LARGE SCALE TRAFFIC NETWORK SIMULATION - A HYBRID APPROACH -

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Abstract

In this article an extension of a hybrid model is presented. Up to date, hybrid models offer good theoretical solutions but are not able to simulate real road network. Indeed, all simulation scenarios are done on a hybrid section composed of two macroscopic sections and a microscopic one. The aim of this paper is to adapt the previously developed hybrid model in order to consider a wide area network including many macroscopic and microscopic sections. Thus, a real flow data will be tested and reliability of hybrid model will be proved. After being validated, one can profit from hybrid approach advantages like; combined traffic flow control (microscopic and macroscopic regulation), simulation of wide area network without taking into account the data processing resources, resolve problem of scale representation in the traffic flow domain and so on. This paper present a hybrid approach founded on the paradigm agent. Each section (macroscopic or microscopic) is represented by an agent that communicates with others in order to ensure conservation and continuity principles of traffic flow. To validate this approach, the results of a hybrid section simulation are compared with those of macroscopic section. Thus, we can show that the actual scheme transmits simultaneously the boundary conditions between the coupled models and translates correctly the information at interfaces.

Keywords: Paradigm agent, traffic flow, hybrid approach, simulation.

Presenting Author's Biography

Mohamed Saïd EL HMAM has received his Ph.D. degree in Computer Science and Automatic in December 2006, from the University of Artois in Béthune, France. He is actually Research Engineer with the Computer Science and Automatic Control Laboratory (LGI2A) of University of Artois. His research interests include multiagent systems as simulation tool applied to transportation systems.

1 Introduction

In the transportation field, simulation represents a major tool in decision-making. It offers an efficient way to test the effect of traffic control measurements, to predict the traffic conditions, to study the impact of the infrastructure planning on the vehicles circulation as well as many others. The existing traffic flow simulators are generally based on macroscopic models; well adapted for the global flow representation and mainly used for the traffic control and surveillance, [1], and so on. Or microscopic; which are focused on the individual vehicle behaviors and dedicated to the simulation and the driver's individual behavior study [2], etc. Due to the complexity of the road networks and their size, it seems necessary to take into account the two levels of representation [3]. In this context, our previous work [4] shows that it is possible to implement a hybrid simulator based on the joint use of a microscopic model founded on agent paradigm [5] and different kinds of macroscopic models. Nevertheless, the crucial problem to solve when designing hybrid scheme is to ensure the continuity of information as well as flow conservation. Theses criteria have been already fulfilled in our previous work. Moreover, models proposed to date [6], Poshinger [7] and Bourrel [8] don't consider more than three sections in the hybrid model, their approach is a first step to introduce hybrid model. In this article we generalize the developed hybrid model in order to simulate a wide-area road network. The final objective is to guarantee an optimal traffic regulation in the urban networks using the long term prediction, without taking into account the data processing resources. There are several others important advantages; analysis of the impact of a microscopic regulation on the remainder studied network [9], the prediction with more precision of the traffic flow state, etc.

This paper presents the first step to simulate wide area network on the basis of hybrid model, the second one that include combined regulation of traffic flow still being under development. The first section of this paper presents a model proposed and outlines the role of each simulation agent. The validation method is then described and some preliminary results are presented.

2 The proposed hybrid model

In the framework of the developed hybrid model, a road network is considered as a set of inter-connected road sections. A road section can be, according to the kind of applied model; macroscopic or microscopic. Each section consists in a set of lanes in which a number of vehicles circulate. When several sections cross, they form intersections, which can have a traffic signal or road sign (priority panel). To reach its destination, a vehicle follows its displacement road plan and adopts variable speed respecting Highway Code. The figure (Fig. 1) presents a simplified scheme of road network composed of intersections, on-ramp and off-ramp elements, and multilane sections on which the vehicles circulate.

