Opportunistic Wireless Internet Access in Vehicular Environments Using Enhanced WAVE Devices

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Abstract

The emerging Car-to-Car communication (C2C) technology, known as Wireless Access in Vehicular Environments (WAVE), enables vehicles on the roadway to communicate with each other and with the roadside infrastructure. In addition to safety-relevant services, drivers may also need Internet access through C2C communications for infotainment services and car maintenance services, as specified in MobilitY and CollAboRative Work in European Vehicle Emergency NeTworks (MYCAREVENT) project. In this article we propose solutions for providing on-board Internet access service to automotive users through C2C communications. The proposed solutions make use of roadside infrastructure and the novel MYCAREVENT Vehicular Communication Gateway (VCG) device. A management scheme is developed for the opportunistic wireless links between On-Board Units (OBUs) and Road-Side Units (RSUs), as well as between OBUs and VCGs in vehicular communications. Furthermore, we invent a novel MAC queue architecture addressing the drawback of the current WAVE MAC protocol in supporting unicast traffic in highly dynamic vehicular environments. At the end, 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 systems. 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 relevant and commercial applications.

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]

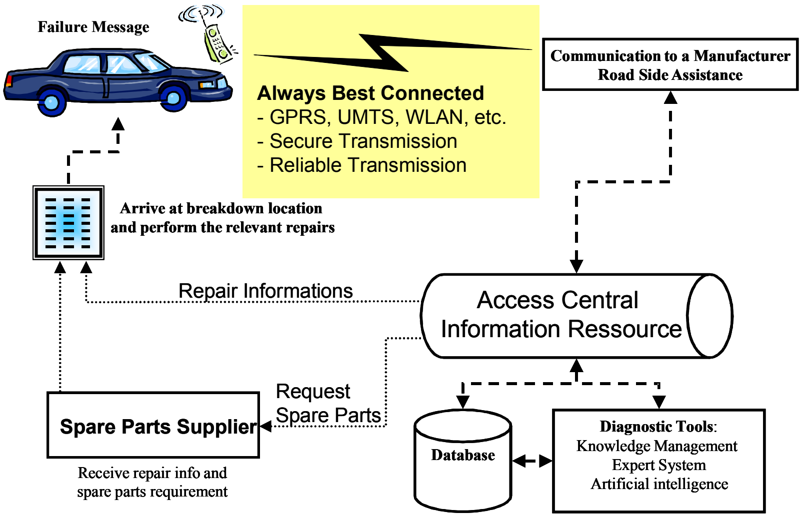

Figure 1. MYCAREVENT information flow

Figure 1 shows the information flow to conduct this service from vehicle failure to the restored mobility. Starting with the car reporting 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.

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, cost and high system complexity make 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 C2C technology is becoming more and more prevailing due to its important role in future active driving safety systems [8]. Furthermore, the WAVE system was designed keeping in mind supports for generic IP services through C2C and C2X wireless links.

In this article, we investigate the feasibility of using the WAVE technology to provide Internet access for automotive users in vehicular environments. Two architectures are studied in this paper. The one is to make use of 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 threefold: 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. 3. We reveal a drawback of the current WAVE MAC protocol in supporting the unicast IP communication in highly dynamic Vehicular Ad-Hoc Network (VANET) and invent a novel MAC queue architecture to solve the problem.

The rest of the article is organized as follows: In section 2 and section 3 we briefly review the WAVE system for vehicular communication and the VCG solution developed in MYCAREVENT project [2], respectively. The two kinds of Internet access solutions in vehicular environments using C2C/C2X technologies 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 stochastic simulation results and discussions. Section 7 concludes the paper with outlooks to future work.

2. The Wireless Access in Vehicular Environments (WAVE) system

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. The system diagram of WAVE is illustrated in Figure 2, where the IEEE 802.11p standard specifies the Physical layer (PHY) and the basic MAC layer. All upper layers in WAVE system are regulated by the IEEE 1609 standard family. [4][9]

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, as required by direct C2C and C2X data exchange. 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.[5]

