A Market-Based Approach of Efficient Resource Allocation Mechanisms in Collaborative Peer-to-Peer Systems

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Peer-to-peer (P2P) systems enable the selection, sharing and aggregation of geographically distributed heterogeneous resources for solving large-scale problems in engineering or science. The management of resources and trading of services in such open and decentralized systems is still a complex undertaking. We propose an interdisciplinary approach to address the resource allocation problem in P2P systems, thus combining existing theories on market mechanisms from Microeconomics, Game Theory concepts and computational techniques from the domain of Artificial Intelligence. We build the formalization of the resource allocation problem and show which of the market mechanisms from Microeconomics suit best to our setup.
Keywords: *P2P Systems, Resource Management, Service Trading, Market Models, Collaboration, Grid Economics*

1 Introduction

The development of collaborative P2P systems has gained territory in recent years for eliminating the inconveniences created by the closed nature of grid systems. These are the most commonly-used applications for the distribution and sharing of data (*Gnutella* or *BitTorrent*), but not widespread in terms of sharing computational resources. The peers are organized in *structured* or *unstructured* networks, it is a decentralized environment where there is no central authority for the co-ordination of actions, being open systems. In this way, *virtual organizations* are created where participants can access the resources at low costs; computing power is therefore available to all, including small and medium enterprises. The collaborative nature of these systems lies in the communication between existing parties for executing transactions with the available resources.

The service based P2P collaborative systems have the same principles, the participants are able to provide any service in the system and there is a permanent collaboration between members ensuring the premises for achieving the attributes of scalability, dynamicity and autonomy. A service is an abstract concept, composed by resources with key characteristics like: price, quality, time and penalty. Each of these features has a particular importance for both the service requestor (buyer) and the service provider (seller).

We propose an ***interdisciplinary*** approach to address the resource allocation problem combining computational techniques with models provided by the microeconomic theory, game theory respectively. While specialists in Computer Science are concerned with providing an optimal and feasible allocation mechanism, the specialists in Economics are focused on the conditions or restrictions to be met in order to obtain the best allocation, being interested in qualitative aspects. In other words, in the case of the first group of scientists the optimality of the resource allocation mechanism depends on the computational complexity of the algorithm so the attention is focused mainly on structural aspects of the environment, the interaction between participants and the constant optimization of the allocation procedure. On the other hand, economists are more interested in the foundation of participants' strategies in the process of resource allocation or service trading and they constantly aim to optimize these strategies considering the possible changes in the environment.

The article is organized as follows. In Section 2 we present the main differences between Grid and P2P systems and the challenges encountered in trading resources and services in such systems. In Section 3 we formulate the resource allocation problem in unstructured P2P systems and we present the key performance indicators for evaluating the market models for resource allocation in Section 4. In Section 5 we adopt a comparative approach when presenting the main market models from the economic theory (these models were proposed for the trading of goods) and we formulate the economic viability of one of these models when considering the procurement of services in P2P systems. Section 6 concludes the paper.

2 Resource allocation in Grid vs. P2P systems

Grid systems are based on a coordinated, dynamic and flexible sharing of resources (computing, storage, etc.) between individuals or within a virtual organization for solving specific problems [1]. The FP6 CoreGrid network of excellence highlights the following aspects in the definition of grid systems: distributed infrastructure, dynamically reconfigurable, scalable and autonomous, provide a location independent access, universal (pervasive), efficient, reliable and secure over a variety of coordinated services that encapsulates and virtualizes resources in order to generate knowledge [2].

The development of such systems was a major first because in the context of Globalization, the World Economy has crossed a process where many changes occurred, imposing the need for rapid adaptation to new conditions. The "New Economy" developed new standards to eliminate the barriers between small organizations and large corporations.

Creating "virtual organizations" [3] is a cheap and viable alternative for small organizations that can now stand along with large corporations and the participation in such communities of excellence significantly reduces their costs. The main characteristics of these organizations are their decentralized nature and the geographical dispersion, each of the participants contributing with own resources in the community.

