Journal of Universal Computer Science, vol. 20, no. 4 (2014), 462-487
submitted: 24/7/13, accepted: 4/3/14, appeared: 1/4/14 © *J.UCS*

Classification of VANET MAC, Routing and Approaches A Detailed Survey

Sana Ajmal
(Center for Advanced Studies in Engineering, Islamabad, Pakistan
sana.ajmal84@yahoo.com)

Asim Rasheed
(CoReNeT, Muhammad Ali Jinnah University, Islamabad, Pakistan
asim@corenet.org.pk)

Amir Qayyum
(CoReNeT, Muhammad Ali Jinnah University, Islamabad, Pakistan
aqayyum@ieee.org)

Aamir Hasan
(Center for Advanced Studies in Engineering, Islamabad, Pakistan
ahasan-cae@nust.edu.pk)

Abstract: Human safety considerations linked with rapidly growing auto mobile market has given special attention to the Intelligent Transportation System (ITS). ITS provides a set of standards for inter vehicular communication with emphasis on safety, traffic efficiency and infotainment related applications. In ITS, the vehicles acting as mobile nodes, form a specialized ad hoc network, known as Vehicular Ad-hoc Network (VANET). Although, VANET and ITS are under intense research since last decade, technology still lacks large scale deployment. Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications are the main research goals of ITS. High relative node velocity and high active node density has presented peculiar challenges to connectivity within VANET. VANET connectivity and routing requirements range from the time critical safety applications, to the time and space hovering, delay tolerant and infotainment applications. This paper reviews connectivity issues in VANET with emphasis on routing, and offers comprehensive literature review on state of the art in VANET routing, with its detailed classifications. It also compares some standard architectures of VANET from MAC, routing and management perspective, i.e., WAVE by IEEE, CALM by ISO, C2CNet by C2C consortium / GeoNet.

Key Words: Vehicular Ad hoc Networks, ITS, Routing Protocols, Routing Metrics
Category: C.2.2

1 Introduction

People around the globe daily face life risks and suffer loss of millions due to mismanaged traffic conditions. Traffic safety and management requirements linked with large scale use of auto-mobiles and trains have given special attention to the Intelligent Transportation Systems (ITS). Efficient ITS can address the critical problem of traffic safety [Rasheed et al., 2013]. The rate of road accidents can be reduced significantly by using proper traffic management applications [Rasheed et al., 2010]. Researchers have made tremendous efforts for achieving this goal by efficient road traffic management, using different applications and protocols.

Taking into account the growth of data networks in our daily life, reliance on wireless networks is increasing manifold. Specialization and precision for different data communication requirements have changed the dynamics of wireless networks. In ITS, the vehicles acting as mobile nodes, form a specialized ad hoc network, known as Vehicular Ad hoc Network (VANET). Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications are the main research goals of communication in ITS .

Finding the most suitable route between sender and receiver is the pre-condition to forward any data between two nodes. Increased mobility in VANETs poses serious challenges to existing routing strategies. Specialized & mixed node deployment patterns and versatile mobility make the problem more complicated. VANET network topologies which are highly fluent in nature, also involve large variations in node densities and relative node velocities.

Routing mainly revolves around three major goals, i.e. efficiently finding most suitable route from source to destination, then updating the new route at run time, on availability of optimum one, and lastly, maintaining the route in case of route failure.

Although, VANET and ITS are under intense research since last decade, VANET routing research is still evolving and the technology still lacks large scale deployment [Brickley et al., 2010, Eichler, 2007, Lin and Lin, 2009, Tsukada et al., 2010]. Many researchers have surveyed and grouped VANET routing protocols [Li and Wang, 2007, Chen et al., 2011, Fonseca and Festag, 2006, Cannone Davide, 2011, Guoqing et al., 2008]. However, these surveys generally consider a limited number of protocols, hence lack comprehensive analyses of routing methodologies.

ITS is working on safe and efficient vehicular systems by providing traffic management solutions and development of deployment platforms. ITS also discusses the security issues related to the safety applications. Organizations like, International Standard Organization (ISO), Institute of Electrical and Electronic Engineers (IEEE) and Car-to-Car Communication Consortium / GeoNet are working on ITS architecture proposals [Mohammad et al., 2011].

Internet Engineering Task Force (IETF) is another standardization body [Bradner, 1999]. IETF is also working on mobile networks and has introduced the concept to Network Mobility (NEMO) in Mobile Ad hoc Networks (MANET). Multiple projects by various European countries have been initiated to realize ITS architectures. Some of these are NOW, COMeSafety, CVIS, SAFESPOT, COOPEERS, GST, GeoNet, FleetNet, GrooveSim, CARLINK, CarTalk2000 etc. [Mohammad et al., 2011].

The rest of the paper is structured as follows. Section II reviews the methodology of current routing strategies. Section III offers a detailed literature review of VANET routing protocols. Section IV discusses standardisation of VANET architectures, followed by the conclusion.

Table 1: Routing Update Strategy Comparison

Localized	**End-to-End**	**Cross Layer**	**Others**
Link Cost	Hop Count	SINR	Historical Flow
Neighbour Count	End-to-End Throughput	Signal Strength	Hop Count to Cluster Head
Actual Link Throughput	End to End Round Trip Time (RTT)	Interference & Channel Switching	ETT (Expected Transmission Time)
Link Life	Per Hop RTT	Node Power	Virtual Predecessor
Link Delay	Node Height	Node Energy	Per-hop Packet Pair
Link Packet Loss Ratio	End-to-End Jitter	Doppler Shift	Effective Number of Transmissions
Link Congestion	Geographical Positions	move angle	Weighted Cumulative ETT
Theoretical Bandwidth	Inter Node Distance	Node Speed	Expected Transmission Count

2 Methodology of Current Routing Strategies

Routing algorithm in the domain of multi-hop networks, has three main aspects. First, what to share for topology determination, i.e. metrics on which routing is based. Second, when and how to exchange the routing metric, i.e. the method to share the selected information among nodes. Third, the approach to use shared information for determination of routes, i.e. criteria for selecting the next hop node. For clarity purposes, we will discuss all three aspects independently.

2.1 Routing Metrics

Researchers have identified many different metrics for route finding. Hundreds of protocols have been proposed, using a single metric or a combination of some. Metrics can be grouped as localised, end-to-end and cross layer, etc. [Liu and Kaiser, 2008, Rasheed et al., 2014].

Table 1 enlists a few commonly used routing metrics. Localized routing metrics determine the next hop node according to the metric value of the neighbouring nodes only. On the other hand, end-to-end based ones, compute the metric value for the entire route. Cross layer routing metrics compute the routing parameters from layers, other than the network layer. In addition to this, a few more complex metrics have also been proposed, e.g. metrics using probability behaviour of traffic, etc [Dahiya and Chauhan, 2010].

2.2 Routing Metrics Sharing Methods

The question of, how to disseminate the routing information, is generally simpler. There are mainly three approaches: 1) periodic metrics sharing, (2) event based metrics sharing, and (3) derivatives of 1 and 2. However, for dissemination of metric information from a single node's perspective, choices are restricted to the first two only [Ahuja, 2010]. The decision between choices for sharing the metric to next hop, is determined by the role of said node, i.e. source or transit node.

2.2.1 Periodic Topology Sharing / Proactive Approach

In this approach, the topology information metrics are shared periodically, regardless of their need. This approach has the benefit of round the clock updated routing tables, however, at the cost of higher overheads [Ahuja, 2010].

2.2.2 Event Triggered Topology Sharing / Reactive Approach

This scheme shares the metrics on need basis only. Routing tables hold till the link breakage or requirement lasts, regardless of decrease in its efficiency or change in network topology. Its main benefit is lower overheads, however, at the cost additional delays in finding the route at the time of need [Ahuja, 2010].

