Routing in Vehicular Ad Hoc Networks: Issues and Protocols

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Abstract

Vehicular ad hoc networks (*VANETs*) are a practical application class of wireless ad hoc networks, which consist of moving vehicles equipped with radio communication capabilities that collaborate to form a temporary network. This paper addresses issues and protocols of *multihop routing* in such emerging networks in the context of safety and infotainment applications. Due to the highly dynamic mobility of vehicles, frequent link breakage and short connection time are inevitable and, thus, the routing is a challenging task and interest for many researchers and industrial community. The frequent and dynamic change of topology makes the *topology-based routing* unreliable but the *position-based routing* more effective. The position-based routing consists of the location service which maps a node id to a geographical position and the forwarding scheme which selects the next hop based on geographical information of the node, its neighbors and the destination. The routing techniques are further categorized into geographical forwarding, trajectory forwarding and opportunistic forwarding based on the forwarding scheme. In this paper, we first present the distinguished properties of VANETs and the challenges and intractable issues posed in designing the routing protocols, followed by the comprehensive survey of existing routing protocols. Then, the different routing protocols designed for VANETs are compared in terms of characteristics, performance and application domains.

Keywords : Vehicular ad hoc network, routing protocol, position based routing, location service, forwarding scheme, mobility.

1. Introduction

Vehicular ad hoc networks (*VANETs*) are a practical application class of mobile ad hoc net-

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※ This article is a revised and extended version of [25] presented at ICEIC 2008.

works (MANETs), where multihop ad hoc paradigm is successfully applied in pragmatic way to extend the Internet and/or to support well defined requirements [1]. VANET can be defined as a distributed and self-organizing communication system composed of moving vehicles with radio communication capabilities that collaborate to form a temporary network. *IEEE 802.11p* or *wireless access in vehicular environment* (*WAVE*) [2] is the result of standardization effort to provide wireless communication capabilities for the vehicular environment with 1000*m* range typically in highway. VANETs are definitely a key area in intelligent transportation systems (ITS's). Existing ITS traffic monitoring systems are infrastructure-based, in which roadside sensors and cameras monitor the traffic density that is transmitted to the centralized unit for further processing. Such systems take long processing time and deployment cost is high and, thus, vehicle-to-vehicle communication is an efficient alternative.

In the past few years, there were several projects focusing on VANETs. CarTalk2000 [3] was a European project for development of co-operative driver assistance systems and self organizing ad hoc radio network as a communication basis with the aim of preparing a future standards. FleetNet [4] was a European program, in which a platform for inter-vehicle communications was developed. The network-on-wheels (NOW) [5] is a German research project started in 2004, the objectives of which was to develop communication protocols and data security algorithms for inter-vehicle ad hoc communication systems to support active safety applications and infotainment applications with infrastructure and between vehicles. Car2Car Communication Consortium [6] was initiated by European vehicle manufacturers to create and establish a European industry standard for car-to-car communication systems based on WLAN components in order to enable the development of active safety applications.

Due to the highly dynamic mobility of vehicles, frequent link breakage and short connection time are inevitable, and routing and network management functionalities highly rely on participating nodes. Therefore, the routing is a challenging task in VANETs. The conventional *topology-based routing* broadly adapted in MANETs is quite unreliable in the VANET environments due to the frequent and dynamic change of topology, but *poison-based routing* (*PBR*) is more robust. The PBR needs *location service* (to localize vehicles) and *forwarding scheme* (to deliver packets) for routing. The forwarding schemes are further classified into three categories: greedy forwarding, trajectory forwarding and opportunistic forwarding [7].In this paper, a comparative survey of routing protocols in VANETs is presented in the context of safety and infotainment applications. Based on the distinguished challenging issues posed in designing the routing protocols, many different routing protocols proposed in the literatures so far are surveyed and compared in terms of characteristics, performance and application domains.

