Wireless Media Streaming over IP-based In-Vehicle Networks

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***Abstract*—We investigate a heterogeneous IP-based network architecture for in-vehicle communication. The wireless technology is an interesting candidate for in-vehicle communication, since it reduces the cabling effort and consequently the cost. In this work, a peripheral wireless network based on the IEEE 802.11 technology is investigated for media streaming in the car. FEC-based multicast and unicast transmissions are studied and compared for the same communication scenarios based on their QoS performance and resource requirements. Moreover, the frame bursting mechanism from the IEEE 802.11e standard has been applied to improve the throughput of small packets over in-vehicle wireless channels.**

I. INTRODUCTION

Today's premium cars contain more than ten distributed audio and video ECUs (Electronic Control Units) such as visual sensors, driver assistance cameras, DVD player etc. Audio and video streams are sent to several receivers such as the CID (Central Information Display), HUD (Head Up Display), rear-seat entertainment sinks as well as the audio amplifier and many loud speakers. The mentioned ECUs are currently interconnected by different automotive specific network technologies such as MOST (Media Oriented Systems Transport), CAN (Controller Area Network), LIN (Local Interconnect Network) and point-to-point links realized by analogue CVBS (Color Video Blanking Signal) and LVDS (Low Voltage Differential Signaling) cables that provide a limited transmission capacity for the growing number of audio and video applications in the car. An IP/Ethernet-based network has been recently proposed in [1] and [2] as an alternative for in-vehicle communication. Also, IP-based wireless communication has been investigated as an extension of the wired in-vehicle network due to its advantages such as flexibility, reduction of cable harness and the risk of cable break.

Multicast realizes a resource-efficient transmission mechanism compared to unicast. However, multicast transmissions over the wireless channel do not perform well due to the lossy channel and the lack of ARQ mechanisms in layer-2. In this paper, an FEC-based multicast mechanism is studied and compared to unicast transmission from the resource usage and QoS performance points of view. The frame bursting mechanism from IEEE 802.11e is used to improve the throughput for small sized packets over the wireless channel. Analytical and simulation models are introduced and investigated for the considered in-vehicle networks.

This paper is structured as follows. First, in Section II the in-vehicle communication system is described. Then, in Section III the analysis methods are introduced. Results are presented and discussed in Section IV. Conclusions and outlook on our future work are given in Section V.

II. SYSTEM DESCRIPTION

A. Requirement Analysis and Traffic Modeling

Traditionally, automotive networks are divided into several domains that correspond to different functionalities, constraints and structures. However, the classification and the number of automotive domains have not been standardized yet and many different approaches can be found in the literature such as [3], [4], [5] and [6]. In this work, the in-vehicle traffic classification and modeling from [7] is used. A brief overview is given in the following.

Real-Time Control Data: This data class defines real-time control messages with strict time requirements. Currently, the strongest maximum end-to-end delay requirement between two communicating ECUs concerns the FlexRey bus and is 2.5 ms. Most of the ECUs have more relaxed delay requirements of $\geq$ 10 ms [7], e.g., the CAN applications considered in this work representing driver assistance sensor systems have a maximum end-to-end delay requirement of 10 ms. Only very low packet loss rates are tolerated by the applications of this data class.

Highly safety critical messages, e.g., from the steer-by-wire application will be transmitted separately via the FlexRay bus and are not included in the analysis of the IP/Ethernet-based in-vehicle network in this work.

Real-Time Audio and Video Streams: Audio, but mostly video data from camera systems or video transmitting sensor systems of driver assistance services belong to this data class. Interactive audio and video applications such as VoIP and video conferencing also fall into this data class. Several cameras are today applied in the car that stream uncompressed video to the destination devices. In this work, we use MPEG-4 video compression[1] without B-frames for real-time video

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[1] MPEG-coded videos consist of 3 frame types, I (Intra)-, P (Predicted)- and B (Bidirectional predicted)-frames.

streaming as explained in [8]. System requirements are given as follows:

