Ambient Intelligence Services Personalization via Social Choice Theory

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Abstract. There are a great number of situations in *Ambient Intelligence* systems which involve users trying to access shared resources such as: music, TVs, decoration, gym machines, air conditioning, etcetera. The use of *Social Choice* theory can be employed in these situations to reach consensus while the social welfare is maximized. This paper proposes a multi-agent system to automate these agreements, points out the main challenges in using this system, and quantifies the benefits of its use in a specific case study by an agent-based social simulation.

Keywords: Service customization and personalization, Social Choice, Ambient Intelligence, Agent-based Social Simulation, Agreement technologies, Multiagent systems

1 Introduction

Ambient Intelligence (AmI) systems need to be aware of the users preferences, intentions, and needs [1] to offer different services whose main goal is to augment their live quality. Some examples of use of AmI are: to design office spaces that smoothly move information between displays, walls, and tables; or, learning to customize lighting and temperature based on learned resident preferences [1]. These services raise an important question: what happen when resources are shared and there are conflicts between users' preferences?. There are cases where there is an obvious answer. For example, regarding temperature, an arithmetic mean among users' preferences seems reasonable. Nevertheless, there are a large number of scenarios where this is not an option such as deciding a TV channel or a lift background music. As a result, AmI services have to reach consensus trying to maximize users' satisfaction.

Although this issue is not usually addressed in AmI specialized literature, fortunately, *agreement technologies* (ATs) [2] have studied it in depth. ATs deal with technologies for practical application of knowledge in order to reach agreements automatically. ATs have covered a large variety of negotiation aspects such as: multi-issue negotiations, concurrent negotiations, strategy-proof mechanisms, argumentation, auctions, voting, etcetera [3]. In this scope, the use of *social choice* theory, which is concerned with the evaluation of alternative methods of collective decision-making [4], appears as a straightforward solution because its primary goal is to make a group decision.

However, social choice has mainly focused on theoretical works which deal with political elections [5]. Therefore, there are a number of dilemmas to be solved in this scope: what are the benefits of using a voting system in an intelligent environment?; what are the most suitable voting systems?; and, what differences does this case present when compared to political elections?. To the best of authors' knowledge, this paper and another authors' contribution [6] are the first works which propose the use of social choice to improve the access to shared services in AmI environments and which quantify its benefits. The experimental results are given in the scope of an intelligent hotel where users can share TV screens in the hall.

The paper is organized as follows. After revising the background in section 2, section 3 studies a general agreement service for AmI environments. Then section 4 presents the experiments conducted and the results obtained. The paper concludes in section 5.

2 Background

The most relevant research streams in *agreement technologies* include:

- *Auction theory*: it analyses protocols and agents' strategies in auctions. Auctions are usually used in systems where the auctioneer wants to sell an item and get the highest possible payment.
- *Negotiation or Bargaining Theory*: the agreement is modelled as a sequential game where agents alternate in making offers according to an underlying protocol.
- *Contracting theory*: a very well-know protocol in this domain is the contract net protocol [7] which allows a contractor agent to contract one or more participant agents to undertake some task.
- *Social Choice Theory*: combining individual preferences, interests, or welfares to reach a collective decision or social welfare in some sense [4].

Among these streams, the authors consider the use of social choice as the most suitable option for resolving conflicts in AmI. The main reason is that it is focused on maximizing social welfare. Furthermore, there are a number of scenarios where users have a peer to peer relationship and, besides expressing their personal preferences, there is nothing else to be said in a negotiation. In contrast, the bargaining theory is also a feasible option for some scenarios, e.g. if agents' preferences may change by argumentation.

As explained by Procaccia [5], *social choice theory* has seen few applications to date. The reason given by the author is that political elections, which are perhaps the most prominent social decision making mechanisms, are very difficult to change. Social choice research has been mainly theoretical, being the work by Arrow et al. [4] its maximum exponent. This research line focuses on verifying that a voting system satisfies certain mathematical properties such as the majority criterion; i.e. if one candidate is preferred by a majority (more than 50%) of voters, then that candidate must win. As seen in the introduction, when

