Toward a Protocol for the Formation of Coalitions of Buyers

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Abstract

It is advantageous to group together for the purchase of a good or a service in order to benefit from a price reduction according to the size of the purchasing group. The bought product must however be the same for all the members of the group and this requires such a group to make compromises on its exact specification. It is therefore necessary, for a given set of consumers, to partition itself into groups (or coalitions) which might satisfy preferences of their members. To this end, we have developed a protocol which finds a "satisfying" partition of consumers. As the search of this partition is equivalent to the $\mathcal{NP}$-hard problem of generating exact set covers, we have tested our protocol by varying the number of agents and the number of possible specifications with random preferences to see under which conditions we can find a solution in a reasonable amount of time and memory space.

Keywords Multilateral negotiation, Coalition formation, Group buying, Software agents, Multiagent systems.

1 INTRODUCTION AND MOTIVATIONS

The next step after the automation of the electronic transfer of money as secure electronic payment will surely be the automation of the negotiation that precedes the monetary transfer. Notice that negotiation here means "the process by which group of agents communicate with one another to try and come to a mutually acceptable agreement on some matter" [7]. Among the different types of negotiation, multiattribute multilateral negotiation, which sustains our protocol for the formation of coalitions of buyers, is one of the most complex because of the multiple issues and parties. Such a negotiation seems to have one of the greatest needs for automation.

Coalition formation has been and continues to be studied in the research field of multiagent systems. A multiagent system consists of multiple computer programs (the agents) that interact among themselves and with their environment (the Internet for example) to accomplish autonomously the task that their owner (usually a human but sometimes another software agent) asked them to do. When they cannot accomplish their tasks by themselves, the agents can form coalitions in order to have the required resources to do such tasks.

Evidently, any formation of a coalition of agents should be sustained by some negotiation between agents. In electronic commerce nowadays, agents negotiate the price of an item, compare prices from multiple sellers' web site and automate many other mundane tasks that occur in buying and selling products and services. It is important to see if they can negotiate between them in order to form a coalition?

It has been claimed that software agents are sometimes more efficient than humans in finding good deals in complex and combinatorial situations [11]. In fact, experiments have shown that humans perform poorly in multiattribute bilateral negotiation even with the help of negotiation support systems (NSS) [9]. Software agents differ from NSS in that they do not help the humans in the negotiation; they do it for them. Since a group of buyers often involve multiattribute multilateral negotiation, it is interesting to investigate the formation of a coalition of agents if such agents can aggregate their demands in order to get a price reduction.

At the beginning of the millennium, buying group sites spread across the Internet from North America and Europe. The idea was attractive since many users believed that such sites could: (a) reduce customer acquisition costs, (b) reach new audiences, (c) test and market promotions, (d) sell excess inventory and (e) provide valuable consumer behavior-related data and analysis [10]. Unfortunately most of these sites have recently closed or redirected their activities. This situation is due to mainly five reasons [2]:

Waiting time too long: consumers must wait for others to join the buying group and sometimes, they considered the waiting time too long for the resulting price reduction.

Higher prices: giants of distribution already buy in large quantities so they shrink the unit price to the minimum in a way that even if you are tens or hundreds in a buying group, you are likely to pay more than you pay at your local stores.

Small choice: group buying sites often negotiated reduced prices with manufacturers in exchange of selling exclusively their products or services and some prestige brands, as high priced fountain pen, did not want to sell their products via group buying sites further reducing the choice.

Misunderstanding of the concept: since most of the sites bought products in large quantities at a unique unit price from the manufacturers, they artificially created a price schedule with decreasing unit price in relation to the quantity bought and some consumers misunderstood this as a swindle.

Critical mass hard to obtain: for forming a coalition of hundreds of consumers interested in the same product at the same time, you need maybe tens of thousands of regular clients and that critical mass is difficult to get at this time.

We believe that as consumers get more connected to the Internet and their fears of making transactions on it are mitigated, the critical mass will be obtained, more people will understand group buying and consequently, the choice will broaden and the waiting time will be shortened. For the aspect of the price shrinking to its maximum by giant distribution companies, we propose applying the concept to customized products or services that these companies do not sell.

