Broadcasting in Vehicular Networks: Issues and Approaches

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***Abstract*— The design of routing protocols is important for vehicular communication networks because of the need to route messages dynamically in the vehicular network. Vehicle mobility patterns caused by varying traffic dynamics and travel behavior lead to considerable complexity in vehicular communication networks. This causes two major routing issues - the broadcast storm problem and the network disconnection problem. In this article, we review communication routing protocols for broadcasting and mechanisms that alleviate the broadcast storm problem. Moreover we analyze the network design considerations in architecture and protocol development, classify and characterize these routing protocols, and conclude with open issues in disseminating messages for vehicular communication networks.**

***Keywords*— routing protocols, safety applications, broadcast, mobility model**

I. Introduction

A. Background

Every year, millions of traffic accidents occur worldwide, resulting in tens of thousands of casualties and billions of dollars in direct economic costs. To combat this problem, for many years now, transportation planners have been pursuing an aggressive agenda to increase road safety. For example, in 2001 the European Transport Policy set the goal to reduce road fatalities by 50% by the year 2010. Similarly, in 2008 the US DOT's Research and Innovative Technology Administration (RITA) challenged the industry to reduce traffic crashes by 90% by 2030. In recent years, various stakeholders have come together to address these short-term and long-term challenges and initiative efforts have been formed, such as the Europe eSafety and US IntelliDrive programs.

To achieve the future road safety vision, new applications are needed to assist drivers to avoid traffic collisions. Vehicular communication networks will play a pivotal role to improve safety, providing information on look-ahead road hazards, traffic conditions, drivers behaving erratically or hiding in blind spots. Dedicated Short Range Communication (DSRC) is the wireless communication medium designed for automotive use for road safety and complementary traffic information.

B. The Routing Problem

Information propagation in a communication network can be statically or dynamically routed depending on complexity of the network. The fundamental design requirement for routing protocols in dynamic networks is that these need to be resilient and ensure that multiple constraints are met with respect to high reliability, scalability and efficiency.

Vehicular ad hoc networks (VANETs) operate in a self-organized manner without permanent infrastructure. VANETs most closely resemble mobile ad hoc networks (MANETs) where dynamic routing protocols are necessary, for example the Ad hoc On-Demand Distance Vector Routing (AODV) in MANET. Furthermore, these communication networks encounter two major routing issues, the broadcast storm problem and the network disconnection problem. The broadcast storm problem occurs when mobile nodes send messages by flooding, causing frequent link layer contention with other nearby broadcasting nodes and result in packet loss due to collisions. This phenomenon has been previously studied in MANET and VANET topologies [8]. For MANET, broadcasting occurs during route discovery or route maintenance, such as AODV route request *hello* messages. For VANET, broadcast routing is commonly used in many safety critical ITS applications. The network disconnection problem for VANET is more severe than MANET due to high mobility caused by fast moving vehicles, sparse traffic densities during off-peak hours, and the limited market penetration rates of vehicles with equipped communication devices, especially in the initial stage. This disconnection time (on the order of a few seconds to several minutes) makes MANET protocols such as AODV unsuitable for VANETs.

Hence, new network protocols are necessary to improve broadcasting in dense networks and routing decisions in sparse networks. In this article, we review routing protocols that address the fundamental broadcast storm problem in vehicular networks. Further, we discuss design considerations based on communication mechanism, traffic characteristics, and application requirements. In later sections, we look at preliminary field trials from initial examination (sometimes referred to as phase 1) on the performance measures based on DSRC. We conclude with future challenges of routing protocols to achieve reliable broadcasting and recommendation of Phase 2 deployments for vehicular communication networks

II. Design Considerations

Taking a systematic approach, we discuss the conditions and constraints of routing protocols imposed by application requirements, communications, and vehicular traffic flow.

A. Applications

Specific ITS applications govern the performance requirements in vehicular communication networks. DSRC messages (for example, emergency services) have greater sensitivity to reliability and distance. In general, traffic-based applications are sensitive to timing latency as critical safety messages received several seconds late or traffic information that is several hours old would not be relevant for many ITS applications.

