



# SURVEY ON VANET TECHNOLOGIES AND SIMULATION MODELS

Yusor Rafid Bahar Al-Mayouf<sup>1</sup>, Mahamod Ismail<sup>1</sup>, Nor Fadzilah Abdullah<sup>1</sup>, Salih M. Al-Qaraawi<sup>2</sup>  
and Omar Adil Mahdi<sup>3</sup>

<sup>1</sup>Department of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia

<sup>2</sup>Department of Computer Engineering, University of Technology, Baghdad, Iraq

<sup>3</sup>Department of Computer System and Technology, Faculty of Computer Science and Information Technology Building, University of Malaya, Kuala Lumpur, Malaysia

E-Mail: [engineer\\_mu2007@yahoo.com](mailto:engineer_mu2007@yahoo.com)

## ABSTRACT

Vehicular ad hoc network (VANET) is a distinctive form of Mobile Ad hoc Network (MANET) that has attracted increasing research attention recently. The purpose of this study is to comprehensively investigate the elements constituting a VANET system and to address several challenges that have to be overcome to enable a reliable wireless communications within a vehicular environment. Furthermore, the study undertakes a survey of the taxonomy of existing VANET routing protocols, with particular emphasis on the strengths and limitations of these protocols in order to help solve VANET routing issues. Moreover, as mobile users demand constant network access regardless of their location, this study seeks to evaluate various mobility models for vehicular networks. A comparison of IEEE 802.11p and Long-Term Evolution (LTE) technologies for several applications in the vehicular networking field is also carried out in the study. One key component in the VANET structure that this study intends to draw special attention is the warning structure consisting of Intelligent Traffic Lights (ITLs), which is designed to inform drivers regarding the existing traffic situation, thus enabling them to make appropriate decisions. Last but not least, the VANET simulation tools for data collection are also evaluated.

**Keywords:** vehicular ad hoc network, routing protocols, mobility models, IEEE 802.11p, LTE, intelligent traffic lights.

## 1. INTRODUCTION

Road safety and vehicle flow management significantly depends on driver awareness of aspects pertaining to traffic and road conditions. To this end, drivers must be provided with precise and up-to-date information. One solution to this is the Vehicular Ad hoc Network (VANET), which is presented in Figure-1 [1, 2]. Inter-vehicle and vehicle-to-roadside communication technologies accumulate all data associated with road traffic mobility including traffic density, speed, direction of vehicles, and weather conditions, with the purpose of regulating road traffic and preventing accidents. In addition, such data are relevant for roadside base station assistance to keep drivers well-informed of the traffic situation as well as for establishing a link between the vehicle-to-vehicle network and an external setup in such a way that various developing wireless technologies like 3G cellular systems, LTE, LTE-Advance (LTE-A), IEEE 802.11p and IEEE 802.16e can be integrated [3, 4]. The incorporation of advanced wireless networks into vehicles is facilitated by the innovative VANET technology, which allows drivers to connect with other users via home-based or office-based networks. This is thanks to mobile connectivity, which also activates the Intelligent Transportation System (ITS) by securing efficient wireless connection among vehicles with no need for fixed infrastructure access. Due to this characteristic, VANET is also referred as Inter-Vehicle Communication (IVC). VANET devices usually take the form of On-Board Units (OBUs), which serve as nodes for information transmission and reception via wireless networks. The access to timely information regarding road incidents, flooding, traffic jams, disruptions and weather conditions

enables drivers to decide, which routes are best to take. From the perspective of the autonomous, self-control, low bandwidth and shared radio transmission settings, VANET shares similarities with the operational technology of a Mobile Ad hoc Network (MANET). The main difference between the two types of networks is that unlike MANET the mobile nodes i.e. moving vehicles exhibit high mobility along the paths and constitute an obstacle to the operation of VANET. Hence, to ensure compatibility with the rapid mobility of VANET nodes, the MANET architecture must be revised to develop an efficient routing protocol.

The objective from present study is significant with regards to the opportunities and challenges found in a VANET system as provide in Fig. 2. Realistic scenarios in a simulation can be achieved with the help of mobility models, which enable vehicles to change direction, accelerate and decelerate in the simulation environment. The significance of the routing protocol is due to the fact that it is geared towards identifying the optimal route to various Road Side Units (RSUs) on the road. Vehicles attain channel access through the implementation of the routing protocol. At intersections, especially in situations of high congestion, drivers must make a decision to take the shortest path to reach a destination. In addition to enabling drivers to make appropriate decisions in traffic congestion, intelligent traffic systems contribute to road accident prevention as well.

The main contribution of this study is summarized below:

- a) A comprehensive survey of the topical research development of opportunities and challenges in VANET system.



- b) Vehicular mobility approaches are illustrated by classifying them in terms of mobility modelling, strengths and weaknesses.
- c) Categorizes routine protocols according to the mechanism of VANETs, especially Vehicle-to-Vehicle (V2V) protocols. In addition, a comparison of the protocols revealed that topology and geographic based routing in terms of their strategies, strengths, and weaknesses.
- d) To efficient and reliable communication between vehicles and transport infrastructure, Comparison between IEEE 802.11p and LTE are provided as VANETs access technologies.
- e) To evaluate the performance of routing protocols in VANET, We focus on development of simulation tools and provide a comparison between them in terms of language used, weaknesses and strengths.

This paper is divided into seven sections. In Section 2, the obstacles and challenges confronted by the VANET technology are outlined. The opportunities of VANETs in terms of utilising an intelligent traffic light system is addressed in Section 3, while Section 4 reviewed the most commonly used mobility models in VANET. In Section 5, an overview and comparison of VANET routing protocols are provided, while Section 6 focused on the IEEE 802.11p and LTE standards for use as a VANET access technology. In Section 7, the VANET evaluation tools are described. Finally, Section 8 concludes the study.

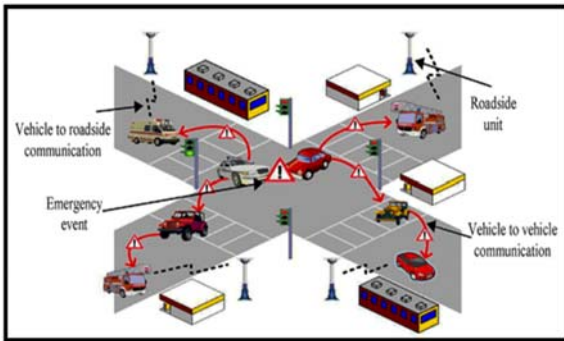


Figure-1. Vehicular ad hoc network [5].

1	2	3	4	5
• Intelligent Traffic Light System	• Mobility Model	• Routing Protocol	• Access Technology	• Evaluation

Figure-2. Opportunities surrounding a VANET system.

