Simulating VANets with FLOURISH

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Abstract

Flourish is a multi-sector collaborative project helping to advance the successful roll out of Connected and Autonomous Vehicles (CAVs) in the UK. The project seeks to develop services that maximise the benefits of CAVs for users and for transport authorities with a specific focus on the needs of the older driver and the use of vehicle information systems. The question to be addressed in the simulation work package concerns how to make best use of the rich source of data offered by connected vehicles, how to process and understand it, how to present it to drivers, or to autonomous vehicle controllers, and how to use it in conjunction with traditional ITS and signals.

To this end, TSS has implemented a VANet (Vehicle Ad-hoc Network) simulation within Aimsun which will operate as a test environment to support research and development of in-vehicle information and control systems and area wide network management algorithms. Within the simulation work package, the emphasis is placed on the use of VANets as an enabler of traffic management and vehicle interaction, focussing on which sets of vehicles can communicate and what data do they exchange rather than on the low level technology used in network provision. This is complemented with provision of a flexible and extendable interface to the simulation to facilitate research into innovative network control and the potential benefits of enhanced vehicle to vehicle awareness.

The Flourish Project

The global market for CAVs is innovative in nature and rapidly growing. In recent years, the UK Government has worked closely with industry and academia to accelerate the UK's capabilities in leading the way in the adoption of 'driverless cars' on national roads. To establish the UK as a global centre of excellence for connected and autonomous vehicles, the government continues to strengthen its commitment to the research and development of CAV capabilities. In February 2016, in its second round of investment, the government awarded £20 million in R&D funding to support the delivery of eight new projects. As a result, the Flourish project received funding to develop innovative new tools that will improve the understanding of user needs and expectations of CAVs, and test capabilities in both urban and suburban networked environments.

The three-year project will develop products and services that maximise the benefits of CAVs for users and transport authorities. By adopting a user-centred approach, Flourish will achieve a better understanding of consumer demands and expectations, including the implications and challenges of an ageing society. Importantly, Flourish will address vulnerabilities in the technology powering CAVs, with a focus on the critical areas of cyber security and wireless communications. Many of the project partners are based in the Bristol and South Gloucestershire region and include: Atkins, Airbus Group, AXA, Age UK, Bristol City Council, Bristol Robotics Lab, Burges Salmond, Designability, Dynniq, OPM Group, South Gloucester Council, TSS-Transport Simulation Systems, Transport Systems Catapult, University of Bristol, and the University of West England.

The project is user centred and places the customer at the heart of its research priorities. This includes developing greater insight into customer interaction and public acceptance of CAVs, and specifically the requirements of an ageing population. The Flourish project therefore covers a number of interacting systems, including in-vehicle and network-level activities using AI based rules engines to implement and co-ordinate vehicle behaviour; human-state monitoring systems and human-machine interaction systems to elicit a driver response; network simulation to gain insight into application of city dashboard management tools; and trials with simulators and physical CAVs, both pods and cars.

The simulation work package is the key to gaining an insight into the effect of using the large amount of data available from CAVs in both the vehicle to modify its behaviour and in the network controller to manage the network using connected vehicle technology as well as traditional ITS and signals. This paper describes the implementation of a VANet capability within the Aimsun simulation software from TSS-Transport Simulation Systems to support that work package.

Vehicle Ad Hoc Networks

A Vehicle Ad Hoc Network is an ephemeral network spontaneously created by a collection of connected vehicles in proximity to each other. The Connected Vehicle Reference Implementation Architecture [1] lists over 100 possible applications of VANets in sustainable travel, fleet operations, network management, public transport management, and in safety based on infrastructure warnings and vehicle to vehicle collaboration.

