

Simulation of the behavior of bidders in first-price sealed-bid auctions on communication networks

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Abstract: - Auction mechanisms have arisen as very efficient methods for scarce resource allocations. For this reason there is a current research topic based on the application of these economics mechanisms to the design of communication networks, mainly in the provision of QoS to new multimedia services. The main research works are oriented to the assignment and pricing rules, that is, the network resource assigned to the user (the bandwidth on a link, or the route of a traffic demand) and the amount of money it is going to cost to him respectively. However, as far as we know, there is a little research focused in the analysis of the behaviour of the user. Note that an auction is in fact a competition where the user will behave selfishly in order to obtain the greater profit. In this paper we present the first results of a simulator which analyzes the behaviour of the user in an auction over a communication link. They obtain the revenue of the auctioneer that is the network provider, and the resource allocation under different schemes of user behaviour, from a very conservative character up to most risky behaviours.

Key-Words: - Network capacity, congestion, auction, bidders' behavior, and simulator.

1 Introduction

Internet network is composed by several interconnected autonomous systems (AS). Each one can be described as a specific network administrated by an independent entity. In our globalized world, a user works and communicates not only with users in his native network, but also with users in other networks. On the other hand, there is a lot of new multimedia services, as VoIP (voice over IP) or "Triple Play" services (telephone+Internet+TV) [1] which are demanding a guaranteed quality of service (QoS). QoS can be measured mainly in terms of bandwidth and transmission delay. The bandwidth is associated to the capacity of the transmission links and the delay depends critically on the route assigned to the demand of the user. Note that a very large route implies the traffic has to go through a large number of network elements and links and therefore the delay increases.

The increasing bandwidth demand of the users causes a high probability of network congestion. In those situations, the network may not fulfill the QoS constrains of real time services. A feasible way to solve this problem may consist of prioritizing the traffic in the network.

We could think of a system where the users prioritize their own traffic themselves. Obviously this pattern would not work, because users (PC's, autonomous systems or humans) will behave selfishly. Hence they will always establish the highest priority for their traffic because they would consider their own demands as the most important ones. This would take us again to a network congestion situation. A more effective strategy for resources assignment and control congestion may be based on traffic priority according to pricing.

Pricing mechanisms have been broadly applied in communication networks [2]. Specifically, economic mechanisms, like auctions, have revealed as appropriate methods for assigning efficiently network resources to the users [3]. This assignment not only consists of bandwidth allocation but also routing inside a single provider (intra-domain) and/or through different autonomous systems (inter-domain) [4]. It is straight forward that these three problems have an increasing complexity as it is shown in Figure 1.

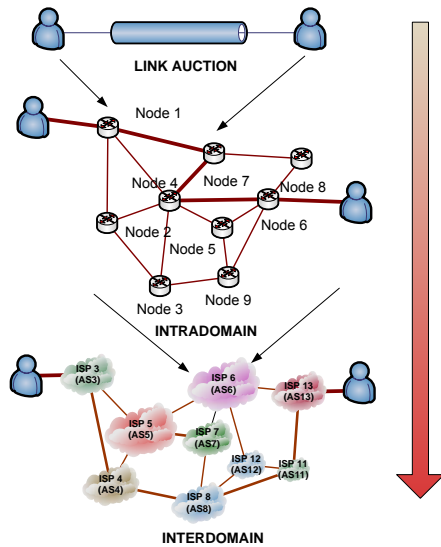


Figure 1 Network resources auctioning scenarios.

An auction is composed of several parts: the auctioneer (network provider), the bidders (service providers and final users), the award auctioned (total transmission capacity through the network) and the assignment and pricing rules. A key factor is the bidders' behavior because an auction is, in fact, a competition, where the users behave selfishly trying to obtain their maximal profit [5]. Our work consists of a study of the users' behavior during the competition for transmissions resources in a communication network through auctioning.

