

DEZENT: A Safety-Critical Real-Time Approach for Decentralized Electric Power Management

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1. Introduction

The major problem for establishing technologies based on solar or wind power, or on renewable energy sources, is an adequate management for the densely networked power sources. This paper describes the first phase of the combined R&D project DEZENT to be funded shortly, between the Schools of Computer Science and Electrical Engineering at the University of Dortmund, devoted to decentralized and adaptive electric power management through a distributed real-time multi-agent architecture. A novel research problem to be specifically faced in this respect is the *appropriate handling of unpredictable consumer requests or producer problems*. Hence a key result for its solution is that the agents can be most adequately supported through the reactive and adaptable real-time services in the safety-critical operating system MELODY (see [WeL97, WLMR99, WBF01] for selective reading). We briefly outline a two-stage distributed negotiation algorithm, for day-ahead planning and handling of unpredictable power needs and supply situations. Through a 3-year experimental study we will evaluate our claim that both individual/ local consumer and global production and distribution costs will be comparably lower than under a centralized management, let alone their superior flexibility and reliability.

2. MELODY

The MELODY project originated in 1988 from unpredictable safety-critical, and equally reliability needs, encountered in military warfare systems. It was funded by General Dynamics. In order to dynamically accommodate such conflicting requirements completely integrated and adaptive service functions had to be designed. Due to the complexity of the endeavor we invented a heuristic modeling and analysis methodology called *Incremental Experimentation*. Fig. 1 represents a very compact scheme of the MELODY architecture displaying both standard and some of the novel integrative services at each site, like the File Assigner, Run-Time Monitor, and their adaptive integration algorithms. (For details please refer to [WeL97].) In this context we consider (control) tasks, while originating at a specific site and occurring aperiodically, to become increasingly critical as their instances con-

tinue missing their deadlines, up to a task-specific limit after which the next upcoming instance's deadline is *essentially critical* or *hard*. (Consider e.g. a shutdown control operation in a nuclear reactor.) In more recent stages the MELODY model was enhanced to provide for reactive services (based on a considerable extension of the *similarity* concept), for both tasks and transactions. Extensive comparative evaluations of traditional concurrency control algorithms and their adaptive extensions proved very convincingly both the adequacy and efficiency of the novel system services (e.g. [WLMR99, WBF01]).

3. DEZENT

In the DEZENT project we started from a power grid structure as to be frequently found e.g. in central Europe (see fig. 2). Power supply is provided through

- long-distance energy transport in a voltage range of 110-380 kV;
- networked sources covering a suburb, or at least larger sections of it (10 kV);
- bus-like network structures covering subdivisions (4 kV).

During the first project phase we will limit ourselves to the producer/ consumer problems within a balance responsibility entity, i.e. a 10 kV power area (see fig. 2). We start with a few key features:

- Producers may be consumers and vice versa.
- Consumer/producer groups tend to be autonomous, exercising market behavior as one characteristic only separate from individual/groups needs and potential, respectively.
- The group structures are certainly a result of the power grid structures available. In contrast, the balancing and negotiation structures (see fig. 3) constitute logical structures that are defined on the ground of *communication/negotiation needs*. For the purpose of our compact discussion we focus on the logical structures by largely abstracting from the underlying power grid.
- Negotiation on behalf of producers and consumers will be done in a distributed fashion, by a variety of agents: *consumer* and *consumer*

group agents, producer and producer group/virtual power station agents. In addition there are agents involved on higher managerial levels (see fig. 3), such as for negotiating between different producer/ consumer groups, up to the network segment level, or even to the medium power network level (balance responsible entity). Also auxiliary functions are carried out by special agents: There are *shopbots agents* which search for matching offers, on behalf of consumer/consumer groups or other negotiating agents. *Pricebots* are agents that combine shopbot information for allowing producers to adjust their price levels (see also [GK99, GK01]).

- There is also a novelty in how we deal with real-time constraints for pricing. A typical request from a consumer could occur in the following example: “In order to take a shower I would like electric energy supply of 26 kW over the period of 1 h between 7:00 and 9:00 a.m. as long as the rate is at most 8 ct/kWh.” The understanding is normally that if the price limit cannot be met by the time line the transaction will be undone since the customer should not lose money (**firm deadline**). The disadvantage here is that the shower may remain cold when the consumer opens the valves. If one adds as a *negotiation range*: “between 8 and 15 ct/kWh” then *adaptive* efforts can be made to make sure that the shower is hot. Of course, as the deadline for the possibly iterative negotiation process (with deadlines for each step) is approached closely the specified consumer deadline *becomes hard or essentially critical*. Thus we consider this deadline to be **conditionally hard** yet through appropriate adaptive transaction support there is a real chance of *satisfying the customer*. Finally assume another extension of the request of the form: “between 8 and 15 cts/kWh but up to 19 cts/kWh of the power sources are ecological”. This would no longer call for scalar measures: also *logical (qualitative)* requirements have to be met. We call the combination of scalar and qualitative measures **relevant measures**.
- The agents’ task is to satisfy real-time consumer requests that call for, or are based on, relevant measures. Similarly producers will present power supply offers under relevance constraints. Since the agents are to be highly reactive a both adaptive and reactive operating system support is needed for carrying out transactions of which the instances occur in an unpredictable manner. This service is just provided through the adaptive real-time and safety-critical operating system MELODY where the measures allowing for system *survivability* just constitute the dependable multi-agent support for handling real-time requests

