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Modeling and Analysis of Artificial Transportation System Based on Multi-agent Technology

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Abstract—**This paper presents the multi-agent architecture for artificial transportation system. In this architecture, Petri net is used as basic model to represent agents. At an intersection, the agents are divided into two groups: one for the traffic-signal and the other for the vehicle flow, which are integrated to represent the behavior of this intersection. In addition, those agents can be used as the modularity to represent urban network of more scale. To coordinate different intersection agents, game theory is used to design coordination strategy between agents. The iterated elimination of strictly dominated strategies algorithm is presented to find Nash equilibrium.**

Index Terms—**Multi-agent technology, Petri net, Game theory, Agent coordination, Artificial transportation.**

I. Introduction

ARTIFICIAL Transportation Systems(ATS) is a natural extension of computer simulations for the analysis and evaluation of transportation systems[1]. The main idea is to integrate various transportation models into artificial transportation environments based on distributed network computing, and to operate the systems in a multi-participator manner for transportation analysis, evaluation, decision making and training. Modeling, computing, experimenting and decision-making are four main issues which cover the fields of multi-agent modeling, P2P/Grid computing, methods developed in complex systems and parallel systems. Among these issues, modeling is the first and fundamental one to the whole system. Thanks to the development of distributed artificial intelligence, we can use agent modeling technology and multi-agent systems theory to address this issue in ATS. In deed, agent based control and multi-agent coordination have been widely discussed and used to study real traffic problems [2].

Multi-agent system theory and technology have been used in variant application including manufacturing, robot soccer, network traffic management, agent based libraries management, WWW information filter, network routing and many other fields. The design process can be divided into three steps: specification, analysis and verification, and implementation. Currently, much research work focuses on using formal tool for agent system specification. In [3], d'Inverno and Luck used formal language Z to provide a framework for describing the agent architecture at different abstract levels. In [4], Fisher used temporal logics and multimodal logics to represent individual agent behaviors where the representations can be executed directly. Xu and his colleagues used Predicate/Transiton(Pr/T) nets, which is a high-level formalism of Petri net , to model logical agent mobility [5]. Using G net, Xu Haiping specified the work mechanism of agents [6].

In this paper, we will introduce a multi-agent architecture for artificial transportation system. In this architecture, Petri net model is used as basic model to describe the behavior of traffic-signal and vehicle flow in an intersection. Through this representation, it is easy to develop multi-agent architecture by modularity for urban network. After this representation, we can get the information of vehicle flow in different direct of an intersection. Based on the information, different coordination theory can be designed to promote the transportation performance when including multiple intersections. As a case study, game theory as coordination strategy is presented which is a general coordination strategy based on self-interest [7].

Section II develops the agent model for traffic-signal and vehicle flow. In section III, the relationship between different intersections will be presented and game theory is introduced to coordinate neighboring intersections. Section IV concludes the paper.

II. Agents Model for Traffic-Signal and Vehicle Flow

In [9], structure of intelligent agents is divided into four types: simple reflex agents, agents that keep track of the world, goal-based agents and utility-based agents. The structure of utility-based agents is given in Figure 1.

In this section, Petri net is presented as the basic model to represent the structure of agent. Before introducing those models, it is useful to analyze the behavior of the intersection.

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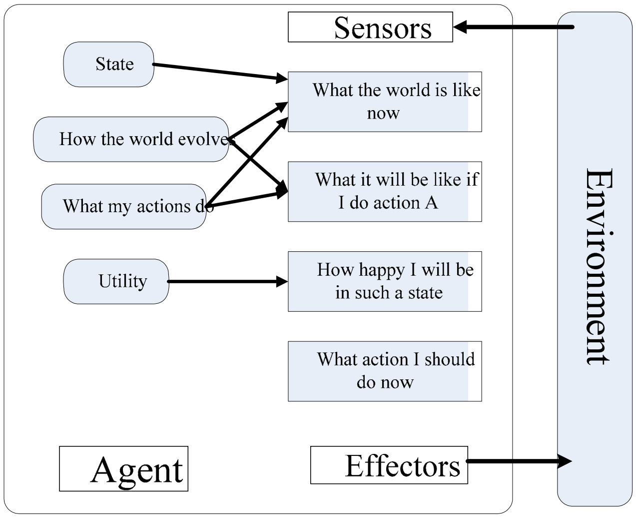

