Analysis of Routing Protocols in Vehicular Ad Hoc Network Applications

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Abstract. Vehicular Ad Hoc Networks (VANETs) are self-organizing, self-healing networks that provide wireless communication among vehicles and roadside equipment. Providing safety and comfort for drivers and passengers is a promising goal of these networks. Designing an appropriate routing protocol according to the network application is one of the essential requirements for implementing a successful vehicular network. In this paper, we report the results of a study on routing protocols related to vehicular applications and their communication needs. In general, all VANET communications can be implemented by either unicast or multicast routing protocols. The results of the study showed that multicast protocols, including geocast and mobility-based routing, are more promising than others for fulfilling the application requirements and, consequently, more research of these protocols is needed.

Keywords: vehicular networks, VANET applications, VANET, ad hoc networks, MANET, routing.

1 Introduction

Every year, millions of road accidents occur in the world. This result in the loss of more than 1.2 million lives and destruction of about 1 to 2% of total of gross national products [1]. Annual averages from 1980 to 2008 in U.S. shows 42,810 people killed and 2.928 million wounded [2], at an estimated economic cost of over 231 billion dollars; more than 40,000 people die and 1.8 million people are injured on European roads each year [3]. Furthermore, traffic jams and stop lights, in large cities create a massive waste of time and fuel, especially during rush hours. Providing a reliable vehicular communication system to transfer and share relevant information with drivers and vehicles can significantly increase road safety and improve traffic distribution on congested roads.

Vehicular Ad Hoc Network (VANET) is a rising subclass of Mobile Ad Hoc Networks (MANETs) which provide wireless communication between mobile nodes (vehicles) and vehicles to roadside equipments. The efficiency of this network depends on how quickly and accurately routing protocols can make decisions to route

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data. Large-scale and highly dynamic topology, frequently partitioned and disconnected network, and patterned mobility of the nodes are some challenging characteristics of VANET which result in significant loss rates and very short communication times [4]. These attributes influence the performance of routing solutions suitable for ordinary MANET. Hence in recent years, researchers have attempted to overcome these problems and propose some new protocols for vehicular networks.

Previous survey studies on VANET routing protocols have been conducted by [4-9]. This study extended the previous studies because it focused on classifying routing protocols based on specific vehicular applications and their requirements to determine an appropriate routing strategy for each application.

2 Vehicular Network Applications

In this section, we present an overview of applications formed by vehicular ad hoc networks, then discuss their requirements with respect to routing, in next section. A good overview of these applications is available in [5, 10-15].

In Figure 1, we demonstrate the different classifications of vehicular ad hoc network applications. VANET applications consist of two main categories: safety and user (non-safety) [12]. Safety applications are the primary purpose of vehicular communication technology development. They increase traffic safety and significantly reduce the number of road accidents by providing warning messages for drivers a few moments before collision. User applications provide information, advertisement and entertainment services for drivers and passengers. Each category can also be divided into several classes. Safety applications are comprised of public safety, traffic management, and traffic coordination and driver assistance applications. User applications include traveler information support and comfort applications [10].

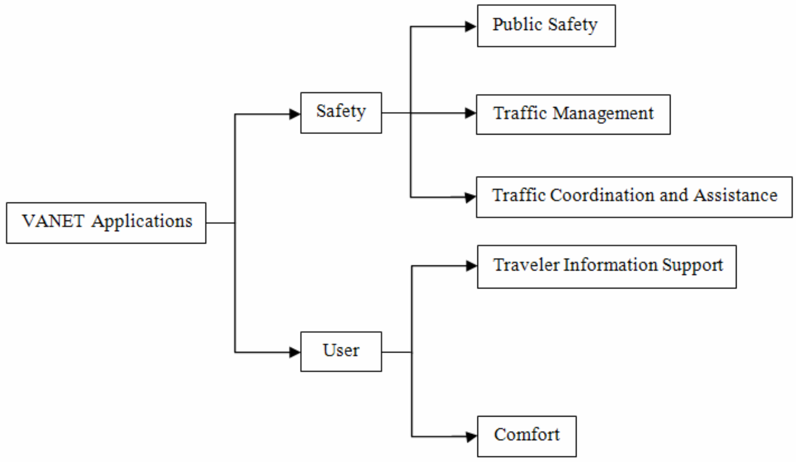

Fig. 1. Vehicular ad hoc network applications

2.1 Safety Applications

Public Safety Applications. This domain primarily refers to applications and systems that try to prevent or lower the number of accidents. Their goal is to protect vehicles and their occupants from damage by accidents.

