An Urban Traffic Control System Based on Mobile Multi-Agents

Zhenjiang Li, Fei-Yue Wang, *Fellow, IEEE,* Qinghai Miao, and Feng He

***Abstract*—This paper presents an urban traffic control system using the multi-agent technology, called aDAPTS for agent-based Distributed and Adaptive Platform for Transportation Systems. Based on the proposed system architecture, we divide an urban traffic system into five different functional modules and define five types of agents correspondingly. The composition and structure of each agent is discussed in detail and the correlation among them is addressed. Methods for verification and validation in artificial transportation systems are also studied in this paper.**

***Index Terms*—Urban Traffic, Signal Control, Agent Control, Artificial Transportation System**

I. Introduction

After entering the 21st century, the urbanization process of the world is getting faster and faster. With the expanse of city size and the increase of vehicle number, congestion, pollution, accident and many other problems are produced. These problems are getting more and more attention and become a large challenge to urban traffic control and management.

As the status and environment of urban traffic change rapidly and uncertainly, it is difficult to implement the urban traffic control and management only using the fixed model and single control method. The urban traffic system is a highly distributed complex system. If we use the centralized control method, huge data transmission is required and strong data processing ability is requested. So it is difficult to implement effective and timely control. Using distributed control method, the coordination and collaboration among subsystems is insufficient. It will cause many bad integrated control effects.

The multi-agent system is a new field of computer science. It was produced with the trend of ubiquitous, connection, intelligence, agent and humanity in the development of computing technology [1]. It provides a good method to implement the control of complex distributed system. Agent is a hardware or software-based computer system in a certain environment. Generally, agent enjoys the following properties: autonomy, social ability, reactivity and pro-activeness [2]. Agent can get the environment information and adopt corresponding action to realize its own design goal. At the same time, agent can cooperate and communicate with other agents and realize the global design goal. Mobile agents are special software objects that are autonomous and have the ability to migrate from one node to another node, carrying logic and data, performing actions on behalf of the user[26]. Urban traffic control has geographically distributed nature and alternating busy-idle operating characteristics, so it is well suited to an agent-based approach [3].

Based on mobile multi-agent technology, we presents an urban traffic control system called aDAPTS (agent-based Distributed and Adaptive Platform for Transportation Systems). The rest of this paper is organized as follows: section Ⅱ proposes a theoretical framework and system architecture for aDAPTS; section Ⅲ discusses the function and structure of agents in aDAPTS; section Ⅳ discusses the software and hardware platform for the system separately; the last section studies the verification and validation methods in artificial transportation systems.

II. A System Architecture for Agent-based Traffic Control

The urban traffic system is a typical distributed control system, which makes its control architecture be distributed. The whole system is divided into several levels and every level executes different control tasks. The control module in every level communicates not only with the module in the high level but also with other modules in the same level. The whole system is described as a network control structure. To this end, we can divide the urban traffic control system into three levels: *organization, coordination, and execution* using the hierarchical architecture developed for intelligent

Manuscript received September 15, 2006. This work was supported in part by a Key Program (60334020) and a General Program (60504025) of the National Natural Science Foundation of China, a Key Sci-Tech Project of Shandong Province (2004GG1104001), a Doctoral Fund (2005006) and the Key Project (2004029) of Shandong Academy of Sciences, and the Open Project Research of the Key Laboratory of Complex Systems and Intelligence Sciences, Chinese Academy of Sciences (20050101).

Zhenjiang Li is with the Key Laboratory of Complex Systems and Intelligence Science, Institute of Automation, Chinese Academy of Sciences, CO 100080 Beijing, P. R. China (corresponding author, phone: 86-10-62554288; fax: 86-10-62548183; e-mail: lzjwhb@gmail.com).

F.-Y. Wang is with the Key Laboratory for Complex Systems and Intelligence Science, Chinese Academy of Sciences, Beijing, China and the Program for Advanced Research in Complex Systems, Department of Systems and Industrial Engineering, University of Arizona, Tucson, AZ 85719, USA. (e-mail: feiyue@sie.arizona.edu).

Qinghai Miao is with the Key Laboratory of Complex Systems and Intelligence Science, Institute of Automation, Chinese Academy of Sciences, CO 100080 Beijing, P. R. China (e-mail: miaoqh@gmail.com).

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control system [4].

In this paper, we divide the components of the traffic control system into several agents: intersection agent, ramp agent, road agent, area agent, and city agent. Intersection agent, ramp agent and road agent locate in the bottom level of the control system. They are the controller of traffic devices and the collector of traffic information. Area agent coordinates the collection of road information and the control of intersection and ramp signal in a certain area. It is the coordination level of the control system. City agent is the global traffic control center and the organization level of the control system. Figure 1 illustrates the architecture of urban traffic control system based on multi-agents.

