VANET Based Advanced Road Traffic Management Systems

NAZMUS SHAKER NAFI
B.Eng. (Communication) (Hons)

A THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Philosophy (Computer Engineering)

School of Electrical Engineering and Computer Science

The University of Newcastle
Callaghan, NSW 2308
Australia

March, 2013
I hereby certify that the work embodied in this thesis is the result of original research and has not been submitted for a higher degree to any other University or Institution.

NAZMUS SHAKER NAFI
ACKNOWLEDGMENTS

First, I want to thank my supervisor, Associate Professor Jamil Khan for his dedication, supervision, and constant support assisting in the development of this research work and thesis. Without him and his constant guide; this project couldn’t be completed.

I would like to extend huge, warm thanks to my senior mates; Reduan, Aditi, Mashud and Awais for their constant support, motivation and help.

My special thanks to Jason, Nur, Saad, Nusrat and Dong. I’m also thankful to the University of Newcastle staff, which provided me full support in the good and hard times of this research.

Finally, last but not least, I want to thank my family; Dad, Mom and Sister for their immense support given to me from thousands of kilometres away. I owe everything to them. Besides this, several people have knowingly and unknowingly helped me in the successful completion of this project.
ABSTRACT

With the increasing number of vehicles on the road, the demand for advanced traffic control systems is on the rise. In future, Intelligent Transportation System (ITS) is envisaged to be a key component of the road traffic management system. To maximize the efficiency of the traffic control system, various ITS applications could be used along with the existing control methods by integrating communications, computing and electronic technologies. A new wireless networking standard known as the IEEE 802.11p has been exclusively developed for the VANET (Vehicular Ad-hoc Network) based next generation transportation systems. The IEEE 802.11p standard can support both V2V (Vehicle to Vehicle) and V2I (Vehicle to Infrastructure) communications mode. For a VANET based ITS, the V2I mode can be used for exchanging signals between traffic control entities and vehicles.

The aim of this research is to utilize a V2I communication architecture to accommodate and integrate two novel applications of an advanced ITS, namely the IRTSS (Intelligent Road Traffic Signalling System) and the PRTMS (Predictive Road Traffic Signalling System). A novel IRTSS has been proposed and implemented using the V2I based VANET architecture to control traffic flow both at isolated and coordinated road intersections. Furthermore, a basic Predictive Road Traffic Management System (PRTMS) has been developed and integrated with the VANET architecture to achieve multi-junction traffic flow control. An OPNET based integrated simulation model has been developed that jointly examines the performance of the proposed road traffic management system and the communications network. A realistic road traffic flow has been embedded in the simulation model that complies with the international road traffic control standards proposed by Vienna Convention on Road Signs and Signals, AsutRoads and United States Department of Transportation (U.S. DoT). Both proposed ITS applications are based on the VANET architecture which could be implemented for a city size road network. The proposed vehicle detection system is relatively advanced compared to the existing sensor based detection systems. The thesis presents a unique co-simulation model that incorporates both road infrastructure, controlled vehicle mobility and a model of a VANET network.

Simulation results are analysed to characterise the VANET based IRTSS and PRTMS systems for a wide area traffic control system. The results indicate that the proposed architecture can efficiently detect and control traffic flows in a large road network with minimum hardware/software resources compared to the existing vehicle detection methods.
# Table of contents

ACKNOWLEDGMENTS ........................................................................................................... i  
ABSTRACT .......................................................................................................................... iii  
List of Figures .................................................................................................................. vii  
List of Tables ................................................................................................................... ix  
Publications ...................................................................................................................... xi  
List of Acronyms ........................................................................................................... xiii  
Chapter 1 ......................................................................................................................... 1  
  Introduction ..................................................................................................................... 1  
    1.1 VANETs Based Road Traffic Management .............................................................. 2  
    1.2 Motivation ............................................................................................................... 6  
    1.3 Scope and Contribution of the thesis ....................................................................... 9  
    1.4 Structure of the thesis .......................................................................................... 11  
    1.4.1 Summary ........................................................................................................... 11  
Chapter 2 ....................................................................................................................... 13  
  Intelligent Traffic Management System-The State of the Art ...................................... 13  
    2.1 Intelligent Transportation System (ITS) ................................................................ 13  
    2.2 Real Time Vehicle Detection and Intelligent road traffic control systems .......... 16  
    2.3 Intelligent Traffic light control Systems ................................................................. 22  
      2.3.1 SCOOT ............................................................................................................. 25  
      2.3.2 SCATS ............................................................................................................ 26  
      2.3.3 OPAC ............................................................................................................. 28  
      2.3.4 RHODES ....................................................................................................... 29  
    2.4 Fuzzy logic based controllers................................................................................... 30  
    2.5 Genetic algorithm based model and hybrid models ............................................... 32  
    2.6 Estimation and prediction based models ................................................................. 33  
    2.7 Intelligent traffic light control using Neural Network and Reinforcement Learning ... 34  
    2.8 Summary ............................................................................................................. 37  
Chapter 3 ....................................................................................................................... 39  
  VANETs and Intelligent Road Traffic Management System ......................................... 39  
    3.1 Introduction to VANETs ....................................................................................... 39  
    3.2 WAVE/DSRC communication architecture ......................................................... 41  
    3.3 IEEE 802.11p Architecture ................................................................................... 47
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.3.1</td>
<td>IEEE 802.11p MAC</td>
<td>47</td>
</tr>
<tr>
<td>3.4</td>
<td>Vehicular mobility modelling</td>
<td>52</td>
</tr>
<tr>
<td>3.5</td>
<td>Summary</td>
<td>55</td>
</tr>
<tr>
<td>4.1</td>
<td>Communication network architecture</td>
<td>57</td>
</tr>
<tr>
<td>4.2</td>
<td>Signalling system</td>
<td>60</td>
</tr>
<tr>
<td>4.3</td>
<td>Simulation Model</td>
<td>66</td>
</tr>
<tr>
<td>4.4</td>
<td>Simulation results and performance analysis</td>
<td>69</td>
</tr>
<tr>
<td>4.5</td>
<td>Summary</td>
<td>75</td>
</tr>
<tr>
<td>5.1</td>
<td>Communication network Architecture</td>
<td>77</td>
</tr>
<tr>
<td>5.2</td>
<td>Predictive Road Traffic Management System (PRTMS)</td>
<td>79</td>
</tr>
<tr>
<td>5.3</td>
<td>Prediction model</td>
<td>81</td>
</tr>
<tr>
<td>5.4</td>
<td>Simulation model</td>
<td>87</td>
</tr>
<tr>
<td>5.5</td>
<td>Simulation Results &amp; Performance Analysis</td>
<td>89</td>
</tr>
<tr>
<td>5.6</td>
<td>Summary</td>
<td>93</td>
</tr>
<tr>
<td>6.1</td>
<td>Conclusions</td>
<td>94</td>
</tr>
<tr>
<td>6.2</td>
<td>Future works</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td><strong>Bibliography</strong></td>
<td>98</td>
</tr>
<tr>
<td></td>
<td><strong>ANNEX-A</strong></td>
<td>107</td>
</tr>
</tbody>
</table>
List of Figures

Figure 1.1: Conceptual architecture of VANET based intelligent road traffic signalling system (IRTSS) ............................................................................................................................................. 5
Figure 2.1: Key components of an ITS .............................................................................................................. 14
Figure 2.2: SCOOT information flow .................................................................................................................. 26
Figure 2.3: SCATS architecture .......................................................................................................................... 27
Figure 2.4: Control Structure of the OPAC ........................................................................................................ 28
Figure 2.5: The RHODES hierarchical architecture ............................................................................................. 29
Figure 2.6: Generic functional blocks of a fuzzy logic based traffic control system ............................................. 31
Figure 2.7: Flow Chart of the Q-Learning Algorithm .............................................................................................. 35
Figure 3.1: Conceptual model of a VANET based IRTSS operating in an isolated intersection ............................. 40
Figure 3.2: Layered architecture for the DSRC communication ............................................................................. 42
Figure 3.3: Setups and Joining Mechanism of WAVE Basic Service Set (WBSS) .................................................. 44
Figure 3.4: Internal architecture of IEEE 802.11p MAC with channel coordination ........................................... 45
Figure 3.5: Medium access mechanism through distributed coordinated function ............................................. 48
Figure 3.6: Medium access mechanism through hybrid coordinated function (HCF) ......................................... 49
Figure 3.7: Illustration of the IEEE802.11p access categories ........................................................................... 50
Figure 3.8: Features of the IRTSS ....................................................................................................................... 51
Figure 3.9: Embedded approach for developing VANET applications .................................................................... 55
Figure 4.1: Illustration of the Road Network and the Communication network architecture for RTS ............................................................................................................................................. 58
Figure 4.2: Flow chart of the adaptive road traffic signal broadcasting algorithm in the RSU .................................. 61
Figure 4.3: Flow chart of the signal state reception algorithm in the OBU ............................................................ 63
Figure 4.4: Two phase signalling system ........................................................................................................... 64
Figure 4.5: IRTSS signal operation ...................................................................................................................... 65
Figure 4.6: RSU process model ............................................................................................................................ 68
Figure 4.7: OBU process model ........................................................................................................................... 68
Figure 4.8: Average number of vehicle arrival at the intersection ......................................................................... 70
Figure 4.9: Average waiting time for different flow densities ............................................................................. 71
Figure 4.10: Average network throughput for different vehicle flows ................................................................... 73
Figure 4.11: Average uplink MAC delay ............................................................................................................. 74
Figure 4.12: Average retransmission attempts for different flow densities .......................................................... 75
Figure 5.1: Conceptual architecture of the traffic guidance system ....................................................................... 78
Figure 5.2: Control flow diagram of the PRMTS ................................................................................................... 79
Figure 5.3: Functional blocks of the intelligent traffic management system .......................................................... 80
Figure 5.4: Intersection properties considered in the proposed PRMTS ................................................................ 82
Figure 5.5: network configuration of the proposed PRTMS ............................................................................... 85
Figure 5.6: Operational flow chart of the central controller .................................................................................. 86
Figure 5.7: Network model for the PRTMS ......................................................................................................... 87
Figure 5.8: Layout of the road network .............................................................................................................. 88
Figure 5.9: Moving average of the predicted vs. Actual vehicle flow measurements .............................................. 90
Figure 5.10: percentage of error ........................................................................................................................ 90
Figure 5.11: Total journey time .......................................................................................................................... 91
Figure 5.12: Total waiting time at the intersections ............................................................................................. 92
Figure 5.13: Vehicle flow (veh/min) at RSU-2 ..................................................................................................... 92
List of Tables

Table 1: Summary of the existing vehicle detection systems ..................................................... 19
Table 2: Intelligent traffic light control systems and detection methods ................................. 21
Table 3: Traffic signalling systems ............................................................................................ 23
Table 4: The DSRC channels, frequency ranges and the channel types ..................................... 42
Table 5: Simulation Parameters .................................................................................................. 69
Table 6: Fairness Index ................................................................................................................ 72
Table 7: Comparison of the maximum waiting time, average waiting time and the standard
deviceation values ...................................................................................................................... 72
Table 8: Average retransmission attempts of the OBUs ............................................................ 74
Table 9: Extended Simulation parameters .................................................................................. 89
Publications

As a result of this research, two referred papers were published in the IET and the IEEE conferences

List of Acronyms

AC Access category
AIM Advance intersection management
AIFSN Arbitration inter-frame space number
AIMS Advance intersection managements system
ARTMS Advance Road Traffic Management System
ATMS Advance Traffic Management System
AP Access point
APTS Automatic Public Transportation System
AVL Automatic Vehicle Location
CANU Communication in Ad Hoc Networks for Ubiquitous Computing
CCH Control channel
CCHI Control Channel Interval
CMAC Cerebellar Model Articulation Controller
CSMA/CA Carrier sensing multiple access and Collision avoidance
CW Contention window
CFP Contention-free period
CP Contention period
CUT Coordinated Universal Time
DBCV Direction Based clustering algorithm
DCF Distributed Coordination Function
DSRC Dedicated Short Range Communication
DIFS Distributed inter-frame time DIFS
EDCA Enhanced distributed channel access
GDF Geographical Data Files
GHG Green house gas
GASCAP Generalized Adaptive Signal Control Algorithm Project
HCF Hybrid coordinated function
HCCA HCF controlled channel access
IEEE-SA IEEE Standard Association
ITS Intelligent Transportation System
IRTSS Intelligent road traffic signalling system
ITC intelligent traffic-light control
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>IIM</td>
<td>Intelligent Intersection management</td>
</tr>
<tr>
<td>ITM</td>
<td>Intelligent Traffic Management</td>
</tr>
<tr>
<td>ICA</td>
<td>Intersection control agent</td>
</tr>
<tr>
<td>ITMS</td>
<td>Intelligent traffic management system</td>
</tr>
<tr>
<td>IDM</td>
<td>Intelligent Driver Model</td>
</tr>
<tr>
<td>IDM-IM</td>
<td>IDM with Intersection Management</td>
</tr>
<tr>
<td>IDM-LC</td>
<td>IDM with Lane Changes</td>
</tr>
<tr>
<td>LLC</td>
<td>Logic Link Control</td>
</tr>
<tr>
<td>MPC</td>
<td>Model predictive control</td>
</tr>
<tr>
<td>MIB</td>
<td>Management information base</td>
</tr>
<tr>
<td>MOGA</td>
<td>Multi objective genetic algorithm</td>
</tr>
<tr>
<td>MANET</td>
<td>Mobile Ad Hoc Network</td>
</tr>
<tr>
<td>MAC</td>
<td>Medium access control</td>
</tr>
<tr>
<td>MLME</td>
<td>MAC Sublayer Management Entity</td>
</tr>
<tr>
<td>OPAC</td>
<td>Optimized Policies for Adaptive Control</td>
</tr>
<tr>
<td>OBUs</td>
<td>On-board Units</td>
</tr>
<tr>
<td>PLME</td>
<td>Physical sublayer management entity</td>
</tr>
<tr>
<td>PIFS</td>
<td>PCF inter-frame space</td>
</tr>
<tr>
<td>PCF</td>
<td>Point coordination Function</td>
</tr>
<tr>
<td>POI</td>
<td>Point of interest</td>
</tr>
<tr>
<td>POG</td>
<td>Point of generation</td>
</tr>
<tr>
<td>PRTMS</td>
<td>Predictive road traffic Management System</td>
</tr>
<tr>
<td>QoS</td>
<td>Quality of Service</td>
</tr>
<tr>
<td>QAP</td>
<td>QoS enhanced AP</td>
</tr>
<tr>
<td>QSTA</td>
<td>QoS enhanced station</td>
</tr>
<tr>
<td>RSU</td>
<td>Road Side Unit</td>
</tr>
<tr>
<td>RFIDs</td>
<td>Radio frequency identifiers</td>
</tr>
<tr>
<td>RGA</td>
<td>Real coded genetic algorithm</td>
</tr>
<tr>
<td>RM</td>
<td>Resource manager</td>
</tr>
<tr>
<td>RCP</td>
<td>Resource command processor</td>
</tr>
<tr>
<td>RMA</td>
<td>Resource manager application</td>
</tr>
<tr>
<td>SCATS</td>
<td>Sydney Coordinated Adaptive Traffic System</td>
</tr>
<tr>
<td>SCOOT</td>
<td>Split Cycle, Offset Optimization Technique</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>SCHs</td>
<td>Service channels</td>
</tr>
<tr>
<td>SIFS</td>
<td>Short inter-frame space</td>
</tr>
<tr>
<td>TCP</td>
<td>Transmission control protocol</td>
</tr>
<tr>
<td>TSP</td>
<td>Transit Signal Priority</td>
</tr>
<tr>
<td>TA</td>
<td>Timing Advertisement</td>
</tr>
<tr>
<td>TXOP</td>
<td>Transmission opportunity</td>
</tr>
<tr>
<td>TSPEC</td>
<td>Traffic specification</td>
</tr>
<tr>
<td>UDP</td>
<td>User datagram protocol</td>
</tr>
<tr>
<td>UTC</td>
<td>Urban traffic control</td>
</tr>
<tr>
<td>UP</td>
<td>User priority</td>
</tr>
<tr>
<td>VANETs</td>
<td>Vehicular Ad-hoc Network</td>
</tr>
<tr>
<td>V2V</td>
<td>Vehicle to vehicle</td>
</tr>
<tr>
<td>V2I</td>
<td>Vehicle to infrastructure</td>
</tr>
<tr>
<td>VIN</td>
<td>Vehicular identification number</td>
</tr>
<tr>
<td>VFC-OPAC</td>
<td>Virtual-Fixed-Cycle OPAC</td>
</tr>
<tr>
<td>VMS</td>
<td>Variable message signs</td>
</tr>
<tr>
<td>WAVE</td>
<td>Wireless access in vehicular environment</td>
</tr>
<tr>
<td>WSNs</td>
<td>Wireless sensor networks</td>
</tr>
<tr>
<td>WME</td>
<td>Wave Management Entity</td>
</tr>
<tr>
<td>WBSS</td>
<td>WAVE basic service set</td>
</tr>
<tr>
<td>WSA</td>
<td>WAVE Service Advertisement</td>
</tr>
<tr>
<td>WSM</td>
<td>Wave Short Message</td>
</tr>
</tbody>
</table>
Chapter 1

Introduction

Around the world, most of the large cities are experiencing traffic congestions, accidents and greenhouse emissions due to ever increasing traffic volume on the roads which in turn is deteriorating the quality of the urban life. On the other hand, inefficient traffic control systems are often causing high delays at traffic intersections and roads by disrupting the normal traffic flows. As the waiting time is increased and more congestion occurring in the road network, huge amount of green house gases are emitted in the environment which is contributing to the global warming. Increased amount of journey time also ends up in spending more money on fuel. Moreover, expanding the existing road network to accommodate rapid population growth and traffic volume is often impractical as well as highly expensive.