2.2.3 Topology Sharing Variants

The two main variations for metric sharing, widely discussed in literature, are:

- Hybrid [Ahuja, 2010] topology sharing approach uses combination of both periodic and event based approaches. Each originating node periodically disseminates its metric information upto specific predefined zone. However, such information beyond the predefined zone is shared on-demand basis only. The zone size may be fixed or may adapt to network conditions.

- History [Liu and Kaiser, 2008] oriented topology sharing technique uses historical data to compute the best possible route, such as, ongoing communication among other nodes or control messages, passing through it. In case of absence of relevant data, a new route is established reactively.

3 Classification of VANET Routing Approaches

Initial concept of VANET roamed around safety applications and emergency alerts for drivers. Resultantly, research for routing in VANETs started with single or few hop communication [Xu et al., 2004, Yin et al., 2004]. The main goal of this research was to provide safety information to nearby vehicles. With the advancement in research, the need emerged to incorporate roadside servers and Internet for management and infotainment purposes. Such requirement demanded multi-hop communication and more robust routing schemes. Accordingly, a large number of VANET protocols emerged to solve different network and application requirements [Yan et al., 2010, Bernsen and Manivannan, 2009, Zeadally et al., 2012, Lee et al., 2009b, Loulloudes et al., 2012]. Researchers generally believe that no single routing approach offers efficiency under varying network conditions. Summary of a few surveys on routing in VANET, is as under:

- Current VANET routing protocols lacks efficiency to answer all practical traffic scenarios.
- V2V based routing protocols do not support delay tolerant networks.
- Non delay tolerant protocols suffer significantly under disconnected network states.
- Most of the routing protocols do not consider current traffic state while determining their routes.
- Topology based routing is not suitable for the rapidly changing networks.
- Proactive routing protocols offer low latency, but unused paths waste a significant part of the available network resources
- Reactive routing protocols offer higher resource availability, but with higher route finding latency.
- Geographic routing protocols may not well perform without accurate and updated location information. Sharing of updated information through periodic beacons consumes sufficient bandwidth.
- Inherent time delay limitation of GPS system [Rasheed and Ajmal, 2009] may cause false information dissemination for many safety applications, e.g. accident alert, etc.
- Geographical routing can form routing loops or a packet can travel longer route due to disconnected network topologies.
- Network partitioning and mapping of geographical regions on road layout is another major limitation of geographical routing.

Table 2: Summary Comparison of VANET Routing Protocols

Class	**Protocol**	**Routing approach**	**Use of cross layer parameter**	**Routing metric**	**Metric sharing approach**
Topology based	AODV	Multi-hop uni-cast routing	Nil	Hop count	Reactive
	AODVv2				Modified AODV
	OLSR	Selection of MPR		Hop Count between cluster heads	Proactive
	OLSRv2				Modified OLSR
Broadcast based	V-TRADE	Zoning based broadcasting	Position & move angle	Distance to destination	Proactive
	DV-CAST	Broadcast to new nodes	Position, move angle & directional antenna		
	PGB	Signal strength	SINR	Hop count	Modified AODV
Cluster based	FROMR	Grid based AMR	Position & street maps		
	XORi	Blind routing through information of identifiers		Hop Count between cluster heads	Modified OLSR
	HCB	Multi-interface transformation	Multiple interfaces		Proactive
	CBRP	Dividing city maps into grids	Position & city maps		
	CBDRP	Cluster head according to move angle	node velocity and move angle		Modified CBRP
	CBLR	Clusters according to node positions	Node position	Minimum distance between cluster heads	Hybrid
Location based	GPSR	Greedy and face routing		Distance to destination	Proactive
	GSR		Position & city maps		Modified GPSR
	GRANT	Extended greedy source routing among clusters		Hop count & weight against shortest path	Proactive

Continued ...

Table 2 – *Continued ...*

Class	**Protocol**	**Routing approach**	**Use of cross layer parameter**	**Routing metric**	**Metric sharing approach**
Geo-cast	IVG	Risk area determination as per node movement	Position, move angle & city maps	Distance to destination zone	Hybrid
	DRGM	Zone of relevance & zone of forwarding	Position & city maps		
	ROVER				
	STMG	Time factor based geo-cast		Broadcast	Proactive
Delay tolerant	GeOpps	Packet arrival time estimation (for shortest distance to destination)	Position & move angle	Distance to destination	
	VADD	Carry-and-forward from mobility prediction	Position & street maps	Minimum delay	
QoS based	GVGrid	Division of a street map into grids		Inter grid distance & disconnection	
	DBR	Delay-bounded greedy & min-cost forwarding	Position	Minimum delay	
	PBR	Use of mobile gateways with WWAN connectivity		Distance to mobile gateway	
Overlay based	GPCR	Elimination of node polarization	Position & city maps	Distance to junction	
	CAR	Anchor Points at road junctions		Hop count	Modified AODV
	LOUVRE	Geo-proactive overlay routing	Node density	Overlay node density	Proactive
Infrastructure based	MOVE	Mobility prediction	Position & move angle	Distance to destination	
	RAR	RSU and mobile gateways	Street maps & RSUs	Distance to RSU	Reactive

Continued ...

Table 2 – *Continued ...*

Class	**Protocol**	**Routing approach**	**Use of cross layer parameter**	**Routing metric**	**Metric sharing approach**
Hybrid	CMGR	Use of connectivity information	Position & street maps	Minimum delay	Proactive
Hybrid	ACAR	Use of mobility models with spatial & geographical dependencies	Position & street maps	Maximum throughput	Proactive
Hybrid	SADV	Deployment of static nodes at road crossings for store and forward	Position & street maps	QoS statistics	Proactive
Hybrid	HLAR	Combination of greedy forwarding & location information	Position	Minimum hops to destination	Modified AODV
Hybrid	AMR	Use of local topology & location information for connectivity probability and delay	Position	Minimum delay	Hybrid
Hybrid	DADCQ	Adaptive decision threshold based upon neighbouring node count, clustering and fading parameters	Position	Adaptive distance thresholds	Reactive
Hybrid	APFIH	Geo-cast transmission based upon epidemic routing	Position	Broadcast	Proactive
Hybrid	PVA	Parked vehicles as road side units	Position	Not defined	Proactive
Hybrid	ILBS	Division of lane structures into grids using Differential Geographic Positioning System	Position	Not defined	Proactive

As a comparison, we studied different routing protocols and their approaches as shown in Table 2. Considering the research targeted towards VANET routing, the routing protocols in VANETs can be classified into the following major categories:

3.1 Topology based Routing Protocols

To start with, a few researchers proposed use of topology based (link state and distance vector) MANET routing protocols for VANET. The examples are AODV [Perkins and Royer, 1999], AODVv2 (DYMO) [Chakeres and Perkins, 2013], OLSR [Clause, 2003] and OLSRv2 [Clausen et al., 2013], etc.

3.1.1 Ad Hoc On-demand Distance Vector version 2 (AODVv2)

The AODVv2 (formerly DYMO) is the successor to AODV, which is a minimum hop based reactive routing protocol. It performs route discovery by multi-casting a request message to destination. Each retransmitting node, records a route towards the originator, and uni-casts a route reply towards backward path. To maintain active routes, it extends route lifetime upon successful transmission.

3.1.2 Optimized Link State Routing Protocol version 2(OLSRv2)

The OLSRv2 is the successor to OLSR, which is a cluster head based table driven proactive protocol. It selects two cluster heads (or Multi Point Relays) from its symmetrically connected two hop neighbours. The difference between both versions is the flexibility and modular design, using shared components, packet format, neighbourhood discovery and handling of multiple interfaces.

