Configuring a Stigmergy-based Traffic Light Controller

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ABSTRACT

Effective traffic light control algorithms are of central importance for reducing congestion. While the currently most effective algorithms rely on expensive infrastructure to obtain knowledge of the traffic state, within the COLOMBO project, low-cost adaptive traffic light controllers have been examined that rely on swarm intelligence principles and the exploitation of V2X data. The swarm-based traffic light controller exploits numerical values that are adapted by the principles of stigmergy and used to switch between lower-level traffic light control strategies. This algorithm has more than 100 parameters that determine its behavior. In our work, we have explored the automatic configuration of this traffic light controller. In fact, the possibility of automatically configuring the parameters of the swarm-based traffic light control algorithm in this case is instrumental for the development of such a method and the high performance reached by it.

Keywords

Traffic light control algorithms; swarm intelligence; automatic algorithm configuration

1. BACKGROUND

The development of traffic light control algorithm is of high importance to manage effectively the ever increasing traffic in cities. The development of traffic light control methods and systems has a long tradition and it is a very active research area in the context of the recent smart city initiatives. Current state-of-the-art systems are based on an adaptive control [8] and use either centralized or decentralized architectures [5, 7]. However, these systems are complex and expensive as, for example, they require a significant number of detectors such as inductive loops and others to obtain knowledge about the current traffic status and to optimize criteria of traffic flow.

The introduction of V2I communication technology from vehicles to infrastructure (or, more general, V2X where X stands for other vehicles, infrastructure etc.) e.g. through the IEEE 802.11-2012 standards gives also other possibilities to obtain information on the status of the traffic. However, the quality of this information depends crucially on the percentage of vehicles that are effectively equipped with such systems, the so called *penetration rates*. These equipments following ETSI standards are only recently being introduced into the market and penetration rates are expected to grow only slowly in the near future with close to 100% penetration rates being expected only sometime around 2030.

Within the COLOMBO project [3], technologies for the exploitation of V2X communication have been explored for traffic surveillance and traffic control through traffic lights taking into account many different levels of penetration rates. In particular, a fully distributed and de-centralized traffic light control algorithm that makes use of the V2X data has been developed [1]. Following these principles, a traffic light control algorithm exploiting principles of stigmergy [6] has been proposed. The main design principles underlying this stigmergy-based traffic light control (sbTLC) algorithm have been described in more depth elsewhere [1]. In a nutshell, sbTLC accumulates the traffic on ingoing and outgoing lanes through a numerical representation. This numerical information correlates with the length of queues in front of traffic lights—the higher the numerical information, the longer possibly are the queues—and with the traffic density in general. For the specific traffic light control, sbTLC relies on low level, *microscopic* policies, each of which performs best under different traffic conditions. In sbTLC, the phase, platoon, marching, and congestion policies are implemented. A main feature of sbTLC is that is implements a probabilistic, *macroscopic* policy that decides which of the microscopic policies to execute in the controlled intersection for the current traffic conditions. The macroscopic policy makes use of the numerical information and maps these through the usage of one, two, or at most three Gaussian functions to a probabilistic decision that decides which of the microscopic policies to execute. However, the way sbTLC is designed leads to a substantial number of parameters that are used, for example, to define the location and spread of the Gaussian functions that define the mapping from numerical information to policy selection, how many Gaussians are used in the mapping for each microscopic policy or other parameters steering the decay of the cumulated information and various thresholds to be used. Overall, in the most recent versions of sbTLC this results in 112 categorical, integer, or real-valued parameters to be set, making the usage of automatic algorithm configuration tools necessary.

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2. AUTOMATIC CONFIGURATION

In our research we have focused on the automatic configuration of the sbTLC algorithm and the development and evaluation of a strategy for the periodic re-tuning and adaptation of the algorithm to changing traffic conditions. For the configuration of sbTLC, that involves essentially setting its tuneable parameters, we employ automatic algorithm configuration tools. The usage of such tools is appealing in this case, due to the large number of parameters that are to be set appropriately. In fact, the availability of the automatic configuration tools has been an enabling technique that made the conception and design of the sbTLC approach manageable as a manual tuning of the parameters was deemed to be infeasible.

The automatic configuration process was setup, using an implementation of sbTLC in the SUMO simulation software for microscopic urban traffic simulation [2]. As basic traffic light scenario, a single intersection was considered, although in extended scenarios tests with crossings equipped with sbTLC controlled traffic lights organized in a grid network or in a corridor were also considered. The training instances consisted of simulated, realistic 24 hours traffic flows and a range of different penetrations rates $pr \in \{1, 2.5, 5, 10, 25, 50, 100\}\%$. As configurator, we have used the `irace` method, which implements various iterated racing algorithms [4]. Tuning was done using a budget of 50 000 evaluations, which leads to an overall training time on ca. 60 computing cores of ca. one CPU day wall-clock time.

The main steps of the experimental campaign comprised initial tuning of the sbTLC algorithm for different penetration rates and a basic sanity check, comparing the tuned configurations to random ones and configurations based on the sbTLC designers intuition. In all cases, the automatic configuration process indicated much improved performance. Next, we have compared the configurations tuned for the various penetration rates to examine their sensitiveness to changes in pr. Figure 1 compares configurations tuned for various penetration rates on a single fixed one. These results show on one side that the tuning is sensitive to the specific penetration rates. In addition, they indicate that configurations that are obtained on high penetration rates are strongly impacted when used in situations where the penetration rates are much lower. In a sense, the obtained configurations exploit the fact that for a high penetration rate the sbTLC algorithm has more information available to make its decision. Third, configurations that are obtained for low penetration rates scale reasonably well to higher penetration rates. For example, the configuration obtained on a penetration rate of 1% is by 17% worse than the configuration obtained on a penetration rate of 100% when being evaluated on a scenario with 100% penetration rate.

This latter observations also indicates that when being faced with increased penetration rates, a re-tuning of the sbTLC algorithm may be beneficial. In fact, in follow-up work also other possible changes of the environment in which the sbTLC algorithm operates have been considered and specific recommendations have been done when occasional re-tunings of the sbTLC algorithm may be advisable.

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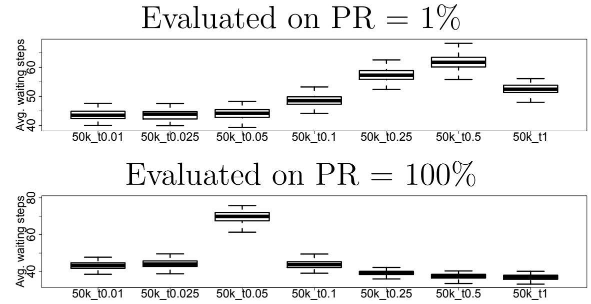

Figure 1: Evaluation of configurations tuned for various penetration rates on one fixed penetration rate (1% on top and 100% on bottom). For example, in the top-most plot, all candidate configurations are compared on a penetration rate of 1% even if they have been tuned considering a higher penetration rate.

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