A Pheromone-based Traffic Management Model for Vehicle Re-routing and Traffic Light Control

(Extended Abstract)

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ABSTRACT

We propose a pheromone-based traffic management model, which simultaneously optimizes vehicle re-routing and traffic light control. Specifically, each car agent deposits multiple digital pheromone on its route. The road infrastructure agents fuse the pheromone to forecast traffic conditions. Once a congested road is predicted, we adopt a proactive vehicle re-routing algorithm for assigning alternative routes to cars before they enter the congested road. At the same time, the traffic light control agents use an online strategy for assigning long time duration of green traffic lights to the roads with a large amount of pheromone. Experimental results confirm its superiority in alleviating traffic congestion.

Categories and Subject Descriptors

I.2.11 [**Distributed Artificial Intelligence**]: Intelligent agents; Multiagent systems

General Terms

Design; Algorithms; Experimentation

Keywords

Agent-based Traffic Management; Pheromone; Proactive Vehicle Re-routing; Online Traffic Light Control; SUMO

1. INTRODUCTION

Traffic congestion is a key problem to cause driver frustration and air pollution in today's urban area [3]. To alleviate this problem, various approaches have been proposed for re-routing vehicles [3] or controlling traffic lights [4]. However, few works have been done to simultaneously consider vehicle re-routing and traffic light control. In this paper, we define a novel digital "pheromone" to bridge these two methods.

2. TRAFFIC MANAGEMENT MODEL

In nature, "pheromone" refers to communication chemical that is mutually understood by the individuals of the same species [3, 2]. Inspired by this concept, we introduce the traffic pheromone and intention pheromone to represent the current and future road conditions, respectively. The *traffic pheromone* is defined to estimate the current traffic density:

$$\tau_1(p,t) = \frac{N(p,t) \times L_{\mathrm{car}}}{L_p \times \mathrm{lanes}(p)}, \quad (1)$$

where $N(p,t)$ is the number of cars on road p in time $(t-1,t]$, L_{car} is the mean length of cars, L_p is the length of road p, and $\mathrm{lanes}(p)$ is the number of lanes on road p.

Suppose that each car reports its route intention to the roadside infrastructure (e.g., using smart phones). We define *intention pheromone* to estimate the future traffic density:

$$\tau_2(p,t+1) = \frac{(I(p,t+1) - O(p,t+1)) \times L_{\mathrm{car}}}{L_p \times \mathrm{lanes}(p)}, \quad (2)$$

where $I(p,t+1)$ and $O(p,t+1)$ are the incoming and outgoing car counts on road p in time $(t,t+1]$, respectively. Both $I(p,t+1)$ and $O(p,t+1)$ take the similar formulation. For instance, $I(p,t+1)$ is formulated as:

$$I(p,t+1) = \sum_{p' \in P_{\mathrm{nei}}} T_g(p') V_f(p') \tau_1(p',t) \times \rho \times \frac{\mathrm{lanes}(p')}{L_{\mathrm{car}}}, \quad (3)$$

where cars move from neighboring roads $p' \in P_{\mathrm{nei}}$ to road p, $T_g(p')$ is the time duration of green traffic lights on road p', $V_f(p')$ is the free speed of road p', and ρ is the proportion of cars that have intention of moving from road p' to road p.

The pheromone update includes evaporation and propagation. We define the evaporation rate as:

$$e(p,t) = \frac{\bar{V}(p,t)}{V_f(p)} \times \frac{1}{1 + |\mathrm{Halts}(p,t)|}, \quad (4)$$

where $\bar{V}(p,t)$ and $|\mathrm{Halts}(p,t)|$ are mean speed and halting car counts on road p in time $(t-1,t]$, respectively. Then, the roadside infrastructures fuse the digital pheromone by:

$$\tau(p,t+1) = (1-e(p,t)) \times \tau_1(p,t) + e(p,t) \times \tau_2(p,t+1). \quad (5)$$

2.1 Pheromone-based Vehicle Re-routing

Once a congested road is forecasted, the roadside infrastructures search new routes for cars using Alg. 1.

2.2 Pheromone-based Traffic Light Control

In this section, we propose traffic light control to automatically set color phases and calculate the time duration of these phases. In Fig. 1, suppose two roads have the competing relationship with $\tau(p_1,t+1) > \tau(p_2,t+1)$. To fully utilize road capacities, road p_1 should be assigned the green

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Input   : G, road network; δ: congestion threshold;
          R′, old routes; t, current time;
Output: Road network with new pheromone G;
Update G's roads with pheromone using Eq. 5;
Find congested roads p ∈ P_con by τ(p, t+1) > δ;
while |P_con| > 0 do
    Find road p ∈ P_con with maximum τ(p, t+1);
    Get neighboring roads P_nei connected to road p;
    Get nodes N_p connected to road p;
    for p′ ∈ P_nei do
        for n ∈ N_p do
            find new routes R(n) by k-shortest path;
        Get car agents C on road p′;
        for c ∈ C do
            Get n ∈ N_p from car c's old route r′ ∈ R′;
            Set new route r = R(n) to car c ;
            Update intention pheromone τ_2(p′, t+1);
        Update pheromone τ(p′, t+1) by Eq. 5;
    Find congested roads p ∈ P_con by τ(p, t+1) > δ;
    Delete the checked road P_con = P_con − p;
Output road network with new pheromone G;
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Algorithm 1: Pheromone-base Vehicle Re-routing.

