PROVIDING ENTERTAINMENT APPLICATIONS IN VANET ENVIRONMENTS

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ABSTRACT

With vehicle-to-vehicle and vehicle-to-infrastructure communications gaining momentum, immense opportunities for developing a new application gamut open up. These range from applications targeting security/safety and efficient transportation to in-car entertainment enjoying multi-player mixed-reality games. The potential of VANETs has been recognized by standardization bodies and other stakeholders, including car manufacturers, that have established multiple consortia and initiatives to explore the capabilities of VANET technologies. From the communication technology perspective, the high speed at which nodes move in VANETs together with the adverse environmental conditions (rapidly changing surroundings, weather, etc.) present great challenges. These have attracted the interest of researchers who have sought to evaluate the performance of these systems, mostly paying attention to the lower layers of the protocol stack (physical and MAC). In this article, we explore the network architecture and protocol stack for supporting a broad range of infotainment applications in VANETs based on IEEE 802.11p and assess VANETs' capabilities to support networked multimedia. To this end, our evaluation focuses on application-layer performance for video streaming over a prototype system based on NEC's Linkbird-MX devices.

INTRODUCTION

Vehicular ad hoc networks (VANETs), a subclass of the broader category of mobile ad hoc networks (MANETs), usually referring to vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and vehicle-to-device/everything (V2X) communications, have been increasingly attracting attention lately. The main reason behind this fact is that vehicular communications are foreseen to integrate driving into a ubiquitous and pervasive network not only enhancing transportation safety and efficiency, but also redefining the way we live, work, and entertain ourselves. The proliferation of consortia and initiatives involving car manufacturers, government agencies, and academia, including, among others, the Car-2-Car Communication Consortium, Vehicle Safety Consortium, Networks-on-Wheels project, Vehicle Infrastructure Integration Program, and Advanced Safety Vehicle Program, leverage the potential societal impact of VANETs.

During the last two decades, several technical groups such as the IEEE 1609 Working Group, the IEEE 802.11p Task Group, ISO TC204 Working Group 16, and the ETSI ITS Technical Committee, were created in an attempt to develop protocol stacks and technical solutions that address the specific requirements of VANETs guaranteeing interoperability between different implementations. In the context of the evolving standards, three main categories of applications are targeted:

- Road safety
- Traffic efficiency
- Value added applications

VANETs constitute the cornerstone of the envisioned intelligent transportation systems (ITS). By enabling vehicles to communicate with each other (V2V), as well as with roadside units (RSUs), VANETs will contribute to safer and more efficient roads by providing timely information to drivers and the authorities concerned. Commercial services are also envisioned (e.g., tolling, comfort, information/entertainment a.k.a "infotainment"), creating incentives for faster adoption of the technology.

VANETs present a challenging environment for protocol and application design due to their low latency and high data rate requirements in a high mobility environment. The IEEE 1609 Working Group has defined the first version of the protocol stack, including the IEEE 802.11p/1609.x protocol families (Fig. 1a), also known as Wireless Access in a Vehicular Environment (WAVE) [1]. The WAVE protocols are designed for the 5.850–5.925 GHz band, the dedicated short-range communications (DSRC) spectrum band in the United States, known as ITS radio service (ITS-RS). This 75 MHz band is divided into one central control channel (CCH) and six service channels (SCHs). The CCH is dedicated to the transmission of traffic safety messages, whereas the SCHs are dedicated to the transfer of various application (infotainment) data. The IEEE 802.11p standard defines the physical (PHY) and medium access control (MAC) layers based on earlier standards for wireless LANs. The standard employs hybrid

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 1536-1284/16/$25.00

coordination function (HCF) controlled channel access and enhanced distributed channel access (EDCA) as the MAC method, which is an enhanced version of the distributed coordination function (DCF) of IEEE 802.11. The EDCA uses carrier sense multiple access with collision avoidance (CSMA/CA). The physical layer adopts orthogonal frequency-division multiplexing (OFDM) as used in IEEE 802.11a.

