Real-Time Multi-Agent Support for Decentralized Management of Electric Power

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Abstract

Establishing clean or renewable energy sources involves the problem of adequate management for the networked power sources, in particular since producers are at the same time also consumers, and vice versa. We describe the first phases of the joint R&D project DEZENT between the School of Computer Science and the College of Electrical Engineering at the University of Dortmund, devoted to decentralized and adaptive electric power management through a distributed real-time multi-agent architecture. Unpredictable consumer requests or producer problems, under distributed control or local autonomy will be the major novelty. We present a distributed real-time negotiation algorithm involving agents on different levels of negotiation, on behalf of producers and consumers of electric energy. Despite the lack of global overview we are able to prove that in our model no coalition of malicious users could take advantage of extreme situations like arising from an abundance as much as from any (artificial) shortage of electric power that are typical problems in “free” or deregulated markets. Our multi-agent system exhibits a very high robustness against power failures compared to centrally controlled architectures. In extensive experiments we demonstrate how, in realistic settings of the German power system structure, the novel algorithms can cope with unforeseen needs and production specifics in a very flexible and adaptive way, taking care of most of the potentially hard deadlines already on the local group level (corresponding to a small subdivision). We further demonstrate that under our decentralized approach customers pay less than under any conventional (global) management policy or structure.

Keywords: safety-critical, real-time systems, embedded systems, distributed systems, multi-agent systems, electronic negotiations, electric power distribution and management

1. Introduction

Renewable energy production. Traditionally, electric power production and distribution are handled in a centralized manner. While serving millions of households at a time even for unpredictable needs of individual households, or within a subdivision, the overall consumption can be predicted over a year with an accuracy of 3 - 5%. This allows for quite a stable planning of capacities, long-term purchases of fuel (coal, oil, nuclear), and of fixed prices, last but not least.

On the other hand, the lack of timely prediction about local or regional consumption peaks requires a very conservative planning of reserve capacities. Also, due to technical constraints in large power plants (like long start-up and shut-down times with extensive maintenance and decreased life times) the generators would run continuously, thereby creating a considerable reserve capacity that may never be used. In addition, market-based phenomena like after the deregulation in California may result in artificial shortages. Finally power failures in globally managed systems are hard to manage as e.g. recently proven through the catastrophic black-outs in the Eastern US and Canada.

In contrast, modern technologies based on solar or wind power, or on other renewable energy sources, are typically realized through highly distributed small or mid-size facilities. In this paper we focus on solar panels, wind power stations, and hydrogen/oxygen-based fuel cells. All of them are absolutely environmentally clean. Fuel cells can be put into the basement of private homes. Their start-up and shut-down times are very short (ca. 1 min.). Through electrolysis hydrogen and oxygen can be produced from excess energy thus allowing for stable “storing” of electric energy. Instead of costs for raw materials, or of their transportation to large power plants, renewable energy comes for free, so

1This work is partially supported by Deutsche Forschungsgemeinschaft (DFG), under contracts WE 2816/4-1 and HA 937/32-1.
there is only the initial investment for the installation and continued maintenance of power facilities, the sources are inexhaustible, and through coupling electric and heat energy, the technical efficiency is well over 90%.

Unpredictable needs and adaptive real-time negotiations. Different from traditional settings consumers are mostly also producers, and vice versa. While a complete autonomy for everyone to take care of his or her needs would be too costly, or unpractical for technical reasons, they should, as producers as much as consumers, have a chance to negotiate prices according to their current needs and supply situation on a peer-to-peer basis. This opens the door for participants acting under their own responsibility yet poses particular novel challenges on an appropriate handling of unpredictable consumer requests and producer offers, under fine-grained time-critical and stringent fault tolerance constraints. Our approach is to create distributed multi-agent services on behalf of the human or electrical actors or actor groups. In fact, with our new algorithms we are able to satisfy even unpredictable needs or offers within a few rounds, through sources in a local setting. Only in very exceptional circumstances will we take advantage of a back-up facility. Negotiations will be successfully finished within 10 - 40 ms, thus guaranteeing timely reaction to actor requests (which take at least .5 sec to come into effect)2. In setting up the negotiations we are not following a traditional market model. In this way we can make sure that malicious users will not manipulate, and cannot take advantage of, extreme supply or need situations.