With a view to solve the aforementioned problems, the Intelligent Transportation System (ITS) has received increased attention in recent years among the industrial and the academic researchers to make roads safer and to make journeys more comfortable. In the urban road network, it is essential to implement ITS based traffic management system in order to eradicate traffic congestions and to offer smoother traffic flows. Different standardization bodies, such as Vienna Convention on Road Signs [1] and Signals, AsutRoads [2] and United States Department of Transportation (U.S. DoT) [3] etc. have also taken significant interests in developing such technologies and protocols to support a number of promising applications based on the vehicular communication standards. A modern ITS aims to develop an Advanced Road Traffic Management System (ARTMS) that is comprised of an intelligent road traffic signalling system (IRTSS) and Advance intersection managements system (AIMS) which will adaptively control the signalling cycles based on the dynamic traffic flow densities at different intersections as well as apply predictive control measures to avoid congestions. To improve the efficiency of the current road intersections and road traffic situation the IRTSS and the AIMS can play a significant role for the modern ITS.
1.1 VANETs Based Road Traffic Management

The Vehicular Ad-hoc Network (VANETs) is the most promising technology used in the modern ITS for increasing the road safety and driving comfort. Even though number of different applications for vehicular communication systems were proposed during 80s, but implementation of those applications on a large scale basis was very difficult and costly without the emergence of the IEEE 802.11 standard family [4], which offer balanced efficiency in terms of performance and system implementation complexities. For time critical ITS applications, mainly the safety applications which require maximum application throughput as it involves human life, can be deployed through a vehicle to vehicle (V2V) communication system using a VANET architecture. A V2V communication architecture relies on an autonomous and distributed system which is created by the vehicles themselves without the support of a fixed infrastructure for data routing. A distributed V2V communication system can be implemented without depending on a centralized entity. Applications such as collision avoidance, lane merging, automatic braking alert etc. are the examples of safety application which can be implemented via a V2V communication system. On the other hand, comparatively less critical safety applications such as centralized traffic management, congestion information dissemination, shortest route selection etc can be implemented using a vehicle to infrastructure (V2I) communication system using a VANET based architecture. In a V2I communication architecture, critical safety and operational data are exchanged between the vehicles and highway infrastructure for various applications of the ITS. By gathering the local or global information on the traffic, the infrastructure acts as a coordinator and then suggests or imposes certain action plans for a group of vehicles. A VANET based V2V communication could offer significant advantages. A simple example could be enforcing the speed zone in a schooling area, in this case a speed controller can transmit speed information over the VANET which could be used by a car control unit and change a car speed to comply with the speed zone requirements. Similarly in accident risk areas or in case of bad weather conditions traffic systems can enforce different driving conditions via a VANET based signaling system. Another main advantage of a VANET based system is that road intersections can receive traffic flow information long before a vehicles arrive at an intersection. Whereas in a sensor based system vehicles can be detected only when it is close to the sensors which are usually
installed nearby the intersection. The main advantage of a V2I based VANET system is that a wide area can be covered and different ITS applications can be integrated in a single system which can significantly improve the overall performance a road network. To establish communication between vehicles and the highway infrastructure all the vehicles are equipped with a communication device named as On Board Unit (OBU) which can operate in motion and also able to exchange information between other OBUs and RSUs (Roadside units). The Road Side Unit (RSU) is the device which is installed as a fixed communication infrastructure to support information exchange in a VANET architecture.

Traffic signaling system is a widely investigated area in the transportation research. Modern ITSs have added new dimensions to this field. In the conventional fixed-cycle traffic signaling system generally there is no real time vehicle detection process and entire process of changing the signal lights depends on the pre calculated signal phases; based on some historical traffic statistics of the adjacent road sections of any particular intersection. Thus efficient utilization of the intersection is not possible. As a result, vehicles spend significant amount of time and fuel at the intersections due to congestions. In some scenarios vehicles need to wait due to the use of pre-timed red duration although there may be no vehicle accessing the intersection at the late night. Moreover, heavy traffic jams could be created due to vehicle overflows in the intersections during the peak hours of the day. Furthermore, in the existing traffic control systems, actuated/traffic-responsive signaling systems, roadside sensors/loop detectors are used to estimate traffic arrivals which generally provide a very limited snapshot of the overall traffic situation. In addition, installation and maintenance costs of these sensors increase the financial pressure on the transportation authorities. However, these control systems apply adaptive road traffic signaling system.

The key objective of the ITS is to provide a smooth traffic flow in the road network as well as improve the traffic flow performance by directly controlling the vehicle movements. Traffic management with an ITS has several advantages over the conventional traffic management methods. Through the newly developed technology of VANETs, an ITS can implement various types of control measures for the advance intersection management (AIM) and for the coordinated traffic control system. Improvement in the performance matrices of such systems relies on reducing the waiting time and congestion level at the intersection, and also on the detection accuracy of the
real time vehicle flows and dissemination of this information for the coordination. The objectives are achieved though the optimization of the green time allocation in order to ensure quick passage of the vehicles and by maximizing intersection capacity utilization while disseminating the real time traffic information among the coordinated intersections to maintain smooth vehicle flows.

The figure 1.1 shows a conceptual architecture of a VANET based IRTSS over a wide area network where the drivers will be updated with various types of safety and non-safety related information during the journey. As shown in the figure 1.1 RSUs are installed at different points of the road network as infrastructure and OBUs are installed in each vehicle running on the street. All the RSUs are inter-connected via the back-bone network and drivers can exchange their information over a large road network. Satellites Global Positioning System (GPS) could also provide important vehicle positioning information (e.g., vehicle speed, latitude, longitude etc.) to the OBUs which can be sent to the RSUs for further processing and to develop useful ITS application. A VANET based system can be used to obtain road traffic information such as traffic volume, intended destination/route information of the vehicles, type of vehicles, etc. to optimize traffic signal lights (i.e., red, green, amber) duration, length of signal cycles, phase timing parameters etc. which can improve traffic flows as well as make vehicles more energy efficient by reducing the engine operating time. At the same time with introduction of new electric vehicles significant opportunities arise to use automatic traffic signaling systems to improve the road safety. An electric vehicle control system could be overridden by an automatic process based on real-time signaling rather than always relying on a driver’s response and judgments. The VANET architecture, based on both vehicle to vehicle (V2V) mode and vehicle to infrastructure (V2I) mode are currently under investigation to develop a possible future intelligent traffic control system[5][6].
In an advance ITS, traffic control decisions are not taken heuristically. As validated traffic models are available which are widely used in the real world as well as in the simulation, the best sequence of the traffic pattern or vehicle flow can be modelled, and future control decisions can be structured by using the advanced optimization tools based on the predicted traffic information. These model based optimization control methods are capable of predicting the future traffic information and make the best control decisions by projecting into a long term scenario. The Model predictive control (MPC) [7] technique is an example of this kind of model based predictive controller.

In most traffic management systems the isolated traffic intersections are controlled by local controllers in a decentralized manner [8-10]. Only local traffic information was accumulated through the sensors (e.g. Wireless sensor networks) with no shared information between the intersections, thus centralized control was not feasible. Nonetheless, it was successful enough to regulate saturated traffic flow with low traffic densities but as the traffic volume increased day by day the need of co-ordinated control
systems have emerged and predictive control measures could be necessary to achieve maximum benefits out of the modern intelligent traffic management systems.

Many research efforts have been carried out to develop solutions to coordinate traffic movements on the urban road network. Different control strategies were proposed in different literature to implement such a system. Coordinated control strategies for fixed-time signalling system use off-line based traffic flow data for the decision process. On the other hand, through the use of VANETs, real-time traffic state information can be exchanged and control schemes can be implemented according to the current measured traffic states. Moreover, as the traffic information can be shared in a wide area network, prediction model could be used to aid the control decisions more accurately and effectively over the road network. The VANET based intelligent traffic management system (ITMS) could be centralized, distributed or hierarchical. The centralized control strategy can offer an optimized traffic control solutions for road network and traffic conditions in order to reduce the total journey time, congestion avoidance, emission control etc. In the distributed control strategy the VANET based local controller will be connected and coordinated in a hierarchical structure where large-scale systems will be divided into multiple levels, on each level, a specific control problem will be solved.

1.2 Motivation

A VANET based V2I communication architecture can be used to design ITS applications like Intelligent Road Traffic Signaling System (IRTSS), Predictive road traffic Management System (PRTMS), Advance intersection management system (AIMS) etc. These ITS applications can be modeled and integrated together to achieve an efficient road traffic management system. In order to implement such systems, a robust communication network is required to facilitate bidirectional information exchange between the network infrastructure and the vehicles [11]. A VANETs based IRTSS can collect traffic information from individual cars and disseminate the information to neighboring signaling nodes over a wide area so that traffic signaling sequencing can be planned in advance to reduce traffic congestions, reduce journey time and minimize green house emissions to dynamically control the traffic signaling cycle. The main advantages of a VANET based intelligent road traffic signal system (IRTSS) are:
i) Reduced infrastructure requirements since no road sensors are required to measure the traffic flow

ii) Scalable, because an IRTSS could be deployed for small (e.g. Isolated intersection) to large road network (e.g. Coordinated intersections).

iii) It offer flexible road traffic information gathering and dissemination opportunities over a wide geographical area.

Similarly, in a VANET based Advance Intersection Management (AIM) system, vehicles can share the real time traffic information for a coordinated intersection management. The distributed traffic monitoring system and the information dissemination system could facilitate the future ITS with an advanced centralized control method. The predictive traffic state observation could play a vital role in congestion avoidance and open up several avenues to optimally reduce the total trip duration and waiting times. Several control sequences can be solved in each control step over the prediction horizon and the estimation of the future traffic condition states can be determined.

A VANET based Advance Traffic Management System (ATMS) has numerous advantages for controlling a large traffic network. The system can deal with multi-input and multi-output problem with constraints, for example different type of traffic control measures can be handled such as modelling adaptive traffic signal control or controlling the speed limits. As the VANET based predictive traffic control system and ATMS can be modelled as a multi-objective optimization problem, the system can be accommodated with different type of control applications such as congestion control, re-routing of the vehicles, and automated vehicular movement etc. As the system uses the feedback information measured from the real time traffic it can work in a closed loop manner. Moreover, the AIM can also handle the sudden variation in the real time traffic and reset the prediction model as per the control requirements.

Nonetheless, design and development of a VANET based IRTSS and ATMS requires validated traffic flow model and proper network infrastructure for its implementation. Performance analysis is also an important step for the development of such ITS applications. To analyse the performance of an ITS for different traffic scenario traffic simulators are widely used for mobility modelling and generating realistic vehicular traces. A simulator must have the capabilities to offer realistic mobility scenarios where
the vehicles will be reacting according to the different type of road conditions. Thus choosing an appropriate traffic simulator and an approach is very crucial to obtain realistic performance data. Moreover, the communication network simulator and the traffic simulator must be inter-linked and should be compatible with a VANET based ITS system. Based on the interaction capabilities vehicular mobility models are classified into three main classes [12]:

- **Isolated Approach:** where the only mobility traces or mobility patterns are generated which can be loaded separately in a network model to analyse the system performance.

- **Embedded Approach:** where the mobility model and the network model is embedded in the same platform. So the mobility model can be directly implemented to the network model.

- **Federated Approach:** where the mobility modelling simulator and the network simulator works in a bidirectional manner through an interface. The mobility traces can be generated and directly fed into the network simulator and the interaction is carried out in a parallel manner through sets of interfaces. Network simulators are available such as ns-2, ns-3, QUALNET, OPNET etc. which can be mapped with mobility modelling simulators such as SUMO, CORSIM, VISSIM etc.

While developing an ITS application the choice of the above mentioned approaches depends on the application and network model requirements. Federated approaches are adopted to analyse application centric models where the application model is developed without any strict network model requirements. The embedded approaches are adopted for the applications with specific network model requirements such as the VANET based IRTSS.

This thesis investigates the design and development of a VANET based IRTSS applications and a predictive ATMS with coordinated traffic management features. The application of a VANET based IRTSS and an AIM are to be integrated and evaluated based on the required performance matrices to model a wide area based traffic management system. The proposed VANET applications and simulation models presented in this thesis show significant improvements of traffic flows in a road network in terms of reduced waiting time and the total journey time. Also with the advanced traffic information dissemination method, the model shows improvement in maintaining
smooth traffic flow by avoiding traffic congestions at different road sections and intersections. Consequently, the VANET based traffic management system presented in this thesis can be extended to implement a larger road area network which may include several sub-networks and mixed road topologies.

1.3 Scope and Contribution of the thesis

A new standard, Dedicated Short Range Communication (DSRC) has been introduced by the IEEE Standard Association (IEEE-SA) board, in order to accommodate the VANET applications and its requirements [4]. A new communication protocol stack is also defined, named as the wireless access in vehicular environment (WAVE) for development of VANET applications. These technologies have been defined in the IEEE802.11p and the IEEE1609 standards. These standards open up wide research opportunities for the modern intelligent transportation system. The main objective of these standards is to ensure interoperability between mobile wireless devices communicating in a situation where transactions must be completed within a shortest possible time. The benefits of using a DSRC for an ITS have been thoroughly explored and examined in many studies [13, 14]. Studies in [15, 16] demonstrated use of video cameras and other traffic sensors to maintain smooth traffic flow and to reroute vehicles by using road side message boards when congestion occurs. Research shows that the travel time [17], lane merge [18], and speed advisory [19] information can be gathered from this road side message boards and was useful to manage traffic movement in real time [14]. By using the real time traffic information data provided by the ITS, drivers will receive updated road condition information leading to safer roads. The applications for the ITS can be introduced via a WAVE/DSRC to implement the following services.

- Traffic monitoring and management
- Providing traveller information
- Incident management
- Enhancing safety of both the road user and worker
- Increasing road capacity/ road utilization
- Law Enforcement
- Tracking and evaluation of contract incentives/disincentives (performance-base contracting)
- Work zone planning
- Cooperative Adaptive Cruise Control
- Forward Collision Warning
• Lane departure Warning
• Lane Changing Warning
• Intersection Collision Avoidance
• Approaching Emergency Vehicle Warning
• Electronic Toll Collection
• Curve speed warning

The main contributions of this thesis are

- Development of a Vehicular Ad-Hoc Network (VANET) based communication infrastructure model (V2I) for Intelligent Traffic Intersection Management (ITIM) system over a wide area network. This includes real time traffic detection and implementation of intelligent traffic signal control system for both isolated and coordinated intersections.
- A VANET based packet communication and control system.
- A Sensor less road traffic estimation and control system.
- A communication network model that suits the vehicular mobility model and the application model.
- Development of an Intelligent Road Traffic Signaling System (IRTSS) where the signal sequences would be changing adaptively with respect to the real time detected traffic flow on the roads. The main objective of the IRTSS is to reduce the average waiting time at the intersections and provide fairness in terms of the average waiting time for all the lanes joining at the intersection. This includes reduction of total journey time by sharing the traffic information among multiple coordinated junctions.
- A coordinated intelligent road traffic control system for a wide area network, which adopts predictive traffic management system on top of a VANET based IRTSS and includes a traffic guidance system to reduce traffic congestions and delays on road.
1.4 Structure of the thesis

This thesis contains six chapters, and this introduction makes the first chapter of the thesis. Chapter 2 presents a literature survey on the research topic. Chapter 3 discusses about the VANET based IRTSS and mobility modelling techniques. Chapter 4 presents the detail of the proposed VANET based IRTSS, its network architecture, signalling system and also presents the simulation results for the performance analysis. In Chapter 5, a predictive road traffic management system (PRTMS) is presented which has been developed based on our proposed IRTSS structure. The performance analysis of the PRTMS is also presented where a simulation model was used to analyse its performance. At the end, discussion on the future work and conclusion are provided in the Chapter 6.

1.4.1 Summary

The content of the main chapters of this thesis are summarized as follows:

- **Chapter 2** presents a literature review on the vehicle detection technologies, some of the current intelligent traffic control systems and intelligent road traffic management systems. Various types of traffic detection systems using loop detectors, sensors, video cameras, radar technologies etc have been reviewed as well as their pros and cons were listed in terms of developing an intelligent traffic control system. The chapter also presents features and functionality of the existing Intelligent Traffic control systems such as SCOOT, SCATS, RHODES, OPAC and MPC etc. Furthermore, Use of different technologies such as fuzzy logic, neural network, genetic algorithm etc. for optimizing traffic control measures were reviewed and presented.

- **Chapter 3** describes the framework for constructing a VANET based IRTSS. It further discusses the associated standards and defines the requirements for developing the communication network architecture and mobility model. Brief description on the IEEE 802.11p/DSRC (Dedicated Short Range Communication) and WAVE (Wireless Access in Vehicular Environment) standard is presented. Both physical and medium access control (MAC) layer properties are discussed for developing the VANETs applications using the IRTSS and the PRTMS algorithms. Review on the basic technologies such as
CSMA/CA, DCF, PCF, HCF etc of the wireless local area network (WLAN), is presented. Nonetheless, importance of the realistic mobility models and traffic control design requirements are investigated and presented.

- **Chapter 4** introduces a VANET based Intelligent Road Traffic Signalling System (IRTSS). In the proposed system vehicles are detected using the VANET infrastructure by exchanging information with the oncoming vehicles at the intersection. The IRTSS optimizes the traffic signal durations adaptively to reduce the waiting time at the intersection. This chapter also describe the developed OPNET simulation model and presents the performance analysis results for the proposed traffic management system and the associated IEEE 802.11p based communications network. The performance of the proposed traffic management system is also compared with that of a conventional traffic signalling system.

- **Chapter 5** introduces a VANET based advance traffic management system that employs a predictive traffic control technique for a large road network comprised of multiple junctions. A VANET based communication network model and the application model of the Predictive Road Traffic Measurement System (PRTMS) are integrated with the IRTSS algorithm to create an intelligent road traffic management system. The developed OPNET Simulation model and performance analysis of the system are also discussed in this chapter.

- **Chapter 6** summarises the results and the achievements relating to the goal and objective of this thesis. Also prospect on the future work relating to the topic is focused and discussed in this chapter.
Chapter 2

Intelligent Traffic Management System-The State of the Art

Due to ongoing population increase in the urban areas throughout the world, the number of vehicles on roads is resulting in severe traffic congestions, accidents and travel delays. This is leading to significant loss of working hours, wastage of fuels and increase in air pollution which in turn is disrupting the day-to-day urban life. Although in many countries of the world, well built and enormous road networks are already in place to efficiently handle the increased volume of traffic it is necessary to introduce intelligent traffic control measures. In order to improve the efficiency of road traffic systems effective traffic control and management strategies need to be adopted. The use of Intelligent Transportation System (ITS) could significantly improve the operation and safety of transport networks by coordinated use of information, communications and control technologies.

2.1 Intelligent Transportation System (ITS)

Intelligent transportation system (ITS) is a set of strategies which addresses the challenges associated with enhancing road safety and congestion reduction measures by deploying cutting edge technologies. Advanced communication techniques, electronic devices, sensors and information processing technologies have enabled the ITS to improve the transportation safety and traffic flow. With the integration of board range of communication networks, management systems and transportation infrastructure, use of the ITS could introduce new prospects of advanced traffic control in the transportation sector. The measures used to quantify the benefits of ITS include traveller safety, traveller mobility, system efficiency, productivity of transportation providers, energy conservation and environmental protection. Survey [20] shows the following benefits that could be achieved by a modern ITS:

- Delays can be reduced between 5% and 40% by implanting adaptive traffic control system and with the advanced traveller information dissemination system.
- With freeway management systems crashes can be minimized up to 40% and the overall travel time can be reduced up to 60%.
- With the implementation of commercial vehicle information systems and freight management system costs can be reduced up to 35% for the vehicle owners.
- The travel time could be reduced up to 50% by implementing transit management system with automatic vehicle location and transit signal priority technology.

