Routing Protocol in Intervehicle Communication Systems: A Survey

Chakkaphong Suthaputchakun and Zhili Sun, University of Surrey

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ABSTRACT

Communication technology for vehicles has become an important topic for research. IEEE standards including IEEE 802.11p and IEEE P1609.1–4 have emerged to provide a framework for intervehicular communication (IVC). However, due to particular characteristics of IVC, such as high mobility, unstable connectivity, and network partitioning, information routing becomes inevitably challenging. This article reviews the recent research progress to highlight research challenges in vehicular routing protocol as a guideline for future development of IVC applications. The article focuses on the IEEE DSRC/WAVE standard. The state of the art in IVC routing protocols is surveyed, and open issues for further research are highlighted in the article.

INTRODUCTION

Road safety improvement is an emerging issue, and has gained major attention from researchers and engineers in the academy and automotive industry [1]. The number of vehicles has rapidly increased in several countries. However, the rate of growth of new roads and highways is much lower than the growth in vehicles. For these reasons, the number of accidents on roads and highways tends 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 occurs. The problem leads to serious delay in transportation systems.

One possible solution to improve road safety is to develop technology based on wireless communication among vehicles. The communication provides drivers with information to drive according to road and traffic conditions. Due to recent advances in wireless communication nowadays, intervehicle communication (IVC) systems become more realistic solutions. Applications of IVC can be roughly divided into two categories.

Passenger comfort applications: Passenger comfort applications aim to make drivers and passengers more comfortable during their travel. This type of application includes games, Internet access, video streaming, and social network services. Most passenger comfort applications usually need to deliver large amounts of data to a specific destination in real time.

Safe driving applications: Safe driving applications, in contrast, aim at making the driving environment safer. Examples of road safety applications are vehicular emergency warning, cooperative adaptive cruise control, highway-rail intersection warning, approaching emergency vehicle warning, and so on.

Figure 1 illustrates a scenario of a 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 rebroadcast hop by hop to cover all road segments. To make these applications more realistic, an intelligent transportation system (ITS) provides an additional framework to enhance road safety. Licensed dedicated short-range communications (DSRC) of 75 MHz spectrum in the 5.9 GHz band based on IEEE 802.11a is allocated for wireless access in vehicular environments (WAVE). A draft standard is also assigned for this technology as IEEE 802.11p and IEEE P1609.1–4 [2].

In this article, our focus is on routing protocol for multihop communications in vehicular ad hoc networks (VANETs). We present recent features of the DSRC/WAVE framework and the relevant IEEE standards. The state of the art in IVC routing protocols is surveyed and discussed, respectively. We highlight open research challenges and issues in this area as a guideline for future development of IVC applications. Finally, we conclude the article.

DSRC/WAVE AND IEEE STANDARDS

WAVE is a major component of DSRC, assigned by the U.S. Federal Communication Commission (FCC) as a set of protocols for vehicular safety applications. WAVE is a term for developing a standard suite, including IEEE 802.11 for the physical and medium access control (PHY/MAC) layers and IEEE P1609.1–4 for network and upper layer operations. Both DSRC and WAVE are normally referred to interchangeably as promising frameworks for IVC.

The architecture of WAVE compared with OSI and TCP/IP reference models is shown in Table 1. As a bottom-up explanation, IEEE 802.11p [2] and IEEE P1609.4 are chosen to provide mechanisms on the PHY and MAC layers. Besides, IEEE P1609.4 is also designed to enhance the effectiveness of mechanisms that

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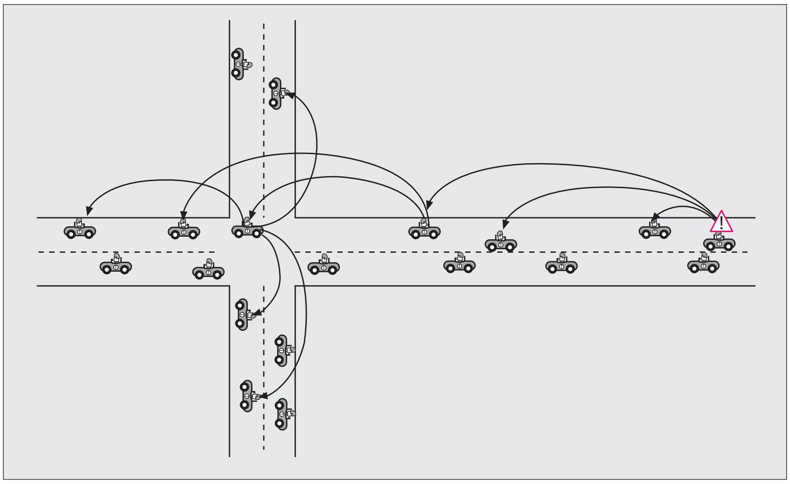

