Review of Adaptive Traffic Control Principles and Deployments in Larger Cities

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Abstract

Adaptive Traffic Control Systems (ATCSs) have been in practical use since early the 1980s. However, for all these years we have seen less than 50 ATCS deployments in the U.S and only few hundred in the entire world. At the time when oversaturated traffic conditions and recurrent lack of funding for retiming signals represent major problems in urban traffic control, it is timely to revisit the old and explore new ATCS available worldwide. The focus of this paper is on major ATCSs deployed worldwide. The paper specifically addresses few ATCS deployments in large metropolitan areas and compares differences between such ATCS deployments and those from smaller urban areas. Major topics covered in the paper are: working principles, system architectures, implementation aspects, and benefits and costs of ATCS deployments. The paper is based on a comprehensive literature review on the ATCS. In addition, the paper facilitates results from a survey of the ATCS users, who are asked to comment on ATCS working principles, implementation issues, configuration and traffic conditions of ATCS installations, system architecture, detectors and communication, and efficiency of ATCS performances.

The first part of paper provides a short history of ATCS and chronology of their developments. Then, major systems such as SCOOT, SCATS, RHODES, OPAC, MOTION, BALANCE, UTOPIA, etc. are classified based on adaptive traffic control logics used by these systems.

The second part of paper presents preliminary findings of a survey done for the USA National Cooperative Highway Research Program's Synthesis study on ATCS. Results from the survey provide insight on what ATCS' users think about current ATCS deployments in the US and other countries throughout the world. The survey covers questions related to:

- Network configuration and traffic characteristics of the ATCS deployment sites
- Major reasons for installing ATCS
- Detection technology and hardware and software requirements and issues
- Communication media and integration of ATCS in Traffic Management Systems
- Quality of the training and needs for future training
- Operations and maintenance of ATCS
- Costs of installation, operation, and maintenance
- Evaluation studies and benefits of the ATCS deployments
- Public perception on the ATCS and lessons learned

Special attention is directed to ATCS deployed in ten large cities and urbanized areas. Responses from ATCS users in Sydney, Los Angeles, Toronto, Detroit etc. are used to draw conclusions on what ATCS users in large metropolitan areas think about their ATCS deployments and how their experiences differ from the rest of respondents who mostly use ATCS in smaller towns.

Evolutionary algorithms for traffic signal optimisation: A survey

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Introduction

The complexity of modern traffic control systems makes their design and optimisation a complex task. Nevertheless, well configured traffic systems are essential to avoid unnecessary congestion in the traffic network and to reduce the negative economic and environmental impact of traffic. Evolutionary algorithms – which are nature-inspired optimisation heuristics – can support traffic engineers in the optimisation process. This paper gives a short introduction to evolutionary algorithms, presents a survey of their application to traffic signal optimisation, and concludes with a summary.

Evolutionary algorithms

Evolutionary algorithms (EAs) are randomised optimisation heuristics that mimic biological evolution to tackle optimisation problems. Their general scheme is simple (compare Figure 1): Starting with a set (called population) of randomly generated initial solutions, an EA selects solutions with a relatively high quality from its population as parents, which are then combined and locally modified by crossover and mutation operators to form new offspring solutions. Based on their quality, some of the parents and offspring are selected to form the next generation of solutions that replaces the old population. This process is repeated until a stopping criterion (usually a maximum number of generations, a time limit, or some quality level) is reached. Selection, crossover, and mutation are randomised operations, where good solutions have a higher chance to survive and generate offspring. Therefore, the overall quality of solutions is likely to improve over time while the random influence of mutation helps to prevent premature convergence on some local optimum.

EAs have been successfully used to solve problems with several conflicting objectives. In the case of more than one contradicting objective, a problem has no single optimal solution but a set of solutions which are all "Pareto-optimal". These solutions form different trade-offs among the contradicting objectives, i.e., they cannot be improved in any objective without worsening at least one other objective. For these multi-objective problems, special multi-objective EAs have been developed. Instead of combining the different objectives into a single fitness function (e.g., by using a weighted sum) and searching for a *single* optimal solution afterwards, multi-objective EAs search for a *set* of "Pareto-optimal" solutions.

Due to the simple working principle of single- and multi-objective EAs and the fact that both are black box algorithms that can be applied to any problem where a quality (or fitness) can be assigned to a solution, EAs are widely used in many real world optimisation problems. Since the beginning of the 1990s they have also been applied to the optimisation of traffic signal controls. Traffic simulations or approximation formulas can be used to estimate the fitness of the evolved control strategies.