Structures and different architecture of ITS systems have been widely investigated and discussed in different literatures as shown in figure 2.1. The figure shows the interaction of different applications and control modules in an ITS system.

![Figure 2.1: Key components of an ITS][21]

**Incident Management System**: Study shows that 50% of the congestion delay occurs due to different kinds of incidents on the roads such as accidents, mechanical breakdown or any unpredictable stopping of the vehicles. Incident management system could reduce the effects of non-recurring congestion by faster detection of these incidents consequently reducing the time for the responding vehicle to arrive at the place of incident. The system could also broadcast the incident information to the other
travellers and suggest alternative routes for reducing the journey time and to avoid congestion [22].

**Transit Management System:** Transit management system could be used by the transit agencies to optimize vehicle resources and to achieve required quality of service with reduced number of vehicles. With the Automatic Public Transportation System (APTS) and Automatic Vehicle Location (AVL) systems it is possible for the transportation authorities to get valuable information about vehicle movements and manage their trips more efficiently. The ITS application like Transit Signal Priority (TSP) is used to improve the on-time performance of buses or light-rail vehicles. Buses those are behind the schedule could get increased green phase and shorter red phases at the intersections to maintain their schedule. Study shows [21] that a TSP could enhance the quality and reliability of bus services. Also, it achieved customer satisfaction and reduced operational cost of the transit agencies.

**Emergency Management System:** Priority to the emergency vehicles, notification of emergency vehicle approach, early identification of the emergency situation etc. could be implemented using an emergency management system. With an advanced ITS a vehicle could observe an emergency situation for example fire or explosion at a particular place and disseminate the information to the corresponding emergency departments as well as relay the information to the other vehicles. As a result, less number of vehicles will approach at the place of incident enabling emergency vehicles to attend the incidence with minimum delay.

**Freight Management System:** Freight movement facility is very important for the economic development of a country. Current application of freight movement mainly focuses on carrier enforcement and regulatory environment such as electronic fund payments, electronic registration, permit application, automated inspection, safety information exchange, border clearance, credential checking, safety screening, weight screening etc.

**Information Management System:** Data accumulated via an ITS can be used as an important resource for the transportation authorities and corresponding agencies. Information could be used for policy making and implementing transportation projects. For example, Statistics of emission level or green house gases could assist the
environmental departments to make future plan to reduce the emission level or it could help the vehicle manufacturing companies to design more eco-friendly vehicles in the future.

**Regional multimodal and traveller information system:** ITS applications such as advance traveller information system could allow drivers to make more effective decisions about their trips. Advanced information on the congestion states and road conditions could help the motorists to avoid problem spots and reduce the total journey time. With the application of different type of safety measures can be adopted such as avoiding unsafe weather conditions, selecting safe time of departure, route planning, alternative route selection, travel time estimation etc.

**Arterial and freeway Management system:** The main objectives of arterial and freeway management systems is to increase road safety, reduce costs, maintain smooth traffic flow by implementing advanced traffic management measures such as adaptive signal control system, variable message signs (VMS), ramp metering etc. Different kinds of detection methods could be used in order to get the real time road traffic information. By using the accumulated data complex control algorithms could be used to manage different road traffic conditions. Application such as Intelligent Road Traffic Signalling System (IRTSS) and Predictive Road Traffic Management System (PRMTS) can be classified as this kind of management system.

The conceptual VANET architecture based IRTSS algorithm is shown in figure 1.4 can offer benefits in various ways from the above mentioned ITS technologies as the integration of the different ITS systems; the intelligent road traffic signalling system could implement more systematic and efficient control measures to regulate the road traffic.

2.2 Real Time Vehicle Detection and Intelligent road traffic control systems

Adaptive and advanced signal control systems coordinates the road traffic flow at intersections by continuously adjusting the signal phase lengths based on the current traffic volumes. Significant amount of research initiatives have been launched in this field over the past decades, particularly in the area of traffic signal control, travel time estimation and routing strategies for vehicles [23-25]. The outcome of the adaptive
systems shows improvements over the fixed cycle signaling system in terms of reducing delays and emission level. While implementing strategies or applications of the ITS such as intelligent traffic-light control (ITC), Intelligent Intersection management (IIM) or Intelligent Traffic Management (ITM) real time vehicle detection comes as the first step to design an ITS system. Real time vehicle detection is an important task in order to make the system efficient and adaptable to different traffic control systems. Most of the previous works on the detection methods of real time traffic in intelligent transportation systems are based on wireless sensor networks (WSNs), Radio frequency identifiers (RFIDs), video and image processing, and loop detectors [26]. Reference [27] proposed an adaptive scheme for changing the signaling phases where vehicle movements and traffic flow is detected using a wireless sensor network (WSN). Road information such as vehicle density, speed, length of the cars were accumulated and sent to the intersection control agent (ICA) to optimize the signaling sequence for the adaptive traffic signal settings. The performance of the system was analyzed in an open loop manner. Traffic flow statistics measured by the wireless sensor network were fed into the traffic simulator for the performance analysis. In reference [26] it was suggested to mount the RFID tags on the vehicles to determine the vehicle density on different roads for implementing intelligent road traffic signaling system. A central computer system will handle the dynamic database where vehicle information will be sorted out by the vehicular identification number (VIN). The computer model can handle number of variables such as type of car, priority of vehicles, time of the day or night etc. The document didn’t present any performance analysis of the RFID based adaptive traffic signaling system. An RFID based system is very similar to currently used e-tag system, however such systems require significant roadside infrastructure to collect vehicle information.

Collecting the data and dissemination of the information plays a vital role for implementing intelligent road traffic signalling system. Early detection technologies used electronic and mechanical devices such as electrical counting boards for counting the passing vehicles. Furthermore, estimations were carried out based on the historical or statistical data. In modern detection methods [28] [29] [30] [31] various types of intrusive and non-intrusive sensors are used which includes both wired and wireless technologies for vehicle detection. Both wired and wireless based data collection and dissemination methods are described in this literature.
**Intrusive sensors**

Inductive loops, magnetometers, micro loop probes, pneumatic road tubes, piezoelectric cables and other weigh-in-motion sensors are included in the category of intrusive sensors. These vehicle detectors are placed on the road surface, sometimes by embedding them under the road surface, or by installing directly on the pavements in the case of pneumatic road tubes. Although, traffic surveillance is the main purpose using these sensors, however, these detection technologies have following limitations [32]

- Disrupts traffic flow at the time of installation.
- Failure associated with the installation on poor road surfaces.
- Reinstallation is needed while resurfacing of roadways and utility repair servicing are carried out.

**Non-intrusive sensors**

The search for an alternative reliable and economic vehicle detection and tracking system has lead researchers to look into more advanced technologies where the detectors could be installed more easily with minimum disruption to the traffic flow. Modern non-intrusive sensors are installed above the lanes to monitor the traffic flow or on the side of a roadway where multiple lanes could be covered. Microwave radar, laser radar, passive infrared, ultrasonic, passive acoustic array etc. are the examples of non intrusive detectors. Sometime combination of different detectors are used together to make the system more robust such as combination of passive infrared and microwave Doppler or passive infrared and ultrasonic. These detectors provide vehicle count, vehicle speed information and multiple detection zone coverage etc. Comparison of the different types of detectors is presented in the table 1 [32]
Table 1: Summary of the existing vehicle detection systems

<table>
<thead>
<tr>
<th>Technology</th>
<th>Strength</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inductive Loop</td>
<td>• Flexible design to satisfy large variety of applications.</td>
<td>• Installation requires pavement cut.</td>
</tr>
<tr>
<td></td>
<td>• Mature, well understood technology.</td>
<td>• Decreases pavement life.</td>
</tr>
<tr>
<td></td>
<td>• Provides basic traffic parameters (e.g., volume, presence, occupancy, speed, headway, and gap).</td>
<td>• Installation and maintenance require lane closure.</td>
</tr>
<tr>
<td></td>
<td>• High frequency excitation models provide classification data.</td>
<td>• Wire loops subject to stresses of traffic and temperature.</td>
</tr>
<tr>
<td>Magnetometer (Two-axis fluxgate magnetometer)</td>
<td>• Less susceptible than loops to stresses of traffic.</td>
<td>• Installation requires pavement cut.</td>
</tr>
<tr>
<td></td>
<td>• Some models transmit data over wireless RF link.</td>
<td>• Decreases pavement life.</td>
</tr>
<tr>
<td></td>
<td>• Installation requires pavement cut.</td>
<td>• Installation and maintenance require lane closure.</td>
</tr>
<tr>
<td></td>
<td>• Cannot detect stopped vehicles.</td>
<td>• Some models have small detection zones.</td>
</tr>
<tr>
<td>Magnetic (Induction or search coil magnetometer)</td>
<td>• Can be used where loops are not feasible (e.g., bridge decks).</td>
<td>• Installation requires pavement cut or tunnelling under roadway.</td>
</tr>
<tr>
<td></td>
<td>• Some models installed under roadway without need for pavement cuts.</td>
<td>• Cannot detect stopped vehicles.</td>
</tr>
<tr>
<td></td>
<td>• Less susceptible than loops to stresses of traffic.</td>
<td></td>
</tr>
<tr>
<td>Microwave Radar</td>
<td>• Generally insensitive to inclement weather.</td>
<td>• Antenna beamwidth and transmitted waveform must be suitable for the application.</td>
</tr>
<tr>
<td></td>
<td>• Direct measurement of speed.</td>
<td>• Doppler sensors cannot detect stopped vehicles.</td>
</tr>
<tr>
<td></td>
<td>• Multiple lane operation available.</td>
<td></td>
</tr>
<tr>
<td>Infrared</td>
<td>• Active sensor transmits multiple beams for accurate measurement of vehicle position, speed, and class.</td>
<td>• Operation of active sensor may be affected by fog when visibility is less than 20 ft or if blowing snow is present.</td>
</tr>
<tr>
<td></td>
<td>• Multi-zone passive sensors measure speed.</td>
<td>• Passive sensor may have reduced sensitivity to vehicles in its field of view in rain and fog.</td>
</tr>
<tr>
<td></td>
<td>• Multiple lane operation available.</td>
<td></td>
</tr>
<tr>
<td>Technology</td>
<td>Strength</td>
<td>Weaknesses</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Ultrasonic</td>
<td>• Multiple lane operation available</td>
<td>• Some environmental conditions such as temperature change and extreme air turbulence can affect performance.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Temperature compensation is built into some models.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Large pulse repetition periods may degrade occupancy measurement on freeways with vehicles travelling at moderate to high speeds.</td>
</tr>
<tr>
<td>Video Image Processor</td>
<td>• Monitors multiple lanes and multiple zones/lane.</td>
<td>• Inclement weather, shadows, vehicle projection into adjacent lanes, day-to night transition, vehicle/road contrast, and water, salt grime, icicles, and cobwebs on camera lens can affect performance.</td>
</tr>
<tr>
<td></td>
<td>• Easy to add and modify detection zones.</td>
<td>• Requires 50 to 60 ft camera mounting height (in a side-mounting configuration) for optimum presence detection and speed measurement.</td>
</tr>
<tr>
<td></td>
<td>• Rich array of data available.</td>
<td>• Some models susceptible to camera motion caused by strong winds.</td>
</tr>
<tr>
<td></td>
<td>• Provides wide-area detection when information gathered at one camera location can be linked to another.</td>
<td>• Generally cost-effective only if many detection zones are required within the field of view of the camera.</td>
</tr>
</tbody>
</table>

Furthermore, a VANET infrastructure could be also used for detecting vehicles on the road. The main advantage a VANET based vehicle detection system can offer is the detection range, which is much higher than any other concurrent detection technology. Various detection methods were used to design intelligent traffic control systems and a brief evaluation report on the detection technologies is presented in [34].

A number of well-known intelligent traffic light control systems are available for controlling traffic at the intersections such as Split Cycle, Offset Optimization
Technique (SCOOT) [33], [35], Sydney Coordinated Adaptive Traffic System (SCATS) [36 37], Optimized Policies for Adaptive Control (OPAC) [38], RHODES [39]. These technologies use wide variety of vehicle detection systems. Operational details of these systems will be discussed in the next section of this chapter. Reference [40] proposed a Direction Based Clustering algorithm (DBCV) based on the VANET which is used to measure the density of the vehicle approaching at an intersection. The model uses the V2V communication architecture and the optimized the adaptive signaling phase is estimated by modifying the Webster’s equation which is widely used for calculating the signal cycle lengths [10]. However, the transmission range is not sufficient to accommodate high volume of approaching vehicles. The reference [41] proposed real-time traffic data detection, green light sequence determination algorithm, and traffic light duration determination algorithm for an adaptive traffic signaling system based on a wireless sensor network (WSN). The main focus of the work was concentrated on the development of an analytical model for the adaptive signal phase determination algorithm to reduce the average waiting time and to reduce the stops during the trip. The reference did not provide detail information about the communication network architecture to implement the algorithm. Details of the detection technologies adopted by the popular traffic control systems are summarized in the table 2.

Table 2: Intelligent traffic light control systems and detection methods

<table>
<thead>
<tr>
<th>System</th>
<th>Sensor Utilized</th>
<th>Sensor Location</th>
<th>Data Collected</th>
<th>Data Processing Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCOOT</td>
<td>Inductive Loop Detector (2m in direction of travel), microwave radar that detects vehicle presence, Video Image Processing (VIP)</td>
<td>Upstream</td>
<td>Volume, Occupancy</td>
<td>Second by second</td>
</tr>
<tr>
<td>SCATS</td>
<td>Inductive loop detectors (ILD) (1.8m wide by 5m long), Video Image Processing (VIP).</td>
<td>Stop line</td>
<td>Volume, Occupancy in most lanes of the subsystem’s critical intersection</td>
<td>Second by second</td>
</tr>
<tr>
<td>System</td>
<td>Sensor Utilized</td>
<td>Sensor Location</td>
<td>Data Collected</td>
<td>Data Processing Interval</td>
</tr>
<tr>
<td>--------</td>
<td>----------------</td>
<td>----------------</td>
<td>----------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>OPAC</td>
<td>ILD, VIP microwave radar that detects vehicle presence, magnetometers with RF data links</td>
<td>Upstream</td>
<td>Volume, Occupancy, Speed</td>
<td>Second by Second</td>
</tr>
<tr>
<td>RHODES</td>
<td>ILD, VIP, microwave radar that detects vehicle presence</td>
<td>Stop line presence, upstream passage</td>
<td>Volume</td>
<td>Second by Second</td>
</tr>
</tbody>
</table>

### 2.3 Intelligent Traffic light control Systems

With the increasing community concerns to the widening and expansion of the road network and increasing traffic volume, it is becoming more difficult to manage traffic congestion by conventional means. New and smarter solutions are required to deal with this problem. Main Roads in Australia already uses the SCATS [36-37] to co-ordinate traffic signals to reduce congestion level and to provide information to the traffic control operators on the congestion levels across the road network. The emergence of ITS has created many opportunities for developing new applications like in-car navigation systems, such as IRTSS, PRTMS etc. These systems will require information on real-time traffic condition. With real time traffic information system these application may improve traffic situation and could make journeys safer [42]. The increased availability of real time traffic information and onboard navigation systems could improve capabilities of individual vehicles on the road. The conventional network wide traffic optimization process, which is based on midterm traffic demand projection, could perform better if adaptive and advanced traffic controllers are used [43].

In modern Intelligent Transportation Systems significant advancements have been seen in developing the traffic signal control systems over last two decades. Fixed-timed traffic controller are less commonly used, where the signalling phases are pre determined based on the statistical analysis. In recent time traffic responsive controller are being widely used while coordinating multiple junctions. For isolated intersection
Sensor based traffic actuated controllers are used. Both traffic responsive and sensor actuated control system adapts with the variation of the phase splits in order to optimize the efficiency and to increase the traffic capacity of intersections. Table 3 shows the different categories of traffic signalling systems, their main characteristics, control mechanism and applications [44][45].

Table 3: Traffic signalling systems

<table>
<thead>
<tr>
<th>Categories</th>
<th>Main Characteristics</th>
<th>Control Technique</th>
<th>Method</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolated Intersection Control</td>
<td>Does not consider timing for adjacent signalized intersections</td>
<td>Fixed Time (Pre-timed)</td>
<td>Assigns right-of-way according to a pre-determined schedule. Computer programs used with average demand volumes for period to compute timing off-line.</td>
<td>Intersection sufficiently isolated from adjacent signalized intersection so that arriving vehicles do not exhibit strong platooning characteristics</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Traffic Actuated Adjusts green time according to real-time demand measured by detectors on one or more approaches</td>
</tr>
<tr>
<td>Time Base Coordination</td>
<td>Coordinates based on common time synchronization.</td>
<td>Pre-timed coordination</td>
<td>Computer programs used with average demand volumes for period to compute timing off line.</td>
<td>Signals sufficiently closely spaced to require coordination</td>
</tr>
<tr>
<td>Interconnected Control</td>
<td>Signals are networked together using wire or wireless techniques Provides field equipment status Downloads timing plans from traffic management centre.</td>
<td>Pre-timed coordination Operator selection of timing plans</td>
<td>Computer programs used with average demand volumes for period to compute timing off line. Operator selection based on special events or external information on incidents or traffic conditions</td>
<td>Pretimed coordination commonly used where variation in day-to-day demand is not excessive Operator selection used for special situations</td>
</tr>
<tr>
<td>Categories</td>
<td>Main Characteristics</td>
<td>Control Technique</td>
<td>Method</td>
<td>Application</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>------------------------------------------</td>
<td>--------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Traffic Adjusted Control</td>
<td>Conventional traffic adjusted operation</td>
<td>Use of traffic sensors to provide traffic adjusted capability</td>
<td>Traffic adjusted selection of timing plans</td>
<td>Traffic adjusted capability employed where variations in day to- day demand may vary significantly at a particular time</td>
</tr>
<tr>
<td>Traffic Responsive Control</td>
<td>Timing plans generated rapidly and automatically using system sensors</td>
<td>Changes signal split adaptively within a cycle. Changes signal cycle offsets within a few minutes.</td>
<td>Uses upstream sensor data to optimize objective function such as delay or controls to level of congestion</td>
<td>Where variations in day-to-day demand may vary significantly or where variations result from unusual traffic patterns or events</td>
</tr>
<tr>
<td>Phase change based on prediction from Traffic measurement at each signalized approach</td>
<td>Phase change based on prediction from traffic measurement at each signalized approach</td>
<td>Uses predictive data change phase. Does not use explicitly defined signal cycles, splits or offsets</td>
<td>Predicts vehicle flow at intersection from sensor data</td>
<td>Same as traffic responsive control. Also responds to random variations in traffic flow</td>
</tr>
</tbody>
</table>

The main objectives of an intelligent traffic light system at an isolated intersection is to maximize the intersection throughput, minimize average waiting time and to minimize the number of stopped vehicles. Noticeable number of studies have focused on this topic with the aim of optimizing the signal phase lengths (green phase lengths). Several techniques and methods have been developed and applied such as fuzzy logic control, learning, neural network, genetic algorithm and so on for the application of intelligent traffic light controller.

