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ANT COLONY OPTIMIZATION FOR TRAFFIC DISPERSION ROUTING

Zhe Cong MSc, Prof. dr. ir. Bart De Schutter, Prof. dr. ir. Robert Babuška
Delft Center for Systems and Control,
Department of Mechanical, Maritime and Materials Engineering,
Delft University of Technology, the Netherlands

ABSTRACT

Ant Colony Optimization (ACO) has proven to be a very powerful optimization heuristic for combinatorial optimization problems. We introduces a new type of ACO algorithm that will be used for routing along multiple routes in a network as opposed to optimizing a single route. Contrary to traditional routing algorithms, the Ant Dispersion Routing (ADR) algorithm has the objective of determining recommended routes for every driver in the network, in order to increase network efficiency. We present the framework for the new ADR algorithm, as well as the design of a new cost function that translates the motivations and objectives of the algorithm.

KEYWORDS

Ant Colony Optimization, Traffic assignment

INTRODUCTION

The objective of traffic dispersion routing algorithm is to dynamically control the traffic network equilibrium such that traffic flow in the network is optimized. The concept of traffic network equilibrium formalized by Wardrop (1952) is acknowledged in the paper, known as Wardrop's first and second principle of equilibrium, *User Equilibrium* (UE) state and *System Optimum* (SO) state.

The problem of traffic control with respect to the UE and the SO states has been studied extensively in the last years. Hong et al. (2007); Rodriguez-Perez et al. (2008) has

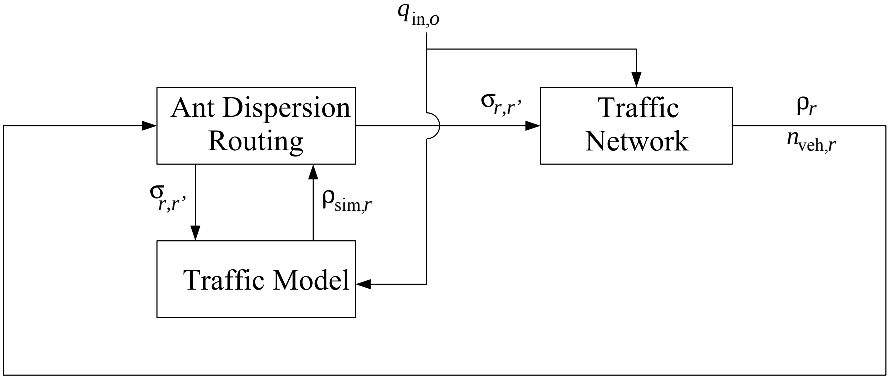

Figure 1: Schematic representation of the closed-loop control traffic system with the ADR algorithm and the traffic prediction model.

published their optimization and control methods for this purpose. In our work, we aim at optimizing traffic routing by balancing both UE and SO states. For this purpose, we introduce a novel routing algorithm, derived from the existing class of ACO algorithms by Dorigo et al. (1996). ACO has widespread applications in traffic assignment Xu et al. (2008). However, most routing algorithms found throughout the literature pursue the UE and do not consider the impact the actions of the users will have on the traffic network. This limitation is the main motivation for the development of the algorithm presented in this paper, the ADR algorithm.

ANT DISPERSION ROUTING ALGORITHM

A schematic representation of the closed-loop operation of the ADR algorithm is given in Figure 1. The traffic network in Figure 1 can be represented on a directed graph $G = (V, E)$, with V the node set and E the link set. We use m and n to denote the link and the node in the graph G, respectively, where $n \in V$ and $m \in E$. Each link m is assigned with a cost function φ_m, which is usually a function of total travel time (TTS).

Then Ant Dispersion Routing Algorithm aims to find out the optimal flow pattern on G. It is composed of two separate main steps, viz. network pruning and flow optimization. The network pruning step consists of a normal ant-based routing algorithm that finds a reduced graph $\hat{G} = (\hat{V}, \hat{E})$ from $G = (V, E)$. $\hat{G}$ has N paths with less travel time costs than other paths, based on the present traffic conditions. Next, the flow optimization steps consists in determining the correct distribution of flows on these paths such that the overall network conditions (expressed in function of the travel time costs) are optimized.