Previous and related work. As a result of the recent power black-out in the US and Canada an extensive discussion has started on how to avoid such accidents. In [WMB05] various concepts are presented for separating different supervisory control functions in energy management, for the purpose of a more flexible reaction to upcoming or unforeseen shortages and other extreme situations. The authors in [IAC+05] advertise establishing complex algorithms for guiding large systems out of chaotic situations. These efforts are complemented in survey articles like [MRS+05] and [GB+05]. The common ground for such initiatives is still a global control concept which in itself is highly inflexible, thus failures can hardly be avoided, and they spread easily in uncontrolled ways. Instead, our completely decentralized approach adapts naturally to unpredictable situations including power failures: In the distributed landscape of production facilities breakdowns have typically a local origin, and our power management handles them in the same mode as for normal functioning.

2 The idea is that negotiations will be initiated every 0.5 sec, and no negotiation will take place before the next period of 0.5 sec starts.

Other extensive investigations about multi-agent systems have been recently pursued in various application domains [AH+01, DF+01, GrK99], including electric power management [CC+01]. All approaches are based on centralized control, with the disadvantages already discussed. In particular, prices in [CC+01] are negotiated within a central auction system, thus open to malicious "market" interventions. Our DEZENT algorithm is, to the best of our knowledge, the first completely decentralized multi-agent algorithm. It has been developed in a key effort of the DEZENT project between the School of Computer Science and the Faculty of Electrical Engineering at the University of Dortmund, in well-funded mid-term research for making the utilization of renewable energy a both ecologically and economically very attractive, if not superior alternative.

In our earlier work [WH+04] we followed a 2-stage approach geared at negotiation cycles of 10 min duration. Therefore we developed a prognostic algorithm (SPA) for estimating the production/consumption levels for small groups with a very high accuracy. In this paper we present negotiation algorithms that operate in the 10 ms range. Here prognosis, as a user-level concern for price setting, is not necessary since the agents experience a static picture during these very short negotiation intervals.

Organization of the paper. In 2.1, we define the negotiation model under assumptions that are quite realistic in the specified application scenario (a 3-level power grid). In 2.2 we introduce our multi-agent negotiation algorithm. We prove in section 3 that malicious behavior of users or user groups will not happen since it will never pay off for users, or of coalitions thereof. Section 4 discusses various performance aspects as derived from extensive simulations. In particular we show for a realistic example scenario that users pay less for electric energy as compared to the traditional centralized production/distribution model. In the concluding section we discuss our findings and briefly outline our future work in the ongoing COMTRANS project. This will be subject to upcoming publications.

2. Distributed Agent Negotiations in DEZENT

2.1 The Model

Our investigation started from a real-world scenario, a typical power grid structure as depicted in fig. 1A. Power supply is provided through

- long-distance energy transport in a voltage range of 110-380 kV;
- medium-range area power grids covering a suburb, or at least larger sections of it (10 kV);

Fig. 1A. Power supply is provided through long-distance energy transport in a voltage range of 110-380 kV; medium-range area power grids covering a suburb, or at least larger sections of it (10 kV);
bus-like network structures covering subdivisions (0.4 kV).

As mentioned in section 1 producers are also consumers to a large extent, ideally negotiating on a peer-to-peer basis regarding their individual needs and supply productions. We will assume that the total needs can be covered through the renewable sources, except for highly unusual (emergency) circumstances where, as a strategic reserve, either a large power plant (110 kV) or a local back-up facility (block heat & power plant (BHPP)) would be available (see fig. 1A). (This assumption is already quite realistic for areas in Southern Germany.)

As indicated in section 1 human and electric actors are represented by agents. Negotiation between such agents will be carried out through balancing group managers (BGMs). While monitoring bids and offers through a blackboard they will arrange for contracts on power quantities on the basis of “close” matches of bids and offers (see fig. 1B).

As a principle negotiations will start independently for the groups on the lowest level (each e.g. corresponding to a small subdivision). If a balance cannot be found for all processes in a group the negotiation scope will be extended to the other groups on the same level, or higher up, under the control of the next-higher BGM. The purpose is to accommodate the unsatisfied processes. Only in the worst case will the back-up services be utilized.

