Approaches to Communication Organization Within Cyber-Physical Systems

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Abstract–This paper discusses various approaches to the organization of information interaction of cyber-physical system's element. The authors model the system behavior in the presence of three possible approaches to the organization of information interaction. The first approach is based on the principle that everyone can communicate with everyone. The second approach is the choice of "leader" for a particular rule, who is carrying out the exchange of information with other elements. The third approach involves the dynamic selection of the leader, based on current requirements. Computer simulation was carried out and best approach was determined.

I. INTRODUION

The development of information technology, such as cyber-physical systems, Internet of things, etc. [1] allows to speak about the increased risk of detection and their use vulnerability [2]. The underlying Industry 4.0 cyber-physical system [3-5] based on the need of communications between elements. However, at the moment the consideration of such systems from the point of view of information security it is not a developed field of science [6]. You can say that the development of cyber-physical systems (CPS) is carried out without taking into account the origin and the implementation of threats.

Based on this, developers of cyber-physical systems open a question of secure information interaction of system elements. To enhance the security of the communication channel it is possible to use various devices and protocols that allow to reduce the cost of deployment of existing security models [7]. It should be noted that the introduction of such systems does not allow to refer to a complete information security system. The reason for this is the attack, carried out without any distinguishing characteristics. These attacks do not have obvious signs of violations information security system, but they can lead to critical consequences [8].

Considering the cyber-physical system as one of the possible implementations of multi-agent systems (MAS), it is possible to talk about the application used to protect the MAS from such attacks methods[9-11]. Given the current level of development of cyber-physical systems and their capacity, the problem of the lack of the ability to test all methods of the system, because the total number of elements of a cyber-physical system can be very large.The solution to this task is to use various approaches to agent communication and interaction.

In this paper we consider a special case of the cyber-physical systems – dynamic spatially distributed system. This class of systems is characterized by a change in the spatial characteristics of the system.

In the chapter "Description" are presented key capabilities and limitations of environment of experiment. There is also presented the basic elements of interaction between agents.

Chapters 3-5 discuss three realized models of interaction between agents. Presented agent's algorithms for sending and receiving messages and sequence generation structures, disadvantages of models.

Chapter six is told about the structure of the simulator and its basic features.

II. DESCRIPTION

In the simulator we consider the problem of the information exchange between the element j of set i and element k of set l. The condition of the simulation is the presence between any two elements e_{ij} and e_{lk} certain communication channel $C(e_{ij}, e_{lk})$.

Account the set of elements of the CPS R, as some given plane that describes a polygon of the functioning of the CPS. Suppose that each agent ri ϵ R has as device physical layer CPS and the device information of level. Assume that the agents R distributed on a plane are not uniform. The total center of mass of the agents can be described by the coordinates l. Then the whole set of agents can be divided into several disjoint subsets such that:

$$R = R_1 \cup \dots \cup R_n.$$

Each of the subsets of agents, R is set as follows:

$$R_i = \{(r, \mu_{R_i}(r)) | r \in R\},$$

where $\mu_{R_i}(r)$ - is the membership function of the element r set Ri.

We can say that the element r CPS relates to many interacting elements R_i in the case that

$$\mu_{R_i}(r) < \mu_{R_j}(r),$$

the membership function can be specified as follows

$$\mu_{R_i}(r) = 1 - \frac{l_i - l_r}{l_i - l},$$

where l_i are the coordinates of the center of mass of set R_i, l_r- coordinates of the element in CPS r, $l_i \neq l$.

In the operation of the CPS we may need the information about interaction of all elements of the CPS located at the site.To meet this need it is possible to use three different approaches:

- Communication without intermediaries;
- Information interaction with in advance unknown intermediaries;
- Communication with pre-defined mediators.

Communication can be divided into two main stages – the stage of identification of interesting element and the stage of information exchange. Phase of identification involves the search of directly interested in the item or the intermediaries. Information exchange involves the transfer, processing and analysis of the content of the message. Under treatment means checking the integrity of the received message.