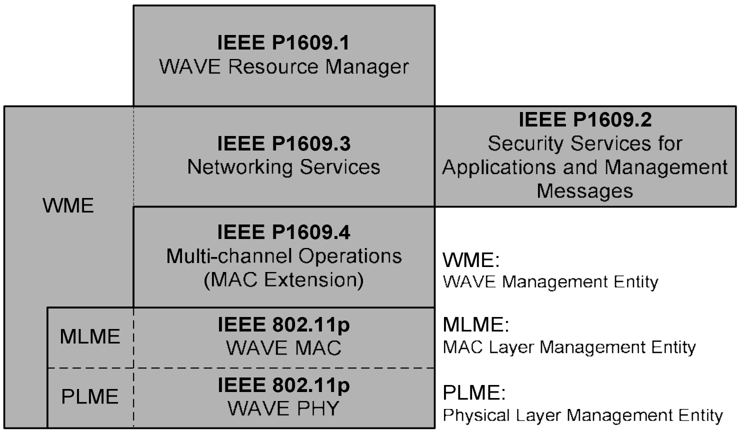

Figure 2. Protocol stack of WAVE system

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 [4]. 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 packets, e.g. danger warning messages and management packets, 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.

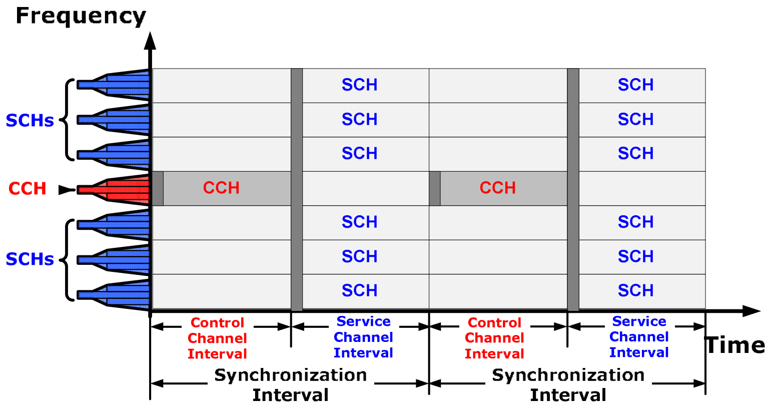

Figure 3. Multi-channel operation in WAVE system

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 can be established in a fully ad-hoc manner, 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][4][9]

- The WBSS is defined based on 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 can be overheard by potential users in range. The service information, e.g. service profile, channel number and routing information, are composed into the WAVE Service Advertisement (WSA) information element, which is carried by the WAVE Announcement (WA) frame at 802.11p MAC layer and periodically broadcast on CCH.

- At the service user side, when a service user receives a WSA frame from a service provider and the service matches its requirement, the service user will locally decide to join in the WBSS. 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 as the network protocol, 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 indicated by the service provider.

- In WAVE system there is no explicit handshake process required to terminate the WBSS when the user is leaving the range of the provider.

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.

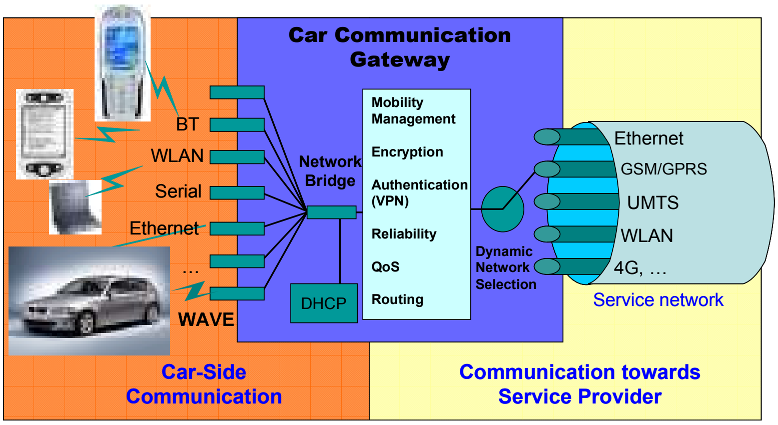

Figure 4. MYCAREVENT Vehicular Communication Gateway (VGC)

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 within 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 presented in this section, as shown in Figure 5 and Figure 6, respectively.