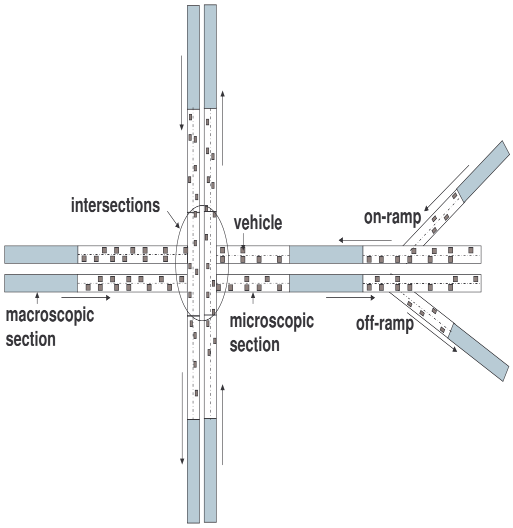

Fig. 1 Road network

The proposed simulation model rests on the use of four reactive agents distributed within three levels as depicted in the diagram (Fig.2).

Each agent represents an abstraction of one road network entity. The agent vehicle characterizes the system (vehicle, car); and constitutes the base level of agent simulation. The intermediate level contains the agents "microSection" and "macroSection" that represent respectively road section studied with the microscopic model and road section viewed at the macroscopic level. All those agents have the same life cycle (Fig.3) in order to implement a homogenous system more easily.

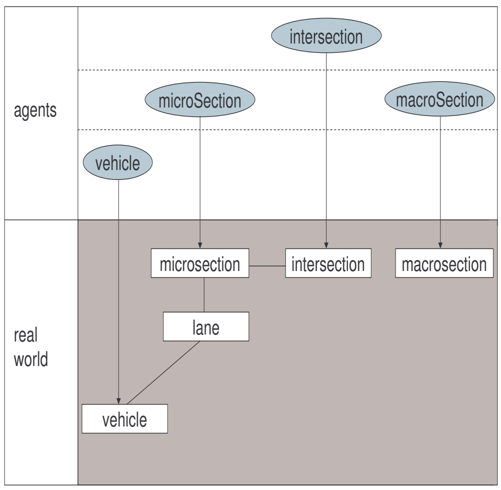

Fig. 2 Simulation agents

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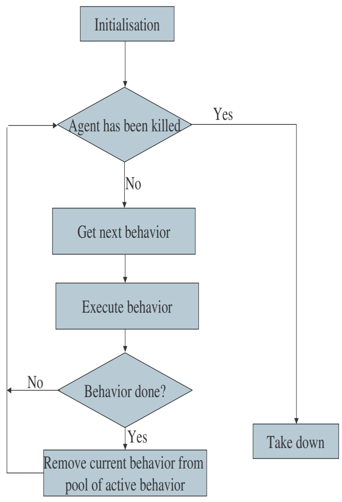

Fig. 3 Agent's life cycle

This life cycle is a JADE agent life cycle (Java Agent DEvelopment Frame) [10]. The choice of JADE is based on the following advantages:

- FIPA (Foundation for Intelligent Physical Agents) is already implemented.
- Important Community.
- Distributed execution on several hosts and types of machines (PC, mobile, etc).
- Concurrent execution of the agents.
- Transparent communication by message (ACL).
- Open Source.

Nevertheless, from the conceptual point of view, levels mean a set of agents able to cooperate in order to resolve a shared problem. For example, agent macroSection and microSection belong to the same level because; both of them cooperate in order to ensure conservation and continuity of flow. On the other hand, agent intersection that is belonging to the high level deals with other kind of problem (traffic control) and use data providing by agent microSection and macroSection. The role of each simulation agent is presented in the following paragraphs.

2.1 Agent vehicle

The agent vehicle is autonomous, has its own goal and its own environment knowledge. This knowledge supposed partial corresponds to driver's vision field. However, it allows the agent to move into its immediate environment. The agent vehicle actions i.e. its physical displacements are the results of its environment perception and its displacements plan. The agent vehicle also executes a behavioural model inspired from human behavior in order to emerge to real flow situations. According to its perception and by executing its behavioral model, agent vehicle can change its lane, move on the current lane or stop. More clarification about behavioral model, lane-changing and car-following one are noted in [11]. The scheme (Fig.4) below illustrates the architecture of agent vehicle.