Figure 1. The structure of utility-based agents

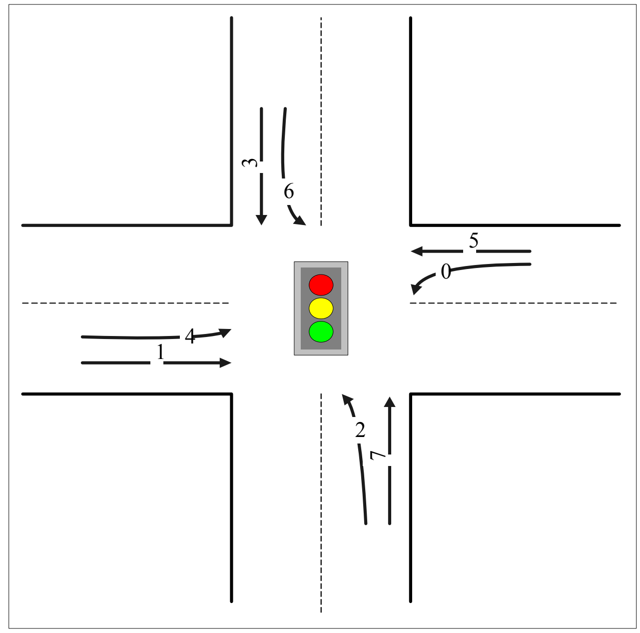

Figure 2. Behavior of the intersection

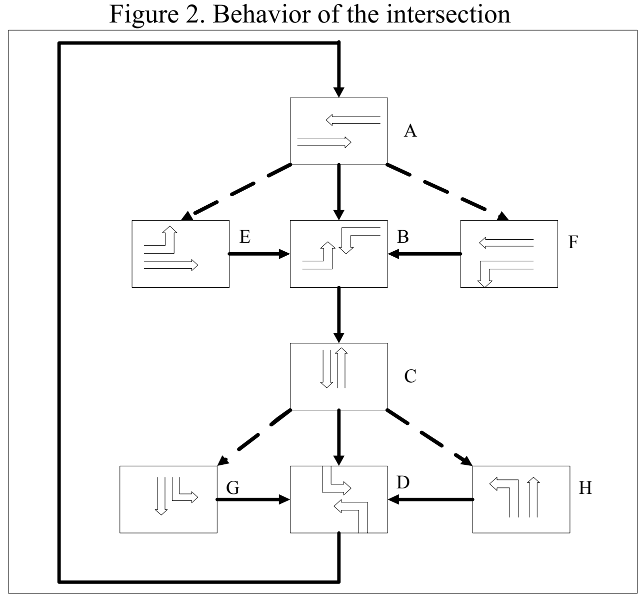

Figure 3. The sequence of phase transition

A. Analysis of Behavior in the Intersection

Figure 2 describes the basic behavior of a classical intersection. Two important terms relate to this intersection: movement and phase. A movement is a specific flow, such as movements 0-7. Movements 1, 3, 5 and 7 are through-right combinations and movement 2, 4, 6 and 8 are left turns. Some movements are pared into a phase. When a phase is selected, all movements relating to this phase get the pass right and those lights for the movement become green, while other lights keep red. For example, in the case of Figure 1, movements 0 and 4 can form phase 0. When phase 0 is selected, the lights for movements 0 and 4 become green and all other lights keep red. Technically, those movements which don't conflict with each other can form phase. This means not only movement 0 can form a phase, but also movements 0 and 5 can form a phase. But it is more efficient when 0 and 5 form a phase. So only eight phases are introduced in Figure 3.

Phase transition can be fixed or changeable. Fixed phase transition can be convenience for drivers, but in some conditions, the passing rate can reduce. For example, according to fixed phase transition, phase B is selected after phase A. If there are more vehicles in movement 5 than in movement 4, it is more efficient to select phase F. So a half-fixed phase transition is given in Figure 3. In normal condition, predefined sequence of phase transitions A-B-C-D-A is selected. If some abnormal conditions discussed above appear, transition sequence A-F-B-C-D-A can be selected.