During phase 1 experiments using DSRC, several road safety scenarios based on cooperative intersection collision avoidance systems (CICAS) have been tested. These scenarios included traffic signal violation warnings, stop sign alerts and left turn signal assistance. According to the U.S. Vehicle Safety Communications Consortium (VSC), a comprehensive list of more than 75 application scenarios for intelligent vehicle safety applications enabled by DSRC have been identified. Interested readers should refer to [1] for detailed descriptions. We list the near and mid-term applications with the greatest potential safety benefits in TABLE 1, along with the corresponding communication and traffic parameters. Further, details relating to and comprehensive classification of different automotive applications in DSRC and performance measures for VANET are reviewed in [2].

TABLE 1. Safety Applications with Greatest Benefits in Near and Mid-Term

	Communication Type	**Transmit Mode**	**Latency (msec)**	**Traffic Information**	**Communication Range (meters)**
Traffic Signal Violation Warning	Infrastructure-to-vehicle Point-to-multipoint	Periodic	~100	Traffic signal status and position, timing, directionality, stopping location, road surface types	~250
Curve Speed Warning	Infrastructure-to-vehicle Point-to-multipoint	Periodic	~100	Curve location, curve speed limits, curvature	~200
Emergency Electronic Brake Lights	Vehicle-to-vehicle Point-to-multipoint	Event driven	~100	Vehicle position, heading, speed, deceleration, road surface condition	~300
Pre-Crash Sensing	Vehicle-to-vehicle Point-to-point	Event driven	~20	Vehicle type, position, speed, acceleration, heading, yaw-rate	~50
Cooperative Forward Collision Warning	Vehicle-to-vehicle Point-to-multipoint	Periodic	~100	Vehicle position, speed, acceleration, heading, yaw-rate	~150
Left Turn Assistant	Vehicle-to-infrastructure Infrastructure-to-vehicle Point-to-multipoint	Periodic	~100	Traffic signal status, timing, directionality, road shape and intersection information, vehicle position, speed, heading	~300
Lane Change Warning	Vehicle-to-vehicle Point-to-multipoint	Periodic	~100	Vehicle position, heading, speed, acceleration, turn signal status	~150
Stop Sign Movement Assistance	Vehicle-to-infrastructure Infrastructure-to-vehicle Point-to-multipoint	Periodic	~100	Vehicle position, heading, speed, warning, turn signal status	~300

Source: Shulman and Deering [6]

B. Communication

In communication networks, information can be sent by a single source node to one (point-to-point) or more target nodes (point-to-multipoint) and the message can be relayed by one or more nodes. The delivery scheme can be unicast, multicast or broadcast and the relay mechanisms are known as single-hop or multi-hop. The behavior of multicast and broadcast systems are different, as the former sends a message to multiple destinations based on specific group attributes while the latter sends a message to all recipients within its coverage area. For example, in vehicular communication networks a group of taxi or courier vehicles in a metropolitan city may only want to relay messages among their fleets. However, an ambulance siren alert must notify all nearby vehicles to pull over rapidly and safely. In recent years, other forms of delivery have been proposed such as geocast. In particular, for vehicular networks, geocast, which is based on geographic routing has been studied extensively by taking a form of greedy forwarding in relaying information to the destination such as most forward within receiver (MFR) or nearest with forward progress (NFP).

Messages can be triggered periodically or transmission may be event-driven. In the periodic case, preventive safety messages are disseminated to keep drivers informed with details such as forward and opposing vehicle speed, acceleration and deceleration values. On the other hand, event-driven messages are delivered occasionally as in the case of a sudden hard braking vehicle for other nearby vehicles. Moreover event-driven messages are relevant for farther vehicles, allowing upstream vehicles to undertake early countermeasures to prevent severe catastrophes such as chain-reaction accidents.

We note that the initial conditions for information propagation in vehicular communication are different from other wireless networks. In vehicular networks, the messages are mostly autonomous and message relevance is based on time and location. Furthermore, the assumptions include the knowledge of digital road layouts, location coordinates (GPS), and in some cases the location of the destination node.

C. Traffic

The mobility patterns of communication nodes in VANET are significantly different from those in conventional wireless networks: vehicles' space-time trajectories are restricted by paved roadways and drivers' choices of origins, destinations, departure times, and routes; positions of vehicles are not independent on a road due to car-following or lane-changing rules; densities of vehicles can vary dramatically along a communication path due to driving behaviors and restrictions caused by network geometry; only a proportion of vehicles are equipped with wireless communication units; and vehicles have practically unlimited power for communications.

