NICTA & RTA PARTNERSHIP FOR TRAFFIC CONTROL INNOVATION

Christian Chong-White, Roads and Traffic Authority of NSW, Sydney, Australia

Bernhard Hengst, Making Sense of Data Research Group, NICTA, Sydney, Australia and Computer Science and Engineering, UNSW, Sydney, Australia

ABSTRACT

NICTA and the New South Wales Roads and Traffic Authority (RTA) have formed a partnership to increase the effectiveness of existing traffic and transport infrastructure using smart technology. The aim is to research and develop new generation traffic control systems to tackle congestion that is estimated to currently cost Australia alone about $10 billion annually. This paper outlines the technical, methodological and collaborative nature of the relationship and shows how the parties complement each other’s experience and expertise. The research benefits from two live RTA contributed test-beds; a traffic signal controlled intersection in Sydney, and a highway roundabout in the Illawarra region. At a high level, the intended design direction of advanced real-time traffic control systems using video sensors, traffic models and optimisation techniques for flexible signal group control, is discussed.

INTRODUCTION

NICTA and the New South Wales Roads and Traffic Authority (RTA) have formed a partnership under the name of Smart Transport and Roads (STaR) in the Intelligent Transport Systems area. The aim is to increase the effectiveness of existing traffic and transport infrastructure using smart technology. This partnership stands on the shoulders of a long history of practical developers that laid the foundations of the successful Sydney Coordinated Adaptive Traffic System (SCATS). The project - as will be explained in this paper - has already motivated new methods of traffic control algorithm modelling and analysis, and the creation of sophisticated practical test beds using traffic sites.

The aggregate social cost of road traffic congestion is estimated by the Bureau of Transport and Regional Economics to have cost Australia $9.4 billion in 2005. This cost is estimated to escalate to $20.4 billion by 2020 under a ‘business as usual’ scenario (BTRE 2007). The aspirational objective of STaR is to reinvent urban transport management in part to mitigate these intimidating statistics. The aim is to reduce travel times, reduce ‘grid-lock’ incidents, reduce congestion, improve safety, improve efficiency of public transport, and to maximise value and extend the life of the investment in roads through the better utilisation of existing infrastructure.

In the rest of this paper, a brief review of SCATS will be given to provide a broader overview of the STaR project. The approach taken for the design, testing and evaluation of future signal group control algorithms will then be discussed.

SCATS BACKGROUND

SCATS is a wide-area traffic control and management system developed and maintained by the RTA. SCATS is operating, at last count, across the world at well in excess of one hundred cities,
that together cover some twenty five thousand SCATS-controlled traffic intersections (TSB 2007).

SCATS provides an integrated control and communication platform which includes

- traffic signal control software
- central monitoring software
- traffic management and coordination software.

For example, the one NSW SCATS system communicates in real-time across an area of 800,642 km² (ABS 2007) and controls 3664 controlled intersections (TSB 2007).

SCATS history can be traced back to the first installation of traffic signals in Sydney in 1933. From that moment forward the importance of traffic signal control to the social and economic activity in Sydney and NSW has motivated significant technical and financial investment by the State on systems which provide responsive control of traffic signals. It is from this investment that SCATS and associated products have evolved, and continue to evolve. For example, SCATS has been interfaced to a bus priority system (Lake and van Drempt 2003) to offer different vehicle-types different levels of service; and SCATS (called SCATSIM) can now operate within a variety of traffic micro-simulation applications to control virtual traffic environments for testing and analysis purposes.

The NICTA-RTA partnership builds on this background by contributing leading-edge information and communication technology (ICT) innovation to the development mix.

THE SMART TRANSPORT AND ROADS PROJECT

The formal research collaboration between the RTA and NICTA known as the STaR project builds on the respective strengths of both organisations. There is a clear need to continue the development of the SCATS system exploiting new and emergent technologies. The RTA is contributing field research opportunities and technology trials. It has extensive domain knowledge and capabilities, and provides an established path to market. NICTA provides additional research funding, research skills, ICT industry collaboration, and scientific credibility.

The STaR project was initiated following an exploratory workshop between the partners in November 2004. At this workshop key RTA needs were identified, prioritised, and research topics selected where NICTA felt best able to contribute. The partners subsequently agreed on four work-packages that comprise the current STaR project.

