The hierarchical nature of the agent system makes it easy to develop and modify such systems by analogy with the hierarchical structure of problem solvers in *individual ostis-systems* [4], [11]

- In traditional systems, often all agents of the system, or at least a significant part of them, may be involved in problem solving. Taking into account the complexity of ostis-systems included in the OSTIS Ecosystem, such a situation is unlikely in the OSTIS Ecosystem and most often in the near future several ostis-systems, most often belonging to one ostis-community, will be involved in problem solving.
- Traditional self-organizing systems are usually considered in isolation from the means of representation of information processed in such systems, i.e. neither the form of representation of processed information, nor the semantics of processed information are explicitly fixed. An important advantage of OSTIS *Ecosystem* and OSTIS *Technology* as a whole is the orientation on unified and universal models of information representation, realized in the form of OSTIS *Technology* and a family of top-level ontologies built on its basis. This approach allows us to say
  - about universality of the developed mechanisms of collective problem solving within OSTIS *Ecosystem*, i.e. the possibility to unlimitedly increase the possibilities of OSTIS *Ecosystem* to automate different kinds of human activities in various fields;
  - about the possibility to describe the agents of the OSTIS Ecosystem by the same means that are used to describe the information processed by the agents, with the required degree of detail. Thus, it becomes possible to analyze the specification of some agents (e.g., their functional capabilities, classes of solved tasks, etc.) by other agents, which opens new opportunities for selforganization in collective problem solving.
  - about the possibility of exchanging information constructions of arbitrary complexity between agents, there is no need to limit the possible semantics of such messages and, moreover, to fix their structure, as it is often done in traditional approaches. It should be emphasized that agents in the framework of the proposed approach do not exchange messages directly, but specify in a common knowledge base the actions they perform, so there are no fundamental restrictions on the content of such specification

The analysis of the presented features allows us to draw the following conclusions:

- Direct application of existing approaches to selforganization in multi-agent systems for solving OSTIS *Ecosystem* problems is not possible due to its essential features, but many known approaches can be adapted for solving a number of specific problems, for example, when organizing the exchange of messages between ostis-systems at the physical level, searching for the most suitable executor for solving this or that task and so on;
- At the same time, OSTIS *Ecosystem* features allow not to consider at the level of collective problem solving a number of non-trivial problems related to reliability assurance and optimization of load distribution between ostis-systems, and open new opportunities to expand the range of possible spheres of human activity automation, to ensure interoperability of corresponding intelligent systems and their collectives and to reduce the labor intensity of their maintenance and evolution.

## IV. Proposed approach to problem solving within the next-generation intelligent computer systems ecosystem

The key difference of the proposed approach to the organization of decentralized problem solving in OSTIS Ecosystem in contrast to traditional approaches to self-organization is that within OSTIS *Ecosystem* we initially in the process of ecosystem development form a hierarchy of ostis-systems and their specification so as to further simplify the process of organizing collective problem solving, in particular, the formation of a collective of performers, the transfer of messages between performers, etc., leaving the opportunity for continuous refinement and improvement. Thus, the agent system is initially built in such a way as to make self-organization more convenient by analogy with the way top-level ontologies are developed to ensure compatibility of ontologies instead of developing ontologies independently of each other and then solving the problem of ontology alignment, which most often turns out to be not trivial at all.

In the paper [14] a methodology for the design of multi-agent systems including five stages is proposed. Let us consider in more detail the application of this methodology in the context of problem solving within the OSTIS *Ecosystem*:

- **Step 1: Analyze the objectives for which the system is being developed.** The purpose of the work in this case is to ensure the potential possibility of solving any problems arising within the OSTIS *Ecosystem*, which requires the availability of universal and unified means of describing the goals and objectives. Within the OSTIS *Technology* framework, common unified means of specification of actions and tasks are proposed [4]. As far as semantic completeness of such tools is concerned (taking into account all possible classes of tasks that may arise), it is proposed to take as a basis the task ontology proposed in [15]
- **Step 2: Designing the overall structure of the multi-agent system.** Within the framework of the considered approach, the structure of the multiagent system is

based on the architecture of the OSTIS *Ecosystem* discussed above and is constantly refined taking into account the addition of new agents to the OSTIS *Ecosystem*. In terms of classification of agents of OSTIS *Ecosystem* at the current stage it is proposed to single out only *corporate ostis-systems* into a separate class due to the fact that they play a special role in the process of organizing collective problem solving. The principles of agents' communication via *corporate ostis-systems* are discussed in more detail at Step 4.

