation for multi-equation models over large data sets many issues for future work exist that might increase the performance of model maintenance.

3.4.3 Summary of the progress

To summarize, the results of the deliverables D4.1-D4.3 comprise an initial specification of all technical aspects with regard to the work package objectives. This includes the review and adaptation of state-of-the-art forecast approaches, the specification of the general MIRACLE forecasting approach, accurate forecast models for energy demand and supply (incl. flex-offers), efficient forecast model maintenance (evaluation and adaption) strategies, as well as initial concepts for the system architecture integration in data management systems and the efficient integration of external information from heterogeneous sources.

As future work, we will further investigate the forecast models and maintenance strategies with regard to enhancing their accuracy and efficiency. Further refinements are needed with regard to the system architecture integration in the sense of an integrated architecture with scheduling and aggregation, but also the integration of external data. In conclusion, the results achieved so far are a meaningful base for the other work packages and a reasonable starting point for further enhancements, which are necessary to meet the overall MIRACLE project objectives.

3.5 Scheduling and Negotiation (WP5)

3.5.1 Objectives of the work package

The objectives of this work package are to analyse the state-of-the-art in energy systems scheduling and energy negotiation, to formulate scheduling of energy production and consumption as a constrained optimization problem, and to specify an iterative approach that integrates scheduling and negotiation as two of the MIRACLE key functionalities.

3.5.2 Results of the work package

The results of this work package are a review of the state-of-the-art in scheduling and negotiation in view of their potentials for the MIRACLE conceptual and infrastructural approach, and the specification of the scheduling and negotiation framework.

3.5.2.1 State-of-the-art analysis

Regarding scheduling, our state-of-the-art report first presented a common type of scheduling problems together with their properties, and introduced some characteristic aspects of the scheduling domain. It then focused on scheduling in energy sector where it identified particular problems: generation scheduling, unit commitment and economic dispatch. Finally, it reviewed methods applied in solving scheduling problems in energy sector, including deterministic and meta-heuristic techniques, with a special attention to the approaches for deregulated markets.

The state-of-the art survey on negotiation approaches started with an introduction to negotiations and two negotiation types: bilateral contracts and auctions. Energy exchange auctions were then described with the focus on hourly bids, block bids, pricing and trading phases. Examples of multi-agent negotiation systems were then presented, taken from related projects and the literature.

Based on this review, meta-heuristic optimization techniques were identified as an appropriate algorithmic platform to be adjusted for the MIRACLE scheduling framework. Their suitability is due to robustness and ability to find near-optimal solutions in uncertain and changing environments. Concerning negotiation, the existing mechanisms will have to be extended with the capability of handling the time attribute of micro-requests for energy demand and supply, and the ability to interact with the scheduling framework in two directions: taking a preliminary schedule to define negotiation goals and applying negotiation to adapt and improve the schedule.

3.5.2.2 Specification of the scheduling framework

Scheduling in MIRACLE occurs after the accepted flex-offers are aggregated and the forecasted data for open contracts is obtained. The result of scheduling is flex-offer assignment in the form of a schedule where the flexibilities of the aggregated flex-offers are fixed (see Figure 5). After scheduling, the flex-offers are disaggregated and flexibilities of elementary flex-offers are fixed as well.

The scheduling framework was specified as a rather independent module that requires certain input (the scheduling interval, the energy exchange, accepted aggregated supply and demand flex-offers with prices, flex-contracts, imbalance prices, open contracts supply and demand forecasts) and provides the needed output (aggregated flex-offers with defined start and end, number of intervals, and energy amount for each time slice). Therefore, from its point of view, a request for creating a new schedule is treated in the same way as a request for rescheduling.