These work-packages are:

**STaR Com - Wireless Mesh Communications**

STaR Com aims to develop networking technologies for a reliable, low-latency, and secure communication platform for traffic control systems. Wireless mesh networks hold out the promise of a cost-effective solution which is easily deployable and expandable to new nodes and new applications. The idea is to deliver critical data reliably and in a timely manner through routing algorithms that exploit the many redundant wireless links between nodes. The routing algorithms incorporate robustness mechanisms to protect the network from collapsing should the wireless nodes be compromised. Techniques for automatic fault prediction, detection, and recovery augment the wireless mesh network with a self-healing capability that reduces maintenance. On-street test-beds developed across selected areas of Sydney are used to validate and demonstrate the technologies.
STaR Sense - Real Time Traffic Sensing and Surveillance

STaR Sense aims to develop video sensors and surveillance technologies capable of providing information about traffic movements for traffic control applications. Traffic flow measurement and vehicle classification together with stopped vehicle detection and the identification of traffic incidents and anomalies offer improved situation awareness for adaptive traffic control systems and provide for more rapid response to traffic incidents. The work-package is developing solutions which can make use of constrained position/angle cameras mounted on existing traffic signals under a range of weather and lighting conditions and the presence of heavy shadow, occlusion and congestion.

STaR Control - Real Time Traffic Control and Modelling

The aim of STaR Control is to research and develop the control algorithms and applications that underpin SCATS. The project employs machine learning and constraint programming technologies to explore new model-based signal group traffic control systems. Prototype control systems are being developed and field-tested for individual intersections and multiple intersection traffic networks. It is driven by signal group control switching constraints and optimisation criteria, such as minimising the number of stops and delay. The STaR Control project is the main focus of this paper and more related details will be provided in subsequent sections.

STaR UI - User Interface

STaR UI seeks to use multimodal user interface technology to assist operator interaction with control room applications. The STaR User Interface project introduces multimodal user interaction into the traffic control systems to improve the efficiency of the operations. The major area of research evaluates the cognitive load control-room operators experience and aims to better balance the way tasks are allocated within the team and presented to individual operators.

Hereinafter, the paper focus is directed towards STaR Control and to some extent also, STaR Sense. In the next two sections the project’s objectives and the concept of signal group control are introduced. An overview is given of the systems design that is intended to future-proof SCATS. Some of the machine learning techniques and evaluation ideas being employed are also discussed.

STAR CONTROL PROJECT DESCRIPTION

The objective of the STaR Control project is to research and prototype flexible real-time traffic control algorithms using advanced traffic models integrating information available from various traffic sensors. Current traffic controllers are based on surprisingly simple microprocessor technology when compared to current everyday personal computers. However, the configuration of these controllers is highly specialised, particularly to adapt them to increasingly complicated traffic site designs. The traffic control problem is facing a number of challenges:

- Uncharacteristic intersection layouts are becoming the norm rather than the exception which increases problem complexity.
- Increasing availability of different detection methods each with unique characteristics, e.g., electronic tag readers, vision systems.
- The move away from considering traffic as a homogeneous quantity towards differentiation, e.g., prioritising public transport over private vehicles, and user pay schemes such as toll roads, potentially road pricing.
The highly specialised nature of existing controller configuration techniques, together with an aging existing expert workforce and a move towards a more transient expert workforce.

Increasing political and social demands to: (a) improve traffic safety, e.g., signalisation, (b) minimise traffic-related negative social and environmental impacts, (c) extract maximal efficiencies out of established traffic networks, and (d) manage incidents that have significant impacts on traffic networks.

The current research attempts to address these issues by developing a transparent and consistent control methodology. In particular the aim is to:

- Achieve 5% reduction in delays and vehicle stoppages with existing road infrastructure.
- Contribute to the next generation of SCATS with sensor fusion, modelling and optimal control research and technology.
- Make the RTA a more informed buyer.

A key strategy is to explore the increased flexibility afforded by signal group control. The project is still in the early stage of research and development and initial experiments using micro-simulation have indicated the potential for significant reductions in delay and the number of stops.

**SIGNAL GROUP CONTROL**

The first order need for traffic signalisation is often motivated by either the need to address traffic safety and/or ensure an equitable distribution of scarce resources; once addressed, the second order need becomes optimising network efficiency. Optimising traffic signal control often involves improving the time allocation of the scarce road-area resource to conflicting, and therefore competing, traffic movement demands.

In generic mathematical terms, 'an optimised, more-constrained system will always produce either: (a) an equal solution, or (b) a less optimal solution, than an alternative lesser constrained but otherwise similar optimised system.' It is in this spirit that the methodology of signal group control (SGC) is introduced in this paper, and it is this spirit that, in part, motivates the STaR Control project.