The conceptual model of a virtual organization could be seen below:

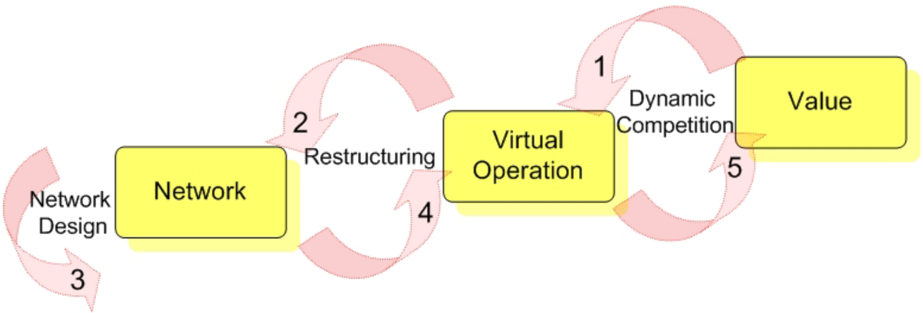

Fig. 1. The conceptual model of a Virtual Organization

Value is the engine that ensures the restructuring of the virtual organization and it is represented by the business opportunity within the network as well as future or yet unexplored markets.

Virtual operations are cooperative processes that combine competences and resources in order to achieve value. The success in realizing and implementing a virtual organization depends on the network (the pre-existing industrial structures that form the network). The development and implementation of virtual operations lead to the evolution of the network and represents the main motivation for its reform. Once the networks are extended, the opportunities of creating new virtual operations become more frequent. By expanding the area of activity, the virtual organization gradually evolves fuelled by dynamic competition, remaining in a permanent creative process with the capacity of self reform.

Among the advantages of this type of virtual organization we consider the following:

- The possibility of permanently renewing the list of organization participants;

- The agreements are flexible and focused on satisfying precise purposes;
- The emphasis on creating new products and services;
- The processes involved in the organization can be rapidly changed by achieving an agreement among partners.

The virtual organization presumes a different manner of perceiving the world by the participants. There are four key features of the virtual organization taken as a process:

- Support for developing connections with a wide variety of potential partners, each having particular competences that are complementary;
- Mobility and prompt response in order to face problems related to distance;
- Synchronization – key aspect for relations among members in the case of decision making;
- The efficiency of the organization is determined by the degree of trust present among the participants.

The major drawback in the current research lies in the centralized and closed nature of the organization, respectively the geographical distribution of resources in traditional grid systems. The participating organizations have different usage policies, cost models, varying load and availability patterns leading to resource management problems in such systems. The producers (resource owners) and consumers (resource users) have different objectives, strategies, requirements and goals.

In the figure below the entities of a grid system and the interaction between them are depicted: the user, the Resource Broker, the Information Service and the available resources.