## 2. CHALLENGES OF A VANET SYSTEM

VANETs are composed of vehicles that are designed to serve as portable nodes and routers for other nodes. VANETs and ad hoc networks are confronted with unique challenges, which affect communication system design and routing protocols [6-9]. Some of the challenges are listed below [10]:

- Highly dynamic network. VANET topologies exhibit variation according to vehicle speed.
- Unstable connectivity. Due to high mobility of vehicles, VANETs experience frequent disconnections. The link is highly expected to be disconnected especially in low-density vehicles. This is a major problem particularly in applications which necessitate ubiquitous Internet access. One probable approach to prevent connectivity disruption is employing various relaying nodes or access spots along the roadside.
- Mobility design and predication. These two elements are essential in the design of VANET network protocol due to the high mobility and vigorously changing topology that characterize this system. Speed and street map can be used to predict future vehicle positions, since pre-established highways, roads, and streets impose restrictions on vehicular nodes.
- Various communication environments. The city environment and the highway environment are the two communication environments in which VANETs are used, being characterized by greater and lesser complexity with regard to traffic conditions. In the city environment, a clear line of sight between the transmitting and receiving nodes cannot be achieved due to wide range of existing obstacles.
- Low latency requirement. In several VANET applications, hard delay bounds are required, despite of not necessitating high data rates.
- Interaction with on-board sensors. Communication links and routing are mediated by the information supplied by on-board sensors with which the nodes are usually equipped. At present, location data for routing are derived from Global Positioning System (GPS) devices which most vehicles possess.
- Infrastructure access. Internet network servers are accessed via communication set-up by roadside consisting of Road Side Units (RSUs) and public hotspots. However, these do not supply complete



wireless coverage and therefore infrastructure is sometimes unavailable for security mechanisms like the use of centralized architecture for the management and distribution of cryptographic keys.

- High application requirements on data delivery. Due to their extreme importance for road accident prevention and safety guarantee, VANET applications are associated with high real-time functionality and reliability requirements. Safety information may become irrelevant due to end-to-end delay of mere seconds, while loss of messages as a result of various factors, including security attacks, may put human lives at risk. VANET applications are characterized by the fact that they are based on a broadcast distribution of data, with the nodes situated in a specific geographic area being considered the destination nodes.
- No confidentiality on safety information. One feature of safety applications is that the information within a message is not confidential as it concerns all road users.

### 3. INTELLIGENT TRAFFIC LIGHT SYSTEMS

In the majority of countries, the main urban centres are confronted with an unprecedented growth in road traffic volume, which reduces the quality of city population due to the associated traffic congestions, accidents and air pollution. This increased volume of road incidents called for the urgent implementation of intelligent road traffic information systems to reduce not only traffic congestions, but also travel time and pollutants emitted by vehicles through the effective monitoring and control of vehicle movements [11, 12]. The VANET system is capable of collecting a range of different road traffic information, including traffic volume, destination/routes, and types of vehicles. It also facilitates short-range communication between vehicles using equipment known as On Board Units (OBUs), and roadside information or communication infrastructure, known as Road Side Units (RSUs). The latter cannot reach all the interested vehicles in an area based on a single hop communication; therefore, multi-hop, inter-vehicle communications are required. The efficiency of data dissemination depends on maintaining the number of forwarding vehicles and vehicles that are not covered to a manageable level. With regard to this, a variety of techniques and approaches have been put forth. The concept underlying the current system design is presented in Fig. 3. RSU is responsible for downlink broadcasting of the information related to signaling and road traffic periodically. In return, the OBU transmits vehicle information, including vehicle ID, type, and destination/route on the uplink. This information is relayed by the RSU to the traffic analysis server in charge of controlling the traffic signal parameters. In the case of a

traffic control system covering a broad area, a backbone network links the RSUs so that they can share traffic information [13].

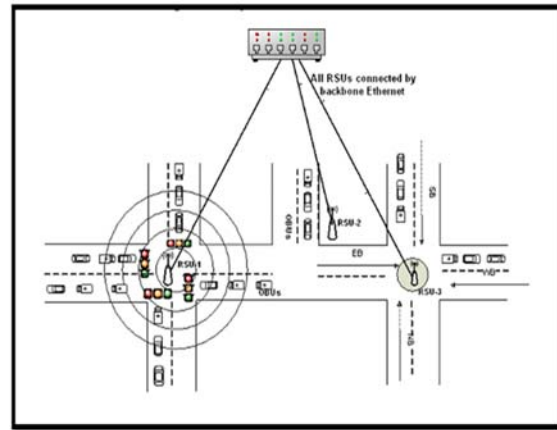


Figure-3. Road network [13].

In recent times, innovative concepts have emerged, with vehicular networks taking centre stage. Intelligent traffic management is an important component of smart cities, which is characterized by the open accessibility of data from Traffic Information Centre (TIC) infrastructures. Furthermore, an aspect of particular significance in a smart city is designing a cautioning system consisting of Intelligent Traffic Lights (ITLs) to inform drivers about number of vehicles and environmental conditions. To enable vehicles to choose a congestion-free path, ITLs gather traffic information, such as traffic density from the moving vehicles, update traffic statistics and transmit the statistics to the vehicles. Moreover, to prevent additional collisions, ITLs send warning messages to vehicles when an accident occurs. ITLs have been the focus of numerous proposals recently. A VANET smart city framework proposal was addressed in [14].

The smart city framework comprises of ITLs set at certain crossroads, where they gather real-time information related to the traffic from mobile vehicles and estimate traffic stats, including number of vehicles in adjoining streets (among successive crossroads). Traffic information is simultaneously shared by the ITLs to the moving vehicles so as to give them prior warning about any accidents that may have occurred. The ability of ITLs to collect information and compute statistics of an entire city arises from the sub-network that they form. In this way, the traffic situation is brought to the attention of the vehicles. Featuring a standard square design, blocks have buildings on each of their four sides. Although they are in charge of managing vehicle traffic, the ITLs do not need to be positioned at every juncture, replacing only a handful of all the traffic lights in a city. As illustrated in Figure-4, ITLs are placed in such a way that they cover an entire intersection and the four streets meeting at that intersection. This is made possible by the omnidirectional propagation pattern employed as the antenna pattern.



Hence, every ITL receives data from the vehicles that move through its cover range. The general assumption is that vehicles possess a Global Positioning System (GPS) device, a helping device for the driver, and complete city map data alongside ITL position, which should help them to identify where the closest ITL is. The procedure of receiving and transmitting traffic statistics between vehicles and ITLs is illustrated in Fig.5. Vehicles are informed about how many other vehicles are there in their transmission range through the exchange of Hello Messages (HM) with their neighbors. Subsequently, the vehicle transmits a Statistic Message (SM) to the closest ITL with information regarding the amount of neighbors. Figure-5 shows how ITL1 uses the SMs received to refresh the statistics about traffic density by averaging current and historical values with an Exponential Weighted Moving Average (EWMA). The results are adequately stored by ITL1, which via the ITL subnetwork, shares them with the other ITLs in the city. After dissemination of traffic information among themselves, the ITLs send back a message to moving vehicles about the updated traffic statistics for a particular period of time. The driver assistant device uses this information to make appropriate trip decisions to avoid congested roads. Furthermore, the information disseminated by the ITLs is also employed by data routing protocols to make forwarding decisions, such as forwarding a packet via streets with higher density where a greater number of forwarding nodes are concentrated.