3.2 Broadcast based Routing Protocols

Broadcast based routing protocols flood the network with data. Although, this approach ensures delivery, but can only work for small scale networks. Improvements over this approach such as V-TRADE and HV-TRADE [Sun et al., 2000] limits the flooding, by reorganizing the network in sub groups. However, significant routing overheads for rebroadcast, are their major performance limitation.

3.2.1 Vector Based Tracing Detection (V-Trade)

V˙TRADE is a location based broadcast protocol, using the ”zoning” concept. It groups its neighbours into different categories, according to their position and movement information. Accordingly, a subset of nodes is selected for broadcast within a group. It enhances the efficiency of a network by reducing broadcast messages. However, determination of groups requires additional overheads.

3.2.2 DV-CAST: Broadcasting in VANET

Distributed Vehicular Broadcast (DV-CAST) [Tonguz et al., 2007] is another position based routing protocol which targets delay tolerant networks. Each vehicle kepng position record of neighbouring vehicles. Each node checks the location of source node on receiving a broadcast before rebroadcasting. It suppress broadcast towards the source by using directional transmission, and ensure delivery to at least one neighbour by rebroadcasting, till the message is received. Thus, the problem of disconnected networks is solved through successful retransmission.

3.2.3 AODV-PGB Preferred Group Broadcasting (PGB)

AODV-PGB [Naumov et al., 2006] modifies the standard AODV, by reducing broadcast overheads for route discovery, etc. It maintains broadcast groups, based on the received signal strength. Each node independently determines rebroadcast decision. It has two drawbacks as: 1) the selected group may not adapt the optimum path towards destination, 2) packets may be duplicated as two nodes in the preferred group can simultaneously broadcast.

3.3 Cluster based Routing Protocols

Cluster based routing e.g. HCB [Xia et al., 2009], is the combination of the above two techniques. In such schemes, each node designates a cluster-head within a subset of nodes. The cluster-head broadcasts the required packet to the cluster members. These protocols answer the scalability issue. However, additional delays and overheads are incurred, while forming and maintaining clusters.

3.3.1 Hierarchical Cluster Based (HCB) Routing

HCB is a layered architecture of nodes and Super nodes. Super nodes can communicate with each other as well as with base stations. Each node attaches itself to the nearest super node to form clusters. In HCB, Super nodes periodically exchange membership information to enable inter-cluster routing, which is performed independently in each cluster.

3.3.2 Cluster Based Routing Protocol (CBRP)

The CBRP [Luo et al., 2010] uses the amalgamation of cluster based routing and geographic routing. The geographic region is divided into square grids. Using node position, each node selects its cluster. RSU is preferred to be selected as a cluster head. Each node maintains a neighbourhood table to store the information about its neighbours. Routing is done in two phases: 1) In setup phase, a cluster head is selected 2) In steady state phase, the routing tree is constructed.

3.3.3 Cluster Based Location Routing (CBLR)

The CBLR [Santos et al., 2004] uses the concept of cluster based routing as an on-demand routing protocol, using node positions. A cluster head maintains a routing table to other cluster heads and cluster members. Each node passes the data to its cluster head for destination nodes outside the cluster. If the destination node is in same cluster, source node sends data to the closest neighbour towards the destination. Otherwise, the source stores the data packet, and starts a timer and broadcasts Location Request packets for the destination.

3.3.4 Cluster-Based Directional Routing Protocol (CBDRP)

In CBDRP [Song et al., 2010], nodes moving in same direction forms a cluster. Cluster head is selected using node velocity and movement direction. The procedure adapted for cluster head is same as CBRP.

3.4 Location based Routing Protocols

Location based routing protocols e.g. GSR [Lochert et al., 2003] & GPSR [Karp and Kung, 2000], are generally claimed to be suitable for VANETs. Information of nodes all along the path, reduces the delay in route determination. Use of location information instead of hierarchical routing tables, significantly reduces routing overheads. However, it can suffer from disconnected topologies and can cause a packet to travel longer route or form a loop [Shah et al., 2005].

3.4.1 Greedy Perimeter Stateless Routing (GPSR)

In GPSR, each forwarding node selects its next hop neighbour, geographically closer to the destination node, also known as greedy mode. If at any hop there are no nodes in the direction of destination (local maximum) then GPSR utilizes a recovery strategy and forwards packet to a node that is closer to the destination than the node where the packet encountered the local maximum.

3.4.2 Geographic Source Routing (GSR)

The GSR uses urban area street maps, along with use of node locations, to overcome the disadvantages of position based routing. GSR computes a route to destination by selecting next hop neighbour along the streets. The path between the source and destination is computed using Dijkstra's algorithm.

3.4.3 Greedy Routing with Abstract Neighbour Table (GRANT)

GRANT [Schnaufer and Effelsberg, 2008] uses the concept of extended greedy source routing, by keeping knowledge about the positions of neighbours up to a predefined number of hops. This allows each node to determine the best possible route, which is selected based on distance to destination, number of hops, and the weight against shortest path. To reduce the node location overheads, GRANT adapts cluster head approach by dividing the total area into clusters.

3.5 Geo-cast Routing Protocols

Geo-cast routing e.g. IVG [Bachir and Benslimane, 2003] is a combination of broadcast routing and position based routing. In this scheme, control and safety information is shared through broadcast, within a specific region around the source. Other schemes can be used for data transmission outside the safety region. Network partitioning and mapping of regions on road layout, is one major limitation of this approach.

3.5.1 Inter-Vehicle Geo-cast (IVG)

The IVG protocol is designed for dissemination of safety alert within a geographical region. The risk region is determined in terms of driving direction and positioning of nodes. Accordingly, a multicast group is formed within region. Periodic rebroadcast is performed for message delivery in disconnected state.

3.5.2 Distributed Robust Geo-cast Multicast Routing Protocol

The distributed robust geo-cast multicast routing protocol [H. P. Joshi and Kihl, 2007] is targeted to deliver packets to vehicles located in a specific geographical region. Zone Of Relevance (ZOR) and Zone Of Forwarding (ZOF) are defined for each geo-cast message. Each node within the ZOR is targeted to receive the packet. Whereas each node in the ZOF forward the geo-cast messages to nodes in the ZOR. Periodic retransmission handles the disconnected topology problem.

3.5.3 RObust VEhicular Routing (ROVER)

ROVER [Kihl et al., 2007] performs flooding for the control packets, and uni-cast for the data packets. Each node is equipped with a GPS, a digital street map and possesses a unique Vehicle Identification Number (VIN). ROVER also uses the concept of ZOR and ZOF. A node accepts the received message only, if it is received within the ZOR. Similarly, nodes within ZOF forward the messages to nodes present within ZOR.

3.5.4 Spatio-temporary Multicast/Geocast Routing Protocol

The spatio-temporary multicast/geo-cast routing protocol [Chen et al., 2010] uses 'time' as an additional parameter for geo-cast transmission. It delivers information to all nodes within a specific geographical region, at a particular point in time. Emergency alerts that are time sensitive, e.g. road block etc. can use this concept for efficient handling of data.

3.6 Delay Tolerant Routing Protocols

Delay tolerant routing e.g. VADD [Zhao and Cao, 2006] & GeOpps [Leontiadis and Mascolo, 2007] is used for sparse networks highway scenarios. In the absence of a next hop neighbour (disconnected topology), packets are buffered till next availability. This approach is also known as carry-and-forward.

3.6.1 Vehicle-Assisted Data Delivery (VADD)

VADD uses the concept of carry-and-forward, based on the predictable vehicle mobility. Each node is equipped with street maps showing traffic statistics at different times of the day. Each forwarding node at a junction, selects the next forwarding path with the smallest packet delivery delay. The expected packet delivery delay of a path can be modeled and expressed by parameters such as road density, average vehicle velocity, and the road distance. Complexity and absence of a particular street map are its major limitations.