In fact, our contribution to the design of a protocol for the formation of coalitions of consumers is a contribution to a long term goal which aims to implement a choiceboard considered as an interactive, online system that lets customers design their own products by choosing from a dynamic menu of attributes, components, prices and delivery options [12]. With such choiceboards, consumers could try to negotiate their preferred values of attributes of products in order to form buying groups that get savings. Another way to revitalize this concept of choiceboard is to apply it to the more expanding domain of business-to-business (B2B) electronic commerce.

This paper is organized as follow. In the next section, we briefly review some related work. Then, in section 3, we present our protocol and in section 4, we detail some experimental results and discuss them. Finally, we conclude in section 5.

2 RELATED WORK

The use of coalition formation for buying groups has recently attracted the attention of researchers. Thus, Tsvetovat and his colleagues have demonstrated the economic incentives of buying groups for consumers as well as manufacturers and providing models of coalition formation in that context [13]. Lerman et al. have described the macroscopic behaviour of coalitions with differential equations when agents are allowed to leave and join a coalition to finally reach a steady state [4]. For their part, Yamamoto et al. have separated agents in coalitions and divided the profit generated by a coalition among its members [14]. Another interesting issue investigated by Ito et al., is on how we can allow sellers to cooperate when a coalition requires more units than a single seller can offer [3]. Another facet has been investigated by Lin et al. and concerns some reputation in the choice of a coalition's manager which represents the other members of a coalition in the negotiation with sellers [6]. Li et al. have studied how combining coalition formation with combinatorial auctions for a more efficient marketplace [5]. Finally, Breban et al. have studied the concept of trust in long term coalitions of buyers and sellers over repeated transactions [1]. None of all these approaches have studied the case where agents are willing to make compromises on their preferred values of attributes in order to form buying groups.

3 OVERVIEW OF THE PROTOCOL

The consumers tell their agent the type of products or services they want (a car for instance or any other product) and their preferences over the possible instances of the chosen type. The agents with the same type are gathered together in a set and each agent has to decide which buying group it wants to join. A solution to this problem is a partition (every agent is in one and only one group) of the set of agents. A partition p is Pareto optimal if there exist no other partition p' such that there is at least one agent which prefers to be in it than in p and all agents are not worse (no agent prefers solution p to solution p').

Notice that there are $2^N - 1$ possible distinct groups for a set of N agents because a group is equivalent to a subset. There are 2^N distinct subsets from a set of N elements. We precisely have $(2^N - 1)$ because we do not consider the empty set as a valid group for the buying group problem. Considering that every group could buy one of the P available products (or services), there are $(2^N - 1) \times P$ possible buying groups.

This is a large number of possibilities even for a small number of agents and products. We thought that by limiting the number of unit of products bought by every agent to one, we could decrease the number of possibilities to $N \times P$. Since what makes a difference in the price is the number of units bought, if we limit to one the number of unit an agent can buys then the number of agents in a group equals the number of unit bought. Then all groups with the same number of agents who buys the same product pay the same unit price and are therefore equivalent in the view of the agents. For example, the buying group made of agents A, B, C and D who buy Product#1 is the same as the buying group made of agents A, F, G, and H buying the same Product#1 and therefore, an agent A needs only to consider the buying group with 4 agents desiring Product#1. Since there are a maximum of N groups with distinct cardinality for a set of N agents, each having the possibility of getting P available products, there are now $N \times P$ possibilities an agent needs to consider. This stands only for the number of possibilities an agent must look upon and not the actual number of buying groups created. But at least, the protocol will only process the number of buying groups created instead of considering all possible ones. A consumer wishing to buy multiple units, say 5 units, could still use the protocol by having as many agents as she wants units, in that case, 5 agents each desiring only one unit of the selected product. This could make the protocol unfair as a consumer desiring 50 units of a product will be paying the same unit price has a consumer desiring only 1 unit while contributing much more to its decrease than its counterparts. Since we target using the protocol for buying/selling customized products which rarely are sold by more than one per consumer, we think that is a good tradeoff considering the associated decrease in possibilities an agent must consider.

