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FEASIBILITY ANALYSIS OF VEHICLE-TO-VEHICLE COMMUNICATION ON SUBURBAN ROAD

ABSTRACT

With the evolution of advanced wireless communication technologies, tremendous efforts have been invested in vehicular networking, particularly the construction of a vehicle-to-vehicle communication system that supports high speed and mobility. In vehicle-to-vehicle communication environment, vehicles constantly exchange information using wireless technology.

This paper aims to propose a vehicle-to-vehicle communication system and validate the feasibility of the system on a suburban road in China. Two vehicles were used equipped with IEEE 802.11p based DSRC (Dedicated Short Range Communications) device to construct a vehicle-to-vehicle communication platform. The system architecture consisting of hardware and software was described in details. Then, communication characteristics such as RSSI (Received Signal Strength Indicator), latency and PLR (packet loss rate) were analyzed. Additionally, GPS-related information (such as ground speed and location) was obtained through field test on a suburban road in Shanghai and Taicang City. The test results demonstrate satisfactory performance of the proposed system.

KEY WORDS

vehicle-to-vehicle communication, Dedicated Short Range Communications, field test, suburban road

1. INTRODUCTION

Most of traffic accidents are preventable by implementing ITS (intelligent transportation system), especially by establishing advanced wireless communication between vehicles. In general, there exist two types of communication paradigms in VANET (Vehicular Ad Hoc Networks): V2I (vehicle-to-infrastructure communication) and V2V (vehicle-to-vehicle communication). V2I pattern can be used in the situation of information exchange between vehicle and roadside. Roadside is normally fixed at an intersection or on a road section. In addition, roadside unit is considered as a repeater for packets delivery. V2I communication mainly focuses on the information of traffic signal, weather and traffic condition [1]. V2V provides 360 degrees awareness. It can be used in the case when information is exchanged between vehicles which mainly focuses on providing information for safety-related applications and driving assistance. In this study, only V2V communication has been considered.

In terms of wireless communication technology for V2V usage, many standards have been developed to specifically support low-latency, reliable and efficient data dissemination. One example standard is IEEE 802.11p, as an enhancement to the original IEEE 802.11a and IEEE 802.11e [2]. In our work, a wireless communication device which supports IEEE 802.11p standard was chosen for the system implementation.

The remainder of this paper is organized as follows: Section 2 reviews the related work in V2V communication platform construction. Section 3 describes the system configuration. Section 4 proposes the field test on a suburban road and Section 5 analyzes the test results. Finally, Section 6 concludes this paper.

2. RELATED WORK

As one of the most important applications of telematics in the intelligent transportation system field, V2V communication has attracted numerous interests of researchers, industries and governments over decades. The key technology of V2V communication is the wireless connection. Various technologies have been developed to assist the information exchanging between vehicles.

Around 1997, Berkeley PATH (Partners Advanced Transportation TecHnology) used 900 MHz communication technology to conduct a platoon of eight cooperative vehicles with a maintained inter-vehicle spacing [3]. Fujii developed a prototype inter-vehicle communication system with four vehicles using infrared rays [4]. Then, very high frequency (VHF) technology was adopted for inter-vehicle communication at the Ohio State University [5]. After that, Tae [6] implemented an inter-vehicle communication system for the vehicle platoon experiments via a testbed with the ISM (Industrial Scientific Medical) band communication technology. In order to achieve a spread spectrum system, the ultra-wide bandwidth (UBW) technology was considered for the construction of inter-vehicle communication system. Takeshi [7] then applied the UBW merit to an inter-vehicle communication, and evaluated the validity of the proposed system. Additionally, off-the-shelf wireless local area network technology, such as microwave, infrared and millimetre wave were adopted in V2V communication system [8, 9]. With the development of wireless communication technology, 3G/4G cellular networks were then used in vehicular networking, which provide high bandwidth for data transmission. The typical usage in real life is General Motors's OnStar system. Furthermore, attention also turned to IEEE 802.11 based technology. Sen [10] used IEEE 802.11a to conduct a V2V communication platform and analyzed the channel performance. Singh[11], Sengupta [12] and Otto[13] used IEEE 802.11b as the radio communication protocol to design a V2V communication prototype system. Matsumoto [14] and Chen [15] then used IEEE 802.11n devices for V2V communication analysis. Based on IEEE 802.11g, Nekoui [16] developed a prototype intersection collision warning system implemented for a real-world scenario that could predict potential collision at the intersection and notify endangered vehicles. In recent years, WiMAX (Worldwide Interoperability for Microwave Access) / IEEE 802.16 networks, supporting high bandwidth and up to 50 kilometres of communication range without direct line-of-sight was considered for vehicular network deployment [17].

The works reviewed above mainly adopted VHF, microwave, infrared and millimetre wave technologies. However, the high speed and mobility of vehicles make it very challenging to establish a reliable connection between vehicles in V2V communication paradigms, which requires wireless communication utilized in V2V communication to support time-critical and high reliability. Along with the development of wireless technology, the emerging IEEE 802.11p standard brings the new orientation of intelligent transportation system. Many studies [18-26] have been engaged in the construction of V2V communication platform based on IEEE 802.11p protocol. Additionally, many national projects such as Connected Vehicle Research Program [27] in the United States, Cooperative Vehicle Infrastructure System (CVIS) [28] in Europe and Smartway [29] in Japan also adopted IEEE 802.11p to conduct V2V communication system.

3. SYSTEM CONFIGURATION

For the communication technology, IEEE 802.11p was chosen, namely WAVE (wireless access in vehicular environment), which is one of the IEEE 802.11 standards designed for high mobility, severe fading in vehicular scenarios, and has been used in other related projects such as CVIS, NOW and PRE-DRIVE C2X. *Figure 1* shows the WAVE protocol stack [30].

