Opportunistic Wireless Internet Access in Vehicular Environments Using Enhanced WAVE Devices

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Abstract

In this paper we study the feasibility of providing automotive users the Internet access using C2C communication with help of roadside infrastructure and the novel Vehicular Communication Gateways (VCG), which is developed in the MYCAREVENT project. A technical solution of managing the opportunistic wireless links between On-Board Units (OBUs) and Road-Side Units (RSUs), as well as between OBUs and VCGs, is developed based on WAVE system. To further enhance the performance of WAVE system concerning IP traffic in highly dynamic vehicular environments we propose a link status aware MAC queue architecture. Stochastic simulation results are presented to prove the concepts and validate the proposed solutions.

1. Introduction

The emerging wireless vehicular communication technologies are intended to improve safety and comfort of transportation system. The newly standardized Wireless Access in Vehicular Environments (WAVE) system is based on the IEEE Wireless Local Area Network (WLAN) technology. It is able to provide broadband Car-to-Car (C2C) and Car-to-Roadside (C2X) communications for both safety and commercial services.

One of the typical commercial services in vehicular environments is the onboard Internet access for car maintenance, which is specified by the MobilitY and CollAboRative Work in European Vehicle Emergency NeTworks (MYCAREVENT) project [1]. MYCAREVENT project is aiming to optimize the European market for after-sales and repair services. Within the project, partners develop and implement new applications and services, which can be accessed remotely and securely. These services will provide the customers with manufacturer specific repair information according to the problems identified by vehicle diagnosis systems. Mobile communication is used to communicate with the On-Board Diagnostic (OBD), to gather breakdown information and to access web based services for repair information. [1] Figure 1 shows the information flow to conduct this service from failure to the restored mobility. Starting with the car re-porting a failure, subsequent information is transmitted to a service provider using mobile communication. This error message is analyzed with an existing database, guidance and repair instructions are provided, and if necessary, a process to deliver additional spare parts is initiated. Transmitting the information enables the roadside assistance solving the problem.

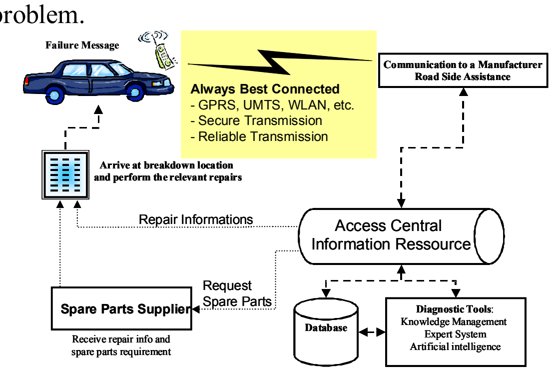

Figure 1. MYCAREVENT Information Flow

This example shows that the ubiquitous Internet access is essential to the future automotive users. To solve the problem the MYCAREVENT consortium investigated the potential of various mobile devices and communication networks and designed an "always best connected" Vehicle Communication Gateway (VCG) for the roadside patrol and the driver. The VCG is able to seamlessly switch among multiple of available mobile communication networks, e.g. GRPS, UMTS or WLAN, and provide continuous, secure and always best data communication between the end user and the backend MYCAREVENT service portal. [2] However, the high cost and high system complexity makes it difficult for VCG devices to achieve a high market penetration ratio in either short- or long-term market perspective. On the contrary, the emerging WAVE technology will become more and more prevailing because of its important role on the driving safety in future transportation systems. Besides, the WAVE system is also designed for providing general IP ser-vice through C2C and C2X wireless links.

In this paper, we investigate the feasibility of using the WAVE technology to provide Internet access for C2C communication users in vehicular environments. Two architectures are studied in this paper. The one is to use the direct communication between WAVE On-Board Units (OBUs) and Road Side Unit (RSU), while the other integrates the MYCAREVENT VCGs and WAVE OBUs. Contributions of this work are two-fold: 1. We propose and prove the concept of using WAVE system to provide the Internet access for on-road automotive users. 2. In order to make use of the opportunistic wireless communication links between OBUs and RSUs/VCGs we developed a dynamic wireless link management solution in vehicular environments.