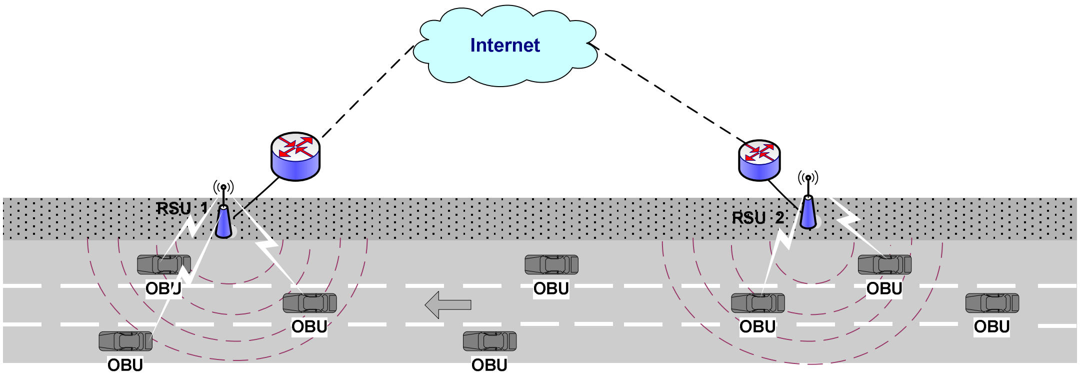

Figure 5. Wireless Internet access through WAVE RSUs

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 [6], where the original IEEE 802.11 WLAN technology is used.

4.2 MYCAREVENT VCG solution

The second solution integrates WAVE C2C/C2X communications with the MYCAREVENT VCGs. As shown in Figure 6, for safety reason all WAVE OBUs have to self-organize into 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 autonomously formed 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.

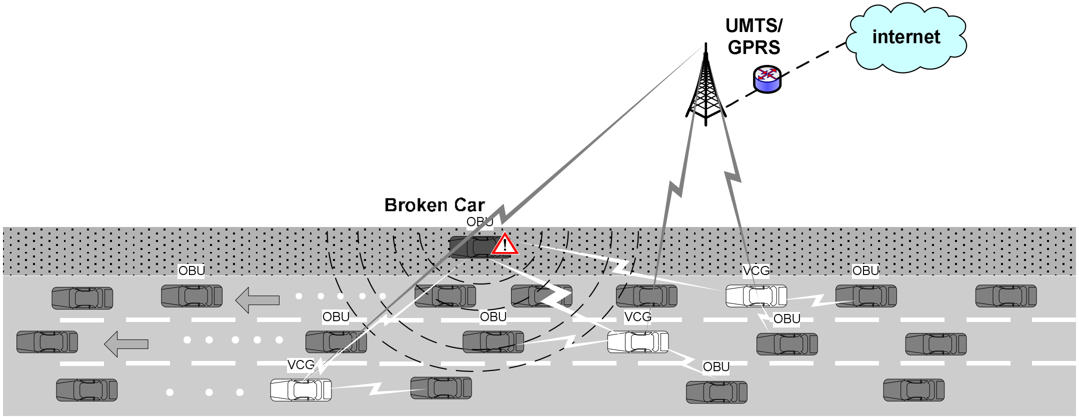

Figure 6. Wireless Internet access through MYCAREVENT VCG

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

5. MAC enhancements to WAVE protocol for Internet access in VANET

Challenges of providing Internet access to automotive users include the unreliable quality of wireless link, non-deterministic communication opportunities and the limited communication duration, which are all owing to high vehicle mobility.

The performance of providing Internet access to automotive users using IEEE WLAN technologies has been studied with field test in [6][7][10][11]. The architecture being studied in these works is known as drive-thru Internet and is similar to the WAVE RSU solution we described in the previous section. Common conclusions from these works include: (1) Although the communication range and duration are limited, the amount of data being delivered is still considerable; (2) The whole communication process of drive-thru Internet consists three phases, namely entry phase, production phase and exit phase and only the production phase is considered to be really productive; (3) The currently protocol can achieve only a small portion of the possible throughput, e.g. 50% [10], due to the sub-optimized protocol; (4) Protocol overhead and efficiency in high mobility environments are the main reasons for the unsatisfied performance. Therefore, one direction to solve these problems is to redesign the protocol taking consideration of the high dynamic feature of VANET. In the following subsections we concentrate on the MAC layer and proposed two mechanisms in this direction. Unlike previous works, our study uses the newly standardized WAVE system, instead of the traditional IEEE 802.11 WLAN, since WAVE is specifically developed for high mobility vehicular environments. Another extension to the previous works is that instead of the simple scenario with only one Internet service user and one provider, we try to figure out the solution for more realistic VANET scenarios consisting of multiple Internet users and access providers.

