Routing Protocol in Inter-Vehicle Communication Systems: A Survey

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***Abstract*— Safety application for driving has recently been the topic of several researches. IEEE standards including IEEE802.11p and IEEEP1609.1-4 have emerged to provide a framework for Inter-Vehicular Communication (IVC). However, due to particular characteristics of IVC, such as high mobility, unstable connectivity, and network partitioning, information routing becomes inevitably challenging. This paper highlights open research challenges and issues in vehicular routing protocol as a guideline for future development of IVC applications. The paper focuses on the IEEE DSRC/WAVE standard. The state-of-the-art in IVC routing protocols are surveyed and compared in the paper.**

***Index Terms*—Routing Protocol, Inter-Vehicle Communication, IVC, Vehicular Ad-hoc Network, VANET, IEEE802.11p, DSRC, WAVE, Survey**

I. Introduction

ROAD safety improvement is an emerging issue and it has gained major attention from researchers and engineers in the academy and automotive industry* [1]. The number of vehicles tends to increase at high rate every year in all countries. However, the growth of the number of roads and highways was more limited than the growth of the number of vehicles. For these reasons, the number of accidents on roads and highways tend to get higher and higher. Besides, the larger number of vehicles also causes serious traffic congestion, especially during rush hours. The congestion becomes more severe if an accident additionally occurs in such area. The problem leads to serious delay in transportation systems.

One possible solution to improve road safety can be developed based on wireless communication among vehicles that it provides drivers with information to drive according to road and traffic conditions. Due to recent advances in wireless communication nowadays, Inter-Vehicle Communication (IVC) systems become more realistic solutions. Applications of IVC can be roughly divided into 2 categories.

Passenger-comfort application aims to make drivers more comfort during their driving, such as supports of game, internet, video steaming, and social network services. The passenger-comfort application needs to delivery huge amount of data to a specific destination in real time. Unicast communication becomes a preference for this application

Safe-driving application, in contrast, is an application aims to make driving environment safer. Examples of road safety applications are vehicular emergency warning, cooperative adaptive cruise control, highway-rail intersection warning, approaching emergency vehicle warning, etc. This paper mainly addresses the safety application, of which information (basically small packets) must be immediately provided to vehicles surrounding and vehicles in risky areas. Therefore, broadcast communication protocol is needed.

Fig. 1 illustrates a scenario of safety application using IVC. There is one vehicle sending a warning message. Arrows represent directions of message dissemination. To warn other drivers, the message is rebroadcasted hop-by-hop to cover all road segments. To make these applications more realistic, Intelligent Transportation System (ITS) provides an additional framework to enhance the road safety. A Licensed Dedicated Short Range Communications (DSRC) of 75 MHz spectrum in the 5.9 GHz band based on IEEE802.11a is allocated for Wireless Access in Vehicular Environments (WAVE). A draft standard is also assigned for this technology as IEEE802.11p and IEEEP1609.1-4 [2].

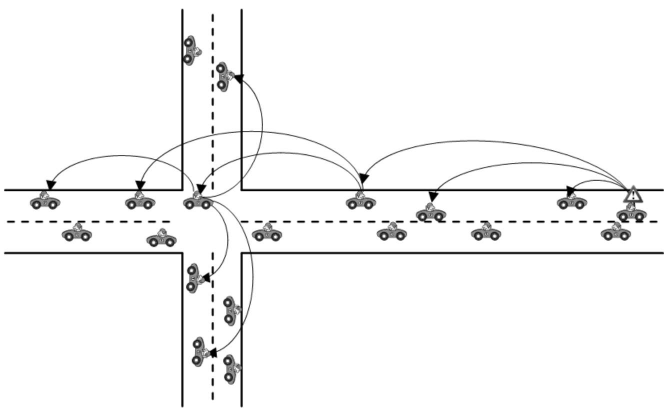

Fig. 1 Example of IVC Scenario

* -"PRE-DRIVE C2X", [Online]. Available: http://www.pre-drive-c2x.eu.
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<table>
<tr><td></td><td>OSI</td><td>TCP/IP</td><td></td></tr>
<tr><td rowspan="4">IEEEP1609.
1</td><td>Application</td><td rowspan="3">Application</td><td rowspan="6">IEEE1609.2
(Security
Service)</td></tr>
<tr><td>Presentation</td></tr>
<tr><td>Session</td></tr>
<tr><td>Transport</td><td>Transport</td></tr>
<tr><td>IEEEP1609.
3</td><td>Network</td><td>Internet</td></tr>
<tr><td rowspan="2">IEEEP1609.
4
IEEE802.11p</td><td>Data Link/ MAC</td><td rowspan="2">Network
Interface</td></tr>
<tr><td>Physical</td><td></td></tr>
</table>