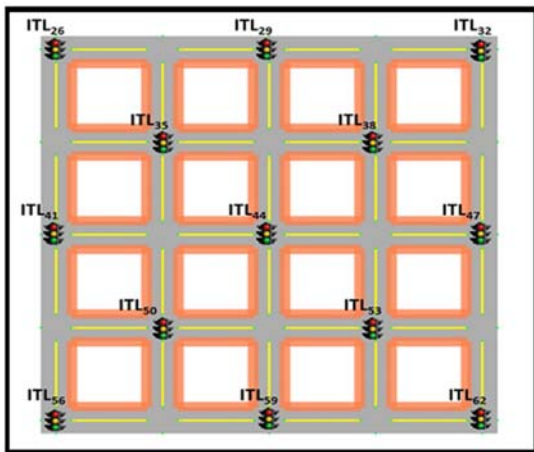


Figure-4. ITL distribution [14].

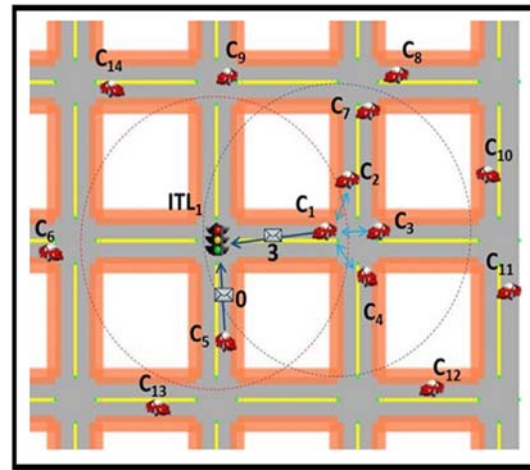


Figure-5. ITL statistics in its intersection [14].

#### 4. MOBILITY MODELS

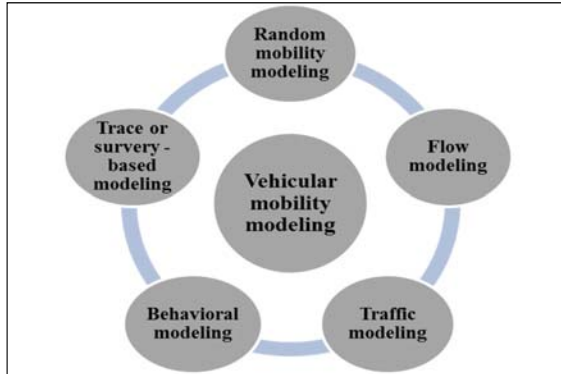
A range of mobility models on vehicular networks are examined in this part. The accelerated and ongoing pace at which wireless networks have been transformed throughout the world is the outcome of many different factors. Given that mobile users constantly demand access remotely, regardless of their location, one important driving factor for mobile networks is mobility. To be considered realistic, a mobility model must contain [15]:

- Total number and respective directions of lanes. Network connectivity is directly influenced by these parameters, as far as protocol operations are concerned. The type of road (e.g. rural road, urban road, city road, or highway), which the vehicles are transiting, determines the traffic pattern. Vehicle acceleration and deceleration are important parameters as well.
- Obstacles. Mobility and wireless communication obstacles must be considered by the mobility model.
- Traffic and weather conditions. Traffic density varies according to time of day. Peak time, including rush hours, weekends, holidays or special events, as well as adverse climatic conditions and unforeseen happenings, is usually associated with heterogeneous traffic density.
- Drivers behavior. Ongoing interaction occurs between drivers and both static and dynamic obstacles including other vehicles and people on foot in the surrounding environment. Hence, the mobility model should be capable of controlling vehicle interactions, including overtaking, traffic jam, preferred paths as well as precautionary measures in situations involving pedestrians.





Vehicular mobility modelling approaches are illustrated in Figure-6, while the ordered classification of mobility modelling, strengths and weaknesses are presented in Table-1.



**Figure-6.** Vehicular mobility modeling approaches [1].

#### 4.1 Random models

The modelling of random mobility patterns for applications in the fields of computer science or telecommunications relies primarily on random models. The straightforward installation of these models and their stochastic properties, which facilitate analytical studies and result reproducibility, are the reason behind their popularity. With the increasing number of applications, accurate mobility patterns are being simulated by models, although they continue to maintain the stochastic nature of random models. However, endeavors to make these models more realistic have proved futile, as they remain unsuitable for modelling vehicular mobility for VANET applications. Both vehicular mobility and mobility parameters like speed, heading and destination are classified as random. Furthermore, the restricted interaction among vehicles is a major limitation of random models.

#### 4.2 Flow models

The necessity for more comprehensive modelling details made simplistic random patterns insufficient in the field of civil and traffic engineering, computer science and telecommunications. This was due to the fact that the former field must consider physical contact amid vehicles as well as the vehicles' interaction with their environment. Considering natural processes, this issue was approached by engineers through the modelling of vehicular mobility as flows. Strengthened by flow theory, flow models are capable of applying single and multi-lane mobility patterns. There are three types of flow models, respectively focusing on microscopic, macroscopic and mesoscopic modelling.

#### 4.3 Traffic models

These models are based on a fine-grained approach that efficiently models how dynamics of the driving are affected by the surrounding vicinity of a vehicle. Vehicular traffic is greatly affected by far-

reaching and coarse-grained traffic effects. Unlike other models, which do not specify actions to be taken at or following intersections, intersection strategies such as green and red traffic lights, turning mechanism including stochastic and pre-computed turns, as well as the global path that a vehicle follows can be modelled by traffic models. The trip and path, which are determined by the parameter of time, are the two interrelated motion patterns into which traffic models can be differentiated.

#### 4.4 Behavioral models

Modelling detailed human behaviors is a complex undertaking, from which the main weakness of the majority of synthetic models arises. It is impossible to make drivers adopt a specific behavior every time, since they are not robots but human beings. The behavioral theory maintains that, aside from the stimulus-response pattern, actions may arise due to societal and physical stimuluses as well as artificial intelligence via a learning procedure. With regard to vehicular traffic, one strong attraction force is represented by the target destination. Repulsion forces will emerge as a result of any obstacle or vehicle located in-between. To attain a directional movement vector, this approach condenses the effect of all attraction or repulsion forces. However, forces change due to vehicular movements, and therefore this calculation must be done at every time step, incurring considerable computational costs, which is the main limitation of this approach. Behavioral theory makes the observation that there is a correlation between factors describing general VANET applications or specific vehicular mobility and human behaviors, which is why it has attracted so much attention. Thus, for VANET applications to be successful, these behaviors must be modelled accurately. This means that rather than relying on pre-established rules, the models should mimic human behaviors like social aspects and vigorous learning or follow AI models in order to become accustomed to any specific scenario in a dynamic manner.

#### 4.5 Trace or Survey models

Motion patterns have been realistically modelled only by a handful of synthetic and highly complicated models due to the complexities involved in vehicular mobility. Another approach could also be adopted. Direct extraction of generic mobility patterns from movement traces could save crucial time, by contrast to the creation of complex models followed by the use of mobility traces or surveys to calibrate them. Extrapolating patterns that are not observed directly by traces is the main challenge of such an approach. However, to some extent, the mobility patterns not observed in the traces may be predicted with the help of complex mathematical models. In many cases, this drawback is linked to measurement campaign type. The insufficient availability of vehicular traces is also a hindrance to the creation of trace-based vehicular mobility models. Other uses of mobility traces include extraction of motion patterns and creation or calibration of mobility models. Moreover, surveys of human behaviors constitute a source of mobility information as well.