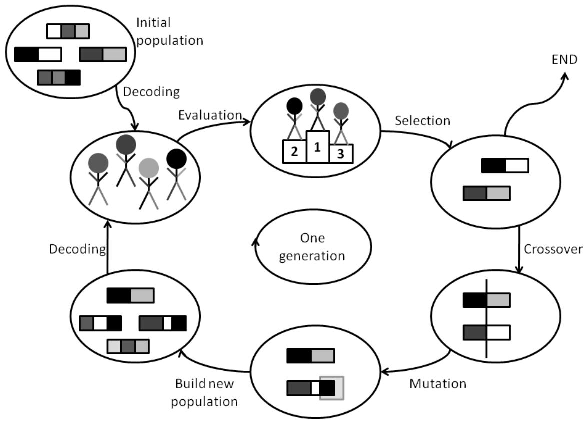

Figure 1: Working principle of evolutionary algorithms

Evolutionary algorithms for traffic signal optimisation

Since the 1990s, several authors applied EAs to traffic control problems. The considerable number of publications can be grouped with respect to the following criteria:

- *Fixed-time vs. traffic-actuated controllers:* In general, the optimisation of traffic-actuated controllers is more complex due to the larger number of available parameters. Therefore, publications dealing with fixed-time controllers should be distinguished from those optimising traffic-actuated controllers.
- *Isolated intersections vs. networks:* While some publications focus on single intersections, others consider networks. In general, the optimisation of networks is more complex, since the necessary coordination among the network's intersections induces additional parameters.
- *Single- vs. multi-objective optimisation:* While in single-objective optimisation only one criterion is considered for optimisation, multi-objective approaches deal with several (possibly contradicting) objectives (common objectives in traffic signal optimisation are delays and stops).
- *On-line vs. off-line optimisation:* Optimisations can be performed during the design time of a traffic system based on historic or expected traffic demands (i.e., off-line) or in parallel to the system's operation based on the current traffic flows (i.e., on-line). While on-line optimisations are generally more flexible, they typically have to cope with strict time requirements.

The first work known to the authors that used EAs for signal timing determination was published by Foy et al. in 1992 [4][1]. In a simulated Manhattan-type network of four simple two-phase intersections, cycle length and green time splits were optimised for a fixed traffic situation. The minimisation of the resulting delays served as the objective. According to Foy et al., their EA found near-optimal solutions which proved the feasibility of EAs for the task.

Stevanovic et al. [6] focus on the optimisation of traffic networks: Their test case was an arterial road of twelve intersections in Park City, USA. They optimised cycle length, offsets, phase sequences, and green splits of the networks' intersections, trying to minimise a performance index that combines delay times and stops into a single objective. The controller considered in their work was a traffic-actuated NEMA controller, the microscopic traffic simulator VISSIM was used for fitness evaluation. Solutions discovered by the EA outperformed timing plans found by SYNCHRO – a traditional optimisation tool – by at least 8%.

Multi-objective approaches are discussed by Sun et al. and Branke et al. among others: Sun et al. investigated the use of NSGA-II – a multi-objective EA – for signal timing optimisation [7]. Delay times and stops were minimised for a two-phase isolated intersection controlled by a fixed-time controller. Approximation formulas by Webster and Akcelik served as objective functions in their experiments.

Branke et al. used NSGA-II for the optimisation of an isolated intersection at Karlsruhe, Germany, that was equipped with a traffic-actuated VS-Plus system [1]. Again, delay time and number of stops served as objectives, but controller settings were evaluated with the help of the simulation software VISSIM. Solutions found by NSGA-II outperformed a reference solution provided by a traffic-engineer with respect to the considered objectives.

In all previous references, EAs have been used for the off-line optimisation of traffic control systems. The on-line use of EAs has only been investigated recently: The research project TRAVOLUTION investigates the use of EAs for network-wide on-line optimisations [3][2]. An EA is used for the optimisation of a frame signal plan that specifies the network-wide cycle time as well as intersection specific offsets, phase sequences, and time frames bounding possible phase endings. Based on the frame signal plan, local traffic-actuated controllers can adapt the green times at each intersection within the specified time frames.

In TRAVOLUTION, optimisation is aimed to minimise a single-objective problem that aggregates the delay at all intersections. Evolved frame signal plans are evaluated using the mesoscopic traffic flow model of the traffic control system BALANCE. The flow model represents the network's traffic demands on-line.