Fig. 2 WAVE Standard Structure compared with OSI and TCP/IP Models

Critical Safety Channel *Critical Safety Applications*	Service Channels (SCH) *Commercial Applications*		Control Channel (CCH) *Channel Control Monitoring*	Service Channels (SCH) *Commercial Applications*		Future Reservation
CH172	CH174	CH176	CH178	CH180	CH182	CH184
5.86 GHz	5.87 GHz	5.88 GHz	5.89 GHz	5.90 GHz	5.91 GHz	5.92 GHz

Fig. 3 Channel Allocation in DSRC

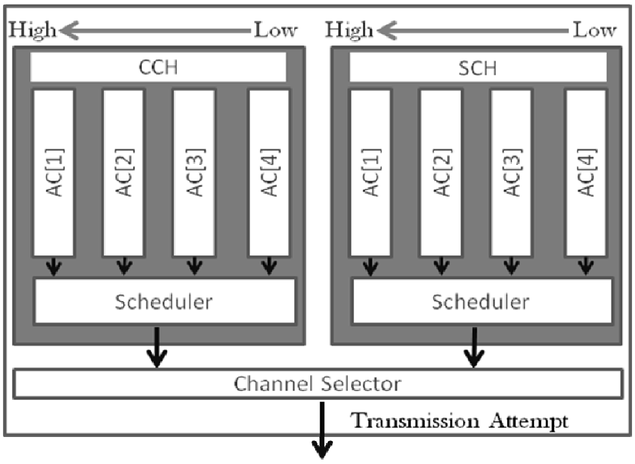

Fig. 4 QoS Queue Structure on a Vehicle in WAVE

In this article, our focus is on routing protocol for multi-hop communications in Vehicular Ad hoc Network (VANET). Section II presents recent features of DSRC/WAVE framework and the relevant IEEE standards. The state-of-the-arts on IVC routing protocols is surveyed and discussed in sections III and IV respectively. Section V highlights open research challenges and issues in this area as a guideline for future development of IVC applications. Finally, section VI concludes the paper.

II. DSRC/WAVE AND IEEE STANDARDS

WAVE is a major component of DSRC, assigned by Federal Communication Commission (FCC) as a set of protocols for vehicular safety application. WAVE is a term for developing standard suite, including IEEE802.11 for PHY/MAC layer and IEEE1609.1-4 for network and upper layer operations. Both DSRC and WAVE are normally referred to interchangeably as a promising framework for IVC.

The architecture of WAVE compared with OSI and TCP/IP models is shown in Fig. 2. As bottom-up explanation, IEEE802.11p [2] is chosen to provide mechanisms on PHY and MAC layers.

IEEEP1609.4 is designed to enhance effectiveness of mechanisms that control the operation of upper layer across multiple channels, and describe the multi-channel operation channel routing and switching for different scenarios. Orthogonal Frequency Division Multiplexing (OFDM) of IEEE802.11a is implemented in WAVE, so that it can achieve data rate from 9 to 27 Mbps and from 3 to 12 Mbps when vehicles move at a velocity below 60 Km/hr and at a velocity between 60 and 120 Km/hr respectively. A channel allocation of DSRC is demonstrated in Fig. 3. There are seven channels grouped into three different types; Service Channel (SCH), Control Channel (CCH), and Critical Safety Channel. The frequency shown in Fig.3 is a center frequency of each channel. All channels equally have 10 MHz in width. CCH is assigned for channel control monitoring, while SCH is for commercial application and Critical Safety Channel is for IVC applications, such as accident avoidance and mitigation. Ch184 is reserved for future usage.

On MAC layer, WAVE refers to CSMA/CA with RTS/CTS, as a mechanism in IEEE802.11, to deal with hidden and exposed terminal problems. WAVE also provides QoS on MAC layer by following the Enhanced Distributed Channel Access (EDCA) mechanism in IEEE802.11e with minor modification. WAVE assigns Access Category (AC) queues on per-channel basis on each vehicle as depicted in Fig. 4. There are two sets of priority queues on each vehicle for critical safety application and commercial application respectively. Each of the channels consists of 4 ACs and contends for channel access according to its priorities. For example, urgent safety messages will contend for channel access faster than commercial messages by waiting for short inter-frame space and contention window.

