An analysis of real-time traffic congestion optimisation through VTL in VANETs

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Abstract: Traffic congestions are a daunting phenomenon that affects thousands of people worldwide in their everyday lives. Owing the rapid proliferation of technologies, the demand for VANET technology is increasing expeditiously to create an environment for a Virtual Traffic Light (VTL) to minimise traffic congestion. The replacement of conventional physical traffic light systems with VTL is cost-efficiently achieved across vehicle networks. In this paper, we summarise the recent state-of-the-art methods of VANETs by discussing the importance of Virtual Traffic Light in VANET, its architecture and real-life applications. Further, work is focused on challenges, characteristics and related domains of allied VANETs applications by filling the gaps of existing surveys along with the latest trends incorporating the concept of VTL. This attempt presents the effectiveness of virtual traffic by including recent work in real scenarios according to research findings. This paper offers a systematic review of current VTL methodologies that promise to show an impactful result in the future. Finally, this attempt comprehensively covers the entire VANET system and highlights certain research gaps of VTL that are still left to be explored. This work will support researchers of this domain by analysing the literature on VTL in VANET during the period 2007–2019.

Keywords: traffic congestion; VANETs; VTL; real-life applications.

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1 Introduction

The current era is a major challenge to road traffic and accidents due to fatalities, injuries and rapid technological development in infrastructure. The 2013 Global Status Report on Road Safety, which focuses on health, indicates that 1.24 million road deaths were reported in 2011, a figure that could rise to 1.9 million by 2020 if nothing is done (WHO, 2013). In Nantulya and Reich (2002), the third cause of death is anticipated to be road crashes by 2020. A correct system with less manual intervention is required to control traffic. A major stage in the development of a new communication system called the VANET (2014). Advances are expected to make the Vehicular Ad-Hoc Network (VANET) field safer and more interesting. The automotive industry continues to build new facilities and vehicle safety measures. Moreover, concerted efforts from academia, industry and various standardisation bodies contributed to the adoption of the Intelligent Transportation System (ITS) (Campolo et al., 2015). Intelligent transport infrastructure is driven by a large rise in the number of vehicles. Traffic jams in many parts of the world are common because of restrictions on road expansion and increased vehicle density. To be able to help the driver change traffic flow conditions, emergency situations, etc., an effective traffic control system is needed. Ad hoc transport networks provide a wide variety of services to mobile users such as increased driving safety and comfort for passengers in a vehicle environment (Hu et al., 2017). Major changes in traffic flow regulation can be seen in view of the recent developments in automated vehicles. Hu et al. (2017); Tonguz et al. (2007); Parul and Umang (2015) and Choudhary and Dwivedi (2018) identified VANET-based traffic information systems, to avoid road congestion by vehicles and to select alternative routes which offer greater traffic flow. Such an intelligent transportation system enables wider use of the road network and distracts drivers from traffic jams. Taking these road connections as a vital tool for the continuity of traffic, Hu et al. (2017) focused on the VANET role inefficient management of these important road network components. VANETs are formed by on-road vehicles acting as nodes of a dynamic ad-hoc network. Wireless communication-equipped units are embedded inside cars to behave as 'computer networks on wheels'. On-road vehicles can broadcast their data to all connected vehicles over the network (Parul and Umang, 2015). The information is exchanged continuously between vehicles and fixed base stations across roads. The increase in traffic and congestion on roads has led to wastage of crucial time spent sitting behind the wheel (Raw et al., 2019). Installation of traffic lights has smoothened the traffic to some extent according to Gershenson and Rosenblueth (2012). However, to mitigate the problem of on-road congestion and thus, reduce the commute time without leveraging huge expenses on traffic lights, Virtual Traffic Lights (VTL) has been suggested. Vehicles act as a VTL using the architecture of a VANET to alleviate the problem of congestion and accidents at road-intersections (Alba et al., 2008). Dedicated Short Range Communication (DSRC) is used by cars to interact with each other working over a frequency of 5.9 GHz. A VTL helps in increasing the throughput of traffic at any road-intersection by dynamic updating of current on-road traffic information (Choudhary et al., 2020; Rao et al., 2020). This further aids in reducing carbon emissions and optimise energy consumptions in a smart city (Umang and Choudhary, 2018; Umang et al., 2010). VTL through VANETs are intended to provide reliable and efficient communication systems for the development of creative solutions, but mobility limitations prevent them from doing so. There is need of an IP-based novel system made up of open threads that communicate with VANETs to form a mesh network among vehicles (Choudhary et al., 2020). This paper discusses all the research work done on VTL and emphasises on need of a novel Open Threads-based infrastructure that will aid in the development of a world of transportation which is more cost-effective, reliable, clean and sustainable.

2 Vehicular ad-hoc network (VANET)

A VANET is an autonomous and self-organising wireless communication network where vehicles behave as nodes in a client-server architecture with continuous exchange of information (Ku et al., 2014).

2.1 VANETs provide two modes of communication system

1) V2V (Vehicle to Vehicle) Communication System
2) V2I (Vehicle to infrastructure) Communication System

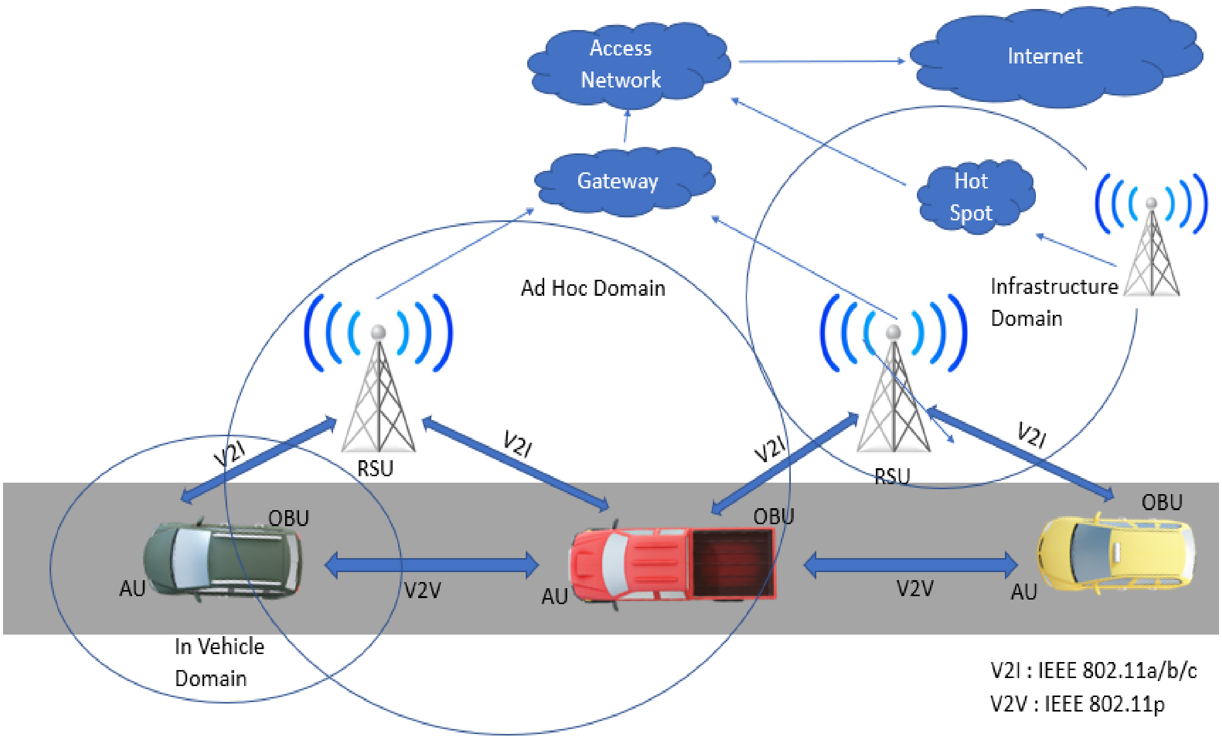
In V2V, each vehicle communicates in an ad-hoc network environment with nearby vehicles and drivers can be made aware of surrounding traffic situation by exchanging information based on it (Santa et al., 2008). V2I provides internet access to the commuters via Roadside Unit (RSU).

2.2 Characteristics of VANET

A VANET possesses a distributed architecture for information sharing instead of a server based centralised architecture. Few important characteristics of VANETs (Bhoi and Khilar, 2014; Doolan and Muntean, 2013; Füßler et al., 2007) are as follows:

1) *Highly dynamic topology*: Owing the high speed vehicles in large number and multiple route availability, VANETs have a rapidly changing vehicle topology, especially on highways where a vehicle's link's lifetime is of a fraction of a minute.
2) *Frequent network disconnection*: A VANET's highly dynamic topology leads to high frequency of change in link connectivity.