3.6.2 Geographical Opportunistic Routing (GeOpps)

GeOpps uses the node position and movement direction information to select the nodes closer to the destination node. It estimates the arrival time of a packet at destination, by calculating the shortest distance to destination. If due to mobility, any other node is found with shorter estimated arrival time than the previous one, packet is forwarded to that node.

3.6.3 SADV: Static-Node-Assisted Adaptive Data Dissemination

SADV [Ding and Xiao, 2010] uses infrastructure nodes at road crossings for storing and forwarding data in the absence of any mobile node. Each mobile node independently decides to pass the data packet to next hop neighbour or to the infrastructure node. The routing decision at each mobile or static node is based on the knowledge of its position on the street map and its communication with neighbours.

3.7 QoS based Routing Protocols

A Quality of Service (QoS) based routing e.g. PBR [Namboodiri and Gao, 2007], performs resource reservation, prior to the start of data transfer. Such guarantees are generally difficult for dynamic networks. However, probabilistic nature of VANET, supports analyses of link reliability using vehicle velocity, position and movement direction of the nodes. The probabilistic nature of the nodes moving on roads (especially on highways) supports this scheme.

3.7.1 Prediction Based Routing (PBR)

The PBR is focused on providing Internet connectivity to vehicles using mobile gateways, with wireless WAN connectivity, specifically on highway scenarios. PBR predicts the duration and expiration of a route to a mobile gateway, using location information and probabilistic movement of nodes on highways. Accordingly, it establishes a new route before a route failure occurs.

3.7.2 Adaptive Message Routing with QoS Support

[Saleet et al., 2009] proposes a QoS based Adaptive Message Routing (AMR) protocol based upon local topology and location information. AMR determines the route with minimum delay, using connectivity probability and hop count threshold. All nodes update their location to RSU. It maintains the backbone routes, whenever a noticeable change in the statistical location of other nodes within its cell boundary is observed.

3.7.3 GVGrid: a QoS Routing Protocol

To improve delivery time and routing reliability, GVGrid [Sun et al., 2006] determines a path to destination using grid approach. A street map is divided into several grids. To find a routing path through minimum number of grids, GVGrid delivers RREQ and RREP messages through different grids. A grid is selected for next hop basing upon the direction and the distance between vehicle and street intersection.

3.7.4 Delay-Bounded Routing Protocol

The delay-bounded routing protocol [Skordylis and Trigoni, 2008] is based on the carry-and-forward schemes for data delivery to RSU. It uses two separate algorithms, i.e. D-Greedy (Delay-bounded Greedy Forwarding) and D-MinCost (Delay-bounded Min-Cost Forwarding) to determine traffic information and the bounded delay time. D-Greedy algorithm adapts only local traffic information from the map, to select the shortest path to destined RSU. D-MinCost algorithm considers the global traffic information in a city to achieve the minimum channel utilization within the constrained delay-time.

3.8 Overlay Routing Protocols

In overlay routing, the routing protocol operates on a set of representative nodes overlaid over network topology, e.g. FROMR [Wu et al., 2010] and GPCR [Lochert et al., 2005]. In the dense networks, nodes use street junctions as decision points for selection of the route. Appropriate selection of overlay map, e.g. junction points, can assist in timely delivery of data using shortest path.

3.8.1 Fast Restoration Multipath Routing (FROMR)

FROMR is a multipath routing based fast recovery protocol, developed using AODV. It rapidly restores a route through alternate path when the original one is broken. To reduce the control overheads, it divides the geographic region into grids. A grid head is selected according to the criteria of longest stay inside grid. Hence it uses a combination of topology based and cluster based routing.

3.8.2 XOR Based Routing Protocols (XORi)

The XORi [Oliveira et al., 2011] is XOR based routing protocol using a combination of topology routing and cluster based routing. It uses the blind routing approach, where the routing is independent of any metric other than a node identifier (identity). This protocol is designed for high mobility conditions in VANETs.

3.8.3 Greedy Perimeter Coordinator Routing (GPCR)

The GPCR uses the concept of elimination of node planarization using street maps. GPCR improves upon GSR by eliminating the requirement of an external static street map for its operation. To avoid potential radio blockade e.g. from buildings, the typical destination-based greedy forwarding strategy is modified. Each node tries to select the next hop along roads up to junctions. At junctions, decision about next road segment is made considering the proximity to destination position.

3.8.4 Connectivity-Aware Routing (CAR)

The CAR [Naumov and Gross, 2007] is an up-gradation of PGB [Naumov et al., 2006], which is an AODV modification for VANET. It limits broadcast and establishes a route by setting the anchor points at intermediate junctions. Each forwarding node records its identity, hop count, and average number of neighbours for route request. On return, destination chooses a routing path with the minimum delivery delay time.

3.8.5 Landmark Overlays for Urban Vehicular Routing Environments (LOUVRE)

The LOUVRE [Lee et al., 2009a] uses the concept of geo-proactive overlay routing where the sequence of overlaid nodes is determined in advance. It assumes that above a given vehicular density threshold, an overlay link remains connected regardless of the vehicular spatio-temporal distribution. Hence, most routes would partially use the same overlay links, while establishing overlay routes based on the specific density threshold. It guarantees global route optimality and reduces the delay for establishing overlay routes.

3.9 Infrastructure based Routing Protocols

Infrastructure or RSU based routing protocols, e.g. RAR [Peng et al., 2006] and MOVE [LeBrun et al., 2005], forms the concept of hybrid networks, where maximum reliance is given to RSU for route to destination. Each RSU, being static in nature, maintains information about other RSUs and mobile nodes directly connected to it.

3.9.1 Motion Vector Routing Algorithm (MOVE)

MOVE is delay tolerant routing protocol based upon RSU. It uses node information related to its velocity and movement direction to select the next hop node closest to destination. MOVE assumes a sparse network where rare opportunistic routing decisions are taken through prediction. Nodes act as mobile routers possessing intermittent connectivity with other nodes or RSUs. MOVE predicts the success rate of the message delivery to any neighbour at a specific instant.

3.9.2 Roadside Aided Routing (RAR)

The RAR is a routing framework for VANETs. It uses the concept of road sectoring using RSUs. Routes are formed using RSUs as well as mobile nodes. In the absence of large scale deployment of RSUs, the performance of these frameworks or routing protocols is not very efficient.

3.10 Cross Layer Hybrid Routing

In the recent past, researchers have come up with the different proposals to answer the complex requirements of highly dynamic networks, such as VANET. The salient of a few state-of-the-art researches for adaptive routing in VANETs is described below:

3.10.1 Connectivity Aware Minimum Delay Geographic Routing

The paper [Shafiee and Leung, 2011] proposes an adaptive Connectivity aware Minimum delay Geographic Routing (CMGR) protocol. The proposed protocol uses delay as the routing metric in dense networks. Link connectivity information is used for route selection in sparse and disconnected topologies. The protocol at each node computes neighbour list and marks updated neighbour list using digital map. Information of the node locations also supports delay tolerant routing. Adaptive frequency allocation for location update beacons, according to node density changes is also supported.

3.10.2 Adaptive Connectivity Aware Routing (ACAR)

The authors [Yang et al., 2010] have tried to target the mobility models with spatial and geographical dependencies being followed in VANET. The authors suggest that from the overall road map, VANET topology consists of one or more sub-graphs. Using the road maps, they have proposed a scheme to select a route with the highest throughput.

3.10.3 Hybrid Location-Based Ad Hoc Routing (HLAR)

The paper [Al-Rabayah and Malaney, 2012] proposes HLAR protocol as a combination of greedy forwarding and location information using reactive routing. The approach answers the problem of sudden topology changes in VANET by using location data. However, with decrease in location information, the protocol adapts towards reactive routing. GPS data is used in modified AODV, to provide geographical routing.