- **3: Designing the internal structure of the agent and the principles of its operation.** Since all OSTIS *Ecosystem* agents are ostis-systems (even users of the OSTIS Ecosystem interact with it through personal ostis-assistants, which are ostissystems [4], [8]), additional specification of the principles of their structure is not required, as it is discussed in detail in the works devoted to the OSTIS Technology [4], [16]. To ensure the possibility of interaction between ostis-systems over the network, it is proposed to add an interface subsystem to each system, which is discussed in more detail in Step 5.
- **Step 4: Develop the principles of agent interaction.** As mentioned earlier, it is proposed to base the principles of agents' communication within OSTIS *Ecosystem* during collective problem solving on the principles of agents' communication in the memory of ostis-systems (sc-agents). In the work [7] an approach is proposed assuming that one of the ostis-systems included in the collective of ostis-systems will be used as a tool of communication for the participants of the collective of ostis-systems. If such collective is formed on a permanent basis (is a *ostis-community* or a part of it), it is proposed to use the *corporate ostis-system* of the specified ostis-community as such communicator system. If a collective of ostis-systems is formed temporarily for solving one or several complex problems, i.e. it is necessary to temporarily involve ostis-systems belonging to several *ostis-communities*, two variants of organizing communication of ostis-systems are possible:

  - One of the systems belonging to such a temporary collective of ostis-systems is selected as a communicator system. In this case, such an ostis-system becomes temporarily the *corporate ostis-system* of the temporary *ostis-community*. Accordingly, in this case it is required to install in the ostis-system an interface subsystem for ostis-systems and to load into its knowledge base the specifications of other ostis-systems participating in the problem solving process. Thus, the cost of preliminary preparation of a collective of ostis-systems for problem solving can be quite serious, and this approach may be ineffective for relatively simple problems solving.
  - The *corporate ostis-system* of the closest hierarchical *ostis-community* is chosen as the communicator system, such that all ostis-systems required for the solution belong either to this ostiscommunity or to more private ostis-communities (possibly on several hierarchical levels). In the example of the *ostis-communities* hierarchy fragment shown in Figure 2 , assuming that the problem solving requires the participation of *ostis-systems* OS1, OS2, and OS3, then the *corporate ostis-system* of *ostis-community* OC1 will be selected as the communicator system.

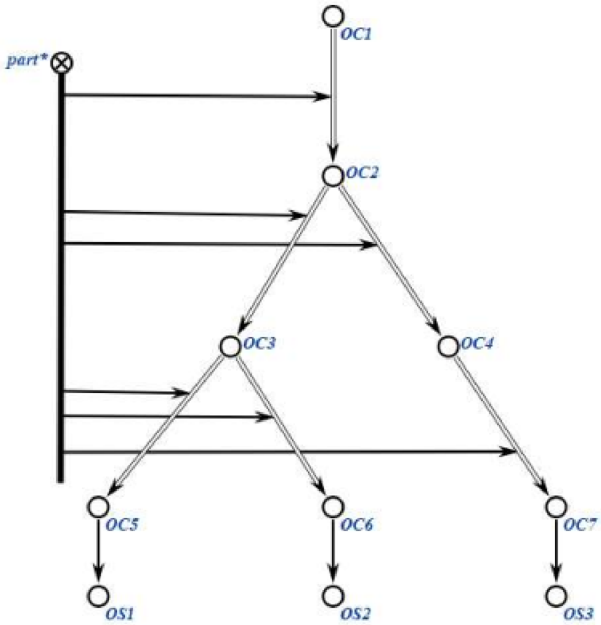


Figure 2: Example of communicator system selection

  According to the above architecture of the OSTIS Ecosystem such an ostis-community will always exist, in the extreme case the role of such a corporate system will be played by the OSTIS *Metasystem*. The disadvantage of this communication option is that sending messages between the participants of the problem solving process may generally take more time due to the increased path between the corporate ostis-system and the ostis-systems which are performers.