Figure 1 Working block diagram of VANET architecture



3) *Mobility modelling and prediction*: Mobility pattern of vehicles depends of several factors such as road pattern, the traffic lights, the speed limits, traffic condition and driving behaviours of drivers.

4) *Variable network density*: Several factors such as road architecture or city environments affect the variability of network density in a VANET.

5) *Geographical type of communication*: VANETs support unicast and multicast communication along with geographical area-based packet forwarding communication.

6) *Offline-infrastructure*: RSUs in any VANET are only available during an on-road vehicle's acting as a node, thus providing an offline infrastructure that is available only during random intervals of time.

7) *Adequate storage and energy*: In a VANET, on-road vehicles acting as nodes possess surplus power and storage in comparison to other ad hoc networks.

8) *Hard delay constraints*: The delivery time for a message or information is critical in a VANET. Information delivered after-time is of no use.

9) *Interaction with on-board sensors*: The OBUs embedded in each vehicle can communicate with vehicle related information to the data centre.

10) *Heterogeneity of applications*: The wide range of applications offered by VANETs can be broadly classified into safety and infotainment applications.

2.3 *Challenges of VANET*

Several characteristics such as mobility constraints along with node connectivity pose a challenge to VANETs (Yousefi et al., 2006). A few of them are listed below:

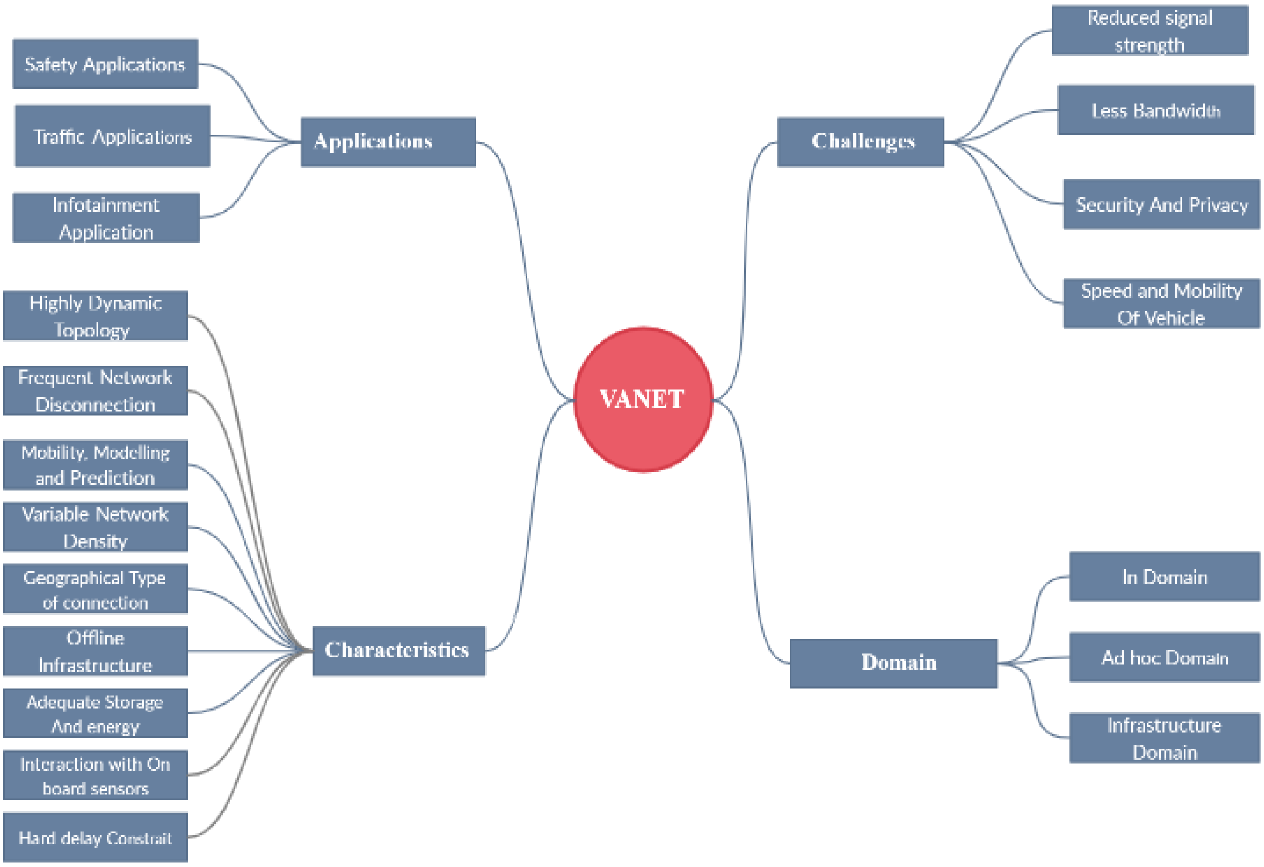
1) *Speed and mobility of vehicles*: The variability in the length of wireless communication window between the vehicles pose a challenge.

2) *Reducing signal strength*: Tall buildings or structures obstruct the communication mechanism between two vehicles (nodes).

3) *Less bandwidth*: A limited bandwidth of 10–20 MHZ to VANET applications requires uniform distribution for fair usage of bandwidth to avoid congestion.

4) *Security and privacy*: VANET applications demand a balance to be maintained between security and privacy of the network.

Figure 2 VANETs: characteristics, applications, challenges, and related domain



3 Traffic control mechanism based on VANET

The congestion management mechanisms in Vehicle Adhoc Networks have been introduced in many ways to achieve seamless communication between vehicles. The design of VANET offers a perfect foundation for the implementation of traffic control mechanisms. Traffic light is considered one of the best ways of reducing traffic congestion. However, the problems raised by the increasingly rising number of vehicles and growing nature of road conditions cannot be faced by the conventional traffic lighting. The idea of reducing installation costs, and the complex control of car traffic flows at intersections, is a guiding force for the replacement of conventional infrastructure-oriented traffic lights by vehicle communications-based Virtual Traffic Lights (VTLs) (Hagenauer et al., 2014; Choudhary et al., 2020). The VTL manages the timing of the traffic signal, thereby strengthening the conventional fixed traffic light system.

VTL is the driving force behind improving health and increasing the environment in terms of energy consumption. VTL happens when a sequence of traffic lights is synchronised to facilitate the uninterrupted flow of traffic over multiple crossings in one direction. Ideally, VTL with the versatility function reflects actual traffic conditions on road. All enterprises are encouraged to incorporate VANETs in vehicles for traffic management system. A VTL of VANETs is organised to overcome the problem of road accidents at intersections (Mohamed, 2013). This system will alleviate traffic delays and reduce traffic light maintenance costs. The current study considers that the combination of the VANET and the VTL mechanism improves urban transport in terms of average speed and energy conservation.

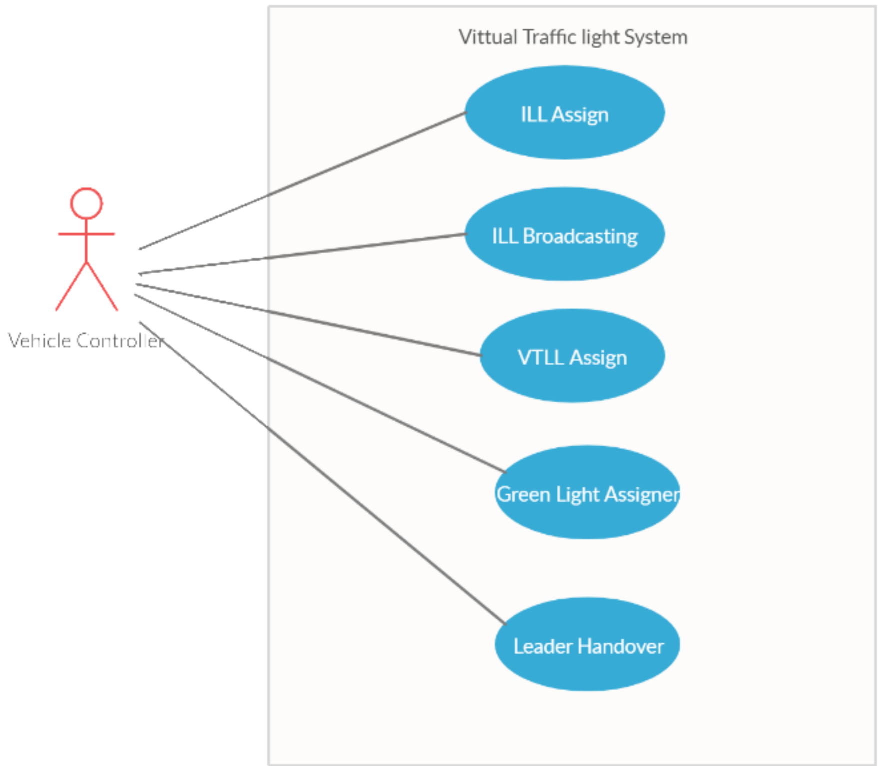
3.1 Incorporating virtual traffic light (VTL) as solution to real life problem

The vehicles act as a VTL using the architecture of a VANET to alleviate the problem of congestion and accidents at road-intersections. At the time of a conflict at a road intersection, the vehicles acting as nodes in the VANET must elect one of them as the leader to take the final decision. The leader node elected unanimously will temporarily configure the infrastructure for traffic light at that road junction. The route information is broadcasted to all the node vehicles by the leader node. All other node vehicles must obey the traffic light decision broadcasted by the leader.