An agent must sorts the possibilities in decreasing order of satisfaction as shown in figure 1. If two possibilities have the same satisfaction level, an agent will prefer the buying group with the most agents in it. If there is the same quantity of agents in the two buying groups, the decision to prefer one group over the other is left at the discretion of the designer.

The satisfaction toward buying a specific product with a specific buying group depends on the unit price paid by that group and on the specifications of the product given by a list of attribute-value couples defining the product as in [8]. For each agent, the most preferred value for an attribute gets a satisfaction measure of 1 and following values in the preference ordering get a smaller and smaller satisfaction measure. We have also used a function F_s which returns the satisfaction of paying a particular price. F_s returns 1 if the price is 0$ (a free product) and 0 if the price equals the reservation price (maximum price the agent is willing to pay) of the agent. Notice that F_s returns intermediate values between 1 and 0 reflecting thus the price between 0$ and the reservation price which depends on the agent. The global satisfaction in buying a product is the weighted aggregate of the satisfactions toward the attribute-value couples defining it and the satisfaction returned by F_s. The total weight of all attributes and the price is 100. A weight of 0 indicates that the corresponding attribute does not matter for the consumer. Of course, if a product is inadmissible for an agent because his price is higher than its reservation price or because of an inadmissible value for an attribute (the agent does not want the color to be red or the seat cover to be in leather), all the buying groups that feature that product are eliminated from that agent list of possibilities. An agent could compromise by joining a buying group with a product with less desirable value for an attribute (a not so pretty color) but a great price overcoming the decrease of satisfaction toward the attribute by an increase of satisfaction toward the price. Figure 1 shows the lists of possibilities sorted from the most preferred to the least preferred of 3 agents with 2

	Agent A	Agent B	Agent C
First choice	Product#2 at 3 units	Product#2 at 3 units	Product#1 at 3 units
	Product#1 at 3 units	Product#2 at 2 units	Product#1 at 2 units
	Product#2 at 2 units	Product#2 at 1 unit	Product#1 at 1 unit
	Product#2 at 1 unit	Product#1 at 3 units	Product#2 at 3 units
	Product#1 at 2 units	Product#1 at 2 units	Product#2 at 2 units
Last choice	Product#1 at 1 unit	Product#1 at 1 unit	Product#2 at 1 unit

Figure 1: Sorted lists of possibilities for three agents with two available products.

available products. Agent A prefers to buy product#2 with the two others agents (which means 3 units bought). Agent B second choice is to buy product#2 with one of the other agents (which means 2 units bought). Agent C third choice is to buy alone product#1 (which means 1 unit bought). The grey boxes indicate possibilities that are *not* individually rational, that is a situation giving less satisfaction than the possibility of acting alone. In this type of situation, buying alone is more advantageous. Such situations are inadmissible here since each agent can buys a product alone.

From their lists of possibilities, the agents give their preferred buying groups one by one from the most preferred to the last individually rational one to a trusted third party named the Grouping Agent by following the protocol of figure 2. The Grouping Agent waits during a period for the consumers' agents to register. After that, the Grouping Agent sends information to the consumer's agents about the number of agents desiring the same type of products, the available instances of the chosen type and an identifier for each agent valid for the duration of the protocol. With that information, each consumer's agent creates and sorts a list of possible buying groups. If that list contains a buying group where the agent buys alone a product, (that is, there exist a product with no inadmissible value for all attributes that when bought at one unit, respect the agent's reservation price), then the agent tells the Grouping Agent that it is ready to propose a buying group. Or else, the agent quits the protocol and the Grouping Agent tells the remaining agents that this agent will not participate in the protocol and to not count it. We do this to assure that there is at least a solution to the problem of forming buying groups. If all agents want a buying group where it buys alone a product, then all agents are in an actual buying group. The algorithm used to form buying groups requires that all agents are in at least one group or there is a possibility that it does *not* find a solution. It would be unfortunate that consumers wait for hours, even days for others consumers to join the protocol to attain a critical mass and tell them later that there is no solution because only one agent did not have an actual buying group. If we did not want a Pareto optimal solution to the problem, we could raise that constraint but Pareto optimality is the major argument in favor of the developed protocol.