- Transmission rate: 7.4 Mbit/s for video data (average data rate of MPEG-4 compressed video streams from [8]), 50.8 kbit/s for VoIP when using the G.726 voice codec which emits a voice packet every 20 ms
- Frame rate: 30 frames/s
- I-frame interval: 15 frames [8]
- Frame resolution: VGA (640×480 pixels)
- End-to-end delay: Max. 33 ms for cameras excluding the video processing time, max. 150 ms for VoIP according to ITU-T G.114.
- Packet loss rate for an adequate media quality: very low

Multimedia Data: Multimedia systems transmit audio and video data for entertainment of the car occupants. Examples are DVD, TV, Audio CD and MP3 applications. The QoS requirements of in-vehicle multimedia applications are as follows:

- Transmission rate: 4-8 Mbit/s (MPEG-2 is mostly applied for multimedia video applications), 128 kbit/s (MP3), 1.4 Mbit/s (Audio CD)
- Frame rate: 25 frames/s
- I-frame interval: 12 frames [9]
- Frame resolution: 720×576 (PAL)
- End-to-end delay: max. 100 ms for Audio CD, max. 200 ms for DVD
- Packet loss rate for an adequate media quality: very low

Best Effort Data: These applications do not require any QoS guarantee. They are not delay sensitive so that lost packets can be retransmitted. This type of traffic includes web browsing data, system maintenance or file transfer data such as downloading a digital map to the navigation system.

Understanding the nature of in-vehicle data flows is very important for an appropriate network design. Statistical models are used in the following to characterize the data flows for further analysis. In-vehicle traffic can be divided into two main groups of constant bit rate (CBR) and variable bit rate (VBR) data flows [7].

1) Constant Bit Rate Applications: In order to analyze a highly loaded network as the worst case transmission scenario, real-time control data and in-vehicle audio sources such as Audio CD and VoIP are modeled as CBR applications operating at their highest bit rates. While the Audio CD application sends data in MTU-sized[2] packets, VoIP is set to transmit data in 80 byte sized packets.

For the real-time control data, it has been assumed that Body-CAN (K-CAN) and Power Train-CAN (PT-CAN) 8-byte messages with maximum transmission rates of 100 kbit/s and 500 kbit/s and packet inter-arrival times of 640 μs and 128 μs are packed into 64-byte Ethernet frames. Thus, they are sent at maximum data rates $R_{K-CAN\ in\ Ethernet} = \frac{64\text{ byte}\cdot 100\text{ kbit/s}}{8\text{ byte}} = 800$ kbit/s and $R_{PT-CAN\ in\ Ethernet} = \frac{64\text{ byte}\cdot 500\text{ kbit/s}}{8\text{ byte}} = 4$ Mbit/s throughout the Ethernet network, respectively.

TABLE I

Configuration table for the analysis of in-vehicle video sources, e.g., DVD and driver assistance cameras in the present work. n and m are the number of P- and B-frames in a GoP, while P_{mean} and B_{mean} define the average P- and B-frame sizes, respectively.

Parameter	Value		Description
	Camera	DVD	
I_{max} [Byte]	128510	178121	The largest I-frame
I_{mean} [Byte]	54904	57191	The average I-frame size
F_{mean} [Byte]	24412	25630	Mean frame size
GoP_{mean} [Byte]	456569	282197	Mean GoP size
$GoP_{upperbound}$	2.33	3.40	GoP_{max}/GoP_{mean}
GoP_{max} [Byte]	1064263	957638	Maximum GoP size
$ratio_{I-frame}$	0.136	0.186	I_{mean}/GoP_{mean}
$ratio_{P-frame}$	0.864	0.293	$n \cdot P_{mean}/GoP_{mean}$
$ratio_{B-frame}$	0	0.521	$m \cdot B_{mean}/GoP_{mean}$
α	2.5	5.0	Pareto Shape parameter

2) Variable Bit Rate Applications: Due to their different frame types, i.e., I-, P- and B-frames with different sizes, MPEG videos imply a variable bit rate. An accurate modeling of the rate variability is essential for an adequate resource planning. As explained in [7], the fractional autoregressive integrated moving-average (F-ARIMA) model with the Pareto distribution has been used to model compressed video streams in the car. Table I lists all applied values to configure video sources as explained in [7]. Video data is sent in large packets up to the size of the MTU throughout the networks.

