MULTIAGENT SYSTEM FOR URBAN VEHICLE TRAFFIC CONTROL

Tiberiu Leția, Adina Aștilean, Camelia Avram,
Mihai Hulea, Honoriu Vălean

Dept. of Automation,
Technical University of Cluj-Napoca, Romania

Abstract: The urban vehicle traffic problems are presented with the most recent and relevant methods proposed to solve them. A solution based on the multiagent system that reacts continuously at the changing of the environment is developed. This adaptive distributed control system takes information from sensors and sends control signal to microcontroller to implement the phase durations. For the verification of the solution a real-time simulator that implements the relevant characteristics of the traffic was used.

Keywords: traffic control, distributed control, adaptive control, real-time systems, intelligent control.

1. INTRODUCTION

The control of the vehicle traffic network containing the urban vehicle traffic and highway traffic is one of the most complex problems. Its solution involves some of the most complex algorithms using knowledge from different domains. The large number of the controlled system characteristics and of the components or the continuous (and significant) variation of the system parameters makes difficult to build a model that catches all the traffic aspects and meets all the requirements.

The aim of this paper is to point out the benefits of a distributed management and control system for urban vehicle traffic that can perform in the same time:

- the real-time signal local control of the traffic lights
- the coordination and cooperation of the local controllers

Huang et al. (1999) present a graph describing the driving mode decision in an intelligent transport system. Liu and Tate (2004) study the effect of the network on the vehicle speeds, on fuel consumption and on air pollution.

Choi et al. (2002) propose a fuzzy controller that is able to cope with traffic congestions appropriately. It uses as an input variable a degree of traffic congestion of upper roads.

Mirchandani and Head (1998) propose a hierarchical architecture urban vehicle traffic control. The system takes as input detector data for real-time measurement of traffic flow, and optimally controls the car flow. The global problem is decomposed into several subproblems that are interconnected in a hierarchical fashion. The system predicts the traffic flows and allows various optimization modules for solving the hierarchical subproblems such that each decision is given for a rolling time horizon.

Porche and Lafortune (1998) analysis the re-routing effects of traffic flow that are introduced by traffic signals. They have shown that the type of traffic signal control and the signal plans are key factors in accounting for shift in traffic flow from drivers selecting different routes.

Several solutions for solving the vehicle traffic problems are based on artificial intelligence using the multiagent systems. According to Rozemond (2001) a multiagent system consists of several agents working in cooperation within a single environment for a universal goal. Individual local agents calculate control decision according to their specification. The coordination between these agents has to be performed to maintain a balance between optimized events at a global and local level. That should ensure that improvements in one area of the traffic network do not overwhelm and damage other parts of the network.

France and Ghorbani (2002) propose for urban vehicle traffic control a multiagent system composed by local traffic agents (which concern with the optimal performance of their assigned intersection) and a coordinator traffic agent that compare the optimal local light pattern against the global concerns. The pattern can be slightly modified to accommodate the global environment, while maintaining the local concerns of the intersections.

Smith (1980) has introduced the contract net protocol for distributed computing. This is a distributed control schemes where no entity in the system has global knowledge. Through message passing, the entities in the system are capable of sharing information, negotiation and cooperation, thus they make decision related to fulfill their goals. Parunak (1988) used the pricing based approaches to implement a kind of contract net for manufacturing control.

The data transmission between computers or microprocessor controllers for urban traffic management and control are specified by the Technical Specification of UK Department for Transport, Local Government and Regions.

Tipsuwan and Chow (2003) present the effect of the message delays on the performances of the networked control systems and propose a method to handle the network delay effect.

2. CONTROL APPROACHES

The vehicle traffic control refers at:
- crossroads (or intersections) control (usually named traffic signal control)
- arterial (a set of linked intersections) control
- network control

The urban vehicle traffic control can be performed on the following ways (or approaches):
- controlling the flows
- controlling the resources
- discrete event control

2.1 Preemption and priority

Urbanik et al. (2003) divide the traffic control tasks on:
- strategic control (implementing coordination, preemption and priority)
- tactical control (containing traditional call, extend detection and traffic flow estimation) and
- state transition logic (handling phase intervals, barriers etc.).