calling for relevant measures under conditionally hard deadlines (see section 1).

The multi-agent structure is highly complex. Due to page limitations we will therefore only give an outline for one of the distributed algorithms presently under investigation.

The DEZENT_1 Algorithm.

The algorithm is executed in 2 modes or stages: A **Day-ahead Planning Procedure** (every hour for a range of 24 hours ahead) and a stage where unpredictable consumer needs or potential power breaks or surplus are to be accommodated (**Unpredictable Needs**). The latter modifies the day-ahead plans and may even influence the subsequent plans. Unpredictable requests will be handled as they arise. (There are different interrupt models.)

Stage I: Day-head Planning

- 24-hour schedules from consumers and producers are combined into profiles of consumer needs and producer potential, for each distributed group.
- Then there will be a balancing procedure in case of insufficient match of profiles: Producers and/or consumers rearrange their schedules (so as to find a “local” match in each group) within predefined ranges.
- If this has been achieved a contractual agreement (price and delivery profile) between consumers and different producer sources (wind/solar power, fuel cell, combined district heat and power station) and their different pricing requirements will be negotiated. (Base-line solution: one price level for all sources.) Technical constraints to be observed: smallest amounts (non-divisible quantities) of power to be produced, minimum daily income, up and down range rates. The negotiation in this initial approach proceeds according to [CCF+01].
- If a balance within a group has not been achieved negotiation agents on the next higher level will take over by organizing a balance through reserve capacities in other groups within their range. *Please note that an energy reserve potential (e. g. through fuel cells) will be maintained both for local and strategic (balance responsible entity) purposes*. The negotiation agents would rely on the information on the group profiles as accumulated in step a).
- The extension described in d) would possibly be extended to still higher levels even including the public network. In our current phase the negotiators on each higher level will calculate a uniform price level for electric power provided from their substructures. In the phases to come negotiations of agents will be differentiating among sources in different substructures.

Day-ahead planning is needed due to technical constraints regarding power sources: combined

district heat and power stations need a considerable amount of time for reaching their full production level as much as for scaling power down/turning off. At the same time the daily look-ahead profiles are quite inaccurate as a negotiation basis, in particular for (small) consumer groups. In order to adequately take care of the considerable amount of unpredictable needs or power break-ins/surplus the distributed negotiation algorithm has a second stage where it is active in handling unpredictability.

Stage II: Unpredictable Needs

Unpredictable needs are typically urgent, and so are power supply problems since a decision about early downscaling power means to minimize the waste of energy. In our current model we consider all unpredictable requests, offers etc. as urgent. Consequently the problem for negotiating delivery of power at “affordable” prices, and by meeting a deadline on short notice becomes increasingly hard. So do the deadlines for the negotiation processes. (As an example, consider a customer coming up with a request for taking a shower within the next 30 sec assuming that heating is done electrically, i.e. after 30 sec an *immediate* demand for 23–26 kW would arise, involving numerous technical electric problems.) In the MELODY terminology the deadlines become essentially critical [WeL97]. In [AHDJ01], a *state of desperateness* will be reached shortly before such a deadline expires. In order to give a basis for a satisfactory solution in due time (such as to avoid cold water pouring from the shower) the customer would indicate in advance a maximal affordable price.

Due to the urgency, unpredictable needs or surplus states are handled as problems between individual consumers and (groups of) producers, or of individual producers and (groups of) consumers. Negotiations are taking place within the whole balance responsible entity (even beyond if need requires) through the negotiation agents, thus neglecting the hierarchical structure.

Work-in-Progress and Conclusions

There is no question that the decentralized and adaptive management for completely proposed power production as proposed here is more reliable than a traditional centralized (hierarchical) system, in particular since consumers are at the same time producers who have a substantial interest in organizing their business in a highly autonomous way. Since they may at any time, directly or through flexibly setting their needs and negotiation frames, exercise their privileges there is a reasonable potential for achieving lower costs for individual consumers than under centralized management and production which are based on long-term (1-year) power consumption profiles. In a completed experimental study based on more elementary negotiation algorithms we have also evaluated our claim that the *overall* production costs can be well expected to compare favorably to the traditional pro-

duction and management practice. While we have now set up negotiation algorithms as outlined in section 3 for a broad and comparative evaluation this is subject to an 3-year research effort in incremental distributed experimentation.

