White Paper

Multi-Agent Traffic Light Optimisation and Coordination

Using Genetic Algorithms and Multi-Agent Systems to Synchronise Intelligent Traffic Lights Across Entire Regions

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Abstract

Correct traffic light phase sequences are critical to efficient traffic flow through road intersections. If the timing of just one set of lights at a junction is one second from optimal, the results can lead to major traffic congestion and delays. Currently, traffic light phases are set using a mixture of experience and empirical techniques to achieve an optimal phase sequence and, in the worst cases, this process can take many months. Any technique to speed up the identification of optimal phasings would have clear benefits to government agencies everywhere.

Thales UK's Research and Technology Group have investigated how Genetic Algorithms can solve "real-world" problems and have obtained some promising results with optimising traffic light phasings. Working with their colleagues at Thales Research and Technology Netherlands they have developed a demonstration solution based on the concept of "software agent communities" – that is, groups of software programs working together for their greater good. This extends the earlier Genetic Algorithms work by using agent-based technologies to enable the rapid optimisation of larger traffic light networks, potentially covering an entire town.

The research reported here is part of the Interactive Collaborative Information Systems (ICIS) project (http://www.icis.decis.nl/), supported by the Dutch Ministry of Economic Affairs, grant nr: BSIK03024.

Keywords

Multi-agent systems; genetic algorithms; traffic control; traffic engineering computing; phase control; traffic light phasing; evolutionary computation; adaptive control

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Introduction

In August 2008, after five years of the congestion charge in central London, and with fewer vehicles entering the charging zone every day, Transport for London's sixth annual report concluded that congestion was still just as bad as it was before the introduction of the charge. A recent article by John Oates in *The Register* has suggested that a reduction in traffic has allowed an increase in road and road-side repairs and improvements to occur, thus impeding traffic flow and offsetting a significant proportion of the gains from the congestion charge.

Traffic congestion is believed to be a major factor affecting the British economy. In fact, in October 2007, The British Chambers of Commerce estimated that congestion costs British industry in excess of £17bn every year. According to the Department for Transport, traffic levels across the UK increased by more than 84% between 1980 and 2006 and this trend is expected to continue for the foreseeable future.

Effective traffic planning and road design are essential to traffic management but clearly the effectiveness will be reduced when unpredictable, unplanned or rapidly changing road works are implemented, unless the planning can adapt appropriately to short notice requests for restrictions, or even detect them as they occur. In other words congestion management should be viewed as less of an optimisation task, in the traditional sense, but more of an adaptation task.

This white paper proposes the use of distributed software agents using Genetic Algorithms to optimise traffic light phasing in real-time, thus adapting rapidly to abnormal road conditions. Improvements in the reaction to gradual changes in normal conditions should also be realised as a result of the finer-grained range of solutions that can be provided.

In built-up areas, one major factor that affects congestion after a major disruption is the phasing of traffic lights. Traffic light phasings can affect traffic congestion in two different ways:

1. Traffic light phases at specific intersections are not optimised for the current traffic flow through that intersection.
2. Traffic light sequences at neighbouring intersections are not synchronised correctly, if at all.

While there has been a significant increase in the development and use of intelligent Adaptive Traffic Control Systems (ATCS) such as the UK Transport Research Laboratory's SCOOT, which attempt to address both of these problems, even the most advanced systems can only adapt to pre-defined phase sequences, and share information across a limited neighbourhood. This stops them from being truly adaptive to unplanned and unexpected changes to traffic flow, such as a road closure due to an accident. Adaptive systems that can control traffic flow over town- or city-sized areas generally require a centralised control system, and tend to switch between a set of phasing plans for each intersection. Los Angeles' Adaptive Traffic Control System (LADOT ATCS) is an example of this.

A major limitation of both of these types of ATCS is that they cannot be truly responsive to large scale disruptions such as the closure of a motorway. These kinds of events have widespread repercussions, and traffic lights over a very large area would need to significantly change their patterns of behaviour to cope with the extreme change in traffic flow. Any system that relies on pre-defined phasing models is unlikely to have a suitable phasing model for every possible variation of traffic condition.