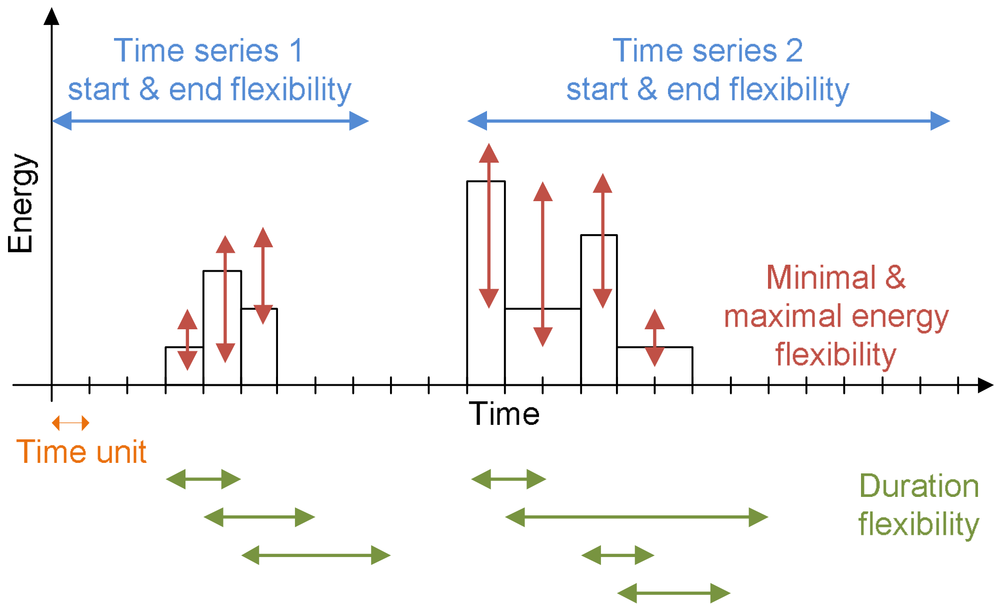

Figure 5: Flexibilities of flex-offers that need to be fixed with scheduling

Through examples ranging from simple to advanced scheduling problems, the scheduling of energy demand and supply was stated in terms of the decision space, the form of schedules, constraints to be satisfied by feasible schedules and an example of optimization criterion. Various algorithms for solving these problems have been outlined and evolutionary algorithms were identified as suitable basis for tackling the problems of high complexity.

3.5.2.3 Specification of the negotiation framework

Negotiation in MIRACLE starts from generating a new flex-offer with parameters describing such constraints as amount of electricity, price and possible time of execution as an interval. A BRP has to make a decision by either accepting or rejecting it and then notify the prosumer before the time specified in the flex-offer. Rejection means that the BRP is not able to match this flex-offer under the specified constraints and this flex-offer is not valid since this moment. The prosumer however can generate a modified flex-offer taking into account the reasons of rejection sent along with the rejection message. In the case of acceptance the BRP sends an acceptance notification to the prosumer the flex-offer is converted to a legal contract which guarantees that the specified amount of electricity will be produced or consumed.

The decision about accepting or rejecting flex-offers is made taking into account the current balance between supply and demand which includes such parameters as internal supply-demand (within this BRP), prices at MBA level (between BRP), current electricity prices on open market, goals and constraints of the BRP. For each moment in time, the price setting module computes a preferred price curve (fare prices) which is then used for accepting or rejecting flex-offers.

Accepted flex-offers are collected and then processed as a group. They are aggregated, then scheduled and finally disaggregated. The scheduling module assigns concrete execution time for aggregated flex-offers where the goal is to optimize various functions like total profit or amount of electricity. Disaggregation procedure assigns concrete execution time to each individual flex-offer. Finally, the assignment message is sent to the prosumer to notify it about the time when consumption or production will start. The process of negotiation between the prosumer and the BRP is shown in Figure 6.