On the other hand, one of the main objectives of coordinating multiple intersections with intelligent traffic light systems is to control the vehicle flow in a dynamic traffic
environment. An intelligent traffic management includes arterial coordination control and road traffic network control. The application of a multi intersection control based on the IRTSS needs to consider the influences of all the isolated intersections within a traffic sub-network. A particular area or region may be considered as a sub-network. Multiple sub-networks can make up the full road network and implement the multi intersection based IRTSS under a centralized controller. The common performance objectives of such systems are to maximize the intersection throughput, minimize the average delay and numbers of stops for each vehicle in the network. Following section briefly summarise different state of art traffic management systems currently in use for both isolated and coordinated intersections.

2.3.1 SCOOT

Hunt et al [46] was the first to develop the Split Cycle, Offset Optimization Technique (SCOOT). SCOOT coordinates the operation of all the traffic signals in a road network and provides good progressive guidance to all vehicles in the network. Also, it responds intelligently as the traffic flow changes while coordinating the traffic signal lights. Embedded sensors are used to detect the real time traffic volumes and some prediction for the traffic pattern and delays are carried out in the SCOOT. The system makes decision based on the traffic information by optimizing the parameters such as cycle length, splits and offsets. The whole road network is divided into sub areas and within a sub-area; all the traffic lights use the same cycle length. By analysing the current red and green timings the split optimizer works at every change of stage to determine whether the stage change time should be advanced, delayed or keep the same. Generally the split optimizer uses increments of 1 to 4 seconds. The offset optimizer operates in every cycle and observes the present situation at each intersection by analysing the cyclic flow profiles estimated for the connected intersections. The cycle time optimizer acts on regional basis, every five minutes or every two and a half minutes, if the cycle time rises rapidly.

A SCOOT based Urban traffic control (UTC) system [47] would comprise a central processor unit, transmission equipment, PC operator terminals and printers as shown in figure 2.2. A roving terminal is used to access the system from outside of the control room. Fault Management and Remote Monitoring Systems provide the operator with an integral fault handling facility. If any fault is detected it would be relayed to the
appropriate maintenance contractor. The UTC sends out instructions to the ‘on street’ equipments such as signal controller and upon receiving the instructions acknowledgement is sent to the UTC. Detectors are used to obtain the traffic information based on the change in the traffic information where the SCOOT responds accordingly. Usually overhead and loop detectors are used for the vehicle detection.

![Figure 2.2: SCOOT information flow](image)

**2.3.2 SCATS**

The Sydney Coordinated Adaptive Traffic System (SCATS) is a well known Intelligent Traffic Control system, widely used in many countries to implement intelligent traffic plans to schedule traffic lights. developed in Sydney, Australia by former constituents of the Roads and Maritime Services in the 1970s, used in Melbourne since 1982 and Western Australia since 1983. [36][47]. A SCATS architecture has three types of controller such as central controller, regional controller and local controller shown in figure 2.3.
Figure 2.3: SCATS architecture

*Local controllers:* are installed at isolated intersections responsible for collecting traffic information extracted from these detectors. These information data are processed and control decisions are put into operation.

*Regional Controller:* several local controllers are controlled and maintained autonomously by this controller. It is regarded as the heart of the SCATS because these controllers are responsible for analysing the information processed by the local controller and then implements the signals through the local controllers.

*Central controller:* responsible for monitoring the entire system and also provides system management support, data backups, system inventory facilities as well as carry out fault analysis.

Optimized Policies for Adaptive Control (OPAC) and RHODES fall in the category of a model based optimization strategy. The most common feature of these strategies is that they can predict the future traffic demand. Data measured by the detectors are stored and based on the historical data prediction of the future traffic pattern is carried out. However, these strategies have limitation as the prediction horizon is not long enough because the longest prediction horizon would be the time taken by vehicles running from the upstream detector to the stop-line of the intersection. Due to this
limitation the control strategies cannot look far enough. There are some macroscopic and microscopic urban traffic models which offer more effective model based traffic control approaches. The traffic dynamics of the whole urban traffic network can be described by these models and the limitations of the previous models can be overcome [48].

2.3.3 OPAC

A real-time signal timing optimization algorithm, Optimized Policies for Adaptive Control (OPAC) strategy was originally developed at the University of Massachusetts [49]. It is featuring a dynamic optimization algorithm with a distributed control strategy which measures the signal timings to minimize total waiting time at intersections and total number of stops at the intersections. Phase durations are constrained only by minimum and maximum green times and are determined by a measured as well as modelled demand, applied by the algorithm. In a coordinated network the phase durations are determined by the virtual length and offsets that are updated based on the real-time data [50].

In [49] the hierarchical version of OPAC named Virtual-Fixed-Cycle OPAC (VFC-OPAC) is presented. The VFC-OPAC has three layer control architecture which is comprised of the Local Control Layer, Coordinated Control Layer and Synchronization Control Layer shown in figure 2.4.

![Control Structure of the OPAC](image)

Figure 2.4: Control Structure of the OPAC [49]

Within the VFC constraint supplied from the Upper synchronization Layer the local control layer implements the OPAC rolling horizon procedure which involves continuous calculation of optimal switching sequences for the predictive horizon. The
offsets are optimized in the Coordination Layer at each intersection in every cycle. The network wide virtual-fixed-cycle is specified at the Synchronization layer. For group of intersections the cycle can be calculated separately. With the changing traffic condition the fixed cycle length and the offsets are updated over time.

### 2.3.4 RHODES

RHODES is a multi-level hierarchical structure which has three levels of control. In the first stage, prediction and estimation of the actual flow profiles are carried out from the sensor data. In the second stage, signal phase timings are altered to optimize some given objectives. The objectives includes minimizing the average delay per vehicle, minimizing the average queues at intersections, and minimizing the number of stops. The RHODES hierarchical structure is shown in figure 2.5. At the bottom level by applying a model based rolling horizon optimization approach the intersection control is carried out. At the middle level, network flow control is carried out according to the prediction and estimation of the traffic flow on the roads and coordinates the network.

![Figure 2.5: The RHODES hierarchical architecture](image)

Furthermore, a dynamic network loading model lies at the highest level which is responsible for capturing the slow-varying characteristics of traffic based on the road
infrastructure or road topology [51]. Road topologies include available routes, road closures, construction, and so on, travel demand (the number of vehicle wanting to go from their origin to their destination), and the drivers’ route selection (routes such that travel times on a selected set of routes from an origin to a destination are nearly equal). Based on these characteristics, the load on each particular road stream is estimated by the system, in terms of vehicles per hour. Based on the estimation RHODES provides allocation of green time (duration of green light at traffic signal) for each different demand pattern and each phase (signal phases for different directions).

2.4 Fuzzy logic based controllers

Zadeh [52 53] introduced the concept of fuzzy logic and then it was first used by Pappis and Mamdani [54] for the application of traffic control. The work focused on applying fuzzy logic to develop an actuated traffic controller. An unsaturated isolated intersection was considered with one way traffic flow. No turning vehicles were considered. The random vehicle arrival was the input parameter. Based on the arrival of the vehicles the paper focused on optimizing the current green signal phase. The term ‘Degree of Confidence’ was used for selecting the best set of signal sequences from a set of possible signal sequences.

Also, in several literature [54-58] it has been shown that fuzzy logic can be applied in order to optimize the traffic control measures at an isolated intersection. Using fuzzy logic is advantageous because it can handle linguistic information by representing it as a fuzzy set. A fuzzy logic based traffic control system includes the following functional blocks shown in figure 2.6. Commonly, the first step for implementing this method is to fuzzify the traffic inputs. For example, the traffic input can be vehicle arrival rate and the queue length in each lane which can be updated for the traffic situation model. Different detection methods can be used in order to measure the arrival rate, vehicle count or queue length etc. Then, the fuzzy output results can be determined by designing the corresponding fuzzy rules. Fuzzy rules are designed based on the membership functions. For a fuzzy logic based traffic control system the main purpose of the fuzzy controller is to give correct order of the signal groups. A set of fuzzy rule can be defined to design the signal groups. So, based on the traffic situation model the signal sequence and timing can be determined. The performance of application developed in fuzzy logic varies by different membership functions. However, the design of fuzzy
rules depends on expert’s knowledge similar to any rule based or knowledge based approach and it is difficult to obtain optimal rules.

![Generic functional blocks of a fuzzy logic based traffic control system](image)

Figure 2.6: Generic functional blocks of a fuzzy logic based traffic control system

Another fuzzy logic based traffic control system is proposed in [59,60]. An isolated intersection with three different vehicle movements such as going through, right turn and left turn were considered. The main objective of the work was to minimize the waiting time at the intersection. With three different traffic inputs the current cycle length, traffic volumes in the green light lane and the traffic volume in the red light lane. The designed fuzzy rules demonstrated better performance compared to the conventional approaches of traffic control methods.

The application of the fuzzy logic for a multiple junction is introduced by Chiu and Chand [61, 62]. An intersection with two-way street was considered where local traffic conditions fuzzy rules specified the cycle time, phase splits and the offset parameters independently. Based on the degree of saturation of each direction at each intersection the cycle length and the splits were adjusted. The average delay was reduced as the adjustments could be tested through the simulation. The fuzzy sets were designed to determine the degree of saturation in order to adjust the offsets which would minimize the number of stops by coordination multiple adjacent intersections.

An eight-phase signalling intersection controlled by fuzzy logic was proposed by Lee et al [63]. Two sensors were installed at each lane to collect real time traffic data. Only forward and left turn movements were permitted at the intersection. Based on the collected information both phase sequences and the phase lengths were changed using an optimization method. With an independent fuzzy rule base, the controller used three modules named as the next phase module, the stop module, and the decision module. By
the next phase module the most urgent phase was chosen while length of the green phase is evaluated by the stop phase module. Decisions are made periodically by the controller. The simulation results show improvements in reducing the average waiting time for different traffic densities.

2.5 Genetic algorithm based model and hybrid models

Goldberg [64] was first to introduce a genetic algorithm which is also broadly mentioned in different scholarly works to solve optimization problems in the field of intelligent traffic light control. Chen and shi [65] designed a traffic flow model and developed a real coded genetic algorithm (RGA) to optimize the green times and the cycle times in order to minimize the intersection throughput.

In [66, 67, 68] genetic algorithms have been applied to control traffic lights in multiple intersections. Foy et. al. [66] is the first to introduce GA in traffic control system for multiple intersections. The author assumed constant traffic flow and optimization was done in specifying the cycle time, splits and offsets. Based on the search characteristics of the GA the traffic light timing was designed and the performance analysis showed improvement in reducing delay.

In another study [67], combined strategy of GA and TRANSYT-7F [68] has been used to optimize phase sequence, cycle length, splits and offsets. The GA handled the phase sequence optimization while the other three were handled by TRANSYT-7F. The work demonstrated two different methods of implementation. To obtain the optimal solution GA and TRANSYT-7F were implemented at the same time in the first method. But in the other method, cycle length, phase sequences and offsets were optimized first with GA and then the adjustment of the green light duration was carried out by the TRANSTY-7F. However, with a longer computational time the first method showed better performance.

Several hybrid techniques are also adopted in different works to control traffic lights at isolated intersection such as a combination of fuzzy logic and learning [69], fuzzy logic, genetic algorithm and learning [70], and fuzzy logic and a genetic algorithm [71-72]. A combination of fuzzy logic, neuro fuzzy and multi objective genetic algorithm (MOGA) has been adopted in [70, 71] for traffic light control. The objective of this study was to integrate all the methods to achieve optimal solutions; to minimize the
waiting time and to reduce the amount of stopped vehicles. The fuzzy logic handles the decision of extending or terminating the current green phase, it also determines the sequences of the phases. The neuro fuzzy is used to predict the traffic parameters for the fuzzy logic controller and optimizing sets are searched by the multi objective genetic algorithm (MOGA) for the fuzzy controller.

2.6 Estimation and prediction based models

Prediction models are controlled systems that can predict the future states. Based on the information of current measured system states, prediction models are able to predict the future system states, future disturbances, and the future control inputs. On the basis of the model a prediction of the process signals over a specified horizon is made. Several research works have been carried out on the predictive urban traffic control methods [74, 7]. Most of these prediction models consist three parts

- Prediction
- Online optimization
- Calculation of the travel time

In [7], properties of the Model predictive control (MPC) is presented which implements and repeats optimal control in a rolling horizon way. During each control step, only the first control sample of the optimal control sequence is implemented subsequently the horizon is shifted one sample and the optimization is restarted again with new information of the measurements. Based on the prediction model of the process the optimization is carried out. The MPC model is useful as it can predict and find the coordinated optimized solution for the entire network in the future. Coordination of different types and numbers of control measures can also be applied via MPC. The controller can deal with the uncertainty of the real world, caused by unpredictable disturbances, (slow) variation over time of the parameters, and mismatch errors of the prediction model, because MPC uses real time feedback and works in a closed loop manner. However, in the implementation phase, MPC suffers with limitation of real-time computation complexity. Computational complexity increases exponentially when the scale of the network becomes bigger.

In [49] a real time adaptive control model for signalized intersections is proposed. A prediction model is incorporated which estimates the future arrival rates and turning
proportions based on the available detector information and signal timing plan. To satisfy the estimated demands the signal control parameters are optimized dynamically cycle by cycle. In this work thirty eight actuated signals are tested in a microscopic simulation study. By using the LINDO, a non linear program solver, the optimum solutions (e.g. minimizing green time and gap time) were achieved.

Several research work have implemented rule- and knowledge based intelligent traffic light control systems in [75-78]. A rule-based control strategy called the Generalized Adaptive Signal Control Algorithm Project (GASCAP) is proposed by Owen and Stallard in reference [78]. The GASCAP is comprised of three key components such as a queue estimation model, a set of rules for controlling uncongested traffic and a fixed time control algorithm for congested traffic. The queue estimation model collects the traffic data from the upstream detectors and predicts the traffic volume approaching the intersection. The major difference between GASCAP and other traffic control optimization approaches is the uncongested traffic control rules. Five sets of rules are defined and based on the estimated data each of these sets can measure the priority values related to the green light demand, coordinating progression, saturation urgency, spillback case and minimum green phase durations respectively. GASCAP simulation results demonstrated improvement in reducing the delay.

2.7 Intelligent traffic light control using Neural Network and Reinforcement Learning

Reinforcement learning algorithms are used to solve sequential decision tasks through trial and error interactions and by assigning reward or penalties for the decision tasks. In a sequential task, optimization of the reward functions is carried out by affecting the state transition through an agent that interacts with the dynamic system. One of the most common reinforcement learning algorithms is the Q-learning. Using trial and error approaches, exploratory agent of the Q-learning explores in a complex and non-deterministic environment and executes the best actions based on the past information. Certain reward or penalties will be achieved and will be stored in the memory for future decision tasks. With the experience gained in each step Q-learning algorithm improves the system performance.
The flow chart of the Q-learning algorithm as shown in figure 2.7 starts with the identification of the current state ‘s’, then by searching for the maximum rewards or by triggering the greedy probability function an action ‘a’ will be chosen from the action list. With the initialized values in the previous steps, Q-value for the action is measured. In a Q-learning algorithm, Q-table is the main component. It's a matrix table where various information extracted from the traffic plan is being stored.

![Flow Chart of the Q-Learning Algorithm](image)

The elements in the Q-table are called Q-values which represent a value for every single states and actions pair. The Q-table defines the experience of the Q-learning. Rewards or penalties are assigned and evaluated by a set of rules defined in the Q-table. Then, Reward is updated in the Q-table and again next state is determined by initiating action from the action table. If the process achieves the stopping criteria of the process, then the process stops or else iterations will continue until the stopping criteria are fulfilled [79].

Neural Networks and reinforcement learning are also being widely mentioned in different literature for traffic light control at isolated intersections. To obtain the optimal
output in both cases some learning methods are used in order to train the input data. The neural network contains a set of training data and expected output data where the weighting coefficients of the neural network need to be optimized to reduce the error between the expected output value and the real output value. In references [67] and [78] reinforcement learning have been applied to solve a traffic light control problem named as the SARSA (State Action Reward State Action). A two phase signalling system was considered in a four direction isolated intersection. Based on the total waiting time of all the vehicles and split timings, a neural network predicts the Q-values for each possible signalling decision. A huge number of states can be dealt with this method and the learning time can be large. However, this method exhibited near optimal performance while comparing with a fixed and a rule-based traffic control system in simulations.

Work proposed by Abdulhai et al [79] shows an adaptive traffic light control strategy where Q learning is used in a two lane and a four direction isolated intersection. Pre-defined average arrival rates were used and the traffic data and the vehicle arrivals were defined as individual poison processes. As the main objective was to reduce the waiting time at the intersection the author considered a fixed cycle time and tried to optimize the duration of the green light. The model considered two state variables, the queue lengths of each lane and the elapsed time from the last change in phase. To store and generalize the value function of the learned action a technique called Cerebellar Model Articulation Controller (CMAC) is proposed. It has been shown that the average waiting time can be reduced up to 50% comparing to a fixed time controller.

An adaptive traffic light control system has been proposed in reference [80] based on a learning algorithm. To acquire the optimum signal phase for each traffic light a road-user based function has been used where the decision is made by the cumulative vote of drivers waiting at the intersection. The proposed algorithm allows drivers to choose the route which has the lowest expected waiting time. This may lead to a crowded state as all the drivers may choose the same route.
2.8 Summary

In this chapter, at first we have presented the key features of the modern intelligent transportation system (ITS). Then, we have discussed about the available vehicle detection technologies used for developing intelligent traffic management system. Comparison between the detection methods are also shown accordingly. State-of-the-art detection methods are summarised and their advantages and deficiencies are discussed in this chapter. To design and implement ITS applications for intelligent traffic management system and to deploy control over a wide area network, real time and larger vehicle detection range is needed. Implementation of adaptive signalling system requires real time updates of the vehicle flow. Also, in advanced traffic management system prediction and estimation of the real time vehicle flow play a vital role. Some popular and widely used traffic control systems such as SCOOT, SCATS, and OPAC etc. are also investigated and their operational features are presented. In addition, various types of technologies used for optimizing the traffic signal durations are discussed.
Chapter 3

VANETs and Intelligent Road Traffic Management System

3.1 Introduction to VANETs

This chapter describes the key aspects of the Vehicular Ad-hoc Networks (VANETs) that are required to design an Intelligent Road Traffic Management System. Details of the IEEE 802.11p based vehicular communication standards is discussed that can be used in an ITS environment. The VANETs based ITS applications are developed and implemented based on the WAVE (Wireless Access in Vehicular Environment) protocol stack and the IEEE 802.11p standard which is also known as DSRC (Dedicated Short Range Communication). To evaluate the performance of the developed VANET based ITS applications realistic traffic models should be considered. Hence, selection criteria for choosing a vehicular mobility model are also discussed in this chapter. Furthermore, features of a VANET based intelligent road traffic signalling system (IRTSS) are also presented.