WAVE utilizes seven 10 MHz channels with a variety of data transmit rate ranging from 3 Mbps to 27 Mbps. WAVE consists of IEEE 802.11p and a suite of IEEE 1609.X standards to guarantee fast reliable message exchange. In the WAVE protocol stack, the bottom layer - IEEE 802.11p defines the PHY and MAC features in a specific vehicular environment; IEEE 1609.4 aims at multi-channel operations and defines a management extension of MAC, which supports switching among channels effectively; the middle layer consists of IEEE 1609.3 and IEEE 1609.2. IEEE 1609.3 defines the WAVE Service Advertisement (WSA), and provides network services routing and addressing services at the network layer; IEEE 1609.2 provides security services and defines the standard mechanisms for authenticating and encrypting messages; in the higher layer, IEEE 1609.1 focuses on resource management and deals with managing multiple simultaneous data streams, memories, and other resources.

In our system, each vehicle equipped with the hardware is described as follows [23]: Two small and compact vehicles had been used for the implementation.

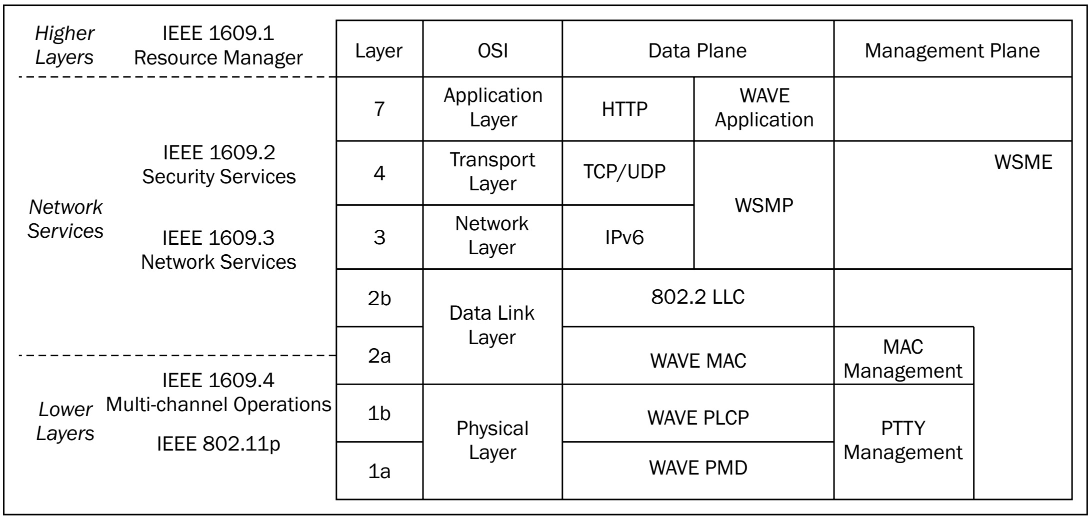


Figure 1 - Overview of WAVE Protocol Stack [30]