After telling the Grouping Agent if they are ready to propose or not, consumers' agents are asked to propose their preferred buying group by removing it from the top of their list of possibilities. When all remaining agents (when an agent has no more buying group to propose, it withdraws from the ask proposal – gives proposal cycle and waits for the results) have answered, the Grouping Agent tries to find a solution. If it cannot, it asks again for the following most preferred buying group of each remaining agent and the cycle restarts until a solution is found.

The problem of generating actual buying groups from proposed ones is equivalent to the combinatorial problem of generating the K-subsets of a N-set (for example, from a set of 10 elements (N), generate all the distinct subsets of this set

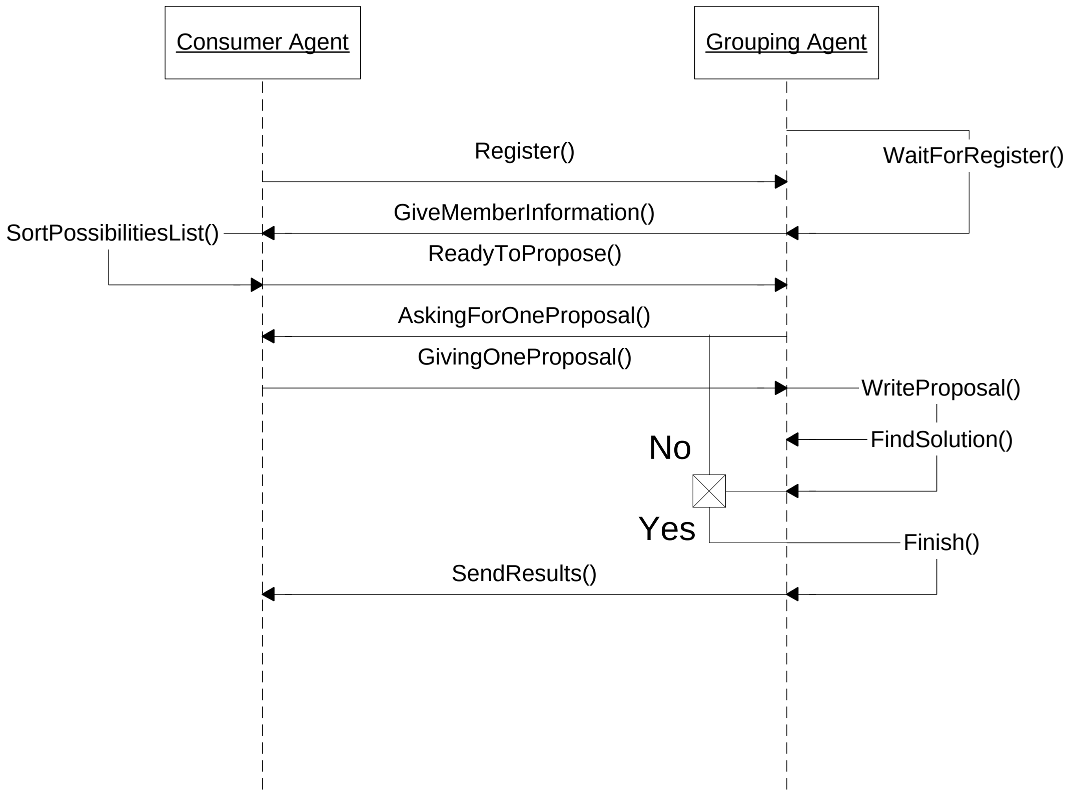

Figure 2: Coalition formation protocol followed by all agents

which has exactly 6 elements (K)). The problem of finding a partition of the set of agents from the generated buying groups is equivalent to the $\mathcal{NP}$-hard problem of generating exact set covers (select pairwise-disjoint subsets from a subset of the power set of a set such that every elements of the set is in one and only one selected subset). Because they are generation problems and not optimization ones, we cannot approximate their solution.