3.10.4 Distribution Adaptive Distance with Channel Quality

Distribution Adaptive Distance with Channel Quality (DADCQ) [Slavik and Mahgoub, 2013] proposes solution for the broadcast storms [Tseng et al., 2002]. It selects the next hop nodes based on adaptive distance thresholds, which are selected according to the changing network environment. Authors have developed a mathematical expression for adaptive decision threshold based upon neighbouring node count, clustering and fading.

3.10.5 Adaptive Probabilistic Flooding for Information Hovering in VANETs

Authors [Xeros et al., 2010] presents an adaptive protocol for geo-cast transmission based upon epidemic routing, with probabilistic flooding to provide limited overheads with maximum reach-ability. Instead of simple broadcast beyond the geo-cast region, this protocol performs probabilistic flooding to minimize the overheads. Authors have considered information hovering as a major problem in many VANET routing protocols. The protocol uses a novel concept of adaptive computation of rebroadcast probability beyond geo-cast region according to node density within geo-cast region.

4 Standardisation of VANET Architectures

Although, a large number of researchers are working on VANET routing issues, the discussion of the VANETs protocol stacks mainly focuses on MAC and PHY layers. All VANET standardisation bodies agree on the use of IEEE 802.1p as a common MAC interface.

IEEE 802.11p is based on frequency band of 5.9 GHz for all of the standards [Brickley et al., 2010]. This band was initially approved by U.S Federal Communications Commission (FCC) under Dynamic Short Range Communication (DSRC) concept. The complete radio spectrum is divided into six service channels (SCH) and one control channel (CCH) with equal bandwidth of 10 MHz each. The CCH is used for emergency messages (originated by safety related applications) and control messages. The SCH is used for all other applications. The entire spectrum is divided into time slots of 50 ms. The CCH communication has priority over the SCH. If the CCH channel is active, all nodes are bound to stop their communication during CCH time frame to receive and transmit emergency messages on CCH channel.

4.1 VANETs Protocol Stacks

ISO has proposed CALM (Continuous Air Interface for Long to Medium range) architecture, IEEE proposed WAVE (Wireless Access in Vehicular Environment) architecture and Car-to-Car Communication Consortium / GeoNet proposed C2CNet architecture. Details of these architectures are defined in subsequent sections.

4.1.1 IEEE WAVE

WAVE is primarily designed for safety applications, only. However, infotainment applications can also be used without modifications. WAVE is strictly based upon DSRC only, and uses two different service sets for network topology handling:

– WAVE Basic Service Set (WBSS) is defined for V2I communication. Any new node can join WBSS on listening a beacon message, without any authentication process.

– WAVE independent basic service set (WIBSS) supports V2V communication.

To handle different layers, WAVE defines six sub-standards (ref Fig 1). IEEE 1609.1 standard deals with the management activities required by the applications. 1609.2 describes the considerations for security parameters. 1609.3 offers Wave Short Messages Protocol (WSMP) for transport and network layer handling of safety applications. 1609.4 defines the coordination between different MAC channels. 1609.5 deals with layer management, while 1609.6 offers an additional middle layer (between transport and application layer) for handling of additional facilities at the applications layer.

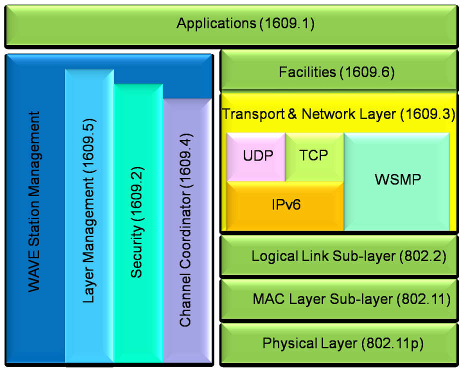

Figure 1: WAVE Architecture

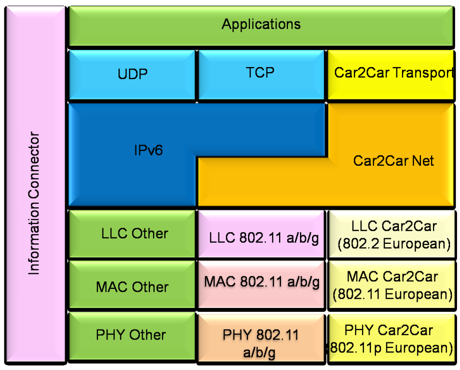

Figure 2: C2C-CC Architecture

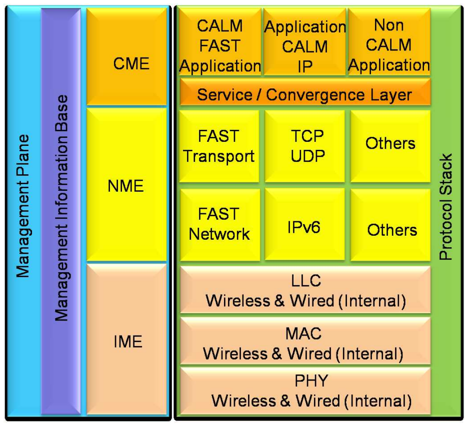

Figure 3: CALM Architecture

4.1.2 ISO CALM

ISO CALM is based on heterogeneous cooperative communication framework, for user transport, using all available interfaces. Its inter and intra layer entities are shown in Fig 3 [ERTICO-ITS, 2009]. In addition to V2V and V2I communication, CALM is designed to handle Vehicle-to-Other interfaces (V2O) communication as well. Less than 1ms link setup time and support for flexibility of incorporation of any future technology, are the CALM highlights.

CALM defines CALM Management Entity (CME) to provide flexibility and adaptability features [Brickley et al., 2010]. It consists of the following three components:

– CALM interface manager monitors and stores the status of each communication interface (CI) and its channel quality.

– CALM Network Manager manages the process of interface handover.

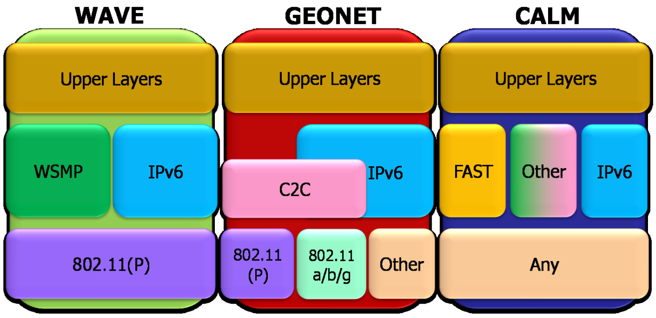

Figure 4: VANET Architecture Comparison

– CALM Application Manager ensures application transmission and QoS requirements.

4.1.3 Car-to-Car Consortium (C2C-CC)

The C2C-CC is focused on development of active safety applications using C2CNet architecture. C2CNet supports multiple interfaces and offers MAC layer based geographical routing [GeoNet, 2010]. Its network layer also provides beaconing for vehicle movement, for use in of geographical routing. C2CNet is incorporated by GeoNet in their comprehensive architecture under project COMeSafety [C2C-CC, 2012].

Unlike WAVE and CALM, safety applications are not restricted to use C2C-CC transport and network layer. Similarly, non-safety applications can also use C2CNet below traditional TCP/IP stack.

4.2 Evaluation of VANET Architectures

Simulation platform for VANET is still an open problem for the research community. There are two types of simulators available for simulation of network topologies, i.e. network simulators and traffic simulators. Both types of simulators are necessary to be used simultaneously to get better results. Thus the proper selection of a simulator is a big question that must be properly analysed and considered before starting any research to avoid improper interaction. MOVE, Trans, VanetMobiSim, NCTUns, NS2, NS3, and NCTUns are the examples for VANET simulators. Table 3 shows the comparisons between the various VANET architectures, achieved through simulations.

