Bulletin of the *Transilvania* University of Braşov
Series I: Engineering Sciences • Vol. 4 (53) No. 2 - 2011

MULTI-AGENT SYSTEMS: TRAFFIC CONTROL APPLICATION

I. COBEANU[1] **V. COMNAC[1]**

Abstract: *Multi-agent system technology has been proposed to model any systems who's resources are distributed (systems that can be found everywhere in the real world). Through system modeling using this technology the system's flexibility and capacity to resolve unpredicted situations that appear inside it, have been improved. In this article multi-agent systems technology advantages and applications are presented. Multi-agent systems can model systems from various domains such as: transportation (road transportation, railroad, air, maritim), industry, healthcare, military. At the end of the article the traffic control application is proposed.*

Key words: *multi-agent systems, application, traffic control.*

1. Introduction

Multi-agent systems technology is used with success in the case of distributed systems. Distributed systems are those systems in which their components can make their own decisions, where each component performs a task so that the entire system can achieve its main goal. In such systems the cooperation between system components to achieve the goal of that system, becomes very important. Distributed systems environment is dynamic and continuously changing. The technology used to model such a system must cope with unpredicted situations that appear in the system [21]. Until now the most appropriate technology to resolve such situations is the multi-agent systems technology. Building applications using this technology improves the system's flexibility and capacity to resolve these unpredicted situations.

Multi-agent systems have seen a proliferation in recent years, being used in applications in various domains. Examples of such domains are: transportation, industry, healthcare, military etc. The architecture of multi-agent systems varies depending on the application it is used in. In making such architecture it is important to know where the intelligent agents are placed and the purpose of each agent. They will have the ability to make their own decisions based on the conditions of the environment to which they belong. Another important point is the coordination of the agents. Each agent must be capable to communicate with other agents. Thus the decisions of each agent will be in accordance with the needs of the entire system.

The architecture presented in detail in this article is the architecture of an urban traffic control application.

The article is structured as follows: in Section 2 the advantages of using multi-

[1] Dept. of Automation, *Transilvania* University of Braşov.

agent systems are presented, in Section 3 detailed presentation of domains and examples of applications where the multi-agent systems paradigm is successfully used, in Section 4 detailed presentation of the proposed traffic control application and at the end the conclusions are presented.

2. Multi-agent systems. Advantages

The multi-agent technology is used with success in case of distributed systems. The distributed systems are those systems in which their components can make their own decisions in such way that each component accomplishes a goal, so the whole system accomplishes a main goal. In distributed system the cooperation between system's components is very important. The system's distributed environment is a dynamic one, being in a continuous change.

In the decentralized control the decisions are taken at every entity's level. In this case the system's entities do not depend on a central unit. The accuracy of the made decisions depends very much on the environment and on the other agents' knowledge. The decisions are better if the environmental knowledge is a good one. The best solutions are taken only if the entities know the state of the whole system. The messages are sent between the agents. Each agent should know what the other agents are doing. Because is very hard for every agent to receive information from all other agents (this situation can lead to network overhead) strategies based on receiving only the information that can affect their behavior are searched. Each agent has a partial vision of the whole system. The decentralized controlled system is a flexible system. The adding of new entities is easy to be done compared with the centralized control.

The technology used to model a distributed system should be able to manage the unpredictable situations appeared in the system's environmental. The multi-agent technology can be used to model the distributed systems. Using the multi-agent technology to model such systems the systems flexibility and their capacity to solve unpredictable situations appeared in the system's environment is improved.

The multi-agent systems have been used in many applications in the last years, being used in applications from different domains. Examples of such domains are: transportation, industry, health, military and others.

A multi-agent system is composed from multiple agents (different entities which can make their own decisions based on the information obtained from their environment). An intelligent agent is an autonomous entity which can observe and react to environment changes and implement actions to achieve his goals.

The multi-agent system's architecture depends on the application in which is used. In order to create such architecture, it is important to know the place where the intelligent agents are in the system, and each agent's goal. The agents will have the ability to make their own decisions according with their environment state.

