Negotiation-Enabled Multi-Agent System for Service Provisioning in Multi-User Scenarios

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***Abstract*—Smart Homes and Environments have been the focus of research for many decades. From connecting devices, to simple automation rules, now Smart Homes are on another level. By introducing cognitive capabilities with Internet of Things, it has become possible to create truly smart systems which offer services that cater to the wishes and needs of users. Researchers proposed very advanced Smart Home systems over the years, but mostly focus on single user scenarios. Scenarios involving multiple users with individual needs and desires that are often opposed to each other are largely neglected. In this paper, we discuss the possibility of the application of software agents, i.e. a multi-agent system in which users are represented by user agents who, knowing the preferences of their users, negotiate with each other to reach a joint decision that best satisfies all users.**

***Index Terms*—intelligent agent, multi-agent system, smart environment, artificial intelligence, Internet of Things, service provisioning**

I. Introduction

Smart Homes have been attracting the attention of academia, industry and the public for many years, being first mentioned in 1984 [1]. In various movies set in the future (in which we live now), Smart Homes are imagined as systems that literally ”read” the minds of their users. According to the predictions, household chores were to be automated to the maximum, from cleaning robots to self-cleaning floors, surfaces, shower stalls, toilets, self-making beds, etc. It has been envisioned that the Smart Home will make it as easy as possible for the user in all aspects of everyday life. For example, in the kitchen, refrigerators are envisioned to monitor their content themselves, watch for the expiration date of food, order missing food themselves, suggest dishes to cook based on the inventory, etc. Also, Smart Homes play a huge role in providing the elderly and disabled with more freedom and safety in their home through various services [2].

II. State of Smart Home Service Provisioning

The first step towards enabling this was Internet of Things (IoT). This enabled the development of applications that, while not fulfilling the ambitious predictions for the 21st century, allowed devices to be controlled via the Internet, i.e., remote. For example, users could manage their home appliances remotely and turn on the AC before they get home so that the temperature is perfect when they get home. The next step was automation, so, for example, users could set the AC system to start operating at 5 pm. But it is important to notice that the ”brain” of the system is actually the user, because it is the user who instructs the system how and what to do. This is described by Wu et al. [3] who consider IoT itself complete in achieving its original goal of connectivity. They insist that further development of IoT must turn to cognition, i.e., giving cognitive capabilities to connected devices, and therefore propose a new concept - the Cognitive Internet of Things. They point out that combining IoT with technologies such as Artificial Intelligence (AI) opens the door to the scenarios described at the beginning of this paper. The combination of IoT and cognitive technologies has already been presented and successfully implemented by many researchers. Smart home systems that track the user’s movements and dynamically adjust device settings in smart spaces according to their preferences and even emotions are no longer just part of the public’s imagination.

Unfortunately, there is an obvious lack of research and solutions in previous proposals and implementations that address scenarios where there are more users [4]. Obviously, it is more difficult to detect the wishes and needs of different people in the same space, especially because of the limited detection methods that can be used due to users’ fears for their privacy and security. For example, cameras are an easy way to detect different users, their location, and their activities in a space, but they present a hard no for many users. Finding common settings that match the preferences of all users is even more difficult. It should be taken into account that not all users are equally flexible when it comes to accepting settings that differ from their preferences. Also, users might take on a different stance on their flexibility in different settings, for example, at home or in the office.

The way preferences are defined and in relation to what also contributes to complications when trying to make decisions about settings that satisfy all users. While contextual awareness is key for defining preferences, the more contextual factors that go into determining preferences, the more combinations the user can choose. Likewise, devices offer more and more options, and as the number of these options and possible contextual combinations increases, preferences become more specific. This, of course, this increases the possibilities of satisfying users, but on the implementation side, it greatly complicates the decision-making process.