As usual in Electrical Engineering, electric energy will be partitioned into arbitrary portions, according to the negotiation needs. Also, for the very short negotiation periods (up to 40 ms, see section 1) the need and supply situation is assumed to be constant\(^4\). All energy produced is available in the whole network. In this way the level structure of the power grid needs not really be closely tied to the agent negotiation structure, except for the back-up facility. Instead, it may be organized according to cooperative structures on the consumer/producer level. In fig. 1, the power grid structure has 3 levels (fig. 1A), the agent structure has 4 (fig. 1B).

Since an actor may be a producer and a consumer at the same time negotiations are initialized as follows: The customer agent, after having computed the difference current_needs – current_production acts as a producer agent if the difference is negative, as a consumer agent if the difference is positive, and it does nothing if the difference is zero. (Of course, there may be consumers who do not produce anything, or producers who (temporarily) consume nothing.)

During each negotiation period consumers issue bids for energy quantities they need, producers offer rates to sell such quantities. Since we assume the need and supply situation not to change during the period under discussion the price for a quantity will not depend on its size, in other words: According to the spirit of the approach there are no long-term negotiations or discounts. As costs for producers arise just for amortization and maintenance a limited negotiation range is deemed appropriate\(^3\).

Within the given range consumers will tend to issue bids on the low side, producers will try to offer power for relatively high rates, each group according to their interests. As the negotiations proceed and unless a deal has been closed producer/consumer rates are lowered, or raised, respectively, from round to round, in order to be finished before a negotiation cycle is finished. (This is regulated through a dynamic measure of criticality or urgency which will be defined below.) The urge is moti-

\(^3\) Since no new negotiation starts before the next 0.5 sec period the negotiators will consider the situation constant for the full interval.

\(^4\) The power production costs per kWh based on amortization and maintenance are calculated as $\text{costs per kWh} = \frac{\text{acquisition costs}}{kWp \cdot (\text{annual output per kWp})} \times 1.5\%$

Average annual maintenance costs for a solar panel is given with 1.5% of the acquisition costs. $kWp$ means KW peak, the peak capacity the panel is capable of producing. The annual output per $kWp$ depends on specifics of the installation site. It ranges between 700kWh and 1300kWh per $kWp$, according to the International Economic Platform for Renewable Energies [IWR05].
vated by the fact that for the next cycle the yet unsatisfied processes would face a narrower negotiation range thus both sides are put to a disadvantage.

2.2 The Collaborative Negotiation Algorithm

I. Negotiation period. As just explained there are producer/consumer agents and balancing group agents. The latter conduct negotiations between producers and consumers on various levels (see fig. 2). On each level negotiations are performed in cycles of 10 rounds each. For the purpose of simplicity we assume that in the model presented, based on synchronized clocks, negotiations in each cycle under a BGM start at the same time, and the duration of a round is 1 ms. After reaching the highest level (level 3 in fig. 2) negotiations will be finished since the remainder needs and power quantities will be handled by the main reserve facility. No new customers will be admitted during this period. We call this a negotiation period. Customers who have been satisfied during the negotiation period do no longer participate (see fig. 3). As a consequence, a producer cannot act as a consumer during a negotiation period, and vice versa.

II. Price frames and adjustments. Negotiations on each level are held within fixed price frames. Frames on the same level have identical sizes. Customers that are unsatisfied after a cycle of one level will continue negotiations on the next higher level, however, the negotiation frames are shrunk by a fixed shrinking value $Sr$ for all levels (20% and 40%, respectively, for two variants in fig. 2), lowering or raising the upper and lower limits, respectively, by half of the percentage. We do not only finalize on matching pairs of bids and offers but also consider bids and offers for contracting that are similar as specified by preset limits for their differences. Similar bids and offers lead to a contract price which is the arithmetic mean value between bid and offer.

Let a current frame at a negotiation level $k$ be denoted by $[A_k, B_k]$; $k = 0, 1, 2, ...$. For a producer/consumer the minimum offer/maximum bid will be $A_k/ B_k$, respectively. The opening bid has to be chosen from $[A_k, ½(B_k + A_k)]$, the opening offer is taken from $[½(B_k + A_k), B_k]$.