The leader, on being selected bears the charge of assigning green light time accordingly to each approaching direction. These timings are either pre-programmed or configured on the spot based on the current traffic parameters such as vehicle density on each road or level of congestion along with the priority of certain road junctions over others, etc. The elected leader vehicle makes its own lane as the red-light lane and let other vehicles coordinate with it and pass on the road. The green signal is pre-empted from a road as soon as the road becomes vacant and another connecting road is assigned the green-light by the leader. Once the leader takes off from the road intersection, its place is taken over by a new vehicle node in the virtual traffic light network. Figure 3 shows the use case diagram of VTL system. The user of this system are the vehicles which are embedded with technology enabled microcontrollers. There are five different use cases associated with the successful working of VTL.

1) *ILL Assign*: An individual leader on the lane is chosen by all vehicles to settle any dispute at a road crossing. The vehicle's proximity to a crossroads in each lane is selected. Other vehicles on the same lane follow the instructions given by Individual Lane Leader (ILL). The vehicle entering the lane first is generally assigned as its leader.
2) *ILL Broadcasting*: Once the leader is assigned, the role of ILL is to broadcast the traffic signal to all the vehicles in the same lane. Vehicles enabled with controllers follow the instruction of their ILL. The signal to be broadcasted by the ILL is given by Virtual Traffic Lane leader.
3) *VTLL Assign*: At the intersection, the virtual traffic light leader must be chosen from all individual lane leaders at the junction. The VTLL leadership is then reported to the individual lane leaders. The temporary light system is uniformly built or designed by the elected leader. The information on the traffic light is then transmitted by the representative or the elected car. Traffic light information transmitted by VTLL is passed to the rest of the Individual lane leaders in the network. The chosen vehicle harmonises with others as it sends it a red-light signal and stops itself.
4) *Green light assign*: The main responsibility of the VTLL is to assign green lights to other lanes one by one. The prioritisation among lanes is decided by the mechanism of VTL. One lane gets the green light and the rest of the lanes receives the red light. After setting green light for all the lanes, VTLL announces green signal for itself.
5) *Leader handover*: When the lane displays green light, the leader has the full right to go ahead. Before leaving a new leader is selected to manage the network of traffic lighting. VTLL then passed the leadership to any other ILL which had a red signal and is stopped at the junction.

Figure 3 Use case diagram of virtual traffic light (VTL)



4 Research findings

Chou et al. (2013) introduced the concept of dynamic traffic lights that adapt their cycles in accordance to the traffic scenario at hand. The throughput and level of congestion at a road intersection can be improved by replacing the static nature of traffic lights to dynamic updating of the span of light signals based on current traffic. VTL is a cost-effective and feasible solution in contrast to highly expensive maintenance of physical traffic lights in any smart city. As compared to the static cycled traffic lights, the average speed of the traffic increased by 10.1% because of the proposed approach.

Ferreira et al. (2020) presented a self-organising system for controlling of traffic lights which hands over the work of physical traffic lights to the ongoing vehicles. They proposed a solution for the problem of congestion management at road intersections that did not require any road side infrastructure. They put forward the idea of vehicles equipped with devices used for vehicle to vehicle V2V communication as a replacement for physical traffic lights.

Nidhi and Lobiyal (2012) presented an evaluation of VANET by its simulation in real world scenario. Owing the highly expensive deployment and great complexity of the system, they considered simulation to the best tool for the basis of research on VANET. A map of JNU was generated with the aid of Google Earth and GIS.

Fernandes (2009) put forward a protocol for in-vehicle traffic signs. On the basis of the self-organised and dispersed characteristics and features of VANET, they are the main technology that allows not only the speedy organisation of wireless networks but also the development of new traffic rules which quickly adapt to traffic change situations. His work aims however to go deeper than traditional road signs and implement a modern way of making interactive road signs just in time and on the spot. Within this research, a distributed protocol is designed to create virtual traffic lights spontaneously between vehicles in a shared and coordinated manner, but without a centralised control infrastructure

Odeh (2013) used genetic algorithm for congestion detection of four junctions covering two highways. This paper provides the use of technology to count the number of vehicles using a video imaging device. Discussed implementation of the genetic algorithm and offered some suggestions aimed at improving the system efficiency and determining, by mobile site, the number of vehicles and the estimated number of people in the region, where change can be made in real time to avoid congestion as much as possible. However, the machine will give a warning message and advertise suspicious scenes (e.g. car crash, ..., etc.). In principle, travel times across the city should be Hagenauer et al. (2014) came up with an approach to elect the leader in a virtual traffic light system for realistic traffic scenarios. Work was also done for realistic scenarios in future with new abstract-based junctions. Results were on the positive side for network load in low to medium range thus, outperforming the physical traffic lights. The expansion of this algorithm is their core contribution layouts at random crossroads. They reviewed the scenarios virtual and practical which revealed VTL effectively uses network power and has a favourable effect on driving conditions and runs stationary light systems with small to medium network loads.

Mohamed (2013) presented a lightning control system for streetlights that illuminates the light only in the presence of a vehicle. This system checks and monitors streetlight automatically. An increase of 53% in the lifetime of the traffic lights and energy savings up to 65% were shown by the system.

Sharma et al. (2013) introduced a traffic control system for decongestion with the help of radio frequency. The system is an emulation of the traffic department's decongestion process. A scheme of prioritisation of emergency vehicles over others has been suggested by the author. The identification of the radio frequency is a technique that uses radio waves to uniquely identify the object.

Füßler et al. (2007) proposed a study on vehicular ad-hoc networks in close associating to MANET. The economical VANETS used ISM band to work on ubiquitous communication. The facility of emergency messages restricted to limited area was also added to the work. They detailed the early vision of a massive MANET to make it easier to communicate on the ISM ribbons and reduced the vision to cars that send emergency information in a geographically limited region. The work explained how these current limitations pose new problems and then suggest that VANETs remain an important area of science.

Ho et al. (2007) aimed on the transport system by designing structures for mobility in vehicles. Node connectivity through VANET was introduced in his work. The requirements and the analytical framework while designing realistic vehicular networks was also mentioned. The key contributions from this paper were described in threefold. In fact, only less than 27% and 13% of the total duration of single-hop connections can be met by two hop and three-hop routes, respectively. For the study of routing algorithms and other network functions in vehicle networks, this kind of knowledge of the performance of MSTs will be significant.

Pandit et al. (2013) aimed at optimising the traffic volume by collection of realistic data of vehicles like their time, speed and position. It described the problem of vehicle travel sign control as a work schedule issue for processors, with jobs matching vehicle platoons. They proposed the first OJF algorithm to reduce the delay at the crossroads by a web-based algorithm. It aimed at proving that the OJF algorithm is 2-competitive, implying that the delay of an optimal offline schedule with perfect arrivals knowing is less than or equal to twice as long. It also shows how a VANET can be used for grouping vehicles into roughly equal platoons, which can then be programmed via OJF referring it as a 2-phase solution where the car traffic is clustered in panels and the OJF algorithm, i.e. the Older Arrival Algorithm First (OAF). The simulation tests demonstrate that the OAF algorithm eliminates car delays when they pass the intersection under light and medium traffic loads, similar to the methods used by vehicles, the Webster system and pre-timed signal control systems.

Penna et al. (2014) projected towards dynamic positioning search in vehicles. Simulation of dynamic nodes in real-world scenarios of rural, urban and Manhattan were done using NS-2 simulator. The signal propagation time helped in the calculating dynamic position of vehicles. Also, the position was confirmed by their second algorithm.

Jin et al. (2017) focused on accident prevention and traffic management techniques for all vehicles (emergency as well as normal). The simulation of all three units: roadside, traffic control and onboard was done using NS-2 simulation software. The positive results via simulation confirmed the road safety with the supply of timely information to all vehicles with accurate measure of packet delivery ratio, throughput and other parameters.

Mala and Varma (2016) analysed the influence of queueing theory towards the traffic management. Bhagwanpur Golambar junction in Muzaffarpur city was analysed for evaluation of system design, waiting time and utilisation.

Nellore and Hancke (2016) proposed a unique methodology for emergency vehicle management. Traffic Management Centre is communicated with using Medium Access protocol and sensor devices for timely delivery of emergency signals. NS-2 simulator shows positive results of PE-MAC on simulation.