Cooperative Collision Avoidance. A collision avoidance system would continuously monitor the vehicle's surroundings (distance to other vehicles) and alert the driver when another vehicle could cause a collision. If necessary, the system can respond with an automatic action (e.g. braking) to prevent an imminent collision [16]. Even if the collision is unavoidable, special safety arrangements can be made to prepare vehicles for accidents (tighten seat belts, pump up air bags, etc.) [10].

Cooperative Collision Warning. Scientists have proposed collision warning systems (also called emergency event warning systems) to reduce the number of vehicle collisions. Vehicles that detect an unexpected event like an accident or a driver on the wrong side of the road could broadcast a warning message to all vehicles in their surrounding area (also known as the Zone of Relevance (ZOR)). This would notify all drivers in the ZOR in advance [16]. These systems also may take post-collision conditions into consideration and inform vehicles near the accident [11].

Traffic Management Applications. Traffic management is another application of VANETs which works to adjust traffic by exchanging messages between vehicles and/or roadside equipments. This avoids traffic jams and their resultant accidents, reducing travel time and fuel consumption. Cooperative road traffic monitoring, traffic light scheduling, vehicle tracking, and emergency vehicle signals are some application examples of this type.

Cooperative Road Traffic Monitoring. This system provides accurate and localized traffic information of a ZOR for a vehicle. The ZOR can be several kilometers around the vehicle, and the information can be disseminated via vehicle-to-vehicle communication in a multi-hop manner. This information is useful in situations such as rerouting and estimating the time to a destination [10].

Traffic Light Scheduling. In this application, vehicles communicate with traffic lights to achieve an optimal schedule. This communication can provide further information which can increase the scheduling efficiency, such as the number of vehicles queued up at a traffic light and vehicles estimated to reach it soon [4].

Vehicle Tracking. In vehicle tracking systems, a vehicle equipped with a GPS can periodically send its location information (coordinates) to a computer at a data center via network technologies. Then, the information can be seen on digital maps via the Internet or specialized software, allowing the vehicle's movements to be followed. This system can be used as a dependable car alarm system to determine whether the vehicle has been stolen. In addition, in transportation or public transit systems, customers can, for example, use the vehicle tracking system to track their cargo or to check the current position of the nearest taxi through the Internet [17].

Emergency Vehicle Signals. The main purpose of emergency vehicle warning signals is to reduce the travel time of emergency vehicles (e.g., ambulances, fire engines, and police cars). The faster an emergency vehicle can get to the scene of an emergency, the higher the probability that lives can be saved [18].When an emergency vehicle is traveling on a roadway, it sends messages to other vehicles so the drivers can clear the way. The message includes extensive information, including the emergency vehicle's current position, lane, speed, destination, and intended route. The vehicle that receives the warning message can also forward it to other vehicles in the path to give the drivers more time to respond. In addition, an emergency vehicle can send messages to traffic lights in a route to set them to green just before the emergency vehicle reaches the intersection [18, 19].

Traffic Coordination and Driver Assistance Applications. In such applications, vehicles work together to coordinate their motions with each other and to also assist drivers to maneuver safely in actions such as passing and changing lanes. A driverless vehicular system is certainly the ultimate objective of the applications [20].

Platooning. The vehicle following or platooning system allows a group of vehicles on highways to follow each other to form a convoy so that they can travel closely and safely [10, 11]. The front vehicle, which is the lead vehicle, periodically sends messages to the group to set the average speed of the convoy. Each driver (or self-driving vehicle) tracks the preceding vehicle closely by accelerating or decelerating the vehicle, according to the information received [21]. Such a system could lead to a higher safety level for passengers due to the vehicles' continuous monitoring of the condition of the road [11]. Platooning also has the potential to increase the throughput of vehicles on highways since the vehicles can travel closer together at higher speeds [10, 21].

Passing and Lane Change Assistance. Passing and changing lanes are often the source of serious lateral accidents because nearby vehicles may be located in the driver's blind spot [10, 21]. In such situations, a lane-change assistance system that has information about the locations of nearby vehicles (e.g., the distance to vehicles in adjacent lanes and their relative speed) can assist a driver by providing a warning when a lane change is unsafe due to the presence of other vehicles [22].

2.2 User Applications

Traveler Information Support. These applications are used to provide updated local information and warnings about road conditions for drivers.