The European Telecommunications Standards Institute (ETSI) similarly adopts the IEEE 802.11p protocol specifications at the physical and MAC layers [2] (ETSI ITS G5 profile of IEEE 802.11p with requirements on decentralized congestion control, DCC, at the MAC layer) and differentiates the higher layers (Fig. 1b). At the network layer, ETSI TC ITS employs the GeoNetworking protocol [3], which provides packet routing in an ad hoc network. GeoNetworking makes use of geographical positions for packet transport and supports the communication among individual ITS stations, as well as the distribution of packets in geographical areas. ETSI TC ITS also adds a "facility" layer in between transport and applications. This layer is responsible for application support (e.g., station positioning, service and message management, mobile station dynamics, local dynamic map [LDM] construction and management, security access), information support (e.g., LDM database, data presentation, location referencing, station type/capabilities) and communication support (e.g., addressing mode, mobility management, geonetworking support, session support). Two main types of messages are foreseen for these operations: cooperative awareness messages (CAMs) and decentralized environmental notification messages (DENMs). An LDM is supported in this layer, which is a database storing and maintaining dynamic data received from other ITS stations through CAM and DENM messages.

While the original impetus for VANETs was traffic safety, it was noticed that allocation of 75 MHz spectrum in the 5.9 GHz band for DSRC in North America opens VANET to multimedia applications including peer-to-peer (P2P) content provisioning and the fast-growing mobile infotainment industry. Most of the research in this area has focused on safety-related applications, while comfort and information/entertainment applications (onboard Internet access, point-of-interest notification, e-map download, networked multimedia, gaming, etc.) have been considered only recently. Notwithstanding, user interest in this kind of applications is expected to become a big market driver in the near future.

In this article, after having completed above a brief overview related to the status of standardization, we describe and evaluate a framework for providing entertainment applications in VANET environments, focusing mainly on the functionality of the IEEE 802.11p protocol and the ETSI ITS standards. To bring our work into focus, in the following section we review recent research efforts related to leveraging IEEE 802.11p-based VANETs for providing multimedia and entertainment applications to users inside moving vehicles. Through our review of prior work, we summarize key findings related to protocol and

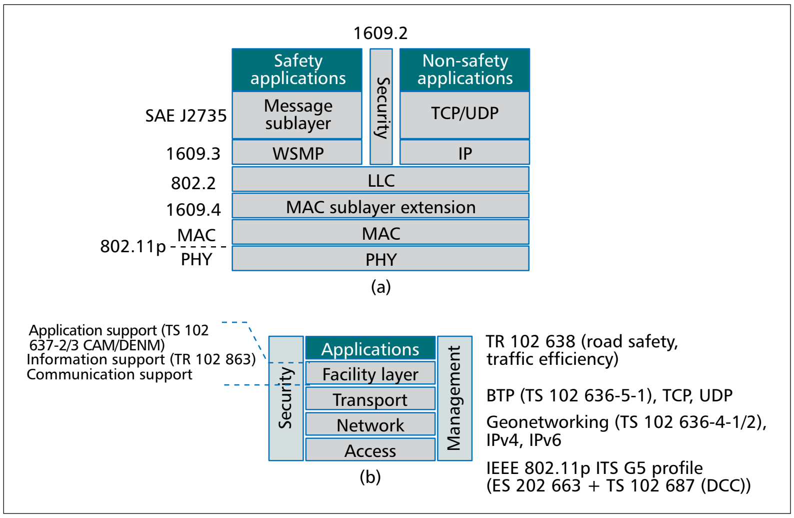

Figure 1. a) IEEE 1609 WG wireless access in vehicular environments (WAVE) protocol stack; b) ETSI ITS TC protocol stack.

system performance, and proposed techniques to maximize them. Additionally, we expose aspects of the protocol functionality, and their impact on the spectrum of potential applications and the service provisioning models. Then we proceed to describe in more detail the network architecture and protocol stacks for supporting a broad range of emerging infotainment applications in VANET environments covering aspects related to network operation, business roles, and protocol stacks. Indicative experimental evaluation results of the VANET described in this article are presented using a prototype system integrating sensing, communication, and application logic based on NEC's Linkbird-MX devices and Car2X communication software development kit (SDK) [4]. Using this system, we evaluate the performance of a video streaming application over IEEE 802.11p between moving vehicles under different conditions providing insight into the impact of video resolution vs. vehicle speeds and vs. different environments. Our conclusions are summarized in the last section.

Prior Work

Since IEEE 802.11p is an emerging, not widely deployed standard, it has attracted significant attention from researchers, and several enhancements have been proposed lately. Research efforts mainly target technical enhancements at the PHY and MAC layers to support real-time applications, which represent a significant part of the set of applications expected in wireless connected entertainment services deployed in a VANET environment. The experience related to large-scale deployments and the support of actual services tailored to the VANET environment is rather limited, and only recently have infotainment applications specifically designed for VANET environments appeared in the literature.