Shinde and Dongre (2017) presented a hybrid of vehicle-to-vehicle and vehicle-to-infrastructure architecture as Vehicle-to-Vehicle-to-Infrastructure (V2V2I) architecture. The fusion acquires the advantages of V2V of fast queries and responses and that of V2I of distributed feature. The traffic information, road conditions, vehicle speed and surface conditions are passed to route the vehicles accordingly.

Zhang et al. (2018) provided a DSRC-based prototype design effort for VTL using DSRC technology. The work carried out show that VTL is feasible with DSRC technology. Preliminary tests from field trials in Pittsburgh of VTL vehicles revealed that VTL is capable of controlling traffic at intersections and reducing passenger travel times. There are two computer modules in the application running on the unit: a VTL logic module and a location module. The location module provides the GPS coordinates and geo-information needed in the decision-making process of the VTL logic module. This information is then used by the VTL logic module for the VTL algorithm.

Martins et al. (2019) presented the prototype Bluetooth Low Energy (BLE), based on an alternative technology to normal vehicle communications. The framework aims to integrate traditional and modern vehicle communication systems in a cohesive management system. In that case, user movement at intersections is controlled by a centralised system, which transmits warnings and virtual light signals using networked transmitters mounted at intersections. Consumers access the above information on their own intelligent computers, thus removing the need for complex light communication infrastructures. This can be inferred from simulations that the suggested program can be used for BLE technologies and personal devices (smartphones for instance) in a real-world scenario. However, the performance of the personal VTL device may be increased by using specialised equipment like the BLE module used and the Raspberry Pi to satisfy the real-time demands of a road safety program that is vital.

A self-adaptive traffic management system is used in Zhou et al. (2010) to track multiple intersections. Wireless sensors gathered real-time traffic data. The number of vehicles at a crossroads, waiting time, count of stops of vehicles and density of vehicles are detected by numerous road sensors. Furthermore, with the corresponding intersection traffic data and traffic patterns as comparisons the optimum green signal time can be determined.

An adaptive multi-target control framework in Duan et al. (2020) relies on a traffic state strengthening system learning to control urban traffic signals. VANET agents will share traffic statistics to get the ideal stop number of the target car, total waiting time and the estimated queue size of the next intersection. The use of adaptive priority management systems will be effective in busses and emergency services than those using the traditional traffic control system.

A traffic light synchronisation framework in Chin et al. (2011) has been proposed in order to maximise traffic signal time, the TSTM framework uses genetic algorithms. Rapid acceleration / deceleration and idling must be stopped to reduce emissions and improve energy efficiency. The recommendations for dynamic speed are based on traffic signal messages in real time that adjust the speed of the vehicle to the green light. The arterial road suggested by [Kuo et al. (2017) was better planned by using a Dynamic Speed Control System (DSDS) protocol. For changing the signal timing and optimum driving speed without slowing, the priority ranges and priority vehicle decision process are used. Table.1 represents Comparative Analysis of research work done during 2007–2019, methodologies and findings for strengthening its related aspects.

Table 1 Comparative analysis of VTL mMethodologies during 2007–2019

No.	*Year*	*Research Area*	*Methodology*	*Findings*	*Research Gaps*
1	2007	Vehicular ad-hoc networks in close association with MANET (Füßler et al., 2007).	Worked on ubiquitous communication using ISM band.	VANETS were enhanced by sending emergency messages in a limited coverage area.	Results were limited to a small coverage area.
2	2007	Node connectivity in vehicular ad hoc networks with structured mobility (Ho et al., 2007).	Worked in giving structures in vehicle mobility of transport system.	An insight to analytical framework and mentioned the requirements used in designing realistic vehicular networks.	Structured mobility limits the driver to change routes.
3	2009	VANET enabled In vehicle traffic signs (Fernandes, 2009).	Creates new traffic rules via Virtual Traffic Light without centralised control infrastructure.	Comparison between VTL and infra-structured-based pre-timed traffic lights is done and VTL tend to show better results.	A complete centralised system which gives flexibility along with uniformity should be added.

Table 1 Comparative analysis of VTL mMethodologies during 2007–2019 (continued)

No.	*Year*	*Research Area*	*Methodology*	*Findings*	*Research Gaps*
4	2010	Self-organised traffic control (Ferreira et al., 2010).	Applied Virtual traffic lights leveraging the cost of physical lights.	Through simulation done on large scale for Porto their solutions scalable and cost-effective.	Information should be imparted to pedestrians too.
5	2012	Performance evaluation of realistic VANET using traffic light scenario (Nidhi and Lobiyal, 2012)	Use tools such as Google Earth and GIS to generate a map of their own university JNU.	The impact of the virtual traffic light is estimated by taking various parameters such as rate at which packet is delivered, number of packets lost on way and chances of router failure.	Bugs by simulator NS2 are unreliable so a mathematical model is also needed.
6	2013	Adaptive virtual traffic light based on VANETS (Chou et al., 2013).	Use adaptive traffic light that changes the cycle of traffic lights dynamically depending on current traffic.	Adaptive traffic light approaches improve traffic by dynamically changing the duration of traffic lights depending on current traffic.	This is basic Virtual Traffic Light system which has not given drivers to route at peak hours and also no care of emergency vehicles.
7	2013	Management of an intelligent traffic light system by using genetic algorithm (Odeh, 2013).	Using Genetic Algorithm to evaluate the results which gets its input from an imaging system.	This system calculates time for green light at each intersection and keeps the track and count of most vehicles.	Incorporates cost at junctions for additional cost of sensors at junctions.
8	2013	Smart street lighting control and monitoring system for electrical power saving by using VANET (2013).	Automate switching the light for parts of the street where vehicles are expected and turns off the light for rest part of the street where there are no vehicles.	It shows an increase of 53% in the lifetime of the traffic lights and saves energy up to 65%.	This algorithm will not work in heavy traffic as the roads will be always loaded. It is not possible in heavy congested areas.
9	2013	Traffic light priority control for emergency vehicle using RFID (Sharma et al., 2013).	Apply new traffic control system using radio frequency that decongests the traffic junction.	In this paper author has proposed a scheme to prioritise the emergency vehicles over other vehicles by tagging the information of emergency vehicle to the cars.	Cost of radio frequency sensors is added. Algorithm fails to prioritise if more than one emergency vehicle is near junction.
10	2013	Adaptive traffic signal control with vehicular ad-hoc Networks (Pandit et al., 2013).	Evolved a new algorithm under the name Oldest Job First (OJF) algorithm, which works on minimising the delay by vehicles at junction.	They accumulate the realistic data of vehicles such as time, speed and position to optimise the volume of traffic.	This algorithm works in two phases by making platoons but fails to give results in heavy traffic.
11	2014	Advanced leader election for virtual traffic lights (Hagenauer et al., 2014).	Developed approaches for realistic traffic scenarios for computing traffic light and electing leader.	They show positive results towards low to medium network load and outperforms stationary traffic lights.	Cannot run efficiently in heavy volume of vehicles. Special conditions are not considered.
12	2014	Evaluation of active position detection in vehicular ad-hoc networks (Penna et al., 2014).	They calculate the dynamic position of vehicles using time involved in signal propagation in their first algorithm and their second algorithm confirms its position using the base station location.	They focused on contributing their work towards simulating dynamic nodes on ns-2 in different scenarios including rural, urban and Manhattan.	Simulator work is done only for single time of day, they should be taken at peak hours and then evaluated.
13	2015	An intelligent traffic management and accident prevention system based on VANET (Kshirsagar and Sutar, 2015).	An algorithm to prevent accidents and managing traffic signals both for emergency vehicles and normal vehicles.	Various parameters including delay, packet delivery ratio, packet loss and throughput are measured, and simulation shows positive results.	Works well for low to high volume of traffic but neither takes the account of emergency vehicles nor the pedestrians.