Figure 1. *Example of an IVC scenario.*

	OSI	TCP/IP	
IEEE P1609.1	Application	Application	IEEE P1609.2 (security service)
	Presentation		
	Session		
	Transport	Transport	
IEEE P1609.3	Network	Internet	
IEEE P1609.4 IEEE 802.11p	Data link/MAC	Network interface	
	Physical		

Table 1. *WAVE standard structure compared with OSI and TCP/IP models.*

control the operation of upper layers across multiple channels, and describe the multichannel operation channel routing and switching for different scenarios. The orthogonal frequency-division multiplexing (OFDM) of IEEE 802.11a is implemented in WAVE, so it can achieve data rate from 9 to 27 Mb/s and from 3 to 12 Mb/s when vehicles move at a velocity below 60 km/h and at a velocity between 60 and 120 km/h, respectively. A channel allocation of DSRC is demonstrated in Fig. 2. There are seven channels grouped into three different types: service channel (SCH), control channel (CCH), and critical safety channel. The frequencies shown for each channel in Fig. 2 are center frequencies. All channels have 10 MHz bandwidth equally. The CCH is assigned for channel control monitoring, while the SCH is for commercial application, and the critical safety channel is for IVC applications, such as accident avoidance and mitigation. Ch184 is reserved for future usage.

On the MAC layer, WAVE refers to carrier sense multiple access with collision avoidance (CSMA/CA) with request/clear to send (RTS/CTS), a mechanism in IEEE 802.11, to deal with the hidden and exposed terminal problems. WAVE also provides quality of service (QoS) on the MAC layer by following the Enhanced Distributed Channel Access (EDCA) mechanism in IEEE 802.11e with minor modification. WAVE assigns access category (AC) queues on a per-channel basis on each vehicle as depicted in Fig. 3. There are two sets of priority queues on each vehicle for critical safety application and commercial application, respectively. The channel selector makes sure that data is transmitted over a valid channel only. Otherwise, the data will be dropped. Each of the channels consists of four 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 shorter interframe spaces and contention windows. Thus, the chance to win channel access becomes higher.

IEEE P1609.3 defines network layer services, which include addressing and routing in support of secure WAVE data exchange. It also defines WAVE short messages (WSM), which provide an efficient WAVE-specific alternative to IP, and defines information management schemes for the WAVE protocol stack.

IEEE P1609.1 deals with resource management, describing key components of WAVE architecture, defining command message formats and data storage formats, defining data flows and resources, and specifying types of devices that may be implemented in vehicles.

Security services for applications and management messages are provided by IEEE P1609.2. The standard defines secure message formats and processes circumstances for using secure message exchanges on network and upper layers.

The State of the Art in Routing Protocols in IVC

The dynamic topology of IVC makes packet routing very challenging. In this section, we classify routing protocols in IVC into three categories:

- Broadcast
- Multicast and geocast
- Unicast schemes

Besides, unicast-based routing protocols can be subdivided into proactive, reactive, prediction-based, and opportunistic routing protocols, as illustrated in Fig. 4. We survey and summarize the routing protocols in IVC according to this classification in the following subsections. However, due to space limitations, some other existing proposals are not covered in this article.

Broadcast-Based Routing Protocols

Broadcast-based routing is a very basic scheme to disseminate data from one sender to all receivers. The broadcast scheme seems to be one possible 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 and speed. However, the drawback of this scheme is high bandwidth usage, high data collision and errors, and low throughput. Flooding is a fundamental example of a broadcast-based routing protocol. Because all vehicles rebroadcast data despite the reception of such data, a large amount of redundant data is transmitted into a channel, wasting bandwidth, raising the data collision ratio, and finally result-

Critical safety channel Critical safety applications	Service channels (SCHs)	Commercial applications	Control channel (CCH) Channel control monitoring	Service channels (SCHs)	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

Figure 2. *Channel allocation in DSRC.*

ing in low network throughput. Nonetheless, the data duplication can be eliminated by assigning an appropriate 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.

