ARTICLE IN PRESS

Swarm and Evolutionary Computation xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Swarm and Evolutionary Computation

journal homepage: www.elsevier.com/locate/swevo

Jaya, harmony search and water cycle algorithms for solving large-scale real-life urban traffic light scheduling problem

Kaizhou Gao*, Yicheng Zhang, Ali Sadollah, Antonios Lentzakis, Rong Su

School of Electrical and Electronic Engineering, Nanyang Technological University, 639798 Singapore

ARTICLE INFO

Keywords:
Urban traffic light scheduling
Large-scale traffic network
Jaya
Water cycle algorithm
Harmony search

ABSTRACT

This paper studies a large-scale urban traffic light scheduling problem (LUTLSP). A centralized model is developed to describe the LUTLSP, where each outgoing flow rate is described as a nonlinear mixed logical switching function over the source link's density, the destination link's density and capacity, and the driver's potential psychological response to the past traffic light signals. The objective is to minimize the total network-wise delay time of all vehicles in a time window. Three metaheuristic optimization algorithms, named as Jaya algorithm, harmony search (HS) and water cycle algorithm (WCA) are implemented to solve the LUTLSP. Since we adopt a discrete-time formulation of LUTLSP, we firstly develop a discrete version of Jaya and WCA. Secondly, some improvement strategies are proposed to speed up the convergence of applied optimizers. Thirdly, a feature based search operator is utilized to improve the search performance of reported optimization methods. Finally, experiments are carried out based on the real traffic data in Singapore. The HS, WCA, Jaya, and their variants are evaluated by solving 11 cases of traffic networks. The comparisons and discussions verify that the considered metaheuristic optimization methods can effectively solve the LUTLSP considerably surpassing the existing traffic light control strategy.

1. Introduction

With the increasing population and number of vehicles, the traffic congestion becomes one of the major bottlenecks of the societal development. The importance of effective urban traffic signal control can never be underestimated owing to the exponentially increasing traffic demands for economic development, which has been significantly constrained by increasingly saturated space. A reasonable traffic lights scheduling strategy can reduce the delay time in an urban traffic network system [1–4].

An urban traffic network consists of a set of links connecting with each other via junctions. Each junction consists of a number of approaches and the crossing area [5,6]. An approach may have one or more lanes but has a unique, independent queue. Approaches are used by corresponding traffic streams (veh/h). Two compatible streams can safely cross the junction simultaneously, while antagonistic streams cannot.

In traditional traffic signal control, a signal cycle is one repetition of the basic series of stages at a junction, where each stage consists of simultaneous traffic light signals allowing a predefined compatible traffic streams to cross the junction simultaneously. The duration of a cycle is called cycle time [7,8]. For safety reasons, constant lost (or inter-green) times of a few seconds are necessarily inserted between consecutive stages to avoid interference between antagonistic streams. For each traffic light, the ratio of the green time and the red time within one cycle is called the split, and the delay between the starting times of green periods of two neighbouring traffic lights along the same traffic route is called offset [9,10].

There are basically four types of different traffic signal control strategies, i.e. fixed time strategies versus traffic responsive strategies, and isolated strategies versus coordinated strategies. Notable strategies proposed in the last few decades include, e.g., MAXBAND [6,11], TRANSYT [6,11], SCOOT [12], OPAC [13], PRODYN [14], CRONOS [15], and RHODES [16]. MAXBAND is a fixed time coordinated strategy, which considers a two-way arterial with n signals (junctions) and specifies the corresponding offsets so as to maximize the number of vehicles that can travel within a given speed rang without stopping at any signal (green wave).