The problem of realization of interaction is ignorance of the elements about compliance communication channels with specific elements. To resolve this ambiguity there must be installed the identified communication channel $L(e_{ij}, e_{lk})$. The first step towards creating such a channel becomes a sending an agent message, formed on the basis of result function of dating $f(e_{ij}, e_{lk})$, by using unidentified channel $\mathrm{C}(e_{ij}, e_{lk})$. After receiving this message, e_{lk} element transmits a response acknowledging receipt of a message based on the function $f(e_{lk}, f(e_{ij}, e_{lk}))$. After an exchange of meeting function between the two elements originate identification communication channel $L(e_{ij}, e_{lk})$, with which it is possible the implementation of information exchange, for message $I(e_{ij}, e_{lk})$ transfer.

To carry out the tasks assigned to the agents was proposed three models: without the use of intermediaries, with a pre-defined mediators and with undetermined intermediaries. In the first case, the message $I(e_{ij}, e_{lk})$ is passed only after the installation of the identified link between the recipient e_{lk} and the sender e_{ij}. In the second, channels identification takes place at a predetermined scheme and interaction takes place by means of transmitting a message $I(e_{ij}, e_{lk})$ through agents who are not the sender or recipient, these agents are set prior to the information exchange. In the third case, a part of the channel before the interaction is identified, and a part directly during simulation. The scheme, for which the message will be transmitted is generated dynamically. Created simulator allows modeling to produce element's action using presented algorithms and data to compare the effectiveness of solutions, based on time figures.

III. Information interaction without intermediaries

Algorithm of delivery message $I(e_{ij}, e_{lk})$ is as follows:

1) Agent e_{ij} checks existence of identified communication channel $L(e_{ij}, e_{lk})$. If such a channel exists, the agent proceeds to step 3 of this algorithm.
2) Agent e_{ij} begins bypassing all available to him unidentified channels $\mathrm{C}(e_{ij}, e_{hd})$ of communication. For each channel, the agent transmits a message dating $f(e_{ij}, e_{hd})$ and waits for a response to his $f(e_{hd}, f(e_{ij}, e_{hd}))$. After that, between them created the identified communication channel $L(e_{ij}, e_{hd})$. If the channel is not a channel $L(e_{ij}, e_{lk})$,, then the process is repeated for the next channel. If the connection is established with an agent e_{lk}, bypassing the communication channels is completed.
3) The agent e_{ij} sends a message $I(e_{ij}, e_{lk})$.
4) Agent e_{lk} sends a message confirming the delivery of the message $I\left(e_{lk}, I(e_{ij}, e_{lk})\right)$.

This model implies that before the start of simulation can exist identify channels between certain agents. Occurred during the message delivery context, remain until the end of the experiment. The model in the simulator presented on Fig.1-3.

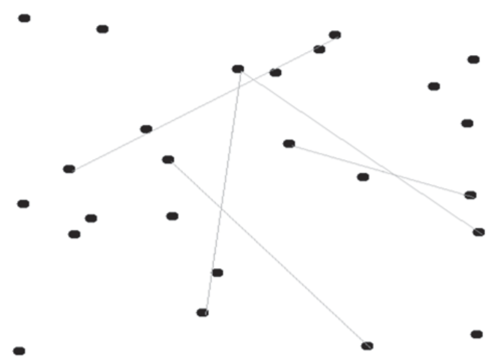

Fig. 1. The model of informational interaction without intermediaries after initialization. Dots are the agents. Lines means communication established between them.

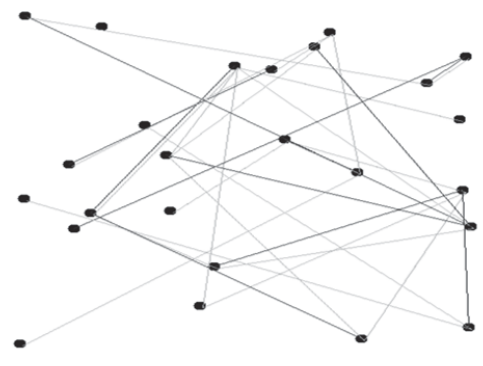

Fig. 2. The model of informational interaction without intermediaries after initialization. Dark grey lines show the ongoing interaction of agents.