Local Information and Advertisements. In this application, a driver could get, for example, local maps, information, or advertisements of restaurants, gas stations, hotels, and parking places when the vehicle approaches specific locations (hot spots). This information can be provided by messages that are broadcasted periodically by access points in the hot spots or by having other vehicles relay the messages [17].

Warnings About Hazardous Road Conditions. This system is designed to notify drivers about hazardous road conditions (e.g., ice, oil, and bumps). A vehicle equipped with sensors can collect data about the road conditions, process the data, identify risky situations, and warn the driver (e.g., about the maximum safe speed on the road). The warning is also sent to other vehicles in the ZOR to inform the drivers about the situation [18].

Comfort. These applications can make travel more enjoyable for drivers and passengers by providing value-added services, such as Internet connectivity and direct communication between two vehicles. Compared to other classes, these services are multi-hop, end-to-end communication, and it is the user's choice whether to use them or not. Hence, their priority is relatively low [19].

Peer-to-Peer. This service allows communication between two vehicles via other vehicles in the network without the need for any application server. Live voice communication, video/voice communication, and instant messaging between drivers and passengers in separate vehicles are some applications of this type [11, 17].

Internet Connectivity. Providing Internet access to the occupants of vehicles, where other wireless Internet technology options (e.g., WiMAX and WiFi) are not available, is a valuable capability because it can provide a wide range of services, including email, web browsing, file transfer, and voice over IP. Even if a vehicle is connected to the Internet via an access point at a hot spot, its occupants can share this connectivity and serve other vehicles through VANET [11].

Drive-through Toll/Park Payment. Although many non-standard systems exist for this application and work well, drive-through toll/park payment capability allows fast and convenient payment transactions without the driver's having to change the vehicle's normal operating speed [22].

3 Communication Requirements of Vehicular Applications

In this section, we report the results of our study of the main communication requirements of vehicular ad hoc applications regarding routing. Although such studies should cover all aspects of the requirements for their effective use, we only considered the most prominent requirements in our study. Knowledge of both applications and requirements is important for the design and analysis of efficient routing solutions according to the targeted applications. Thus, we assessed the requirements of the applications introduced in the previous section, and these requirements are summarized in Table 1. The information included in Table 1 is described below.

Implementation Type. Vehicular communication (VC) systems are classified according to their implementation requirements into inter-vehicle communication (IVC) (also called vehicle-to-vehicle (V2V) communication) and roadside-to-vehicle communication (RVC) (also called infrastructure-to-vehicle (I2V) and vehicle-to-infrastructure (V2I)). IVC systems are used in applications in which vehicles want to exchange data, whereas RVC systems are used in case the information must be transmitted between roadside units (RSUs) and the vehicles.

IVC is an ad hoc, infrastructureless communication model, without any assistance of RSUs; it only requires some on-board units (OBUs), also called in-vehicle equipment (IVE), to exchange information among vehicles. In this case, depending on the distance between the vehicles, communicate can occur as single-hop or multi-hop IVC (SIVC or MIVC) [10]. Applications such as lane-change assistance, which require short-range communication, use SIVC systems. MIVC systems are used in applications that require long-range communication, such as monitoring road traffic and Internet connectivity. An MIVC system is more complex than an SIVC system and requires multi-hop routing. For example, connectivity of the nodes in a network that has a low density of vehicles is not guaranteed, and data may be lost. Therefore, the appropriate design of multi-hop routing protocols requires further consideration.

In RVC systems, RSUs communicate with OBUs. Depending on the application, such systems can be divided into sparse RVC (SRVC) systems and ubiquitous RVC (URVC) systems [10]. SRVC systems are useful for application services at hot spots, e.g., scheduling traffic lights, a business that wishes to inform travelers of its location and prices, and drive-through payment for parking at an airport. These systems can be combined with IVC systems to provide longer transmission ranges. A URVC system is intended for providing high-speed communication across all roads via RSUs. By having such a system, all vehicular applications can be designed, but it is very difficult to achieve that due to the considerable costs for full coverage of all roads, especially in large countries.

Communication Type. In vehicular networks, communication types are similar to one-to-one, one-to-many, and one-to-all in conventional networks, which have been adapted for vehicular communications. In one-to-one communications (unicast), messages are sent from one vehicle to another specific vehicle via MIVC systems. Such communications usually require a long period of connectivity between the vehicles to operate effectively, but, in most cases, vehicular networks are highly dynamic networks with intermittent connectivity. Furthermore, few VANET applications (e.g., vehicle tracking and peer-to-peer) require one-to-one communications.