4.2.1 MAC and PHY Layers

Fig 4 shows the layer wise comparison of all three architecture stacks. As we can observe that the WAVE architecture is not flexible in terms of MAC and PHY. IEEE 802.11p can be used for scenarios where the focus is on short range communication.

Table 3: Comparison between WAVE, CALM and C2C-CC

Parameters	**WAVE**	**CALM**	**C2C-CC**
Focused on	Only 802.11p at MAC layer for purely emergency messages	Multiple media (802.11p, DSRC, WLAN etc)	Car to car multi-hop and geo networking
PHY Layer	DSRC only	Combination of different technologies	DSRC and other WLAN standards
Wireless Technology	Only PHY layers specific to 802.11p	Interface Abstraction	Support for Media Dependent and Media Independent Part
Group Addressing	Via WBSS	Via Service Initialization	Geo-Addressing
Communication Mode	Uni-cast	Uni-cast, Broad-cast	Uni-cast, Broad-cast, Geo-uni-cast, Geo-broadcast
Support for Application Types	Safety Non-IP & Non Safety IPV6	Non-IP CALM Aware, IPV6 CALM Aware & Legacy	Active Safety, Traffic Efficiency & Infotainment
Security issues	Defined procedures like certificates and signatures	Not very clearly defined and addressed	Different procedures adopted like certificate etc

IEEE WAVE allows only one option at the MAC layer, i.e. 802.11p. It uses the concept of the dedicated control channel through which urgent traffic can be prioritized. ISO CALM is a combination of different technologies from 802.11p to UMTS. Hence it requires a lot of coordination for implementation of interface handover. In C2C-CC architecture different MAC and PHY layer protocols and WLAN options can be used, like IEEE 802.11/a/b/g/p.

4.2.2 Network Layer

By default, IEEE WAVE is based on standard IPv6 design, hence its use for location based safety and awareness messages is limited. To cater the requirements of safety applications, WAVE offers single hop broadcast based messaging protocol named WSMP. On the other hand, C2C-CC supports traditional IP based applications as well as safety applications over a geographical region. It uses C2CNet for non-IP urgent messages and TCP/UDP and IP protocol stack for traditional services. ISO CALM is highly adaptive in terms of network layer protocols. It supports IPv6 for traditional IP services, FAST for emergency and safety messaging and any other protocols through use of management services. Hence, ISO CALM supports location based routing protocols, delay torrent routing protocols as well as adaptive routing protocols.

4.2.3 Management Stack

WAVE architecture is the simplest among all as it is based on traditional IP stack. However, it provides station, channel and layer management facilities. Due to adaptive design and open support for all available technologies, ISO CALM is highly dependent on its management stack. C2C-CC has adequate and well defined security mechanisms. It supports the scenarios where traffic load management by providing different information to the drivers, is required. Additionally C2C-CC clearly defines its suitability for different applications like forward collision avoidance, crossing traffic, red light violation, local danger warning, electronic toll collection, emergency vehicles warning etc. No such definitions are available in WAVE and CALM architectures.

4.2.4 Simulation Support

WAVE is also popular among researchers as this is the only architecture with full simulation support. Although, it has limited degree of freedom of research activities, however, open source simulators, like NCTUns, often provide extended protocol stack support. This support assists researchers to use other options at the MAC layer as well. NCTUns supports the protocol stack of IEEE 802.11p/WAVE, but it does not provide support for IPV6 and Wave Short Message Protocol (WSMP). Many researchers have investigated the various aspects of WAVE. Some have also done performance evaluation at lower layers and presented their modification proposals [Eichler, 2007, Lin and Lin, 2009]. Contrary to IEEE WAVE, so far, no known open source simulator support is available for the complete CALM protocol stack as well as C2C-CC.

SAFESPOT project documentation provides a lot of material for this comparison. The comparisons show that for short range communication, the two better options are WAVE and C2C-CC. In C2C-CC, there is a provision for single and multi-hop as well as Geo-hop communications so we need more resources for multi hop communications in terms of buffer space and processing for each packet. The main difference is the flexibility parameter. It can be concluded here that C2C-CC provides flexibility to use multiple interfaces and multiple MAC and network layer protocols. It is also fast and reliable due to its geographical routing concept. So it will be suitable to adapt for vehicular communication. However, still there is no open source simulator for C2C-CC, which is a big hurdle for the research community.

5 Conclusion

ITS is a major step towards road safety. With the research advancement, many new avenues have been highlighted by the research community. These avenues include QoS support for infotainment services, on road health services and pedestrian detection etc.

In this paper, We discussed the role of routing protocols with respect to what to share to make routing table, i.e. routing metrics, and how to share those metrics to make a routing table. Different routing metrics and sharing schemes used in wired and wireless networks were described. After detailed literature review of state of the art in VANET, it can be concluded that no single approach can satisfy all VANET related issues. Accordingly, state of the art and subsequent analyses show that adaptive routing is more suitable for the dynamic VANET topologies.

Standardization is a very important issue for global ITS deployment. In this paper, a review of standardized architectures for VANET is provided. WAVE, C2C-CC and CALM were found to be the dominating protocol stacks. It is important for efficient deployment of VANET that all standardization agencies provide a well-coordinated solution.

A comparative analysis of these protocol stacks was performed and C2C-CC was found to be a more suitable candidate for VANET communication due to its flexibility in terms of protocol options, media access and security. Although simulation tools for C2C-CC are not available as open source, but its flexibility can offer promising results.

References

[Ahuja, 2010] Ahuja, R. (2010). Simulation based performance evaluation and comparison of reactive, proactive and hybrid routing protocols based on random waypoint mobility model. *International Journal of Computer Applications*, 7(11).

[Al-Rabayah and Malaney, 2012] Al-Rabayah, M. and Malaney, R. (2012). A new scalable hybrid routing protocol for vanets. *Vehicular Technology, IEEE Transactions on*, 61(6):2625–2635.

[Bachir and Benslimane, 2003] Bachir, A. and Benslimane, A. (2003). A multicast protocol in ad hoc networks inter-vehicle geocast. In *Vehicular Technology Conference, 2003. VTC 2003-Spring. The 57th IEEE Semiannual*, volume 4, pages 2456–2460 vol.4.

[Bernsen and Manivannan, 2009] Bernsen, J. and Manivannan, D. (2009). Unicast routing protocols for vehicular ad hoc networks: A critical comparison and classification. *Pervasive and Mobile Computing*, 5(1):1–18.

[Bradner, 1999] Bradner, S. (1999). The internet engineering task force. *Open sources: Voices from the open source revolution*, pages 47–52.

[Brickley et al., 2010] Brickley, O., Koubek, M., Rea, S., and Pesch, D. (2010). A network centric simulation environment for calm-based cooperative vehicular systems. In *Proceedings of the 3rd International ICST Conference on Simulation Tools and Techniques*, page 75. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering).

[C2C-CC, 2012] C2C-CC (2012). Car 2 car communication consortium manifesto.

[Cannone Davide, 2011] Cannone Davide, Naldi Maurizio, I. G. F. B. A. (2011). A simulator of a mobile ad-hoc network in a hostile environment. In *SIMULTECH 2011 - Proceedings of 1st International Conference on Simulation and Modeling Methodologies, Technologies and Applications*, pages 413–417.

[Chakeres and Perkins, 2013] Chakeres, I. D. and Perkins, C. E. (2013). Dynamic manet on-demand routing protocol. Technical report, IETF Internet Draft, draft-ietf-manet-dymo-26.txt.

