Implementation and Demonstration of WAVE Networking Services for Intelligent Transportation Systems*

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Abstract. Intelligent Transportation System has been a hot topic during the past decades. The Wireless Access in Vehicular Environments (WAVE) system is a radio communication system which is capable of providing safety, efficiency and sustainability. Major researches have been done to evaluate the performance of IEEE 802.11p which concerns PHY and MAC layer. However, the networking services provided by IEEE 1609.3 are essential contributors to the low-latency and low-overhead characteristics, which deserves its attentions. In this paper, after a detailed description of both Data Plane and Management Plane functions of the IEEE 1609.3, we implement this particular standard based on Linux system and develop a GUI program to demonstrate three safety related application scenarios.

Keywords: ITS, V2V, DSRC, WAVE, IEEE 1609.3, Safety-related applications.

1 Introduction

According to statistics, traffic accidents accounted for $230 billion in damaged property, 2889000 nonfatal injuries and 42643 deaths in 2003 in USA alone [6]. World Health Organization (WHO) reported that more than 100 million people died in traffic accidents worldwide and financial loss caused by traffic accidents reach up to $ 500 billion one year [7]. Most of those accidents can be avoided through vital safety and emergency information exchange between vehicles. Wireless communication technologies have the potential to enable a host of safety related applications in vehicular environment to prevent collisions and save thousands of lives. It was reported that over 50% of interviewed consumers are interested in the idea of connected cars and 22% of them are willing to

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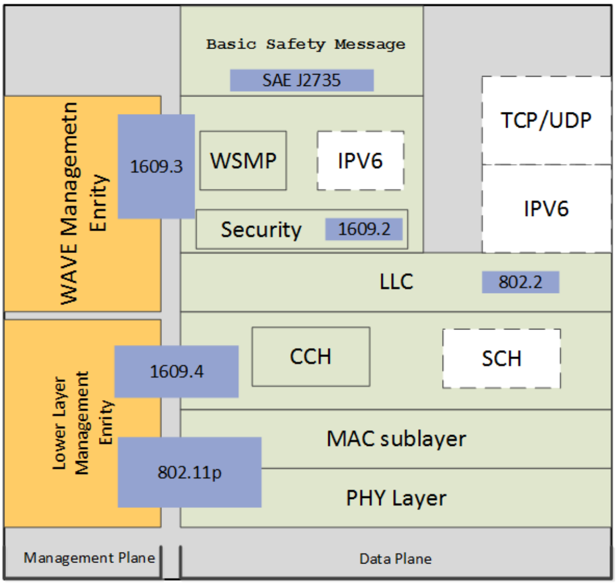

Fig. 1. WAVE stack

pay $30 to $65 per month for value-added connectivity services while on the road [12]. The U.S. Federal Communications Commission allocated 75 MHz of licensed spectrum in the 5.9 GHz (from 5.850 GHz to 5.925 GHz) for Dedicated Short-Range Communication (DSRC). The primary goal for deploying DSRC is to enable collision prevention applications[10]. The US Department of Transportation and several automakers in the United States have teamed up to study DSRC-based collision avoidance [8]. IEEE series of standards for Wireless Access in Vehicular Environment (WAVE) is currently considered as the most promising technology for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication.

Fig. 1 illustrates the protocol stack for DSRC communications: IEEE 802.11p for PHY and MAC layers, IEEE 1609.4 for channel switching, IEEE 1609.2 for security services, IEEE 1609.3 for networking services and SAE J2735 message set dictionary standard for application layer [2][3][4][5].

The IEEE 1609.3 which provides networking services is the core of the WAVE protocol stack. Industrial, governmental and university research efforts have been made in projects around the world, such as Vehicle Infrastructure Integration (VII) and Vehicle Safety Communication(VSC) in USA, Smartway and ITS-Safety 2010 in Japan and CVIS in Europe. In early 2014, the Department of Transportation in USA announced plans for a regulatory proposal that would require V2V communication devices, which uses the WAVE protocol stack, in the next year. Detailed descriptions and implementation of IEEE 1609.3, application scenarios design and demonstrations are given in the following sections.

2 Descriptions of IEEE 1609.3 Standard

WAVE Networking Services are specified in IEEE 1609.3 standard and consist of data plane and management plane. In this section, detailed descriptions of the IEEE 1609.3 standard are be given [3].