The behavior of one-to-many (multicast) and one-to-all (broadcast) protocols are different; the former sends a message to multiple vehicles based on a particular group definition, while, in the latter, the message is disseminated to all vehicles. In each vehicle, the MAC layer (IEEE 802.11p standard) normally does single-hop broadcast by disseminating a message to the vehicles in its transmission range. Each time a vehicle receives a broadcast message, it is stored and immediately rebroadcasts it to the neighbors. This procedure could lead to message flooding (broadcast storm problem) [23], especially in high traffic density scenarios, and make a non-scalable network. In vehicular applications, selective broadcast is more applicable than full broadcast. Selective broadcast, which is a kind of multicast protocol, is an optimized broadcast mechanism with a reduced area for involving vehicles. A fleet of taxis that relays messages among themselves is an example of a multicast system, whereas an ambulance alarm message, which must be conveyed to all nearby vehicles so they can pull over quickly and safely, is a selective broadcast system [24].

Table 1. VANET application requirements regarding routing (***- extremely needed, **- needed, *- not needed)

Application		Implementation type	Communication Type	Transmission Mode	Real-time requirement
Public Safety	Cooperative collision avoidance	SIVC or MIVC (highway) SRVC (intersection)	One-to-many	Periodic	***
	Cooperative collision warning	MIVC (highway) SIVC or MIVC or SRVC(intersection)	One-to-many	Event-driven	***
Traffic management	Cooperative road traffic monitoring	MIVC	One-to-many	Periodic	**
	Traffic light Scheduling	SRVC	One-to-many	Periodic	**
	Vehicle tracking	SRVC	One-to-one	Periodic	**
	Emergency vehicle signals	MIVC (other vehicles)	One-to-many	Event-driven	***
		SRVC (traffic lights)	One-to-one		
Traffic coordination and driver assistance	Platooning	SIVC or MIVC	One-to-many	Periodic	***
	Passing and lane change assistance	SIVC	One-to-many	Periodic	***
Traveler information support	Local information and advertisements	SRVC or MIVC	One-to-many	Periodic	*
	Road conditions warning	MIVC	One-to-many	Event-driven	**
Comfort	Peer-to-peer	MIVC	One-to-one	Normal	*
	Internet connectivity	MIVC	One-to-one	Normal	*
	Drive-through toll/park payment	SRVC	One-to-one	Normal	*

Transmission Mode. All VANET applications, depending on their functionality, get data from other vehicles, sensors, or both. Each application processes the data and then sends appropriate messages to adjacent vehicles or to roadside equipment. Safety applications send messages to alert people in nearby vehicles to an unsafe condition. Messages that are sent periodically to nearby vehicles to make them aware of a vehicle's current status (e.g., location, speed, and direction) in order to avoid accidents are called periodic messages or beacons. They may also be used in other non-safety applications, such as to provide advertisement data. Event-driven or alert messages that contain the location of the vehicle, the time, and the event type are emergency warning messages sent to other vehicles upon detection of an unsafe condition. These messages have very high priority to make sure that all vehicles receive the message quickly and accurately. In some applications, such as Internet connectivity service, there is no need for any periodic or event-driven messages. These applications are transmitted based on normal transmission mode in conventional networks.

Real-time Requirement. Minimum latency is an important factor for vehicular safety applications. Real-time safety information must be delivered as soon as possible to vehicles that need the information to avoid injuries to passengers or damage to the vehicles. IEEE 802.11p, which was introduced by the IEEE group as a MAC-layer standard for vehicular communications, also defined the minimum allowable latency as 200 μsec. In general, end-to-end delay is one of the important performance metrics in all communication protocols.

4 Application-Based Classification of Routing Protocols

Table 1 indicates that few VANET applications require unicast routing protocols to communicate. In most cases, a sender sends messages to a group of receivers located behind the sender, such as those encounter a specific hazardous event, or in front of it such as those could transmit the road information, or in a given geographic area, for instance near to a designated spot such as a rainy area, or those can provide a particular service such as fleet of taxis. Such applications are assimilated into multicast communications. In the following, we discuss each of the communication protocols and their types. Also, Table 2 lists routing protocols according to the types.

4.1 Unicast Routing Protocols

Unicast protocols depend principally on either the network topology (such as destination-sequenced, distance-vector (DSDV) routing [25] and ad hoc on-demand distance vector (AODV) routing [25]) or geographical position of the vehicles (such as greedy-perimeter stateless routing (GPSR) [4] and connectivity-aware routing (CAR) [4]).