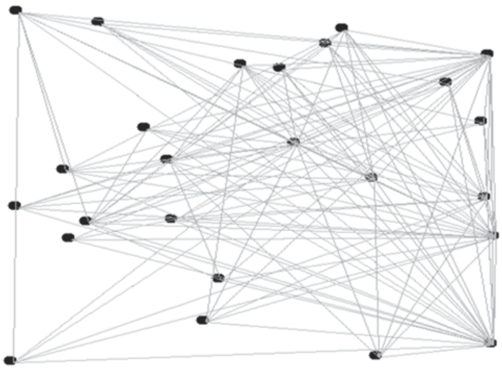

Fig. 3. The model of informational interaction without intermediaries after initialization. The end of work

On Fig. 4 you can see UML-presentation of this model work.

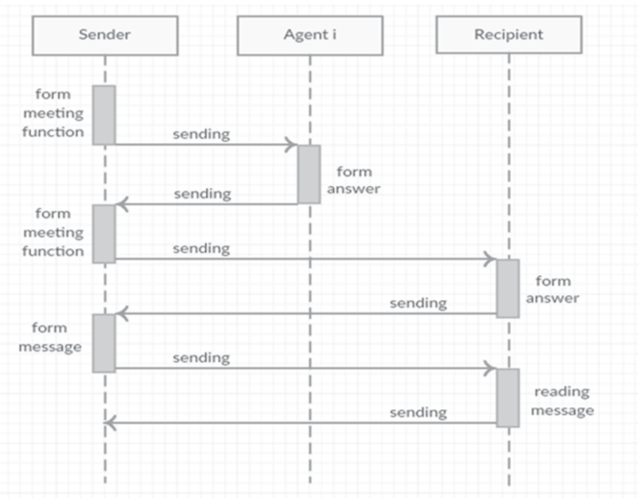

Fig. 4 Uml presentation of Information interaction without intermediaries. Here “agent i” is random agent before formation of identificated channel between sender and recipient.

During this model's work creates a large number of the identified communication channels that are not used for sending targeted messages. This problem gains more importance with the increasing number of agents. For visual display was constructed graph (Fig. 5) based on the average number of identification of channels (steps) until finding the necessary connection and number of agents.

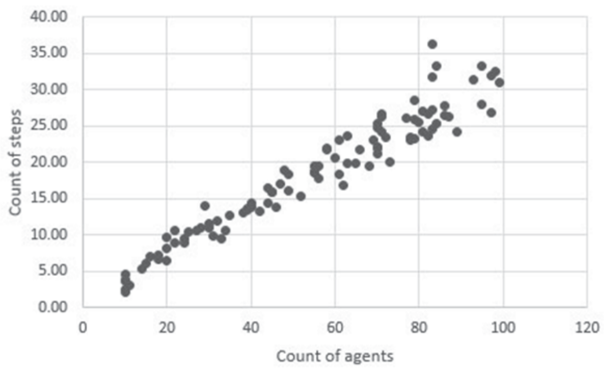

Fig. 5. Dependence of the average number of channel's identification(steps) until finding the necessary connection

IV. The model of informational interaction with undetermined intermediaries

When using this interaction scheme, there is prepared the structure of the identified communication channels. To create it execute following steps:

1) Swarm is divided into clusters. In the simulation used the K-means algorithm and clustering is based on the location of agents in space.
2) In each cluster set identified the channels of communication between all agents.

The preparation of the structure is presented in Fig. 5.

During operation of the model in the structure may be new identified communication channels. Algorithm of actions of the agent e_{ij} to send a message to $I(e_{ij}, e_{lk})$ is shown below:

1) Check is the recipient e_{lk} member of the sender's cluster i=l. If so, there is an identified communication channel $L(e_{ij}, e_{lk})$, according to which a message is sent $I(e_{ij}, e_{lk})$.
2) If the cluster sender and receiver do not match i≠l, then, if there is an identified communication channel $L(e_{ij}, e_{lv})$ between the sender e_{ij} and any agent from a cluster of the recipient e_{lv}, a message is sent, $I(e_{ij}, e_{lk})$ on this channel.
3) If the message is not sent, then there is a identified channel available to the agent-sending the identified communication channels $L(e_{ij}, e_{pv})$. For each channel, a request is sent $Q(e_{ij}, e_{pv}, l)$ which aims to find out if the agent e_{pv} identified communication channel $L(e_{pv}, e_{lm})$, where the agent e_{lm} belongs to cluster agent of the recipient. If the answer to the query is positive, such a channel exists, a message $I(e_{ij}, e_{lk})$ is sent by channel $L(e_{ij}, e_{pv})$
4) If the message is not sent, it is randomly selected unidentified channel $C(e_{ij}, e_{pv})$. It sends a message about the installation proposal identified channel $f(e_{ij}, e_{pv})$. After receiving the response, the identification of this channel. The agent repeats the procedure from paragraph 3 of this algorithm.