traffic light and road p_2 is red. we assume the time duration of green traffic lights for road p_1, denoted as $T_g(p_1)$, satisfies:

$$\tau(p_1, t+1) \times (1 - \frac{T_g(p_1)V_f(p_1)}{L_{p_1}}) = \tau(p_2, t+1). \quad (6)$$

Then, the time duration of green traffic lights on road p_1 is:

$$T_g(p_1) = \frac{L_{p_1} \times (\tau(p_1, t+1) - \tau(p_2, t+1))}{V_f(p_1) \times \tau(p_1, t+1)}. \quad (7)$$

To avoid traffic lights changing too frequently or cars waiting too long, the time duration is bounded to [4s, 90s].

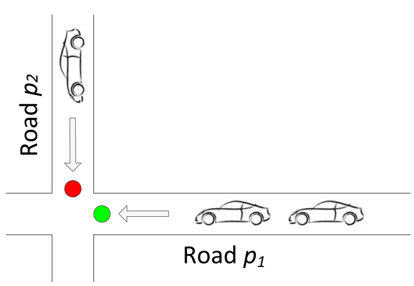

Figure 1: Pheromone-based Traffic Light Control.

3. EXPERIMENTATION

We verify our traffic management model on two road networks (i.e., Grid and Cityhall) by the simulation of urban mobility platform, SUMO 0.18.0 [1]. Two classical algorithms are introduced: "Baseline" does not control re-routing and traffic lights, and "DUA" (dynamic user assignment) is the best re-routing algorithm by far [1].

The pheromone-based traffic light control (TLC) reports the better results than Baseline, and pheromone-based vehicle re-routing algorithm (Re-routing) is better than TLC. To explain, TLC will assign the default traffic lights (i.e., T_g = 4s by Eq. 7) to two competing roads if they have similar traffic pheromone. Thus, TLC is only suitable to the unbalance traffic scenarios. In comparison to TLC, Re-routing searches alternative routes for avoiding traffic congestion. On the other hand, DUA is better than Baseline, TLC and Re-routing. In essential, DUA is an offline algorithm using the trail-and-error procedure to evaluate candidate routes. Thus, DUA is only designed for simulation because vehicles' movement in realistic transportation system is irrevocable.

Table 1: Results by Traffic Management Models.

	Con. Roads	Traffic Density	Arr. Vehs	Travel Time
Grid Network				
Baseline	23.2	0.709±0.173	339	314.5
TLC	10.0	0.355±0.243	1177	152.8
Re-routing	4.9	0.256±0.221	1800	170.4
DUA	3.2	0.218±0.198	1770	144.7
Re-routing+TLC	**0.3**	**0.102±0.112**	**1896**	**94.2**
Cityhall Network				
Baseline	21.4	0.340±0.358	397	440.6
TLC	11.5	0.245±0.325	555	434.1
Re-routing	9.5	0.209±0.320	618	446.1
DUA	7.3	0.179±0.296	696	378.8
Re-routing+TLC	**3.4**	**0.099±0.223**	**705**	**344.6**

*Con. Roads: congested roads, Arr. Vehs: arrived vehicles

Furthermore, our traffic management model integrates the advantages of vehicle re-routing and traffic light control. From Table 1, our model is better than Baseline, TLC, Re-routing and DUA. In particular, road conditions become better when using our model. In Table 1, the average number of congested roads on Grid and Cityhall are 0.3 and 3.4, respectively. On the other hand, the driver experience also increases through our model. The arrived vehicles on Grid and Cityhall are 1,896 and 705, respectively.

4. CONCLUSION AND FUTURE WORK

In this paper, a pheromone-based traffic management model is proposed for re-routing vehicles and controlling traffic lights simultaneously. In future, we will examine our model on other complex road networks. We also plan to extend our model to Vehicle Ad Hoc Network (VANET).

5. ACKNOWLEDGEMENT

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6. REFERENCES

[1] M. Behrisch, L. Bieker, J. Erdmann, and D. Krajzewicz. SUMO – simulation of urban mobility: an overview. In *SIMUL*, pages 55–60, 2011.

[2] S. Jiang, J. Zhang, and Y. Ong. A multiagent evolutionary framework based on trust for multiobjective optimization. In *AAMAS*, pages 299–306. ACM, 2012.

[3] O. Masutani, H. Sasaki, H. Iwasaki, Y. Ando, Y. Fukazawa, and S. Honiden. Pheromone model: application to traffic congestion prediction. In *AAMAS*, pages 1171–1172. ACM, 2005.

[4] J. Sánchez, M. Galán, and E. Rubio. Applying a traffic lights evolutionary optimization technique to a real case: "las ramblas" area in santa cruz de tenerife. *IEEE TEC*, 12:25–40, 2008.