Online Communities for Agent Collaboration in Cyber-Physical-Social Systems

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Abstract. The paper focuses on resource collaboration in cyber-physical-social systems. Technologies of ontologies, intelligent agents, and online communities are used to enable interoperability of human and non-human resources. An agent ontology and major principles of agent collaboration are proposed. The proposed ontology is based on the earlier developed ontology for resource self-organization. That ontology is specialised for agent collaboration empowered by online communities. The examples from smart room domain and smart travelling domain are concerned with scenarios of agent collaboration.

Keywords: cyber-physical-social systems, agent collaboration, online communities, ontology, context, smart space

1 Introduction

Cyber-Physical-Social Systems (CPSSs) are a new generation of networked systems, wherein humans are an integral part. This is enabled to a considerable degree by the fact that networked computers are everywhere, not only in the form of personal computers but also in the form of cell phones, tablets, smart appliances, etc. The benefit of CPSSs is twofold. On the one hand, while cyber-physical systems provide computation facility for personal usage, CPSSs offer computation facility for social use. On the other hand, in the CPSSs, humans are not only service consumers, but "collaborators" as well. Humans may provide data, process data, make decisions, and act on the data outputs. Integration of social resources into technical systems may improve the systems in a number of directions. For instance, humans may contribute to increase intelligence of the systems, situation awareness, system scalability, etc.

The tight combination and coordination between systems' computational, physical, and social elements make CPSSs different from other forms of systems. The paradigm of CPSSs involves networks of people (social networks), intelligent devices, and mobile personal computing and communication devices, which form CPSSs [1]. The necessity in integration different networked technologies such as computing networks, sensor networks, and social networks attracted significant interest of researchers from social science, computer science, computer engineering, electronic engineering, etc. The mentioned technologies deal with different kinds of resources from physical, cyber, and social worlds. Enabling these heterogeneous resources to be interoperable is essential for CPSSs.

The first thing to attain resource interoperability is a common context understanding by resources. In this direction, the Semantic Web proposes ontologies as the key technology to allow heterogeneous objects come to the same meaning. The second thing for resource interoperability is the resource capabilities to communicate. CPSSs comprise human and non-human resources. Technology of intelligent agents is a good solution to provide the non-human resources with communication capabilities. At present, online communications become common human practice. In the paper this practice is proposed to be applied to agent communication.

The paper proposes an agent ontology and major principles of agent collaboration. The proposed ontology is based on the earlier developed ontology for self-organization of resources of CPSSs [2, 3]. In this paper the ontology is specialised for agent collaboration empowered by online communities.

The rest of the paper is organized as follows. Section 2 offers the ontology of CPSS and its specialization for agent collaboration. Section 3 postulates major principles of agent collaboration in CPSSs. Scenarios of agent collaboration are considered in Section 4. Main concluding remarks are given in Conclusion.

2 Cyber-Physical-Social System

A CPSS consists of cyber space, physical space, and mental space [4]. These spaces are represented by sets of *resources*. The physical space consists of various interacting information and computational *physical devices*. These devices united on the communication basis organize the cyber space. The mental space is represented by *humans* with their knowledge, mental capabilities, and sociocultural elements.

All the three spaces are tightly related. Information from cyberspace *interacts* with physical space (*physical devices*) and mental space (*humans*). In this research the interaction between these spaces is organized through online communities.

Due to complexity of CPSSs, differences in the operation of cyber, physical, and mental components, and significant interdependencies among these components, software agents are seemed a promising technology to model interactions between the spaces [5, adapted]. Agents are autonomous and intelligent objects. It is proposed to provide each resource with an agent. The agent invokes the resource's services, interacts with other agents, and models the resource's behaviour.

