Tobias Rückelt, Daniel Burgstahler, Frank Englert, Christian Gottron, Sebastian Zöller, Ralf Steinmetz:
A Concept for Vehicle Internet Connectivity for Non-Safety Applications. In: Proceedings of the 8th IEEE LCN International Workshop On User MObility and VEhicular Networks (IEEE ON-MOVE 2014), September 2014.

A Concept for Vehicle Internet Connectivity for Non-Safety Applications

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***Abstract*—Internet access to multimedia content in vehicles today is only possible via cellular networks which offer insufficient bandwidth. By using additional V2X technology in a hybrid manner, vehicles can benefit from additional bandwidth to receive enhanced internet connectivity. We introduce a holistic concept that pursues the vision of an optimal use of available access networks in a vehicular environment combined with a managed resource utilization in a user-centric way to result in maximum user experience and economic efficiency. The resulting internet connection introduces further opportunities for value-added services that maximize Quality of Experience and allows further personalization.**

***Index Terms*—V2X, vehicle, internet, network management, handover, network prediction, scheduling**

I. INTRODUCTION

Vehicle to vehicle/X communication will play a superior role in future vehicular systems. The most famous applications for this technology are road safety and traffic efficiency. Besides that, it can additionally be used to provide individual communication for internet based value-added infotainment features. These features can immediately create a new driver experience and create the possibility to personalize your car.

However, an appropriate quality for this connection is hard to achieve due to high mobility of participants. Available network access points will most probably never be seen longer than a few seconds. This property is a big challenge for the still young V2X technology.

Existing communication concepts do not cover hybrid communication in depth. Transmissions over different channels are not treated dynamically such that applications can not benefit from multi-channel availability. We discuss the potential of LTE and ETSI ITS-G5B for this application and point out their most promising properties. We additionally identify key features in section III which are required to realize an efficient and hybrid use of available communication resources.

Nevertheless, throughput is a rare resource whose availability frequently changes in hybrid V2X communications. In contrast, congestion control algorithms of current transport protocols are designed for constant or slowly changing conditions. These mechanisms alone are therefore not suitable for this highly dynamic environment. We therefore introduce the concept of a scheduling entity that assists existing mechanisms. It is capable of predicting potential connection disruptions and schedules data flows more efficiently between existing links. This concept allows faster handovers and prearranging of future communication flows. Over all, we expect an improvement of the Quality of Experience from our solution.

In the following, a theoretical assessment of technology for hybrid vehicular communication is performed in section II. In section III our concept is specified. We afterwards discuss related work in section IV and close our paper with the conclusion in section V.

II. ASSESSMENT OF TECHNOLOGY

Current concepts for hybrid vehicular communication incorporate cellular mobile internet connections as well as ETSI ITS-G5 technology. ETSI has defined different channels in the ITS-G5 frequency. Current research is focused on channels, which are only allowed to use for safety relevant data exchange. Besides this, there exist further service channels that we can use for other applications and that are defined in ITS-G5B. We integrate the use of these bandwidths into our concept. Its dedicated frequency range covers two bands of 10 MHz width and can provide a data rate of 6 Mbit/s each. In contrast, modern LTE radio masts can provide a cumulated data rate of about 300 Mbit/s and thereby easily outperform an ITS-G5B hotspot. But there are two serious reasons which still make ITS-G5B an interesting and promising technology to connect vehicles to the internet.

First, the range of an ITS-G5 transceiver is much smaller than such of an LTE radio mast. Under idealized consideration of a regular orbicular wave propagation and based on a range of 0.3 to 0.6 km, the covered area of an ITS-G5 transceiver is 0.3 km^2 to 2 km^2. An LTE radio mast in urban environment on 2.6 GHz band reaches a distance of about 3 km, on 800MHz band it even reaches 10 km. The resulting covered areas are 28.3 km^2 and 300 km^2, respectively. Assuming clients to be evenly spread and using available networks at best effort, the maximum possible data rate for each client is proportional to the data rate per area. Hereby, an LTE radio mast provides 10.6 to 1 Mbit/s per km^2 whereas an ITS-G5 Roadside Station (IRS) provides about 40 to 3.75 Mbit/s per km^2. This calculation is subsumed in Table I. Consequently, according to this rough assessment, ITS-G5B provides by tendency a better throughput than LTE for internet access of vehicles under the above mentioned presumptions.