IEEEP1609.3 is implemented on network layers as illustrated in Fig. 2. IEEEP1609.3 defines network layer services, which includes addressing and routing in support of secure WAVE data exchange. It also defines WAVE Short Messages (WSM) which provides an efficient WAVE-specific alternative to IP, and defines information management schemes for WAVE protocol stack.

IEEEP1609.1 deals with resource management; describes key components of WAVE architecture, defines command message formats and data storage formats, defines data flows and resources, and specifies types of devices that may be implemented in vehicles.

Security services for applications and management messages are provided by IEEEP1609.2. The standard defines secure message formats and processes circumstances for using secure message exchanges on network and upper layers.

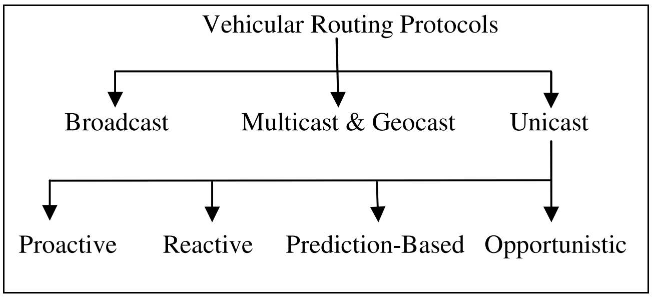

Fig. 5 Categories of vehicular routing protocols

III. The State of the Arts on Routing Protocol in IVC

Dynamic topology of IVC makes packet routing very challenging. In this section, we classify routing protocols in IVC into three categories; (i) broadcast, (ii) multicast and geocast, and (iii) unicast schemes. Besides, unicast-based routing protocol can be subdivided into proactive, reactive, prediction-based and opportunistic routing protocols illustrated in Fig.5. We survey and summarize the routing protocols in IVC according to these classifications in the following subsections.

A. *Broadcast-based routing protocols*

Broadcast-based routing protocol is a very basic scheme to disseminate data from one sender to several receivers. The broadcast scheme seems to be the best solution for data dissemination in a high mobility network, which needs a fully distributed solution. The network does not need maintenance of routing tables, and information of each individual vehicle, such as position, speed, etc. However, the drawback of this scheme is high bandwidth usage, high data collision and errors, and low throughput. Flooding is a fundamental example of broadcast-based routing protocol. Because all vehicles rebroadcast data regardless a receipt of such data, a large amount of redundancy data is transmitted into a channel, wasting bandwidth, raising data collision ratio, and finally resulting in low network throughput. Nonetheless, the data duplication can be eliminated by assigning an appropriated relay to rebroadcast data. Only one vehicle is responsible for rebroadcasting data. Therefore, the amount of data traffic in the network is reduced drastically, leading to more effective bandwidth utilization. There are a number of mechanisms dealing with the selection of a relay vehicle.

1) Smart Broadcast (SB): SB aims to maximize the progress of the message along the propagation line and minimize broadcast delay [3]. Network is partitioned into sectors. It is assumed that each vehicle is capable of sensing its own position and calculating a sector it belongs to. The protocol applies contention mechanism of IEEE802.11 to elect a relay vehicle.

The source starts the process by sending Request to Broadcast (RTB). Upon a receipt of RTB, each vehicle calculates its belonging sector and Contention Window size (CW). Vehicles along with different sectors will have different and non-overlapping values of CW sets. The set of CW values of outermost sector will be smallest, thus, vehicles belong to this sector will contend for a channel access faster than other vehicles and have higher probability to be elected as a relay vehicle. Election of the farthest vehicle as a relay node, making a transmission as far as possible, effectively helps utilizing bandwidth.

After channel contention, a vehicle will transmit Clear to Broadcast (CTB) packet. If there is no collision during CTB transmission, such node will become a relay vehicle. The source vehicle then transmits MAC-broadcast frame to all vehicles in its communication range, but only the relay vehicle will rebroadcast such a packet to the next communication hop. The process will repeat. However, in case of CTB collision, the rest of vehicles will continue to contend for channel access and send CTB after backoff counter reaches zero. This makes protocol more robust. In the worst-case scenario, source waits for longest CW and there is no successful CTB transmission. The source vehicles will restart the whole process again.