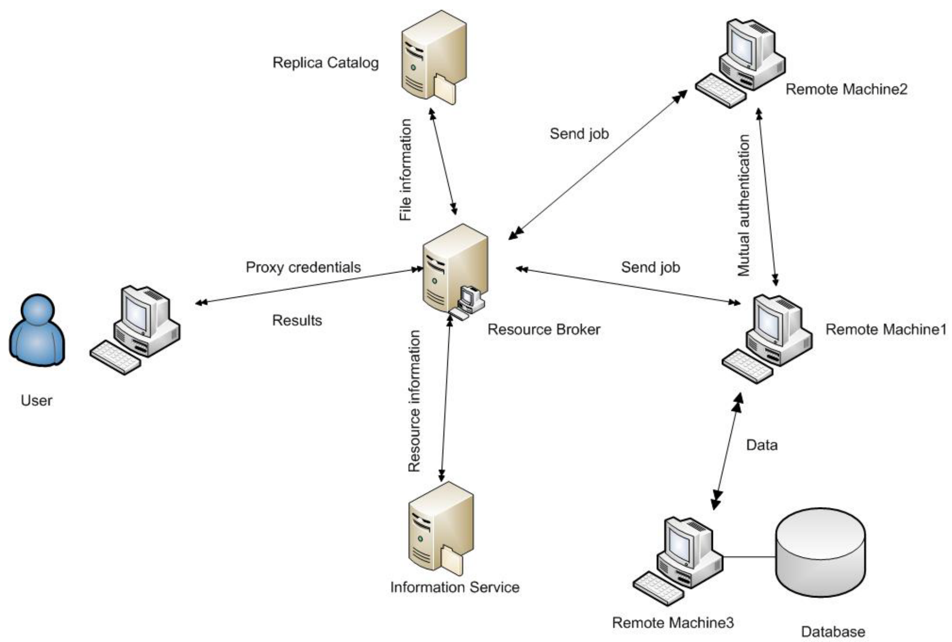

Fig. 2. The architecture of a working grid

For each user there is a resource broker. Its role will be to find the desired resources and send the program to the resource. When we address the resource term, we consider computational and network resources or any device that is able to participate in grid. These resources implement some mechanisms that allow the discovery of their structure, state and capabilities [3].

The Resource Broker contacts the Information Service to find the appropriate resource. The Information Service maintains detailed information about all available resources in the grid. The resource broker will select one of these resources and send a job to him. After authentication, the remote resource will execute the user program. To execute this task another re-source (on another machine) may be needed. If the user has the proper credentials to access this new resource, the current machine will be authenticated in the user's name and it will have the possibility to access the new resource to complete the job.

The Resource Broker can also access the Replica Catalog to locate data. This replica management system controls when and where copy of the files have been created and contains in-formation about where files are stored. In other words, this system contains a mapping between logical file names and their physical location.

The management of resources in grid systems is a current problem, primarily due to their geographical distribution and heterogeneity. The branch called ***Grid Economics*** proposes the use of market models from Economics to evaluate and to set the price of the resources achieving an efficient management of these [4]. Implementing these models will encourage the users to disclose their real value associated with a resource in order to execute a particular task.

The implementation of market models in grid systems has several advantages and consequences outside the efficient management of resources: it is an incentive for organizations regarding the provision of resources in a grid on a large scale. Thus, the grid can be viewed as a viable business model, causing a shift of vision of the continuous need for computing power for academic or commercial use.

In the case of grid systems two allocation methods were proposed: static allocation and dynamic allocation.

In the ***static allocation*** of resource sharing, some arrangements are made in advance and the price is set for the resources which will be used. However, it was found that this allocation is not an optimal one from the grid participants' point of view because it doesn't consider the parameters related to the usefulness of resources in time for each of the participants (in time some participants may appreciate that their resources have a 0 utility, while others who have a strong need for those resources and after the negotiation process obtained a very small percentage compared to their current needs, maintains a much higher utility than normal). An-other drawback for this type of allocation occurs when one of the participants in negotiations cannot meet its contractual obligations due to the emergence of various special situations: network error, server collapse, reorganization. In this case, other participants will have to bear the costs even if they did not need those resources.

To remove these shortcomings ***dynamic allocation*** mechanisms have been developed: the ability of "donating" resources (but here the problem of non-cooperation of participants arises, who can also be "selfish"), redistribution of resources within each task for each participant, first come first served or intelligent allocation mechanisms that involves a tracking of the participants' tasks and keep records on the inputs, in order to continuously redistribute the resources in correlation with the current needs.

The P2P collaborative systems incorporate a scalability factor, helping them to eliminate the shortcomings of grid systems. These systems are also self-organizing and include internal mechanisms that solve the lack of structure. The sharing of resources is done on the basis of reciprocity: a peer will have access to a resource only after it contributed with his own re-sources in the system.

A participant in a P2P system is a resource provider and consumer in the same time: computing power, storage or bandwidth, the sharing of resources being achieved in a very dynamic environment [5]. Considering that both types of systems have been developed to solve the same problem, namely the sharing of resources, and considering the decentralized nature of P2P systems in [6] the convergence of grid with P2P systems is proposed.

The peers are organized in two types of networks:

- Structured networks (Chord [7], Pastry [8] or CAN [9]) are organized around DHTs and have a routing algorithm of messages for information retrieval;
- Unstructured P2P networks where there is a free communication between existing participants.

In unstructured P2P networks the free-rider problem often arises. Some peers use services purchased from other peers without contributing with resources in the system. The result is a society characterized by unfairness, contributing to lower the performance of the system. Therefore, a robust P2P system has to incorporate strong mechanisms to encourage the participants to contribute with their own resources in the system.