**Table-1.** Classification of mobility modeling [16-25].

Model	Mobility modeling	Weaknesses	Strengths
Random Waypoint	Random	Fails to simulate a real mobility scenario Limitation of velocity decay	Simplicity Extensively available
Manhattan	Random	Confines the operation of vehicles to urban grids Unrealistic	Changing lanes is permitted when traversing crossroads
Cellular Automata	Flow	Incidental or unnecessary changes in speed and their impact on the flow of traffic are not taken into account	Intricacy in computation is decreased
Lighthill-Whitham-Richard	Flow	A major hindrance to the modelling of vehicular use in towns and cities	Streamlined computational intricacy resulting in the capacity for extensive modelling of traffic
Car Following	Flow	The distant view of the flow of traffic is not taken into account Scenarios in which relative velocity is zero at small spacing are not taken into account Differences between scenarios of high risk and those of comparable starting speed and spacing are not taken into account	Oversee vehicular operation in order to minimize incidents
Queue	Flow	Traffic jams Longer journey time	The capacity to simulate convoluted junctions and extremely extensive urban areas
Agent-Centric	Traffic	Fiscal burden of computation	Capacity to instantly simulate the effects of a traffic incident
Flow-Centric	Traffic	Inability to manage the behavior of a specific vehicle in a given traffic scenario Overly difficult to identify other routes	Scalability
Multi-Agent	Behavioral	Transport strategy affected by levels of congestion	Ability to model both public and private travel on actual local routes with a significant degree of accuracy
UDel	Trace	Given that mobility and radio propagation traces are individually created, this is classed as isolated	Realistically Extensive grids of vehicles Capacity to simulate road use during the day along with vehicular motion

## 5. ROUTING PROTOCOLS

Provision of optimal paths among network nodes through maximization of throughput, minimization of packet loss and regulation of overhead is the primary aim of routing protocol. VANET is characterized by a highly vibrant topology, enormous and inconstant network size, rapid mobility, ad-hoc and distributed communication [26, 27]. To ensure compatibility with various VANET environments, such characteristics demand efficient routing and VANET protocols that are resource-effective. In the present part, a survey of VANET routing mechanisms is conducted, with emphasis on the various VANET routing schemes and classifications of VANET routing protocols, especially Vehicle-to-Vehicle (V2V) routing protocols.

The main VANET routing protocols are categorized as follows:

- Characteristics and techniques: Topology, Position, Geo-cast and Cluster
- Network organization: Hierarchical, Flat and Position
- Strategies: Proactive, Reactive and Hybrid
- Information packet forwarding: Geographic and Topology
- Quality of services: Network topology, Route discovery and MAC layer interaction

- Communication type: Unicast, Broadcast and Multicast

One particular classification that is typically used as comparison is the routing information employed in packet forwarding, which focuses primarily on routing based on topology and geographic. These classification will be linked to the different categories stated above based on the different types of schemes are compared in terms of their strategies used, strengths and weaknesses, as shown in Table-2 [28-31].

### 5.1 Topology-based routing protocol

This protocol is conventionally used in MANETs and maintains routing tables which contain link information. Depending on this information, the decision of transmitting information from source node to destination node is made. Proactive, reactive and hybrid are the three kinds of topology-based routing protocols [32, 33].

#### 5.1.1 Reactive routing protocols

Regularly renew the routing table and search routing paths only when necessary, which is why they are identified as “on-demand” routing protocols. A route discovery operation is initiated to discover routes to the destination. If a route is detected or confirmation regarding unavailability of route is received, this process terminates after exploring possible route permutations. The network overhead is diminished by maintaining routes solely when



required. The source node floods a route request message by initiating a route discovery process if path to a destination is unavailable and required. In response to this route request message, any node that has route available for reaching the destination or the destination node itself unicasts route reply message to the source node [34]. The main application of reactive routing protocols is large-size mobile ad hoc networks characterized by high mobility and frequent topology changes [35]. Reactive routing protocols tend to actively maintain routes, since node mobility may cause existing routes to become disconnected. Compared to other routing protocols, reactive routing protocols possess more effective scalability. On the other hand, due to route searching, source nodes in reactive routing protocols forward data packets only after protracted delays. Table 2 presents examples of reactive routing protocols [36-42].

### 5.1.2 Proactive or “Table-Driven” routing protocols

Permit a network node to store routes information for every other node by maintaining a routing table which stores next hop node IDs against every table entry through which destination node can be reached, irrespective of the necessity for the route. In order to reflect network topology changes, the table should be updated frequently as well as broadcasted periodically to neighbors. Increased overhead is a likely outcome of this scheme, particularly in a network of high mobility. Nevertheless, routes to destinations are invariably available if required [26]. Route selection is typically undertaken by proactive protocols based on shortest path algorithms via two routing approaches, namely, link state strategy and distance vector strategy. Table 2 presents examples of proactive routing protocols [31, 33, 38, 43-45]. These types of protocols have predetermined routes to destination, and thus do not need to discover routes. Additionally, proactive protocols have a good performance in low mobility networks because they periodically update routing information. By contrast to reactive routing protocols, however, proactive protocols have a lower performance in high mobility and density networks. Available bandwidth consumption and network overhead increase due to unused routes is another limitation of proactive protocols [27].

### 5.1.3 Hybrid routing protocols

Consisting of proactive and reactive routing characteristics, hybrid routing protocols are intended to lessen control overhead of proactive protocols and meet delay bounds by eliminating route discovery phase of on-demand routing protocols. To reliably discover and maintain routes, the network is broken down into multiple regions by the hybrid protocols. Furthermore, the network is separated into inside and outside regions by every node; routes to inside region nodes are maintained through a proactive routing mechanism, while the outside region nodes are reached via a route discovery mechanism [32]. Table 2 presents instances of hybrid routing protocols [34, 46]. What sets this type of protocol aside from pure proactive and pure reactive protocols is a higher

scalability, which is the result of cooperation between network nodes, with the most suitable nodes being chosen to setup a route, thus lowering the number of rebroadcast messages.

## 5.2 Geographic-based or “Position” routing protocols

These protocols make use of position information in the routing procedure, whereby the source employs its geographic position instead of the network address to send a packet to the destination. In this protocol, all nodes depend on the Geographic Position System (GPS) to detect not only their location but also the location of their neighbors, identifying the latter as nodes located inside their radio range. The source stores the destination position within the packet header so that it does not need to discover or maintain routes or know about network topology when the need to send a packet arises. Instead, the packet can be directly sent to the destination [26, 32]. Consequently, by comparison to topology-based routing protocols, geographic-based routing protocols are more steady and appropriate for VANET because of highly mobile scenario. Delay Tolerant Network (DTN) protocols, Non-Delay Tolerant Network protocols (Non-DTN) and hybrid protocols are the three kinds of existing position-based routing protocols.