VANets are formed as vehicles detect transmissions from other vehicles then, while they are in range of each other, they are able to exchange information about their location and activity. By aggregating this information a vehicle is able to infer the pattern of the traffic around it and hence amend its own behaviour accordingly. One example application described in Eze et al. [2] uses VANet information to provide a collision warning to a driver just a few seconds prior to the moment of the crash based on data from adjacent vehicles and their imminent conflict. It predicts a 60% reduction in collisions.

A VANet may also include a static wireless station in a Roadside Unit (RSU), in effect a part of the road network management infrastructure. Including an RSU fixes the location of a VANet and its members are then the vehicles in the adjacent area. The RSU may then link to the network traffic management system and become both a data gathering tool and an information dissemination device as a part of the wider ITS system.

Communications Hierarchy

The Open Systems Interconnection (OSI) [3] model is a conceptual framework that characterises the components and functions of a communications network. It aim is to ensure interoperability in networks by abstracting the functions of the network into seven defined layers and separating these functions such that the technology servicing each function is replaceable without disturbing the layers above and below it. The lower layers are concerned with the electromagnetic and optical technology of data exchange, the higher levels with the codification of the information in the communication. Put simply, it is why our email continues to work when we replace our copper wire broadband with fibre, and why our web browsers work on PCs, Macs, and Android tablets. With abstraction and separation, a change in a lower layer transmission technology does not affect the higher level information exchange and conversely, the interface and device presenting the information is independent of the means of transmitting that information.

The same OSI model can be used to describe VANets, and, as often happens when using the OSI model to describe a communication system; layers are conceptually merged to simplify the system into functional clusters. Figure 1 shows a conceptual mode of a VANet in 3 layers where:

- The Physical Layer represents the communication protocols in the wireless media. It corresponds to levels 1, 2, 3, and 4 of the OSI model.
- The Network Layer represents the membership of the VANets and hence the community of vehicles and static RSUs that exchange information. It corresponds to level 5, the session layer, of the OSI model.
- The Application Layer represents the information exchanged between vehicles and the programming interfaces to derive it from the vehicle activity and on reception, to present it to the vehicle control systems (or driver). It corresponds to level s 6 and 7, the presentation and application layers, of the OSI model.