B. Considered Networks and Transmission Scenarios

In [1] we have proposed a novel network architecture for in-vehicle audio and video communication based on standard IP and Full-duplex Fast Ethernet. Moreover, a QoS-API is introduced that statically assigns priority levels to the different applications and maps them to the IEEE 802.1p field of the Ethernet MAC frames. Also, QoS-aware switches are used with 4 priority queues per output port to forward Ethernet packets according to their priority tags. The strict priority scheduling is used for the highest priority queue (K-/PT-CAN data ⟶ queue 0) while the other three queues support the weighted fair queuing mechanism (Camera, VoIP ⟶ queue 1; DVD, Audio CD ⟶ queue 2; best-effort data ⟶ queue 3) [10]. [7] extends the analysis of [1] by taking into account the network topology. The simplest applicable network topologies for in-vehicle communication, i.e., double star, unidirectional ring and daisy chain are analyzed based on their cost requirements in terms of component effort and resource usage. Due to high stockpile cost requirements for the maintenance of cable harness that is needed for different car equipments, daisy chain turned out to be inappropriate for the in-vehicle network.

Our analysis has also shown large traffic bursts entering the network from video sources, i.e., cameras and DVD due to the large picture frames (I-frames). Traffic shapers have been applied to video sources to smooth the generated bursts and

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[2] MTU is defined here to be 1500 bytes.

TABLE II

SHAPER SETTINGS AND THE REQUIRED SERVICE RATE (PER STREAM) FOR BOTH TOPOLOGIES FROM FIG. 1 AND 2. ALL RATES ARE GIVEN IN MBIT/S. THE BUCKET SIZE b IS GIVEN IN BYTES. β AND T_{burst} DEFINE THE NORMALIZED BURST CAPACITY AND THE NORMALIZED BURST LENGTH [13].

		(β, T_{burst})	p	b	r	R
Double Star	Cam	(2.25,0.13)	39.01	182330	16.58	37.36
	DVD	(3.5,0.61)	17.03	39263	15.96	16.22
Ring	Cam	(2.25,0.11)	46.11	203050	16.58	44.03
	DVD	(3.5,0.61)	17.03	39260	15.96	16.82

avoid overload situations in the network. Token Bucket shapers [11] with the settings introduced in Table II turned out to be appropriate for in-vehicle video sources. The service rates R in Table II are analytically computed according to the method introduced in [12] and [11].

In this article, the above mentioned double star and ring network topologies are extended with a WLAN access point connected to two wireless receivers (Fig. 1 and 2) and investigated for a worst case transmission scenario in terms of network load. The IEEE 802.11g standard has been used for wireless communication in the car due to its wide availability in consumer and professional electronic segments, comparably high transmission rate and low cost. However, for future use, other wide band wireless technologies such as Ultra Wide Band and IEEE 802.11n can also be taken into consideration. In order to provide QoS to the packets sent from the wired to the wireless network, priority queues are introduced at the output port of the access point. The above mentioned four priority queues of switches are extended with an additional queue with the highest priority and strict priority scheduling for the WLAN management data[3]. All five cameras from Fig. 1 and 2 are assumed to send video frames to the network simultaneously representing the top-, side- and rear-view cameras that are processed by one image processing unit integrated in the headunit. In addition to the five cameras, Audio CD, VoIP, and also K- and PT-CAN applications send data to the wired receiver. The wireless receivers (WHost1 and WHost2 in Fig. 1 and 2) represent the rear-seat entertainment sinks in the car. Both receive data from the Camera 5, K- and PT-CAN applications, Audio CD and the DVD player. The FTP/TCP-based best-effort data is only sent to WHost1. Even though this transmission scenario represents a rare situation in the car, it is important to be considered if the network is expected to work flawlessly at any time.

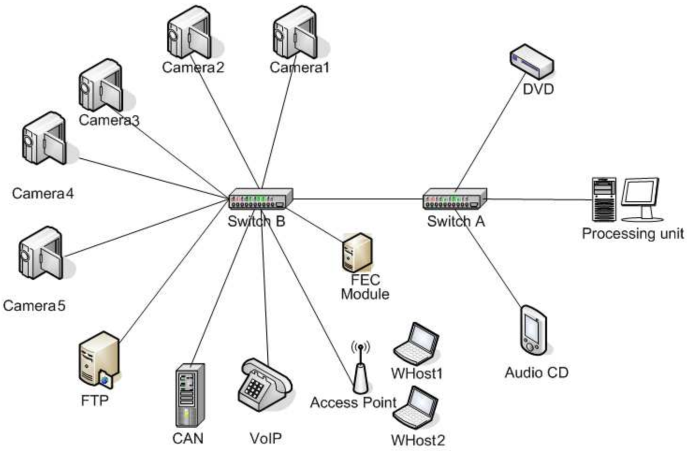

Fig. 1. The analyzed double star topology. K- and PT-CAN applications both run on one server.