The remainder of this paper is organized as follows: The important properties of VANETs are described in the following section. Section 3 summarizes design issues in routing. Existing routing protocols for VANETs are introduced, discussed and compared in Section 4. Finally, some open issues and concluding remarks are covered in Section 5.

2. Properties of VANETs

A VANET is an instantaneous and challenging class of MANETs. It behaves as a MANET and shares different MANET properties. However, properties like driver behavior, mobility constraints and high mobility of vehicles cause frequent link breakage and long latency, which lead some differences from MANETs:

• *Network topology*: Due to the high speed of vehicles, the network topology changes very frequently. It could be affected by driver's behavior as well [7].

• *Network density and variability*: The network density directly depends on the number of vehicles in a particular location and can be varied at different time, road condition, etc.

• *Connectivity and low latency*: Vehicles can join and leave the network in very short time leading to frequent network partitioning. Such a partitioning reduces the lifetime of routes. For dissemination of safety information, low latency of 100 milliseconds should be guaranteed [8].

• *Energy and processing capacity*: VANET nodes (vehicles) have powerful and rechargeable energy source and high processing capacity.

• *Displacement environment*: Vehicles are constrained to move within the road infrastructures such as highway and city roads. Moreover, the constraint imposed by the environment (e.g., buildings) affect the quality of radio transmission.

3. Issues in Routing

A VANET is a distributed and temporary communication system formed by a number of vehicles without any infrastructure and, thus, the routing in a VANET relies on vehicles that have unique properties such as high mobility. The frequent topology changes and mobility constraints cause the challenges in routing. Following issues may be considerable for reliable and efficient routing while designing new routing protocols:

• *Connectivity of link*: Vehicles can leave and join another network in very short time. This may cause frequent link breakage and resulting route failure. Therefore, the reliability of links might be the important issue.

• *Latency*: The interest and popularity of VANET are growing because of driver safety and other infotainment applications. The U.S. Department of Transportation's vehicle safety communication project defines 100 milliseconds of latency for the requirements for safety applications [8].

• *Obstacle*: In the city roads, high buildings are the radio obstacle for the DSRC wireless channel, and the transmission may be failed in such situations.

• *QoS*: Only the position information of vehicles is not sufficient for QoS routing protocol but also other parameters such as the movement direction of vehicles, velocity, and acceleration are issues for efficient routing.

4. Routing Protocols

The conventional *topology-based routing* protocols need to maintain global routing information of a network. Since the high mobility of vehicles leads to frequent topology change and link breakage, the topology-based routing protocols are not suitable for VANETs. On the other hand, the *position-based routing* (*PBR*) protocols are reliable and efficient for the vehicular environment that requires position information about geographic position of participating nodes. The position information of nodes can be obtained from global positioning system (GPS) or location service schemes [9]. The PBR protocols consist of *location service* which maps node id to geographical position and *forwarding schemes* which selects the next hop neighbor based on geographical information of the node, neighbors and destination to forward the data [10].

In this section, we review and compare the existing routing protocols proposed so far for VANETs in the literatures. For the systematic classification of various routing protocols, we categorize them into three domains of geographic forwarding based routing protocols, trajectory forwarding based routing protocols and opportunistic forwarding based routing protocols on the basis of the forwarding schemes as in [7]. They are reviewed in the following three subsections and compared in Section 4.4.

4.1 Geographic Forwarding Based Protocols

In these protocols, the geographic position of nodes is necessary to forward the packet in a greedy way to the neighbor which is geographically closest to the destination. If the node (which contains the packet to be forwarded) does not find the neighbor closer to the destination than itself within its radio range, the greedy algorithm may fail.

Greedy Perimeter Stateless Routing (GPSR): GPSR [11] combines greedy forwarding on full network graph with perimeter forwarding using planar graph traversal where greedy forwarding is not possible. The planar graph is a graph with no intersection between any two edges. The graph formed by an ad hoc network is generally not a planar graph. It is important to know that the decision as to whether an edge is within the planar subgraph can be made locally by each node, since each node knows the position of all its neighbors [9]. When packet reaches a location closer than where the greedy forwarding is previously failed, the packet successively continue greedy progress toward the destination without the risk of local maximum.

