Markets and Negotiations in the Grid Economy:
How decentralized and centralized economic approaches perform

Georg Buss, Werner Streitberger, Torsten Eymann, Daniel Veit

Universität Mannheim
Stiftungslehrstuhl für Allgemeine Betriebswirtschaftslehre und Wirtschaftsinformatik
- E-Business und E-Government -
Schloss
68131 Mannheim
{buss|veit}@uni-mannheim.de

Universität Bayreuth
Lehrstuhl für Wirtschaftsinformatik
95440 Bayreuth
{werner.streitberger|torsten.eymann}@uni-bayreuth.de

Abstract: Within several communities, dynamic and flexible allocation of computational resources is in the center of the current research interest. Grid Computing, e-Infrastructures, GÉANT, Utility Computing are several of the fields, which intensely work on such approaches. However, after seeing substantial progress on physically accessing computational facilities through innovative middleware (such as Globus), economic approaches have to be developed in order to efficiently utilize the resources. In this paper, the technical and economic performance of a centralized, market-based and a decentralized – Catallaxy-based – allocation mechanism for computational resources is compared using application-oriented metrics to measure the outcomes. The results show, that the efficiency of the mechanisms largely depends on the number of interacting stakeholders, the dynamics of the market as well as the topology applied for decentralized mechanisms.

1 Introduction

Within recent years, strong efforts have been conducted to create dynamically adaptable, on-demand utilizable and heterogeneously accessible computational infrastructures, which allow for a distributed multi-user spontaneous utilization. In consequence, in order to achieve this, several initiatives have been launched which stem from different communities. Within the field of, Grid Computing, e-Infrastructures, GÉANT, Utility Computing many concepts have emerged, which all have in common to reach a stage of resource utilization that allows for a more flexible access. Significant work is carried out by the Open Grid Forum (OGF), which can be seen as one of the key drivers to provide the technical foundation for this development. Nevertheless, after finding solutions for dynamic middleware access to distributed resources through the creation of appropriate standards, the aim must be that normal end-users are encouraged to utilize such services. The only way achieving this is to enable easy to use, economically feasible services.

Within our approach, we focus on Application Layer Networks which do – at the same time – address the inclusion of hardware-oriented services and user friendly application oriented services. Therefore, these complex interdependencies are broken down into two types of interrelated markets: a resource market - which involves trading of computational and data resources, such as processors, memory, etc. and a service market - which involves trading of application services.

The market for trading services is spanned around basic services as sellers and complex services as buyers:

- **Complex Service** A complex service is a standard modular software application which needs a specific set of basic service capabilities for fulfilling its goals (the demand for specific complex service types is triggered by applications). An internal logic translates the requirements of a complex service to a set or sequence of modular basic services.
- **Basic Service** A basic service is a module includable in a complex service.

The environment of the resource market mainly comprises basic services and resource services:

- **Basic Service** A basic service is a modular software application which needs a set of resources for fulfilling its goals, i.e. for executing a specific application that a complex service requires.
- **Resource Service** A resource service is a computing resource which encapsulates the computation capabilities as a service.

Figure 1 illustrates the scenario. A complex service is requesting a specific type of PDF creator service, which will be allocated to the agent. Furthermore, the required resources (CPU and hard disk) are allocated to the PDF creator service. The basic service acts as a trading intermediary, i.e. the service knows what the agents are demanding and which resources are available for executing the services.

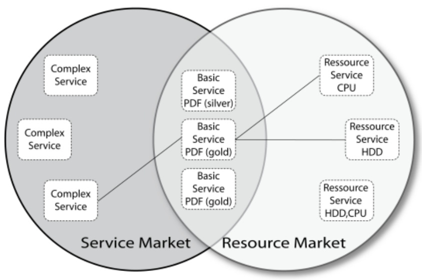


Figure 1: CATNETS Scenario: Service and Resource Market

The products traded on the service market are completely standardized. There are no quality or capability differences between service instances of a specific service type. Quality of service levels are modeled defining new service types (e.g. PDF gold and silver). Therefore the only negotiable attribute for such a product is the price whereas on the resource market bundles of multi-attribute products are traded.