Network Pruning

we use Ant Colony Optimization to find the best route r_1 from G as follow:

First, we define a pheromone deposit τ_m on each link, with τ_m related to cost function φ_m. Thus the probability of choosing link m' from link m at an intersection is:

$$p_{m,m'} = \begin{cases} \dfrac{\tau_{m'}}{\sum_{l \in \mathcal{N}_m} \tau_l} & \text{if } m' \in \mathcal{N}_m \\ 0 & \text{otherwise} \end{cases}, \tag{1}$$

with $\mathcal{N}_m$ the set of links connected to link m at the intersection. All ants iteratively make these decisions in order to find routes through the network.

Then each route are evaluated to determine the update of pheromone deposit τ_m, which is done by calculating the travel time cost φ_i of each route i based on the sum of cost φ_m on each link m Therefore, the global pheromone update is then defined as:

$$\tau_m \leftarrow (1 - \alpha_{\text{evap}})\tau_m + \sum_{\substack{i \in \mathcal{I}; \\ m \in \mathcal{R}_i}} \Delta\tau_i \, , \forall m \, ; \, \exists i \in \mathcal{I}; m \in \mathcal{R}_i. \tag{2}$$

where α_{evap} is the pheromone evaporation rate, $\mathcal{I}$ is the set of routes found by the ants, and $\mathcal{R}_i$ is the set of links in route i.

Each ant repeats (1) and (2) until stop criterion is satisfied. Then at last route r_1 can be extracted from G as:

$$r_1 = \arg\max_m (\tau_m) \tag{3}$$

We store r_1 into $\hat{G}$ and remove r_1 from G, and then use the algorithm above to find the best routes r_2, r_3, and so on, in the new G. Accordingly, we get $\hat{G} = \{r_1, r_2, \ldots, r_N\}$

Flow Optimization

Now that the fastest routes have been identified, the ADR algorithm can proceed to optimize the distribution of traffic flows in this reduced network $\hat{G}$. A clear departure must be made from the ACO when it comes to the optimization of flows since, when the ACO converges, it always converges to only one optimal route. We want to optimize the distribution of flows that leads to a better usage of the network as opposed to finding the optimal route which will benefit the first drivers to use it, but in time and for many drivers may cause severe congestion. This happens due to the fact that the more ants use a route, the more attractive that route becomes, because of the pheromone deposits. The pheromone deposit function in ADR thus cannot be based on the number of ants using it. Instead, the pheromone deposits are based on the aggregated solutions of all ants. Likewise, the function should incorporate the cost of a route φ_i, and the network cost Ω, which is defined as:

$$\Omega = \frac{\sum_{i=1}^{n_{\text{r}}} \varphi_i n_{\text{veh},i}}{\sum_{i=1}^{n_{\text{r}}} n_{\text{veh},i}}. \tag{4}$$

where $n_{\text{veh},i}$ is number of vehicles on route i. The number of vehicles ants can be calculated by the number of ants so that densities can be correctly calculated according to the traffic model used by ADR. Let $n_{\text{ants},i}$ be the number of ants using route i, n_{veh} be the total number of vehicles, and n_{ants} be the total number of ants. So $n_{\text{veh},i}$ is:

$$n_{\text{veh},i} = n_{\text{ants},i} \frac{n_{\text{veh}}}{n_{\text{ants}}}. \tag{5}$$

Similarly to the network pruning part presented above, the ants have the objective of finding the best solution according to the probability function defined in (1). Instead of the pheromone deposit equation representing a minimization of costs, we create a new pheromone deposit equation to represent a minimization of differences between costs. It will be expected to minimize the cost of each route φ_i and the network cost Ω. The new pheromone deposit is defined as follows:

$$\Delta\tau_i = \frac{1}{\varphi_i} + \frac{W}{\Omega}, \tag{6}$$

with W a weighting factor. We introduce (6) into (2), then we optimize the flow on network with distributing ants on multiple routes. The control signal is the splitting rate $\sigma_{r,r'}$ shown in Figure 1, which can be calculated as:

$$\sigma_{r,r'} = \frac{n_{\text{ants},r}}{n_{\text{ants},r'}} \tag{7}$$

CONCLUSION

We have introduced a novel ant-based traffic routing algorithm that optimizes the distribution of traffic flows. The ADR algorithm was designed to solve the traffic network equilibrium problem, which is a complex optimization problem since it has two conflicting objectives: reducing travel times of individual drivers, while improving network efficiency. This algorithm is model-based, scalable, and computationally efficient. In ADR, the ants negotiate several optimal solutions to decide on the set of solutions that is best for the colony.

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