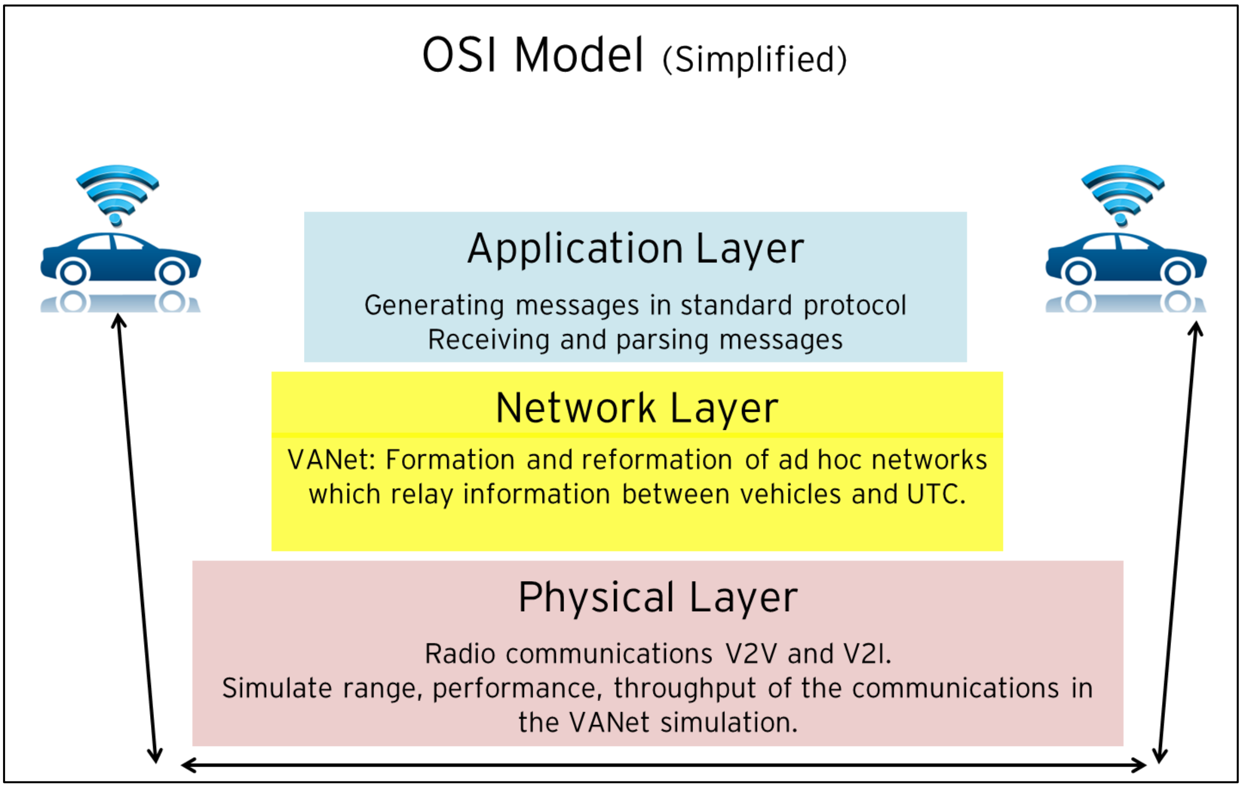

Figure 1 VANet Simplified OSI Model

Physical Layer

The Physical Layer is concerned with transmission and reception of information. It is built on wireless communications technology and allows vehicles to exchange packets of data with other vehicles and static devices within range. The physical layer can be based on several different technologies, in different wavebands and with different encoding methods. IEEE802.11 is a widely used wireless protocol; it is used in domestic broadband routers and other Wifi products. The IEEE 802.11p amendment to that standard is specifically oriented to vehicular networks that may only exist for a short time and hence must establish connection efficiently and rapidly with lightweight association protocols to expedite membership of a VANet. Similarly, 5G mobile telephony technology is also proposed as a communications medium to support VANets with the same consideration of using light weight protocols to establish the connection between vehicles.

Network Layer

The Network Layer is concerned with the membership of a VANet and which vehicles and RSUs are able to exchange data. Although the protocol to physically join and leave a network is linked to the Physical Layer, the membership of a VANet is abstracted here to represent a virtual network of connected vehicles and RSUs, each able to exchange data.

Application Layer

The Application Layer defines the data to be exchanged and how it is presented to the data user. Within Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) (Collectively V2X) communications there are many putative applications but few accepted standards and those standards that are prevalent are not application specific, but instead are generic information standards. The common standards are the Collaborative Awareness Message

(CAM) [4], the Decentralised Environmental Notification Message (DENM) [5] and the Signal Phase And Timing Extended Message (SPATEM)

The CAM message is issued by vehicles at a frequency of up to 10Hz. It includes information about the vehicle, what it is, where it is, what it is doing, and other information relevant to emergency vehicles or hazardous loads. The specification of what it is doing at the time the message is generated includes speed, lane position, and acceleration, and can also include information about the vehicle environment, inferred through windscreen wiper, turn signal, or lights operation. The CAM message is designed to inform other vehicles but does not offer any negotiated co-operation with any other vehicles.

The DENM message is issued by an "ITS station" which may be a vehicle or may be a static RSU. Its purpose is to inform vehicles about the road conditions extant in the network. As with the CAM message, it informs, but it does not offer any negotiated actions between infrastructure and vehicle. The DENM message contains warnings of vehicles which are emergency braking, of stationary vehicles, of congestion, and of environmental factors such as road works, road surface condition, and weather conditions.

The SPATEM message is issued by an RSU attached to a signal controller and provides real time information about the current signal state and the residual time before a stage change. It is complemented by the MAP Extended Message (MAPEM) which describes the road topology. A vehicle receiving a SPATEM and MAPEM message will know what turns are permitted at a junction, and when that will change.