2.1 Data Plane

The data plane defines two different networking protocols: Internet Protocol Version 6 (IPv6) and WAVE Short Message Protocol (WSMP) [1]. These two protocols can be distinguished by a 2-octet field called Ethertype in the LLC (Logical Link Control) header. The hexadecimal values of the Ethertype indicating IPv6 and WSMP are 0x86DD and 0x88DC, respectively. WSMP is specifically designed for the efficiency of WAVE devices in vehicular environment which allows applications to directly control physical parameters i.e., channel number, transmitter power and data rate used in transmitting messages. The minimum packet overhead for UDP/IPv6 is 48 bytes, while for WSMP 5 bytes is enough, and even with options and extensions it rarely exceeed 20 bytes, which is quite valuable for vehicular communications concerning lower latency and higher reliability.

Fig. 2 below illustrates the Wave Short Message (WSM) exchange flow between the sender and receiver. When a higher layer entity wants WSMs to be sent on its behalf, it sends a WSM-WaveShortMessage.request to WSMP. On receipt of the request, WSMP calculates the length of the WSM data and compare with a predefined parameter WsmMaxLengh. Upon successful verification, the data is delivered to lower layers for subsequent transmission operations.

The lower layers of receiving side deliver the received WSMs to WSMP. Then WSMP shall pass the received information to the destination higher layer entity if the ProviderServiceIdentifier (PSID) from WSMP header exists in WsmServiceRequestTable in Management Information Base (MIB), otherwise the messages are to be abandoned.

2.2 Management Plane

Management functions are performed by the WAVE Management Entity (WME). Two WAVE device roles are defined. Devices transmitting WAVE Service Advertisements (WSAs) which indicate the availability for data exchange assume

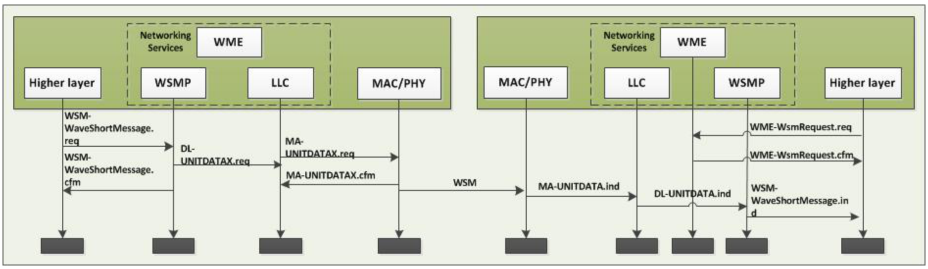

Fig. 2. WSM flow

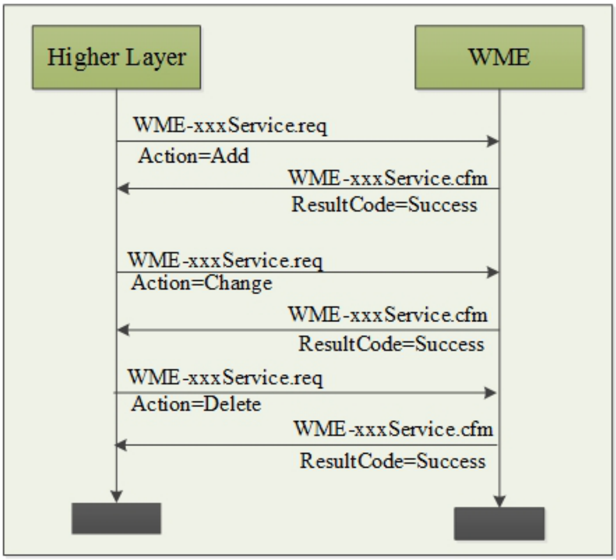

Fig. 3. Service request information flow

the provider role while those can receive WSAs and have the potential to participate in data exchanges perform the user role. A WAVE device may assume one, both or neither role. One of the main functions of the WME is accepting service requests from higher layers which may cause management messages to be transmitted periodically or provide Service Channel (SCH) access. Fig. 3 shows the service request primitives defined in the standard.

WAVE devices may monitor WSA to collect currently available services nearby. The WME maintains information about requested and available services for use in the MIB. The main informations in MIB are listed in four tables: ProviderServiceRequestTable, UserServiceRequestTable, WsmServiceRequestTable and CchServiceRequestTable. The WME may exchange management data with other entities such as higher layer entities, MAC Layer Management and Security Management Entity. Meanwhile, the WME controls the data exchange parameters like data rate and transmit power in the data plane.

2.3 Information Format

Wave Short Message (WSM). The WSM format consists of variable-length header and corresponding payload.

WSMP Version: One octet contains 4-bit WSMP version number and 4 reserved bits for future use. A device that receives a WSMP packet with a higher version number should discard the packet.