### 5.2.1 Delay tolerant network protocols

Protocols can be the best routing approach to be used in large-scale networks that exhibit recurrent disconnections and link failures, unavoidable and prolonged delays, limited bandwidth, power and battery limitations, and extensive bit fault rates [28]. The network applies the store and forward scheme, whereby nodes collaborate with one another to forward packets. However, due to the fact that the transmission range of the nodes is restricted, packets' transmission is associated with extensive delays. As a mobile node, the DTN node forms routes to other nodes when the latter are within its transmission range. Another feature of the DTN protocol is that packets are likely to be stored for a certain duration at intermediate nodes because uninterrupted end-to-end connectivity is not certain [44, 46]. Given these considerations of DTN network, the development of a routing approach is quite challenging. In the following part, several DTN routing protocols are discussed [28, 46, 47].

### 5.2.2 Non delay tolerant network protocols

This class of protocols represent geographic routing approaches which are compatible solely with high density networks, because they disregard a disconnectivity problem and instead presume the existence of sufficient nodes to accomplish successful communication. The scheme underpinning these protocols involves packet forwarding by a node to the nearest neighbor of the destination. This presents an obvious problem, as the absence of neighbor closest to the destination will make the approach unsuccessful. Examples of Non-DTN protocols are presented in [27, 48].



### 5.2.3 Hybrid position - based routing protocols

This class of protocols is capable of lowering routing overhead and they do not need to construct or maintain a routing table. Furthermore, these protocols display scalability as they employ only location information regarding neighbors and destination nodes. Nevertheless, there are a number of drawbacks that limit the use of position routing protocols, as follows [49]: A key factor dictating how well position routing performs is accurate location information, and therefore location accuracy can be said to determine the performance of position routing. If no neighbor node is present in the

proximity of the destination, position routing may fail. The backup process is the solution applied by position routing to the absence of a neighbor nearest to the destination. However, to cover extensive distances to the destinations, this process necessitates packets, which could also be used to move in a bounded circular region or else they might get dropped. Examples of hybrid protocols are given in [49, 50].

In Table-3, topology-based as well as position routing protocol are compared for strengths, weaknesses and approaches employed.

**Table-2.** Comparison of VANETs routing protocols.

Routing Protocol	Route computation	Routing type	Strategies	Weaknesses	Strengths
AODV	Reactive-Topology	Unicast	Destination	Reduced the packet delivery ratio Significant delays Greater network overhead	Ease of use Less requirement for memory Real-time feedback for modulating road conditions and reduction of route looping Significant dynamic network topology, and extensive network coverage
DSR	Reactive-Topology	Unicast	Source and routing of information caching	Reduced packet delivery ratio Reduced mobility Greater degree of traffic overhead	High level of responsiveness to frequent variations in network
TORA	Reactive-Topology	Unicast	Link reversal	In particular for extensively dynamic VANETs, overhead routing applies	Capability for each network node to have a route Broadcast of control message is decreased
DSDV	Proactive-Topology	Unicast	Distance Vector	Overhead expansion of the greater network Multiple routes unavailable Traffic jams Intricacies in communication	Ensures the loop free routes Decreased overhead control message The routing table is smaller in size overall
FSR	Proactive-Topology	Unicast	Link State	Intricacies in communication More routing tables Inability discover the route	Efficient decrease of overhead Scalability
OLSR	Proactive-Topology	Broadcast	Link State	Reduce the packet delivery ratio	Flexible in incorporating various operating systems Dynamic topology Can be used in situations in which low latency is needed
ZRP	Hybrid-Topology	Broadcast	Overlapping Zones	Is not relevant for topology which fluctuates significantly or in dynamic situations	Avoided overhead Congestion decreased
ZHLS	Hybrid-Topology	Unicast	Non Overlapping Zones	A fixed zone map per specific node is required	Decreased transmission overhead Adaptable to the dynamic topology
VADD	DTN-Position	Unicast	Carry and forward	Differences in topology and number of vehicles leading to delay	Decreased the delay in packet delivery
GeOpps	DTN-Position	Unicast	Store, carry and forward	Difficulties in estimating the extent of delays	Route estimation does not rely on all nodes Route topology and node mobility are the only influencers of rate of transmission
GPCR	Non DTN-Position	Unicast	Greedy forwarding and procedure repair	Greater transmission delay	Global details not required
GPSR	Non DTN-Position	Unicast	Greedy and perimeter forwarding	Link breakdown as a result of greater mobility and frequent topology Greater packet loss Increased latency Failure to update packet header Intricacy Greater delay	Scalability Forwarding packet decision dynamically
HLAR	Hybrid-Position	Unicast	AODV protocol with greedy forwarding	Potentially routing is not reliable	Decreased overhead control routing Scalability New details on increased size position are given



**Table-3.** Comparison between topology-based and position-based routing.

Routing protocol	Approaches employed	Strengths	Weaknesses
Topology	Details located within the routing table are associated with packet forwarding	Shortest route (source -destination) Capacity to handle unicast, multicast and broadcast messages Consumption resource is reduced Beaconless Preservation of bandwidth	Increased overhead Delays in routes discover and maintaining Frequent network modifications Needless flooding
Position	Beaconing Vehicles position information Global positioning service	Global route maintenance is not required Greater consistency in situations with increased mobility Increased suitability for network distributed nodes Smallest overhead and scalability	Limitations in highway situations Location server deadlock issues Absence of a satellite signal

## 6. ACCESS TECHNOLOGIES

Recently, the demand for vehicles has increased exponentially in response to the expansion of the transportation infrastructure (roads, highways, etc.). This has led to the prioritisation of public security against traffic accidents, traffic efficiency and passenger convenience. To this end, an information technology framework combining communication technologies with transport infrastructure and vehicles has become an urgent necessity. Such a technological framework could foster various vehicular networking applications that could ensure driving safety by gathering and disseminating information about vehicle speed, location, traffic status, and congestion conditions. The successful introduction of this framework depends on the existence of efficient and reliable communication between vehicles and transport infrastructure. In relation to this, vehicular communication based on IEEE 802.11p has been extensively researched, leading to the creation of the scheme Wireless Access in Vehicular Environment (WAVE), consisting of different protocols and configurations for vehicle based wireless environments. Of the various components of the WAVE protocol, the most important is IEEE 802.11p, which is a version of IEEE 802.11 that has been tailored for the vehicular networking environment.