These messages have been implemented in the Aimsun V2X simulation extension.

Vehicle and Network Actions

The information received through the Application Layer will be acted upon by the vehicles or by the Network Control Centre. In the Flourish project this is the role of a Vehicle Rules Engine contained in the vehicle simulation. The Rules Engine receives information from the VANet, is aware of the status of the vehicle and those vehicles around it, and is also aware of network control measures such as traffic signals or the guidance from traditional ITS. The Rules Engine must then determine the action of the vehicle based on the information it has and the intention of the vehicle, i.e. its destination, its desired speed, its next turn. The Vehicle Rules Engine is equally capable of simulating an autonomous vehicle or the actions of a driver vehicle, albeit in the latter case, there is an added complication of modelling a driver's reaction to the information presented by the vehicle. In this, the simulation work package will take guidance from another Flourish work package examining the Human Machine Interface (HMI) in particular with regards to the needs of the ageing driver.

The same information is also received by the RSU where the Local Rules Engine may aggregate data before communicating it to the Network Control Centre or may generate a local RSU originated transmission, i.e. a DENM packet with local information. The Network Control Centre will receive data from several RSUs, merge it with data from existing detector, loops, ANPR, etc. and use it to manage the network using its own Network Rules Engine. A machine learning approach is being adopted in the Flourish project to implement this Rules Engine and enable the Network Control Centre to react to developing network conditions and control them through VANet messages, signals, and traditional ITS.

VANets in Aimsun

The focus of the Flourish project is on the use of VANets to improve the traveller's journey experience. The strategy in the simulation work package is therefore to focus on the Application Layer and the Network Layer and to simulate the Physical Layer using a stochastic approach calibrated with data derived from physical trials and from studies with a physical communications emulator. The Application and Network Layers are the key layers in studying how data can assist in enhancing the journey by providing in car advice and by network management, in short the emphasis in the simulation work package is on which sets of vehicles can communicate and what data do they exchange rather than on how they communicate and what technology do they use.

Figure 2 shows the software architecture of the V2X Communications Extension implemented in Aimsun for the Flourish project. The key new development is the addition of the V2X Communications Extension based in the Aimsun Applications Programming Interface (API) which is designed to be used in dynamic simulations. In Aimsun a dynamic simulation is one where individual vehicles are simulated following dynamic paths which can vary as the simulation proceeds and as path costs change, as vehicles are diverted by ITS and, now, by V2X actions.

Within a dynamic simulation, the individual vehicles may be simulated by microsimulation, by mesoscopic simulation or by a hybrid simulation including both microsimulation and mesoscopic simulation in a single model; the structure of Aimsun separates the dynamic path choice for a vehicle from the method of loading the network and moving those vehicles in it. This means that if the study was to look at the effect of V2X information on path choice behaviour over a large area; a mesoscopic model could be used which would be faster to run and simpler to calibrate than a microsimulation model. If however the study was to look at enhanced vehicle awareness at a junction scale, a microsimulation model would be more appropriate. For the two cases combined, a hybrid model could be used.

The V2X Router is the core of this extension and simulates the Network Layer which manages the interchange of the CAM, DENM and SPAT packets between vehicles and the infrastructure RSUs. The V2X Router is supported by the Transmission module to simulate the Physical Layer, which in this project simply provides a configurable probability of transmission based on range and packet frequency. The Vehicle and the RSU, Comms modules encode and decode the CAM, DENM and SPAT packets.