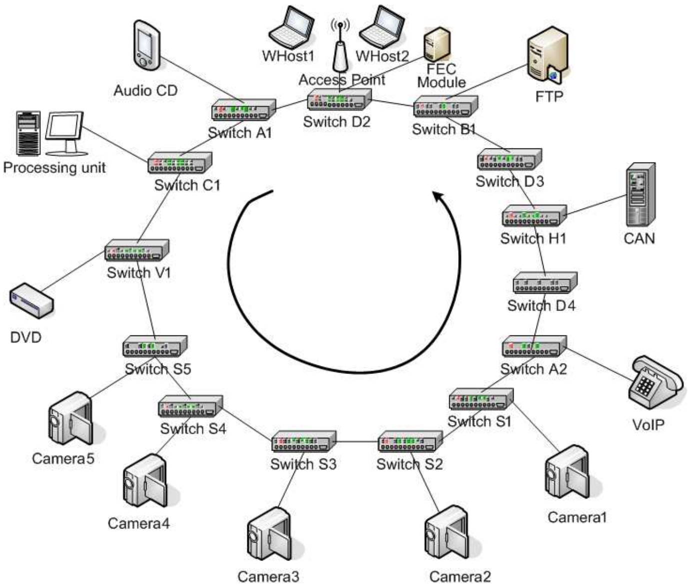

Fig. 2. The analyzed unidirectional ring topology. K- and PT-CAN applications both run on one server.

TABLE III

THE CONSIDERED MULTICAST GROUPS IN THIS WORK.

Multicast Source	**Group Members**
K-/PT-CAN	Processing Unit, WHost1, WHost2
Camera 1-4	Processing Unit
Camera 5	Processing Unit, WHost1, WHost2
VoIP	Processing Unit
DVD	WHost1, WHost2
Audio CD	Processing Unit, WHost1, WHost2

In the above mentioned transmission scenario, most of the streams are sent to more than one receiver. This indicates the need for multicast transmissions in order to reduce the required network resources. The considered multicast groups are shown in Table III. As mentioned in [14], multicast transmission over lossy wireless channels is quite challenging due to the lack of the ARQ mechanism in layer-2 that protects unicast transmissions. Several error recovery schemes based on Forward Error Correction (FEC) codes have been proposed in the literature to support multicast transmissions over lossy wireless channels. [15] proposes an adaptive FEC algorithm that outperforms other FEC-based mechanisms in terms of the number of reconstructed packets. This approach achieves a comparably low overhead, since it continuously adapts the number of FEC packets to the channel condition. It also

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[3] Access point queues: WLAN management data ⟶ queue 0; K-/PT-CAN data ⟶ queue 1; Camera, VoIP ⟶ queue 2; DVD, Audio CD ⟶ queue 3; best-effort data ⟶ queue 4

keeps the end-to-end delay low, because it does not retransmit packets in contrast to ARQ-based mechanisms. Accordingly, the adaptive FEC has been selected in this work to protect wireless multicast transmissions in the car. As shown in Fig. 1 and 2, an external FEC module connected to the same switch as the access point participates in all multicast groups and generates the required FEC packets for the wireless receivers. Thus, low end-to-end delays for FEC packets are guaranteed and the infrastructure of the access point and multicast sources is kept unmodified. According to [15], the adaptive FEC algorithm placed in the FEC module periodically sends loss queries to wireless clients in order to detect the current packet loss rates. Thus, it adapts the number of FEC packets for the next transmission and communicates this update by sending control messages to wireless clients.

Channel measurements in the car with the two wireless receivers placed in the front and back of the car have shown that more than 90% of all losses are single packet losses, about 5% consist of two consecutive packets and the rest defines larger bursts. Independent of packet size and data rate, a maximum bit error rate of 2% has been observed in the car [16].

