REAL-TIME COORDINATION STRATEGY FOR CONTROL TRAFFIC APPLICATIONS

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

Abstract: *Coordination in multi-agent systems is a very important problem. Coordination represents the mechanism through which the behavior each agent in the system contributes to reaching the global system goal. This article proposes a real-time strategy for control traffic application. The goal of the coordination strategy proposed is to realize the control of cars from a distribution company for various products. The proposed strategy is adaptable to unpredicted situations in the system and is a decentralized strategy. Rescheduling the agents' behavior is made based on incidents detected in traffic.*

Key words: *coordination, real-time, multi-agent system, traffic control.*

1. Introduction

Multi-agent systems are composed from independent entities named agents. These agents must coordinate their behaviours so that it will lead to accomplishing the main goal of the multi-agent system. The mechanism through which these behaviours are interconnected is called coordination. Coordination in a multi-agent system is indispensable, because without coordination, the agents will act chaotically, without regard to the state of the system or to the global goal of the system.

An agent in order to take a decision must know the environment and the activities of the other agents. For a better understanding of the environment a great amount of information is necessary to be transferred. In the case when the strategy is based on agent communication, a decrease of the information volume transmitted which can lead to a system overhead.

This article wants to present a real-time coordination strategy. The goal of the coordination strategy proposed is to realise the control of cars from a distribution company for various products. The agents that deliver the goods establish their behavior according to the incidents appeared in traffic. These incidents are detected at a global level by an Incident Detection Agent. This agent detects the incidents appeared in traffic using the CEP (*Complex Event Processing*) technology and transmits the resulted complex events to the agents that deliver the goods. These, based on these events, reconfigure their routes so that they arrive at the clients in the established time interval. The initial routes are calculated by a Delivery Agent using the CSP (*Constraint Satisfaction Problem*) technology.

The article is structured as follows: in section 2 presents the problem of coordination in multi-agent systems with realisation techniques and evaluation criteria for the coordination strategy, in section 3 the proposed strategy is presented, related work, the way the communication is made, a local

---

[1] Centre "Automatics Electronics and Computers", *Transilvania* University of Braşov.

scheduling agent, strategy implementation, and evaluation of this strategy. Finally the conclusions are presented.

2. Coordination in Multi-Agent System

Coordination represents a very important problem in the case of multi-agents systems. It represents the process through which each agent takes his own decisions so that the whole system can accomplish the global goal. Without coordination in a multi-agent system, each agent acts chaotically, without taking into account the system's condition, without being able to accomplish the system's global goal. Coordination insures the fact that each problem of the main goal is included in the activity of an agent and that all agents schedule their behavior so that they accomplish the problem assigned to them [9].

2.1. Coordination techniques

Following research regarding the mode of coordination strategies creation in multiagent systems, different techniques, protocols and mechanisms, used for coordination creation, have resulted. In [3] the following techniques for creation of coordination are presented: organizational structuring, contracting, Contract Net Protocol, multi-agent planning, negotiation, auctions for resolving conflicts, market-oriented programming, coalition formation in coordination, argumentation in coordination. Besides these techniques have been developed also adaptive learning techniques. These solve the problem of learning coordination rules, integration of learning aspects such as trust and reputation in order to facilitate coordination.

Communication between agents can represent an important factor in creating their coordination. An advantage of this approach is represented by the fact that agents do not need to predict the actions of the other agents [12]. Communication in a

multi-agent system is made using special languages named ACL (*Agent Communication Languages*). The most common are KQML (Knowledge Query Manipulation Language) [7] and FIPA ACL [4].

2.2. Coordination criteria

In order to be able to analyze the performance of a coordination mechanism, in [3] citing [8] the following criteria are presented: predictivity (the ability to determine the future state of the agents and the environment), adaptability (the ability to cope with new situations or unpredicted events), action control (can be centralized or decentralized, in function of the level where the tasks for each agent are established), communication mode (this can be accomplished through interaction, perception, or direct communication in the case when the coordination is based on communication), conflicts (the ability to avoid conflicts or the ability to solve them), information exchange, agents (these are homogeneous or heterogeneous but they must be capable), applications, advantages, disadvantages.

3. Real-Time Coordination Strategies in Traffic Control Applications

In the case of a multi-agent system, in order to establish the best coordination of the agents and their decisions in order to be the closest to the optimal decisions, a very good knowing of the environment is required by every agent and a good knowledge of each agent's activities is required. In the majority of situations, the systems are dynamic, each agent being obliged to adapt his behavior to the actual state of the system. In these cases it becomes important that the coordination strategies are being realised in real time, making a good adaptation to new situations or unpredicted events.

The time in which an agent reconfigures its behavior in regard to the activities of the other agents and the environment, must be as short as possible. The factors influencing this time are: communication between agents (in case the strategy is based on communication), environment perception, the time in which the agents take their own decisions, the negotiation process between agents etc.