SGC is a term given to controlling the display of individual traffic signals as maximally independent units insofar as possible. SGC aims to remove unnecessary control constraints, such as `phase constraints' that are common to current traffic controllers. Phase constraints associate non-conflicting signal groups and corresponding movements into sets where all signal groups in the set run concurrently. The disadvantage of the phase approach is that often the time allocation is made on the phase level producing a `one size fits all' approach. The effect is less optimised resource allocation to signal groups/movements. This `inefficiency effect' is more pronounced the more variation in demand that exists across the signal groups within the phase. Current controllers attempt to bend the phase concept to reduce these inefficiencies with some success; however, this rectification is limited by the complexity needed to work-around the fundamental phase concept. The solution is to remove the phase as a fundamental concept in the control methodology.

The motivation behind SGC is to 'free up' the control system to allow for better optimised traffic control decision-making. The effect aims to deliver improved outcomes for road and pedestrian users, and minimise adverse transport-related societal and environmental impacts.

SGC on its own does not ensure optimal decisions. Rather, SGC attempts to minimise control constraints that each act as inhibitors on the potential scope of optimisation. It is incumbent on the optimisation method to fully capitalise the potential scope offered under SGC. It is for this reason that the STaR Control project is considering SGC in tandem with advanced optimisation methods.
ADVANCED CONTROLLER DESIGN

Echoing Ashby's first law of cybernetics (Ashby and Conant 1970) formulated the principle that a good regulator, by necessity, must include a model of whatever it is that it is controlling. The STaR controller design explicitly includes a dynamic predictive model of the traffic and signal state.

A realistic traffic model is complex and is described by many state variables. In principle, machine learning techniques, for example Markov Decision theory, can find optimal control solutions once a predictive model is available. In practice, the computational complexity of high dimensional problems makes it impossible to find optimal solutions in real-time. Bellman (1961) referred to this issue as the 'curse of dimensionality'. The STaR controller design is based on formal machine learning techniques and overcomes the curse of dimensionality by judicious approximations that find near-optimal solutions.

At a high level the STaR Controller agent involves two main components, a model and an optimiser as illustrated in Figure 1 also shows the control agent interacting in real-time with the traffic domain. This interaction involves input from sensors such as loop detectors and cameras, and the control output providing the light switching policy.

MODELS

This paper argued in the previous section that a model is a key component of the overall controller design. The STaR controller uses several different traffic models.

The control structure is hierarchical with models of traffic features connected to form individual traffic intersection models. Intersection models in turn are abstracted and combined to form whole traffic regions, albeit at a coarser granularity. This type of layered modelling by decomposition into a hierarchy is one method by which a control system can attempt to overcome the curse of dimensionality.

SCATS primarily uses loop detectors. This project is designed to extend the domain of applicable sensors. One important design feature is that the control agent is largely sensor
agnostic. By this, it is meant that various types of sensors can be used in plug-and-play, mix-and-match modes. While the current research is focused on loop-detector and video sensing, the design allows for other sensor information such as infra-red, RFID and vehicle GPS.

The great advantage of modelling traffic state is that it can provide the optimiser with traffic information along road sections that are devoid of sensors. For example, loop-detectors at stop-lines by themselves are not able to anticipate approaching traffic. A model can track vehicles that have passed through one intersection and the following intersection can then anticipate the vehicle’s arrival and take appropriate action to minimise its delay. In heavy traffic a model can predict better real-time estimates of queue length than a simple queue detection system that relies on a single detector at fixed point.

MACHINE LEARNING TECHNIQUES

Models are necessary but not sufficient for good control. An intersection controller that is constrained to use a limited set of phases in a predetermined order will not perform as well as one allowed the flexibility of signal group control. Equally, a more reactive controller in the stochastic setting of traffic has the capacity to perform better than one constrained to switch at predetermined times. However, the increased flexibility comes at a cost. It is not sufficient now for the controller to adjust cycle length and split timings. Instead it must search the richer hypothesis space of potential control policies for ones that optimise a given objective function. The objective function can be easily formulated to apply control policies targeted to a specific problem. The STaR Control project merges these ideas to produce an innovative traffic controller design that will return improved performance outcomes and work towards addressing the mentioned challenges facing the traffic control problem.

EVALUATION

An important aspect of controller design is to ensure that it is robust in the face of chaotic traffic movements and road conditions. STaR controllers are tested both in simulation and under real-life traffic conditions in the field. The first and the less expensive method is to use a traffic micro-simulation as a substitute for the real-world. To date, the traffic micro-simulator used is Paramics from Portrait Software PLC. Even under similar road conditions the statistical nature of traffic inter-arrival rates can lead to major variations in performance. It is therefore important that the variance between runs is studied and analysed as a key part of controller performance evaluation. The partners have developed their own ‘plug-in’ to Paramics for this purpose. Figure 2 shows example statistics for delay at an intersection for two controllers. Each controller is tested over 20 runs with different random seeds and the variance of the mean performance estimated over time. It is clear that one controller is significantly better in this scenario than the other. These types of graphs allow us to test for statistically significant differences in performance over time and to visually inspect the degree of variance between runs.
Figure 2. The performance comparison of two controller types. The x-axis shows simulation time in seconds, the y-axis average travel-time delay per vehicle.