Each agent also specifies a device-specific urgency $pre_{urg}$ and strategy parameters $s_1$ and $t_1$. They characterize the gradient of the bidding and offer curves, respectively. When after round $n; n \in [0, 9]$ the unsatisfied agents adjust their bids/offers this will be done according to:

$$bid(n+1) = \frac{1}{e^{urg_b(n)}} + B_k$$

Formula 1

$$offer(n+1) = \frac{1}{e^{urg_o(n)}} + A_k$$

Formula 2

$$urg_b(n) = \frac{pre_{urg} \cdot n}{s_1} + s_2$$

Formula 3

$$urg_o(n) = \frac{pre_{urg} \cdot n}{t_1} + t_2$$

Formula 4

The $s_2$ and $t_2$ are determined by the opening bid or offer, respectively.

$$s_2 = -\log(B_k - \text{opening bid})$$

Formula 5

$$t_2 = -\log(\text{opening offer} - A_k)$$

Formula 6

Bidding and offering curves, after starting from their opening values, asymptotically approach $B_k$ and $A_k$, respectively, with increasing $n$.

III. Contracting. At the end of each round unsatisfied consumers are identified and sorted by the BGM for current level $k$, according to their current bids. Then the consumers are processed top-down starting with the highest bidding consumer. Offers similar to the bid of the first consumer are identified and sorted by price. Offers are processed top-down as well.

For closing a contract between the first-listed consumer and the first-listed producer the needs of the consumer will be fulfilled as far as possible, within...
the following constraint: *Only up to X Wh\(^5\) will be granted to the consumer at a time.* (This prevents any consumer to purchase a very high amount of energy, thus leaving other consumers out in the cold!) After purchasing X Wh from one or more producers the current consumer’s negotiation is interrupted, and the algorithm proceeds with the next-listed consumer. After processing the last-listed consumer, the algorithm starts again with first interrupted consumer (from the top of the list), allowing it to continue its negotiation for up to another X Wh. Going through the customer procedure again it proceeds until no match can be found in the current round any more. The algorithm stops and proceeds with the next round (and the afore mentioned bid/offer adjustments). (This approach is quite similar to the Round Robin mechanism found in process-scheduling to maximize CPU-utilization and to prevent starvation of late or low-priority processes).

When a contract between a similar bid and offer has been closed (on a maximum of X Wh!) we distinguish the following cases for handling the total quantities:

1. The needed quantity is only a fraction of the offered size. The offer of the producer is adjusted to the difference of the need and the current size of the offer. The highest bidder is deleted. The algorithm proceeds with the next consumer.

2. The offered quantity matches the needed one exactly. Producer and consumer are deleted, and the algorithm proceeds with the next consumer.

3. The needed quantity is not completely covered by the offer. The need of the bidder is adjusted to the difference of his current need and the given offer size, the producer is deleted, and the algorithm proceeds to identify the next similar producer.

4. If the need of the consumer is not yet satisfied but no similar offers are identified or left, the algorithm proceeds with the next consumer.

Fig. 3 illustrates the progression of the negotiation algorithm under a BGM during one cycle. In this example there are 6 consumers (ascending curves) and 5 producers (descending curves) participating. Encircled bid/offer pairs (of similar values) and numbers correspond to the order in which contracts are closed. According to the first three cases of the afore mentioned algorithm, on contracting either the consumer curve ends (contract 2) due to needed quantities smaller than offers, or the producer curve ends (contracts 3, 4) due to offers smaller than needed quantities. Finally both curves end since needed and offered quantities quantities match exactly (contracts 1, 5, 6). In this example two consumers remain unsatisfied by the end of the tenth round. They start with the lowest possible bid and do not adapt fast. Conversely, the curves that are contracted at 1 start rather high (consumer) or low (Producer), respectively and they adapt their values very fast.

