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Network traffic control based on a mesoscopic dynamic flow model

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ABSTRACT

The paper focuses on Network Traffic Control based on aggregate traffic flow variables, aiming at signal settings which are consistent with within-day traffic flow dynamics. The proposed optimisation strategy is based on two successive steps: the first step refers to each single junction optimisation (green timings), the second to network coordination (offsets). Both of the optimisation problems are solved through meta-heuristic algorithms: the optimisation of green timings is carried out through a multi-criteria Genetic Algorithm whereas offset optimisation is achieved with the mono-criterion Hill Climbing algorithm. To guarantee proper queuing and spillback simulation, an advanced mesoscopic traffic flow model is embedded within the network optimisation method. The adopted mesoscopic traffic flow model also includes link horizontal queue modelling. The results attained through the proposed optimisation framework are compared with those obtained through benchmark tools.

1. Background and motivation

This paper proposes a Network flow based Traffic Control method carried out through two successive steps: the first step refers to each single junction optimisation (green timings), the second to network coordination (offsets).

Furthermore, the adopted traffic flow modelling is a mesoscopic packet based approach, TRAFFMED (Traffic Analysis and Flow Forecasting Mesoscopic Dynamic) developed from an existing model for evacuation plan design (Di Gangi, 2011).

In the following the most used approaches for network traffic control are summarised with respect to the existing literature.

1.1. Strategies for network signal setting design

In general, strategies for signalised junctions may be classified as flow based (A) or vehicle arrival based (B).

In the case of flow based strategies (A), the input data are aggregate variables. Such strategies can be implemented as:

(A.1) fixed timing plans (pre-timed), as long as the settings are constant over periods of the day, depending on the flow evaluation based on historic values;

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(A.2) timing plan selection, when the plan is periodically updated in real-time by choosing a plan from among a library of pre-timed signal plans depending on detected flows;
(A.3) timing plan computation, when the plan is periodically updated in real-time by computing a new plan depending on detected flows.

In the case of strategies based on disaggregate input data (B), the signal settings are obtained by detecting vehicles approaching the junction.

1.1.1. Flow based strategies

One of the most used flow based network control strategies (strategy A.1) is the TRANSYT method, first developed by Robertson in 1969 and then enhanced in successive releases (Vincent et al., 1980; Chard and Lines, 1987; Binning et al., 2010). Such a method is based on traffic modelling through cyclic flow profiles of arrivals at each junction; results of the traffic model are used to compute a performance index, P.I. (i.e. the sum of a weighted linear combination of delays and the number of stops per unit time) assuming signal timings and node offsets as optimisation variables and stage composition and sequence as input. In recent versions apart from the Platoon Dispersion Model (PDM), the Cell Transmission Model (CTM; see Daganzo, 1994) can be used for traffic flow modelling; meta-heuristic algorithms (Hill Climbing or Simulated Annealing) are applied for signal setting optimisation.

Notwithstanding their wide-spread use, fixed timing strategies may perform poorly when actual flows are greatly different from those used for optimisation due to within-day fluctuations, as well as day-to-day variations. In order to overcome such a limitation, some authors have developed network control strategies based on real-time observed flows, despite them generating high operational costs (in terms of sensors, communications, local controllers, etc.). Methods which fall within such a group are SCOOT (Split Cycle Offset Optimisation Technique; Hunt et al., 1981; Bretherton et al., 1998; Stevanovic et al., 2009) and SCATS (Luk, 1984; Stevanovic et al., 2008). These require traffic data to be updated on-line in order to get input flow for the optimiser (such as TRANSYT, Binning et al., 2010) and arrange green timings, offsets and cycle time duration. These methods match the off-line approach with on-line data (strategies A.2 and A.3).

Whichever optimisation method is employed, Network flow based Traffic Control strategies require within-day-dynamic traffic flow modelling. Several approaches can be adopted for within-day dynamics in a transportation network. They can be classified with respect to: (i) users' variables, which can be aggregate variables, such as path link flow and link density or disaggregate variables such as trajectory and the position of a single user; (ii) the level of service variables, such as travel time or space mean speed which may refer to a flow of users or to each single user. Three main groups of within-day dynamic models are identified:

- Macroscopic models where users' behaviour variables are aggregate (link density or entry flows can be obtained from the vehicle position on the link) as well as level of service variables (space mean speed, link performance functions are derived from fundamental diagram);
- Mesoscopic models where users' behaviour variables are disaggregate (packets of users or single users are considered; link density or entry flows can be obtained from packets/users position on the link) and the level of service variables are aggregate (such as space mean speed; link performance functions are derived from the fundamental diagram);
- Microscopic models where users' behaviour variables are disaggregate (single users are considered; link density or entry flows can be obtained from the users' position on the link) as well as the level of service variables (time speed and link performance functions are derived from the drivers' behaviour models such as car-following models).

Almost all Network flow based Traffic Control strategies proposed in literature use macroscopic models (see Cantarella et al., 2015 for an in depth analysis of the state of the art), whereas very rarely, microscopic models are used in embedded optimisation methods. Very few authors have investigated the effect of traffic management in a mesoscopic traffic simulation (DYNAMIT; Ben-Akiva et al., 1996; DYNASMART, Jayakrishnan et al., 1994; CONTRAM; Leonard et al., 1989). This paper proposes a Network flow based Traffic Control strategy (NTC TRAFFMED) using a mesoscopic discrete packet modelling. Indeed, major emphasis is not placed on the mesoscopic model but on the integration within the optimisation procedure. To the authors' knowledge such an approach has been never pursued.

The State of the art in terms of mesoscopic traffic flow models is discussed in more details in the following Section 1.2.

1.1.2. Vehicle activated strategies

For the sake of completeness, a brief review on network traffic responsive control strategies (i.e. vehicle-actuated control), which require knowledge of vehicle arrivals (strategy B), has been hereunder developed.

DYPIC (Robertson and Bertherton, 1974) is a backward dynamic programming algorithm based on the rolling horizon procedure for the heuristic solution search. Three steps can be identified: first of all, a planning horizon is split into a 'head' period with detected traffic information and a 'tail' period with synthesised traffic information; secondly, an optimal policy is calculated for the entire horizon and implemented only for the 'head' period and finally, for the next discrete time interval, when new detected information is available, the process rolls forward and repeats itself. Gartner (1983) gives a detailed description of the rolling horizon approach in OPAC. Rather than aiming at dynamic programming, OPAC uses a technique named Optimal Sequential Constrained Search to plan for the entire horizon, penalising queues left after the horizon.