Another important point is the agents' coordination. Each agent has to communicate with the other agents. In this way the agents' decisions are taken in concordance with the whole system's state.

The architecture presented in this article is the architecture of a traffic control application which proposes to detect the incidents appeared in traffic in real-time, and to change the agents' behavior based on this data.

In literature a lot of applications are proposed which present the multi-agent system technology integration in the transportation domain. This kind of application belongs to the road transportation.

The use of multi-agent systems technology to build control applications in transportation domain is natural because the application resources (cars, trains, airplanes) are resources distributed in space. Using this technology the communication and collaboration between different components of the whole system can be created. In this way it is possible to realize the system control.

Because transportation systems are dynamic systems, their control should be made in real-time. This way the system can respond immediately to the changes that appear in the system. The real-time control becomes very important in these applications because having a fast response to the changes that appear in the system helps the necessary actions to avoid the incidents to be taken.

3. Domains Where Multi-Agent Systems Can Be Used

The intelligent agents and multi-agent systems represent a big step in the development of a new generation of software systems. These software systems are used especially in distributed applications. Using the multi-agent technology to model such systems the systems flexibility and their capacity to solve unpredictable situations appeared in the system's environment is improved. Multi-agent systems are used in many applications from different and various domains. Examples of such domains are presented in this section.

3.1. Transportation domain

The use of multi-agent systems to build applications in the transportation domain is natural because the resources of such an application (cars, trains, airplanes, shipping containers etc.) are spatially distributed. Using this technology permits the communication and collaboration between different parts of the whole system (subsystems), so that it is possible to control them. Because these systems are dynamic, their control must be made real time. Thus the system can respond immediately to changes that appear in the environment. Real time control becomes very important in these applications because only by having a fast response to changes in the environment can the necessary measures to avoid incidents be taken.

Another application valid for any means of transportation is the supply with raw materials of various warehouses, factories or production lines [9]. Such an application using multi-agent technology for this purpose is presented in [19]. The system presented has the role to coordinate the procurement process logistics for the most important fishery cooperatives. This system increases the flexibility of the supply chain and permits the members of this chain to be more receptive.

Next are presented a few applications from the transportation domain. They are listed according to the type of transportation to which they belong.

3.1.1. Road transportation

Most applications in the transportation domain have dealt with the road transportation. In the big urban centres the traffic has increased significantly due to the increased number of personal cars users. To avoid traffic jams that occur due to street congestions it was necessary to create control applications. The main purpose of the applications is to reduce the time spent by the drivers in traffic.

In order to avoid the traffic jams a series of strategies have been realized through which the traffic lights in the intersections are controlled. In each intersection there is one intelligent agent that monitors the

status of the intersection: number of cars entering the intersection (every car that enters the intersection announces its entry to the coordinating agent), number of cars exiting the intersection etc. Depending on the data, the coordinating agent decides how to move the cars so that the time spent by them in the intersection is as small as possible [6]. Traffic control applications can control the time intervals for the traffic light so that the cars time of passage through the intersection is the smallest. Depending on the cars passing flow, the time interval in which the traffic light is on green and on red is modified. Each traffic light is considered to be an agent that has as input data the actual state of the intersection [2], [4], [7].

Another application in this domain is the control of cars from a distribution company for various materials, food etc. [13], [16]. In this case each car is one agent that must deliver the product to the client. For a shorter product delivery time, the agents must have the capacity to communicate and cooperate among themselves. Based on data obtained, every agent can make the right decision regarding the delivery method. The agent coordination is inspired by bee behavior [18].

3.1.2. Rail transportation

In railroad transportation initially traffic control systems had been centralized. In the last period, once with the development of multi-agent systems approaches have emerged that use the multi-agent system technology to solve the problem of controlling trains on a railway section [3]. These applications aim to resolve the problem of rerouting in case a train is delayed. Each agent has the capacity to generate solutions so that the delays of the trains on that section to be minimal and to avoid incidents. In the railway system based on agents, the expected tasks are sent to the coordinating agent through the human-machine interface of each agent. The tasks are submitted to the evaluating agent, the model selection agent and the forecasting agent. After evaluation the results are then returned to the agent who takes the necessary actions necessary for orientation [15].