![Figure 3: Contracting for Energy Quantities](image)

The algorithm proceeds from level \(k\) to level \((k+1)\) if unsatisfied users are left on level \(k\). The BGM on level \((k+1)\) starts with collecting all these users. Then BGM checks for each opening offer or bid from level \(k\) whether or not it fits into \([\frac{1}{2}(B_{k+1} + A_{k+1}), B_{k+1}]\) or \([A_{k+1}, \frac{1}{2}(B_{k+1} + A_{k+1})]\), respectively.

If the check is positive the values remain unchanged for level \((k+1)\). Otherwise the value would be outside of \([A_{k+1}, B_{k+1}]\), and the opening bid/offer will be adjusted to \(A_{k+1}/ B_{k+1}\), respectively.

### 3. Security Against Malicious Users (Fairness)

Under decentralized control some particular scenarios are conceivable for malicious users, especially since a user may simultaneously control some particular scenario. As he might not find many users with urgent needs. As he would intentioned to shift the next-higher Level. In the larger population to be expected there he may be able to find enough customers who would be willing to pay the requested rates.

\(^5\) Watt-hour
3) The strategy in 2) may even be more effective if it were possible to collect global information and wait for urgent needs to arise.

4) As a kind of terrorist attack a malicious coalition of alleged consumers may purchase all available renewable energy just in order to leave the remainder consumers with the very expensive reserve energy (see 4.3).

Over time token profits might add up to make a few rich or many poor (scenario 4). We combine our arguments against this into the

**Theorem:** No malicious user, or a coalition thereof, can take advantage under the circumstances listed in 1)-4) as long as customers react, over cycles and negotiation periods, according to their own experiences, by adjusting their policies.

**Proof:**

1) According to 2.2.1 a consumer cannot change into a producer during a negotiation period – not even before the next negotiation starts (see 1 and 2.1). Since the negotiations are about electric energy for an interval of 0.5 sec energy which is unused during this time is no more available thereafter. During this period there can be no shortage for other consumers, due to the \textit{Round_Robin} procedure described in 2.2.III.

2) If a producer puts up a very high offer such that he would be pushed up to a higher level the price will knocked down as the negotiation frames shrink considerably. As the targeted consumers with urgent needs would at the same time have their rates pushed up one way or the other, a matching would likely occur at resulting prices that would be lower for the producer. Even worse: If they are not forced (on higher levels) into a contract based on the mean average of their original prices both of them would have to rely on the main reserve capacity which will be awkward for both (see the discussion in 4.3). (At last there is only a small population left on higher levels anyway as our performance figures in section 4 show.)

3) There is no long-term negotiation in our model (2.1), so there is no useful global information available. Besides: Since the producer costs come just from amortization and maintenance the initial frame sizes can, at any rate, be assumed pretty narrow (see footnote 4) in 2.1).

4) This behavior is prevented through the \textit{Round_Robin} procedure in 2.2.III.

### 4. Performance Evaluation

#### 4.1 Experimental Setup

In order to assess the performance of the negotiation algorithm in terms of unsatisfied and propagated agents as well as duration of negotiation cycles we have run extensive simulation experiments. In these experiments, we first measured the algorithm’s processing time for one cycle of 10 rounds for an increasing number of agents. Experiments were run on a Pentium III (600MHz) with 512MB of memory. In further experiments we wanted to determine the number of unsatisfied agents while varying negotiation frames and similarities, under an increasing number of agents. The experimental setup of negotiation parameters is shown in table 1. The values were randomized within the given intervals. Each test series was performed 5000 times and results were averaged.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
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<tbody>
<tr>
<td>( B )</td>
<td>10-27 ( \varepsilon )</td>
</tr>
<tr>
<td>( A )</td>
<td>0 ( \varepsilon )</td>
</tr>
<tr>
<td>\textit{pre}_urg</td>
<td>1-2</td>
</tr>
<tr>
<td>( s_1, t_1 )</td>
<td>10-15</td>
</tr>
<tr>
<td>\textit{opening_offer}</td>
<td>( \in \left[ \frac{A}{2}, B \right] )</td>
</tr>
<tr>
<td>\textit{opening_bid}</td>
<td>( \in \left[ A, \frac{B}{2} \right] )</td>
</tr>
<tr>
<td>( X )</td>
<td>50 Wh</td>
</tr>
<tr>
<td>consumer need</td>
<td>1-50 Wh</td>
</tr>
<tr>
<td>producer production</td>
<td>1-50 Wh</td>
</tr>
<tr>
<td>( A )</td>
<td>lower bound of initial negotiation margin</td>
</tr>
<tr>
<td>( B )</td>
<td>upper bound of initial negotiation margin</td>
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</tbody>
</table>