It is important to note that in the presence of such a communicator system, agents at the logical level do not exchange messages directly, but communicate by specifying their actions in the shared memory of the communicator system; nevertheless, at the physical level, messages are forwarded between ostis-systems, generally physically located in different nodes of the network, arbitrarily distant from each other. This idea

of separating the logical and physical layers of communication is realized within the concept of *overlay networks* [17]. An overlay network is a virtual network whose structure differs from the real communication network on the basis of which this overlay network functions. The idea of using *corporate ostis-systems* as a basis for agents' communication in such a network and a repository of agents' specifications and methods provided by them can be considered as a new stage of development of the idea of P2P agent platform developed by the FIPA consortium [17]. The main idea of such a platform is to provide all agents in the network with the possibility of semantic search for the services they need, as well as to search for agents that possess the required services. Another function of the platform is to support transparent communication between agents-customers and agents-owners of services [17]. In general, an agent network may have several such platforms, each responsible for a different segment of the network, similar to the way a *corporate ostis-system* is responsible for a corresponding *ostis-community*.
To implement the language of interaction between ostis-systems, it is proposed to use the ideas of wave programming [18], [19], as well as insertion programming [20], [21] as a basis. Later variants of the wave language theory development were called Spatial Grasp Technology [18], [19], within which Spatial Grasp Language is developed accordingly. Implementing such interaction requires the development of at least two levels of languages:

- transport layer defining the principles of recording SC-code constructions in some format convenient for network transmission. As a variant of such language it is proposed to use SCs-code [4];
- semantic level defining the content of messages transmitted over the network. The SCP language, which is the basic programming language for ostis-systems, is proposed to be used as a basis for such a language [4].

It is important to note that within the framework of the proposed approach, the *corporate ostis-system* acts as a common information resource and notifies the participants of the problem solving process about the events, but does not control the problem solving process directly. Thus, it is not a question of rigid imperative management, but of more flexible declarative. This allows us to realize the advantages of the sc-agent interaction mechanism in a shared semantic memory [4], [11], such as modifiability of the agent system, convenience of its design and others.

- **Step 5: Develop the detailed architecture of the multi-agent system.** At this stage, it is supposed to clarify the principles of interaction between agents and the environment, taking into account the previously clarified agent structure and the principles of their interaction.
  Implementation of the proposed approach assumes that each ostis-system will include a communication interface subsystem that will receive messages from the external environment (from the *corporate ostis=system*), transform them into tasks for internal scagents of the *ostis-system*, and then transform the result of their work into a response message and send it to the corresponding recipient. An important feature of such a subsystem is that it behaves as a sc-agent when interacting with internal sc-agents and communicates with other sc-agents according to the same principles. This allows to ensure the independence of the development and evolution of such a subsystem from other components of the ostis-system and to exclude the necessity to take into account the fact of future interaction of the ostis-system with other ostis-systems at the stage of its design. In other words, an ostis-system solves a subtask within a distributed collective of ostissystems just as if it were solving a problem explicitly formulated, for example, by a user. This approach greatly simplifies the design of ostis-systems collectives, eliminating explicit dependencies between them and the need to provide for the necessity of collective problem solving in advance.
  In turn, each *corporate ostis-system*, when interpreting a particular method, interacts with other ostis-systems as if they were internal sc-agents of this ostis-system. Thus, each *corporate ostis-system* includes an interface subsystem that converts events in the memory of the corporate *ostis-system* into messages to other *ostis-systems* and response messages from these *ostis-systems* into corresponding information constructs in the knowledge base of the *corporate ostis-system*. This approach allows to ensure the independence of *corporate ostis-systems* from other ostis-systems participating in the problem solving process and to exclude the necessity to provide in advance the necessity of collective problem solving not only when designing conventional ostis-systems, but also when designing *corporate ostis-systems*. An illustration of this approach will be given below.

From the point of view of the modern classification of self-organization methods in multi-agent systems [17], the proposed approach of agent interaction at the logical level can be considered as a kind of mechanism based on indirect interactions of organizational agents. Mecha-