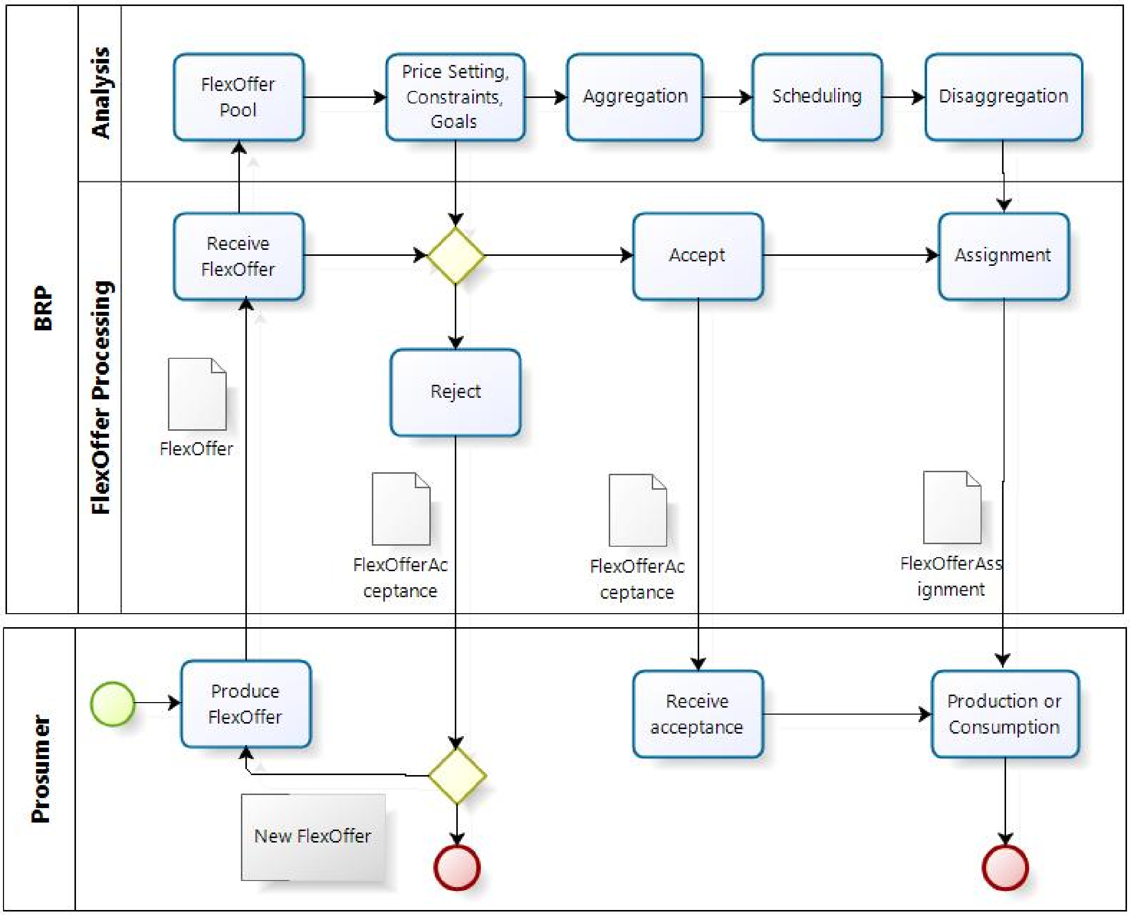

Figure 6: Negotiation process in MIRACLE

3.5.3 Summary of the progress

The state-of-the-art in scheduling and negotiation in energy systems has been reviewed and the initial versions of the MIRACLE scheduling and negotiation frameworks were specified. These specifications cover the objectives and procedures of the two frameworks, their relation with other MIRACLE core components, i.e.data aggregation / disaggregation and forecasting, and outline the algorithms to be used. The specifications will be refined to cover the objectives formally and the algorithms in greater detail in D5.3 which is due in M16.