Provider Service Identifier: This field determines the appropriate higher layer destination of the WSM. For bandwidth efficiency, PSID is defined in a variable-length format from 1 octet to 4 octets.

WSMP Header Extension Fields: Channel Number, Data Rate and Transmit Power Used are the three extension fields defined in current version of IEEE 1609.3.

WAVE Service Advertisement (WSA). WSA is generated by WME to broadcast available services to nearby vehicles. Normally most services are provided by Roadside Unit (RSU), but Onboard Unit (OBU) could also send WSA. WSA should be carried within an IEEE 802.11 Vendor Specific Action (VSA) management frame. The WSA format consists of the following fields:

WAVE Version: The current value is 1, WSAs with a higher version value should be discarded.

Change Count: This field is used by the recipient to determine whether a WSA is a repeat of the previous from the same source. The sender shall increment its value modulo-4 when it updates the content of the WSA. This is an efficient way for a receiver to filter out duplicate WSAs.

WSA Header Extension Fields: The current standard includes 6 extensions: Repeat Rate, Transmit Power Used, 2DLocation, 3DLocationAndConfidence, Advertiser Identifier and Country String.

Service Info: This field may include 0 to 32 instances of a Service Info unit. Each unit contains a detailed description of a service, such as PSID, Service Priority, Channel Index and so on.

Channel Info: 0 to 32 instances Channel Info unit composes this field. Each unit provides key parameters of the channel such as Channel Number, Data Rate and Transmit Power Level. A Service Info unit is linked to a Channel Info unit by the Channel Index.

WAVE Routing Advertisement: WRA is an optional field of the WSA. It is present only if a services utilizes the IPv6 protocol. The WRA provides information about how to connect to the Internet, indicating receiving devices how to configure to participate in the advertised IPv6 network. Each WSA contains at most one WRA.

3 Implementation of IEEE 1609.3

3.1 Data Plane Development

Different from UDP/IPv6 protocols, WSMP allows applications to directly control physical parameters which can be encapsulated into WSM header extension fields. WSM header is more efficient and flexible than UDP/IPv6 header in case of vehicular communication. The main task in the data plane is encapsulation and decapsulation of WSM frame. To facilitate the process, a dedicated data structure called struct wsmp_buff is designed, along with four operation functions (wbf_put, wbf_push, wbf_pull and wbf_reserve). Fig. 4 describes a detailed WSM flow from the sender's application layer to the receiver's application layer.

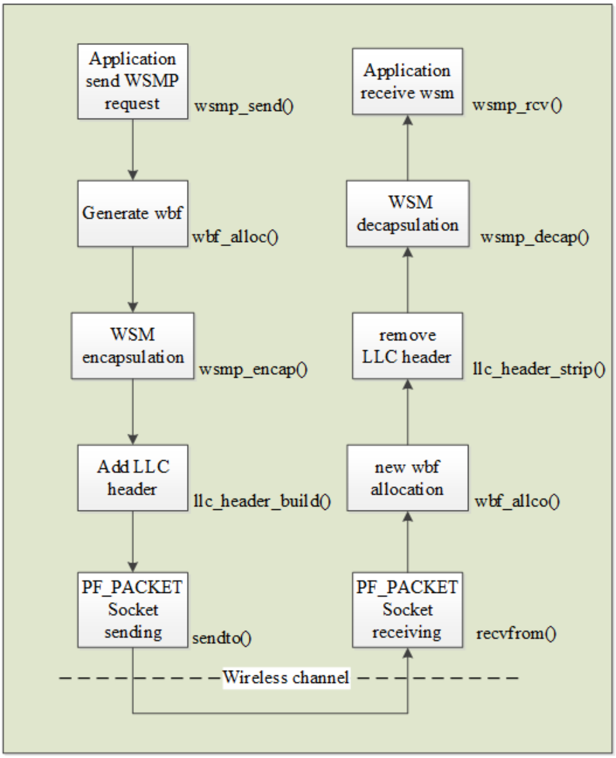

Fig. 4. WSM sending and receiving flow

The application layer of the sender calls wsmp_send to request WSMs to be sent on its behalf. After encapsulating WSM and adding LLC header, the data is transmitted through PF_PACKET socket which calls the actual transmitting function of network card. On the receiver side, the received data goes through the process of decapsulation corresponding to the encapsulation on the sender's side. Finally, the application layer obtains the actual data it needs.