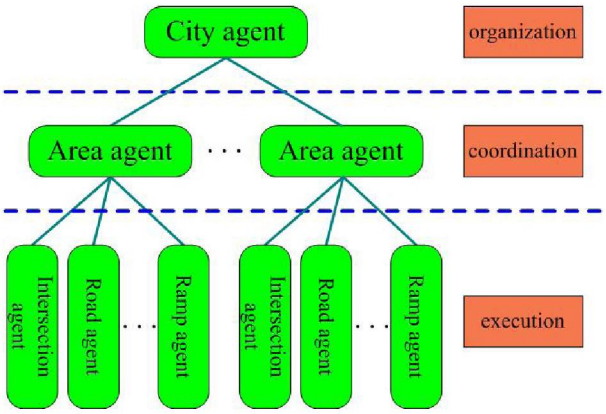

Figure 1. The architecture of urban traffic control system based on multi-agents

City agent and many area agents are connected through WANs. Each area agent and intersection agents, road agents, ramp agents in the area are connected through LANs. When WANs are disconnected or not working, area agent as the regional traffic control center can coordinate traffic detection and control in the area. When LANs are disconnected or not working, intersection agent, ramp agent, and road agent can execute their own tasks separately.

Those intersection agents and ramp agents with high performance controller can improve their own control ability. *Application-specific operating systems* (ASOSs) will be the key to effective, reliable real-time traffic operations on them. The implementation of many intelligent and complex control algorithms can improve the control effect greatly.

For those intersection agents and ramp agents with low performance controller, the corresponding area agent and city agent can perform reasoning and planning for task sequences and produce software control agents and dispatch them to the execution level. By using simple strategies for local implementation while keeping complex facilities for remote enhancement, the "local simple, remote complex" design of networked systems is implemented [5].

III. Function and Structure of Agents in The System

As described in section Ⅱ, there are five types of agents in the traffic control system. In this section, we will discuss their functions and structures one by one.

Intersection agent: it is the executor of road traffic control. When the network is connected, it communicates with area agent, local road agent, and intersection agents nearby, and then it makes the control strategy and executes. When the network is disconnected, it ensures the intersection signal control through the default control strategy.

Figure 2 shows the structure of intersection agent. Decision-making module produces the intersection control strategy based on the traffic environment information getting from road agent and the control strategy downloading from area agent. It also cooperates with intersection agents nearby. Control module transforms the control strategy into control signal and acts on the traffic environment. Communication module performs information transmission with other agents. When intersection agent loses the communication with area agent, it can produce the control strategy with the local detecting data sent by road agent and its own default strategy.

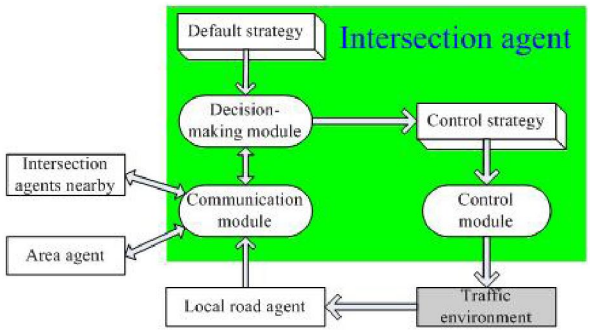

Figure 2. The structure of intersection agent

Ramp agent: nowadays urban expressway occupies most of traffic volume in many big cities and efficient ramp metering control methods are urgently needed. Ramp agent controls the entrance and exit ramp of urban expressway. It has the similar structure with intersection agent. Communication module performs information transmission with road agent, area agent and other ramp agents. Based on the information of expressway, the decision-making module produces ramp metering control strategy through its own learning mechanism. At the same time, it coordinates with other ramp agents and guarantees the most passing vehicle numbers of urban expressway.

Road agent: it is the collector of road traffic environment information and the promulgator of road guidance information. Road agent gets real-time traffic flow through the detecting devices settled in the intersections and roads. These data are stored and transmitted to area agent and local

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intersection agents. It also can analyze these traffic flow information and produce control requests to the local intersection agents. It receives the traffic guidance information from area agent and sends them to the display devices.

The structure of road agent is showed in figure 3. The detecting module gets the traffic information from many kinds of detecting devices. The decision-making module stores and analyses the traffic data getting from the detecting module. By communicating with local intersection agents or ramp agents, the decision-making module synthesizes the local traffic information and area traffic information, then produces road traffic guidance information. At last, the information releasing module transforms the traffic guidance information into display signal and sends it to display devices settled in the road.