3.6 Trial test integration & validation (WP6)

3.6.1 Objectives of the work package

The objective of this work package is the creation of an appropriate realistic environment in which the developed system methodology and algorithms can be deployed and evaluated under trial test conditions. The testing environment should allow a broad range of external parties to connect their equipment and applications to the environment and also to evaluate the impact of the developed technology on the roles in the MIRACLE energy scenarios: More specifically:

- For TSOs the possible use of aggregated energy supply/consumptions data on forecasting for the improvement of scheduling and of the energy insertions into the grid.
- For LDEs the possible use of improved real-time data on energy-price supply and demand for the improvement of the trading business processes and to the optimisation of the energy generation process.
- For community consumers the possible use of data on energy-price supply and demand for reducing energy costs including the derived functional requirements and constraints for IPM for making best use of its role as an active agent on the grid

3.6.2 Results of the work package

In this work package, the results produced so far has to do with the current systems in existence as well as the trial sites where the testing of the development system will take place. Those systems are described to their background, characteristics and specifics so that capabilities, possibilities and alternatives to be identified. Moreover, the approaches, solutions and experiences of other similar projects have been investigated. Projects that are in the same general field as the Miracle project, and which are now in the developing or concluding phases and which – to the extent that the concepts and solutions are already formulated and available for interested parties outside the project partners – could be used as references for state-of-the-art in the neighbouring and cross-section fields with Miracle are described.

3.6.2.1 Current Systems Description

3.6.2.1.1 MeRegio Project

MeRegio standing for “Minimum Emission Region” was set up in the course of the “E-Energy Program” of the Federal Ministry of Economics and Technology of Germany with the objective to develop regions with power supply systems that are optimized with respect to their greenhouse gas emissions. The project’s approach is mainly based on three components:

- E-Energy marketplaces, which bring together all energy market roles (e.g. utilities, owners of distributed generation, end customers, and intermediaries) for an efficient allocation of energy and system services;
- an innovative technical energy infrastructure (smart grid), which provides the foundation for future proliferation of distributed generation and the development of pervasive demand side management;

- and a powerful information and communication infrastructure that links the physical infrastructure to the marketplaces, which allows to operate the infrastructure according to the specific market situation at hand.

The project focuses on developing technical and economic concepts, which implement the three components and puts them to work in a “real” pilot region with 1.000 participants in the areas of Göppingen and Freiamt (Baden Württemberg, Germany). Furthermore, the project plans to develop a minimum emission certificate for the regions using new specifications and standards based on the experiences gathered in the field test. At the end of the project this certificate is planned to be available for all regions which actively reduce their greenhouse gas emissions.
The project integrates conventional power plants, distributed combined heat and power plants (CHP), distributed energy storage systems, as well as renewable energy sources like wind turbines and photovoltaic systems mostly at customer level. Demand response will be achieved via various regional energy marketplaces for the allocation of energy and ancillary services resulting in dynamic rates, control signals for home appliances, and an overall power management.
In the project MeRegio the efficient coordination of energy supply and demand will be developed and tested using 1.000 existing EnBW B2C and B2B customers. Different mechanisms are to be implemented for matching supply and demand such as dynamic tariffs that provide an incentive to shift loads, or auctioning mechanisms that can help establish new business models, such as aggregators who bundle the Distributed Energy Resources (DERs) and resell capacities. Existing and emerging technologies for DER integration will be applied including a broad range of DER types, communication platforms for smart metering (at B2B and B2C level) and distribution automation.
The MeRegio data will be used as an input for the trial cases of Miracle System on TSO and LDE level.

3.6.2.1.2 CRES test bed

CRES Experimental Microgrid is used in order to study the performance of stand-alone or interconnected hybrid systems and micro grids, but also as a simulator of autonomous mini-grids, like the power systems of islands. For this scope, the system is equipped with a number of devices which offer lots of capabilities for various cases of study. The most important advantages of the system are the following:

- It integrates a number of devices which cover a wide range of study cases (stand-alone or interconnected, single or three phase operation).
- It utilizes many innovative systems with plenty of abilities towards the smart grids context.
- The power level of the micro grid is high enough to give realistic experimental results (especially when micro grids or residential consumers are considered).
- It provides easy access to the operation of all of its components through a user-friendly graphical environment locally and through remote computers.
- It provides a wide range of data measurements which cover a large number of applications.