The simulation results show that SB provides low latency, but experiences low message progress; shorter additional distance covered by the message in a re–broadcast phase, on average.

2) Priority based Routing Protocol in VANET (PRP): The PRP is designed based on IEEE802.11e standard. It aims to provide fully decentralized routing protocol, different quality of services (QoS) for different message priorities, and maximum message dissemination distance per hop [4]. Both PRP and SB implement contention mechanism for relay vehicle election. In addition, the contention mechanism is also applied for message prioritization. Thus, one difference between SB and PRP is that PRP is able to provide differential services for different priorities of messages, e.g. urgent messages are transmitted faster than other lower priority messages. The other difference is PRP also considers data dissemination in all segments of a road at intersections.

3) Urban Multi-hop Broadcast (UMB): The UMB objectives are similar to those of SB and PRP; collision avoidance, channel utilization, broadcast communication reliability [5]. UMB also considers data dissemination in all directions at intersections. To avoid a hidden terminal problem, UMB makes use of RTB/CTB handshake scheme with only one recipient. A source vehicle obeys CSMA/CA mechanism to transmitting a RTB packet, which includes both sender's position and a broadcast direction. Once vehicles in dissemination direction receive RTB, they calculate distance from the source and start transmitting black-burst; a channel jamming signal, for a period of time as a proportion to the calculated distance. For example the farthest vehicle will transmit the longest black-burst. After each vehicle finishes the transmission of black-burst, it turns to listen to the channel immediately. If the vehicle senses that the channel is idle, it will become a relay vehicle. It then sends CTB back to the source. Depending upon CTB reception, the source will send a broadcast packet, which includes identification (ID) of the relay vehicle. In contrast, if a vehicle senses that the channel is not idle yet after finishing black-burst transmission. It will notice that it is not elected as a relay vehicle and does nothing.

In the worst scenario, if there are more than one vehicle finishing black-burst transmission and sending CTB out at the same time. Due to unrecognized CTB, the source will repeat relay node selection process only for such vehicles. Besides, UMB makes use of infrastructure to directionally rebroadcast packets at intersections. With the application of black-burst transmission, it results in high broadcast latency and wasting of bandwidth.

B. Multicast and Geocast-based routing protocols

Safety application sometimes requires a communication among a group of vehicles. Some information may be useful for just only small group of vehicles; not all of them. Geocast-based routing protocol, which is one type of multicast-based routing protocols, is capable of disseminating data from one to many nodes in a specific geographical region. Therefore, it becomes the most suitable solution to only disseminate data to vehicles for which such data is useful.

1) Inter-Vehicle Geocast (IVG): IVG is proposed for effective and scalable dissemination of safety messages to vehicles in risk areas only [6]. A source broadcasts a message to other vehicles. Each vehicle who has received the message waits for a period of time called a defer time, before rebroadcasting the message. A duration of defer time is inversely proportional to vehicle's distance; the furthest vehicle waits shorter and rebroadcasts faster.

IVG also presents a concept of "too much late" area where a distance of a vehicle to an accident becomes less than vehicle's braking distance. The rebroadcast period must ensure that vehicles are informed before they penetrate the too much late area. Time to live (TTL) is also chosen for avoiding infinite dissemination of alarm messages. The simulation results show achievements in both reliability and scalability.

C. Unicast-based routing protocols

Unicast-based routing protocol is point-to-point communication. A routing path needs to be maintained as stable as possible during communication. However, dynamic nature of VANET can cause serious path disruptions. Therefore, several mechanisms are required to manage unstable path problems in unicast-based communication, and hence make protocol more complicated and have high overhead. According to the previous classification, there are 4 categories of unicast-based routing protocol shown in Fig. 5.

Proactive routing protocol periodically creates and updates new route of each pair of vehicles. It basically suffers from how to determine the optimal period for route creation and update. Too short of period makes the protocol suffered from high overhead. In contrast, too long of period makes the protocol suffered from frequent route failures.

Reactive protocol, on the other hand, creates a new route only when the existing one is broken. Therefore, overhead is lower than that of proactive protocol, but higher route failures. In addition, it also lacks ability to determine a better route, due to no periodically route updating.