When the award auctioned is a single item, there is a unique winner of the process. But in our case, the award consists of a transmission capacity Q , which maybe divided in multiple units. Due to existence of network congestion, not all demands can be served and an allocation rule is needed. The allocation rule determines how to split and assign the resource, i.e. which bidders will access to the network and which capacity (q_i) will use each one. Due to the limited transmission capacity of the network, resources assignment must fulfill the condition of the equation (1.1), where M users demand a portion of Q capacity. a_i is the assigned capacity to the user i by the auctioneer. x_i represents a binary value that is "one" when the user receives some capacity (is a winner of the auction) and "zero" in other case. Note that a_i maybe does not correspond to the demanded capacity q_i . Nevertheless $a_i \leq q_i$

$$\sum_{i=1}^M x_i a_i \leq Q \quad (1.1)$$

In auction mechanisms in economy environments with multiple goods, it is not always guaranteed that

all winners pay the same price per unit. Pricing rule fixes the price c_i to pay by each bidder i which receives a portion of the award.

It is straightforward that bidders wish to pay as less as possible. On communications, the valuations of the bidders are private, the bidders and auctioneer do not know the valuation of others bidders. Each user i value the auctioned capacity q_i in a different way. The value is represented as a valuation function θ_i . Figure 2 shows three types of valuation functions. Functions as case (A) corresponds to non-elastic demands, where the valuation does not change with the amount of capacity requested, whereas cases (B) and (C) belong to situations of elastic demands. In (B) the valuation function has a constant gradient, more capacity is more valued in a proportional way. Case (C) has a variable gradient valuation/capacity.

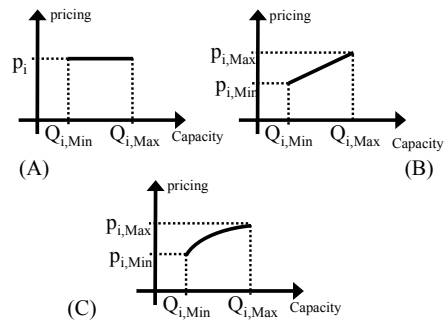


Figure 2 Valuation functions according to user's capacity

The auctioneer can assign the demanded capacity q_i to the user i , or a value $a_i < q_i$.

Let $\theta_i(q_i)$ the valuation function of the capacity q_i of user i as $\theta_i(q_i)$. The user always bids a price $p_i \leq \theta_i(q_i)$ because of he wants to buy as cheap as possible. We denote the utility function (or user's benefit) as the subtraction of the valuation of an assigned resource a_i and the cost c_i that the user pay for it. See the equation (1.2) where U_i means the utility function of user i .

$$U_i = \theta_i(a_i) - c_i \quad (1.2)$$

As said before, in an auctioning process the bidders behave selfishly and untruthfully, bidding fewer amounts than they value the resource.

On the other hand, the network provider wishes to maximize his revenue. The auctioneer will split the total resource Q in a manner that he gets the maximum profit, see equation (1.3), where again x_i is equals to "one" if the user i receives some capacity and "zero" in other case.

$$\sum_{i=1}^M x_i c_i \quad (1.3)$$

We also consider that the requirements of users change with time. A user i needs a capacity q_{i0} during a specific time period changing after. For example, consider the case where the user is in a video conference during a period, and when he finishes his needs are smaller, to send a data file by ftp for example. A video conference requests more capacity than simple data transmission with real time, so he is willing to pay more in the first case than in the second. Due the variability of the user's needs, the network provider will perform several auctions per day in order to use more efficiently his facilities.

Users' behavior has a lot of influence on the results of auctioning because of the process implies competition of bidders. Our proposal is an auctioning simulator of competition for a transmission link of a communication network. The kind of auction is first-price sealed bid. The simulator intends to analyze and compare different users' behavior.

The document is organized as follows: in section 2 we describe the fundamentals of auctioning and the main types of auctions. Section 3 proposes a simulator of bidders' behavior in a first-price sealed bid auction. We include a set of results obtained with the simulator and conclusions. In the last section, we comment on our future working lines.

2 Auctions types

Auctioning is a method of allocation scarce resources; it is based on the users' competition. The auctioneer (the Service Provider in communications networks) wishes to get the largest benefit as possible, whereas the bidders want to pay as little as necessary [6].