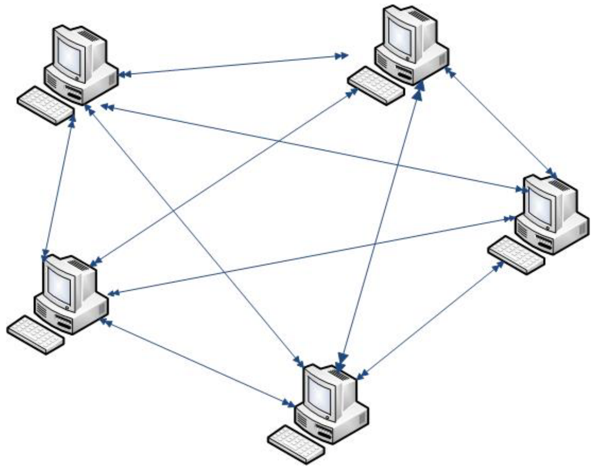

Fig. 3. Unstructured P2P network

Grid and P2P systems have some common goals namely the sharing, selection and aggregation of geographically distributed heterogeneous resources for solving large scale problems in science, engineering and commerce. The following table highlights the main similarities and differences between the two types of systems:

Table 1. A general comparison between Grid and P2P Systems

Characteristics	Grid	P2P
General purpose	• Resource sharing	• Resource sharing
Target Communities	• Academic communities • E-commerce	• Anonymous individuals
Resources	• Powerful, diverse, better connected • Storage system, database, cluster	• File-sharing • Intermittent participation, weakly connected
Applications	• Data intensive • Resolving complex tasks: numerical simulations • Flexibility	• Vertically integrated • Sharing computer cycles or files • Scalability
Scale and Failure	• Modest number of participants: institutions, simultaneous users (hundreds) • Large amount of activity	• Millions of participants • Significant amount of activity
Services and Infrastructure	• Services for resource access, data movement, autentication, authorization, discovery; • Persistent services –	• Integration of simple resources; • Protocols designed to provide specific vertical functionality;

	operated over extended periods; • Multi-purpose services;	• The persistence of protocols are not engineered, but this is an emergent property; • The need of complex services over time: incentives for fair sharing and reputation management;

3 Formalization of the Resource Allocation Problem

We consider a resource allocation mechanism that allows source peers to provide differentiated services to competing peers. Source peers provide services and allocate their resources to serve competing peers and competing peers consume resources and use the resources allocated by source peers.

These ends could be seen as rational agents whose main goal is to maximize their preferences under the restriction that the resources they trade are limited.

Definition 1: An economic agent i can be represented by a tuple (X_i, u_i, w_i) where $X_i \subseteq R^l$ is a subset of the Euclidian l-dimensional space of goods such that:

- $X_i \neq \theta$
- X_i is bounded below, closed and convex
- $if\ x_1 \in X_i\ and\ \exists x_2,\ x_1 \leq x_2$ $then\ x_2 \in X_i$
- $w_i \in X_i$ is finite
- $u_i : X_i \to \Re$ is a quasi-concave, continuous utility function
- $w_i \in X_i$ is its initial endowment

Definition 2: A pure exchange economy is a tuple: $\varepsilon = \left((X_i, u_i, w_i)_{i=1}^n, w\right)$ where n is the number of consumers in the economy and $w = \sum_{i=1}^n w_i$.

In our context, we operate in a virtual environment where there are n service providers and consumers.

In a P2P system, a peer, seen as an intelligent agent could be both provider and consumer at the same time. We consider the set of all services that can be traded: $X = \{x_1, x_2, \ldots, x_n\}$, where $\forall x \in X$. Consider the set P of service providers, where $S : P \to \wp(X), \forall p \in P$, respectively the set C of service consumers, where $S : C \to \wp(X), \forall c \in C$, $\wp$ is the powerset operator.