Regarding its configuration, three layers are distinguished, which are in interaction: a) the power components layer which includes all generators, consumers and the electrical installation parts of the micro grid b) communication and control layer consisting of data acquisition and control units, and c) the interface console used for the supervision and control of the system.

The microgrid's power components layer consists of:

- Photovoltaic generators of two independent PV arrays with multi-crystalline silicon modules and capacities of 1.1 kWp and 4.4 kWp respectively.
- Photovoltaic inverters for the interconnection of PV arrays to the three phase power line.
- Battery storage with two separate battery banks for the storage of the produced electricity.
- Battery inverters for the interconnection of the batteries with the AC grid.
- Diesel generator of 400 VAC, 50 Hz, 12.5 kVA.
- Loads including a load bank of resistors totaling 20 kW, a three-phase capacitive load, a three-phase induction motor of 2.2 kW and two small single phase water pumps.
- Load controllers for shedding of loads
- Reverse osmosis desalination unit of 3.5 kW maximum consumption.

The microgrid's communication and control layer consists of the system Interbus based on the serial RS-485 protocol. All power units are accompanied by analog and digital I/O devices that communicate through the Interbus protocol, transferring data to the interface console and control signals to all controllable devices as it is shown in figure 2.

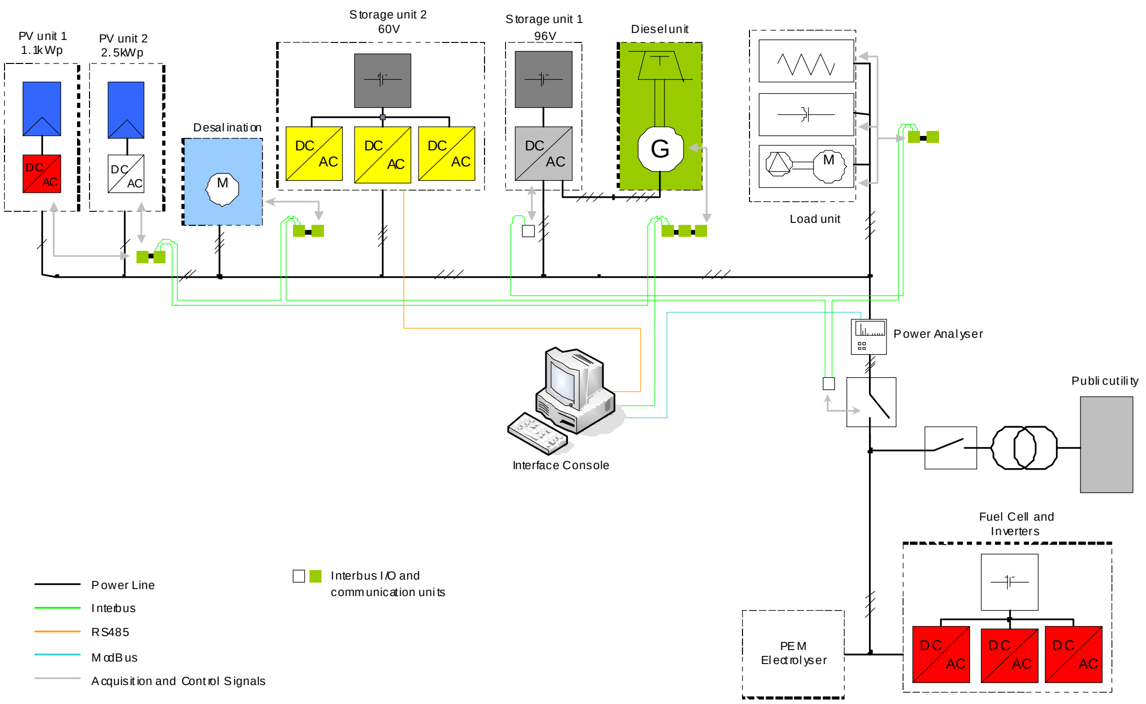

Figure 1: Block diagram of the experimental micro grid

The microgrid's Graphical interface and supervision console is developed in Lab VIEW providing the user with capabilities such as easy access to all the devices, data acquisition monitoring and storage to files for further processing and ability of operation remotely through web publishing tool.