VANETs opening up to multimedia applications make possible new solution offerings and service models, including P2P content provisioning and the fast-growing mobile infotainment industry [5]. The first content sharing application for VANETs using the cooperative P2P model, The experience related to large scale deployments and the support of actual services tailored to the VANET environment is rather limited and only lately infotainment applications specifically designed for VANET environments have appeared in the literature.

CarTorrent, was presented in [6]. It employs an efficient P2P content sharing protocol and system for vehicular nodes demonstrating the detection of available files with periodic gossips and successful downloading of files over a real VANET. The P2P model is attracting interest in VANETs since the small transmission window from a vehicle to an access point (AP), high mobility of vehicles, and the intermittent and short-lived connectivity to an AP provide incentives for vehicles to cooperate with one another to obtain information from the Internet. Since a key component of services that can be provided by VANETs is infotainment dissemination, allowing users in vehicles to receive road information or data from the road infrastructure, the authors in [7] investigated the merits of using geographical information to disseminate data in a VANET. Three enhanced dissemination algorithms were proposed, shown to outperform a distance-based forwarding algorithm, using an additional information set known or easily obtainable by the vehicles. The performance metric of interest in this case is the number of nodes reached by one or more broadcast messages, in an area greater than the physical coverage area of a RSU, without using additional signaling or any neighborhood information. In [8], the authors investigated multicast transmission of vocal messages (focusing on MP3 streams in an urban context) using the ad hoc mode of the IEEE 802.11b standard in VANET environments. Different solutions for guaranteeing V2I connectivity were described, ranging from software enhancements to the use of omnidirectional or directional antennas, and an optimized client-server streaming software suite was demonstrated in a real-world network testbed. The results in [8] showed that transmission of multicast vocal messages with acceptable quality is strongly dependent on hardware and software parameters, as well as parameters related to each specific scenario (e.g., the presence of traffic). The results also showed that the distribution of packet errors can be modeled once the context is known, and appropriate interleaving techniques can be used to guarantee high-quality real-time communication almost free from long error bursts. Finally, in [9] a paradigm shift in multiplayer gaming in the context of VANETs was proposed. Inspired by the pervasive computing vision, the authors envisaged a gaming environment that extends beyond computer-generated virtual reality surroundings to a real-world mixed-reality environment, leveraging the technology support that is available in games today combined with the real world experience that is inherent in a moving vehicle.

In this context, one of the most prominent issues in VANETs regards the quick, epidemic, and scalable delivery of game events and state updates among all players [10]. Typically, such services employ a communication model where game messages are transmitted through a multihop ad hoc network among a group of vehicles (i.e., a car platoon) covering an area of a few kilometers. Besides the typical mechanisms used by Internet games to compensate for high delay, jitter, and packet loss while gaming in a VANET environment, specific requirements for connection duration awareness, fast switching between players and sessions, and disconnection tolerance hold [9]. At the same time, the dynamic and interactive nature of the VANET environment creates new opportunities for games over VANETs (ones that do not require overly long game sessions). The new possibilities offered in the context of VANETs include location awareness (the ability to incorporate the physical world in the game state, thus creating a mixed-reality experience), mixed-reality potential (exploiting the increased power of the gaming hardware available in a vehicle to incorporate real-world properties in a mobile mixed-reality application), player-based game content creation (players could be contributors to the game by creating game objects for specific physical locations of interest), and new types of game worlds (since players in VANETs are likely to display locality of interest and form self-organizing groups based on their location in the real — as opposed to virtual — world). Coupling the above distinguishing features of VANET games with the existence of Internet connectivity could create a much more dynamic and interactive gaming environment compared to that available for Internet games.

Network Architecture

Network Infrastructure

In the context of all of the above studies, ITS applications and infotainment service delivery exploit both V2I communication between a vehicle and the infrastructure and V2V communication among vehicles. In V2I mode, an RSU is capable of communicating (apart from the vehicles in its transmission range) with an application server located at the premises of the traffic management or road operation authorities through any legacy wired or wireless communication technology (Fig. 2). We consider that such devices can be attached to traffic light posts or posts carrying either lights or cameras on highways where access to power and communication networks is provided. The RSUs execute a multitude of functions, including forwarding of data (to increase the coverage of the ad hoc network), transmission and reception of application data from the vehicles (e.g., collecting measurements and disseminating warnings or decisions made at the traffic control center, TCC), communication with the road operation authorities and TCC (which can further control the operation of traffic lights and variable message signs, VMS), and Internet access provisioning to cars. Vehicles equipped with onboard units (OBUs) travel on the road participating in ITS and can also deliver a broad range of infotainment applications to their passengers. The OBUs consist of a system equipped with sensing devices (e.g., humidity sensor, temperature sensor, accelerometer, gyroscope, CO_2 sensor) and with a device capable of communicating with user devices inside the vehicle or other vehicles, or devices installed at the roadside (infrastructure).