For various applications employing vehicular networks, the IEEE 802.11p [51] is the implementation standard. In addition to Physical (PHY) and Medium Access Control (MAC) layers, this standard also includes upper layer protocols. The PHY layer is characterized by the fact that the IEEE 802.11a 20MHz bandwidth is reduced to 10MHz bandwidth, cutting the 6-54Mbps data rate by half to 3-27Mbps. On the other hand, the MAC layer represents 802.11e Enhanced Distributed Channel Access (EDCA) associated with Quality of Service (QoS) assistance. Autonomous communication between OBUs i.e. vehicle-to-vehicle and between OBUs and RSUs i.e. vehicle-to-infrastructure is made possible by the combined function of the PHY and MAC layers. Considerable challenges with regard to overall network performance are posed by the lack of channel access mechanism based on infrastructure support and wireless communication between highly mobile vehicles across varying channel

conditions. Nevertheless, the reliability of the IEEE 802.11p standard is jeopardized by its decentralized nature, which is caused by physical characteristics such as difficult Non-Line of Sight (NLOS) reception of packet, mobility of the nodes and fading channel conditions. Scalability constitutes a major problem as well as an increase in the number of participant's results in performance deterioration. One key factor in the development of VANETs is MAC. Thus, given the above considerations, when evaluating MAC proposals for VANETs, several MAC metrics and specifications must be taken into account:

- Probability of successful delivery of packets to the destination
- Channel access time
- Mechanism for controlling congestion
- Robustness against fading
- Priority control for messages

A range of medium access control methods have been formulated and adjusted for application in VANETs. These approaches have been derived from the IEEE 802.11a wireless LAN standard that uses CSMA [1]:

- Time-Division Multiple Access: R-ALOHA, CSAP, DCAP and STDMA
- Space-Division Multiple Access: LCA
- Code-Division Multiple Access: MCS/CDMA and UTRA-TDD

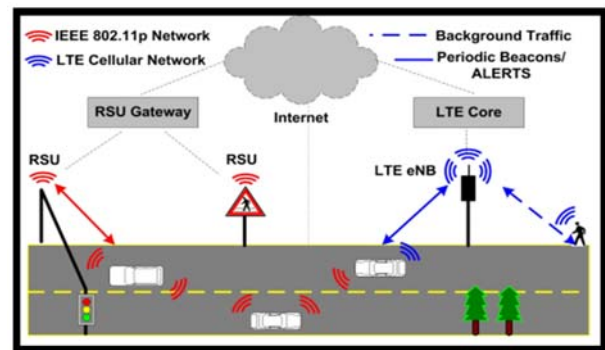
From the perspective of throughput and lower latencies, one promising solution to the varying performance specifications of a wide spectrum of vehicular network applications is LTE [52], a standard extended by 3rd Generation Partnership Program (3GPP). Theoretically, downlink data rate of 150Mbps can be



achieved in a 20MHz downlink spectrum, while uplink data rate of 50Mbps can be achieved in a 20MHz uplink spectrum. A delay of 5ms is integrated with this in the user plane. The performance efficacy and optimal cost of LTE technology are achieved by the simplified network architecture containing a finite number of network elements and complex resource utilization algorithms. The Radio Access Network (RAN) of the LTE network architecture is contained in the base station or eNodeB (eNB) and is responsible for not only controlling radio and managing functionalities but also enabling communication among User Equipment (UE) and LTE core network. Furthermore, the eNB is linked to the Evolved Packet Core (EPC) that is responsible for managing mobility, controlling QoS, and interoperability with legacy 3GPP and non-3GPP access technologies. In order to support such applications, LTE technology-enabled OBUs with smartphone connections are proposed. However, even though enhanced reliability and scalability can be achieved via the existing infrastructure, the delivery of delay bounded data across the LTE connection and efficient sharing of resources with cellular network users remain a key challenge. Nonetheless, despite the fact that LTE technology provides better capacity, reliability and scalability, attaining strict latency specifications over the cellular connection, particularly when there is high cellular network traffic load, is still challenging.

Vehicular networking architectures employing infrastructure-less network based on IEEE 802.11p or infrastructure-based cellular (LTE) network are compared in the following part. Figure-7 presents an urban scenario for such architectures. The ad hoc communication based on IEEE 802.11p is shown on the left side of the figure, where a backbone network links several RSUs to a

gateway and supplies Internet access. A different vehicular networking approach is illustrated on the right-hand side, whereby cellular network-enabled OBUs or smartphones communicate across the wireless medium by taking advantage of the existing cellular infrastructure (LTE). In terms of data flow, in-vehicle OBUs resort to direct or RSU-mediated interaction to explore and gather pertinent information and periodically exchange beacon messages in an ad hoc manner. Cellular network's base station node (eNB in LTE) could also facilitate this interaction, in which case, the beacons received at the eNB can only be disseminated to the other vehicles in the network after they have gone through the whole LTE core network. The general assumption is that eNB uses multiple unicast transmissions to send the beacon messages. Access technologies related to vehicular communication are compared in Table-4.



**Figure-7.** Urban scenario using IEEE 802.11p and LTE [53].

**Table-4.** Comparison of VANETs access technologies.

Performance	IEEE 802.11p	LTE
Topology	Acceptable	High
Mobility	Low vehicle density	Suitable for most vehicular networking applications
Message Transmission	Ad-hoc Manner	(eNB) comprises the Radio Access Network (RAN)
Latency	Low	High
Data Rate	3Mbps -27Mbps depending on MCS selection	Downlink data rate of 150Mbps – uplink data rate of 50Mbps
Channel Bandwidth	10 MHz	20 MHz
Transmission Power	25dBm	eNB(40) / UE(20)dBm
End – End Delay	High	Low
Reliability	Limited	High
Scalability	Low	High
Capacity	Low	High
Cost	Low	High



## 7. VANET SIMULATION TOOLS

Simulation tools are the focus of the present part. A range of simulation tools have been used to evaluate and simulate the performance of routing protocols in VANET [19]. Table-5 provides a comparison of VANET simulation tools in languages, weaknesses and strengths. Simulators are categorized into three types:

- Simulators for mobility generation: provide software environments capable of generating movement of vehicles in trace files.

- Simulators for network analysis: employed to analyze network protocol performance, but does not include complex mobility models.
- Simulators with integration support: merging of vehicle mobility and network simulators.

**Table-5.** Comparison of VANET simulation tools [54-59].

Simulator	Type	Languages	Weaknesses	Strengths
Vanet-MobiSim	Mobility	Java	No information on how to execute Feedback not available	Mobility traces produced in various formats Mobility simulations that are adaptable Authentic vehicle mobility modelling is possible
TranSim	Mobility	C	No code available for modelling of networks Proprietary licensing of software	Vehicle synergy is modelled via a cellular automaton
SUMO	Mobility	C++	Complexity in configuration and interface	Highly portable and functional across various scenarios Designed for use in traffic strategies and enhancement of route layout
MOVE	Mobility	C++	No functionality exists to model networks	Capability to import maps from Google Earth website Users are capable of accessing the mobility traces that are produced
NS-2	Network	C++	Low scalability Only bi- or omni-directional receivers are permitted Manual programming of node is required Assigned and aligned modelling assignments are not facilitated	Fast production of extensive situations results from the implementation of split-language programming Wired and wireless networks are permitted
OPNET	Network	C	Commercial Reduced communication technology negatively impacts connectivity and service discovery Static topology	Wired and wireless networks are permitted Increased collection of protocol simulations Scalability
OMNeT	Network	C++	Not user-friendly Slow simulator Large memory requirements Many modelling forms are not permitted	Authentication Upscaling of network modelling is permitted Use of a graphical user interface to construct and implement models Network and mobility models are accommodated
SWANS++	Integrated	Java	Switching of lanes is not permitted Feedback not available between modules of networking and mobility	More extensive network modelling is possible Models are generated rapidly Lower memory usage
GrooveNet	Integrated	C	One way road elevation and altitude of traffic are not available in the map database	Various simulations representing communication, travel and traffic control are permitted More extensive modelling Counties can be continuously accessed in real time
TraNS	Integrated	C++	SUMO is incapable of receiving NS-2 files, resulting in a joint inability to generate a realistic model	VANET can be accurately modelled Vehicle patterns can be effected by VANET information exchange within the mobility simulation Increased capacity for upscaling or adjustment
NCTUns	Integrated	C++	Limited upscaling is possible	Various route portions can be used in the generation of a broad range of maps Vehicular operation can be independently managed VANET is facilitated by evaluation Network protocol stacking is permitted