TEST BEDS

The RTA-NICTA collaboration has motivated the enhancement of two existing traffic intersection sites for use as R&D test beds. The details of these sites are:
Figure 3. Barker St Intersection SCATS site view.

Sydney traffic signal controlled intersection at the junction of Anzac Parade and Barker Street at Kensington, NSW. The intersection has a mixture of exclusive and shared lanes, a significant pedestrian presence, a range of signal group display variations, and a sophisticated controller configuration. All approach lanes have inductive loop detectors at the stop-line. The intersection is visualised in the SCATS graphics in Figure 3.
NSW signal controlled roundabout at the junction of the Princes Highway and Illawarra Highway at Albion Park, NSW. The problem of a controlled roundabout is relatively uncommon in NSW. Signalised control was originally implemented due to the problem of long waiting times for users that were disadvantaged due to high opposing flow and fundamental roundabout give-way rules. The two high-flow Princes Highway approaches only, of the three, are signalised. All approach lanes have inductive loop detectors set back from the stop-line that are used in part to indicate the presence of a queue and an indicative measure of demand. The roundabout is visualised in the SCATS graphics in Figure 4.

The Sydney site was chosen primarily due to the proximity to the relevant NICTA research laboratory and the regional site was selected because of uniqueness of the traffic problem.

Both sites are presently under SCATS real-time signalised control and loop detector measurement. Video cameras have been installed to facilitate video surveillance for off-line R&D purposes, live manual analysis, and future real-time measurement to supplement existing loop detector information. Modified loop detector cards have been developed and fitted to each controller to enable real-time access to the inductive loop detector outputs. Real-time measurements from both the inductive loop and video systems are available at the NICTA laboratory.

CONCLUSION

This paper describes the collaborative relationship between NICTA and the RTA on the STaR project. The aim of the project is to research and develop `smart' ICT traffic control solutions. The parties complement each other by bringing together Australian ICT expertise and a long history of traffic control innovation including the SCATS system. STaR weaves together four threads covering: communication, sensing, control, and user interface applications.

High-level aspects of STaR Control were discussed with an R&D emphasis on modelling, machine learning and optimisation. At this early stage the project has delivered several new
approaches for testing traffic controllers in traffic micro-simulation and has prepared two extensive test-bed sites.

ACKNOWLEDGEMENTS

National ICT Australia is funded by the Australian Government's Department of Communications, Information Technology, and the Arts and the Australian Research Council through Backing Australia's Ability and the ICT Research Centre of Excellence programs.

The authors acknowledge the contribution from their respective organisations, the RTA and NICTA and the many other participants on the STaR Control project - from the RTA: Doug Quail, Peter Lowrie and Carlos Aydos; from NICTA: Enyang Huang, Phil Kilby, Toby Walsh, Paul Tyler, Michael Maher, Nobuyuki Morioka, Robert Fitch, George Katsirelos, Glenn Geers and Geoff Goeldner.

REFERENCES


AUTHOR BIOGRAPHIES

Mr Christian Chong-White has a background involving the analysis, design and commissioning of electricity market systems (Australia, U.S.A.) and traffic management systems (Australia). Notable applications include neural network demand forecasting, linear program market pricing, and constraint-based control–systems. His recent work involves the strategic design of the next generation of RTA traffic controller software. Mr Chong-White is studying a Master of Transport Management from the Institute of Transport and Logistics Studies, University of Sydney, and holds a Master of Finance and Economics by research (University of Technology, Sydney), and a Bachelor of Engineering – electrical (University of South Australia).

Bernhard Hengst has had several years experience in operations research in Australia and overseas, applying science to corporate end-use applications. Applications included scheduling, linear/mixed integer programming and dynamic programming for investment analyses and construction of continuous structural models for the UK economy. Dr Hengst has had extensive experience in the general management of business units, including sales, marketing, purchasing, budgeting, accounting, staff management and strategic planning. His doctoral research topic was "Discovering Hierarchy in Reinforcement Learning". Dr Hengst was a participant and co-supervisor of the world leading Robocup UNSW/NICTA Sony Legged team that researched and developed real-time, integrated, multi-agent systems.