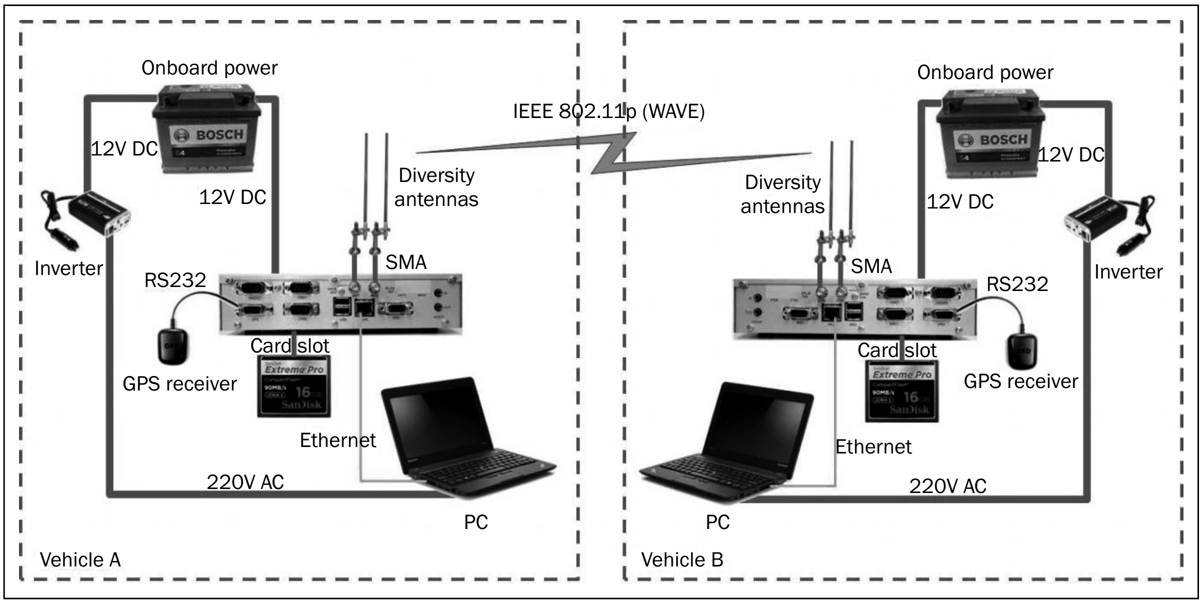


Figure 2 - Connectivity of primary devices in the system

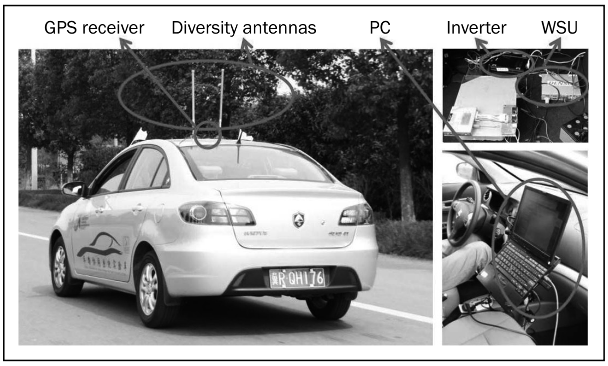


Figure 3 - Primary devices installation onboard vehicle

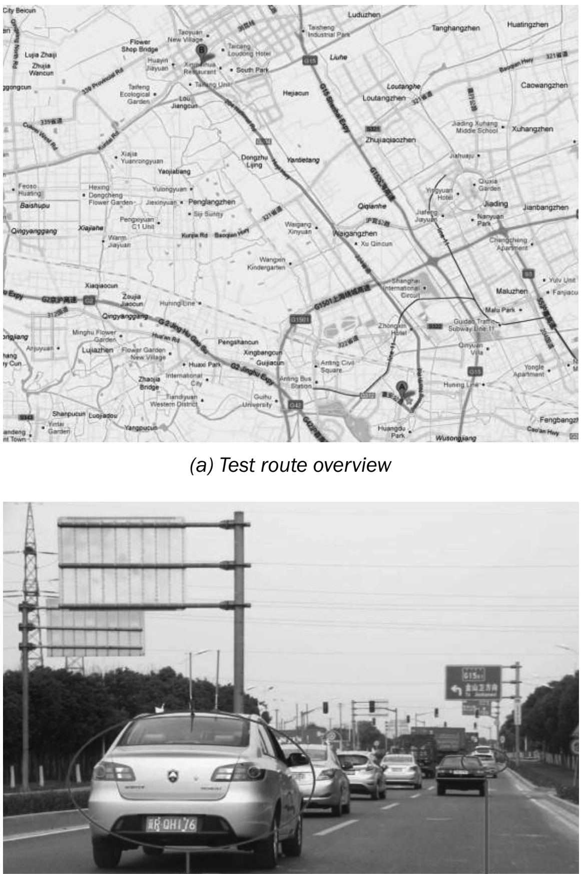
The proposed system was based on IEEE 802.11p. The DENSO WSU (Wireless Safety Unit) was chosen as it supports the WAVE protocol with low latency and high reliability. Diversity antennas were connected to each WSU and mounted near the roof centre. For positioning, a Garmin 15L OEM receiver was connected to WSU. A GPS receiver was used to determine the 3D position (latitude, longitude and altitude) of the vehicle and to calculate other related information, such as ground speed, OD (origin destination) and trip distance. A PC was connected to the WSU through Ethernet for configuration. A compact flash (CF) card was installed in the WSU, and all data were logged to CF card in real time. Literature [21] and [23] illustrated the more detailed installation [21, 23]. *Figure 2* demonstrates the connection of primary devices in the proposed system and *Figure 3* shows the primary devices installation in the experimental vehicle.

For communication, the radio channel was set to 153 with a frequency of 5,765 MHz. Since larger packets would lead to larger PER (Packet Error Rate), a payload of 300-Byte UDP (User Datagram Protocol) was applied for exchange, including vehicle identification, local time, vehicle longitude, vehicle latitude, vehicle speed and other blank fields. The sending rate was set at 50 Hz (time interval of packet delivery was 20 milliseconds). The receiver received packets as a callback method, so perfect reception would receive at the same rate of 50 Hz. The sending power was configured as 20 dBm. Moreover, based on the characteristics of 5.8 GHz communication technology, the communication range was set at about 1,000 m. Each vehicle would receive the timely 300-Byte packets from another vehicle through WAVE protocol.

4. FIELD TEST DEPLOYMENT

The system was implemented to demonstrate the functionality of V2V communication. The North Jiasong Road and 204 National Road in Shanghai and Taicang Cities with a few building structures and roadside tree plantations were selected. *Figure 4* shows the test route.

The distance between the origin and destination is about 25 kilometres. The route was separated into two sections: 1) the road with two lanes in each direction (about 16 kilometres); 2) the road with four lanes in each direction (about 9 kilometres). The opposite road was divided by a middle separator. The test road corresponds to vehicular speed limits of 60 kilometres per hour in the first link (in Shanghai) and limits of 80 kilometres per hour in the second link (in Taicang).



(a) Test route overview

CHANGAN Yuexiang Ford Focus

(b) Vehicles travelling on the suburban road

Figure 4 - Field test on the suburban road

The test was conducted on March 16th, 2012, from 08:44:30 to 09:30:25 in UTC (Coordinated Universal Time), and performed with a VANET of two compact vehicles: a Ford Focus and a CHANGAN Yuexiang. Each vehicle was equipped with the devices as described in Section 3.

The communication between two vehicles was only available when they stayed within the communication range. In our test, the drivers were asked to keep the appropriate distance (within 1,000 m) to another vehicle. In order to evaluate the system performance in normal and real traffic condition, two vehicles travelled at random speeds and distances, including the conditions of line-of-sight, non line-of-sight, blockage by other vehicles, and restrained by traffic signal.

End-to-end delay is critical in VANET due to the safety-related message delivery. The accurate sending and receiving time according to the accurate timing based on GPS technology was also collected. The WSU was synchronized to UTC time by implementing an estimator, and GPS had been used as a UTC time input to the estimator that changed the GPS time reference to UTC 1970-01-01 00:00:00.000 000.

5. TEST RESULTS

All the data were logged into the CF (Compact Flash) card periodically. Take a set of sample data:

Radio=0, Chan=153, PSID=1000, Mode=Raw (Raw mode provides the IEEE 802.11p functionality for performance testing), Date: 120316, Time: 084530.000, Seq#=12133, Rx Time=1331887530.026211, Tx Time=1331887530.025450, Data Rate=12, Tx Power=20, Data Len=100, MisPkt=0, OorPkt=0, RcvPkt=5193, Success=100.00%, Rss=-39, Latency=(0.43, 0.78, 13.23) ms, Remote lat=31.283852, Remote long=121.207270, Remote err=0, Remote Groundspeed=4.537639 , Local lat= 31.283742, Local long= 121.207290, Local err=0, Local Groundspeed=5.164583, Distance= 12.38, Raw Chan Busy (Raw mode channel busy ratio) =0%;

where:

Chan: transmit channel. In our test, channel 153 (5765 MHz) was used;

PSID: provider service identifier, the vehicles located in one VANET should have the same PSID;

Date and time: logged date and time in UTC;

Seq#: the received sequence number;

Rx Time and Tx Time: packet received/sent time in UTC;

Data Len: data payload for transmission;

Table 1 - Performance of communication in the field test (vehicle A receiving)

Parameter	Value
Channel	153
Packets sent (vehicle B)	137,750
Packets received	137,034
Missed packets	716
Out-of-order packets	0
Success rate	99.48%
Latency	Minimum: 0.43 millisecond Average: 0.77 millisecond Maximum: 13.23 millisecond
Raw channel busy	0%

MisPkt: number of missed packet;
OorPkt: number of out-of-order packet;
RcvPkt: number of received packet;
Success: packet success rate;
Rss: received signal strength indicator;
Latency: packet transmission delay, (minimum value, average value, maximum value);
Distance: distance between sender and receiver in metres.