Topological Routing. Topology-based routing algorithms only count the network topology (including nodes and communication links) to find the routes of the messages. Topology-based schemes, which are mostly associated with MANET routing, use a proactive or reactive approach to create routes. In the proactive approach (also called the table-driven approach), e.g., DSDV, optimized link state routing (OLSR) [25], and fisheye state routing (FSR) [25], all nodes send periodic routing messages to create or update routing tables, even if there are no traffic data. These protocols require excessive control messages and consume additional bandwidth. On the contrary, reactive or on-demand protocols, such as AODV, temporally-ordered routing algorithm (TORA) [25], and dynamic source routing (DSR) [25], create routes only when they are needed to send data to a destination. These protocols use flooding, and there is a delay to find routes before data can be sent. In highly-dynamic vehicular networks, both protocols are inefficient, because the construction and maintenance overhead of the routes increase as network dynamics increases [26].

Several improvements have been proposed for these protocols to support highly-dynamic vehicular networks. Fast OLSR [27] tries to bear the network dynamic by adapting the frequency of periodic messages. In earlier work [28], it was proposed that additional geographical information be provided for the route request packets of the AODV routing protocol. All such enhancements still are considered as topological routing with some improvement in routing performance.

Position-based Routing. Geographical position-based protocols do not establish the route between the source and the destination. On-the-fly forwarding decisions are based on the position of the destination and the positions of neighbors. These protocols consist of three main components i.e., beaconing, location service, and forwarding strategies [9, 38].

Nodes use beaconing to broadcast short messages (beacons) periodically to inform neighbors of their unique ID and current position. Neighbors use the information they receive to update their location tables. In this way, information related to next-hop neighbors is obtained from the beacons. Information about the position of a destination can be obtained from a location management service or by flooding messages in the anticipated destination area to find the desired node and get its reply. The requirement associated with forwarding methods is to forward messages from a source to a destination effectively.

There are three kinds of forwarding in vehicular position-based routing protocols: greedy forwarding, directional flooding [34, 38], and hierarchical forwarding [34]. In greedy forwarding (e.g., GPSR, greedy perimeter coordinator routing (GPCR) [4], GVGrid [39], anchor-based street and traffic aware routing (A-STAR) [4, 40], and vehicle-assisted data delivery (VADD) [4, 41]), after a node has determined the location of the destination, the closest neighbor to the destination is selected as a next hop, and messages are sent to this neighbor. The algorithm is repeated at the nodes within the forwarding path until the message reaches the destination. On the other hand, directional flooding (such as the mobility-centric data dissemination algorithm for vehicular networks (MDDV) [33, 42]) disseminates messages to the nodes located in the same direction as the destination by flooding. Recipients rebroadcast the messages if they are situated in the geographical area specified by the information in the message. In this case, improved broadcasting algorithms can be used to avoid broadcast storms and minimize overhead. In hierarchical forwarding (e.g., GeoGRID [43]), the network is divided into several clusters. A cluster is a set of nodes that have some common characteristics (such as direction and speed) and are stable for a given period of time. Clusters forward messages to each other via gateway nodes. Several levels of the clusters can be defined.

Table 2. Routing protocols according to the kind of communication in VANET applications

Unicast		**Multicast**	
Topological	Position-based	Geocast	Mobility
AODV	GPSR (manet)	DRG [35]	LBF [37]
CBRP [25]	CAR	GAMER	MDDV
DSR	ACAR [29]	GeoGRID	OABS
OLSR	DREAM [25]	IVG [36]	ODAM [24]
Fast OLSR	GPCR	LBM	RBM [36]
HSR [25]	GSR [4]	GHM [36]	SB [24]
DSDV	LAR (manet)[25]	PBM [36]	SOTIS [10]
FSR	LORA-CBF [21]	SPBM [36]	VTRADE [20]
TORA	MDDV	RSGM [36]	UMB [24]
LMR [25]	MORA [30]		VADD
WRP [25]	MURU [31]		ROMGSP
	VADD		
	SAR [18]		
	A-STAR		
	STAR (manet)[25]		
	GeoOpps [4]		
	MaxProp [32]		
	PDGR [33]		
	GyTAR [4, 34]		
	GRANT [4]		
	PBR [26]		
	GVGrid		
	GeoGRID		

In position-based routing protocols, when network dynamics increase, determining the positions of the destination and the neighbors becomes unstable. As a result, the destination position is not valid when the message reaches that point. To deal with this problem, the defined geographical area of the destination can be increased, but this also leads to an increased number of nodes in that area and bandwidth waste. However, some studies show that position-based routing is more appropriate than topological routing in highly-dynamic vehicular networks.