For the functioning of this model you must have model behavior of agents depending on the type and content of the received message. Such a model for agent e_{pv} received a message from the agent e_{cd} consists of the following rules:

1) A received message $f(e_{cd}, e_{pv})$.
   Action: send a message $f(e_{pv}, f(e_{cd}, e_{pv})\ )$ confirming the installation of the identified communication channel.
2) Received message $I(e_{ij}, e_{pv})$.
   A message destined to this agent.
   Action: send a message confirming receipt of the message, to the last agent in the chain e_{cd}.
3) Received message $I(e_{ij}, e_{pk})$

The message is intended for the agent from agent's e_{pv} cluster. Consequently, there is an identified communication channel $L(e_{pv}, e_{pk})$. Action: send a message $I(e_{ij}, e_{pk})$ by channel $L(e_{pv}, e_{pk})$.

4) Received message $Q(e_{ij}, e_{pv}, l)$
Action: check availability of the identified channel $L(e_{pv}, e_{lt})$, where e_{lt} any agent of cluster l. Then respond to the request in accordance with the check result, using the channel $L(e_{pv}, e_{pk})$
5) Received message $I(e_{ij}, e_{mk})$
If received such a message, the agent e_{pv} there is an identified communication channel $L(e_{pv}, e_{mt})$, where the agent e_{mt} belongs to cluster m, as the agent-recipient e_{mk}.
Action: send a message $I(e_{ij}, e_{mk})$ by channel $L(e_{pv}, e_{mt})$.

Thus, during operation of the scheme of message's transfer are generated dynamically. The model in the simulator is presented in Fig. 7.

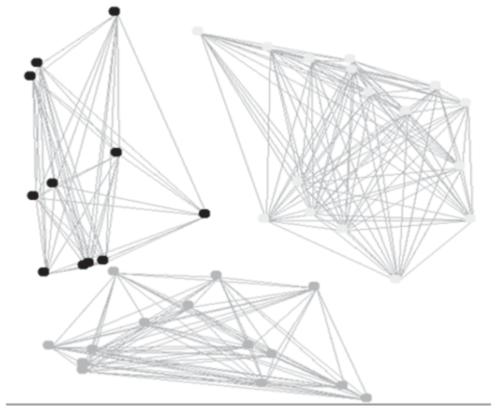

Fig. 6. model of informational interaction with undetermined intermediaries. The structure of the relations after initialization

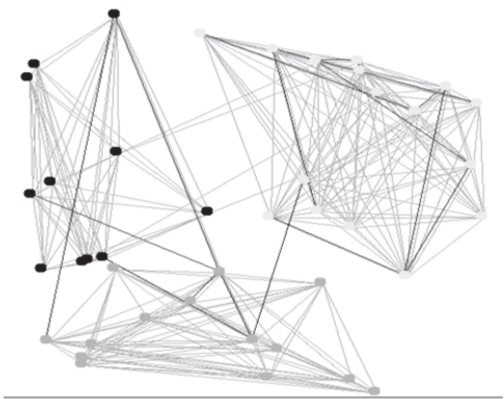

Fig. 7. model of informational interaction with undetermined intermediaries. Model in work.

As seen in the chart presented in Fig. 9, this model of interaction allows to reduce the number of steps the agent to send the message through the use of intermediaries and pre-prepared structure of the identified channels.

V. Model of information interaction by means of pre-defined mediators

This model also includes creation the identified channels of communication before the agent's interaction. Its preparation includes the following steps:

1) The partitioning swarm of agents into clusters. In the simulation used the K-means algorithm, clustering is based on the location of agents in space.
2) The choice of the leaders of the clusters. Each cluster selects a leader closest to the center of mass of the cluster.
3) Installation of the identified channels. In each cluster all agents have identified channel with leader. Also, these communication channels are created between all the leaders of the clusters.