**Table 1: Values of the Experimental Setup**

#### 4.2 Results

Figure 4 shows the average completion time of a cycle for up to 4000 agents (50 % producers, 50 % consumers). For a balancing group that consists of a thousand households, a common size for small urban settlements, the processing time of one cycle is well below 10 ms. Therefore an assumption of 30-40 ms for the complete negotiation time up to three levels (see introduction) is well founded.
Figure 5 shows the number of unsatisfied agents after a cycle of 10 rounds measured against variations of negotiation frames from 10-27¢ with a constant similarity of 3¢ for up to 3000 agents.

Figure 6 shows the number of unsatisfied agents after a cycle of 10 rounds measured against variations of similarity from 1.7-5¢ with a constant negotiation frame of 18¢ for up to 3000 agents.

The common impression in fig. 5 and 6 is that under extreme conditions regarding the frame size and the similarity, there are difficulties for contracting on the lowest level, for a small number of participants. However, this diminishes quickly both with the increasing number of participants and more moderate frame size and similarity parameter. This result is in good congruence with our expectations.

4.3 An Exemplary Numerical Study

According to German law every producer of renewable energy is currently reimbursed 50¢ per KWh which he feeds into the “public” network while he purchases energy from the network for ca. 14¢ / KWh. For the past 5 years this led to a sharp increase of alternative energy production totaling 11.3 % by now. If the development continues on this pace 100 % coverage would be reached by 2020! While reimbursement will be gradually lowered very few large power plants would eventually survive, only to serve as reserve or back-up facilities. Long-distance energy transport would crumble, yet also the amount of electro-smog. At the same time the prices for energy from such sources would rocket, for obvious reasons. We conducted an exemplary study for 3000 agents (50% producers, 50% consumers) with a fixed similarity range of 2¢ (see table. 2). We operated with a very modest increase of the purchasing rate for reserve energy (21¢ / KWh). The rate for potential producer refunds, in turn, was set very low (5¢ / KWh), even under the expectations just discussed. On the production side even the minimum frame rates are sufficient for covering the amortization and maintenance costs.

Unsatisfied agents were propagated onto a higher level and adjusted to the smaller negotiation frame according to the algorithm described earlier. The results of our study are listed in Table 2. They show that in this experimental setup a very large number of agents gets completely satisfied within a negotiation period of 2 cycles with shrinking values $Sr = 10\%$, $20\%$ and $40\%$ (7, 4, and 2 out of 3000, respectively). On level 3, the business is finalized for the remainder users, for $Sr = 40\%$. For 10% and 20% as $Sr$ values, 1 and 2 users are left to the main reserve facility, respectively.
Taking into account that 10% is an extremely low shrinking factor it is still remarkable that eventually only 2 customers are not handled through local sources. Nevertheless, 99.3% of all users have been successful during the first cycle. It is clear that a dynamically increasing shrinking factor would be successful during the first cycle. It is clear that a shrinking factor it is still remarkable that eventually

<table>
<thead>
<tr>
<th>Unsatisfied participants against negotiation frame size</th>
<th>Level 1</th>
</tr>
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<tbody>
<tr>
<td>6-20 €</td>
<td>23 (out of 3000)</td>
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<table>
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<tr>
<th>Unsatisfied participants against negotiation frame size</th>
<th>Level 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.7-19.3 €</td>
<td>7 (out of 23)</td>
</tr>
<tr>
<td>( (Sr = 10%) )</td>
<td></td>
</tr>
<tr>
<td>7.4-18.6 €</td>
<td>4 (out of 23)</td>
</tr>
<tr>
<td>( (Sr = 20%) )</td>
<td></td>
</tr>
<tr>
<td>8.8-17.2 €</td>
<td>2 (out of 23)</td>
</tr>
<tr>
<td>( (Sr = 40%) )</td>
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<table>
<thead>
<tr>
<th>Unsatisfied participants against negotiation frame size</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.4-18.6 €</td>
<td>2 (out of 7)</td>
</tr>
<tr>
<td>( (Sr = 10%) )</td>
<td></td>
</tr>
<tr>
<td>8.8-17.2 €</td>
<td>1 (out of 4)</td>
</tr>
<tr>
<td>( (Sr = 20%) )</td>
<td></td>
</tr>
<tr>
<td>10.2-15 €</td>
<td>0 (out of 2)</td>
</tr>
<tr>
<td>( (Sr = 40%) )</td>
<td></td>
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Table 2: Numerical Study