The remaining of this paper is organized as follows: In section 2 and section 3 we briefly review the WAVE system for vehicular communication and the VCG solution developed by MYCAREVENT project [2], respectively. The two architectures of Internet access in vehicular environments using C2C/C2X wireless links are described in section 4. In section 5, we concentrate on the MAC layer protocol of the solutions and present the dynamic link management scheme and the enhanced MAC queue architecture regarding the high mobility in VANETs. Section 6 presents simulative evaluation results and Section 7 concludes the paper with outlooks on future work.

2. Wireless Access in Vehicular Environments (WAVE)

In order to support various safety and commercial applications in vehicular environments, the IEEE 1609 and IEEE 802.11p [3] task groups developed an IEEE 802.11 WLAN based C2C/C2X communication system, known as Wireless Access in Vehicular Environments (WAVE). This system works on the 5.9GHz ITS frequency band regulated by FCC in the U.S. and by ETSI in Europe. Blocks of WAVE system are illustrated in Figure 2, where IEEE 802.11p standard specifies the Physical layer (PHY) and the basic MAC. All above layers of WAVE are regulated by the IEEE 1609 standard family.

The IEEE 802.11p PHY is based on the Orthogonal Frequency-Division Multiplexing (OFDM) technology providing up to 27Mb/s data rate out of 10MHz bandwidth. The typical communication distance in WAVE system is from 300m to 1000m. The IEEE 802.11p MAC layer is exactly the Distributed Coordination Function (DCF) in IEEE 802.11, which follows the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme.

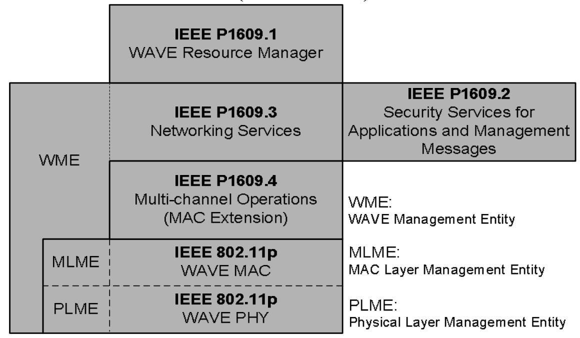

Figure 2. Protocol stack of WAVE

The 5.9GHz ITS frequency band consisting of multiple frequency channels, including one Control Channel (CCH) for system control and safety service usages and plural Service Channels (SCHs) for non-safety commercial applications, e.g. IP traffics. In order to efficiently coordinate the channel access to the CCH and multiple SCHs, a globally synchronized channel coordination scheme based on the Coordinated Universal Time (UTC) was developed in IEEE P1609.4 [3]. As show in Figure 3, the channel time is divided into synchronization intervals with a fixed length of 100ms, consisting of a CCH interval and a SCH interval, each of 50ms. According to the coordination scheme all devices have to tune to CCH during all CCH intervals, where high priority frames, e.g. danger warning messages and management frames, are exchanged. During SCH intervals, devices can optionally switch to SCHs in order to perform non-safety applications, like Internet access. This scheme allows WAVE devices to perform non-safety applications on SCHs without missing important messages on CCH.

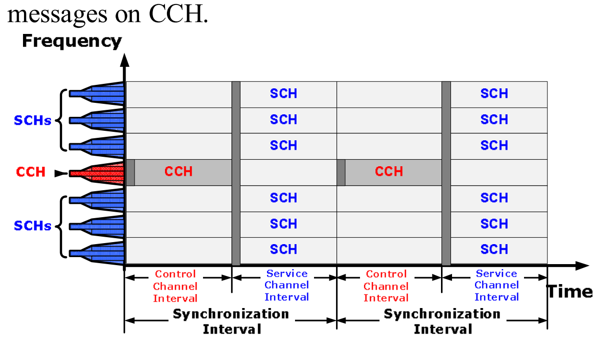

Figure 3. Multi-channel operation in WAVE

Owing to the high dynamic feature of VANET, usually vehicles can only perform opportunistic data exchange with limited communication duration. Therefore, unlike in traditional IEEE 802.11 networks, the Basic Service Set (BSS) in WAVE system is reformed into WAVE BSS (WBSS) which is established in a fully ad-hoc manor, where no association or authentication is required between communicating OBUs and RSUs. The process of using WBSS to perform data communication services is specified as follows [3]:

- The WBSS is defined based on the WAVE service, e.g. the Internet access service. A WAVE device can take a role of the service either as the service provider or as the service user.
- It is the duty of a service provider to periodically broadcast the information of services that it is offering to the neighboring potential users. The service information, e.g. service profile, channel number and routing information, are composed into the WAVE Service Advertisement (WSA), which is carried by the WAVE Announcement (WA) frame at 802.11p MAC layer and periodically broadcast on CCH. [4]
- At the service user side, when a service user receives a WSA from a service provider and the service matches its requirement, the service user will locally decide to join in the WBSS. And in the next SCH interval, it will switch to the SCH channel as specified in the WSA to perform the service. In case the service uses IP, in contrary to pure broadcast services, an additional handshake are required between the service provide and the service user to establish the data link.
- Exchange of service data is performed on the dedicated SCH channel as specified by the service provider.
- In WAVE system there is no explicit termination process required between the transmitter and receiver when the user is leaving the WBSS.

It can be seen that the organization of WBSS in WAVE is in favor of reducing the management overhead and tolerating the mobility of vehicle in VANET. Based on this idea and the above described protocol we develop a dynamic link management scheme for wireless Internet access in vehicular environments, as presented in section 5.

3. MYCAREVENT Vehicular Communication Gateway (VCG)

The main idea of MYCAREVENT VCG is to incorporate several communication systems such as GPRS, UMTS and WLAN and to provide the gateway users "always best connected" Internet access services. Figure 4 shows the architecture and functionalities of VCG.

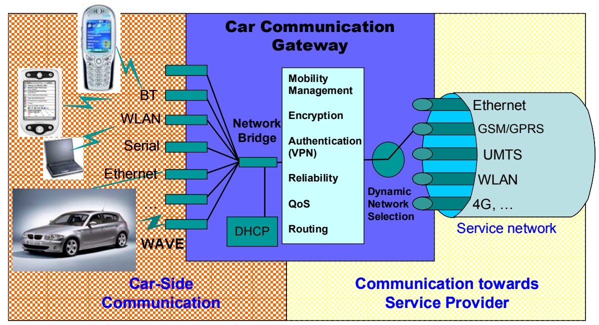

Figure 4. MYCAREVENT Vehicular Communication Gateway

On the right hand side of Figure 4 the communication towards the service provider is depicted. Several communication media are envisaged. A dynamic network selection chooses the most suitable communication medium according to Quality of Service (QoS) criteria. Moreover, this could also be a combination of two or more parallel communication technologies for better QoS support. The left part describes a classical gateway design, except that many different technologies can be used to attach to the gateway as the central point of communication. Mobile devices, such as the roadside patrol's laptop, driver's PDA or other C2C OBUs will be able to connect to the gateway. The functions mobility management (MM), encryption, authentication, QoS mapping, enhanced reliability and routing are shown in the middle of Figure 4. Thus, the gateway offers an advanced and flexible communication service, through which the Car-side users can enjoy the encrypted and reliable communication with in the range of VCG. Opportunistic internet access is also possible for occasionally passing by OBUs, if an efficient service discovery and link management scheme can be used between the VCG and the OBUs.

4. Internet access in vehicular environments with WAVE devices

Two architectures of Internet access in vehicular environments using WAVE technology are proposed in this section, as shown in Figure 5 and Figure 6, respectively.

4.1. WAVE RSU Solution

In the WAVE system, the roadside infrastructure, i.e., RSUs usually have connection to the IP backbone and can act as the Internet access service providers for passing by OBUs. The Internet access will be a WAVE service provided on SCHs. This solution is also known as drive-thru Internet in [5], where the original IEEE 802.11 WLAN technology is used.