4.2 Multicast Routing Protocols

Multicast routing protocols consist of two classes: geocast protocols and mobility-based protocols.

Geocast Routing. The geocast approach is basically multicast, position-based routing. In geocast routing, messages are sent from one source node to all other nodes within a ZOR. This routing is used in many VANET applications. For example, in cooperative collision warning systems, a vehicle detects an accident, reports it immediately, and warns nearby vehicles. Vehicles outside the ZOR are not notified in order to avoid unnecessary and hasty reactions [6]. Geocast routing protocols work by defining two zones: the target zone and the forwarding zone.

The forwarding zone includes at least the target zone and a route between the source node and that zone. When an intermediate node receives a message, as in the unicast directional flooding procedure, the message is forwarded provided that the node belongs to the forwarding zone. When it arrives at the target zone, the message receiver broadcasts it to all neighbors only if the node belongs to the target zone and the message has not been received before. Location-based multicast (LBM) [36, 43] is an example of such a routing protocol. GAMER [43], as a geocast protocol, dynamically adjusts the size of the forwarding area depending on the current state of the network.

Mobility-based Routing. In some vehicular applications, such as warning messages for dangerous road surface conditions and unexpected fog banks, suitable broadcast strategies must be defined that are capable of delivering warning messages to the highest number of upstream vehicles in the shortest possible time [44]. To meet these requirements, a mobility-based approach is needed. In this situation, the destination of the message is determined according to the mobility of the vehicles, digital maps, or exchanges of messages. In the optimized adaptive broadcast scheme (OABS) [45], emergency warning messages are transmitted rapidly from an abnormal vehicle to others by adjusting the probability and delay of rebroadcast based on the number of one-hop and two-hop neighbors. Another example of a mobility-based routing protocol is the receive on most stable group path (ROMSGP) protocol [17, 46]. The key idea in this protocol is to group vehicles according to their velocity vectors to ensure that vehicles that belong to the same group are generally moving together and that the routes used by vehicles from the same group have high levels of stability. Then, the protocol determines and sets up the most stable route among the possible routes.

As mentioned earlier, Table 2 lists most of the proposed protocols according to the routing types named in this section. By comparing Table 1 and Table 2, a mismatch between application requirements and proposed protocols can be seen.

5 Conclusions

According to the application requirements, VANET routing protocols are classified as unicast, multicast, and broadcast. Furthermore, regarding selective broadcast behavior of vehicular applications, the classifications can be reduced to unicast and multicast. Each class contains some routing protocols designed for specific requirements. The survey showed that, although all types of protocols are needed, less research has been done on the design of the multicast routing protocol even though most of the applications require this kind of protocol.

In future work, this classification could be improved by considering other parameters. For instance, traffic density (i.e., whether traffic is sparse or dense) may be counted as another factor for refining the classification or, in MIVC, the next hop decision can be considered as sender-oriented (decide before transmitting the message) or receiver-oriented (decide after transmitting the message). Since safety is the most important and frequently used application of VANET, secure routing is another challenging issue that should be studied precisely.

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References

1. Peden, M.: World Report on Road Traffic Injury Prevention. World Health Organization (2004)
2. Fatality Analysis Reporting System, `http://www-fars.nhtsa.dot.gov/Main/index.aspx`
3. ICT for smart, safe & clean mobility, `http://www.icarsupport.org/`
4. Lee, K., Lee, U., Gerla, M.: Survey of Routing Protocols in Vehicular Ad Hoc Networks. In: Chapter in Vehicular Ad-oc Networks: Developments and Challenges (2010)
5. Willke, T.L., Tientrakool, P., Maxemchuk, N.F.: A Survey of Inter-vehicle Communication Protocols and Their Applications. IEEE Communications Surveys & Tutorials 11, 3–20 (2009)
6. Li, F., Wang, Y.: Routing in Vehicular Ad Hoc Networks: A Survey. IEEE Vehicular Technology Magazine 2, 12–22 (2008)
7. Bernsen, J., Manivannan, D.: Unicast Routing Protocols for Vehicular Ad Hoc Networks: A Critical Comparison and Classification. Pervasive and Mobile Computing 5, 1–18 (2009)
8. Gongjun, Y., Mitton, N., Li, X.: Reliable Routing in Vehicular Ad hoc Networks. In: The 7th International Workshop on Wireless Ad Hoc and Sensor Networking (2010)
9. Tee, C.A.T.H., Lee, A.C.R.: Survey of Position Based Routing for Inter Vehicle Communication System. In: First International Conference on Distributed Framework and Applications, pp. 174–182 (October 2008)