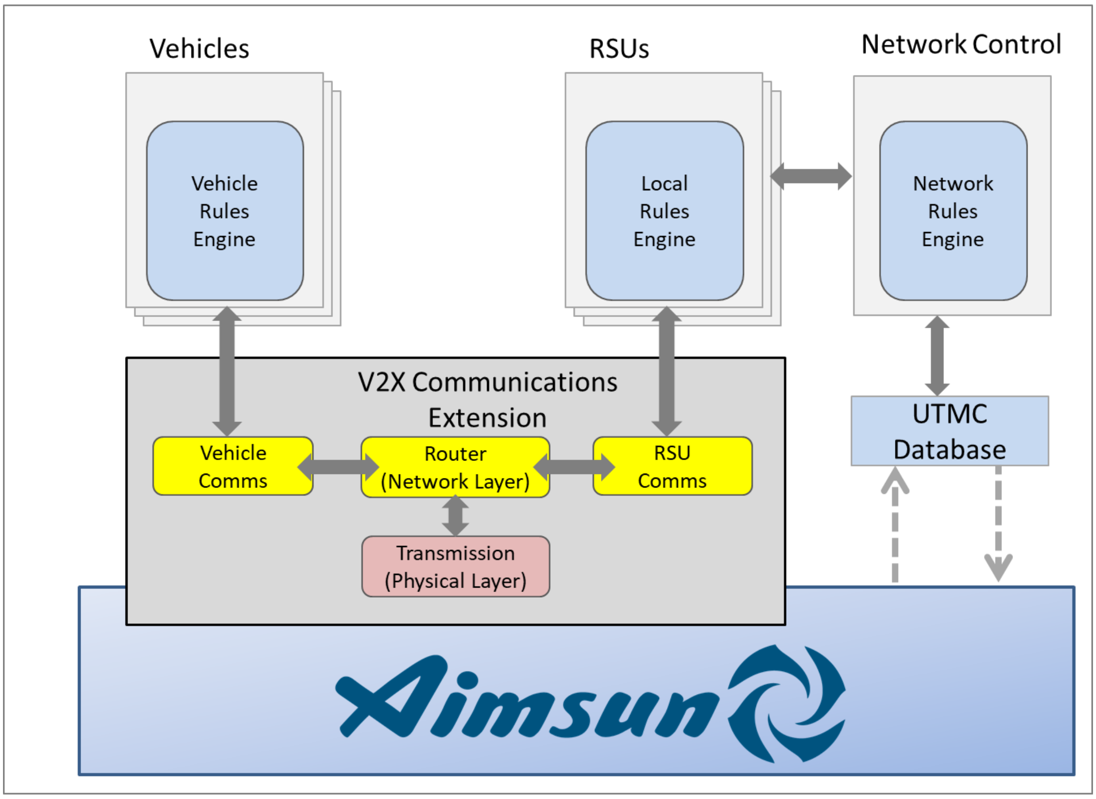

Figure 2 Flourish Simulation Software Architecture

The Rules Engines are programmed externally to Aimsun, using the new V2X API extension, they process data derived from the V2X extension and combine it with other data from the simulation. In the Vehicle Rules Engine, this data is the current status of the vehicle, the status of the vehicles around it, and its future intentions such as the next turn or the vehicle path. In the Network Rules Engine this data is derived from a proxy for a UTMC database which derives its data from the simulation API and presents it to the Network Control Centre in a format the control centre can readily read.