The preemption in traffic control means a need for a special mode of operation that causes to leave the normal operation suddenly. The priority means a need to enhance or to prefer a particular movement (or flows) while maintaining normal operation.

In the same domain of distributed artificial intelligence, Bazzan (2005) proposes, for solving the urban vehicle traffic, a multiagent system that uses techniques of evolutionary game theory. The decentralized policy of control, coordination and cooperation are sustained by components that know the global changes of the traffic network.

2.2 Adaptive control systems

The urban vehicle traffic is a large dynamic system (structured as a net) with many input and output flows (related usually to all the nodes). The system parameters include the split of the flows (composing other flows) in all the intersections. The parameters of the input-output flows and of the splits are variable continuously and characterize the system behavior. An adaptive control system involves the taking into account of the controlled system changing for the control decisions making. Due to the dimension of the system, a centralized solution is not practical. A distributed approach has the problem of collecting of necessary information in short periods of time such that the system's change is not significant that the decisions be deprecated and their application be inefficient.

To control the traffic, the agents have to gather information, cooperate, take decisions and apply the control signals.

2.3 Perception of the environment

The agents can take information about the controlled processes using different types of sensors (magnetic loops, video cameras, microwaves etc.) and communicate with other agents or traffic operators.

To fulfill it goals, the agent of an intersection can use:
- local information:
    - rates of flows (number of cars per time unit)
    - lengths of cars queues (number of cars waiting on a lane in front of the stop line)
    - density (number of cars on a specified area)

- events (the arrival of ordinary or special cars, gap between platoons, pass over a specified point, switching of barriers etc.)
    - states of zones like presence of number of cars into a defined space (usually from the stop lines)
    - attaining the critical queue length
- information provided from the controllers assigned to neighbor intersections:
    - the loading of the intersection (i.e. the density of cars from its input lanes)
    - the flows split (from the input lanes to output lanes)
    - the expected of car rates or number of cars for the next period of time
- information provided by operator(s) like:
    - priorities of the lanes
    - lanes capacities (i.e. maximum possible queue lengths)
    - critical queue length (i.e. the queue length that if it is overwhelmed this can leads to congestions)
    - allocations of the input lanes of an intersection to phases (if they are fixed)

The information provided by different types of detectors (sensors or devices):
- a car passes over the point signaled by detector
- presence of a car over a point signaled by detector
- presence of cars into an area (i.e. number of cars)
- occupancy – the percentage of time when vehicles are above a point (measured by a sensor)
- vehicle speeds

The traffic flows are controlled by fixed signs, traffic lights and information sent by radio to the drivers.

The main goals of the urban traffic management and control system are:
- to avoid congestions as much as possible
- to maximize the overall capacity of the traffic system
- to maximize the flows on some specified routes
- to minimize the travel times
- to synchronize the traffic signals in order to provide continuous movement of the flows on specified routes at fixed speeds
- to minimize the energy consumption and implicit the air pollution

There are some decisions to be taken for signal traffic control:
- the partition of the traffic movements through crossroads into different phases such that the movements of cars in each phase are conflict free (the allocation of lanes to phases can be fixed or variable)
- the choosing of working with fixed or variable cycle time (for each intersection)
- the determination of the cycle times
- the determination of the cycle time split (including the order of the phases) and the phase-change interval

2.4 Control methods

Control methods for fixed cycle time are:
- pre-timed
- semi-actuated
- fully actuated
    - pre-timed scheme selection
    - timing modification (volume density control)
    - traffic-responsive signal plan generation

Solutions applied with variable cycle time are based on:
- phase time extension:
    - extended phase time until a gap out - The phase has a minimum green duration that is extended if cars are coming until the gap expiration time is met. The gap duration can be decreased in time or after a number of cars counted during the current cycle.
    - extended phase time until a timeout - The phase has a minimum green duration that is extended if cars are coming until a maximum time.
- volume density control – When one vehicle passes over the detector during yellow and red, the phase is assured to be serviced with its minimum green. For each successive vehicle that passes over the detector, a specified increment is added to the green time. If the total number vehicle multiplied by the time increment is grater than the minimum initial time, then that values is used for the green duration, up to maximum green duration

3 THE PROPOSED CONTROL SYSTEM

The decision control system is composed from a set of agents that work with a coordinator component and/or on cooperation between the software components (as can be seen in figure 1). The agents can chose different goals (improve the crossroad throughput, avoid congestion, perform the crossing of the special cars etc.) taking into account global or local information about the traffic system.

