Implementation and Field Test of a Small-scale WAVE system in IEEE 802.11p V2R/V2V Environments

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Abstract: Vehicular communications have become more and more popular as a way to increase the comfort and safety of the transportation systems. The IEEE 802.11p/1609.x protocol stack, also known as the Wireless Access in Vehicular Environment (WAVE), has attracted much attention from researches. A large number of literatures and simulation platforms have been proposed for the performance evaluation and enhancements for the WAVE protocol stack. While very few real and available testbed is presented, due to the low availability and high cost of IEEE 802.11p/WAVE fully compliant hardware and software. Therefore many simulation results are misleading as the protocol standard is just partially implemented and the testing environment is not real-world representative. In this paper, an implementation of the WAVE standard using commercial off-the-shelf IEEE 802.11 hardware is presented. It provides seamless dual-channel and multi-channel access with synchronous channel switching, which consistently matches IEEE 1609.3/4 protocol. The performance of the implemented system is obtained via a series of testing and validation.

Keywords: testbed; 802.11p; WAVE; ath5k; channel switching

1 Introduction

Vehicular Ad Hoc Networks (VANETs) are considered to play a cornerstone role in the deployment of Intelligent Transportation System (ITS). IEEE has defined the protocol stack IEEE 802.11p/1609.x families to facilitate the application of Wireless Access in Vehicular Environments (WAVE). The protocol stack has attracted much attention recently. Here the paper gives a brief introduction to the key features of the protocol stack.

The IEEE 802.11p defines the WAVE physical (PHY) and medium access control (MAC) layer standard. The PHY layer of the 802.11p is an amendment to the IEEE 802.11a standard. The 75MHz spectrum band (5.850-5.925 GHz) is divided into one control channel (CCH) and six service channels (SCHs).

The IEEE 1609.3 specifies the multi-channel operation within a WAVE Basic Service Set (WBSS). When a service provider wants to provide services for WBSS users, it broadcasts WAVE service advertisement (WSA) frames on the CCH to announce the availability of services. A WSA frame records the detailed list of services provided by the Provider and their corresponding SCH allocation. Upon receiving the WSA frames, the users can join the interested WAVE basic service set (WBSS) to get the needed services.

IEEE1609.4 provides enhancements to the IEEE802.11p MAC by supporting multi-channel operation. Different types of messages are transmitted via different types of channels(CCH and SCHs). The channel coordination is achieved by interval-based mechanism. The On-Board Units (OBUs) and RoadSide Units (RSUs) utilize the GPS 1PSS signal or other pulse synchronized approach to achieve the time synchronization. A sync interval is composed of one CCH interval and a following SCH interval. The default channel of WAVE/DSRC unit is the CCH. Three channel access mechanisms, including alternating access, immediate access, and extended access, are also specified in the IEEE 1609.4.

The emerging interest in vehicular networks led to many researchers developing corresponding platforms to evaluate the features of this technology in real-world scenarios. Despite this, due to the low availability and high cost of IEEE 802.11p/WAVE fully compliant hardware and software, many of these experiments have been performed with other communication standards, which generate, in many cases, misleading results, which are not representative of real-world vehicular communications. For these reasons, this paper gives a description about the fully compliant implementation of the IEEE 802.11p/1609.3/4 testbed. We have put much effort in the implementation of the protocol stack and its performance validation in various scenarios. The remaining of the paper is organized as follows. Section II presents related work in the area of available implementations of vehicular networks. Section III introduces the implementation of our testbed platform. Section IV presents the performance testing results of the platform. Section V concludes the paper and investigates the future work.

2 Related work

Ref. [1] presented the implementation of an IEEE 802.11p/WAVE compliant MAC/PHY solution. The system complies with the strict channel switching timings using GPS time synchronization, providing access to two different types of wireless channels in a seamless way for the end user. It contributed much to the real IEEE 802.11p/WAVE platform. But it only gave a delay variation graph with no other indications such as

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throughput, communication distance, etc., for the performance testing. Ref. [2] introduced the development of an 802.11p communication system with adjustable transmission power, but it did not touch upon IEEE 1609.3/4. In [3], Vandenberghe W et al. presented how an approximation of the IEEE 802.11p standard can be implemented using commercial off-the-shelf (COTS) IEEE 802.11a hardware with some specific software adjustments. Ho K Y et al. [4] modified an 802.11a chipset in order to make it compliant with the 802.11p standards. The communication between an on-board unit and a roadside unit was tested in the deployed system in a real urban road scenario. Using this approach, the transmission range was up to be 300 m with acceptable packet loss and latency. Lin et al. [5] used a WAVE radio created by Savari Networks, and their research focuses primarily on developing useful testing techniques for DSRC systems.