The term "*auction*" means "to increase", however, not all auctions processes have ascending price schemes. William Vickrey categorized the auctioning strategies into 4 types according to the manner the bids are put up [7].

2.1 English auction

English auction is the standard method and also the most known. The valuation of the award is increasing from the beginning to the end of the process. The auctioneer starts revealing the lowest acceptable price for the goods to sell. He requests successively higher bids from the buyers until anyone wish to offer more than the latest sum. At this point the goods are assigned to the latest bidder. This kind of auction is very common when there is a single award, so there is a unique winner.

The two main disadvantages are "winner's curse" and collusions. "Winner's curse" is produced when the bidder pays more than what the award is worth.¹

2.2 Dutch auction

A Dutch auction starts with an exceedingly high price for the item. The price is decreasing progressively until a buyer shows his interest to acquire it. When there are multiple units of an item, the bidders get in units with at lower prices successively until the units run out. The allocation and pricing rules of Dutch auctions are different to the English ones. During an English auction, a high interested buyer has more response time to buy, in the sense that if other bidder offers a higher price, the first one has the opportunity to pay more and get the item. In a Dutch auction, the very interested buyer must ahead of the rest of bidders. The first one which accepts the price, anyone more can get out the award. In this way, the auctioneer wins more usually in Dutch auctions than in English ones.

2.3 First-price sealed-bid auction

In a sealed bid auction, no others bidders know the bid price of anyone. The process has two stages: at first, the bidders inform to the auctioneer their bid prices and at second step the winners are announced. The term "first-price" specifies the allocation rule mentioned in the introduction. In the second stage, the bid prices are sorted from high to low. For single item, the winner is who bid the highest price, for multiple units, they are selected from this sorted list until the units are exhausted. Reynolds [2] refers to this characteristic as "discriminatory" because not all winners pay the same per unit. The bidder strategy will be to put near the winning bid prices interval but inside the lowest part, so he would pay less than the others.

2.4 Vickrey auction

Under a Vickrey auction, the price paid for each user, is the loss of declared welfare he imposes to others users due to his presence in the auction. This mechanism satisfies the following conditions:

- Incentive compatibility: for each user, bidding truthfully is a dominant strategy. They present offers similar to their real valuation functions.

¹ Collusions consist of the agreement among bidders (called "ring" in economy world), where they agree on a highest amount, and anybody bid more than this fixed amount.

- Individual rationality: each truthful bidder obtains a non-negative utility as equation (1.2).

4 Implementation of simulator

In this section we present the implementation of a simulator to auction specific network resources. It analyzes the users' behavior in competition. As said before, we select the first-price sealed-bid auction. Sealed auctions are nearer to communication applications than English and Dutch ones. The computational complexity of a Vickrey auction is NP ("Non-deterministic Polynomial time") whereas the complexity of a first-price sealed-bid auction is only polynomial time. We select first-price auctioning as an approximation of second-price one.

The system is composed by the following parts: the network provider (the auctioneer), the transmission capacity of a single link (Q , the item to sell by multiple portions a_i), and the potential users (PC's, autonomous systems or humans, who are the M bidders). The link under analysis connects two any nodes N_1 and N_2 of a network. Figure 3 represents the described system. We consider the link is under congestion, so the network provider must prioritize the traffic through auctioning. The assigned capacity by an auction must keep the equation (1.1) and also is advisable to produce the maximum revenue to the network provider.

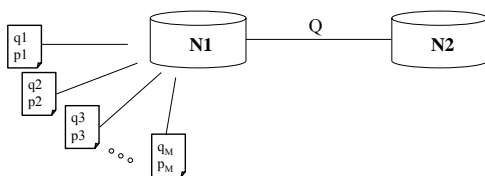


Figure 3 Auction of M bidders for the capacity of a single link of a network.

Consider a vector $q = (q_1, q_2 \dots q_M)$ which represents the capacity bided by M users. Obviously they have different valuations of the demands so they are willing to pay different prices, named as $p = (p_1, p_2 \dots p_M)$. Remember that bidders really want to pay as least as possible as long as it gets some capacity.