## 8. CONCLUSIONS

Mobility models, routing protocols, access technologies, and simulators for VANETs have been surveyed in this study. Road systems, RSU structure and intelligent traffic light system have also been discussed in detail. In smart cities, VANETs take the form of ITLs which ensure greater road safety as well as driver safety. These ITLs collect statistics which benefit data routing protocols, facilitating the identification of the paths which are most likely to guarantee the success of packet

forwarding to a destination. High mobility and constrained degree of freedom in movement patterns are the main characteristics of VANET. It is essential for vehicular mobility patterns to be realistic and users must comprehend how the requirements of the applications are correlated to the chosen mobility models. The common goal of all routing protocols is reduction of network overhead and transmission delay, and improvement of network throughput. However, selecting a routing protocol with an efficient performance in any network environment



situation is a major challenge in VANETs. For example, despite being compatible with a high mobility environment, a protocol may be affected by end-to-end delay, whereas other protocols may not be appropriate for high mobility environment but are capable of rapid packet delivery. As a result, a comparison of VANET routing protocols to determine which protocol has the highest performance in every environment situation is difficult to accomplish. Nevertheless, this study managed to conduct an analysis of two types of routing protocols on the basis of related protocols. Results reveal that in urban as well as rural scenarios the performance of position-based routing exceeded that of topology-based routing. According to access technology, LTE has a greater delay, reliability and scalability performance than IEEE 802.11p. The latter is more suitable for network topologies that are less dense. Furthermore, to allow users to provide feedback regarding model efficiency and its application, the VANET simulator must be an open source and should include documentation as well. In addition, to permit the examination of single pieces of the simulation process, it is important for the structure of the model to be modular in nature.

#### ACKNOWLEDGMENTS

We are grateful to the Universiti Kebangsaan Malaysia department of Electrical, Electronic and System Engineering and the University of Baghdad department of Computer Sciences, for their various forms of support, provision of expertise and for providing us with all the necessary facilities for the research. We also place on record, our sense of gratitude to all those who directly or indirectly, have lend us their hand and assistance throughout this venture.

#### REFERENCES

- [1] Hartenstein H. and K. Laberteaux. 2009. VANET vehicular applications and inter-networking technologies. Vol. 1. John Wiley and Sons.
- [2] Misra S., I. Woungang and S.C. Misra. 2009. Guide to wireless ad hoc networks. Springer Science and Business Media.
- [3] Akyildiz I.F., D.M. Gutierrez-Estevez and E.C. Reyes. 2010. The evolution to 4G cellular systems: LTE-Advanced. Physical Communication. 3(4): 217-244.
- [4] Sharef Z.T., A.E. Alaradi and B.a.T. Sharef. 2012. Performance evaluation for WiMAX 802.16 e OFDMA physical layer. In: Computational Intelligence, Communication Systems and Networks (CICSyN), 2012 Fourth International Conference on. IEEE.
- [5] Sharef B.T., R.A. Alsaqour and M. Ismail. 2014. Vehicular communication ad hoc routing protocols: A survey. Journal of Network and Computer Applications. 40: 363-396.
- [6] Fonseca E. and A. Festag. 2006. A survey of existing approaches for secure ad hoc routing and their applicability to VANETS. NEC network laboratories. 28: 1-28.
- [7] Korkmaz G., *et al.* 2004. Urban multi-hop broadcast protocol for inter-vehicle communication systems. in Proceedings of the 1<sup>st</sup> ACM international workshop on Vehicular ad hoc networks. ACM.
- [8] Rivas D.A., *et al.* 2011. Security on VANETs: Privacy, misbehaving nodes, false information and secure data aggregation. Journal of Network and Computer Applications. 34(6): 1942-1955.
- [9] Sharef B.T., *et al.* 2013. A comparison of various vehicular ad hoc routing protocols based on communication environments. In: Proceedings of the 7<sup>th</sup> International Conference on Ubiquitous Information Management and Communication. ACM.
- [10] Zeadally S., *et al.* 2012. Vehicular ad hoc networks (VANETS): status, results, and challenges. Telecommunication Systems. 50(4): 217-241.
- [11] Alsabaan M., *et al.* 2010. Vehicular networks for reduction of fuel consumption and CO<sub>2</sub> emission. In: Industrial Informatics (INDIN), 2010 8<sup>th</sup> IEEE International Conference on. IEEE.
- [12] Zhou B., J. Cao and H. Wu. 2011. Adaptive traffic light control of multiple intersections in wsn-based its. in Vehicular Technology Conference (VTC Spring), 2011 IEEE 73<sup>rd</sup>. IEEE.
- [13] Nafi N.S. and J.Y. Khan. 2012. A VANET based intelligent road traffic signalling system. In: Telecommunication Networks and Applications Conference (ATNAC), 2012 Australasian. IEEE.
- [14] Barba C.T., *et al.* 2012. Smart city for VANETs using warning messages, traffic statistics and intelligent traffic lights. in Intelligent Vehicles Symposium (IV), 2012 IEEE. IEEE.
- [15] Spaho E., *et al.* 2011. Vanet simulators: A survey on mobility and routing protocols. In: Broadband and Wireless Computing, Communication and