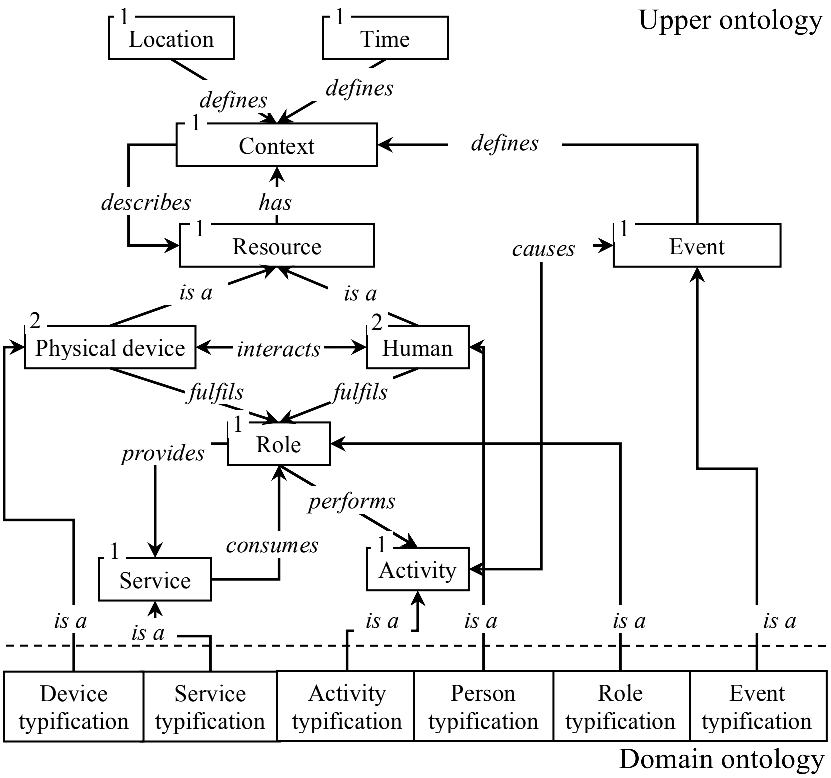
Context determines the purpose of resource interactions. The understanding of the context by agents is achieved by using a common ontology for context modelling.

2.1 Ontology

According to [6], any information describing an entity's context falls into one of five categories for context information: *individuality*, *activity*, *location*, *time*, and *relations*. The individuality category contains properties and attributes describing the entity itself. The category activity covers all tasks this entity may be involved in. The context categories location and time provide the spatio-temporal coordinates of the respective entity. Finally, the relations category represents information about any possible relation the entity may establish with another entity.

Ontologies serve to model context by ontologies' means. Usually, such ontologies consist of the upper ontology for general concepts, and domain specific ontologies representing knowledge of different application domains [7, 8, 9]. The upper ontology is shared by these domains. As a rule, the upper ontology represents concepts that are common for all context-aware applications (*Context Entity*, *Time*, *Location*, *Person*, *Agent*, *Activity*, etc.) and provide flexible extensibility to add specific concepts in different application domains (i.e., *Cell Phone* can be a subclass of *Device*).

The proposed ontology for CPSSs has been built by experts based on the context categorization above and contextual ontologies. The main requirement to the ontology was to take into account the specifics of the social component. Most of the upper-level concepts of the developed ontology (Fig. 1) correspond to the categories used to describe entities' contexts. At this level, resources are thought of as the entities whose contexts are to be described. Relations are represented by ontology relationships.



is a and *has* relationships are 1:∞

arities of other relationships are undefined

Fig. 1. Upper ontology for cyber-physical-social systems

Based on the analysis of various context ontologies (e.g., [10, 11, 12]) the experts introduced in the ontology two more categories: *service* and *role*. The category "*service*" represents resource functionality. *Role* is a position of a resource according to which the resource performs some activity. The specialization of resources as *human* and non-human (*physical devices*) was introduced in the ontology to consider social constituent of CPSSs.

In the ontology (Fig. 1), resource's *context* is defined by *location*, *time*, *resource* individuality, and *event*. Resources *perform* some *activity* according to the *roles* they fulfil in the current context and depending on the type of *event*. At the same time, the type of *activity* that a *resource* performs *causes* a type of *event*. For example, the *event* of a phone call defines the human *activity* as answer the phone. But, when a person raises the hand at the lecture time, this *activity causes* an *event* as, for instance, lecture interruption. This explains bidirectionality of '*causes*' relationship between *event* and *activity*. *The resources* have some functionality in result of which they provide *services*. The services *provided* by one resource are *consumed* by other ones.