For the needs of Miracle project a number of tests under real consumption/production conditions will be performed. For this purpose, the use of the building of PVs at CRES is also proposed as a test field.
This test field consists of a single floor building of 440 m^2 and houses, the department of PVs and DER systems and it comprises offices and laboratories. On the roof a PV array of 22 kWp total capacity is installed, where the main electricity consumption of the site is due to the central heat pump used in order to cover heating/cooling needs during the year. The pump is accompanied by a water circulation pump and fan coils across the building. Apart from the heating/cooling system the rest of electricity consumption is due to lights, computers, laboratory and office equipment, etc.

3.6.2.2 Projects related to the Miracle project

3.6.2.2.1 FENIX project

FENIX investigated the possibility of operation and management of distributed energy sources on the level of electricity distribution network would be carried out in the same manner as it is presently done on the level of the transmission network. The DER were treated as a virtual power plant, emphasizing their new importance in assuring the stability of the grid. Distributed energy sources are also central to MIRACLE project, since the micro-request based trading of energy implies a number of prosumers.

3.6.2.2.2 EU-DEEP project

EU-DEEP project has part of its activities and studies focused on Demand Side Management and Load Aggregation, similarly to MIRACLE. Especially two of the five conducted experiments included testing of aggregation of micro-CHPs in the German residential sector, while in Greece the feasibility of decentralized control architecture for load and generation aggregation

3.6.2.2.3 AEOLUS project

AEOLUS is relevant to Miracle primarily through its decentralized controlling techniques. Both in Miracle and AEOLUS, systems at low levels are controlled based on plans that are established at high levels. AEOLUS's wind farm controlling methods might be used to support the scheduling of Miracle to make subsystems collectively react to instabilities based on real-time measurements in the electricity network, related to MIRACLE WP5.

3.6.2.2.4 MORE MICROGRIDS project

From a general perspective, MoreMicrogrids and Miracle have similarities because both projects focus on the distribution grid. The general objective of these projects is the development of strategies and algorithms for obtaining balance between demand and supply which is one of the most critical challenges in the development of future grids.

3.6.2.2.5 ADDRESS project

Both projects follow the same objective of balancing and shaping/sharing energy load in order to achieve flexible and reliable energy provisioning. Furthermore, both projects use the price as a regulatory metric. Also, both projects focus on distributed, scalable communication architecture (in the sense of a SW system) with different levels of aggregation and optimization.

3.6.2.2.6 EDISON project

EDISON idea of shifting demand to a different time only applies for new and additional demand (as recharging electric cars is not part of the current demand) but not for the general demand that always exists. Also the possibility to be able to “buffer” energy when balancing the grid is exploited. In Miracle such buffering is not possible and the grid is balanced only through mid and long term scheduling of demand/supply. EDISON does not have any concept of stated, expected demand, like the micro-requests of MIRACLE, and seem to only consider demand at a rather aggregated level.

3.6.2.2.7 DLC-VIT4IP project

The developed system of DLC+VIT4IP can be a precondition for the MIRACLE micro-request-based approach without the need for DSL (domain specific language). For this reason the aimed architecture might be an alternative for the physical implementation (HW) of data transfer within the distributed MIRACLE system architecture.

3.6.2.2.8 Smart House/ Smart Grid

The interfaces developed on Smart House/ Smart Grid are technologies for energy management that allow controlling appliances and are therefore related to MIRACLE. Also, the Power Matcher component is a hierarchically organized market-based control concept for matching of supply and demand. It is related to MIRACLE negotiation. The three concepts and their relation to the MIRACLE project are described in this section.