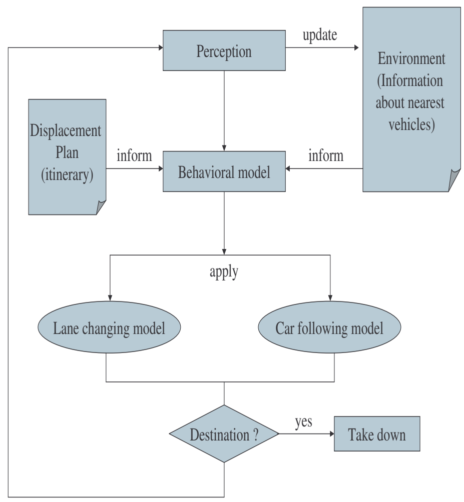

Fig. 4 Architecture of agent vehicle

2.2 Agents microSection and macroSection behavior

At the intermediate level, the agent microSection main task is to create, synchronize (scheduler) and destroy the agents vehicle at each microscopic simulation time step. Also, it aggregates macroscopic data (concentration, flow and speed) from vehicle microscopic data (position, speed).

At the same level, the agent macroSection calculates average values of the flow, the speed and the concentration - of the section which represents-, each macroscopic simulation time step. For this, it applies one of the macroscopic models LWR, ZHANG, PAYNE according to the application requirement. The agent macroSection communicates with agents forming its environment in order to transmit boundary conditions.

Both agents communicate with their environment that can be formed of the agents macroSection or microSection according to its location in the network in order to transmit boundary conditions. Transmission of information must be synchronized and ensure flow conservation and continuity.

Agents communicate either by direct message (FIPA Agent Communication Language) and Blackboard. Directs messages are resource consuming, they are used exclusively to ensure synchronization. On the other

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hand, shared information is stored in the Blackboard, which the access is instantaneous and brisk.

According to its location, agent microSection can communicate with one or many agent micro(macro)Section. One can distinguish three positions:

- Position 1: agent microSection communicates with a downstream agent microSection.
  In this case, it ensures the migration of vehicles towards destination section. Hence, according to the circulation condition on the destination section, agent microSection decides to authorize or not vehicles to leave the current section. Information (headway) about circulation condition on the destination section is transmitted via informative message to the upstream microSection agent. Each time step, downstream agent microSection checks the headway in the entry of microscopic section. If it is not sufficient, it sends a message to upstream agent microSection informing him that it is not possible to receive more vehicles. Receiving message, upstream agent microSection avoid outgoing vehicle to access the destination microscopic section.
- Position 2: agent microSection communicates with a downstream agent macroSection.
  In this configuration, it ensures the aggregation of the microscopic data to be transmitted to agent macroSection. Indeed, it calculates permanently the number of vehicle leaving the microscopic section during macroscopic time step (flow) and average value of their speed. This data (flow and speed) will be communicated next time step to agent macroSection. Thus, it will be informed about circulation condition on the upstream microscopic section and constraint must be ensured. On the other hand, fictitious agent vehicle are created by agent microSection on the entry of downstream macroscopic section . As it has been proved in our previous works, creation of those agents is very important to make certain the upstream propagation of constraints [4].
- Position 3: agent microSection communicates with an upstream agent macroSection.
  To ensure upstream constraint propagation, agent microSection calculates each time step the concentration (number of vehicle per km) in the entry of microscopic section and communicates it to the agent macroSection. On the other hand, agent macroSection transmits exit flow as a number of vehicles to be created during macroscopic time step and speed in the last macroscopic cell to agent microSection. Using the exit flow q_e the agent macroSection calculates the period p between two successive vehicles arriving in the entry of microscopic section. Afterwards, it creates the list of the moments when the vehicles must be created ($t_k = p(\frac{1}{2} + k)$) [4]. This list will be transmitted by informative message to agent microSection. Respecting the creation instants, agent microSection generates vehicles. Those vehicles will be created with a speed equal to the speed received from agent macroSection. In this way upstream and downstream constraint propagation will be ensured.

2.3 Agent intersection

Finally, the higher level contains the agent intersection, which deals with flow control. When two (or more) road sections cross they formed an intersection. An intersection can be, according to its geometry, a crossroad or rounabout. Also, an intersection can be of type traffic lights or road sign (priority panel) (Fig. 5).