10. Sichitiu, M.L., Kihl, M.: Inter-Vehicle Communication Systems: A Survey. IEEE Communications Surveys & Tutorials 10, 88–105 (2008)
11. Khaled, Y., Tsukada, M., Santa, J., Choi, J., Ernst, T.: A Usage Oriented Analysis of Vehicular Networks: from Technologies to Applications. Journal of Communications 4, 357–368 (2009)
12. Toor, Y., Muhlethaler, P., Laouiti, A.: Vehicle Ad Hoc Networks: Applications and Related Technical Issues. IEEE Communications Surveys & Tutorials 10, 74–88 (2008)
13. Hartenstein, H., Laberteaux, K.P.: A Tutorial Survey on Vehicular Ad Hoc Networks. IEEE Communications Magazine 46, 164–171 (2008)
14. Yousefi, S., Mousavi, M.S., Fathy, M.: Vehicular Ad Hoc Networks (VANETs): Challenges and Perspectives. In: Proceedings of the 6th International Conference on ITS Telecommunications, pp. 761–766 (2006)
15. Caveney, D.: Cooperative Vehicular Safety Applications. IEEE Control Systems Magazine 30, 38–53 (2010)
16. Wolf, M.: Security Engineering for Vehicular IT Systems. Vieweg and Teubner, Germany (2009)
17. Huang, C., Chang, Y.: Telematics Communication Technologies and Vehicular Networks: Wireless Architectures and Applications. Information Science Reference-Imprint of: IGI Publishing Hershey, PA (2009)
18. Olariu, S., Weigle, M.: Vehicular Networks: From Theory to Practice. Chapman & Hall/CRC, Boca Raton (2009)
19. Plossl, K., Nowey, T., Mletzko, C.: Towards a Security Architecture for Vehicular Ad Hoc Networks. In: The First International IEEE Conference on Availability, Reliability and Security, p. 8 (2006)
20. Moustafa, H., Zhang, Y.: Vehicular Networks: Techniques, Standards, and Applications. Auerbach Publications Boston, MA, USA (2009)
21. By, E., Guo, H., Cover, H., Access, P.: Automotive Informatics and Communicative Systems: Principles in Vehicular Networks and Data Exchange. Information Science Reference, Hershey, New York (2009)
22. Popescu-Zeletin, R., Radusch, I., Rigani, M.: Vehicular-2-X Communication: State-of-the-Art and Research in Mobile Vehicular Ad Hoc Networks. Springer, Heidelberg (2009)
23. Tonguz, O.K., Wisitpongphan, N., Parikh, J.S., Fan, B., Mudalige, P., Sadekar, V.K.: On the Broadcast Storm Problem in Ad hoc Wireless Networks. In: 3rd International Conference on Broadband Communications, Networks and Systems, pp. 1–11 (2006)
24. Chen, R., Wen-Long, J., Regan, A.: Broadcasting Safety Information in Vehicular Networks: Issues and Approaches. IEEE Network 24, 20–25 (2010)
25. Abolhasan, M., Wysocki, T., Dutkiewicz, E.: A Review of Routing Protocols for Mobile Ad Hoc Networks. Ad Hoc Networks 2, 1–22 (2004)
26. Namboodiri, V., Lixin, G.: Prediction-Based Routing for Vehicular Ad Hoc Networks. IEEE Transactions on Vehicular Technology 56, 2332–2345 (2007)
27. Benzaid, M., Minet, P., Al Agha, K.: Integrating Fast Mobility in the OLSR Routing Protocol. In: 4th International Workshop on Mobile and Wireless Communications Network, pp. 217–221 (2002)
28. Fukuhara, T., Warabino, T., Ohseki, T., Saito, K., Sugiyama, K., Nishida, T., Eguchi, K.: Broadcast Methods for Inter-vehicle Communications System. In: IEEE Wireless Communications and Networking Conference, pp. 2252–2257 (2005)
29. Yang, Q., Lim, A., Li, S., Fang, J., Agrawal, P.: Acar: Adaptive Connectivity Aware Routing for Vehicular Ad Hoc Networks in City Scenarios. Mobile Networks and Applications 15, 36–60 (2010)