Service Delivery Models and Business Roles

In terms of business roles, while road infrastructure lies mainly under the administrative domain of road network providers (owners and investors) and roadway service suppliers (managers and operators), the emerging trend for ITS provides a strong motivation for an evolution to a hybrid model where the road infrastructure provider also becomes a network service provider as well as a content and service provider in order to support and exploit a broader range of added value services to its customers. Hence, since communication with a centralized TCC is already foreseen for traffic safety, control, and efficiency applications, this centralized node can be enhanced in order to also support this kind of added value service, which may range from plain Internet access (e.g., under favorable pricing conditions) to personalized information forwarding, multimedia content downloading/streaming, customized interactive games (possibly enhanced with mixed environment contexts), and other types of evolving entertainment services.

Network Deployment and Operation Modes

In this context, the installed infrastructure (i.e., RSUs) can be used as network access points (APs) for delivering infotainment services to moving vehicles in range (Figs. 2a and 2c). Depending on the deployment (e.g., highway, urban, rural environment) and techno-economic model (i.e., cost to deploy and maintain) only a certain degree of infrastructure support (e.g., RSUs, cameras, sensors) may be available. Hence, the need exists for V2V communication, where a network is constructed in an ad hoc fashion, and no infrastructure is necessary except for the wireless network interfaces inside vehicles, which are likely to be a standard feature in vehicles in the near future (Fig. 2d). Given the diverse performance requirements from a wide spectrum of vehicular networking applications, several advocate the feasibility of the Long Term Evolution (LTE) standard of the Third Generation Partnership Project (3GPP) as an emerging solution. To this end, we envision multi-technology OBUs that will support a number of network interfaces including LTE for wide-area wireless access, as well as WiFi or other short-range wireless communication technologies for connecting user devices inside the vehicle, which may also serve as network access provisioning technologies when appropriate APs are found in range (e.g., in dense urban environments, Fig. 2b). While different access technologies may be used in a complementary way, in this article we focus our study on the use of IEEE 802.11p as an enabling technology for leveraging ITS to support infotainment applications in either V2I or V2V mode.

Apart from the physical and MAC layer enhancements of IEEE 802.11p to improve ad hoc communications of vehicles moving at high speeds, ETSI has chosen the so-called GeoNetworking routing protocol as the core networking protocol for vehicular communication. This protocol supports point-to-point and point-to-multipoint communication as well as multihop communication supporting both a) the forwarding of data toward the geographical position of a single destination node for unicast communication and b) the distribution of data in a geographical region. GeoNetworking is an ad hoc routing protocol utilizing geographical positions for data transfer. It is assumed that each vehicle is aware of its geographical position (e.g., via GPS) and periodically advertises this information to its neighboring vehicles (in so-called beacon messages). Hence, an IEEE 802.11p-enabled device is informed about all other IEEE 802.11p devices located within its direct communication range (one-hop neighbors), and maintains a neighbor table in soft state containing all known neighbors IDs and their geographical positions. Leveraging the capabilities to distribute information based on geographical routing enables innovative applications mainly by exploiting the protocol capabilities for selective addressing of geographical areas as targets of data packets. Thus, traffic safety applications can exploit the fact that a vehicle can specify a well-delimited geographic area to which the messages should be delivered/broadcast. Intermediate vehicles serve only as message relays, and only the vehicles located within the target area terminate messages at the application layer, conveying related information to the driver as appropriate. In this way, the vehicles that are actually affected by a dangerous situation or a traffic-related event are notified, whereas vehicles unaffected by the event are not targeted.