We define that a user i has an offer range as show in Figure 4. He values the q_i capacity as $P_{Max,i}$, which is the valuation function $\theta_i(q_i)$, whereas the user offers

a value $p_i < P_{Max,i} \cdot P_{Min}$, represents a minimum of the valuation of the good.

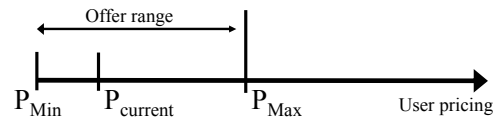


Figure 4 Pricing ranges for offers from an individual user.

The result of each auction is a set of winners who share the available capacity. Let us write the vector $\underline{a} = (a_1, a_2 \dots a_M)$ where a_i means the assigned capacity to the bidder i . The vector \underline{a} participate in equation (1.1). The cost of the assigned capacity is written as a vector $\underline{c} = (c_1, c_2 \dots c_M)$, that characterizes the price that users pay for the transmission service.

Due to an auction is really a competition, the users' behavior has a lot of influence on the results of the process, chiefly with successive auctions. We consider systems where bidders remember the results of the last auction. That means bidders fix their offers according to the capacity assigned in the last auction. The basic behavior consists of increasing the price for next auction if they didn't get any capacity, and decreasing the offered price if they got before some capacity. A first classification of bidders according to their behavior distinguishes three kinds of users: risk-seeking (sometimes called risk-loving), risk-averse (or risk-hating) and neutral-risk users:

- A risk-seeking bidder has high variation of pricing between two consecutive auctions, his behavior is aggressive in sense of he changes sharply prices.
- Risk-averse bidders change slightly the price of the last auction, they have a previsible behavior.
- Neutral-risk bidders have a middle behavior among risk-seeking and risk-averse one.

Of course it is possible to expand this first classification finding new groups inside each large type. For example, risk-averse users can be more or less conservative. A conservative bidder never decreases his offered price, he only increases it if he didn't get any capacity before. We establish the width of the decision window of these kinds of behaviors.

- A risk-seeking user with a value "zero" of x_i selects always a random bid between the previous p_i and his valuation of the goods (P_{Max}). See Figure 5(A) dotted area. The range from p_i and P_{Max} is named decision window. A risk-seeking bidder who won the previous auction fix his

following offer as a random price between p_i and the minimum P_{Min} as we can see in Figure 5(A) scratched area. In this case the decision window is the gap between p_i and P_{Min} .

- A risk-neutral bidder behavior is showed in Figure 5(B), where the decision window is the 50% of the risk-seeking one. If the user won the last auction then he selects a random price between last p_i and (P_{Max}) .
- Figure 6 represents behavior of risk-averse bidders. We assign a width of 20% for the decision windows. If the user has a value of x_i equals 1, the behavior of conservative and non-conservative users is the same (Figure 6 dotted areas). They increase the offer a random percentage from 0% to 20%. If the user has a value of $x_i=0$ then only the non-conservative bidders decrease their following offers if they won the last auction, see Figure 6(A) scratched area whereas the conservative ones keep their previous price P_o , as shows Figure 6(B).

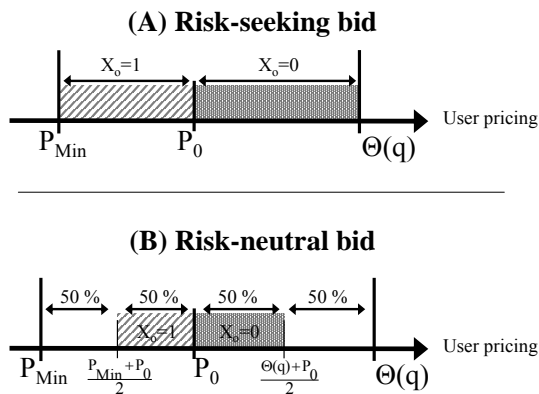


Figure 5 Behavior of bidders. (A) Risk-seeking users; (B) Risk-neutral users.