5.1.1. Dynamic Link Management in VANET

As studied by Hadaller et al. [10] 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 highly efficient 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 at WAVE MAC layer. The links between OBUs and RSUs are consistently monitored and managed in each session. That means the MAC entities of OBUs and RSUs can perform data communication only when the link state is healthy enough. This is important in realistic VANET scenarios, as when multiple users share the same channel resource, unnecessary transmissions may produce pure interference 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 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 process is shown in Figure 7. Generally the process follows the WBSS operation specified in section 2. In order to cope with the high mobility in VANET, we propose to suspend all existing wireless links at the end of each SCH interval. A suspended link can be resumed in the next SCH interval only if a successful WSA and service request handshake is performed between the corresponding provider and user in the CCH preceding the next SCH. Otherwise it keeps suspended. If a link has been suspended for n continuous synchronization intervals, it is will be abandoned, as the pair may have already been out the range of communication. According to the WAVE standard, the synchronization interval 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.

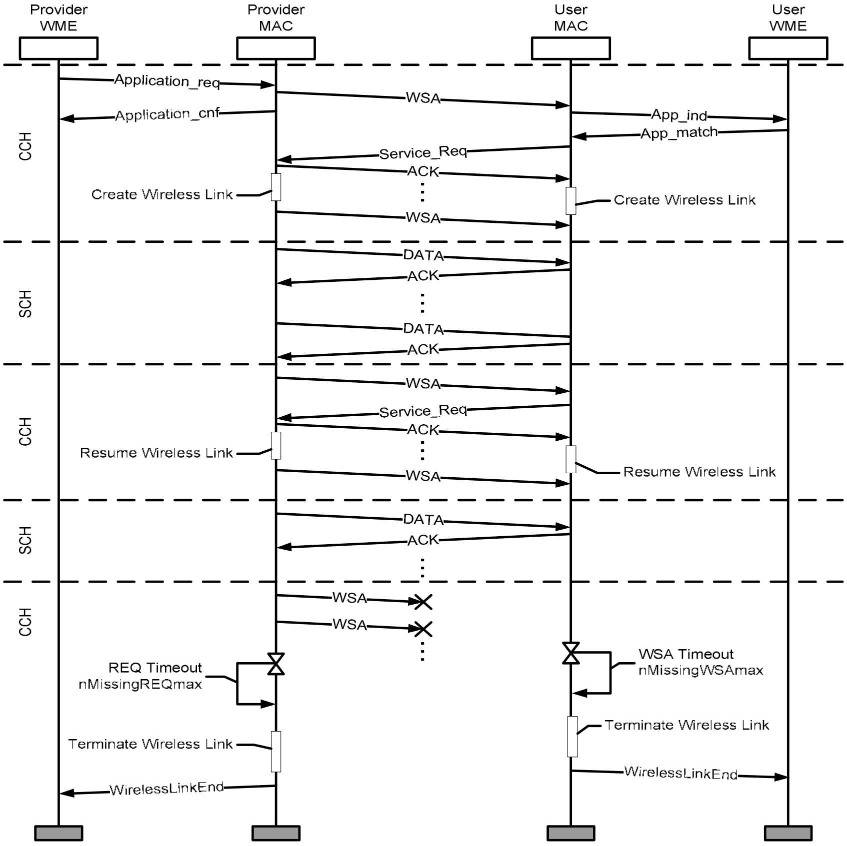

Figure 7. MSC of dynamic link management scheme for WAVE IP traffic services

5.1.2. Enhanced WAVE MAC Queue Architecture for VANET

In this section we invent a novel architecture of packet queuing scheme to the current WAVE MAC for better performance in highly dynamic VANET.

In order to support data traffics of different priorities the current WAVE MAC employ the same MAC queue architecture as in IEEE 802.11e [5], which is shown in Figure 8. In the WAVE system, two groups of traffic queues are maintained independently for CCH and SCH access. In each group four traffic queues are assigned to four Access Categories (ACs), which are mapped to four different user priorities of the traffic. Each queue is a virtual station conducting backoff independently and competing for the channel access with other queues in the same group. The Internal Contention is to choose a winner of the competition according to user priorities. These two groups of queues work alternatively during CCH and SCH interval, which is managed by the Channel Selector. It can be seen that all data packets of the same priority are filled in to the same queue, no matter which wireless link they belong to. Moreover, according to the IEEE 802.11p MAC, the queue works in a First-In-First-Out (FIFO) way and a packet will not be removed from the queue until it is successfully acknowledged or the retry limit of the packet is reached.