Half-fixed phase transition can bring addition flexibility when coordinating neighboring intersections is needed. In this context, fixed phase deviation must be kept. But the duration time of phase A in intersection 1 can be different from that in intersection 2 in some cases. In those cases, we can add a phase between phase A and phase B so that $T_1(A)+T_1(F)=T_2(A)$.

B. Agent Model for Traffic-signal

The behavior of an intersection can be divided into two parts: traffic-signal behavior and vehicle behavior. Because of complexity of an intersection's behavior, previous research mainly focused on traffic-signal behavior [10] [11]. In order to describe the relationship between different traffic-signal agents, it is necessary to develop vehicle flow agent because it is the medium of different traffic-signal agents.

Figure 4 shows the Petri net model of a phase in the traffic-signal agent. Once a token is deposited into place GG (Go Green), transition T1 (Start Green) is fired and tokens are deposited into place ST (Start Time), M (Controller signal) and DG (Display Green).

After minimum time, transition T2 (Minimum time) is fired and a token is deposited into place EG (Extend Green) which is the choice condition: choosing next operation from extension and ending the green displaying. Whether extending or ending, a token is deposited into place RG (Reset Green). The token in place RG will remove and a token will be added into place GR (Go Red). Because the moving of the token from RG to GR is related to phase transition, it will be explained in detail when introducing phase transition. Now supposing that a token has been deposited into GR (Go Red), the transition T6 fires and a token is deposited into place SY (Start Yellow). After the yellow time, a token is deposited into place EY (End Yellow) and transition T8 fires which means that the vehicles associated with this direct cannot pass the intersection and the light becomes red.

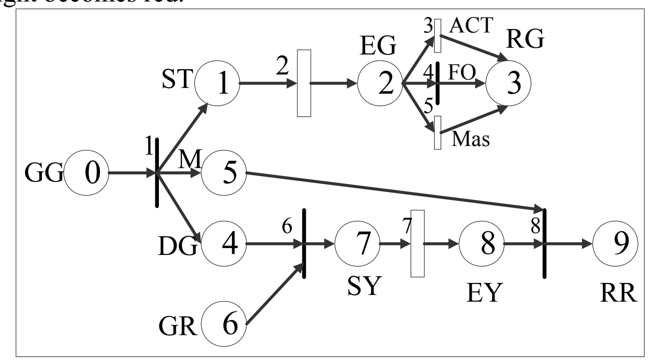

Figure 4. Petri net model for traffic-signal

In [11], phase transition is given. Figure 5 shows the phase transition from A to B and from A to E. In the case from A to B, after the token is deposited into RG, transition T1 moves token from RG1 and RG5 to GR1 and GR5 which ends the time of green and starts yellow of phase A. According transition T2, light 1 and light 5 become red and tokens are deposited into RR1 (Reset Red) and RR5. At this time, light 1 and light 5 become red and other lights have not become green, so the duration time of transition T2 is the time of whole red.

In the case from A to E, because light1 keep green in phase A and E, the process is different from A to B. While light becoming yellow is controlled by GR, light keeping green is controlled by CG (continue green). The token in DG is removed into DG' when phase transition from A to E, which means light 1 keeps green in phase A and E.

In previous descript, it is difficult to describe how to move tokens from GR1 and GR5 to RR1 and RR5. To address this issue, it is necessary to combine Figure 4 to Figure 5(a). The integrated figure of phase transition from A to B is presented in Figure 6. From this figure, it is easy to observe the process from GR1 to RR1.

Figure 4 and Figure 5(b) can not directly be integrated because of coupling among A, E and B. Light 1 always keeps green in phase A and phase E, and light 4 always keeps green in phase E and B. A, E and B must be integrated as whole to describe the process from A to E and from E to B. Figure 7 show this integrated Petri net model. Starting from GG1 in phase A, light 1 keeps green until transition SY1 fires in phase B. The vehicles in movement 1 always keep passing until the end of yellow in phase B. Same situation can be seen in light 4 and movement 4 in phase E and phase B.