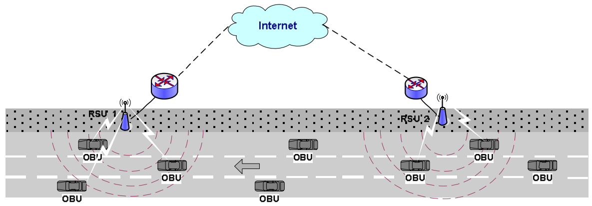

Figure 5. Wireless Internet access through WAVE RSUs

4.2. MYCAREVENT VCG solution

The second solution integrates the WAVE C2C/C2X communication with the MYCAREVENT VCG. As shown in Figure 6, for safety reason WAVE OBUs have to self-organize into a VANET on the roadway and keep communicating with each other. Some of these vehicles that have VCG equipped may operate as the Internet access gateways of the autonomous VANET. The VCGs, in this case, on the one hand connect to the Internet service provider through UMTS, GPRS or WiMAX, while on the other hand provide Internet access using the WAVE C2C communication to other surrounding vehicles. In the example illustrated in Figure 6 a broken vehicle located outside the RSU range may have opportunity to get Internet access via the passing by VCGs.

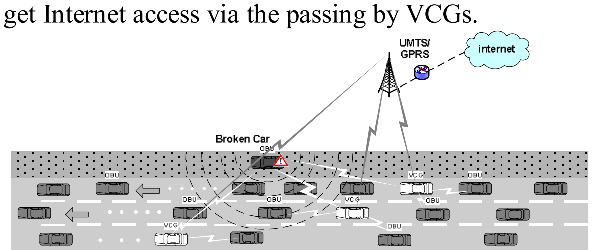

Figure 6. Wireless Internet access through MYCAREVENT VCG

The common point of these two architectures is that WAVE C2C users have to discover the opportunistic Internet access services provided by either RSUs or VCGs, and efficiently perform data communication within the limited duration in VANET.

5. MAC enhancements for Internet access in VANET with WAVE devices

As studied by Hadaller et al. [6] the ability of MAC layer protocol in dealing the highly dynamic opportunistic wireless link is essential to the throughput performance. In this section, we propose a dynamic link management scheme using the WBSS concept developed in WAVE.

The main idea is that instead of treating the drive-thru process as a while session, the process is divided into multiple of sub-sessions, which are mapped to the synchronization intervals of WAVE MAC. The links between OBUs and RSUs are consistently monitored and managed in each session. That means the MAC entities on OBUs and RSUs will perform data communication only when the link state is healthy enough. This is important to realistic VANET scenarios, as when multiple users share the same channel resource, unnecessary transmissions may produce interferences and congest the channel.

Based on the CCH/SCH interval structure and the WBSS concept in WAVE we design a link state monitor and management scheme. The scheme composed with the periodical WSA frame from RUS and a hand shake process before the each data exchange on SCH.

The Message Sequence Chart (MSC) for the service discovery and link establishment is shown in Figure 7, which generally follows the WBSS operation process specified in section 2. In order to cope with the high mobility in VANET, we propose a dynamic wireless link management scheme. That is, at the end of each SCH interval all existing wireless links are suspended. A suspended link can be resumed in the next SCH interval only if the WSA and service request handshake for it is successful in the next CCH. Otherwise it is suspended for a whole synchronization interval. If a link has been suspended for *n* continuous synchronization intervals, it is will be abandoned, as the peer may have already left the range of communication. According to the WAVE standard, the synchronization is 100ms, consisting 50ms CCH interval and 50ms SCH interval, which is short enough to trace the position update of vehicles. Although this process introduces overhead for link management, the overhead is on the CCH and will not hinder the data transmission on SCHs. This link management scheme can efficiently reduce unnecessary interference and guarantee the system throughput, especially when the number of user and provider is large.