Generally, the agents' activities are:
- An agent gathers information from local event handler, their neighbor agents and coordinator agent (if it exits and works).

- The agent takes decisions using the current gathered information and the collected information (storied form previous iterations) and applying some rules.
- The agent communicates the decisions and some of local information to its neighbor and to the coordinator (if that exists).
- The agent applying the control commands to local actuators.

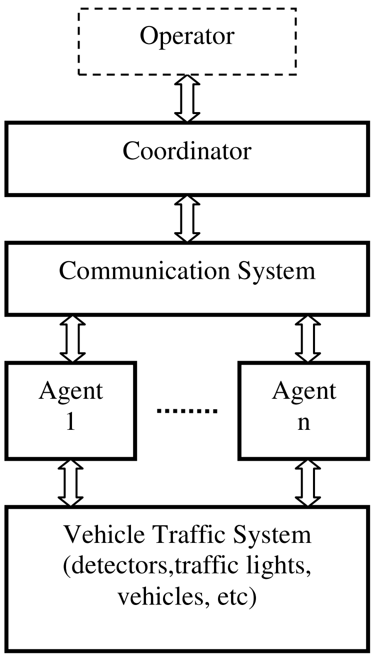

Figure 1. The structure of the vehicle traffic system

I. The agents can work with fixed duration of the cycle:
a. The phases' order is fixed. The problem is to adjust the phases' durations weighting neighbor requests.
b. The phases' order is variable. The problem is to determine the phases' order using the criteria:
- preemption request – from the local event handler
- criticality – received from the neighbor intersections
- importance – priority

To calculate the phases' durations the agents use the weighted neighbors requests and coordinator recommendations. The neighbors' requests can be expressed in numbers of cars admitted during the granted durations. The coordinator recommendations are limitations of cars admitted to cross the intersection to specified lanes. The coordinator calculates its recommendations taking into account cars' density in all areas of the system.

II. The agents can work with variable duration of the cycle. When the input lane length is longer than 100 meters there is place to form car queues, but these have to fulfill the requirement to not exceed the critical lengths signaled by the presence detectors. The figure 2 presents a traffic structure composed by two intersections. The input flow rates u_k (k=1,2,3) can be measured (i.e. counted). The same is the situations with the output flow rates u_k (k=1,2,3). The presence detectors q_c and q_m signal if the cars queue length waiting to the stop line
We denote by:
- T be the cycle duration
- d_i, i=1,1, ..., numberOfPhases the phases' durations
- r_i car rate of the phase i, i.e. the number entering in the main lane of the phase during of a cycle
- minOpenTime the minimum duration of opening of a phase
- numberOfPhases the number of phases of the crossroad
- δ_j the estimated difference between the cars entering lane in j and exiting from the lane j during a cycle
- switchingTime the sum of all durations necessary to switch the traffic lights from red to green or vice versa plus the clearance time if that exists.

The detectors provide for the phase i, that control the exit of the cars from the lane j, the information:
- u_k, k=1,2, 3, 4 – the number of cars entering during each cycle in the lane
- g_c^j, g_m^j – flags signaling that the car queues of the lane j reached the corresponding presence detectors (critical point, minimum point)