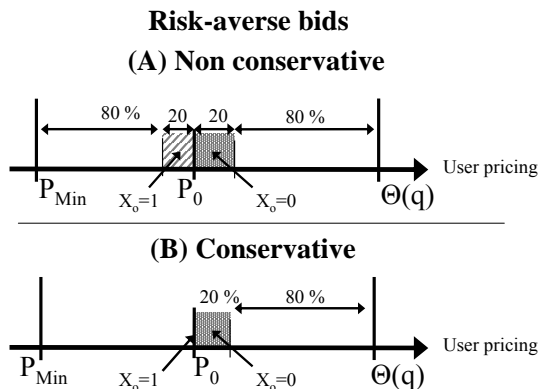


Figure 6 Behavior of risk-averse bidders. (A) Non-conservative users; (B) Conservative users.

5 Results

A large set of experiments have been performed but for the sake of simplicity we are going to present only three considering the user' classification mentioned above. We assume that winner always obtain the demanded capacity q_i , it implies $a_i=q_i$. Next we define the three different simulation scenarios explained in this section. They are represented in Figure 7:

- Scenario 1: all bidders are risk-neutral.
- Scenario 2: 50% of users have risk-seeking behavior and 50% risk-averse (non-conservative) one.
- Scenario 3: distribution of population as 20% risk-seeking bidders; 30% of risk-neutral users; 25 % conservative and 25% non-conservative risk-averse users.

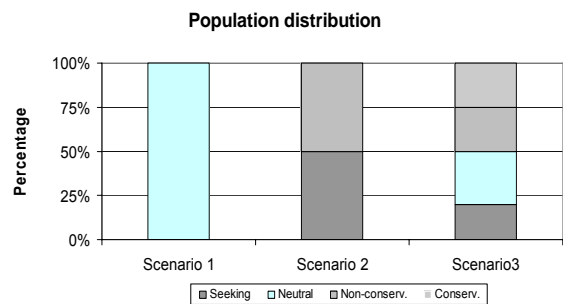


Figure 7 Distribution of the population of the three different scenarios according the risk characteristic of users.

The size of population is fixed to 40, as it may be the number of employers of a small-medium company that demands transmission facilities to a service provider. The auctioneer, that is, the service provider, auctions his capacity every 10 minutes during the 24 hours of days. We have selected this time slot because this is the average duration of an ftp session. This frequency means 148 auctions per day. Therefore each simulation contains 150 auctions as approximation of this scenario.

First we compare the total revenue of the service provider for the three scenarios. Figure 8 shows the accumulated revenue for each distribution. Note that scenario 3 contributes with a higher income to the auctioneer than the others, whereas scenarios 1 and 2 produce similar revenue.

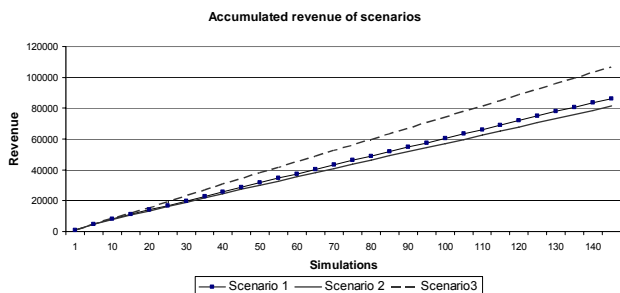


Figure 8 Revenue of the service provider for scenarios 1, 2 and 3.

Concerning scenario 2, Figure 9 shows the accumulated revenue produced by each set of users (risk-seeking and non-conservative ones) and the percentage of assigned capacity of each set of users represented by the striped and shadowed areas. After some transitory time, risk-averse bidders reach more capacity than the risk-loving ones. Note further that the risk-seeking group wins less capacity, paying more, than non-conservative group whose decision window is tighter (remember Figure 6).

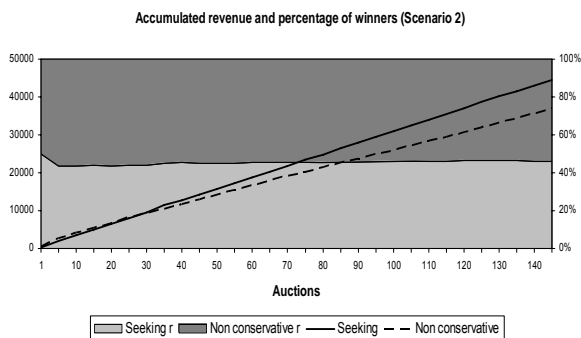


Figure 9 Results of simulation with the scenario 2.