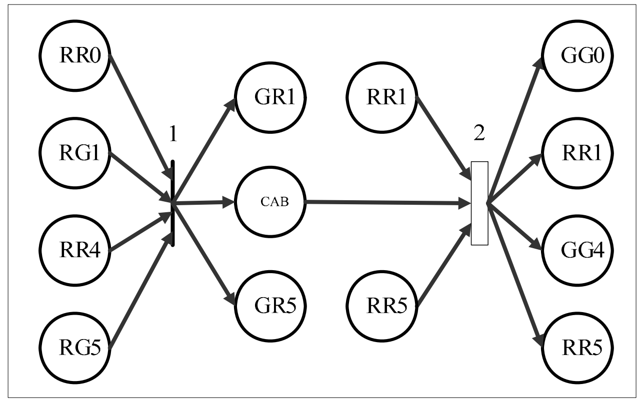

Figure 5(a). Petri net model of phase transition AB

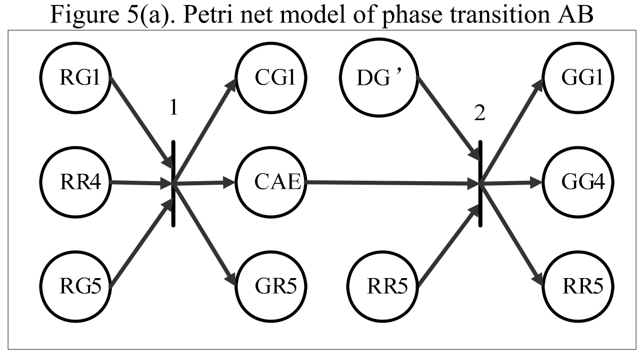

Figure 5(b). Petri net model of phase transition AE

C. Agent Model for Vehicle Flow

In previous part, Petri net for traffic-signal has been presented. Under the control of traffic-signal, vehicles can flow from the east, south, west and north to responding direction. In this section, the Petri net model of agent for vehicle flow is presented. The input vehicles from the east can be divided into two parts: some vehicles move to the south in movement 0 and others move to the west in movement 5 (technically, vehicles from the east can go to other direct including the north and the east). When those vehicles reach the intersection, they are stored in IP0 and IP5 as tokens. If there is a token in M0 or M5, which means light 0 or light 5 is green, the vehicles as tokens move to output place OP_0 or OP_5. After passing the intersection, the tokens in OP_0 combine to OP_3 and the combined vehicles become output vehicles in the south which can become the input vehicles for next intersection.

III. Coordination Mechanism Between Agents

In previous section, Petri nets of agents for traffic-signal and vehicle flow are presented, which describe the behavior of individual intersection. However, an intersection cannot function independent of other intersections. So it is necessary to analyze the interaction among neighboring intersection agents.

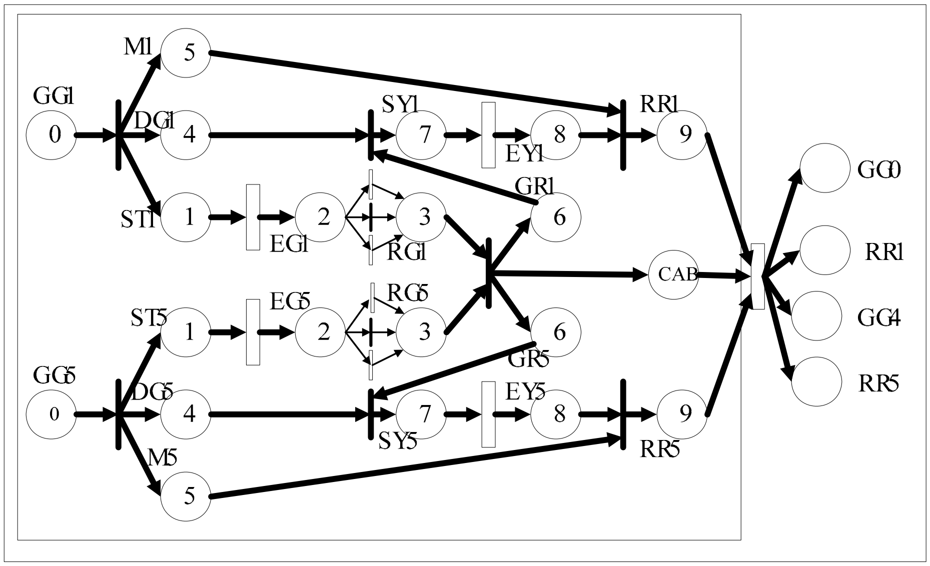

Figure 6. Phase transition from A to B.