3.2 Management Plane Development

Compared to the data plane, Management plane components are the core of the IEEE 1609.3 protocol. The main three functions performed by WME are:

1. Processing service requests from higher layers
2. Monitoring WSA
3. Maintaining Management Information Base

To accomplish these three functions, four main components are proposed: Main process, Service requests processing thread, WSA sending thread and WSA processing thread. The main process initiates the values in MIB, then

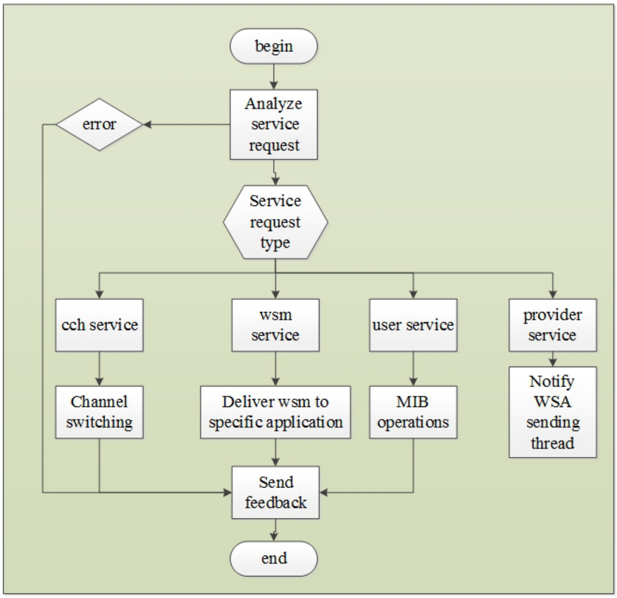

Fig. 5. Service request processing flow

keeps listening for WSAs and service requests. If any service requests arrive, a service requests processing thread are created. It gets the specific service request through analyzing the data from inter-process communication. Fig. 5 illustrates corresponding actions against different service requests. In particular, if provider service request arrives, a WSA is generated and broadcasted periodically based on key parameters from the request. Monitoring and processing WSA is a vital function. After resolving the received WSA, available services are added to UserAvailableServiceTable in MIB and if these services match those in UserServiceRequestTable, one service is selected as per service priorities.

4 Application Scenarios Design and Demonstrations

Vehicular networking applications can be divided into three categories [9]: road safety applications, traffic efficiency and management applications and infotainment applications. Road safety applications are primarily to largely decrease the probability of traffic accidents and the loss of life while improving traffic flow and coordination is the focus of traffic efficiency and management applications. Examples of infotainment applications include point of interest, local electronic media downloading and parking zone management. Despite various applications, the most important use case for a WAVE system is still communications between vehicles for the purpose of enabling collision avoidance applications, i.e., road safety applications. In this section, we focus on three use cases: Vulnerable Road User Warning (VRUW), Emergency Vehicle Warning (EVW) and Emergency Brake Warning (EBW). The main message type vehicles use is Basic Safety

Table 1. Use cases requirements

Application scenarios	Reliability requirements	Minimum broadcast frequency	Maximum latency time
Vulnerable Road User Warning	High	1 Hz	100 ms
Emergency Vehicle Warning	High	10 Hz	100 ms
Emergency Brake Warning	High	10 Hz	100 ms

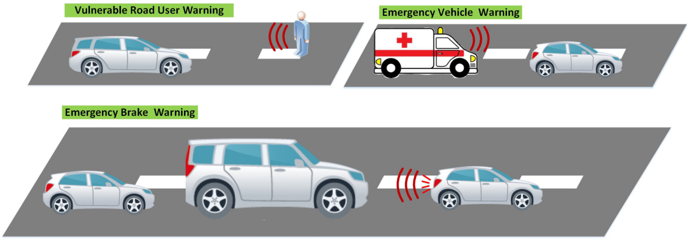

Fig. 6. Use cases

Message (BSM) which refers to SAE J2735. Table 1 gives the requirements of these three use cases.

As shown in Fig. 6, for the first use case, vulnerable road users, like pedestrians and cyclists, broadcast their presence with BSMs periodically, and vehicles equipped with WAVE devices can get information about their presence, trajectory and speed through decoding the BSMs. If vehicles are too close to the vulnerable users, a warning is then given to the drivers. In this way, potential accidents may be avoided to a large extent.

Emergency vehicles have a much higher risk of being involved in accidents than normal vehicles during emergency response trips. The probability of traffic accidents of emergency vehicle is higher than normal vehicles [11]. One of the explanation of this phenomenon is that drivers nearby can not determine the location and trajectory of the emergency vehicle. Therefore, it is necessary and effective to broadcast the vehicles' BSMs to nearby vehicles which would perform a better maneuver.

