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Adaptive group-based signal control by reinforcement learning

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Abstract

Group-based signal control is one of the most prevalent control schemes in the European countries. The major advantage of group-based control is its capability in providing flexible phase structures. The current group-based control systems are usually implemented with rather simple timing logics, e.g. vehicle actuated logic. However, such a timing logic is not sufficient to respond to the traffic environment whose inputs, i.e. traffic demands, dynamically change over time. Therefore, the primary objective of this paper is to formulate the existing group-based signal controller as a multi-agent system. The proposed signal control system is capable of making intelligent timing decisions by utilizing machine learning techniques. In this regard, reinforcement learning is a potential solution because of its self-learning properties in a dynamic environment. This paper, thus, proposes an adaptive signal control system, enabled by a reinforcement learning algorithm, in the context of group-based phasing technique. Two different learning algorithms, Q-learning and SARSA, have been investigated and tested on a four-legged intersection. The experiments are carried out by means of an open-source traffic simulation tool, SUMO. Performances on traffic mobility of the adaptive group-based signal control systems are compared against those of a well-established group-based fixed time control system. In the testbed experiments, simulation results reveal that the learning-based adaptive signal controller outperforms group-based fixed time signal controller with regards to the improvements in traffic mobility efficiency. In addition, SARSA learning is a more suitable implementation for the proposed adaptive group-based signal control system compared to the Q-learning approach.

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Keywords: Adaptive traffic signal control; Group-based phasing; Intelligent timing decision; Reinforcement learning

1. Introduction

Traffic signal control is a commonly used control facility for urban traffic management. Signal phasing is one of the key elements for designing a signal control system. Phasing techniques are usually classified into two types, group-based phasing and stage-based phasing. Previous studies have shown that group-based signal control, in comparison to stage-based signal control, has the potential to improve traffic mobility (Wong et al., 2002) and sustainability (Jin et al., 2015). The major advantage of group-based phasing lies in the aspect of green time allocations, especially when imbalanced traffic demands on different approaches appear. In general, traffic movements associated with larger de-

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mands deserve relatively longer green time. Group-based control assigns a setting of green times to each single traffic movement rather than a group of compatible movements so that phase pictures are generated considering real-time traffic patterns. Therefore, travel delay caused by the inefficient phase formation can be reduced by applying group-based phasing techniques. However, the existing group-based control systems usually apply rather simple timing logics while they attempt no real-time systematic optimization. For example, LHOVRA, the dominant isolated signal control strategy in Swedish, is a typical group-based and vehicle actuated control system (Kronborg and Davidsson, 1993). Although LHOVRA is able to decide extend-or-terminate decisions for the active phase in response to traffic volumes, extension time is fixed during the operation and signal times for a movement merely depend on the presence of vehicles on that movement.

Reinforcement learning (RL) has been considered as a well-suited learning method for traffic signal control application. Thorpe and Anderson (1996) firstly applied a RL algorithm to control an isolated signalized intersection. The simulation results showed that RL-based signal control outperformed fixed time control by reducing average waiting times for all vehicles. Furthermore, Abdoos et al. (2011) proposed a RL-based signal controller that performed better than the fixed-time signal controller irrespective of the settings of traffic demand. In terms of state representations, RL-based research directions, on signal control system, can be divided into two branches, intersection-based approach and vehicle-based approach. Intersection-based states are represented by traffic-related indicators measured on the basis of intersection. For instance, Abdulhai et al. (2003) applied a simple RL technique to an isolated traffic signal, in which states include queue lengths on four approaches and the elapsed phase times of signal controllers. As reported by Prashanth and Bhatnagar (2011), intersection-based state-space representation suffers from the curse of dimensionality because scale of the state-space of such a representation will dramatically grow as the number of intersections increase. Previous studies have put many efforts on reducing the size of space states when RL-based signal control system is applied on a road network consisting of several intersections. For example, El-Tantawy et al. (2013) implemented the decentralized design for signal control system which is less computationally expensive compared to the centralized system. Prashanth and Bhatnagar (2011) implemented feature-based state representations to reduce the size of state space. If value functions are computed with respect to vehicles during the learning process, such a RL signal control is based on vehicle-based approach. This research direction began from Wiering (2000) who utilized RL to control traffic light agents for the purpose of minimizing the overall waiting time of vehicles. In terms of vehicle-based approaches, the number of states scales acceptably for large networks because it grows linearly with the number of vehicles (Khamis and Gomaa, 2014). However, the requirements are strict for a vehicle-based control system in a real-world application because vehicles are required to high-frequently send their travel information to the signal controller in order to update state information.

Kosonen (2003) presented a pioneering step in formulating group-based as an agent-based system. He applied fuzzy logic as the timing logic. Although fuzzy inference is more representative compared with vehicle actuated timing logic, the control system cannot continuously optimize fuzzy control parameters in response to the changes in the traffic environment. Therefore, the primary goal of this paper is to propose a multi-agent signal control system, in the context of group-based phasing techniques, by using reinforcement learning technique. The proposed signal control system can on-line generate intelligent signal timings based on traffic conditions on the entire intersection. In this study, state representation is intersection-based due to the existing infrastructure situations. The remainder of this paper is organized as follows. Next section presents adaptive group-based signal control system in multi-agent system framework. Design elements of signal control agent will be interpreted in the subsequent section. Section 4 will describe the testbed experiments. Followed by that, preliminary findings from the experiment results will be elaborated and also discussed.

2. Adaptive group-based signal control

2.1. Group-based phasing

Signal group and phase are two basic components of group-based phasing techniques. A signal group is defined as a group of traffic movements that are always controlled by the same traffic light indications. Phase is the combination of signal groups. In group-based signal control system, timings are directly assigned to signal groups. Fig. 1 gives an example to depict how group-based signal control operates. Signal groups are required to be non-conflict with each