This effect would even be stronger if the similarity range would be kept large enough for matching requests and offers.

Currently we are preparing for very extensive simulation experiments to get a complete overview of the picture resulting from our study. However, the study shows a very clear tendency for the reserve capacity being very rarely utilized. Thus the perspective for our decentralized solution for managing the distribution of electric energy is that the costs for producers could be more than covered while the consumer costs are to be expected much lower than under the traditional management, even if compared to the current rates (14 € / KWh).

An executable JAR-file including the source code of the algorithm can be downloaded under:

http://ls3-www.cs.uni-dortmund.de/Dezent/dezent.jar

5. Conclusion and Future Work

We have defined a novel distributed real-time negotiation algorithm for agents taking care of producers and consumers of renewable energy. While being a key instrument for developing an adaptive distributed control system for the well-funded mid-term research project DEZENT it is an unprecedented algorithm for multi-agent systems in its own right.

Our numerical study works under realistic parameter settings. It became clear that such energy systems should turn out to be more economical for individual consumers than the traditional centralized architectures. The major incentive for our approach came from the fact that renewable energy is mostly for free, inexhaustible, and has no ecologically negative impact. This allowed both for narrow negotiation ranges and a specific real-time concept. Different from market models in any related scientific discipline we do not utilize long-term negotiations or discount rates.

In this paper we described a simplified version of the DEZENT algorithm. We restricted ourselves to time-synchronized negotiations on all levels just in order to reduce the descriptonal complexity, for the sake of conceptional clarity. For the same reason we did not include a feature for customers to drop out from negotiations once preset price expectations would not be met. Such features would not change any property demonstrated here.

Obviously the flexibility and scalability of our distributed solution are very high. As long as the balance group managers (BGMs) are operational the control system is completely fault tolerant to failures of energy providers, directing customers smoothly to relying on neighboring sources or, in the extreme, to the main reserve capacity. More generally the system is reacting with a very high robustness to unexpected events. If the BGMs would be supported through RAID architectures this functionality could be guaranteed, thus blackout or artificial shortage phenomena like discussed in section 1 would be prevented from occurring.

A purely technical argumentation may hide the fact that in the envisioned novel energy systems the users themselves, as producers or consumers, individually or as small groups, exert a remarkable amount of control, hence also of responsibility. Given that in our current studies (see 4.3) most negotiations involve just small numbers of users (i.e. the contracting is mostly done on lower levels) one could expect a novel cooperative attitude among them. This is even more so since the users do not really know how contracting happens. (They do not have to know since they can from the beginning rely on the absence of malicious behavior or, at least, of any success thereof.)

Recent progress in electric technology led to the idea of including novel forms of fuel cells into the
design of decentralized wind and sun-based energy production. This motivated much of our work. In the near future we should be able to replace the main reserve capacity (traditional large power plants) through more regional block heating and power plants that could serve as back-up facilities for large suburbs.

Our current and future work includes a new distributed implementation of the DEZENT algorithm to be supported through the adaptive real-time services of our MELODY system [WBF01, WL97, WLM+99] which is just ported to a new tailored real-time Linux kernel. This work is in parallel to our COMTRANS project (in cooperation with the Fraunhofer Institute on Material Flow and Logistics at the University of Dortmund). It is devoted to completely decentralized management of large-scale integrated production and transport planning through multi-agent support. Here we benefit from a mutual inspiration between these projects and the involved disciplines. We will report further on this work in upcoming publications.

6. References