In this paper, an urban traffic light control problem as a scheduling problem is formulated, aiming to reduce the total waiting time over a given finite horizon. A traffic network is described by a flow dynamic model similar to the Daganzo's cell transmission model [17]. One of the

* Corresponding author.
E-mail addresses: gaokaizh@aliyun.com (K. Gao), yzhang088@e.ntu.edu.sg (Y. Zhang), sadollah@ntu.edu.sg (A. Sadollah), ANTONIOS001@e.ntu.edu.sg (A. Lentzakis), rsu@ntu.edu.sg (R. Su).

http://dx.doi.org/10.1016/j.swevo.2017.05.002
Received 25 August 2016; Received in revised form 9 February 2017; Accepted 13 May 2017

Please cite this article as: Gao, K., Swarm and Evolutionary Computation (2017), http://dx.doi.org/10.1016/j.swevo.2017.05.002

key contributions in this model is to describe each outgoing flow rate as a nonlinear mixed logical switching function over the source link's density, the destination link's density and capacity, and the driver's potential psychological response to the past traffic light signals. This outgoing flow rate model makes the proposed approach applicable to both under-saturated and over-saturated situations.

The traditional concepts of cycles, splits, and offsets are not adopted in this framework, making the proposed approach fall in the class of model-based optimization methods, where each traffic light is assigned with a green light period in real time by the network controller.

Due to the large scale of an ordinary traffic network, which usually consists of hundreds of junctions and thousands of road links, the high computational complexity in optimization becomes the major hurdle for the implementation of the real-time scheduling strategies. To solve the traffic light control problem, many researchers proposed various optimization approaches. An architecture for traffic light cycles optimization is proposed based on Genetic Algorithm (GA) and Cellular Automata Simulators (CAS) [18], and a case study has been done to validate the architecture in a real-life traffic network [2]. Also, for the cycle program of traffic lights, Particle Swarm Optimization (PSO) based approach is proposed and worked together with a microscopic traffic simulator [19], and a case study in the real-life traffic network validated the significant profits of the proposed approach [4].

In the literature [20], a continuous traffic flow network model is discussed, in which the switching of the traffic light states is modelled as a discrete decision. The numerical discussion relied on the equivalent reformulation of the original problem and a mixed-integer discretization of the flow dynamics. Derived heuristics are employed to solve the large-scale optimization. In Ref. [21], distributed coordination of exploration and exploitation, and reinforcement learning are studied in a complex simulator and multiple objectives of traffic light control are discussed.

Among various approaches, metaheuristic optimization algorithms (e.g., GA, PSO and derived heuristics) are considered as a new trend for solving many real-life optimization and scheduling problems, e.g. permutation flow shop scheduling [22], robotic cell scheduling [23], route planning [24,25], traveling salesman problems [26], wireless sensor network [27], and so on and so forth.

Compared with commonly used optimizers such as GA and PSO, new metaheuristics try to overcome the weakness and problems seen in common metaheuristics. This is the first and main motivation behind of using new algorithms, which can be seen in the literature [28,29].

The curse of dimensionality usually happens in large-scale problems, and most optimization methods developed in 1970's are not fully designed for handling this type of problems. Owing to the complexity concern, many optimization methods have been proposed since 2000. The main reason of using such algorithms is the simple coding strategy and better performance reported by their developers in the literature.

In this study, three optimizers including harmony search (HS), water cycle algorithm (WCA), and Jaya algorithm have been implemented to solve the real-life large-scale urban traffic light scheduling problems (LUTLSP).

The Jaya is a simple and a recently developed metaheuristic proposed by R.V. Rao [28]. Compared with the most existing metaheuristic algorithms, the advantage of Jaya is that it does not require any algorithm-specific parameters and require only common controlling parameters (i.e., population size and number of iterations). The Jaya algorithm has been compared with several metaheuristics, e.g. GA and PSO [28]. The experiments and discussions verified the competitiveness of Jaya algorithm compared with the reported optimizers.

The WCA, inspired by the water cycle process in nature, has been proposed as a metaheuristic optimization method [29]. The surface run-off model (i.e., a phase in water cycle process) is simulated in the WCA in order to update current candidate solutions and generate new individuals. The efficiency and validity of the WCA has been examined for unconstrained, constrained engineering design problems, and truss structures [29–31]. Recently, different applications and improved versions of WCA have been implemented in the literature, finding optimal operation of reservoir systems [32], detecting optimum reactive power dispatch problems [33], rough set theory [34] and antenna array pattern synthesis [35].