[Chen et al., 2011] Chen, W., Guha, R. K., Kwon, T. J., Lee, J., and Hsu, Y.-Y. (2011). A survey and challenges in routing and data dissemination in vehicular ad hoc networks. *Wireless Communications and Mobile Computing*, 11(7):787–795.

[Chen et al., 2010] Chen, Y.-S., Lin, Y.-W., and Lee, S.-L. (2010). A mobicast routing protocol in vehicular ad-hoc networks. *Mobile Networks and Applications*, 15(1):20–35.

[Clause, 2003] Clause, Jacquet, P. (2003). Optimized link state routing protocol (olsr). *rfc3626.txt*.

[Clausen et al., 2013] Clausen, T., Dearlove, C., Jacquet, P., et al. (2013). The optimized link state routing protocol version 2. *draft-ietf-manet-olsrv2-19, Work in progress*.

[Dahiya and Chauhan, 2010] Dahiya, A. and Chauhan, R. (2010). A comparative study of manet and vanet environment. *Journal of Computing*, 2(7):87–92.

[Ding and Xiao, 2010] Ding, Y. and Xiao, L. (2010). Sadv: Static-node-assisted adaptive data dissemination in vehicular networks. *Vehicular Technology, IEEE Transactions on*, 59(5):2445–2455.

[Eichler, 2007] Eichler, S. (2007). Performance evaluation of the ieee 802.11 p wave communication standard. In *Vehicular Technology Conference, 2007. VTC-2007 Fall. 2007 IEEE 66th*, pages 2199–2203. IEEE.

[ERTICO-ITS, 2009] ERTICO-ITS (2009). Final release d2 esafety recommendation note.

[Fonseca and Festag, 2006] Fonseca, E. and Festag, A. (2006). A survey of existing approaches for secure ad hoc routing and their applicability to vanets. *NEC network laboratories*, 28:1–28.

[GeoNet, 2010] GeoNet (2010). Final geonet specification, geonet deliverable d2.2. *GeoNet. Website at http://www.geonet-project.eu/*.

[Guoqing et al., 2008] Guoqing, Z., Dejun, M., Zhong, X., Weili, Y., and Xiaoyan, C. (2008). A survey on the routing schemes of urban vehicular ad hoc networks. In *Control Conference, 2008. CCC 2008. 27th Chinese*, pages 338–343. IEEE.

[H. P. Joshi and Kihl, 2007] H. P. Joshi, M. S. and Kihl, M. (2007). Distributed robust geo-cast multicast routing for inter-vehicle communication. In *WEIRD Workshop on WiMax, Wireless and Mobility*, pages 9–21.

[Karp and Kung, 2000] Karp, B. and Kung, H.-T. (2000). Gpsr: Greedy perimeter stateless routing for wireless networks. In *Proceedings of the 6th annual international conference on Mobile computing and networking*, pages 243–254. ACM.

[Kihl et al., 2007] Kihl, M., Sichitiu, M., Ekeroth, T., and Rozenberg, M. (2007). Reliable geographical multicast routing in vehicular ad-hoc networks. In *Wired/Wireless Internet Communications*, pages 315–325. Springer.

[LeBrun et al., 2005] LeBrun, J., Chuah, C.-N., Ghosal, D., and Zhang, M. (2005). Knowledge-based opportunistic forwarding in vehicular wireless ad hoc networks. In *Vehicular technology conference, 2005. VTC 2005-Spring. 2005 IEEE 61st*, volume 4, pages 2289–2293. IEEE.

[Lee et al., 2009a] Lee, K., Le, M., Harri, J., and Gerla, M. (2009a). Taking the louvre approach. *Vehicular Technology Magazine, IEEE*, 4(1):86–92.

[Lee et al., 2009b] Lee, K. C., Lee, U., and Gerla, M. (2009b). Survey of routing protocols in vehicular ad hoc networks. *Advances in Vehicular Ad-Hoc Networks: Developments and Challenges, IGI Global*, 21.

[Leontiadis and Mascolo, 2007] Leontiadis, I. and Mascolo, C. (2007). Geopps: Geographical opportunistic routing for vehicular networks. In *World of Wireless, Mobile and Multimedia Networks, 2007. WoWMoM 2007. IEEE International Symposium on a*, pages 1–6. IEEE.

[Li and Wang, 2007] Li, F. and Wang, Y. (2007). Routing in vehicular ad hoc networks: A survey. *Vehicular Technology Magazine, IEEE*, 2(2):12–22.

[Lin and Lin, 2009] Lin, K.-C. and Lin, C.-H. (2009). Development of telematics communication system with wave dsrc. In *Systems, Man and Cybernetics, 2009. SMC 2009. IEEE International Conference on*, pages 4158–4163. IEEE.

[Liu and Kaiser, 2008] Liu, C. and Kaiser, J. (2008). *A survey of mobile ad hoc network routing protocols*. Universität Ulm, Fakultät für Informatik.

[Lochert et al., 2003] Lochert, C., Hartenstein, H., Tian, J., Fussler, H., Hermann, D., and Mauve, M. (2003). A routing strategy for vehicular ad hoc networks in city environments. In *Intelligent Vehicles Symposium, 2003. Proceedings. IEEE*, pages 156–161. IEEE.

[Lochert et al., 2005] Lochert, C., Mauve, M., Füßler, H., and Hartenstein, H. (2005). Geographic routing in city scenarios. *ACM SIGMOBILE Mobile Computing and Communications Review*, 9(1):69–72.

[Loulloudes et al., 2012] Loulloudes, N., Pallis, G., and Dikaiakos, M. D. (2012). On the performance evaluation of vanet routing protocols in large-scale urban environments (poster). In *Vehicular Networking Conference (VNC), 2012 IEEE*, pages 129–136. IEEE.

[Luo et al., 2010] Luo, Y., Zhang, W., and Hu, Y. (2010). A new cluster based routing protocol for vanet. In *Networks Security Wireless Communications and Trusted Computing (NSWCTC), 2010 Second International Conference on*, volume 1, pages 176–180. IEEE.

[Mohammad et al., 2011] Mohammad, S. A., Rasheed, A., and Qayyum, A. (2011). Vanet architectures and protocol stacks: a survey. In *Communication Technologies for Vehicles*, pages 95–105. Springer.

[Murray et al., 2008] Murray, T., Cojocari, M., and Fu, H. (2008). Measuring the performance of ieee 802.11 p using ns-2 simulator for vehicular networks. In *Electro/Information Technology, 2008. EIT 2008. IEEE International Conference on*, pages 498–503. IEEE.

[Namboodiri and Gao, 2007] Namboodiri, V. and Gao, L. (2007). Prediction-based routing for vehicular ad hoc networks. *IEEE Transactions on Vehicular Technology*, 56(4):2332–2345.

[Naumov et al., 2006] Naumov, V., Baumann, R., and Gross, T. (2006). An evaluation of intervehicle ad hoc networks based on realistic vehicular traces. In *Proceedings of the 7th ACM international symposium on Mobile ad hoc networking and computing*, pages 108–119. ACM.

[Naumov and Gross, 2007] Naumov, V. and Gross, T. R. (2007). Connectivity-aware routing (car) in vehicular ad-hoc networks. In *INFOCOM 2007. 26th IEEE International Conference on Computer Communications. IEEE*, pages 1919–1927. IEEE.

[Oliveira et al., 2011] Oliveira, R., Garridot, A., Pasquini, R., Liu, M., Bernardo, L., Dinis, R., and Pinto, P. (2011). Towards the use of xor-based routing protocols in vehicular ad hoc networks. In *Vehicular Technology Conference (VTC Spring), 2011 IEEE 73rd*, pages 1–6. IEEE.

[Peng et al., 2006] Peng, Y., Abichar, Z., and Chang, J. M. (2006). Roadside-aided routing (rar) in vehicular networks. In *Communications, 2006. ICC'06. IEEE International Conference on*, volume 8, pages 3602–3607. IEEE.