4 RESULTS AND DISCUSSION

We tested the previous protocol on a Pentium 4 with 1.4 GHz processor, 256 Meg of RAM of which 130 Meg was dedicated to the execution of the protocol. It was developed using Java JDK 1.4 and Jack 3.5, a framework for programming software agents. This protocol has been evaluated for several numbers of agents (2, 3, 4, 5, 10, 15 and 20) and quantities of products (2, 10, 100 and 1000). We have precisely executed the protocol a thousand times for each number of agents – quantity of products couple (a thousand times of 2 agents with 2 available products for example) with random preferences for the agents and always the same list of available products with their price schedule. Each of the 5 times we executed the protocol for the case of 20 agents and 2 products, the program went out of memory (even with 130 Meg of available memory). So we consider the case with 20 agents to be the limit of the protocol on the fore-mentioned computer platform and focus our attention on the cases with 15 agents or less. After the evaluation was completed we run the protocol on a different platform which had more memory but less processing speed. With 450 Meg of dedicated memory this time, we had enough memory for cases with 20 agents but not for cases with 25 agents.

Figure 3 demonstrates the mean time (in milliseconds) of the 1000 executions of the protocol for each couple between the moment the Grouping Agent sends information to registered consumers' agents to the time it sends the solution to them. As expected, the execution increase with the quantity of available product but it remains sublinear on a logarithmic scale meaning that the complexity is *less* than exponential for the studied range (2 to 15 agents). This result is a little surprising due to the presence of two combinatorial problems. We explain this by the incentive of being a lot in a buying group in order to benefit from a price reduction which pushes agents to aggregate quickly and by the fact that the list of possibilities of each agent is bounded to individually rational buying groups which limit greatly the number of proposal rounds.