While there have been a considerable number of studies looking at customized DSRC systems, there has not been much research into deploying an integrated IEEE802.11p/WAVE system. In this paper, we present our implementation and a series of testing cases for the platform. The results validate the robustness of the platform. Moreover, the platform brings enormous potential for practical deployment.

3 5.9 GHz WAVE System Implementation

3.1 IEEE 802.11p Physical Parameters

Our testbed is implemented with network card based on Atheros AR5414 wireless chipset, which supports the radio operation in the DSRC range of 5.85 GHz – 5.92 GHz with seven 10 MHz band, as specified in the IEEE 802.11p standard. The wireless module can support transmission powers as high as 24dBm with a power supply as 3.3V. The network card had no driver support for IEEE 802.11p standard. We develop a custom driver to support IEEE802.11p based on the open source ath5k driver that supported AR5xxx chipset versions in IEEE 802.11 a/b/g mode, as the IEEE 802.11p has a little difference to other IEEE 802.11 series protocols. The ath5k driver is provided by the Linux Wireless development group. The kernel version of the Linux system is 3.2.43 as it is available for this open source driver.

The main modifications include the number of channels, the size of channel bandwidth, and the modulation and coding schemes according to the specifications in IEEE 802.11p. The data transmission rates are halved varying from 3 to 27Mbps rather than 6-54Mbps in order to adapt to the high mobility environment. The hardware configuration and channel registration are controlled by the MAC part of the net subsystem. Furthermore, identifying different communicating devices by the basic service set identifications (BSSIDs) is optionally ignored and consequently the filter of BSSID is disabled in order to allow stations to deliver message out of a simple group. Meanwhile, the transmission of standard beacons is disabled when configuring an IEEE 802.11 wireless network interface in infrastructural or ad-hoc mode.

Starting with Linux kernel with a version that is later than 2.6.28, the ath5k driver uses a new regulatory framework called CRDA. CRDA allows changing rules to compliance with regulatory restrictions of different regulatory domains worldwide, including the US FCC. In order to operate in the DSRC frequency band regardless of the restrictions in the regulatory domain the card uses, modifications of rules have been added into the CRDA.

3.2 IEEE 1609.4 Channel Switching and Synchronization

As required in IEEE 1609.4 protocol, WAVE devices should be able to tune to the CCH and SCH alternatively. The multi-channel operation scheme is to allow even cheaper single-radio devices to transmit safety and non-safety related messages using different channel resources.

The guard intervals are extended to be longer than the sum of the channel switching delay and the synchronization error at the beginning of each channel interval to reduce the timing inaccuracy effects. In the ad-hoc mode, when channel switching operation starts, the IBSS that is being used will be left and the net interface will try to scan an existing IBSS to join. If no available IBSS is found, a new IBSS will be created. In this procedure, synchronize_rcu function is called several times to ensure the achievement of synchronization for critical sections. In other words, fast channel switching mechanism within the required interval was not supported. However, the channel switching in the WAVE mode has no relevance with the complicated IBSS operation. Moreover, fast channel switching is available for AR5414 radio chipset theoretically. Thus, a *local* environment is made to support the requirements mentioned above in a working entity. The *local* module provides APIs in mac80211 module to handle the command of hardware configuration from user space. The mac80211 module deals with device registration and interface configuration in the networking subsystem. When channel is switching, the hardware's interrupt mask is saved in register and transmission and reception is disabled. After stop PCU and DMA, hardware configuration is reset and all characteristics that were disabled before will be waked or initialized. The average delay for channel switching is near 1.7ms through more than 1000 times trail.

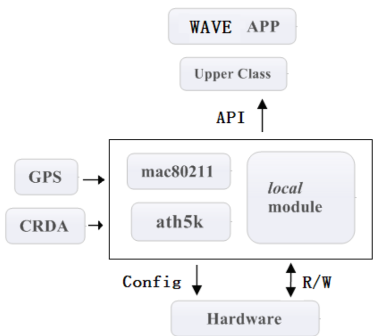


Figure 1. *local* module structure

As suggested in IEEE 1609.4, the time synchronization is achieved in the synchronization module via receiving a 1PSS signal generated by a GPS receiver. In our case, the system raise an interrupt according to the signal, and the corresponding callback function is triggered to adjust the timestamp. The synchronization inaccuracy is reduced within 1ms through this approach.