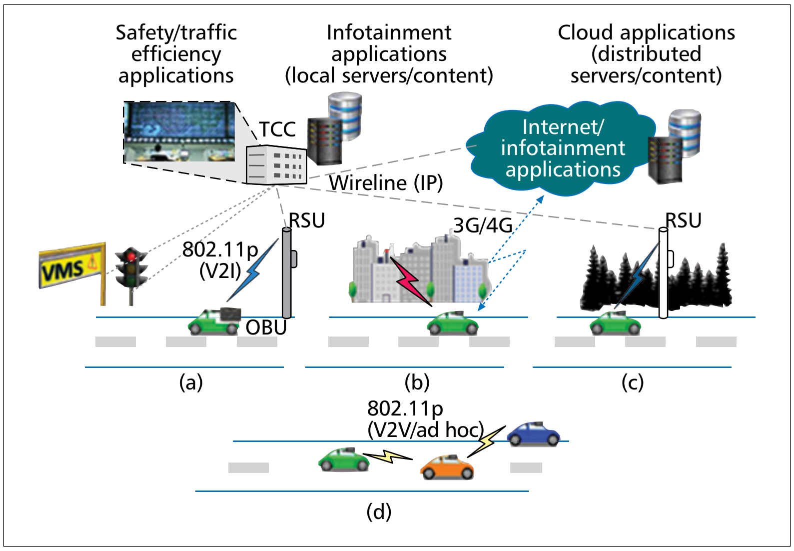

Figure 2. V2I and V2V communication models for supporting both ITS and infotainment applications.

The same feature can also be used by added value infotainment services including multimedia content delivery, gaming, social networking, and so on. Thus, personalized information forwarding and content streaming applications may utilize both the V2I communication mode as well as ad hoc multihop information forwarding over GeoNetworking. Geographical and topological information may be exploited by applications like the file sharing application of [5] and the geographically aware infotainment data dissemination of [6], as well as the mixed-reality gaming environment, combined with the real-world experience that is inherent in a moving vehicle, described in [8]. Furthermore, new types of context-aware services may be envisaged exploiting the geographical awareness of the enriched IEEE 802.11p functionality (position, direction, etc.).

However, apart from the provision of a versatile communication infrastructure that can efficiently utilize the available mechanisms at

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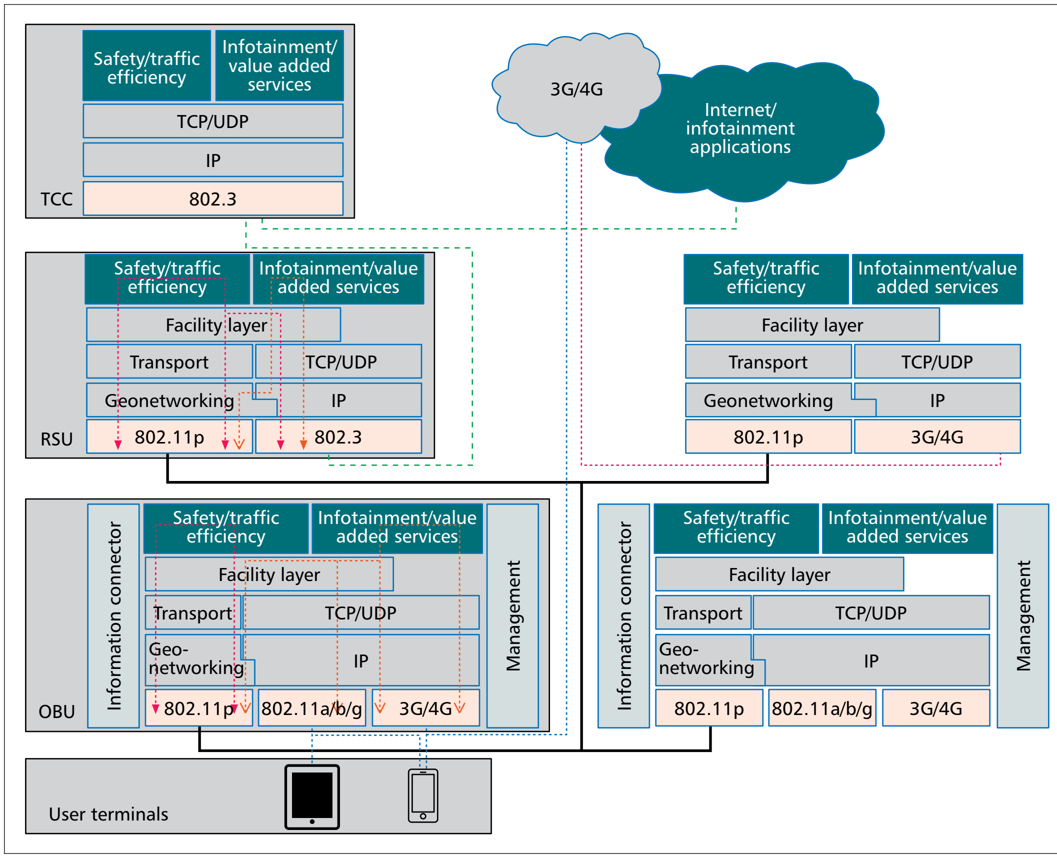