In order to trade instances of these services, economic approaches based on existing findings have to be adapted. Hence the primary target of this paper is the quantitative comparison between the technical and economic efficiency of market-based resource allocation mechanisms in service-oriented Grid Computing networks. Here, two fundamentally different approaches are compared: A centralized – auction-based – market mechanism and a decentralized Catallaxy-based – market mechanism.

This paper is organized as follows. Section 2 reviews related work on market based resource allocation mechanisms. Section 3 describes the Metrics framework which is used to compare both mechanisms to each other. Content to section 4 is the description of the scenario set and the evaluation of simulation runs. Section 5 concludes the paper.

2 Related Work

The use of market mechanisms for allocating computer resources is not a completely new phenomenon. Within the scope of the POPCORN project Regev and Nisan propose the application of a Vickrey auction for the allocation of computational resources in distributed systems [RN00]. Buyya motivated the transfer of market-based concepts from distributed systems to Grids [Bu01]. However, he proposed classical one-sided auction types, which cannot account for combinatorial bids. Wolski et al. compare classical auctions with a bargaining market [Wo03]. As a result, they come to the conclusion that the bargaining market is superior to an auction based market. Eymann et al. introduce a decentralized bargaining system for resource allocation in Grids, which incorporates the underlying topology of the Grid market [Ey03].
Subramoniam et al. account for combinatorial bids by providing a *tâtonement* process for allocation and pricing [SMT02]. Wellman et al. model single-sided auction protocols for the allocation and scheduling of resources under consideration of different time constraints [We01]. Conen goes one step further by designing a combinatorial bidding procedure for job scheduling including different running, starting, and ending times of jobs on a processing machine [Co02]. However, these approaches are single-sided and favor monopolistic sellers or monopsonistic buyers in a way that they allocate greater portions of the surplus. Installing competition on both sides is deemed superior, as no particular market side is systematically put at advantage.

For both, the centralized – auction based – and the decentralized – Catallaxy based – market mechanisms have been implemented. For the centralized service market, we implemented a double auction institution [Fr91]. Such auctions are organized by means of order books, each for a set of homogeneous goods. So there is an order book for each basic service type. Buyers and sellers submit their bids in a sealed way to the auctioneer. The auctioneer aggregates the bids to form supply and demand curves. Once these curves are aggregated, they are used to set a specific price for trading – the price at which supply equals demand.

An adequate market mechanism for the resource market has to support simultaneous trading of multiple buyers and sellers, as well as an immediate resource allocation. Furthermore, the mechanism has to support bundle orders – i.e. all-or-nothing orders on multiple resources – as basic services usually demand a combination of computer resources. For comprising the different capacities of the resources (i.e. resources can differ in their quality), the mechanism has to support bids on multi-attribute resources.

Reviewing the requirements and surveying the literature, no classical auction mechanism is directly applicable to the resource market. Instead, a multi-attribute combinatorial exchange (MACE) is applied that satisfies the described requirements [Sc07]. On both markets the auctioneer is integrated into the CATNETS simulator as an agent that has access to the market implementation [St07b].

The decentralized approach uses on both markets a bilateral bargaining mechanism, which implements the service selection decision in the requesting client itself. Service and resource discovery is realized by means of a flooding algorithm. For negotiations between two agents an iterative bilateral negotiation protocol, similar to a contract-net, is used since no complete information is available [ST98]. Both agents approximate to the trade-off point in iterative steps exchanging offers and counter-offers. This process is described as monotonic concession protocol [RZ94]. If an agent receives an offer or counter-offer, it decides to either make a concession or send the same price as in the last negotiation until the negotiation ends with an accept or a reject. After the negotiation, the autonomous agents adapt their negotiation strategies using a feedback learning algorithm.

3 Metrics Framework

It is often useful to be able to compare two allocation methods using a single index or number. Such an index provides an aggregated behavior of an allocation method with reference to a number of features [St07a]. Figure 2 shows the measured data and the aggregated indices of the measurement methodology which establishes the shape of a pyramid. Data are the basic units of information, collected through technical monitoring of the application layer network. Parameters which are likely to be of significance within the application and the resource allocation mechanism are selected for measurement. These parameters define the raw disaggregated data. To ease the analysis of the raw data, they are collected from different experiments (simulation runs) into a database.