In Fig. 1, upper indices in the boxes representing the ontology concepts indicate the taxonomical level of these concepts. All the concepts of the upper ontology are intended to be specialised in the application domains.

Common context represents the current situation in a CPSS. It is made up of the contexts of the resources. The common context is the basis for agent interactions. The purpose of these interactions is providing resources' services on demand. An agent ontology is proposed below.

2.2 Agent

Fig. 2 represents the agent's ontology, which is based on the upper ontology above. The concepts of the upper ontology are greyed. The concepts defined in the agent's ontology are expected to be specified in particular application domains. The main concepts of the ontology are described below.

Agent is an autonomous software entity that can either alone or working with other agents, provide *services* on demand. *Agent* is used to represent CPSS' resources of both types: *physical devices* and *humans*. *Agent* is capable to make requests to resources and *provide* their services.

Agent is described by *profile*. The agent's *profile* is represented by means of the agent's *internal ontology* and in a way understandable by other agents of the CPSS. The *internal ontology* harmonises with the common ontology of the application domain. The profile represents agent's properties (name, language, *roles*, *preferences*, *strategies*, etc.) and the *services* this agent provides. The set of *services* defines the agent's *functionality* or a set of cyber-physical-social functions the agent can perform. Through functionality the agent can change the common *context*.

Preference is an agent's attitude towards a set of own and/or CPSS' states and/or against other states. The *preferences* influence the agent's *behaviour* in the CPSS.

Behaviour is the agent's capability to perform certain actions according to its *role* in order to provide services. The *behaviour* is defined directly by the agent's *preferences* and indirectly by the *strategy*.