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As part of its ongoing research into real-world applications of truly intelligent systems, Thales UK has prototyped a novel approach to addressing the problem of managing traffic flow over large areas. Instead of relying on massive, computationally intensive simulation models, or local specific control systems, Thales UK has developed a demonstration solution based on the concept of "software agent communities" – that is, groups of software programs working together for their greater good. This solution is a working example of a "self-organising traffic light control" system, a research area that is currently receiving much academic and industrial interest. In the Thales UK solution, a software agent is responsible for modelling and optimising the traffic flow through a specific area, usually a traffic light controlled intersection. This "intersection agent" uses internal traffic flow models, and real-time sensor data as inputs into a Genetic Algorithm to identify traffic light phasings that optimise the current traffic flow through its area of responsibility. The agent then passes on data about the resulting traffic flow to its neighbouring intersection agents, to ensure that these agents are also optimising to the most accurate traffic flow information. In this way, traffic flow changes cascade through the system, minimising the risk of unexpected traffic congestion in areas remote from the original disruption. Moreover, the use of Evolutionary Algorithms means that the Intersection Agents are not reliant on pre-programmed phase sequences, and are able to discover new optimum phase sequences for the prevailing traffic.

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Background Technology

Software Agents

Software Agents can demonstrate a number of characteristics, and some of the popular labels that are applied to them include being 'autonomous', 'co-operative', 'adaptive' and 'mobile'. However, an agent need not demonstrate all or any of these characteristics and at its most basic level the term 'agent' simply represents a way to describe a software process with an independent thread of execution that has internally defined goals or tasks. Nevertheless, agent systems do tend to be modular and decentralised, which makes them scalable, maintainable and resilient, and their use tends to allow dynamic solutions. This makes multi-agent systems ideal for addressing distributed and adaptive situations. Today many applications, including virus and spam filters and in-car route planners, use software agents to perform tasks that once used to be explicitly performed by the operator.

Within this context, software agent communities are groups of collaborative software agents, which cooperate to achieve a common goal. Each "Intersection Agent", as described above, is a member of a community whose purpose it is to optimise traffic flow throughout the region controlled by the Intersection Agent Community. This region could be as small as a single traffic light controlled intersection, or as large as an entire city.

Evolutionary Algorithms

The concept of Evolutionary Algorithms was introduced in the 1960s and was inspired by Darwin's theory of evolution. They are optimisation techniques based on the concepts of natural selection and genetics, and it is an umbrella term used to describe computer based problem solving systems which use computational models of the evolutionary processes as key elements in their design and implementation.

In principle, Evolutionary Algorithms can solve any computable problem, though they are particularly well suited to problems where:

- The number of possible solutions is large
- The optimal solution is not necessarily required (though it may be desired)
- There are many variable factors which need to be optimised simultaneously
- The problem is difficult to describe mathematically
- The solution space is highly non-linear

The most commonly used of all the Evolutionary Algorithms are Genetic Algorithms. A Genetic Algorithm searches a vast solution space for one or more good solutions to a problem by evolving a population of candidate solutions. Each of these solutions contains a set of encoded parameters that completely describe the solution. This set of parameters can then be considered the “genome” of the individual, with each parameter comprising of one or more “chromosomes”.

Every iteration, or “generation”, produces a population of candidate solutions. Each solution is then evaluated to see how well it solves the problem. The fittest solutions in this population are then “mated” and “evolved” to generate new solutions for the next generation, which is evaluated again. Over a number of generations, the population of candidate solutions tends to evolve towards a set of viable solutions.

In the Thales UK prototype, Intersection Agents make use of Genetic Algorithms to identify the optimal traffic light phasing sequence for the current traffic conditions. The use of a Genetic Algorithm enables each Intersection Agent to discover sequences that best fit the prevailing traffic conditions. This has a major advantage over systems that rely on predefined phasings, as it is virtually impossible to predefine and pre-program every possible optimal phase sequence for all possible traffic conditions.

Implementing a Multi-Agent Solution

The Thales UK Approach

Thales UK has been successfully developing real-world solutions that make use of intelligent systems since the early 1990s. Most notably, this programme of R&D initiated the development of the well-known TALON ANPR[1] system, which is based on neural network character recognition and adaptive plate location techniques. It is now owned, developed, and sold by Appian Technology PLC. As part of this ongoing intelligent systems programme, Thales UK began work to investigate the use of Genetic Algorithms for traffic light sequencing in 2002 and has recently revisited and enhanced this work to exploit the latest technological advances in multi-agent systems. By combining multi-agent systems with Genetic Algorithms, Thales UK has demonstrated the following solution that can manage traffic flow over very large areas through the use of:

1. Collaborative Intersection Agents – to manage the local traffic optimisation process and to exchange relevant information with neighbouring Intersection Agents.
2. Traffic flow data – Traffic flow information from neighbouring Intersection Agents, and potentially from roadside sensor systems, are used as inputs to the Evolutionary Algorithm.