Table 1 Comparative analysis of VTL mMethodologies during 2007–2019 (continued)

No.	*Year*	*Research Area*	*Methodology*	*Findings*	*Research Gaps*
14	2016	Minimisation of traffic congestion by using queueing theory (Mala Varma, 2016).	Applying the theory of queueing towards the traffic management for Bhagwanpur Golambar junction in Muzaffarpur city.	Using Queuing theory, a number of parameters are evaluated like waiting time, system design and utilisation.	The Reason for choosing the queuing model (M/M/1), is not given. There are other models too.
15	2016	Traffic management for emergency vehicle priority based on visual sensing (Nellore and Hancke, 2016).	In this paper they used sensors devices along with Medium Access protocol to communicate with Traffic Management Centre to decrease delay.	NS-2 simulator shows positive results of PE-MAC in context to end-to-end delay, throughput, and energy consumption.	Simulator must also be worked on parameters like packet drop ratio, etc.
16	2017	VANET system for traffic management (Shinde and Dongre, 2017).	Introduced vehicle-to-vehicle-to-infrastructure (V2V2I) architecture, which has fused basic architectures of vehicle-to-vehicle and vehicle-to-infrastructure.	They pass information of traffic, conditions of road, speed of vehicles on road and condition of surface to vehicles, which route accordingly to the data provided.	Does not work with multilane traffic.
17	2018	Virtual traffic lights: system design and implementation (Zhang et al., 2018)	They used an OBU optimised GPS system for the position of vehicles in our project. For the current usage, the OBU will use the GPS tracker the car provides for a high-end car with a more accurate GPS device.	In this work, VTL technology as a potential alternative has been checked for prevention of congestion and for reducing passenger travel time at peak hours and non-rush hours.	This work lacks in managing VTL with pedestrians.
18	2019	Towards personal virtual traffic lights (Martins et al., 2019)	Introduced a new Computer Traffic Light Systems Architecture which has special characteristics, as it exploits the existing ubiquity of intelligent devices and implementing a simulated traffic lighting network.	The program was introduced using low-cost, readily usable devices and tested in real-life scenarios.	The proposed work passively collects information, rather we want users to take an active role. This move would allow the overall system's adaptability, encourage controllers to take smarter decisions, boost traffic management and planning, and hopefully give users a better experience.
19	2020	Model-predictive-control complex-path tracking for self-driving cars (Farag, 2020)	This paper proposes a robust Model-Predictive-Control (MPC) controller for Self-Driving Cars (SDC) that enables efficient complex track manoeuvring.	The results show that the proposed controller outperforms other traditional controllers such as PID thanks to its tuning technique.	Simulation results must include both micro- and macro-traffic movements.

5 Identified research gaps in virtual traffic light

A novel approach for congestion management has been proposed through VTL. By reducing the long hours of people sitting behind the wheel during traffic jams, VTL has evidently benefitted the urban workers in smart cities thereby increasing their productivity in a cost-effective manner leading to a greener environment. The tedious and static job of traffic light management to work in an efficient manner has been reduced to a significant level by the dynamic updating of the lights based on current traffic scenario via inter-vehicle communication in a VTL using VANETs. Congestion management has become an easy to do job with the help of live updates and decisions on the traffic light signals based on vehicle density at any road. However, few issues that are still left to be addressed would be the reliability and latency of the system. These issues are intended to be addressed in the presented work with the proposal of existence of VTL equipped vehicles in the model.

However, certain subjects have been failed by the algorithms as discussed below:

5.1 No dynamic information is being shared with the pedestrians on the roads to be updated in accordance to the sudden change in the traffic lights

Motor vehicles have precedence over pedestrians on the traffic signals in most of the proposed algorithms. To further attain this, road management authorities should revitalise road traffic signals and redistribute delays at intersections from pedestrians to cars. Researchers continue to concentrate on long-term decisions, including infrastructure and land development. But the shortest decision, the number of seconds of green light each move takes at an intersection, shape perception of how feasible to walk or drive at a time to a certain destination. This affects travel options, destinations, and travel types. In the name of safety and efficiency, this limits the rights and privileges of pedestrians while promoting drivers. Introducing virtual traffic light signals made moving motor vehicles a priority at the cost of pedestrians, which slowed down the city's effective travel speed. Pedestrians are now waiting at intersections for about 20% of their time as these algorithms fail to update the change in traffic lights to pedestrians. Regarding vehicle-dominated cities, these algorithms are programmed to give the consequences of making it easier to drive, and more difficult to walk are consistent.

5.2 The analysis of the results is being restricted to a narrow perspective due to the limited coverage area

Regulation of traffic is one of the main technical ways of controlling traffic flows, increasing congestion and even reducing pollution. The advances and innovations in information technology, computer technology and machine science have also been followed by growth. The method of self-adaptive control will best use the total traffic power of the road network in contrast with timing control and actuated control and efficiently increase road traffic performance. Data obtained by the current traffic control system and other existing system is limited. V2V and V2I solutions are configured for the optimisation of the public transport network activity of the system but the results remain narrow due to limited coverage.

5.3 VTLs are proved to be more efficient in case of structured single-lane junctions as compared to multi-lane ones

Under the system of traffic management, the lane is part of a path designed to be used by one single line of vehicles, to regulate, monitor the drivers and to avoid conflicts in traffic. Most public tracks have at least two lanes, with one lane divided in each direction. Multi-lanes are marked with road surface markers on numerous roads and have busier two-way routes. Multi-roads are often divided by two mid-lane roads. VTL algorithms are modelled on structured single lanes and evaluated while multi-lane evaluation is assumed. The algorithms may overlook the complete traffic information resulting in simultaneous cross junction in multiple lanes without collision.

5.4 In case of high traffic volume or uncertain flow, certain gaps may arise in the algorithm

Many VTL protocols in the urban environment use transport information, that is, real time road vehicle densities and traffic densities, so that disconnections along the transit route and high transport delays are avoided. Much has recently been introduced in real-time vehicle-based traffic management systems data. Some current protocols do not however explain how real-time traffic is received. Studies used accelerometers for the identification and sensing of traffic. There are some algorithm who notice this problem, but the delay in question and the expense for building infrastructure have been ignored.

5.5 Certain areas such as the security of passengers and lesser bandwidth are still needed to be worked upon

VANET are faced with several security and privacy challenges. However, faulty vehicles present a range of security and contact problems for VANETs in VTL, the entire correspondence is available, leaving VANETs more vulnerable to attacks. It ensures that the attacker will alter, capture and insert messages into VANETs and erase them. The intruder, for example, will control the signals used to direct cars along the way. The intruder will make modifications to these communications and spread incorrect information on the road causing traffic congestions, road collisions, threats, etc.

5.6 The adaptability of an algorithm according to the rush hours is a must

Many people go to work in the morning from residential areas to work place in many big cities. The effect is the trend of communication on the roads is from home to workplace when other roads are open in the opposite direction. All that is resolved in the evening, though. The reversing lane should be used as a traffic management strategy to accommodate asymmetric traffic flow in both directions on one segment of the route. This is an effective means of using current road infrastructure in full and of increasing the availability of highways. The reverse lane can help to a certain extent to reduce traffic congestion. There is need of considerable attention to be paid in traffic flow during rush hours. In practice, misuse of the adaptability of algorithm during rush hours can result in the entire road network becoming worse. Lane reversal congestion on the one side may be alleviated, but other parts of the network are more congested.

5.7 Prioritisation of lanes or vehicles needs to be considered as special cases

In any intelligent traffic management scheme, traffic light control plays an important role. The green series and the length of green light are the two primary aspects of traffic light regulation. Many traffic lights in many countries have set sequences and light lengths. Nevertheless, fixed control approaches only function for secure and normal traffic, but not for complex traffic situations. In view of the current situation, the green light sequence is established without considering the potential existence of emergency vehicles. Emergency vehicles, such as ambulances, police cars, fire engines, etc., will then wait at an intersection, as seen in Figure 1, for their arrival at their destination to be delayed causing loss of life and property.

6 Research dimensions in virtual traffic light

In this busy world, every hour we have should not be spent on traffic. Imagine a technology which will save commute time by reducing travel time by 40% or more. This dream is being fulfilled and marketed by technology developed by virtual traffic lights. There are different dimensions on which researchers have contributed in VTL. Some of them are discussed below.

6.1 Based on smart traffic system

Fernandez et al. (2016) and Cruz-Piris et al. (2018) suggested that the speed and number of vehicles be assessed by placing sensors on road sides for specific lengths. Cruz-Piris et al. (2018) aimed to optimise a sensing network by analysing the topology of the traffic network and then using the information given by this network to control the traffic lights intelligently using a MAS. After evaluating the data, they concluded that selecting the sensor positions from a central measurement map provides valuable and accurate information for ITS applications. Fernandez et al. (2016) introduced an ontological architecture designed to improve the driving environment through a network of traffic sensors. The device performs various tasks automatically to increase driver safety and comfort by means of sensor information. The design suggested is an architecture of four layers. In these papers, Nevertheless, due to the disparity between the projected vehicle speeds and the exact time of arrival at intersections the proposed sensor systems are not optimal. Ding et al. (2014) suggested providing vehicles with predictive traffic data, but this approach will not alleviate the issue of congestion. Drivers wishing to reach either destination by selecting congested roads, may simultaneously choose the same roads. De Charette and Nashashibi (2009); Premachandra et al. (2010) and Shao et al. (2019) suggested solutions for the control of traffic lighting by applying imaging techniques to identify road congestion using cameras. Nevertheless, these approaches are costly and may not be enough when weather and vision are bad.