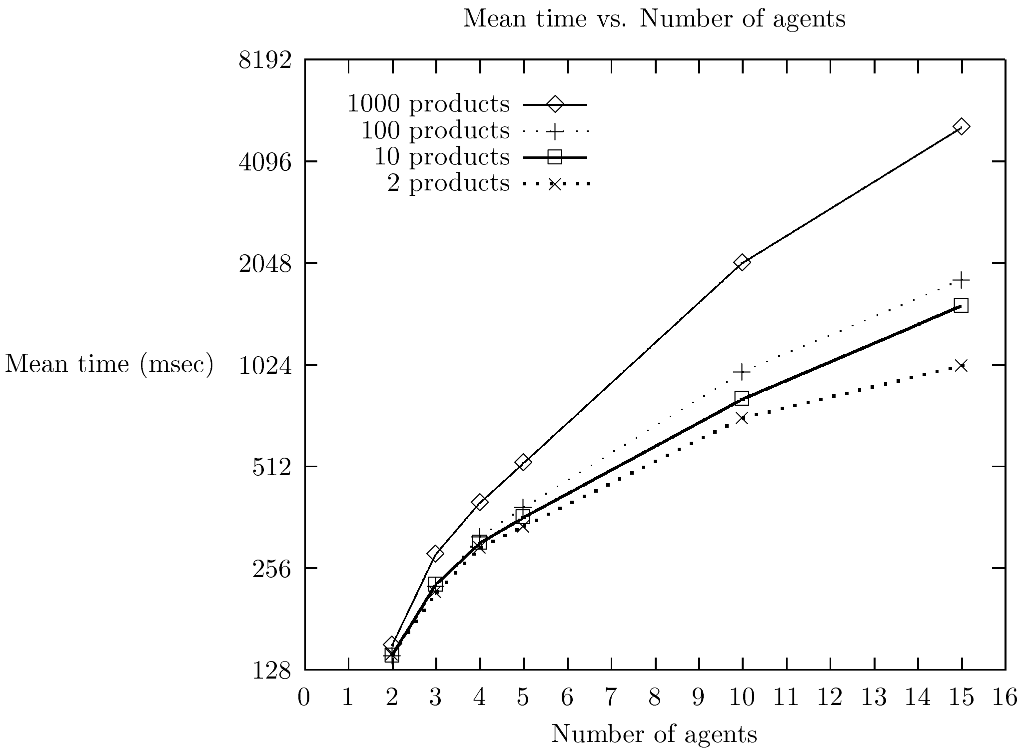

Figure 3: Mean time of execution versus the number of consumers' agents in the protocol for different quantities of available products.

Figure 4 demonstrates the mean quantity of memory used (in nodes which are the data structure representing an agent in an actual buying group) of the 1000 executions of the protocol for each agents-products couple. Curiously, a greater quantity of available products leads to less used memory. This comes from the ratio of agents to products. The greater this ratio is, the more dense the agents are in the products space and agents are more likely to form actual buying groups stored in the implementation of the protocol as linked nodes which take memory space. This is the reason why the case of 20 agents and 2 products (a ratio of $20/2 = 10$) exceeds the memory capacity of the test platform. The case of 20 agents and 100 products used much less memory but we cannot assure that it would not become a case of 20 agents and 2 products if all the agents decide that the same 98 products of the 100 are inadmissible (reservation price exceeded or inadmissible value for an attribute). If this ratio is low, the agents are most sparse in the product space and they form less actual buying groups (resulting in less memory space used) because their preferences are more far from one another.

Table 1 shows the change in the behaviour of the consumers participating in the protocol in relation to the normal habit of buying the most preferred product alone at the local store. A change of behaviour occurs in two situations:

- the consumer buys his preferred product at a lesser price than the one paid for one unit;
- she buys another product.