Figure 3. V2I and V2V protocol stacks for ITS and infotainment applications.

the access and network layers, a highly dynamic VANET also requires advanced facilities for timely service discovery and delivery. In this context, the capabilities of IEEE 802.11p to provide fast network attachment (by eliminating time consuming authentication and association procedures) can be exploited, together with efficient mechanisms for locating services in a distributed environment [11, 12], and establishing sessions between service consumers and providers over optimum (i.e., less congested) paths [13].

Protocol Stacks

Figure 3 presents an overall protocol stack and all possible network interfaces and data flows that may be used in the scenarios for supporting both ITS and infotainment applications in VANETs described in Fig. 2. As mentioned above, different communication modes may also be used depending on the application (e.g., centralized vs. P2P applications). In the next section, we describe the integration and development of specific components of the OBU and RSU shown in Fig. 3, which were used to evaluate the performance of entertainment applications over IEEE 802.11p-based VANETs. Due to the absence of an actual TCC in our experiments and the lack of other wireless interfaces, only IEEE 802.11p and 802.3 interfaces available on NEC's Linkbird-MX devices were used.

Experimental Setup

The capability of a VANET based on IEEE 802.11p and the ETSI GeoNetworking facilities to support networked multimedia, an important category of infotainment applications, was evaluated through a representative video streaming application running between two laptops used as end terminals hosted in two cars, while multihop forwarding was also tested, where the video stream was received by an intermediate node and forwarded to a third node. Each terminal was connected through an Ethernet interface to a Linkbird-MX platform (OBU) supporting communication through IEEE 802.11p and the ETSI GeoNetworking protocol (Fig. 4a). This platform, which comes in a package of 11 × 14 cm, is powered by a 64-bit MIPS microprocessor running at 266 MHz, and provides multiple serial interfaces (USB and RS232) for attaching peripheral devices like sensors and GPS receivers. The Linkbird-MX comes with a Linux operating system to deliver an open development platform and is accompanied by NEC's Car2X communication SDK and application programming interface (API) [4], providing geographical routing with advanced features and C-based development tools.

For wireless communication between the OBUs, external 10 dBi omnidirectional antennas suitable for the 5.9 GHz band were attached to each platform and mounted on the cars' roofs (Fig. 4a). The IEEE 802.11p channel bandwidth was set to 10 MHz, the data rate was fixed at 3 Mb/s, and the maximum transmission power of the IEEE 802.11p network cards was set to the maximum value of 21 dBm.

At the network layer, communication between the laptops and the OBUs takes place over IP, while the communication between OBUs is based on the GeoNetworking protocol. To implement such gateway functionality at the OBU, the Linkbird-MX platform connected to the video streaming server ran a custom application written in C which retrieved the UDP payload of the incoming video packets, included that payload in a topologically scoped broadcast (TSB) message, and transmitted the message through the IEEE 802.11p interface. The TSB message type was selected due to its native support of content dissemination to multiple receivers; however, software can be extended to equally support additional types of messages like GeoUnicast and geographically scoped broadcast [3]. At the receiving end, the OBU connected to the video streaming client implemented the reverse procedure, that is, it retrieved the TSB payload from the incoming message, formed a UDP packet including that payload, and transmitted the packet to the video client. End-to-end communication between the video server and the client was based on RTP running on top of UDP.

For the evaluation of the performance of the video streaming application over the aforementioned system, we used three MPEG4 video traces encoded with different data rates and group of pictures (GOP) sizes. The traces were produced from the same raw video having a CIF resolution and comprising 4500 frames (the raw video was synthesized by concatenating several smaller video traces obtained from [14]). All videos were encoded with a rate of 30 frames/s, and consisted of I- and P-frames transmitted through RTP packets of maximum size 1024 bytes (including the RTP header). The first video (in the following, it is referred to as Video_low) had a data rate of 203 kb/s and a GOP size of 20 frames, while the second (Video_medium) and third (Video_high) ones had a GOP size of 10 frames and bit rates of 278 kb/s and 529 kb/s, respectively. The EvalVid toolkit [15] was used for video streaming and performance evaluation, while the QuickTime Player was used at the client side for visualization of the video content in real time.