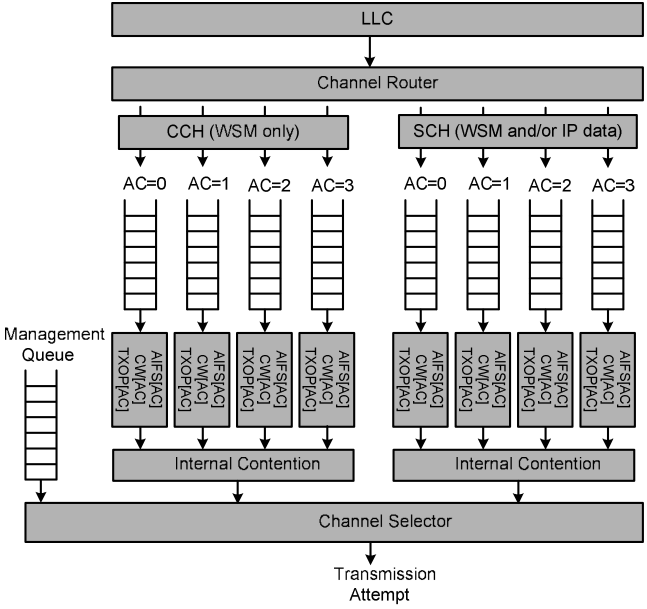

Figure 8. IEEE 1609.4 WAVE MAC queue architecture

However, this scheme has a drawback in high mobility VANET. As shown in Figure 9, packets of the same priority but for different wireless links are buffered into the same FIFO queue. The problem occurs when a wireless link is broken because of vehicle movement. The obsolete packets of the broken link are retransmitted again and again, which blocks the packets for the other wireless links that are alive, until the dynamic wireless link management realizes the link is out of date and discards all its obsolete packets from the queue.

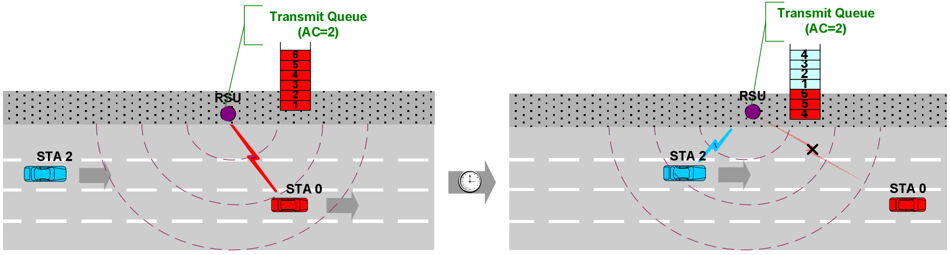

Figure 9. Obsolete packet problem with WAVE MAC queue

To solve this problem we propose a new MAC queue architecture, namely wireless Link Based Queue (LBQ) architecture, as shown in Figure 10. Comparing to the old architecture there are two major differences. The first one is that for each wireless link there is a unique queue, i.e. only packets of this wireless link are stored. The second change is that in addition to the Internal Contention among different ACs, we introduce a second level of Internal Contention among different wireless links of the same AC. Combined with the dynamic wireless link manage scheme described in the previous subsection, this architecture allows only packets of wireless links that are alive compete the channel access. Therefore, the waste of channel resource caused by obsolete packets can be avoided, i.e. achieving better system performance, as we shown with simulation results in section 6.