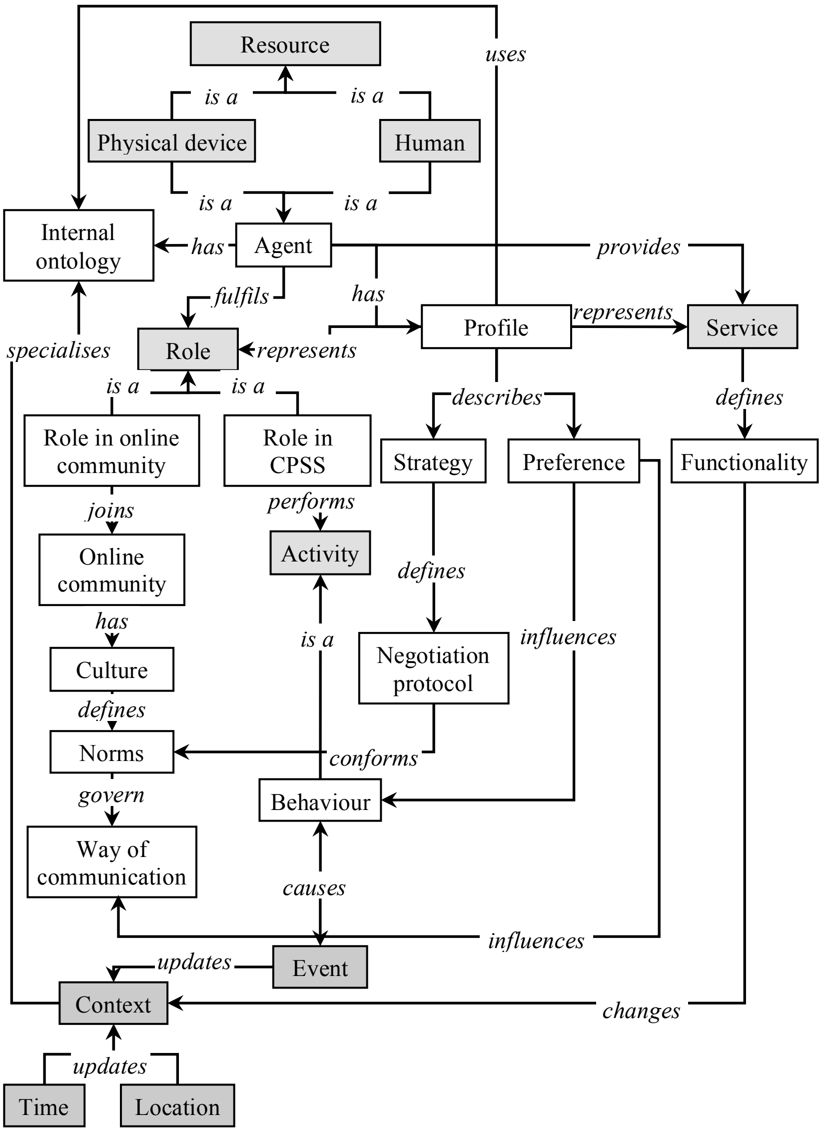


Fig. 2. Agent ontology

Strategy is a pre-defined model of agent organization to provide services (e.g., interest groups, hierarchical, etc.). The *strategy* defines the negotiation protocol.

Agents negotiate to provide CPSS' *services*. A distinguishing feature of any CPSS is that humans in these systems are not only consumers of services provided by the CPSS but also services providers. This means the agents representing the both types of resources participate in the negotiations. *Online communities* are used for the agent negotiations.

Online community is a virtual community whose members interact with each other via the Internet. Online communities are characterized by communication type (synchronous/asynchronous); interests (universal, single-purpose group, event-based group, etc.); supporting technologies (video, voice, messaging, etc.); culture; and other properties. Recently, cultures of Internet-based communities have received much attention [13]. In this paper online communities are characterized from this point of view. *Culture* supposes language used to communicate and some *norms* which govern the *way* of agent *communications in* the online *community*. Communities may differentiate in their *cultures*.

Norms are communication patterns or information exchange patterns (e.g., direct reciprocity, indirect reciprocity, preferential attachment [14]) specific for a particular *online community*.

Way of communication is the pattern that the agent uses to communicate with other agents and negotiate with them in an *online community*. The agents' *preferences* may influence on the way of communication if the agents do not violate community *norms*. *Agent* can join a community with different *roles*.

Role is a position of an agent according to which the agent behaves. Roles an agent fulfils in *online communities* (e.g., visitor, novice, regular, etc.) differentiate from the roles this agent fulfils in the CPSS (e.g., information resource, manager, decision maker, executive, etc.).

The agents' *internal ontology* represents problems the agent is capable to solve. *Context* specialises problems that the agent has to solve in the current situation. *Events* happening in the CPSS and produced as results of agents behaviour cause changes in *context*, the context is updated accordingly.

Negotiation protocol is a set of basic rules to implement the pre-defined agent organization *strategy*. The main protocols include voting, bargaining, auctions, general equilibrium market mechanisms, coalition games, and constraint networks. The protocol conforms to the *norms* accepted in *online communities*.

3 Agent Collaboration

This Section presents principals of agent collaboration. In the CPSS the agents communicate for two main purposes: 1) they establish links and exchange information for better situation awareness; and 2) they negotiate and make agreements for coordination of their activities for a proposed solution.

As it is said above, the agents communicate using a protocol able to implement the strategy of agent organisation. In this research, such a strategy is agent collaboration to provide services on demand. The following major principles of collaboration are used as the basis for agent organization:

1. *Contribution*: the agents have to cooperate with each other to make the best contribution into the overall system's benefit – not into the agents' own benefits.
2. *Task performance*: the main goal is to complete the task performance – not to get profit out of it.

3. *Non-mediated interaction*: the agents operate in a decentralized community and in most of the negotiation processes there are no agents managing the negotiation process and making a final decision.
4. *Common terms*: since the agents work in the same system they use common terms for negotiation. This is achieved via usage of the common shared ontology.
5. *Trust*: since the agents work in the same system they can completely trust each other (the agents do not have to verify information received from other agents).
6. *Conformity*: agents' way of communications conforms to the norms accepted in online communities these agents join.