3.1. Related work

In literature different multi-agent systems architectures are presented that are used in traffic control. These propose different coordination strategies for agents with the goal to avoid traffic jams in order to reduce the time spent by the drivers in traffic.

A car coordination mechanism (used to reduce the time spent in traffic, the driven distance, the number of turns, also used to minimize free flow to link velocity ratio, volume to capacity ratio) is presented in [1]. The mechanism used to coordinate the agents that create the routes, the agents that monitor and predict the length of the standing queue, its size, and the departure rate, is negotiation. The negotiation is mediated by another agent that attributes path different utility values.

In [6] is presented the coordination of agents in intersections. 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. Communication between agents is made based on a protocol that establishes the structure of the messages sent in the system. The sent messages have a defined structure for each agent (the request for creation of a reservation, change, cancellation etc. and the actions which the car should make).

Another approach for crossroads control is to control the time intervals for the traffic light so that the cars time of passage through the intersection is the smallest. The techniques used in [2] to establish such a control are game theory and reinforcement learning.

3.2. Proposed strategy coordination

The goal of the strategy coordination proposed is to realise the control of cars from a distribution company for various materials, food etc. The delivery agents' paths must be configured in order that every client is served in the established time interval.

To the multi-agent system architecture proposed in [5] a delivery agent was added, that realises the initialization of the routes for all agents. Not all materials that must be delivered are in the same depot. That is why the initial route calculation limits to a multi-depot vehicle routing problem with time windows. After creation of initial routes each agent takes his own decisions in order to deliver all attributed products in the established time intervals.

The decisions of each agent that delivers products are realised according to the state of the system. The state of the system is watched real time by the Incident Detection Agent. It informs the delivery agents about the actual state of the system, they being able to recalculate new routes, so that the delivery time intervals are respected.

As following the way for information exchange in the multi-agent systems as well as the agent's decision making process are presented.

• Communication

The important goal in establishing a coordination strategy based on communi-

cation between agents is to reduce the number of messages exchanged in the system. This because a great number of messages drives to a system overhead.

Communication in the proposed multi-agent system is made based on events. In an event based system the reduction of component connectivity is accomplished, conducting to each component independence.

In order to realize the event processing in the system and to detect the incidents that appear in traffic, in real time, the technology used for modelling the Incident Detection Agent is CEP. This technology realises the event association with the time when the event occurred, correlating simple events so that complex events are resulted. Complex events which resulted are those that signal the occurrence of incidents in traffic such as: accidents, traffic jams etc. Incidents are signalled in real time, the CEP engine insuring a bigger throughput.

Agents that deliver products receive only these complex events, other information not being necessary in order to have knowledge of the traffic situation.

• Local agent scheduling

Scheduling represents an important applications field for CSP. Using variables and constraints for modeling scheduling problems, a good flexibility of problem representation and a good power of reasoning is achieved [11].

It is not recommended to use techniques which generate an optimal solution for solving scheduling problems. The optimal solution obtained with such techniques may not correspond to the actual best solution of the problem and also the time required for finding the solution tends in increase consistently (the majority of problems being NP-hard). In addition, the environment is most of the times dynamic

requiring fast reaction times limiting the available time for optimal solution finding.

Route scheduling is done at Agent Delivery level as well as at each agent level.

At Agent Delivery level route scheduling for all agents is realised, and is done only at the route initialisation, based on time intervals at which the goods must be delivered to the clients and the costs of each street.

At each mobile agent level, the route scheduling is done only at the moment when on a street that is part of the route an incident appears. Based on the new street costs the rerouting is established.

• Strategy Implementation

The multi-agent system was simulated using the CoReMo platform. The CoReMo Platform was developed with the goal of providing real-time scheduling in event-driven mobile agents applications. CoReMo is a simulation platform based on Repast [10], a multi-agent system simulation framework.

The road network is represented with a graph. Each of the arcs has a cost associated to it. The arc costs represent the approximation of the time needed to pass through them.

On the market a lot of suppliers and specialists emerged who develop CEP platforms. From these platforms the Esper [14] engine was selected in order to create the real-time detection of incidents that appear in traffic.

The Esper CEP is written in Java and uses EPL (*Event Processing Language*) as an event processing language. EPL is an optimized language for dealing with high frequency time-based event data. EPL is a SQL-like language that provides the possibility to express filtering, aggregation, joins or sliding windows. It also provides a semantics pattern to express complex

temporal causality among events. An example of such a temporal causality is the "followed by" relationship.

Complex events, signalled by the Incident Detection Agent, show the apparition of traffic jams. This is done through comparing the link density with a standard density. In case when the density of a street is greater than the standard density, the cost of that street will increase.

The new street costs are sent to the agents whose routes contain the streets on which incidents were detected. Based on these costs each agent must reconfigure their behaviour (change the route), so that the goods are delivered according with the established arrival time at the clients.