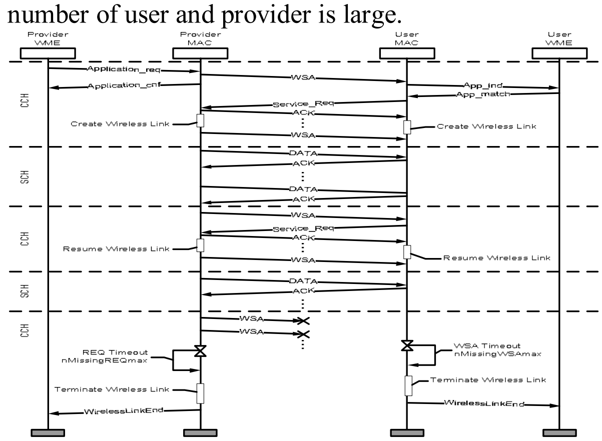

Figure 7. MSC of dynamic link management scheme for WAVE IP traffic services

In cooperation with the dynamic link management scheme we developed a novel MAC layer queue architecture. Unlike in the original 802.11e MAC, where all packets belonging to the same user priority have to wait in a single FIFO queue for transmission, we put packets of different wireless links into independent queues, even they are of the same user priority. In this way the obsolete packets of broken links will not block packets of other links that are still alive.

6. Simulation results

Simulative performance evaluations are conducted with the Wireless Access Radio Protocol II (WARP2) simulation environment developed in the chair of communication networks, RWTH-Aachen University. The WAVE MAC and PHY protocols have been implemented in WARP2. All simulations are performed with the WAVE CCH/SCH multi-channel architecture, as specified in section 2. In the simulations, all devices are assumed to be perfectly synchronized in order to perform the CCH/SCH switching. It has to be mentioned that the CCH interval takes only half of the overall channel time. The simulation parameters are taken from the current IEEE 802.11p standard draft [3].

First of all, we show the effectiveness of the dynamic link management scheme and the enhanced MAC queue architecture. The simulation scenario is depicted in Figure 8, where three OBUs pass by two WAVE RSUs in sequence. Each vehicle initiates an IP wireless link according to the link management process specified in section 5 and downloads data from the RSU. All OBU and RSU use queue size of 50, PHY mode of 16QAM½, i.e. 12Mb/s, MAC Service Data Unit (MSDU) size of 512B and overloaded traffic source for each link.

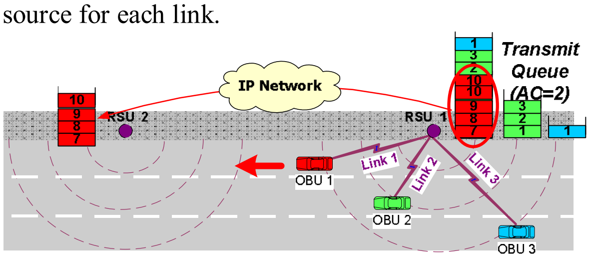

Figure 8. Simulation scenario for the MAC queue enhancement

Figure 9 show the instant throughput over the time duration that the vehicle is in range of each RSU. The instant throughput is evaluated with the time interval of 100ms. On the right hand side of Figure 9, it is observed that with the original WAVE MAC queue architecture the throughputs of the later two cars, i.e. the green one and the blue one, are seriously deteriorated due to the obsolete packets of the first car (red) in the same queue. However, with the novel Link Based Queue (LBQ) architecture and the dynamic link management scheme proposed in this paper, as shown on the right side of Figure 9, the instant throughputs of the green and the blue vehicles are great improved, as according to the LBQ scheme the packets for each link are maintained in logically separated queues. Consequently, the overall system throughput with LBQ architecture is much butter than the one with current WAVE MAC queue architecture.

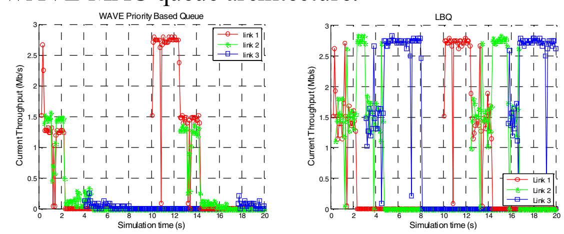

Figure 9. Instant throughput with link based MAC queue

Secondly, we evaluate the MYCAREVENT VCG solution for Internet access in vehicular environments with considerations on the VCG Market penetration ratio. The scenario is shown in Figure 6, where a crashed vehicle stops at the roadside and uses WAVE C2C communication to VCG for the opportunistic Internet access. In this work, our focus is on the performance of opportunistic WAVE C2C communication. For the reason of simplicity, we model the link between each VCG and the UMTS base station as the constant bit rate link of 384kb/s, and the data buffer on each VCG can hold 50 packets for each C2C link.