Smart Broadcast — SB aims to maximize the progress of the message along the propagation line and minimize broadcast delay [3]. Network is partitioned into sectors of geographic areas. It is assumed that each vehicle is capable of sensing its own position and calculating a sector to which it belongs. The protocol applies a contention mechanism of IEEE 802.11 to elect a relay vehicle.

The source starts the process by sending a request to broadcast (RTB). Upon receipt of an RTB, each vehicle calculates the sector it belongs to and the contention window (CW) time slot. Vehicles in different sectors have different and non-overlapping values of CW sets. The set of CW values of the outermost sector will be smallest; thus, vehicles in this sector will contend for channel access faster than other vehicles and have higher probability of being elected as a relay vehicle. Election of the farthest vehicle as a relay node makes transmission more effective and effectively utilizes bandwidth.

After channel contention, a vehicle will transmit a clear to broadcast (CTB) packet. If there is no collision during CTB transmission, this node will become a relay vehicle. The source vehicle then transmits a 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 the vehicles will continue to contend for channel access and send CTB after the backoff counter reaches zero. This makes the protocol more robust. In the worst case scenario, the source waits for the longest CW and there is no successful CTB transmission. The source vehicles will then restart the whole process.

Priority-Based Routing Protocol in VANET — The PRP is designed based on IEEE 802.11e. It aims to provide a fully decentralized routing protocol, a QoS mechanism for different message priorities, and maximum message dissemination distance per hop [4]. Both PRP and SB implement a 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 differentiated services for different priorities of messages (e.g., urgent messages are transmitted sooner than lower-priority messages). The other difference is that PRP also considers data dissemination in all segments of a road at intersections.

Urban Multihop Broadcast — UMB has similar objectives as the SB and PRP: collision avoidance, channel utilization, and broadcast communication reliability [5]. In addition, UMB also considers data dissemination in all directions at intersections. To avoid a hidden terminal problem, UMB makes use of an RTB/CTB handshake scheme with only one recipient. A source vehicle obeys carrier sense multiple access with collision avoidance (CSMA/CA) to transmit an RTB packet, which includes both the sender's position and a broadcast direction. Once vehicles in the dissemination direction receive the RTB, they calculate their 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. After each vehicle finishes the transmission of black-burst, it begins to listen to the channel immediately. If the vehicle senses that the channel is idle, it will become a relay vehicle. It then sends a CTB back to the source. Depending on 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 even after finishing black-burst transmission, it will notice that it is not elected as a relay vehicle and do nothing.

In the worst case scenario, if there are more than one vehicle finishing black-burst transmission and sending CTBs out at the same time, the source will repeat the relay node selection process only for such vehicles. Besides, UMB makes use of infrastructure to directionally rebroadcast packets at intersections.

Multicast and Geocast-Based Routing Protocols

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

Intervehicle Geocast — 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 that has received the message waits for a period of time, called a defer time, before rebroadcasting the message. The duration of defer time is inversely proportional to the vehicle's distance; the furthest vehicle waits the shortest time and rebroadcasts fastest.

IVG also presents the concept of a "much too late" area where the distance of a vehicle to an accident site becomes less than the vehicle's braking distance. The rebroadcast period must ensure that vehicles are informed before they penetrate the much too late area. A time to live (TTL) is also chosen to avoid infinite dissemination of alarm messages.

UNICAST-BASED ROUTING PROTOCOLS

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

A proactive routing protocol periodically creates and updates the new routes of each pair of vehicles. It basically suffers from the complexity of how to determine the optimal period for route creation and update. Too short periods make the protocol suffer from high overhead. Conversely, too long periods make the protocol suffer from frequent route failures.

A reactive protocol, on the other hand, creates a new route only when the existing one is broken. Therefore, its overhead is lower than that of a proactive protocol, but the number of route failures is higher. In addition, it also lacks the ability to determine a better route due to lack of periodic updates of routing information.

