A Continuous Negotiation Based Model for Traffic Regulation at an Intersection

(Extended Abstract)

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ABSTRACT

Urban congestion is a major problem in our society for quality of life and for productivity. The increasing communication abilities of vehicles and recent advances in artificial intelligence allow new solutions to be considered for traffic regulation, based on real-time information and distributed cooperative decision-making models. The paper presents a mechanism allowing a distributed regulation of the right-of-way of the vehicles at an intersection. The decision-making relies on an automatic negotiation between communication-equipped vehicles, taking into account the travel context and the constraints of each vehicle. During this negotiation, the vehicles exchange arguments, in order to take into account various types of information, on individual and network scales. Our mechanism deals with the continuous aspect of the traffic flow and performs a real-time regulation.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence—*Multiagent systems*

Keywords

Urban traffic control, regulation, negotiation, cooperative systems, intersection, multi-agent system

1. INTRODUCTION

Today's communication technology enables the design of regulation methods based on real-time communication of accurate information. In [3], K. Dresner and P. Stone propose a right-of-way awarding mechanism based on reservation for autonomous vehicles. It relies on a policy called FCFS (First Come First Served), granting the right-of-way to each vehicle asking for it, as soon as possible. This paper shows a possibility to take some steps towards new foundations of interactions. Based on this, we propose a new negotiation framework for an agent-based traffic regulation and tackle the continuous aspect of the traffic flow. In such negotiations, vehicles build various right-of-way awarding proposals that we call "configurations". These configurations are expounded to the other vehicles of their area, that can raise arguments about the benefits and drawbacks of each configuration. With the help of the intersection, that contributes to the coordination of the interactions, the vehicles decide on the configuration to adopt collectively.

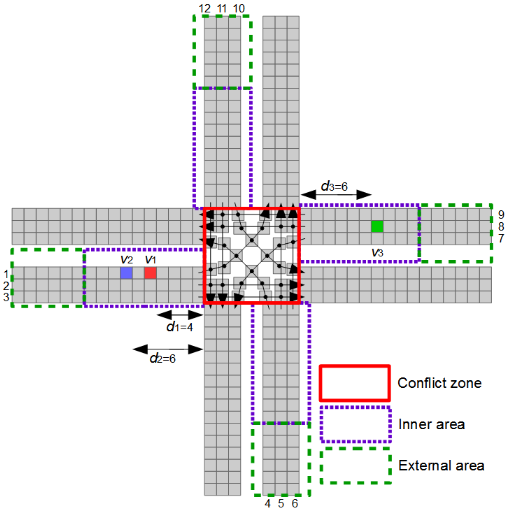

Figure 1: Intersection with 12 approaches

2. MODELING THE RIGHT-OF-WAY ALLOCATION PROBLEM TO BUILD CONFIGURATIONS

In order to build configurations, we model the right-of-way allocation problem as a Constraint Satisfaction Problem (CSP). The CSP fits our problem since it is easy to represent the structural rules of our problem (physical constraints and safety constraints) with 3 types of constraints. (1) Distance constraint: a vehicle has to cross the distance separating it from the conflict zone before entering it. (2) Anteriority constraint: a vehicle cannot enter the conflict

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zone before the vehicles preceding it on its lane (this rule could be removed with a more complex model that would take overtaking into account). (3) Conflict constraint: two vehicles cannot be in the same cell at the same time. If the vehicles belong to the same lane or trajectory, the moving rules of the vehicles prevent this case. However, if a cell is a conflict point then we have to model this rule for the vehicles belonging to different trajectories. This rule must be reinforced for safety reasons. Indeed, adding a time lapse t_{safe} between the passage of a vehicle on a cell and the passage of a vehicle in a conflicting trajectory on this cell enhances the drivers' safety.

With this CSP model, an agent uses a solver to find compatible admission dates (i.e. respecting the above constraints) for a set of vehicles approaching an intersection.