On Fig. 8 you can see UML-presentation of this model work.

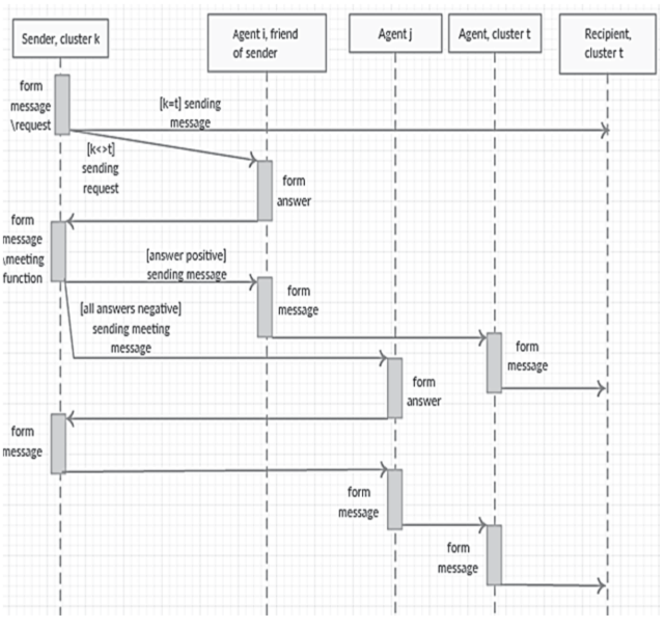

Fig. 8 Uml presentation of informational interaction with undetermined intermediaries. Here "Agent i" is all agents which have identificated channel with sender, "Agent j" is any agent which have not identificated channel with sender.

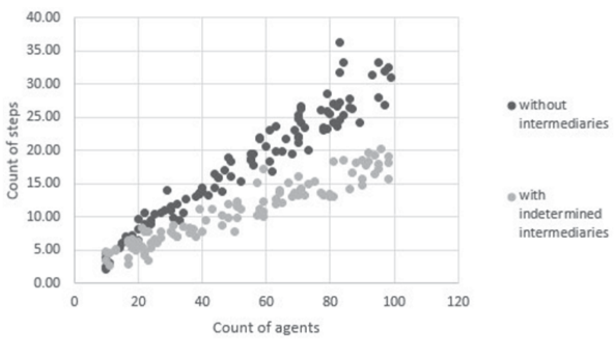

Fig. 9. Comparison of dependencies of the number of steps agents the number of agents in the models without intermediaries and with uncertain mediators.

The leader is chosen by maximizing of function $\mu_{R_i}(r)$. Thus, the leader is the most abstracted from the cluster edge (Fig. 10).

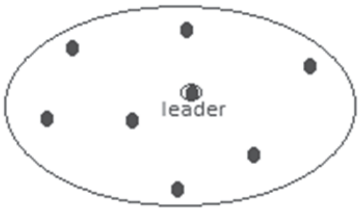

Fig. 10 Demonstrating exemplary leader position.

The communication channel in the model is represented by a set of communication channels between the agent-sender, and the leader of its cluster, a cluster leader agent-sender, and cluster leader agent recipient, cluster leader of agent-recipient's cluster and agent-recipient:

$$C(e_{ij}, e_{lk}) = C(e_{ij}, e_{i\,lead}) + C(e_{i\,lead}, e_{l\,lead}) + C(e_{l\,lead}, e_{lk})$$

Thus, the action of agent e_{ij} to send a message $I(e_{ij}, e_{lk})$ will depend on whether he is a leader and in which cluster he is exist:

1) The agent-sender is leader of agent-recipient's cluster:

$$e_{ij} = e_{j\,lead}$$

In this case, there is an identified communication channel $L(e_{ij}, e_{lk})$. Agent, the sender conveys the message $I(e_{ij}, e_{lk})$ using this channel.