The evaluation of the centralized and decentralized allocation approach uses a set of ten technical metrics, which comprehend generic, easy to measure parameters, which can subsequently be aggregated. The ten technical layer metrics can be classified into: (I) efficiency measures (number of requests, number of acceptances); (II) utility measures (agent satisfaction); (III) time metrics (discovery time, negotiation time, allocation time, and service provisioning time) which are measures of the rate of change of market processes; and a message-based metric (IV) to measure the activity of users to communicate to find resources and services (number of messages). These disaggregated Indicators provide the first stage of evaluation, and comprise of a number of independently measured values. They help to improve the implementation of the resource allocation mechanisms.

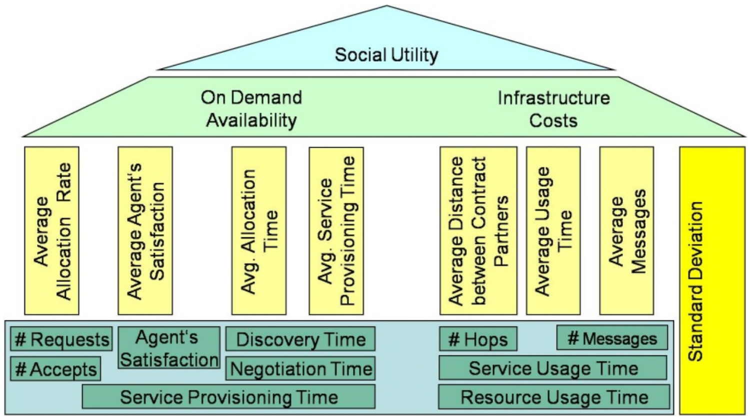


Figure 2: Metrics pyramid for evaluation

The simple indicator layer defines a set of independent metrics which are normalized. The benefit of normalized indicators is twofold: the first benefit is to get interoperability between the different metrics used to compose upper level indicators. This is achieved mainly by normalization to the interval between 0 and 1 which let the metrics leave their initial measurement system units. The second benefit is the ordinal measurement system. We build an ordinal measurement system in which the precision of system behavior related to a specific metric is better than the value approach. The size of the metric value in absolute numbers is not meaningful any more, and the evaluation and interpretation can only be performed in a relative fashion, i.e. comparing the same metric for two or more experiments. This makes it easier to find valid functions for the layers above, such as on demand availability and infrastructure cost.

The aggregated metrics at the simple indicator layer are:

Allocation Rate: This metric is a measure of the efficiency of the allocation process, which is computed using the number of requests and number of accepts. A buyer can demand services, but there is no guarantee that the allocation mechanism (centralized or decentralized exchange) performs a match between demand and supply.

Agent Satisfaction: The agent satisfaction is defined as the ratio between the agent's subjective reservation value and the agreement price. This metric implicitly shows the average surplus of buyers and sellers in the system. A low value means that an agent has not been able to complete its goals successfully during the negotiation process. A high value means that the agent can constitute good results satisfying its requirements.

Allocation Time: This is the additional time needed for allocation on the service and resource market. It refers to the overhead introduced during the allocation process. The overhead is the sum of the service allocation time and the resource allocation time.

Provisioning Time: This indicator evaluates the time needed from the starting point of discovery until the final delivery of the service

Distance between Contract Partners: Message latency is the messaging time incurred by agents, and it is proportional to the distance between the sending and receiving nodes. The distance metric it is normalized taking into account the number of links between the trading agents. This measure addresses the costs in terms of time and space to trade with longer distance traders. The normalization is performed with respect to the worst situation for an agent: to trade with an agent at the other side of the network when the topology is a line with all agents in a row.

Agent Usage Time: The agent usage will be evaluated by the time an agent spends for negotiation or service/resource delivery. This evaluation would be conducted for each agent type.

Messages: This metric is used to measure the total number of messages exchanged between two agents. The message normalization uses the total number of messages exchanged.