The experiments took place on a cloudy winter day, and addressed three different routes and motion scenarios (Fig. 4b). In the first scenario (A) the two cars performed random moves in a spacious parking lot at 10–30 km/h keeping a varying distance of 5–50 m between them over a 500 m path. In the second scenario (B), the cars traveled on an uncongested road on a 1.6 km long path in a suburban environment at 50 km/h and a distance of 30–50 m from each other, while in the third scenario (C) the cars traveled on a moderately congested three-lane highway at 90 km/h keeping a distance of 60–100 m between them over a 4.4 km long path. In all scenarios line of sight was maintained between the moving vehicles.

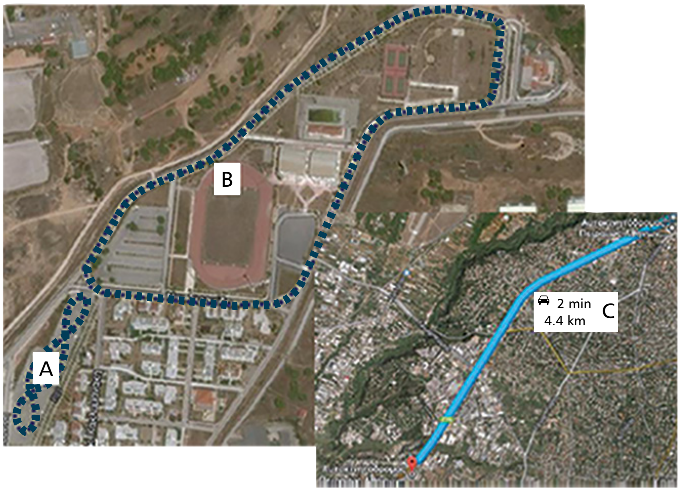

Figure 4. a) The experimental setup used on vehicles; b) the routes used in the experiments.

Performance Evaluation Results

The average video data rates measured at the receiver for the different traces and motion scenarios are depicted in Fig. 5a. The results show that there is a deviation between the sending and receiving rates even for the slow motion scenario (parking lot). The receiving rate degradation is due to packet loss and is more severe in the highway motion scenario. In order to verify that these losses are due to the environment and not to our testing equipment, we conducted additional experiments with the cars placed at fixed positions and varying distances between them (100–300 m). Those tests showed that the reception of the videos (including the Video_high trace) was error-free when a line of sight path was in place between the transmitter and the receiver.

To further evaluate the impact of packet loss, we illustrate in Fig. 5b the fraction of incomplete video frames (a video frame is considered to be incomplete if at least one of its packets is lost) and the lost IP packets in the case of the highway experiment. The results show that the video with the highest bit rate (Video_high) experiences the largest IP packet loss, which results in a high ratio of corrupted I-frames. This is due to the fact that for this video trace the I-frames are significantly larger than the corresponding frames of the Video_medium and Video_low traces. In all cases, the frames that suffer the most are the I-frames because of their larger size compared to the size of the P-frames.

In order to link the video performance assessed through the application rate and the IP packet loss with objective evaluation of video quality, we include results on the average peak signal-to-noise ratio (PSNR) measured for each video trace and motion scenario (Fig. 6). The impact of other network-layer performance characteristics like packet delay and delay variation