3.6.3 Summary of the progress

The specifications and capabilities of the trial test sites have been well explored and defined. Also, the relation of MIRACLE with the similar project have been identified and into the next months meetings with their project teams and common presentations are about to happen. From the beginning of the second year of MIRACLE the planned trial cases focused on three actors of electricity grids, TSO/DSO, LDE, and the community of individual households are to be designed along with each control component for each actor case. Discussion and work programming is set to be initiated on the first MIRACLE project meeting which is to be held on the early months of 2011. The work for the trial cases design is to be documented on D 6.2 deliverable “Specification and design of trial cases” programmed on M21.

3.7 Standardization (WP7)

3.7.1 Objectives of the work package

This work package runs in parallel with the other packages during almost the entire lifecycle of the project and focuses on standardisation, dissemination and exploitation of the project results. Its main objectives include the preparation of specifications and proposals for a formal standard to be maintained even after the project’s lifetime, the widest possible dissemination of project results to both the research community and industrial parties, and the analysis of further exploitation methods, including the drafting of appropriate exploitation plans.
It is important to note that this WP covers the combined efforts of all partners. While the respective task leaders are responsible to ensure that necessary actions are coordinated appropriately, all other partners will nevertheless contribute to these tasks with their very individual dissemination & exploitation efforts. In accordance with the package’s title, the involved partners will be assigned to the three task forces

- Standardisation
- Dissemination

- Exploitation.

The standardisation task force aims to deliver a specification that (1) can be used as a thorough basis for a formal standard of a European standardisation body, and (2) is supported by the main industry and government stakeholders in the area of energy supply and demand. We will arrange for reviews by external stakeholders and integrate their suggestions into a formal standard proposal. The review procedure is of an open design and vital for industry commitment. We need to ensure that a standardisation body takes responsibility for our standards beyond the lifetime of the MIRACLE project. For this purpose, a concrete roadmap will be defined to help us organise both the preparation of our standardisation efforts and the actual standardisation activities.

In order to obtain an open standard for the events involved with data aggregation and control of energy demand and supply, we collect the specifications from other work packages and transform them into a consistent set of standard documents. Thereby, our focus is to select those parts that should eventually form the formal standard and combine them into a complete, correct, compact and non-ambiguous standardisation proposal. This means that WP7 will not add technical details to the specifications from other work packages. Instead, we organise the process of generating a first-draft standard specification such that there is consensus among the partners within the project. This initial version is then used as a basis for discussion with external stakeholders. In order to get an open standard specification that can be easily adopted as a standard after the lifetime of the project, these external stakeholders are invited to participate actively in bringing in requests for changes. Once request for changes have been collected, decisions will be made on whether or not they will be accepted. Thereby, the technical know-how of partners involved in WP1 and WP2 is needed, and based on their evaluation of the requests for change, a new version of the MIRACLE standard will be developed.

The dissemination task force will ensure that MIRACLE project results are published and disseminated on the widest level possible, both in the scientific and the industrial community. This includes appropriate quality assurance processes and the preparation of roadmaps to spend our budget as efficiently as possible while reaching the broadest possible audience at the same time.

The exploitation task force, finally, is responsible to prepare and coordinate appropriate exploitation activities in order to ensure that MIRACLE results will have a lasting impact on existing and future products and services long beyond the lifetime of the MIRACLE project. For this purpose, potential exploitation venues and projects/products will be evaluated for their suitability and respective actions will be initiated.

3.7.2 Results of the work package

The results of dissemination and exploitation are described in separate chapters.

3.7.2.1 D7.1: Standardisation Roadmap

Deliverable D7.1 was delivered in June 2010 and presents a roadmap towards the standardisation of the MIRACLE specifications for the exchange of information around management of energy demand and supply. A long list of 15 potential standardisation organisations has been set-up and briefly described with respect to three criteria: type of standardisation organisation, its geographic scope and focus on energy management. From this list a short list of 4 different standardisation organisations has been selected. These are CEN/CENELEC, IEC, IEEE and the combination of ebIX and ENTSO-E. For these organisations, an additional four criteria have been described, namely openness of organisation, complexity of procedures, impact on the energy sector and potential success of standardisation of the MIRACLE specifications.