According to the multi-channel operation in the WAVE mode, when a station wants to provide a service to other stations, it first needs to execute the MLME-REGISTERTXPROFILE primitive to build a WAVE basic service set (WBSS) in order to let other stations join the WBSS. The station forming the WBSS is called "the provider" and the one joining the WBSS is called "the user".

When the provider wants to form a WBSS, it executes the MLMEX-SCHSTART primitive whose parameters include service channel identifier etc. Correspondingly, the user executes the MLMEX-SCHSTART primitive to response the provider. After that, the user succeeds to join the WBSS. At the beginning of the next SCH interval, both the provider and the user switch from the CCH to the same SCH negotiated in the MLMEX-SCHSTART primitives. Then, the provider and the user exchange the service message during the SCH interval. Before ending the WBSS, the provider can execute the MLMEX-SCHSTART primitive during each CCH interval to let other users have the chances to join the WBSS. When finish the service, the provider executes the MLMEX-SCHEND primitive to cease access to the indicated SCH. Then the users execute the MLMEX-SCHEND primitive to confirm the outcome of provider's MLMEX-SCHEND.

Some approaches are made to arrange packets until it is sent out or dropped. Seven queues are established for transmission in the seven channels respectively. Different packets are queued in different buffers according to their specified types that are configured in the upper classes through the API provided by the *local* system. In this paper, two simple original modes are created for channel assignment.

(a)Small-scale WAVE system (b)802.11p network card (c)High-gain outdoor antenna

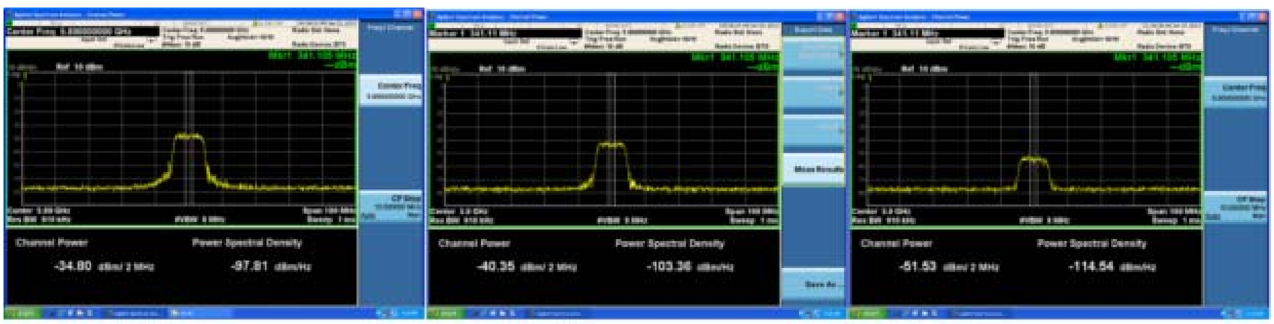
Figure 2. System View

Mode 1: At the beginning of the WAVE mode, a fixed SCH is chosen and the system is working in a dual-channel situation. All service messages will be queued and transmitted in the specified SCH.

Mode 2: As the device can detect WSA packets during the CCH interval, registering the SCHs being used and the number of the existing services is available. When assigning a new channel to handle the service request, a SCH which has less services load will be chose. If several SCHs are in the same condition, one of them will be randomly selected.

3.3 System Implementation

As the figure 2 shows, (a) is the integrated platform of the WAVE system terminal; (b) is the network card that supports the 802.11p; (c) is the high-gain outdoor antenna. The terminal is based on the M20 workstation which has a mini-PCI interface for the network card. In the outdoor environment, the antenna is a key factor of the communication quality. At the system's development, a 5.8 GHz 802.11a antenna is used with the device. Here we choose a 9dBi outdoor antenna. Through testing, the communication range is about 400 meters.



(a)24dBm at 5.89GHz (b)18dBm at 5.9GHz (c)1dBm at 5.9GHz

Figure 3. Captured spectrum

4 Performance Validation

Since the system is deployed from the entire ath5k driver project, it is difficult to know whether the modifications made to it actually achieve the expected results sometimes. To make sure we are working at the correct configurations, we have tested the performance to verify the actual condition.

4.1 Physical Parameters Capture

An Agilent X-Series Signal Analyzer is used to capture the signal working spectrum. One device is configured for broadcasting WSA messages for one minute with no delays. During signal capturing, the device was placed 10 cm distant from the analyzer's antenna to obtain clear images of the received signal. Several channels are tested with transmission powers of 1, 18, and 24 dBm.