The second reason that pleads for the use of ETSI ITS-G5B concerns possible customers. LTE can be used by everybody

TABLE I
COMPARISON OF ITS-G5B AND LTE

type (range)	data rate per hotspot	range in km	area in km^2	data rate per km^2
ITS-G5B$_{low}$	12 Mbit/s	0.3	0.3	40 Mbit/s
LTE$_{low}$	300 Mbit/s	3	28.3	10.6 Mbit/s
ITS-G5B$_{high}$	12 Mbit/s	0.6	2	3.75 Mbit/s
LTE$_{high}$	300 Mbit/s	10	300	1 Mbit/s

who pays for it. These are especially smart-phone users but also home users living in areas with a bad wired internet connection. Vehicles will have to share available bandwidths with them which results in potentially lower data rates than assumed above. In contrast, ITS-G5B access will most probably be limited to vehicle services and must not be shared. However, the coverage of these networks will be quite sparse so that cellular mobile internet is still required. We therefore integrate these two technologies into our concept of hybrid communication for vehicle internet access. However, it is not limited to them.

III. KEY FEATURES AND CONCEPT

In the following, we specify our holistic concept that is depicted in Figure 1. We identify and discuss key features for optimization of an internet connection for vehicles. We first focus on resource availability, then we have a look on resource utilization. We finally show up dependencies between the identified key features and propose a way to couple them to gain additional performance.

A. Key Features of Resource Availability

To be able to use different connections in parallel in an efficient manner, a multi-homing concept is required. Therefore, *multi-homing* is the first key feature of our concept.

We presume a scenario in which ETSI ITS-G5B internet access points and possibly other wireless technology span accessible networks, especially around high-trafficked junctions and streets. High mobility is an inherent characteristic in vehicular networks. Therefore, changes of network access points happen very frequently. Using conventional protocol stacks, connections would be disrupted and time out regularly on such changes. This would make the internet connection quite unusable from a user-centric point of view. Table II shows theoretical connection times of a vehicle passing an IRS over vehicle speed and maximum range of the wireless connection. Chosen IRS ranges are based on measurements of Gozalvez [1].

TABLE II
THEORETICAL DURATION OF IRS CONNECTIONS IN SECONDS

	Maximum IRS range in meters				
vehicle speed in km/h	**100**	**200**	**400**	**800**	**1500**
50	11.11	22.22	44.44	88.89	166.67
80	6.94	13.89	27.78	55.56	104.17
100	5.56	11.11	22.22	44.44	83.33
130	4.27	8.55	17.09	34.19	64.10
180	3.09	6.17	12.35	24.69	46.30

Considering a default highway scenario with a vehicle speed of 130 km/h and an IRS range of 400 meters, we receive a theoretical duration of 17.09 seconds for a connection of a passing vehicle. A conventional protocol stack would require about 3-4 seconds to establish the connection before transferring data. This is about 20% of the overall connection time and is therefore a waste of potentially usable network resources.

The problem hereby is the connection interruption and timeout during change of network access point. Therefore, the second key feature of our concept is a *handover mechanism* which allows change of network access points without disruption of the connection. This counteracts the above discussed loss in performance. For efficient network usage, handovers have to be triggered on different layers. Triggering allows proactive handovers which help to avoid unwanted connection timeouts. Therefore, the third key feature of our concept in the scope of resource availability is a *management entity* to control handovers for individual connections of applications.

B. Key Features of Resource Utilization

Current concepts on resource utilization usually use available resources at best effort. Applications set up TCP connections and leave this task to the protocol or to network nodes. Multiple TCP connections then compete for higher data rates and thereby balance each other. This works fine on networks with nearly constant characteristics. However, hybrid vehicular networks are very dynamic and change their characteristics very frequently. Moreover, due to multi-homing, different data paths are available that also differ in their characteristics. Available data rates are often very limited and may collapse or rise within seconds.

These challenging characteristics in hybrid V2X communication cannot be satisfied by default balancing mechanisms alone. To master those challenges, the congestion and balancing mechanisms have to be assisted. Therefore, resource utilization has to be adapted actively such that relevant connections keep oversupplied whenever possible. Let us first have a closer look on resource utilization itself. It depends on user action and automatically triggered communication. Communication based on user action may either be a request that requires instant reaction or a request which is delay-tolerant in some degree. Especially automatically triggered and delay-tolerant communication can be delayed to keep the connectivity in state of oversupply. Therefore, the first key factor of our concept in resource utilization is a *scheduling of communication* that allows to influence utilization actively to assist default protocol mechanisms.