The harmony search (HS) algorithm is a relatively new metaheuristic optimization method recently developed by Geem et al. [36] for solving combinatorial optimization problems. It imitates the music improvisation process of musicians. The HS and its variants have been employed to solve various optimization problems such as water distribution networks [37], flow shop scheduling problems [38,39], job shop scheduling problems [40], and knapsack problems [41].

Recently, the optimization results for small scale networks have been studied in the literature. It is worth mentioning that as the size of the network grows, the computational complexity in terms of number of design variables increases. In this paper, the goal is extending the small size network to the large scale and using recently developed optimization methods for tackling the large scale LUTLSP. Based on the advantage and successful applications of Jaya and WCA, novel discrete versions of these two algorithms have been developed for tackling the LUTLSP. Some improvement strategies are proposed to speed up the convergence of discrete Jaya and WCA. It is worth pointing out that as the HS, initially, was proposed for solving discrete optimization problems, therefore, there is no new discretization strategy used in the HS in this paper. For all applied optimizers, a feature based search operator is utilized to improve the search performance.

The remainder of this paper is organized as follows. Section 2 describes the mathematical model of LUTLSP and its constraints. In Section 3, the Jaya, WCA, and HS algorithms are introduced in details along with their improvements. Section 4 represents the experimental setup, comparisons, statistical tests, and discussions of the obtained optimization results in form of tables and figures. Finally, we conclude this paper with some highlighted points and future works in Section 5.

2. LUTLSP model and description

A traffic network consists of a set of links and junctions. For instance, a simple unidirectional traffic network is depicted in Fig. 1, where each junction has only two antagonistic traffic flows. In this paper, a discrete time model has been proposed based on the cell transmission. To simplify our technical discussions, some key notations in urban traffic signal scheduling problem formulation are listed as given in Table 1.

The following assumptions about a traffic network has been made [42], which is suitable for a deterministic analysis:

- The network entrance and exit models are known.
- The link turning ratios in the network are known.
- Each vehicle inside the network will leave the network, delayed only by traffic signals.

In the studied traffic flow model, the following types of constraints are considered: (1) the stage status constraints, (2) the link volume

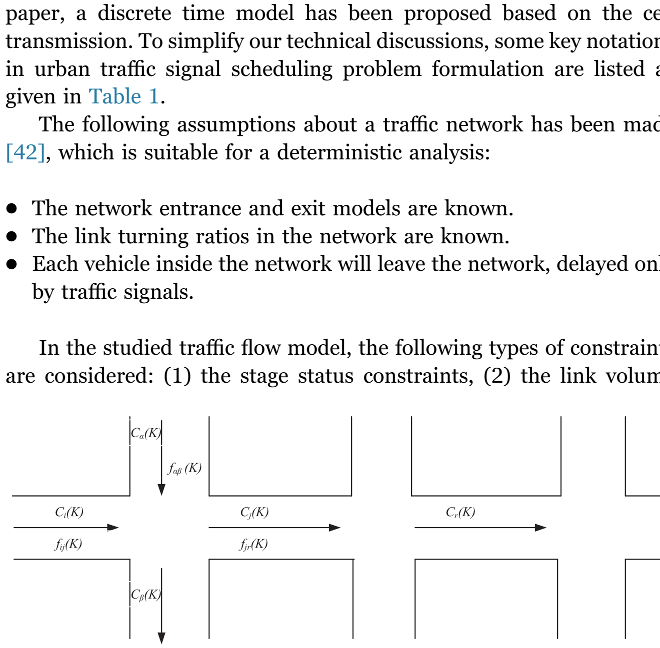

Fig. 1. A simple schematic view of a traffic network.