As any negotiation protocol requires an objective function to operate, it is proposed to use "utility" of the solution taking into account preferences of an agent as the objective function. The utility characterizes the "usefulness" of the solution for a role. This utility can be calculated as a weighted sum of utilities of various activities including into the solution.

Below, two scenarios of agent collaboration are considered.

4 Use Cases

The scenarios proposed in this Section illustrate different aspects of agent collaboration. The first scenario focuses on domain-oriented ontology specialization and agent communications in different online communities. The second one gives an idea of the communication scenario in the part of "utility" of the solution.

4.1 Smart meeting room

The application domain considered in this Section is smart meeting room, which is a kind of CPSS. The following scenario is treated.

In the meeting room a plan of business development is discussing. The real-time data for the spreadsheets used in the business plan come from various corporative information resources and projected in the screen. A meeting participant suggests refining an aggregate function. For this some additional data are needed. No resources available in the meeting room can provide the required data. The agents find a consultant who provides the missing data.

Fig. 3 presents partly the specialization of the agent ontology for the scenario in question. In the given part, concepts relevant to the scenario are presented only; some relationships are left out for a better readability. The scenario involves humans fulfilling three roles: *meeting leader*, *meeting participants* (these two roles are common for meetings), and *consultant*. Agents responsible for interactions with computational or information resources other than humans (shortly, IR agents) fulfil the role of *information resource*. Interactions here mean requesting the resource and providing its services. The person planning to fulfil the role of *meeting leader* registers in advance to this role and information about the role is read from the *profile* of this person.

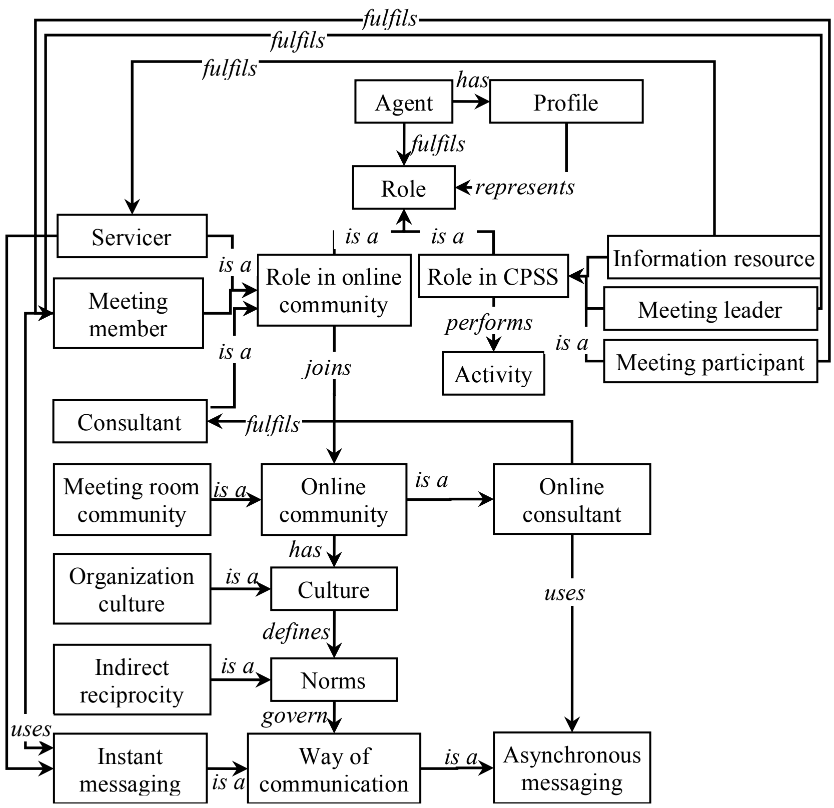


Fig. 3. Agent ontology for smart meeting room (a part)

In the scenario the agents firstly request the computational and information resources available in the meeting room for the needed data. When the agents find out that the required data are unavailable, they send online messages to the meeting participants. The agents communicate via the *meeting room community* that is a kind of *online community*.