Another significant parameter that influences data transmission over wireless channels is the packet size. Smaller packets produce a higher overhead than larger packets for the same transmission rate and hence limit the throughput. The channel access is another factor that limits the throughput for small packets. Thus, the smaller the packet is, the lower is the achieved throughput. An interesting solution to this issue is the frame bursting mechanism proposed in the IEEE 802.11e standard which provides a dedicated transmission time, called transmission opportunity (TXOP), to each sender. During TXOP the sender is allowed to transmit as many frames as the time slot allows without competing for the channel access. By using the formulas from [17] and [18] and the WLAN parameters **SlotTime** = 9 μs, **DIFSTime** = 28 μs, **SIFSTime** = 10 μs, **CW**$_{min}$ = 31 μs, **tPLCPHeader** = 4 μs, **tPLCPPreamble** = 16 μs, **tSymbol** = 4 μs, throughput values have been computed analytically for different packet sizes with and without frame bursting. Simulations have been conducted that confirm the analytical results as shown in Fig. 3.

Since all ECUs and their transmission scenarios are known before the network startup, it is possible to guarantee QoS by an accurate resource planning before data transmission is initiated. The analytical and simulation models are described in the following.

III. APPLIED METHODS

A. Analytical Model

In order to compute the required service rates in the IEEE 802.11g network, the R values from Table II that represent the service rates in the in-vehicle Fast Ethernet network are scaled according to the WLAN throughput values from Fig. 3 as

$$\frac{R_{100\,Mbit/s}}{\text{Fast Ethernet Throughput} - R_{CAN}} = \frac{R_{54\,Mbit/s}}{\text{WLAN Throughput}}. \tag{1}$$

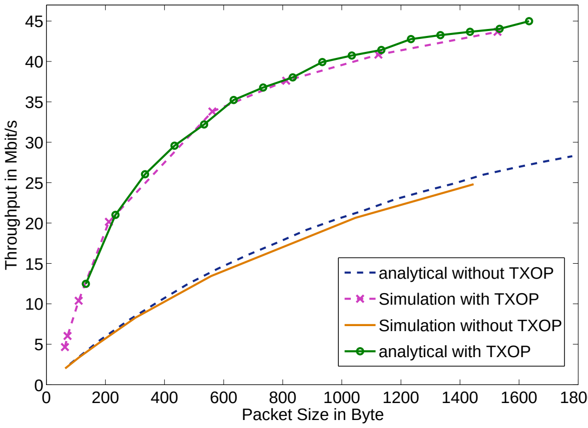

Fig. 3. IEEE 802.11g throughput values.

$R_{100\,Mbit/s}$ represents the service rate in the wired Fast Ethernet network with 100 Mbit/s throughput, R_{CAN} the required data rate for K- and PT-CAN packets of 4.8 Mbit/s (Section II-A1) and $R_{54\,Mbit/s}$ defines the required service rate in the 802.11g network (Nominal bit rate: 54 Mbit/s), which depends on the throughput values from Fig. 3 limited by the packet size. By computing the initial delay $Z = \sum_{j=1}^{i} Z_j = \sum_{j=1}^{i} \left(\frac{C_j}{R} + D_j \right)$ with the packetization delay C_j and the head-of-line blocking delay D_j at the j^{th} network element (refer to [11] and [12]), R set to $R_{54\,Mbit/s}$ for the 802.11g channel, and the buffer size according to [12], resource requirement values can be calculated for the 802.11g access point and channel.