- Applications (BWCCA), 2011 International Conference on. IEEE.
- [16] Bai F., N. Sadagopan and A. Helmy. 2003. IMPORTANT: A framework to systematically analyze the Impact of Mobility on Performance of Routing protocols for Adhoc Networks. in INFOCOM 2003. Twenty-second annual joint conferences of the IEEE computer and communications. IEEE societies. IEEE.
- [17] Brackstone M. and M. McDonald. 1999. Car-following: a historical review. Transportation Research Part F: Traffic Psychology and Behaviour. 2(4): 181-196.
- [18] Cetin N., A. Burri and K. Nagel. 2003. A large-scale multi-agent traffic microsimulation based on queue model. in The third swiss transport research conference.
- [19] Härrä J., F. Filali and C. Bonnet. 2009. Mobility models for vehicular ad hoc networks: a survey and taxonomy. Communications Surveys and Tutorials, IEEE. 11(4): 19-41.
- [20] Hoogendoorn S.P. and P.H. Bovy. 2001. State-of-the-art of vehicular traffic flow modelling. Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering. 215(4): 283-303.
- [21] Legendre F., *et al.* 2006. Reconsidering microscopic mobility modeling for self-organizing networks. Network, IEEE. 20(6): 4-12.
- [22] Models U. 2007. UDel Models for Simulation of Urban Mobile Wireless Networks.
- [23] Nagel K., P. Wagner and R. Woesler. 2003. Still flowing: Approaches to traffic flow and traffic jam modeling. Operations research. 51(5): 681-710.
- [24] Queck T., B. Schüenemann and I. Radusch. 2008. Runtime infrastructure for simulating vehicle-2-x communication scenarios. In: Proceedings of the fifth ACM international workshop on VehiculAr Inter-NETworking. ACM.
- [25] Saha A.K. and D.B. Johnson. 2004. Modeling mobility for vehicular ad-hoc networks. in Proceedings of the 1<sup>st</sup> ACM international workshop on Vehicular ad hoc networks. ACM.
- [26] Lee K.C., U. Lee and M. Gerla. 2010. Survey of routing protocols in vehicular ad hoc networks. Advances in vehicular ad-hoc networks: Developments and challenges. pp. 149-170.
- [27] Paul B. and M.J. Islam. 2012. Survey over VANET routing protocols for vehicle to vehicle communication. IOSR Journal of Computer Engineering (IOSRJCE), ISSN. pp. 2278-0661.
- [28] Allal S. and S. Boudjit. 2013. Geocast Routing Protocols for VANETs: Survey and Geometry-Driven Scheme Proposal. Journal of Internet Services and Information Security (JISIS). 3(1/2): 20-36.
- [29] Hanzo L. and R. Tafazolli. 2007. A survey of QoS routing solutions for mobile ad hoc networks. Communications Surveys and Tutorials, IEEE. 9(2): 50-70.
- [30] Kumar R. and M. Dave. 2011. A comparative study of Various Routing Protocols in VANET. arXiv preprint arXiv:1108.2094.
- [31] Vijayalaskhmi M., A. Patel and L. Kulkarni. 2011. QoS parameter analysis on AODV and DSDV protocols in a wireless network. International Journal of Communication Network and Security. 1(1): 62-70.
- [32] Al-Doori M. 2011. Directional routing techniques in vanet.
- [33] Bernsen J. and D. Manivannan. 2008. Greedy routing protocols for vehicular ad hoc networks. In: Wireless Communications and Mobile Computing Conference, 2008. IWCMC'08. International. IEEE.
- [34] Abolhasan M., T. Wysocki and E. Dutkiewicz. 2004. A review of routing protocols for mobile ad hoc networks. Ad hoc networks. 2(1): 1-22.
- [35] Frank R., *et al.* 2011. Performance bound for routing in urban scenarios. In: Proceedings of the 7<sup>th</sup> Asian Internet Engineering Conference. ACM.
- [36] Johnson D.B. and D.A. Maltz. 1996. Dynamic source routing in ad hoc wireless networks, in Mobile computing. Springer. pp. 153-181.
- [37] Johnson, M. and D.A. Maltz, Broch. 2001. DSR: The Dynamic Source Routing Protocol for Multi-HopWireless Ad Hoc networks. Ad Hoc Networking. pp. 139-172.



- [38] Kohli, S., B. Kaur, and S. Bindra, A comparative study of Routing Protocols in VANET. Proceedings of ISCET, 2010.
- [39] Naumov V., R. Baumann and T. Gross. 2006. An evaluation of inter-vehicle ad hoc networks based on realistic vehicular traces. In: Proceedings of the 7<sup>th</sup> ACM international symposium on Mobile ad hoc networking and computing. ACM.
- [40] Park, V. and S. Corson. 2001. Temporally Ordered Routing Algorithm (TORA) version 1 functional specification, draft-ietf-manet-tora-spec-04. txt. Work in progress. IETF.
- [41] Perkins C., E. Belding-Royer and S. Das. 2003. Ad hoc on-demand distance vector (AODV) routing.
- [42] Walia, G.K., A Survey on Reactive Routing Protocols of the Mobile Ad hoc Networks. International Journal of Computer Applications, 2013. 64(22): p. 45-51.
- [43] Haerri J., F. Filali and C. Bonnet. 2006. Performance comparison of AODV and OLSR in VANETs urban environments under realistic mobility patterns. In: Proceedings of the 5<sup>th</sup> IFIP mediterranean ad-hoc networking workshop.
- [44] Sharma Y.M. and D.S. Mukherjee. 2012. A Contemporary Proportional Exploration of Numerous Routing Protocols in VANET. International Journal of Computer Applications (0975-8887) Vol. 2012.
- [45] Toutouh J. and E. Alba. 2011. Optimizing OLSR in VANETS with differential evolution: A comprehensive study. In: Proceedings of the first ACM international symposium on Design and analysis of intelligent vehicular networks and applications. ACM.
- [46] Schaumann J. 2002. Analysis of the zone routing protocol. Course CS765, Stevens Institute of Technology Hoboken, New Jersey, USA.
- [47] Karimi R., *et al.* 2011. Non DTN Geographic Routing Protocols for Vehicular Ad Hoc Networks. International Journal of Computer Science Issues (IJCSI). 8(5).
- [48] Cho K.-H. and M.-W. Ryu. 2012. A survey of greedy routing protocols for vehicular ad hoc networks. Smart CR. 2(2): 125-137.
- [49] Al-Rabayah, M. and R. Malaney. 2010. A new hybrid location-based ad hoc routing protocol. In: Global Telecommunications Conference (GLOBECOM 2010), 2010 IEEE. IEEE.
- [50] Parameswaran T., C. Palanisamy and S. Bharathi. A Survey on Routing Protocols in Vanet.
- [51] Association I.S. 802.11 p-2010-ieee standard for information technology-local and metropolitan area networks-specific requirements-part 11: Wireless lan medium access control (MAC) and physical layer (PHY) specifications amendment 6: Wireless access in vehicular environments. URL <http://standards.ieee.org/findstds/standard/802.11p-2010.html>.
- [52] Access E.U.T.R. 2008. Physical channels and modulation (Release 8). 3GPP TS. 36: V9.
- [53] Mir Z.H. and F. Filali. 2014. On the Performance Comparison between IEEE 802.11 p and LTE-Based Vehicular Networks. in Vehicular Technology Conference (VTC Spring), 2014 IEEE 79<sup>th</sup>. IEEE.
- [54] De Marco G., M. Tadauchi, and L. Barolli. 2007. CAVENET: Description and analysis of a toolbox for vehicular networks simulation. In: Parallel and Distributed Systems, 2007 International Conference on. IEEE.
- [55] Fiore M., *et al.* 2007. Vehicular mobility simulation for VANETs. in Simulation Symposium, 2007. ANSS'07. 40<sup>th</sup> Annual. IEEE.
- [56] Kamadi F.K., Z.H. Mo and K.-c. Lan. 2007. Rapid generation of realistic mobility models for VANET. in Wireless Communications and Networking Conference, 2007. WCNC 2007. IEEE. IEEE.
- [57] Mangharam R., *et al.* 2006. Groovenet: A hybrid simulator for vehicle-to-vehicle networks. In: Mobile and Ubiquitous Systems: Networking and Services, 2006 Third Annual International Conference on. IEEE.
- [58] Piorkowski M., *et al.* 2006. Joint Traffic and Network Simulator for VANETs. in Proc. of Mobile and Information Communication Systems Conference (MICS-2006).
- [59] Smith L., R. Beckman and K. Baggerly. 1995. TRANSIMS: Transportation analysis and simulation system. Los Alamos National Lab., NM (United States).