6.2 Based on queueing theory approach

Queue theory approach uses sensors at any junction and sensors collect the queue size to measure the time of green light. Mala and Varma (2016) focused on queueing principle-based mathematical conditions and formulas. Its implementation covers several current scenarios, including congestion of traffic. The research presents real traffic flow survey at various times and locations in Bhagwanpur Muzaffarpur City Golambar intersection. The principle of queueing is used to reduce the traffic congestion that leads to Traffic Jam. This work is focused on the most widely used M / M /1 queue method. This queuing method assumes that Poisson arriving with rate μ is uniformly distributed negatively (i.e., by the Poisson process) and the customer service time with parameter μ. In this method, all customers are presumed are independent i.e., their system decision independent from other users. It suggests that the average number of customers served is the arrival and service rate ratio. The service rate of μ should always exceed the arrival rate of α for a stable system and therefore μ should always be less than one. It is therefore also known as the server use factor given by $(\rho = \lambda / \mu)$.

The average time spent on the system is equal to the total time spent on a system by the customer, offered by $(Ws = 1/(\mu - \lambda))$. The average time a customer is waiting at line ignoring service is the average time mentioned as $(Wq = \lambda / \mu \ (\mu - \lambda))$. It concluded that the arrival rate reached in comparison to the respective service rate in some of the channels leading to the intersection is close to 1.

6.3 Based on fuzzy logic approach

In fuzzy logic regulation, sensors are applied to detect the number of vehicles on each route to assess the time at the crossing for the vehicles. Pour et al. (2020) minimised queue lengths on each side of the intersection during peak hours, considering the entry and exit rates on each side of the intersection as fluctuated rates. A Weight Relative Deviation (WRD) calculation was used to equate the New Defuzsation Method (NDM) with the Centroid Point Defuzzification Method (CPDM). The output of their proposed NDM and CPDM system is evaluated with GA. As a common performance metric, they used the Weight Relative Deviation (WRD) to compare these algorithms. Their findings are Analysed using the Variance Analysis (ANOVA) test. It shows that the NDM statistically provides better outputs than CPDM in this problem. Gokulan and Srinivasan (2010) used a multi-agent distributed approach for the implementation of a traffic-responsive signal control system, namely the Geometric Fluid-induced Multi-Agent Method (GFMAS), based on a fluid-inference system of geometric form 2. GFMAS accommodates the different degrees of ambiguity present in the traffic signal controller's inputs and rules base. Simulation models of agents built in PARAMICS have been tested on a simulated street network that replicates an environment in Singapore'' central business district. The proposed GFMAS signal management met the expectations when the usual traffic flow situations were tested. The findings show the flexibility and potential for future growth of the new multi-agent architecture. Qiao et al. (2011) proposed a model in which the composition of phases is assumed to be predetermined and the phase sequence and signal time can be changed. The control cycle involves two sequential phases: green-phase selection and green-time transfer, and for both phases two fuzzy controllers have been developed: the Green-Phase Selector (GPS) and the Green-Time Adapter (GTA). In the first stage, the Traffic Urgency Degree (TUD) of all the entry lanes is calculated with GPS, based on traffic data collected, and considering the TUD, the next green phase is then selected. For the second phase, according to the traffic condition of the entry lanes of the selected phase the green time of the selected phase is calculated by GTA.

The linguistic value set is translated to a random number of every fuzzy element. They assumed x and y denote the GPS/GTA inputs and z output. $x \in \{i \mid i = 1, 2, ..., l\}$ $y \in \{j \mid j = 1, 2, ..., m\}$ $z \in \{k \mid k = 1, 2, ..., n\}$ where *l*, *m* and *n* denote the number of elements in the correct sets of linguistic value. The chromosome representing all the fuzzy rules of GPS / GTA were presented by $g1,\ g2, ...,\ gr-1,\ gr,\ gr+1, ...,\ gR$ where $gr \in \{k \mid k = 1, 2, ..., n\}$. The *r*-th fuzzy law proposed is If x = ceil(r/m) and $y = r - m \cdot (x-1)$, then $z = gr$. A simulation software was developed using Visual C++ to analyse the performance of various control models by using a series of synchronous simulations.

6.4 Based on genetic algorithm

Odeh (2013) analysed and described a strategy to install a sensor network in the intersections of different cities. Their method of graph development is based on organisational constraints and analyses the graphs in terms of local and global connectivity. The program receives data and information from a visual processing device that records and interprets photographs in which vehicles can be tracked and counted. This data is submitted to a genetic algorithm-based program. The program makes a real-time determination deciding the green light time at each intersection for each traffic signal. The genetic algorithm used in this analysis includes chromosome codification and assessment. Chromosome codification includes a vector of 16 random numbers (genes) is a candidate solution (chromosome). Every gene that fits a green traffic light period consists of a random number between 15 and 35 sec. Chromosome assessment is achieved by believing that any vehicle has an average of 3 seconds to escape the current spot. C' IM = CIM – tg / 3, where the C' IM is number of vehicles just after green signal, tg is green light time. These networks whose grade distribution fits into a gamma distribution fail to display the normal random graphs models.

6.5 Based on adaptation of virtual traffic light system

Another approach has been developed for the VTL traffic light network. Ferreira et al. (2010) introduced the first VTL algorithm for VANET. In this algorithm, vehicles traveling in the same direction are a cluster consisting of a head and a cluster member. The head of the cluster is the vehicle nearest to the crossing, and the chief of the cluster is the vehicle which is further from the crossing. The cluster leader shall pick the objectives and transmit the VTL messages. A new VTL leader is then selected when the VTL leader leaves the crossroads. The large scale simulations performed for Porto, Portugal's second largest city, provide clear proof of the feasibility and significant gain of the scheme in terms of flow rate increases. Many researchers have researched and implemented similar simulations and performance analyses since the first work was published on VTL. Viriyasitavat et al. (2013) suggested a coexisting model that would allow VTL fitted vehicles to match with VTL-free vehicles. It addresses this outstanding issue by proposing a transition model in which VTL-vehicles benefit from the VTL technology while coexisting and sharing the streets with current non-VTL vehicles. The proposed co-existence model seems very promising as it shows how judicious policy decisions by Department of Transportations of different countries could expedite the adoption of the Virtual Traffic Lights technology.

Results have shown that the proposed model could provide the drivers of vehicles strong incentives to adopt the VTL technology much faster than otherwise. Chou et al. (2013) suggested a VTL process adaptation scheme focused on the existing form of traffic and vehicles. The scheme consists of three phases: planning, management, and service. Every vehicle collects neighbouring information in the planning stage to determine the vehicle leader by receiving a beacon message with basic information on vehicles, such as position, speed, journey time and identification. The leader establishes and manages his own VTL in the management level. Throughout the operational process, the leader sends the signals to all vehicles. Münst et al. (2020) used mobile communication and cloud computing to operate a two-phase VTL program. In the first step, vehicles send their own data to the cloud data network. In the second phase, the cloud infrastructure sends suggestions to all VTL vehicles to the intersection to pass or wait. Yapp and Kornecki (2015) suggested that VTL would implement a risk management system for safety analysis. They also recommended ways to develop the VTL and provide more reliable results and provided the directions to be applied if new VTL errors occur. Bazzi et al. (2016) implemented an algorithm that determines priorities for virtual VTL road intersections. This VANET algorithm is based on IEEE 802.11p. Vehicles share location information based on broadcast messages and transmit messages for priority and traffic decision based on unicast messages. All vehicles share common road map and VTL information databases. This algorithm operates in two phases: priority definition phase and the priority definition phase. The VTL algorithm gives the vehicle priority at the intersection in the first stage. In the second point, priority vehicles offer priority to the next. This system ensures that a single vehicle moves concurrently. Whereas the VTL scheme increases vehicles' average speeds over conventional traffic lights, all VTL research papers share the design header and leader. The network is unstable depending on such a moving node. The light controller's function is reliable on the basis of a fixed node. RSU is therefore a better alternative than the traffic light controller.

7 Conclusion and future scope

Continuous population growth in the world is a significant obstacle for transport systems. The traditional approaches have become ineffective to address complex and complicated problems in the management of transport. These challenging problems need to be addressed through more economic, more efficient and thus smarter methods. Traffic control mechanism based on Vehicular Ad Hoc Networks (VANETs) are used to reduce the traffic congestion around the busy squares or highways. Owing to their wide range of applications and services such as safety, improved traffic performance and infotainment the VANETs have been studied intensively. The paper identifies a clear taxonomy of characteristics and challenges of VANET, along with mechanisms to mitigate traffic congestions. The research exhibits the advantages of using VTL in the near future over static traffic light systems. A detailed comparative analysis of various VTL systems is accomplished by research findings on VTL from 2005 to 2019. A comprehensive list of research gaps of current VTL system designs based on findings is listed so that it can be accomplished in future. Research dimensions have been categorised into smart traffic system, fuzzy logic, queueing theory and genetic algorithms.

For the future of the work, VTL designed till date can be made even more efficient by sharing dynamic information of traffic signals with pedestrians. Since of the small geographic area, VTL's are presented from a specific perspective. Next generation VTL's supporting large geographical areas is the need of future. VTL's must also organise effective multi-lane junctions. In future VTL's must work on large volumes of traffic and unpredictable flow of traffic. Some areas, such as driver's security and less bandwidth, also needs to be tackled. The adaptability of VTL during rush hour is needed to be further enhanced to mitigate congestion. The prioritisation of emergency and VIP vehicles must be addressed to make VTL beneficial for all.