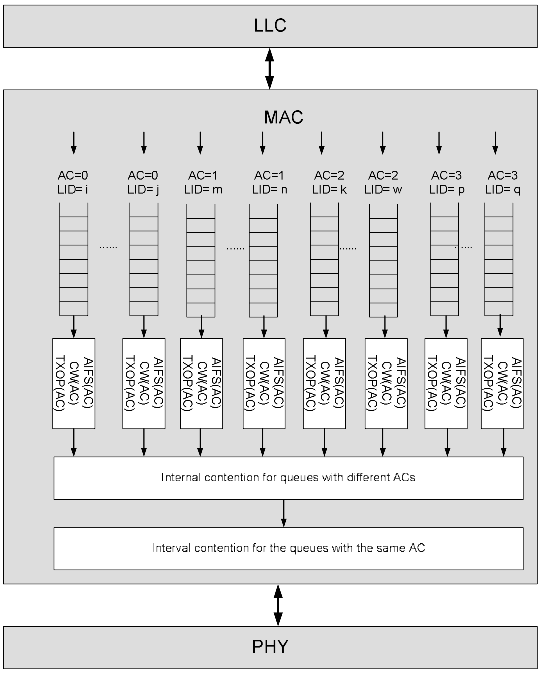

Figure 10. Wireless link based MAC queue architecture for WAVE

6. Simulation results

Simulative performance evaluations are conducted with the Wireless Access Radio Protocol II (WARP2) simulation environment developed in chair of communication networks, RWTH Aachen University. The WAVE MAC and PHY protocols have been implemented in WARP2. [12] 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. Thus, the results shown here represent half of the capability of IEEE 802.11p PHY. The simulation parameters are taken from the current IEEE 802.11p standard draft, as shown in Table 1.

Table 1. PHY&MAC relevant parameters

Parameter	Value
OFDM symbol duration	8 μs
PLCL preamble length	32 μs
PLCP header length	8 μs
pSlotTime	16 μs
pSIFS	32 μs
pDIFS	64 μs
MAC frame header size	30 B
ACK frame header size	10 B

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 11, where three OBUs pass by two WAVE RSUs in sequence. Each vehicle initiates an IP 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 at MAC layer, PHY mode of 16QAM½, i.e. 12Mb/s, MAC Service Data Unit (MSDU) size of 512B and overloaded traffic source for each link. Figure 12 shows the distance between each vehicle and the closest RSU to it.

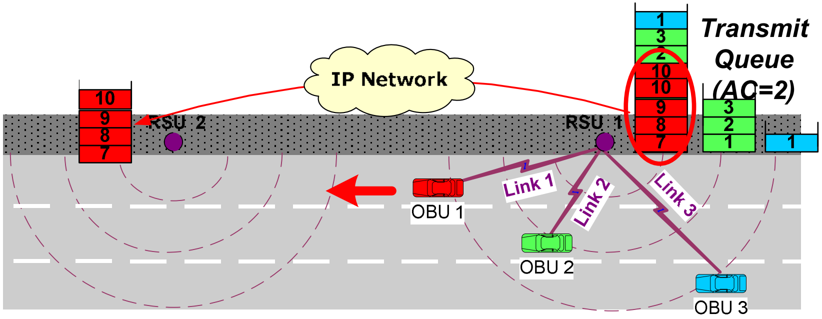

Figure 11. Simulation scenario for the MAC queue enhancement

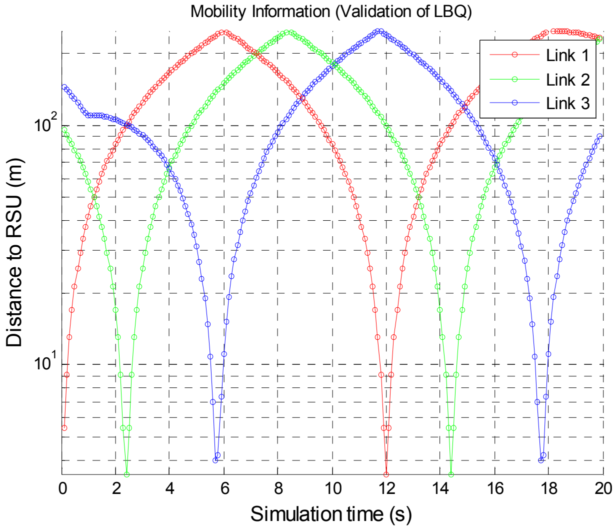

Figure 12. Distance between each vehicle and RSUs

Figure 13 and Figure 14 show the instant throughput over time, during which vehicles are moving from the range of RSU1 to that of RSU2. The instant throughput is evaluated with the time interval of 100ms. In Figure 13, 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 proposed Link Based Queue (LBQ) architecture and the dynamic link management scheme the instant throughputs of the green and the blue vehicles are greatly improved, as shown in Figure 14, since according to the LBQ scheme the packets of each wireless link are maintained in logically separated queues. Consequently, the overall system throughput with LBQ architecture is much higher than that with the current WAVE MAC queue architecture.