The first and the last one-minute data were neglected because they could bring a big fluctuation. The total number of sent packets can be calculated according to the following expression:

$$Converttosecond\ (Time_{end} - Time_{start}) * D_r \quad (1)$$

where, $Time_{start}$ denotes the start moment of the test (08:44:30), $Time_{end}$ denotes the end moment of the test (09:30:25), D_r denotes the message delivery rate (50 packets per second). Due to the recorded GPS time reference to the UTC time, the latency can be calculated as follows:

$$Packet\ Latency = Time_{packet\ received} - Time_{packet\ sent} \quad (2)$$

Table 1 and *Table 2* summarize the communication performance of vehicle A and vehicle B:

Table 2 - Performance of communication in the field test (vehicle B receiving)

Parameter	Value
Channel	153
Packets sent (vehicle B)	137,750
Packets received	137,027
Missed packets	723
Out-of-order packets	0
Success rate	99.47%
Latency	Minimum: 0.48 millisecond Average: 0.79 millisecond Maximum: 14.70 millisecond
Raw channel busy	0%

From *Table 1*, the number of total sent packets (data transmitted from vehicle B to vehicle A) is 137,750. With 716 packets lost, the number of received packets is 137,034. No packet was out-of-order and the success rate reached a high value of 99.48%.

From *Table 2*, the number of total sent packets (data transmitted from vehicle A to vehicle B) is 137,750. With 723 packets lost, the number of received packets is 137,027. No packet was out-of-order and the success rate also reached a high value of 99.47%.

The statistics show that the packet loss rate and packet out-of-order rate are fairly low (packet loss rate is less than 1% and packet out-of-order rate is 0%). Low latency is important since vehicles will travel large distances in very short periods of time. From *Table 1* and *Table 2*, the proposed system supports a latency less than 20 milliseconds in our test, corresponding to the typical latency (100 milliseconds, defined by the Vehicle Safety Communications Consortium [31]), which indicates that the system is qualified for safety-related information exchange.

The RSSI and latency performance were analyzed then. The results are shown in Figures 5 to 12.

From *Figure 5* to *Figure 12*, the RSSI values fluctuate from -100 dBm to -25 dBm. The average value of RSSI is