2) The agent-sender is the leader of the cluster, but the sender's cluster does not coincide with a cluster of agent-recipient:

$$e_{ij} = e_{i\,lead}$$
$$i \neq l$$

Agent- sender needs to send a message $I(e_{ij}, e_{lk})$ to the leader of the cluster of agent-recipient, using the identified channel $L(e_{ij}, e_{l\,lead})$.

3) The agent-sender is not a leader. Agents are not leaders have only one identified communication channel established with the leader of their cluster. Therefore, all transmissions pass through it. Agent-sender conveys the message $I(e_{ij}, e_{lk})$ by channel $L(e_{ij}, e_{i\,lead})$

In addition to the actions of the agents to send the message, the model lays their behavior when it receives a message. These rules, to the agent e_{ab} received message $I(e_{ij}, e_{lk})$ from the agent e_{cd} are described by the following algorithm:

1) If the message is intended for the agent.

$$e_{ab} = e_{lk}$$

Agent e_{ab} transmits a confirmation of receipt of message to the last agent in the chain e_{cd}. His actions come to an end. It should be noted that this point is always for agents that are not among the leaders of the clusters, as they only receive their intended messages.

2) If the agent is a leader, and the message is for the agent of his cluster.

$$e_{ab} = e_{a\,lead}$$
$$a = l$$

Agent e_{ab} sends the message $I(e_{ij}, e_{lk})$ to the recipient e_{lk} using the identified communication channel $L(e_{ab}, e_{lk})$. It is also goes a confirmation of receipt message to the agent e_{cd} in the chain of transmission.

3) If the agent is a leader, and the message is not for the agent of his cluster.

$$e_{ab} = e_{a\,lead}$$
$$a \neq l$$

Agent e_{ab} sends the message $I(e_{ij}, e_{lk})$ to the leader $e_{l\,lead}$ of the cluster agent-recipient by the identified communication channel $I(e_{ab}, e_{l\,lead})$. It is also goes a confirmation of receipt message to the agent e_{cd} in the chain of transmission.

On Fig. 11 you can see UML-presentation of this model work.

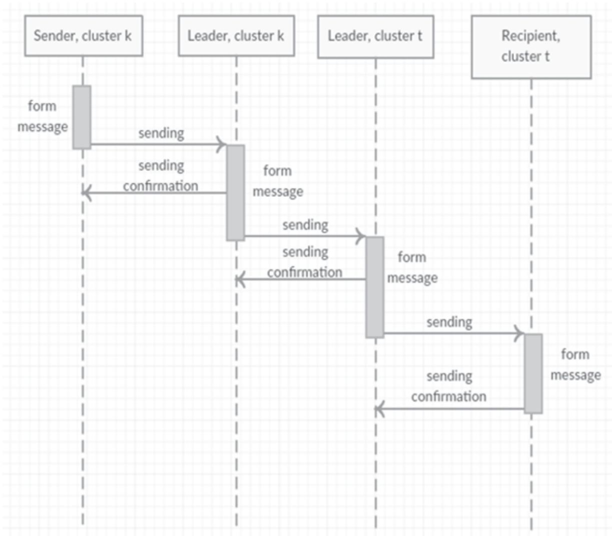

Fig. 11 UML-presentation of information interaction by means of pre-defined mediators.

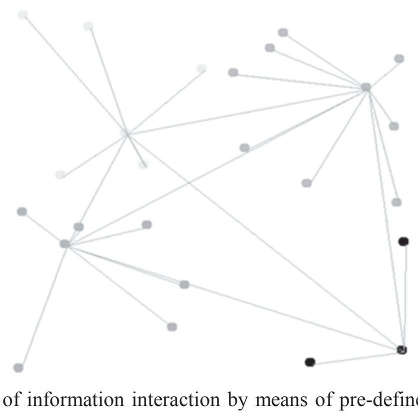

Fig. 12. Model of information interaction by means of pre-defined mediators after the structure of the identified channels

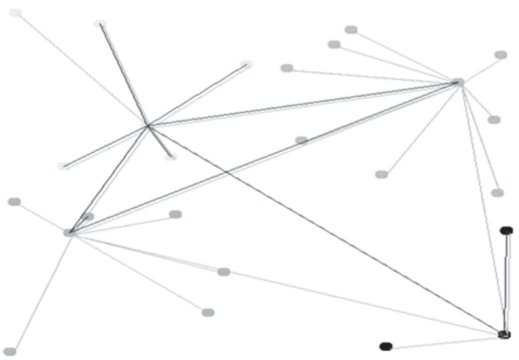

Fig. 13. Model of information interaction by means of pre-defined mediators in work.