3. RIGHT-OF-WAY NEGOTIATION MODEL

Each vehicle builds configurations allowing it to cross the intersection, however only one configuration will be applied at a given moment. A negotiation process takes place to select it. The mechanism we propose relies on an argumentation-based model [4]. Through the negotiation process, agents aim to reach a collective agreement by making concessions. Each vehicle has a weight given by the intersections.

For safety reasons, the intersection has a current configuration at any time. The agents use this configuration as a starting point for negotiation. The goal of an agent through the negotiation is to change this current configuration c_{cur} by another that improves its individual utility. In a negotiation the agents rely on a communication language to interact. The set of possible negotiation speech acts is the following: $Acts = \{Offer, Argue, Accept, Refuse\}$.

Offer(c_{new}, c_{cur}): with this move, an agent offers that a configuration c_{new} replaces the configuration c_{cur}. An agent can only make each offer move once.

Argue$(c, arg(c))$: with this move, an agent gives an argument in favor of c or against c.

Accept(c_{new}, c_{cur}): with this move, an agent accepts that a configuration c_{new} replaces the configuration c_{cur}.

Refuse(c_{new}, c_{cur}): with this move, an agent refuses that a configuration c_{new} replaces the configuration c_{cur}.

c_{new} is accepted iff an acceptation threshold is reached by the vehicles accepting the configuration.

The vehicles have the ability to communicate and to choose collectively a configuration for the intersection. However, since the flow of vehicles is continuous, the mechanism has to manage this dynamic aspect by defining the agents that take part in each negotiation step, the vehicles for which this configuration provides an admission date, and the conditions under which this configuration could be revised once chosen. In order to manage technical failures, the intersection has a current configuration c_{cur} at any time.

In this paper, we present two policies to manage the continuity problem : Iterated Policy (IP) and Continuous Policy (CP). We distinguish two areas on the approaches of the intersection: the inner area, where all the vehicles are about to reach the conflict zone in a short term, and the external area, where the agents will reach the conflict zone in a slightly longer term (cf. Figure 1).

When IP is applied, the vehicle agents join the negotiation by waves. At a given instant, only the vehicles of the last wave (i.e. who entered the inner area since the last iteration) are able to negociate. The admission dates of the vehicles of previous waves cannot be revised, so the vehicles only negotiate the admission dates of the vehicles of the current wave. Of course, the admission dates of previous waves are taken into account, the vehcles only negotiate configurations that extend the configuration accepted in the previous iteration.

When CP is applied the vehicles dynamically join the current negotiation while entering the inner area. A vehicle entering the area receives an admission date given by the intersection using FCFS to extend the current configuration by adding the new vehicle. The vehicles negotiate the complete configuration, so the current configuration of the intersection can be totally revised by a collective decision.

This work has been implemented in Java with the Choco library for CSP [2], on an intersection with 12 approaches similar to the one on Figure 1. Agents are implemented as threads and reason individually: each agent has its own solver and its own negotiation strategy. The average number of vehicles in V^{inn} is 30 (density $\simeq 0.3$). On a personal computer (RAM 2Gb, 1.9 GHz mono-core processor), one second is enough to run the solver and compute several good configurations for about 30 vehicles, and the negotiation time is low enough to enable to run the mechanism in real time.

4. CONCLUSION AND FUTURE WORK

In this paper, we have proposed a coordination mechanism which represents a large step towards easing traffic, minimizing time losses while respecting safety constraints. This paper has made three significant contributions. Firstly, it defined the problem of intelligent agent-based intersection management. Secondly, it presented a negotiation mechanism that deals with continuous negotiations and applies a set of policies, and behavior rules that show how to exploit this framework over intersection control methods. This paper has taken one step forward to show how a system can take action to manage the decision of the vehicles cooperatively. This paper suggested that it is both algorithmically feasible and reasonable in terms of delay and computational cost to enable such sophisticated reasoning.

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