A conceptual model of communication for intelligent agents in the infrastructure of smart transportation systems

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Abstract. In this article, at a conceptual level, the issues of data exchange between objects of a complex cyber-physical system using a multi-agent approach are considered. A multi-agent communication model of intelligent agents is described, which is the interaction of participants in the Smart Transportation information management space. Unmanned vehicles, pedestrian mobile devices, smart traffic lights, traffic signs and other infrastructure of the Smart City are considered as model agents.

1. Introduction

Today, one of the fastest growing areas of interest is the cyberspace of intelligent transport systems. These are complex cyberphysical systems (CPS), arising as a result of the interaction of people, software, Internet services through technological devices, and communication networks [1].

The main components of any cyberphysical system (figure 1) are:

- the physical layer of the system (various objects of the real diverse physical world);
- the digital layer of the system (data about the system stored in computers, algorithms for managing physical objects, information processing algorithms, etc.);
- the interface of the interaction of the digital and physical layer (various sensors, control mechanisms, etc.);
- an interface for the interaction of the digital and physical layer with a person (various HR technologies).

These components interact with each other in time and space, form a single ecosystem aimed at solving a specific problem.

When considering CPS, it is necessary to evaluate the security of the system from the point of view of communication interaction. A key factor is an attacker gaining the ability to influence physical and production processes through informational exposure. Due to the peculiarities of the structure of such systems, attacks on them can be carried out both intentionally (by cyber criminals) and by negligence (by employees who have access to the CPS). Consequently, the harm done to the system can be either direct (loss of information, disabling the system), or indirect (spamming). In addition, a violation of information security without human intervention is possible if the implementation of the system involves its independent development.
As part of further CPS studies, unmanned vehicles (UMV) will be considered as objects of smart transportation (Smart Transportation) [2].

The basis of the Smart & Safe City concept is the smart environment for the interaction of cyberphysical devices, cloud computing, computing resources, and mobile communication systems for organizing ubiquitous access.

The close integration of CPS with technological processes associated with the management of a large number of UMVs capable of changing their behavior leads to the need to create new models for describing information interaction and ensuring the information security of such systems. One of the approaches to formulate a conceptual model of the Smart Transportation infrastructure is multi-agent modeling [3].

2. Conceptual model for communication of intelligent agents

The formal model of a multi-agent communication system of intelligent agents for the Smart Transportation infrastructure can be represented as follows [4, 5]:

\[ MAC = \langle A, E, N, ORG \rangle \]  

Where \( A \) is the set of agents; \( E = \{ e \} \) is the environment in which this MAC is located; \( N \) is the set of Smart Transportation infrastructure nodes; \( ORG \) is a set of basic organizational structures corresponding to specific functions (roles) of agents.

We make a number of assumptions about the elements of the MAC:

- each intelligent MAS agent is autonomous, has an individual perception of the environment of the smart city \( E \), its actions are characterized by a local objective utility function;
- the environment of smart city \( E \) is dynamic and indefinite, its initial model of behavior in the general case may not be known;
- management and interactions between agents are decentralized;
- messaging between agents imitates information and control flows;
agents tailor their local behaviour to a changing environment. Within the framework of the organizational structures of the MAC, violating agents that pose a threat to the information security of the Smart Transportation infrastructure can be represented. These threats include [6, 7]: unauthorized passive interception of messages in the process of inter-agent communications; violation of the integrity of the transmitted data; unauthorized access to data; denial of service; interception of requests with their subsequent modification and reproduction; refusal to receive or send data, etc. As part of further research, we will assume that many agent roles are limited to five types of agent groups:

\[
Rl = \{A_{UV}, A_{inf}, A_{OF}, A_{CS}, A_{at}\},
\]

\[A_{UV}\] (Unmanned Vehicles) - unmanned vehicles that are participants in the information exchange of the Smart Transportation infrastructure.

\[A_{inf}\] (information) - agents for transmitting informational messages. Such agents include all participants in the Smart Transportation information and control space, transmitting information to an unmanned vehicle (pedestrian mobile devices, smart traffic lights, traffic signs, and other infrastructure).

\[A_{OF}\] (OpenFog) - agents of fog computing services. Such agents include external UMV dispatch services, cloud service support environments within the cyber-physical system of a smart city.

\[A_{CS}\] (Control System) - agents of the internal automatic control of the operation and functions of an unmanned vehicle, supporting the operation of the human-vehicle, vehicle-external interaction interfaces.

\[A_{at}\] (attack) - agents acting in the interests of attackers, seeking to gain full control over the UMV.