The approach (which is a developed version of an off-line system presented previously in [2]) has been evaluated in a field test at Ingolstadt, Germany, which includes 46 intersections within the city's main road network. The intersections are grouped into three sub-networks for which frame signal plans are separately optimised. Frame signal plans evolved by an EA were compared to a basic scenario having only local actuated control and to frame signal plans optimised by a hill climber that is part of BALANCE. Using the EA, delays could be reduced by 21% compared to the basic scenario and by 10% compared to the hill climber. The number of stops were reduced by 17% and 8%, respectively.

The use of EAs for on-line optimisations is also investigated in a project on Organic Traffic Control. In [5], an EA is combined with a Learning Classifier System (LCS) – which is a rule-based on-line learning mechanism – in order to form an adaptive learning intersection control system. While the LCS is responsible for the on-line selection of signal plans (based on detected traffic flows at the intersection), an EA is used to evolve necessary signal plans that are included in the LCS' rule set. For two intersections located at Hamburg, Germany, simulation studies using the microscopic simulator AIMSUN showed that delays could be reduced by 6% to 12% compared to a reference solution provided by a traffic-engineer. Recently, the approach has been extended to traffic networks [8]. In contrast to TRAVOLUTION, the cycle time and offsets are determined by a decentralised collaboration protocol among participating intersections.

Summary

Since their first application to a traffic signal optimisation problem in the beginning of the 1990s, EAs have been widely used for traffic signal optimisations by many researches from different fields of science. Most of the published results report EAs to be competitive to traditional optimisation approaches or hand-made signal plans, often indicating that evolved results could even outperform the former reference solutions. Therefore, EAs can support traffic engineers in designing and optimising traffic signals.

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Application of High Resolution Traffic Signal Controller Data for Platoon Visualization and Optimization of Signal Offsets

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Abstract

This paper introduces the Purdue Progression Diagram (PPD) as a visualization tool for evaluating coordinated arterial operations. This diagram plots the arrival time of each vehicle at the intersection using input from setback detectors, in combination with information about the phase state (red and green interval). On a detailed level it is possible to view the arrival of each platoon relative to the provided green time. At a network level, the performance of the green band can be qualitatively evaluated. Quantitative measures can be extracted from aggregation of the data for system management and optimization. Example data from a four intersection signalized arterial system in Noblesville, Indiana is used to illustrate the concepts introduced in the paper.

Modellbasierte Netzsteuerungen – Neue Algorithmen und aktuelle Evaluierungsergebnisse von Motion

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English Abstract

Adaptive network control systems are more and more recognized in Germany and its neighbor countries, as they make an increase in transport quality possible. A major player contributing to this progress is Motion which up to now has been implemented by Siemens in more than ten cities either in Germany and internationally. Based on an hierachical approach, which locates the adaptive part in the traffic center, it is sufficient that the model based control methods run an adaptation of the controllers only every 5-15 minutes. This allows for some decisive changes in structure and algorithms of the network control methods:

- There is no need for traffic state estimation on a 1-second time scale. State estimation algorithms can be used that work with aggregated data, based on a minute or cycle time aggregation.
- Missing aggregated detector measurements can be replaced by methods using averaged values without the need to model them in a 1-second time discretisation.
- There is enough CPU time to run extended algorithms for the optimisation for a network wide coordination. By this fact a system wide optimium can be reached in principal.

To substitute missing or faulty detector count values within Motion, a new algorithm is presented, that isn't based on the daily patterns of measurements, but takes into account recent measurements of neighbouring detectors. For each of the detectors used by Motion the measurements are collected in histograms, showing the frequency of each measurement value relative to the frequency of all other values measured on the respective detector.

In case of a measurement failure the histograms of the failed detector and its neighbour detectors are accumulated to sum curves, standardized by 100%. The recent flow values measured on the neighbouring detectors are reflected by their individual sum curves, producing specific percentage values. The percentages lead to an average value, which is finally applied to the sum curve of the failing detector. The resulted flow value can be used as substitution for missing measurements. Please see "Abbildung 1" for details.

In the second part a newly developed optimisation algorithm for coordination calculation is presented in its basic approach principles. This algorithm will be published in detail in the next time.

In the last section of the paper recent evaluation results of Motion in the German city of Muenster (North-Rhine Westphalia) are presented. Motion in Muenster was deployed in order to optimise 24 controllers in a line, which had local traffic actuation and public bus prioritisation. During the morning peak hour an improvement of 35% / 27% (inbound traffic / outbound traffic) in waiting times and 35% / 12% in number of stops could be achieved against a manually well-planned coordination. During the evening peak hour improvements of 33% / 21% in waiting times and 30% / 26% in number of stops could be reached.