Geographic Source Routing (GSR): GSR [12] combines PBR with topological knowledge of the road; it is obtained from a navigation system. It uses reactive location service (RLS) to know the current position of the desired communication partner. When the querying node requires position information of neighboring nodes, it floods the '*position request*' containing its id to the network in reactive way. When the corresponding node receives the request, it sends '*position reply*' to the querying node. With the position information of neighbor nodes, the sender node computes a sequence of junctions, through which a packet has to traverse to reach its destination using city map. Note that the sequence of junctions can be either contained in the packet header or computed by each forwarding node [12]. Forwarding a packet to successive junctions is done on the basis of greedy forwarding and using Dijkstra's shortest path algorithm, and the distance from source to destination can be calculated based on the city map. When a route break occurs, GSR uses the recovery strategy '*fall back on greedy mode*' to bypass the particular node.

Virtual Vertex Routing (VVR): VVR [13] uses the line information (i.e. roads, rails and courses) of each vehicle, which is provided by navigation system or digital road map equipped in vehicles. It forwards packet in greedy way to the intermediate nodes and solves the so-called *routing hole problem.* If the node density is high enough, routing holes occur rarely and geographic routing is effective [14]. However, it is claimed in [13] that the node density is much more dependent on the layout of lines. So, the high node density does not help to solve the routing hole problem if all the vehicles lie on a specific line. VVR represents the network as a graph and uses the concept of *virtual vertex* (i.e., the adjacent crossing point of two vertices). The intermediate nodes in the proximity of vertex perform routing towards destination using Floyd algorithm. To tackle the routing hole problem, VVR-greedy routing (VVR-GR) and VVR-face routing (VVR-FR) schemes are proposed as well [13]. VVR-GR reduces the recovery time of routing holes and VVR-FR can guarantee the delivery of packets.

Improved Greedy Traffic Aware Routing Protocol (GyTAR): GyTAR [15] is an improved greedy traffic aware, intersection-based geographic routing protocol which uses real-time traffic density information and movement prediction to route packets. It consists of two modules of (i) selection of junctions through which a packet must pass to reach its destination and (ii) an improved greedy forwarding mechanism between two junctions [15]. When a vehicle receives a packet, it computes its next junction with the highest score by considering traffic density and curve-metric distance to the destination. The junction with the highest score is geographically closest to the destination vehicle and has the highest vehicular traffic. Between two adjacent junctions, the packets are forwarded through the vehicles on between the successive junctions by using improved greedy forwarding. Each vehicle maintains a table containing position, velocity and direction of each neighboring vehicles, and the table is updated by periodically exchanging HELLO messages among vehicles. Using the information in the table, forwarding vehicles select their next hop neighbor which is closest to the destination junction.

4.2 Trajectory Forwarding Based Protocols

In these protocols, messages are directed along with the predefined trajectory or path. The performance of these routing protocols is satisfactory even in the network with sparseness condition. The forwarding trajectory is an extended path from source to destination and helps to limit data propagation and, thus, it reduces message overhead and no end-to-end connectivity is assumed.

Connectivity Aware Routing (CAR): CAR [16]finds a connected path between source and destination and maintains it permanently. CAR uses adaptive beaconing mechanism containing velocity vector of vehicles. Every node updates its neighbor table containing sender of beacons, sets its own and neighbors' velocity vector, and sets the expiration time for an entry in the table. In CAR, two type of guards are defined: *standing guard* and *traveling guard*. The standing guard gives geographic area information of nodes and the traveling guard contains velocity vector. Preferred group broadcasting in data dissemination mode helps to find destination and a path to it. If two velocity vectors are almost parallel with a very small angle between them, the two vehicles can serve as a relay of the packet to destination each other. If the direction of two velocity vectors is different, the node adds an anchor to a broadcast packet. When several path discovery requests are received, the destination chooses a path with better connectivity and lower delay [16]. CAR uses mechanism of advanced greedy forwarding and forwards packet to the neighbor closest to the next anchor point. CAR handles routing errors using two mechanisms of *timeout algorithm with active waiting* and *cycle walk around error recovery*.