To sum up there are some catastrophic effects due to the exponential rise in traffic on highways. These problems require an adaptive approach to maintain road protection and reduce road congestion. New paradigms including cloud storage and the internet are required to ensure intercommunication between road vehicles. VANETs are developed to provide reliable and productive connectivity systems for the development of creative solutions. There is need of an IP-based new architecture consisting of open threads interconnected by VANETs that exchange information to establish a network of vehicles between vehicles. This new technology will help to achieve a cleaner and greener, more cost-effective, safer and healthier world of transport (Choudhary et al., 2020).

References

Alba, E., Luna, S. and Toutouh, J. (2008) 'Accuracy and efficiency in simulating VANETs', *Proceedings of the Communications in Computer and Information Science*, Vol. 14, pp.568–578. Doi: 10.1007/978-3-540-87477-5_60.

Available online at: https://www.researchgate.net/publication/258391330_Fuzzy_Multiobjective_Traffic_Light_Signal_Optimization (accessed on 06 July 2020).

Bazzi, A., Zanella, A. and Masini, B.M. (2016) 'A distributed virtual traffic light algorithm exploiting short range V2V communications', *Ad Hoc Networks*, Vol. 49, pp.42–57. Doi: 10.1016/j.adhoc.2016.06.006.

Bhoi, S.K. and Khilar, P.M. (2014) 'Vehicular communication: a survey', *IET Networks*, Vol. 3, No. 3, pp.204–217. Doi: 10.1049/iet-net.2013.0065.

Campolo, C., Molinaro, A. and Scopigno, R. (2015) *Vehicular Ad Hoc Networks Standards, Solutions, and Research*, Springer International Publishing. Doi: 10.1007/978-3-319-15497-8.

Chin, Y.K., Yong, K.C., Bolong, N., Yang, S.S. and Teo, K.T.K. (2011) 'Multiple intersections traffic signal timing optimization with genetic algorithm', *Proceedings of the IEEE International Conference on Control System, Computing and Engineering*, pp.454–459. Doi: 10.1109/ICCSCE.2011.6190569.

Chou, L-D., Tseng, J-H. and Yang, J-Y. (2013) 'Adaptive virtual traffic light based on VANETs for mitigating congestion in Smart City', *Proceedings of the 3rd International Conference on The Society of Digital Information and Communication Technology and Its Applications*, pp.40–44.

Chou, L-D., Yang, J-Y. and Tseng, J-H. (2013) *Adaptive Virtual Traffic Light Based on VANETs for mitigating congestion in Smart City, Semantic Scholar*. Available online at: https://www.semanticscholar.org/paper/ADAPTIVE-VIRTUAL-TRAFFIC-LIGHT-BASED-ON-VANETS-FOR-Chou-Tseng/5371f80e0be0d4603103903b7d68c9c881aece64.

Choudhary, P. and Dwivedi, R.K. (2018) 'A novel framework for prioritizing emergency vehicles through queueing theory', *International Journal of Engineering and Advanced Technology (IJEAT)*, Vol. 8, No. 3, pp.661–666.

Choudhary, P., Dwivedi, R. and Singh, U. (2020) 'Open threads-enabled mesh networks in vehicles for real-time traffic monitoring', *IoT and Cloud Computing Advancements in Vehicular Ad-Hoc Networks*, Doi: 10.4018/978-1-7998-2570-8.ch006.

Choudhary, P., Dwivedi, R.K. and Singh, U. (2020) 'Estimating traffic congestion by queuing theory', *SSRN Electronic Journal*. Doi: 10.2139/ssrn.3568534.

Choudhary, P., Dwivedi, R.K. and Singh, U. (2020) 'Novel algorithm for leader election process in virtual traffic light protocol', *International Journal of Information Technology*, Vol. 12, No. 1, pp.113–117. Doi: 10.1007/s41870-019-00305-x.

Cruz-Piris, L., Rivera, D., Fernandez, S. and Marsa-Maestre, I. (2018) 'Optimized sensor network and multi-agent decision support for smart traffic light management', *Sensors*, Vol. 18, No. 2. Doi: 10.3390/s18020435.

De Charette, R. and Nashashibi, F. (2009) 'Traffic light recognition using image processing compared to learning processes', *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp.333–338. Doi: 10.1109/IROS.2009.5353941.

Ding, Y., Liu, Y.Z., Gong, X.Y. and Wang, W.D. (2014) 'Road traffic and geography topology based opportunistic routing for VANETs', *Journal of China Universities of Posts and Telecommunications*, Vol. 21, No. 4, pp.32–39. Doi: 10.1016/S1005-8885(14)60313-7.

Doolan, R. and Muntean, G.M. (2013) 'VANET-enabled eco-friendly road characteristics-aware routing for vehicular traffic', *Proceedings of the IEEE Vehicular Technology Conference*, pp.1–5. Doi: 10.1109/VTCSpring.2013.6692807.

Duan, H., Li, Z. and Zhang, Y. (2020) *Multiobjective Reinforcement Learning for Traffic Signal Control Using Vehicular Ad Hoc Network*. Available online at: https://www.researchgate.net/publication/47696378_Multiobjective_Reinforcement_Learning_for_Traffic_Signal_Control_Using_Vehicular_Ad_Hoc_Network (accessed on 07 July 2020).

Farag, W.A. (2020) 'Model-predictive-control complex-path tracking for self-driving cars', *International Journal of Modelling, Identification and Control*, Vol. 34, No. 3, pp.265–277. Doi:10.1504/IJMIC.2020.111624.

Fernandes, R. (2009) 'VANET-enabled in-vehicle traffic signs', *International Journal of Scientific Research in Computer Science, Engineering and Information Technology*, Vol. 3, No. 1.

Fernandez, S., Hadfi, R., Ito, T., Marsa-Maestre, I. and Velasco, J. (2016) 'Ontology-based architecture for intelligent transportation systems using a traffic sensor network', *Sensors*, Vol. 16, No. 8. Doi: 10.3390/s16081287.

Ferreira, M., Fernandes, R., Conceição, H., Viriyasitavat, W. and Tonguz, O. K. (2020) 'Self-organized traffic control', *Proceedings of the Annual International Conference on Mobile Computing and Networking*, pp.85–89. Doi: 10.1145/1860058.1860077.

Ferreira, M., Fernandes, R., Conceição, H., Viriyasitavat, W. and Tonguz, O.K. (2010) 'Self-organized traffic control', *Proceedings of the seventh ACM international workshop on Vehicular Inter Networking*, pp.85–90. Doi: 10.1145/1860058.1860077.

Füßler, H., Schnaufer, S., Transier, M. and Effelsberg, W. (2007) 'Vehicular ad-hoc networks: from vision to reality and back', *Proceedings of the 4th Annual Conference on Wireless on Demand Network Systems and Services*, pp.80–83. Doi: 10.1109/WONS.2007.340477.

Gershenson, C. and Rosenblueth, D.A. (2012) 'Self-organizing traffic lights at multiple-street intersections', *Complexity*, Vol. 17, No. 4, pp.23–39. Doi: 10.1002/cplx.20392.

Gokulan, B.P. and Srinivasan, D. (2010) 'Distributed geometric fuzzy multiagent urban traffic signal control', *IEEE Transactions on Intelligent Transportation Systems*, Vol. 11, No. 3, pp.714–727. Doi: 10.1109/TITS.2010.2050688.

Hagenauer, F., Baldemaier, P., Dressler, F. and Sommer, C. (2014) 'Advanced leader election for virtual traffic lights', *ZTE Communication on Special Issue VANET*, Vol. 12, No. 1, pp.11–16. Doi: 10.3969/j.issn.1673-5188.2014.01.002.

Hagenauer, F., Baldemaier, P., Dressler, F. and Sommer, C. (2014) 'Advanced leader election for virtual traffic lights', *ZTE Communications*, Vol. 12, No. 1, pp.11–16.

Ho, I.W.H., Leung, K.K., Polak, J.W. and Mangharam, R. (2007) 'Node connectivity in vehicular ad hoc networks with structured mobility', *32nd IEEE Conference on Local Computer Networks*. Available online at: https://ieeexplore.ieee.org/document/4367896 (accessed on 07 July 2020).

Hu, J., Xu, L., He, X. and Meng, W. (2017) 'Abnormal driving detection based on normalized driving behavior', *IEEE Transactions on Vehicular Technology*, Vol. 66, No. 8, pp.6645–6652. Doi: 10.1109/TVT.2017.2660497.

Jin, J., Ma, X. and Kosonen, I. (2017) 'An intelligent control system for traffic lights with simulation-based evaluation', *Control Engineering Practice*, Vol. 58, pp.24–33. Doi: 10.1016/j.conengprac.2016.09.009.