30. Granelli, F., Boato, G., Kliazovich, D.: MORA: A Movement-based Routing Algorithm for Vehicle Ad Hoc Networks. In: 1st IEEE Workshop AutoNet (2006)
31. Mo, Z., Zhu, H., Makki, K., Pissinou, N.: MURU: A Multi-Hop Routing Protocol for Urban Vehicular Ad Hoc Networks. In: Third Annual International Conference on Mobile and Ubiquitous Systems: Networking & Services, pp. 1–8 (2006)
32. Burgess, J., Gallagher, B., Jensen, D., Levine, B.N.: MaxProp: Routing for Vehicle-Based Disruption-Tolerant Networks. In: 25th IEEE International Conference on Computer Communications, pp. 1–11 (2006)
33. Prasanth, K., Duraiswamy, K., Jayasudha, K., Chandrasekar, C.: Minimizing End-to-end Delay in Vehicular Ad Hoc Network Using Edge Node Based Greedy Routing. In: First International Conference on Advanced Computing, pp. 135–140 (2009)
34. Jerbi, M., Senouci, S.M., Rasheed, T., Ghamri-Doudane, Y.: Towards Efficient Geographic Routing in Urban Vehicular Networks. IEEE Transactions on Vehicular Technology 58, 5048–5059 (2009)
35. Joshi, H.P.: Distributed Robust Geocast: A Multicast Protocol for Inter-vehicle Communication. Dept. of Computer Networking and Electrical Engineering, Master's Thesis. NCSU (2007)
36. Wai, C., Guha, R.K., Taek Jin, K., Lee, J., Hsu, I.Y.: A Survey and Challenges in Routing and Data Dissemination in Vehicular Ad-Hoc Networks. In: IEEE International Conference on Vehicular Electronics and Safety, pp. 328–333 (2008)
37. Oh, S., Kang, J., Gruteser, M.: Location-Based Flooding Techniques for Vehicular Emergency Messaging. In: Third Annual International Conference on Mobile and Ubiquitous Systems: Networking & Services, pp. 1–9 (2006)
38. Harsch, C., Festag, A., Papadimitratos, P.: Secure Position-Based Routing for VANETs. In: 66th IEEE Vehicular Technology Conference, pp. 26–30 (2007)
39. Sun, W., Yamaguchi, H., Yukimasa, K., Kusumoto, S.: GVGrid: A QoS Routing Protocol for Vehicular Ad Hoc Networks. In: 14th IEEE International Workshop on Quality of Service, pp. 130–139 (2006)
40. Seet, B.-C., Liu, G., Lee, F.B.S., Foh, C.-H., Wong, K.-J., Lee, K.-K.: A-STAR: A Mobile Ad Hoc Routing Strategy for Metropolis Vehicular Communications. In: Mitrou, N.M., Kontovasilis, K., Rouskas, G.N., Iliadis, I., Merakos, L. (eds.) NETWORKING 2004. LNCS, vol. 3042, pp. 989–999. Springer, Heidelberg (2004)
41. Jing, Z., Guohong, C.: VADD: Vehicle-Assisted Data Delivery in Vehicular Ad Hoc Networks. IEEE Transactions on Vehicular Technology 57, 1910–1922 (2008)
42. Wu, H., Fujimoto, R., Guensler, R., Hunter, M.: MDDV: A Mobility-centric Data Dissemination Algorithm for Vehicular Networks. In: 1st ACM International Workshop on Vehicular Ad Hoc Networks, pp. 47–56 (2004)
43. Maihofer, C.: A Survey of Geocast Routing Protocols. IEEE Communications Surveys & Tutorials 6, 32–42 (2004)
44. Fasolo, E., Zanella, A., Zorzi, M.: An Effective Broadcast Scheme for Alert Message Propagation in Vehicular Ad hoc Networks. In: IEEE International Conference on Communications, pp. 3960–3965 (2006)
45. Alshaer, H., Horlait, E.: An Optimized Adaptive Broadcast Scheme for Inter-vehicle Communication. In: 61st IEEE Vehicular Technology Conference, vol. 2845, pp. 2840–2844 (2005)
46. Taleb, T., Sakhaee, E., Jamalipour, A., Hashimoto, K., Kato, N., Nemoto, Y.: A Stable Routing Protocol to Support ITS Services in VANET Networks. IEEE Transactions on Vehicular Technology 56, 3337–3347 (2007)