An analysis on the topological properties of vehicular networks shows that mobility models can have dramatic impact on network protocol performance [4]. Furthermore, MANET mobility models such as the random waypoint model do not accurately describe the movement of vehicles in traffic networks. Two popular mobility models for vehicular communication that generate movements at the microscopic level include SUMO and VanetMobiSim, incorporating aspects of car following model developed by Stefan Krauss and the TSIS-CORSIM traffic simulator.

Vehicle movements can be further complicated by other factors such as traffic signals and stop signs in arterial roads and ramp meters on highways. Hence, another approach to formulate the mobility model involves using realistic vehicular traces to account for other variables. Some research have adopted this method and use mobility data from SUVnet (taxi traces via GPS) and BTL/NG-SIM (vehicle traces via loop detectors).

D. Integrated Layered Paradigm

A variety of characteristics can impact the performance of vehicular communication networks including mobility model, connectivity, delay, and communication capacity. Designing communication systems for vehicular networks is challenging due to the dynamics of these characteristics. In order to meet the design goals of reliability and scalability, routing protocols must include an integrated paradigm that considers the communication, traffic, and application characteristics. Further, a cross-layer design approach should be implemented in this integrated paradigm, allowing the application layer requirements (for example, safety or traffic messages) to be shared with the networking protocol stack. For example, traffic density can affect connectivity and such information can be fed to the lower layer of network stack and adjust power levels (transmission range) for vehicular network communications. In other cases, ITS traffic information applications can tolerate small delay and can allow messages to be queued at intermediate relay points (vehicles) prior to sending the information to the intended destination when the connectivity is low. Instead of using an instantaneous broadcasting protocol, the communication system can opt to use a delay-tolerant geocast protocol that sends messages when it is near other vehicles or a traffic collection roadside station.

III. Classification of Broadcast and sparse network routing protocols

In this section, we present a classification scheme of routing protocols for vehicular communication networks. There are a number of references on routing for vehicular communication networks, which consider various unicast routing protocols [3], a top-down approach analyzing the protocol stack [7], lessons learned [9] and tutorial survey [5] in vehicular networks. We focus our review on broadcast routing protocols and qualitative comparison on the communication and traffic characteristics in TABLE 2. In certain cases, the literature on broadcast routing protocol did not specify the simulation environment, road topology, and mobility models used in their evaluation. For these situations, we omit their discussion and leave the table field entries blank. Then, in section IV we describe each of the routing protocols in greater depth and supplement with preliminary discussion of communication performance based on actual DSRC field experiments.

A. Broadcast Protocols

In vehicular networks, reducing message flooding in broadcasting is important to increase the reliability of disseminating safety messages to other vehicles. In the traditional literature for MANET, several suppression schemes have been proposed to improve the overall reliability of the shared communication channel can be applicable for broadcasting. These schemes include probabilistic-based, counter-based, distance-based, and location-based methods. These schemes have been adopted in broadcasting for vehicular communication networks along with new methods such as cluster-based and traffic-based methods. In probabilistic-based methods, messages are broadcasted with a given probability p and in many cases this probability is based on the protocol’s back-off timer. In location and position-based methods, messages are broadcasted based on the geographic area of the transmitting and receiving vehicle locations. In distance and hop-based methods, messages are broadcasted by considering the neighboring distances and hop count from the transmitting node. Cluster-based methods broadcast messages to vehicle groups, for example to a platoon of vehicles with common paths. In Table 2, we also mention the network simulator and mobility model, and describe the traffic characteristics that are part of the simulation environment and design factors for evaluating these broadcast routing protocols.