Prediction-based routing protocol can be considered as an optimal solution between proactive and reactive protocols. The protocol takes advantage of proactive protocol without route failures as in reactive protocol. Using of current information of each vehicle, the protocol predicts a probability of route breaking and search for alternative routes before the communication is disrupted.

In case, routing protocols cannot find a reachable route between each pair of vehicles. Messages will be normally dropped. Opportunistic routing protocol becomes a solution to deliver messages even if there is no route between vehicles. By storing messages until a destination is reachable, the messages then will be forwarded to the destination with longer delay as a tradeoff. Therefore, with high delay, the opportunistic protocol is suitable to implement in delay tolerated network but inapplicable for safety application.

1) Location-Based Routing Algorithm with Cluster-Based Flooding (LORA-CBF): LORA-CBF has goals to improve packet forwarding decision, propose predictive algorithm, and improve scalability of the protocol [7]. LORA-CBF is hierarchical-based protocol. Cluster heads need to maintain cluster tables. The cluster tables normally contain addresses and locations of both member and gateway vehicles; gateway vehicles are allowed to communicate with other cluster heads. Before transmission, a source vehicle determines a destination location by checking the routing table. If the location is found, the source vehicle transmits packet to the closest neighbor to the destination. Otherwise, the source broadcasts a Location Request (LREQ) and waits for Location Reply (LREP). Upon a reception of the location, a packet is sent to the closest neighbor to the destination. The process repeats until the packet is delivered. However, since the cluster heads need to maintain the cluster tables, high overhead of control packet is unavoidable.

2) Greedy Perimeter Coordinator Routing (GPCR): GPCR is proposed to take advantage of streets and junctions to form a natural planar graph without exploiting additional global information, such as a static street map. GPCR consists of two operations; a restricted greedy forwarding and a repair strategy [8]. During the restricted greedy forwarding operation, the source forwards a message towards a destination. No decision is made on each vehicle, except vehicles on junctions. The messages tend to be forwarded to vehicles on a junction rather than vehicles across the junction. To achieve this, vehicles on the junction called "coordinators" will broadcast their roles along with position information. If there are many vehicles on the junction, source will randomly pick one vehicle as a relay. The elected relay vehicle decides a street to which a message will be transmitted. The restricted greedy forwarding operation will be repeated. However, GPCR is a position-based unicast communication, source vehicles need to have destination's positions resulting in high overhead of information exchange.

3) Prediction-Based Routing protocol (PBR): PBR takes advantage of predictable mobility patterns of vehicles on highways [9]. Deterministic motion patterns and speeds of vehicles are used for roughly determination of how long routes will exist. Predicted route lifetime is implemented to preemptively create new route before the existing one is broken. The simulation results show PBR succeeds in providing lower rate of dropped packets than those of both reactive and proactive protocols. However, its overhead is a little bit higher than that of reactive protocol.

4) Opportunistic Routing in DTN (GeoDTN+Nav): GeoDTN+Nav is designed for delay tolerant routing when a direct route to a destination does not exist [10]. This situation can be normally happen after peak hours or at night when a number of vehicles is very low leading to network partitioning problem. In this case, traditional routing protocols will generally drop messages. In GeoDTN+Nav, in contrast, a vehicle will carry messages and wait for a right opportunity to forward them to other better qualified vehicles toward the destination. Therefore, the protocol is suitable for real time video stream rather than safety application, since the streaming video can tolerate delay tolerated while safety application cannot. The results show that GeoDTN+Nav achieve in high delivery ratio as a tradeoff with longer delay.

IV. Comparisons and Discussions

The summary of all routing protocols in terms of routing category, mobility model, intersection consideration, and network topology is depicted in Table I.

Routing category column shows three classifications, as presented previously, to which each routing protocol belongs. SB, PRP, IVG, LORA-CBF, and PRB implement highway scenario in the simulations, while UWB, GPCR, and GeoDTN+Nav considers city environment in which there are higher number of vehicles with slower movement's speed. Message routing at intersections is taken into consideration only in PRP, UMB, GPCR, and GeoDTN+Nav, while the others deal only with communication on straight roads and highways. Since IVC network tends to be established on the fly, almost all routing protocols are implemented on flat networks, except LORA-CBF, which considers cluster-based network instead. There are a number of techniques implemented for message forwarding, such as uses of contention window, black-burst, defer time, cluster-table, and greedy forwarding concept.