Anchor-Based Street and Traffic Aware Routing (A-STAR): A-STAR [17] uses spatial information of street map to compute the sequence of anchor or junction with less weight. The weight can be assigned to each street based on density of vehicles in the street. Note here that low weight represents high density or traffic and vice versa. This uses static information but the real traffic information is needed. So, it is required that the weight of each anchor is recomputed from map information, resulting in the so-called *dynamic rated map* [17]. The street at which local maximum occurred is marked by 'out of service' temporarily ,and this information is distributed to the network by piggybacking them into the packet to be recovered and prevents traversing through the anchor at which local maxim occurred.

Spatially Aware Routing (SAR): SAR [18] uses a spatial model to predict and avoid forwarding failures due to permanent topology holes. Using the spatial model called parser proposed in [19], the topology information of roads can be extracted from a digital road map in geographic data format (GDF). Spatial model is based on the extracted topology information, which is known as graph spatial model $G(E,V)$ consists of a set V of vertices and a set $E$of edges. SAR consists of *geographic source route* (*GSR*) and GSR-based packet forwarding. In the spatial model, a source vehicle calculates the shortest path P to the destination using the shortest path algorithm. Then, the source vehicle sets GSR to P consisting of intermediate vertices. In the GSR-based forwarding, all data packets are marked by source, destination and intermediate vehicles along with GSR. When a forwarding vehicle finds the vertex to be located within its radio, that vertex will be removed from the GSR and packets will be forwarded to the next vertex of the GSR.

4.3 Opportunistic Forwarding Based Protocols

In these protocols, data packets are stored and forwarded opportunistically. When a packet is forwarded to an intermediate node, a copy of the packet may remain with the transmitting vehicle, which may be forwarded later again to improve reliability. Note that no end-to-end path can be assumed in these protocols.

Geographical Opportunistic Routing (GeOpps): In GeOpps [20], each vehicle calculates its suggested route and the estimated time of arrival (ETA) of vehicles to the destination is calculated using the information contained in the navigation system. When a vehicle gets a packet, it calculates the nearest point (NP) to reach the destination from its suggested route. If the vehicle (with the packet to de forwarded) encounters one or more vehicles in its suggested route, it uses *utility function* to calculate the minimum estimated time of delivery (METD) of packet through the neighbor vehicles and itself using map information. Therefore, METD = ETA to NP + ETA from NP to D. Then, the intermediate forwarding vehicle forwards packets to the vehicle with the lowest METD value.

Mobility Centric Data Dissemination Algorithm (MDDV): MDDV [21] combines the idea of geographic forwarding, trajectory forwarding and opportunistic forwarding. A road network can be assumed as a directed graph, where nodes represent intersections, edges represent road segments and geographic distance can be obtain. A forwarding trajectory is a path extending from source to destination with the smallest sum of weights in the weighted road graph. Dissemination length is the lowest weight from source to destination in the weighted graph. The dissemination length of road segment is used as the weight for the link in a road graph. Dissemination process consists of forwarding phase and propagation phase. A message is forwarded through intermediate nodes and the node which holds message is known as *message head*. To increase reliability, MDDV forwards messages to the set of nodes around the message head. Vehicles store messages until memory buffer is full and drop the packet when they leaves passive state during the forwarding phase and leaves active state during the propagation phase.