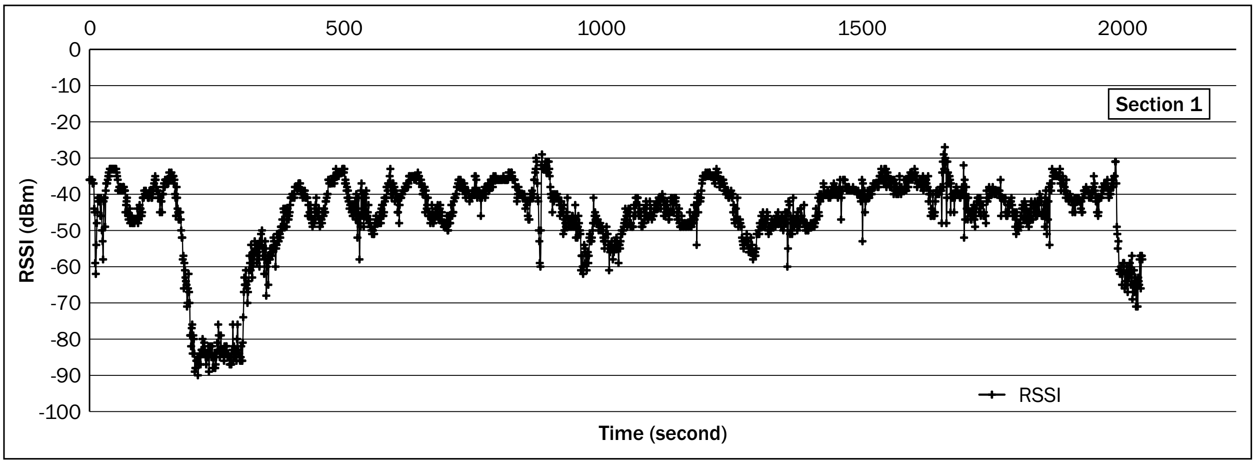


Figure 5 - RSSI performance of vehicle A on road section 1

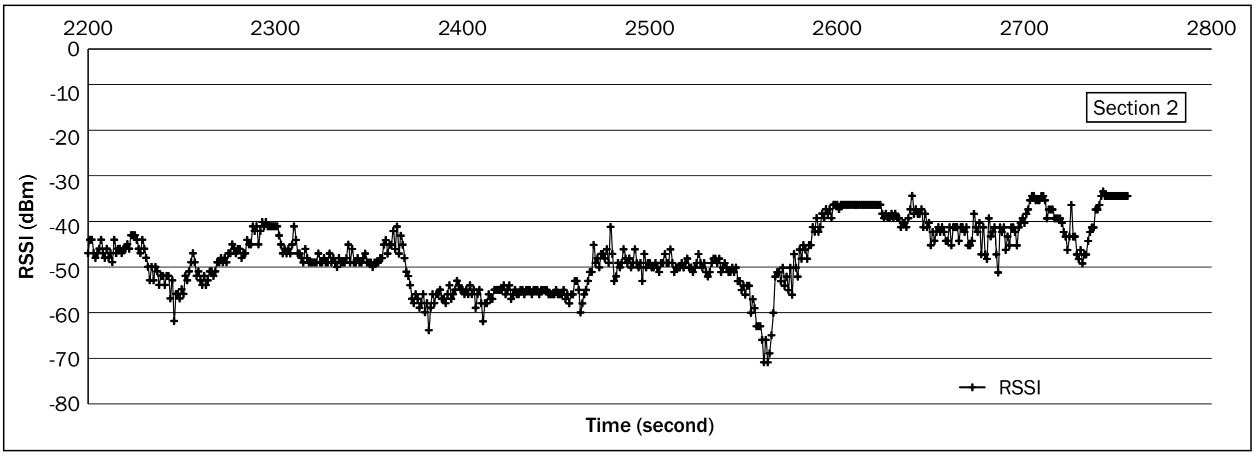


Figure 6 - RSSI performance of vehicle A on road section 2

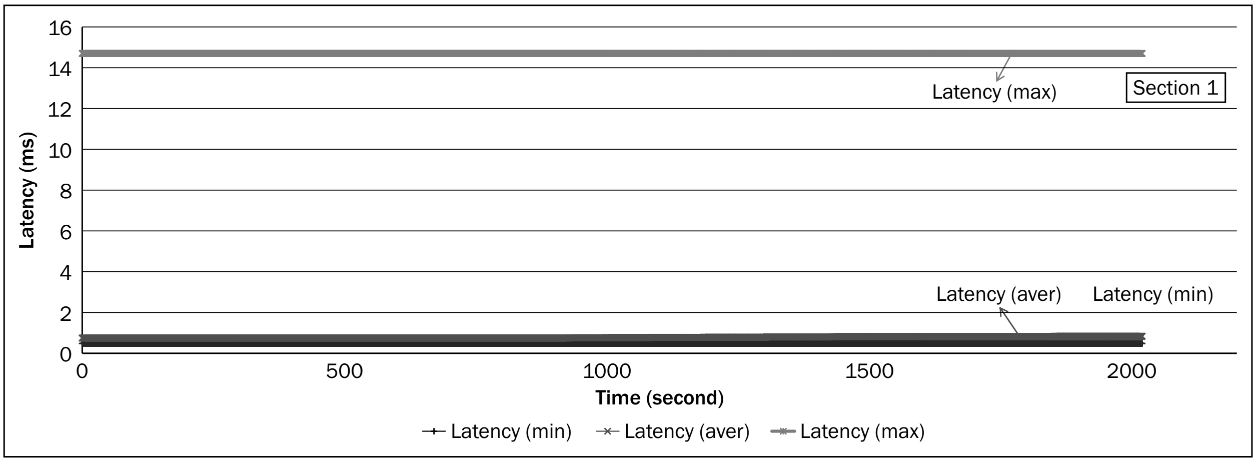


Figure 7 - Latency performance of vehicle A on road section 1

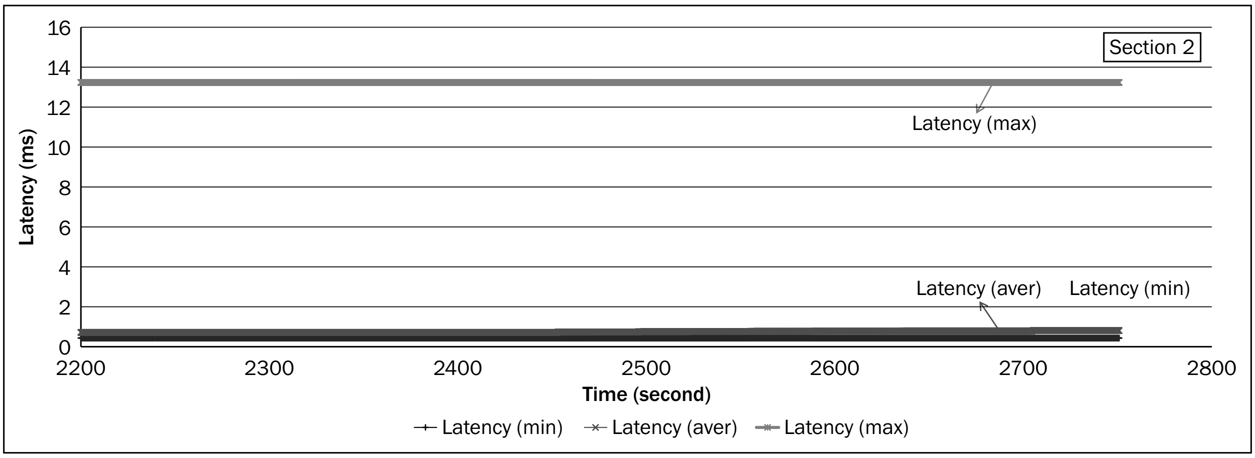


Figure 8 - Latency performance of vehicle A on road section 2

about -50 dBm, which indicates that the RSSI performs well in our test. All the latency values are lower than 15 milliseconds, which outperforms the typical value (100 milliseconds). The results indicate that the communication performance of the proposed system undoubtedly meets the requirement of V2V communication on suburban roads. The most interesting result that was found is that the latency is very stable and does not fluctuate during our test on the suburban road. The reason may be explained by the high reliability of the WSU.

Since the two vehicles were connected and were exchanging GPS-related information by the WAVE protocol, each vehicle stored the whole VANET propagation data. Therefore, the following data were collected

