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Descent direction algorithm with multicommodity flow problem for signal optimization and traffic assignment jointly

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Dedicated to Professor Giulio Erberto Cantarella

Abstract

Network managers wish to optimize control parameters such as signal setting which are very related to the traffic assignment models. On the other hand traffic assignment patterns as an important instrument for predicting the amount of flow on network links are dependent to control decisions. According to the significance of this concept, some important papers about this mutually relation are reviewed in this paper. Then we implement a nonlinear algorithm on a minimal cost multicommodity flow (MCMF) problem to optimize some control policies subject to optimal flows. Although we take signal times into account, but this approach has a far more reaching application in urban network control and design. We employ a hybrid intelligent algorithm integrating decent direction algorithm and an interior point algorithm in a mutually consistent scheme for obtaining optimal signals and equilibrium flows. An example is given to illustrate the effectiveness of our scheme.

Keywords: Signal setting; Traffic assignment; Multicommodity flows

1. Introduction

Associate with the advances in travelling information systems, users of this systems are interested to choose shortest paths for their trips. Thus it is expected that optimization aspects become important over and over and be followed in real problems. On the other hand, due to the system managers' policies, each control parameter such as signal times, has an important influence on the definition of shortest path. The target of signal setting is to increase the level of service in the transportation system. Thank to this point of view, some customize softwares are produced for signal optimization, such as SIGNAL, SCOOT and TRANSYT. But with respect to their independency by traffic flows, maybe these are not complete. So, some of the researchers try to introduce these aspects jointly. This standpoint has been presented by Pavese [56] in 1968. Then in 1980, some contradiction examples were given by Smith [63], which showed the classic views

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such as "equisaturation" policy can not take optimal system with stable equilibrium. Besides, his examples illustrated these control systems may increase total time of users' journey up to 30%. Thus he proposed a new control system named as "PO" for obtaining maximum capacity and stability. Almost synchronously, Allsop and Charlesworth [5], employed a mutually consistent approach for signal optimization. In this scheme, in each step of algorithm, first by a nonlinear optimization technique, optimal signal times are found and then the results are reported to another level for assigning flows on the optimal pathes with respect to one equilibrium principle. Also, they used metamodel approach in their work which is a worthwhile idea in simulation optimization in recent works [10], i.e. polynomial interpolation for approximating the value of performance system was utilized. This idea is followed by many next engineers and scientists, e.g. an iterative procedure was made by Cantarella et al. [12] for equilibrium network traffic joint with optimal signal settings. However, Gershwin and Tan [32] revealed that signal timing and links flows which were obtained by Allsop and Charlesworth' idea are not optimal in general. Sometimes after, Marcotte [47,48] presented an exact scheme and some heuristic methods for signal optimizing and obtained good results on his examples. Besides, in recent works, Cantarella et al. [13] presented some new heuristics for lane layout and signal setting. Also Smith [64,65] gathered the mathematical bases of this problem. In 90's some attempts be happened under bilevel programming. For example, Heydecher and Khoo [39] gave signal timing optimization by sequentially linear approximation of traffic assignment. Also, Yang and Yagar [73] suggested a new and interesting idea with respect to sensitivity analysis to solve these joint problems. Also Cascetta [14], gave two conditions with respect to locally and globally optima for a given performance index. A classification of the methods for optimizing in these branches was published by Marcotte [48], Cantarella et al. [11–13]. Besides, a brief review on methods for signal optimization and traffic assignment was gathered by Ghatee [33].

In utilizing nonlinear algorithms [8] for signal optimization, we may notice to papers presented by Smith et al. [65] and Clegg [22]. They used the steepest descent algorithm on equilibrium flows. Also Chiou [18] used a mixed search with projected gradient method which was previously utilized by Sheffi and Powell [60]. Another interesting results has been given by experiments by Cascetta [14], Lee and Machemehl [44] which shows different methods may produce diverse solutions. This contradiction is derived from nonconvexity of problem. Also they asserted as much as the dimension of network increases, the rate of saturation increases. Chiou [19,20] utilized some of these nonlinear methods for signal optimization and more generally control problem joint with traffic assignment and gave some interesting methods and heuristic for finding their optimal solutions. Cipriani [21] embedded Armijo rule in steepest descent algorithm and found optimal signals in urban interchanges. Also, simulation optimization which combines a meta-heuristic algorithm such as genetic algorithm associate with assignment softwares such as PFE (Path Flow Estimator) is an important idea in recent work published by Ceylan and Bell [15,16].

We believe this concept may be improved by network flows algorithms [1]. For example in [30, Section 3] a collection of the network flows methods such as multiobjective shortest path with respect to different labels [4], gateway paths [46], K-shortest paths [49], K-similar paths [59], dissimilar paths [3], Pareto dissimilar paths [25,26], virtual paths [62], side constrained traffic assignment with column generation [43,67], constrained K-shortest paths [75], shortest paths with forbidden routes [69], stochastic shortest paths [51,52], multicriteria stochastic, time-varying paths [55] and fuzzy shortest path [54], was discussed. Also thank to the travellers' target to move through shortest paths, utilizing minimal cost multicommodity flow (MCMF) problem [6,41] appears as a reasonable choice. This concept is especially highlighted where ATIS (Advanced Traveller Information System) is extended. So we can employ this approach as a sub-procedure in place of traffic assignment algorithms. MCMF problems with integer flows can be solved by combining Lagrangian relaxation technique and branch and bound [28], also by price-directive or resource-directive decompositions. Besides Dantzig-Wolfe decomposition which iteratively solves Lagrangian subproblems has played an important role for multicommodity problem on column generation techniques, (see e.g. Ford and Fulkerson [29], Ahuja [1, Section 17] or Ghatee [30, Section 6] for a survey). Also some above addressed approaches such as K-shortest paths, K-similar paths or dissimilar paths can be utilized for multicommodity problem with path-flow formulation as a heuristic in place of column generation [34]. Also some of these approaches which proposed by Miller-Hooks and Mahmashani [51,52] or Okada [54] can be utilized to model uncertainty in transportation. For example, with respect to same idea some combinatorial algorithms for transmitting one commodity were proposed in [36] and for stochastic version with two-commodity in [45].