Kshirsagar, N. and Sutar, U.S. (2015) 'An intelligent traffic management and accident prevention system based on VANET', *International Journal of Science and Research*, Vol. 4, pp. 2319–7064. Doi: 10.1109/TLA.2015.7040664.

Ku, I., Lu, Y., Gerla, M., Gomes, R.L., Ongaro, F. and Cerqueira, E. (2014) 'Towards software-defined VANET: architecture and services', *Proceedings of the 13th Annual Mediterranean Ad Hoc Networking Workshop*, pp.103–110. Doi: 10.1109/MedHocNet.2014.6849111.

Kuo, Y.W., Chang, Y.J., Tseng, C.W., Der Chou, L. and Shen, T.Y. (2017) 'Green wave-based virtual traffic light management scheme with VANETs', *International Journal of Ad Hoc Ubiquitous Computing*, Vol. 24, Nos. 1/2, pp.22–32. Doi: 10.1504/ijahuc.2017.10001718.

Mala and Varma, S.P. (2016) 'Minimization of traffic congestion by using queueing theory', *IOSR Journal of Mathematics*, Vol. 12, No. 1, pp.116–122. Doi: 10.9790/5728-1212116122.

Martins, V. et al. (2019) 'Towards personal virtual traffic lights', *Information*, Vol. 10, No. 1. Doi: 10.3390/INFO10010032.

Mohamed, S.A.E. (2013) 'Smart street lighting control and monitoring system for electrical power saving by using VANET', *International Journal of Communications, Network and System Sciences*, Vol. 06, No. 08, pp.351–360. Doi: 10.4236/ijcns.2013.68038.

Münst, W., Dannheim C., Mäder, M. and Gay, N. (2020) 'Virtual traffic lights: managing intersections in the cloud', *Proceedings of the 7th International Workshop on Reliable Networks Design and Modeling (RNDM)*, IEEE, Germany. Available online at: https://ieeexplore.ieee.org/document/7325248 (accessed on 07 July 2020).

Nantulya, V.M. and Reich, M.R. (2002) 'The neglected epidemic: road traffic injuries in developing countries', *British Medical Journal*, Vol. 324, No. 7346. pp.1139–1141. Doi: 10.1136/bmj.324.7346.1139.

Nellore, K. and Hancke, G.P. (2016) 'Traffic management for emergency vehicle priority based on visual sensing', *Sensors*, Vol. 16, No. 11. Doi: 10.3390/s16111892.

Nidhi, N. and Lobiyal, D.K. (2012) 'Performance evaluation of realistic VANET using traffic light scenario', *International Journal of Wireless and Mobile Networks*, Vol. 4, No. 1, pp.237–249. Doi: 10.5121/ijwmn.2012.4118.

Odeh, S.M. (2013) 'Management of an intelligent traffic light system by using genetic algorithm', *Journal of Image and Graphics*, Vol.1, No. 2, pp.90–93. Doi: 10.12720/joig.1.2.90-93.

Pandit, K., Ghosal, D., Zhang, H.M. and Chuah, C.N. (2013) 'Adaptive traffic signal control with vehicular ad hoc networks', *IEEE Transactions on Vehicular Technology*, Vol. 62, No. 4, pp.1459–1471. Doi: 10.1109/TVT.2013.2241460.

Parul, C. and Umang (2015) 'A literature review on vehicular ad hoc network for intelligent transport', *Proceedings of the 2nd International Conference on Computing for Sustainable Global Development (INDIACom)*, IEEE, New Delhi, India.

Penna, K., Yalavarthi, V., Fu, H. and Zhu, Y. (2014) 'Evaluation of active position detection in vehicular ad hoc networks', *International Joint Conference on Neural Networks (IJCNN)*, IEEE, China. Available online at: https://ieeexplore.ieee.org/document/6889978 (accessed on 07 July 2020).

Penna, K., Yalavarthi, V., Fu, H. and Zhu, Y. (2014) 'Evaluation of active position detection in vehicular ad hoc networks', *Proceedings of the International Joint Conference on Neural Networks*, pp.2234–2239. Doi: 10.1109/IJCNN.2014.6889978.

Pour, N.S., Asadi, H. and Kheradmand, M.P. (2020) 'Fuzzy multiobjective traffic light signal optimization', *Journal of Applied Mathematics*, pp.1–7.

Premachandra, H.C.N. et al. (2010) 'High-speed-camera image processing based LED traffic light detection for road-to-vehicle visible light communication', *Proceedings of the IEEE Intelligent Vehicles Symposium*, pp.793–798. Doi: 10.1109/IVS.2010.5548097.

Qiao, J., Yang, N. and Gao, J. (2011) 'Two-stage fuzzy logic controller for signalized intersection', *IEEE Transactions on Systems, Man, and Cybernetics: Part A Systems and Humans*, Vol. 41, No. 1, pp.178–184. Doi: 10.1109/TSMCA.2010.2052606.

Rao, R.S., Jain, V., Kaiwartya, O and Singh, N. (2020) *IoT and Cloud Computing Advancements in Vehicular Ad-Hoc Networks*, Computer Science & IT Books | IGI Global, IGI Global Publisher of Timely Knowledge. Available online at: https://www.igi-global.com/book/iot-cloud-computing-advancements-vehicular/237005 (accessed on 14 August 2020).

Raw, R.S., Kumar, M. and Singh, N. (2019) 'Security challenges, issues and their solutions for vanet', *International Journal of Network Security and Its Applications*, Vol. 5, No. 5. Doi: 10.5121/ijnsa.2013.5508.

Santa, J., Gómez-Skarmeta, A.F. and Sánchez-Artigas, M. (2008) 'Architecture and evaluation of a unified V2V and V2I communication system based on cellular networks', *Computer on Communications*, Vol. 31, No. 12, pp.2850–2861. Doi: 10.1016/j.comcom.2007.12.008.

Shao, K., Zheng, J. and Huang, K. (2019) 'Robust active steering control for vehicle rollover prevention', *International Journal of Modelling, Identification and Control*, Vol. 32, pp.70. Doi: 10.1504/IJMIC.2019.101956.

Sharma, S., Pithora, A., Gupta, G., Goel, M. and Sinha, M. (2013) 'Traffic light priority control for emergency vehicle using RFID', *International Journal of Innovations in Engineering and Technology*, Vol. 2, No. 2, pp.363–366.

Shinde, P.G. and Dongre, M.M. (2017) *Traffic congestion detection with complex event processing in VANET*, IEEE Conference Publication. Available online at: https://ieeexplore.ieee.org/document/8065852 (accessed on 07 July 2020).

Tonguz, O., Wisitpongphan, N., Bai, F., Mudalige, P. and Sadekar, V. (2007) 'Broadcasting in VANET', *Mobile Networking for Vehicular Environments*, pp.7–12. Doi: 10.1109/MOVE.2007.4300825.

Umang and Choudhary, P. (2018) 'Analyzing virtual traffic light using state machine in vehicular ad hoc network', *Proceedings of the Advances in Intelligent Systems and Computing*, Vol. 638, pp.239–245. Doi: 10.1007/978-981-10-6005-2_25.

Umang, S., Reddy, B.V.R. and Hoda M.N. (2010) 'Enhanced intrusion detection system for malicious node detection in ad hoc routing protocol using minimal energy consumption', *Communications IET*, Vol. 4, pp.2084–2094. Doi: 10.1049/iet-com.2009.0616.

Viriyasitavat, W., Roldan, J.M. and Tonguz, O.K. (2013) 'Accelerating the adoption of virtual traffic lights through policy decisions', *Proceedings of the International Conference on Connected Vehicles and Expo*, pp.443–444. Doi: 10.1109/ICCVE.2013.6799833.

WHO (2013) *WHO | Global status report on road safety 2013*. Available online at: https://www.who.int/violence_injury_prevention/road_safety_status/2013/en/ (accessed on 27 July 2020).

Yapp, J. and Kornecki, A.J. (2015) 'Safety analysis of virtual traffic lights', *Proceedings of the 20th International Conference on Methods and Models in Automation and Robotics*, pp.505–510. Doi: 10.1109/MMAR.2015.7283927.

Yousefi, S., Mousavi, M.S. and Fathy, M. (2006) 'Vehicular ad hoc networks (VANETs): challenges and perspectives', *Proceedings of the 6th International Conference on ITS Telecommunications*, pp.761–766. Doi: 10.1109/ITST.2006.289012.

Zhang, R. et al. (2018) 'Virtual traffic lights: system design and implementation', *IEEE Vehicular Technology Conference*, pp.1–5. Doi: 10.1109/VTCFall.2018.8690709.

Zhou, B., Cao, J., Zeng, X. and Wu, H. (2010) 'Adaptive traffic light control in wireless sensor network-based intelligent transportation system', *IEEE Vehicular Technology Conference*, pp.1–5. Doi: 10.1109/VETECF.2010.5594435.