Required inputs of this scheduling are available resources on the one hand and requested resources on the other hand. Therefore, the scheduler needs information about networks and about applications. To close the information gap between the scheduler and applications, we introduce *user and application profiles* as second key factor of resource utilization. User profiles create a common guideline for communication based on user preferences. It contains properties about the user's

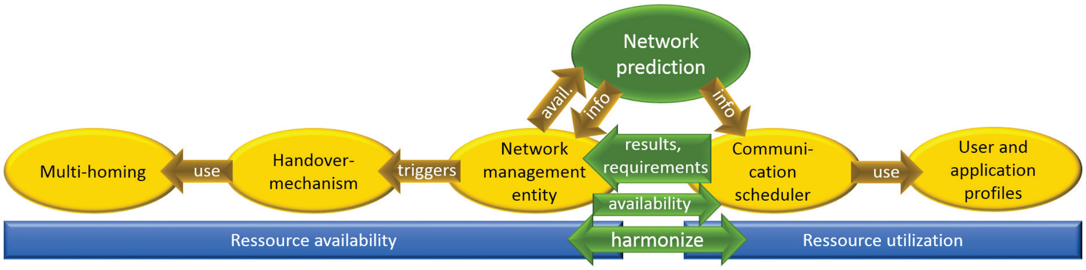

Fig. 1. Identified key features and their dependencies

willingness to pay for higher performance in communication, his priorities for e.g. higher throughput, lower delays and latencies, and general priority to meet application specific requirements. Application requirements are the second part of the identified key factor. Applications have individual requirements on connections which reflect bounds on values of properties of communication for a good usability. These properties are explicitly and quantitatively detailed in an application profile. It can be influenced by the application itself or externally by the system or user. To close the information gap between network resource availability and the scheduler, an interface has to be exposed providing the details in interest. This important interface is specified in the following.

C. Harmonization of Key Features

The scheduler needs to know available resources and their quality from each network connection. Therefore, the network management entity exposes an interface which delivers this information to the communication scheduler. The network management entity administrates handovers and connection establishment. If there are different networks available, it has to decide to which one it should connect and to which data should be passed. Besides measurement-based information about the networks, this also depends on application requirements. Therefore, the scheduler exposes an interface to the network management entity from which it can request the planned communication schedule and currently most required network properties. Based on this information and the collected properties of the network access points at choice, the management entity can decide to which network the connection should be established.

Delay-tolerant incoming communication requests are in general most interesting for scheduling. They allow to perform communication at different times. Using information from pure measurement of currently available resources, the scheduler could delay such requests for communication only heuristically or opportunistically assuming that there will be free resources available in the future.

However, assuming a certain deployment rate of accessible short range communication ITS-G5B IRS, especially at main junctions, a rather good prediction of the next IRS the vehicle passes, appears to be achievable without much effort. We therefore have a look at Figure 2. We imagine a vehicle (arrow in Figure 2) which is leaving an IRS covered area at a certain location heading west. Based on this information, the arrival of the vehicle at the IRS in its west is very probable. The probability is enhanced by the fact that road networks are relatively coarsemeshed and allow limited routes to take. Moreover, the fact that drivers aim at a destination makes random behavior very unlikely. Their preference to follow main streets furthermore enhance the probability of common route selection. On this basis, we introduce an assisting key factor, a *network prediction* component, which performs network based prediction of the position at which the vehicle will leave the current access network and the most probable network access points a vehicle will arrive at next. From the prediction, the estimated time of arrival can be derived in the next step. This helps to estimate future available resources. This information can be integrated into the scheduling to plan execution of delay-tolerant communication. In addition, the information is passed to the network management entity. The prediction allows to perform proactive handover before network exit. Additionally, preparation of connection establishment to the next network access point can be performed in advance so that data transmission can start earlier. This helps to use available resources of network access points more efficiently.

