OPTIMAL DYNAMIC GREEN TIME FOR DISTRIBUTED SIGNAL CONTROL

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1 INTRODUCTION

A variety of traffic signal control strategies for urban intersections exist, aiming at road safety and network optimization. Due to the high complexity in many of those strategies, a back-pressure algorithm is presented in [1]. In that algorithm, all signals are determined by local controller independently and a maximum network throughput is claimed.

This algorithm determines the phase to be activated based on the so-called back-pressure, i.e. the difference in the queue length between the upstream and the downstream queue for a movement. The back-pressure of a phase is a sum of back-pressure of movements in the phase. The phase with the highest back-pressure will be activated. In this algorithm, two concepts are important: *slot time* and *all red time*. “Slot time” is defined as a control time step, and “all red time” is defined as a period when all the signals for the intersection are red. The all red time occurs when the intersection switches the activated phase. Then, for safety reasons, all directions have a red light, allowing all vehicles in incompatible movements to leave the conflict area.

In the original presentation of the backpressure algorithm [1], all red time was not taken into account. This might influence the traffic flow performance of the algorithm. The other potential thread of the algorithm is the possible large effect of a failing detector. Because the activated phase is only determined by the back-pressure, a failing detector might cause a wrong back-pressure continuously, so a wrong phase would be activated, which might have a long lasting effect on the green time. In this paper, an optimal dynamic slot time approach will be presented which overcomes both of these issues.

2 METHODOLOGY

To resolve above problems, an optimal dynamic slot time approach is presented. This approach extends the basic back-pressure strategy by calculating an optimal dynamic slot time and making a slot time synchronization mechanism.

Moreover, to overcome the low robustness, it is proposed that the same phase cannot be activated in two successive slot times. Because this paper only take two-phase intersection into account, this is also called *periodic* in this paper. Therefore, this periodic strategy has determined the activated phase sequence at the beginning. The calculation of slot time is activated after the next activated phase has been determined.

According to the back-pressure algorithm, the dynamic slot time (T_{slot}) for the periodic strategy is related to two variables: back-pressure difference between phases and upstream queue length in the next activated phase.

Let's firstly consider the difference between the back-pressure of chosen phase (B_a) and the non-chosen phase (B_n). If the difference between the two is large, a long green time is required to reduce this large difference, and hence a long slot time is suitable.

Secondly, even if the back-pressure difference is small, but the back-pressure for each directions is high, the queues for each direction are long. In this case, no intersection capacity should be wasted by the all red time. So also then, long green time, and hence long slot time is chosen.

Therefore, we propose to calculate the slot time based on a minimum slot time (τ) and add a dynamic part τ_a to that. In line with the above reasoning, the dynamic part is proportional to the back-pressure difference and proportional to the maximum queue length, and bounded by minimum and maximum values. For this paper, we take 0 and 50 seconds respectively for these bounds. In equations, we hence propose the following:

$$T_{slot}\left(t\right)=\tau+\max\left(0,\min\left(50,\tau_A\left(t\right)\right)\right) \tag{1}$$

$$\tau_A\left(t\right)=\alpha\left(\mathrm{B}_a\left(t\right)-\mathrm{B}_n\left(t\right)\right)Q_{up}^{\max *}\left(t\right) \tag{2}$$

In this equation, $Q_{up}^{\max *}\left(t\right)$ is the maximum upstream queue length in the next activated phase at time t. Note that for periodic control, the back-pressure now only determines the duration of the green time (via the slot time), rather than the activated phase, since these alternate.

Finally, the slot times are either determined for each junction separately (referred to as *Local*) or synchronized for the whole network, determined by one critical junction (labelled as *Critical*). All above approaches are tested with simulations.

3 RESULTS

The performances of the fixed and dynamic slot time strategy in simulations are shown in Table 1 and Table 2, respectively. According to these two tables, it is concluded that a dynamic periodic slot time calculation is preferred. If a critical junction is used to synchronize the slot time for the whole network the maximum network throughput is achieved ($TTS=1.1217\times10^5 veh\cdot h$). Note that the best performance of fixed slot time strategy is based on the knowledge of OD matrix which is difficult and complex to predict precisely right now. So the advantage of the dynamic slot time approach is not only a save of TTS, around 6.5% compared to the best performance of periodic fixed strategy, but also a higher practical possibility. This approach tries to keep and make use of the advantage of the back-pressure algorithm to make the strategy more realistic, optimal and practical.

Table 1 Fixed slot time strategy performance

	$TTS_{LOWEST}\,(veh \cdot h)$	$Max\,queue_{LOWEST}\,(veh)$
Aperiodic	2.9×10^5	21.07
Periodic	1.2×10^5	21.02

Table 2 Dynamic slot time strategy performance

Simulation scenarios		Criticality parameter	$TTS\,(veh \cdot h)$
			Dynamic
Aperiodic	Critical	Back-pressure	5.5551×10^5
		Back-pressure difference	5.5551×10^5
	Local		1.1066×10^6
Periodic	Critical	Back-pressure	1.1217×10^5
		Back-pressure difference	1.1217×10^5
	Local		9.5729×10^5

4 FINDING & CONCLUSION

Based on simulations, we conclude a slot time calculation approach to extend the basic back-pressure signal control strategy. This approach takes the all red time into consideration and overcomes the low robustness of the basic one. At the same time a maximum throughput is achieved. Besides, the dynamic slot time approach is more practical than the fixed one. Please note that in [1] the slot time is only considered as a control time step, so it is assumed that the slot time is fixed and aperiodic. The extended back-pressure strategy presented in this paper performs – for the case study – better than the original. Since [1] has claimed that back-pressure algorithms is significantly better than the SCATS, it is reasonable to assume that this extended back-pressure algorithm also outperforms SCATS.

REFERENCES

1. Wongpiromsarn, T., T. Uthaicharoenpong, W. Yu, E. Frazzoli, and W. Danwei. *Distributed traffic signal control for maximum network throughput*. in *Intelligent Transportation Systems (ITSC), 2012 15th International IEEE Conference on*. 2012.