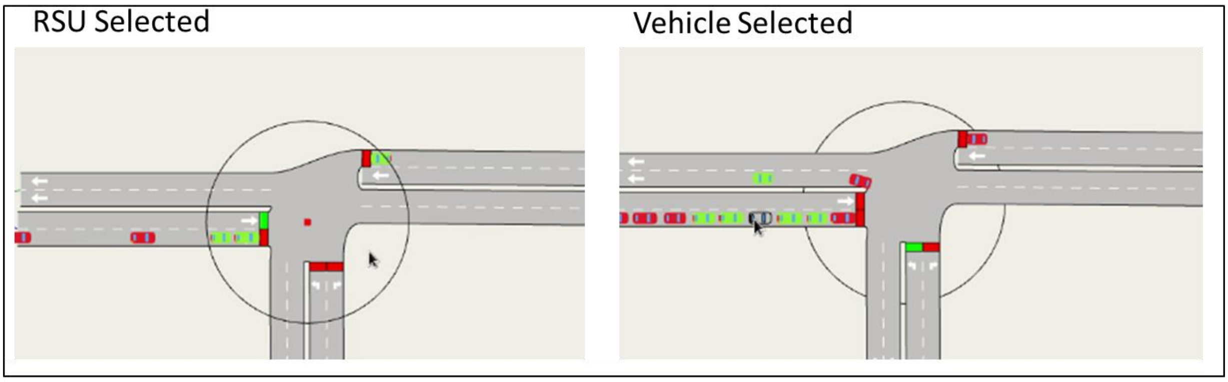

Figure 3 Connected Vehicle View

Figure 3 shows the simulation using an Aimsun view mode which has been configured to colour all vehicles that are in a VANet with the selected object in green, the rest in red. In one view the RSU has been selected, in the other, a vehicle is selected. In both cases the transmission range is small to facilitate a clear view. As vehicles move in and out of range, and if they are designated as connected vehicles, their colour changes to indicate if they are a member of a VANet and hence communicating with the selected vehicle or object.

Simulating with VANets

Use cases

Use cases proposed to test the simulation system in Flourish include those based in local optimisation of vehicle behaviour in small areas, and in strategic network responses.

Local optimisation use cases are based around interactions between vehicles and are not necessarily dependent on the presence of an RSU. Whatever the range of sensors that vehicles may use in the future to help them navigate, their sensory range will be limited to their immediate surroundings. The first use case uses the V2V communications to improve this sensory range beyond a vehicle's own 'eyes and ears', helping it to anticipate changes in traffic further up the road, better understand where non-connected vehicles (which are not equipped to communicate with connected vehicles) are located around them, and to work better in conditions of adverse visibility, possibly seeing around corners. The goal is to improve safety and to reduce congestion.

A more advanced local optimisation use case refers to a group of connected vehicles sharing driving intentions with others in the immediate vicinity to improve awareness and optimise real-time manoeuvring. This use case evaluates connectivity, security and trust requirements to enable a more cooperative system of vehicle collaborative manoeuvring with the Vehicle Rules Engine handling information from other vehicles. The complicating factor in his use case is that of driver operated vehicles and non-connected vehicles placing a load on the Vehicle Rules Engine to infer their presence and their reactions.

Strategic use cases are concerned with the actions of the Network Control Centre to manage the road network when presented with data from connected vehicles to augment the data already collected from existing devices such as loops and ANPR. Current incident management relies on sparse information such as observation of video feeds. Increasingly, however, this is only undertaken as a reality check once the 'alarm' has been raised through other forms of incident recognition i.e. detecting unexpected drops in measured traffic flows or speeds. Data from connected vehicles could be a key resource to enhance a Traffic Managers' ability to detect incidents and implement control strategies to minimise disruption on the network. Incident detection will be made substantially faster and more accurate when data directly from connected vehicles is collected, allowing a greater level of granularity in spatial detection as well as reduction in detection times.

Flourish also expects to be able to use connected vehicle data to enable trialling of "City Cycle" management where a City Cycle is an integrated suite of management actions based on extensive and current data. A City Cycle may be chosen to optimise journey times, to optimise event management, or to optimise air quality - depending on circumstances. Once the cycle is chosen, vehicle behaviour is influenced via V2X communications as well as by more conventional ITS means to achieve the planned effect.

In all cases it is important to understand how latency, data accuracy, and sampling rates will affect information available to network controllers. It is also important to understand how the proportion of connected vehicles in the national fleet and how the positioning and density of RSUs affects the quality of the Network Control Centre reactions to detected conditions. It is axiomatic that if 100% of the vehicle fleet was connected, the Network Control Centre would be able to accurately know the state of the city traffic and manage it accordingly. What percentage of connected vehicles and spread of RSUs is required to yield sufficient data for improved management is one of the fundamental questions that may be answered using the VANet simulation developed by TSS in the Flourish project.