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

If routing protocols cannot find a reachable route between each pair of vehicles, messages would normally be dropped. An 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 are then forwarded to the destination with longer delay as a trade-off. Therefore, with high delay, the opportunistic protocol is suitable to implement in a delay-tolerant network but is not applicable for safety application.

Location-Based Routing Algorithm with Cluster-Based Flooding — LORA-CBF aims to improve packet forwarding decisions, proposes a predictive algorithm, and improves the scalability of the protocol [7]. LORA-CBF is a hierarchy-based protocol where a network is divided into clusters. A cluster head is assigned to each cluster as a control unit. The 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 a packet to the closest neighbor of the destination. Otherwise, the source broadcasts a location request (LREQ) and waits for a location reply (LREP). Upon reception of the location, a packet is sent to the closest neighbor of the destination. The process repeats until the packet is delivered. However, since the cluster heads need to maintain cluster tables, high overhead of control packets is unavoidable.

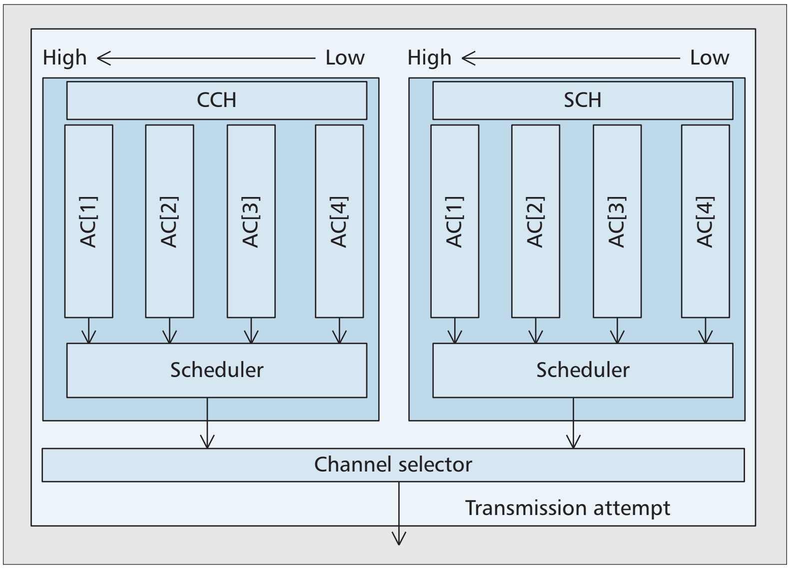

Figure 3. *QoS queue structure on a vehicle in WAVE.*

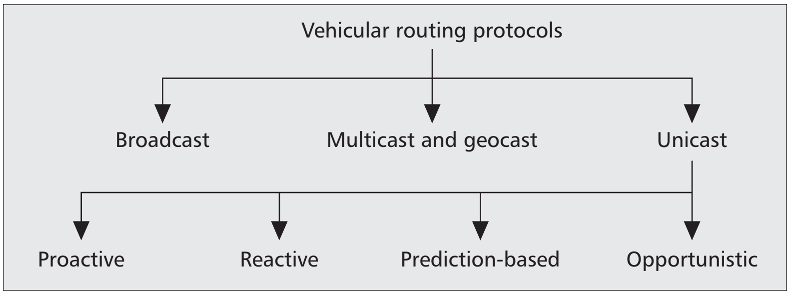

Figure 4. *Categories of vehicular routing protocols.*

Greedy Perimeter Coordinator Routing — 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 toward a destination. No decision is made on each vehicle, except vehicles at junctions. The messages tend to be forwarded to vehicles at a junction rather than vehicles across the junction. To achieve this, vehicles at the junction called *coordinators* will broadcast their

Protocol	Routing category	Mobility model	Intersection consideration	Network topology	Methodology
SB	Broadcast	Highway	No	Flat	Contention window
PRP	Broadcast	Highway	Yes	Flat	Contention window
UMB	Broadcast	City	Yes	Flat	Black-burst
IVG	Geocast	Highway	No	Flat	Defer time
LORA-CBF	Unicast (proactive)	Highway	No	Hierarchy	Cluster table maintenance
GPCR	Unicast (reactive)	City	Yes	Flat	Greedy forwarding
PRB	Unicast (prediction-based)	Highway	No	Flat	Route failure prediction
GeoDTN+Nav	Unicast (opportunistic)	City	Yes	Flat	Opportunistic

Table 2. *Summary of routing protocols in IVC.*

roles along with position information. If there are many vehicles at the junction, the source will randomly pick one vehicle as a relay. The elected relay vehicle decides on a street to which a message will be transmitted. The restricted greedy forwarding operation is repeated. However, because GPCR is a position-based unicast communication, source vehicles need to have destination positions, resulting in high overhead of information exchange.