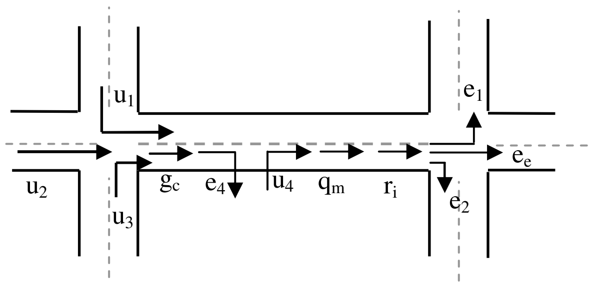

Figure 2. Vehicle traffic flow between two crossroads

The balance equation for the flows from figure 2 is:

$$u_1+ u_2+ u_3+ u_4= e_1+ e_2+ e_3+ e_4$$

The rate r_i of the flow that exits from the lane i is:

$$r_i= u_1+u_2+ u_3+ u_4 - e_4 \quad \text{or}$$
$$r_i= u_1+u_2+u_3+\delta_j$$

where the value $\delta_j= u_4-e_4$ cannot be measured by the detectors from practical reasons.

An adaptive algorithm for calculation of the phase durations is:

- for each phase i
  - if (g_c^j) the δ_j++
  - if(!g_m^j & (δ_j >0)) the δ_j--
  - set the minimum d_i=minOpenTime
  - calculate the lane output expected rate with the relation $r_i= u_1+u_2+u_3+\delta_j$
- calculate $D=T - \sum_i d_i$ – switchingTime
- divide D proportional with r_i (i=1,2, …, numberOf Phases) and add each of them to the corresponding d_i

This algorithm takes as inputs the rates u_i (i=1, 2, 3) and calculates the durations d_i of the phases adapting the estimations of the values δ_j (j=1, 2, …).

When the input lanes are shorter than 100 meters, there are no places to form the waiting queues. If the order of phases is not chosen correctly and adapted to the current situation, the queues overwhelm the lanes' capacities and that can lead to congestions. The algorithm proposed is approximately similar with earliest deadline first algorithm from the task scheduling in real-time systems. This real-time algorithm schedules the phases taking into account the moments of times when the corresponding waiting queues overwhelm the input lanes' capacities (considered the deadlines of the phases to be open). If some lanes will not overwhelm their capacities during the current cycle, they are scheduled taking into account their priorities.

The algorithm takes as inputs the cars queues remained from the precedence cycle, the moments of times when the neighbor crossroads introduce given numbers of cars into each input lane. The neighbor intersections are supposed to keep their orders of phases and work with fixed cycle times. The distances being short, the delays introduced until the cars reach the queues can be ignored. The durations d_i of opening the phases are calculated using the adaptive algorithm with constant values for δ_j (j=1, 2, …, numberOfPhases).

Another solution is one that uses agents to choose the goals of traffic control. An agent uses the information to determine if its controlled intersection and the neighbor crossroads are prone to congestions. In this case, the agent uses a set of rules to decide the durations of the phases to avoid as much as possible the congestions and send information to other agent for reducing its input flows. If the system is far to be affected of congestion it uses algorithms that

4 VERIFICATION OF THE PROPOSED SOLUTION

The verification of the solution has been made by simulation. There are simulators that adapt a set of fixed and legal speed limits or use the speed limit as functions that vary continuously in space or taking into account the weather conditions.

The used traffic simulation model is based on a fixed time increment (0.5 second) that is used for updating the speed and position of vehicles. The vehicles are individually characterized by some technical parameters like maximum speed, acceleration and deceleration, length, or driver behavior (i.e. aggressivity). The road characteristics (like adherence) or weather conditions are also modeled. The vehicle speeds depend on the mentioned factor as well as the car density on the roads. The vehicles can follow pre-defined fixed routes or their movements through crossroads are chosen stochastically.

5 CONCLUSIONS

The proposed control system implemented by different algorithms is a general adaptive system to the traffic conditions. When the traffic flows are at a low level, the discrete event algorithms are working better. When the traffic is at a medium loading the price based algorithms are more suited. In the case of high loading of the traffic, the multiagent control system can delay the appearance of the congestions.

The proposed algorithm is able to avoid the congestions of the vehicle traffic system at a higher traffic volume that one working with fixed phase durations. The cooperation between agents maintains a better distribution of the cars on the roads delaying the situations that can lead to congestions.

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