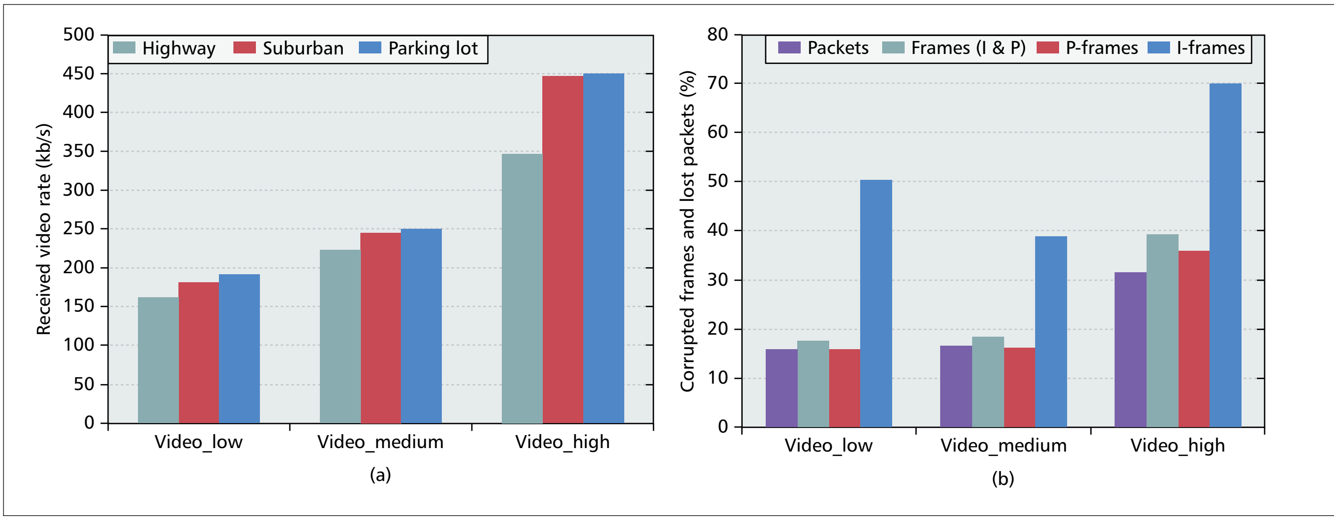

Figure 5. a) Received video data rate for different motion scenarios; b) percentage of incomplete frames and lost packets for the highway scenario.

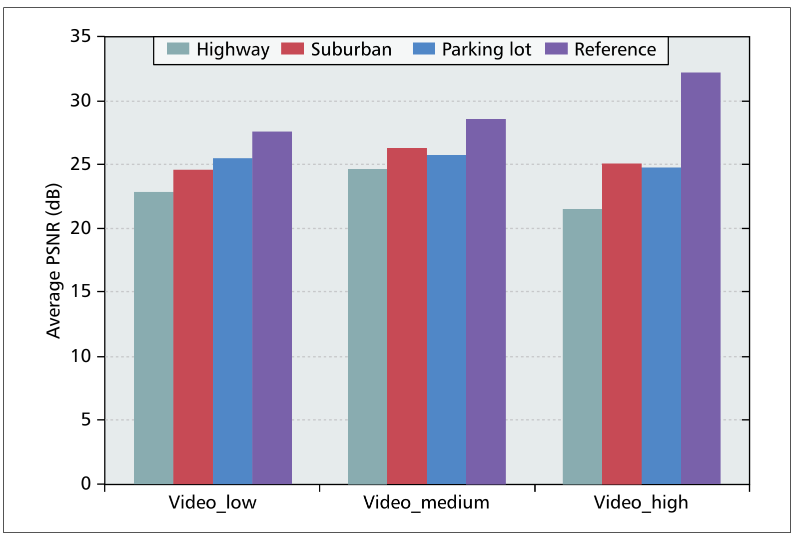

Figure 6. Objective quality of received video traces for different motion scenarios.

is not observed in the presented tests because of the direct connection between the sender and the receiver, and the fact that an adequate 3 s buffering took place at the video client. The reported PSNR corresponds to the quality of the received (MPEG4-encoded) video measured against the uncompressed raw video. The PSNR of the encoded video sent by the transmitter against the raw video has also been included to serve as the reference value. The results for the highway scenario show a good match with the results of Fig. 5b, illustrating that a video with a moderate bit rate and appropriate GOP size (like the Video_medium trace) can be received in such a high motion scenario with acceptable quality. This result was also verified by the subjective evaluation of the videos that was made during the experiments by observing the output of the video client. The results also show that the performance of a streaming video application is improved in case vehicles move at lower speeds (this conclusion is also supported by the results of Fig. 5a).

Conclusions

The standardization of VANETs to efficiently support a wide variety of applications with different requirements is a catalyst for widespread deployment of V2V and V2I technologies. While road safety and traffic efficiency applications in principle generate low data rate flows, infotainment applications, which have the potential to accelerate the adoption of these technologies, inject higher volumes of traffic and have strict quality requirements. We explore the performance of a video streaming application running over a VANET prototype system following the IEEE 802.11p and ETSI ITS protocol stack. The tests were performed for different videos, different vehicle speeds, and different environments (including highway and suburban roads). The results showed that at least acceptable quality can be achieved with proper configuration and handling of the available communication and application parameters. To this end, we believe that the currently standardized IEEE 802.11p and ETSI ITS VANET protocol stack can be effectively used to deliver value added applications and services to people and redefine the traveling experience.

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Biographies

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