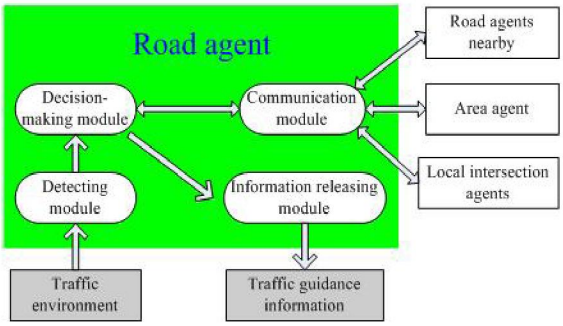

Figure 3. The structure of road agent

Area agent: it is the supervisor of all intersection agents, ramp agents, and road agents in an area. It obtains traffic status information from road agents and traffic control information from intersection agents or ramp agents. Based on short-time forecasting of area traffic flow and its own learning and reasoning mechanism, area agent produces control strategy of every intersection agent or ramp agent. It also produces traffic guidance information of every road agent. These control strategies and guidance information are deployed to the appropriate executor through LANs as software control agents on a control-on-demand basis. An area agent also communicates with other area agents and city agent through WANs.

As showed in fig. 4, area agent is composed of four modules: communication module, decision-making module, forecast module, and learning module. Communication module realizes the data transmission based on specific protocol. Forecast module implements short-time traffic flow forecasting based on the detecting information and sends the forecast results to decision-making module. Decision-making module then makes the control & guidance strategies. Learning module updates the parameters of decision-making module.

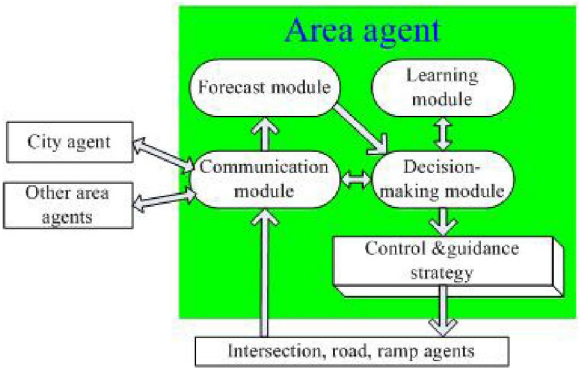

Figure 4. The structure of area agent

City agent: it is the global traffic operation center of the city. It collects and analyzes the traffic status information sent by area agents. City agent accomplishes complex computing, learning, optimizing, and updating. It also makes long-time forecasting of the whole city traffic flow and divides the city areas dynamically.

IV. SOFTWARE AND HARDWARE PLATFORM FOR ADAPTS

In order to implement the function of every agent in agent-based traffic control system, we need to build a software platform for aDAPTS. City agent as the control center and the coordinator of all area agents should provide these functions: a control agent naming service, a control agent factory, a control agent repository, performance management, etc [3]. As discussed in previous sections, control algorithms are decomposed into many simple task-oriented control agents distributed over a network. An area agent is the dispatcher and arbitrator of these control agents. For every area agent, we build a local gateway and coordinator which works as a local network communication gateway and coordinates local control agents. The application software embedded in intersection agents and ramp agents can download control agents from corresponding area agent through LAN. The architecture of the software platform is described in figure 5.

In the proposed three-level system architecture, those agents in execution layer maybe adopt different hardware and software. In order to make them operate corporately, we must provide a coherent mechanism. CORBA (Common Object Request Broker Architecture) provides a normal framework for objects in a heterogeneous, distributed environment to interoperate. Although CORBA provides a middleware for traffic execution agents to coordinate and communication, the object in it is static. We can combine mobile-agent programming and CORBA together to implement the control agents to migrate from remote traffic centers to field traffic control devices or from one device to another.

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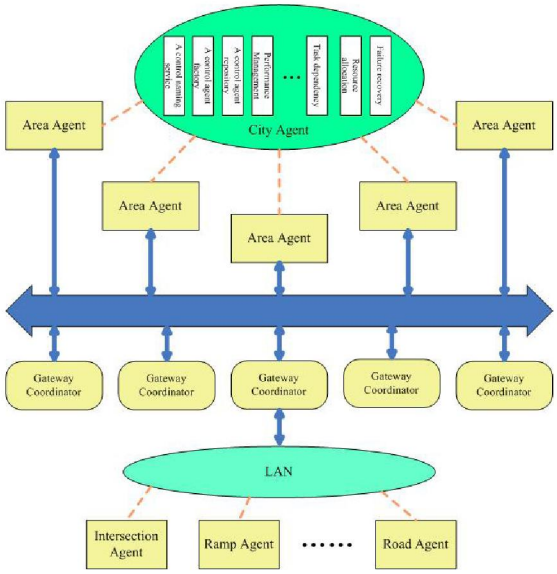