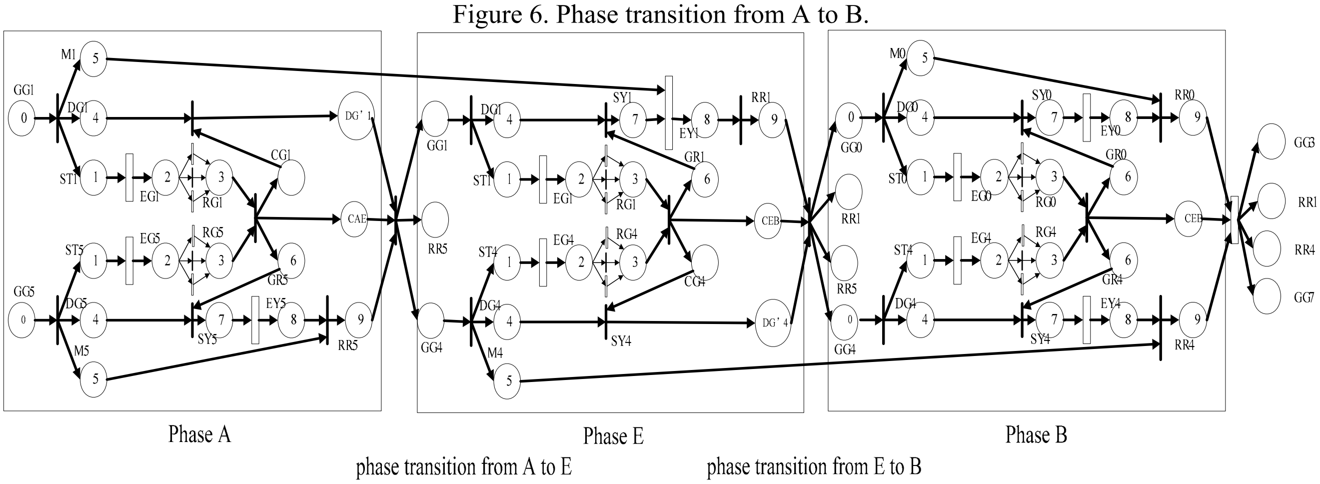

Figure 7. Phase transition from A to E and from E to B.

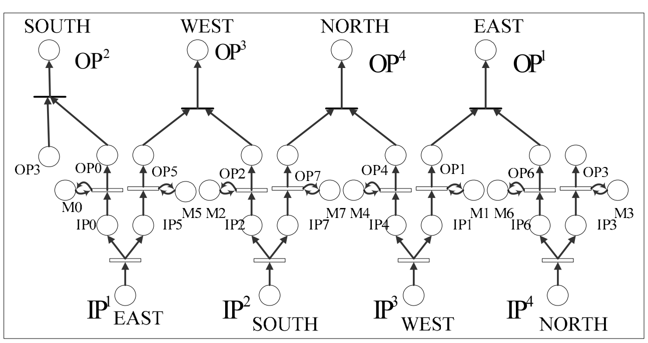

Figure 9. Petri net for vehicle flow

In traffic network including two intersections as showing in Figure 9, output vehicles in east direction of intersection 1 (EAST output OP_1^1) become the input vehicles in west direction of intersection 2 (WEST input IP_2^3). On the other side, input vehicles in east direction of intersection 1 (EAST input IP_1^1) come from the output vehicles in west direction of intersection 2 (WEST output OP_2^3). So, Petri net for different intersection can be integrated to model two intersection agents. Figure 10 shows the whole Petri net for two intersections. According to this way, it is easy to develop Petri net for urban network by modularity.

Based on the information from Petri net model for different agents, all agents can make decision rationally. In this section, the coordination strategy of agents is introduced [8].