With opportunistic strategy (store and forward) of GeoDTN+Nav, the protocol achieves very high reliability even at low number of vehicles. Due to network partitioning problem, the other protocols cannot deliver message to other vehicles causing low communication reliability. In contrast, at high number of vehicles, the other protocols perform better and are able to guarantee higher reliability.

To be scalable, a lightweight protocol and low network overhead are required. Broadcast protocols, such as SB, PRP, and UWB, outperform the others since they are fully distributed and result in low network overhead. The rest of the protocols have higher overhead. For example, IVG, LORA-CBF, GPCR, PRB and GeoDTN+Nav are geocast and unicast protocol, which require vehicles' positions for route maintenance. Therefore, when vehicles' density is high, such protocols require high amount of data exchange, intensifying network overhead and lowering network scalability.

TABLE I
Summary of Routing Protocols in IVC

Protocol	Routing Category	Mobility Model	Intersection Consideration	Network Topology	Methodology
SB	Broadcast	Highway	No	Flat	Contention Window
PRP	Broadcast	Highway	Yes	Flat	Contention Window
UWB	Broadcast	City	Yes	Flat	Black-Burst
IVG	Geocast	Highway	No	Flat	Defer Time
LORA-CBF	Unicast	Highway	No	Hierarchical	Cluster Table Maintenance
GPCR	Unicast	City	Yes	Flat	Greedy Forwarding
PRB	Unicast	Highway	No	Flat	Route Failure Prediction
GeoDTN +Nav	Unicast	City	Yes	Flat	Opportunistic

SB and PRP have the shortest delay, since they are broadcast-based communication; no need for route discovery. Besides broadcast-based communication, they also implement contention window concept for shortening relay vehicle selection process. In contrast, UWB and IVG implement black-burst and defer time; additional waiting time before transmitting a message, thus, both face additional delay. Unicast-based communication needs route discovery before message forwarding, which causes LORA-CBF, GPCR and PBR to have longer delay. Besides, due to opportunistic delivery, GeoDTN+Nav provides the largest delay but highest reliability as a tradeoff.

To be flexible, routing protocols should be able to deal with vehicle entering and leaving the network from time to time. Broadcast-based protocols, such as SB, PRP, and UWB, have rarely impact from vehicles entering or leaving the network. The other protocols, in contrast, need updated information. Therefore, vehicles entering or leaving the network frequently make a major impact on information update causing high amount of network overhead.

Since situations on road and highway may vary from very urgent to general, messages should be tagged with priority before transmission. Therefore, routing protocol must be able to provide different QoS for different message priorities. Among all existing routing protocols, PRP is the only protocol taking message priority into account. The simulation result shows that the protocol achieves in provide differential service in term of delay for different message's priorities.

None of reviewed protocols provide secure vehicular communication. However, since information of safety application is sensitive and can lead to any dangerous during driving, security becomes a compulsory feature of vehicular routing protocol. Consequently, the security mechanism is needed to be taken into consideration for future proposal of a routing protocol.

V. Open Issues and Areas for Research in Inter-Vehicle Communication Systems

Even though a number of researches in IVC have been proposed, there still are several remaining issues for further research. This section summarizes open issues and areas for research in IVC as a guideline for future development of safety applications.

A. *Open Issues and Areas for Research in IVC*

In this section, we present some challenges on network layers of IVC. Routing control in IVC raises diverse challenges and issues in an implementation, due to its uniqueness. For example, a dynamic topology of vehicular network makes communication routes unstable and routing maintenance difficult, resulting in high latency, low reliability, non-scalability, inflexibility, low fault tolerance, and security issues.

1) Real Time Transmission and Delay Constraint

In many cases of driving accidents, drivers usually do not have enough time to deal with a suddenly occurred situation. IVC can alleviate the problem by distributing information in real time, especially an urgent one, to extend drivers' perceptions. Even in blink of an eye, if a driver receives information on time, he may be safe from an accident. Consequently, communication routes need to be maintained all the time or be constructed on the fly for real time information dissemination.

2) High Mobility and Rapid Topology Changing

IVC urges another new challenge in mobility. Vehicles move fast, but predictably as they usually move along road topology. The mobility causes rapid topology changes and frequent disruptions in communication. Therefore, future development of vehicular routing protocols must deal with this dynamic topology well. Broadcast based communication may become one solution to provide effective data dissemination regardless the fast-changing topology.