3.1.3. Air transportation

In air transport applications were proposed which control the airplane routing, for avoiding incidents at the landing or take off. By utilizing the multi-agent technology the distances between airplanes can be controlled, so the incidents will be avoided, delays necessary for taking off can be calculated, the airplanes can be rerouted in case of an incident appearance [1].

3.1.4. Maritime transportation

In the maritime transport applications were proposed which realize the container transport in a maritime port, or submarine coordination used to research the oceans (these applications are described also in the military application section).

The container transport in a port is a hard job because of the big number of containers, vehicles and cranes used to take the containers from the ship and to deposit or to transport them outside the port. In such an application each vehicle, crane etc. can take its own decision. These decisions should be taken in accordance with the other vehicles, cranes etc. [11].

3.2. Industry domain

Multi-agent system technology is proposed to be used in applications with autonomous robots, network sensors.

In case of the autonomous robots, like distributed systems in general, the whole

system should accomplish a goal. This goal is divided, in accordance with what each agent can do, in more sub-goals. These sub-goals have to be executed by each robot, so the whole system can accomplish its main goal. If one robot can't accomplish its sub-goal, the other agents have to take its goal, so the main goal will be accomplished [12], [17].

3.3. Health domain

In this domain applications regarding patient's diagnostic were proposed. A manager agent gets all the symptoms from the patient. After that, in concordance with the symptoms, asks different specialist agents for help. These agents separately generate the diagnostic. At the next step it will begin the specialists' coordination for reaching the final diagnostic [20].

3.4. Military domain

In military domain are proposed applications that have as purpose the soldier's coordination on the battlefield, the military ships, submarines, and airplanes coordination. The application's main idea is to develop autonomous systems which soldiers and fighting devices should have.

The main objective is to realize the entities coordination in such manner that the missions are a success. Software agents, being part of the multi-agent system, have the ability to communicate between them, so each agent knows all the time about the other agents' actions [8].

4. Traffic Control Application

The application proposed in this article belongs to the transportation domain (the road transportation). This application is designed to detect in real-time the incidents that appear in traffic, and based on the obtained data to change the cars' route. The route planning should be done in such manner that the cars' time spent in traffic be as short as possible, and in the same time to accomplish the arrival times at each location where the agents have to reach a goal.

The proposed scenario can be used in such applications where a car starts its route from a start point (origin), reaches the intermediary points where the driver should get to and then gets to the destination. All the intermediary points are characterized by some time intervals. These time intervals should be respected by the cars. For example: the bank is closing at a fixed hour, clients are at home at different time intervals.

Another example where the scenario can be used is the home delivery of different products, services etc. Each company employee who delivers products to the clients' home has a plan to respect during the day. This plan contains the clients' addresses, the time the employee should arrive at each client (these hours are given after speaking with the clients), and the time to arrive at the destination.

The first step in developing this application is to initialize the cars' route (the route planning is done in such way the employee accomplishes the day's plan). The cars' starting point, the intermediary points where the clients are and destination point are given as input data. Very important are the time intervals the employee arrives at each client and at the destination. When the planning of a new route is necessary, the times intervals should be respected as much as possible.

The second step which should be made is to detect the incidents that appear in traffic. Based on the incidents information the new route planning of optimal new routes which are followed by cars is done. The incident detection has to be done in real time, so the cars can plan their new routes

in concordance with the traffic conditions. Any delay, appeared at the incident detection, can produce situations in which the planning of new routes is not giving the best solutions (the cars can be blocked in traffic). If there is rapid incident detection, the problem of incidents avoidance can be solved. The planned routes will avoid the road where an accident or a traffic jam appeared.

The last step is to change the cars' routes in such way for the employee to accomplish his daily plan (to arrive at each client in the given time interval, and to decrease as much as possible the time spent by cars in traffic).

To create the control application proposed in this article the multi-agent technology is used. The main advantage of using this technology to model the cars' behavior is the fact that the agents are active entities which interact with their environment and with the other agents [5]. Each car is considered as a mobile agent.