In the last use case, vehicles provide the emergency brake warning information when they have to brake emergently. This information lasts for several seconds to make vehicles behind to be aware. Vehicles which have the potential to get a crush send a warning to the drivers preventing accidents from happening.

A GUI program is developed with Qt4 in Linux to support these three use cases simultaneously for both sender and receiver. Users can choose the sender role to broadcast BSMs in different scenarios. As depicted in Fig. 7, those who choose receiver can see the display of relative distance and location on a simple

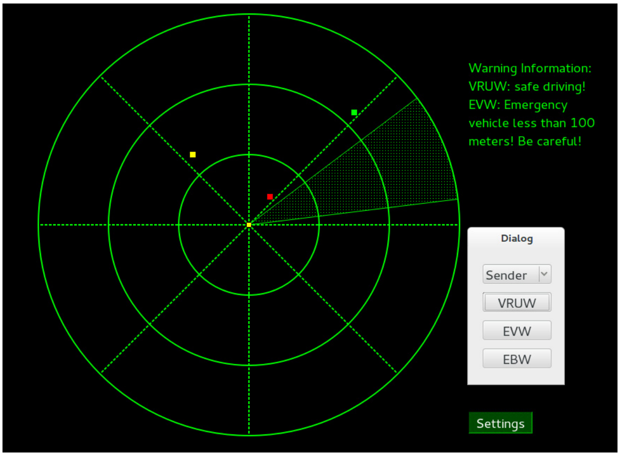

Fig. 7. Receiver side program

map and different warning messages are shown under the radar view for each scenarios chosen. We tested that the network delay of V2V communications is around $1ms$ while the delay of cellular networks is mostly more than 100 ms, which means with WAVE, the display of nearby drivers is real-time. This visualized program is effective and intuitive for drivers equipped with WAVE devices to use while driving.

5 Conclusions

Vehicles are evolving into a stage where information can be shared to improve road safety and traffic efficiency. The development of IEEE 1609.3 and demonstration of application scenarios in this paper makes efficient and reliable communications in vehicular networks visible and applicable. Drivers with the aid of V2V communications are aware of the traffic conditions nearby and can be informed of potential danger in advance. However, there are still several areas for further improvements. Privacy of drivers is a basic right, so the tradeoff between the authentication, privacy and liability becomes a challenge. Under the constrains of vehicular speeds, unreliable connectivity and fast topological changes, how to provide excellent delay performance still needs more research efforts.

References

[1] Guide for Wireless Access in Vehicular Environments (WAVE) - Architecture, 1–77 (2014)
[2] Standard for Wireless Access in Vehicular Environments Security Services for Applications and Management Messages, 1–289 (2013)
[3] Standard for Wireless Access in Vehicular Environments (WAVE) - Networking Services, 1–212 (2010)

[4] IEEE Standard for Wireless Access in Vehicular Environments (WAVE)–Multi-channel Operation, 1–89 (2011)
[5] Standard for Information technology–Local and metropolitan area networks–Specific requirements–Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 6: Wireless Access in Vehicular Environments, 1–51 (2010)
[6] Morgan, Y.L.: Notes on DSRC & WAVE Standards Suite: Its Architecture, Design, and Characteristics. IEEE Communications Surveys & Tutorials, 504–518 (2010)
[7] Martinez, F.J., Chai-Keong, T.: Emergency Services in Future Intelligent Transportation Systems Based on Vehicular Communication Networks. IEEE Intelligent Transportation Systems Magazine, 6–20 (2010)
[8] Kenney, J.B.: Dedicated Short-Range Communications (DSRC) Standards in the United States. Proceedings of the IEEE, 1162–1182 (2011)
[9] Karagiannis, Altintas, Ekici: Vehicular Networking: A Survey and Tutorial on Requirements, Architectures, Challenges, Standards and Solutions. IEEE Communications Surveys & Tutorials, 584–616 (2011)
[10] Wang, S., Fan, C., Hsu, C.-H., Sun, Q., Yang, F.: A Vertical Handoff Method via Self-Selection Decision Tree for Internet of Vehicles. IEEE Systems Journal (2014)
[11] Buchenscheit, Schaub, Kargl.: A VANET-based emergency vehicle warning system. In: IEEE Vehicular Networking Conference, pp. 1–8 (2009)
[12] Araniti, Campolo, Condoluci.: LTE for vehicular networking: a survey. IEEE Communications Magazine, 148–157 (2013)