In this scenario a three-lane highway on one direction is considered with vehicles allocated with inter-vehicle distance of 60, 80 and 100 on slow, middle and fast lanes, respectively. The scenario parameters are given in Table 1.

TABLE 1
SIMULATION PARAMETERS OF MYCAREVENT VCG SOLUTION

Parameter	Value
Vehicle speed	80, 120 and 160 km/h
Vehicle density	39 vehicle/km
TX Power	200 mW
PHY mode	BPSK ½ (3Mb/s)
Traffic load	384 kb/s/VCG
Packet size	512 B
Penetration ratio of VCG	1%-9%, 10%-100%

The VCG penetration ratio is defined as the ratio of number of vehicles equipped with VCG devices to overall number of vehicles in the scenarios. Vehicles with VCG are randomly distributed in each simulation.

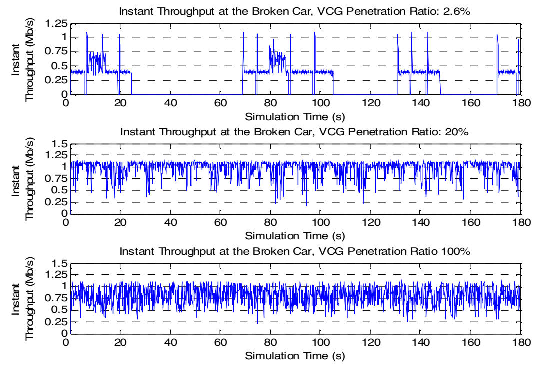

Figure 10. Instant throughput at the broken car vs. VCG penetration ratios

Figure 10 shows the instant throughput when the penetration ratio of VCG is 2.6%, i.e., 2 out of 78 vehicles have VCG devices, 20.5% and 100%, respectively. It is obvious that due to the limited communication range of OBUs and VCGs, the link can be established only when the broken car and certain VCG are in range of each other, which is referred to as opportunistic communication. When the market penetration ratio of VCG is low, e.g. 2.6% in the upper part of Figure 10, the link between OBU and VCG are intermittent and the average throughput is fairly low. If the VCG penetration ratio reaches 20%, the broken car can have almost continuous Internet access all through the time. The reason is that with the given vehicle density, communication range and penetration rate of 20.5%, statistically there are always 3-4 VCGs in the range of the broken car.

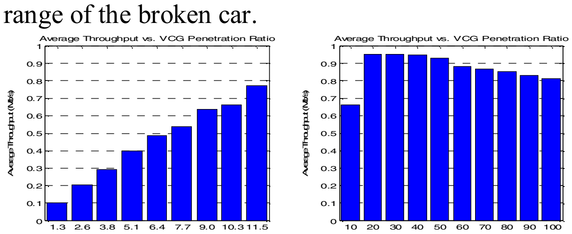

Figure 11. Average throughput vs. VCG penetration ratio

By multiplexing the simultaneously existing C2C links to multiple VCGs, the broken car can reach the maximum throughput that is supported by the IEEE 802.11p SCH, i.e. about 1Mb/s using BPSK½ mode. The results on the left side of Figure 11 also show a almost linearity relationship between the average throughput and increasing penetration ratio of VCG till 11.5%. However, simply increasing the penetration ratio of VCGs does not help anymore after 20%. As shown in both the lower part of Figure 10 and on the right part of Figure 11, the average throughput decreases with the increasing VCG penetration ratio. It is due to the CSMA scheme of IEEE 802.11p MAC, whose performance deteriorates with the number of contending stations in range.

7. Conclusion

In this paper, starting from a typical Internet access application on the roadway for car maintenance we studied the feasibility of providing Internet access in VANET to automotive users through WAVE C2C/C2X wireless communication. Two architectures of providing Internet access to WAVE device users using OBU to RSU communication and using OBU to VCG communication are presented. Additionally, our study on the MAC layer protocol shows that with the proposed dynamic link management scheme and the link status based MAC queue architecture, the WAVE system can efficiently support Internet access application in highly dynamic vehicular environments.

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