Regardless of the role of the intelligent agent, its abstract architecture can be described by a number of common properties [8]. The external environment of agent E can be described using multiple ES (Environment States). Possible agent actions are described using a variety of Ac (actions). In the future, action scenarios corresponding to individual agent roles will be described. The agent carries out the selection of a specific action from the set of possibilities, based on the current state of the external environment:

\[Action: ES^* \rightarrow Ac\]  \hspace{1cm} (3)

Where \(ES^*\) is the current state of the external environment for the Smart Transportation infrastructure. Accounting for (2), formula (3) will be as such:

\[Action_{UV}: ES_{UV}^* \rightarrow Ac_{UV},\]
\[Action_{inf}: ES_{inf}^* \rightarrow Ac_{inf},\]
\[Action_{OF}: ES_{OF}^* \rightarrow Ac_{OF},\]
\[Action_{CS}: ES_{CS}^* \rightarrow Ac_{CS},\]
\[Action_{at}: ES_{at}^* \rightarrow Ac_{at},\]  \hspace{1cm} (4)

while

\[
ES^* \subseteq ES_{UV}^* \times ES_{inf}^* \times ES_{OF}^* \times ES_{CS}^* \times ES_{at}^*,
\]
\[
Ac \subseteq Ac_{UV} \times Ac_{inf} \times Ac_{OF} \times Ac_{CS} \times Ac_{at}.
\]

In turn, the actions of an agent affect the state of the external environment, which, depending on its current state and the effects of agents, can go into one of many states. The behaviour of the environment can be described by the function:

\[Env: ES^* \times Ac \rightarrow 2^{ES \times Ac}.
\]

It must be considered that an intelligent agent has the property of perception of the environment. The agent perceives the outside world is limited, so he is not have available full information about the global state. This is due to the fact that the model of a complete picture of the world [9, 10] for any agent is
incomplete. An agent models informational situations, but also to a limited extent, within the framework of his perception. We introduce the set of Per possible perceptions and a function that describes how certain states of the environment are perceived by the agent.

\[ \text{Perception: } ES \rightarrow Per. \] (7)

In this case, the action of the agent is determined by the current perception of the state of the environment:

\[ \text{Action}_{UV}: Per_{UV}^* \rightarrow Ac_{UV}, \]
\[ \text{Action}_{inf}: Per_{inf}^* \rightarrow Ac_{inf}, \]
\[ \text{Action}_{OF}: Per_{OF}^* \rightarrow Ac_{OF}, \]
\[ \text{Action}_{CS}: Per_{CS}^* \rightarrow Ac_{CS}, \]
\[ \text{Action}_{at}: Per_{at}^* \rightarrow Ac_{at}, \] (8)

Only in rare cases can an agent possess complete information about the external environment sufficient to uniquely identify its state. On the other hand, most often the agent does not need complete information about the state of the external environment to make a decision, and only that part of the information is important that can affect the execution of the agent’s actions and/or lead to negative consequences.