It should be noted that the installation of windmills (in the 5 MW range), of solar panels, or of fuel cells is heavily subsidized in several European countries thus stimulating technological developments and creating a strong drive to change (over a span of 30–40 years) the whole landscape of power production as well as the habits of power consumption. (So far, in Germany already 9% of the total energy consumption originates from ecologically clean or renewable sources.) To our knowledge, DEZENT is the first *integrated* R&D effort to lay the needed foundation for this purpose. We substantially rely on the matching support structures of the reactive and adaptive real-time operating system MELODY.

References

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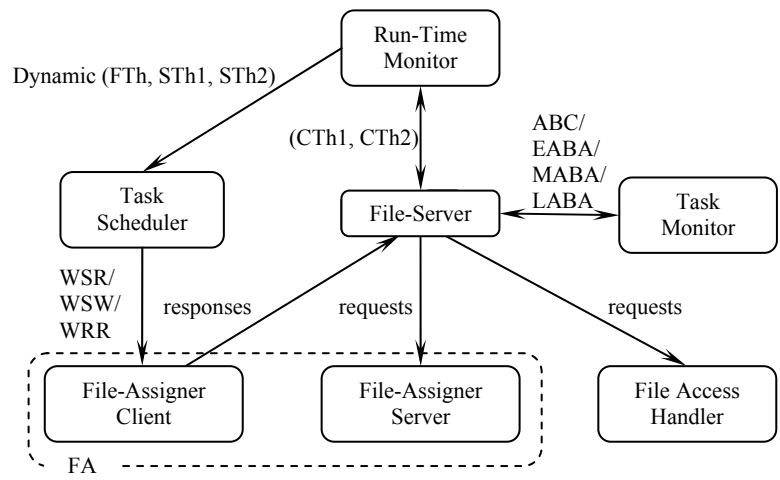


Figure 1: MELODY Architecture

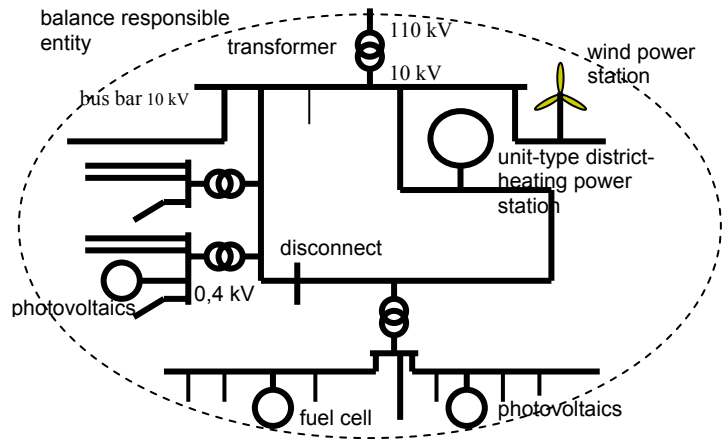


Figure 2: Power Grid

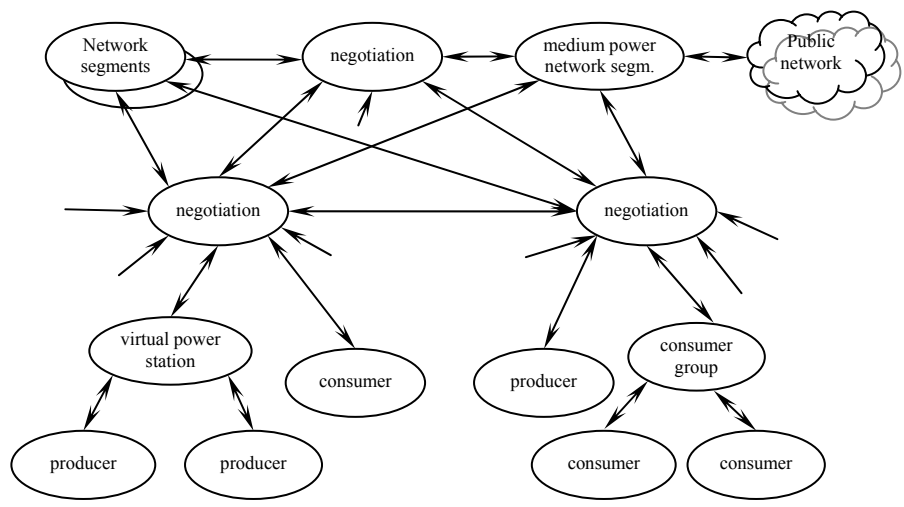


Figure 3: Network of Agents