Before discuss, some hypothesis are presented:

1. every agent is self-interest;
2. the number of vehicles in every direction is λ except east direction of intersection 1 and west direction of intersection2, and the numbers in east direction of intersection 1 and west direction of intersection2 are zero;
3. in every direction, the passing rate of vehicles is $\alpha(0 \le \alpha \le 1)$

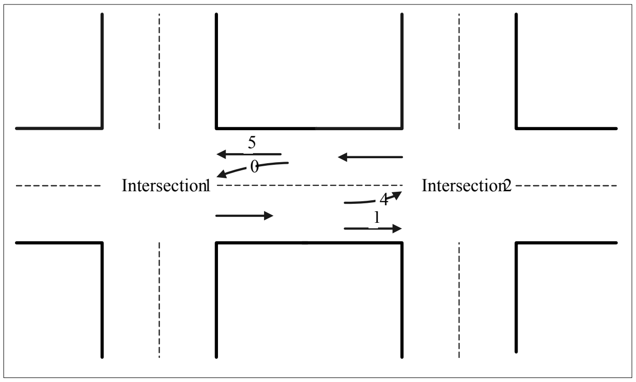

Figure 10. Traffic network including two intersections.

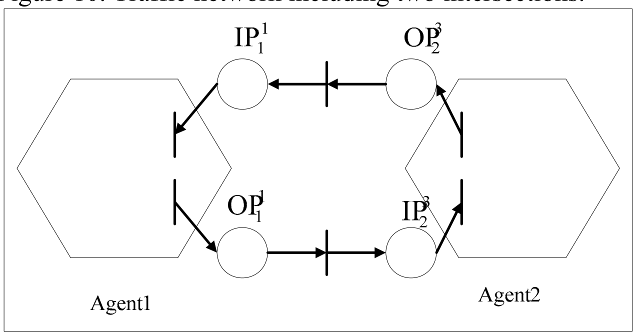

Figure 11. Communication between two traffic-signal agents

When phase A ends, agents for intersection 1 and intersection 2 both have three strategies for next phase: determining which phase is selected in phase E, B and F. According to some computation, the payoff matrix can get:

$$
\begin{array}{cc}
 & \text{Agent 2} \\
 & \begin{array}{ccc} \text{E} & \text{B} & \text{F} \end{array} \\
\text{Agent1} \begin{array}{c} \text{E} \\ \text{B} \\ \text{F} \end{array} & \begin{bmatrix} (2\lambda,3\lambda) & (2\lambda,2\lambda+\alpha\lambda+\alpha^2\lambda) & (2\lambda+\alpha\lambda,2\lambda+\alpha\lambda) \\ (2\lambda+\alpha\lambda,3\lambda) & (2\lambda+\alpha\lambda,2\lambda+\alpha\lambda) & (2\lambda+\alpha\lambda+\alpha^2\lambda,2\lambda) \\ (3\lambda,3\lambda) & (3\lambda,2\lambda+\alpha\lambda+\alpha^2\lambda) & (3\lambda,2\lambda) \end{bmatrix}
\end{array}
$$

Iterated elimination of strictly dominated strategies algorithm is presented to find Nash Equilibrium:

Step1: if there is dominated strategy, go to Step 2, or go to Step 3;

Step2: eliminate dominated strategy, get a new game, and go to Step 1;

Step 3: if current game includes only one strategy profile, this strategy profile is Nash equilibrium.

According to this algorithm, {E, F} can be found to be the Nash equilibrium. This means that the agent of intersection 1 will select phase E and the agent of intersection 2 will select phase F.

IV. Conclusion

In this paper, we present the model of agents for intersection in artificial transportation system. Petri net is used as basic model. Based on the analysis of interactions between neighboring intersections, game theory is presented to coordinate the agents and Nash equilibrium is got through the iterated elimination of strictly dominated strategies algorithm.

This paper's contribution include: 1) Half-fixed phase transition is presented and the corresponding Petri net is developed. 2) The behavior of intersection is divided into traffic-signal behavior and vehicle flow behavior and they are integrated by some interface place to describe the whole behavior. 3) Based on the contribution 2 urban traffic network can be modeled through modularity. 4) Game theory is presented to coordinate different intersection agent and Nash equilibrium is got through the presented algorithm.

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