3) Reliability and Quality of Service (QoS)

In vehicle environment, wide ranges of events can occur; some may be critical, but others may not. For example, if one vehicle experiences an abnormality and it is suddenly stopped in a middle of a highway, fatal information related to this situation needs to be transmitted to other following vehicles immediately with high reliability. This makes sure that other drivers get prompt information and drive more carefully to avoid an accident. On the contrary, another may detect the presence of fog, which makes driving inconvenient. This situation, compared with the previous one, is lesser important. Information related to this situation may not either need to be transmitted as quickly as possible or require high transmission reliability. Therefore, information must be tagged for priority before transmission. Routing protocol in IVC will treat all information regarding their priorities to achieve both reliability and QoS.

Many researchers evaluated performance of IEE802.11e application on IVC. However, IEEE802.11e only provides QoS on MAC layer, thus, only guarantee one-hop QoS. In fact QoS must be provided across layers so that the protocol can guarantee various QoS aspects, such as low end-to-end latency, fast routing path and reliable dissemination for vital information. Consequently, QoS on network and upper layers become the other interesting research areas which need to be taken into account for future proposed vehicular communication protocol.

4) Scalability and Flexibility

A number of vehicles may depend upon an area. For example, in rural area, where the number of vehicles is quite low, it becomes very difficult to maintain network connectivity without Road Side Unit (RSU). Allocation of RSUs requires large amount of investment. Some research makes use of less stringent power constraint by expand communication range with higher transmission power to make each vehicle more reachable without RSU support.

In contrast, city area is normally very crowded. Therefore, the number of vehicles is normally higher than that in a rural area. When the number of vehicles is high, routing protocols need to minimize overhead or control packet as much as possible, since a lot of vehicles need to communicate with the others. In fact, a communication channel should be dedicated for safety communication rather than control overhead. This becomes other challenge for a design of future vehicular protocol.

5) Fault Tolerance

Because VANET is usually setup on the fly, several vehicles may enter and leave a network from time to time. During transmission of information along with one route, if a vehicle leaves the network suddenly, routing protocol should be able to manage this problem by constructing a new route as soon as possible. Prediction of route failure in advanced can help to alleviate the problem, but require high amount of update information exchange, leading to unscalable communication. This becomes an additional open challenge in vehicular environment.

6) Security Enhancement

Among the routing protocol recently proposed, few consider communication security. In fact, security is one of the most challenging and important issue for safety application based on IVC. A malicious vehicle can easily gain benefit from others if no security is implemented in a routing protocol and can cause diverse ranges of damages. In disaster scenario, the cost of misinformation could be extremely high. Bogus information can also be used by terrorist leading naive people into a trap, such as dead-end tunnel.

To protect the network from forged information injection, the communication in IVC must achieve authentication, integrity and non-repudiation, so that no unauthorized vehicle can enter the network, and all authorized vehicles cannot modify content of any packets and have to be responsible in their information transmission. In addition, privacy information, such as location and travel route, may be considered sensitive. All drivers must not be able to learn privacy information of others. Therefore, secure communication becomes a promising area of research for future vehicular communication.

VI. CONCLUSION

In this paper, we have provided an in-depth review of proposed routing protocols. It can be seen from the review and further research that various routing protocols are proposed to achieve an effective information routing. However, due to unique characteristic of vehicular communication, it raises several open issues and areas for research, such as communication reliability, QoS and security.

Because of high mobility and variable network density, communication reliability becomes a challenging issue. Future routing protocol need to effectively provide high reliability regardless the number of vehicles. One solution is a proposal of multi-mode protocol, such as combination of broadcast and opportunistic protocols. The multi-mode protocol can switch between each mode regarding number of vehicles to optimize communication reliability.

QoS of one-hop communication is promising on MAC layer with IEEE801.11e standard, but it is not well considered for multi-hop communication. This raises new challenges on cross-layer QoS (between MAC and upper layers) in routing protocol design to provide differential service for different priorities of communication in message routing.

Security enhancement is also required for further proposed protocols since vehicular communication can be misused for urging any serious situations. Therefore, security mechanisms, such as authentication and non-repudiation, are mandatory for future routing protocol design to protect the network from misleading information.

Although there are many efforts have been put into research in IVC but still many issues remain for future research.

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