A service is characterized by m attributes such as time, quality, price and penalty, forming the set of attributes A : $SA : X \to \wp(A)$

Both service providers and consumers have different preferences over the characteristics of the service associating different weights to them, which express the importance of those characteristics. Consider the set W of the weights of all attributes of the service: $AW : A \to \wp(W), \forall w \in W$ and the sum of all weights of the attributes must be 1: $\sum_{i=1}^m w_i = 1$

Also, each attribute of the service has a different evaluation in the service provider's and consumer's opinion. The evaluation function has the following structure:

$$AEV : A \to \wp(EV)$$

Participants' satisfaction after using a service is measured by a utility function that is usually linear-additive and has the following form:

$$U(x) = \sum_{j=1}^m w_j(x) * ev_j(x)$$

4 Evaluation Criteria of Resource Allocation Mechanisms

In unstructured P2P collaborative systems fairness is an important criterion in building re-source trading mechanisms.

In economic theory many market mechanisms has been developed over time which ensures a perfect equilibrium between providers (those who allocate resources) and consumers (buyers). Fairness can be explained from an economic perspective in two ways:

- maximizing social welfare [10];
- maximizing the minimum utility obtained by the agents (*maxmin fairness*) [11].

Social welfare is the sum of all agents' utilities or payoffs for a given solution of the game [16]. It expresses the total welfare of society and allows the comparison of different resource trading mechanisms.

A special case of maxmin fairness is used in data communication [12] literature, while social welfare maximization is used especially in bandwidth allocation problems [13] [14] [15].

These mechanisms are designed for the trading of heterogeneous services or to negotiate the price of these services, while maximizing the social welfare.

If the trading of services in a P2P system is seen as an non-cooperative game where the participants are selfish and rational, it is important to consider other performance criteria for comparing different strategies: the Pareto efficiency [17] Nash [18] or Kalai-Smorodinsky solutions [19].

Definition 3 (*Pareto domination*): Strategy profile s dominates strategy profile s' if for all $i \in N$, $u_i(s) \geq u_i(s')$, and there exist some $j \in N$ for which $u_j(s) > u_j(s')$.

In a Pareto dominated strategy profile some players can be made better off without making any other players worse off.

Definition 4 (*Pareto optimality*): Strategy profile s is Pareto optimal or strictly Pareto efficient, if there is not another strategy profile $s' \in S$ that Pareto dominates s.

The set of Pareto efficient solutions form the ***Pareto frontier***, and the main goal in a game is to find solutions which lie on this frontier.

Informally, a set of strategies are in Nash equilibrium if no player can obtain better results by unilaterally changing his strategy. Formally we define $s_{-i} = (s_1, \ldots, s_{i-1}, s_{i+1}, \ldots, s_n)$ a strategy profile s without agent i's strategy. We can write $s = (s_i, s_{-i})$

Definition 5 (*Best response*): Player i's best response to the strategy profile s_{-i} is a mixed strategy $s_i^* \in S_i$ such that $u_i(s_i^*, s_{-i}) \geq u_i(s_i, s_{-i})$ for all strategies $s_i \in S_i$.

The Nash point represents the solution that maximizes the product of utilities obtained by the players.

According to Nash, a solution should satisfy certain axioms:

- Invariance to affine transformations or invariance to equivalent utility representations;
- Pareto optimality;
- Independence of irrelevant alternatives;
- Symmetry;

The Kalai-Smorodinsky solution is based on an egalitarian approach; it eliminates the 3rd of Nash's axioms, independence of irrelevant alternatives and considers that it can be substituted by an appropriate monotonicity condition. This is the solution which attempts to grant equal gain to both parties.

In our model developed for the trading of services in P2P collaborative environments we have to consider all these criteria for evaluating the performance of the strategies and maximize the participants' individual satisfaction.

In the next section we present in a comparative approach the economic models that stay on the basis of participants' interaction in a P2P system and we argue which of these models suit best to our setup.