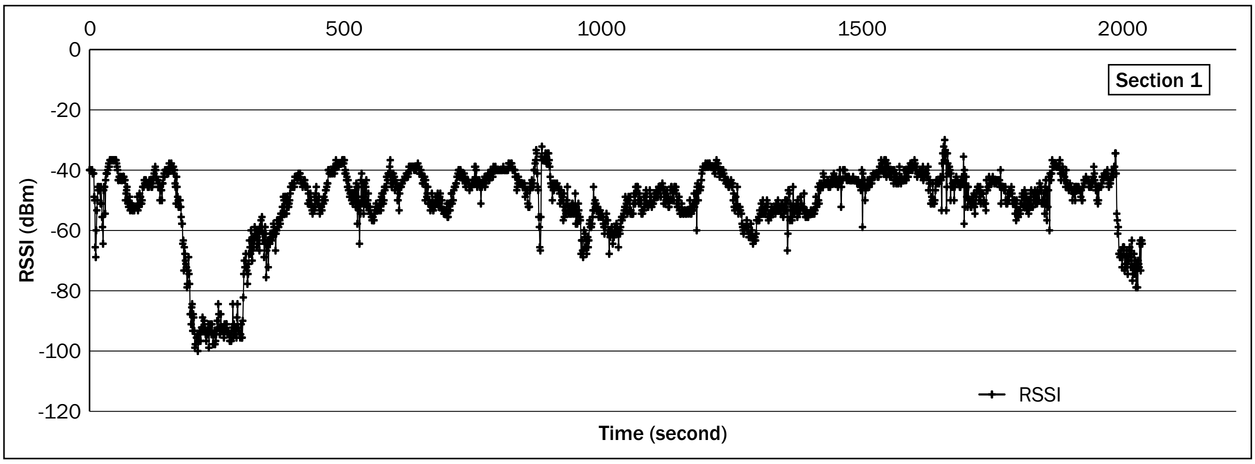


Figure 9 - RSSI performance of vehicle B on road section 1

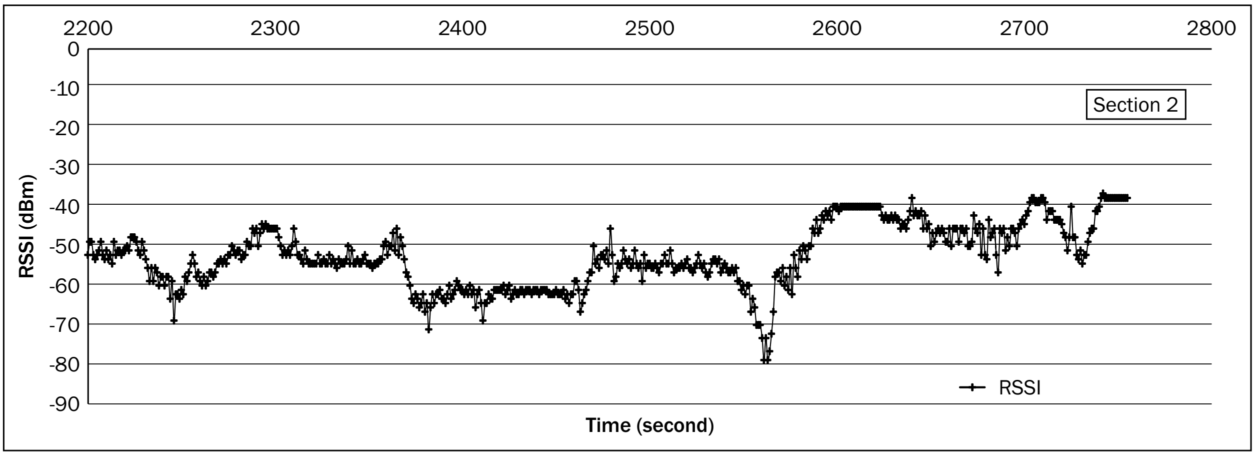


Figure 10 - RSSI performance of vehicle B on road section 2

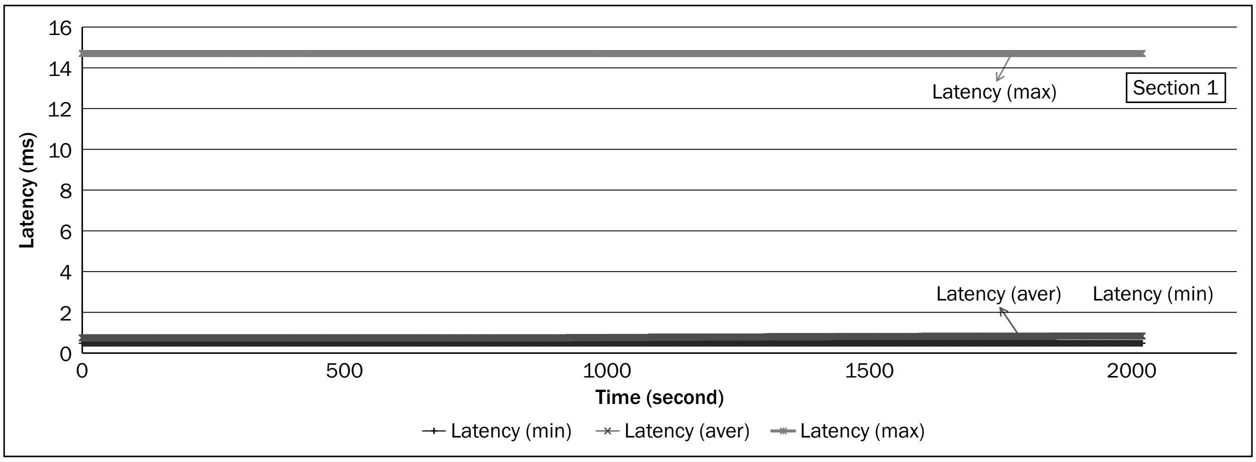


Figure 11 - Latency performance of vehicle B on road section 1

from one of the two vehicles. *Figure 13* shows GPS matching results.

In *Figure 13*, all the data were obtained through one vehicle, and the matching results show the routes of both vehicles. In this case, it can be inferred that the data were indeed exchanged by wireless communication technology. In addition, the GPS receiver functioned well and provided a lane-layer positioning accuracy in most cases. When lane-change was performed the GPS receiver recorded the manoeuvre successfully, which can be seen in the bottom right corner in *Figure 13* (b). When the vehicles stopped at an intersection, the GPS positioning data were almost motionless. Unfolding the matching