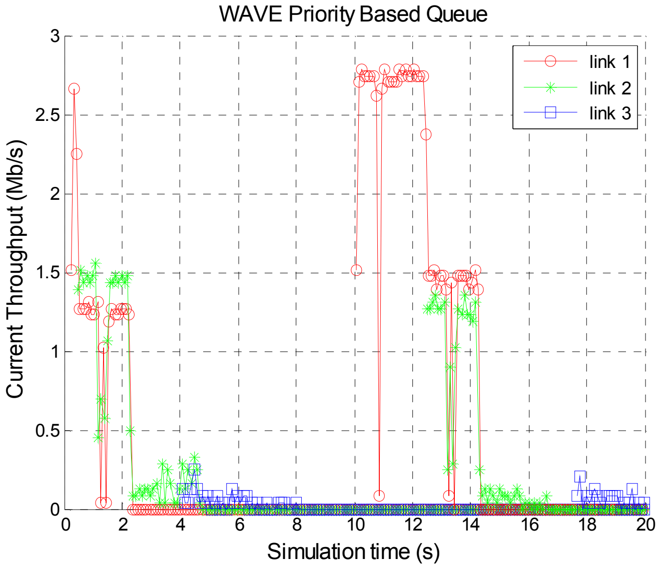

Figure 13. Instant throughput without link based MAC queue

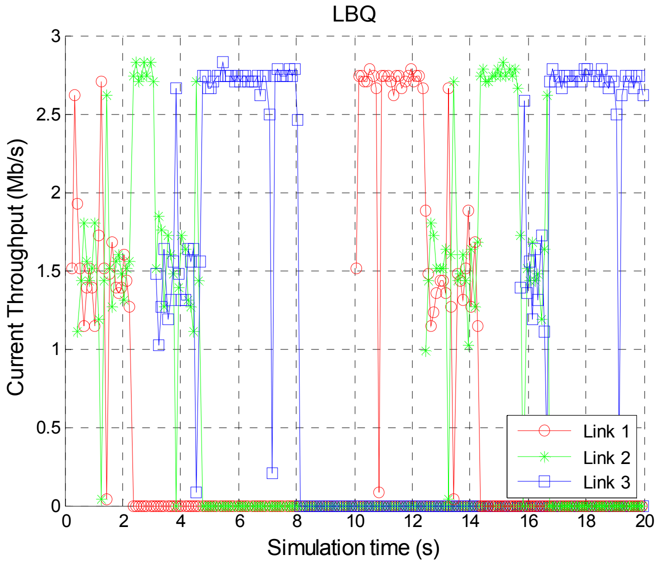

Figure 14. Instant throughput with link based MAC queue (b)

Secondly, we evaluate the MYCAREVENT VCG solution for Internet access in vehicular environments taking account of 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 2.

Table 2. 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 1/2 (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 vehicles equipped with VCG devices to overall number of vehicles in the scenarios. Vehicles with VCG are randomly distributed in each simulation.

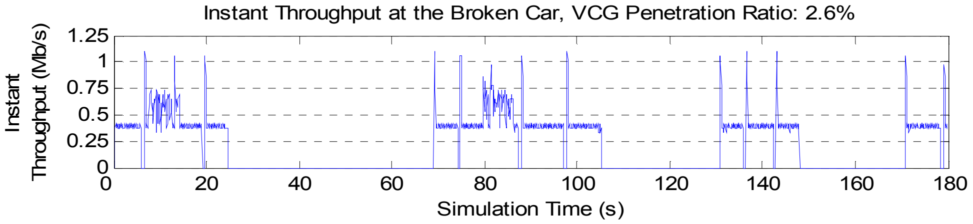

Figure 15. Instant throughput at the broken car (VCG penetration ratio 2.6%)

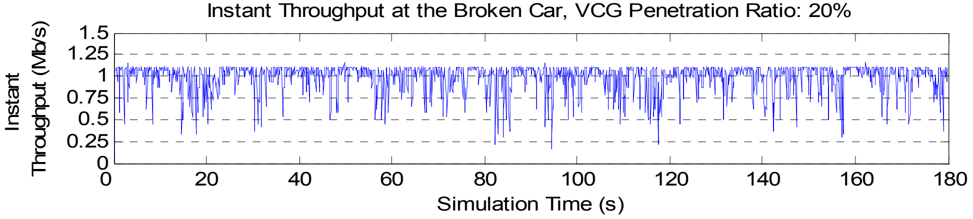

Figure 16. Instant throughput at the broken car (VCG penetration ratio 20.5%)