[1] Racal Research Ltd., now Thales Research and Technology (UK) Ltd, developed the TALON Automatic Number Plate Recognition system. Talon was sold through Racal Messenger Ltd., which is now part of Appian Technology PLC.

3. Evolutionary Algorithms – to discover optimal traffic light phasings for the prevailing traffic flow conditions.

The following sections will describe the Thales UK solution in more detail.

System Architecture

The Thales UK demonstrator represents a complex road network by connecting together a large number of simple small units. We can represent the road network, shown in Figure 1, using three Intersection Agents as shown in Figure 2. These three Intersection Agents communicate with each other to ensure that traffic flow is optimised across the entire area, and that an over-optimisation of traffic flow through an intersection by one agent does not cause subsequent problems for its neighbours.

Figure 1 - Crown Street, Reading, UK. Source: OpenStreetMap

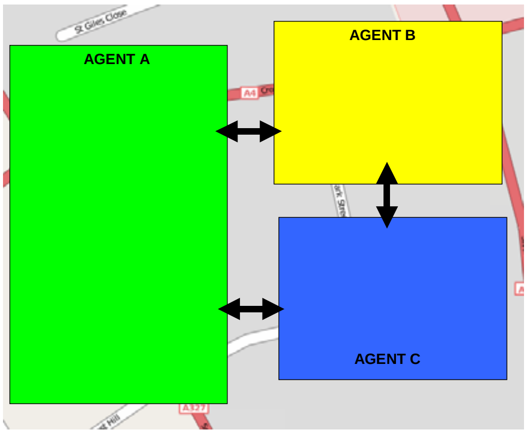

Figure 2 - An example of Intersection Agents for Crown Street

This "building block" concept leads to a simple but effective architecture, such as shown in Figure 3. Intersection Agents manage traffic flow through their intersections and pass two types of traffic flow data to each other:

- Exit-flow data – information on how many vehicles are expected to exit one agent and enter its neighbour
- Entry-capacity data - information on how many vehicles can enter from the agent's neighbour before its entry roads become congested

To pass information between any two agents, each agent simply needs to know the unique name of its neighbouring agent, and the name(s) of the interconnecting road(s). At present, this information is loaded into each Intersection Agent as part of its local road network model file but, in the future, it could easily be provided through a "Regional Road Network Server". An Address Brokering service is used (via an Address Resolution Broker) to resolve the target agent's names into an address in much the same way that an instant messaging service does.

Implementing a Regional Road Network Server would enable the road network models in each Intersection Agent to be updated from a central control room to reflect temporary road closures, or to reflect changes to an Intersection Agent's neighbours after changes to the road network.

It is important to note here that neither the Address Resolution Broker nor the Regional Road Network Server act as decision-making processors, and that all traffic flow optimisations are made by the Intersection Agents. Additionally, it is worth noting that these Intersection Agents can either be hosted at the location of the intersection, or at a central control centre, depending on the costs of roll-out, and available communication channels, etc.

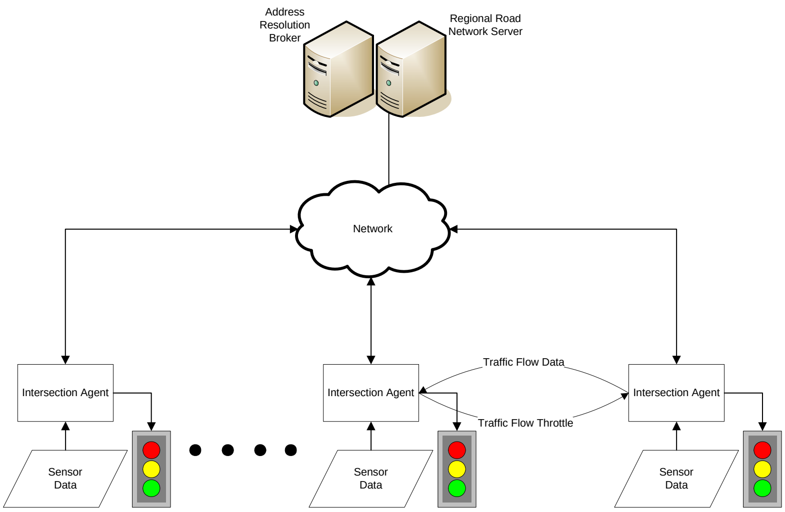

Figure 3 - System Architecture

Intersection Agents

The Intersection Agent has been designed with three components and a "plug and play" internal structure. The components are:

- An optimiser – in this case a genetic algorithm
- A traffic flow simulator
- Road network model

The selected optimiser, the chosen simulator to be used by the optimiser, and the road network model can all be changed. This flexible design means that different simulators and optimisers (including third party tools) can be used to meet different requirements. For example micro-simulation, which requires greater processing time, but produces more accurate results, could be used for planning and research, while statistical macro-simulation, which is faster, but is also less accurate, can be used for disruptive or unplanned situations.

In addition to managing the optimisation process, the Intersection Agent is responsible for handling inter-agent communication, and updating the traffic flow models to reflect changes to traffic flow (based on the incoming data from its neighbours).

The Optimiser and Simulator

At the heart of the Intersection Agent is an optimiser and simulator that are used together to discover traffic light phase sequences which will optimise traffic flow in the prevailing conditions. The use of a Genetic Algorithm for the optimiser has a major advantage over systems that rely on predefined sequences, as the Genetic Algorithm enables each Intersection Agent to discover sequences that may not resemble any predefined sequence, but may be optimal for the current traffic conditions. To enable in-depth analysis of the optimisation process, a bespoke simulator is presently utilised by the Intersection Agent. In future this simulator (or a third party tool) could be optimised to achieve a satisfactory balance between discovery time and phase sequence performance.

The selected genome for the traffic light optimiser is based on a repeating list of events that are applied to the intersections controlled by the Intersection Agent. The underlying list structure was chosen as it allows variable length phase sequences and straightforward evolution of candidate solutions. Each item in the list is a single event, which contains the name of the intersection to which the event will apply, the state for that particular intersection, and the time until the next event in the list will occur. Figure 4 shows an example event sequence. Here, the intersection is represented by a letter and the new state by a number.

B6	C4	A1	C2	B7	A2	C5	B1	B4	C2	A5	C5

Time

Figure 4 - An example event sequence

To identify the best available solution from the population, the optimiser repeatedly runs the traffic flow simulator for every traffic light phase sequence in a given generation. The best performing sequences are then used to generate the subsequent generation of phase sequences, and over a number of generations, the best candidate phase sequence is identified.

For the current optimisation process, traffic flow is measured by calculating the “maximum expected waiting time” that any simulated vehicle would have to wait while in the Agent’s road network. The maximum waiting time was selected as the most suitable measure because the primary alternative, maximum throughput, was found to be strongly biased towards routes with high traffic flows. This meant that, in extreme cases, routes with small volumes of traffic could be completely discarded from the solution. By calculating the maximum waiting time for each traffic light phase sequence, the system tends to concentrate on the worst case behaviour of the network, and by optimising this metric (i.e. trying to minimise the maximum waiting times over a number of generations), the system tends to optimise the overall flow through the entire network.

Road Network Model

The roads and intersections that an Intersection Agent controls are represented by an internal model, which is loaded from a configuration file that describes the road network as a topological network. This could easily be modified to accept any Geographical Information System (GIS) data source.

Graphical User Interface

Figure 5 shows the Intersection Agent's Graphical User Interface (GUI). This user interface allows an operator to monitor and manage the Intersection Agent's optimisation process. In this GUI, the top left panel shows a topological representation of the intersection, while the top right shows the optimisation performance, and the bottom panel shows the current optimal phase sequence.