[Perkins and Royer, 1999] Perkins, C. E. and Royer, E. M. (1999). Ad-hoc on-demand distance vector routing. In *Mobile Computing Systems and Applications, 1999. Proceedings. WMCSA'99. Second IEEE Workshop on*, pages 90–100. IEEE.

[Rasheed and Ajmal, 2009] Rasheed, A. and Ajmal, S. (2009). 3d-a doppler, directivity and distance based architecture for selecting stable routing links in vanets. In *Computer, Control and Communication, 2009. IC4 2009. 2nd International Conference on*, pages 1–5. IEEE.

[Rasheed et al., 2014] Rasheed, A., Ajmal, S., and Qayyum, A. (2014). Protocol independent adaptive route update for vanet. *The Scientific World Journal*, 2014:10.

[Rasheed et al., 2010] Rasheed, A., Qayyum, A., and Ajmal, S. (2010). Security architecture parameters in vanets. In *Information and Emerging Technologies (ICIET), 2010 International Conference on*, pages 1–6. IEEE.

[Rasheed et al., 2013] Rasheed, A., Zia, H., Hashmi, F., Hadi, U., Naim, W., and Ajmal, S. (2013). Fleet & convoy management using vanet. *Journal of Computer Networks*, 1(1):1–9.

[Saleet et al., 2009] Saleet, H., Langar, R., Basir, O., and Boutaba, R. (2009). Adaptive message routing with qos support in vehicular ad hoc networks. In *Global Telecommunications Conference, 2009. GLOBECOM 2009. IEEE*, pages 1–6. IEEE.

[Santos et al., 2004] Santos, R., Edwards, R., Edwards, A., and Belis, D. (2004). A novel cluster-based location routing algorithm for inter-vehicular communication. In *Personal, Indoor and Mobile Radio Communications, 2004. PIMRC 2004. 15th IEEE International Symposium on*, volume 2, pages 1032–1036. IEEE.

[Schnaufer and Effelsberg, 2008] Schnaufer, S. and Effelsberg, W. (2008). Position-based unicast routing for city scenarios. In *World of Wireless, Mobile and Multimedia Networks, 2008. WoWMoM 2008. 2008 International Symposium on a*, pages 1–8. IEEE.

[Shafiee and Leung, 2011] Shafiee, K. and Leung, V. (2011). Connectivity-aware minimum-delay geographic routing with vehicle tracking in vanets. *Ad Hoc Networks*, 9(2):131–141.

[Shah et al., 2005] Shah, R. C., Wolisz, A., and Rabaey, J. M. (2005). On the performance of geographical routing in the presence of localization errors [ad hoc network applications]. In *Communications, 2005. ICC 2005. 2005 IEEE International Conference on*, volume 5, pages 2979–2985. IEEE.

[Skordylis and Trigoni, 2008] Skordylis, A. and Trigoni, N. (2008). Delay-bounded routing in vehicular ad-hoc networks. In *Proceedings of the 9th ACM international symposium on Mobile ad hoc networking and computing*, pages 341–350. ACM.

[Slavik and Mahgoub, 2013] Slavik, M. and Mahgoub, I. (2013). Spatial distribution and channel quality adaptive protocol for multi-hop wireless broadcast routing in vanet.

[Song et al., 2010] Song, T., Xia, W., Song, T., and Shen, L. (2010). A cluster-based directional routing protocol in vanet. In *Communication Technology (ICCT), 2010 12th IEEE International Conference on*, pages 1172–1175. IEEE.

[Sun et al., 2000] Sun, M.-T., Feng, W.-C., Lai, T.-H., Yamada, K., Okada, H., and Fujimura, K. (2000). Gps-based message broadcasting for inter-vehicle communication. In *Parallel Processing, 2000. Proceedings. 2000 International Conference on*, pages 279–286. IEEE.

[Sun et al., 2006] Sun, W., Yamaguchi, H., Yukimasa, K., and Kusumoto, S. (2006). Gvgrid: A qos routing protocol for vehicular ad hoc networks. In *Quality of Service, 2006. IWQoS 2006. 14th IEEE International Workshop on*, pages 130–139. IEEE.

[Tonguz et al., 2007] Tonguz, O., Wisitpongphan, N., Bai, F., Mudalige, P., and Sadekar, V. (2007). Broadcasting in vanet. In *2007 mobile networking for vehicular environments*, pages 7–12. IEEE.

[Tseng et al., 2002] Tseng, Y.-C., Ni, S.-Y., Chen, Y.-S., and Sheu, J.-P. (2002). The broadcast storm problem in a mobile ad hoc network. *Wireless networks*, 8(2/3):153–167.

[Tsukada et al., 2010] Tsukada, M., Jemaa, I. B., Menouar, H., Zhang, W., Goleva, M., and Ernst, T. (2010). Experimental evaluation for ipv6 over vanet geographic routing. In *Proceedings of the 6th International Wireless Communications and Mobile Computing Conference*, pages 736–741. ACM.

[Wang et al., 2008] Wang, Y., Ahmed, A., Krishnamachari, B., and Psounis, K. (2008). Ieee 802.11 p performance evaluation and protocol enhancement. In *Vehicular Electronics and Safety, 2008. ICVES 2008. IEEE International Conference on*, pages 317–322. IEEE.

[Wu et al., 2010] Wu, C.-S., Hu, S.-C., and Hsu, C.-S. (2010). Design of fast restoration multipath routing in vanets. In *Computer Symposium (ICS), 2010 International*, pages 73–78. IEEE.

[Xeros et al., 2010] Xeros, A., Lestas, M., Andreou, M., and Pitsillides, A. (2010). Adaptive probabilistic flooding for information hovering in vanets. In *Vehicular Networking Conference (VNC), 2010 IEEE*, pages 239–246. IEEE.

[Xia et al., 2009] Xia, Y., Yeo, C. K., and Lee, B. S. (2009). Hierarchical cluster based routing for highly mobile heterogeneous manet. In *Network and Service Security, 2009. N2S'09. International Conference on*, pages 1–6. IEEE.

[Xu et al., 2004] Xu, Q., Mak, T., Ko, J., and Sengupta, R. (2004). Vehicle-to-vehicle safety messaging in dsrc. In *Proceedings of the 1st ACM international workshop on Vehicular ad hoc networks*, pages 19–28. ACM.

[Yan et al., 2010] Yan, G., Mitton, N., and Li, X. (2010). Reliable routing protocols in vehicular ad hoc networks. In *Proceedings of the Seventh Workshop on Wireless Ad hoc and Sensor Networks (WWASN2010)*, pages 21–25.

[Yang et al., 2010] Yang, Q., Lim, A., Li, S., Fang, J., and Agrawal, P. (2010). Acar: adaptive connectivity aware routing for vehicular ad hoc networks in city scenarios. *Mobile Networks and Applications*, 15(1):36–60.

[Yin et al., 2004] Yin, J., ElBatt, T., Yeung, G., Ryu, B., Habermas, S., Krishnan, H., and Talty, T. (2004). Performance evaluation of safety applications over dsrc vehicular ad hoc networks. In *Proceedings of the 1st ACM international workshop on Vehicular ad hoc networks*, pages 1–9. ACM.

[Zeadally et al., 2012] Zeadally, S., Hunt, R., Chen, Y.-S., Irwin, A., and Hassan, A. (2012). Vehicular ad hoc networks (vanets): status, results, and challenges. *Telecommunication Systems*, 50(4):217–241.

[Zhao and Cao, 2006] Zhao, J. and Cao, G. (2006). Vadd: Vehicle-assisted data delivery in vehicular ad hoc networks. In *IEEE infocom*, volume 6, page 57.