As each agent, each car has a defined goal. In the proposed application case the goal is to arrive at each client in a desired time interval, to cover a shorter distance between the clients, and to respect the arrival time at the destination.

Each agent (car in the scenario proposed) has the ability to make its own decisions, without being coordinated at a central level. Each agent has access in real-time to the traffic status. Based on the traffic status the agents can make their own decisions regarding their route. The chosen route has to respect as much as possible the arriving times to clients, and to destination.

4.1. Proposed Multi-Agent System Architecture

The multi-agent system architecture for the proposed traffic control application is presented below. Using this architecture seeks to keep the systems entities autonomy (to make their own decisions) without being necessary to use a central coordinator. In the same time it seeks to increase the system's flexibility (to make easier adding or deleting agents).

Each car existing in the monitored area is considered an agent. The agents are mobile because they are moving on the road and in intersections network. The advantages of using mobile agents are: decreasing network latency, reducing the network load, executing asynchronous and autonomous actions, dynamically adaptive, having the ability to dynamically develop new software components [14].

Beside mobile agents in the system architecture an agent who will detect the incidents that appeared in the controlled area is introduced. This agent is called Incident Detection Agent and is doing globally the incident detection. This is necessary because for every mobile agent (car) to detect the incidents that appear in traffic, a big number of messages transmitted between the agents is needed. The delays appeared at message transmission will lead to important detection delays. When a specialized agent is used to detect the incidents, the sent messages number in the network decreases.

The disadvantages of using incident detection at the local level, at the agents' level are: the number of messages sent between agents is growing (this situation can lead to network overhead), and that the agents don't have a global image of the system (to have a more complete global image the agent needs to receive a lot of massages from the other agents) [10]. Without a complete system image it becomes very hard to detect all the incidents which can influence the agent's behavior.

The Incident Detection Agent receives information about agents and about the environment. Based on this information the

agent generates the incident information. This information is sent back to the agents.

Each agent plans its own route based on the detected incident information. Planning the new routes is necessary only if on its road an incident appears. The new plans have to be generated in a short time, so the agent can avoid the blocked area.

The part involving changing the agent's behavior will be done at each agent level. This will be done locally because the agents have different goals (origin points, intermediary points and destination points). This data is known at the local level, a big computational effort being necessary if each route is to be calculated globally and then the resulted routes to be transmitted to each agent.

5. Conclusions

This article proposes to show the advantages of using multi-agent system technology in distributed systems, which are the domains where this paradigm can be used and a proposed traffic control application. On one hand a system modelled with this technology grows the system's flexibility. If new components appear in the system, or if others go out does not represent a problem for this kind of implementation. On the other hand this kind of applications can solve unpredictable situations that appear in the system. The decisions for solving the problems can be taken in real time. Because the systems are distributed, each system's component can make its own decision in concordance with the appeared situations. Multi-agent technology was introduced in various domains. In this paper some examples of application from each domain were presented. In detail was presented only the proposed application: the control traffic application. In literature a lot of applications using multi-agent systems technology were proposed but only a few were implemented. The next researches propose to implement the control traffic application.

Acknowledgements

This paper is supported by the Sectoral Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and by the Romanian Government under the contract number POSDRU: ID59321.

References

1. Agogino, A.K., Tumer, K.: *Regulating Air Traffic Flow with Coupled Agents.* In: Autonomous Agents & Multiagent Systems/Agent Theories, Architectures, and Languages, ATAL, 2008, p. 535-542.
2. Bazzan, A.L.: *A Distributed Approach for Coordination of Traffic Signal Agents*. In: Journal Autonomous Agents and Multi-Agent Systems **10** (2005) No. 2, p. 131-164.
3. Bocker, J., Lind, J., et al.: *Using a Multi-Agent Approach to Optimize the Train Coupling and Sharing System*. In: European Journal of Operational Research **131** (2001) No. 2, p. 242-252.
4. Choy, M.C., Srinivasan, D., Cheu, R.L.: *Cooperative, Hybrid Agent Architecture for Real-Time Traffic Signal Control*. In: IEEE Transaction on Systems, Man and Cybernetics, Part A: Systems and Humans **33** (2003) No. 5, p. 597-607.
5. Dia, H.: *An Agent-Based Approach to Modeling Driver Route Choise Behaviour under the Influence of Real-Time Information*. In: Transportation Research Part **C 10** (2002) No. 5, p. 331-349.
6. Dresner, K., Stone, P.: *Multiagent Traffic Management: An Improved Intersection Control Mechanism*. In:

The Fourth International Joint Conference on Autonomous Agents and Multiagent Systems, Utrech, Netherlands, 25-29 July, 2005, p. 471-477.
7. Dresner, K., Stone, P.: *A Multiagent Approach to Autonomous Intersection Management.* In: Journal of Artificial Intelligence Research **31** (2008) No. 1, p. 591-656.
8. Ekanayake, S., Pathirana, P.N.: *Smart Cluster Bombs - Control of Multi-Agent Systems for Military Applications*. In: Proceedings of the IEEE International Conference on Networking, Sensing and Control, London, UK, 10-14 April, 2007, p. 471-476.
9. Fox, M., Barbuceanu, M., et al.: *Agent-Oriented Supply-Chain Management*. In: International Journal of Flexible Manufacturing Systems **V12** (2000) No. 2, p. 165-188.
10. Halle, S., Chaib-draa, B.: *A Collaborative Driving System Based on Multiagent Modeling and Simulations*. In: Transportation Research Part **C 13** (2005) No. 4, p. 320-345.
11. Henesey, L.E.: *Multi-Agent Systems for Container Terminal Management*. In: Ph.D. Thesis, Citeseer, Blekinge Institute of Technology, Department of Systems and Software Engineering, Sweden, 2006.
12. Jennings, N.R.: *Controlling Cooperative Problem Solving in Industrial Multi-Agent Systems using Joint Intension*. In: Artificial Intelligence **75** (1995) No. 2, p. 195-240.
13. Kohout, R., Erol, K.: *In-Time Agent-Based Vehicle Routing with a Stochastic Improvement Heuristic*. In: 11th Conference on Innovative Applications of Artificial Intelligence, Orlando, Florida, USA, 18-22 July, 1999, p. 864-869.
14. Lange, D.B., Oshima, M.: *Seven Good Reasons for Mobile Agents*. In: Commun. ACM **42** (1999) No. 3, p. 88-89.
15. Liu, Y., Liu, H., et al.: *Agent Based Urban Rail Transport Ridership Forecast System*. In: Digital Ecosystems and Technologies (EDT) International Conference on E-Health Networking, Shenzhen, China, 17-18 April, 2010, p. 256-259.
16. Mester, D., Braysy, O.: *Active Guided Evolution Strategies for Large-Scale Vehicle Routing Problems with Time Windows*. In: Computers & Operations Research **32** (2005) No. 6, p. 1593-1614.
17. Tanenbaum, A.S., Steen, M.V.: *Distributed Systems Principles and Paradigms*. New York. Prentice Hall, 2002.
18. Teodorovic, D.: *Swarm Intelligence Systems for Transportation Engineering: Principles and Applications*. In: Transportation Research Part C: Emerging Technologies **16** (2008) No. 6, p. 651-657.
19. Wang, Y.-L.: *Flexible and Responsive Multi-Agent Based Logistics Coordination Management*. In: The 2nd IEEE International Conference on Information Management and Engineering (ICIME), Chengdu, Sichuan, China, 16-18 April, 2010, p. 43-47.
20. Yang, Q., Shieh, J.S.: *A Multi-Agent Prototype System for Medical Diagnosis*. In: 3rd International Conference on Intelligent System and Knowledge Engineering, Xiamen, China, 17-19 November, 2008, p. 1265-1270.
21. Zambonelli, F., Van Dyke Parunak, H.: *Signs of a Revolution in Computer Science and Software Engineering*. In: Proceedings of the 3rd International Conference on Engineering Societies in the Agents World III, Madrid, Spain, 3-7 September, 2002, p. 13-28.