The main aim of an IRTSS is to coordinate vehicle movements through different roads, junctions and other traffic structures. An intelligent road traffic system can react to change of traffic flows, road layouts and other time based events quicker than a conventional road traffic system. Current generation IRTSS controls the traffic flows using the traffic lights by controlling its timings, sequences and cycle time. Allocation time for dispatching vehicles to its desired road can be varied by using a simple time based method or by using complex algorithms which can be based on real time traffic detections mechanism. Most of the countries use the standard traffic signalling cycle which consists of three different phases which are green, amber and red. Some different signalling phases may be implemented according to the design of the road and allowable traffic movements at intersections. The control logic specifies the allocated time for each phases. According to the Highway Administration of Washington D.C. [44] a traffic controller can respond to the oncoming traffic at an intersection in two different ways. These schemes include fixed and actuated or adaptive traffic signal control techniques. Strategies to control traffic at the intersections which include
isolated intersection control, arterial control and network control. The adaptive signal control technique respond to the real time traffic demand which is an important attribute of an intelligent traffic control (ITC) system. Detection and estimation of real time road traffic is a significant challenge to develop an adaptive traffic signal controller. Figure 3.1 shows a conceptual model of an IRTSS operating in an isolated intersection under the VANET environment. Here the road side unit (RSU) acts as intelligent intersection manager, advance travellers information provider as well as an intelligent road traffic controller.

Figure 3.1: Conceptual model of a VANET based IRTSS operating in an isolated intersection

The IRTSS uses the RSU to periodically broadcast control signal and traffic signal phase information. The signal sequences are varied with the dynamic traffic volume. The Intersection management scheme tries to maximize the utilization of the intersection by reducing the waiting time. The isolated intersections can be connected by an Ethernet backbone network which can introduce traffic load balance mechanism for a traffic guidance system. Following sections introduce the VANETs and associated standards in detail before proceeding to the design section (presented in chapter 4).
3.2 WAVE/DSRC communication architecture

The VANET is a specialized form of the Mobile Ad Hoc Network (MANET) specially categorized for the short range communication among the roaming vehicles as well as between the vehicles and the roadside information infrastructure. Usually, the moving vehicles are equipped with On Board Units (OBU) (IEEE802.11p based units) communicating with RSUs to exchange traffic and signalling information. For the wireless access in the vehicular environment (WAVE) a new WLAN standard IEEE802.11p was developed. The IEEE802.11p standard is also referred to as a Dedicated Short Range Communication (DSRC) standard that introduces baseline architecture for the V2V and V2I communications. The licensed spectrum of 75MHz has been allocated at 5.9GHz for the DSRC applications [81]. The physical layer of the IEEE 802.11p standard is similar to the IEEE 802.11a standard. Although in both cases the OFDM (Orthogonal Frequency Division Multiplexing) technique has been adopted but the channel width has been reduced to 10MHz from 20MHz for the DSRC applications. The reason behind this is to reduce delay spread caused by the mobility characteristic of the vehicular network. The total bandwidth of 75MHz is divided into seven channels consists of one control channel (CCH) and six service channels (SCHs). Traffic safety massages are transmitted through the CCH while the application data are transmitted via the SCHs. Four data classes are supported by the both CCH and SCH channels with different transmission priority. The standard supports transfer rates between 6Mbps to 27Mbps. The CCH is used for broadcasting. It’s also used for unicast communication by inserting the destination address into the medium access control (MAC) frame [82]. If two service channels are combined to one 20MHz channel the transmission data rate can reach up to 54Mbps. The maximum downlink and the uplink power should be less than 1.995 watt. Table 4 shows the DSRC channels, frequency range and the channel types.
Table 4: The DSRC channels, frequency ranges and the channel types

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel Number</td>
<td>172</td>
<td>174</td>
<td>176</td>
<td>178</td>
<td>180</td>
<td>182</td>
<td>184</td>
</tr>
<tr>
<td>Channel Type</td>
<td>Service Channel</td>
<td>Service Channel</td>
<td>Service Channel</td>
<td>Control Channel</td>
<td>Service Channel</td>
<td>Service Channel</td>
<td>Service Channel</td>
</tr>
</tbody>
</table>

Figure 3.2 shows the WAVE protocol stack. As seen in the figure, WAVE protocol stack is comprised of IEEE 802.11p and IEEE802.2 based MAC & PHY layers and IEEE 1609 based network, transport and application layers. The WAVE MAC supports multichannel operation which is based on the IEEE 1609.4 standards.
To deal with the upper layers in the WAVE architecture the IEEE 1609 group has developed four standards which are listed below

- IEEE 1609.1 (Resource Manager): specifies a WAVE application for remote resource access. It includes resource manager (RM), resource command processor (RCP) and resource manager application (RMA). The RM is the provider of the application, RCP is the user of the application and RMA is the remote entity. RCP and RM are placed both in OBU and RSU. The RMA controls the services provided by the RM to the RCP. RMA sends a command to the RM for remote resource access. The RM forwards the command to the RCP. The RCP then communicates with the RMA through RM [83][84].

- IEEE 1609.2 (Security Services): specifies algorithms and mechanisms for secure data transfer between WAVE units.

- IEEE 1609.3 (Networking Services): defines functions and services at the Logic Link Control (LLC), network and transport layers of the WAVE protocol stack. These services are known as the Networking services which includes the data plane and Wave Management Entity (WME). The IEEE 1609.3 standard has defined a new transport layer protocol known as the Wave Short Message Protocol (WSMP) which enables the transmission of WSM messages for high priority safety purposes. For non safety purposes, the IPv6 has been supported along with the transmission control protocol (TCP) and user datagram protocol (UDP) transport layers. The parameters of IP messages are stored in a transmitter profile. The LLC layer is also implemented in every WAVE device. After the LLC receives a MAC service data unit, it forwards the packet to the IPv6 layer or the WSMP layer according to the corresponding packet field. The WME manages service requests including the provider service request massage, user service request massage, WSM service request message and CCH service request etc. The provider service request could be made by any WAVE device which is interested to share a service and send WSA messages using the SCH channel [83][85]. Figure 3.3 shows the joining procedures and setups for the WAVE basic service set (WBSS).
IEEE 1609.4 (Multi Channel Operation): The multi channel operation for the WAVE is defined in the IEEE 1609.4 standard which sits in between the MAC layer and the IEEE 802.2 Logic link control (LLC). The WAVE architecture supports a multi channel mechanism comprising one control channel (CCH) and multiple service channels (SCH). The safety messages and the WAVE Service Advertisement (WSA) are transmitted on the CCH while service and business applications are run on the SCH. The future WAVE devices would include both single and multi channel radios. Single channel radio can either transmit or receive data on any radio channel. On the other hand, multi channel radio device can simultaneously transmit on one channel and receive on another radio channel. For single channel radio devices to work with the multi channel devices in future vehicular environments, time division multiple access is used. The time is divided into Control Channel Interval (CCHI) and Service Channel Interval (SCHI) of 50ms each. A coordination scheme allows all WAVE stations to monitor during the control channel at the same time and switch to a desired application on a service channel during the SCH interval. This synchronisation is done through the Coordinated Universal Time (UTC) global clock signal available from GPS. A guard interval of 4ms is introduced at the start of each channel interval. The guard interval allows sufficient time to overcome the inaccuracy in timing and channel switching for the radio devices. The safety messages are shared on the CCH in the CCHI while the service messages and...
data exchange is done on the SCH during the SCHI. In case of emergency, vehicles can also utilize the SCHI for transmission of safety messages. The IEEE 1609.4 stack manages functions of channel routing, user priority control and channel coordination. The channel routing function manages the routing of data from LLC layer to the appropriate channel and access category as shown in Figure 3.4. Two types of packets are defined in the WAVE standard. The IP packets are used to transmit non-safety messages while the Wave Short Message (WSM) packets are used for safety messages. The WSM are short messages whose transmission parameters such as channel, data rate and transmit power can be directly controlled by the higher layers so that all the nodes receive the messages within a certain time delay. They are suited for safety applications which have higher priority and require low transmission delay. The channel router identifies the type of packet from the packet header and forwards the WSM packet to the CCH or to the SCH and the IP packet to the current SCH.

![Figure 3.4: Internal architecture of IEEE 802.11p MAC with channel coordination [81]](image)

The user priority is assigned using the enhanced distributed channel access (EDCA) access mechanism and four access categories are defined for medium
access contention [85][86]. EDCA access mechanism and the corresponding access categories are discussed in the next sections of this chapter.

**Data Plane services [85]-**

- Channel coordination: Channel intervals are coordinated by the MAC sub-layers so that data packets are transmitted on the proper channel at the right time.
- Channel routing: Inbound and outbound higher layer data are handled by The MAC sub-layer. Routing of data packets from the LLC to the designated channel and setting parameters (e.g., transmit power) for WAVE transmissions are included in this specification.
- User priority: By using enhanced distributed channel access (EDCA) functionality specified in IEEE Std 802.11, QoS is supported through assigning user priority (UP) and related access category (AC).

**Management Plane Services [85]-**

- Multi-channel synchronization: Synchronization function with the objective of aligning channel intervals among communicating WAVE devices is implemented by the MLME through the information derived locally and received over the air. The MLME provides the capability to generate Timing Advertisement (TA) frames to distribute system timing information and monitor received TA frames.
- Channel access: Access to specific radio channels is controlled by the MLME in support of communication requests received from the WME.
- Vendor Specific Action frames: The MLME accepts incoming VSA frames and pass them to the WAVE Management Entity. The MLME could also generate VSA frames for transmission at the request of WME.
- MIB maintenance: Management information base (MIB) containing configuration and status information is maintained by the MLME.
3.3 IEEE 802.11p Architecture

The wireless access in vehicular environment (WAVE) has been developed by two different task groups of IEEE named group p and group 1609. The protocol stack covers IEEE 802.11p and IEEE 1609 standards [85] [87]. The MAC and the PHY layers are handled by the IEEE802.11p protocol and the upper layers are handle by the IEEE1609 [27]. MAC Sub-layer Management Entity (MLME) and the Physical sub-layer management entity (PLME) handle the management functions of the MAC and the physical layer.

3.3.1 IEEE 802.11p MAC

IEEE 802.11p medium access (MAC) mechanism is same as the legacy WLAN standards such as IEEE 802.11a/b/g that uses Distributed Coordination Function (DCF) and Point coordination Function (PCF) as a medium access mechanism. DCF adopts the ‘listen before talk’ scheme through the Carrier sensing multiple access and Collision avoidance (CSMA/CA) technique of IEEE802.11 MAC protocol. Figure 3.5 illustrates the medium access mechanism with DCF. Whenever a station wants to send a packet, it senses the channel and if the channel remains free for a distributed inter-frame time (DIFS) (34μs in 802.11a), it transmits the packet. In legacy IEEE 802.11, time is slotted in a basic time unit, denoted by ‘Slot Time’ (9μs in 802.11a), which is equal to the time needed to detect the transmission of a packet from any other station. If the channel is busy, the station defers its transmission until the end of the current transmission. Then, it waits for an additional DIFS interval and takes a random backoff time. In CSMA/CA, a binary exponential backoff mechanism is used where the number of backoff slots is uniformly chosen in the range (0, CW-1). CW represents the contention window size. The initial backoff window size is set to CWmin. If two or more stations select the same backoff slot, collision occurs and the backoff window size is doubled for each retransmission until it reaches the maximum value, CWmax.
Figure 3.5: Medium access mechanism through distributed coordinated function

The backoff period is determined by each station individually by the following equation

\[
\text{Backoff period} = \text{DIFS} + (\text{Number of Backoff slots} \times \text{slot time})
\]  

(1)

On successful reception of a packet the receiver station sends an ACK frame after a short inter-frame space (SIFS) time (9 µs in 802.11a). If the ACK frame is not received within timeout period it is assumed that a collision has occurred and the retransmission is scheduled. If the retransmission attempt reaches the maximum limit the packet is discarded. As all the stations have same medium access priority in the DCF and uses the same contention window as there is no provision to differentiate the stations and their traffic. Thus the DCF offers no QoS support. An improvement over the DCF functionality is the point coordination function (PCF) which is used to support QoS for delay-sensitive services. The PCF process is centrally coordinated by the Point Coordinator (PC) which is typically the WAN AP and thereby provides prioritized access to the wireless medium. The PCF mechanism has a contention-free period (CFP) and a contention period (CP). Together they form a super-frame and alternate periodically over time. The PCF is used for accessing the medium during the CFP, whereas the DCF is used during the CP. During the CFP, the PC polls each SS station asking for the transmission of a pending frame. If the PC receives no response from a polled station after waiting for a PCF inter-frame space (PIFS) (25 µs in 802.11a) it polls the next station, if any. The major drawbacks of the PCF mechanism include unpredictable beacon delays and unknown transmission durations of the polled stations.
The basic IEEE 802.11a MAC can only support Best effort services, to support QoS based services an Enhanced Distributed Channel Access (EDCA) MAC procedure is used in the IEEE802.11p standard, which is defined by the IEEE802.11e standard [87]. The physical layer parameters remain same as the IEEE 802.11a standards in this case. But it uses a Hybrid Coordination function (HCF) as a Medium Access Mechanism (MAC) to take into account QoS requirements of different types of traffic shown in the Figure 3.6. HCF includes a contention-based Enhanced Distributed Channel Access (EDCA) mechanism and a contention free HCF controlled channel access (HCCA) mechanism. HCF uses hybrid coordinator (HC) which resides within the QoS enhanced AP (QAP). The HCF introduces a new mechanism called transmission opportunity (TXOP). It’s a time interval during which a QoS enhanced station (QSTA) is allowed to transmit frames. Thus, a QSTA can initiate multiple transmissions within the TXOP time. In EDCA, the QoS support is realized through introducing multiple access categories (ACs) in each QoS station (QSTA).

![Medium access mechanism through hybrid coordinated function (HCF)](image)

EDCA has four ACs based on 8 user-priorities (UP) similar to that of the 802.1d based Ethernet standard. The ACs are labelled according to their target application, i.e., AC_VO (voice), AC_VI (video), AC_BE (best effort), and AC_BK (background). The
EDCA parameter set defines the priorities in medium access by setting individual inter-frame spaces, contention windows, EDCA-TXOP and many other access category parameters.

Figure 3.7 illustrates the ACs and their backoff entities. Each station independently contends for the TXOP and starts the backoff counter after sensing the medium idle for an Arbitration inter-frame space (AIFS) which depends on AC. The traffic with highest access category (AC) has the highest priority to transmit packets due to the use of a shorter channel sensing time. Each access category has different values of AIFS. The minimum AIFS time is equal to the DIFS time and can be enlarged per AC with the help of the arbitration inter-frame space number (AIFSN). The AIFSN defines the duration of AIFS according to the following Eq. (2).

\[
AIFS[AC] = SIFS + (Slot\ time) \times AIFSN[AC]; \quad AIFSN[AC] \geq 2
\]  

Figure 3.7: Illustration of the IEEE802.11p access categories

Through the EDCA traffic prioritization can be done by assigning different access categories based on the QoS requirement of the traffic flow. Safety massages can be high priority message which can fall into higher access category to the channel. Higher access category massages that will use a shorter channel sensing time and the lowest
value of AIFS and $CW_{\text{min}}$ [88][89]. In HCCA, the HC uses PIFS to gain control of the channel and then allocates TXOPs to QSTAs, which are referred as HCCA TXOPs or polled TXOPs. HCCA can poll the QSTAs during contention periods (CPs), and HCCA takes into account QSTAs’ specific flow requirements in packet scheduling. After grabbing the channel, the HC polls QSTAs in turn according to its polling list. In order to be included in the polling list of the HC, a QSTA must send a QoS reservation request using the traffic specification (TSPEC) parameters. The major TSPEC parameters [90] include:

- **Mean data rate** $(r)$: the average bit rate for packet transmission, in bits per second.
- **Delay bound** $(D)$: the maximum delay allowed, in milliseconds
- **Maximum service interval** $(S_{\text{Imax}})$: the maximum time allowed between consecutive TXOPs allocated to the same station, in microseconds.
- **Nominal MSDU size** $(L)$: the nominal size of a packet, in octets.
- **Minimum PHY rate** $(R)$: the minimum physical bit rate assumed by the scheduler, in bits per second.

Dedicated short range communication (DSRC) or IEEE 802.11p standard supports a wide range of applications that can be implemented by an IRTSS. Figure 3.8 shows the IEEE 802.11p MAC architecture supported IRTSS and its prospects in term of various applications such as isolated intersection management, multi junction traffic management, predictive traffic management and emission modeling.

Figure 3.8: Features of the IRTSS
Any VANET application development requires a communication network model based on the characteristics of its applications. To develop an intelligent traffic management system using a VANET, a validated network mobility model should be considered which can be integrated with the communication model in order to analyse the performance of the application. To develop a VANET based application for an intelligent road traffic signaling (IRTSS) system following aspects of both vehicular and communication system models should be carefully handled

- Protocol design must consider requirements for all applications and their data traffic characteristics.
- Efficient information dissemination scheme needs to be developed (e.g. Periodic Broadcast, Unicast, One hop, Multi-hop communication)
- Realistic Mobility modelling of the vehicles with different topologies (e.g. urban scenario, highway scenario) and with traffic signalling system.
- Real time vehicle detection, location measurement and traffic condition information accumulation (speed, accident detection, congestion information etc.)
- For emergency vehicles at the intersection priority based mechanism should be considered.
- Design of an efficient algorithm that can adaptively change the signal sequences and the phases of the intelligent signalling system while providing fairness in the waiting time of different lanes joining at the intersection.
- Predictive traffic computation mechanism and modelling the reaction of the intersection or traffic controller.
- Implementation of the developed application in a wide area network.