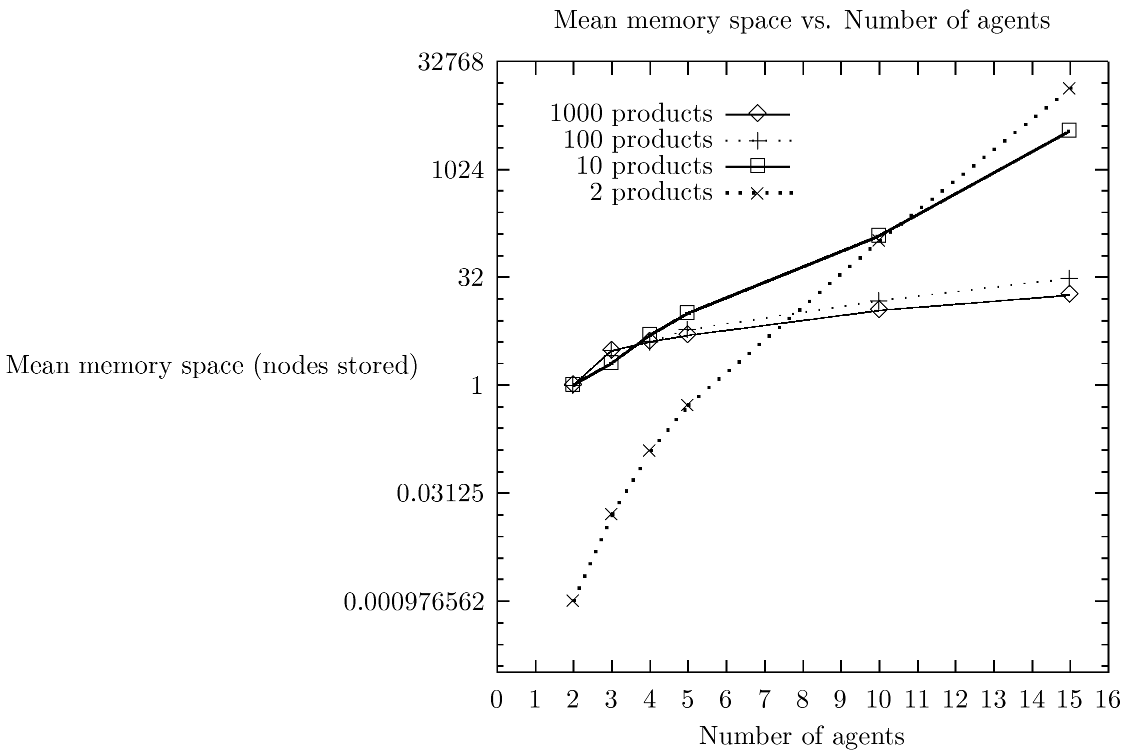

Figure 4: Mean memory space used versus the number of consumers' agents in the protocol for different quantities of available products

The first column of table 1 indicates the "number of agents – quantity of available products" couple being tested, the second column is the mean percentage of consumers (over one thousand executions of the protocol) who change behaviour, the third column is the mean percentage of consumers (over one thousand executions of the protocol) who pay less for its most preferred product among those who change behaviour and the fourth column is the complement to a 100% of the third column because if a consumer has changed her behaviour and not paid less its most preferred product, it is because she bought another product.

All else being equal, the fewer products, the better chance the protocol has of changing the behaviour of the consumers because they are more dense in the space of possible products and it is easier to aggregate in buying group and change that way their behaviour. This is the same reason why for the same quantity of available products, the higher the number of agents, the higher the percentage of behaviour changes. If there are few products, the consumers are more likely to still buy their preferred product at a reduced price than buy another product. But as the choice of product gets bigger, they will take the opportunities to join an attractive buying group that offers another product as the proportion of percentages of the third and fourth columns of table 1 indicates. The 99,9% of behaviour changes for the 10 agents and 2 products case was caused by one execution where 9 of the 10 agents desired a product and not the second and the other agent wanted the second product and not the first so it ended up buying alone its preferred product (and only one acceptable).

Agent-product couples	Change behaviour	Pay less same product	Buy different product
15–2	100%	100%	0%
10–2	99,9%	100%	0%
5–2	100%	100%	0%
4–2	100%	100%	0%
3–2	100%	100%	0%
2–2	100%	100%	0%
15–10	91,3%	58,2%	41,8%
10–10	86,6%	64,9%	35,1%
5–10	77,3%	67,6%	32,4%
4–10	74,8%	65,5%	34,5%
3–10	67,7%	62,2%	37,8%
2–10	50,5%	60,6%	39,4%
15–100	50,4%	59,9%	40,1%
10–100	42,6%	59,7%	40,3%
5–100	30,8%	56,7%	43,3%
4–100	24,9%	56,0%	44,0%
3–100	18,5%	57,8%	42,2%
2–100	12,0%	53,8%	46,2%
15–1000	22,2%	33,2%	66,8%
10–1000	20,0%	31,7%	68,3%
5–1000	18,4%	31,2%	68,8%
4–1000	17,3%	32,8%	67,2%
3–1000	14,9%	34,5%	65,5%
2–1000	9,3%	37,1%	62,9%

Table 1: Percentage of change and of the type of change in the consumers' behaviour caused by the protocol in function of the "number of agents – quantity of available products" couples.

5 CONCLUSION AND FUTURE WORK

In this paper, we presented a protocol for group buying that returns a Pareto optimal solution and changes the buying behaviour of consumers from the normal habit of buying the most preferred product alone at the local store. More changes of buying behaviour occur as the agents are more dense in the space of possible products. When the agents are dense in the space of possible products, they buy the same product as they would alone but at a reduced price. If agents are more sparse in the space of possible products, they take the opportunity to join a group that buy another product than the one they would have bought alone. Its execution time complexity is *less* than exponential but its memory requirements limit its use to no more than 15 agents in cases of a high ratio (around 10) of number of agents to quantity of products on the computer platform used for evaluation.

Future work includes the test and tuning of a heuristic to find the solution faster in certain cases and further evaluation of the protocol with different distributions of agents' preferences on products, of available products' specifications and of price schedules.

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