The Screenshot of the captured spectrum for various transmission powers can be seen in Fig.3. From the waveforms, the device was transmitting at the proper center frequency with 10MHz of bandwidth.

4.2 Dual-channel Switching

To evaluate the system performance in channel switching environment, the device is tested in some particular scenarios. Working in a dual-channel environment, one device is transmitting two types of packets at a constant speed in CCH and SCH alternatively with no delays. The reception results can be seen in Fig. 4, which is obvious worse than in the static environment. The average RTT of the packets across the SCH was 1.697 ms by using the ping command when transmitting packets within the SCH. The performance can be promoted when a specified 5.9 GHz 802.11p antenna is used.

4.3 Transmitting Data Rate

Moreover, various data rates are measured to compare with the configured value. A traffic generator is used to send packets fulfilling the channel. The results are shown in Table 1.

4.4 Distance Test

Another experiment is performed under different distances between two devices. Within the experiment, the transmit power for each device is 24dBm and the data rate is adjusted adaptively. The result is averaged from sending 20000 packets of 800bytes in two channels (10000 for each).

Fig. 5 shows the performance in terms of packet loss rate and latency. It can be observed that the transmission is efficient when the distance is within 300 meters and the packet loss rate and latency deprave rapidly with the increase of distance.

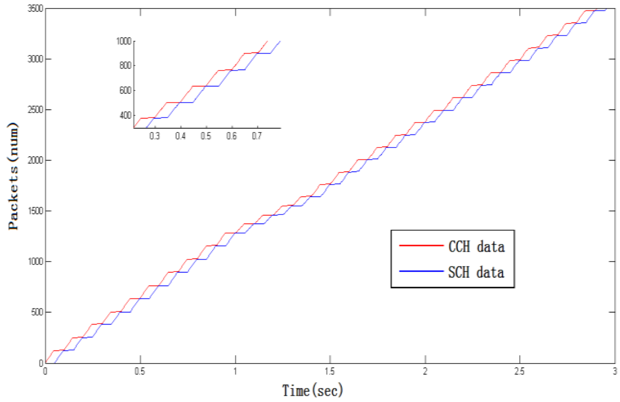


Figure 4. Reception of dual-channel

Table I Data Rate

Configuration	Measurement
3 Mbps	2.36 Mbps
4.5 Mbps	3.39 Mbps
6 Mbps	4.35 Mbps
9 Mbps	5.10 Mbps
12 Mbps	6.57 Mbps
18 Mbps	8.09 Mbps
24 Mbps	9.94 Mbps
27 Mbps	10.99 Mbps

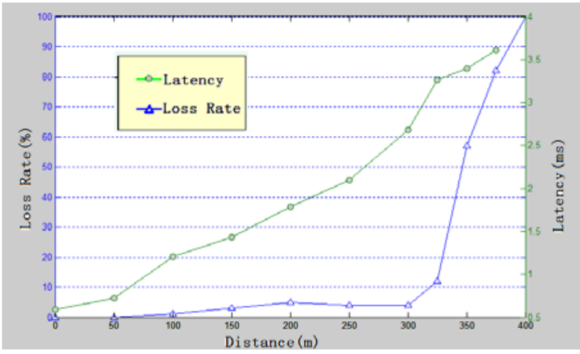


Figure 5. Latency and Loss Rate in different distance

4.5 Simple V2R Scenario

The performance evaluation of the V2R communication is carried out using a simple testing scenario with three devices. At the beginning, OBU1 joins a WBSS on a negotiated SCH and communicate with a RSU, which acts as the WBSS provider. The communication performs well and the transmission delay is acceptable. After a while, OBU2 joins the WBSS and communicates with the RSU as well. There will be transmission contention between OBU1 and OBU2 and the transmission delay increases without doubt. Later then, OBU1 leaves the WBSS and consequently the transmission delay of OBU2 decreases. Fig.6 shows the variation of delay of the OBUs.

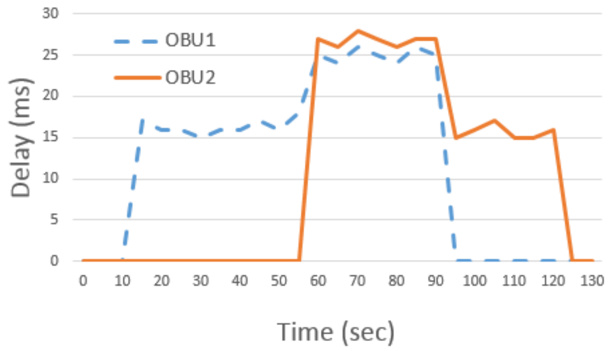


Figure 6. Delay of OBUs

5 Conclusion and Future Work

This paper presents an implementation of the IEEE 802.11p/WAVE standard for vehicular communications using the Linux kernel 3.2.43 and open-source driver ath5k. The test results verify that the platform guarantees the QoS requirements defined in the protocols. This implementation provides seamless dual-channel and multi-channel access with synchronous channel switching.