TABLE 2. BROADCAST ROUTING IN VEHICULAR NETWORKS

Broadcast Routing Protocols	Communication Characteristics					Traffic Characteristics				
	Location/Position-based	Distance/Hop-based	Cluster-based	Probabilistic-based	Network Simulator	Arterial Road	Highways	Traffic Density/Vehicle Speed	Data Aggregation	Mobility Model
UMB, 2004	√	√			WS	√				Negative exponential (headways) and Gaussian (speed)
TrafficView, 2004					*ns*-2		√	√	√	Random Waypoint model
MDDV, 2004			√		QualNet	√	√			CORSIM and Atlanta road traces
ODAM, 2004	√	√			*ns*-2					
OAPB/DB, 2005	√			√	*ns*-2	√				
AMB, 2006	√				WS	√				Negative exponential (headways) and Gaussian (speed)
SB, 2006	√	√								Negative exponential (headways)
MHVB, 2006	√				*ns*-2		√			Microscopic traffic simulator
D-FPAV, 2006		√			*ns*-2		√			DaimlerChrysler road traces
BBR, 2007	√				OPNET	√				Geographic and Traffic Information model
REACT, 2007	√				*ns*-2		√	√		Nagel and Schreckenberg cellular automata
DV-CAST, 2007				√						
FB, 2007		√								
DBAMAC, 2007			√		*ns*-2		√			IMPORTANT mobility tool
LDMA, 2007	√				GrooveNet		√			Street Speed model
PAB, 2008	√			√	*ns*-2		√	√		Road Design Manual
REAR, 2008				√	*ns*-2		√			Manhattan model
CTR, 2009	√	√			*ns*-2		√			

IV. OVERVIEW OF PROTOCOLS IN VEHICULAR NETWORKS

A. Broadcasting

We note here that several broadcast routing protocols (e.g. UMB, SB, MDDV, MHVB, DV-CAST, PAB, CTR) use more than one scheme as seen in TABLE 2. In the following discussion, we mention each protocol only when the related scheme is primary to the protocol design.

1) Traffic-based routing

The TrafficView protocol is a part of the broader e-Road project with the goal of building a scalable and reliable infrastructure for IVC systems. In TrafficView, the message data contain information on a list of vehicle IDs and its own vehicle position, vehicle speed, and broadcast duration time. TrafficView conserves bandwidth and deals with flow control of broadcast messages by aggregating multiple data packets based on relative vehicle distances and message timestamps. For examples, two vehicles on the same highway lane traveling with similar speeds will have similar vehicle positions and vehicle trajectories. Hence, when updated information on vehicle positions are available, vehicle speeds may not be necessary. A prototype of TrafficView was implemented using GPS on a PDA and the data aggregation algorithm was tested on the network simulator *ns*-2.

The Optimized Adaptive Probabilistic Broadcast and Deterministic Broadcast (OAPB/DB) protocol uses an adaptive approach to rebroadcast emergency warning messages by considering the incident zone area and local vehicle density with periodic heartbeat messages of vehicles that are within two-hops of distance. The mobility scenarios include uniform traffic with two road lanes.

Distributed Vehicular Broadcast (DV-CAST) uses local one-hop neighbor topology to make routing decisions. The protocol adjusts the back-off timer based on the local traffic density, and compute forward and opposing direction connectivity with periodic heartbeat messages. Moreover DV-CAST is adaptive to the totally disconnected network and can temporarily wait-and-hold a packet until the vehicle hears heartbeat messages from other vehicles.

2) *Location and Position-based routing*

The Urban Multi-Hop Broadcast (UMB) protocol uses a combined approach to broadcast messages in an urban road network (27). For two-directional roads, it selects the node that is farthest away (MFR) as relay using the black-burst method. When a vehicle enters the intersection, UMB uses fixed repeaters to disseminate messages to all directions except that of the originating source. Ad-Hoc Multi-Hop Broadcast (AMB) protocol is an enhancement to UMB that does not require repeaters (infrastructure-less) by nominating the node closest to the intersection position as the relay node for broadcasting. Both UMB and AMB use a custom built Wireless Simulator modeling the medium access control (MAC) and physical layer of 802.11b. Vehicle movement was constructed using MATLAB with an exponential distribution for vehicle interspacing and speed assignment following a Gaussian distribution. The road structure includes bi-directional traffic with one and four intersection road scenarios.

Smart Broadcast (SB) is similar to UMB but uses a different back-off timer scheme based on the sender and receiver node distance. Simulation results in MATLAB compare the two indicate better performance for SB than UMB with constant message propagation speed while message propagation speed is faster for UMB in one-hop transmission. In another approach, Position-based Adaptive Broadcast (PAB) determines the back-off timer based on vehicle position and vehicle speed to prevent window contention in packet transmissions. The mobility scenario for PAB includes an eight lane bi-directional highway using the Minnesota DOT road design manual.