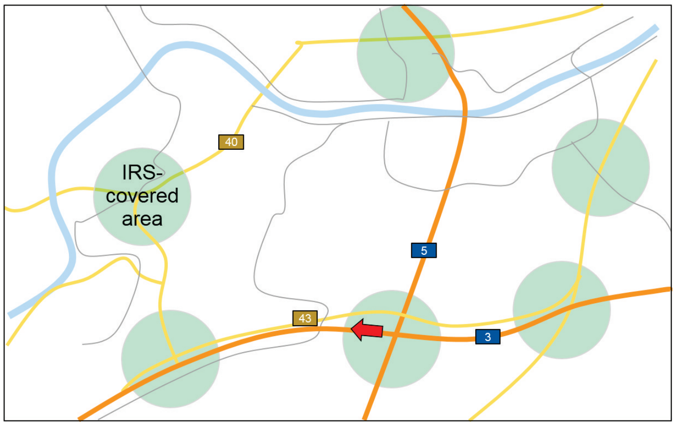

Fig. 2. Prediction Map

IV. RELATED WORK

First, we have a look on hybrid communication in vehicular networks. Second, we compare two promising protocols which address our key factors of multi-homing and handover.

A. Hybrid Communication in Vehicular Networks

A hybrid strategy using cellular networks and wireless adhoc networks like ETSI ITS-G5 simultaneously covers the needs of most vehicular applications. In the research projects SimTD and DriveC2X, hybrid communication has already been used. But their use was limited to ETSI ITS-G5A safety channels and a static assignment of applications to network interfaces. In the research project CONVERGE, the choice of the network path is planned to be adaptive. At SCORE@F, first experiments on host mobility in vehicular networks have been accomplished. However, official results or details are not published yet.

B. Mobility Protocol for Hybrid Networks

To be able to use different technologies efficiently in a hybrid manner, fast and application dependent handovers between technologies without disruption of the connection are necessary. This allows to use the connection that fits best at any point of time. Additionally, multi-homing should be supported to enable the use of all media in parallel. The protocols Multipath-TCP and SHIM6 are our preferred candidates which support these features. They are discussed in the following.

1) Multipath TCP (MP-TCP): A transport layer protocol extension which realizes handover and multi-homing in an efficient way is MP-TCP. It uses header extension of default TCP to transport additional connection information. Therefore, it remains compatible to the common protocol stack. It supports connection forking so that a single data stream can be split to use multiple different channels in parallel. This can be used for fine grained load balancing. Raiciu [2] and Paasch [3] analyzed the performance of MP-TCP concerning handover delays and throughput in depth. Load sharing by forking is possible but still requires further optimization in packet reordering as pointed out by Nguyen [4]. MP-TCP gains remarkable results and is therefore a good candidate to realize the desired features. However, connection management overhead has to be spent per MP-TCP connection. This makes its use attractive only for large data streams. Therefore, connection management for smaller messages as well as for transport protocols except TCP have to be handled externally.

2) SHIM6: SHIM6 is a site multi-homing protocol between network and transport layer which has been enhanced by Dhraief to support client mobility [5]. The basic concept is based on the idea of separation of the identifier and locator roles of IP addresses. SHIM6 introduces an upper layer identifier (ULID) that represents a dynamic connection to the transport layer. It is able to establish multiple links on network layer using the IP protocol. The used IP addresses are called locators. By the ability to map locators dynamically to ULIDs, handovers can be hidden from transport layer protocols. Context forking mechanisms for load balancing like in Multipath TCP have also been proposed by Nordmark [6] and Achour [7] but still lack an implementation. The delay for proactive handover has been reduced to about 20-25ms by Achour [8]. Neglectable packet loss is achieved using enhancements from Mudassir [9]. A bad handover performance for TCP has often been considered, because handover is completely hidden from upper layers. Rahman [10] was able to confound this assumption experimentally.

V. CONCLUSION AND FUTURE WORK

Internet access in vehicles is today only provided insufficiently from cellular networks. We identified V2X technology to be appropriate to enhance this connection in a hybrid manner. We analyzed communication characteristics of the hybrid system in detail and extracted the challenging points. They impose tough requirements on the communication management which default protocol mechanisms cannot meet. We therefore identified six key factors which are required to master those challenges. Based on these key factors we developed a system concept that is able to handle the challenging communication characteristics. It is composed of a communication scheduler, a handover management system and network prediction which are closely coupled in order to gain optimal network utilization. Improved network utilization and optimized handover leads to higher throughput rates and therefore to better Quality of Experience.

In the future, we plan to implement the components of our concept step by step. We are currently integrating MP-TCP and SHIM6 into our framework and plan to do an experimental performance evaluation and comparison. Simultaneously, we are implementing the network prediction by means of machine learning mechanisms. We are also in contact with psychologists to improve our basic mathematical model of the communication scheduler on Quality of Experience.

ACKNOWLEDGMENT

This work was funded within the project CONVERGE by the German Federal Ministries of Education and Research as well as Economic Affairs and Energy.

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