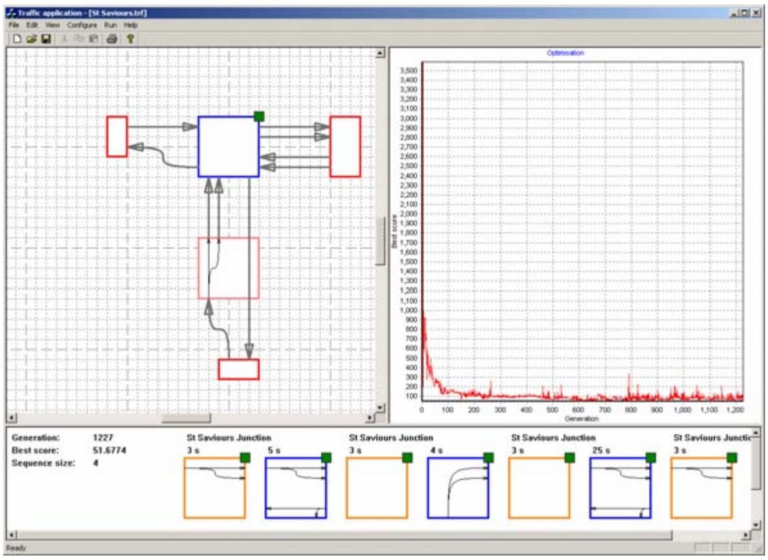

Figure 5 - An Intersection Agent.

For the situation shown in Figure 5, the Genetic Algorithm was initialised with a set of arbitrary, random phase sequences. This initial set could use some predefined sequences to speed convergence. However, genetic diversity is the key to the discovery process, and use of a random initialisation set aids this aspect, and also represents a "worst case scenario" where it is very unlikely that any of the initial sequences will be close to the optimal solution.

Initial Results

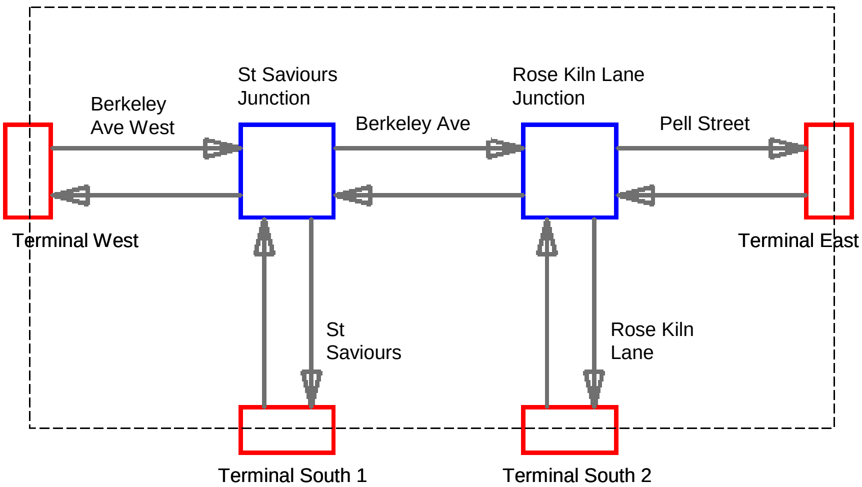

Figure 6 – A Section of Berkeley Avenue, Reading, UK.

To test the benefit of splitting up a complex agent into a simpler configuration of Intersection Agents, a dual "T" intersection model was developed. The data used for these experiments are based on observations of 5:00pm traffic flows at the St. Saviours Road/Berkeley Avenue and the Berkeley Avenue/Rose Kiln Lane intersections in Reading, United Kingdom (Figure 6). Table 1 and Table 2 summarise the traffic flow data and turning probabilities.

Road	**Entering Rate (vehicles per hour)**
Berkeley Avenue (West)	724
Pell Street	896
St Saviours Road	289
Rose Kiln Lane	1504

Table 1 - Vehicle rates for the dual 'T' intersection network

Rose Kiln Lane Junction

	To Rose Kiln Lane	**To Pell Street**	**To Berkeley Avenue**
From Rose Kiln Lane		0.316	0.684
From Pell Street	0.382		0.618
From Berkeley Avenue	0.538	0.462	

St Saviours Junction

	To St Saviours Road	**To Berkeley Avenue**	**To Berkeley Avenue (West)**
From St Saviours Road		0.489	0.511
From Berkeley Avenue	0.091		0.909
From Berkeley Avenue (West)	0.779	0.221	

Table 2 – Turn probabilities for the dual 'T' intersection network

The following experiments were set up:

Experiment 1. Centrally controlled multiple intersections – In this experiment, one Intersection Agent was used to optimise the traffic light phase sequences for both intersections. This was used to identify a benchmark solution.