Border node Based Routing (BBR) elects only the edge nodes to rebroadcast messages. The edge node provides better coverage in sparse networks and is determined based on minimum common one-hop neighbors between the broadcasted nodes. BBR uses the commercial OPNET modeler network simulator and the GTI mobility model that generates trajectories based on geographic (digital road map) and realistic traffic information from a transportation department. Routing Protocol for Emergency Applications in Car-to-Car Networks using Trajectories (REACT) is also position-based but gives more influence on the forwarding trajectory and angle. It integrates the position-based information with the Time Division Multiple Access 802.11 MAC.

Multi-hop vehicular broadcast (MHVB) uses a position-based scheme to adjust the packet transmission interval. The two proposed methods for packet retransmissions in MHVB include the distance between sender and receiver, and the traffic congestion level which is determined by a multitude of threshold values that include number of nearby vehicles, number of vehicles in the forward and opposing direction, and vehicle speed. A subsequent improvement for MHVB was later published that include more efficient angular coverage from sender to receiver and introduces a dynamic scheduling algorithm that prioritizes received packets.

Finally, Location Division Multiple Access (LDMA) is a MAC scheme that ensures bounded delay for multi-hop vehicular networks. To evaluate the proposed technique, LDMA compares four schemes including probabilistic-based, distance-based, location-based, and neighbor-based adaptive rebroadcast link layer models. LDMA is tested using GrooveNet, a hybrid vehicular network virtualization platform that use road maps from the US Census Bureau, for simulation and on-road studies. GrooveNet used simplified movement patterns that include Fixed mobility (stationary vehicles) and Street Speed mobility where vehicles cannot exceed the given speed limit.

3) *Distance and Hop-based routing*

Fast Broadcast (FB) is a distance-based protocol that minimizes forwarding hops when transmitting messages. It contains two components, the estimation and broadcast phase. In the estimation phase, the protocol adjusts the transmission range using heartbeat messages to detect backward nodes. In the broadcast phase, it gives higher priority to vehicles that are farther away from the source node to forward the broadcast message.

The Cut-Through Re-broadcasting (CTR) also gives higher priority to rebroadcast alarm messages to farther vehicles within transmission range but operate in a multi-channel environment. Similarly, Optimized Dissemination of Alarm Message (ODAM) has a “defertime” to broadcast messages, computed based on the inverse proportional distance between receiver and source node. For ODAM, broadcast messages can only occur within risk zone area, determined with a dynamic multicast group based on vehicles proximity with the accident site. We note that selecting nodes based on the most forwarded within range scheme is efficient with respect to minimizing hop counts. However, it incurs the drawback of lower reception rates (delivery ratio) due to loss in radio power from longer propagation distances.

Distributed Fair Transmit Power Assignment for Vehicular Ad Hoc Network (D-FPAV) describes a scheme that provides fairness in broadcasting heartbeat messages by dynamically adjusting every node’s transmission power based on distance to other neighboring nodes. The method enables all nodes to share the channel capacity fairly. Although power control and adjustment is a well explored research topic for wireless networks in general, D-FPAV is unique as it investigates the problem in the context of broadcasting in vehicular networks and using realistic movement traces obtained from DaimlerChrysler in a German highway.

4) *Cluster-based routing*

The Mobility-Centric Data Dissemination Algorithm for Vehicular Networks (MDDV) is a cluster-based protocol that reliably forwards messages in complex traffic networks that include high vehicle mobility, high and low density areas. The MDDV protocol partitions vehicles into groups based on common travel routes (geographic and trajectory-based) and runs a localized broadcast routing algorithm to continuously forward messages to the head node in the cluster pack and moves closer to the intended destination. Results from MDDV indicate the routing protocol performance depends on the market penetration rate of vehicle-to-vehicle communication and road traffic density, which is affected by the time of day with its realistic movement traces

Dynamic Backbone-Assisted MAC (DBA-MAC) is a cluster-based broadcast for message propagation based on cross-layer intersection in the MAC. For a group of interconnected vehicles, higher priority nodes within the cluster are considered backbone members and are able to broadcast messages. The process of choosing backbone nodes within the cluster occurs periodically by selecting nodes that are farther apart to minimize hop count.