5 Economic models for Resource Allocation in P2P systems

The development of an efficient mechanism for allocating resources in such P2P systems is a challenge nowadays because there are limited resources and thus there is a need for a rational use of them. An optimal allocation mechanism must satisfy the following requirements:

- All participants must be able to allocate resources;
- Resources must be allocated to participants who need them (without waste of re-sources);

- Each participant should be able to have a specification of preferences over resource attributes;
- The change of preferences over time must be considered;
- Each participant can obtain more resources than those allocated initially (e.g. those resulted from a static allocation technique);
- The resources have to be used in the most efficient way.
- The maximization of each participant's individual utility in a P2P system must be achieved;

In the micro- and macroeconomics literature several theories have been developed that state the foundation of market models. These include:

- commodity market models;
- bargaining (negotiation) models;
- auction models;
- posted price models;
- tendering or contract-net models;
- bid-based proportional resource sharing models;
- cooperative bartering models;
- monopoly and oligopoly.

In the following sections we detail each of these market models.

5.1 Commodity market models

In the case of commodity markets we treat resources like: disk storage, CPU or bandwidth. These models belong to the class of price-based models along with auctions.

There are several pricing schemes: flat fee (consumers pay a fix price for a certain period), usage duration (the price is determined depending on the usage period of a certain resource), subscription (the user pays a fixed price for a certain duration), supply and demand based, which is the most important scheme from an economical point of view and states that the price of a certain resource changes dynamically according to supply and demand. In [20] such a resource allocation mechanism is presented which is based on commodity markets where resources like CPU and disk storage are considered. The pricing scheme used here is the fourth one so the equilibrium price is reached when the supply and the demand are equal.

The main disadvantage of the first three price models is that they do not consider the supply and demand for a particular resource or service. If there is a huge demand for a particular re-source or service, is not indicated to trade them at a low cost. In the opposite case, if the demand for the resource is low, it is advised to decrease the price for attracting new users.

5.2 Bargaining

The *bilateral bargaining* between a service supplier and consumer requires the existence of two participants who have common interests in terms of cooperation, but have conflicting interests because of their selfishness [27] [28]. The main goal is a contract in favour of both parties (*agreement*) in order to maximize their individual satisfaction. Bilateral negotiation is a form of non-cooperative game where there is a well-defined set of rules and strategies, the participants' rationality is assumed and the main goal is to find an equilibrium point that is optimal, to meet each participant's expectations [27] [29].

The negotiation protocol is an important element which coordinates the negotiation stages (acceptance of offers, the ending of negotiation), events resulted from the interaction between participants. The protocol also follows the validity of participants' actions at different stages (which messages can be exchanged and when) [30].

The *alternating offers protocol* of Rubinstein [31] is the most popular protocol which coordinates the negotiations between participants, offers and counteroffers, to obtain an agreement over the resources during transactions. We have to consider the number of resources exchanged in a time period (*one-issue* or *multi-issue* negotiations) depending on which we distinguish two types: *sequential* and *simultaneous* negotiations.

The figure below presents a service negotiation scenario based on the alternating offers protocol in a P2P system:

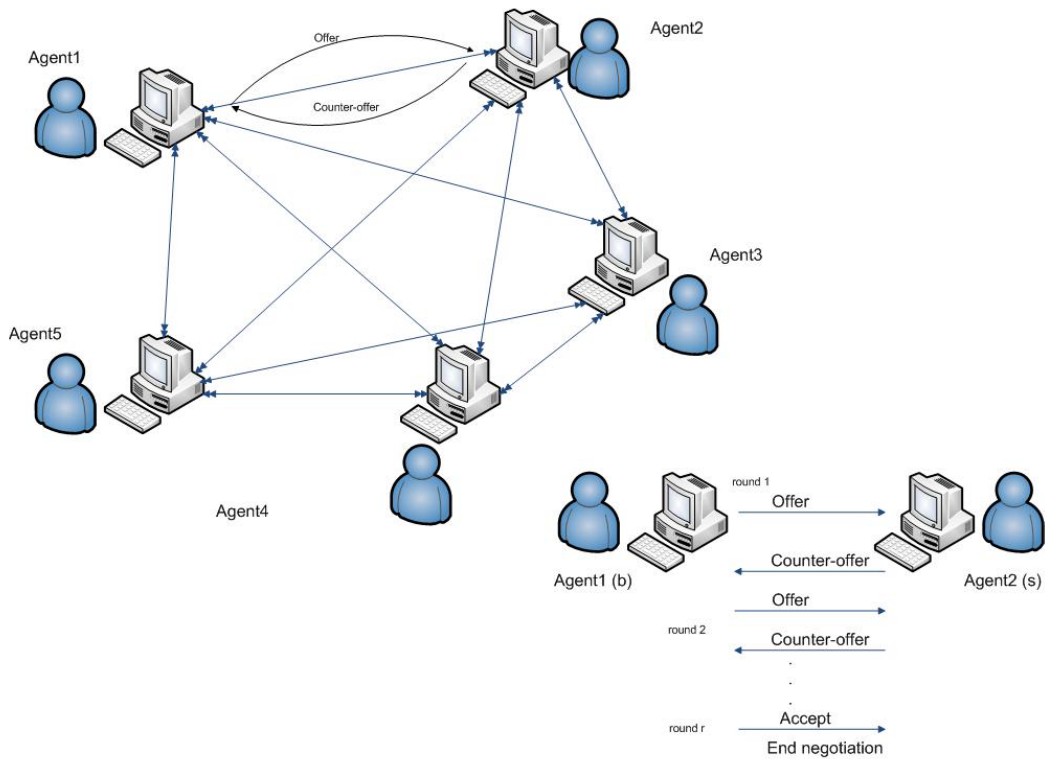

Fig. 4. A negotiation scenario between a service provider and consumer in a P2P unstructured network

In a collaborative P2P system an one-to-many negotiation model between service providers and consumers can be a viable solution considering the open communication between participants. The alternating offers protocol is a flexible and easily implementable solution for such open and decentralized systems.

5.3 Auctions

Auction models may be considered one-to-many negotiations between a service provider and many consumers. Price is the most important attribute under bidding. The main participant is the auctioneer who sets the rules of the auction, as to be acceptable for both service providers and consumers. The market mechanisms in this case are used to force negotiations on a clearing price for a particular service.

In an auction setup there are two types of bidding models: open and closed. In open bidding the participants will always know other participants' bids and they could update the sale price for a particular service, while in closed bidding they won't have this information. The auctioneer sets a deadline for the auction and until this deadline he receives bids from the participants. When the deadline expires he evaluates the proposals and announces the winner of the auction.

Depending on these parameters auctions can be classified in 4 types:

- English Auction (first-price open cry);
- First-price sealed-bid auction;
- Vickrey (Second-price sealed-bid) auction [23];
- Dutch Auction;
- Double Auction (Continuous).

In *English auctions (first-price open cry)* the bids are ascending which means that the participant who offers the highest price for a particular service will win. When none of the participants want to increase the price anymore, the auction ends and the service will be provided to the winner.

A strategy consists of a series of bids and is a function of the private value, estimates of other participants' valuations and the past bids of others. In private value English auctions a dominant strategy is to bid only a small amount over the current price and quit

the auction when the participant has reached his reservation value.
In *first-price sealed-bid auctions* each participant submits a bid without knowing others' bids. Anyone who bids the highest price wins the auction at the proposed price. In this case the bidder's strategy is a function of his private value and the prior beliefs of other bidders' valuations. There is no dominant strategy for bidding in this type of auctions. A bidder's best strategy is to bid less than his true valuation, with an amount that depends on others' bids.
In the *Vickrey auction (second-price sealed-bid)* each participant submits a bid without knowing others' bids. The highest bidder wins the service at the price of the second highest bidder. [23] A bidder's strategy is a set of bids as a function of his private value and the prior beliefs of others' bids. The dominant strategy in private value Vickrey auctions is to bid the true valuation.
In the *Dutch auction* the auctioneer starts with a high bid or price and lowers the price until one of the participants in the auction takes the service at the current price. This type of auction is similar to the first-price sealed-bid auction, the bid matters only if it is the highest.
An example of a system which belongs to the class of auctions is the Spawn system described in [25].
The *Double auctions* [24] are the most popular trading mechanisms used worldwide. For ex-ample on the stock market, the buy orders (bids) and the sell orders (asks) may be submitted at anytime during the trading period. If a buy order and a sell order are compatible in terms of price or requirements a trade is executed immediately. These orders are continuously ranked from the highest to the lowest to generate the demand and supply profiles.
In the case of periodic double auctions, the bids are collected in a certain time interval and after that the market is cleared. [26].
An overview of the auction mechanisms is depicted in the figure below:

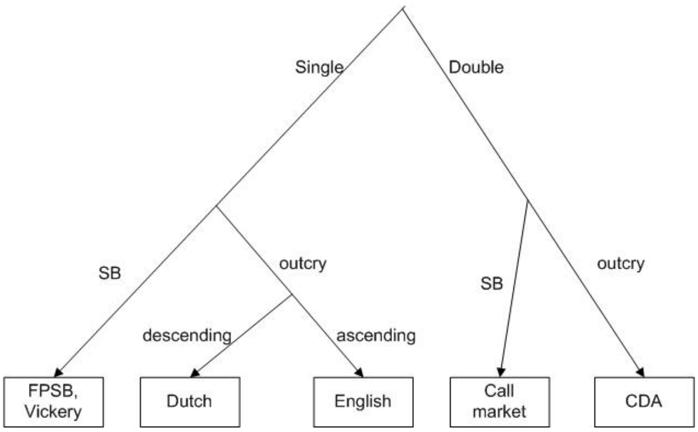

Fig. 5. Types of auction mechanisms

In a collaborative P2P system an auction model would be a viable solution with one draw-back: the relatively centralized organization which requires the need for an auctioneer is not suitable in such open and decentralized systems.
Considering a hybrid model of negotiation and auction for the trading of services would be appropriate for such open systems and would ensure the maximization of participants' individual satisfaction.

5.4 Posted price models

These models are similar with commodity markets except that the participants can advertise some special offers which include reduced prices for resources or services for attracting new users.
Peers negotiate directly between them, considering special offers and low prices mainly.

5.5 Tendering/Contract Net models

The advantage of this model is that when a seller is unable to provide an appropriate ser-

vice, the buyer could start negotiating with other sellers. This model has also disadvantages: a task may be assigned to a less appropriate seller in the case that other sellers are busy and do not respond to the buyer's request. Also, the buyer is not obligated to inform sellers that they did not win the contract.
This model could be seen as an one-shot negotiation where service providers respond to the service consumers' request with accept or refuse messages.

5.6 Bid-based Proportional Resource Sharing Model

The Proportional Share Protocol (PSP) is an example of many-to-many auctions and is used for scheduling tasks and allocating resources in computational clusters. Several tasks could be executed at a server in the same time and the allocation of a certain resource is made ac-cording to its bid price, being strongly correlated with the sum of bids prices of all tasks which are executed [22].
The users receive credits or tokens to access the resource. The value of the credit depends on the demand for a specific resource and the participant's evaluation for that resource in the moment of usage.

5.7 Cooperative Bartering Model

The idea of this model is the sharing of resources by each participant, creating a computational environment that way. Those who contribute with their resources in a community have access to other participants' resources from that community. The main problem is the amount of resources that a participant can get compared with the amount of resources that he contributed within the organization.

5.8. Monopoly/Oligopoly

These two models are taken from the economic theory and regulate the market mechanisms. Sometimes, only one service provider can perform a certain task, therefore it dominates the network, it is a monopoly situation. Those who use the service do not influence the price of that service, the only alternative is to buy at the price offered by the only service provider.
In the second case there are a small number of service providers that dominate the network (oligopolists) and set the price for a particular service, this situation lying between the two extremes: a competitive and a monopoly market.

6 Conclusions

We have outlined the main challenges encountered when resource allocation and service trading mechanisms in open and decentralized environments such as P2P collaborative systems are considered. We presented the main market models taken from Economics, considering that auctions and negotiations suit best to our setup.
In the future we intend to develop a strategy based on one-to-many negotiations that provide good solutions for a decentralized environment. Also, we propose the use of learning methods for the opponents' preferences in order to streamline the negotiation between participants and for a rapid adaptation to changes occurred in the environment.
The proposed negotiation strategy will be tested in an unstructured P2P architecture where many types of participants with different preferences will be present. Thus, it is desirable that the proposed mechanism to be automatic and give good results if changes appear in the environment. The efficiency of the mechanism will be evaluated in a comparative approach using performance indicators taken from literature: Nash product, Pareto efficiency or Kalai-Smorodinski solution.

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