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

Opportunistic Routing in DTN — GeoDTN+Nav is designed for delay-/disruption-tolerant routing when a direct route to a destination does not exist [10]. This situation can normally happen after peak hours or at night when the number of vehicles is very low, leading to a network partitioning problem. In this case, traditional routing protocols generally drop messages. In GeoDTN+Nav, in contrast, a vehicle will carry messages and wait for the right opportunity to forward them to better qualified vehicles toward the destination. Therefore, the protocol is suitable for real-time video streaming rather than safety application, since the streaming video can tolerate delay while safety application cannot. Thus, GeoDTN+Nav achieves a high delivery ratio at the expense of longer delay.

Comparisons and Discussions

Table 2 summarizes all routing protocols in terms of routing category, mobility model, intersection consideration, and network topology.

The routing category column shows three classifications, as presented previously, to which each routing protocol belongs. SB, PRP, IVG, LORA-CBF, and PRB implement highway scenarios in the simulations, while UMB, GPCR, and GeoDTN+Nav consider the city environment in which there is a higher number of vehicles with slower movements. 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 an IVC network tends to be established dynamically, almost all routing protocols are implemented on flat networks, except LORA-CBF, which considers a cluster-based network instead. There are a number of techniques implemented for message forwarding, such as the use of contention windows, black-burst, defer time, cluster tables, and the greedy forwarding concept.

With the opportunistic strategy (store and forward) of GeoDTN+Nav, the protocol achieves very high reliability even at low numbers of vehicles. Due to the network partitioning problem, the other protocols cannot deliver messages to other vehicles, causing low communication reliability. In contrast, at high numbers 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 UMB 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 protocols, which require vehicles' positions for route maintenance. Therefore, when vehicles' density is high, such protocols require a high amount of data exchange, intensifying network overhead and lowering network scalability.

SB and PRP have the shortest delay, since they are broadcast-based communication with no need for route discovery. Besides broadcast-based communication, they also implement the contention window concept for shortening the relay vehicle selection process. In contrast, UMB and IVG implement black-burst and defer time; these mean additional waiting time before transmitting a message, so 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 trade-off.

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

Since situations on roads and highways may vary from very urgent to general, messages should be tagged with priority before transmission. Therefore, a 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 provides differentiated service in terms of delay for different message priorities.

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

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

Even though a number of routing protocols in IVC have been proposed, there are still several remaining issues for further research. We present some challenges on network layers of IVC. Routing control in IVC raises diverse challenges and issues in an implementation. For example, a dynamic topology makes communication routes unstable and routing maintenance difficult, resulting in high latency, low reliability, non-scalability, inflexibility, low fault tolerance, and security issues.

Real Time Transmission and Delay Constraint

In driving accidents, drivers usually do not have enough time to deal with a suddenly occurring situation. IVC can alleviate the problem by distributing information in real time, especially urgent information, to extend drivers' perceptions. Even in the blink of an eye, if a driver receives information on time, s/he may be kept 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.

High Mobility and Rapid Topology Changing

IVC presents another new challenge in mobility. Vehicles move fast but predictably as they usually move along road topology. 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 of the fast-changing topology.

Reliability and Quality of Service

In the vehicular 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 the middle of a highway, information related to this situation needs to be transmitted to other following vehicles immediately with high reliability. This makes sure that other drivers get information promptly and drive more carefully to avoid an accident. On the contrary, another may detect the presence of fog, which makes driving inconvenient. This situation is less urgent than the previous one. Information related to this situation does not need to be transmitted as quickly as possible or require high transmission reliability. Therefore, information must be tagged for priority before transmission. A routing protocol in IVC will treat all information according to its priority to achieve both reliability and QoS.