Movement Prediction Based Routing (MOPR): MOPR [22] takes into account of position, direction and speed of vehicles to predict vehicles' future position and size of data to send. It uses *stable route* in which intermediate nodes are moving in similar direction and speed with respect to source and destination vehicles. If transmission starts at t_0 and time needed to transmit data is T, MOPR first estimates the position of vehicles at time $t_0 + T$. Then, it estimates the distance at time $t_0 + T$ taking into account a processing time between each node and its neighbors in the route. If this distance is longer than the communication radio range, then the route is not considered as stable. It avoids link ruptures so the frame loss rate is reduced while improving the network efficiency by predicting future nodes' positions.

Prediction Based Routing (PBR): PBR [23] uses predictable motion of vehicles along with readily available location and velocity information of vehicles to predict route lifetimes to create new route before existing one fails. The link formed by the vehicles moving in same direction has longer duration than that moving in opposite direction. To establish a route, a source node broadcasts route request (RREQ) packet with a time to live (TTL) value specifying the number of hops to search for a gateway that would have the required route. If the source gets multiple routes for the same gateway, it chooses the route with the maximum predicted route lifetime. Based on the velocity and location information of predecessor available in route response (RREP) packet and those of itself, all the intermediate nodes predict the lifetime of the link between the two nodes using the prediction algorithm: $lifetime_{link} = R - |d_{ij}| / |v_i - v_j|$, where R is the communication range, $|d_{ij}|$ is the absolute distance between two nodes i and j, and v_i and v_j are the corresponding velocities of nodes i and j.

Motion Vector (MOVE): MOVE [24] uses velocity information to make forwarding decisions. In MOVE, vehicles are used as mobile routers to collect and deliver a data between static nodes (road side sensors and a central server). A message is cached for an arbitrary amount of time at the mobile carrier or intermediate static node. The destination node is static and its position is known globally throughout the network. MOVE leverages the knowledge of relative velocities of a mobile router and its neighboring nodes to predict the closest distance to the destination. In [24], authors described different ways of determining the closest distance and rules for making forwarding decisions in the MOVE algorithm.

4.4 Comparison

In Table 1, the different routing protocols discussed earlier are compared in terms of their characteristics, performance and application domains. For performance issues, major performance metrics such as scalability, delay, delivery ratio and overhead are studied.

In the geographic forwarding based routing protocols, GPSR is scalable under the increasing number of nodes but its overhead increases due

Table 1. Comparison of different routing protocols.

Category	Routing protocol	Characteristics	Performance	Applications focused
Geographic forwarding	GPSR	Uses planar graph traversal for packet forwarding in perimeter mode	Scalable under the increasing number of nodes and increasing mobility rate	Vehicular networks with frequent route failure
	GSR	Combines position and topological information in routing decision	Performs well at the high mobility of nodes	City areas
	GyTAR	Uses real time traffic information and movement prediction	Efficient usage of network resource and low end-to-end delay	City environments
	VVR	Uses the proximity of vertex	Delivery ratio is 100% and routing overhead remains constant as speed increases.	Vehicular networks with frequent routing hole condition
Trajectory forwarding	SAPR	Uses spatial model to predict and avoid forwarding failure	Significantly improves forwarding performance in situations with many permanent topology hole	City environments
	CAR	Provides connectivity path between source and destination	High delivery ratio and low overhead even with increased density	Inter-vehicle communication in the city and on the highway
	A-STAR	Uses spatial information for routing decisions and selects path with higher connectivity	Improves packet delivery while maintaining reasonable end-to-end delay	Metropolis vehicular communications
Opportunistic forwarding	PBR	Uses predicted route lifetime to create a new route before existing route fails	Significantly improves route failure, higher packet delivery ratio and control overhead	Highway areas
	GeOpps	Uses concept of the nearest point and the estimated time of arrival to the destination	Delivery ratio is very high and the required minimum number of hops is constant with the increased number of vehicles.	Vehicular networks with constantly changing topology and no end-to-end connectivity
	MDDV	Exploits vehicle mobility for data dissemination	Improves delivery efficiency but the overhead is similar to that of central intelligence scheme	Frequently partitioned and highly mobile vehicular networks
	MOPR	Predicts future nodes' position	Reduces frame loss rate	Reactive routing in VANETs
	MOVE	Uses velocity information to make forwarding decision	Delivers data successfully with the minimal delay	Data collection and delivery between static nodes (roadside sensors a central server)