Experiment 2. Collaboratively controlled intersections – In this experiment, two Intersection Agents (one managing the Rose Kiln Lane intersection, and the other managing the St Saviours Road Intersection) were used to evaluate the performance of collaborative Intersection Agents. For this experiment, each Intersection Agent was run on a separate PC.

Figure 7 and Figure 8 show the outcomes of these experiments. In both of these Figures the blue line represents the results achieved by the "all-in-one" Intersection Agent used for Experiment 1, while the red and green lines represent the results achieved by the two Intersection Agents used in Experiment 2[2]. Figure 7 shows the traffic light optimisation process over 1000 generations, while Figure 8 shows the convergence rate for the two experiments. The "jitters" that can be seen in the waiting times for Experiment 2 are the result of the two

[2] In these graphs, "SSR" stand for St Saviours Road, and "RKL" for Rose Kiln Lane.

Intersection Agents passing any changes to the expected traffic flow between each other at the end of each generation in the optimisation process.

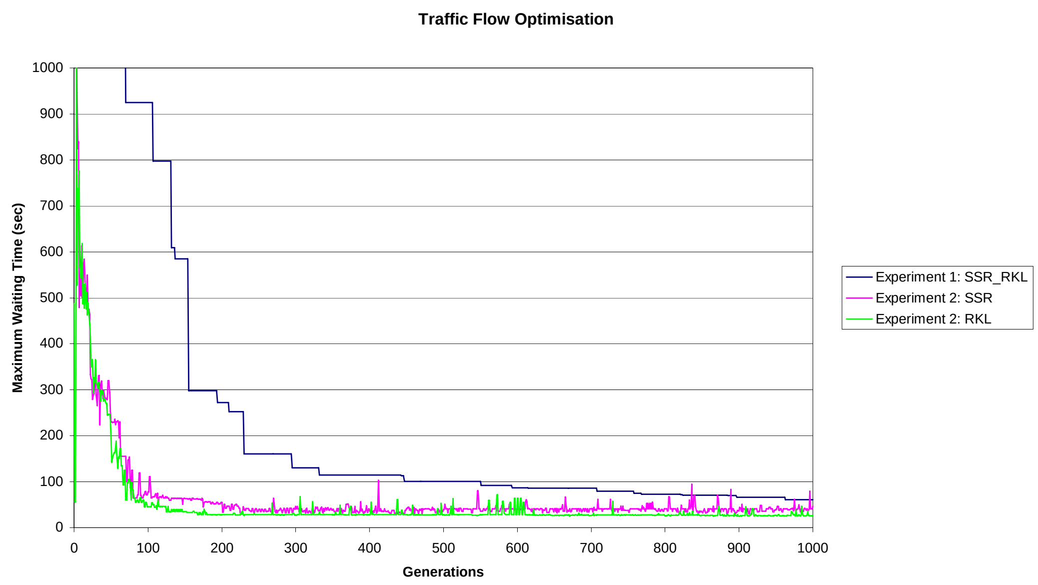

Figure 7 – Maximum Waiting Times (Generations)