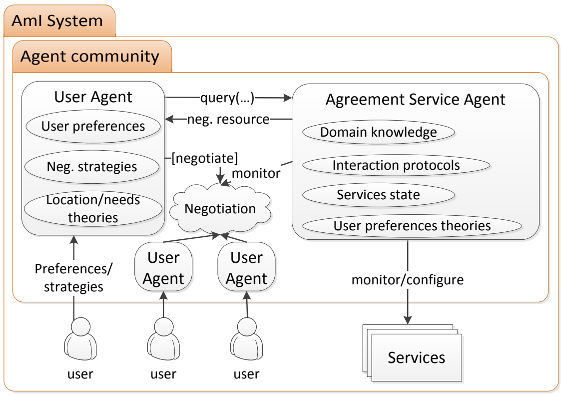

Fig. 1. A general multi-agent based agreement service for intelligent environments

social choice is used to resolve to conflicts in shared resources into AmI environments these theoretical studies do not respond to a series of questions of great interest such as how much satisfaction should developers expect after including these techniques. To answer these questions, it is necessary a simulation-based experimental research.

Aseere et al. [8] present one of the few works which: (1) combines social choice with an practical application distinct from political elections; and which (2) gives experimental results to quantify the benefits obtained. These authors propose a multi-agent system based on an iterative voting protocol where student agents could vote to decide which courses the university would be running.

3 A multi-agent system combining social choice and ambient intelligence

The generic agreement service for shared resources in intelligent environments is assumed to be a *multi-agent system* [9] for several reasons: (1) the agent theory has covered a great variety of negotiation aspects [3] and, therefore, these systems are very appropriate for an agreement service; and, (2) this paradigm has been widely used for the development of AmI given the *Agent-based Ubiquitous Computing* [10] (although it does not fully cover AmI [11]).

Figure 1 summarizes this multi-agent system. Basically, there are a number of users which can use one of several shared resources in the environment and an agent community which aims to maximize the satisfaction of users.

Each user has assigned an agent, *user agent* (UA), which negotiates on her behalf. The basic elements needed for this are: (1) the preferences of the user with regard to a service, which allow the UA to obtain what the user wants; and (2) the agreement strategies (or negotiation strategies), which allow the UA to make the best out of her participation [12]. Assuming these two basic elements, there are several possible final AmI systems which fit this design. In the most complex case, the user agent has to detect this information. Regarding indoor location, there are a number of works which deal with this problem by using wireless technologies such as Global Positioning System (GPS) [13], Radio Frequency IDentification (RFID), wireless local area network (WLAN), mobile cellular network, wireless mesh networks [14], bluetooth, etcetera [15]. Identifying the different users and their locations is very challenging, but the problem is even more complicated if the user does not give her service preferences. Assuming that the configuration given for the service is the preferred by the user and conducting learning algorithms is feasible [16]. On the other hand, if this service is shared, users may not like the parameters given. Therefore, sentiment analysis and detecting emotions through face recognition techniques would be necessary in this case.

The second agent included in this generic system is the *Agreement Service Agent* (ASA). The ASA provides UAs with the necessary information to negotiate. Firstly, the ASA contains Domain knowledge of services which can be as simple as a list of services with their possible configurations (music themes or TV programs currently available) or an ontology establishing different relations among these configurations. Secondly, the ASA gives the agreement protocols, specified in high-level agent communication languages (ACLs, e.g. FIPA-ACL [17]), which allows UAs to interact independently of the technology employed in their development. These agreement protocols are the negotiation rules, the rules governing the negotiation which have to be shared among negotiating agents regardless of their agreement strategies [12]. Thirdly, the ASA also monitors the negotiations carried out by the UAs and stores the service state (current configuration, current users, etcetera). Finally, the ASA may use the information obtained by monitoring negotiations to elaborate theories about users preferences which can be employed to give a better service [18]. For example, these theories could be used to advance the results of a negotiation or to suggest one of several services according to the preferences similarity among the current users of the service and the incoming user. Note that the ASA is a smart agent according to Nwana classification [19] because its autonomy, cooperation and learning; whereas UAs, assuming that the needs and location learning are not included, are collaborative agents.

4 Experimental results

To hint at the potential of the system described above, this section presents an agent-based social simulation to quantify the benefits of using social choice in a well-known scenario. This scenario presents a hotel floor where there is a shared hall with three large television screens that can be used by different clients or users. Figure 2 shows the floor and the shared services marked in circles. Users have *user agents* (UAs) which know their preferences for the shared service and their location. When more than one client accesses a shared resource simultaneously, UAs contact an *agreement service agent* (ASA) to try to reach

Fig. 2. Hotel floor to evaluate system proposed

an agreement by some social choice method. This ASA can suggest another service to the UA based on past interactions performed by the latter agent. Once a consensus is reached among different UAs, the ASA selects the chosen configuration. The voting is repeated again when new clients join the group or a client that accesses the resource leaves it.