Simulations with population from scenario 3 have some important conclusions obtained from Figure 10 and Figure 11. The first one is that the system reaches stabilization after a transitory period. After 50 auctions the capacity is allocated in the same average proportions: 40.5% of the goods are assigned to the conservative users; 26.5% are allocated to neutral bidders; 19.5% are assigned to risk-seeking and 13.5% of the facilities are located to the non-conservative users. This percentage is represented on the column F in Figure 10. The column A on the same figure represents the distribution of the total population.

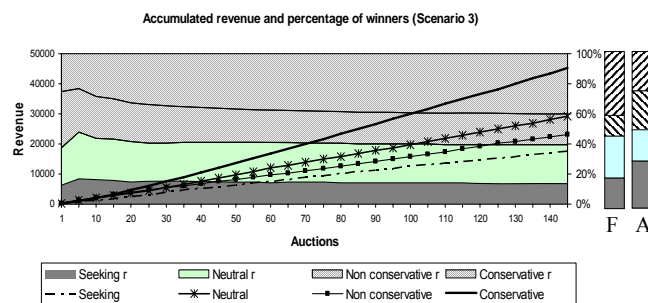


Figure 10 Accumulated revenue and assignment of capacity for scenario 3. (A) is the population distribution. (F) is the average proportion of winners.

The curves on the figure mean the accumulated revenue per type of users. These revenues are proportional to the described column F in the sense that the biggest quantity comes from the mayor winners of auctions, the conservative one. More representative are the curves of Figure 11, where the accumulated revenue has been weight up users. In this way we have the revenue per user of each kind of risk and each auction. It is really interesting to see the risk-seeking bidders are who pay more individually however they receive always the least quantity of capacity.

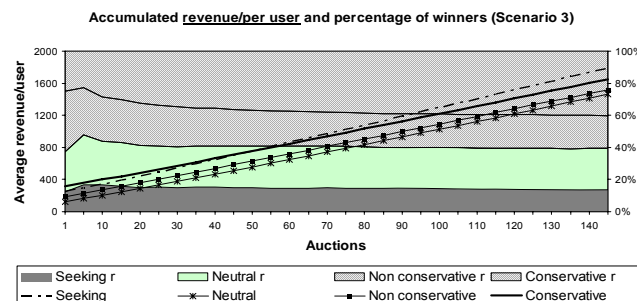


Figure 11 Accumulated revenue per user with a population of scenario 3

Finally, Figure 12 maps the allocation of capacity to the users on the three scenarios. The assignment is represented by a simple black dot in the user column. Rows represent consecutive auctions. Note that in the third scenario the conservative strategy is the best the conservative users obtain capacity in the majority of the auctions. This means that they get profit from the aggressive strategy of the risky users.

6 Future research

This paper shows the first results in the development of a simulator of the user behavior in auctions for

communication network resources. We have considered a single link with capacity constraints and different user characters. The bids of the users change with time depending on the past auctions and on their own natures. Under the defined conditions we can observe that the results tend to stabilize. The maximum revenue of the auctioneer is obtained in the real scenario due to the strong competition of the users. Note that the risk seeking users pay the highest individual amount although they obtain less capacity than the other groups. This situation is produced by the kind of auction.

Regarding future work lines, the first research work consists of improving the simulator with new, and more realistic, behavior patterns, based mainly in Gaussian distributions. The assignment and pricing rules will be also improved changing the first price sealed mechanism by a Vickrey auction which satisfies the Nash criteria. Finally we will compare the results of the simulator with analytical studies derived from the application of modern heuristics to this kind of economic mechanisms.

7 Acknowledgments

The research explained in this paper is being financed by the Network of Excellence EuroNGI: Design and Engineering of the Next Generation Internet, of the VI European Framework, contract N° IST 50-7613 and the project of the University of Alcalá : “Desarrollo de métodos y modelos algorítmicos para la optimización multicapa de redes dorsales basadas en GMPLS”, UAH PI 2005/079.