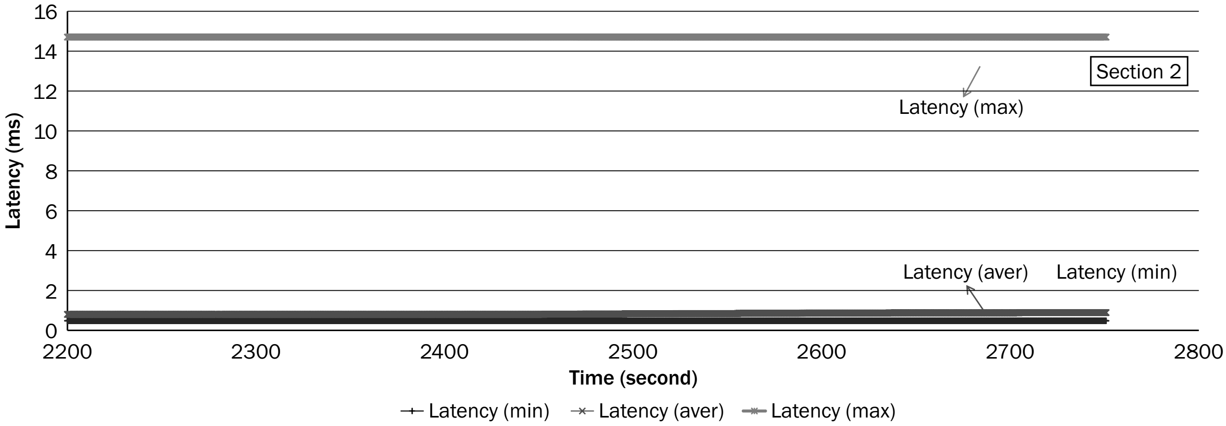


Figure 12 - Latency performance of vehicle B on road section 2

(a) Bird's-eye view of the test route

(b) Section of the test route

Figure 13 - GPS matching results

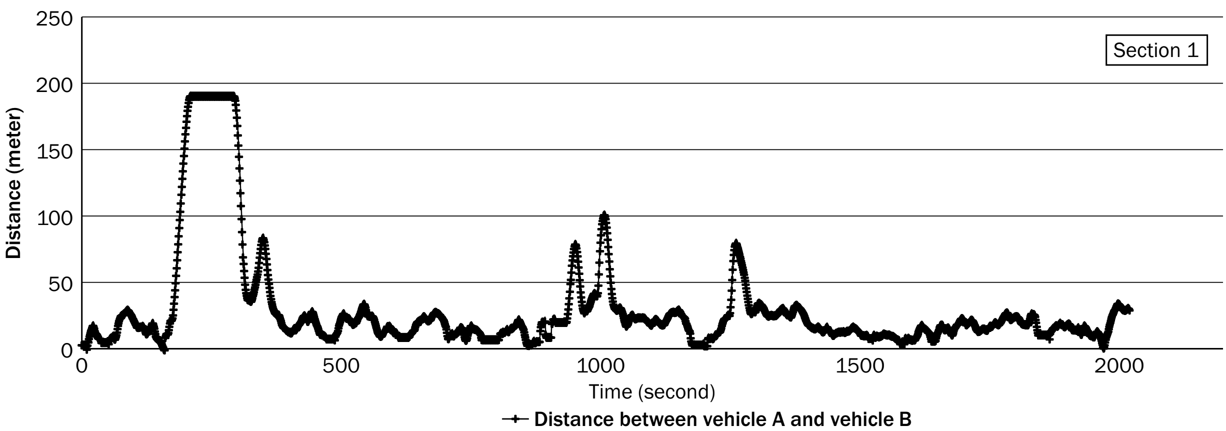


Figure 14 - Distance between vehicle A and vehicle B on road section 1

data in Google earth, the overlapped position points can be seen from the top left corner in *Figure 13* (b).

Based on the recorded GPS data *Figure 14* and *Figure 15* show the distance between vehicle A and vehicle B on each road section.

The distance was calculated using the recorded latitude and longitude data. From *Figure 14* and *Figure 15*, the distance values are all above zero and have an uncertain curvature, which means two vehicles travelled at a random order and speed. In the start and end periods, the distance value is near zero, which indicates in these cases, the two vehicles were in a stationary status and kept a close range between each other.

Figure 16 and *Figure 17* show the speed variation of vehicle A and vehicle B on each road section.

In the start and end periods, both vehicles stopped, which can be reflected in *Figure 16* and *Figure 17* where the recorded speeds were both zero. During the test, when both speeds decreased to zero, it indicated that both vehicles encountered red light and stopped at a signalized intersection. The speed curves of vehicle A