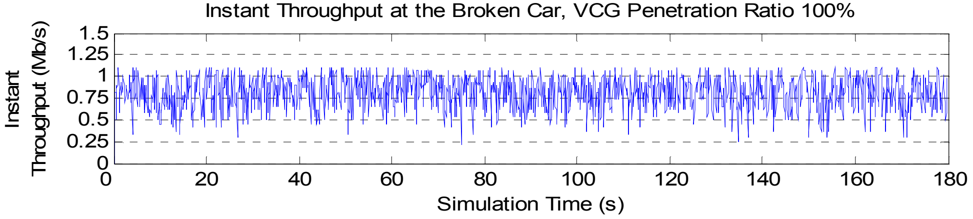

Figure 17. Instant throughput at the broken car (VCG penetration ratio 100%)

Figure 15-Figure 17 show 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 Figure 15, the link between OBU and VCG are intermittent and the average throughput is fairly low. If the VCG penetration ratio reaches 20.5%, 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.

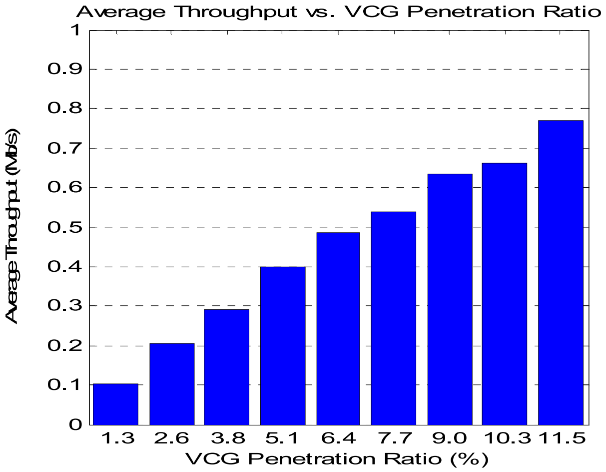

Figure 18. Average throughput vs. VCG penetration ratio (a)

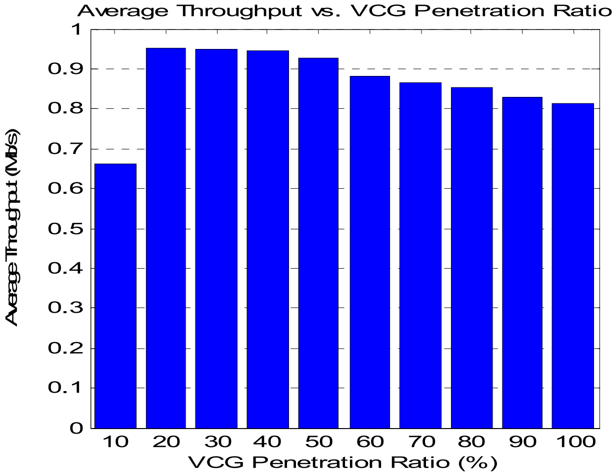

Figure 19. Average throughput vs. VCG penetration ratio (b)

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 BPSK1/2 mode. The results in Figure 18 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 Figure 17 and Figure 19, 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 increasing number of contending stations in range.

7. Conclusion

Starting from a typical Internet access application on the roadway for car maintenance, in this article we studied the solution for providing Internet access to automotive users through WAVE C2C/C2X wireless communication. Two architectures of providing Internet access to drivers using OBU to RSU communication and using OBU to VCG communication are presented. Additionally, our study on the MAC layer protocol shows that using the proposed dynamic link management scheme and the link status based MAC queue architecture, the

WAVE system can efficiently support Internet access application even in highly dynamic vehicular environments.

In this work we conducted an early attempt toward using WAVE C2C/C2X communication for providing general IP services to automotive users. However, to make the wireless Internet access really happen on the roadway we have still many open problems, such as the user privacy and information security problems, routing and data buffering issues in dynamic network, cost and billing problems, etc. During the study, we realize that most of the challenging issues are results from the movement of vehicles and the dynamic network topology. To deal with these problems, the ability of environment awareness is required at each of the OBU. For the future work, we would like to enhance the current WAVE protocol with mobility awareness and use the acquired information to further improve the channel access efficiency.

8. Acknowledgement

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