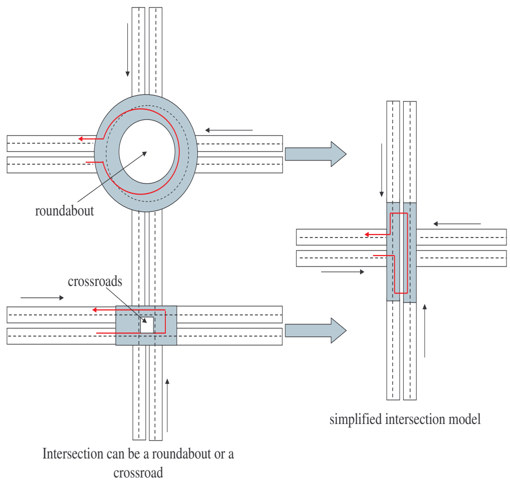

Fig. 5 Simplified intersection model

To ensure the safety of vehicles sharing the crossroad and in order to have an easy flow, an agent called ”intersection” is created on each crossroad. This agent adopts different behaviors according to the intersection type. In the case of traffic light, agent intersection applies a predefined phasing plan and calculates green light timing and cycle length using the following Webster’s (simplified) equation [12]:

$$C = \frac{1.5L + 5}{1 - Y} \quad (1)$$

where L is the lost time per cycle, and Y is the critical lane volume (flow) divided by the saturation flow, summed over all phases. Cycle length C is bounded by a maximum value (120 sec)–for limiting waiting times in different approaches–and a minimum value (40 sec)–to enable pedestrians to cross the road in safety. Information about lane (lane volume) is transmitted by agent microSection to agent intersection each time step. After being calculated, a green light timing and phasing will be transmitted to each agent microSection forming the intersection. Once receiving this information, agents microSection decide to authorize or avoid[1] vehicles to

To block the circulation of vehicles, an obstacle is introduced enter the intersection. On the other hand, agent intersection which deals with priority panel crossroad asked agents microSection about position and speed of each vehicle being tempted by crossing the intersection. According to their positions and speeds, agent intersection calculates the future positions of each agent. If agent of lane having the priority is very far and will not reach the crossroad before vehicle circulating on the no priority lane, agent intersection transmits message to agent microSection representing this section in order to authorize agent vehicle to enter the intersection. Otherwise, a message avoiding him to cross the intersection will be send to agent microSection [11].

After this brief presentation of simulation agent, the following paragraph describes the validation approach.

2.4 Validation

To validate hybrid model, we have simulated circulation of vehicle on two parallel sections. The first one is simulated using LWR macroscopic model and the second one is performed (carried-out) using the developed hybrid model. The principle of this simulation scheme (Fig. 6) is to generate the same signal (flow) at the entry of each section and to follow evolution in a time interval of concentration and flow values. This allows the validation of the fact that the traffic flow behavior is the same either in macroscopic or hybrid sections.

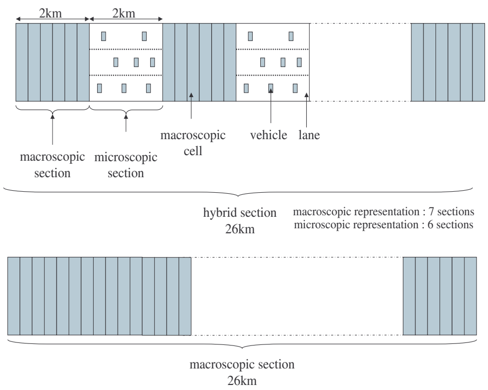

Fig. 6 Experience scheme

In this experience a LWR [13, 14] model is applied[2]. It is based on three variables (concentration ρ , flow q and average speed v) and three equations:

$$q(x,t) = \rho(x,t) \cdot v(x,t) \tag{2}$$

$$\frac{\partial q(x,t)}{\partial x} + \frac{\partial \rho(x,t)}{\partial t} = 0 \tag{3}$$

$$v = v_{eq}(\rho(x,t)) \tag{4}$$

For numerical reason, a discretized version of the LWR model is applied. Each link is divided into cells of length Δx , and we define a time step Δt. For each cell i , we define ρ_i^t , the average concentration at time t , and q_i^t, the average exit flow from t to $t+\Delta t$. At each time t , ρ_i^t is known for all i , and $\rho_i^{t+\Delta t}$ is computed applying the conservation of vehicles, which leads to the following formula:

$$\rho_i^{t+\Delta t} = \rho_i^t + \frac{\Delta t}{\Delta x}(q_{i-1}^t - q_i^t) \tag{5}$$

To compute q_i^t, two functions are introduced: the traffic supply $\Omega_i(\rho_i^t)$ and the traffic demand $\Delta_i(\rho_i^t)$

$$q_i^t = min(\Delta_i(\rho_i^{t-1}); \Omega_{i+1}(\rho_{i+1}^{t-1})) \tag{6}$$

A consequence of those definitions is that boundary conditions for a link are the upstream demand at the entry point and the downstream supply at the exit point. This model is valid if the two discretization steps Δx and Δt t satisfy the following inequality CFL(Courant-Friedrichs-Lewy) $\frac{\Delta x}{\Delta t} \geq v_f$. Where v_f being the free-flow speed.