Based on this set of seven criteria in total, CEN/CENELEC has been selected as the target standardisation organisation. The MIRACLE project will strive to get a so-called CEN Workshop Agreement (CWA) as the standardisation product at the end of the project. The roadmap towards this CWA is worked-out in more detail and the coordination with CEN/CENELEC during the project is described. Thereby, the CWA process is aligned with the original planning of the WP7 deliverables of MIRACLE. The resulting CWA can be used after the lifetime of the MIRACLE project as a basis for further standardisation towards a European Norm (EN), which is the highest level of formal standardisation to be achieved within Europe.
The main conclusion and advice is that the MIRACLE project should adhere to the roadmap sketched in this document and try to align the WP7 activities during M18 and M36 with a CWA process at CEN/CENELEC.

3.7.3 Summary of the progress

WP7 is making the first steps on a path towards standardisation of the MIRACLE specifications. The intention is to start a CEN Workshop Agreement (CWA) to bring in the specifications and involve the most important stakeholders in the area of smart grids. Since D7.1 was produced in June 2010, a lobby has started for such a CWA and especially for the necessary funding of a national normalisation institute that has to provide for the secretarial work of such a CWA. Up to now, this funding has not been found, as it has also not been reserved for in the MIRACLE project itself. Therefore, several other activities have been initiated.
First, the contacts with ENTSO-E and ebIX have been strengthened in order to study the possibilities for adopting the MIRACLE specifications as ebIX specifications. If so, this can be considered as a non-formal pre-standard.
Secondly, the project has gotten into contact with a Joint Working Group of CEN/CENELEC on a Roadmap Report for standardisation of Smart Grids. The work on the MIRACLE specifications has become part of this roadmap report. In this way, the MIRACLE project is visible to the European standardisation community as being active on developing specifications for matching flexible energy demand and supply.
Thirdly, in parallel, a mandate on smart grid standardisation is in preparation by the European Commission. It is hoped for that the roadmap report of the CEN/CENELEC JWG is used as a basis for the response to this mandate. Thereby, this gives an opportunity to standardise the MIRACLE specifications in a CEN/CENELEC working group that is activated as a result of this mandate.

4 Dissemination in 2010

The dissemination activities are undertaken in each of the different work packages. This has led to a website, some publications, cooperation with other initiatives and with standardisation bodies. See section 4 for more details.

4.1 Website

The MIRACLE website is accessible via http://www.miracle-project.eu. It contains general information about the project, the consortium and summaries of deliverables and other publications.

4.2 Publications

Berthold et al: Exploiting renewable by request based balancing energy demand and supply; Proc. of the 11th IAEE European Conference, August 25-18, 2010, http://www.iaee2010.org/?q=node/83

Ulrike Fischer, Matthias Boehm, Wolfgang Lehner: Offline Design Tuning for Hierarchies of Forecast Models; Appears In: Proceedings der GI-Fachtagung für Datenbanksysteme in Business, Technology und Web (BTW 2011, Feb 28 – Mar 4 2011, Kaiserslautern, Germany), 2011.

4.3 Cooperation with other projects and initiatives

MIRACLE cooperates with other projects in the smart grid area namely MEREGIO, SmartHouse/SmartGrid, DLC-VIT4iP, and NOBEL. An overview about related projects is given in deliverable D6.1 "Report on current systems".
So far, we have participated or plan to participate in the following cooperation activities:

- May 2010, SAP Research Karlsruhe: Presentation of MIRACLE project to SAP colleagues working in the MEREGIO, SmartHouse/SmartGrid and Nobel project
- November 2010, Technische Universität Dresden: Presentation of the MIRACLE project at the consortium meeting of the DLC-VIT4IP project on November 23rd, 2010

5 Exploitation in 2010

Exploitation activities have not yet been initiated as the results are not yet mature enough. On the other hand, contact with main stakeholders on the progress of the project is maintained. In that way, usage of the MIRACLE results after the lifespan of the project is enabled as much as possible.