VI. Description of the simulator

Created simulator was made with Java. The simulation takes place in real time. The basic conditions for the modeling of steel limited speed of message transmission and the ability of the agent to process only one request at a time.

The main features of the simulator are:

- Conduct custom experiments. Custom parameters include such values as: the number of agents, number of tasks, the factors responsible for the complexity of the message processing and the parameters for individual models of information transmission, various graphical options, and more.
- Visual demonstration of the processes.
- Collect statistics, such as average elapsed time for delivery of the message; the distance traveled by a message; the number of agent actions performed to send a message to others.
- Easy integration of new models of communication due to the structure of the program.

The main classes of the simulator include:

- Agent. An instance of this class represents one of the interacting agents. It stores data such as its location, identification number, group membership, task list, other agents, of which the identified communication channel. The class provides methods to send and receive agent messages, adding and deleting tasks and other.
- Queue. Each instance of the class Agent the bound instance of this class. He is responsible for the sequential processing of requests and allows to control it.
- Message. Class instances are messages passed between agents. In each instance of data is stored about the sender and the recipient, length, type, and history messages.
- Logic. This abstract class contains a method to create a task for the agent, his reaction when receiving the message and his actions to complete the task. Different implementations of this class represent a variety of interaction models.
- Frame. The class is responsible for rendering of all elements and of the processes.
- Simulator. This class stores a list of all agents, a view of the executable models are generated for all objects and statistics.
- Stats. This class collects statistics of simulator's work. It includes number of agent's actions to send targeted messages, the number of agents in the message transmission chain, time spent on the task. Also this class calculate average value.
- Generator. This class is responsible for generating agents in the field, creation structures of interaction models and the generation of tasks.
- Params. In this class are stored initial parameters of the experiment, there is download them from the xml file.
- Clusterator. This class performs clustering agents. The result of clustering are also stored in this class.

For example below shows code for model from chapter 3.

```
Send Message
        For  agents a ∈ friends of sender
                If a=recipient then
                        return
                end if
        end for
        for agents a∉friends of sender
                a.send(f(owner,a))
                if a.readMessage()=f(a,f(owner,a))
                        a.send(I(owner,a))
                        return
                end if
        end for
end
```

VII. Comparison of models

For comparison, efficiencies of the models were taken the dependence of the average time spent on message delivery of the number of agents. Fig. 14 shows that the model with pre-defined mediators is superior to the other two models. In addition to less time required for message delivery model with several agents is more predictable, due to the lack of the element of chance.

VIII. Conclusion

As a result of this work produced a universal means of modeling various communication structures. With its use was held a comparative analysis of the three models of interaction between agents. It was found that the preparation of a rational connection structure before the interaction of agents greatly improves the time performance of the model.

The structure of created simulator has to further its modernization. In future studies planning involving different types of agents. The study of the impact of their behavior on the number and data transfer processes. It is assumed that introduction of intruders in the model can reduce the effectiveness of the models with the prepared connection structures.

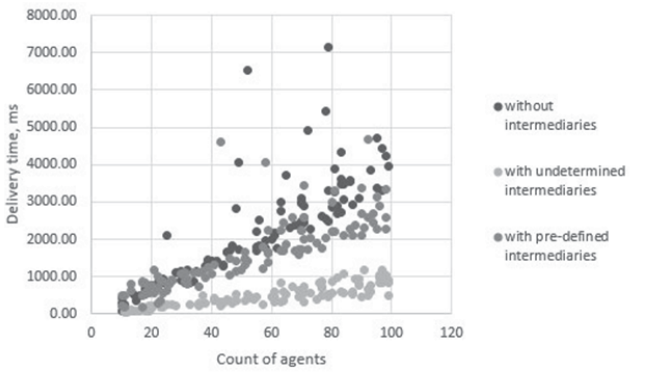

Fig. 14. Dependence of the average time spent on message delivery of the number of agents.

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