Figure 5. The architecture of software platform for aDAPTS

There exists an increasing problem in software development: The large number of configurations that need to be developed and maintained. If third parties want to develop and provide traffic agents for services, they need to complete these configurations and the time-to-market is long. So we adopt OSGI as the operation protocol for agent-based control. OSGI (Open Services Gateway Initiative) are specifications which define a standardized, component oriented, computing environment for networked services. The main component of OSGI architecture is the service gateway. It can connect many sorts of smart devices and enable them to seamlessly communicate with each other or to receive a variety of services from providers. As a result, devices and modules with OSGI architectures can be applied directly to agent-based control for networked traffic.

Besides the software platform, we also need to build a hardware platform for remote programmable and configurable traffic devices. We use PC-based workstation with Linux operation system and JVM (Java Virtual Machine) as the hardware platform. All sorts of traffic devices such as traffic signal controller, loop detector, video detector, etc. are connected to this platform through LANs. These hardware platforms then communicate with remote server through WANs. Figure 6 illustrates the hardware network for aDAPTS.

V. Verification and Validation Methods in Artificial Transportation Systems

There exist many difficulties in testing and validating an urban traffic control system based on multi-agents. Field experiment is the most direct and efficient method, however, due to the complexity and particularity of urban traffic systems, this method needs a great deal of money and time. Moreover, it may bring bad effects to urban traffic. As a result, the feasibility of this method is low. Theory analysis can illuminate the performance of the system at a certain extent, but because of lacking for practical data, it has low reliability.

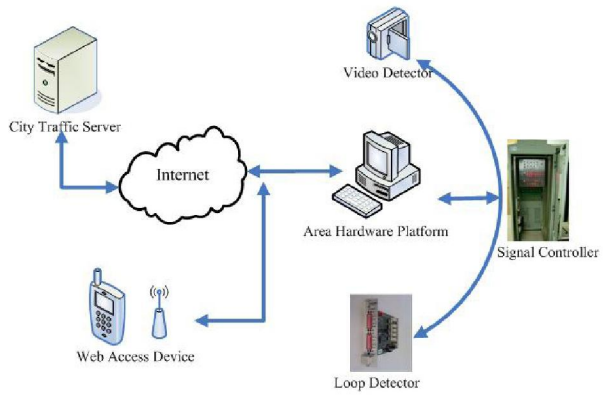

Figure 6. The hardware network for aDAPTS

In order to solve these difficulties, professor Fei-Yue Wang presented the concept of artificial transportation system [6] [7]. The main idea is to use the theories and methods of artificial society and upgrade traffic simulation method to higher level and wider perspective. Using mainframe and agent-based programming technologies, we can "develop" and "cultivate" transportation systems. In artificial transportation system, we can test the traffic system conveniently and repeatedly without any cost. As the test can be done before installing the real system, it can provide objective, comprehensive, and reliable information for evaluation and improvement of traffic systems in time.

Agent-oriented programming is the main technology used in developing artificial transportation system. An artificial transportation system is usually consists of the following three parts [8] [9] [10]:

1) ***Agents***
   Agents themselves can be man, vehicle, device, traffic rule, etc., involved in the transportation system. They all have their own internal status, behavior rules, thinking methods, grow process, and life cycles. They can interact with environment and adjust these characteristics according to the responds of the interactions.
2) ***Environments***
   Environments are the space where all kinds of agents live and active. They can correspond to both real transportation environment and some test conditions, which are in the form of virtual mathematical or computing processes. The environments are often represented as the spaces and the connected network or grid for agents to store goods, enact the regulations, interact with each other, etc.

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3) *Regulations*

Regulations specify the rules and steps to be followed when agents act and interact with the environment. The governed areas range from simple intersections control and driver behavior to complex area traffic flow coordination, logistics planning, transportation investment and construction, and the influences between the transportation and its environment.

Thus it can be seen that the functional agents in traffic control system presented in this paper are the basic components of the artificial transportation system. In order to test and validate the traffic control system in the artificial transportation system, the first step is to model these agents. Adopting the agent-oriented programming method and utilizing many existing agent development tools, these agents can be created easily. In this paper, we use JADE (Java Agent Development Framework) as the agent development tool. JADE is a software framework fully implemented in the Java language. It simplifies the implementation of multi-agent systems through a middle-ware that complies with the FIPA specifications and through a set of graphical tools that supports the debugging and deployment phases [11] [12]. Figure 6 is the architecture of a generic JADE agent [13].