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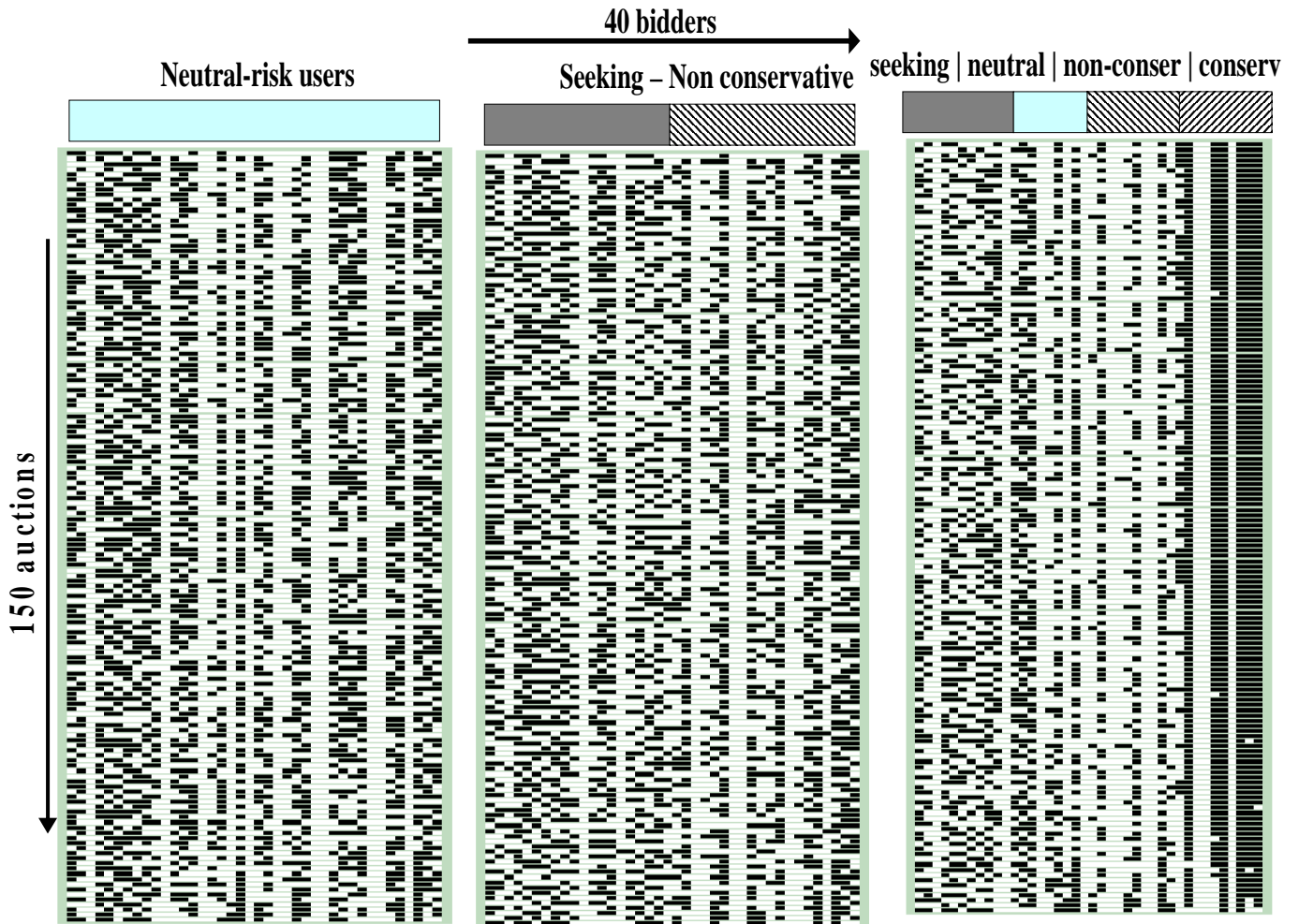


Figure 12 Representation of the allocation to the users in the successive auctions in the considered scenarios.