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Robust adaptive strategies for the guidance of users in road networks

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Abstract

We present an algorithm for optimal guidance of users in road networks. It is a "stochastic-on-time-arrival (SOTA)"-like algorithm which calculates optimal guidance strategies with reliable paths, for road network origin-destination pairs. Our contribution consists here in extending an existing SOTA algorithm, in order to include robustness of the guidance strategy, towards path failures.

The idea of SOTA algorithms is to calculate the maximum probability of reaching a destination node, starting from any node of a road network, and given a time budget. This calculus gives the optimal path for every origin-destination pair of nodes in the network, with an associated optimal adaptive guidance strategy.

We propose here an extension of this approach in order to take into account the existence and the performance of alternative detours of the selected paths, in the calculus of the guidance strategy. We take into account the fact that one or many links of the selected optimal path may fail during the travel. We then consider that users may be sensitive to path changing. That is to say that they may prefer paths with efficient alternative detours, with respect to paths without, or with less efficient detours, even with a loss in the average travel time, and/or in its reliability.

In order to take into account such behaviors, we propose a model that includes the existence as well as the performance of detours for selected paths, in the calculus of the travel time reliability. This new way of calculating travel time reliability guarantees a kind of robustness of the guidance strategies.

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1. Introduction

The optimal guidance problem of users in transportation networks knows a renewed interest in recent years. This is due mainly to the fast development of new technologies of information and communications. This development has made possible and necessary the development of real-time mobile and/or GPS computing applications, where adaptive algorithms give optimal solutions, updated according to the traffic conditions, and with better guarantees in terms of reliability, robustness and risk, compared to prior solutions. Optimal routing in transportation networks with highly varying traffic conditions is a challenging problem due to the stochastic nature of travel-time on links of the network. Depending on the users' preferences, an optimal route might need to consider notions of both the expected value the travel-time and its reliability (variance). This is a multi criterion optimization problem that is in general hard to solve.

Loui (1983) defined a formulation of routing optimality as a route with the Least Expected Time (LET).The LET problem has been well investigated and numerous efficient algorithms have been proposed to solve the different variants of the problem; see for example Fu and Rilett (1998), Miller-Hooks and Mahmassani (2001), waller and Ziliaskopoulos (2002). However, there are several frameworks in which the LET solution is not adequate, because it does not take into consideration the variance of travel-time distributions and does not give any guarantee on its reliability.

A very natural definition of a reliable optimal path is given in the Stochastic On Time Arrival (SOTA) approach, presented by Frank (1969). This formulation permits yet to obtain satisfactory adaptive solution in terms of travel time reliability. A formulation of the SOTA problem using stochastic optimal control is presented by Bertsekas (2005). Fan and al (2006) formulated it as a stochastic dynamic programming problem, and solved it using a standard successive approximation (SA). However, in presence of cycles on the network, as is the case with all road networks, there is no finite bound on the maximum number of iterations required for the convergence of the algorithm. As an alternative, Nie et al. (2006) proposed a discrete approximation algorithm for the SOTA problem which converges in a finite number of steps and runs in pseudo-polynomial time.

Samaranayake et al. (2012) presented a number of optimization techniques in order to speed up the computation time of the algorithm. The approach includes a label-setting algorithm based on the existence of a uniform strictly positive minimum link travel-time, advanced convolution methods centered on the Fast Fourier Transform and the approch of zero-delay convolution, and localization techniques for determining an optimal order of policy computation. However, the performance of all of these algorithms is limited by the large search space of the problem. Sabran et al. (2014) have shown how preprocessing methods can be used to further reduce the computation time of the SOTA problem. Unfortunately, the structure of the SOTA problem formulation limits the types of preprocessing methods that can be used for this problem, and prevents massive running time reductions in the deterministic case. Recently, Kobitzsch et al. (2014) presented a novel approach to reduce the immense computational effort of stochastic routing based on existing techniques for alternative routes. In an extensive experimental study, they showed that the process of stochastic route planning can be speed-up immensely without sacrificing much in terms of accuracy.

In this paper, we focus on the reliable path problem that aims to find an adaptive optimal routing strategy, which takes into account the existence and the performance of alternative detours of the selected paths in the road network. That is to say, we assume that one or many links of the selected optimal path may fail during the travel, and that users may be sensitive to path changing. Some users may then prefer paths with efficient alternative detours, with respect to paths without or with less efficient detours.

Our approach is based on the idea of Frank (1969) considering that a reliable path from a given origin to a given destination maximizes the probability of realizing a travel time less than a given time budget. Thus, we propose an adaptation of this approach introducing robustness in the selection of the optimal path. We base here on the routing model of Samaranayak (2011). From the probability distributions of travel times through the links of the network,