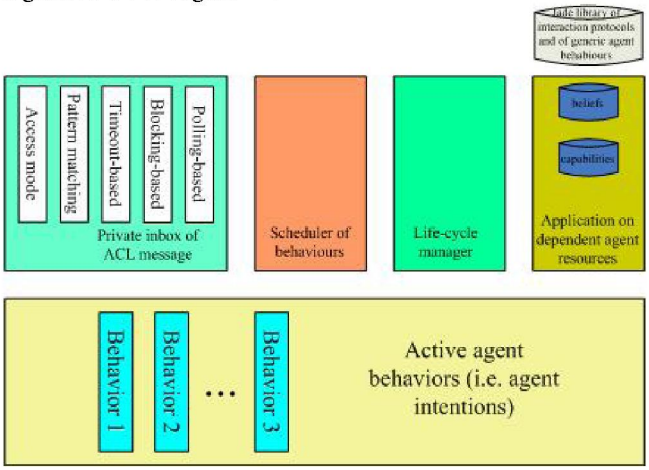

Figure6. The architecture of a generic JADE agent

We take intersection agent as an example and describe its creating process. Firstly, the intersection agent is created by extending the *jade.core.Agent* class and redefining the *setup ()* method. Each agent instance is identified by an AID (*jade.core.AID*).

```
import jade.core.Agent
public class IntersectionAgent extends Agent {
  protected void setup () {
    System.out.println ("Agent "+getLocalName () +"
started.") ;} ……
    }
```

Secondly, the agent's behaviors are created by extending the *jade.core.behaviours.Behabiour* class. The behaviors of the agent are divided into three types: "one shot" behaviors, "cyclic" behaviors, and "complex" behaviors. The main task of an intersection agent is controlling the traffic signal periodically. So its *action ()* method executes the same operation in every cycle. Besides this, the intersection agent has many other tasks such as coordinating with other agents, making control strategies, changing control algorithms, and so on. These tasks are complex behaviors embedded a state and their *action ()* method executes different operations depending on their state.

Lastly, the communication mechanism among agents is defined. The communication model in JADE is based on asynchronous message passing and message format is defined by the ACL language (FIPA). Message exchanged by agents are instances of the *jade.lang.acl.ACLMessage* class. For example, the road agent sends a traffic flow message to intersection agent. It is as simple as creating an *ACLMessage* object and calling the *send ()* method of the *Agent* class.

```
ACLMessage msg = new ACLMessage
(ACLMessage.INFORM);
msg.addReceiver (new AID (Intersection,
AID.ISLOCALNAME));
msg.setLanguage ("English");
msg.setOntology
("Traffic-Information-Ontology");
msg.setContent ("vehicle number is 15");
send (msg);
```

JADE provides many advanced functions such as managing content expressions, interaction protocols, mobility, security, and so on. We can use these functions based on the actual requirements of the functional agents in urban traffic control system.

Because of the modeling method of the artificial transportation system is also based on agent-oriented programming, the functional agents created by JADE can be added in artificial transportation system easily. The environment information can be sent to these agents through message based on the ACL language. In this way, the traffic control system and artificial transportation system are integrated together. The validity and performance of the traffic control system based on multi-agents can be tested and validated.

VI. Conclusion and Future Work

On the basis of mobile multi-agent technology, this paper proposed a hierarchical architecture of the urban traffic control system. Five types of agents are described and structured elaborately. The software and hardware platform are built and discussed. The method of creating agents using

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JADE is given, then the qualitative validation and quantitative evaluation of the traffic control system in the artificial transportation system can be implemented. At present, the research of artificial transportation system is in the starting stage and the application of multi-agent technology in the traffic control system is still in the theory level. With the development and improvement of artificial transportation system, validating the feasibility and reliability of traffic control system based on multi-agents forwardly and taking it into actual use are the research emphases in the future.

ACKNOWLEDGMENT

This work was supported in part by a Key Program (60334020) and a General Program (60504025) of the National Natural Science Foundation of China, a Key Sci-Tech Project of Shandong Province (2004GG1104001), a Doctoral Fund (2005006) and the Key Project (2004029) of Shandong Academy of Sciences, and the Open Project Research of the Key Laboratory of Complex Systems and Intelligence Sciences, Chinese Academy of Sciences (20050101). Especially, we thank Professor Fei-Yue Wang for his support and useful suggestions to this work.

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