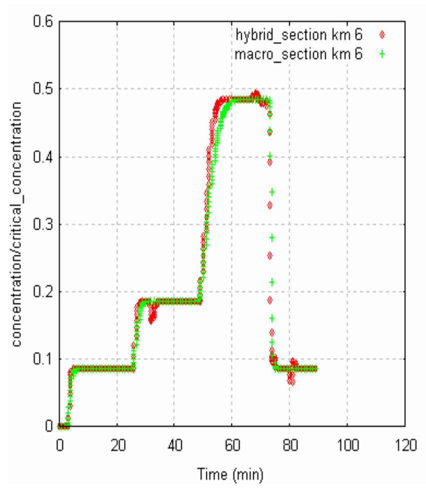

Fig. 7 Concentration in 6th km

During this experience flow and concentration values have been extracted at the kilometre 6 and 10 of the sections[3]. Results (Fig. 7), (Fig. 8), (Fig. 9), (Fig. 10) show that hybrid model conserve the same form of the entry flow. Furthermore, amplitude of signal is conserved.

3 Conclusion

This paper proposes a generalization of the hybrid simulation concept to deal with more complex and large road networks. In this topic, the paper describes the

The developed hybrid model is generic; however, any other model can be used

Theses measurement points are chosen arbitrary, one can of course take others

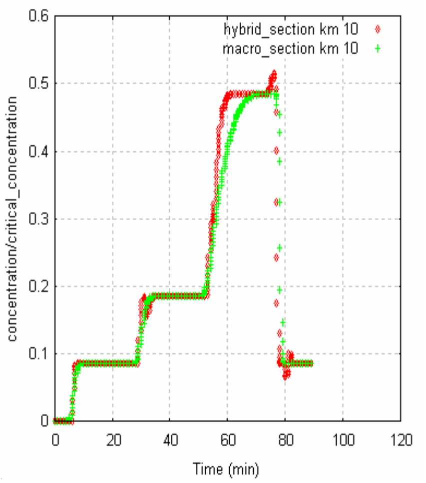

Fig. 8 Concentration in 10th km

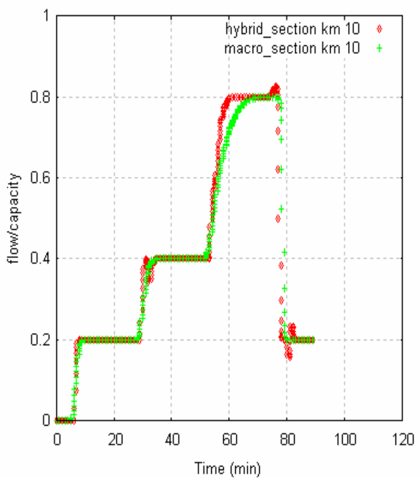

Fig. 10 Flow in 10th km

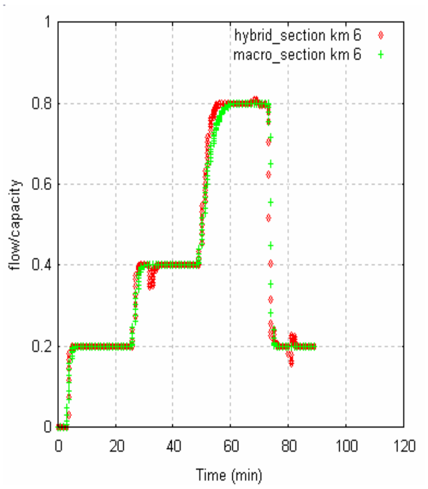

Fig. 9 Flow in 6th km

principle of the proposed simulation aspect and demonstrates how communication between the agents ”microsection” and ”macrosection” can ensure the flow continuity and conservation. The relevance of the proposed approach is illustrated via the simulation of a relatively complex network and will later be validated with real network simulation using real traffic flow data.

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