to location registration and lookup traffic for location database. In GyTAR, the delivery ratio is not satisfactory whereas packets are delivered with lower end-to-end delay. In VVR, the packet delivery ratio is 100% and overhead remains constant as speed increases but the delay increases with increased speed.

In the trajectory forwarding based routing protocols, CAR outperforms other two routing protocols because its delivery ratio is improved and overhead is reduced with increased density. On the other hand, A-STAR improves the packet delivery ratio while maintaining the reasonable end-to-end delay.

In the opportunistic forwarding based routing protocols, MDDV, GeOpps and PBR give higher delivery ratio than the other protocols. MOPR significantly reduces the frame loss rate and MOVE can deliver packets with the minimum delay. In addition, MDDV supports all of the forwarding schemes.

Of all the routing protocols studied in this paper, VVR is the best one in terms of delivery ratio while MDDV should be the choice if the minimal overhead is the primary concern. Furthermore, it should be noticed that GPSR gives good scalability and GyTAR gives low end-to-end delay.

5. Conclusions and Open Issues

In this paper, a comparative survey of routing protocols in VANETs has been presented in the context of safety and infotainment applications. Based on the distinguished challenging issues posed in designing the routing protocols, many different routing protocols proposed in the literatures so far have been discussed and compared in terms of characteristics, performance and application domains. The geographic forwarding based routing protocols are mainly focused on the vehicle position and density for making routing decisions. In particular, GyTAR forwards packets through anchors and perform well in city environments. On the other hand, the trajectory forwarding based routing protocols are mostly focus on the connectivity and lifetime of routes and forward the packets along with the route with high connectivity and long life time. Finally, the opportunistic forwarding based routing protocols predict vehicles' future position and movement using different techniques and opportunistically select the next packet carrier to forward the packet to destination. Of them, VVR is the best one in terms of packet delivery ratio (which is 100% as mentioned earlier) while MDDV should be the choice if the minimal overhead is the primary concern.

Routing in VANETs has attracted a lot of attention to researchers in recent years and introduced many challenges. Vehicle mobility, frequent link breakage, and frequent topology changes are primary issues while available bandwidth, hidden and exposed terminal, and obstacles can be taken as secondary issues for routing.

In CAR, constructing the minimal infrastructure in the form of 'guard' along with a path from source to destination is an open issue. Another technical issue in the VANET routing is to make intermediate vehicles more flexible in manipulating messages. That is, the intermediate vehicles may specify a better forwarding trajectory, change the destination region, and aggregate multiple messages based on the spatial and temporal semantics of target applications. Real-time road density can be inferred by observing transmitted packets and vehicle movement patterns, but further study is needed in terms of workload characterization. Also, a comparison of data delivery schemes under various traffic conditions and vehicle failure models may be an important topic. The tradeoff between the radio range and the network capacity in the dynamic environments is also an open issue. Note here that the transmitting power is not a major issue in VANETs but the radio interference (due to high power) is a major issue requiring the careful design of power control. Most routing protocols use effective parameters for single layer, but cross-layer design and optimization can improve quality of service (QoS) as well as the routing performance.

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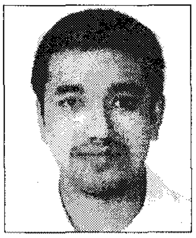

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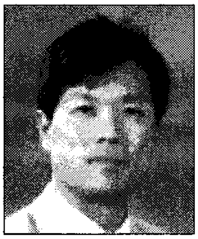

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