5) *Probabilistic-based routing*

In the Receipt Estimation Alarm Routing (REAR) protocol, nodes that relay broadcast messages are selected based on their estimated message received value. This is computed based on the received signal strength and packet loss rates for packets that nodes receive and this information is exchanged with neighboring nodes using heartbeat messages. Hence, nodes with higher delivery ratios are likely candidates to flood messages in the network. This reduces redundant broadcasting to nodes that have a higher probability of contention conflict with other nodes. REAR is based on the Manhattan mobility model for urban areas and a highway scenario with bi-directional single lane traffic.

B. *Practical Design and Development*

The new DSRC wireless medium has made formidable progress in the past few years. In this section, we look at the practical design efforts for DSRC, experimental results from field tests and future phase 2 development recommendations.

1) *DSRC Communication*

Safety messages in the application layer are typically small, 100 bytes or less in raw data size. The packets are mostly autonomous and message relevance based on time and location. To ensure critical safety messages can be disseminated quickly to other neighboring vehicles, DSRC broadcast messages are transmitted at minimum every 100 millisecond and contain each vehicle's time-stamped position, heading, and speed. Comparatively, these periodic messages can be considered as heartbeat keep-alive packets.

For the transport and network layer, messages based on the DSRC radio can be transmitted using conventional network stack or an alternative approach using wave short message (WSM) protocol, mainly for broadcast. At the transport layer, UDP is preferred as TCP contains more header overhead and TCP's close coupling in flow and congestion control do not perform well in wireless networks. The network layer uses IPv6 for better network mobility features, quality-of-service, and greater address space availability necessary for the system with more than 500 million vehicles worldwide. In the lower layers, DSRC is based on multiple radio channel (for example, in the US DSRC standard, 1 control dedicated for broadcasting and 6 service channels with 10 MHz band). The MAC is based on IEEE 802.11a with modifications in low-overhead adjustment by removing acknowledgment and retransmissions in broadcast and re-defined as IEEE 802.11p.

2) *Empirical Results*

In the past few years, field trials have been conducted to fine tune DSRC. Initial results indicate packet error rates (PER) can be affected by urban canyon dramatically, caused by radio signal degradation due to multi-path fading [10]. The vehicle height profile can also significantly affect the transmission range for DSRC communication devices. Initial road test experiments indicate 20% PER with about 150 WSM messages per second and the results are better for shorter (300 bytes) rather than longer messages (1200 bytes) since longer packet length consumes more overall channel time.

C. *Future Recommendations for Phase 2*

The phase 1 stage provides strong proof of concept for DSRC but the technology has not achieved widespread deployment. For instance, in the communication link layer, back-off counter, channel access priority, hidden terminals, and message generation intervals remain as open issues. Traffic characteristics including traffic densities and the dynamics that leads to heavy congestion, and specific vehicle movements such as shockwaves and rarefaction waves can be considered in the communication protocol design. One interesting approach by *Artimy et al.* proposes to use dynamic transmission range assignment for the communication based on local traffic density estimation using the Nagel-Schreckenberg vehicle traffic model.

In addition, the use and management for a variety of services between vehicles and roadside stations has not been investigated thoroughly. Yet another concern with sending messages between vehicles is the accuracy and management of the reported data. Finally, security and privacy are major issues that need to be explored with mechanisms to prevent message tampering and vehicle anonymity.

V. CONCLUSION

In this article, we classify and survey routing protocols for broadcasting in vehicular networks that addresses the broadcast storm problem. Systematic consideration of the requirements and constraints imposed by applications, communication, and vehicular traffic flow are necessary for communication routing protocol design. For example, mobility model can describe information on vehicle headways, which is useful since vehicles need to be within transmission range to communicate. For future research, traffic characteristics should be incorporated into the network protocol design by adjusting configuration parameters such as dynamic transmission power adjustment, packet transmission frequencies, and delay aspect of message forwarding (within transmission time window based on vehicle position and speed). These issues, along with other improvements in the communication protocol stack, will be important future research questions related to the design of reliable, scalable, and efficient broadcast routing protocols for vehicular communication networks.

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