The normalized, technical metrics are taken as input for the economic metric layer. The economic metric layer aggregates the metrics using mean and variance of the simple indicators. The aggregated economic layer is defined by two indexes: On DeMand availabilty (*ODM*) and Infrastructure Costs (*IC*). Both contain information about the ability of the system to provide the service to a user for the centralized and decentralized allocation approaches and the costs needed to provide them at a high abstraction level. ODM is a composite indicator obtained as mean of simple indicators, and may be derived as:

$$\text{ODM} = 1/4\ (\text{AllocationRate} + \text{AgentSatisfaction} + \text{AllocationTime} + \text{ServiceProvisioningTime})$$

Infrastructure Cost (IC) is calculated in the same way. It is also a mean of multiple simple indicators, and may be derived as:

$$\text{IC} = 1/3\ (\text{Distance} + \text{UsageTime} + \text{Messages})$$

It may be possible to model some of these metrics as stochastic variables, giving a mean and standard deviation over which the given metric varies. In economic applications, variance would be a measure for the overall “risk” to achieve stability of a given metric development.

The final social utility index is

$$\text{SocialUtility} = 0,5\mu_{\text{IC}}^2 + 0,5\mu_{(1-\text{ODM})}^2 + 0,5\sigma_{\text{IC}}^2 + 0,5\sigma_{(1-\text{ODM})}^2$$

The weights are set to 0.5 for all evaluations of the allocation approaches. This assumes equal importance of both composite indexes and enables a better comparison of the different scenarios. If one or the other index should be more or less emphasized, a policy maker for a concrete application layer network can adjust the final evaluation function.

4 Scenarios, Experiment Setup and Findings

The goal of this section is to evaluate how the centralized approach and the decentralized approach deal with the same number of agents within topologies differing in size. Section 4.1 presents the scenarios which were developed for the evaluation. In Section 4.2 the experiment setup, which is the same for all experiments, is introduced. Finally in Section 4.3 the simulation results are presented and evaluated.

4.1 Scenarios

The service types on service and resource markets are the same for all evaluated scenarios. Three complex service types, four basic service types and three resource service types are specified.

Three scenarios are created whose topologies have up to 50 nodes. The network is partially connected; not all nodes are connected to each other like in a fully connected mesh. The links have a constant maximum bandwidth of 1024 Mb/s. The nodes' failure probability is zero. The agents are randomly distributed on the nodes in each scenario. 20% of the total agents' number is complex service agents, 40% are basic service agents and 40% are resource service agents. A complex service agent is able to handle each type of complex service request. The basic service and resource service agents are dedicated to a specific service type. The number of agent types is uniformly distributed.

The scenarios are defined as follows:

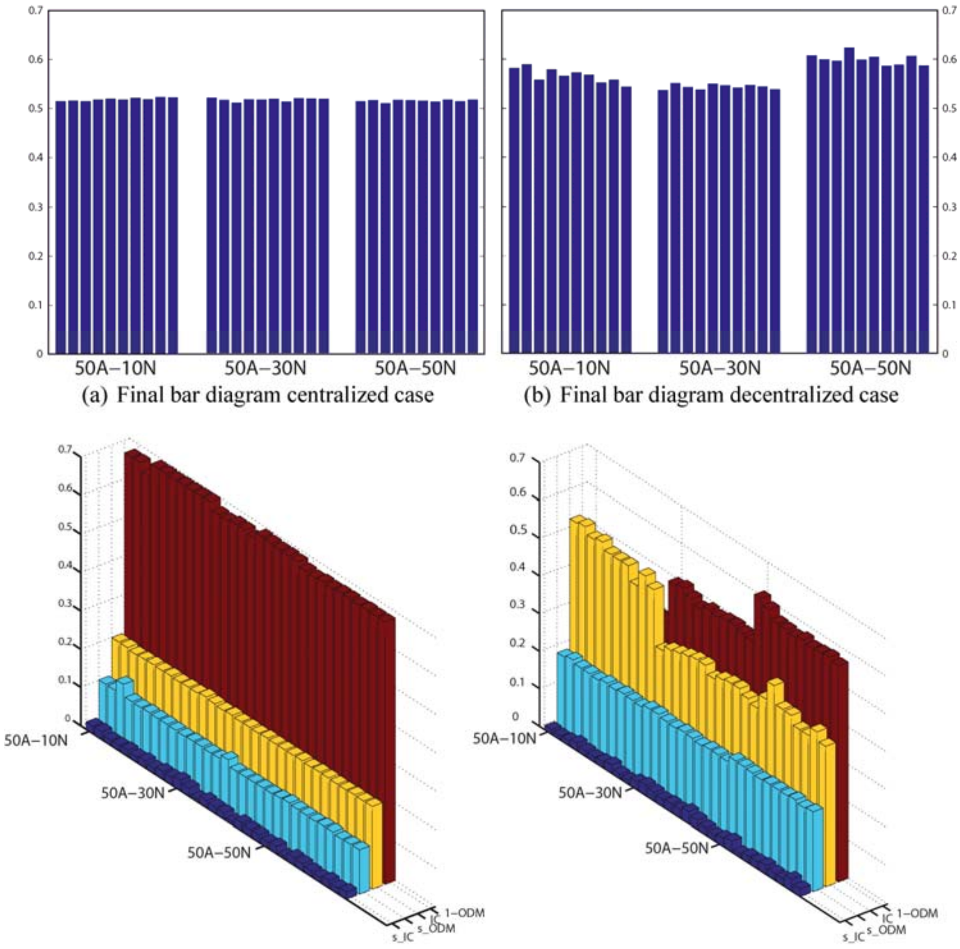
1. 50A_10N: 50 agents within a topology of 10 nodes
2. 50A_30N: 50 agents within a topology of 30 nodes
3. 50A_50N: 50 agents within a topology of 50 nodes

4.2 Experiment Setup

Each experiment is started with 1000 complex service requests. Demand is submitted randomly to the complex service agents. The time interval between the submissions of complex service requests is set to 1000 milliseconds. The basic service execution time is set to 100 milliseconds. Both markets are connected, which means the budget of a basic service buyer is limited by the earnings it has achieved on the service market.

4.3 Simulation Results and Findings

Figure 3 and Figure 4 comprise the recorded simulation parameters for all simulation runs in centralized and decentralized mode. In both figures the subfigures (a), (c) and