Many researchers have evaluated the performance of IEE802.11e application on IVC. However, IEEE 802.11e only provides QoS on the MAC layer, thus only guaranteeing 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, a fast routing path, and reliable dissemination for vital information. Consequently, QoS on the network and upper layers becomes another interesting research area that must be taken into account for future proposed vehicular communication protocols.

Scalability and Flexibility

A number of vehicles may depend on an area. For example, in a rural area, where the number of vehicles is quite low, it becomes very difficult to maintain network connectivity without roadside units (RSUs), infrastructure units implemented to support communication. Deployment of RSUs requires large investments. Some researchers make use of less stringent power constraints by expanding communication range with higher transmission power to make each vehicle reachable even without RSU support.

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

Among all existing routing protocols, PRP is the only protocol taking message priority into account. The simulation result shows that the protocol provides differentiated service in terms of delay for different message priorities.

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

FAULT TOLERANCE

Because a VANET is usually set up on the fly, several vehicles may enter and leave a network from time to time. During transmission of information along one route, if a vehicle leaves the network suddenly, a routing protocol should be able to manage this problem by constructing a new route as soon as possible. Prediction of route failure in advance can help to alleviate the problem, but requires a high amount of update information exchange, leading to unscalable communication.

SECURITY ENHANCEMENT

Security is one of the most challenging and important issues 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 a disaster scenario, the cost of misinformation could be extremely high. Bogus information can also be used by terrorists to lead innocent people into a trap such as a 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 must be responsible in their information transmission. In addition, privacy information, such as locations and travel routes, may be considered sensitive. All drivers must not be able to learn privacy information of others. Therefore, secure communication is also an important area of research for future vehicular communication.

CONCLUSION

In this article, we have provided an in-depth review of proposed routing protocols. It can be seen from the review that various routing protocols are proposed to achieve effective information routing. However, due to the unique characteristics 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 protocols need to effectively provide high reliability regardless of the number of vehicles. One solution proposed is a multimode protocol, such as a combination of broadcast and opportunistic protocols. The multimode protocol can switch between each mode depending on the number of vehicles to optimize communication reliability.

QoS of communication on the MAC layer with IEEE 801.11e is promising, but is not well considered for multihop communication. This raises new challenges on cross-layer QoS (between MAC and upper layers) in routing protocol design to provide differentiated service for different priorities of communication in message routing.

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

Outcomes of these areas of research will improve IVC and safe driving for users.

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BIOGRAPHIES

CHAKKAPHONG SUTHAPUTCHAKUN (c.suthaputchakun@surrey.ac.uk) received his B.Eng. in computer engineering from King Mongkut's University of Technology Thonburi, Thailand, in 2002. In 2006 he received his M.S. in electrical and computer engineering from University of Massachusetts, Amherst. Now he is on leave from Bangkok University to pursue his Ph.D. in electronic engineering at the University of Surrey, United Kingdom. His research interests are computer networks and security emphasizing WLAN, MANET, secure routing protocols, MAC protocols, next-generation wireless networks, and their applications.

ZHILI SUN (z.sun@surrey.ac.uk), Chair of Communication Networking, has been with the Centre for Communication Systems Research (CCSR), Department of Electronic Engineering, Faculty of Engineering and Physical Sciences, University of Surrey since 1993. He got his B.Sc. in mathematics from Nanjing University, China, in 1982, and Ph.D. in computer science from Lancaster University, United Kingdom, in 1991. He worked as a postdoctoral research fellow with Queen Mary University of London from 1989 to 1993. He has been principal investigator and technical co-coordinator on many projects within the EU framework programs, ESA, EPSRC, and industry, and has published over 125 papers in international journals, book chapters, and conferences. He has published a book as sole author titled *Satellite Networking — Principles and Protocols* (Wiley, 2005), and was a contributing editor to *IP Networking over Next Generation Satellite Systems* (Springer, 2008) and the 5th edition of the textbook *Satellite Communications Systems — Systems, Techniques and Technology* (Wiley, 2009). His research interests include wireless and sensor networks, satellite communications, mobile operating systems, traffic engineering, Internet protocols and architecture, QoS, multicast, and security.