Scenarios and Experiments

The algorithms being developed to implement new traffic management algorithms using connected vehicle data are based in machine learning as the best technique to efficiently manage the potentially vastly increased quantity of data flowing into the Network Control Centre. The definition of a machine learning algorithm however is that it gives computers the ability to learn without being explicitly programmed and that they do this by recognising patterns in the relationship between inputs, actions, and outputs. In this case, by making data driven predictions of the effect of a set of traffic management actions implemented in a specific set of circumstances. This requires many experiments with different inputs and different actions to build up the number of examples required to enable the machine learning algorithms to identify these patterns and learn which performs best in achieving the KPIs such as those used to define the efficacy of a "City Cycle"

This depth of knowledge, when using a new technology that does not yet exist on the road, may only be achieved through simulation and acquiring that knowledge requires many simulation runs. These runs must be made with different network demand due to events or due to systematic or stochastic variations, different road conditions such as control systems or roadworks, and different VANet parameters such as the number of equipped vehicles and the location and number of RSUs. A significant model management task.

Aimsun manages variations to a base model using Scenarios and Experiments and by modularisation of the model components. An Aimsun model file will contain a base road network and if changes are made to that network, they are held as "Geometry Configurations"; the difference between a base and a design network. It will also contain a set of OD matrices for example a base matrix, a low, medium and high growth matrix, and a number of development matrices. These are assembled into a "Traffic Demand" to define the different demand options. Signal Control Plans and the Public Transport Plans are similarly assembled from re-usable components.

Within a Scenario, the modeller specifies which subnet of the model is used, what geometry, demand, signals, and public transport plans are used and, if the model includes strategic traffic on fixed routes as well as local traffic on dynamically varying routes, which set of route paths are used. A Scenario can have a number of Experiments attached to it where each Experiment owns the Replications that run the model as described in the Scenario, with changes specific to that Experiment. A set of Experiments owned by one Scenario may alter the proportion of connected vehicles in the fleet or another set may trigger different incidents in the network to open or close lanes, close junctions, impose speed limits or create temporary blockages.

The Aimsun Scenario and Experiment manager provides an efficient method of generating the multiple instances of a traffic model required by the machine learning algorithms of the Network Control Centre. It operates by combining re-usable components of the model in a Scenario to create the test network with its different demands and controls and incidents, and then uses a set of Experiments linked to that Scenario to impose its management actions on the Scenario and to investigate the effect of those actions under different connected vehicle proportions and RSU configurations. Creating Scenarios and Experiments with different combinations of model components and actions may also be automated using Aimsun Scripting to speed the process and also to program sampling algorithms to manage the combinatorial explosion of options to test.

Conclusions

The Flourish Project has wide aspirations to improve the journey experience for travellers with a particular emphasis on the aging driver demographic. The technology underlying this goal is use of VANets to allow vehicles to communicate between themselves and with the Network Control Centre. At one end point in this communication, information is presented via the vehicle HMI to the driver to assist them in their journey, at the other end point of the communication the data gathered from connected vehicles is used in the Network Control Centre by an AI machine learning algorithm designed to operate in the presence of large quantities of data to develop heuristics based on simulated outputs and learn how to respond to manage the network and achieve the KPIs defined by a "City Cycle".

To investigate this use of V2X communications, Aimsun has been extended to include a VANet simulation based on the existing API for dynamic microsimulation or mesoscopic simulation models where a proportion of vehicles can be marked as "connected" and where RSUs may be positioned in the simulated network. The emphasis on the Aimsun extensions is to provide the capability to develop tools for better network management and to learn how to use the connected vehicle data in a vehicle.

Acknowledgments

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