The road network represents entry data for the scheduling algorithm. Because transcribing the whole road network as entry data is not feasible as it is extensively time consuming it was necessary to obtain a simplified graph, derived from the one describing the road network.

The nodes of the simplified graph consist only of the starting depot, the destination depot and the clients. The graphs arcs represent the most cost effective connections between depots and every client and the connections between all clients.

The constraint programming solver in which the application was implemented is Choco [13]. The Choco solver was chosen because it is a Java open-source constraint programming library. It is built based on an event-based propagation mechanism with backtrack able structures. It can manipulate a great number of variables. In this library over 70 constraints are defined.

The time in which the initial routes are generated is in the order of seconds varying based on the number of depots, agents and clients. The time in which new routes are generated at each agent's level is less than a second, which makes the agents decisions being considered to be made in real time.

• Strategy Evaluation

The goal of the strategy presented in this article is that the agents cope with unpredicted events occurring in the system. The agents, based on the real-time incidents occurred in traffic, reconfigure their behaviour so that they respect the tasks given to them (delivering the goods to the clients in the established time interval).

The control is a distributed control because the decision to change the agents' behaviour is made at each agent level. Even if the incidents detection is done globally, the decision remains local. Only the route initialisation is done at a centralized level by the Delivery Agent.

Agent communication is made based on events, conducting to a decrease of exchanged messages in the system. This decrease is possible because detecting incidents is done globally and the agents receive only events that signal the occurrence of incidents. Agents do not communicate per say, but the messages transmitted in the system are of environment perception.

The conflicts are avoided through this strategy by agents avoiding the incidents occurred in traffic, scheduling new routes.

This strategy is not a predictive strategy because the agents' behaviour is influenced only by the events detected in real-time. There is no database containing data regarding events occurred in traffic in previous days.

4. Conclusion

Coordination in a multi-agent system is extremely important. Through coordination it is ensured that the agents accomplish the global system goal. Coordination can be realised through many techniques. The coordination strategy presented in this article is evaluated based on the evaluation criteria of a strategy. The application in which this coordination is proposed is an application for

traffic control (scenario for goods delivery to clients in certain time intervals). The strategy is real-time strategy. The advantages of this strategy are that the agents are more reactive to new situations occurred in traffic and unpredicted events, distributed control, decreased volume of transmitted information in the system, conflict avoidance.

Acknowledgements

References

1. Adler, J.L., Satapathy, G., et al.: *A Multi-Agent Approach To Cooperative Traffic Management and Route Guidance*. In: Transportation Research Part B **39** (2005), p. 297-318.

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. Bedrouni, A., Mittu, R., et al.: *Distributed Intelligent Systems. A Coordination Perspective*. Springer, 2009.

4. Bellifemine, F., Bergenti, F., et al.: *JADE - A FIPA-Compliant Agent Framework*. In: Proceedings of 4th International Conference on the Practical Applications of Agents and MultiAgent Systems, London, 1999, p. 97-108.

5. Cobeanu, I., Comnac, V.: *Multi-Agent Systems: Traffic Control Application*. In: Bulletin of the *Transilvania* University of Braşov, Vol. 4 (53) No. 2, Series I, 2011, p. 107-114.

6. Dresner, K., Stone, P.: *A Multiagent Approach to Autonomous Intersection Management*. In: Journal of Artificial Intelligence Research **31** (2008) No. 1, p. 591-656.

7. Finin, T., Labrou, Y., Mayfield, J.: *KQML as an Agent Communication Language*. In: Proceedings of 3rd International Conference on Information and Knowledge Management, Maryland, 1994, p. 456-463.

8. Frozza, R., Alvares L.O.: *Criteria for the Analysis of Coordination in Multi-Agent Applications*. In: LNCS **2315** (2002), p. 433-453.

9. Jennings, N.R.: *Commitments and Conventions: The Foundation of Coordination in Multi-Agent Systems*. In: Knowledge Engineering Review **8** (1993) No. 3, p. 1-54.

10. North, M.J., Collier, N.T., Vos, J.R.: *Experiences Creating Tree Implementations on the Repast Agent Modeling Toolkit*. In: ACM Transactions on Modeling and Computer Simulation **16** (2006) No. 1, p. 1-25.

11. Policella, N., Cesta, A., et al.: *From Precedence Constraint Posting to Partial Order Schedules: A CSP Approach to Robust Scheduling*. In: Journal AI Communications - Constraint Programming for Planning and Scheduling **20** (2007) Issue 3, p. 163-180.

12. Vlassis, N.: *A Concise Introduction to Multiagent Systems and Distributed Artificial Intelligence*. In: Synthesis Lectures on Artificial Intelligence and Machine Learning **1** (2007) No. 1, p. 1-71.

13. *** *Choco*. Available at: http://www.emn.fr/z-info/chocosolver/. Accessed: 10.01.2012.

14. *** *EsperTech, Reference Documentation*. Available at: http://esper.codehaus.org/. Accessed: 22.10.2011.