The agent, depending on the internal state and perception of the environment, performs actions leading to a change in its internal state. To formalize this process, we introduce the set of internal states IS (Internal State) and the transition function:

\[ \text{Transit: } IS^* \times Per \rightarrow IS. \] (9)

Agent actions in this case are described:

\[ \text{Action}_{UV}: IS_{UV}^* \rightarrow Ac_{UV}, \]
\[ \text{Action}_{inf}: IS_{inf}^* \rightarrow Ac_{inf}, \]
\[ \text{Action}_{OF}: IS_{OF}^* \rightarrow Ac_{OF}, \]
\[ \text{Action}_{CS}: IS_{CS}^* \rightarrow Ac_{CS}, \]
\[ \text{Action}_{at}: IS_{at}^* \rightarrow Ac_{at}, \] (10)

An intelligent agent has the property of self-learning. We assume that the transition of the agent to a new state is associated with information about the action performed by the agent in the previous step, and all the earlier information was already analysed by the agent. In this case, it is necessary to include information about the actions performed by the agent explicitly in the input data of the action selection function:

\[ \text{Action}_{UV}: (Per_{UV} \times Ac_{UV})^* \rightarrow Ac_{UV}, \]
\[ \text{Action}_{inf}: (Per_{inf} \times Ac_{inf})^* \rightarrow Ac_{inf}, \]
\[ \text{Action}_{OF}: (Per_{OF} \times Ac_{OF})^* \rightarrow Ac_{OF}, \]
\[ \text{Action}_{CS}: (Per_{CS} \times Ac_{CS})^* \rightarrow Ac_{CS}, \]
\[ \text{Action}_{at}: (Per_{at} \times Ac_{at})^* \rightarrow Ac_{at}, \] (11)

\[ \text{Transit: } IS^* \times Per \times Ac^* \rightarrow IS. \] (12)

Considering a distant tuple (1) We set the set of N nodes of the Smart Transportation infrastructure as a tuple of elements:
\[ N = \langle T, R, P, F \rangle, \]  
(13)

Where \( T \) is the set of types of equipment corresponding to the infrastructure node Smart City; \( R \) is the set of functional roles of the node (dispatch node, motion control node, data storage node); \( P \) is the set of software components used by the nodes; \( F: R \rightarrow P \) is a function that implements the mapping of the set of functional roles of the node to the set of software components (software). Software and / or hardware component of software are protocols that implement a set of rules and allow connecting and exchanging data between two or more devices connected to the network.

The organizational structure of the agent is formally described as:

\[ \text{ORG} = \langle G, Rl, Cp, Ac, Per, Sc, L, IS \rangle, \]  
(14)

Where \( G \) is the triad of the agent’s goals that he must achieve in order to solve the functional task assigned to him; \( Rl \) is the set of agent roles in which he must act in order to achieve the corresponding goals; five roles are specified for the model, according to (2); \( Cp \) is many skills (competence) of the agent, which he must possess in order to fulfill the corresponding role; \( Ac \) is the set of agent actions; \( Per \) is the agent’s many perceptions of environmental conditions; \( Sc \) is many scenarios (strategies) of agent behaviour in the direction of achieving the corresponding goals; \( L \) is many languages of information exchange; \( IS \) is the set of internal states of the agent; \( Prf \) is a set of laws (rules, principle) and restrictions on the functioning of the agent, and the restriction is determined by the triad \((Rl, Ac, L)\).

Agent behaviour scenarios include three types:

\[ Sc = \langle Sc_{UV}, Sc_{OF}, Sc_{at} \rangle, \]  
(15)

\( Sc_{UV} \) - Legitimate activities of Smart Transportation infrastructure Smart Transportation; \( Sc_{OF} \) - are scenarios of containment of attacking agents and counteraction to attacks, as well as scenarios of \( Sc_{at} \) at of attack implementation. Each of the scenarios, in turn, contains many sub-scenarios, the goal of the script, the algorithm for achieving the goal, the nodes involved in the script.

This article presents a conceptual model (1-15) of informational interaction of agents within the framework of the cyber-physical system Smart Transportation, the main goal is to explore the possibilities of the proposed approach to multi-agent modelling, a more developed approach to adaptation will be presented by subsequent authors.

3. Conclusion

In this work, the conceptual level defines the roles of the main agents and describes the interaction processes of their interaction with the Smart Transportation infrastructure. The described approach is the development of the ideology of situational management with the allocation of five roles of agents of a multi-agent system, which will make it possible in the future to significantly simplify the modelling of cyber-physical systems with the support of the required level of quality of service for communication services.

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