The experiments are conducted during 2000 time steps and repeated 100 times with different users populations. The voting systems considered are: Range voting, plurality voting, cumulative voting, Borda voting and approval voting [4]. The basic metrics to quantify the suitability of a voting system is the *accumulated satisfaction* (*as*, satisfaction of the population from the beginning of the experimen) and the *maximum time without wanted configuration* (mwc, the worst user's wait for something she wants). The experiments show the arithmetic mean of these metrics for the 100 different populations. Inasmuch as the *"time step"* unit is employed to discuss the time dimension, the specific machine where the simulations have been conducted is irrelevant.

The results for different voting methods are shown in figure 3. Regarding the accumulated satisfaction (*as*), the range voting offers the best performance: 69%. On the other hand, the worst result is with a basis policy included in the experiments: the first user in accessing the resource decides the configuration (the second one decides when this leaves, and so on). This gives an accumulated satisfaction of 57%. Therefore, in this case, voting methods can increase satisfaction by 12%.

One interesting difference between the social choice application considered in this paper and the hegemonic case contemplated in social choice literature, political elections, is that, even giving random preferences, there are significant differences in satisfaction. In political elections and a number of cases, random preferences cause uniform results whatever is decided with whatever method used because there are always plenty of voters happy with the election result. As shown in the experiments, this does not happen when different subsets of users vote when they want to use a shared service.

In addition to the two extreme cases discussed above, the Borda method gets 67%, Approval 65%, Cumulative voting 61%, and Plurality 60%. Therefore,

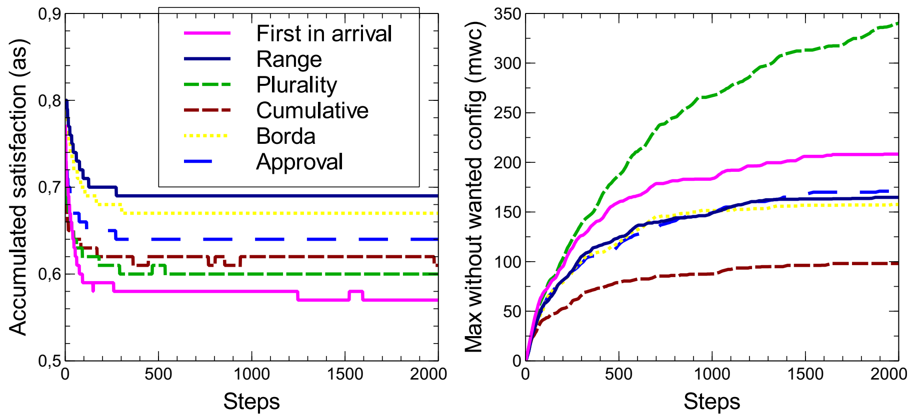

Fig. 3. Experimental results, different voting methods without pre-selection techniques

although range voting gets 4% more satisfaction, Approval voting could be employed due to its better usability, i.e. it is easier for users to decide whether a configuration is approved or not than marking each option.

5 Conclusion and future works

This paper hints at the potential of considering social choice techniques automated by multi-agent systems in intelligent environments. For the case study considered, the results show that the use of range voting achieves 12% more *as* than the basis method which consists of allowing the first user in accessing the resource to decide the configuration. The approval voting, which presents a better usability than range voting, gets 8% more *as*. However, if the service owner is more interested in avoiding long waits, cumulative voting gives the best *mwc*: 98.1 time steps. Although this result is less than half the time required with the basis method, the worst result according to this metric is given by the most commonly used voting method, the plurality method (304.2 t.s.).

Concerning the future works, there are a number of considerations which would improve the system presented. Firstly, the inclusion of location and need theories in the user agent model. Secondly, the consideration of tactical voting and the effect that different populations with different strategies can cause in different voting systems. Finally, there are a large number of voting systems which could be considered besides those included. Another future line is the application of social choice to emergency management to enhance aspects such as coordination [20] and situation-aware systems [21].

Acknowledgments

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