B. Simulation Model

Network performance analysis by simulations is a widely used method in the research community. While analytical evaluations deliver fast but not always realistic results due to simplifications and assumptions, simulations offer more realistic results for larger and more complex networks. In this work, the INET framework from the OMNeT++ (Objective Modular Network Testbed in C++) network simulation tool has been used to simulate the in-vehicle communication network. OMNeT++ is a discrete event simulator based on C++. It is highly modular, scalable, and free of charge for the research community. The INET framework provides all components of a communication network such as switches, access points, cables, servers, hosts etc. The duration of each simulation has been set to 600 s. The wired Full-duplex Ethernet network is configured according to [7]. The 802.11g access point of the INET framework has been extended with 5 priority output queues as explained in Section II-B. The FEC application is added to the INET UDP application of the FEC module and wireless receivers according to [19]. The frequency of loss queries and control messages of the adaptive FEC mechanism (see Section II-B) is set to 2 s and 2.1 s, respectively to achieve a good error recovery performance. The wireless receivers WHost1 and WHost2 both have a distance of 5 m to the access point. To model packet losses over the 802.11g channel a simplified Gilbert Elliot model has been applied. It has basically two parameters *meanGood* and *meanBad*. These parameters correspond to the average time spent in each state before a transition to the other state, i.e., the mean state sojourn times. In the bad state, all packets are marked as corrupted so that upon arrival at the receivers, they are discarded and considered as lost. The main difference compared to the original Gilbert Elliot model is that the transition probabilities are fixed in the sense that the probability to stay in a state after the sojourn time is elapsed is equal to zero. According to the channel measurement results from Section II-B, *meanGood* is defined to be 1 while *meanBad* is set to 0.02 for the simulations in order to model the 2% error rate of the in-vehicle wireless channel.

IV. Results

The applied adaptive FEC mechanism reduces the introduced 2% packet loss rate down to 0.48% by imposing an overhead of 25% on average which is tolerable for in-vehicle wireless communication. The comparably low overhead underlines the advantage of multicast over unicast which would require a separate transmission of each stream for each of the two wireless receivers in the car. Accordingly, multicast with the adaptive FEC is the prefered approach and is therefore further discussed in the following.

Table IV shows the analytically computed resource requirements for the video applications in the considered wireless network. The indicated queue sizes define the required queues in the access point to avoid packet losses due to buffer overflow. Since high priority CAN packets influence the initial delay Z and thus the required resources, the number of switches forwarding the CAN data is also indicated for each network in Table IV. A comparison of the analytical queue size results (Table IV) with those obtained via simulations (Table V without FEC queue size consideration) shows that, as expected, the analytical model defines an upper bound for the required network resources. The unacceptably large Q3 sizes, 583 and 1007 MTU-sized packets in ring and double star networks, respectively, indicate the large number of FEC packets needed for the two applications DVD and Audio CD that are both assigned to Q3 scheduled by weighted fair queuing. However, according to Table V, the application of TXOP reduces the required buffer size significantly in both topologies which is a very promising result for in-vehicle wireless communication. Table VI indicates the amount of lost and late packets for the two wireless hosts (WHost1/ WHost2) in the considered in-vehicle networks from Fig. 1 and 2 with the FEC overhead. According to the channel measurement results mentioned in Section II-B, lost and late packet rates do not differ much between the two receivers that are positioned at equal distances to the access point. Since all buffers are dimensioned carefully according to the introduced analytical model, packet drops can be excluded. All loss rates in Table VI indicate packet losses caused by adverse channel conditions. The applied Gilbert Elliot model introduces 2% packet loss rate. Therefore, all loss rates in Table VI are around 2%. Additionally, the application of TXOP improves the QoS performance in terms of lost and late packet rates. While the transmission of both PT- and K-CAN packets is not possible without TXOP, since both applications overload the WLAN channel due to the low throughputs caused by their small packet size of 64 bytes (Fig. 3), the application of TXOP enables K-CAN to transmit its data. Due to its higher data rate, PT-CAN data still cannot be transmitted without saturating the wireless channel. Table VII extends the results of Table VI by considering the K-CAN data when TXOP is applied. While the loss rates remain around 2%, Camera5 late packet rates increase when transmitting the K-CAN data due to the output queue scheduling mechanisms in the access point. A comparison of the TXOP performance results for ring and double star from Tables VI and VII shows a higher late packet rate for the ring network that corresponds to [7] and is due to the higher number of cascaded switches in the ring.

TABLE V

Maximum queue usage [# MTU-sized packets] with and without frame bursting (TXOP) obtained by simulations. Due to large throughput requirements CAN applications are disabled. Q0, Q2, Q3 and Q4 stand for queues 0, 2, 3 and 4, respectively.