The *meeting room community* comprises agents available in the meeting room. IR agents and humans are joined to the community automatically. IR agents are assigned the role of *servicers*. Humans are joined when they enter the room. In the community they are assigned the role of *meeting members*.

The *meeting room community* accepts the *organization culture*. According to *norms* this *culture* defines, contribution to an individual stimulates greater general contribution to the organization. Communication pattern of *indirect reciprocity* is the most suitable to support this idea. Indirect reciprocity is a communication pattern characterized by indirect chains of communication that support generalized exchange [15]. This pattern goes with the principle 1 (Section 4) of agent collaboration. The *meeting room community* supports *instant messaging*.

The agents search for a person who can provide the required data outside the meeting room. They apply to an *online consultant* who is not a meeting member. As well as the meeting room community, this consultant accepts the *organization culture*. The consultant window supports *asynchronous messaging*.

Fig. 3 does not provide a specialisation for the *activity* concept. Examples of meeting room activities are presenting, discussing, requesting for a service, etc.

Fig. 4 presents the communications between the agents. Firstly, they communicate with the object to obtain the required data from the resources available in the meeting room. In the figure, one message to IR agent represents a set of messages sent to agents responsible for the interactions with the computational and information resources. Then, when the needed data were not found, they send messages to the meeting participants. In the messages the agents inquire if the participants are aware where the data can be found.

One participant recommends requesting a department responsible for data storage. The agent of this participant sends the message to the online consultant of the department. In the consultant window it is required to leave the phone number of the person whom the consultant can call back. The agent leaves the number of the meeting leader. The data of interest become available after the phone conversation.

The messaging between the agents is displayed to humans as follows. On the personal devices of the leader meeting and the meeting participants only messages meant for them are displayed. At that, it does not matter who sent the message (agent or human). The messages between the IRs' agents are not displayed on the personal devices of humans.

In the considered above scenario the agent's ontology is used to define the way of agent communication depending on the agent role and organization culture.

4.2 Smart travelling

Smart travelling demonstrates how "utility" of the solution can be applied to receive a solution the most "useful" for a particular agent. The following scenario is considered:

One wants to re-fuel the car and have a dinner in a decent restaurant. Instead of finding a cheapest gas station, the agents find a gas station located near a restaurant, which has a good feedback from its customers or belongs to the brand preferred by this person.

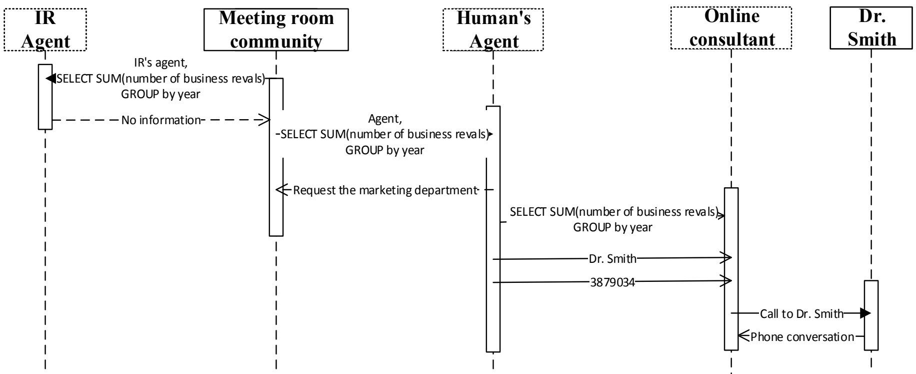


Fig. 4. Agent communication in smart meeting scenario

The person in the scenario fulfils two roles: driver and restaurant client. For the presentation below, change of roles is not important. It is supposed that the agent representing this person fulfils the role of driver.

The scenario solution consists of two actions: visiting a restaurant and refuelling the car. Besides the user's agent and agents representing resources, three more agents are involved in negotiation: restaurant advisor, gas station advisor and planner (this agent, responsible for time keeping, is involved in almost any scenario in order to avoid solutions, which would suggest driving too far away). Each of the three agents are assigned certain functions calculating degree of usefulness of their suggestions for the driver (e.g., visiting a café with average customer ratings has a lowest utility, visiting a nice restaurant with high customer ratings is estimated has a higher utility, and visiting the favourite driver's restaurant has the highest utility). The utility scale of the planner agent might depend on usual distances driven by the driver, its preferences and current schedule. The total system's utility of the solution depends on the contributions of each participating agent. The appropriate mathematical models are yet to be developed.