3.4 Vehicular mobility modelling

As mentioned earlier, there are two important aspects while designing a vehicular communication system. One is the Vehicular Mobility Model and other is the Communication network model. Both models have specific requirements based on the application requirements. In a VANET a realistic vehicular mobility model is needed in order to analyse the performance of the road traffic system. In reference [12] [91] a comprehensive framework and recommendation for modelling the vehicular mobility in
VANETs is being discussed. Mobility models have been classified in four different categories in the literature such as synthetic models, survey based models, trace-based models, traffic simulators-based models. A synthetic model uses a mathematical model while the survey based model uses the mobility patterns extracted from roadside. In an information trace based system the mobility pattern is extracted either from real mobility traces or by using a simulator. Traffic simulator based models use validated traffic simulators to get these traces. It has been identified [8] that the following attributes are important while considering any simulator for the vehicular mobility modelling

- Accurate and realistic topological maps (Intersections, lane and categories of streets with speed limits etc.)
- Attraction/repulsion points (Specifying source and destination points)
- Vehicles characteristics (Heavy duty, Light duty, Emergency vehicles etc.)
- Smooth deceleration and acceleration
- Human driving patterns (overtaking, traffic jam, preferred paths etc.)
- Intersection Management (Traffic lights, stop signs, obstacles etc.)

In reference [91], a vehicular mobility simulator for the VANET has been proposed, called VanetMobiSim that employed a model called Intelligent Driver Model (IDM). It’s mentioned that two extensions of the IDM model, called IDM with Intersection Management (IDM-IM) and IDM with Lane Changes (IDM-LC) are available in VanetMobiSim extensions. These models have capabilities of controlling crossroads by traffic signs and lane changing control according game theoretical approach.

VanetMobiSim is validated vehicular mobility modeller which can be used for modelling automotive motions in both microscopic and macroscopic levels. VanetMobiSim is able to produce the realistic mobility model and in an open loop approach it’s possible to those traces for a suitable network simulator. The traces must be modified for the particular network simulator. CANU (Communication in Ad Hoc Networks for Ubiquitous Computing) Mobility Simulation [12][91] Environment which is a flexible framework for user mobility modelling, includes the extension of VanetMobiSim. The JAVA-based environment CanuMobisim supports mobility traces generation in different formats for different network simulators such as NS2, GloMoSim, Qualnet etc. It allows extraction of maps from Geographical Data Files.
(GDF). Maps can be also imported from US census Bureau TIGER database or also can be generated from Voronoi tessellation. Multi-lane roads, separate directional flows, differentiated speed constraints and traffic signs at intersections are also supported in the macroscopic level. On the other hand, new mobility models, infrastructure interaction for V2V and V2I communications can be implemented. The vehicle will behave according to the surrounding condition on the road infrastructure, nearby vehicles and other road constraints. Mobility patterns of the VanetMobiSim have been validated against the TSIS-CORSIM - a well known and validated traffic generator which proves the high level of realism achieved by the VanetMobiSim. Reference [12] shows that VanetMobiSim can generate realistic vehicular traces and the trace files can be fed into network simulator for generating mobility patterns to the user nodes. The network simulator has to be compatible with the trace input of the mobility modeller. However, the trace files of the VanetMobiSim do not give any direct information about the following parameters

- route based normalized traffic density
- average speeds on a particular road
- total journey time of a vehicle
- arrival rate in a particular intersection
- total waiting time of a particular vehicle
- average waiting time in any particular intersection

Due to the limitations associated with the isolated approach and the federated approach, we focused on developing an embedded communication system based on the VANETs which could serve us by integrating both communication network model and vehicular mobility model together. An embedded approach offers wide range of functionality as both of the models can work on a single platform. Developed models can interact with each other in a close loop manner and performance analysis could be carried out more easily for the developed IRTS application as the system’s reaction could be observed in the real time. Figure 3.9 shows the functional blocks of an embedded approach to develop VANET applications in a wide area network. Communication network model and the realistic mobility model are laid on the same platform.
3.5 Summary

This chapter investigated the communication network standards such as the IEEE802.11p/DSRC standard and the WAVE protocol stack for developing VANETs based applications. Details of the IEEE 802.11p MAC and Physical layer parameters and associated technologies are presented. Moreover, features of the VANET based Intelligent Road Traffic Signalling System (IRTSS) are presented and the communication network requirements are identified accordingly. Also, requirements for developing realistic mobility models are investigated and features of VANETs are described to accommodate the ITS applications.
Chapter 4

A Novel VANET based Intelligent Road Traffic System (IRTSS)

4.1 Communication network architecture

Road Traffic Information System is a key component of the modern intelligent transportation system (ITS). Road signalling systems can be made more efficient if real time information from different road sensors and vehicles can be fed into a wide area controller to optimize the traffic flow, journey time, as well as safety of road users. The VANET architecture provides an excellent framework to develop an advanced road traffic signalling system. In the existing road traffic signalling systems, road side sensors are typically used on busy roads to estimate traffic arrivals in some busy locations of the city that provides a very limited snapshot of the total traffic scenario [41]. Due to high cost and infrastructure installation problems, such systems cannot be extended over all areas of the city. To combat the above problem, a novel VANET based intelligent road traffic signalling system (IRTSS) has been proposed in this chapter. A VANET based Vehicle to Infrastructure (V2I) based road traffic control system can collect traffic information from individual cars and share the road traffic information over a wide area network to dynamically control the traffic signalling cycle.

The proposed scheme receives the total traffic information over a large road network by using the VANET infrastructure and disseminates the traffic information to the neighbouring signalling nodes over a wide area communication network. This information is then used to plan the traffic signal sequences in order to reduce traffic congestions and journey time. The proposed method allows the road traffic controllers to get more accurate and reliable traffic information from the roads. To analyse the performance of the proposed scheme, an application model has been developed and implemented in OPNET.
The communication infrastructure of the proposed IRTSS is shown in figure 4.1. The system utilizes the basic architecture of the V2I communication application of the Dedicated Short Range Communication (DSRC) architecture consisting of Road Side Units (RSUs) and Onboard Units (OBUs), where RSUs are connected through an Ethernet backbone. Each RSU covers around 0.5 km transmission radius that allows the all cars approaching a junction to communicate with the RSU. The RSU via the broadcast packets send the signaling information based on received traffic information. At any particular road intersections such as crossroad or T-junctions the RSUs can be used to disseminate the traffic signaling information to the OBUs. The driver has to react with information received by the OBUs embedded in the vehicle navigation system. For a wide area signaling system each RSU receives information from its neighboring RSUs and computes the traffic load at each junction based on its own traffic count and also on the number of expected vehicles approaching from the neighboring junctions. By controlling the transmission distance of each cell, the RSU’s can obtain approaching traffic information (i.e. traffic flow intensity) in advance. The proposed system is far advanced and flexible than the current sensor based systems because the detection range is much larger and can be implemented in over a wide area network.

Figure 4.1: Illustration of the Road Network and the Communication network architecture for RTS
The basic packet transmission mechanism used in the IEEE 802.11 protocol is the distributed coordination function (DCF). The CSMA/CA protocol is used in the 802.11p standard which utilizes the DCF to transmit packets in the contention mode. The DCF technique can support the ad hoc network without any infrastructure elements such as the access point [92]. For applications such as intelligent road traffic signalling system (IRTSS) the VANET needs to accommodate mobility of the vehicles. Usually the speed of the vehicles in an urban road network can reach up to 22.22m/s (80 km/h) and the IEEE 802.11p standard is designed to support vehicular mobility in the wireless environment (discussed in chapter 3). The latency requirements of the IRTSS are moderate (1s), particularly for the city traffic [93]. After entering the RSU coverage, vehicles could be detected successfully long before it reaches the intersection. With a maximum speed of 22.22m/s, a vehicle can travel up to 22.22m within 1s. So, even with the maximum transmission delay of 1s, a vehicle could be detected before it travels more than 22.22m, after entering the coverage. Hence, it is feasible for a VANET based system to accurately obtain traffic information using the on board unit (OBU) within a vehicle.

One of the main design issues of the IRTSS is to control the total channel traffic so that QoS (Quality of Service) can be maintained. A road infrastructure unit known as the RSU is responsible for periodically broadcasting signalling and other road traffic information on the downlink of a communication network. For the IRTSS application, car OBU is required to send vehicle information such as OBU ID, position of the vehicle, remaining time to reach the intersection, destination and current route etc. via the uplink to the RSU. The OBU supplies information packet via the IEEE802.11p MAC on the uplink. The RSU supplies the information to the traffic analysis server that controls the traffic signal parameters. For a wide area network based traffic control system the RSUs are connected by a backbone network where RSUs can exchange traffic information.
4.2 Signalling system

A traffic controller is the device used to control signal lights at the intersection. To understand the signalling system at the intersections and to design an IRTSS, number of definitions and notations are discussed and elaborated below [94]:

**Cycle**: A signal cycle is one complete rotation through all of the signal lights (i.e. Red, Amber and Green light).

**Cycle length**: Cycle length is the time in seconds that it takes a signal to complete one full cycle of indications. It indicates the time interval between the starting of green for one approach till the next time the green starts.

**Interval**: It indicates the change from one stage to another. There are two types of intervals: change interval and clearance interval. Change interval is also called the yellow time indicates the interval between the green and red signal indications for an approach. Clearance interval is also called ‘all red’ which is included after each yellow interval indicating a period when all signal faces show red and is used for clearing the vehicles at intersections.

**Green interval**: It is the green indication for a particular movement or set of movements and is denoted by $G_i$. This is the actual duration the green light of a traffic signal is turned on.

**Red interval**: It is the red indication for a particular movement or set of movements and is denoted by $R_i$. This is the actual duration the red light of a traffic signal is turned on.

**Phase**: A phase is the green interval plus the change and clearance intervals that follow it. Thus, during green interval, non conflicting movements are assigned into each phase. It allows a set of movements to flow and safely halt the flow before the phase of another set of movements start.

**Lost time**: It indicates the time during which the intersection is not effectively utilized for any movement. For example, when the signal for an approach turns from red to green, the driver of the vehicle which is in the front of the queue will take some time to perceive the signal (usually called as reaction time) and some time will be lost here before he moves.

**Critical lane**: During any green signal phase, several lanes on one or more approaches are permitted to move. One of these will have the most intense traffic. Thus it requires
more time than any other lane moving at the same time. If sufficient time is allocated for this lane, then all other lanes will also be well accommodated. There will be one and only one critical lane in each signal phase. The volume of this critical lane is called critical lane volume.

The operating mechanism of our proposed IRTSS is based on the smooth message interaction between the RSU and the OBU. The RSU operational flow diagram is shown in figure 4.2. RSUs are installed at the intersections and at the road junctions. The RSU broadcasts the signalling information based on the measured statistics of the traffic flow coming at an intersection. The RSU process model developed in the OPNET, implements a unique optimization scheme to adjust the timings of the adaptive signalling system. Whenever an OBU comes within the coverage area of a RSU and gets the first broadcast message from the RSU, the OBU keeps on sending unicast massages with an interval of 5 sec to the corresponding RSU to update its speed, position (latitude and longitude), and time to reach the intersection. The RSU updates the list of the active OBUs in the range after every 5 sec and broadcasts the current traffic signal state every second to all OBUs.

![Flow chart of the adaptive road traffic signal broadcasting algorithm in the RSU](image)

Figure 4.2: Flow chart of the adaptive road traffic signal broadcasting algorithm in the RSU
The application latency requirement of the IRTSS algorithm is the main reason behind considering the broadcasting interval of 1s in the RSU process model. After successful detection of a vehicle, the RSU will update the signalling state on every second to the approaching vehicle. If the delay is longer than the waiting time at the intersection then the number of vehicle will be increasing and the signal phase durations will be longer. So the 1s broadcasting interval will enable the vehicles to take necessary actions such as stopping or continue with an optimum speed towards the intersection. On the other hand, the main reason behind choosing the 5 sec interval for the unicast packets is to allow smooth and successful detection of vehicles without creating a high network load. For example, if the unicast interval is too long then vehicles may cross the coverage area of a RSU without being detected. Alternatively, if the unicast interval is too short, the vehicle needs to send more packets to the RSU which in turn will increase the communications load. Thus, considering a maximum speed of 60 km/h (16.6 m/s) and RSU coverage of 500m, RSUs should be able to successfully detect a vehicle with a 5 sec unicast interval. Moreover, if the unicast transmission fails, the OBU will get enough opportunities to retransmit its request before it reaches the intersection.

The OBU checks the current signal phase durations, measures remaining time duration to reach the intersection and continuously updates this information at every reception of the broadcast packets. Figure 4.3 shows the operational flow chart of the OBU process model. All the OBUs are continuously updated every second with the current signal state information, for example, Green, Amber or RED signal durations at the intersection. Thus the OBUs can take necessary actions such as whether to decelerate, stop or to continue its current speed based on the information.
We have implemented two phase signalling system in our proposed IRTSS. The full signal cycle comprises the total time taken by the two phases named as \( P_1 \) and \( P_2 \) shown in figure 4.4. It shows the conventional vehicle movement pattern for the two phased traffic signalling system. Each signal phase comprises minimum green duration, adaptive green duration (variable green light duration), fixed amber duration, clearance time and red duration. In our proposed IRTSS the green duration and the cycle length is fully adaptive based on the oncoming traffic flow. Figure 4.5 shows the time splits and the signalling sequences of our proposed IRTSS.
Optimization of the signal durations in the case of an adaptive IRTSS is a challenging issue as it has to consider large number of factors such as arrival rate of the vehicles, vehicle density, saturation flow etc. In our model the optimization has been implemented by adjusting the signal phase durations according to the amount of the vehicle flow coming from different directions at an intersection. Four different directions of the vehicle flow have been defined named as East Bound (EB), West Bound (WB), South Bound (SB) and North Bound (NB). The amber time calculation has been illustrated in the Eq. (3) [95]. Safe intersection clearance time has been considered in the proposed signalling system. The safe deceleration time and the acceleration time have also been considered in the signal cycle design. The operational mechanism is described below. The proposed IRTSS contains two phase signalling system. Each phase ($P_1$ & $P_2$) contains green, amber and red phases. The RSU detects the number of vehicles coming from the east and west direction (EB & WB) and selects...
the critical lane volume, which is denoted as $Z_1$. Similarly, the critical lane volume for the south and north (SB & NB) bound is measured, which is denoted as $Z_2$. Amber light duration is calculated by

$$y = t + \frac{v}{2d+2gG} + \frac{w+1}{v} \quad (3)$$

Where $y$ is the amber duration, $t$ is the clearance time (s), $d$ represents the safe deceleration value (m/s$^2$), $v$ is the speed of the vehicle (m/s), $g$ is the gravitational force (9.81 m/s$^2$), $G$ represents the grade or slope, $l$ is the length of the vehicle (m) and $w$ is the width of the intersection.

$$G_1 = L_t + h \times (Z_1) \quad (4)$$

$$G_2 = L_t + h \times (Z_2) \quad (5)$$

$$P_1 = G_1 + R_1 \quad (6)$$

$$P_2 = G_2 + R_2 \quad (7)$$

The phase durations ($P_1$ and $P_2$) of our proposed IRTSS is measured by the Eq. (6) and Eq. (7) respectively. Here, $G_1$ and $R_1$ are green and red duration respectively in the phase $P_1$. Similarly $G_2$ and $R_2$ are green and red duration respectively in the phase $P_2$. $h$ is the saturation headway (s) which is the headway of the vehicles in a stable moving platoon, and $L_t$ is the lost time which includes the start up time. By considering the amber period comprised with the red duration

$$R_1 = G_2 + y \quad (8)$$

$$R_2 = G_1 + y \quad (9)$$

However, with this analytical model the lower critical lane timing value suffers with high average waiting time at the intersection if the critical lane volume difference is very high. Using the above equations in OPNET simulation model it has been found that if percentage of any critical lane traffic volume exceeds a certain percentage of the total critical lane traffic volume then vehicles in the lower percentage critical lane suffers with high average waiting time. This is because the higher vehicle flow density lanes require green duration while the vehicles of the other lanes have to wait until those vehicles are cleared from the intersection. In order to solve this problem and to maintain
fairness in the average waiting time of different flow densities in different lanes, a modified phase duration calculation has been adopted. Assuming, \( R \) is the critical lane volume ratio. When it exceeds the optimum threshold value the system cannot maintain the fairness. If the ratio of the critical lane volume reaches the optimum threshold \( R_t \), then the modified green duration is calculated using following equations.

**Case 1:**

\[
\frac{Z_1}{Z_1 + Z_2} > R_t \quad (10)
\]

\[
G_1 = L_t + h \times Z_2 \quad (11)
\]

\[
G_2 = 2L_t + h \times Z_2 \quad (12)
\]

**Case 2:**

\[
\frac{Z_2}{Z_1 + Z_2} > R_t \quad (13)
\]

\[
G_1 = 2L_t + h \times Z_1 \quad (14)
\]

\[
G_2 = L_t + h \times Z_1 \quad (15)
\]

**4.3 Simulation Model**

Figure 4.1 presents the road topology and the communication network architecture that we considered for developing the simulation model. In the simulation model, Road side units (RSUs) are installed at the intersections and in the road junctions. RSU detects the oncoming vehicles via VANETs and works as the traffic controller. Real time vehicle detection is carried out though VANETs message interaction between the RSUs and OBUs. Computation and optimization is done within the RSUs and adaptive signal durations are broadcasted from the RSUs to the oncoming vehicles.

In order to implement the proposed IRTSS and to analyse the performance of the system we have developed a discrete event simulation model using OPNET Modeller 17.1. OPNET modeller uses a powerful finite state machine (FSM) approach to support detailed specification of applications, algorithms, and queuing policies. This model is an embedded model where the vehicular mobility and the network architecture modelling have been integrated on the same platform. As, mentioned earlier, the simulation model consists of two different types of nodes- RSUs and OBUs. The communication network
is based on the IEEE 802.11p WLAN MAC protocol where the RSU acts as the WLAN access point (AP) and the OBU acts as the WLAN mobile stations (vehicles).

Each individual node model is comprised of standard WLAN MAC modules (antennas, MAC processor and a MAC Interface processor) along with an application module that implements the proposed intelligent RTS scheme. Both RSU and OBU have got different application module based on the VANET based intelligent RTS system requirements. The transmission frequency was set to 5.9 GHz and the transmission link was modelled using free space path loss model of WLAN. The free space path loss model was used to calculate the received signal strength. Since at this stage the work is studying the development of the IRTSS algorithm, it was not the intention of the work to introduce complicated propagation models such ray tracing model which may introduce additional packet losses.