Max. Queue	Ring			Double Star		
	No TXOP		TXOP	No TXOP		TXOP
	No FEC	FEC	FEC	No FEC	FEC	FEC
Q0	1	1	1	1	1	1
Q2	63	123	67	56	351	44
Q3	62	583	44	55	1007	35
Q4	31	36	25	30	34	28

TABLE VII

Late and lost packet rates for all applications including K-CAN sending data to WHost1/ WHost2 with frame bursting (TXOP) obtained by simulations.

Appl.	Ring		Double Star	
	loss%	late%	loss%	late%
Camera5	2.08/ 2.17	0.70/ 0.71	2.09/ 1.91	0.30/ 0.30
DVD	2.20/ 2.06	0/ 0	2.13/ 1.82	0/ 0
Audio CD	2.25/ 2.18	0/ 0	2.03/ 1.94	0/ 0
K-CAN	2.11/ 2.10	0/ 0	2.04/ 1.92	0.001/ 0.001

V. Conclusion and Outlook

Multicast outperforms unicast in wired and wireless networks by reducing the amount of required resources. This statement is also valid when considering FEC overhead for multicast transmissions over wireless channels. The introduced analytical and simulation models have shown that given a certain amount of resources, the in-vehicle WLAN network can transmit up to a certain amount of data with an acceptable QoS performance depending on data rate and packet size. The smaller the packet size, the lower is the achieved throughput and the worse is the transmission performance. By using frame bursting (TXOP), it is possible to transmit data streams with small sized packets up to a certain data rate. Thus, it is possible to send K-CAN packets with a data rate of 0.8 Mbit/s over the

TABLE IV

ANALYTICALLY COMPUTED QUEUE SIZE REQUIREMENTS AND SERVICE RATES IN THE ACCESS POINT. Q2 AND Q3 DEFINE QUEUES 2 AND 3, RESPECTIVELY.

Topology	Queue	# Switches with/ without CAN influence	$R_{54\,Mbit/s}$ [Mbit/s]	Z [ms]	Queue Size [# MTU packets]
Ring	Camera (Q2)	7 / 4	12.239	8.22	164
	DVD (Q3)	8 / 4	4.674	28.61	314
Double Star	Camera (Q2)	0 / 1	10.384	3.14	159
	DVD (Q3)	1 / 1	4.5072	13.13	311

TABLE VI

LATE AND LOST PACKET RATES FOR ALL APPLICATIONS SENDING DATA TO WHOST1/ WHOST2 WITH AND WITHOUT FRAME BURSTING (TXOP) OBTAINED BY SIMULATIONS. DUE TO LARGE THROUGHPUT REQUIREMENTS CAN APPLICATIONS ARE DISABLED.

Appl.	Ring				Double Star			
	No TXOP		TXOP		No TXOP		TXOP	
	loss%	late%	loss%	late%	loss%	late%	loss%	late%
Camera5	2.11/ 2.12	2.51/ 2.48	1.90/ 2.00	0.34/ 0.34	2.10/ 2.18	3.44/ 3.39	1.99/ 1.91	0.07/ 0.07
DVD	2.04/ 2.09	0.92/ 0.90	1.18/ 1.91	0/ 0	2.16/ 2.18	1.59/ 1.60	2.14/ 1.91	0/0
Audio CD	2.15/ 2.11	0.84/ 0.82	2.10/ 2.22	0/ 0	2.16/ 2.26	1.18/ 1.18	1.21/ 1.04	0/0

802.11g channel together with audio and video data while PT-CAN with a data rate of 4 Mbit/s could not be transmitted. In general, the application of frame bursting improves the transmission quality in terms of lost and late packet rates, also for data streams with large packets, while it reduces the required buffer size. Accordingly, it is recommended to use multicast transmissions and apply frame bursting for in-vehicle wireless communication.

In our future work, broadband wireless technologies such as UWB will be investigated for an application in the car and compared with the currently applied WLAN technology.

REFERENCES

[1] Mehrnoush Rahmani, Joachim Hillebrand, Wolfgang Hintermaier, Eckehard Steinbach and Richard Bogenberger, “A Novel Network Architecture for In-Vehicle Audio and Video Communication,” *IEEE Broadband Convergence Networks Workshop, Munich, Germany*, May 2007.