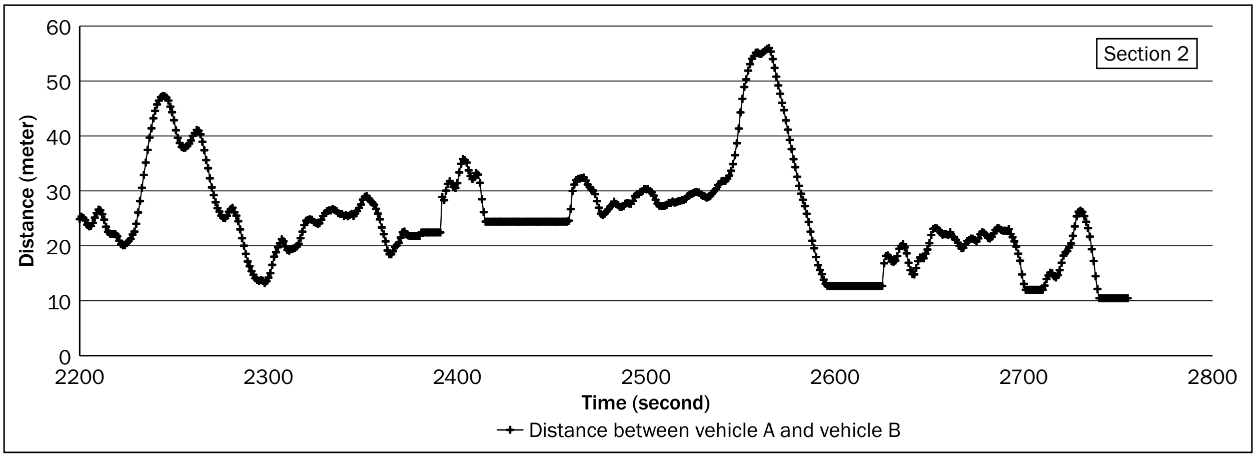


Figure 15 - Distance between vehicle A and vehicle B on road section 2

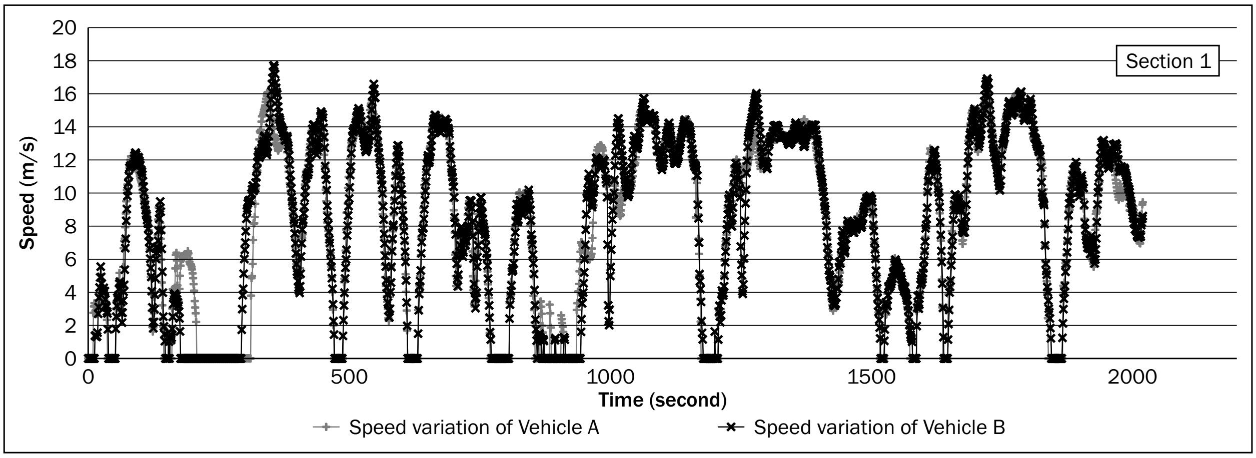


Figure 16 - Speed variation of vehicle A and vehicle B on road section 1

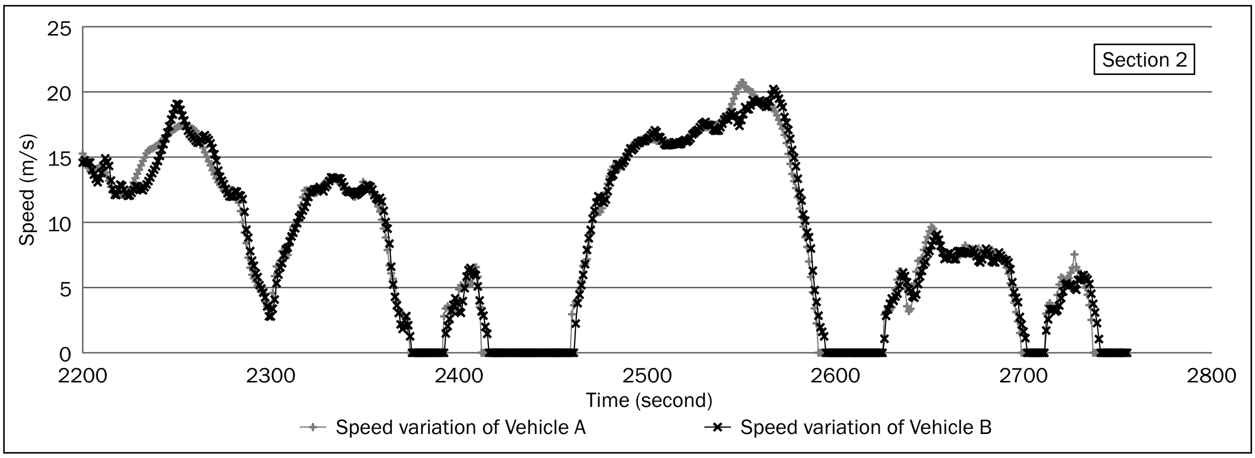


Figure 17 - Speed variation of vehicle A and vehicle B on road section 2

and vehicle B are almost the same, which indicates that the two vehicles travelled within a close distance corresponding to the information shown in *Figure 14* and *Figure 15*.

In this section, the test results in the aspects of wireless communication characteristics and GPS-related information processing have been analyzed.

6. CONCLUSION

This work has been dedicated to performing a vehicle-to-vehicle communication system for information exchange between two vehicles. The deployment on suburban road of Shanghai and Taicang City have been presented in detail. Furthermore, the RSSI, latency and packet loss rate performance of wireless communication technology were analyzed, and the GPS-related information was also processed to show the accuracy of the proposed system.

The tests validated the feasibility of IEEE 802.11p in vehicle-to-vehicle communication scenarios. The scenarios can represent the common situation on suburban roads in China. In addition, the test results obtained plenty of realistic data, which can be a reference for V2X (vehicle-to-vehicle, vehicle-to-infrastructure) companies and researchers. Finally, the test results show the IEEE 802.11p based prototype system is capable of real-time information exchange in a simple vehicle-to-vehicle paradigm.

Nevertheless, the construction of V2V communication system remains an open issue and is still in the early stages of development in China. Concerning future work, more onboard units will be installed in vehicles to evaluate the feasibility of numerous communication nodes in VANET.

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摘要

市郊道路环境下车车通信可靠性分析

随着先进的无线通信技术的发展，带动了大量车载通信网络的研究，尤其是在构建支持高速运行车辆的车载通信网络方面。在车辆间通信环境中，基于无线通信技术，车辆间可不停地进行信息交互。

本文旨在提出一个车车通信系统，并在中国的郊区道路进行实地可行性验证。使用两辆装配有IEEE 802.11p专用短程通信协议的车辆进行车车通信平台构建。对系统的硬件和软件构成分别进行了详细的介绍。接着对接收信号强度指示（RSSI）、延迟、丢包率进行了分析。此外，在上海和太仓市郊道路中的GPS相关信息，如速度和位置信息也被收集用于系统的可行性分析。测试结果表明提出系统的表现满足既定要求。

关键词

车车通信，专用短程通信协议，实地测试，市郊道路

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