In order to such mechanism would operate efficiently, it requires a continuous adjustment of the agents' utilities. This can be done through collecting information and knowledge from different resources. The following resources are among them:

1. User feedback (the driver can increase or reduce the utility of a certain service). This is a reliable information source; however, in real life it is very unlikely, that the driver will provide such a feedback.
2. Initial driver profile (the driver can fill out the initial preferences in his/her profile). This is also a reliable information source but such information will be outdated after some time.
3. Analysis of driver decisions (there can be a resource, which analyses if the driver followed the proposed solution, or which solution is preferred if several alternative solutions are presented to the driver). This is a less reliable information source, but such information will never be outdated and development of learning algorithms can significantly improve such feedback.
4. Analysis of decisions of drivers with similar interests/habits. This source originates from the method of collaborative filtering used in group recommendation systems.

The interactions between agents are presented in Fig. 5. They are based on usage of AppLink (reference) [16] for interaction with the car. The AppLink is in-car infotainment system that can communicate with third party services and mobile devices for information driver support. In addition to the information already stored in the resources (associated databases, user settings, revealed preferences, etc.), the mentioned above agents acquire information from other resources, namely:

- Gas station advisor obtains current car location, gas level, and predefined driver preferences.
- Restaurant advisor obtains current car location and predefined driver preferences.
- Planner obtains driver's schedule from his/her smart phone and predefined driver preferences to estimate current time restrictions.

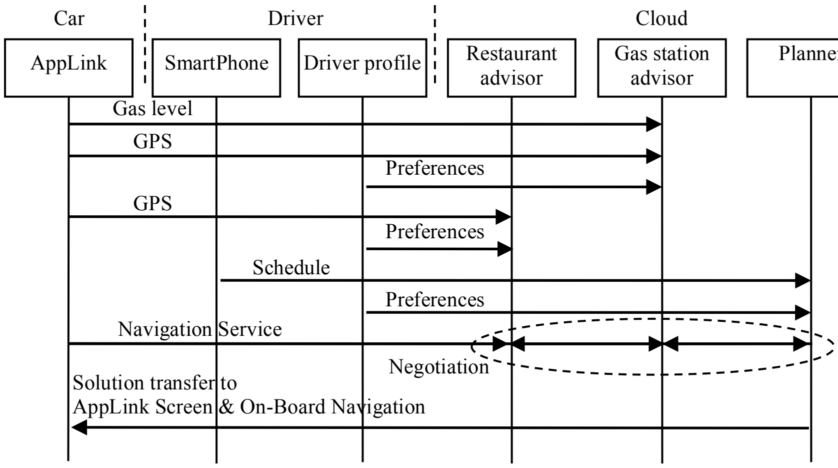


Fig. 5. Agent communication in smart travelling scenario

After that, the agents negotiate in order to generate one or several alternative solutions based on the driver requirements. During this negotiation, they can query available navigation system to estimate the driving time between different locations. Finally, the generated solutions are transferred to the AppLink screen so that the driver could choose the most appropriate one, and to the in-car navigation system.

5 Conclusion

An agent onlogy empowered by online communities for agent collaboration in CPSSs and major principles of agent collaboration were proposed. “Utility” of the solution taking into account preferences of an agent was proposed as the objective function for agent negotiation. Scenarios of agent collaboration in smart meeting room and in smart travelling domain were considered. The former scenario illustrates opportunities the online communities offer for communication of human and non-human resources of CPSSs. The latter one shows how “utility” of the solution can be applied to receive a solution the most "useful" for a particular agent role.

The research presented is ongoing. The paper reports some theoretical results. In the future, an agent negotiation protocol, which would take into account cultural norms of different online communities and utility of the solution is planned to be developed.

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