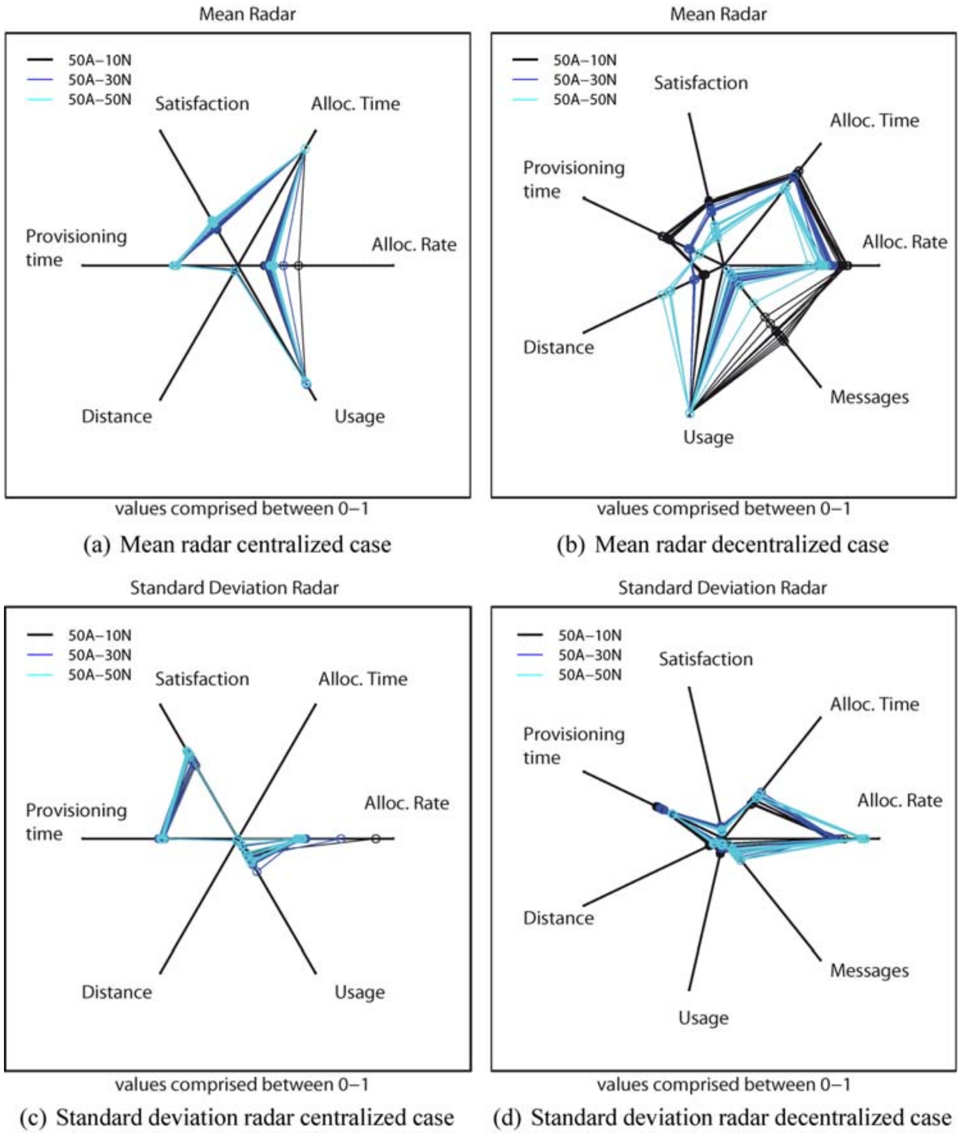


(a) Final bar diagram centralized case (b) Final bar diagram decentralized case

(c) IC and 1-ODM diagram centralized case (d) IC and 1-ODM diagram decentralized case

Figure 3: Final social utility index and economical indicators for centralized and decentralized simulation runs

(b), (d) show the results for the simulation runs performed in centralized and decentralized mode respectively. The figures 3 (a) and (b) depict the final social utility index for each simulation run performed in centralized and decentralized mode. This index is computed of the corresponding economical indicators presented in the figures 3 (c) and (d). The most left bar of a final social utility index diagram belongs to the most left set of bars in the corresponding economical indicators figure. The economical indicators itself are computed of the values recorded at the technical layer. The mean and standard deviation values of these parameters for centralized and decentralized case simulation runs are shown in figure 4. Depending on the scenario in which they were obtained they are plotted in a different color.



(a) Mean radar centralized case

(b) Mean radar decentralized case

(c) Standard deviation radar centralized case

(d) Standard deviation radar decentralized case

Figure 4: Parameters recorded at the technical layer for each simulation run

The final social utility index is computed as a value between zero and one. The higher the utility of the system is, the closer it is to zero. As figure 3 (a) shows the final index is approximately constant for all simulation runs performed in centralized mode. Even if the topology size changes the final index does not fluctuate. The parameters the social utility index is computed of are depicted in figure 3(c). They do also not change significantly over all simulation runs and scenarios. A high inverse on demand availability (1-ODM) and low IC can be observed. The low IC indicator values are reasoned by the very low and constant mean value of the distance parameter. This value flattens the second influencing value of IC, which is usage (figures 4 (a) and (c)). The 1-ODM value is driven by the allocation time parameter as well as the low allocation rate.

The small deviations of the overall results imply that the density of agents within a topology does not influence the performance of the centralized mechanism. This is an obvious observation for a market mechanism where supply and demand are coordinated by a central auctioneer. As long as the winner determination problem can be solved in time, results will differ only slightly.

For simulation runs performed in decentralized mode the final social utility index values are slightly fluctuating between the single runs of the same scenario. Furthermore the final values change significantly if the topology size changes (figure 3b). Evaluating figure 3(d) this is caused by fluctuating 1-ODM and IC values. These indicators change significantly between different scenarios. In the scenario 50A_10N, a low 1-ODM and high IC can be observed, whereas this changes for the scenarios 50A_30N and 50A_50N. Here, the graph shows a high 1-ODM and lower IC. The related standard deviation values (s_1-ODM and s_IC) are approximately constant over all simulation runs. The figures 4(b) and 4(d) show the mean and standard deviation values for the parameters the IC and 1-ODM values are computed of. The figures show a significant change in the mean values for the runs performed for different scenarios. The related standard deviation values differ only slightly (except the allocation rate).