In the future, we will transplant the PC based platform to an embedded development board. The implementation also includes the development of a complete vehicular network stack from the MAC layer to the upper layers. The user can get more information about the vehicle from the platform. This approach extends the testbed with an OBD (On Board Device). As a consequence, the testbed will be more practical and beneficial.

References

[1] Ameixieira C, Matos J, Moreira R, et al. An IEEE 802.11 p/WAVE implementation with synchronous channel switching for seamless dual-channel access (poster)[C]//Vehicular Networking Conference (VNC), 2011 IEEE. IEEE, 2011: 214-221.

[2] Kamal F, Lou E, Zhao V. Design and validation of a small-scale 5.9 GHz DSRC system for vehicular communication[C]//Electrical & Computer Engineering (CCECE), 2012 25th IEEE Canadian Conference on. IEEE, 2012: 1-4.

[3] Vandenberghe W, Moerman I, Demeester P. Approximation of the IEEE 802.11 p standard using commercial off-the-shelf IEEE 802.11 a hardware[C]//ITS Telecommunications (ITST), 2011 11th International Conference on. IEEE, 2011: 21-26.

[4] Ho K Y, Kang P C, Hsu C H, et al. Implementation of WAVE/DSRC devices for vehicular communications [C] // Computer Communication Control and Automation (3CA), 2010 International Symposium on. IEEE, 2010, 2: 522-525.

[5] Lin C S, Chen B C, Lin J C. Field test and performance improvement in IEEE 802.11 p V2R/R2V environments[C]//Communications Workshops (ICC), 2010 IEEE International Conference on. IEEE, 2010: 1-5.

[6] Agafonovs, Nikolajs, Girts Strazdins, and Modris Greitans. "Accessible, customizable, high-performance IEEE 802.11 p vehicular communication solution." Ad Hoc Networking Workshop (Med-Hoc-Net), 2012 The 11th Annual Mediterranean. IEEE, 2012.

[7] Campolo, Claudia, and Antonella Molinaro. "Vehicle-to-roadside multihop data delivery in 802.11 p/WAVE vehicular ad hoc networks." Global Telecommunications Conference (GLOBECOM 2010), 2010 IEEE. IEEE, 2010.

[8] Du, Yingtian, et al. "Performance analysis and enhancement of IEEE 802.11 p/1609 protocol family in vehicular environments." Intelligent Transportation Systems (ITSC), 2010 13th International IEEE Conference on. IEEE, 2010.

[9] Chu, Jui-Hung, et al. "Cognitive radio enabled multi-channel access for vehicular communications." Vehicular Technology Conference Fall (VTC 2010-Fall), 2010 IEEE 72nd. IEEE, 2010.

[10] Grafling, Sebastian, Petri Mahonen, and Janne Riihijarvi. "Performance evaluation of IEEE 1609 WAVE and IEEE 802.11 p for vehicular communications." Ubiquitous and Future Networks (ICUFN), 2010 Second International Conference on. IEEE, 2010.

[11] Chen, Qi, Daniel Jiang, and Luca Delgrossi. "IEEE 1609.4 DSRC multi-channel operations and its implications on vehicle safety communications." Vehicular Networking Conference (VNC), 2009 IEEE. IEEE, 2009.

[12] Campolo, Claudia, Alessandro Cortese, and Antonella Molinaro. "CRaSCH: a cooperative scheme for service channel reservation in 802.11 p/WAVE vehicular ad hoc networks." Ultra Modern Telecommunications & Workshops, 2009. ICUMT'09. International Conference on. IEEE, 2009.

[13] Wang, S. Y., et al. "Improving the channel utilization of IEEE 802.11 p/1609 networks." Wireless Communications and Networking Conference, 2009. WCNC 2009. IEEE. IEEE, 2009.

[14] Ghandour, Ali J., et al. "Modeling and simulation of WAVE 1609.4-based multi-channel vehicular ad hoc networks." Proceedings of the 5th International ICST Conference on Simulation Tools and Techniques. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), 2012.