Both the RSU and the OBU node models contain transmitter module, a receiver module, a WLAN MAC module and a custom application module. The developed FSM application module for RSU and OBU are shown in the figure 4.6 and figure 4.7 respectively. The FSM in the RSU application module has two different states: the init and the RSU process. The init state initializes the state variables and loads the node attributes. The RSU process sends the periodic broadcast packets, updates the list of the on board units from the received OBU packets and sets the signal light for the optimized IRTSS. The function SRC_ARRVL/xmt() receive the generated packet from the packet generator and send broadcast packets. Whereas the (RCV_ARRVL)/rcv() receives the unicast packets sent from the OBU and updates the number of the OBU within the range. The (CHNG_LIGHT)/change_light() implements the adaptive algorithm and sets the traffic light phase duration.
Similarly, the FSM of the OBU application module contains two different states: the *init* and the *obu process*. The *init* state initializes the state variables and loads the node attributes. The *obu process* sends position information via unicast message and receives the optimized IRTSS signalling information via the broadcast massages. In the OBU process model the function BCAST_RCVD/bcast_process() receive the broadcasts packets sent from the RSU and starts sending the unicast with a defined interval period. The Function END_SIM/record_stat() is responsible for invoke an interrupt when the OBU goes out of the coverage area and accumulate the result statistics in the OPNET simulation model.
4.4 Simulation results and performance analysis

The simulation model was run with different vehicle flows densities from different directions both for fixed and adaptive signal cycle system. Important simulation parameters that we considered in the simulation model are summarized in the table 5.

Table 5: Simulation Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Rate</td>
<td>6 Mbps</td>
</tr>
<tr>
<td>Vehicle flow (EW-NS veh/h)</td>
<td>400:400,400:300,400:200,300:200</td>
</tr>
<tr>
<td>Road/Lane type</td>
<td>Bidirectional crossroads</td>
</tr>
<tr>
<td>Transmission Range</td>
<td>500 m</td>
</tr>
<tr>
<td>RSU transmit power</td>
<td>5 mW</td>
</tr>
<tr>
<td>OBU transmit power</td>
<td>5 mW</td>
</tr>
<tr>
<td>RSU broadcast interval</td>
<td>1s</td>
</tr>
<tr>
<td>Channel Bandwidth</td>
<td>10MHz</td>
</tr>
<tr>
<td>Total Packet length</td>
<td>1350 bits</td>
</tr>
<tr>
<td>RSU and OBU payload</td>
<td>838 bits</td>
</tr>
<tr>
<td>Length of the vehicle</td>
<td>6 m</td>
</tr>
<tr>
<td>Max Speed of the vehicles</td>
<td>60km/h</td>
</tr>
<tr>
<td>Simulation Run time</td>
<td>5400s</td>
</tr>
<tr>
<td>Width of the intersection</td>
<td>30m</td>
</tr>
<tr>
<td>Start up time</td>
<td>4s</td>
</tr>
<tr>
<td>Saturation headway</td>
<td>2s</td>
</tr>
<tr>
<td>Intersection clearance time</td>
<td>1s</td>
</tr>
</tbody>
</table>

According to the standard [ref], IEEE 802.11p supports data rates of 3-27 Mbps (3, 4.5, 6, 9, 12, 18, 24, and 27 Mbps). In the developed OPNET model of IRTSS data rate of 6 Mbps was considered because according to practical measurements, 6Mbps data rate is optimal for the vehicular communication [96].
Figure 4.8 shows the average number of vehicles arrival at an intersection where the vehicle flow density was 400 (veh/h) in the EW (East West) direction and 200 (veh/h) in the NS (North South) direction. These vehicle flow statistics was measured using the OBU RSU architecture as described in the previous section. The simulated traffic value corresponds to the traffic volume theoretically we selected for the analysis. To prove the effectiveness of a VANET based IRTSS we measured the waiting time of a four directional road junction using the adaptive traffic signalling light. Using the 802.11p MAC protocol the RSU collects all data from vehicles approaching and leaving the junctions to estimate the traffic volume and to control the traffic light sequences.

![Figure 4.8: Average number of vehicle arrival at the intersection](image)

Figure 4.9 shows the average waiting time of traffic moving through the junction. The figure compare the waiting time of the vehicles using the adaptive and fixed light sequences. With the adaptive algorithm an average reduction of 37.29% in the average waiting time can be achieved at the intersection compared to the fixed cycle time in all directions. Four sets of simulation scenario were created based on different vehicle flow densities in different directions. In each set, simulations were run both for the adaptive and fixed signalling system. Then, the average waiting time at the intersection was measured.
Results show that the adaptive algorithm can be biased to offer priority to a certain direction if needed. Without use of any priority the signalling system should offer fairness to traffic moving from all directions. To calculate the fairness index we used the Jain’s fairness index as shown in Eq. (16) [97]. It should be noted that the value of the fairness depends on the variable $R_t$ which further depends on the value of the critical lane ratios. The value of $R_t$ can be obtained using Eq. (10) and Eq. (13). For this study, $R_t = 0.75$ provided the highest fairness index among all the lanes which is obtained after several trials from the simulation model.

The measured fairness index values are listed in Table 6 for different vehicle flow densities using the adaptive signalling system. The table shows that in our proposed IRTSS the traffic flows in different directions have very similar services i.e. waiting time is very close to each as shown by the fairness index.

$$F_{\text{index}} = \frac{\left(\sum_{i=1}^{N} X_i\right)^2}{N \sum_{i=1}^{N} X_i^2}$$

(16)
Table 6: Fairness Index

<table>
<thead>
<tr>
<th>Flow Density (Veh/h)</th>
<th>Fairness Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>EW400_NS400</td>
<td>0.991</td>
</tr>
<tr>
<td>EW400_NS300</td>
<td>0.994</td>
</tr>
<tr>
<td>EW400_NS200</td>
<td>0.997</td>
</tr>
<tr>
<td>EW300_NS200</td>
<td>0.990</td>
</tr>
</tbody>
</table>

Table 7 lists the maximum waiting time and its standard deviation for different traffic densities in different directions. The table shows that the maximum waiting time of traffic flows is lower for the adaptive signalling technique compared to the fixed cycle signalling system. In case of the proposed IRTSS, the value standard deviation is small as compare to the fixed signalling system which implies small variation in the average waiting time. Thus the system is more stable and efficient in reducing the average waiting time at the intersection compared to the fixed signalling system, where the average waiting time is higher and the Standard Deviation values show large variation in the average waiting time. The waiting time at a junction is influenced by the volume of traffic as well as by the arrival pattern of traffic from different directions.

Table 7: Comparison of the maximum waiting time, average waiting time and the standard deviation values

<table>
<thead>
<tr>
<th>Flow Densities (veh/h)</th>
<th>Proposed IRTSS (Avg. waiting time)</th>
<th>Fixed signaling (Avg. waiting time)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max (s)</td>
<td>Avg (s)</td>
</tr>
<tr>
<td>EW400-NS400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EB</td>
<td>38</td>
<td>7.967</td>
</tr>
<tr>
<td>WB</td>
<td>42</td>
<td>8.075</td>
</tr>
<tr>
<td>SB</td>
<td>38</td>
<td>8.767</td>
</tr>
<tr>
<td>NB</td>
<td>40</td>
<td>6.79</td>
</tr>
<tr>
<td>EW400-NS300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EB</td>
<td>38</td>
<td>6.57</td>
</tr>
<tr>
<td>WB</td>
<td>34</td>
<td>6.96</td>
</tr>
<tr>
<td>SB</td>
<td>37</td>
<td>7.66</td>
</tr>
<tr>
<td>NB</td>
<td>44</td>
<td>8.01</td>
</tr>
<tr>
<td>EW400-NS200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EB</td>
<td>36</td>
<td>7.57</td>
</tr>
<tr>
<td>WB</td>
<td>37</td>
<td>7.10</td>
</tr>
<tr>
<td>SB</td>
<td>38</td>
<td>8.13</td>
</tr>
<tr>
<td>NB</td>
<td>34</td>
<td>7.9</td>
</tr>
<tr>
<td>Flow Densities (veh/h)</td>
<td>Max (s)</td>
<td>Avg (s)</td>
</tr>
<tr>
<td>-----------------------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>EW300-NS200</td>
<td>EB</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>WB</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>SB</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>NB</td>
<td>34</td>
</tr>
</tbody>
</table>

Next we turn our attention to the performance of the communication network. Figure 4.10 shows the average network throughput of the VANET to support the RSU and OBU packet transmissions for different vehicle densities. The transmission coverage area of the RSU is 500 meters. As the vehicle flow increases, more OBUs come within the transmission range hence the uplink throughput rises.

![Figure 4.10: Average network throughput for different vehicle flows](image)

The average uplink medium access delay (MAC delay) is shown in the figure 4.11. As the flow density and the contention level increases the average uplink MAC delay also increases. The uplink MAC delay represents total queuing and contention delays of the data, management, transmission delay, propagation delay and ACK frames transmitted by all WLAN MACs in the network. For each frame, this delay is calculated as the duration from the time when it is inserted into the transmission queue, which is arrival time for higher layer data packets until the time when acknowledgement is received. However, in our proposed IRTSS the average MAC delay remained in the satisfactory limit to run the system feasibly.
The average downlink MAC delay is 227 µs. The downlink MAC delay is the time difference when the packet was actually sent from the application layer of the RSU and the time when the packet was actually received at the receiver (OBU). The uplink MAC delay is influenced by both uplink and downlink traffic because both share the same channel. In order to maintain low uplink delay we maintained very low downlink traffic volume.

If a packet is not successfully transmitted from a station, the corresponding station retransmits the packet. When the retransmission attempt reaches the maximum limit the packet is discarded. Table 8 shows the average retransmission attempts of the OBUs for the proposed IRTSS. The result shows that the average retransmission attempts remain within the range of 0.18-0.2 which is very low.

Table 8: Average retransmission attempts of the OBUs

<table>
<thead>
<tr>
<th>Network statistic</th>
<th>Flow Densities (veh/h)</th>
<th>Mean</th>
<th>Max</th>
<th>Min</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retransmission Attempts</td>
<td><strong>EW400-NS400</strong></td>
<td>0.0178</td>
<td>3</td>
<td>0</td>
<td>0.117</td>
</tr>
<tr>
<td></td>
<td><strong>EW400-NS300</strong></td>
<td>0.0200</td>
<td>3</td>
<td>0</td>
<td>0.161</td>
</tr>
<tr>
<td></td>
<td><strong>EW400-NS200</strong></td>
<td>0.0182</td>
<td>3</td>
<td>0</td>
<td>0.134</td>
</tr>
<tr>
<td></td>
<td><strong>EW300-NS200</strong></td>
<td>0.0200</td>
<td>3</td>
<td>0</td>
<td>0.164</td>
</tr>
</tbody>
</table>
Figure 4.12 shows the average retransmission attempts for all the vehicle densities. While the OBUs get the first broadcast packet from the RSU, corresponding OBUs try to access the medium immediately. As all the OBUs are nomadic it is very important to design the system in such a way that the IRTSS can successfully detect all the OBUs that come in the range within a very short time. In the proposed IRTSS when the RSU receives any unicast message from the OBUs, it detects the vehicle and updates the list of the OBUs. With a very low retransmission attempts shown in the results (table 8) and with an average vehicle speed of 50-60 km/h, all the OBUs of the proposed IRTSS were detected right after entering the coverage area. The average distance while RSU detects an oncoming vehicle is 495m. The measured average received Signal to noise ratio (SNR) of the broadcast packet is 17.10 dB.

![Figure 4.12: Average retransmission attempts for different flow densities](image)

### 4.5 Summary

A novel VANET based intelligent road traffic signalling system has been presented in this chapter. The intelligent traffic signal uses an adaptive signalling scheme that optimizes the signal durations based on a real-time traffic estimation technique. The IRTSS has been developed based on a simplistic VANET architecture. The model is further developed to implement a wide area traffic control system presented in the chapter 5. In VANETs, vehicles could be detected long before they reach an intersection. The Novelty of the proposed algorithm is that the vehicle detection and traffic control functionalities can be implemented using the VANET infrastructure without any additional resource requirements. Also, the proposed system is scalable. Also the detection range is much larger than the existing detection technologies and it can be implemented for a large road network. Simulation results are shown in order to
analyse the performance of the proposed IRTSS Results show considerable improvements in terms of reducing the average waiting time at the intersection.
Chapter 5

A VANET based coordinated traffic managements via the IRTSS

5.1 Communication network Architecture

In this chapter a VANET based predictive road traffic management system (PRTMS) is proposed. The developed system implements an advanced multi junction traffic control system using the PRTMS algorithm to coordinate multiple traffic intersections over a large road network. The scenario considered for this study contains multiple junctions on a stretch of an urban road network. The corresponding communication network architecture consists of intersections equipped with Road Side Units (RSUs). The RSUs are responsible for co-ordinating and exchanging traffic statistics to the Onboard Units (OBUs) as well as to the other RSUs installed at different intersections. Under the proposed scheme, each ITS enabled vehicle transmits its intended destination or point of interest (POI) to the adjacent RSUs. The RSUs relays the collected information to a central controller. Based on this information, the central controller generates a specific route plan for the corresponding vehicle. In addition, the controller identifies the possible congestion scenarios towards the intended POI and uses a predictive traffic control algorithm to re-route the vehicles to avoid the congestion.

Figure 5.1 shows the conceptual model diagram for an advanced traffic guidance system with our proposed IRTSS. The intersections are equipped with RSUs which are connected to a central coordinator via a wide area network. All the RSUs are monitoring and sending the traffic flow information to the central controller. Based on the instantaneous vehicle flow information by the RSUs, the central controller predicts the estimated future vehicle flow of individual intersections and adaptively re-route the vehicles to reduce the traffic congestion.
Using the real time measurement data, the prediction algorithm estimates the future traffic flow at each intersection to effectively maximise the road traffic capacity and to minimise the total journey time. The communication system used in this work represents a vehicle to infrastructure (V2I) communication system. All RSU based intersections are interconnected via an Ethernet network to cover a wide area where all the intersections can exchange the road traffic information in order to develop the application of PRTMS.

The control flow diagram of the PRTMS is shown in the figure 5.2. The system implements a centralised control system using a VANET based V2I infrastructure. First, the local controllers generate the first control layer where data are accumulated from the vehicles by the RSUs. The information data packet consists of various types of information such as the position of the OBU, speed, and intended destination etc. Traffic volume at certain road sections or in a certain part of the road network is measured in the first layer.
At the second level of control, the central controller accumulates data from the local controllers and process them based on the developed VANETs application of PRTMS. The central controller is responsible for three tasks in our proposed PRTMS:

- Collecting information from all RSUs using the wide area network.
- Based on traffic flow information, it predicts the future flows at different intersections.
- Predict the future congestion states and adaptively re-route the vehicles to minimize the road congestion using the VANET infrastructure.

### 5.2 Predictive Road Traffic Management System (PRTMS)

Prediction and Optimization are the two main areas of focus of the feedback traffic control system used in the wide area network to regulate the traffic flow. For an urban traffic control management technique, many model based control strategies and prediction models are developed based on simple traffic models. For example OPAC [49-50], MPC [7] and RHODES[51] etc are some of the control methods used in these control approaches mainly using simple traffic flow forecasting models based on the traffic statistics gathered by the detectors. From the above mentioned models, MPC [7] came up with moderately detailed prediction model which could predict the traffic flow.
dynamics in the future. However, in this method the main challenges arise in optimizing the control parameters online. In most of the cases the optimization problems are solved off line with a feedback regulator where the model uses the real time measured traffic states to derive control decisions. While designing a prediction model, it is very important to handle the tradeoffs between the computational complexity and accuracy of the control method, while at the same time the system must execute the tasks in real time. However, distributed network architecture can offer better performance as it reduces the size of the control area. As more sub-networks are considered the central controller distributes the control over the small sub-networks and the local controllers can effectively handle the online computational complexity [48].

A VANET based traffic prediction model is discussed in the following sections of this chapter. A microscopic traffic model is used in the OPNET simulation; model to analyse the performance of the proposed IRTSS. The VANET based prediction model offers faster online computational features with limited computational errors. Figure 5.3 shows the basic functional blocks of the proposed VANET based traffic management system. It is an integration of the IRTSS (discussed in chapter 4) and the predictive road traffic measurement system (PRTMS). In this model the road traffic information is collected via the VANET using RSU-OBU communication link. Road traffic information is collected at the central controller where control algorithms are used to predict future traffic flows. The details of the prediction model are discussed in the next section.

![Figure 5.3: Functional blocks of the intelligent traffic management system](image-url)
5.3 Prediction model

In order to implement the advanced road traffic management system, it is very important to develop a predictive algorithm that can estimate the future traffic states at different intersections. The proposed prediction model for road traffic management system has been developed based on the Linear Prediction Model [98-99]. With real-time traffic state information, a linear prediction model will estimate the future traffic conditions. Varieties of applications in different fields of transportation and signal processing engineering such as data forecasting, speech coding, video coding, speech recognition, signal restoration, traffic flow model, etc., have used linear prediction models. Linear prediction models are often referred to as autoregressive (AR) processes in the statistical literature [98-99]. In a linear system, if the system input and output at time ‘’ are indicated by and respectively, then the linear prediction algorithm predicts future output by using the previous input and output of the system. At time , the prediction of is calculated by using the Eq. (17).

\[ \hat{y}(n) = \sum_{k=1}^{P} a(k)y(n - k) + \sum_{k=0}^{N} b(k)x(n - k) \]  

(17)

Where, \( \hat{y}(n) \) refers to the estimate or prediction of \( y(n) \). The coefficient \( a(k) \) and \( b(k) \) are determined in such a way that \( \hat{y}(n) \) approximates the real output of \( y(n) \) as accurately as possible through autocorrelation method.

In the proposed model of PRTMS, a modified linear prediction model is used to best fit the developed traffic flow model in OPNET to minimize the prediction error. A real-time data aggregation is done in order to get the most recent traffic flow pattern based on which the weighting coefficient is updated.

In figure 5.4, intersections are shown where movements of vehicles in different directions are indicated. To describe the prediction model, we are denoting the intersection with ‘’ the lane with ‘’ the number of arriving vehicles from any lane to the intersections at any particular time ‘’ is \( L_{ji}^t \). So, the total number of vehicles at the intersection can be represented by

\[ R_j^t = \sum_{i=1}^{4} L_{ji}^t \]  

(18)
Figure 5.4: Intersection properties considered in the proposed PRMTS

If, the current time is ‘t’, and a vehicle needs T sec to travel from intersection (J-1) to J, the controller at intersection (J-1) is required to predict the future traffic intensity at intersection J, \((t+T)\) sec advance in order to successfully reroute the vehicle. From the VANET based IRTSS, the real-time traffic information \(\{R_j^{k,t}\}_{k=t-N+1} \) (at time ‘t’), can be used to approximate the value of \(R_j^{t+1}\) at time \((t+1)\),

\[
P_{t+1} = w_1R_j^{t-N+1} + w_2R_j^{t-N+2} + \ldots + w_NR_j^t
\]

(19)

Where, \(P_{t+1}\) is the predicted value of \(R_j^{t+1}\) and \(N\) is the number of weighting coefficients (i.e. \(w_1, w_2, \ldots, w_N\)).