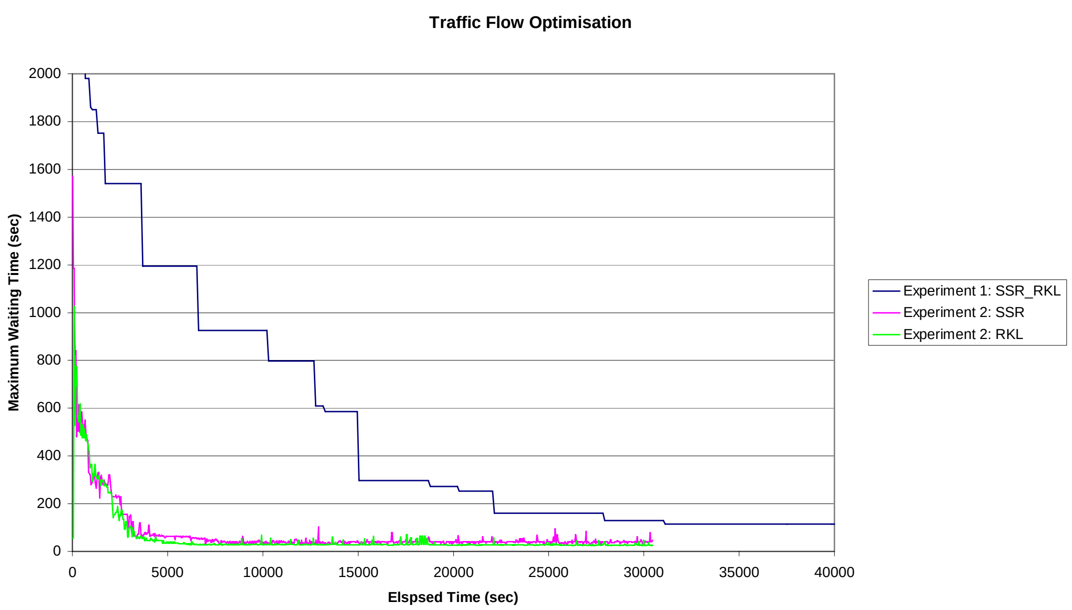

Figure 8 - Maximum Waiting Time (Elapsed Time)

What is clear from both figures is that by using multiple Collaborative Intersection Agents, traffic flow through the road network is optimised in fewer generations, and in significantly less time, than the centralised approach. After 1000 generations, the maximum expected waiting time achieved by Experiment 1 is 61seconds, whereas the maximum expected waiting time achieved by Experiment 2 was 37 seconds. Arguably more important than this result is the fact that both Intersection Agents in Experiment 2 converge to their optimal solution at a significantly faster rate then the all-in-one solution from Experiment 1, as shown in Figure 8.

The convergence times of the multi-agent approach imply that a realistic network could be optimised in a number of hours, however it is believed that to provide a solution that can optimise for sudden changes in the network (such as an accident or road works which block a lane), a system is required that will optimise in tens of minutes. To address this issue Thales UK is currently working on an improved simulator component that uses a bulk statistical model of the traffic rather than the current “per vehicle” micro simulation.

For completeness, the phase sequences generated by Experiment 1 are shown in Figure 9. Even after 1000 generations, this phase sequence is not optimal, and that additional throughput could easily be achieved by applying some simple intelligence to this sequence. (For example, the first phase for Rose Kiln Lane could easily allow traffic arriving from the south to turn left.) However, these changes are not likely to improve the maximum waiting times, as they do not represent traffic flow along high capacity congestion-critical routes.

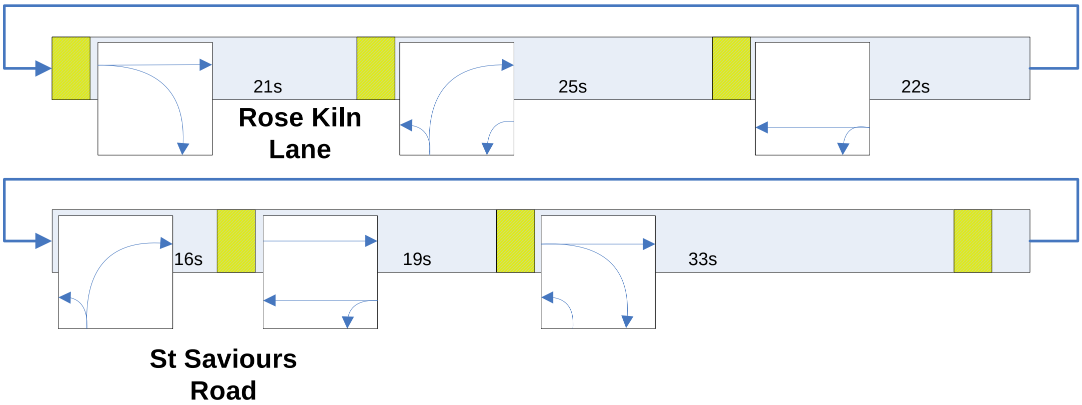

Figure 9 - Traffic Light Phase Sequence - Experiment 1

Conclusions

The initial experiments described in this white paper have shown the potential advantages of using collaborative software agent communities to optimise traffic flow through a road network. These advantages are:

- Each Intersection Agent can manage congestion locally, reducing software and modelling complexity
- Each agent can adapt its traffic light phase sequences to best fit changing traffic conditions, both expected and unexpected
- Each agent can discover completely new phase sequences to better fit unexpected traffic conditions
- Changes in traffic flow can cascade through the road network system, reducing the risk of unexpected disruptions occurring in areas remote from the area of the original disruption

In the future, Thales UK intends to expand on these initial experiments to optimise traffic flow through larger multiple intersection road networks, and to improve the performance of the optimiser.

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