[2] Rainer Steffen, Richard Bogenberger, Joachim Hillebrand, Wolfgang Hintermaier, Mehrnoush Rahmani, and Andreas Winckler, “Design and Realization of an IP-based In-car Network Architecture,” *The First Annual International Symposium on Vehicular Computing Systems, Trinity College Dublin, Ireland*, July 2008.

[3] Alberto Sangiovanni-Vincentelli, “Automotive electronics: Trends and challenges,” Detroit, MI, October 2000, In convergence 2000.

[4] Francoise Simonot-Lion, “In Car Embedded Electronic Architectures: How to Ensure their Safety,” *5th IFAC International Conference on Fieldbus Systems and their Applications, Aveiro, Portugal*, July 2003.

[5] Hans-Georg Frischkorn, *Automotive Architecture Requirements*, BMW internal presentation, September 2005.

[6] AUTOSAR Organization, “Automotive Open System Architecture,” http://www.autosar.org.

[7] Mehrnoush Rahmani, Rainer Steffen, Ktawut Tappayuthpijarn, Giuseppe Giordano, Eckehard Steinbach and Richard Bogenberger, “Performance Analysis of Different Network Topologies for In-Vehicle Audio and Video Communication,” *4th International Telecommunication Networking Workshop on QoS in Multiservice IP Networks (QoS-IP), Venice, Italy*, February 2008.

[8] Mehrnoush Rahmani, Holger Kloess, Wolfgang Hintermaier, and Eckehard Steinbach, “Real-time video compression for driver assistance camera systems,” *The First Annual International Symposium on Vehicular Computing Systems, Trinity College Dublin, Ireland*, July 2008.

[9] TU Berlin, “MPEG-4 and H.263 Video Traces for Network Performance Evaluation,” http://www.tkn.tu-berlin.de/research/trace/trace.html.

[10] Heiner Dercks, “Konzeption und Implementierung einer SIP-gesteuerten DiffServ-Domäne,” M.S. thesis, Fachhochschule Köln, May 2006.

[11] Sanaa Sharafeddine, *IP Network Planning for Realtime Services with Statistical QoS Guarantees*, Dissertation, Technische Universität München, http://deposit.ddb.de/cgi-bin/dokserv?idn=977700828, München, Germany, January 2005.

[12] Leonidas Georgiadis, Roch Guérin, Vinod G. J. Peris and Rajendran Rajan, “Efficient Support of Delay and Rate Guarantees in an Internet,” *ACM SIGCOMM*, vol. 26, pp. 106–116, New York, NY, USA, October 1996.

[13] Mohammad F. Alam, Mohammad Atiquzzaman, Mohammad A. Karim, “Traffic Shaping for MPEG Video Transmission over the Next Generation Internet,” *Computer Communications*, vol. 23, no. 14, pp. 1336–1348, August 2000.

[14] Vincent Roca et al, “A survey of multicast technologies,” Tech. Rep., Universite Pierre e Marie Curie (Paris 6), LIP6-CNRS, Network and Performance Group, September 2000.

[15] Jong-Suk Ahn, Seung-Wook Hong and John Heidemann, “An Adaptive FEC Code Control Algorithm for Mobile Wireless Sensor Networks,” *Journal of Communications and Networks*, vol. 7, no. 4, pp. 489–499, 2005.

[16] Vincenzo Santoro, “Analysis and Implementation of Forward Error Correction Mechanisms for Multimedia Streaming in Wireless Networks,” M.S. thesis, Eurecom in cooperation with BMW Group Research and Technology, 2007.

[17] Youngsoo Kim, Sunghyun Choi, Kyunghun Jang, and Hyosun Hwang, “Throughput enhancement of IEEE 802.11 WLAN via frame aggregation,” *60th Vehicular Technology Conference (VTC)-Fall*, vol. 4, pp. 3030–3034, Los Angeles, CA, USA, September 2004.

[18] Sorin Cocorada, “Experimental Evaluation of the Throughput of Unacknowledged UDP Traffic in an IEEE 802.11E/G WLAN,” *RECENT*, vol. 8, no. 1, pp. 15–21, March 2007.

[19] Iwao Sasase, Alex Fung, “Hybrid local recovery scheme for reliable multicast using group-aided multicast scheme,” *IEEE Wireless Communications and Networking Conference (WCNC)*, pp. 3478–3482, Hong Kong, March 2007.