Similarly, the value of \(R_j^{t+2}\) is predicted by

\[
P_{t+2} = w_1R_j^{t-N+2} + w_2R_j^{t-N+3} + \ldots + w_NR_{t+1}
\]

(20)

The generalized form of the prediction of the traffic flow at time \((t+1)\)

\[
P_{t+T} = \sum_{k=1}^{T-1} p_{t+T-k}w_{N-T+2} + \sum_{k=T}^{N+1} R_j^{t+T-k}w_{N-k}
\]

(21)

To determine the coefficient ‘\(w\)’, we have taken \(M\) numbers of previous data sample (i.e. \(R_j^t, R_j^{t-1}, \ldots, R_j^{t-M+1}\)), where \((M>N)\)
Let,
\[ R_m = \frac{1}{M} \sum_{k=t-M+1}^{t} R_j^k \]  \hspace{1cm} (22)

And,
\[ \bar{R}_j^i = R_j^i - R_m \]  \hspace{1cm} (23)

Then, the following algorithm is proposed to calculate the ‘w’. The algorithm is a simple extension of the linear prediction algorithm.

So,
\[
\begin{bmatrix}
R_j^{t-M+1} & R_j^{t-M+2} & \cdots & R_j^{t-M+N} \\
R_j^{t-M+2} & R_j^{t-N+3} & \cdots & R_j^{t-M+N+1} \\
\vdots & \vdots & \ddots & \vdots \\
R_j^{t-M+N} & \cdots & \cdots & R_j^{t-M+2N-1} \\
R_j^{t-M+S} & \cdots & \cdots & R_j^{t-1}
\end{bmatrix}
\begin{bmatrix}
w_1 \\
w_2 \\
\vdots \\
w_N
\end{bmatrix}
= 
\begin{bmatrix}
R_j^{t-M+N+1} \\
R_j^{t-M+N+2} \\
\vdots \\
R_j^{t-M+2N} \\
R_j^{t}
\end{bmatrix}  \hspace{1cm} (24)

Now, Let
\[
A= 
\begin{bmatrix}
R_j^{t-M+1} & R_j^{t-M+2} & \cdots & R_j^{t-M+N} \\
R_j^{t-M+2} & R_j^{t-N+3} & \cdots & R_j^{t-M+N+1} \\
\vdots & \vdots & \ddots & \vdots \\
R_j^{t-M+N} & \cdots & \cdots & R_j^{t-M+2N-1} \\
R_j^{t-M+S} & \cdots & \cdots & R_j^{t-1}
\end{bmatrix} \hspace{1cm} (25)
\]

w= \begin{bmatrix} w_1 \\ \vdots \\ w_N \end{bmatrix} \hspace{1cm} (26)

And,
\[
Y= 
\begin{bmatrix}
R_j^{t-M+N+1} \\
R_j^{t-M+N+2} \\
\vdots \\
R_j^{t-M+2N} \\
R_j^{t}
\end{bmatrix} \hspace{1cm} (27)
\]

So, Re-writing the Eq. (24)
\[ Aw = Y \]  \hspace{1cm} (28)
Let us define,

\[ e_1 = |w_1 R_{ij}^{t-M+1} + w_2 R_{ij}^{t-M+2} + \ldots + w_N R_{ij}^{t-M+N} - R_{ij}^{t-M+N+1}| \]  

\[ e_2 = |w_1 R_{ij}^{t-M+2} + w_2 R_{ij}^{t-M+3} + \ldots + w_N R_{ij}^{t-M+N+1} - R_{ij}^{t-M+N+2}| \]  

\[ e_s = |w_1 R_{ij}^{t-M+N} + w_2 R_{ij}^{t-M+N+1} + \ldots + w_N R_{ij}^{t-M+2N-1} - R_{ij}^{t-M+2N}| \]

Where, \(|\cdot|\) indicates absolute value. The motive of choosing \(w_1 \ldots w_N\) is such that \(e_1 \ldots e_s\) is minimized. One of the way to calculate \(w_1 \ldots w_N\) is the least square solution of Eq. (28).

The least square solution selects \(w_1 \ldots w_N\) such that \(e_1^2 + e_2^2 + \ldots + (e_s)^2\) is minimized. In mathematical form the optimization of the least square problem can be defined as

\[ \min_w ||Aw - Y||_2^2 \]

This is a convex optimization problem and this problem can be solved by linear programming method. In fact, the optimization has a compact form of solution. The well known solution of this problem is [100]

\[ w = (A^TA)^{-1}A^TY \]

So, the Eq. (21) and Eq. (22) become

\[ \bar{P}_{t+T} = \sum_{k=1}^{T-1} \bar{P}_{t+T-k}W_{N-T+2} + \sum_{k=T}^{N+1} \bar{R}_{j}^{t+T-k}W_{N-K} \]

And,

\[ P_{t+T} = \bar{P}_{t+T} + R_m \]

The operation methods for the proposed PRTMS depend on periodic message exchange and information dissemination scheme between the OBUs and RSUs, also between the RSUs and the central controller. One is the fixed interface, which handles the communications between the RSUs and the central controller. The second interface is the wireless interface which is responsible for handling communications between the RSUs and OBUs. As stated earlier in the chapter 4, as the IRTSS accumulates the real time traffic flow statistics and adaptively changes the traffic signal sequences to improve traffic flows at different junctions. In PRTMS those aggregated traffic state measurements are used and the intersection coordination is carried out according to the control measures using by the predictive algorithm.
Figure 5.5 shows the network configuration of the proposed PRMTS. Within the Ethernet network, RSUs are connected to the central controller via Ethernet links. In the wireless network, OBU's are detected by the RUS's. Through IRTSS each RSU broadcast one packet every second to all the OBU's within the coverage. After receiving the broadcast packets each OBU start sending unicast message to the RSU every 5s. On the other hand, RSU sends the traffic flow information every minute to the central controller via Ethernet network. With the information received from the RSUs, the central controller predicts the future traffic states at different RSUs and every minute one message is sent to the corresponding RSUs with the congestion state information of the neighbouring RUSs and route plan information to avoid congestion. Based on the future traffic intensity level and the congestion information, the central controller re-routes the vehicles to avoid the congested road section. The RUSs disseminates the information to the OBU's via broadcast messages. At the same time, through the wireless network interface the IRTSS optimizes the signal cycles to minimize the waiting time at the intersections. Thus, total journey time could be reduced by implementing the predictive control mechanism.
Figure 5.6 shows the operational flow chart of the central controller. Whenever the central controller receives a unicast message from an RSU installed at any intersection, it predicts the future traffic flow at that intersection using the current traffic flow and the intended destination information of the vehicles. Based on the predicted level of vehicle flow, the central controller sends the routing information to the RSUs. At any intersection the vehicles could be re-routed according to this updated routing information to avoid congestion.
5.4 Simulation model

In order to implement the proposed PRTMS algorithm and to analyse the performance of the PRTMS, we have developed a discrete event simulation model using OPNET Modeler 17.1. Both RSU and OBU have got different application module based on the VANET based PRTMS’s requirements. The transmission frequency was set to 5.9 GHz and the transmission link was modelled using free space path loss model of WLAN.

The developed network model is shown in the figure 5.7. All the RUSs is connected via 10Gbps Ethernet link. The connected RSU MACs must always operate in a full-duplex mode as the 802.3ae standard does not support half-duplex operation. Propagation delay is based on the distance between two nodes. As previously mentioned RSUs broadcast one packet every second and from the broadcast packet an OBU detects the RSU. Consequently, OBU sends one unicast packet every 5s after entering the RSUs coverage. Also, RSUs provide bridging functionality between the IEEE 802.11p based wireless network and IEEE 802.3ae based Ethernet network.

![Network model for the PRTMS](image)

Figure 5.7: Network model for the PRTMS

Layout of the road network used in the simulation is shown in the figure 5.8. Vehicles were generated from different generation points (i.e. P1, P2, P3, P4, P5) in order to create the vehicle flow of 300 veh/h at all the intersections. From the generation points, a specific point of generation (PoG) (shown in figure 5.8) was chosen and the vehicles that started their journey from that generation point were considered for analysing the system performance. Two sets of simulations have been run; where in the
first simulation both applications of IRTSS and PRTMS were running together while in another one only IRTSS was used.

The total average journey time and average waiting time of the specified vehicles have been measured and compared to evaluate the improvement of the system. By using the 802.11p MAC protocol, the RSUs collect all the data from vehicles approaching to and leaving from the connected intersections and with the prediction algorithm estimation of the future traffic volume is carried out to re-route the vehicles by avoiding the congestion. The maximum speed of the vehicles was 60km/h and the distances between each intersection was considered 3km. Through the controller, a RSU can get the predicted traffic flow information of neighbouring RSUs by using the prediction algorithm. Using the algorithm, in the simulation a RSU can predict neighbouring RSUs traffic intensity 3 minutes in advance. The important simulation parameters are listed in the Table 9.
Table 9: Extended Simulation parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Rate</td>
<td>6 Mbps</td>
</tr>
<tr>
<td>Vehicle flow (EW-NS veh/h)</td>
<td>300 veh/h at all the junctions</td>
</tr>
<tr>
<td>Road/Lane type</td>
<td>Bidirectional crossroads, T-junctions</td>
</tr>
<tr>
<td>Transmission Range</td>
<td>500 m</td>
</tr>
<tr>
<td>RSU and OBU Transmit power</td>
<td>5 mW</td>
</tr>
<tr>
<td>RSU to RSU broadcast interval</td>
<td>60 s</td>
</tr>
<tr>
<td>RSU broadcast interval</td>
<td>1s</td>
</tr>
<tr>
<td>Initial Data Aggregation time</td>
<td>1080 s</td>
</tr>
<tr>
<td>Prediction interval</td>
<td>180 s</td>
</tr>
<tr>
<td>Channel Bandwidth</td>
<td>10MHz</td>
</tr>
<tr>
<td>Packet length</td>
<td>1300 bits</td>
</tr>
<tr>
<td>Max Speed of the vehicles</td>
<td>60km/h</td>
</tr>
<tr>
<td>Simulation Run time</td>
<td>4500s</td>
</tr>
<tr>
<td>Width of the intersection</td>
<td>30m</td>
</tr>
<tr>
<td>Area of the road network</td>
<td>(12 X 6) Square Kilometre</td>
</tr>
<tr>
<td>Number of signalised intersections</td>
<td>3</td>
</tr>
<tr>
<td>Ethernet Link type</td>
<td>10Gbps Ethernet duplex link</td>
</tr>
</tbody>
</table>

5.5 Simulation Results & Performance Analysis

To evaluate the performance of the proposed VANET application of PRTMS, at first, we have analysed the accuracy of our prediction algorithm by comparing the real measurements of the traffic flow with the predicted traffic flow measurements. In the next step, we have presented results that show improvements in the road traffic conditions by reducing the total journey time and waiting time of the vehicles while implementing PRTMS.

Figure 5.9 shows the predicted measurements of the average traffic flow compared to the actual measurements. Here, the actual measurement is the real time traffic flow. These measurements obtained from the traffic flow information sent by the RSUs to the central controller. With the proposed algorithm of the PRMTS, as per the line curve shows, the predicted measurements are close to the actual flow measurements and the
prediction curve tends to follow the curve of the actual measurements with the minimum percentage of error that can be achieved through the proposed linear prediction method.

The average percentage of error has been calculated up to 13.07% with a standard deviation of 7.25. In figure 5.10 the percentage of error over time has been presented.
As an important performance metrics, the total journey time taken by the vehicles running in both simulations are compared and shown in figure 5.11, to evaluate the performance of the proposed PRMTS. With the prediction algorithm the proposed system tries to minimize the total journey time of each individual vehicle running in the road network. With the proposed PRMTS, the vehicles took almost half journey time to complete their trip as compared to the journey time of those vehicles where no predictive traffic guidance system was used. As the vehicles were re-routed to the less congested road sections, all the vehicles reduced their total journey time significantly comparing to those vehicles running without PRMTS.

The total journey time is calculated from the Eq. (36)

\[
\text{Total journey time} = N \times (\text{trajectory travel time}) + M \times (\text{Waiting time})
\]

\(N = \text{number of trajectories}\)
\(M = \text{number of intersections}\)

The figure 5.12 shows the total waiting time of the vehicles at different intersections and compares the time consumed by the vehicles running with PRTMS and without PRTMS. The results show that with the proposed prediction algorithm implemented, the
vehicles would be able to reduce their waiting time significantly compared to the vehicles running without any predictive control measures. The figure 5.12 shows that with the predictive algorithm, maximum vehicles on the road network had to wait for 20 seconds in total or below. Also some vehicles waiting time zero as they don’t need to stop at any intersection.

![Figure 5.12: Total waiting time at the intersections](image)

In figure 5.13, vehicle flow at RSU-2 (lane-1) has been shown. The x-axis represents simulation time in minutes and the y-axis represents vehicle flow (Veh/min). The graph shows that with the proposed PRTMS the vehicle flow was reduced at the intersection as more vehicles were given alternative route plan.

![Figure 5.13: Vehicle flow (veh/min) at RSU-2](image)
5.6 Summary

A novel VANET based predictive road traffic management system has been presented in this chapter. The predictive road traffic management system adopts a predictive scheme that estimates the future traffic intensities at different intersections and based on the predicted traffic information, a central controller reduces the congestion level by re-routing the vehicles. The PRTMS has been developed based on a simplistic VANET architecture and a modified linear prediction algorithm is used to estimate the future traffic states at the intersection. In the simulation model, coordinated intersections were considered and the simulation results were analysed to show the performance of the proposed intelligent traffic management system. Results show improvement in terms of reducing the total journey time of the vehicles. In addition, the performance of the prediction algorithm is also presented.
Chapter 6

Conclusions and Directions for future works

6.1 Conclusions

This chapter summarises the research work presented in this thesis and also proposes some future works in the field of VANET based traffic management system.

The thesis investigated and presented characteristics of a VANET based traffic management systems particularly focussing on vehicle detection method, an adaptive road traffic signalling system and a predictive road traffic control system. State-of-art technologies on the Intelligent Road Traffic Management System and Predictive Road Traffic management systems are reviewed and presented accordingly for the development of two VANET based ITS applications named as Intelligent Road Traffic Signalling System (IRTSS) and Predictive Road Traffic Management System (PRTMS). To implement the developed applications employing the VANET architecture, communication standards such as IEEE 802.11p/DSRC (Dedicated short range communication) and WAVE (wireless access in the vehicular environment) are thoroughly reviewed and OPNET based simulation models were developed to study the performance.

To develop the application of IRTSS, both communication network architecture and mobility model were embedded and implemented on a same simulation platform. In chapter 4 an OPNET based simulation model is presented and results are shown for the performance analysis of the proposed IRTSS. Result shows that the proposed VANET based IRTSS considerably reduces the waiting time at intersections compare to the fixed time signal control system. In the communication network performance analysis, result shows full feasibility for implementing the developed ITS application via V2I communication architecture of VANETs.

On the other hand, the main objective of developing the PRTMS algorithm is to avoid traffic congestion and to maintain smooth vehicle flow at the intersections. With a predictive traffic flow measurement system vehicles are capable of knowing future traffic flow states far before they reach at any intersection on the way to the destination.
With the proposed PRTMS algorithm, the traffic controller could provide alternative route plans for the vehicles to avoid the traffic congestion. An OPNET based simulation model is presented in chapter 5, where multiple intersections are equipped with the developed PRTMS application. Accordingly, Simulation results are shown for the performance analysis. With the proposed PRTMS each vehicle in the road network could successfully receive the congestion information in advance and their route plan could be changed accordingly to avoid congestions. The simulation results show considerable improvement in reducing the total journey time and waiting time of the vehicles.

6.2 Future works

Future work should particularly focus on extending the proposed IRTSS and PRTMS models to reduce the emission level. In reference [101] a V2V communication network based emission model has been presented. The infrastructure less model used V2V communication scheme for implementing virtual traffic light signalling system and showed improvement of 20% reduction of CO$_2$ gas emission in the high density road scenario. By incorporating a validated emission model suited with our proposed IRTSS, substantial reduction of harmful emission gases can be achieved. Emission models can be divided into three categories named as macroscopic, mesoscopic, and microscopic models (Definitions are provided in ANNEX-A).

In the initial phase to incorporate the developed IRTSS and PRTMS algorithms with an efficient emission model will require a proper modelling of the microscopic emission model. As the developed applications are based on microscopic vehicular mobility model it opens up a wider aspect to develop a VANET based application to reduce the green house gas (GHG) emission level. Reference [101] proposed a microscopic emission model for reducing the green house emissions.

Another potential area of future investigation could be incorporating features of Vehicular Social Networks (VSNs) [102-103] with the proposed ITS applications. Research and development of the VSN is still in its initial phase and is destined to develop more interactive ITS applications for the travellers on the road. Finally, implementing ITS applications like IRTSS and PRTMS in real world scenario will be economically challenging. Building proper infrastructure will require sophisticated
planning skills and physical effort. Vehicles and road sections will need to be equipped with devices like OBUs and RSUs.
Bibliography


R. Li, J. Li, and H. Lu, “ Multi-layer traffic signal control model based on fuzzy control and genetic algorithm”, American Society on Civil Engineering, Part of Applications and Advanced Technology in transportation.


ANNEX-A

The ‘ANNEX A’ presents attributes of the physical layer parameters at the RSU node model of the IRTSS developed in OPNET modeller. Also, the RSU and OBU node models of the proposed PRTMS are shown. The RSU process model and the IEEE 802.11p WLAN MAC process models are also presented respectively.

ANNEX Figure 1: The IEEE Physical layer configuration in OPNET at RSU
ANNEX figure 2: WLAN based RSU node model in OPNET

ANNEX figure 3: WLAN based OBU node model in OPNET
ANNEX figure 4: RSU process model for the PRTMS

ANNEX figure 5: The IEEE 802.11p MAC process model in OPNET modeler
Macroscopic Model: for evaluating the impacts of the transportation projects, macroscopic vehicle fuel consumption and emission models are being used as primary tool. These models estimate pollutant emissions and fuel consumption mainly based on the average travel speed of the traffic flow. A transportation planning model is used to determine the average speed and total vehicle-miles of travel for the network or facility being considered. Then, an emission model such as MOBILE5, MOBILE6 (EPA, 2002) or EMFAC (CARB, 1991) could be used to compute the average fuel consumption and emission rates for the facility. [98]

Mesoscopic Model: in this kind of models disaggregated trip variables are used such as the average speed, the number of stops, and stopped delay for estimating the vehicle’s emission rates on a link-by-link basis.

Microscopic Model: in this kind of models from the relation between instantaneous measurement of explanatory variables (such as vehicle power, tractive force, acceleration or speed) and dependent variables (instantaneous fuel consumption and emission rates) the instantaneous fuel consumption and emission models are derived. Vehicle characteristics, traffic conditions, environmental conditions and roadway conditions are required to estimate vehicle fuel consumption and emission rates.