III. Multi-Agent System for Decision Making

There are a number of rules that can be used to combine all the user's preferred settings into a single setting according to certain principles. For example, the plurality rule, the anti-plurality rule, which are simple and straightforward, or the Borda rule, or the more complex Kemeny rule [5]. The approach with such rules suggests that the user's preferences are passed to a central element that makes the decision, and at that point the user's or his representative's involvement in the decision ceases. We propose to solve this problem using a Multi-Agent system, as Software Agents have extremely useful attributes such as autonomy, reactivity, proactivity, learning, cooperation and mobility [6]. Each user is represented by an agent that participates in the negotiation process. In this way, the user agent contributes to decision making in a more active way than in a centralized approach and advocates for its user's preferences. The goal of user agents is to maximize their utility functions, taking into account a new element - the flexibility factor that users set to express their willingness to deviate from their preferred settings. The proposed Multi-Agent System features two types of agents:

- smart space agent, and
- user agent(s),

where the number of user agents is determined by the number of users in the smart space, i.e., every user has his own user agent. The smart space agent provides user agents with contextual information about the smart space pertaining to a particular service, as shown on Figure 1. In this way, interoperability is ensured because user agents do not need to access IoT devices and platforms themselves and know the different setup options, but the smart space agent itself provides them with the necessary information in an agreed uniform manner, i.e., in a syntax understood by the user agent.

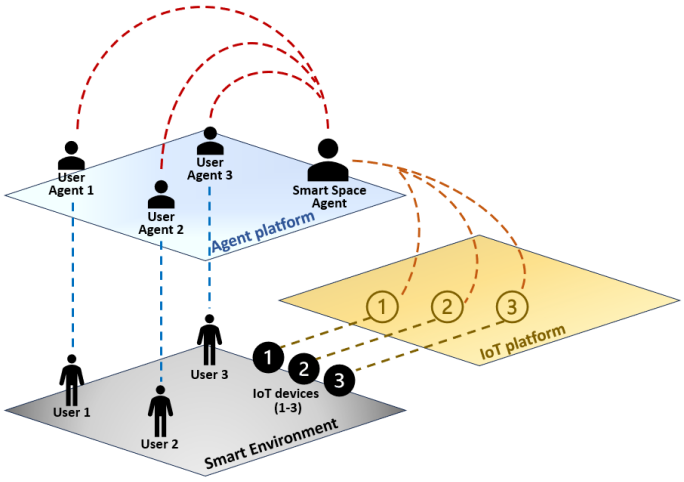

Fig. 1. System overview

User agents predict their user's preferences based on their recorded preferences with an Artificial Neural Network (ANN). The inputs of the ANN are context information directly influencing the service. For example, for the AC system, that would be the indoor and outdoor temperatures, time of day and season. The definition of preference can be further upgraded, for example with a short-term weather forecast for more efficient energy-management.

There are several established negotiation procedures. For example, chain negotiation where the negotiation process continues from participant to participant passing on their proposal based on their neighbours proposals. This may result in the proposal at the end of the chain to be completely different from the preferences of the participants who were at the beginning of the chain, so that their preferences are not taken into account. The goal is to create a negotiation process that does not disregard any participant.

Another goal is to reach a decision with as few messages exchanged between participants as possible. Accordingly, one logical idea would be to group the participants, i.e. user agents according to preferences in order to shorten the negotiation process. While this seems like a good one, there is a problem when changing the context that affects user preference. Consequently, it would be necessary to regroup every time there is a change in context. For example, that includes scenarios where a user is entering or leaving the space, and sensor readings changing as they affect preferences. It is necessary to design the grouping of users in such a way that there are no such problems when the context changes. In this way, it would be possible to reduce the number of messages exchanged, as the number of participants in the negotiation is reduced, since only representatives of groups can continue negotiations alone or negotiate within their group, so that it is not necessary for each agent to negotiate with each agent.

IV. Conclusion

Software agents represent an enormous potential for the development of truly intelligent spaces that meet the needs and wishes of users without their intervention. It is necessary to pay close attention to the negotiation processes between agents in order to realize the possibility of satisfying multiple users simultaneously while optimizing the number of messages and the duration of negotiations. Grouping users by a specific key seems like a good way to go, but it is necessary to simultaneously consider the scalability of the solution and the resistance of the system organization to changes in context.

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