The deviations of the final social utility index values between the different scenarios show that the topology size influences the outcome of the decentralized approach. Two effects can be observed if the topology size is increased and the number of agents remains constant. On the one hand the number of negotiation partners decreases. This is caused by the parameter hopcount which limits the range of the call for proposal messages. The decreasing number of negotiation partners results in decreasing IC. On the other hand in a bigger network topology the 1-ODM increases. This is mainly caused by the decreasing number of negotiation partners. The less the negotiation partners are available the higher the probability is that they are busy. These to effects are verified by the values IC and 1-ODM are computed of. The bigger the topology the more the numbers of sent messages declines. Again, the reason is that the number of possible negotiation partners decreases, whereas the distance value rises a little bit and the usage parameter is constant. That causes a declining IC value. The 1-ODM value decrease is caused by a decreasing allocation rate as well as a decreasing satisfaction. The best final result using the decentralized mechanism was achieved in the scenario 50A_30N. In that case, IC and 1-ODM are balanced best.

Comparing the results performed in centralized mode to the results performed in decentralized mode it can be observed that the utility in centralized mode is in all cases lower than the utility in decentralized mode (figure 3 (a) and (b)). Moreover, the index is stable for the centralized simulation runs whereas it fluctuates in decentralized case. Evaluating the figures 3 (c) and (d) there are two reasons: The proportion of IC to 1-ODM in centralized case is better than in decentralized case. In detail the ODM of resources in decentralized case cannot compensate the corresponding very high infrastructure costs. Furthermore, the higher deviation of the 1-ODM value influences the overall results of decentralized case negative. Regarding figure 4 (b) the driver of the good on demand availability in decentralized case is the very good value of the allocation rate. The centralized case turns the tide because of its low IC costs (distance and usage) and the lower deviations overall technical parameters.

The comparison between centralized and decentralized case for that type of scenarios shows that the proportion between the costs for the search of possible negotiation partners (IC) and the 1-ODM is better for the centralized case. Specifically the decentralized case suffers from high IC costs caused by the negotiations. That is not only the messages send; also the usage of the agents is much higher. A high agent usage is caused by two factors: service delivery and negotiation phases.

5 Conclusions

The core contribution of our paper is a quantitative comparison between common centralized economic allocation mechanisms and decentralized negotiation formats based on von Hayek's Catallaxy for a specific set of scenarios. Core issues along which the identification of the appropriate mechanism has to be aligned to are: The size of the allocation problem, the communication intensity, the distribution of the prices offered by the participants and the dynamics of the market. All these parameters again depend upon the industry branch in which the individual application, for which the mechanism should be deployed, is located. The lessons learnt are:

- The Catallactic mechanism needs to be improved in terms of the number of messages to be sent for coordination. This is because there is no predictable number of negotiation rounds compared to centralized auctioneer.
- The configuration complexity in terms of the number of parameters compared with other economic mechanisms is very high in the Catallactic mechanism. On the one hand, this flexibility enables to find a good parameter configuration for different scenarios. On the other hand, there is no default configuration proved itself to be applicable in a large number of scenarios.
- Comparison with centralized mechanisms is difficult since the performance depends on each catallactic agents` strategy in the respective scenarios. In the centralized case, the auctioneer`s decisions only depend on the incoming supply / demand messages. Catallactic agents follow a heuristic strategy whereas the centralized auctioneer implements a formal allocation mechanism with theoretical foundations.

The investigated approaches may be subsumed in the field of Grid Economics. In this field, currently strong efforts are bundled in order to identify methodologies that are applicable for dynamically allocating computational resources to applications. Future work applies the market mechanisms in a fully functional Grid Middleware to validate the simulation results.

Acknowledgements
This work was partly funded by the European Commission under contract FP6-003769. For further information, visit the CATNETS web site: http://www.catnets.org.

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